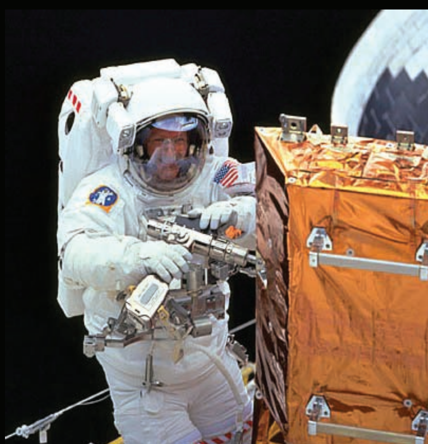
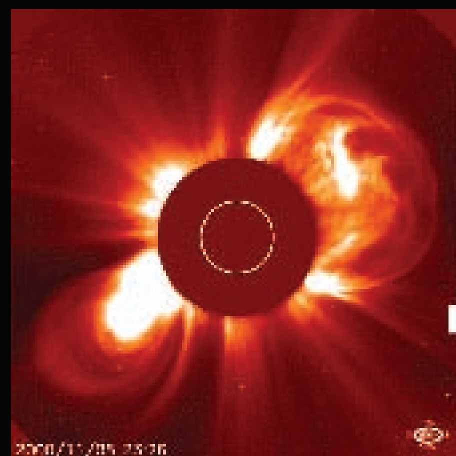
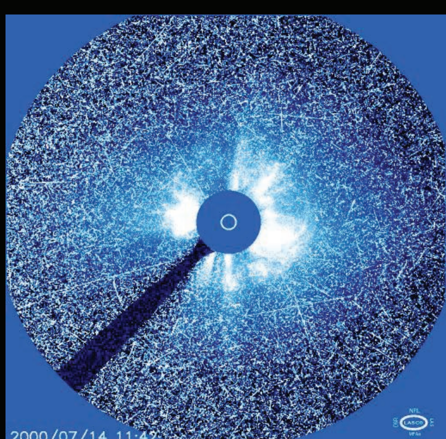
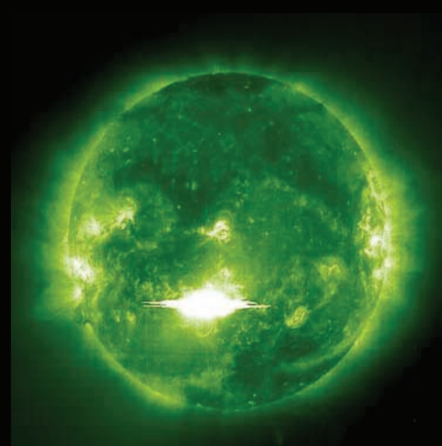
National Aeronautics and Space Administration

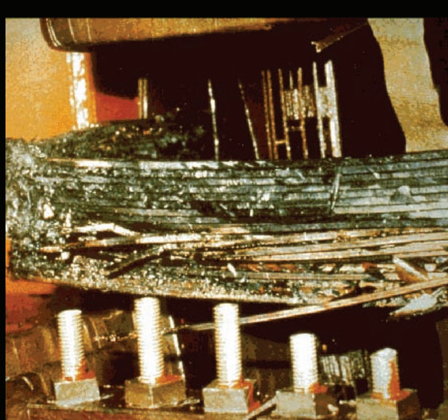
Space Weather Math



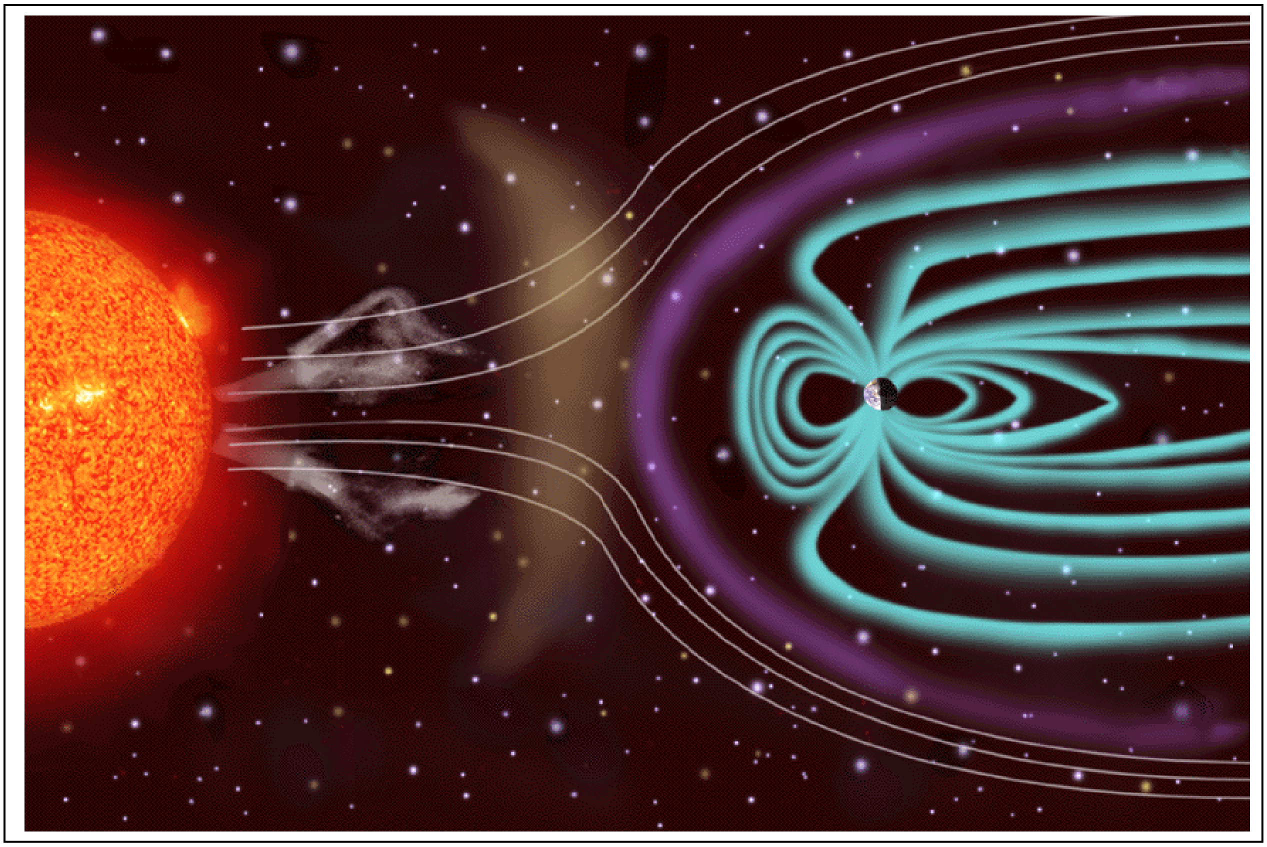








Space Weather Math



Mathematical problems featuring space weather applications

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This collection of activities is based on a weekly series of space science problems distributed to thousands of teachers during the 2004-2011 school year. They were intended for students looking for additional challenges in the math and physical science curriculum in grades 7 through 12. The problems were created to be authentic glimpses of modern science and engineering issues, often involving actual research data.

The problems were designed to be ‘one-pagers’ with a Teacher’s Guide and Answer Key as a second page. This compact form was deemed very popular by participating teachers.

Acknowledgments:

We would like to thank Dr. Eric Christian for a careful reading of this resource for accuracy, and for his many valuable comments. Ms. Elaine Lewis, co-Director of the NASA Space Weather Action Center, was instrumental in writing the 'How to use this resource' essay to help teachers better integrate the problems into classroom situations. We also thank Dr. Rita Karl, Director of Education for the Challenger Center for Space Science Education (www.challenger.org), who provided guidance for how this resource could be improved and extended so that students running space activity simulations could better incorporate space weather issues into their simulated space journeys.

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Front and Back Covers: ISS Astronaut (NASA); Images of the sun (NASA/ESA SOHO LASCO and EIT); Transformer damage (John Kappenman, MetaTech Corp); Aurora borealis (The Morrison Family: Eielson AFB, Alaska); Back: Solar Wind (E. Endo and National Geophysical Data Center); Interior illustrations: Page xii:1947 Sunspot (National Solar Observatory); Geomagnetic Field (Tamas Gambosi: U. Michigan). Page xxvii Van Allen Belts (NASA/Cluster); Page. xxix; GPS Satellite (USAF); Page xxx Space Weather Impacts (NOAA); Page xxxii Power lines and aircraft (Stock Photos); Page xxxiii Climate variability diagram (NOAA); Page xxxiv Telstar satellite (NASA and AT&T Bell Labs). All other images and figures in this book are reproduced courtesy of NASA and NASA missions and as noted in the credits on each page where appropriate.

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Alignment with Standards

AAAS Project:2061 Benchmarks

(9-12) - Mathematical modeling aids in technological design by simulating how a proposed system might behave.

2B/H1 ---- Mathematics provides a precise language to describe objects and events and the relationships among them. In addition, mathematics provides tools for solving problems, analyzing data, and making logical arguments.

2B/H3 ----- Much of the work of mathematicians involves a modeling cycle, consisting of three steps: (1) using abstractions to represent things or ideas, (2) manipulating the abstractions according to some logical rules, and (3) checking how well the results match the original things or ideas. The actual thinking need not follow this order. 2C/H2

Mathematics Topic Matrix

Topic	Problem Numbers																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Inquiry					X	X												X	X												
Technology, rulers	X	X	X	X		X	X									X	X				X	X	X	X	X			X	X		X
Numbers, patterns, percentages					X				X	X	X			X	X																
Averages									X	X		X	X														X				
Time, distance, speed									X	X							X			X	X	X	X	X	X	X	X	X	X		X
Areas and volumes								X																							
Scale drawings	X	X	X	X		X	X										X			X	X	X	X	X	X						
Geometry							X	X																							
Probability, odds																															
Scientific Notation								X																						X	
Unit Conversions	X	X	X	X		X		X								X	X				X	X	X	X	X	X	X	X	X		X
Fractions																															
Graph or Table Analysis									X	X		X	X	X	X			X	X	X	X	X	X							X	
Pie Graphs															X																
Linear Equations																															
Rates & Slopes																															
Solving for X							X																								
Evaluating Fns							X																X							X	
Modeling							X																								
Trigonometry							X																								
Logarithms																															
Calculus																															
Measurement	X	X	X	X	X																										
Algebra							X																X								
Pythagorean Theorem							X																								

Mathematics Topic Matrix

Topic	Problem Numbers																														
	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
Inquiry							X									X													X		
Technology, rulers								X	X			X																			
Numbers, patterns, percentages				X		X				X			X	X	X	X		X											X	X	X
Averages											X																				
Time, distance, speed	X	X	X										X	X			X	X		X	X	X					X				
Areas and volumes																												X			
Scale drawings								X	X			X																			
Geometry			X						X																						
Probability, odds						X											X											X			
Scientific Notation					X			X																							
Unit Conversions					X														X	X	X	X		X	X	X	X				
Fractions																															
Graph or Table Analysis	X	X		X	X					X	X		X	X			X	X		X	X	X	X	X	X	X	X		X	X	X
Pie Graphs																															
Linear Equations																															
Rates & Slopes																															
Solving for X				X																											
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Logarithms																															
Calculus																															
Measurement																															
Algebra																															
Pythagorean Theorem																															

Mathematics Topic Matrix

Topic	Problem Numbers																													
	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
Inquiry									X			X	X	X	X	X															
Technology, rulers																															
Numbers, patterns, percentages	X	X	X	X	X	X			X			X	X				X	X	X	X	X	X	X		X	X	X				X
Averages										X			X												X			X	X	X	
Time, distance, speed		X	X	X	X	X	X						X	X	X	X															
Areas and volumes																															
Scale drawings																															
Geometry																															
Probability, odds											X						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Scientific Notation																															
Unit Conversions																															X
Fractions																															
Graph or Table Analysis	X	X	X	X	X	X	X	X	X	X	X									X				X	X	X	X	X	X	X	X
Pie Graphs																															
Linear Equations		X	X	X	X	X		X																							
Rates & Slopes		X	X	X	X	X	X																								
Solving for X		X	X	X	X	X		X																							
Evaluating Fns																															
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Trigonometry																															
Logarithms																															
Calculus																															
Measurement																															
Algebra																															
Pythagorean Theorem																															

Mathematics Topic Matrix

Topic	Problem Numbers																														
	94	95	96																												
Inquiry																															
Technology, rulers																															
Numbers, patterns, percentages																															
Averages	X	X																													
Time, distance, speed																															
Areas and volumes																															
Scale drawings																															
Geometry																															
Probability, odds	X	X																													
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Graph or Table Analysis	X	X	X																												
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Pythagorean Theorem																															

How to Use this Resource

Teachers continue to look for ways to make math meaningful by providing students with problems and examples demonstrating its applications in everyday life. **Space Weather Math** offers math applications through one of the strongest motivators-the mysteries of our Sun.

Space Weather Math is designed to be used as a supplement for teaching mathematical topics and will work very well as a supplement with the Space Weather Action Center, as students track a solar storm from the Sun until it impacts our magnetosphere. http://sunearthday/swac The problems can be used to enhance understanding of the mathematical concept, or as a good assessment of student mastery.

In modeling phenomena, students should encounter a variety of common kinds of relationships depicted in graphs (direct proportions, inverses, accelerating and saturating curves, and maximums and minimums) and therefore develop the habit of entertaining these possibilities when two quantities might be related. None of these terms need be used at first, however. Although the various forms of energy appear very different, each can be measured in a way that makes it possible to keep track of how much of one form is converted into another. Whenever the amount of energy in one place diminishes the amount in other places or forms increases by the same amount. 4E/H1 In any system of atoms or molecules, the statistical odds are that the atoms or molecules will end up with less order than they originally had and that the thermal energy will be spread out more evenly. The amount of order in a system may stay the same or increase, but only if the surrounding environment becomes even less ordered. The total amount of order in the universe always tends to decrease. 4E/H2*(Benchmark, Physical Setting- Energy Transformation)*

Technological problems and advances often create a demand for new scientific knowledge, and new technologies make it possible for scientists to extend their research in new ways or to undertake entirely new lines of research. The very availability of new technology itself often sparks scientific advances. 3A/H1 Mathematics, creativity, logic, and originality are all needed to improve technology. 3A/H2 Technology usually affects society more directly than science does because technology solves practical problems and serves human needs (and also creates new problems and needs). 3A/H3a*(Benchmarks, Nature of Technology-Technology and Science)*

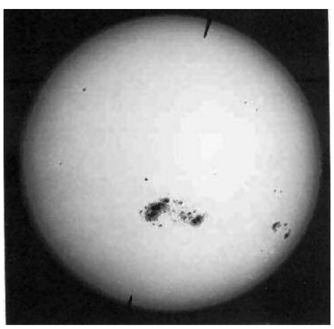
An integrated classroom technique provides a challenge in math and science classrooms, through a more intricate method for using **Space Weather Math**. Read the scenario that follows:

> Ms. Smith teaches 3 middle school classes that are a combination of math and science. She has seen an increased interest in the Sun as it becomes more active heading to maximum. She decided to use the Space Weather Action Center to have students analyzing data and the Space Weather Math book to use the images to teach scale. The students were very excited as they watched the Sun each day in the space Weather Media Viewer and learned the math skills effectively through the problems in the Space Weather Math book.

Introduction

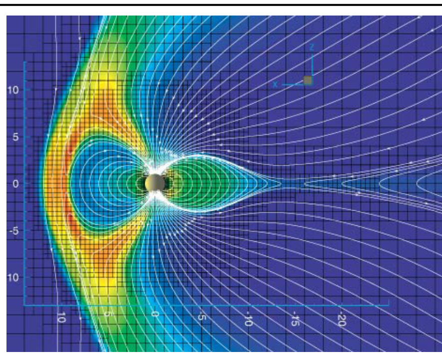
We live next to a very stormy star, the Sun, but you would hardly notice anything unusual most of the time. Its constant sunshine hides spectacular changes. But unless you lived in the Arctic and Antarctic regions of Earth, you would have no clue. Only the dazzling glow of the Northern Lights suggests that invisible forces are clashing in space. These forces may cause all kinds of problems for us, and our expensive technology. It doesn't take long for a 'solar storm' to get here, either. Once a storm arrives, it can cause changes in Earth's magnetic field, which lead to the displays of the aurora which humans have marveled at for thousands of years. Aurora light up the sky with billions of watts of power and cover millions of square kilometers. Why does all this happen? (*Photo- Auroral curtain1/18/2005 by The Morrisons - strangecosmos.coms)*

Space Weather



It has to do with Earth's magnetic field and how it is disturbed by solar storms and the solar wind. The wind carries its own magnetic field with it, and travels at speeds of millions of kilometers per hour. Scientists keep track of this interplanetary storminess using numbers that follow its ups and downs just like meteorologists follow a storm's speed, pressure and humidity. Periods of increased and decreased solar activity come and go every 11 years. Solar flares also have their own story to tell just like flashes of lightning in a bad storm. (*Photo - 1947 Sunspot - NSO)*

Models and Forecasting



Scientists have to keep track of many different kinds of phenomena in the universe, both big and small. That's why they have invented a way to write very big and very small numbers using 'scientific notation. They also have to master how to think in three-dimensions and how to use mathematical models. Once they find the right models, they can use them to make better predictions of when the next solar storm will arrive here at Earth, and what it will do when it gets here!

(Model of Geomagnetic field - University of Michigan)

Space Weather – Scientific Research

Many of the details about how the sun works, and its interaction with our planet, are hidden from view by Earth's atmosphere. This atmosphere blocks important clues about the sun that are present in the ultraviolet and at shorter wavelengths of the solar spectrum. That's why satellites operating in space have become so important in helping scientists understand the sun in detail.

For thousands of years we have enjoyed the constant flow of sunlight that heats our world, but in fact the sun is an inconstant star. According to measurements by satellites such as SMM and SORCE, sunspots and other active regions on the solar surface can change the amount of sunlight falling on Earth by up to 0.3%. The ultraviolet radiation from the sun also follows the sunspot cycle, being measurably more intense during sunspot maximum than during minimum. Ultraviolet radiation is an important energy source for Earth's upper atmosphere. Thanks to careful satellite studies over that last 30 years, scientists have detected changes in ozone concentrations, and intriguing correlations in other lower atmosphere and troposphere systems .These all imply that even small changes on the sun can have large effects in Earth's atmosphere and climate systems. Satellite technology has made it possible to study these changes in detail from day to day, and year to year.

Believe it or not, satellites have made it possible to use 'sunquakes' to study the interior of the sun the same way geologists use Earthquakes to explore the interior of Earth. This new science is called helioseismology. Solar physicists using the SOHO satellite measure changes in the surface of the sun, and use them to determine the location of solar storms on the far-side of the sun. The shock waves from these storms travel at different speeds and directions as they travel through the sun .This information can be mathematically modeled to create pictures of the interior of the sun that match up with predictions made decades ago. This also means that far-side active regions can be detected long before they rotate onto the Earth-facing hemisphere. Helioseismology has also uncovered flows of plasma thousands of kilometers wide that look like terrestrial 'jet streams' in our atmosphere. These solar jet streams appear to be important in regulating the 11-year solar activity cycle itself.

In terms of the amount of energy released over a period of time, solar flares are the most intense storms in the solar system. In 30 minutes or less, they generate enough energy to power Earth's electrical systems for thousands of years. Astronomers thought flares only got hot enough to generate x-ray light – requiring temperatures of 50,000 C. Satellites launched at the beginning of the Space Age soon discovered that some of the most violent flares create gamma-rays. This means nuclear reactions take place, not only inside the core of the sun, but on its surface too.

Why do solar flares happen? Astronomers have been studying this question since the 1930's. Thanks to the data from satellite observatories such as OSO, RHESSI and Yohkoh, we now think that solar flares happen when powerful magnetic fields on the sun become tangled and reform into new shapes. Astronomers call this process 'magnetic reconnection'. A loop of solar magnetism forms an arch above the solar surface. The hottest gas exists at the top of the arch where magnetic fields are being pulled apart and reshaped into simpler forms. This transformation releases energy, causing gases to flow, triggering the flare event. Since the 1950's physicists have created detailed models of these changes and flows, but only recently have satellites been able to measure changes on the sun and actually test these theories.

The corona of the sun has been studied during total solar eclipses since the 1830's .During eclipses, the extended atmosphere of the sun can be easily seen. Since the 1960's astronomers have wondered why the corona has a temperature of millions of degrees Centigrade while the surface is only 6000 C. Thanks to satellite studies such as TRACE and the work done by Skylab astronauts, we now see the corona as a system of hundreds or thousands of magnetic arcades and loops. Innumerable bright points of x-ray energy called micro-flares, also dot the solar surface, lasting for a few hours. Micro-flares and coronal magnetic loops are the key ingredients that work together to keep the corona so hot. Magnetic energy, when released, can heat solar gases to high temperatures. This ‘plasma’ then flows into the loops of magnetism that act like invisible bottles, keeping the corona close to the sun in most places, and very hot.

Small-scale magnetic changes in flares and micro-flares also create large surface fields, as small magnetic regions are broken apart and re-knit into larger magnetic systems. The largest structures are often seen by satellites such as TRACE, SOHO and Yohkoh in the form of spectacular prominences, and arches. During solar flares, these magnetic arches are loaded with cool gas and become unstable .Like an inflated balloon that is released, they can be ejected from the sun and pass outwards into interplanetary space at speeds in excess of 200 km/sec. Originally called Coronal Transients during earlier studies by SMM and Skylab, they are now commonly referred to as Coronal Mass Ejections or CMEs. CMEs can be tracked by the SOHO, WIND and ACE satellites from the solar surface to the distance of the Earth. These solar storms, when they arrive at Earth, can cause satellite damage and electrical power outages, so scientists try to develop means for predicting when they will happen and how long they will take to reach Earth.

The constant heating of the solar corona leads to its expansion into space as the solar wind. This wind, and its changes in density, speed and magnetism, can be measured by spacecraft such as ACE and Ulysses from a variety of locations in the solar system revealing complex structure due to shocks and reconnecting regions. The wind coming from the sun’s poles has a low-density and high speed .The wind from the sun’s equatorial zones has a higher density and slower speed. Apollo astronauts and modern space probes such as Genesis have taken samples of this wind and it seems to be rich in the kinds of atoms that the sun is made from: hydrogen and helium, as well as many other heavy elements, but also elements like iron that are launched into the wind during solar flares.

The Earth is a frequent recipient of impacting magnetic clouds and solar flare energy, especially at times during the sunspot cycle when solar activity is the most frequent. For over two centuries, these solar storm conditions have been the cause of many adverse technological impacts. This has led to a dramatic increase in interest to understand the Earth's environment in space and how this environment is affected by solar storms.

Earth's magnetic field is not rigid, but can be easily distorted into a comet-like shape during solar CME passages observed by the SOHO and ACE satellites. These distortions release huge amounts of magnetic energy called Geomagnetic Storms. The aurora we see in the Arctic and Antarctic Regions are caused by these severe magnetic storms and can be studied by the TIMED, Polar and IMAGE satellites. During a magnetic storm, Earth's magnetic field evolves through a sequence of shapes that have been observed by satellites such as GEOTAIL. These changes are mirrored in the sequence of changes seen during auroral events, which have been observed for centuries. The exact sequence of events leading up to geomagnetic storms, and the transformation of magnetic energy was studied by the THEMIS satellites, which confirmed the sequence of events in time.

The extension of the upper atmosphere into space has been investigated, and found to be a very dynamic system that is directly affected by solar activity. Fountains of ionized oxygen atoms detected by the Polar and IMAGE satellites are ejected into space during severe solar storms. Moments later, a circulating river of these atoms, called the ring current' flows around Earth's equator for several hours before vanishing as the storm subsides. The inner edge of the ring current observed by the IMAGE satellites is located ~12,000 km above Earth where it interacts in a dramatic way with the upper atmosphere.

Most textbooks that discuss the van Allen Belts show it as a pair of nested ‘donuts’ filled with high-energy electrons and protons. The belts are separated by a so-called 'slot region' devoid of high-energy electrons. During geomagnetic storms, The Sampex and IMAGE satellites can see that the outer radiation belts move inward towards Earth, causing the size of the slot region to decrease. The IMAGE satellite has discovered that this region can also be evacuated through the agency of low-frequency radio waves generated by thunderstorms. Although the origin of the Van Allen belt particles remains something of a mystery even today, it is unlikely that solar particles are the major source. Instead, the source may be Earth itself, combined with some as yet unknown process that amplifies their energies.

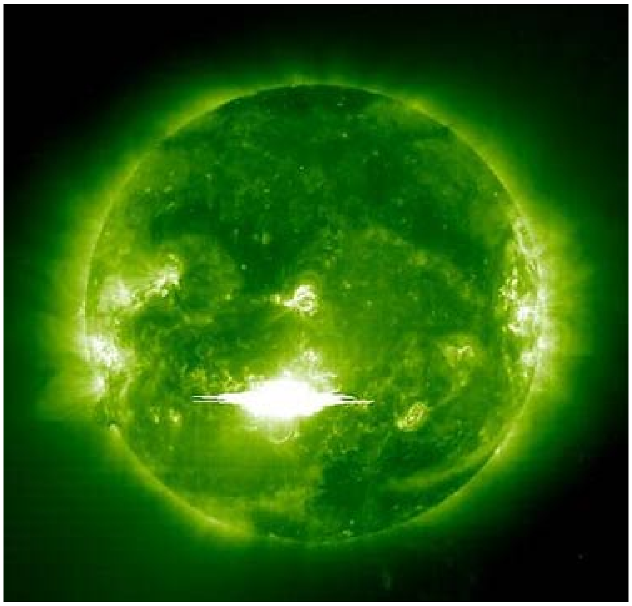
Understanding the Sun-Earth system has become more critical as satellites and human activity in space have become more common. The changing solar, interplanetary and geospace environment is now referred to as ‘space weather’, and like more conventional terrestrial storms, causes billions of dollars of damage to satellite operations, and ground-based electrical systems. During the previous solar activity cycle (1996-2006), many new technologies were developed to anticipate and study solar and geomagnetic storm events in a coordinated program of ‘cradle to grave’ international investigations provided by the International Solar and Terrestrial Physics (ISTP) program. New NASA spacecraft, such as SDO, STEREO and Hinode will continue these investigations during the next activity cycle (2006-2017). Meanwhile, although research satellites provide tremendous assistance to commercial satellite operators and power grid managers in anticipating severe solar storms by up to 72 hours, their purpose is research-directed. What is needed is a constellation of satellites in space, analogous to conventional weather satellites operated by NOAA, to provide dedicated sentinels for commercial space weather forecasters.

Space Weather – The Major Elements

Solar Flares

A solar flare on the sun may last only an hour but is capable of emitting huge amounts of high-energy particles as well as electromagnetic radiation such as ultraviolet and x-rays. The total energy release can be measured in thousands or millions of equivalent hydrogen bombs going off all at once.

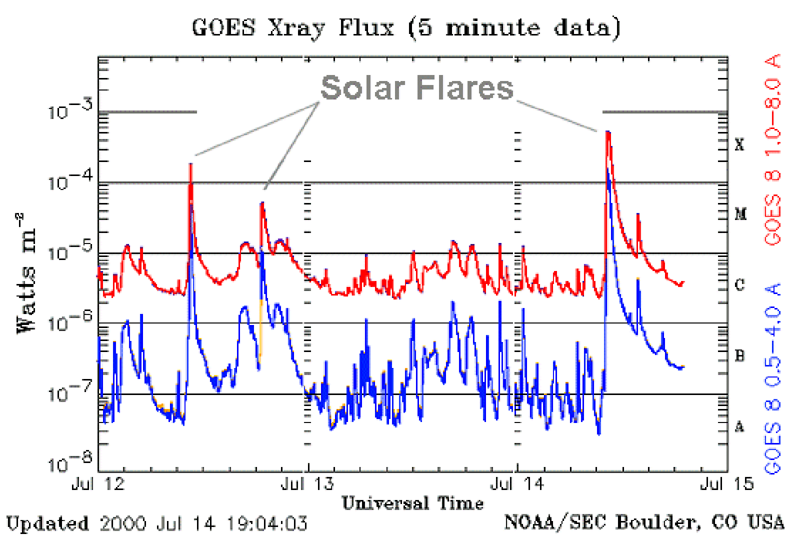
Flares are caused by magnetic fields near sunspots that have become tangled, and over the course of a few hours, release the stored magnetic energy.



Most of this energy causes local heating of the plasma to temperatures as high as 50 million degrees C. This release of energy produces an intense burst of electromagnetic radiation, especially at x-ray energies, but also spanning much of the electromagnetic spectrum from radio to gamma rays as well. Traveling at the speed of light, X-rays can make the journey from the sun to Earth in just under 9 minutes. Accompanying the flare event, particles such as electrons, protons or low-mass atomic nuclei can be accelerated to very high energies, with speeds approaching that of light. If directed towards Earth, these solar energetic particles (SEPs) can make the trip in under an hour. It is usually possible to anticipate what sunspot regions on the sun can produce these flares, but the exact time is not predictable to within a day of the event itself.

Under favorable conditions of Earth-sun geometry, the x-rays can reach Earth and cause heating of the upper atmosphere. As the upper atmosphere expands, satellites in low Earth orbit below 500 km will experience increased drag, causing premature reentry if not corrected. This is generally not a problem for manned flight with destinations beyond Earth, but is a continuing problem for NASA assets such as the International Space Station (ISS). The human consequences of these x-rays are generally modest. Spacesuits and the bulkheads and walls of spacecraft provide excellent shielding so that little excess radiation is biologically absorbed by the x-rays and other electromagnetic components to solar flares.

Solar flares are commonly classified by their X-ray brightness. The graph below shows the x-ray emission from the sun recorded by the GOES satellite, with the solar flares indicated. The ‘class’ of the flare is noted on the right-hand edge of the graph and is demarcated by a 10x increase in x-ray intensity with each class change upwards. B-class flares are about 10x as intense as A-class flares, while a C-class flare is 10x as intense as a B-class flare and so on.

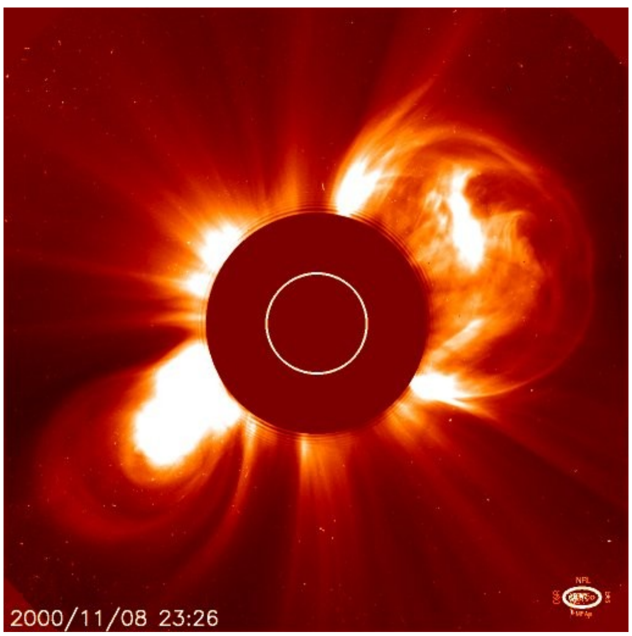


Because of their number, M-class flares can be more of a problem than the X-class flares. Over 16,000 flares were produced on the sun during the last sunspot cycle; Only about 100 of these were X-class flares.

Note how quickly the x-ray intensity increases as the flare reaches its peak. It is not possible to predict in real-time whether a given increase will lead to an X-class event or a less risky C or M-class flare. Accurate classification can only be done after the entire event has completed, which usually takes a few hours after the peak is detected.

Coronal Mass Ejections

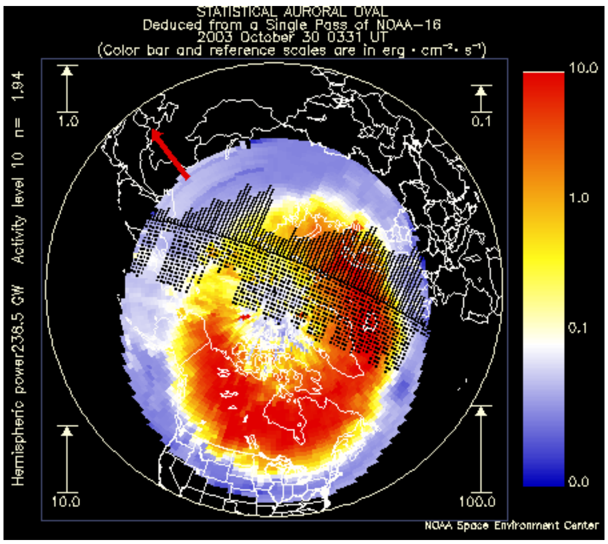
Coronal Mass Ejections (CME) are clouds of plasma and magnetic fields launched from the sun. Most are not directed towards Earth but can nevertheless be viewed leaving the solar vicinity by instruments on the SOHO satellite. They may be caused by magnetic fields in the upper atmosphere of the sun that have become unstable, perhaps because of some powerful disturbance in the solar photosphere or chromosphere such as a large solar flare eruption, or a shockwave from a distant explosion that happens to pass by.



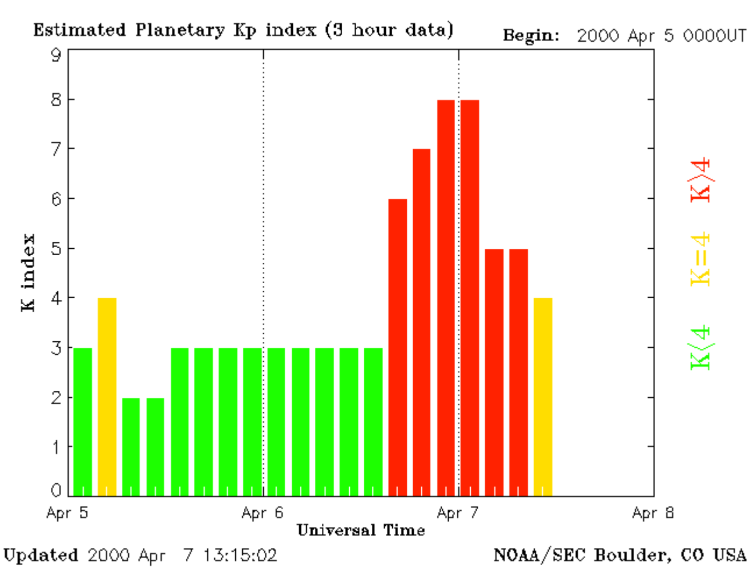
The SOHO satellite detected 1,600 CMEs during the last sunspot cycle between 1996-2008. Many of these were expanding away from Earth because they were produced on the far-side of the sun. About 500 were ejected towards Earth during this 11-year period, mostly during the sunspot maximum years. Most of these Earth-directed CMEs led to minor geomagnetic disturbances because their magnetic fields were oriented in the same direction as Earth's field in the northern hemisphere. 50% of these 'halo' CMEs had favorable 'southward-directed' fields and produced many spectacular aurora and geomagnetic storms. CMEs take up to 4 days to arrive at Earth from the time they are spotted in images such as the one above. The fastest CMEs can make the journey in as little as 15 hours!

Geomagnetic Storms

Arriving at Earth, CMEs compress Earth's magnetic field on the sun-side, and trigger the Northern Lights. They also cause 'geomagnetic storms' which are disturbances in the direction and strength of Earth's magnetic field. Depending



on the scale of the CME and its speed, geomagnetic storms can last for hours or entire days at a time. The severity of the event is usually measured by several geophysical indices, Kp and AA, which directly measure the magnitude of the magnetic changes. The Kp index can vary from 1-2 during mild 'stormy' days, to 8-9 for the most intense magnetic storms. The image shows a geomagnetic storm causing an auroral 'oval' over the North Pole. The NPOESS satellite that created this image can measure how active the auroras are at the present time, but cannot be used to predict conditions days or weeks in the future.

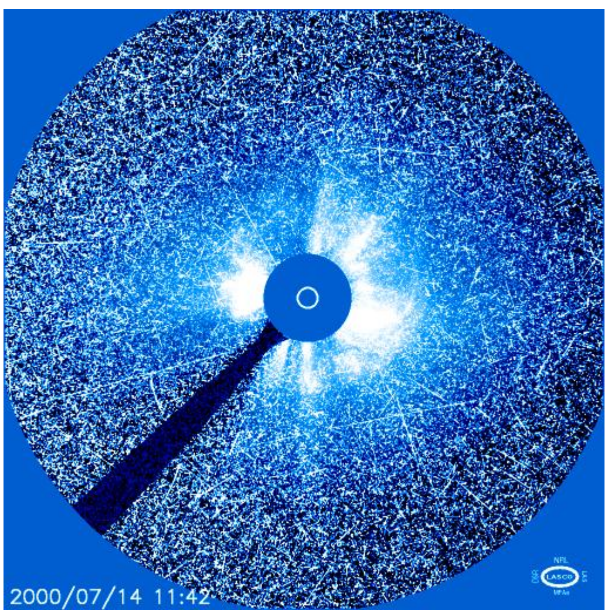


This bar graph of Kp index shows a magnetic storm (red) that occurred on April 7, 2000. The index indicated how much change has occurred in the Earth's magnetic field during the previous 3-hours based on 20 observatory measurements on the ground across the globe. Note how quickly conditions changed from a minor Kp=3 condition to a major storm state with Kp=6-8.

Intense geomagnetic and solar storms are rare during times of sunspot minimum, but become more common around sunspot maximum and the years immediately following sunspot maximum. They are also more common during the equinox months of March and September. Although not all solar flares lead to the ejection of CMEs, the most powerful 'X-class' flares often correlate with large CME events. Consequently, the detection of a strong X-flare may be followed within hours of the ejection of a CME. Moreover, some CMEs produce intense bursts of high-energy protons that are accelerated by the compression of the CME magnetic fields. These 'solar proton events' or SPEs are similar to the Solar Energetic Particle (SEP) events produced by solar flares, but can achieve higher particle energies, leading to enhanced electronic anomalies in computers, and harm to astronauts.

The CME compression of Earth's magnetic field can cause currents to flow in the ionosphere that also induce currents in the ground, affecting telegraph systems and electrical power grids worldwide. In space, geomagnetic storms create the conditions that lead to enhanced charging of satellite and spacecraft surfaces. This can led to degradation of solar panels and discharges that lead to false-commands, data corruption and other electronic anomalies. The SPEs that sometimes occur during the initial phases of CMEs can cause satellite anomalies, electronic ‘false commands’ and data corruption. There are no direct human health effects from CMEs, however the SPEs generated by some CMEs each Earth within an hour and cause increased radiation exposure to astronauts, even when shielded inside spacecraft.

CMEs and their associated phenomena can affect electrical systems and cause false-commands and data corruption. Electrical problems from the induced currents only occur after the CME has arrived at Earth. False-commands and other electrical anomalies in satellite electronics can occur soon after the CME is launched from the sun as the SPEs reach Earth. SPEs are hazardous to astronauts, even when they are operating within Earth's magnetic field. Some CMEs may even be lethal if an astronaut is on EVA. Under normal spacecraft shielding conditions, SPEs slightly elevate the accumulated radiation dosages of astronauts. Since exposure and long-term medical conditions are proportional to accumulated dose over a lifetime, astronauts should always seek out additional shielding when a SPE is in progress.



Solar Proton Events

Solar Proton Events (SPEs), and other energetic particle showers are high energy particles that can penetrate spacesuits and spacecraft and lead to excessive radiation dosages that, over the long term, can accumulate to become a significant hazard. Generally, if a solar active region (e.g. sunspot region) is displaying conditions that may lead to a solar flare, a hightened state of alert for potentially ensuing SEPs is warranted. They can be caused by intense solar flares, but are more commonly related to CMEs withing which intense shock waves can accelerate particles to high energy soon after ejection by the sun.

The image from the SOHO satellite shows a Solar Proton Event causing 'snow' on an imaging sensor. The SEP particles entered the sensor and corrupted the data in thousands of pixels of the image causing the streaks and white points. This condition faded after a few minutes once the CME ejection near the sun began to abate.

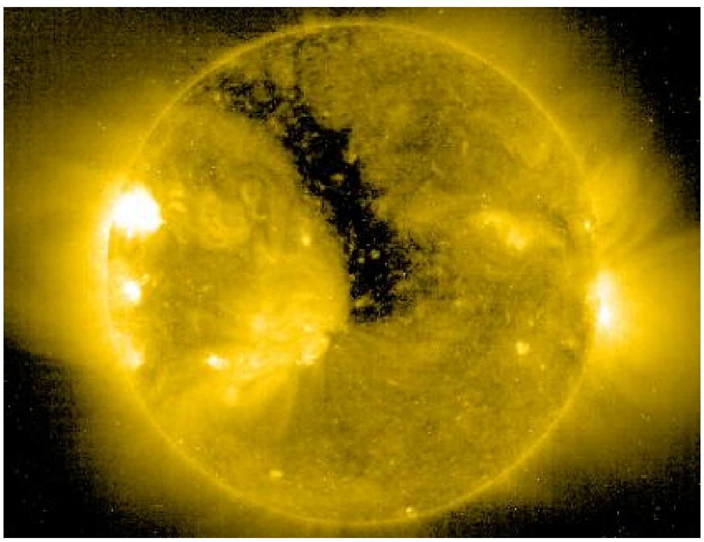
Space walks or other EVAs should probably not be conducted during these states. It is common for ISS astronauts to move operations into more heavily shielded areas of the station for the few hours that an actual flare is in progress, and when SEP particles may be expected to arrive. The arrival of the x-rays is a good harbinger for the SEPs.

Depending on the energy spectrum of the SEPs, they can penetrate many kinds of shielding, and even at low levels, cause computer operations 'anomalies'. These can include data corruption, or 'false commands' which have to be caught and countermanded by satellite or mission operators. At times, computers have to be 'rebooted' or suffer operating system anomalies that can lead to lockups. Generally, low-energy SEPs can be shielded and reduced to low levels, but high-energy SEPs generate secondary particles within the shielding itself leading to additional problems.

Solar flare forecasts (e.g. NOAA) usually state conditions as '80% probability of a flare within the next 24-hours'. When solar flare conditions are forecast, Missions can proceed normally, but astronauts should seek additional shielding opportunities if available, and be alert for any false-commands or data irregularities caused by SEP events during the 1-5 hour period following the actual x-ray flare event.

Coronal Holes

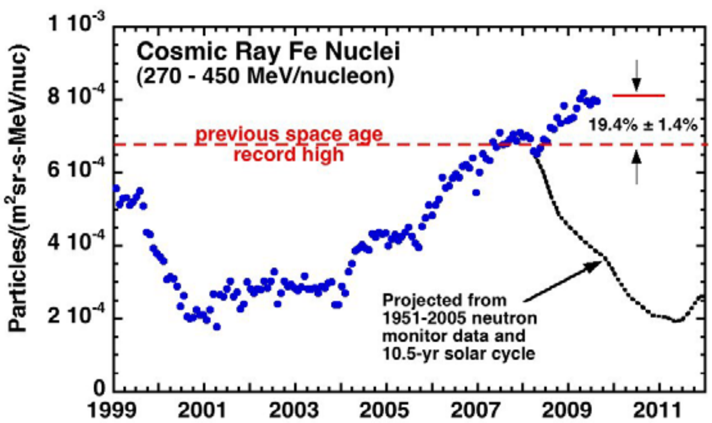
Magnetic fields near the sun sometimes open up into interplanetary space so that charged particles can travel from the sun and deep into interplanetary space. These regions are called coronal holes and are the source of high-speed solar wind streams (HSWS). The pressure of the plasma flowing out of a coronal hole can trigger geomagnetic storms.



As for CME-triggered geomagnetic storms, HSWSs can also produce the Northern Lights, but are not as effective in causing significant electrical disruptions.

Cosmic Rays

These high-energy particles, mostly electrons, protons and low-mass nuclei come from several sources, distant interstellar space beyond our solar system, the heliopause beyond the orbit of Pluto, and the sun itself. Although Earth's magnetic field shields the terrestrial space environment from most of these particles, they are especially common in interplanetary space. During sunspot maximum, the magnetic field of the sun and the solar wind are relatively extended through out the inner solar system, so cosmic ray flows are reduced out to the orbit of mars. During sunspot minimum, the solar field is less extended and so the intensity of cosmic rays in the Earth-mars region is enhanced. Cosmic rays penetrate most forms of shielding, and so remain a hazard to technology and human health.

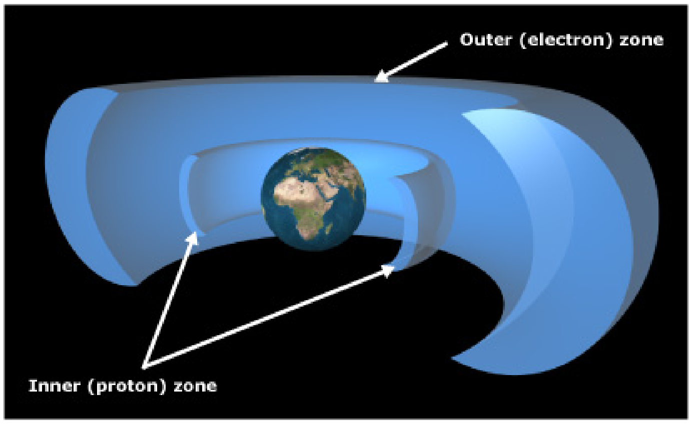


Like SEPs and SPEs associated with solar flares and CMEs, cosmic rays penetrate satellite and spacecraft walls and can cause electrical upsets and 'glitches' in computer systems. These events can cause false-commands and corrupt stored data. Unlike the short-term effects of SEPs and SPEs, cosmic rays are a nearly constant source of background radiation that leads to large accumulated lifetime radiation dosages proportional to the number of days that astronauts are away from Earth and its protecting magnetic field environment.

Cosmic rays contribute to a steady,, daily dose of environmental radiation that is nearly independent of shielding. There is a slight reduction in exposure during times of sunspot maximum conditions provided that astronauts do not leave the inner solar system inside the asteroid belt. The anti-correlation of intensity with solar cycle is the only means of predicting the intensity variation over time. No 'storm' events correlated with cosmic rays are known to exist.

Radiation Belts and Trapped Particles

These are found only in the Earth's environment inside its magnetic field in space. They are not an issue for interplanetary or lunar travel. Although prolonged, unshielded exposure to these high-energy particle belts can be lethal, generally, manned spacecraft only take a small part of an hour to traverse these belts, and in most cases, trajectories avoid the belts entirely.



Satellites that orbit in the belts (GPS) experience frequent glitches in operation, and accumulated radiation aging of satellite systems and electronics. Manned space craft spend so little time traversing the Belts that there is no radiation impact to astronauts unless they are conducting EVAs, which is a very unlikely scenario.

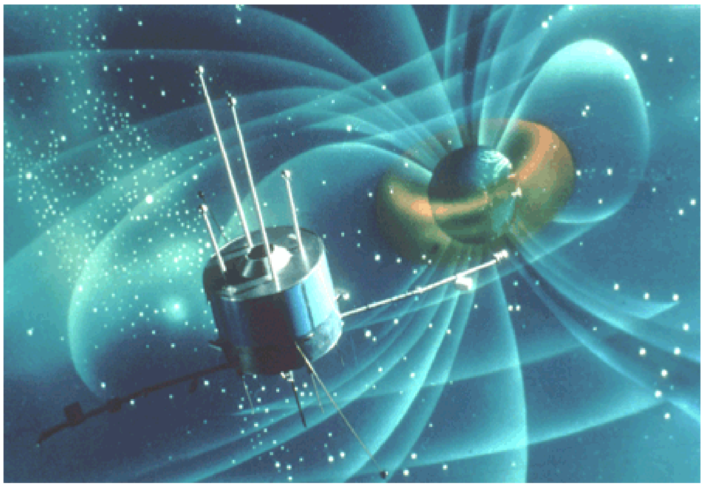
Human Impacts to Astronauts

Lunar Missions: The transit phase is short enough that cosmic rays are not a significant risk factor. It is expected that the 2-3 day journey will not be scheduled during a period when a known solar active region is producing flares or CMEs. If scheduling does not permit launching during a quiet period, magnetically complex regions on the sun will need to be monitored and the NOAA/SEC space weather indices monitored for indications that a solar flare event has a heightened probability. If a halo CME has been launched, and/or an x-ray flare of class M or X detected, astronauts must prepare for the arrival of high-energy particles within the hour. They must return from EVAs and seek out shielded regions in the spacecraft for a duration that could last several hours. Radiation monitors will indicate when the storm event has passed. During the event, computers and other critical digital electronics must also be monitored for signs of data corruption and false-commands. For long-duration stays on the moon, shielding must be available for astronauts either in a landed spacecraft, or beneath lunar regolith in a habitation module.

Mars and Comet Missions: These are long-duration journeys outside Earth's magnetic field. Cosmic rays are a constant background contributing to a steady increase in human dosages. More access to CME plasma will occur as the orbits traverse a lager volume of space through which CMEs are known to travel. As the spacecraft distance from the Earth increases, astronauts will be less and less able to rely on the vantage points provided by Earth-based satellite observations of the sun (SOHO etc) to help forecast upcoming events unless they bring similar imaging technology with them. Increasingly, astronauts will not have advanced knowledge of incoming radiation events being imaged and measured by distant Earth satellites.

Space Weather and Human Impacts

Human life is linked to the behavior of the Sun. Changes in the Sun's long-term brightness cause ice ages, and the 11-year solar cycle of activity causes powerful flares and coronal mass ejections that impact Earth, disrupt telecommunications and navigation, threaten astronauts, damage satellites, and disable electric power grids. As society becomes increasingly dependent on space-based technologies, humankind's vulnerability to space weather becomes more apparent, and the need to understand and mitigate these effects becomes more urgent.



NASA's objective is to understand and predict the causes of space weather by studying the Sun, the heliosphere, and planetary environments as a single connected system. Research into the nature of solar activity and its effects on the solar system will help safeguard the journeys of robotic and human explorers. (NASA Strategic Plan 2006, sub-goal 3B)

The earliest investigations of how solar storms affect our technology began in the mid-1800's. The appearance of large sunspots was found to be correlated with intense aurora, and with telegraph outages. Since then, scientists have explored and theorized about the many ways in which solar activity can cause communications outages, electrical power blackouts and excess radiation exposure to astronauts and even commercial airline passengers and flight crews.

Space weather research spans both the scientific research community, who are trying to understand the Sun-Earth system, and engineering community who are trying to understand how specific technological systems are affected. Because solar flares can increase radiation exposure to astronauts, NASA has been investigating space weather and its mitigation since the beginning of the Space Age.

Most scientists working in this complex area are supported by a variety of research grants from NASA and from the National Science Foundation. The research is routinely published in the open literature. The Department of Defense and many commercial industries (e.g. satellite and electric power) also have research programs to forecast space weather and its impacts, however, this research is generally classified and not openly published.

Since the first astronaut entered space, NASA has paid close attention to the problem of radiation exposure. Since 1960, over 400 astronauts and cosmonauts have been exposed to the space environment from as little as 90 minutes to over 200 days.

The NASA 'Longitudinal Study' has followed the medical histories of each astronaut in minute detail to uncover any signs that their brief exposures have led to increased risks for a variety of known radiation-related, medical conditions.

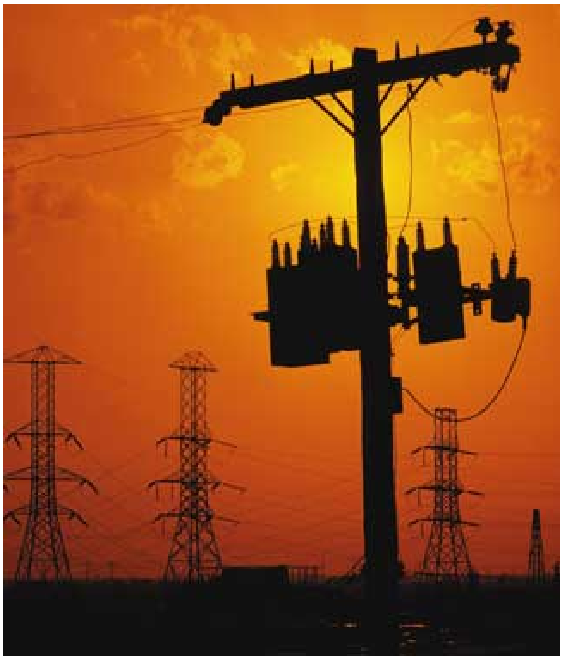
Looking farther ahead to years-long expeditions to Mars, NASA scientists and engineers are working to overcome the daunting challenges of minimizing astronaut radiation dosages, and returning the explorers safely to Earth, with no long-term medical problems.

Since scientists first experimented with radioactive elements and explored the mysteries of cosmic rays, the topic of 'radiation' has been a popular science fiction tool to create monsters. In reality, humans live and work in an environment awash in many forms of natural radiation, and have done so for millions of years. Were it not for this 'background radiation', it is likely that evolution itself would grind to a stop without this relentless mechanism for mutating genes.

Radiation comes in two basic forms: Electromagnetic, and particulate. Each of these forms can be further classified as 'ionizing' or 'non-ionizing' depending on whether the radiation carries enough energy to strip electrons from their atomic imprisonment. Each of these forms has its own complex behavior as it penetrates or is absorbed by matter, whether that matter is in the form of organic material or inert electronic circuitry.

NASA is interested in all forms of radiation that are capable of affecting astronauts and the organic systems they depend on. NASA is also interested in radiation which can alter the operations of electronic circuits which control spacecraft and spacecraft systems.

Solar storms have affected ground-based communications and electrical systems since the time that these systems became commonplace. During the 1800's, telegraph systems were frequently disrupted by severe magnetic storms, such as the spectacular events of August 28 and September 2, 1859.

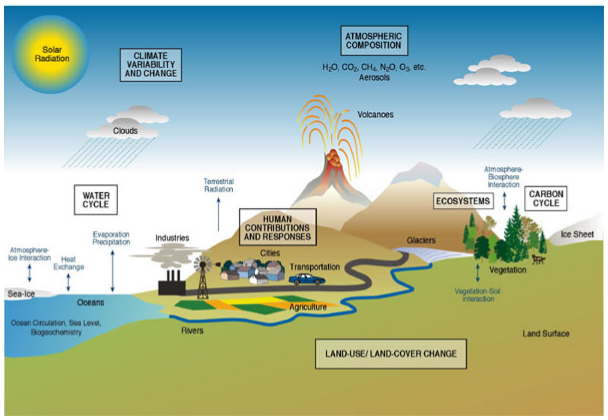


During the 20th Century, solar flares regularly caused so much interference that global shortwave communications outages were a commonplace nuisance during the 1930's - 1950's.

Once elaborate electrical power grids were installed spanning entire continents, they too fell victim to solar storms, such as the major electrical blackouts in Quebec during March, 13, 1989 and southern Sweden on October 29, 2003.

In order to operate economically, modern passenger jets fly at altitudes above 30,000 feet where the atmosphere is less dense providing less friction and greater fuel economy. With little atmosphere to shield them, passenger jets receive substantially higher dosages of cosmic rays and other forms of natural background radiation. This is especially true along the increasingly popular polar routes from New York to destinations in Eastern Asia such as Tokyo and Beijing. Although ordinary passengers need not worry about the slight increases from occasional solar flares, airline crews are coming under increasing scrutiny because of their constant exposure. Some airline companies such as United and American Airlines now take expensive precautionary steps to move flight paths to lower altitudes during solar flares.

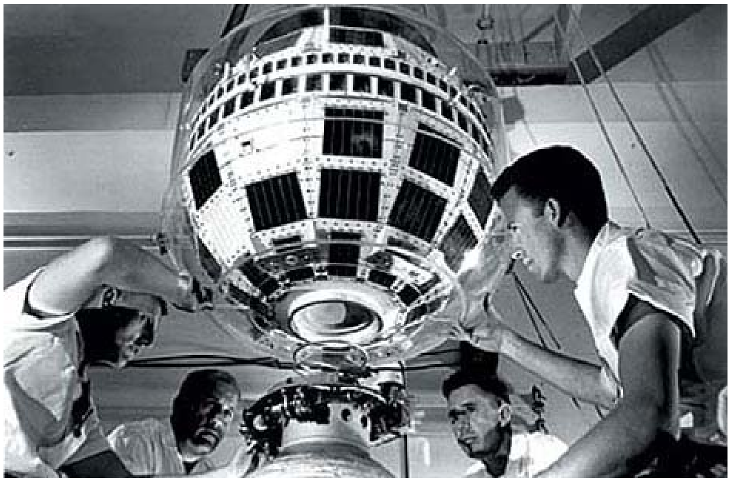
The Maunder Minimum (1645-1715) was a period of time when few sunspots were observed for nearly 70 years, despite careful telescopic studies by multiple observers. This time also corresponded to the European 'Little Ice Age' which brought severe, cold winters to otherwise moderate climates. Scientists now believe that there is a direct connection between sunspot activity and the heating of the atmosphere, which can cause long-term climate changes.



The output of the Sun can vary by up to two tenths of a percent over the 11-year solar cycle. Temporary decreases of up to one-half percent have been observed. Atmospheric scientists say that this variation is significant and that it can modify climate over time. Plant growth has been shown to vary over the 11-year sunspot and 22-year magnetic cycles of the Sun, as evidenced in tree-ring records.

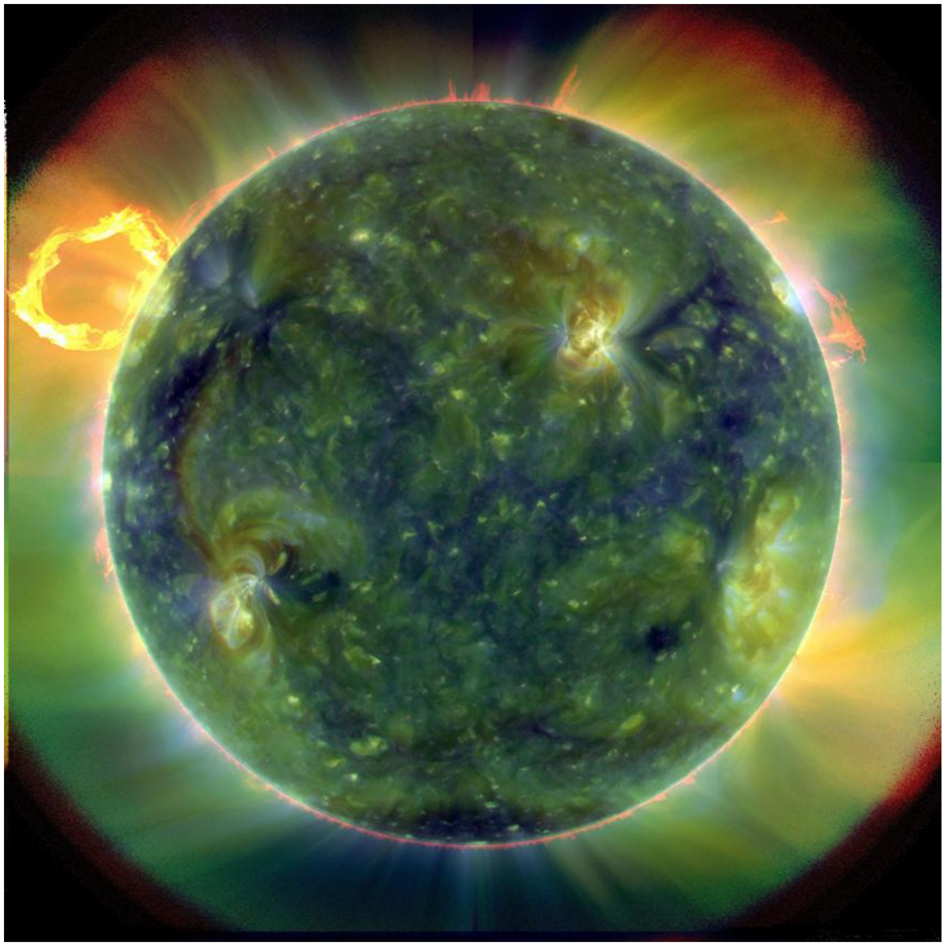
During solar proton events, many more energetic particles reach Earth's middle atmosphere. There they cause molecular ionization, creating chemicals that destroy atmospheric ozone and allow increased amounts of harmful solar ultraviolet radiation to reach Earth's surface. A solar proton event in 1982 resulted in a temporary 70% decrease in ozone densities. During a large solar storm, a portion of the upper stratosphere in the Polar Regions can lose up to 20 percent of its ozone and cool as much as 3°C, an effect that can last for several weeks.

Solar flares and other forms of solar activity have been known to cause problems for satellites and space technology since the dawn of the Space Age.



The first satellite to fail from a space weather event was the Telstar communications satellite launched in July, 1962. A few months later it suffered a malfunction when an electrical component built up a large charge due to constant exposure to the space environment. Technicians powered-down the satellite and then re-started it, which dissipated the extra charge, and the satellite was returned to service. Since then, our current network of over 950 satellites have been affected by solar storms on a regular basis. Most of these effects are brief and barely noticed by ground-based satellite operators. Others have caused complete satellite failure.

Engineers are constantly testing prospective satellite components to make certain that they can withstand the most severe solar storms. The result of this effort has been new generations of satellites that operate for 10 to 15 years or longer, with only occasional episodes of anomalous behavior.



On April 21, 2010 NASA's Solar Dynamics Observatory released its much-awaited 'First Light' images of the sun. The image above shows a full-disk, multi-wavelength, extreme ultraviolet image of the sun taken by SDO on March 30, 2010. False colors trace different gas temperatures. Black indicates very low temperatures near 10,000 K close to the solar surface (photosphere). Reds are relatively cool plasma (a gas consisting of atoms stripped of some of their electrons) heated to 60,000 Kelvin (100,000 F); blues, greens and white are hotter plasma with temperatures greater than 1 million Kelvin (2,000,000 F).

Problem 1 – The radius of the sun is 690,000 kilometers. Using a millimeter ruler, what is the scale of this image in kilometers/millimeter?

Problem 2 – What are the smallest features you can find on this image, and how large are they in kilometers, and in comparison to Earth if the radius of Earth is 6378 kilometers?

Problem 3 – Where is the coolest gas (coronal holes), and the hottest gas (micro flares), located in this image?

Problem 1 – The radius of the sun is 690,000 kilometers. Using a millimeter ruler, what is the scale of these images in kilometers/millimeter?

Answer: The diameter of the Sun is 98 millimeters, so the scale is 1,380,000 km/98 mm = **14,000 km/mm**.

Problem 2 – What are the smallest features you can find on this image, and how large are they in kilometers, and in comparison to Earth if the radius of Earth is 6378 kilometers?

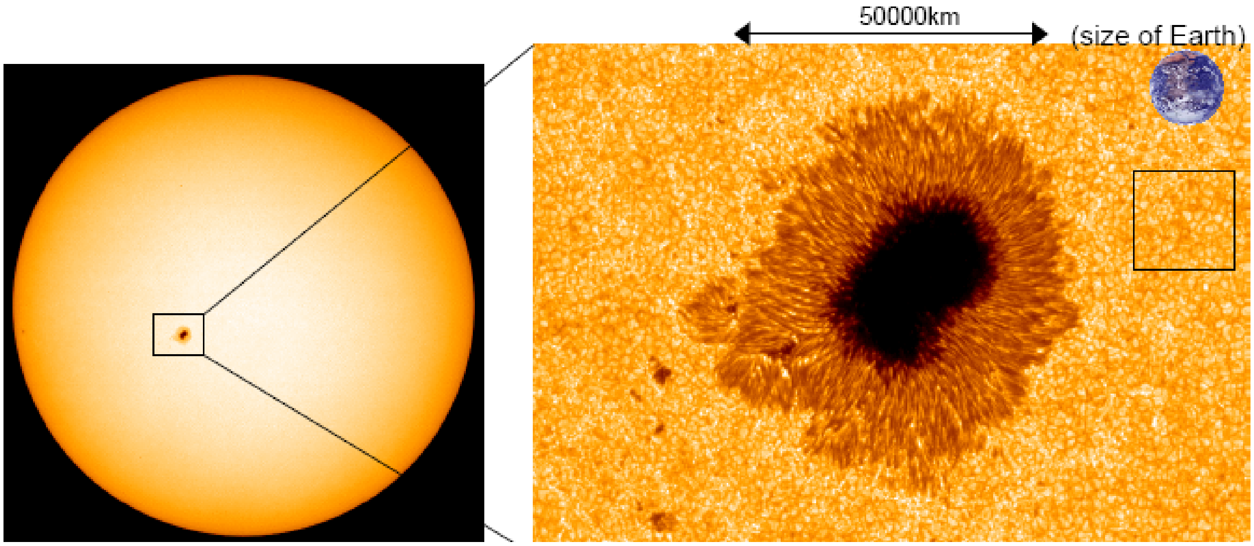
Answer: **Students should see numerous bright points speckling the surface, the smallest of these are about 0.5 mm across or 7,000 km. This is slightly larger than ½ the diameter of Earth.**

Problem 3 – Where is the coolest gas (coronal holes), and the hottest gas (micro flares), located in this image?

Answer: **There are large irregular blotches all across the disk of the sun that are dark blue-black. These are regions where there is little of the hot coronal gas and only the 'cold' photosphere can be seen. The hottest gas seems to reside in the corona, and in the very small point-like 'microflare' regions that are generally no larger than the size of Earth**.

Note: Microflares were first observed, clearly, by the Hinode satellite between 2007-2009. Some solar physicists believe that these microflares, which erupt violently, are ejecting hot plasma that eventually ends up in the corona to replenish it. Because the corona never disappears, these microflares happen all the time no matter what part of the sunspot cycle is occurring.

Close-up of a Sunspot by Hinode



After a successful launch on September 22, 2006 the Hinode solar observatory caught a glimpse of a large sunspot on November 4, 2006. An instrument called the Solar Optical Telescope (SOT) captured this image, showing sunspot details on the solar surface.

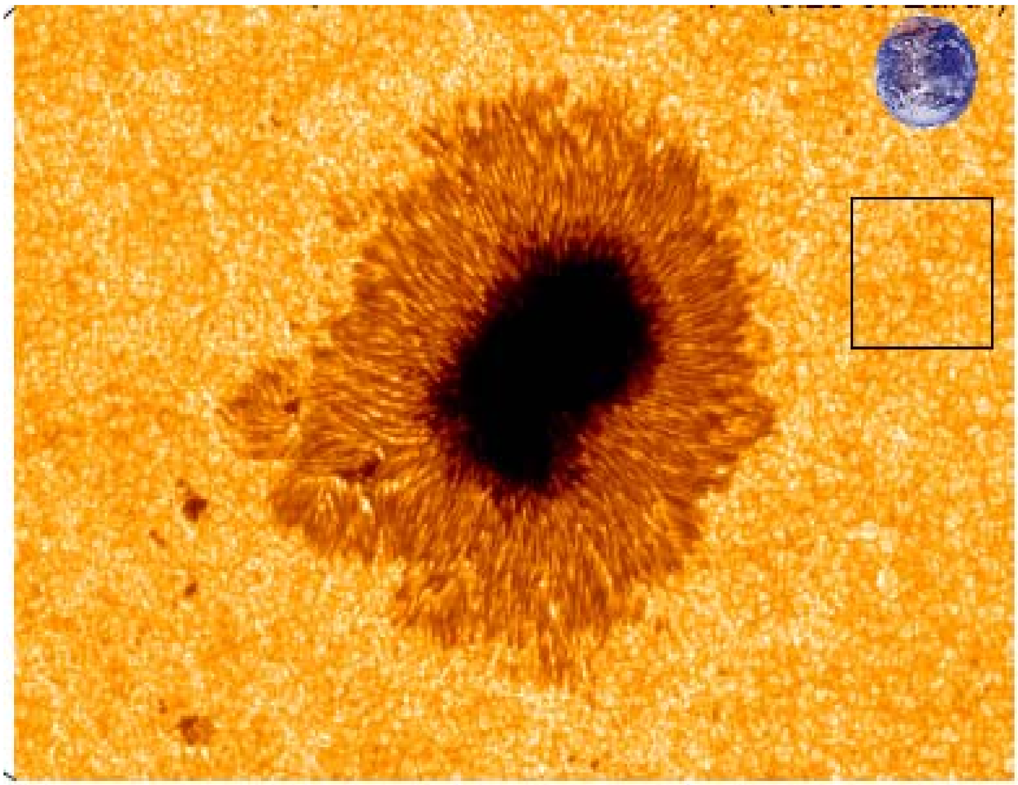
Problem 1 - Based on the distance between the arrow points, what is the scale of the image on the right in units of kilometers per millimeter?

Problem 2 - What is the size of the smallest detail you can see in the image?

Problem 3 - Compared to familiar things on the surface of Earth, how big would the smallest feature in the solar image be?

Problem 4 - The gold-colored, textured surface is the photosphere of the sun. The texturing is produced by heated gas that is flowing up to the surface from the hot interior of the sun. The convecting gases form cells, called granulations, at the surface, with upwelling gas flowing from the center of each cell, outwards to the cell boundary, where it cools and flows back down to deeper layers. What is the average size of a granulation cell within the square?

Problem 5 - Measure several granulation cells at different distances from the sunspot, and plot the average size you get versus distance from the spot center. Do granulation cells have about the same size near the sunspot, or do they tend to become larger or smaller as you approach the sunspot?



Problem 1 - From the 40 millimeter length of the 50,000 km arrow marker, the scale of the image is 50,000 km/40 mm = 1250 kilometers per millimeter

Problem 2 - Depending on the copy quality, the smallest detail is about 0.5 millimeters or 0.5 x 1250 = 625 kilometers across but details that are 1 or 2 mm across are also acceptable.

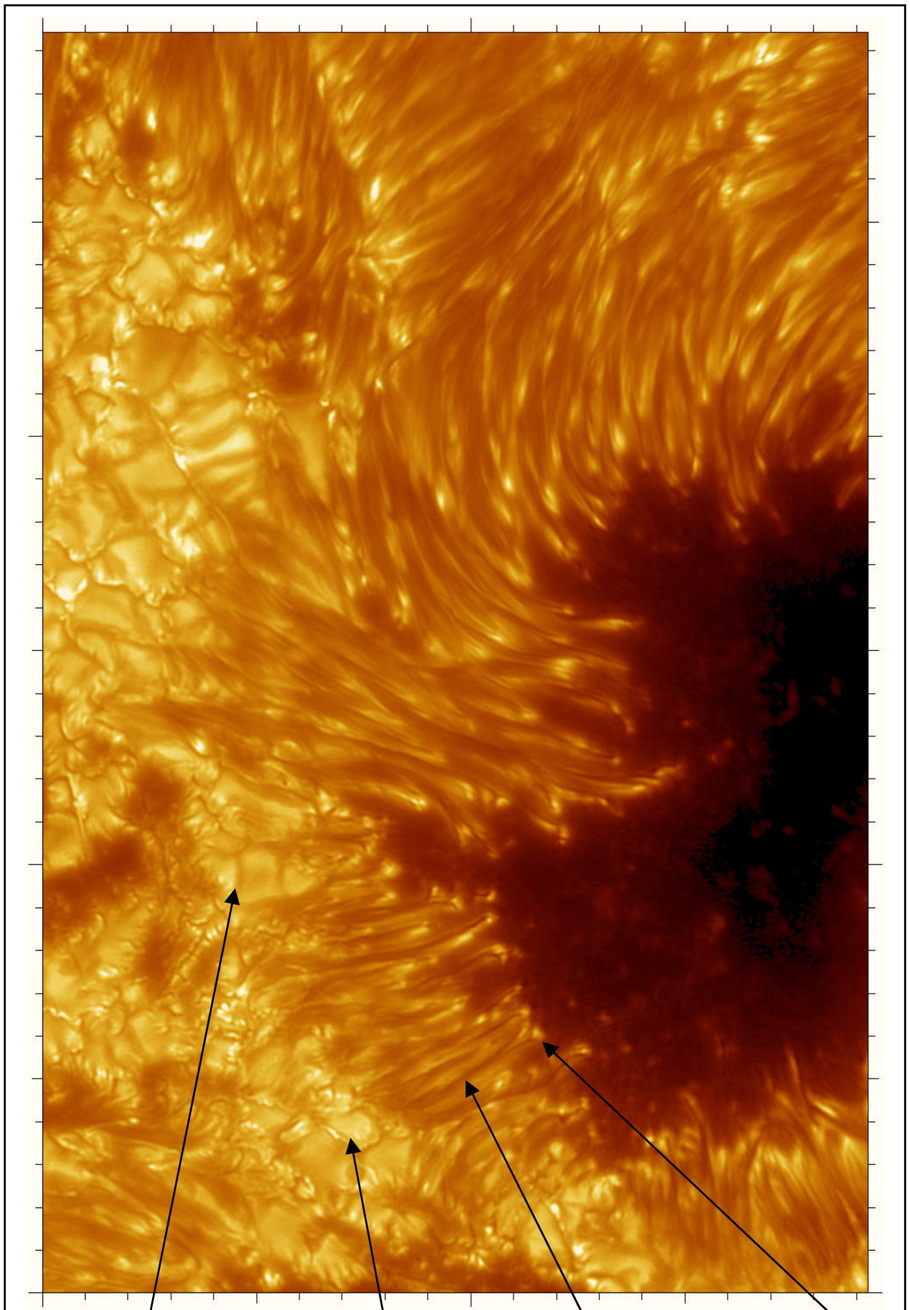
Problem 3 - Similar features on Earth would be continents like Greenland (1,800 km) or England (700 km).

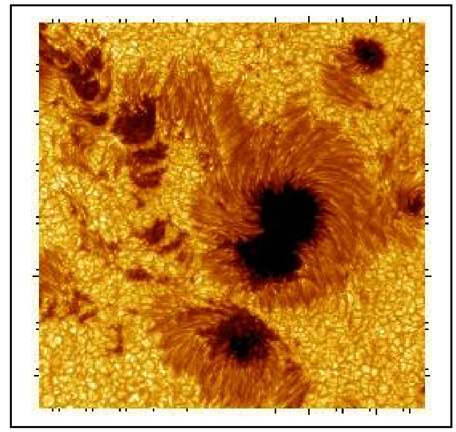
Problem 4 - Measure about 5 cells to get: 1.5 mm, 1.0 mm, 0.8mm, 1.2mm and 1.4 mm. The average is about 1.2 mm, so the average size is (1.2) x 1250km = 1,500 km.

Problem 5 - Students should measure about 5 granulation cells in three groups; Group 1 should be far from the center of the spot. Group 3 should be as close to the outer, tan-colored, 'penumbra' of the spot as possible, and Group 2 should be about half-way in between Group 1 and 3. The average granulation sizes do not change significantly.

Solar Surface Details with the Swedish Vacuum Telescope

The sun is our nearest star. From Earth we can see its surface in great detail. The images below were taken with the 1-meter Swedish Vacuum Telescope on the island of La Palma, by astronomers at the Royal Swedish Academy of Sciences. The image to the right is a view of sunspots on July 15, 2002. The enlarged view to the left shows never-before-seen details near the edge of the largest spot. Use a millimeter ruler, and the fact that the dimensions of the left image are 19,300 km x 29,500 km, to determine the scale of the photograph, and then answer the questions. See the arrows below to identify the various solar features mentioned in the questions.





Problem 1 - What is the scale of the image in km/mm?

Problem 2 – What is the smallest feature you can see in the image?

Problem 3 – What is the average size of a solar granulation region?

Problem 4 – How long and wide are the Dark Filaments?

Problem 5 – How large are the Bright Spots?

Problem 6 – Draw a circle centered on this picture that is the size of Earth (radius = 6,378 km). How big are the features you measured compared to familiar Earth features?

Problem 1 - What is the scale of the image in km/mm? **Answer:** the image is about 108mm x 164mm so the scale is 19300/108 = 179 km/mm.

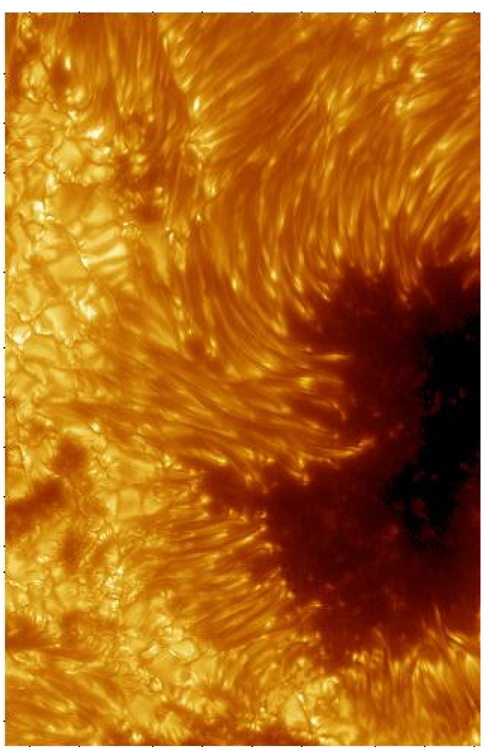
Problem 2 – What is the smallest feature you can see in the image? **Answer:** Students should be able to find features, such as the Granulation Boundaries, that are only 0.5 mm across, or 0.5 x 179 = 90 km across.

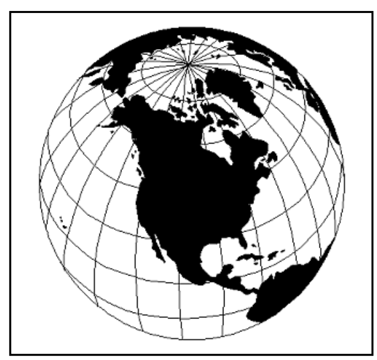
Problem 3 – What is the average size of a solar granulation region? **Answer:** Students should measure several of the granulation regions. They are easier to see if you hold the image at arms length. Typical sizes are about 5 mm so that 5 x 179 is about 900 km across.

Problem 4 – How long and wide are the Dark Filaments? **Answer:** Students should average together several measurements. Typical dimensions will be about 20mm x 2mm or 3,600 km long and about 360 km wide.

Problem 5– How large are the Bright Spots? **Answer:** Students should average several measurements and obtain values near 1 mm, for a size of about 180 km across.

Problem 6 – Draw a circle centered on this picture that is the size of Earth (radius = 6,378 km). How big are the features you measured compared to familiar Earth features? **Answer:** See below.





Granulation Region – Size of a large US state.

Bright Spot – Size of a small US state or Hawaii

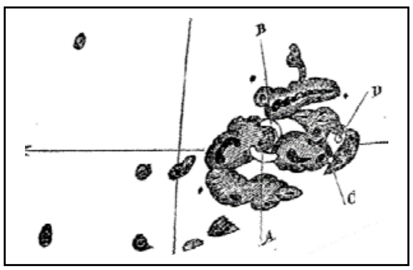
Filament – As long as the USA, and as narrow as Baja California or Florida.

Monster Sunspots! 4

Sunspots have been observed for thousands of years because, from time to time, the sun produces spots that are so large they can be seen from Earth with the naked eye…with the proper protection. Ancient observers would look at the sun near sunrise or sunset when Earth's atmosphere provided enough shielding to very briefly look at the sun for a few minutes. Astronomers keep track of these large 'super spots' because they often produce violent solar storms as their magnetic fields become tangled up into complex shapes.

Below are sketches and photographs of some large sunspots that have been observed during the last 150 years. They have been reproduced at scales that make it easy to study their details, but do not show how big they are compared to each other.

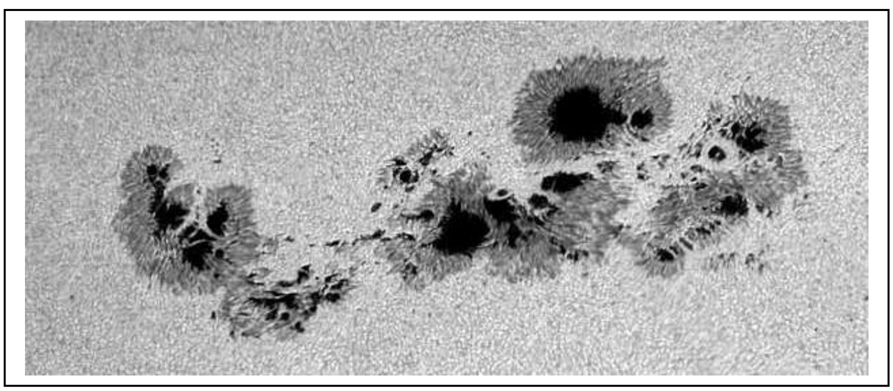
Problem: By using a millimeter ruler, use the indicated scales for each image to compute the physical sizes of the three sunspots in kilometers. Can you sort them by their true physical size?

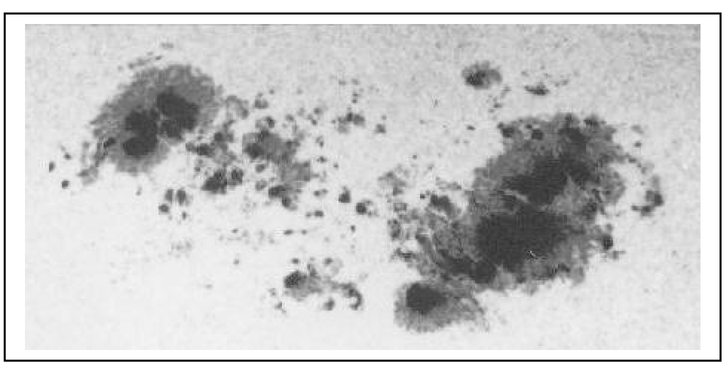


Top is the sunspot drawn by Richard Carrington on August 28, 1859 at a scale of 5,700 kilometers/mm.

Middle is a photograph of a sunspot seen on March 29, 2000 at a scale of 23,500 kilometers/cm.

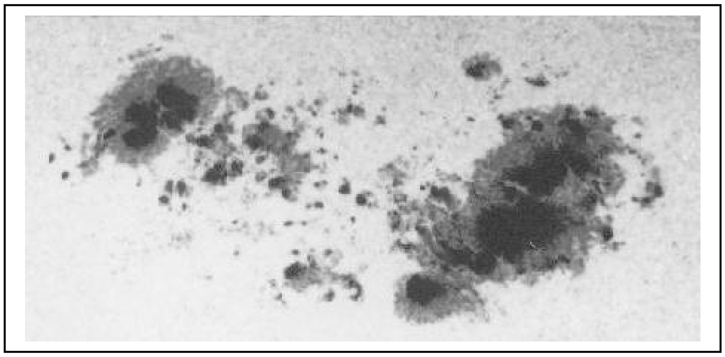
Bottom is a sunspot seen on April 8, 1947 at a scale of 100,000 kilometers/inch



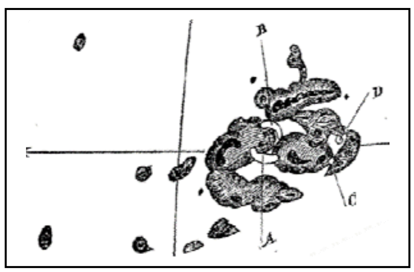


Answer Key:

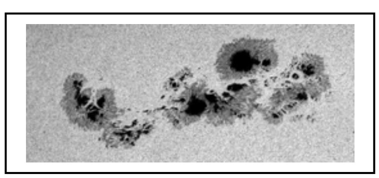
Images ordered from largest to smallest and to scale:



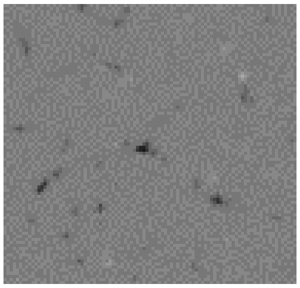
Sunspot seen on April 8, 1947 reproduced at a scale of 100,000 kilometers/inch. The linear extent on the page is 7 centimeters, so the length in inches is 7 / 2.5 = 2.8 inches. The true length is then 2.8 x 100,000 = <u>280,000 kilometers.</u>



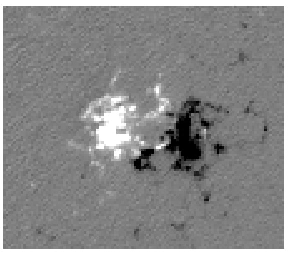
The sunspot drawn by Richard Carrington on August 28, 1859 at a scale of 5,700 kilometers/mm. With a ruler, the distance from the left to the right of the group is about 40 millimeters, so the true length is about 40 x 5,700 = <u>228,000 kilometers.</u>



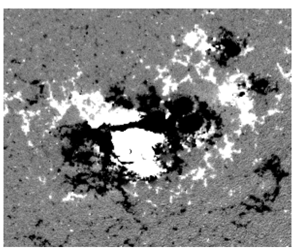
A photograph of a sunspot seen on March 29, 2000 at a scale of 23,500 kilometers/cm. The length of the spot is 90 millimeters or 9 centimeters. The true length is then 211,500 kilometers.



September 29, 2008
Alpha-Pores



June 2, 2009
Beta - Simple spot



October 29, 2003
Gamma - Complex spot

Solar flares are produced by magnetic releases of energy in sunspots. The more complex the magnetic field, the more likely a solar flare will result. Sunspots are magnetically classified according to the alpha, beta, gamma, and delta 'Mt Wilson' scheme:

α ….. A group having only one polarity.

β…… A group of magnetic polarities, with a simple division between them.

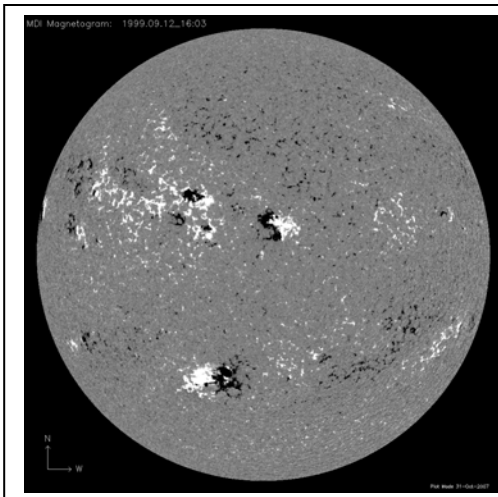
β–γ …A bipolar group in which no continuous line can be drawn separating spots of opposite polarities.

γ…….. A complex active region not classifiable as a bipolar group.

δ……. A complex magnetic configuration consisting of opposite polarity umbrae within the same penumbra.

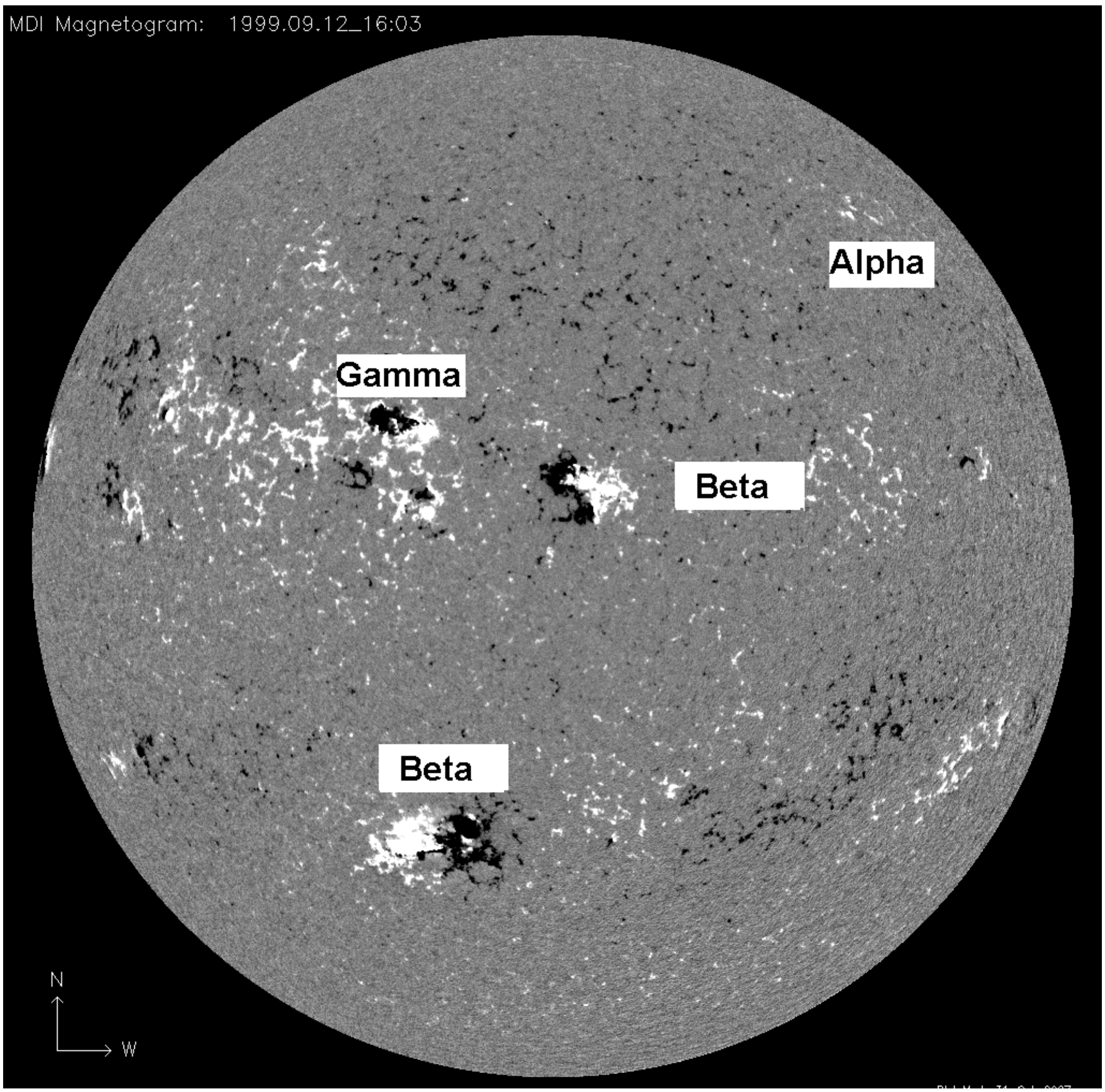
The images to the left are from the SOHO/MDI instrument in which North polarities are white and South polarities are black. Solar flares are more common in sunspots with complex magnetic classifications such as β–γ, γ or δ.

Problem 1 - What classifications would you assign to the sunspots in the bottom image obtained on September 12, 1999?

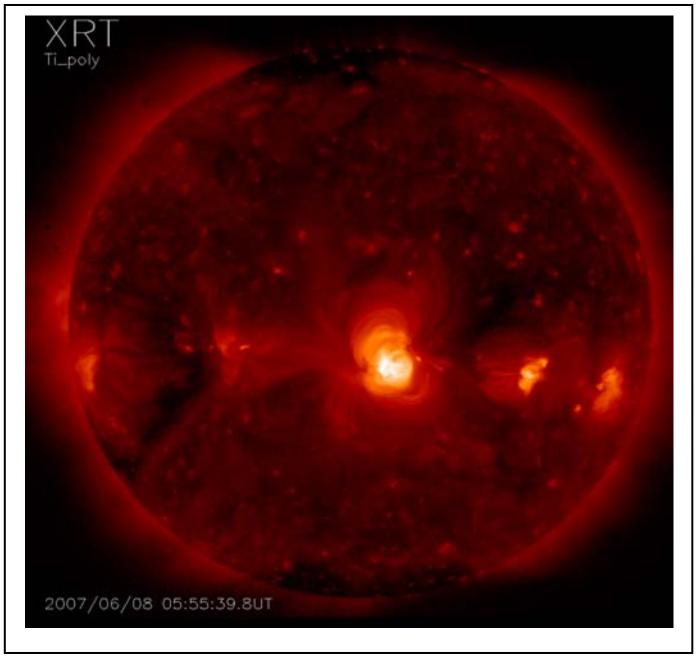


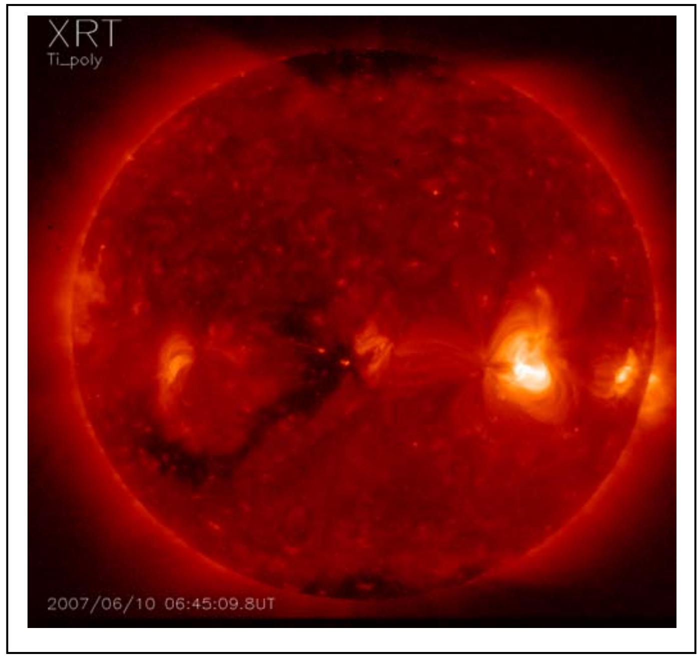
The SOHO/MDI instrument website has a complete archive of full-sun magnetograms at **http://soi.stanford.edu/production/mag_gifs.html**. Classifications can be found in the Solar Region Summaries at the Space Weather Prediction Center:
http://www.swpc.noaa.gov/ftpmenu/forecasts/SRS.html

Problem 1 - What classifications would you assign to the sunspots in the bottom image obtained on September 12, 1999?
Answer: The image below has the suggested classifications for the major active regions. Assignment of a classification to the more complex spots can be difficult for non-professionals, but students should be able to distinguish the major classes, α, β and γ.



Using Hinode to Estimate Solar Rotation





The sun, like many other celestial bodies, spins around on an axis that passes through its center. The rotation of the sun, together with the turbulent motion of the sun's outer surface, work together to create magnetic forces. These forces give rise to sunspots, prominences, solar flares and ejections of matter from the solar surface.

The X-ray telescope on the Hinode satellite creates movies of the rotating sun, and makes it easy to see this motion. A pair of these images is shown above taken on June 8, 2007 (Left); June 10 2007 (Right) at around 06:00 UT.

Although the sun is a sphere, it appears as a flat disk in these pictures when in fact the center of the sun is bulging out of the page at you! We are going to neglect this distortion and estimate how many days it takes the sun to spin once around on its axis.

The radius of the sun is 696,000 kilometers.

Problem 1 - Using the information provided in the images, calculate the speed of the sun's rotation in kilometers/sec and in miles/hour.

Problem 2 – About how many days does it take to rotate once at the equator?

Inquiry Question: What geometric factor produces the largest uncertainty in your estimate, and can you come up with a method to minimize it to get a more accurate rotation period?

Answer Key:

Problem 1 - Using the information provided in the images, calculate the speed of the sun's rotation in kilometers/sec and in miles/hour.

First, from the diameter of the sun's disk, calculate the image scale of each picture in kilometers per millimeter.

Diameter= 76 mm. so radius = 38 mm. Scale = (696,000 km)/38 mm = 18,400 km/mm

Then, find the center of the sun disk, and using this as a reference, place the millimeter ruler parallel to the sun's equator, measure the distance to the very bright 'active region' to the right of the center in each picture. Convert the millimeter measure into kilometers using the image scale.

Picture 1: June 8 distance = 4 mm d = 4 mm (18,400 km/mm) = 74,000 km
Picture 2; June 10 distance = 22 mm d = 22 mm (18,400 km/mm) = 404,000 km

Calculate the average distance traveled between June 8 and June 10.

Distance = (404,000 - 74,000) = 330,000 km

Divide this distance by the number of elapsed days (2 days)…………….. 165,000 km/day

Convert this to kilometers per hour………………………………………….. 6,875 km/hour

Convert this to kilometers per second……………………………………….. 1.9 km/sec

Convert this to miles per hour ……………………………………………… 4,400 miles/hour

Problem 2 – About how many days does it take to rotate once at the equator?

The circumference of the sun is 2 π (696,000 km) = 4,400,000 kilometers.

The equatorial speed is 66,000 km/day so the number of days equals
4,400,000/165,000 = **26.6 days.**

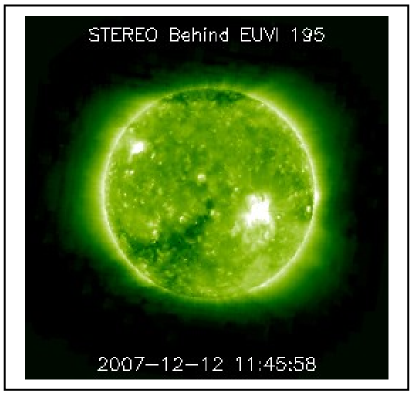
Inquiry Question:
Because the sun is a sphere, measuring the distance of the spot from the center of the sun on June 10 gives a distorted linear measure due to foreshortening.

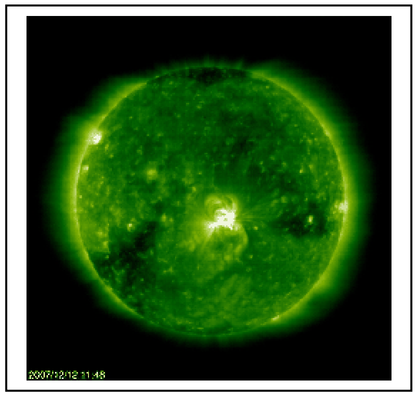
The sun has rotated about 20 degrees during the 2 days, so that means a full rotation would take about (365/20) x 2 days = 36.5 days which is closer to the equatorial speed of the sun of 35 days.

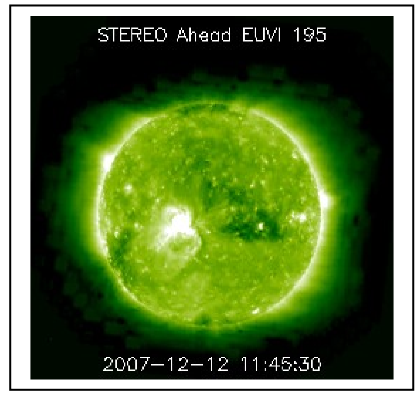
Seeing Solar Storms in STEREO

Two NASA, STEREO satellites take images of the sun and its surroundings from two separate vantage points along Earth's orbit. From these two locations, one located ahead of the Earth, and the other located behind the Earth along its orbit, they can create stereo images of the 3-dimensional locations of solar storms on or near the solar surface.

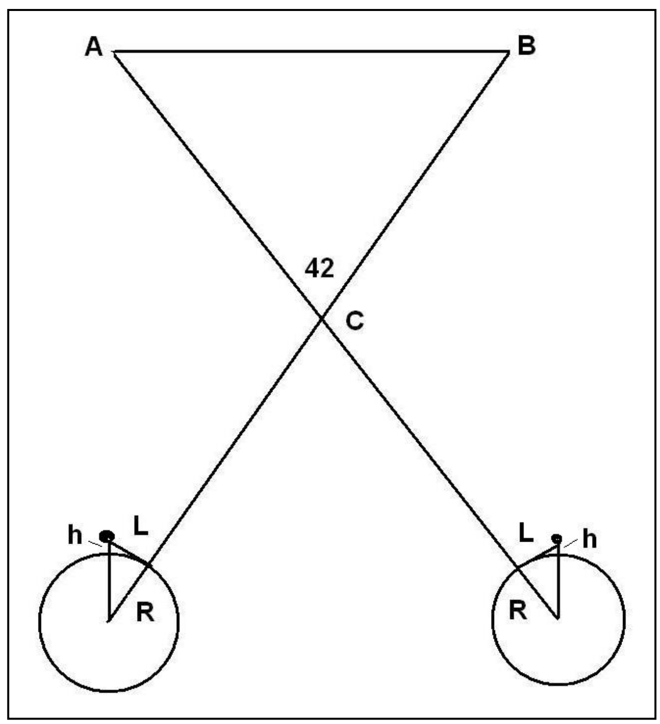
The three images below, taken on December 12, 2007, combine the data from the two STEREO satellites (left and right) taken from these two locations, with the single image taken by the SOHO satellite located half-way between the two STEREO satellites (middle). Notice that there is a large storm event, called Active Region 978, located on the sun. The changing location of AR978 with respect to the SOHO image shows the perspective change seen from the STEREO satellites. You can experience the same *Parallax Effect* by holding your thumb at arms length, and looking at it, first with the left eye, then with the right eye. The location of your thumb will shift in relation to background objects in the room.







The diagram to the right shows the relevant parallax geometry for the two satellites A and B, separated by an angle of 42 degrees as seen from the sun. The diagram lengths are not drawn to scale. The radius of the sun is 696,000 km.



Problem 1: With a millimeter ruler, determine the scale of each image in km/mm. How many kilometers did AR978 shift from the center position (SOHO location for AR) between the two STEREO images? This is the average measure of 'L' in the diagram.

Problem 2: Using the Pythagorean Theorem, determine the equation for the height, h, in terms of R and L. Assume the relevant triangle is a right triangle.

Problem 3: How high (h) above the sun's surface, called the photosphere, was the AR978 viewed by STEREO and SOHO on December 12, 2007?

Answer Key

Problem 1: With a millimeter ruler, determine the scale of each image in km/mm. How many kilometers did AR978 shift from the center position (SOHO location for AR) between the two STEREO images? This is the measure of 'L' in the diagram.

Answer:

STEREO-Left image, sun diameter = 28 mm, actual = 1,392,000 km, so the scale is
1392000 km / 28mm = **49,700 km/mm**
SOHO-center sun diameter = 36 mm, so the scale is
1392000 km/36mm = **38,700 km/mm**
STEREO-right sun diameter = 29 mm, so the scale is
1392000 km / 29 mm = **48,000 km/mm**

Taking the location of the SOHO image for AR978 as the reference, the left-hand image shows that AR978 is about 5 mm to the right of the SOHO location which equals 5 mm x 49,700 km/mm = 248,000 km. From the right-hand STEREO image, we see that AR978 is about 5 mm to the left of the SOHO position or 5 mm x 48,000 km/mm = 240,000 km.
The average is 244,000 kilometers.

Problem 2: Using the Pythagorean Theorem, determine the equation for the height, h, in terms of R and L.

Answer: $(R + h)^2 = R^2 + L^2$

$$h = (R^2 + L^2)^{1/2} - R$$

Problem 3: How high (h) above the sun's surface, called the photosphere, was the AR978 viewed by STEREO and SOHO on December 12, 2007?

Answer: $h = ((244{,}000)^2 + (696{,}000)^2)^{1/2} - 696{,}000$

$$h = 737{,}500 - 696{,}000$$

$$h = 41{,}500 \text{ kilometers}$$

Hinode Studies Loopy Sunspots!

The solar surface is not only a hot, convecting ocean of gas, but is laced with magnetism. The sun's magnetic field can be concentrated into sunspots, and when solar gases interact with these magnetic fields, their light lets scientists study the complex 'loopy' patterns that the magnetic fields make as they expand into space. The above image was taken by NASA's TRACE satellite and shows one of these magnetic loops rising above the surface near two sunspots. The horseshoe shape of the magnetic field is anchored at its two 'feet' in the dark sunspot regions. The heated gases become trapped by the magnetic forces in sunspot loops, which act like magnetic bottles. The gases are free to flow along the lines of magnetic force, but not across them. The above image only tells scientists where the gases are, and the shape of the magnetic field, which isn't enough information for scientists to fully understand the physical conditions within these magnetic loops. Satellites such as Hinode carry instruments like the EUV Imaging Spectrometer, which lets scientists measure the temperatures of the gases and their densities as well.

Problem 1: The Hinode satellite studied a coronal loop on January 20, 2007 associated with Active Region AR 10938, which was shaped like a semi-circle with a radius of 20,000 kilometers, forming a cylindrical tube with a base radius of 1000 kilometers. What was the total volume of this magnetic loop in cubic centimeters assuming that it is shaped like a cylinder?

Problem 2: The Hinode EUV Imaging Spectrometer was able to determine that the density of the gas within this magnetic loop was about 2 billion hydrogen atoms per cubic centimeter. If a hydrogen atom has a mass of 1.6×10^{-24} grams, what was the total mass of the gas trapped within this cylindrical loop in metric tons?

Answer Key:

Problem 1: The Hinode satellite studied a coronal loop on January 20, 2007 associated with Active Region AR 10938, which was shaped like a semi-circle with a radius of 20,000 kilometers, forming a cylindrical tube with a base radius of 1000 kilometers. What was the total volume of this magnetic loop in cubic centimeters assuming that it is shaped like a cylinder?

Answer: The length (h) of the cylinder is 1/2 the circumference of the circle with a radius of 20,000 km or $h = 1/2\ (2\pi\ R) = 3.14 \times 20{,}000$ km = 62,800 km

The volume of a cylinder is $V = \pi\ R^2\ h$ so that the volume of the loop is

$V = \pi\ (1000\ \text{km})^2 \times 62{,}800$ km

$= 2.0 \times 10^{11}$ cubic kilometers.

1 cubic kilometer = 10^{15} cubic centimeters so

= **2.0×10^{26} cubic centimeters**

Problem 2: The Hinode EUV Imaging Spectrometer was able to determine that the density of the gas within this magnetic loop was about 2 billion hydrogen atoms per cubic centimeter. If a hydrogen atom has a mass of 1.6×10^{-24} grams, what was the total mass of the gas trapped within this cylindrical loop in metric tons?

Answer: The total mass is the product of the density times the volume, so

Density = 2×10^9 particles/cc x (1.6×10^{-24} grams/particle) = 3.2×10^{-15} grams/cm^3

The approximate volume of the magnetic loop in cubic centimeters is

$V = (2.0 \times 10^{11}\ \text{km}^3) \times (1.0 \times 10^{15}\ \text{cm}^3/\text{km}^3)$

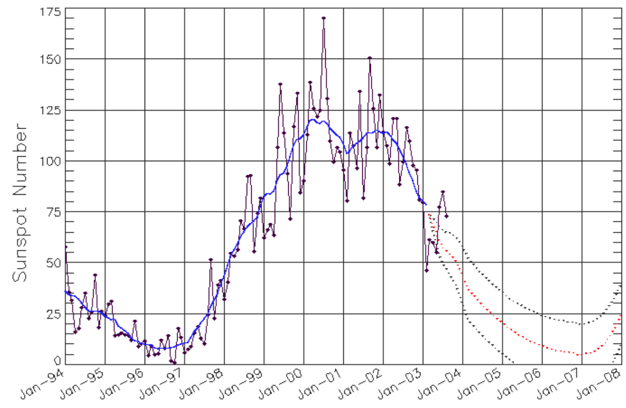
$= 2.0 \times 10^{26}\ \text{cm}^3$

Mass = Density x Volume = (3.2×10^{-15} grams/cm^3) x (2.0×10^{26} cm^3) = $6.4 \times 10^{26-15}$ = 6.4×10^{11} grams or 6.4×10^{8} kilograms or **640,000 metric tons.**

Sunspot cycles

The Sun is an active star that goes through cycles of high and low activity. Scientists mark these changes by counting sunspots. The numbers of spots increase and decrease about every 11 years in what scientists call the Sunspot Cycle.

This activity will let you investigate how many years typically elapse between the sunspot cycles. Is the cycle really, exactly 11-years long?



The sunspot cycle between 1994 and 2008

Scientists study many phenomena that run in cycles. The Sun provides a number of such 'natural rhythms' in the solar system.

- Sequences of numbers often have maximum and minimum values that re-occur periodically.

Here's how to do it!

Consider the following measurements taken every 5 minutes:

100, 200, 300, 200, 100, 200, 300, 200

1. **There are two maxima (value '300').**
2. **The maxima are separated by 4 intervals.**
3. **The cycle has a period of 4 x 5 = 20 minutes.**
4. **The pairs of minima (value = 100) are also separated by this same period of time.**

Now you try!

Sunspot Numbers

Solar Maximum | Solar Minimum

Year	Number	Year	Number
2000	125	1996	9
1990	146	1986	14
1980	154	1976	13
1969	106	1964	10
1957	190	1954	4
1947	152	1944	10
1937	114	1933	6
1928	78	1923	6
1917	104	1913	1
1905	63	1901	3
1893	85	1889	6
1883	64	1879	3
1870	170	1867	7

This table gives the sunspot numbers for pairs of maximums and minimums in the sunspot cycle.

1) From the solar maximum data, calculate the number of years between each pair of maxima.

2) From the solar minimum data, calculate the number of years between each pair of minima.

3) What is the average time between solar maxima?

4) What is the average time between solar minima?

5) Combining the answers to #3 and #4, what is the average sunspot cycle length?

Answer Key

Problem 1)
Maxima Table:

Year	Difference
2000	
1990	10
1980	10
1969	11
1957	12
1947	10
1937	10
1928	9
1917	11
1905	12
1893	12
1883	10
1870	13

Problem 2)
Minima Table:

Year	Difference
1996	
1986	10
1976	10
1964	12
1954	10
1944	10
1933	11
1923	10
1913	10
1901	12
1889	12
1879	10
1867	12

Problem 3)

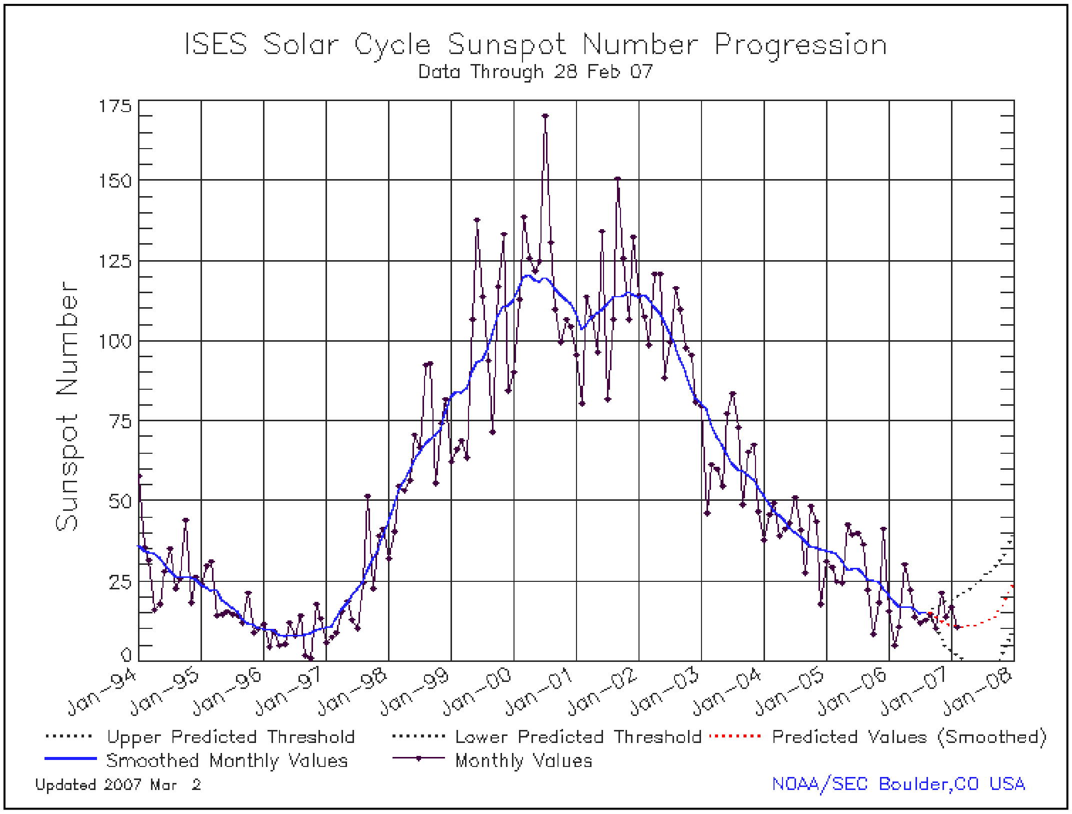
Average time = (10 + 10 + 11 + 12 + 10 + 10 + 9 + 11 + 12 + 12 + 10 + 13)/12 = 130/12 = 10.8 years between sunspot maxima.

Problem 4)

Average time = (10 + 10 + 12 + 10 + 10 +11 + 10 + 10 + 12 + 12 + 10 + 12)/12 = 129/12 = 10.8 years between sunspot maxima.

Problem 5)

Average length = (10.8 + 10.8) / 2 = 10.8 years.



The above plot shows the current sunspot cycle (Number 23) based on the average monthly sunspot counts since January, 1994.

Problem 1 - About when (month and year) did Sunspot Cycle 23 begin?

Problem 2 - About when (month and year) did Sunspot Cycle 23 reach its maximum?

Problem 3 - A) What was the average minimum sunspot count during the years of the previous sunspot minimum? B) What do you think the average sunspot count will be during the current sunspot minimum?

Problem 4 - What is the number of years between sunspot minima to the nearest tenth of a year?

Problem 5 - How long did Cycle 23 take to reach sunspot maximum?

Problem 6 - When (year, month) do you predict we will reach sunspot maximum during the next cycle (Cycle 24)?

Problem 7 - When (year, month) do you think the next sunspot minimum will occur?

Problem 8 - During which part of the sunspot cycle is there A) the greatest month-to-month variation in the number of sunspots counted? B) The least variation in the number counted?

Answer Key:

Problem 1 - When (month and year) did Sunspot Cycle 23 begin?
Answer: Around July, 1996

Problem 2 - When (month and year) did Sunspot Cycle 23 reach its maximum?
Answer: Around July, 2000 and a second maximum near September, 2001

Problem 3 - A) What was the average minimum sunspot count during the previous sunspot minimum?
Answer: From the graph the monthly numbers are 5,8,6,6,12,8,13,1,0,16,13,6 for an average of 8 sunspots during 1996.

B) What do you think the average sunspot count will be during the current sunspot minimum?
Answer: About 12.

Problem 4 - What is the number of years between sunspot minima to the nearest tenth of a year?
Answer: The first minimum was on July, 1996 and the current minimum seems to be around March ,2007 so the difference is 2007.25 - 1996.58 = 10.7 years.

Problem 5 - How long did Cycle 23 take to reach sunspot maximum?
Answer: The first maximum occurred on July 2000, the minimum was July 1996, so it took 4 years.

Problem 6 - When (year, month) do you predict we will reach sunspot maximum during the next cycle (Cycle 24)?
Answer: If we add 4 years to the current minimum on March, 2007 we get March, 2011.

Problem 7 - When (year, month) do you think the next sunspot minimum will occur?
Answer: From our answer to Problem 4, if we add 10.7 years to March, 2007 we get 2007.25 + 10.7 = 2017.95 or December, 2017.

Problem 8 - During which part of the sunspot cycle is there A) the greatest month-to-month variation in the number of sunspots counted? B) The least variation in the number counted?
Answer: Looking at the graph, the largest variations from month to month occur near sunspot maximum, and the least variations occur near sunspot minimum.

Sunspot Size and the Sunspot Cycle

Sunspots are some of the most interesting, and longest studied, phenomena on the sun's surface. They were known to ancient Chinese observers over 2000 years ago. Below is a list of the largest sunspots seen since 1859. Their sizes are given in terms of the area of the solar hemisphere facing earth. For example, '3600' means 3600 millionths of the solar area or (3600/1000000). On this scale, the area of Earth is '169'. All of these spots were large enough to be seen with the naked eye when proper (and safe!) viewing glasses were used.

Date	Size	Earths
February 10, 1917	3600	**21.3**
January 25, 1926	3700	
January 18, 1938	3650	
February 6, 1946	5250	
July 27, 1946	4700	
March 10, 1947	4650	
April 7, 1947	6150	
May 16, 1951	4850	
Nov. 14, 1970	3500	
August 23, 1971	3500	
October 30, 1972	4120	
Nov. 11, 1980	3820	
July 28, 1981	3800	

Date	Size	Earths
October 14, 1981	4180	
October 19, 1981	4500	
February 10, 1982	3800	
June 18, 1982	4400	
July 15, 1982	4900	
April 28, 1984	5400	
May 13, 1984	3700	
March 13, 1989	5230	
September 5, 1989	3500	

Years of Peak Sunspot Activity:

Sunspot Cycle	Peak Year
14	1906
15	1917
16	1928
17	1937
18	1947
19	1958
20	1968
21	1979
22	1989

Question 1: The peaks of the 11-year sunspot cycle during the 20th century occurred during the years shown to the left. On average, how close to sunspot maximum do the largest spots occur?

Question 2: From this sample, do more of these spots happen in the 5 years before sunspot maximum, or within 5 years after sunspot maximum?

Question 3: Convert the sunspot areas into an equivalent area of the Earth. (Note the first one has been done as an example). What is the average large spot size in terms of Earth?

Date	Size	Area In Earths	Nearest Sunspot Max. Year	Difference In Years
February 10, 1917	3600	21.3	1917	0
January 25, 1926	3700	21.9	1928	-2
January 18, 1938	3650	21.6	1937	+1
February 6, 1946	5250	31.1	1947	-1
July 27, 1946	4700	27.8	1947	-1
March 10, 1947	4650	27.5	1947	0
April 7, 1947	6150	36.4	1947	0
May 16, 1951	4850	28.7	1951	0
Nov. 14, 1970	3500	20.7	1968	+2
August 23, 1971	3500	20.7	1968	+3
October 30, 1972	4120	24.4	1968	+4
Nov. 11, 1980	3820	22.6	1979	+1
July 28, 1981	3800	22.5	1979	+2
October 14, 1981	4180	24.7	1979	+2
October 19, 1981	4500	26.6	1979	+2
February 10, 1982	3800	22.5	1979	+3
June 18, 1982	4400	26.0	1979	+3
July 15, 1982	4900	29.0	1979	+3
April 28, 1984	5400	32.0	1989	-5
May 13, 1984	3700	21.9	1989	-5
March 13, 1989	5230	31.0	1989	0
September 5, 1989	3500	20.7	1989	0

Question 1: On average, how close to sunspot maximum do the largest spots occur? **Answer**: Find the average of the differences in last column = 0 years. So, the largest sunspots occur, on average, close to the peak of the sunspot cycle.

Question 2: For this sample, do more of these spots happen in the 5 years before sunspot maximum, or within 5 years after sunspot maximum? **Answer**: More happen after the peak. Five happen before the peak (negative differences) and 11 happen after the peak (Positive differences).

Question 3: What is the average large spot size in terms of Earth? **Answer:** Average = (561.6/22) = 25.5 Earth Areas.

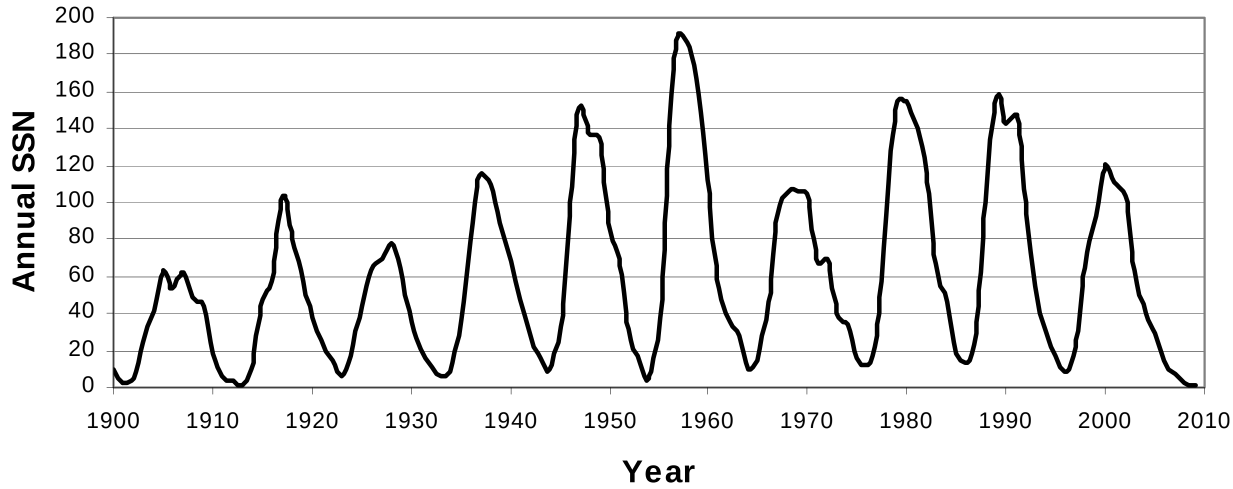
Table of Sunspot Numbers Since 1900

Year	SSN	Year	SSN	Year	SSN	Year	SSN
1900	9	1928	78	1956	142	1984	46
1901	3	1929	65	1957	190	1985	18
1902	5	1930	36	1958	185	1986	13
1903	24	1931	21	1959	159	1987	29
1904	42	1932	11	1960	112	1988	100
1905	63	1933	6	1961	54	1989	158
1906	54	1934	9	1962	38	1990	142
1907	62	1935	36	1963	28	1991	146
1908	49	1936	80	1964	10	1992	94
1909	44	1937	114	1965	15	1993	55
1910	19	1938	110	1966	47	1994	30
1911	6	1939	89	1967	94	1995	18
1912	4	1940	68	1968	106	1996	9
1913	1	1941	47	1969	106	1997	21
1914	10	1942	31	1970	105	1998	64
1915	47	1943	16	1971	67	1999	93
1916	57	1944	10	1972	69	2000	120
1917	104	1945	33	1973	38	2001	111
1918	81	1946	93	1974	34	2002	104
1919	64	1947	152	1975	15	2003	64
1920	38	1948	136	1976	13	2004	40
1921	26	1949	135	1977	27	2005	30
1922	14	1950	84	1978	93	2006	15
1923	6	1951	69	1979	155	2007	8
1924	17	1952	31	1980	155	2008	3
1925	44	1953	14	1981	140	2009	2
1926	64	1954	4	1982	116		
1927	69	1955	38	1983	67		

In 1843, the German astronomer Samuel Schwab plotted the number of sunspots on a graph and discovered that the number of sunspots on the sun was not the same every year, but goes through a cyclical increase and decrease over time. The table above gives the average number of sunspots (SSN) detected each year since 1900.

Problem 1 - Graph the data in the table over the domain [1900, 2009] and range [0,200]. How many sunspot cycles can you count over this time interval?

Problem 2 - What is the average period of the sunspot cycle during this time interval?



Problem 1 - Graph the data in the table over the domain [1900, 2009] and range [0,200]. How many sunspot cycles can you count over this time interval?

Answer: **There are 10 complete cycles**.

Problem 2 - What is the average period of the sunspot cycle during this time interval?

Answer: The time interval is 109 years during which 10 cycles occur for an average period of **10.9 years**.

Note: Additional sunspot data can be found at

Spaceweather.com **http://www.spaceweather.com/java/archive.html**

NASA Marshall Spaceflight Center **http://solarscience.msfc.nasa.gov/SunspotCycle.shtml**

NOAA Space Weather Prediction Center

http://www.swpc.noaa.gov/ftpmenu/warehouse.html

Select year from list, select file 'DSD.txt' and open. Column 5 gives average SSN for given day.

Are you ready for Sunspot Cycle 24?

In 2007, the best estimates and observations suggested that we had just entered sunspot minimum, and that the next solar activity cycle might begin during the first few months of 2008. In May, 2007, solar physicist Dr. William Pesnell at the NASA, Goddard Spaceflight Center tabulated all of the current predictions for when the next sunspot cycle (2008-2019) will reach its peak. These predictions, reported by many other solar scientists are shown in the table below.

Current Predictions for the Next Sunspot Maximum

Author	Prediction Year	Spots	Year	Method Used
Horstman	2005	185	2010.5	Last 5 cycles
Thompson	2006	180		Precurser
Tsirulnik	1997	180	2014	Global Max
Podladchikova	2006	174		Integral SSN
Dikpati	2006	167		Dynamo Model
Hathaway	2006	160		AA Index
Pesnell	2006	160	2010.6	Cycle 24 = Cycle22
Maris & Onicia	2006	145	2009.9	Neural Network Forecast
Hathaway	2004	145	2010	Meridional Circulation
Gholipour	2005	145	2011.5	Spectral Analysis
Chopra & Davis	2006	140	2012.5	Disturbed Day Analysis
Kennewell	2006	130		H-alpha synoptic charts
Tritakis	2006	133	2009.5	Statistics of Rz
Tlatov	2006	130		H-alpha Charts
Nevanlinna	2007	124		AA at solar minimum
Kim	2004	122	2010.9	Cycle parameter study
Pesnell	2006	120	2010	Cycle 24 = Cycle 23
Tlatov	2006	115		Unipolar region size
Tlatov	2006	115		Large Scale magnetic field
Prochasta	2006	119		Average of Cycles 1 to 23
De Meyer	2003	110		Transfer function model
Euler & Smith	2006	122	2011.2	McNish-Lincoln Model
Hiremath	2007	110	2012	Autoregressive Model
Tlatov	2006	110		Magnetic Moments
Lantos	2006	108	2011	Even/Odd cycle pattern
Kane	1999	105	2010.5	Spectral Components
Pesnell	2006	101	2012.6	Linear Prediction
Wang	2002	101	2012.3	Solar Cycle Statistics
Roth	2006	89	2011.1	Moving averages
Duhau	2003	87		Sunspot Maxima and AA
Baranovski	2006	80	2012	Non-Linear Dynamo model
Schatten	2005	80	2012	Polar Field Precurser
Choudhuri	2007	80		Flux Transport Dynamo
Javariah	2007	74		Low-Lat. Spot Groups
Svalgaard	2005	70		Polar magnetic field
Kontor	2006	70	2012.9	Statistical extrapolation
Badalyan	2001	50	2010.5	Coronal Line
Cliverd	2006	38		Atmospheric Radiocarbon
Maris	2004	50		Flare energy during Cycle 23

Problem 1: What is the average year for the predicted sunspot maximum?

Problem 2: What is the average prediction for the total number of sunspots during the next sunspot maximum?

Problem 3: Which scientist has offered the most predictions? Do they show any trends?

Problem 4: What is the average prediction for the total sunspots during each prediction year from 2003 to 2006?

Problem 5: As we get closer to sunspot minimum in 2008, have the predictions for the peak sunspots become larger, smaller, or remain unchanged on average?

Problem 6: Which methods give the most different prediction for the peak sunspot number, compared to the average of the predictions made during 2006?

Answer Key:

Problem 1: What is the average year for the predicted sunspot maximum?
Answer: There are 21 predictions, with an average year of 2011.3. This corresponds to about March, 2011.

Problem 2: What is the average prediction for the total number of sunspots during the next sunspot maximum?
Answer: The average of the 39 estimates in column 3 is 116 sunspots at sunspot maximum.

Problem 3: Which scientist has offered the most predictions? Do they show any trends?
Answer: Tlatov has offered 4 predictions, all made in the year 2006. The predicted numbers were 130, 115, 115 and 110. There does not seem to be a significant trend towards larger or smaller predictions by this scientist. The median value is 115 and the mode is also 115.

Problem 4: What is the average prediction for the total sunspots during each prediction year from 2003 to 2006?
Answer: Group the predictions according to the prediction year and then find the average for that year.

2003: 110, 87 average = 98

2004: 145, 122, 50 average= 106

2005: 185,145,80,70 average= 120

2006: 180,174,167,160,160,145,140,130,133,130,120, 115,115,119,122,110,108,101,89,80,70,38 **average= 123**

Problem 5: As we get closer to sunspot minimum in 2008, have the predictions for the peak sunspots become larger, smaller, or remain unchanged on average?
Answer: Based on the answer to problem 4, it appears that the predictions have tended to get larger, increasing from about 98 to 123 between 2003 and 2006.

Problem 6: Which methods give the most different prediction for the peak sunspot number, compared to the average of the predictions made during 2006?
Answer: Cliverd's Atmospheric Radiocarbon Method (38 spots), Badalyan's Coronal Line Method (50 spots), and Maris's Flare Energy during Cycle 23 (50 spots) seem to be the farthest from the average predictions that have been made by other forecasting methods.

Solar flares

Solar flares are powerful explosions of energy and matter from the Sun's surface. One explosion, lasting only a few minutes, could power the entire United States for a full year. Astronauts have to be protected from solar flares because the most powerful ones can kill an astronaut if they were working outside their spacecraft.

In this exercise, you will learn how scientists classify flares, and how to decode them.

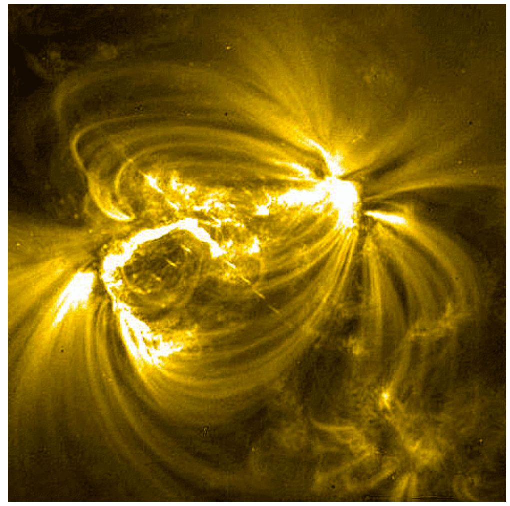


Image of Sun showing flare-like eruption.

Scientists create alphabetic and numerical scales to classify phenomena, and to assign names to specific events.

- Simple equations can serve as codes.

Here's how to do it!

A solar flare scale uses three multipliers defined by the letter codes C = 1.0, M=10.0, X=1000.0.

- A solar flare might be classified as M5.8 which means a brightness of (10.0) x (5.8) = 58.0.
- A second solar flare might be classified as X15.6 which means (1000.0) x (15.6) = 15,600.0

The X15.6 flare is (15,600/58) = 269 times brighter than the M5.8 flare.

Now you try!

The GEOS satellite has an X-ray monitor that records daily solar flare activity. The table below shows the flares detected between January 11 and March 3, 2000.

Flare Codes for Major Events

Date	Code	Date	Code
1-11	M1.5	2-12	M1.7
1-12	M2.8	2-17	M2.5
1-18	M3.9	2-18	C2.7
1-22	M1.0	2-20	M2.4
1-24	C5.3	2-21	M1.8
1-25	C6.8	2-22	M1.2
2-3	C8.4	2-23	C6.8
2-4	M3.0	2-24	M1.1
2-5	X1.2	2-26	M1.0
2-6	C2.4	3-1	C6.9
2-8	M1.3	3-2	X1.1

1) What was the brightest flare detected during this time?

2) What was the faintest flare detected during this time?

3) How much brighter was the brightest flare than the faintest flare?

4) What percentage of the flares were brighter than M1.0?

Answer Key

Problem 1 - X1.2 on February 5 with a brightness of (1000) x 1.2 = 1,200

Problem 2 - C2.4 on February 6 with a brightness of (1.0) x 2.4 = 2.4

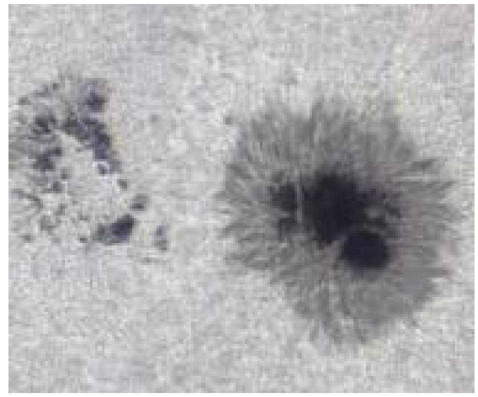
Problem 3 - 1200/2.4 = 500 times brighter

Problem 4 - There are a total of 22 flares in this table. There are 13 flares brighter than M1.0 but not equal to M1.0. The percentage is then (13/22)x100% = 59%

Sunspots and Solar Flares

Sunspots are some of the most interesting, and longest studied, phenomena on the sun's surface. The table below shows the areas of several sunspots observed between November 6 and January 19, 2004. In comparison, the surface area of Earth is '169' units on the sunspot scale. The table also shows the brightest flare seen from the vicinity of the sunspots. Flares are ranked by their brightness 'C', 'M' and 'X' with M-class flares being 10x more luminous that C-class flares, and X-class flares being 10x brighter than M-class flares.

Date	Spot #	Area	Flare
Nov 6	#696	820	M
Nov 7	#696	910	M
Nov 8	#696	650	X
Nov 10	#696	730	M
Nov 11	#696	470	X
Dec 2	#708	130	M
Dec 3	#708	150	M
Dec 9	#709	20	C
Dec 29	#713	150	M
Dec 30	#715	260	M
Dec 31	#715	350	M
Jan 1	#715	220	M
Jan 2	#715	180	X
Jan 4	#715	130	C
Jan 10	#719	100	M
Jan 14	#718	160	C
Jan 15	#720	1540	M
Jan 16	#720	1620	X
Jan 17	#720	1630	M
Jan 18	#720	1460	X
Jan 19	#720	1400	M



During the 75 day time period covered by this table, there were a total of (720-696=) 24 catalogued sunspots. The table shows only those cataloged sunspots that were active in producing flares during this time. Sunspot areas are in terms of millionths of the solar hemisphere area, so '1630' means 0.163% of the Sun's face. Earth's area = 169 millionths by comparison!

Sunspot and solar flare data from NOAA SWN data archive at http://www.sec.noaa.gov/Data/index.html

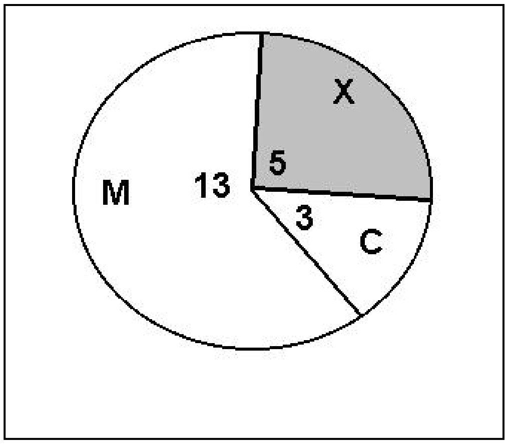
Problem 1 - Construct a pie chart for the X, M and C-class flare data. During this 75-day period, what percentage of flares are X-class?

Problem 2 - What percentage of sunspots produce X-class flares?

Problem 3 - What percentage of sunspots did not produce any flares during this time?

Problem 4 - What seems to be the minimum size for a sunspot that produces an X-class flare? An M-class flare? A C-class flare?

Problem 5 - If the area of Earth is '169' in the sunspot units used in the above tables, what are the maximum and minimum size of the sunspots compared to the area of Earth?



Note, there are 21 flares in the table.
X = 5 flares
M = 13 flares
C = 3 flares.
The pie chart angles are
21 = 360 degrees
X = (5/21)x360 = 86 degrees
M = (13/21)x360 = 223 degrees
C = (3/21)x360 = 51 degrees.
And to check: 223+86+51 = 360.

Problem 1: With a pie chart, what percentage of flares were X-type?
Answer: 5 out of 21 or (5/21)x100% = 24%

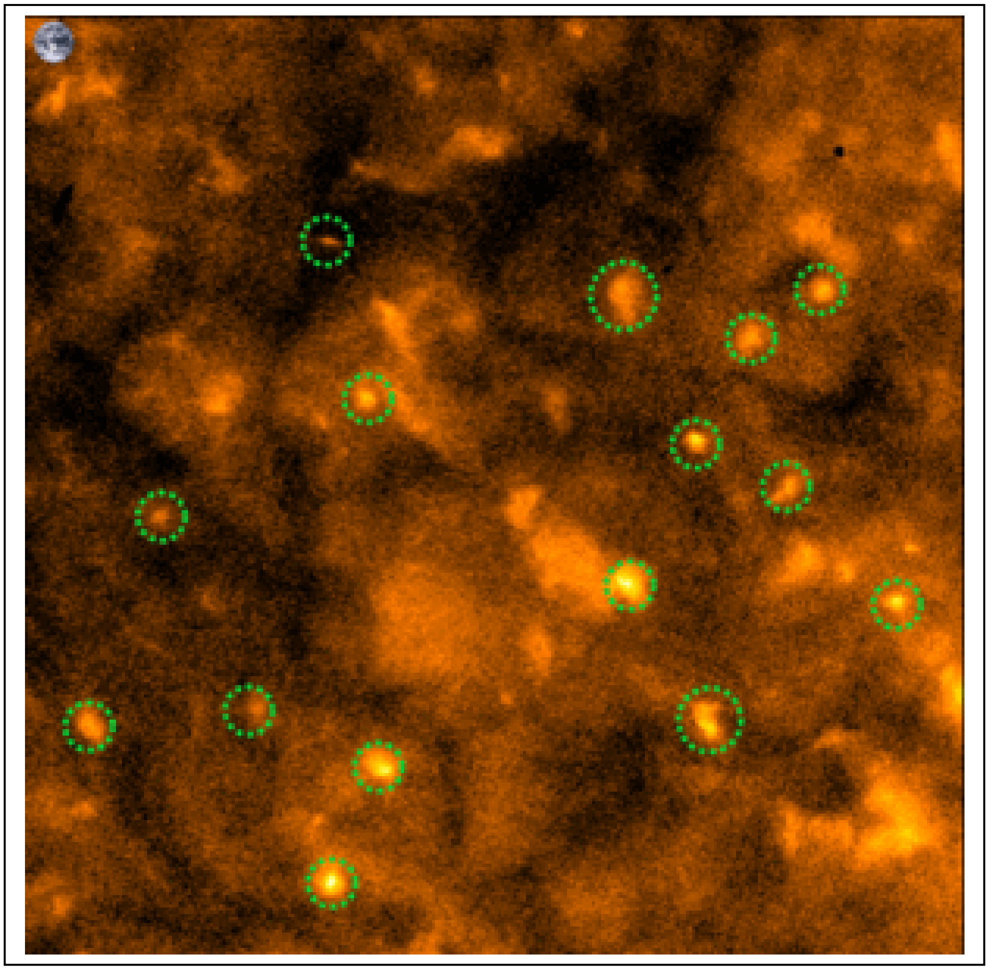
Problem 2: During this 75-day period, what percentage of flares are X-class flares?
Answer: There are 24 sunspots in the sample because the catalog numbers run from 720 to 698 as stated in the table caption (A 'reading to be informed' activity). There were three sunspots listed in the table that produced X-class flares: #696, #715, #720. The percentage is (3/24)x100% = 12.5% which may be rounded to 13%.

Problem 3: What percentage of sunspots did not produce flares during this time?
Answer: There were only 8 sunspots in the table that produced flares, so there were 16 out of 24 that did not produce any flares. This is (16/24)x100% = 67%. An important thing for students to note is that MOST sunspots do not produce any significant flares.

Problem 4: What seems to be the minimum size for a sunspot that produces an X-class flare? An M-class flare? A C-class flare?
Answer: Students may reasonably answer by saying that there doesn't seem to be any definite correlation for the X and M-class flares! For X-class flares, you can have them if the area is between 180 and 1620. For M-class flares, spots with areas from 130 to 1630 can have them. The two possibilities overlap. For C-class flares, they seem to be most common in the smaller spots from 20 – 130 in area, but the sample in the table is so small we cant really tell if this is a genuine correlation or not. Also, we have only shown in the table the largest flares on a given day, and smaller flares may also have occurred for many of these spots.

Problem: If the area of Earth is '169' in the sunspot units used in the above tables, what are the maximum and minimum size of the sunspots compared to the area of Earth?
Answer: The smallest spot size occurred for #709 with an equivalent size of (20/169)x100% = 11% of Earth's area. The largest spot was #720 with a size equal to (1630/169) = 9.6 times Earth's area.

Hinode Sees Mysterious Solar Micro-flares



The Sun's surface is not only speckled with sunspots, it is also dotted with intense spots of X-ray light called 'X-ray Bright Points'. Although sunspots can be over 100,000 kilometers across and easily seen with a telescope, X-ray Bright Points are so small even the largest solar telescope only sees a few of them with enough detail to reveal their true shapes. X-ray Bright Points release their energy by converting tangled magnetic fields into smoother ones. This liberates large quantities of stored magnetic energy. For that reason, these Bright Points can be thought of as micro-flares.

Hinode's X-ray Telescope (XRT) can now see the details in some of the Bright Points and allow scientists to see small magnetic loops. In the image above, individual bright points are circled in green. A few of them can be resolved into tiny magnetic loops. These data were taken on March 16, 2007. The image is 300 x 300 pixels in size. Each pixel views an area on the sun that is 1 arcsecond x 1 arcsecond on a side.

Problem 1: If the diameter of the Sun is 1800 arcseconds, and has a radius of 696,000 km, what is the scale of the above image in A) kilometers per arcsecond? B) kilometers/millimeter?

Problem 2: What are the dimensions, in kilometers, of the smallest circled Bright Point in the image?

Problem 3: How many Bright Points cover the solar surface if the above picture is typical?

Answer Key:

Problem 1: If the diameter of the sun measures 1800 arcseconds and has a radius of 696,000 km, what is the scale of the above image in kilometers per arcsecond?

Answer: A) The solar radius is 1800 arcseconds/2 = 900 arcseconds which physically equals 696,000 km, so the scale is 696,000/900 = **773 kilometers/arcsecond**.

B) The image is 300 pixels across, which measures 115 millimeters with a ruler. Each pixel is 1 arcsecond in size, so this represents 773 km/arcsec x 300 = 232,000 km. The ruler says that this equals 115 mm, so the image scale is 232,000 km/115 mm = **2,020 km/mm**.

Problem 2: What are the dimensions of the smallest circled Bright Point in the image?

Answer: With a ruler, the circled Bright Point at the top of the picture seems to be the smallest. It measures about 2 millimeters across and 1 millimeter wide. This corresponds to about **4000 x 2000 km.**

Problem 3: How many Bright Points cover the solar surface if the above picture is typical?

Answer:

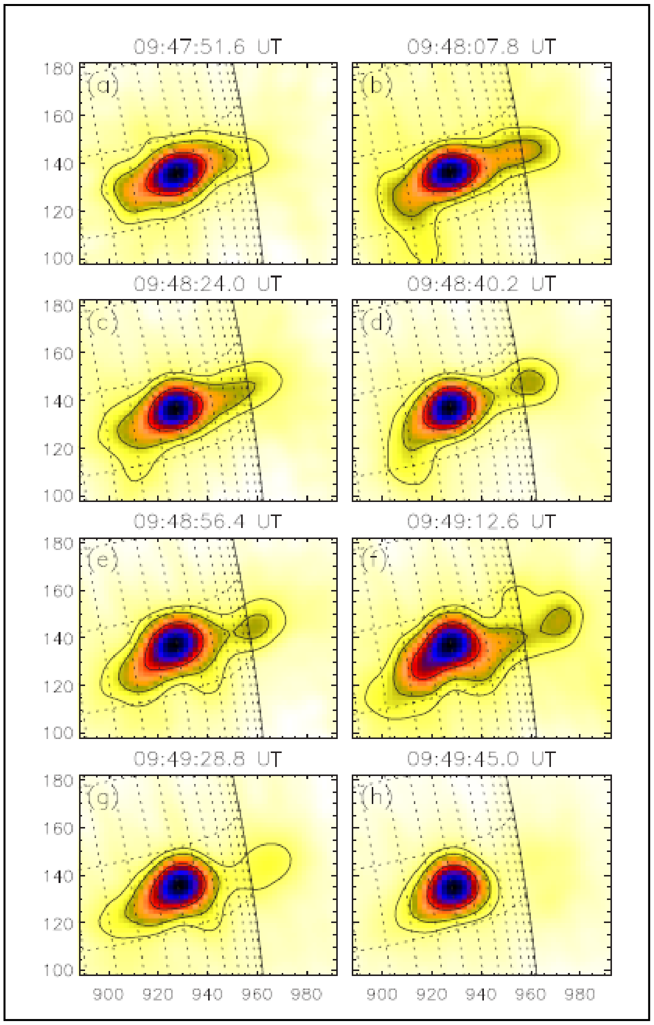
The sun is a sphere with a radius of 696,000 kilometers. The area of a sphere is given by $4 \pi R^2$, so the surface area of the sun is $4 \times 3.141 \times (696{,}000 \text{ km})^2 = 6.1 \times 10^{12}$ kilometers^2.

The size of the Hinode image is 300 pixels x 773 km/pixel = 232,000 km on a side. The area covered is about (232,000 km x 232,000 km) = $5.4 \times 10^{\mathbf{10}}$ km$^{\mathbf{2}}$. Note, this is an approximation because of the distortion of a flat image attempting to represent a curved spherical surface. The actual solar surface area covered is actually a bit larger.

The solar surface is about $6.1 \times 10^{\mathbf{12}}$ km$^{\mathbf{2}}$ / $5.4 \times 10^{\mathbf{10}}$ km$^{\mathbf{2}}$ = 113 times larger than the Hinode image.

There are 16 Bright Points in the Hinode image, so there would be 15 x 113 = **1,695** Bright Points covering the full solar surface if the Hinode image is typical.

RHESSI Observes Super-fast Solar Flares !



NASA's Ramaty High Energy Solar Spectroscopic Imager (RHESSI) satellite has been studying solar flares since 2002. The sequence of figures to the left shows a flaring region observed on November 3, 2003. This flare was rated as 'X3.9' making it an extremely powerful event. A detailed study of this flare by astronomer Dr. Astrid Veronig and her colleagues at the Institute of Physics of the University of Graz in Austria allowed scientists to determine the physical properties of this event. During the 4-minute flaring event, gas temperatures of over 45 million Kelvin were reached in a gas with a density of 400 billion atoms/cc.

The figures each have a field of view of 80 second of arc x 100 seconds of arc, where one 'arcsecond' = 1/3600 of a degree). The diameter of the sun in these angular units is 1950 seconds of arc, and its physical diameter is 1,392,000 kilometers.

Each image shows the main flare region (blue) and Images D, E and F show a second plasma cloud being ejected by the flaring region.

"X-ray sources and magnetic reconnection in the X3.9 flare of 2003 November 3" A. Veronig et al., Astronomy and Astrophysics, 2005 vol. 446, p.675.

Problem 1 - From the information in the text, what is the size of each box in kilometers?

Problem 2 - What is the scale of each image in kilometers per millimeter?

Problem 3 - Between Image D and Image F, how much time elapsed?

Problem 4 - Between Image D and Image F, how far did the plasma cloud travel in kilometers?

Problem 5 - Between Image D and Image F, what was the average speed of the plasma cloud in kilometers per second?

Problem 6 - The SR-71 Blackbird holds the official Air Speed Record for a manned airbreathing jet aircraft with a speed of 3,529.56 km/h (2,188 mph). It was capable of taking off and landing unassisted on conventional runways. The record was set on July 28, 1976 by Eldon W. Joersz near Beale Air Force Base in California. Would the SR-71 have been able to out-run the plasma cloud?

Answer Key:

Problem 1 - From the information in the text, what is the size of each box in kilometers?

Answer: (100 arc-sec/1950-arcsec) x 1,392,000 km = 71,400 km.
(80 arcsec/1950 arcsec0 x 1,392,000 km = 57,100 km.
The boxes are **71,400 x 57,100 km in size**.

Problem 2 - What is the scale of each image in kilometers per millimeter?
Answer: The 100-arcsec edge of a box measures 34 millimeters, so the scale is (71,400 km/34 mm) = **2,100 km/mm**

Problem 3 - Between Image D and Image F, how much time elapsed?
Answer: 09:49:12.6 UT - 09: 48: 40.2 UT = 72.6 - 40.2 = **30.4 seconds.**

Problem 4 - Between Image D and Image F, how far did the plasma cloud travel in kilometers?
Answer: In Image D it was 12 millimeters from the flare center. In Image F it was 15 millimeters from the flare center, for a net change of 3 millimeters or 3 mm x 2,100 km/mm = **6,300 kilometers.**

Problem 5 - Between Image D and Image F, what was the average speed of the cloud in kilometers per second?
Answer: The speed was 6,300 kilometers/30.4 seconds or **207 kilometers/sec.**

Problem 6 - The SR-71 Blackbird holds the official Air Speed Record for a manned air-breathing jet aircraft with a speed of 3,529.56 km/h (2,188 mph). It was capable of taking off and landing unassisted on conventional runways. The record was set on July 28, 1976 by Eldon W. Joersz near Beale Air Force Base in California. Would the SR-71 have been able to out-run the plasma cloud?

Answer: The SR-71 traveled at a speed of 3,530 km/hour. There are 3,600 seconds in an hour, so the speed was 3,530 km/hr x 1 hr/3600 sec = 0.98 kilometers/sec. **The solar flare blob was traveling at 207 kilometers per second or nearly 210 times faster! The plasma cloud wins!!!**

Solar Proton Events (SPEs) can cause satellite damage and produce harmful radiation dosages for astronauts working and traveling in space. The table below lists all the SPEs between 1997 and 2004 with intensities greater than 300 particle Flux Units (pFU). Study this table and answer the questions that follow.

Date	SPE Intensity (pFUs)	Solar Flare Brightness (Relative)
Nov 7, 2004	495	200.0
Jul 25, 2004	2,086	10.0
Nov 4. 2003	353	2800.0
Nov 2, 2003	1,570	
Oct 28, 2003	29,500	1700.0
Oct 26, 2003	466	100.0
Nov 9, 2002	404	40.0
Aug 24, 2002	317	300.0
May 22, 2002	820	5.0
April 21, 2002	2,520	100.0
Dec 26, 2001	779	70.0
Nov 22, 2001	18,900	90.0
Nov 4, 2001	31,700	100.0
Oct 1, 2001	2,360	90.0
Sep 24, 2001	12,900	200.0
Apr 18, 2001	951	2.0
Apr 10, 2001	355	200.0
Apr 2, 2001	1,110	2000.0
Nov 24, 2000	942	200.0
Nov 8, 2000	14,800	70.0
Sep 12, 2000	320	10.0
July 14, 2000	24,000	500.0
Nov 14, 1998	310	1.0
Sep 30, 1998	1,200	20.0
Aug 24, 1998	670	100.0
May 6, 1998	210	200.0
April 20, 1998	1,700	10.0
Nov 6, 1997	490	900.0

Question 1: What is the range of the SPE intensities recorded for the period from 1997 to 2004?

Question 2: What is the frequency of SPE events for each year?

Question 3: Is there a relationship between the SPE intensity and the solar flare brightness?

Question 4: Do the brightest solar flares produce the most intense SPEs? Give examples that demonstrate your answer.

Question 5: The sunspot cycle had the largest number of sunspots during 2000. What is unusual about the frequency of SPEs and 'sunspot maximum'?

Question 6: Are there more SPEs during certain months of the year?

Applying what you have learned.

Satellites lose 2% of their electrical power for every SPE brighter than 15,000 pFUs. If a satellite was launched in 1997, how much power loss will it have suffered by the end of 2004?

If the satellite systems require 4500 watts to operate, how could the designers have insured that the satellite received all the power it needed by the end of 2004?

Once in a while. the sun lets loose with a powerful burst of energy similar to a solar flare, but potentially far more lethal. Solar Proton Events (SPEs) are streams of protons that are accelerated to high energies near the solar surface, lasting from hours to as much as a day or two. As these protons arrive at Earth, they can scour solar panels on satellites costing them several years worth of power. When the particles slam into metal in satellites or in spacecraft, they can produce secondary nuclear particles and electrons that can damage delicate circuitry, or even endanger astronaut health. This activity will have students examine a list of the SPEs since 1996 from the archive at http://image.gsfc.nasa.gov/poetry/weekly/SEPsince1976.htm which was produced by scientists at the National Geophysical Data Center. Students will analyze the table and answer questions on its statistical content.

Question 1: What is the range of the SPE intensities recorded for the period from 1997 to 2005? **Answer:** The range is [210, 31700]

Question 2: What is the frequency of SPE events for each year? **Answer:** 1997 = 1, 1998 = 5, 1999 = 0, 2000 = 4, 2001 = 8, 2002 = 4, 2003 = 4, 2004 = 2, which can be bar-graphed.

Question 3: Is there a relationship between the SPE intensity and the solar flare brightness? **Answer:** No. The most intense SPEs can have solar flares that span nearly the entire brightness range for flares.

Question 4: Do the brightest solar flares produce the most intense SPEs? Give examples that demonstrate your answer. **Answer:** No. See, for example November 4, 2003 and Nove,ber 4, 2001.

Question 5: The sunspot cycle had the largest number of sunspots during 2000. What is unusual about the frequency of SPEs and 'sunspot maximum'? **Answer:** There are far more SPEs after sunspot maximum than before sunspot maximum.

Question 6: Are there more SPEs during certain months of the year? **Answer:** Yes. November and April have more SPEs!

If a satellite was launched in 1997, how much power loss will it have suffered by 2005? **Answer:** There were 5 SPEs during this time that were brighter than 15,000 pFUs so the satellites lose 5 x 2% = 10% of their electrical power between 1997-2005.

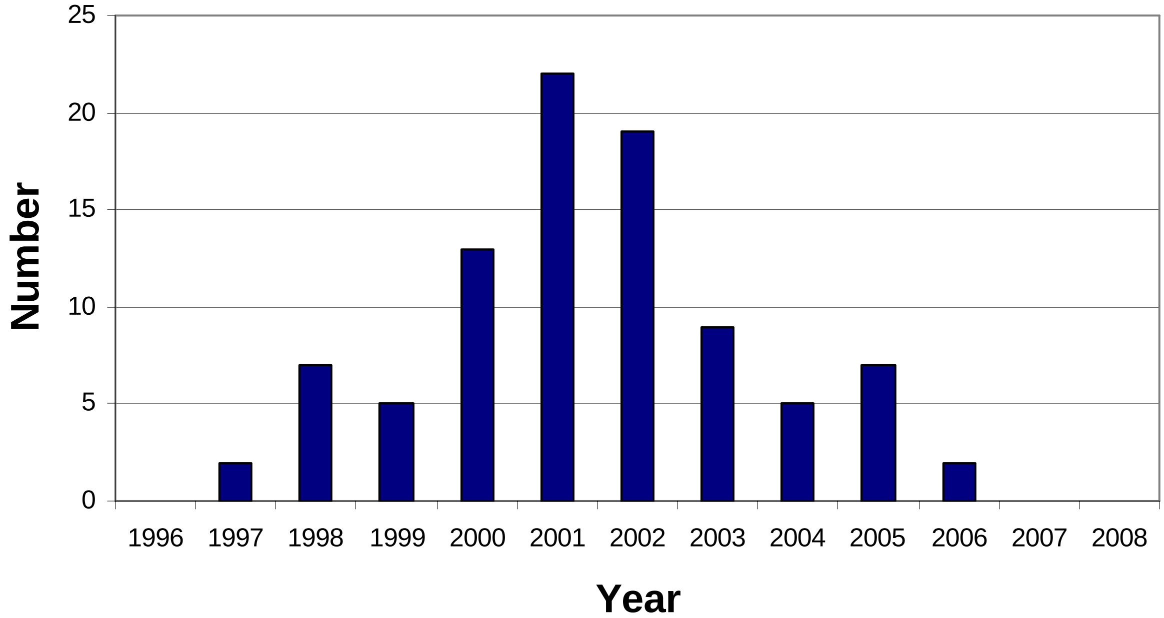
If the satellite systems require at least 4500 watts to operate, how could the designers have insured that the satellite received all the power it needed by 2005? **Answer:** Just make the solar panels 10% larger to they produce 4900 watts at launch. By the end of 2004, the power will have declined 10% to 4500 watts which is still enough power to keep the equipment operating!

	Date	SPE (pFU)		Date	SPE (pFU)		Date	SPE (pFU)
1	11/4/1997	72	32	4/15/2001	951	63	7/22/2002	28
2	11/6/1997	490	33	4/18/2001	321	64	8/14/2002	26
3	4/20/1998	1,700	34	4/28/2001	57	65	8/22/2002	36
4	5/2/1998	150	35	5/7/2001	30	66	8/24/2002	317
5	5/6/1998	210	36	6/15/2001	26	67	9/7/2002	208
6	8/24/1998	670	37	8/10/2001	17	68	11/9/2002	404
7	9/25/1998	44	38	8/16/2001	493	69	5/28/2003	121
8	9/30/1998	1,200	39	9/15/2001	11	70	5/31/2003	27
9	11/8/1998	11	40	9/24/2001	12,900	71	6/18/2003	24
10	1/23/1999	14	41	10/1/2001	2,360	72	10/26/2003	466
11	4/24/1999	32	42	10/19/2001	11	73	10/28/2003	29,500
12	5/5/1999	14	43	10/22/2001	24	74	11/2/2003	1,570
13	6/2/1999	48	44	11/4/2001	31,700	75	11/4/2003	353
14	6/4/1999	64	45	11/19/2001	34	76	11/21/2003	13
15	2/18/2000	13	46	11/22/2001	18,900	77	12/2/2003	86
16	4/4/2000	55	47	12/26/2001	779	78	4/11/2004	35
17	6/7/2000	84	48	12/29/2001	76	79	7/25/2004	2,086
18	6/10/2000	46	49	12/30/2001	108	80	9/13/2004	273
19	7/14/2000	24,000	50	1/10/2002	91	81	11/1/2004	63
20	7/22/2000	17	51	1/15/2002	15	82	11/7/2004	495
21	7/28/2000	18	52	2/20/2002	13	83	1/16/2005	5,040
22	8/11/2000	17	53	3/17/2002	13	84	5/14/2005	3,140
23	9/12/2000	320	54	3/18/2002	53	85	6/16/2005	44
24	10/16/2000	15	55	3/20/2002	19	86	7/14/2005	134
25	10/26/2000	15	56	3/22/2002	16	87	7/27/2005	41
26	11/8/2000	14,800	57	4/17/2002	24	88	8/22/2005	330
27	11/24/2000	942	58	4/21/2002	2,520	89	9/8/2005	1,880
28	1/28/2001	49	59	5/22/2002	820	90	12/6/2006	1,980
29	3/29/2001	35	60	7/7/2002	22	91	12/13/2006	698
30	4/2/2001	1,110	61	7/16/2002	234			
31	4/10/2001	355	62	7/19/2002	31			

Solar Proton Events (SPEs) are intense 'storms' of high-energy protons that can harm astronauts and damage satellite electronics. The table above lists the 91 significant SPEs detected during the 23rd Sunspot Cycle (1996-2008). During the 11 years of the sunspot cycle:

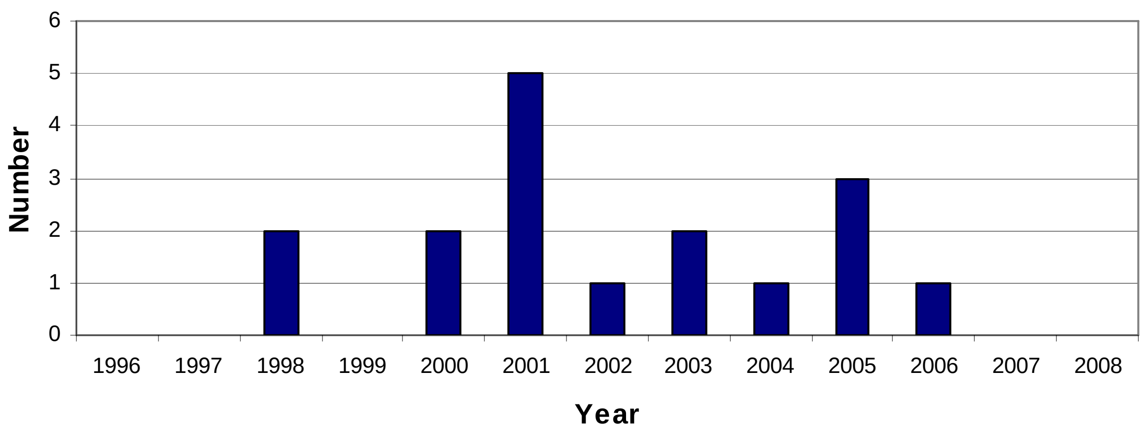
Problem 1 – Relative to the peak of the sunspot cycle, when do most of the SPEs occur? Create a histogram to support your claim.

Problem 2 - SPEs are measured in terms of their intensity in particles per square centimeter per second defined as '1 pFU'. When do the most intense SPEs occur for which the intensities exceed 1000 pFU?



Problem 1 - From a histogram of the data, when do most of the SPEs occur?
Answer: **From the graph above, most of them occur near the peak of the sunspot cycle (2001)**

Problem 2 - SPEs are measured in terms of their intensity in particles per square centimeter per second defined as '1 pFU'. When do the most intense SPEs occur for which the intensities exceed 1000 pFU?



Answer: **Few occur before sunspot maximum, and the peak year is sunspot maximum (2001), with most of the events occurring during the 5 years following sunspot maximum. The most intense SPE occurred in 2000 (2), and 2001 (4), 2003 (1) which again cluster within a few years +/- the year of sunspot maximum.**

Estimating SPE Arrival Times

Speed	%c	Earth			Distance from Sun in Astronomical Units							
(km/s)		1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2
150000	50	17	18	20	22	23	25	27	28	30	32	33
180000	60	14	15	17	18	19	21	22	24	25	26	28
210000	70	12	13	14	15	17	18	19	20	21	23	24
240000	80	10	11	13	14	15	16	17	18	19	20	21
270000	90	9	10	11	12	13	14	15	16	17	18	19
285000	95	9	10	11	11	12	13	14	15	16	17	18

The shaded values in the table above give the arrival times (in minutes) to the various distances, given the speed of the high-energy solar protons indicated in the first column, and in terms of the percentage of light-speed in column 2. The distances are given in Astronomical Units (AUs) where 1.0 AU is the distance from the sun to Earth (150 million km).

Problem 1 - An astronomer detects a powerful X-ray flare on the sun, and expects that it was a source of energetic solar protons. The X-rays travel at the speed of light and make the journey to Earth in 8.5 minutes. If the X-ray flare, called F1120, was first spotted at 11:20:00 UT when did the solar X-rays actually leave the solar surface?

Problem 2 - The energy and speed of the solar protons from F1120 is not known, but the astronomer thinks that they are in the range from 50% to 95% the speed of light. If the solar protons were emitted at the same time the solar flare erupted on the sun, what are the earliest and latest times that they could arrive at Earth?

Problem 3 – Given the maximum likely speed of the protons, how soon after the x-ray flare was detected at Earth did the solar protons start to arrive?

Problem 1 - An astronomer detects a powerful X-ray flare on the sun, and expects that it was a source of energetic solar protons. The X-rays travel at the speed of light and make the journey to Earth in 8.5 minutes. If the X-ray flare, called F1120, was first spotted at 11:20:00 UT when did the solar X-rays actually leave the solar surface?

Answer: 8.5 minutes earlier in time so 11:20:00 - 00:08:30 = **11:11:30 UT**.

Problem 2 - The energy and speed of the solar protons from F1120 is not known, but the astronomer thinks that they are in the range from 50% to 95% the speed of light. If the solar protons were emitted at the same time the solar flare erupted on the sun, what are the earliest and latest times that they could arrive at Earth?

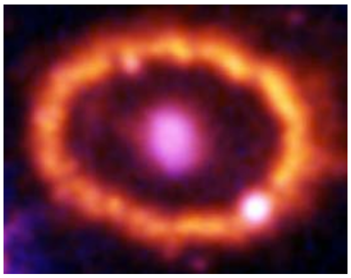
Answer: The proton transit times range from 9 minutes to 17 minutes, so the arrival times would be from 11:11:30 UT + 00:09:00 = **11:21:30 UT** to 11:11:30 UT + 00:17:30 = **11:29:00 UT**.

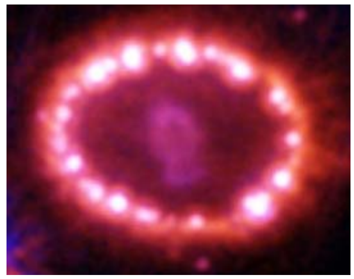
Problem 3 - Given the maximum likely speed of the protons, how soon after the x-ray flare was detected at Earth did the solar protons start to arrive?

Answer: The flare X- rays arrived at 11:20:00 UT and the earliest protons arrived at 11:21:30 so the time difference is just **one and a half minutes**

Measuring Speed in the Universe

Objects in space move. To figure out how fast they move, astronomers use many different techniques depending on what they are investigating. In this activity, you will measure the speed of astronomical phenomena using the scaling clues and the time intervals between photographs of three phenomena: A supernova explosion, a coronal mass ejection, and a solar flare shock wave.



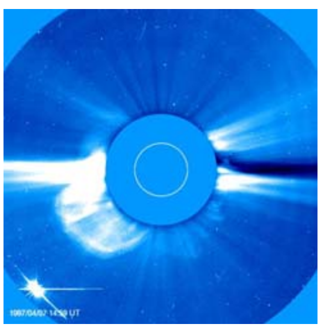


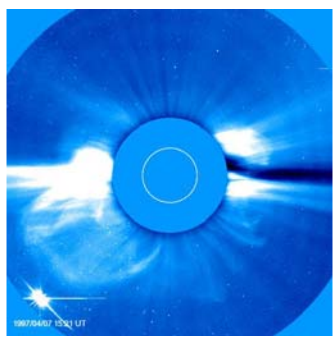
Measure the change in longest dimension of the inner blob of light. The outer ring is about one light-year in diameter. The left-hand image was taken by the Hubble Space Telescope in March, 1995. The right-hand image was taken in November, 2003. Note 1 light-year = 9.2 trillion km.

Problem 1: Supernova 1987A was photographed 7.7 years apart to study its expanding shell of gas. What is the speed of this material shown in the photographs in:

A) light-years per year?
B) kilometers per second?

For more information, visit: http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/



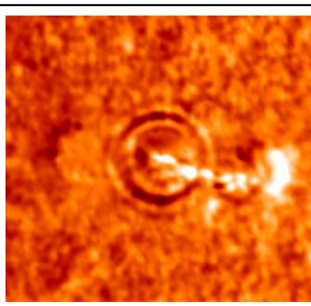


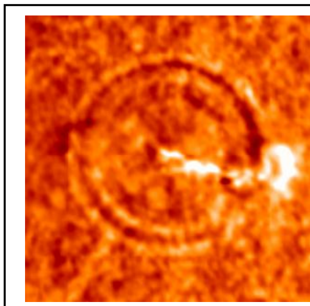
The white circle is the diameter of the sun (1.4 million km). Images taken at 14:59 UT (left) and 15:21 UT (right).

Problem 2: Closer to Earth, solar storms provide another example of violent motion. How fast did this coronal mass ejection travel in:

A) kilometers per second?
B) kilometers per day?

CME observed by the SOHO satellite on April 7, 1997.





Each picture is 150 million meters on a side. The difference in time between the images is one hour.

Problem 3 – A solar flare on July 9, 1996 caused a phenomenon called a Morton Wave to travel across the sun's surface. What was its speed in:

A) kilometers per hour?
B) kilometers per second?

More information: http://www.solarviews.com/eng/sohopr3.htm

Problem 1: Supernova 1987A was photographed 7.7 years apart to study its expanding shell of gas. What is the speed of this material shown in the photographs in: A) light-years (LY) per year? B) kilometers per second?

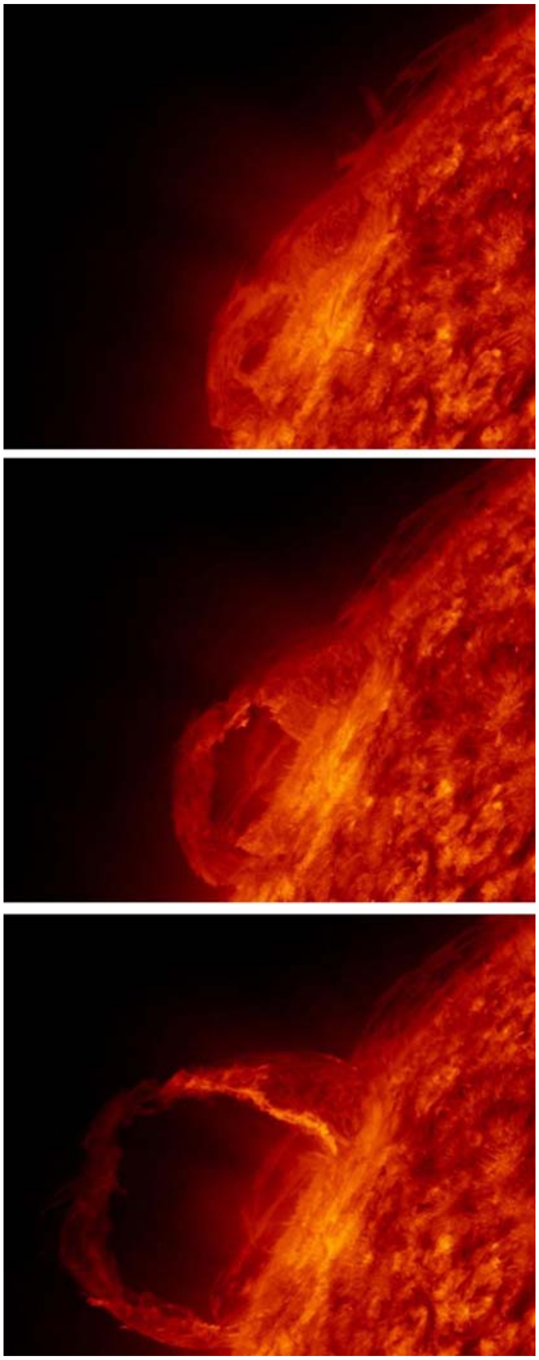
Answer: Using a millimeter ruler and the stated size of the image, the scale is about 30mm = 1 LY. The central 'blob' which is the supernova shell has an initial diameter of 5mm and a final largest diameter of 10mm, so its **radius** has increased by 2.5mm which equals (2.5mm/30mm)x 1LY = 0.085 LY. The difference in time between the images is 7.7 years so A) 0.085 LY/7.7 yrs = 0.010 Light-years/year, and for 3.1×10^7 seconds in a year, B) $9.2 \times 10^{12} \times 0.010/3.1 \times 10^7$ = 3,100 km/sec.

Problem 2: Closer to Earth, solar storms provide another example of violent motion. How fast did this coronal mass ejection travel in: A) kilometers per second? B) kilometers per day?

Answer: The scale of the prints is about 7 mm = 1.4 million km. If you measure the distance from the center of the sun circle to the outer edge of the CME in the lower left corner of each picture, you get about 13.5 mm and 19 mm respectively. This equals a **change** in distance of (5.5mm/7mm) x 1.4 million km = 1.1 million km. The difference in time between the two images is 22 minutes or 1320 seconds, so A) the speed is about 1.1 million km/1320 sec = 833 km/sec. There are 24x60x60 = 86400 seconds in a day, so B) is about 833 x 86400 = 72 million km/day.

Problem 3 – A solar flare on July 9, 1996 caused a phenomenon called a Morton Wave to travel across the sun's surface. What was its speed in: A) kilometers per second? B) kilometers per hour?

Answer: The image scale is 37 mm = 150 million meters. The circles represent the shock wave, and the outer ring radius has increased from 7mm to 12mm in one hour. This is a distance change of (5mm/37mm)x 150 million meters = 20 million meters or 20,000 kilometers. A) 20,000 kilometers/hour. B) There are 3600 seconds in an hour so 20,000/3600 = 5.6 km/sec.



On April 21, 2010 NASA's Solar Dynamics Observatory released its much-awaited 'First Light' images of the Sun. Among them was a sequence of images taken on March 30, showing an eruptive prominence ejecting millions of tons of plasma into space. A plasma is a gas consisting of atoms stripped of some of their electrons.

The three images to the left show selected scenes from the first 'high definition' movie of this event. The top image was taken at 17:50:49, the middle image at 18:02:09 and the bottom image at 18:13:29.

Problem 1 – The width of the image is 300,000 kilometers. Using a millimeter ruler, what is the scale of these images in kilometers/millimeter?

Problem 2 – If the Earth were represented by a disk the size of a penny (10 millimeters), on this same scale how big was the loop of the eruptive prominence in the bottom image if the radius of Earth is 6,378 kilometers?

Problem 3 – What was the average speed of the prominence in A) kilometers/second? B) Kilometers/hour? C) Miles/hour?

For additional views of this prominence, see the NASA/SDO movies at:
http://svs.gsfc.nasa.gov/vis/a000000/a003600/a003693/index.html

or to read the Press Release:
http://www.nasa.gov/mission_pages/sdo/news/first-light.html

Problem 1 – The width of the image is 300,000 kilometers. Using a millimeter ruler, what is the scale of these images in kilometers/millimeter?

Answer: The width is 70 millimeters so the scale is 300,000 km/70 mm **= 4,300 km/mm**

Problem 2 – If the Earth were represented by a disk the size of a penny (10 millimeters), on this same scale how big was the loop of the eruptive prominence in the bottom image if the radius of Earth is 6,378 kilometers?

Answer: **The diameter of the loop is about 35 millimeters or 35mm x 4300km/mm = 150,000 km. The diameter of Earth is 13,000 km, so the loop is 12 times the diameter of Earth. At the scale of the penny, 13 penny/Earth's can fit across a scaled drawing of the loop.**

Problem 3 – What was the average speed of the prominence in A) kilometers/second? B) Kilometers/hour? C) Miles/hour?

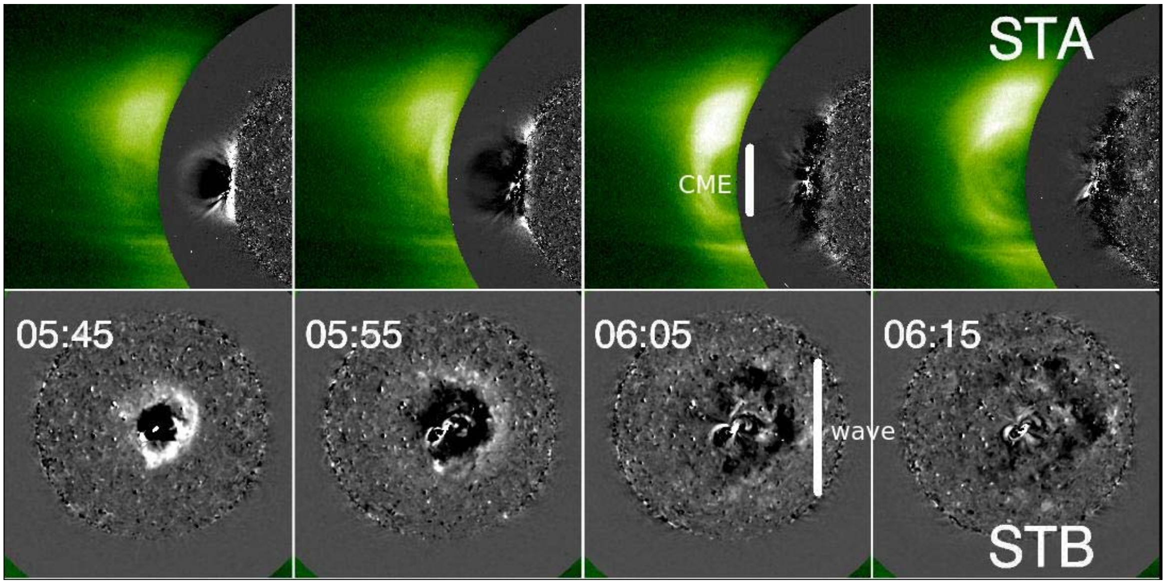
Answer: Speed = distance traveled / time elapsed.
In the bottom image, draw a straight line from the lower right corner THROUGH the peak of the coronal loop. Now draw this same line at the same angle on the other two images. With a millimeter ruler, measure the distance along the line from the lower right corner to the edge of the loop along the line. Example:
Top: 47 mm ;
Middle: 52 mm,
Bottom: 67 mm.
The loop has moved 67mm – 47mm = 20 millimeters. At the scale of the image this equals 20mm x 4,300 km/mm so D = 86,000 km.

The time between the bottom and top images is 18:13:29 – 17:50:49 or 22minutes and 40 seconds or 1360 seconds.

A) The average speed of the loop is then S = 86,000 km/1360 sec = **63 km/sec**.

B) 63 km/sec x 3600 sec/hr = **227,000 km/hour**.

C) 227,000 km/hr x 0.62 miles/km = **140,000 miles/hour**.



A solar tsunami that occurred in February 13, 2009 has recently been identified in the data from NASA's STEREO satellites. It was spotted rushing across the Sun's surface. The blast hurled a billion-ton Coronal Mass Ejection (CME) into space and sent a tsunami racing along the sun's surface. STEREO recorded the wave from two positions separated by 90 degrees, giving researchers a spectacular view of the event. Satellite A (STA) provided a side-view of the CME, while Satellite B (STB) viewed the CME from directly above. The technical name for the 'tsunami' is a "fast-mode magnetohydrodynamic wave" – or "MHD wave" for short. The one STEREO saw raced outward at 560,000 mph (250 km/s) packing as much energy as 2,400 megatons of TNT.

Problem 1 - In the lower strip of images, the sun's disk is defined by the mottled circular area, which has a physical radius of 696,000 kilometers. Use a millimeter ruler to determine the scale of these images in kilometers/mm.

Problem 2 - The white circular ring defines the outer edge of the expanding MHD wave. How many kilometers did the ring expand between 05:45 and 06:15? (Note '05:45' means 5:45 o'clock Universal Time).

Problem 3 - From your answers to Problem 1 and 2, what was the approximate speed of this MHD wave in kilometers/sec?

Problem 4 - Kinetic Energy is defined by the equation K.E. = $1/2\ m\ V^2$ where m is the mass of the object in kilograms, and V is its speed in meters/sec. Suppose the mass of the CME was about 1 million metric tons, use your answer to Problem 3 to calculate the K.E., which will be in units of Joules.

Problem 5 - If 1 kiloton of TNT has the explosive energy of 4.1×10^{12} Joules, how many megatons of TNT does the kinetic energy of the tsunami represent?

Problem 1 - In the lower strip of images, the sun's disk is defined by the mottled circular area, which has a physical radius of 696,000 kilometers. Use a millimeter ruler to determine the scale of these images in kilometers/mm.

Answer: The diameter is 31 millimeters ,which corresponds to 2 x 696,000 km or 1,392,000 km. The scale is then 1,392,000 km/31mm = 45,000 km/mm.

Problem 2 - The white circular ring defines the outer edge of the expanding MHD wave. How many kilometers did the ring expand between 05:45 and 06:15? (Note '05:45' means 5:45 o'clock Universal Time).

Answer: From the scale of 45,000 km/mm, the difference in the ring radii is 12mm - 5 mm = 7mm which corresponds to 7 mm x (45,000 km/1 mm) = 315,000 kilometers. Students answers may vary depending on where they defined the outer edge of the ring.

Problem 3 - From your answers to Problem 1 and 2, what was the approximate speed of this MHD wave in kilometers/sec?

Answer: The time difference is 06:15 - 05:45 = 30 minutes. The speed was about 315,000 km / 30 minutes = 11,000 kilometers/minute, which is 11,000 km/minute x (1 minute/60 seconds) = 180 kilometers/sec.

Problem 4 - Kinetic Energy is defined by the equation K.E. = 1/2 m V^2 where m is the mass of the object in kilograms, and V is its speed in meters/sec. Suppose the mass of the CME was about 1 million metric tons, use your answer to Problem 3 to calculate the K.E., which will be in units of Joules.

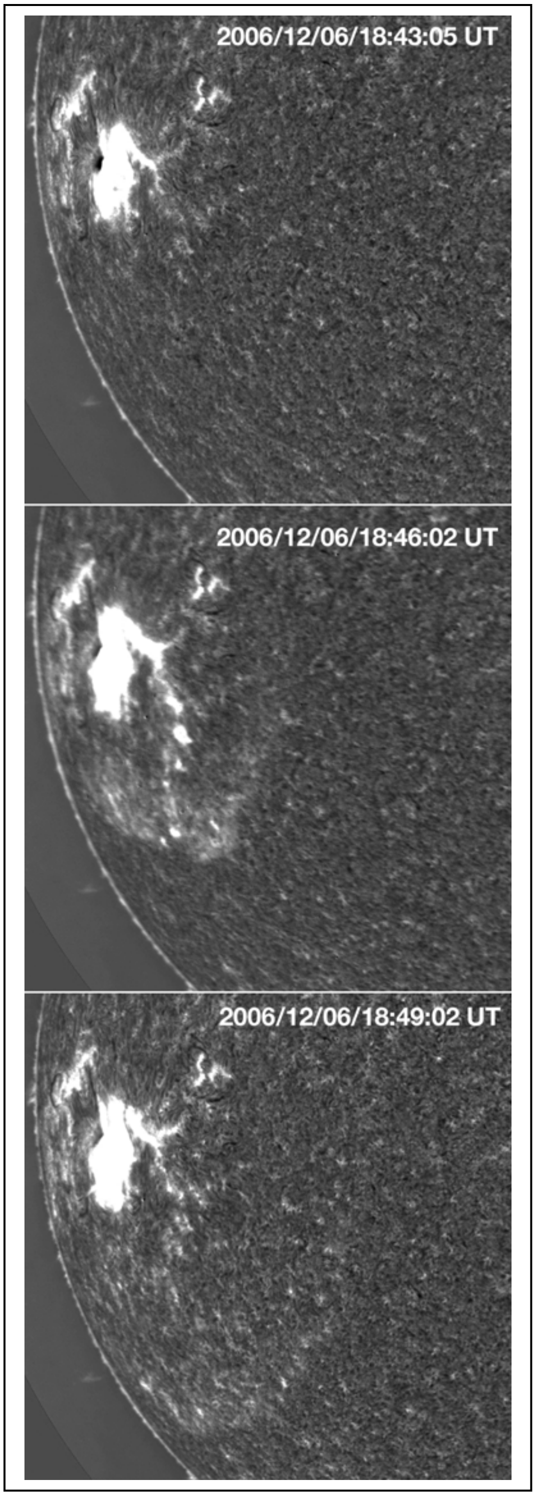
Answer: The mass of the CME was 1 billion metric tons. There are 1,000 kilograms in 1 metric ton, so the mass was 1.0×10^{12} kilograms. The speed is 180 km/sec which is 180,000 meters/sec. The kinetic energy is then about $0.5 \times 1.0 \times 10^{12} \times (180{,}000)^2 =$ **1.6×10^{22} Joules.**

Problem 5 - If 1 kiloton of TNT has the explosive energy of 4.1×10^{12} Joules, how many megatons of TNT does the kinetic energy of the tsunami represent?

Amswer: 1.6×10^{22} Joules x (1 kiloton TNT/4.1×10^{12} Joules) = 3.9×10^{9} kilotons TNT. Since 1 megaton = 1,000 kilotons, we have an explosive yield of **3,900,000 megatons TNT**. (Note; this answer differs from the STEREO estimate because the speed is approximate, and does not include the curvature of the sun).

Teacher Note: Additional information, and movies of the event, can be found at the STEREO website: **http://stereo.gsfc.nasa.gov/news/SolarTsunami.shtml.** Also published in the Astrophysical Journal Letters (*ApJ* **700** L182-L186)

Measuring the Speed of a Solar Tsunami!



Moments after a major class X-6 solar flare erupted at 18:43:59 Universal Time on December 6, 2006, the National Solar Observatory's new Optical Solar Patrol Camera captured a movie of a shock wave 'tsunami' emerging from Sunspot 930 and traveling across the solar surface. The three images to the left show the progress of this Morton Wave. The moving solar gasses can easily be seen. You can watch the entire movie and see it more clearly (http://image.gsfc.nasa.gov/poetry/weekly/MortonW ave.mpeg).

<u>Note: because the event is seen near the solar limb, there is quite a bit of fore-shortening so the motion will appear slower than what the images suggest.</u>

Problem 1: From the portion of the sun's edge shown in the images, complete the solar 'circle'. What is the radius of the sun's disk in millimeters?

Problem 2: Given that the physical radius of the sun is 696,000 kilometers, what is the scale of each image in kilometers/millimeter?

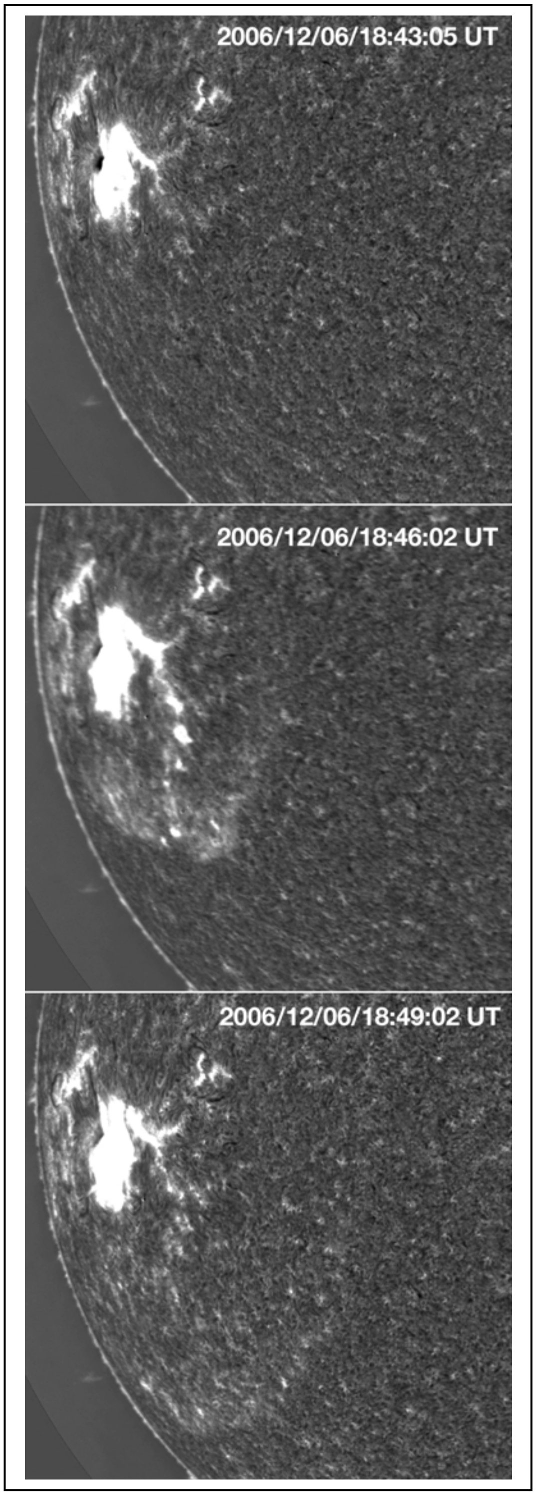
Problem 3: Select a spot near the center of the sunspot (large white spot in the image), and a location on the leading edge of the shock wave. What is the distance in kilometers from the center of the sunspot, to the leading edge of the shock wave in each image?

Problem 4: The images were taken at 18:43:05, 18:47:03 and 18:50:11 Universal Time. How much elapsed time has occurred between these images?

Problem 5: From your answers to Problem 3 and 4, what was the speed of the Morton Wave in kilometers per hour between the three images? B) did the wave accelerate or decelerate as it expanded?

Problem 6: The speed of the Space Shuttle is 44,000 kilometers/hour. The speed of a passenger jet is 900 kilometers/hour. Would the Morton Wave have overtaken the passenger jet? The Space Shuttle?

Answer Key:



Problem 1: From the portion of the sun's edge shown in the images, complete the solar 'circle'. What is the radius of the sun's disk in millimeters?

Answer: About 158 millimeters using a regular dessert plate as a guide.

Problem 2: Given that the physical radius of the sun is 696,000 kilometers, what is the scale of each image in kilometers/millimeter?

Answer: 696,000/158 = 4,405 kilometers/millimeter

Problem 3: What is the distance in kilometers from the center of the sunspot, to the leading edge of the shock wave in each image?

Answer:

Image 2 = 27 mm = 27x4405 = 119,000 km
Image 3 = 38 mm = 167,000 km

Problem 4: The images were taken at 18:43:05, 18:47:03 and 18:50:11 Universal Time. How much elapsed time has occurred between these images?

Answer: Image 1 - Image 2 = 3 minutes 58 seconds
Image 2 - Image 3 = 3 minutes 8 seconds

Problem 5: From your answers to Problem 3 and 4, A) what was the speed of the Morton Wave in kilometers per hour between the three images?

Answer:

V12 = 119,000 km/3.9 min x (60 min/1 hr)
= 1.8 million kilometers/hour

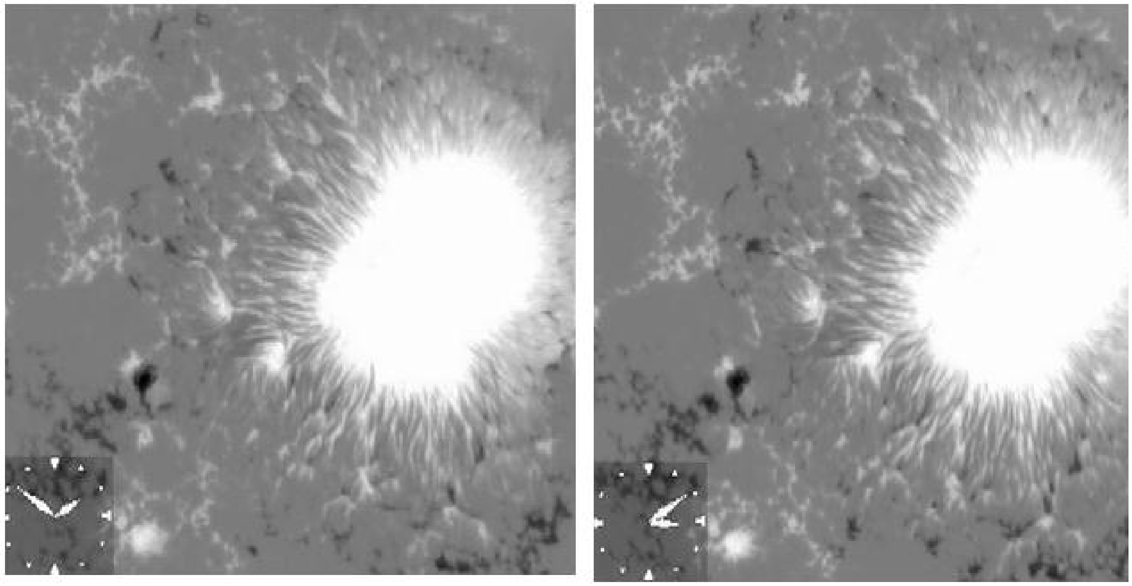
V23 = 167,000/3.1 min x (60 min/1 hr)
= 3.2 million kilometers/hour

B) Did the speed of the wave accelerate or decelerate?
Answer: Because V23 > V12 the wave accelerated.

Problem 6: The speed of the Space Shuttle is 44,000 kilometers/hour. The speed of a passenger jet is 900 kilometers/hour. Would the Morton Wave have overtaken the passenger jet? The Space Shuttle?

Answer: It would easily have overtaken the Space Shuttle! Because of fore-shortening, the actual speed of the wave was even higher than the estimates from the images, so the speed could have been well over 4 million km/hr.

Hinode Sees Moving Magnetic Filaments



These two images were taken by the Hinode solar observatory on October 30, 2006. The size of each image is 34,300 km on a side. The clock face shows the time when each image was taken, and represents the face of an ordinary 12-hour clock.

Problem 1 - What is the scale of each image in kilometers per millimeter?

Problem 2 - What is the elapsed time between each image in; A) hours and minutes? B) decimal hours? C) seconds?

Carefully study each image and look for at least 5 features that have changed their location between the two images. (Hint, use the nearest edge of the image as a reference).

Problem 3 - What direction are they moving relative to the sunspot?

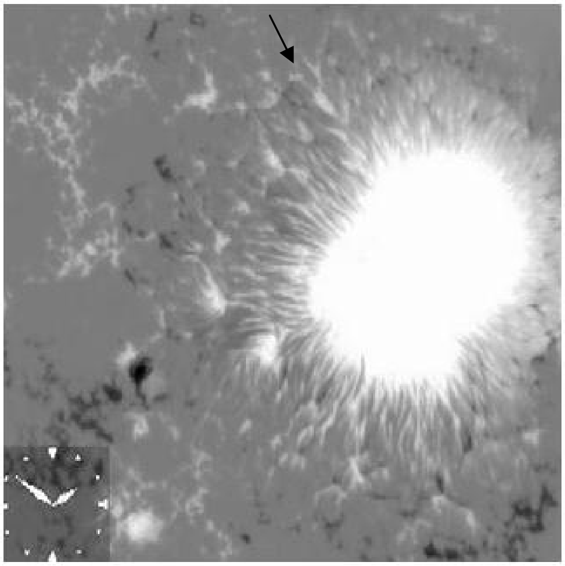
Problem 4 - How far, in millimeters have they traveled on the image?

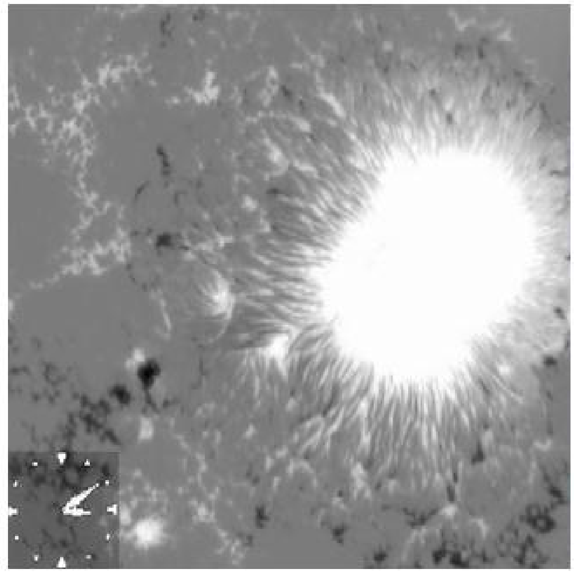
Problem 5 - From your answers to questions 1, 2 and 4, calculate their speed in kilometers per second, and kilometers per hour.

Problem 6 - A fast passenger jet plane travels at 600 miles per hour. The Space Shuttle travels 28,000 miles per hour. If 1.0 kilometer = 0.64 miles, how fast do these two craft travel in kilometers per second?

Problem 7 - Can the Space Shuttle out-race any of the features you identified in the sunspot image?

Answer Key:





Problem 1 - What is the scale of each image in kilometers per millimeter? **Answer:** The pictures are 75 mm on a side, so the scale is 34,300 km /75mm = **457 km/mm**

Problem 2 - What is the elapsed time between each image in;

A) hours and minutes? About 1 hour and 20 minutes.
B) decimal hours? About 1.3 hours
C) seconds? About 1.3 hours x 3600 seconds/hour = 4700 seconds

Carefully study each image and look for at least 5 features that have changed their location between the two images. (Hint, use the nearest edge of the image as a reference). Students may also use transparent paper or film, overlay the paper on each image, and mark the locations carefully.
The above picture shows one feature as an example.

Problem 3 - What direction are they moving relative to the sunspot?
Answer: Most of the features seem to be moving away from the sunspot.

Problem 4 - How far, in millimeters have they traveled on the image? **Answer:** The feature in the above image has moved about 2 millimeters.

Problem 5 - From your answers to questions 1, 2 and 4, calculate their speed in kilometers per second, and kilometers per hour. **Answer:** 2 mm x 457 km/mm = 914 kilometers in 4700 seconds = 0.2 kilometers/sec or 703 kilometers/hour.

Problem 6 - A fast passenger jet plane travels at 600 miles per hour. The Space Shuttle travels 28,000 miles per hour. If 1.0 kilometer = 0.64 miles, how fast do these two craft travel in kilometers per second? Jet speed = 600 miles/hr x (1 / 3600 sec/hr) x (1 km/0.64 miles) = **0.26 km/sec**. Shuttle = 28,000 x (1/3600) x (1/0.64) = **12.2 km/sec.**

Problem 7 - Can the Space Shuttle out-race any of the features you identified in the sunspot image? **Answer:** Yes, in fact a passenger plane can probably keep up with the feature in the example above!

The Speed of a Coronal Mass Ejection

The last few days from November 6 - 9, 2004 were very active days for solar and auroral events. A major sunspot group, AR 0696, with a complex magnetic field produced several Coronal Mass Ejections (CME) and flares during this time. (A CME is billion-ton cloud of gas ejected by the sun at millions of kilometers per hour). The latest ones were an X2.0-class solar flare on Nov 7, 16:06 UT and a CME. On November 9 and 12:00 UT, the beginnings of a major geomagnetic storm started. The NOAA Space Weather Bulletin announced that:

The Geomagnetic field is expected to be at unsettled to major storm levels on 09 November due to the arrival of a CME associated with the X2.0 flare observed on 07 November. Unsettled to minor storm levels are expected on 10 November. Quiet to active levels are expected on 11 November.

Many observers as far south as Texas and Oklahoma reported seeing beautiful aurora on Sunday night from an earlier CME/flare combination on Saturday, November 6th. In the space provided below, calculate the speed of the CME as it traveled to Earth between November 7th - 9th assuming that the distance to Earth is 93 million miles, or 147 million kilometers.

Problem 1 - How long did it take for the CME to arrive?

Problem 2 - What is the speed of the CME in miles per hour?

Problem 3 - What is the speed of the CME in kilometers per hour?

Problem 4 - What is the speed of the CME in miles per second?

Problem 5 - What is the speed of the CME in kilometers per second?

The distance to the Earth is 93 million miles or 147 million kilometers.
Start time = November 7 at 16:06 UT
Arrival time = November 9 at 12:00 UT

Problem 1 - How long did it take for the CME to arrive?
Answer: November 7 at 16:06 UT to November 8 at 16:06 UT is 24 hours.
From Nov 8 at 16:06 to Nov 9 at 12:00 UT is
(24:00 - 16:06) + 12:00
= 7:54 + 12:00
= **19 hours and 54 minutes**.
Total time = 24 hours + 19 hours and 54 minutes = 43 hours and 54 minutes.

Problem 2 - What is the speed of the CME in miles per hour?
Answer: In decimal units, the travel time from question 1 equals 43.9 hours.
The distance is 93 million miles so the speed is 93 million miles/43.9hours
or **2.1 million miles per hour**.

Problem 3 - What is the speed of the CME in kilometers per hour?
Answer: Use the conversion that 1.0 miles = 1.6 kilometers, then
2.1 million miles/hour x 1.6 km/mile = **3.4 million kilometers per hour**

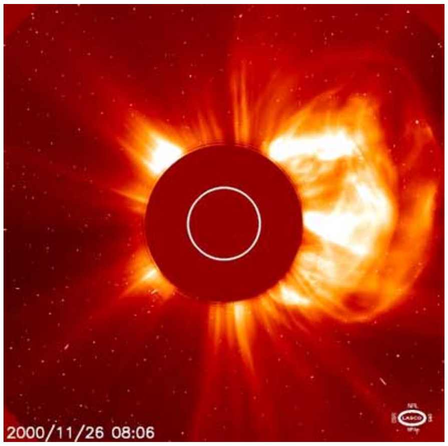
Problem 4 - What is the speed of the CME in miles per second?
Answer: Convert hours to seconds by
1 hour x 60 minutes/hour x 60 seconds/minute = 3,600 seconds.
Then from question 2: 2.1 million miles/hour divided by 3600 seconds/hour
= **583 miles/second.**

Problem 5 - What is the speed of the CME in kilometers per second?
Answer: From question 3 and the conversion of 1 hour = 3600 seconds:
3.4 million kilometers / second divided by 3600 seconds/hour
= **944 kilometers/sec**.

Solar storm speeds

The sun often ejects clouds of gases into space. Some of these fast-moving clouds can be directed at Earth. Astronomers call them Coronal Mass Ejections (or CMEs). When these CMEs arrive, they can cause spectacular auroras, damage satellites, or cause electrical blackouts.

In this exercise, you will learn how scientists use the speeds of these clouds to predict when they will arrive at Earth.



The sun ejects clouds of gas into space carrying billions of tons of matter.

Scientists need to know how fast things move in order to study where they come from and what causes them.

- The speed of an object is defined as the distance it travels divided by the time it takes.

Here's how to do it!

The ACE satellite measures the speed of the solar wind and clouds of gas from the sun. Its sensor detects a cloud moving at 980 kilometers per second. How long will it take for it to travel from the spacecraft to Earth, if the distance is 1.5 million kilometers?

Answer: Time = (1,500,000 km) / (980 km/sec)
= 1,530 seconds

Now you try!

Cloud Speeds

Date	Speed (km/s)
5-10-02	423.0
5-18-02	497.0
5-23-02	897.0
7-12-02	548.0
7-20-02	931.0
7-23-02	516.0
9-19-02	756.0
1-11-02	647.0
1-19-02	455.0
3-05-02	705.0
3-18-02	480.0
3-29-02	379.0
4-01-02	795.0
8-10-02	469.0

The table shows cloud speeds measured in kilometers per second. Assume that the clouds detected by the ACE satellite were the CMEs produced on the sun.

1) What was the fastest speed measured?

2) What was the slowest speed measured?

3) What was the average speed measured?

4) What is the fastest speed in miles per hour?

5) If the sun is 150 million kilometers from Earth, how many hours would it take the fastest and the slowest CMEs to reach Earth?

Answer Key

Problem 1 - 931 kilometers/sec

Problem 2 - 379 kilometers/sec

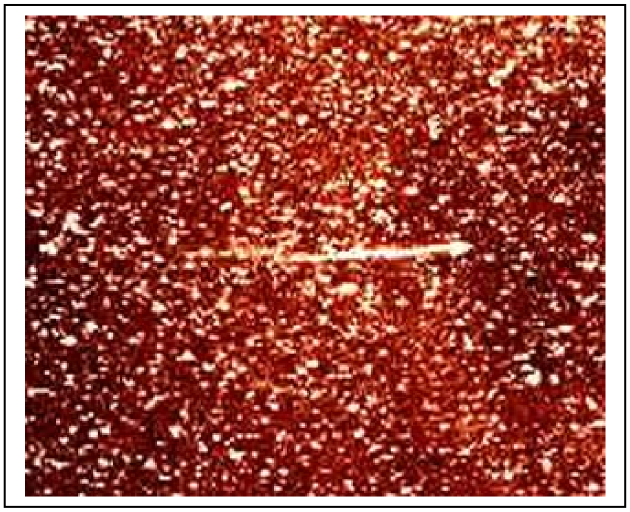
Problem 3 - 8498/14 = 607 kilometers/sec

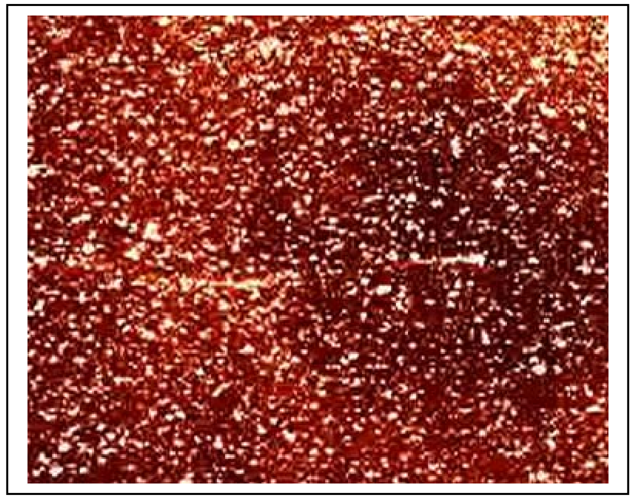
Problem 4 - (931) x (3600) x 0.62 = 2.1 million miles/hour

Problem 5 - Fastest: 150,000,000/931 = 161.000 seconds or 44.8 hours
Slowest: 150,000,000/379 = 396,000 seconds or 110 hours

STEREO Sees Comet Encke's Tail Disrupted by a CME

On April 20, 2007, NASA's STEREO satellite witnessed a rare solar system event. The Comet Encke had just passed inside the orbit of Venus and was at a distance of 114 million kilometers from STEREO-A ,when a Coronal Mass Ejection occurred on the sun. The cloud of magnetized gas passed over the comet's tail at 18:50 UT, and moments later caused the tail of the comet to break into two. The two images below show two images from the tail breakup sequence. The left image was taken at 18:10 UT and the right image was taken at 20:50 UT. Each image subtends an angular size of 6.4 degrees x 5.3 degrees. For comparison, the Full Moon would correspond to a circle with a diameter of 0.5 degrees.





Problem 1 - What is the scale of the images in arcminutes per millimeter? (1 degree=60 arcminutes)

Problem 2 - How many seconds elapsed between the time the two images were taken by the STEREO-A satellite?

Problem 3 - The left image shows the comet with an intact tail. The right image shows the tail separated from the head of the comet (the right-most bright feature along the comet's horizontal axis which we will call Point A), and flowing to the left. Meanwhile, you can see that the comet has already begun to reform a new tail. Carefully examine the right-hand image and identify the right-most end of the ejected tail (Call it Point B). Note that star images do not move, and are more nearly point-like than the tail gases. How far, in millimeters, is Point B from Point A?

Problem 4 - From the image scale, convert your answer to Problem 3 into arcminutes.

Problem 5 - The distance of the comet was 114 million kilometers, and at that distance, one arcminute of angular separation corresponds to 33,000 kilometers. How far did the tail fragment travel between the times of the two images?

Problem 6 - What was the speed of the tail fragment?

Problem 7 - If the comet's speed was about 40 km/sec and the CME speed was at least several hundred times faster, based on your answer to Problem 6, was the comet fragment 'left behind' or did the CME carry it off?

Answer Key:

Problem 1 - What is the scale of the images in arcminutes per millimeter? (1 degree=60 arcminutes)

Answer: horizontally, the image span 6.4 degrees x 60 minutes/degree = 384 arcminutes. The length is 77 millimeters, so the scale is 384/77 = **5.0 arcminutes/mm**

Problem 2 - How many seconds elapsed between the time the two images were taken by the STEREO-A satellite?

Answer: 20:50 - 18:10 = 2 hours and 40 minutes = 160 minutes or **9600 seconds.**

Problem 3 - The left image shows the comet with an intact tail. The right image shows the tail separated from the head of the comet (the right-most bright feature along the comets horizontal axis which we will call Point A), and flowing to the left. Meanwhile, you can see that the comet has already begun to reform a new tail. Carefully examine the right-hand image and identify the right-most end of the ejected tail (Call it Point B). Note that star images do not move, and are more nearly point-like than the tail gases. How far, in millimeters, is Point B from Point A?

Answer: An answer near **17 millimeters** is acceptable, but students may measure from 15 to 20 millimeters as reasonable answers.

Problem 4 - From the image scale, convert your answer to Problem 3 into arcminutes.

Answer: 17 millimeters x 5 arcminutes/mm = **85 arcminutes**.

Problem 5 - The distance of the comet was 114 million kilometers, and at that distance, one arcminute of angular separation corresponds to 33,000 kilometers. How far did the tail fragment travel between the times of the two images?

Answer: 85 arcminutes x 33,000 kilometers/arcminute = **2.8 million kilometers.**

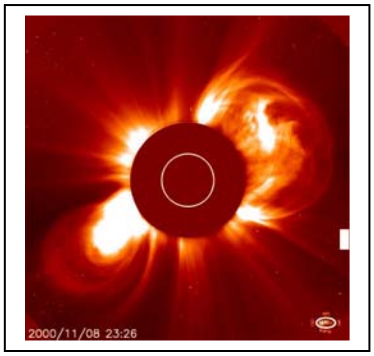
Problem 6 - What was the speed of the tail fragment?

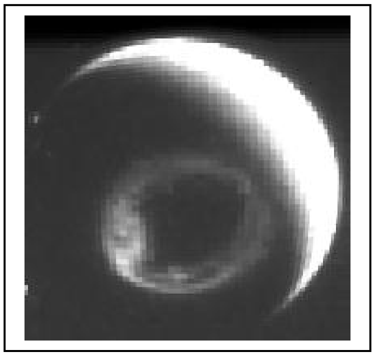
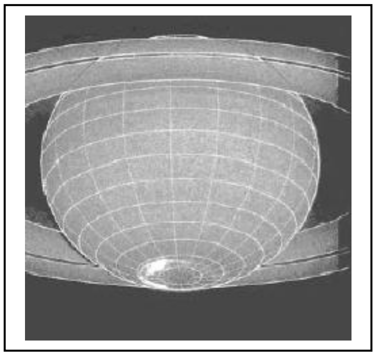
Answer: 2.8 million kilometers/9600 seconds = **292 kilometers/second.**

Problem 7 - If the comet's speed was about 40 km/sec and the CME speed was at least several hundred times faster, based on your answer to Problem 6, was the comet fragment 'left behind' or did the CME carry it off?
Answer: The speed in Problem 6 is much closer to the CME speed than the comet speed, so the fragment was carried off by the CME and not ejected by the comet.

This collision was studied in detail by Dr. Angelos Vourlidas and his colleagues at the Naval Research laboratory in Washington, D.C and the Rutherford Laboratory in England. They deduced from a more careful analysis that the CME speed was about 500 km/sec and the solar wind speed was about 420 km/sec. The tail fragment was carried off by the CME. Details can be found in The Astrophysical Journal (Letters), vol. 668, pp L79-L82 which was published on October 10, 2007. A movie of the encounter may be seen at the STEREO web site (http://stereo.gsfc.nasa.gov) in their movie gallery.

An Interplanetary Shock Wave



Sun - CME Earth - Aurora Saturn - Aurora

On November 8, 2000 the sun ejected a billion-ton cloud of gas called a coronal mass ejection or CME. On November 12, the CME collided with Earth and produced a brilliant aurora detected from space by the IMAGE satellite.

On December 8, the Hubble Space Telescope detected an aurora on Saturn. During the period from November to December, 2000, Earth, Jupiter and Saturn were almost lined-up with each other. Assuming that the three planets were located on a straight line drawn from the sun to Saturn, with distances from the sun of 150 million, 778 million and 1.43 billion kilometers respectively, answer the questions below:

Problem 1 – How many days did the disturbance take to reach Earth and Saturn?

Problem 2 – What was the average speed of the CME in its journey between the Sun and Earth in millions of km per hour?

Problem 3 – What was the average speed of the CME in its journey between Earth and Saturn in millions of km per hour?

Problem 4 – Did the CME accelerate or decelerate as it traveled from the Sun to Saturn?

Problem 5 – How long would the disturbance have taken to reach Jupiter as it passed Earth's orbit?

Problem 6 – On what date would you have expected to see aurora on Jupiter?

On November 8, 2000 the sun ejected a billion-ton cloud of gas called a coronal mass ejection or CME. On November 12, the CME collided with Earth and produced a brilliant aurora detected from space by the IMAGE satellite. On December 8, the Hubble Space telescope detected an aurora on Saturn. During the period from November to December, 2000, Earth, Jupiter and Saturn were almost lined-up with each other. Assuming that the three planets were located on a straight line drawn from the sun to Saturn, with distances from the sun of 150 million, 778 million and 1.43 billion kilometers respectively, answer the questions below:

1 – How many days did the disturbance take to reach Earth and Saturn?
Answer: Earth = 4 days; Saturn = 30 days.

2 – What was the average speed of the CME in its journey between the Sun and Earth in millions of km per hour? **Answer:** Sun to Earth = 150 million km. Time = 4 days x 24 hrs = 96 hrs so Speed = 150 million km/96hr = **1.5 million km/hr.**

3 – What was the average speed of the CME in its journey between Earth and Saturn in millions of km per hour? **Answer:** Distance = 1,430 – 150 = 1,280 million km. Time = 30 days x 24h = 720 hrs so Speed = 1,280 million km/720hrs = **1.8 million km/hr.**

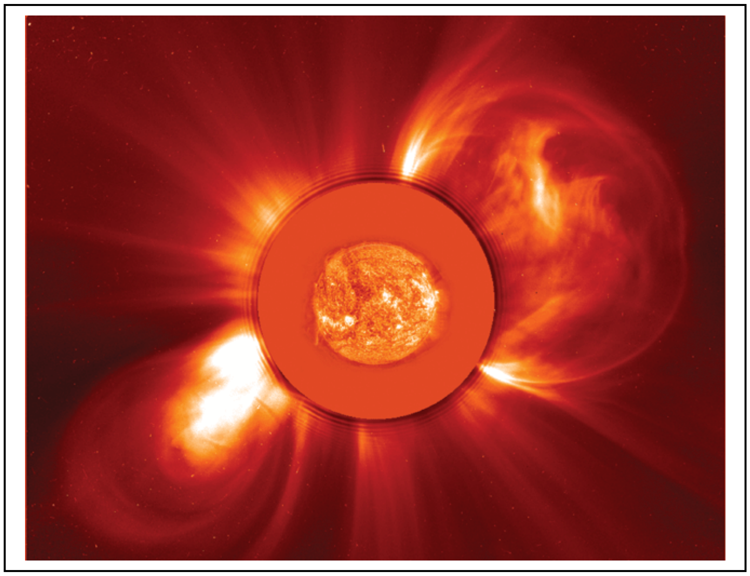
4 – Did the CME accelerate or decelerate as it traveled from the Sun to Saturn? **Answer: The CME accelerated from 1.5 million km/hr to 1.8 million km/hr.**

5 – How long would the disturbance have taken to reach Jupiter as it passed Earth's orbit? **Answer:** Jupiter is located 778 million km from the Sun or (778 – 150 =) 628 million km from Earth. Because the CME is accelerating, it is important that students realize that it is more accurate to use the average speed of the CME between Earth and Saturn which is (1.8 + 1.5)/2 = 1.7 million km/hr. The travel time to Jupiter is then 628/1.7 = **369 hours.**

6 – On what date would you have expected to see aurora on Jupiter? **Answer:** Add 369 hours (~ 15 days) to the date of arrival at Earth to get **November 23.** According to radio observations of Jupiter, the actual date of the aurora was November 20. Note: If we had used the Sun-Earth average speed of 1.5 million km/hr to get a travel time of 628/1.5 = 418 hours, the arrival date would have been November 29, which is 9 days later than the actual storm. This points out that the CME was accelerating after passing Earth, and its speed was between 1.5 and 1.8 million km/hr.

For more details about this interesting research, read the article by Renee Prange et al. "An Interplanetary Shock Traced by Planetary Auroral Storms from the Sun to Saturn" published in the journal Nature on November 4, 2004, vol. 432, p. 78. Also visit the Physics Web online article "Saturn gets a shock" at http://www.physicsweb.org/articles/news/8/11/2/1

CME Kinetic Energy and Mass



Kinetic energy is the energy that a body has by virtue of its mass and speed. Mathematically, it is expressed as one-half of the product of the mass of the object (in kilograms), times the square of the objects speed (in meters/sec).

$$\textbf{K.E. = 0.5 m V}^2$$

Between October 1996 and May 2006, the SOHO satellite detected and cataloged 11,031 coronal mass ejections (CMEs) like the one seen in the figure to the left. There was enough data available to determine the properties for 2,131 events. The table below gives values for ten of these CMEs.

Date	Speed (km/s)	K.E. (Joules)	Mass (kilograms)
4/8/1996		1.1×10^{20}	2.2×10^{9}
8/22/2000	388	1.3×10^{22}	
6/10/2001	731	8.2×10^{23}	
1/18/2002	64		2.6×10^{10}
5/16/2002	1,310		7.8×10^{10}
10/7/2002		7.8×10^{21}	3.0×10^{10}
1/24/2003	387	9.1×10^{18}	
10/31/2003	2,198	1.6×10^{24}	
11/2/2003		9.3×10^{25}	4.5×10^{13}
11/10/2004	3,387		9.6×10^{12}

Problem 1 - Complete the table by determining the value of the missing entries using the formula for Kinetic Energy.

Problem 2 - What is the minimum and maximum range for the observed kinetic energies for the 10 CMEs? The largest hydrogen bomb ever tested was the Tsar Bomba in 1961 and was equivalent to 50 megatons of TNT. It had a yield of 5×10^{23} Joules. What is the equivalent yield for the largest CME in megatons, and 'Tsar Bombas'?

Problem 3 - What are the equivalent masses of the smallest and largest CMEs in metric tons?

Problem 4 - Compare the mass of the largest CME to the mass of a small mountain. Assume that the mountain can be represented as a cone with a volume given by $1/3\ \pi\ R^2\ H$ where R is the base radius and H is the height in meters, and assume the density of rock is 3 grams/cm^3.

Date	Speed (km/s)	K.E. (Joules)	Mass (kilograms)
4/8/1996	**316**	1.1×10^{20}	2.2×10^{9}
8/22/2000	388	1.3×10^{22}	**1.7×10^{11}**
6/10/2001	731	8.2×10^{23}	**3.1×10^{12}**
1/18/2002	64	**5.3×10^{19}**	2.6×10^{10}
5/16/2002	1,310	**6.7×10^{22}**	7.8×10^{10}
10/7/2002	**721**	7.8×10^{21}	3.0×10^{10}
1/24/2003	387	9.1×10^{18}	**1.2×10^{8}**
10/31/2003	2,198	1.6×10^{24}	**6.6×10^{11}**
11/2/2003	**2,033**	9.3×10^{25}	4.5×10^{13}
11/10/2004	3,387	**5.5×10^{25}**	9.6×10^{12}

Problem 1: Complete the table by determining the value of the missing entries using the formula for Kinetic Energy.

Answer: See above answers.

Problem 2: What is the minimum and maximum range for the observed kinetic energies for the 10 CMEs?

Answer: Maximum = 9.3×10^{25} Joules. Minimum = 5.3×10^{19} Joules

The largest hydrogen bomb ever tested was the *Tsar Bomba* in 1961 and was equivalent to 50 megatons of TNT. It had a yield of 5×10^{23} Joules. What is the equivalent yield for the largest CME in megatons, and 'Tsar Bombas'?

Answer: The CME on November 2, 2003 was equal to
$(9.3 \times 10^{25}/5 \times 10^{23})$ = 186 Tsar Bombas,
and an equivalent TNT yield of 186 x 50 megatons = **9,300 megatons!**

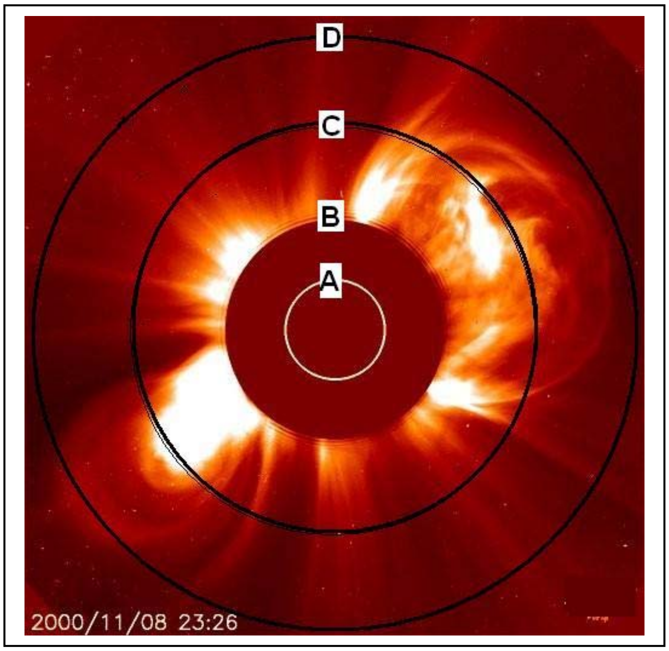
Problem 3: What are the equivalent masses of the smallest and largest CMEs in metric tons?

Answer: One metric ton is 1,000 kilograms. The smallest mass was for the January 24, 2003 CME with about 120,000 tons. The largest mass was for the November 2, 2003 'Halloween Storm' with about **45 billion metric tons.**

Problem 4: Compare the mass of the largest CME to the mass of a small mountain. Assume that the mountain can be represented as a cone with a volume given by $V = 1/3 \pi R^2 H$ where R is the base radius and H is the height in meters, and assume the density of rock is 3 grams/cm^3.

Answer: One possibility is for a mountain with a base radius of R = 1 kilometers, and a height of 50 meters. The cone volume is $0.33 \times 3.14 \times (1000)^2 \times 50 = 5.2 \times 10^7$ cubic meters. The rock density of 3 gm/cm^3 converted into kg per cubic meters is 0.003 kg/$(.01)^3$ = 3000 kg/m^3. This yields a mountain with a mass of **156 billion tons,** which is close to the largest CME mass in the table. So CMEs, though impressive in size, carry no more mass than a small hill on Earth!

Estimating Halo CME Speeds



Frames	Cadence (seconds)					
	10	15	20	**25**	30	35
1	2333	1556	1167	**933**	778	667
2	1167	778	583	**467**	389	333
3	778	519	389	**311**	259	222
4	583	389	292	**233**	194	167
5	467	311	233	**187**	156	133

The SOHO satellite LASCO instrument takes images of the sun every 24 seconds in order to detect the movement of coronal mass ejections such as the one shown in the image to the left. The circles indicate the scale of the image in multiples of the solar radius (690,000 kilometers). By counting the number of consecutive frames required for the CME to move between circles B and D, the speed of the CME can be estimated.

The table above gives the speed of the CME in kilometers/sec, based on the time between the frames (cadence) and the number of frames required for the CME to move from Circle B to D.

Problem 1 - An astronomer watches the CME on one satellite which has a cadence of 15 seconds between frames, and it moves from B to D in 5 frames. A second satellite has a cadence of 35 seconds. How many frames will the second satellite require to see the CME move the same distance?

Problem 2 - Using this method, an astronomer wants to observe very fast CMEs with speeds between 934 and 4,666 km/sec. What must the cadence be for these measurements to be possible?

Problem 1 - An astronomer watches the CME on one satellite which has a cadence of 15 seconds between frames, and it moves from B to D in 5 frames. A second satellite has a cadence of 35 seconds. How many frames will the second satellite require to see the CME move the same distance?

Answer: From the first satellite and the table, the speed is 311 km/sec. If the cadence of the second satellite is **35 seconds**, it will see the CME move the same distance in about 2 frames.

Problem 2 - Using this method, an astronomer wants to observe very fast CMEs with speeds between 934 and 4,666 km/sec. What must the cadence be for these measurements to be possible?

Answer: **The speeds are twice as fast as the range of speeds measurable with a cadence of 10 seconds/frame. Because for a given number of frames the speed is linear with the cadence, reducing the cadence to 5 seconds/frame the required speeds can be measured within an interval of 5 frames.**

Estimating Halo CME Arrival Times

Speed (km/s)	Distance from the Sun in Astronomical Units										
	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2
300	139	153	167	181	194	208	222	236	250	264	278
400	104	115	125	135	146	156	167	177	188	198	208
500	83	92	100	108	117	125	133	142	150	158	167
600	69	76	83	90	97	104	111	118	125	132	139
700	60	65	71	77	83	89	95	101	107	113	119
800	52	57	63	68	73	78	83	89	94	99	104
900	46	51	56	60	65	69	74	79	83	88	93
1000	42	46	50	54	58	63	67	71	75	79	83
1100	38	42	45	49	53	57	61	64	68	72	76
1200	35	38	42	45	49	52	56	59	63	66	69
1300	32	35	38	42	45	48	51	54	58	61	64
1400	30	33	36	39	42	45	48	51	54	57	60
1500	28	31	33	36	39	42	44	47	50	53	56
1600	26	29	31	34	36	39	42	44	47	49	52
1700	25	27	29	32	34	37	39	42	44	47	49
1800	23	25	28	30	32	35	37	39	42	44	46
1900	22	24	26	29	31	33	35	37	39	42	44
2000	21	23	25	27	29	31	33	35	38	40	42
2100	20	22	24	26	28	30	32	34	36	38	40
2200	19	21	23	25	27	28	30	32	34	36	38
2300	18	20	22	24	25	27	29	31	33	34	36
2400	17	19	21	23	24	26	28	30	31	33	35
2500	17	18	20	22	23	25	27	28	30	32	33
2600	16	18	19	21	22	24	26	27	29	30	32
2700	15	17	19	20	22	23	25	26	28	29	31
2800	15	16	18	19	21	22	24	25	27	28	30
2900	14	16	17	19	20	22	23	24	26	27	29
3000	14	15	17	18	19	21	22	24	25	26	28

The shaded values in the table above give the arrival times (in hours) to the various distances in Astronomical Units, given the speed of the coronal mass ejection (CME) indicated in the first column. The distance from Earth to the sun (150 million km) is defined to be exactly 1 Astronomical Unit (1.0 AU). A 'Halo' CME is an explosive expulsion of heated gas from the sun directed towards Earth.

Problem 1 - Suppose that the planet Earth and Mars are in opposition, which means that a straight line can be drawn from the center of the sun directly through the centers of Earth and Mars. Astronomers at Earth detect a CME leaving the sun at a speed of 1500 km/sec. When will this CME arrive at Earth and how long afterwards will it arrive at Mars located at a distance of 1.5 AU?

Problem 2 - A CME leaves the sun at a speed of 900 km/sec on July 4, 2015 at 13:00 UT. On what dates and times will it arrive at A) Earth? B) Mars? C) An asteroid located at 1.9 AU?

Problem 1 - Suppose that the planet Earth and Mars are in opposition, which means that a straight line can be drawn from the center of the sun directly through the centers of Earth and Mars. Astronomers at Earth detect a CME leaving the sun at a speed of 1500 km/sec. When will this CME arrive at Earth (1.0 AU) and how long afterwards will it arrive at Mars located at a distance of 1.5 AU?

Answer: From the table, look at the row for '1500' in Column 1 and under '1.0' AU the time for arrival at Earth is about **26 hours**. In the column for Mars at '1.5' the arrival time is 39 hours, so it takes **13 additional hours for the CME to arrive at Mars**.

Problem 2 - A CME leaves the sun at a speed of 900 km/sec on July 4, 2015 at 13:00 UT. On what dates and times will it arrive at A) Earth? B) Mars? C) An asteroid located at 1.9 AU?

Answer: A) The transit time to Earth is 46 hours so adding 46 hours to the given date and time we get an additional 1 day and 22 hours so July 4, 2015 at 13:00 + 1 day and 22:00 gives July 5, 2015 at 35:00 which becomes **July 6, 2015 at 11:00 UT**.

B) The transit time is 69 hours or 2 days + 21 hours, which gives July 6, 2015 and 34:00 or **July 7, 2015 at 10:00 UT**.

C) The transit time is 88 hours or 3 days and 16:00 which becomes July 7, 2015 at 29:00 or **July 8, 2015 at 05:00 UT**.

Histogram of Halo CME Speeds: 1996-2008

Speed (km/s)	N	Speed (km/s)	N	Speed (km/s)	N
0	1	1000	20	2000	9
100	6	1100	22	2100	3
200	8	1200	14	2200	4
300	19	1300	21	2300	3
400	38	1400	13	2400	4
500	33	1500	14	2500	4
600	33	1600	11	2600	2
700	25	1700	12	2700	0
800	30	1800	9	2800	1
900	30	1900	7		

During the past sunspot cycle, there were nearly 2,000 events, called coronal mass ejections (CMEs) in which the sun ejected huge clouds of plasma into space. When directed at earth, these clouds can arrive within a few days and cause disturbances in Earth's magnetic field, called geomagnetic storms.

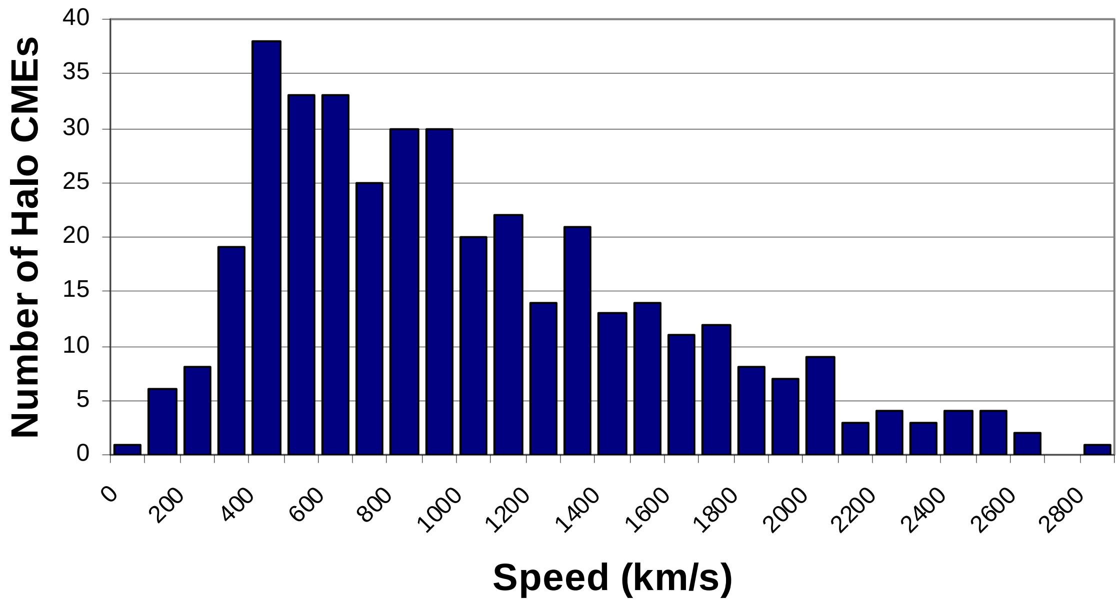
The arrival time is determined by the transit speed. The table to the left gives the speeds for a sample of Earth-directed CMEs.

Problem 1 - Create a histogram of the frequency data in the table.

Problem 2 - For this distribution of CME speeds, what are the A) mean speed? B) median speed?

Problem 3 - If the distance to the sun from Earth is 150 million kilometers, what is the average transit time, in days, represented by the histogram of CME speeds?

Problem 1 - Create a histogram of the frequency data in the table.

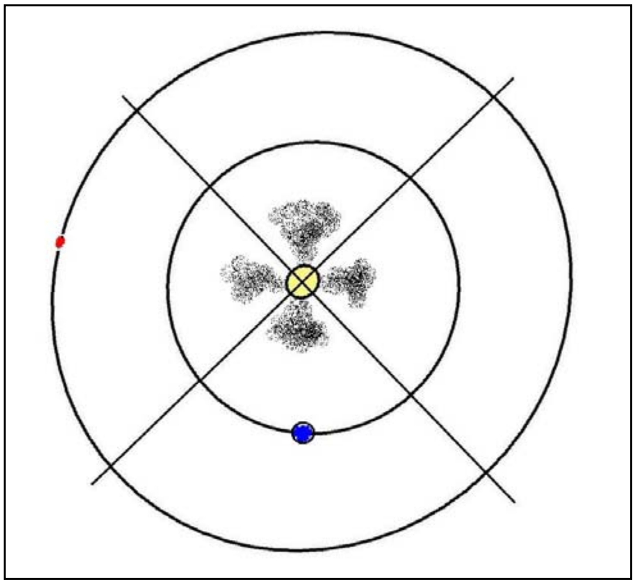


Problem 2 - For this distribution of CME speeds, what are the A) mean speed? B) median speed?

Answer: A) From the table, the average speed is found by the sun of the products of the speeds and Ns divided by the total number of tabulated CMEs which equals 395 events, so Va = (388700/395) so **Va = 984 km/sec**.
B) The median speed is the speed for which half of the events are below and half are above. From the table, N = 395/2 = 197, so **Vm = 800 km/sec**.

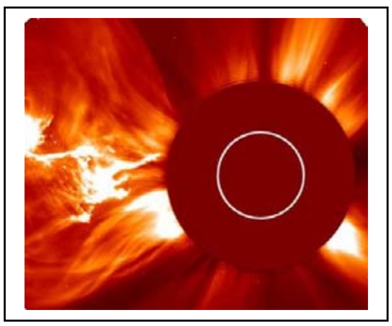
Problem 3 - If the distance to the sun from Earth is 150 million kilometers, what is the average transit time, in days, represented by the histogram of CME speeds?

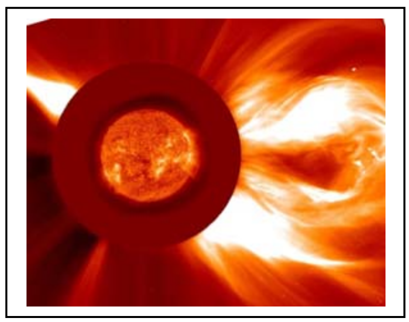
Answer: T = 150 million km / 984 km/s so T = 152,632 seconds which is about 42.4 hours or **T = 1.8 days**.

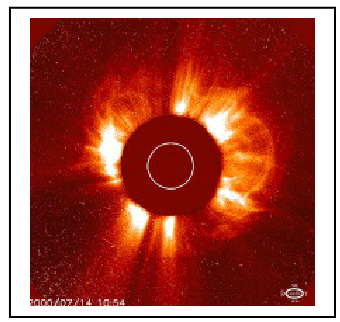


Although we cannot accurately determine the direction of travel of a coronal mass ejection (CME), images taken from one vantage point can often be used to learn the approximate direction of travel.

The diagram shows four CMEs ejected by the sun in 4 quadrants. The lower quadrant includes Earth. CMEs ejected into this quadrant often look like halos of gas (lower left image) as do CMEs ejected from the far-side of the sun (top quadrant). CMEs in the other two quadrants look like the remaining two images.







Problem 1 - The red dot in the diagram is the planet Mars. Which of the CMEs shown in the views above may be directed towards an eventual arrival at Mars?

Problem 2 - Suppose the above images were taken by a solar observatory orbiting Mars. Which of the CMEs might eventually collide with Earth - the blue dot in the diagram?

Problem 3 - Halo CMEs, such as the one in the right-hand image, are moving either towards the observer or directly away, having been ejected either from active regions on the near-side of the sun or the far-side. Radio bursts are often detected just before a CME is ejected. If a radio burst was not detected from a halo CME, is it headed towards Earth or away from Earth?

Problem 1 - The red dot in the diagram is the planet Mars. Which of the CMEs shown in the view above may be directed towards an eventual arrival at Mars?

Answer: **The first CME on the far-left is most likely headed in the general direction of Mars.**

Problem 2 - Suppose the above images were taken by a solar observatory orbiting Mars. Which of the CMEs might eventually collide with Earth - the blue dot in the diagram?

Answer: **From the location of Mars, the first CME on the far-left would be headed directly away from Earth. The CME on the far-right is headed towards Mars, and so the middle CME is headed in the general direction of Earth.**

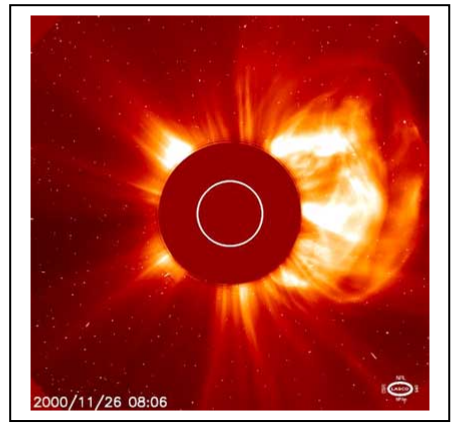
Problem 3 - Halo CMEs, such as the one in the right-hand image, are moving either towards the observer or directly away, having been ejected either from active regions on the near-side of the sun or the far-side. Radio bursts are often detected just before a CME is ejected. If a radio burst was not detected from a halo CME, is it headed towards Earth or away from Earth?

Answer: **Because radio waves cannot pass through the sun, halo CMEs that are not accompanied by radio bursts are probably far-side events traveling directly away from Earth, while halo CMEs with radio bursts are on the near-side of the sun and may be headed towards Earth.**

Solar flares are powerful releases of energy in the tangled A_**magnetic fields** of the sun, thousands of kilometers above certain sunspots. Within a few minutes, these B_________ attempt to reconnect themselves into simpler shapes, releasing their stored energy. This energy heats the local C_______ to millions of degrees, producing tremendous blasts of x-ray and gamma ray energy. Within 8.5 minutes, this D________ energy can reach Earth and disrupt the ionosphere. The E__________ is the region of our atmosphere where radio waves can be reflected back to the ground so that we can send radio programs and messages around the world. But during F_________, radio broadcasting can be shut down for hours.

Scientists eventually discovered that, in addition to flares, discharges of plasma from the sun could also occur. With satellite sensors in space, they eventually caught sight of how the sun could from time to time release billions of tons of plasma traveling at millions of miles per hour. When these magnetized plasma clouds wash across Earth's magnetic field – called the G___________, these clouds can dump huge amounts of matter and energy into Earth's environment. H_______ and magnetic storms are often the consequence of these I____________________.

The entire Earth-Sun system follows a complicated give-and-take when severe solar J_______ occur. Earth counteracts this onslaught of plasma and energy by a complex series of adjustments only available to it because it has a powerful magnetic field. With the magnetic field, most of the solar storm energy is diverted. What little enters the magnetosphere eventually finds its way into circulating K___________ which return some, but not all of the magnetospheric plasma back to the solar wind – a constant stream of matter that leaves the solar surface. Solar storms cause Earth's magnetic field to be pulled into the shape of a L________. The distant M____________ can snap like pulled taffy as it attempts to relieve the magnetic stresses building up in the system. The released energy causes currents of N_______________ to flow into the upper atmosphere where they collide with atoms of oxygen and nitrogen to produce the spectacular displays of the Aurora Borealis and O_________________.



Coronal Mass Ejection (CME) seen by SOHO satellite.

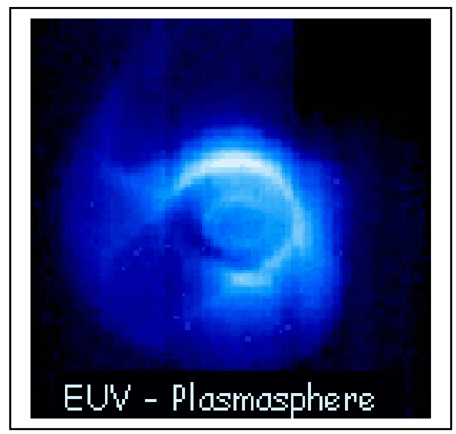


IMAGE sees Earth's upper atmosphere – the Plasmasphere.

-4 = Ring current	-9 = ionosphere	4 = electromagnetic
0 = Magnetotail	-3 = solar flares	10 = oxygen
3 = Plasma	8 = corona	1 = Coronal Mass Ejection
-7 = Sunspot	-1 = magnetosphere	-11 = stratosphere
2 = Aurora	11 = atmosphere	12 = plasmasphere
-10 = Ozone layer	**6 = magnetic fields**	5 = Aurora Australis
-6 = Comet	9 = sphere	-8 = photosphere
7 = Fields	-2 = storms	-5 = charged particles

Solve these equations for X to find the number in the Word Bank. Write the word on the indicated lettered line in the essay, then answer the questions below.

A $(x - 2) - 4 = 0$ **Answer: x= 6. From Word Bank 6 = 'magnetic fields'**

B $2(3-x) + 8 = 0$

C $8x - 2(2x - 4) + 4(4 - 3x) = 0$

D $-3x + 4 = 5x - 28$

E $-15 - 2x = 3(x + 10)$

F $4x - 4 - (3x - 4) + 3 = 0$

G $-(2x - 3) - (8 + 3x) = 0$

H $-(4x - 18) + 4(4 - 2x) - 2(3x-1) = 0$

I $-(3-4x) + 2(5-6x) - 6 = 3(2x - 5) - (x-3)$

J $-(2x + 8) + 6x = -16$

K $3(2x + 10) + 3x + 6 = 0$

L $-x + 3(2x - 5) + 3x = 2x - 51$

M $-x + 5 + (3x - 2) + 6 = 3(x + 3) - 2x$

N $-6(x+5) = 0$

O $5(x + 5) + 10(x - 3) = 70$

Question 1: Do the particles that cause aurora come from Earth's environment or directly from the Sun?

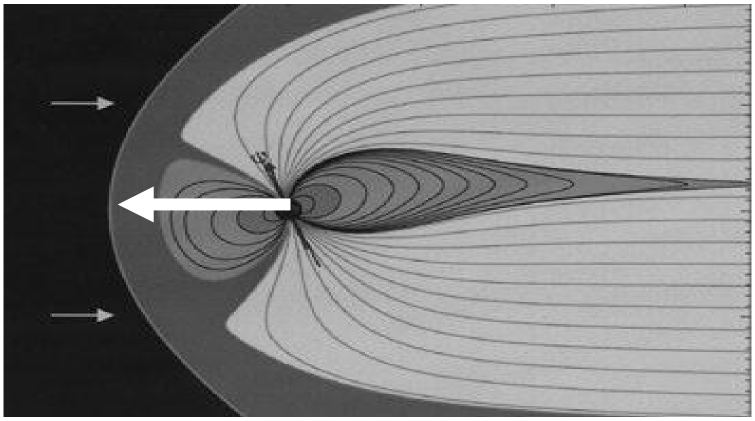
Question 2: What is a Coronal Mass Ejection?

Question 3: What roles do magnetic fields play in causing disturbances on the sun and Earth?

Question 4: Where does the energy come from to cause solar storms and aurora?

Question 5: How does Earth's magnetic field prevent solar storms from reaching the atmosphere?

The Bow Shock



When the solar wind flows past Earth, it pushes on Earth's magnetic field and compresses it. There is a point in space called the magnetopause where the pressure of the solar wind balances the outward pressure of Earth's magnetic field. The distance from the Earth, R, (white arrow in drawing) where these two pressures are balanced is given by the equation:

$$R^6 = \frac{0.72}{8\pi D V^2}$$

In this equation, D is the density in grams per cubic centimeter (cc) of the gas (solar wind, etc) that collides with Earth's magnetic field, and V is the speed of this gas in centimeters per second. Let's do an example to see how this equation works!

The solar wind has a typical speed of 450 km/s or equivalently V = 4.5 x 10^7 cm/s. To find the density of the solar wind in grams/cc we have to do a two-step calculation. The wind usually has a particle density of about 5 particles/cc, and since these particles are typically protons (each with a mass of 1.6 x 10^{-24} gm) the density is then 5 x (1.6 x 10^{-24} gm)/cc so that D = 1.28 x 10^{-23} gm/cc.

We substitute D and V into the equation and get R^6 = 1105242.6. so that R = $(1105242.6)^{1/6}$. To solve this, we use a calculator with a key labeled **Y^x** First type '1105242.6' and hit the '**Enter**' key. Then type '0.1666' (which equals 1/6) and press the **Y^X** key. In this case the answer will be '10.16' and it represents the value of R in multiples of the radius of Earth (6378 kilometers). Scientists simplify the mathematical calculation by using the radius of Earth as their unit of distance, but if you want to convert 10.16 Earth radii to kilometers, just multiply it by '6378 km' which is the radius of Earth to get 64,800 kilometers. That is the distance from the center of Earth to the magnetopause where the magnetic pressure is equal to the solar wind pressure for the selected speed and density. These will change significantly during a 'solar storm'.

Now lets apply this example to finding the magnetopause distance for some of the storms that have encountered Earth in the last five years. Complete the table below, rounding the answer to three significant figures:

Storm	Date	Day Of Year	Density (particle/cc)	Speed (km/s)	R (km)
1	11/20/2003	324	49.1	630	
2	10/29/2003	302	10.6	2125	
3	11/06/2001	310	15.5	670	
4	3/31/2001	90	70.6	783	
5	7/15/2000	197	4.5	958	

Question: The fastest speed for a solar storm 'cloud' is 1500 km/s. What must the density be in order that the magnetopause is pushed into the orbits of the geosynchronous communication satellites at 6.6 Re?

The information about these storms and other events can be obtained from the NASA ACE satellite by selecting data for H* density and V_x (GSE)

http://www.srl.caltech.edu/ACE/ASC/level2/lvl2DATA_MAG-SWEPAM.html

Storm	Date	Day Of Year	Density (particle/cc)	Speed (km/s)	R (km)
1	11/20/2003	324	49.1	630	42,700
2	10/29/2003	302	10.6	2125	37,000
3	11/06/2001	310	15.5	670	51,000
4	3/31/2001	90	70.6	783	37,600
5	7/15/2000	197	4.5	958	54,800

Question: The fastest speed for a solar storm 'cloud' is 3000 km/s. What must the density be in order that the magnetopause is pushed into the orbits of the geosynchronous communication satellites at 6.6 Re (42,000 km)?

Answer: Solve the equation for D to get:

$$\boxed{D = \frac{0.72}{8\pi R^6 V^2}}$$

For 1500 km/s V = 1.5 x 10^8 cm/s, and for R = 6.6, we have

$$D = 0.72/ (8 \times 3.14 \times 6.6^6 \times (1.5 \times 10^8)^2) = 1.52 \times 10^{-23} \text{ gm/cc}$$

Since a proton has a mass of 1.6 x 10^{-24} grams, this value for the density, D, is equal to (1.52 x 10^{-23}/ 1.6 x 10^{-24}) = 9.5 protons/cc.

For Extra Credit, have students compute the density if the solar storm pushed the magnetopause to the orbit of the Space Station (about R = 1.01 RE).
Answer: D = 3 x 10^{-19} gm/cc or 187,000 protons/cc. A storm with this density has never been detected, and would be catastrophic!

Kp	Dst -50 to -99 nT	Dst < -100 nT	Total
9	0	8	8
8	0	15	15
7	13	35	48
Total	13	58	61

The GOES satellites, which orbit Earth, have detectors that can measure the intensity of the protons and electrons that make up the van Allen Radiation Belts.

Since a number of important satellite systems including the well-known GPS constellation operate within the van Allen belts, it is important to know just how solar storms can change the environment near these satellites.

Between May 15, 1997 and December 31, 2003 a total of 753 daily measurements were made of the intensity of the electrons and protons in the vicinity of the NOAA-15 satellite for all days where the intensity index, B, was 2 or greater. Two magnetic disturbance indices were used to predict the belt intensity index, B. During this 753-day ensemble, the table above indicates the number of days that the two magnetic indices showed significant activity.

Problem 1 - Given that the proton and electron levels are enhanced, what is the probability that either or both of the magnetic indices will also be enhanced?

Problem 2 - The radiation belt indices can be split into an electron and a proton index. During the 71 days that Kp > 6, the electron index registered 11 days when the Be > 10.0. The proton index registered 34 days during which Bp > 10.0. Which index appears to be the most affected by the geomagnetic conditions measured by Kp for severe storms?

Problem 3 - For the 71 days for which Kp > 6 geomagnetic conditions existed, there were 18 days during which Dst < -200. Among these 18 days, Be > 10.0 for 3 days and Bp > 10 for 11 days. There were 40 days for which Dst was between -100 and -199. Of these days, Be > 10 for 6 days and Bp > 10 for 15 days. Are the electron and proton belts more active during days when Dst has its largest negative values?

Radiation belt indices from http://www.swpc.noaa.gov/ftpmenu/lists/bi.html

Problem 1 - Given that the proton and electron levels are enhanced, what is the probability that either or both of the magnetic indices will also be enhanced?

Answer: Out of the 753 days, only 61 days had enhanced geomagnetic indices so the probability is 100% x (61/753) = 8%. This means that, given the belt index is high, there is only a 1 chance in 12 that the geomagnetic indices will also be elevated.

Problem 2 - The radiation belt indices can be split into an electron and a proton index. During the 71 days that Kp > 6, the electron index registered 11 days when the Be > 10.0. The proton index registered 34 days during which Bp > 10.0. Which index appears to be the most affected by the geomagnetic conditions measured by Kp for severe storms?

Answer: The proton index recorded nearly three times as many days of disturbance as the electron index, so the proton belt seems to be the most affected by the geomagnetic conditions during severe storms.

Problem 3 - For the 71 days for which Kp > 6 geomagnetic conditions existed, there were 18 days during which Dst < -200. Among these 18 days, Be > 10.0 for 3 days and Bp > 10 for 11 days. There were 40 days for which Dst was between -100 and -199. Of these days, Be > 10 for 6 days and Bp > 10 for 15 days. Are the electron and proton belts more active during days when Dst has its largest negative values?

Answer: We can construct the table:

Dst	Be > 10	Bp > 10	Total
<-200 nT	3	11	18
-100 nT to -199 nT	6	15	40
Total	9	26	58

For the Be index, there were 9 days total, of which 3/9 had extreme values for Dst so P = 33%

For the Bp index ,there were 26 days total, of which 18/26 had extreme values for Dst so P = 69%.

For geomagnetically-active days (Kp > 6), the proton index seems to be about twice as 'active' when Dst is indicating a large disturbance for which Dst < -200 nT.

Drawing an Aurora from a Narrative

An aurora is a spectacular, visual experience for every human that has watched it. Although scientists want to study it to learn about its secrets, other observers prefer to simply experience the phenomenon for its beauty and awesome mystery. Here is a vivid description of an aurora observed on August 28, 1859 by Captain Stanard from Cleveland, Ohio.

"At 9:00 PM, a belt began to rise up in the north, and as the convex edge attained a height of about 40 degrees above the horizon, it began to shoot out long, attenuated bright rays close together, moving slowly to the west and reaching to the zenith. Near the convex edge they were of a bright yellow, changing as they shot up to orange, and near the zenith to a bright red, the middle and lower ends remaining yellow and orange. As the fiery points of the rays shot into the broad belt overhead, which had still remained like a belt of luminous fog, the whole thing was changed in an instant into bright red color. The color deepening as it neared the eastern horizon, to a bright crimson, and at the western end near the star Arcturus, into a bright scarlet, gradually growing fainter in the zenith, and increasing in brightness nearer the horizon. After 15 minutes it resolved itself into converging rays that came from the zenith."

" At 9:45 PM, A double arch formed from two narrow ribbons of light 15 degrees wide running from Canes Venatici to the southern edge of Perseus. The bright star Capella shining through the narrow black space between them. Ten minutes later, bright rays suddenly shot up in quick successive flashes from the lower through the upper arch, reaching nearly to the zenith, and moving slowly to the west until they reached the constellation Corona Borealis, lighting up the northwestern sky with yellow, orange and red. There commenced a sudden flashing of horizontal wavy bands from the upper arch towards the zenith."

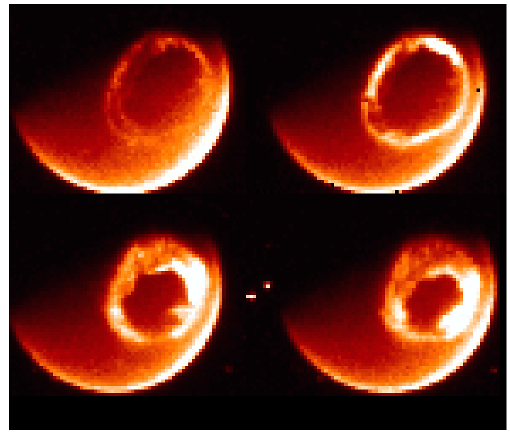
From the information in this description, try to recreate what Mr. Stanard saw for one particular moment as he watched the aurora dance across the sky. Use colored pencils, crayons, watercolors or other media to render a view of the aurora based on this description.

Use the following space for your rendering:

How Big is an Aurora?

The IMAGE satellite orbits Earth, and has a camera that can view the Northern and Southern Lights from space. As the solar activity level increases and decreases, the size of the aurora increases and decreases.

This activity will let you use data from this satellite to measure the diameter of the Auroral Oval and its changes during a solar storm event.



The ring of Northern Lights from space.

Scientists use satellites to study phenomena that are too vast to be studied from the ground.

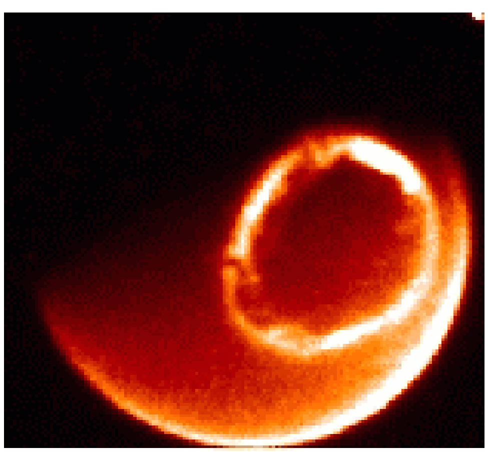
- Photographs can be used to measure the size of an object.

Here's how to do it!

1. **With a ruler, measure the diameter of the Earth's disk in millimeters in the illustration. (Answer: About 30 mm)**
2. **The diameter of the Earth in this image is 13,000 kilometers, so the scale of the image is (13000 km)/(30 mm) = 433 kilometers/mm.**
3. **The diameter of the Oval is about 15 mm, so using the image scale, the diameter of the Oval is:**

15 x 433 = 6,500 kilometers

Now you try!



This photograph is from the IMAGE 'Far-Ultraviolet Imager' instrument obtained on July 14, 2000. It shows the size of the auroral oval during a severe solar storm.

1) Estimate the inside and outside diameters of the auroral oval.

2) Calculate the oval's area in millions of square kilometers.

Answer Key

The diameter of the partial Earth disk is about 60 millimeters. The scale of the image is therefore 13,000/60 = 217 kilometers/mm

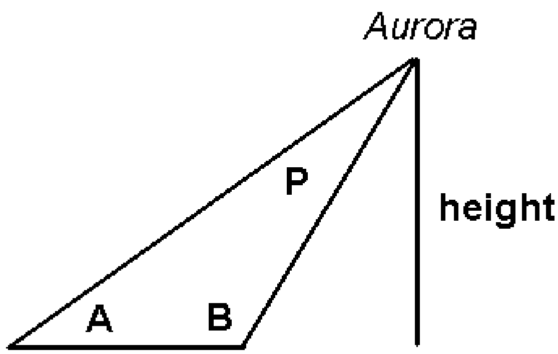
Problem 1) The diameter of the inside of the oval is about 20 millimeters or 20 x 217 = 4340 kilometers. The outside diameter of the oval is about 27 millimeters or 27 x 217 = 5860 kilometers.

Problem 2) The area of the oval is found by taking the difference of the larger and smaller circles. The area of the two circles with diameters of 5860 and 4340 kilometers is found by using the formula for the area of a circle, $A = \pi R^2$, with $\pi = 3.14$, and R = 5860/2 = 2930 kilometers for the larger circle and R = 4340/2 = 2170 kilometers for the smaller circle. The larger circle area is $A = 3.14 (2930)^2 = 2.69 \times 10^7$ square kilometers.
The smaller circle area is $A = 3.14 (2170)^2 = 1.48 \times 10^7$ square kilometers. Subtracting the larger from the smaller gives the oval area of 1.21×10^7 square kilometers, or 12.1 million square kilometers in the units requested.

How High is an Aurora?

Image courtesy Tim Tomljanovich, http://www.nsaclub.org/photos/aurora/

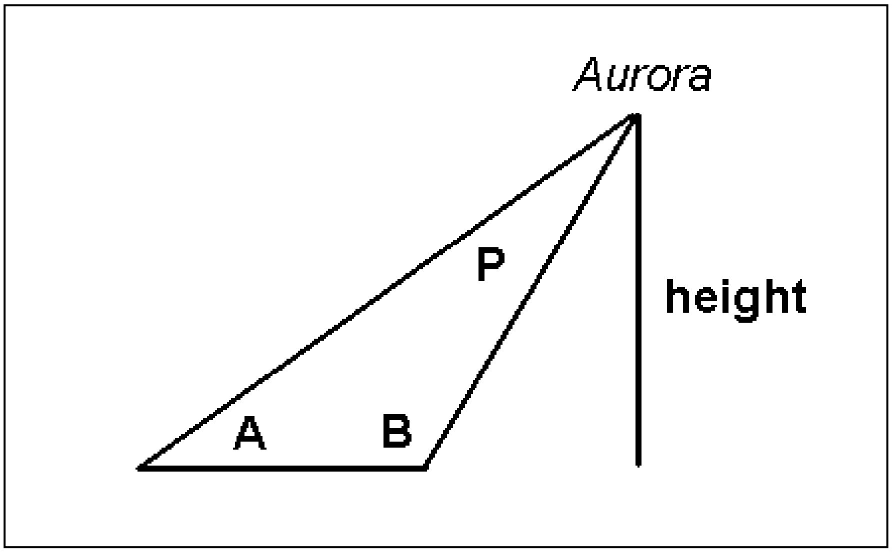
For thousands of years, people living at northern latitudes had no idea how high up the Aurora Borealis was located. Before the advent of photography in the 1880's, auroral observers tried to determine the height of aurora by the method of triangulation. One of the earliest of these measurements was made by the French scientist Jean-Jacques d'Ortous de Mairan between 1731 and 1751. From two stations 20 km apart, observers measured the angles A and B between the ground and a specific spot on an aurora. From the geometry of the triangle, they estimated that aurora's height was between 650 - 1,000 km above the ground. More precise measurements yielded estimates from 70 to 200 kilometers.



Question 1 - Suppose that two observers were located 30 kilometers apart. Observer A measured an angle of 53 degrees and Observer B measured an angle of 114 degrees. By making a scaled drawing of this triangle, what was the height of the auroral feature they were studying?

Question 2 - Use a protractor to measure the vertex angle, P. What happens to the measurement of angle P if you decrease the 'baseline' distance between the observers to 5 kilometers?

Question 3 – What would the measurements of the two angles be if the aurora were located over a spot half-way between the two observers?



Question 1 - Suppose that two observers were located 30 kilometers apart. Observer A measured an angle of 53 degrees and Observer B measured an angle of 114 degrees. By making a scaled drawing of this triangle, what was the height of the auroral feature they were studying?
Answer: Students should get an answer near 100 kilometers.

Question 2 - Use a protractor to measure the vertex angle, P. What happens to the measurement of angle P if you decrease the 'baseline' distance between the observers to 5 kilometers?
Answer: The angle P should have a measure of 180 – 114 – 53 = 13 degrees. If the baseline is decreased to 5 kilometers with Observer A moving towards Observer B and Observer B remaining at the previous location, Observer B will measure an angle of 114 degrees, Observer A will measure 64 degrees, angle P will decrease to 180 – 114 – 64 = 2 degrees. This is a very small angle to accurately measure.

Question 3 – What would the measurements of the two angles be if the aurora were located over a spot half-way between the two observers who are 30 kilometers apart?
Answer : From a scaled drawing A = B = 80 degrees.

Aurora Power!

Scientists use decimal numbers a lot when measuring objects or processes! This activity uses data from the National Oceanic and Atmospheric Administration (NOAA) POES satellite to compare the Northern Lights displays in terms of how many watts of energy they produce.

Note: A kilowatt is one thousand watts, but a gigawatt is one billion watts! A kilowatt of electricity can run a small house, but a gigawatt can run a small city.

Auroras are very common to see in northern regions of Canada and Alaska. They light up the skies in swirling color.

Scientists make measurements that are usually expressed in decimal form.

Applied decimal arithmetic: addition, subtraction and division

Here's how to do it!

How much more powerful was an aurora with 987.45 gigawatts, than an aurora with 324.98 gigawatts?

987.45 gigawatts
- 324.98 gigawatts

662.47 gigawatts

Now you try!

Aurora Power

Date	Power
4-11-01	528.1
4-18-01	828.3
11-24-01	497.7
2-18-00	17.6
8-27-01	96.5
11-6-01	484.7
5-23-02	387.3
2-5-02	244.8
9-4-02	580.2

This table lists some major storms detected by the NOAA POES satellite, and the total power that they produced in gigawatts (Gw). Use this table to answer the questions below.

1) What was the difference in power between the strongest and weakest aurora detected?

2) If 48 storms like the one on February 18, 2000 were combined, how much different would they be than the power from the strongest storm in the table?

3) What is the sum of the power for all nine storms?

4) How many times more powerful was the April 18, 2001 storm than the storm detected on August 27, 2001?

Answer Key

Problem 1 - 828.3 - 17.6 = 810.7 gigawatts

Problem 2 - 48 x 17.6 = 844.8 gigawatts compared to one storm with 828.3 gigawatts

Problem 3 - 3,665.2 gigawatts or 3.6652 trillion watts

Problem 4 - 828.3/96.5 = 46.6 times greater

Aurora Power Comparison

Power is a physical quantity that tells us how rapidly work is being performed, and energy expended to do the work. The common unit of power used by scientists is the watt. In your home there are many electrical items that are measured by the number of watts of electricity they consume in order to operate. The most energy-consuming items involve an electrical motor, which will do work to move air in your air conditioner, or to keep food cold in your refrigerator. When combined together, your home electrical consumption can be thousands of watts per week. The table below shows some typical numbers for the watts involved in operating various kinds of systems you are familiar with.

System	Watts	Energy source
Flash light	5	Battery
Reading lamp	100	Electric Utility Company
Television	90	Electric Utility Company
Computer	200	Electric Utility Company
Refrigerator	500	Electric Utility Company
Small House	1,000	Electric Utility Company
Small town	5 million	Fossil Fuels
Big city	5 billion	Fossil Fuels
United States	420 billion	Fossil Fuels

Scientists can measure the power of an aurora by measuring how much light they produce, and then using these measurements in mathematical formulas to calculate the power needed to produce the light. The table below shows some measurements made during the November 20, 2003 Great Aurora, which you may have been able to see if your nighttime skies were clear! The table gives the time in Column 1 and 2 the estimated power in units of BILLIONS of watts in the North and South Hemispheres

Time	**Power (South)**	**Power (North)**
13:57	403	141
14:47	149	149
15:27	339	305
16:26	432	531
17:07	279	657
17:18	251	446
18:08	500	315
18:46	428	1108
19:18	288	112
19:49	362	383
20:26	132	234
21:32	149	144

Question 1 - When did the peak power occur in the North and South Hemispheres?

Question 2 – What was the average power produced by the aurora during the tabulated time interval in each hemisphere?

Question 3: - What was the total power produced from the aurora in both hemispheres?

Question 4: - For how many years could the United States operate with the total power produced by this aurora?

Time	Power (South)	Power (North)
13:57	403	141
14:49	149	149
15:27	339	305
16:26	432	531
17:07	279	657
17:18	251	446
18:08	500	315
18:46	428	1108
19:18	288	112
19:49	362	383
20:26	132	234
21:32	149	144

Question 1 - When did the peak power occur in the North and South Hemispheres?
Answer: In the Northern Hemisphere it occurred at 18:46 UT. In the Southern Hemisphere it occurred at 18:08 UT.

Question 2 – What was the average power produced by the aurora during the tabulated time interval in each hemisphere?
Answer: North = 337.1 billion watts. South = 309.3 billion watts.

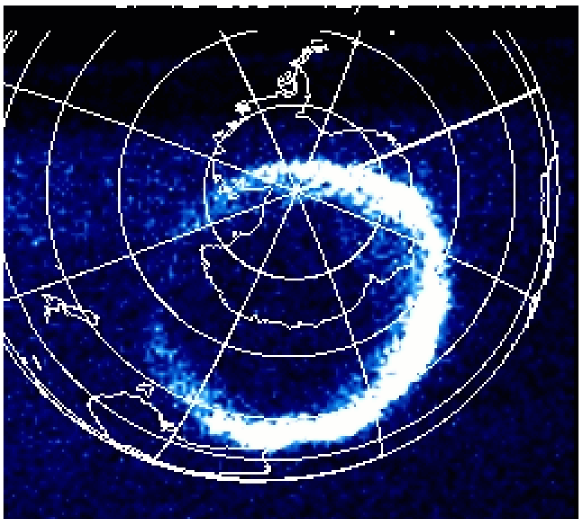
Question 3: - What was the total power produced from the aurora in both hemispheres?
Answer: South = 3712 billion watts, North = 4525 billion watts . Total = 8237 billion watts.

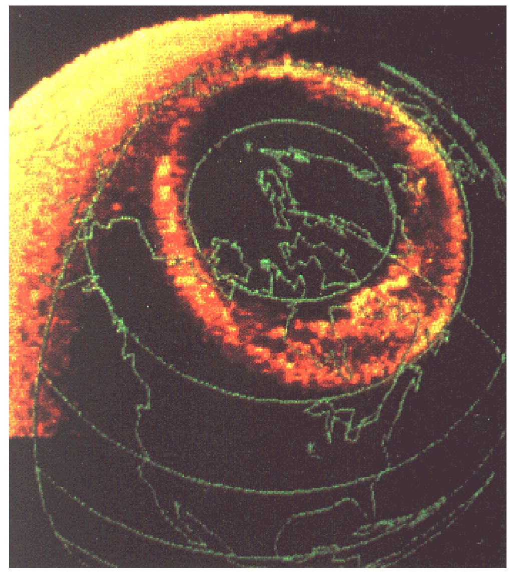
Question 4: - For how many years could the United States operate with the total power produced by this aurora?
Answer: In one year, the table shows US electricity consumption is about 420 billion watts per year. The total aurora power in both hemispheres for this particular storm was 8237 billion watts, so the US could be supported for 8237/420 = 19.6 years. The reason we don't collect 'aurora power' is that it is spread out over million of square miles and not concentrated as are other forms of usable energy.

The North and South Magnetic Poles

The aurora form a glowing halo of light above Earth's North and South Polar Regions. Because aurora are caused by charged particles that are affected by Earth's magnetic field, the Auroral Ovals are centered in Earth's magnetic poles, not its geographic poles about which the planet rotates.

The photos below, were taken of the two polar aurora by the NASA, IMAGE FUV (Left) and the Polar (right) instruments. The data has been colorized to bring out details of interest to scientists.





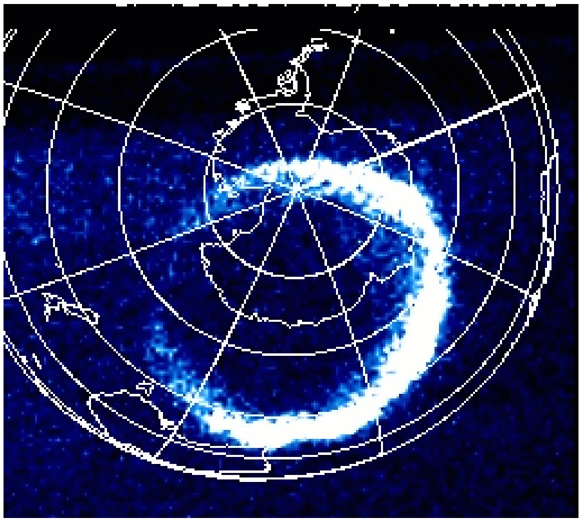
Question 1 - The South Magnetic Pole is located in the Northern Hemisphere. From the appropriate image above, locate this magnetic pole on a map.

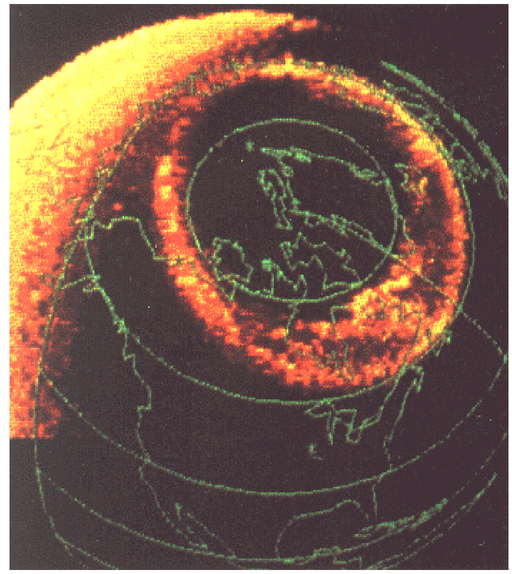
Question 2 -- The North Magnetic Pole is located in the Southern Hemisphere. From the appropriate image above, locate this magnetic pole on a map.

Question 3: -- From the geographic clues in the map, estimate the diameter of the auroral oval in kilometers. (Hint: The radius of Earth is 6,378 kilometers)

Question 4: – What interesting geographic features would you find if you traveled to each of the magnetic poles? If you were going to undertake an expedition to each pole, describe your journey starting from your city or town and mention any special or unusual gear you would bring.

Question 5: Using a compass, and the idea that likes repel and opposites attract, why don't the names of the magnetic poles match the hemispheres they are in?





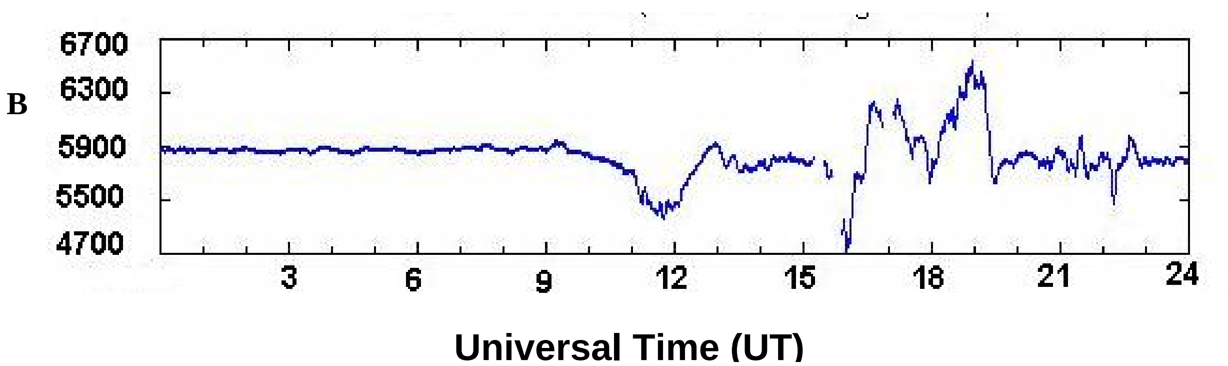
Question 1 - The South Magnetic Pole is located in the Northern Hemisphere. From the appropriate image above, locate this magnetic pole on a map.
Answer: *The right-hand image from the Polar satellite shows the Arctic Region and the contours of Greenland and North America/Canada. From a world map, students can estimate that the center of the auroral oval is near longitude 105 West and latitude 83 North)*
Question 2 -- The North Magnetic Pole is located in the Southern Hemisphere. From the appropriate image above, locate this magnetic pole on a map.
Answer: *The left-hand image from the IMAGE satellite shows Antarctica. The center of the auroral oval is near longitude 110 West and latitude 72 South.*
Question 3: -- From the clues in the map, estimate the diameter of the auroral oval in kilometers. (Hint: The radius of Earth is 6,378 kilometers)
Answer: *The diameter of each coordinate grid covers Earth, so the diameter of the grid is the diameter of Earth. Calculate the scale of each image (kilometers per millimeter) and multiply by the diameter of each auroral oval in millimeters. For the north polar aurora, its diameter is about 6400 kilometers. For the south polar aurora, the diameter is about 6,000 kilometers.*
Question 4: – What interesting geographic features would you find if you traveled to each of the magnetic poles? If you were going to undertake an expedition to each pole, describe your journey starting from your city or town and mention any special or unusual gear you would bring.
Answer: *Accept any reasonable answer related to icy climates (Antarctica – permanent ice) or the north polar sea (ice or water location depending on season)*
Question 5: Using a compass, and the idea that likes repel and opposites attract, why don't the names of the magnetic poles match the hemispheres they are in?
Answer: *In the Northern Hemisphere, the 'N' on the compass is a north-type magnet by the way we defined the naming convention for magnets, so it will be attracted to a south-type pole, which is therefore the polarity of the pole in the Northern Hemisphere.*

Magnetic Storms

Magnetic Storms are disturbances in Earth's magnetic field that can be detected from the ground using sensitive instruments called magnetometers. Dozens of these instruments located at 'Magnetic Observatories' around the world keep track of these disturbances. The graph below shows these changes during a 24-hour period on October 24, 2003.

The vertical axis in the plot gives the magnitude, B, of this magnetic change on Earth that is in the East to West direction. The strength of a magnet can be described in terms of a unit called a Tesla. On this plot, the vertical axis gives the magnetic strength in units of nano-Teslas (nT). One nano-Tesla is one billionth of a Tesla (so 1 billion nano-Teslas = 1 Tesla) . We can see that on this day, Earth's magnetic field varied between 4700 and 6700 nano-Teslas.

The horizontal axis is the time measured in Universal Time (UT). When scientists study events that change in time, they often use Universal Time, which is also known as Greenwich Mean Time. All scientific measurements are referred to this standard of time keeping to avoid problems converting from one time zone to another. Universal Time or 'UT' follows a 24-hour clock, so that 6:00 PM is written as 18:00 and 1:00 PM is written as 13:00. Use the time calculator at http://www.indiana.edu/~animal/fun/conversions/worldtime.html to convert your local time to Universal Time!



Question 1 – If a magnetometer measured a magnetic field of 137,000 nT, how many Teslas would that correspond to?

Question 2 – What is the corresponding Universal Time for 9:45 PM?

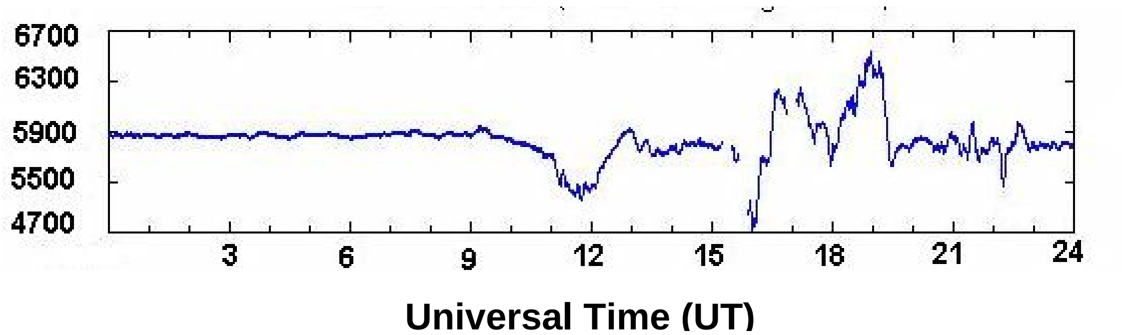
Question 3 - From the above graph, at what time was the magnetic storm most severe in terms of the absolute magnitude of its change in B?

Question 4 – At what time did the storm episode begin and end?

Question 5 – As a percentage of 5900 nT, what was the largest change in the magnetic field?

Question 6 - How long did the magnetic storm last?

B



Question 1 – If a magnetometer measured a magnetic field of 137,000 nT, how many Teslas would that correspond to?
Answer : 137,000 nT x (1 Tesla / 1 billion nT) = 0.000137 Teslas.

Question 2 – What is the corresponding Universal Time for 9:45 PM?
Answer : 21:45 UT.

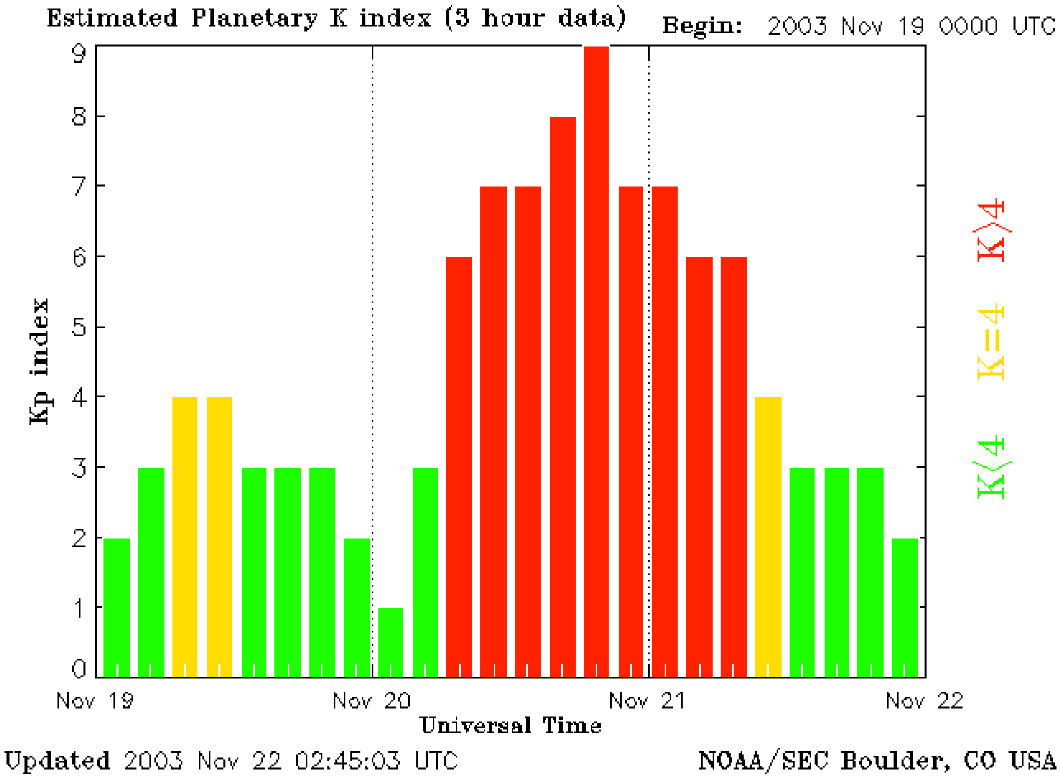
Question 3 - From the above graph, at what time was the magnetic storm most severe?
Answer: Students should look for the largest 'absolute magnitude' change in the graph from the 'average' level of 5900 nT. That occurs at about 16:00 UT.

Question 4 – At what time did the storm episode begin and end?
Answer: The 'calm' periods occurred between 00:00 and 09:00 and from 23:00 to 24:00. The storm period occurred between 09:00 and 21:00 UT

Question 5 – As a percentage of 5900 nT, what was the largest change in the magnetic field?
Answer: The largest change in terms of absolute magnitude occurred at 16:00 when the magnetic field went from 5900 nT to 4700 nT. This is a decrease of 1200 nT. As a percentage this was (1200/5900) x 100% = 20% from the non-storm conditions.

Question 6 - How long did the magnetic storm last?
Answer: The entire storm lasted 21:00 – 09:00 = 12 hours.

Magnetic Storms and the Kp Index



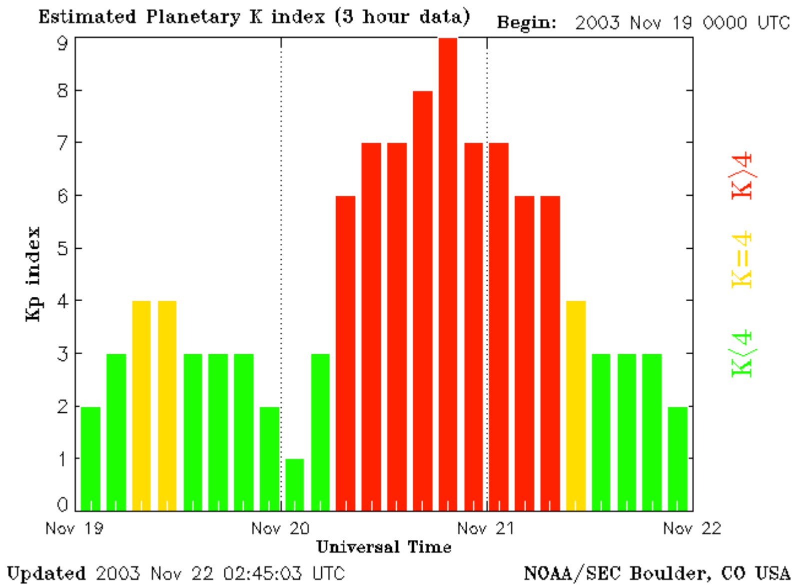
Magnetic observatories generate a huge amount of data – far too much for anyone to digest easily. To help scientists take a quick measure of Earth's magnetic storminess, they invented the 'Planetary Variability' index. The magnitude of the disturbance in Earth's magnetic field is measured at 13 observatories and then averaged together. This average value is then reported every three hours as the **Kp Index**.

The bar graph above shows the changes in this index during the time of a major magnetic storm on November 20, 2003. Prior to the storm, Earth's magnetic field was in a typically disturbed state with variations between Kp 2 to 4. But after a solar disturbance collided with the magnetic field, the variations jumped to Kp 7 and higher within a few hours. This particular storm caused spectacular Northern Lights seen all across North America and Northern Europe.

Question 1 – If each bar is 3-hours wide, how long did the storm last above a level of Kp = 4?

Question 2 – At what time did the storm reach its maximum Kp value?

Question 3 - If New York City is 4 hours behind Universal Time, what time was it in New York during the height of the storm?



Question 1 – If each bar is 3-hours wide, how long did the storm last?
Answer: The red portion of the bar graph which covers the most intense phase of the storm extends 9 bars or 9 x 3h = 27 hours!

Question 2 – At what time did the storm reach its maximum Kp value?
Answer: This occurred at the bar which spans the times 19:00 to 21:00 UT so you can take the start time as 19:00 UT, or the end time 21:00 UT or the mid-point time of the bar of 20:30 UT.

Question 3 - If New York City is 4 hours behind Universal Time, what time was it in New York during the height of the storm?
Answer: Taking the mid-time of 20:30 UT, the Eastern Standard Time in New York would be 20:30 – 4:00 = 16:30 EST or 4:30 PM.

Summary of Storm Days

Kp	Bz>+20	Bz<-20	Days
9	2	6	8
8	5	6	19
7	4	4	58
<6	13	2	861
Total	24	18	946

This table gives the number of days for which the two storm indicators, Kp and Bz satisfied the stated limits.

Kp is determined by measuring disturbances in the ground-level geomagnetic field on a 3-hour average during the day.

Bz is the strength and direction of the solar wind magnetic field measured by the ACE spacecraft.

The Advanced Composition Explorer (ACE) spacecraft is located 1.5 million kilometers from Earth in the direction of the sun at Lagrange Point 1. From this location, its SWEPAM sensor can directly measure the magnetic field of the solar wind and coronal mass ejections (CMEs) as they pass by the spacecraft.

It has been known for some time that the 'Z-component' of the magnetic field, called Bz, is a strong predictor of how violently Earth's magnetic field will be upset by the passing plasma clouds from the sun. The general level of geomagnetic disturbance is measured on a 9-point scale called Kp. Very strong storms have a Kp=9 while modest disturbances register Kp=1 or 2 on this scale. The most dramatic Aurora occur during prolonged periods with Kp = 8 or 9.

During the entire sunspot cycle from 1996-2008, ACE measured a number of magnetic disturbances that could be correlated against the Kp index. The results are summarized in the above table in terms of the number of days that the stated conditions were satisfied during the entire sunspot cycle. For example, out of a total of 861 days for which Bz > 6.0 nT or Bz < -6.0 nT, there were 58 days during which Kp=7. Solar physicists refer to negative Bz values as indicating that the direction of the magnetic field (polarity) is south-directed relative to the orientation of Earth's geographic pole, and positive Bz indicating a northward orientation.

Problem 1 - Suppose we are trying to predict the severity of a geomagnetic storm using Bz as an indicator. For a given value of Kp, which Bz orientation is the most reliable predictor?

Problem 2 - Suppose we consider two geomagnetic conditions, 'stormy' with Kp=7,8 or 9, and 'Calm' with Kp<6. A) What is the probability that Bz > +20 nT will indicate stormy conditions? B) What is the probability that Bz < -20 nT will indicate stormy conditions?

Problem 3 - The ACE satellite measures Bz = -60 nT. What is the probability that a geomagnetic storm with Kp > 8 will occur?

Kp	Bz>+20	Bz<-20	Days
9	2	6	8
8	5	6	19
7	4	4	58
<6	13	2	861
Total	24	18	946

Problem 1 - Suppose we are trying to predict the severity of a geomagnetic storm using Bz as an indicator. For a given value of Kp, which Bz orientation is the most reliable predictor?

Answer: Kp = 9: Bz > +20 nT P = 2/8 Bz < -20 nT P = 6/8
Kp = 8: Bz > +20 nT P = 5/19 Bz < -20 nT P = 6/19
Kp = 7: Bz > +20 nT P = 4/58 Bz < -20 nT P = 4/58

So for Kp=9 the south-directed orientation has the highest reliability with a probability of 6/8 = 75%. For weaker storms (Kp=7 or 8) the reliability is 50%.

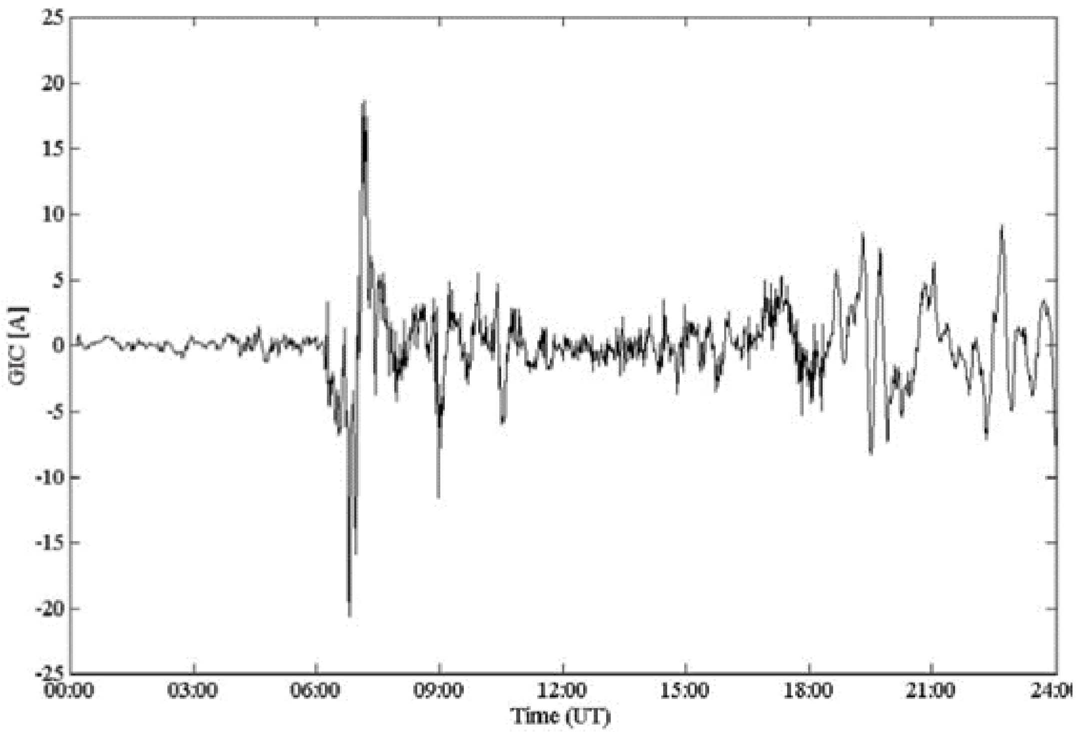
Problem 2 - Suppose we consider two geomagnetic conditions, 'stormy' with Kp=7,8 or 9, and 'Calm' with Kp<6. A) What is the probability that Bz > +20 nT will indicate stormy conditions? B) What is the probability that Bz < -20 nT will indicate stormy conditions?

Answer: A) Adding the numbers in the Bz>+20 nT column, there are 2+5+4 = 11 days with Stormy conditions and 13 days with Calm conditions. The probability that a strong 'north directed' field indicates Stormy conditions is just **P=11/24** and for Calm conditions it is P=13/24.

B) Adding the numbers in the Bz < -20 nT column, there are 6+6+4 = 16 days with Stormy conditions and 2 days with Calm conditions. The probability that a strong 'south directed' field indicates Stormy conditions is just **P=16/18** and for Calm conditions it is P=2/18, so the south-directed Bz is most reliable for indicating the chance of Stormy geomagnetic conditions. It is 8-times more effective than using the north-directed Bz.

Problem 3 - The ACE satellite measures Bz = -60 nT. What is the probability that a geomagnetic storm with Kp > 8 will occur?

Answer: From the table, column 3, the number of days is 6+6 = 12 out of a total of 18 days for which Bz < -20 nT were recorded, so the probability is P = 12/18 or **P=67%**.



Disturbances in the magnetic field of Earth can induce currents to flow in the ionosphere. These currents, in turn, can magnetically induce currents to flow in the ground. The flow of ground currents into transformers in our electric power grid can even cause blackouts and other problems. The 'Halloween Storm' between October 28-30, 2003 created ground currents that damaged transformers in the electrical power grid of South Africa. Electrical power blackouts from this storm also affected 50,000 people in southern Sweden.

The figure above shows the strength of the current flowing into a transformer in Port Elizabeth, South Africa on October 29, 2003 at the indicated times given in Universal Time (UT) (Courtesy E.H. Bernardi, University of Cape Town, SA)

Problem 1 - What is the maximum current change, in amperes, between the smallest and the largest values of the major storm event near 07:00 UT?

Problem 2 - About how many minutes did it take for the event near 07:00 UT to change from its smallest to its largest current value?

Problem 3 - The amount of heat energy, in joules, that is generated by this current change can be estimated from the product of the transformer voltage, V, in volts, the current change, I, in amperes, and the duration of the change, T in seconds, so that E = V x I x T. If the transformer operates at V = 500,000 Volts, from your estimates for I and T, how many joules of heat did this transformer absorb during the GIC event?

Problem 1 - What is the maximum current change, in amperes, between the smallest and the largest values of the major storm event near 07:00 UT?

Answer: The current change was about -28 amperes to +18 amperes for a total change of + 18 - (-28) = **46 amperes**. Students estimates may vary.

Problem 2 - About how many minutes did it take for the event near 07:00 UT to change from its smallest to its largest current value?

Answer: Depending on how well students can measure the change with a ruler, estimates of **about 20 minutes** are acceptable.

Problem 3 - The amount of heat energy, in joules, that is generated by this current change can be estimated from the product of the transformer voltage, V, the current change, I, and the duration of the change, T so that E = V x I x T. If the transformer operates at V = 500,000 Volts, from your estimates for I and T, how many joules of heat did this transformer absorb during the GIC event?

Answer: E = 500,000 x 48 x (20 minutes x 60 sec/1 min)
So **E = 480 million Joules**.

Note: This is enough energy to cause heat damage to a transformer if it is not properly cooled to anticipate such storm events. The image below shows damage to a transformer in Port Elizabeth South Africa in which some of the plates were partially melted.

Time (Minutes)	B (nT)
0	30
1	100
2	-200
3	-250
4	300
5	-20
6	210
7	-75
8	450
9	-400
10	550
11	120
12	-50
13	-350
14	700
15	-400
16	100
17	0
18	-250
19	150
20	0
21	225
22	-500
23	800
24	-150

The speed with which the ground-level geomagnetic field changes is what determines how strong the resulting ground currents will be. It is determined by measuring the change in the magnetic field strength, dB, given in nanoTeslas (nT) and dividing this by the time interval, dT, of the change in minutes.

During the Quebec Blackout of 1989, dB/dt values of 500 nT/minute were recorded. During the 1921 geomagnetic storm, dB/dt values as high as 4000 nT/minute were reached in some geographic regions.

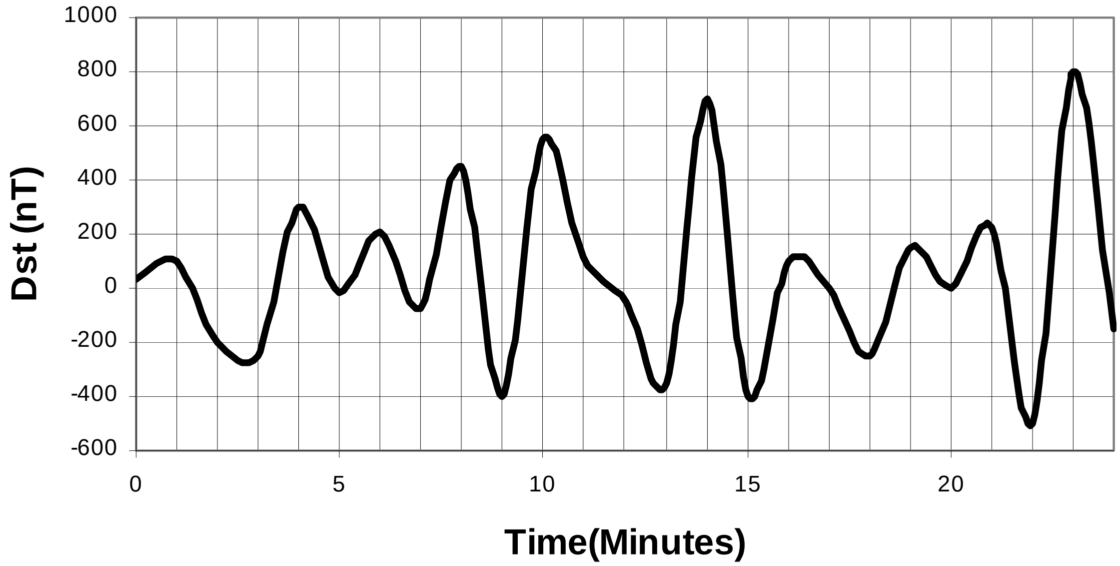
The table to the left shows the ground-level magnetic field change during a hypothetical severe magnetic storm.

Problem 1 - Plot the magnetic data as a line graph.

Problem 2 - For each 1-minute interval in time, calculate the <u>magnitude</u> of dB/dt, in units of nT/minute.

Problem 3 - Between what times were the highest dB/dt values reached, and what were these values?

Problem 4 - If the strongest geomagnetically-induced currents (GICs) affecting power grid transformers occurs for the highest values of dB/dt, during which times would a power plant operator be most concerned for the safety of her power grid transformers?



Problem 1 - Plot the magnetic data as a line graph. Answer: **See above.**

Problem 2 - For each 1-minute interval in time, calculate the magnitude of dB/dt, in units of nT/minute. Answer: **See table below.**

Minutes	B (nT)	dB/dt (nT/min)	Minutes	B (nT)	dB/dt (nT/min)
0	30		13	-350	300
1	100	70	14	700	1050
2	-200	300	15	-400	1100
3	-250	50	16	100	500
4	300	550	17	0	100
5	-20	320	18	-250	250
6	210	230	19	150	400
7	-75	285	20	0	150
8	450	525	21	225	225
9	-400	850	22	-500	725
10	550	950	23	800	1300
11	120	430	24	-150	950
12	-50	170			

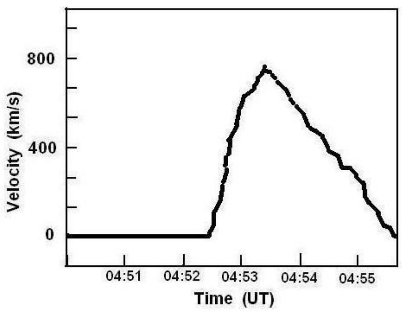
Problem 3 - Between what times were the highest dB/dt values reached, and what were these values? Answer: **Between 13-15 minutes, and between 22 and 23 minutes.**

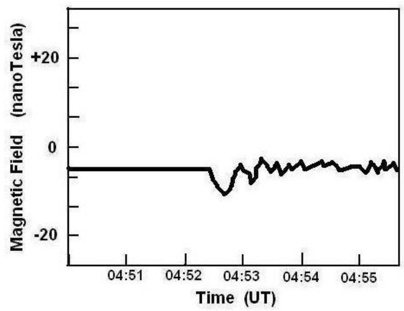
Problem 4 - If the strongest geomagnetically-induced currents affecting power grid transformers occurs for the highest values of dB/dt, during which times would a power plant operator be most concerned for the safety of her power grid transformers?
Answer: From the historical data for the Quebec Blackout which happened when dB/dt > 500 nT/min, based on this tabulated data, **the times between 4 minutes and 24 minutes are the most hazardous.**

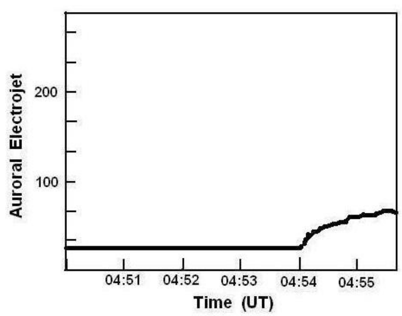
THEMIS: A Magnetic Case of 'What came first?'

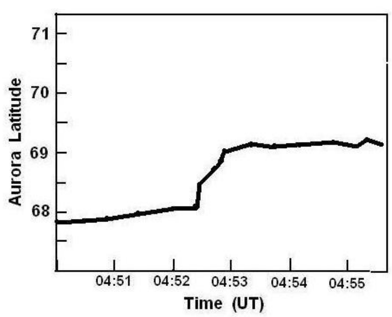
The NASA, THEMIS satellite constellation consists of five satellites, P1, P2, P3, P4 and P5, launched on February 17, 2007. The scientific goal was to determine the sequence of events connecting disturbances in Earth's distant magnetic field (a process called magnetic reconnection), with the start of magnetic storms and aurora near Earth.

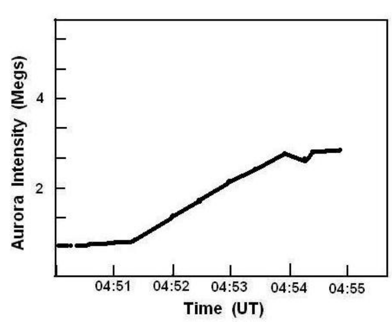
The science team assembled the data shown in the graphs to the left. The event that triggered this sequence was a 'magnetic reconnection' in Earth's magnetic field that took place at about 4:50:03 at a location about 160,000 km from Earth. (Note these plots have been greatly simplified for clarity! See the original article in the journal *Science*, August 15, 2008, vol. 321, pp.931: Figure 2 and 3)











Problem 1 - At about what times do each of the plots begin to show a significant change in the quantity being measured?

Problem 2 - What is the timeline for the start of each plotted event?

Problem 3 - How long was the elapsed time between the increase in particle velocity at the P3 satellite, and the enhancement of the auroral electrojet?

Problem 4 - The P3 satellite was located 74,000 km from Earth. If the auroral electrojet is a stream of charged particles that flows in Earth's upper atmosphere of Earth, what was the speed of the event in km/sec between the P3 location and when the electrojet started to form?

Problem 5 - What was the time difference between the magnetic reconnection event at 04:50:03 and the start of the auroral change in latitude?

Problem 6 - How fast did the particles travel from the reconnection region to the Earth when the auroral 'substorm' began?

Problem 7 - Before the THEMIS observations, one theory said that the disturbances near the P3 satellite would come before the reconnection occurred. What does the data say about this theory?

Answer Key

Problem 1 - Answer: The times below were reported in the scientific journals based on the actual data. Student answers may vary slightly depending on their ability to interpolate the values on the horizontal axis. For best results, use a millimeter ruler to determine the scale of the axis in seconds/mm.
Plot 1: Particle velocity increase detected at P3: **4:52:27**
Plot 2: Magnetic field change at P3: **4:52:27**
Plot 3: Auroral electrojet amplification in the ionosphere: **4:54:00**
Plot 4: Substorm expansion; Latitude increase northwards: **4:52:21**
Plot 5: Auroral intensity change; arrival of particles at Earth that were generated by magnetic reconnection. **4:51:39**

Problem 2 - Answer:
4:51:39: Auroral intensity change; arrival of particles at Earth generated by the magnetic reconnection.
4:52:21: Substorm expansion: Latitude increase northwards
4:52:27: Particle velocity increase detected at P3 due to earthward flow of particles.
4:52:27: Magnetic field change at P3
4:54:00: Auroral electrojet amplification in the ionosphere.

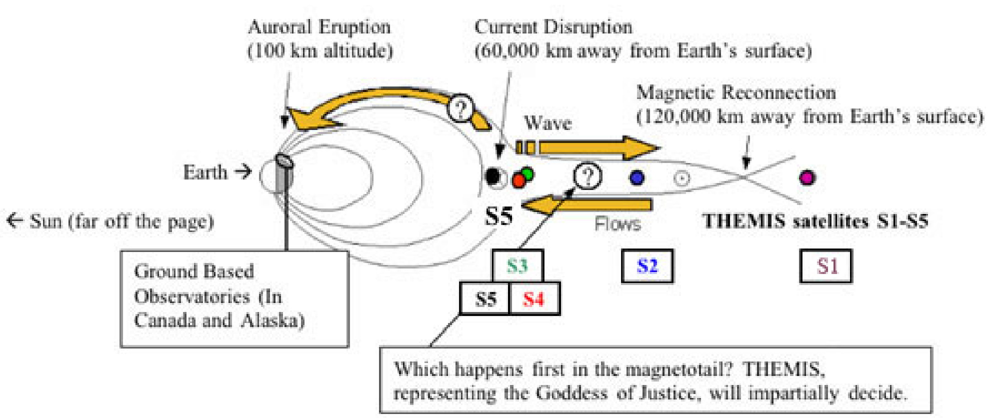
Problem 3 - Answer: 4:54:00 - 4:52:27 = 1minute and 33 seconds = **93 seconds.**

Problem 4 - Answer: 74,000 km / 93 seconds = **796 km/sec.**

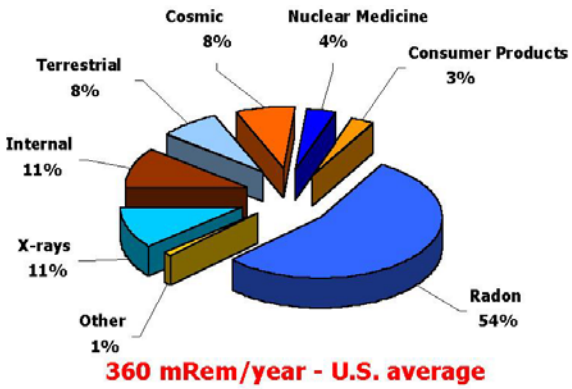
Problem 5 - Answer: 4:52:21 - 4:50:03 = 2m 18s = **138 seconds.**

Problem 6 -Answer: The distance traveled was 160,000 kilometers in 138 seconds, for an average speed of 160,000 km /138s = **1,160 km/sec** if no allowance is made for the radius of the earth (6378km) and the height of the ionosphere (300 km). If these allowances are made, then (160,000 - 6378 - 300) km /138s = **1,110 km/sec.**

Problem 7 - Answer: Because the reconnection event happened at 04:50:03 ,this was about 2:27 before the disturbances at P3 in the particles speeds were recorded, so the theory in which P3 happened first is not consistent with the new data.



Radiation Unit Conversions



To understand the effect that radiation has on biological systems, a number of different systems for measurement have arisen over the last 50 years. European scientists prefer to use Grays and Seiverts while American scientists still use Rads and Rems!

The chart to the left shows your typical radiation dosage on the ground and the factors that contribute to it.

Basic Unit Conversions:

1 Curie = 37 billion disintegrations/sec

1 Gray = 100 Rads	0.001 = 1 milli
1 Rad = 0.01 Joules/kg	0.000001 = 1 micro
1 Seivert = 100 Rems	1 lifetime = 70 years
1 Roentgen = 0.000258 Charges/kg	1 year = 8760 hours
1 microCoulomb/kg = 46 milliRem	1 Coulomb = 6.24 billion billion charges

Convert:

1 . 360 milliRem per year to ………………………….microSeiverts per hour

2. 7.8 milliRem per day to …………………………..Rem per year

3. 1 Rad per day to …………………………………..Grays per year

4. 360 milliRem per year to …………………………..Rems per lifetime

5. 3.0 Roentgens to ………………………………. charges per gram

6. 5.6 Seiverts per year to …………………………..milliRem per day

7. 537.0 milliGrays per year to ……………….……..milliRads per hour

Unit Conversion Exercises

Answer Key

1 . 360 milliRem per year to ……………………………**0.41 microSeiverts per hour**
360 milliRem/yr x 1Rem/1000 milliRem x 1 year/8760 hours = 0.000041 Rem/hour
0.000041 Rem/hour x 1.0 Seiverts/100 Rem = 0.00000041 Seiverts/hour
0.00000041 Seiverts/hour x 1 microSeivert/0.000001Seivert = 0.41 microSeiverts/hour

2. 7.8 milliRem per day to ……………………….……**2.8 Rem per year**
7.8 milliRem/day x 365 days/year = 2847.0 milliRem/year
2847.0 milliRem/year x 1.0 Rem/1000milliRem = 2.8 Rem/year

3. 1 Rad per day to ……………………………………..…**3.65 Grays per year**
1 Rad/day x 365 days/year x 1 Gray/100 Rads = 3.65 Grays/year

4. 360 milliRem per year to ………………………………**25.2 Rems per lifetime**
360 milliRem/year x 70 years/lifetime x 1 Rem/1000 milliRem = 25.2 Rems/lifetime

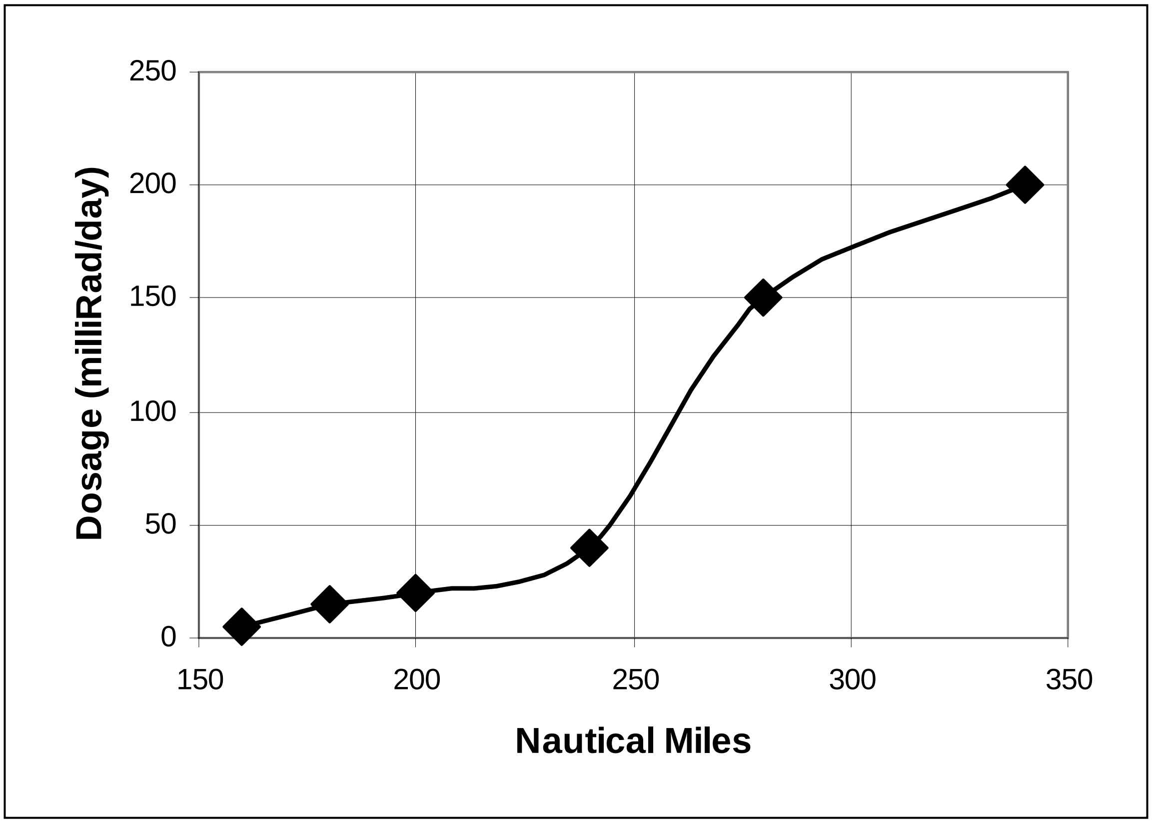
5. 3.0 Roentgens to …………………………..…**0.000000774 charges per gram**
3.0 Roentgens x 0.000258 charges/kg per Roentgen = 0.000774 charges/kg
0.000774 charges/kilogram x 1.0 kg/1000 gram = 0.000000774 charges/gram

6. 5.6 Seiverts per year to ………………………………**1530 milliRem per day**
5.6 Seiverts/year x 1.0 Year/365 days x 100 Rem/1.0 Seivert = 1.53 Rem/day
1.53 Rem/day x 1000 milliRem/Rem = 1530 milliRem/day

7. 537.0 milliGrays per year to …………………………**6.13 milliRads per hour**
537.0 milliGrays/year x 1.0 years/8760 hours x 100 Rads/1.0 Gray = 6.13 milliRads/hour

Note: There are many different conversion 'chains' that the students can offer. The challenge is to set up each ratio correctly with the right number in the numerator and denominator!

A Study of Astronaut Radiation Dosages



The typical radiation dosage on the ground is about 1.0 milliRad/day or 365 milliRad/year. This dosage is considered safe, and it is an unavoidable part of the natural background that we live and work within. In space, however, this normal background dosage is significantly exceeded. The graph above shows the average radiation dosages encountered by Space Shuttle astronauts during six Space Shuttle missions (from left to right: STS-42, 51, 51B, 37, 33 and 31).

Problem 1 - What was the daily radiation exposure experienced during the STS-31 mission?

Problem 2 - The International Space Station orbits Earth at an altitude of about 200 Nautical Miles. For a typical astronaut stay of 90 days, what will be the astronaut's average dose on the ISS?

Problem 3 - If the ISS astronaut remained on the ground during this 90-day mission, how much of a dosage would he have acquired?

Answer Key

Problem 1 - What was the daily radiation exposure experienced during the STS-31 mission?

Answer: From the graph, the dosage is **200 milliRads/day**.

Problem 2 - The International Space Station orbits Earth at an altitude of about 200 Nautical Miles. For a typical astronaut stay of 90 days, what will be the astronaut's average dose on the ISS?

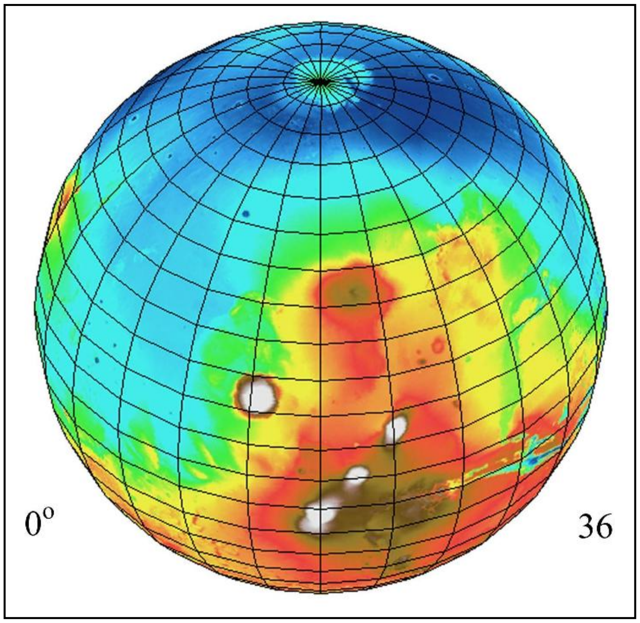
Answer: At an altitude of 200 NM, the daily dosage is about 40 milliRads/day. During the 90-day mission, the astronaut absorbs about 40 milliRads/day x 90 days = **3,600 milliRads or 3.6 Rads of radiation**.

Problem 3 - If the ISS astronaut remained on the ground during this 90-day mission, how much of a dosage would he have acquired?

Answer: The introductory paragraph says that on the ground the dosage is 365 milliRad/year, so for 90 days the total radiation exposure is
365 milliRads x (90/365) = **90 milliRads**.

Note: The radiation exposure by the astronaut is the equivalent of 3600/365 = 9.8 years of ground-level exposure during a period of 90 days.

Having a Hot Time on Mars!



Mars has virtually no atmosphere leaving its surface unprotected from solar and cosmic radiation.

This figure, created with the NASA, MARIE instrument on the Odyssey spacecraft orbiting Mars, shows the unshielded surface radiation dosages:

Color	Rem/yr
Brown	20
Orange	18
Yellow	16
Light blue	13
Dark blue	10

Astronauts landing on Mars will want to minimize their total radiation exposure during the 540 days they will stay on the surface. Assume that the Mars astronauts used improved post-Apollo spacesuit technology providing a shielding reduction of 1/8, and that the Mars Habitat provided a 1/20 radiation reduction.

Problem 1 - The typical, unshielded radiation dose on the surface of Earth for cosmic rays is about 0.040 Rems/yr. By what factor is the unshielded, minimum radiation exposure for Mars astronauts in excess of the normal terrestrial rates?

Problem 2 - The Mars explorers would like to spend 2 hours in spacesuits and the remaining 24-hours inside the Mars Habitat during each of the 540-days of exploration on Mars. What would be the approximate total dose for the astronauts in the 'dark blue' polar regions at the end of A) a single day? B) 1 Earth-year? C) the entire Mars visit?

Problem 3 - The total background+lifestyle dose on Earth at ground-level is about 360 milliRem/yr. How many extra years of radiation exposure will an astronaut accumulate exploring the surface of Mars rather than 'staying home'?

Answer key

Problem 1 - The typical, unshielded radiation dose on the surface of Earth for cosmic rays is about 0.040 Rems/yr. By what factor is the unshielded, minimum radiation exposure for Mars astronauts in excess of the normal terrestrial rates?

Answer: The lowest mapped rates are about 10 Rem/yr, so this is about 10 Rem/0.040 Rem = 250-times higher than terrestrial ground rates.

Problem 2 - The Mars explorers would like to spend 2 hours in spacesuits and the remaining 24-hours inside the Mars Habitat during each of the 540-days of exploration on Mars. What would be the approximate total dose for the astronauts in the 'dark blue' polar regions at the end of A) a single day? B) 1 Earth-year? C) the entire Mars visit?

Answer: The dark blue region corresponds to 10 Rem/yr or 27 milliRem/day, assuming 1 Earth-year = 365 days. In terms of an hourly rate we have for 1 day = 24 hours that the dose rate is 1.1 milliRem/hr.

A) For the Mars Habitat, its shielding reduces the daily dose by 1/20 so for 22 hours the dose will be 1.1 milliRem/hr x (1/20) x 22 hrs = 1.21 milliRem. The spacesuit dose would be 1.1 milliRem/hr x (1/8) x 2 hrs = 0.28 milliRem ,so the total daily accumulated dose would be 1.21 + 0.28 = **1.49 milliRem/day**.

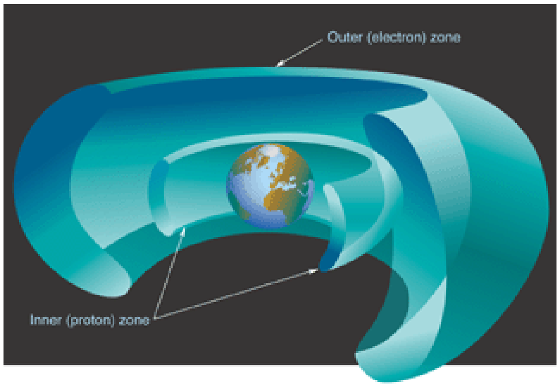
B) For one Earth-year the accumulated dose would be 1.49 milliRem/day x 365 days = **543 milliRem/yr or 0.54 Rem/yr.**

C) For 540-days, the total dose would be 1.49 milliRem/day x 540 days = **805 milliRem or 0.80 Rem.**

Problem 3 - The total background+lifestyle dose on Earth at ground-level is about 360 milliRem/yr. How many extra years of radiation exposure will an astronaut accumulate exploring the surface of Mars rather than 'staying home'?

Answer: If he spent 540-days on Earth, he would have accumulated 360 milliRem/yr x 540 days/365 days= 532 milliRem. On Mars the total accumulation would have been 805 milliRem for 540 days. The excess accumulation is just 805 milliRem - 532 milliRem = 273 milliRem. This equals 273/360 = **0.76 additional years**.

The Deadly Van Allen Belts?

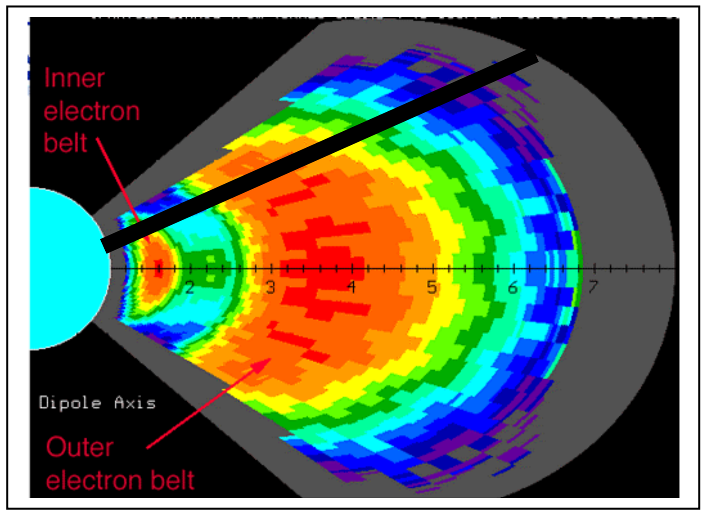


In 1958, Dr. James Van Allen discovered a collection of high-energy particle clouds within 40,000 km of Earth. Arranged like two nested donuts, the inner belt is mainly energetic protons, while the outer belts contain both protons and electrons. These belts have long been known as 'bad news' for satellites and astronauts, with potentially deadly consequences if you spend too much time within them. The figure below, produced by scientists from the NASA, CRRES satellite, shows the radiation dosages at various locations within the belts.

Blue = 0.0001 Rads/sec Green= 0.001 Rads/sec Yellow= 0.005 Rads/sec Orange= 0.01 Rads/sec and Red= 0.05 Rads/sec.

The numbers along the horizontal axis give the distance from Earth in multiples of the Earth radius (1 Re=6378 km). The Inner van Allen Belt is located at about 1.6 Re. The Outer van Allen Belt is located at about 4.0 Re. At a distance of 2.2 Re, there is a 'gap' region in between these belts. Satellites such as the Global Positioning System (GPS) orbit in this gap region where radiation effects are minimum.

The International Space Station and Space Shuttle, on this scale, orbit very near the edge of the blue 'Earth disk' in the figure, so are well below the Van Allen Belts.



Apollo astronauts, and astronauts in the upcoming visits to the Moon, will have to travel through some of these belt regions because the orbit of the Moon lies along the fastest line-of-travel from Earth. On the scale of the above figure, the distance to the Moon is 60 Re.

1. The speed of the spacecraft will be about 25,000 km/hour. If the spacecraft travels along the indicated path (black bar), how long, in minutes, will it spend in the Blue, Green, Yellow, Orange and Red regions?

2. Given the indicated radiation dosages in Rads/sec for each zone, what will be the dosages that the astronauts receive in each zone?

3. What will be the total radiation dosage in Rads for the transit through the belts?

4. Some people believe that the Apollo moon landings were a hoax because astronauts would have been instantly killed in the radiation belts. According to the US Occupation Safety and Health Agency (OSHA) a lethal radiation dosage is 300 Rads in one hour. What is your answer to the 'moon landing hoax' believers?

Note: According to radiation dosimeters carried by Apollo astronauts, their total dosage for the entire trip to the moon and return was not more than 2 Rads over 6 days.

Answer Key:

Apollo astronauts, and astronauts in the upcoming visits to the Moon, will have to travel through some of these belt regions because the orbit of the Moon lies along the fastest line-of-travel from Earth. On the scale of the above figure, the distance to the Moon is 60 Re.

1. The speed of the spacecraft will be about 25,000 km/hour. If the spacecraft travels along the indicated path, how long, in minutes, will it spend in the Blue, Green, Yellow, Orange and Red regions? Note: transit estimates may vary depending on how accurately students measure figure.

Blue: 1.8 Re x (6378 km/Re) x (1 hour/25,000 km) x (60 minutes/1 hour) =	27.6 minutes
Yellow: (1.4 x 6378) /25,000 x 60 =	6.1 minutes
Orange: (1.0 x 6378) / 25,000 x 60 =	15.3 minutes
Green: (0.25 x 6378)/25,000 x 60 =	3.8 minutes
Red:	0 minutes

Total transit time………………………. 52.8 minutes

2. Given the indicated radiation dosages in Rads/sec for each zone, what will be the dosages that the astronauts receive in each zone?

Blue: = 27.6 minutes x (60 sec/ 1 minute) x (0.0001 Rads/sec) =	0.17 Rads
Yellow = 6.1 minutes x 60 sec/minute x 0.005 rads/sec =	1.83 Rads
Orange = 15.3 minutes x (60 sec/minute) x 0.01 rads/sec =	9.18 Rads
Green = 3.8 minutes x (60 sec/minute) x 0.001 rads/sec =	0.23 Rads

3. What will be the total radiation dosage in Rads for the transit through the belts?

0.17 + 1.83 + 9.18 + 0.23 = 11.4 Rads

4. Some people believe that the Apollo moon landings were a hoax because astronauts would have been instantly killed in the radiation belts. According to the US Occupation Safety and Health Agency (OSHA) a lethal radiation dosage is 300 Rads in one hour. What is your answer to the 'moon landing hoax' believers?

Note: According to radiation dosimeters carried by Apollo astronauts, their total dosage for the entire trip to the moon and return was not more than 2 Rads over 6 days.

The total dosage for the trip is only 11.4 Rads in 52.8 minutes. Because 52.8 minutes is equal to 0.88 hours, his is equal to a dosage of 11.4 Rads / 0.88 hours = 13 Rads in one hour, which is well below the 300 Rads in one hour that is considered to be lethal.

Also, this radiation exposure would be for an astronaut outside the spacecraft during the transit through the belts. The radiation shielding inside the spacecraft cuts down the 13 Rads/hour exposure so that it is completely harmless.

	Date	SPE (pFU)		Date	SPE (pFU)		Date	SPE (pFU)
1	11/4/1997	72	32	4/15/2001	951	63	7/22/2002	28
2	11/6/1997	490	33	4/18/2001	321	64	8/14/2002	26
3	4/20/1998	1,700	34	4/28/2001	57	65	8/22/2002	36
4	5/2/1998	150	35	5/7/2001	30	66	8/24/2002	317
5	5/6/1998	210	36	6/15/2001	26	67	9/7/2002	208
6	8/24/1998	670	37	8/10/2001	17	68	11/9/2002	404
7	9/25/1998	44	38	8/16/2001	493	69	5/28/2003	121
8	9/30/1998	1,200	39	9/15/2001	11	70	5/31/2003	27
9	11/8/1998	11	40	9/24/2001	12,900	71	6/18/2003	24
10	1/23/1999	14	41	10/1/2001	2,360	72	10/26/2003	466
11	4/24/1999	32	42	10/19/2001	11	73	10/28/2003	29,500
12	5/5/1999	14	43	10/22/2001	24	74	11/2/2003	1,570
13	6/2/1999	48	44	11/4/2001	31,700	75	11/4/2003	353
14	6/4/1999	64	45	11/19/2001	34	76	11/21/2003	13
15	2/18/2000	13	46	11/22/2001	18,900	77	12/2/2003	86
16	4/4/2000	55	47	12/26/2001	779	78	4/11/2004	35
17	6/7/2000	84	48	12/29/2001	76	79	7/25/2004	2,086
18	6/10/2000	46	49	12/30/2001	108	80	9/13/2004	273
19	7/14/2000	24,000	50	1/10/2002	91	81	11/1/2004	63
20	7/22/2000	17	51	1/15/2002	15	82	11/7/2004	495
21	7/28/2000	18	52	2/20/2002	13	83	1/16/2005	5,040
22	8/11/2000	17	53	3/17/2002	13	84	5/14/2005	3,140
23	9/12/2000	320	54	3/18/2002	53	85	6/16/2005	44
24	10/16/2000	15	55	3/20/2002	19	86	7/14/2005	134
25	10/26/2000	15	56	3/22/2002	16	87	7/27/2005	41
26	11/8/2000	14,800	57	4/17/2002	24	88	8/22/2005	330
27	11/24/2000	942	58	4/21/2002	2,520	89	9/8/2005	1,880
28	1/28/2001	49	59	5/22/2002	820	90	12/6/2006	1,980
29	3/29/2001	35	60	7/7/2002	22	91	12/13/2006	698
30	4/2/2001	1,110	61	7/16/2002	234			
31	4/10/2001	355	62	7/19/2002	31			

The high-energy particles in SPEs are a hazard to astronauts because this radiation can penetrate the shielding provided by spacesuits and spacecraft. Radiation dosage in given in terms of milliREMs. Typically on the surface of Earth we are exposed to about 370 milliREM of natural radiation each year. The table above gives the intensity of each SPE detected between 1996-2008. To convert the particle flux uints (pFUs) into milliREMS we use the following approximate conversion constants: Spacesuits: 10,000 pFU = 100 milliREM; Spacecraft: 10,000 pFU = 10 milliREM

Problem 1 - What was the human radiation exposure in a spacesuit to the 5 most intense SPEs during the tabulated period?

Problem 2 - What was the human radiation exposure inside a spacecraft to the 5 most intense SPEs during the tabulated period?

To convert the pFUs into milliREMS we use the following approximate conversion constants: Spacesuits: 10,000 pFU = 100 milliREM; Spacecraft: 10,000 pFU = 10 milliREM

Problem 1 - What was the human radiation exposure in a spacesuit to the 5 most intense SPEs during the tabulated period?
Answer: The SPEs were 31,700 (11/4/2001); 29,500 (10/28/2003); 24,000 (7/14/2000); 18,900 (11/22/2001) and 14,800 (11/8/2000). The dosages were
31,700 pFU x 100 milliRem/10,000 = **317 milliRem**
29,500 pFU x 100 milliRem/10,000 = **295 milliRem**
24,000pFU x 100 milliRem/10,000 = **240 milliRem**
18,900 pFU x 100 milliRem/10,000 = **189 milliRem**
14,800 pFU x 100 milliRem/10,000 = **148 milliRem**

Problem 2 - What was the human radiation exposure inside a spacecraft to the 5 most intense SPEs during the tabulated period?
Answer:
31,700 pFU x 10 milliRem/10,000 = **32 milliRem**
29,500 pFU x 10 milliRem/10,000 = **30 milliRem**
24,000pFU x 10 milliRem/10,000 = **24 milliRem**
18,900 pFU x 10 milliRem/10,000 = **19 milliRem**
14,800 pFU x 10 milliRem/10,000 = **15 milliRem**

Note: At ground level, a one-year radiation dose is about 350 milliRem from natural sources, so a spacesuited astronaut exposed to a strong SPE receives about a years worth of radiation exposure in a matter of a few hours.

Total Dose (Rem)	Medical Impact
5000	Predicted radiation from a Carrington Superstorm in a spacesuit (1 gm/cm2 shielding) in deep space
500	100% lethal dose for humans in 30 days.
400	Predicted radiation from the August 1972 flare in a spacesuit.
200	Predicted radiation from a Carrington Superstorm with 10 gm/cm2 shielding in deep space
100	About 5 out of every 100 people will experience a fatal cancer at this level if delivered over a short time (minutes to hours)
50	Radiation absorbed by spacesuited astronauts from January 15, 2005 solar flare
40	Predicted one-year cosmic ray dosage in interplanetary space during sunspot minimum with shielding
30	Estimated dosage from February 1956 solar proton event with 20 gm/cm2 shielding
29	Predicted radiation from a Carrington Superstorm with 20 gm/cm2 shielding at ISS altitudes (400km)
25	A typical lifetime accumulated radiation dosage for person living on the surface of Earth.
20	Maximum measured, unshielded radiation dosage per year on the surface of Mars
15	Estimated dosage from August 1972 solar proton event with 20 gm/cm2 shielding
10	Predicted one-year cosmic ray dosage in interplanetary space during sunspot maximum with shielding
5.0	Lowest annual dosage for which no increases average human cancer rates have been detected.
3.0	Radiation exposure for a 90-day stay in the International Space Station during average space weather conditions
2.0	Radiation dosage for Apollo Astronauts visiting the moon and returning to Earth
1.0	Radiation absorbed by ISS astronauts from January 15, 2005 solar flare
1.0	Maximum allowed for uranium miners inhaling rock dust each year
0.8	14-day stay inside Space Shuttle during solar maximum and highest orbit elevation
0.3	Average cosmic ray and natural background exposure each year
0.01	One flight across the North Pole from new York to Tokyo

The radiation dosages encountered by astronauts in space in properly shielded spacecraft rarely exceed the 'nuisance' level. There are no known examples of deaths directly attributable to excess radiation exposure among the over 300 astronauts that have worked in space for prolonged periods of time. Nevertheless, there are believed to be risks associated with even moderate radiation exposure. Radiation is measured in two ways:

Total absorbed dose (Rems)
Dosage rate (milliRems/hour)

A solar flare delivers a lot of radiation in a small amount of time, while cosmic rays deliver small amounts of radiation for a long period of time. Although the dosage rates are very different, their total absorbed dose can be similiar over a lifetime. The table to the left gives the various levels of radiation total dosage from a variety of sources.

Suppose that a round trip to Mars took 1.0 years through space, with an additional 0.5-year stay on the surface.

Problem 1 - What would be the total radiation exposure in rems if the trip occurred during sunspot minimum, and shielded astronauts encountered 2 flares like the one on January 15, 2005?

Problem 2 - How many times more radiation would these astronauts absorb in a year than if they had stayed on Earth?

Problem 1 - What would be the total radiation exposure in rems if the trip occurred during sunspot minimum, and encountered 2 flares like the one on January 15, 2005?
Answer: 40 rem from cosmic rays, 2x 1 rem for the flares, and 20x0.5 =10 rem on Mars gives **32 rem total** over 1.5 years.

Problem 2 - How many times more radiation would these astronauts absorb in a year than if they had stayed on Earth?
Answer: One year on Earth has a dosage of about 0.3 rems each year. The average Mars traveler in Problem 1 experienced 32 rem in 1.5 years or 21 rems/year, so this is about 21/0.3 = **70 times the Earth surface amoun**t.

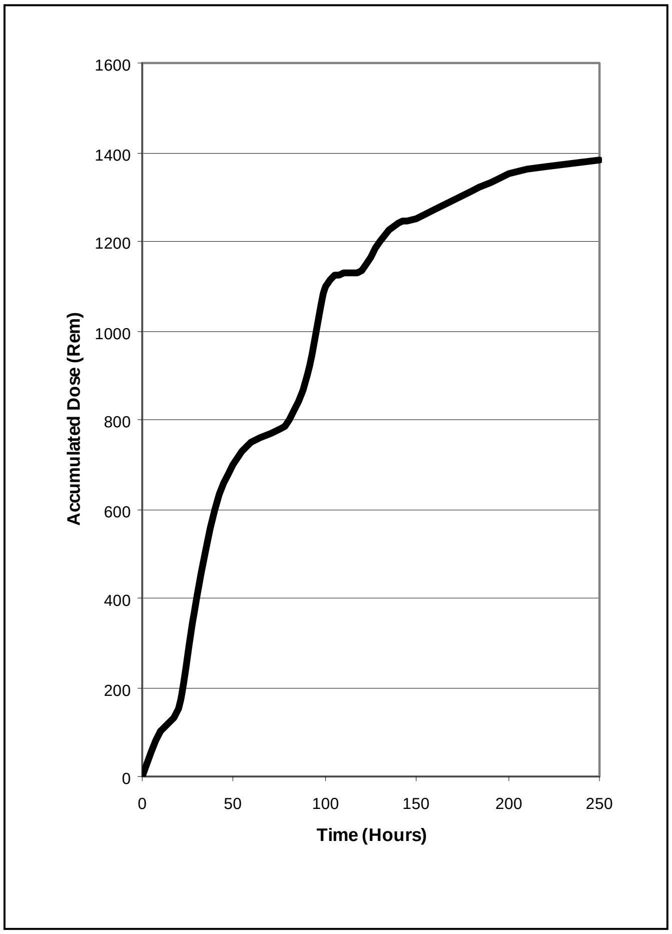
Space radiation has not been a serious problem for NASA human missions because they have been short in duration or have occurred in low Earth orbit, within the protective magnetic field of the Earth," said Philip Scarpa, M.D., a NASA flight surgeon at NASA's Kennedy Space Center in Florida and co-investigator in the study. "However, if we plan to leave low Earth orbit to go back to the moon for long durations or on to Mars, we need to better investigate this issue and assess the risk to the astronauts in order to know whether we need to develop countermeasures such as medications or improved shielding. We currently know very little about the effects of space radiation, especially heavy element cosmic radiation, which is expected on future space missions and was the type of radiation used in this study.

"In addition, we should expect that within each critical organ system, there may be different cell sensitivities that need to be considered when defining space radiation dose limits." Scarpa said.

The finding raises questions about the cognitive and emotional risks associated with radiation exposure during human space exploration missions.

"There is a growing body of evidence that the death of these types of cells is a potential adverse effect of radiation during cancer treatment, but it's not been discussed in terms of space travel," said Jack M. Parent, M.D., a neurologist at the University of Michigan who was not involved in the research. "Radiation has been associated with adverse cognitive effects, which is a potential hazard during space missions. Shielding and other measures to block the effects of radiation have to be strongly considered. The subject certainly deserves more study."

From http://www.news-medical.net/news/2007/12/12/33415.aspx?page=2



The Solar Proton Event (SPE) of October, 1989 produced an intense series of radiation events that spanned about 250 hours in time before the particle stream ended. SPEs are high-energy protons created by powerful explosions on the sun, and travel at nearly the speed of light. When they arrive at Earth, that are a severe hazard for astronauts, and can damage satellites and their sensitive electrical systems.

Dr. Lawrence Townsend at the University of Tennessee calculated the intensity versus time history of the October, 1989 event to calculate the total, unshielded, accumulated radiation dosage shown in the graph to the left.

Problem 1 - What was the total radiation dose in Rems from the October 1989 Solar Proton Event after 250 hours (10.4 days)?

Problem 2 - A spacecraft is designed with aluminum walls that have a combined shielding of 19 gm/cm^2 to reduce incoming radiation by a factor of 500 times. What accumulated radiation dose in Rems would the astronauts have been exposed to after

A) 100 hours?

B) 200 hours?

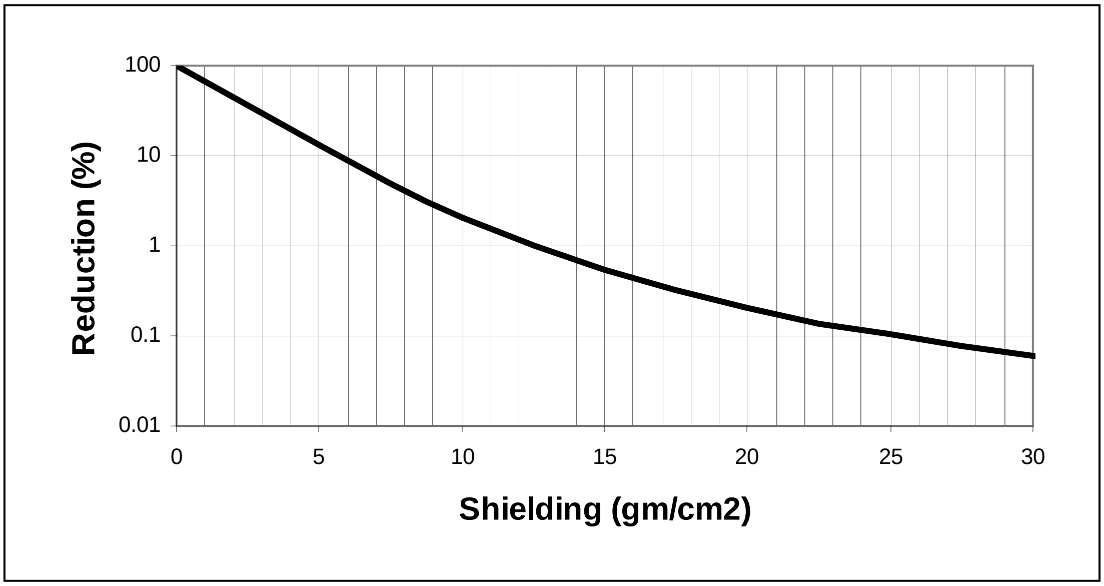
Problem 1 - What was the total radiation dose from the October 1989 Solar Proton Event after 250 hours (10.4 days)? Answer: **About 1380 rems**.

Problem 2 - A spacecraft is designed with aluminum walls that have a combined shielding of 19 gm/cm^2 to reduce incoming radiation by a factor of 500 times. What accumulated radiation dose in Rems would the astronauts have been exposed to after A) 100 hours? B) 200 hours?

Answer: A) At 100-hours, the outside dose is about 1120 rems. A 500x reduction yields a dose at that time of 1120/500 = **2.2 rems**. B) At 200 hours, the outside dose is about 1350 rems, so the inside astronaut dose is 1350/500 = **2.7 rems**.

Note: At ground-level on Earth, the background dose is 0.3 rems/year so a lifetime dose is about 20 rems. When properly shielded, astronauts are not exposed to hazardous levels of radiation even during intense solar flares…unless they happen to be outside the spacecraft in a spacesuit. Under those conditions, the radiation shielding is only 1 gm/cm^2, and radiation is only reduced by about 10%, making a Solar Proton Event like the one in October 1989 equal to 1380 rems x 0.8 = 1,104 rems which is lethal. This is why EVAs are the most risky undertaking by astronauts.

How to Calculate Shielding Thickness



Most people have heard that radiation can be blocked or 'shielded' so that it does less harm to humans. Often, substances such as lead are used when weight is not an issue. But for space applications, weight costs money, approximately $8,000 per pound for Earth-orbiting payloads.

Radiation in space can be electromagnetic (x-rays and gamma rays) or particulate (protons, electrons, alpha-particles), and each has to be blocked to safe levels so that satellites and astronauts are not harmed.

There are many different materials that can be used as radiation shielding. We will focus on aluminum, which is a common ingredient to spacecraft and satellite walls. The curve above gives the percentage of reduction in the radiation as a function of the shielding coefficient in grams/cm^2. Spacesuits typically have 1 gm/cm^2 of shielding while the walls of the Space Shuttle can be 10 gm/cm^2.

Problem 1 - A plate of aluminum is 4.8 centimeters thick. If the density of aluminum is 2.7 gm/cm^3, what will be A) the shielding coefficient? B) The reduction factor of the radiation passing through the shield?

Problem 2 - A rare Carrington Superflare produces about 6,000 rem on the outside wall of a spacecraft. What must be the shielding thickness so that no more than 6 rem makes it through to the astronauts?

Problem 3 - The astronauts in a spacecraft will be in space for 2 years, in a radiation environment that could produce as much as 500 rems/year of radiation. What is the minimum spacecraft wall thickness that will allow the astronauts to accumulate no more than 1 rem of radiation during the entire voyage?

Problem 1 - A plate of aluminum is 4.8 centimeters thick. If the density of aluminum is 2.7 gm/cm^3, what will be A) the shielding coefficient? B) The reduction factor of the radiation passing through the shield?

Answer: A) 2.7 gm/cm^3 x 4.8 cm = **13 gm/cm^2**. B) From the graph, at a shielding of 13 gm/cm^2, the curve indicates 1%' so the radiation has been reduced in strength by a factor of **100 times**.

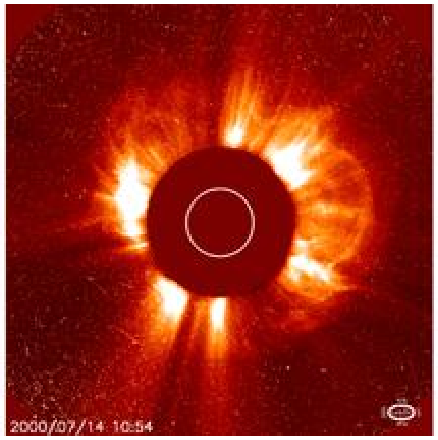
Problem 2 - A rare Carrington Superflare produces about 6,000 rem on the outside wall of a spacecraft. What must be the shielding thickness so that no more than 6 rem makes it through to the astronauts?

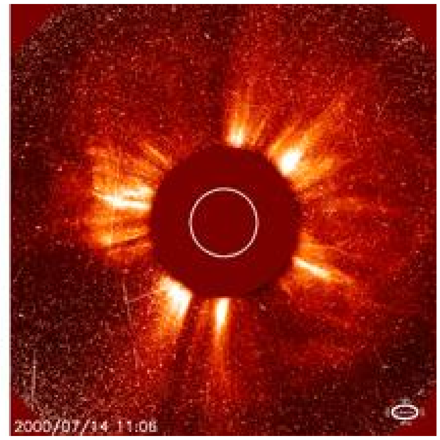
Answer: We need to reduce the radiation to 100% x (6/6000) = 0.10%. From the curve, this will occur for shielding greater than about **25 gm/cm^2**.

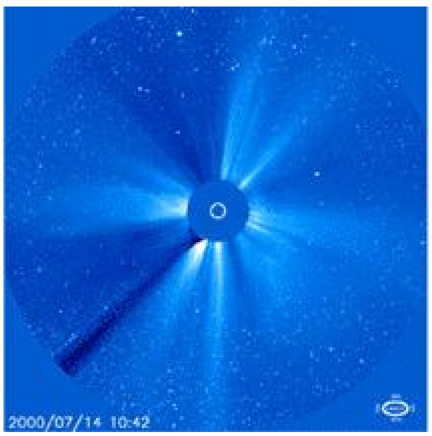
Problem 3 - The astronauts in a spacecraft will be in space for 2 years, in a radiation environment that could produce as much as 500 rems/year of radiation. What is the minimum spacecraft wall thickness that will allow the astronauts to accumulate no more than 1 rem of radiation during the entire voyage?

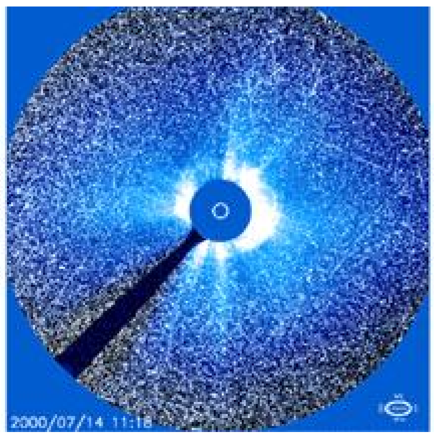
Answer: The total radiation dosage for the trip is 2 years x (500 rem/year) = 1000 rems. We want this to me no more than 1 rem inside the spacecraft so the incoming radiation it must be reduced by a factor of 1/1000 or 0.1%. From the vertical scale on the graph we see that '0.1' corresponds to a shielding of 24 gm/cm^2 of aluminum. Because the density of aluminum is 2.7 gm/cm^3, the wall thickness would be 24/2.7 = **8.9 centimeters**. This is the minimum thickness, and thicker walls will reduce the radiation levels even further.

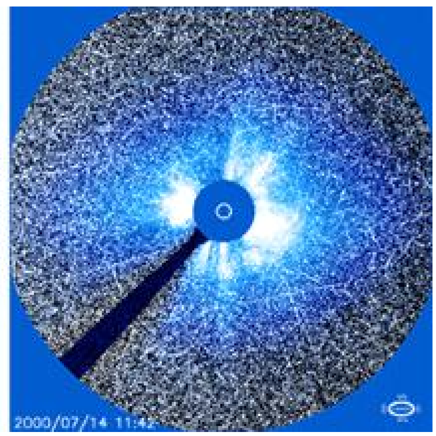
Data Corruption by High-Energy Particles

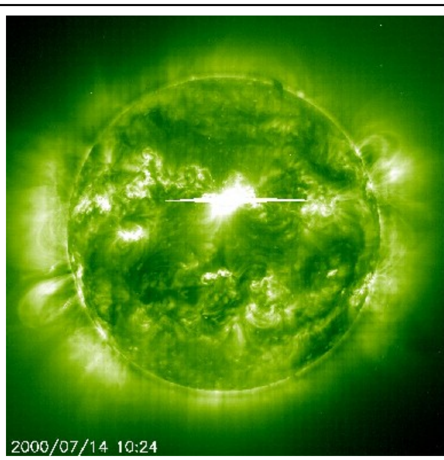












Solar flares can severely affect sensitive instruments in space and corrupt the data that they produce. On July 14, 2000 the sun produced a powerful X-class flare, which was captured by instruments onboard the Solar and Heliospheric Observatory (SOHO). The EIT imager operating at a wavelength of 195 Angstroms, showed a brilliant flash of light (left image). When these particles arrived at the SOHO satellite some time later, they caused the imaging equipment to develop ‘snow’ as the individual particles streaked through the sensitive electronic equipment. The above images taken by the SOHO LASCO c2 and c3 imagers show what happened to that instrument when this shower of particles arrived. The date and time information (hr : min) is given in the lower left corner of each image, and give the approximate times of the events.

Problem 1: At about what time did the solar flare first erupt on the sun?
Problem 2: At about what time did the LASCO imagers begin to show significant signs of the particles having arrived?
Problem 3: If the SOHO satellite was located 147 million kilometers from the sun, about what was the speed of the arriving particles?
Problem 4: If the speed of light is 300,000 km/sec, what percentage of light-speed were the particles traveling?

Answer Key:

Problem 1: At about what time did the solar flare first erupt on the sun?

Answer: The EIT image time says 10:24 or 10 hours and 24 minutes Universal Time The reason this is not an exact time is because the images were taken at set times, and not at the exact times of the start or end of the events. To within the 24-minute interval between successive EIT images, we will assume that 10:24 UT is the closest time.

Problem 2: At about what time did the LASCO imagers begin to show significant signs of the particles having arrived?

Answer: The top sequence shows that the 'snow began to fall' at 10:54 UT. The second sequence suggests a later time near 11:18. However, the 11:18 time is later than the 10:54 time. The time interval between exposures is 24 minutes, but the top series started at 10:30 and ended at 10:54 UT, while the lower series started at 10:42 and ended at 11:18. That means, comparing the exposures between the two series, the snow arrived between 10:42 and 10:54 UT. We can split the difference and assume that the snow began around 10:48 UT.

Problem 3: If the SOHO satellite was located 147 million kilometers from the sun, about what was the speed of the arriving particles?

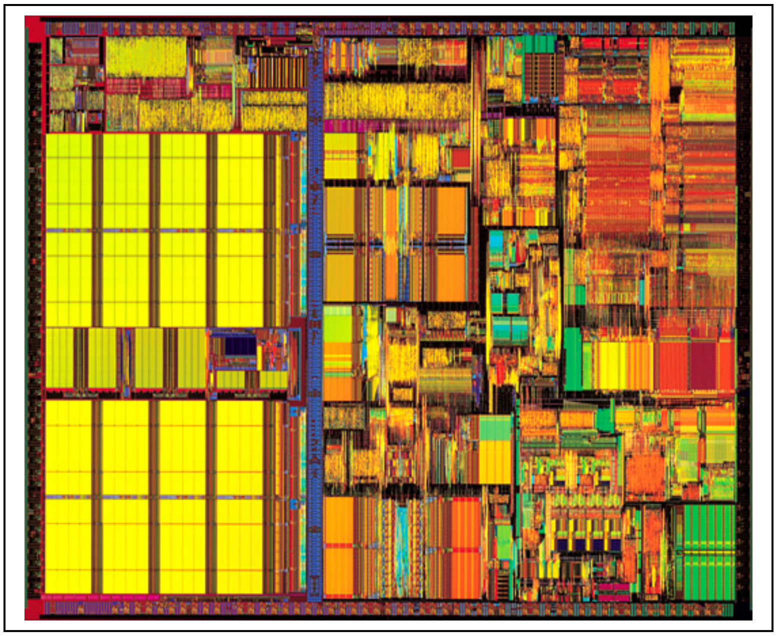
Answer: The elapsed time between the sighting of the flare by EIT (10:24 UT) and the beginning of the snow seen by LASCO (10:48 UT) is 10:48 UT – 10:24 UT = 24 minutes. The speed of the particles was about 147 million km/24 minutes or 6.1 million km/minute.

Problem 4: If the speed of light is 300,000 km/sec, what percentage of light-speed were the particles traveling?

Answer: Converting 6.1 million km/minute into km/sec we get 6,100,000 km/sec x (1 min /60 sec) or 102,000 kilometers/sec. Comparing this to the speed of light we see that the particles traveled at (102,000/300,000)x100% = 34% the speed of light!

Note: Because these damaging high-speed particles can arrive only a half-hour after the x-ray flash is first seen on the sun, it can be very difficult to protect sensitive equipment from these storms of particles if you wait for the first sighting of the solar flare flash. In some cases, science research satellites have actually been permanently damaged by these particle storms.

Computer Memory and Glitches



Computers are used in space, but that means they can get clobbered by radiation and develop 'glitches' in the way they work. Sometimes these glitches cause the satellite to fail, or transmit corrupted data.

This is a photo of the Pentium III microprocessor board is about 15 cm wide. The solid, colored rectangular areas are memory locations that store data, the computer operating system, and other critical information.

Suppose that 2/3 of the area of a satellite's processor memory is used for data storage, 1/4 is for the computer's operating system, and the remainder is for program storage.

Problem 1 - Suppose that the total size of the memory is 1,200 megabytes. How many megabytes are available for program storage?

Problem 2 - Suppose that for a satellite in space, cosmic rays cause glitches and errors in the computer memory at a rate of 1 glitch per hour for every 1 gigabytes of memory. If the satellite is in operation for 10 hours, how many glitches will this satellite's memory encounter?

Problem 3 - Given the areas of the different computer memory functions, how many glitches would you expect in the operating system memory?

Problem 4 - After 10 hours of operation, about how many operating system failures would you expect, and what would be the average time between operating system failures?

Problem 5 - An engineer decides to re-design the satellite's memory by splitting up the memory for the operating system into 4 separate areas. Why do you think this design might reduce the number of glitches caused by the cosmic rays, or why would this not work?

Answer Key

Problem 1 - Suppose that the total size of the memory is 1,200 megabytes. How many megabytes are available for program storage? Answer: Program storage is 1 - 2/3 - 1/4 = 12/12 - 8/12 - 3/12 = 1/12 of the memory. Since there are 1,200 megabytes of computer memory for all functions, the program memory occupies 1,200 megabytes x 1/12 = **100 megabytes**.

Problem 2 - Suppose that for a satellite in space, cosmic rays cause glitches and errors in the computer memory at a rate of 1 glitch per hour for every 1 gigabytes of memory. If the satellite is in operation for 10 hours, how many glitches will this satellite's memory encounter? Answer: The computer memory is 1,200 megabytes and since 1,000 megabytes = 1 gigabyte, the memory is 1.2 gigabytes in size. 1 glitch/hour per gigabyte x 1.2 gigabytes = 1.2 glitches/hour. For 10 hours the total number of glitches will be 1.2 x 10 = **12 glitches for the entire memory area.**

Problem 3 - Given the areas of the different computer memory functions, how many glitches would you expect in the operating system memory? Answer: The operating system occupies 1/4 of the memory, so if the glitches are random, the operating system should experience 12 glitches x 1/4 = **3 glitches.**

Problem 4 - After 10 hours of operation, about how many operating system failures would you expect, and what would be the average time between operating system failures? Answer: In 10 hours, the average time between operating system glitches would be 10 hours / 3 glitches = **3 1/3 hours between glitches.**

Problem 5 - An engineer decides to re-design the satellite's memory by splitting up the memory for the operating system into 4 separate areas. Why do you think this design might reduce the number of glitches caused by the cosmic rays, or why would this not work? Answer: **No, because the total area of the operating system memory is exactly the same, so the probability that it will receive a glitch remains the same as before.**

A Bit of Satellite Math

In the table below you will find information about the communication satellites that were launched in 2005. Assume that each satellite will survive until the year when its lifespan expires. Most are designed to last 15 years before needing replacement. Solar storms and cosmic rays damage the satellite solar panels and cause a 2% decrease in electrical power. Assume that this means that the satellite loses 2% of its transponders each year. Each satellite transponder can carry 2 channels of regular (analog) TV programs, or 6 channels of digital TV programs.

Name	Lifespan In years	Number of Transponders	Cost (million $)	Retire year	Revenue (million $)	Break even year
Hotbird-7A	15	38	200			
Arabsat 4A	15	40	200			
AMC-12	16	72	280			
StarOne C2	13	44	150			
Insat-4A	12	24	67			
Intelsat IA-8	13	64	320			
Spaceway-2	13	48	250			
DirecTV-8	12	32	260			
AMC-23	15	38	280			
Anik F1R	15	56	250			
Echostar 10	15	32	250			
Chinasat-8	15	52	100			
Telkom-2	15	24	150			
Thaicom-4	12	38	400			
Galaxy-14	15	24	270			
Galaxy-15	15	24	270			
Apstar-6	14	50	225			
Asiasat-6	12	50	200			
Express AM3	12	28	290			
Express AM2	12	28	290			
Measat-3	15	48	132			

Problem 1 - A) What is the total number of transponders carried by these satellites? B) How many analog satellite TV channels can be supported by these satellites? C) How many digital TV channels can be supported by these satellites?

Problem 2 - In Column 4, determine the retirement year of the satellite given its launch year and lifespan. A) What is the earliest year when this group of satellites will begin to retire? B) What year will the oldest satellites retire? C) How old will you be when the last satellite is retired?

Problem 3 - Satellite transponders are rented by the satellite owner to TV companies to carry their programs. A typical transponder costs $1.2 million to lease each year, and this represents income to the satellite owner. In Column 6, calculate the annual revenue from each satellite's transponders in millions of dollars. A) What is the total revenue each year from these satellites? B) Which satellite makes the most money each year? C) Which satellites make the least money each year?

Problem 4 - For each satellite, by what year will its cumulative revenue equal the cost of the satellite? This is the 'break even' year when the satellite has paid for itself and from this year on is producing a net profit to the owner. Enter the break-even year in Column 7.

<u>For Experts:</u> A) If the Hotbird-7A satellite actually loses 3% of its transponders each year, how much money will the satellite have lost by the break-even year because of space weather? Assume it loses the same number of transponders each year beginning with its first year.

Name	Lifespan In years	Number of Transponders	Cost (million $)	Retire year	Revenue (million $)	Break even year
Hotbird-7A	15	38	200	2020	45.6	2010
Arabsat 4A	15	40	200	2020	48.0	2010
AMC-12	16	72	280	2021	86.4	2009
StarOne C2	13	44	150	2018	52.8	2008
Insat-4A	12	24	67	2017	28.8	2008
Intelsat IA-8	13	64	320	2018	76.8	2010
Spaceway-2	13	48	250	2018	57.6	2010
DirecTV-8	12	32	260	2017	38.4	2012
AMC-23	15	38	280	2020	45.6	2012
Anik F1R	15	56	250	2020	67.2	2009
Echostar 10	15	32	250	2020	38.4	2012
Chinasat-8	15	52	100	2020	62.4	2007
Telkom-2	15	24	150	2020	28.8	2011
Thaicom-4	12	38	400	2017	45.6	2014
Galaxy-14	15	24	270	2020	28.8	2015
Galaxy-15	15	24	270	2020	28.8	2015
Apstar-6	14	50	225	2019	60.0	2009
Asiasat-6	12	50	200	2017	60.0	2009
Express AM3	12	28	290	2017	33.6	2014
Express AM2	12	28	290	2017	33.6	2014
Measat-3	15	48	132	2020	57.6	2008

Problem 1) A) What is the total number of transponders carried by these satellites? B) How many analog satellite TV channels can be supported by these satellites? C) How many digital TV channels can be supported by these satellites? Answer; A) 854 transponders; B) About 854 x 2 = 1708 analog TV channels. C) About 854 x 6 = 5124 digital TV channels.

Problem 2) In Column 4, determine the retirement year of the satellite given its launch year and lifespan. A) What is the earliest year when this group of satellites will begin to retire? B) What year will the oldest satellites retire? C) How old will you be when the last satellite is retired? Answer: A) The year 2017. B) The year 2020 C) For a 14-year old student in 2005, you will be 14+15 = 29 years old when the oldest satellite retires.

Problem 3) Satellite transponders are rented by the satellite owner to TV companies to carry their programs. A typical transponder costs $1.2 million to lease each year, and this represents income to the satellite owner. In Column 6, calculate the annual revenue from each satellite's transponders in millions of dollars. A) What is the total revenue each year from these satellites? B) Which satellite makes the most money each year? C) Which satellite makes the least money each year? Answer: A) 1.0248 billion dollars. B) AMC-12, C) Insat-4A, Telkom-2, Galaxy-14 and Galaxy-15.

Problem 4) For each satellite, by what year will its cumulative revenue equal the cost of the satellite? This is the 'break even' year when the satellite has paid for itself and from this year on is producing a net profit to the owner. Enter the break-even year in Column 7. Answer Example: Hotbird-7a makes $45.6 million each year. It cost $200 million, so it will take (200/45.6) = 4.4 years. Rounding-up, it was launched in 2005, so by 2005+5 = 2010 it will have paid for itself. Rounding-down, students may also use 2005+4 = 2009.

For Experts. A) If the Hotbird-7A satellite loses 3% of its transponders each year how much money will the satellite have lost by its break-even year because of space weather? Assume it loses the same number of transponders each year beginning with its first year. Answer: Hotbird-7A reaches its break-even year 4 years after launch. It will lose 38 x 0.03 = 1 transponder the first year, and the same number for each of the remaining 3 years. The cumulative transponder loss for each year is 1 ,2, 3 ,4. for a cumulative loss of 1.2 + 2.4 + 3.6 + 4.8 = $12 million. Select some other satellites to do the same calculation. You may also want to do this on a spreadsheet! What will be the total loss of revenue due to space weather for this entire collection of satellites?

The International Space Station is a 400-ton, $160 billion platform that supports an international team of 3-5 astronauts for tours of duty lasting up to 6 months at a time. Like all satellites that orbit close to Earth, the atmosphere causes the ISS orbit to decay steadily every day, so the ISS has to be 're-boosted' every few months to prevent it from burning up in the atmosphere.

Problem 1 - Based on the following information, what is the altitude of the ISS by April 2009?

"In January, the altitude was 340 kilometers. By March it has lost 8 kilometers before the Progress-59 supply ship raised its altitude by 5 kilometers. In May, the ISS lost 4 1/2 kilometers and was re-boosted by the Progess-60 supply ship by 5 1/2 kilometers. Again the ISS continued to lose altitude by 5 1/2 kilometers by July when the Progress-61 supply ship raised its orbit by 9 1/2 kilometers. The ISS altitude then fell by 3 kilometers by October when the Soyuz TMA-11 mission re-boosted the station by 5 kilometers. The ISS continued to lose altitude until late December, 2007 when it had lost a total of 8 1/2 kilometers since its last re-boost by Soyuz. Since December 2007, the total of all the declines and re-boosts added up to a net change of + 11 1/2 kilometers by April 2009. "

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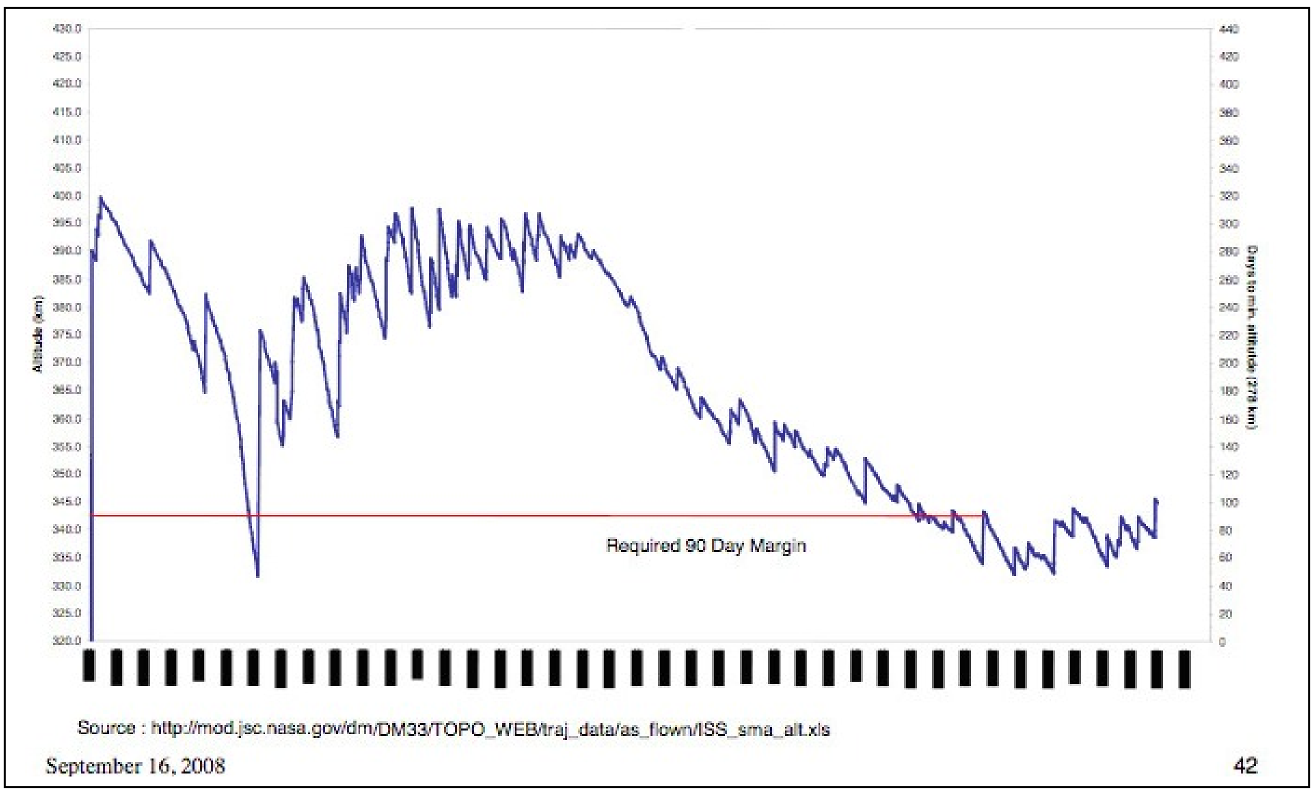
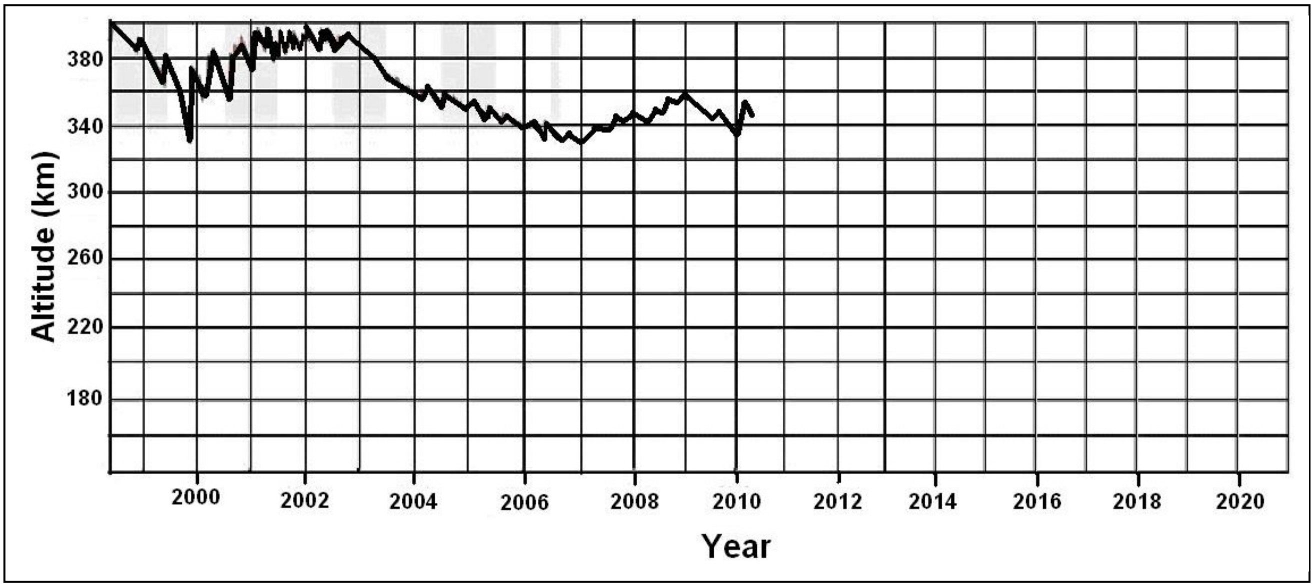
Answer: 340 kilometers - 8 kilometers + 5 kilometers - 4 1/2 kilometers + 5 1/2 kilometers - 5 1/2 kilometers + 9 1/2 kilometers - 3 kilometers + 5 kilometers - 8 1/2 kilometers + 11 1/2 kilometers = 347 kilometers.

Note to Teacher: The figure below shows the altitude changes between November 1998 and July 2008.



The International Space Station - Follow that graph!

At the present time, the International Space Station is losing about 300 feet (90 meters) of altitude every day. Its current altitude is about 345 km after a 7.0-km re-boost by the Automated Transfer Vehicle, Jules Vern spacecraft on June 20, 2008. The graph below shows the ISS altitude since 1999.



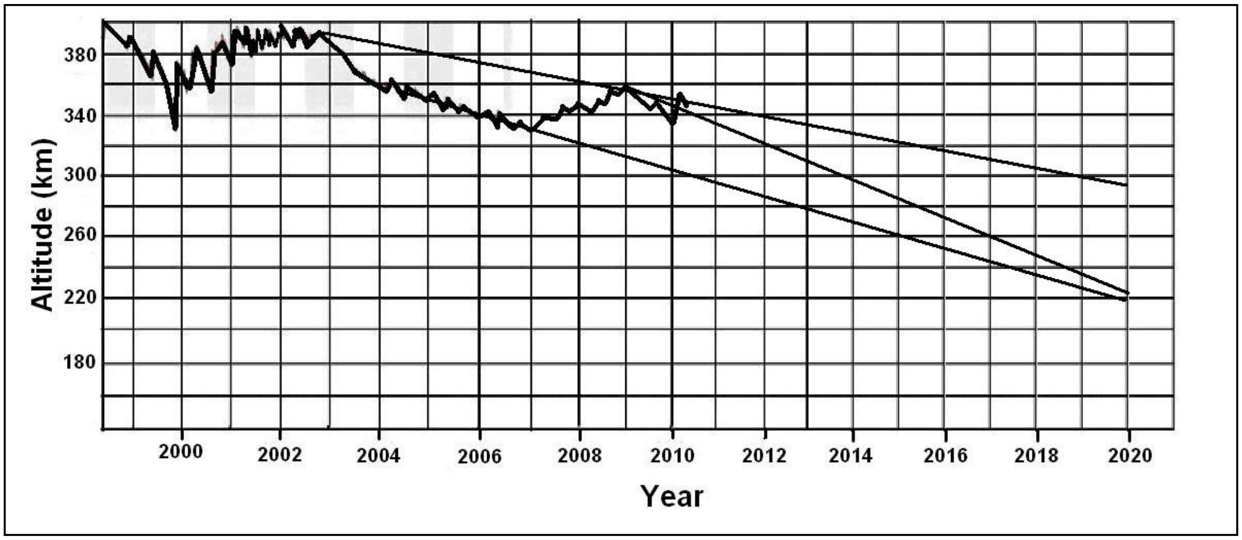
The drag of Earth's atmosphere causes the ISS altitude to decrease each day, and this is accelerated during sunspot maximum (between 2000-2001) when the dense atmosphere extends to a much higher altitude. At altitudes below about 200 km, spacecraft orbits decay and burn up within a week.

Problem 1 - From the present trends, what do you expect the altitude of the ISS to be between 2010 until its retirement year around 2020?

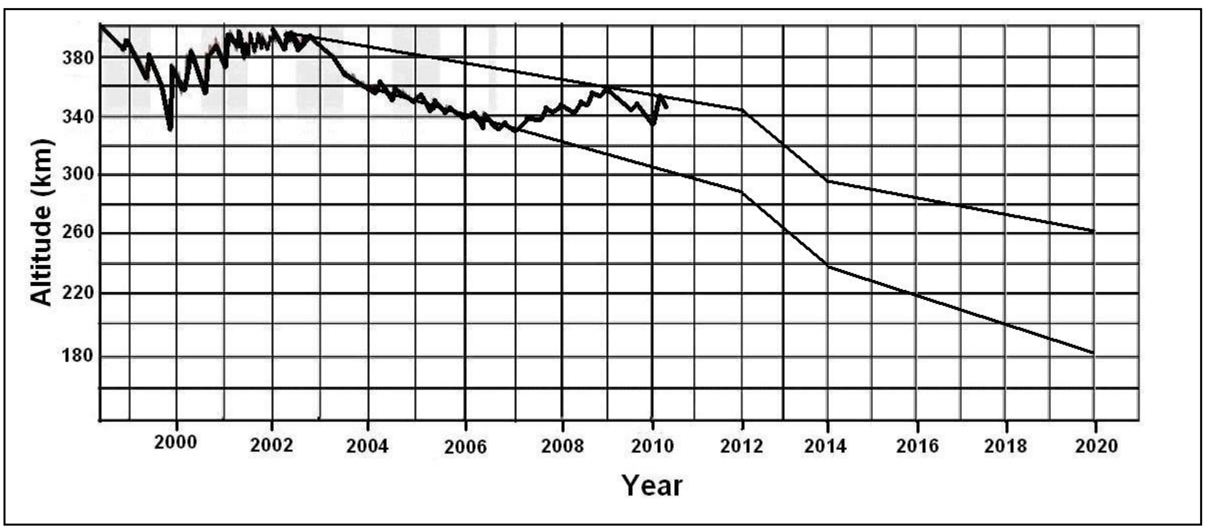
Problem 2 - Sunspot maximum will occur between 2012-2014, and we might expect a 50-km decline in altitude during this period if the solar activity weaker than the peak in 2000, which is currently forecasted. Including this effect, what might be the altitude of the ISS in 2020? Is the ISS in danger of atmospheric burn-up?

Problem 3 - What are the uncertainties in predicting ISS re-entry, and what strategy would you use if you were the Program Manager for the ISS?

Problem 1 – **Answer: The graph below shows several plausible linear trends depending on which features you use as a model for the slope. The predicted altitude would be between 220 and 300 km** .



Problem 2 - The graph below shows, for example, two forecasts that follow the extremes of the general decline trend, but then assume all of the altitude loss occurred between 2012-2014 at 50 km. Note that the range of altitudes in the graph in either case is 180-260 km. This places the ISS in danger of burn-up before its retirement year in 2014.

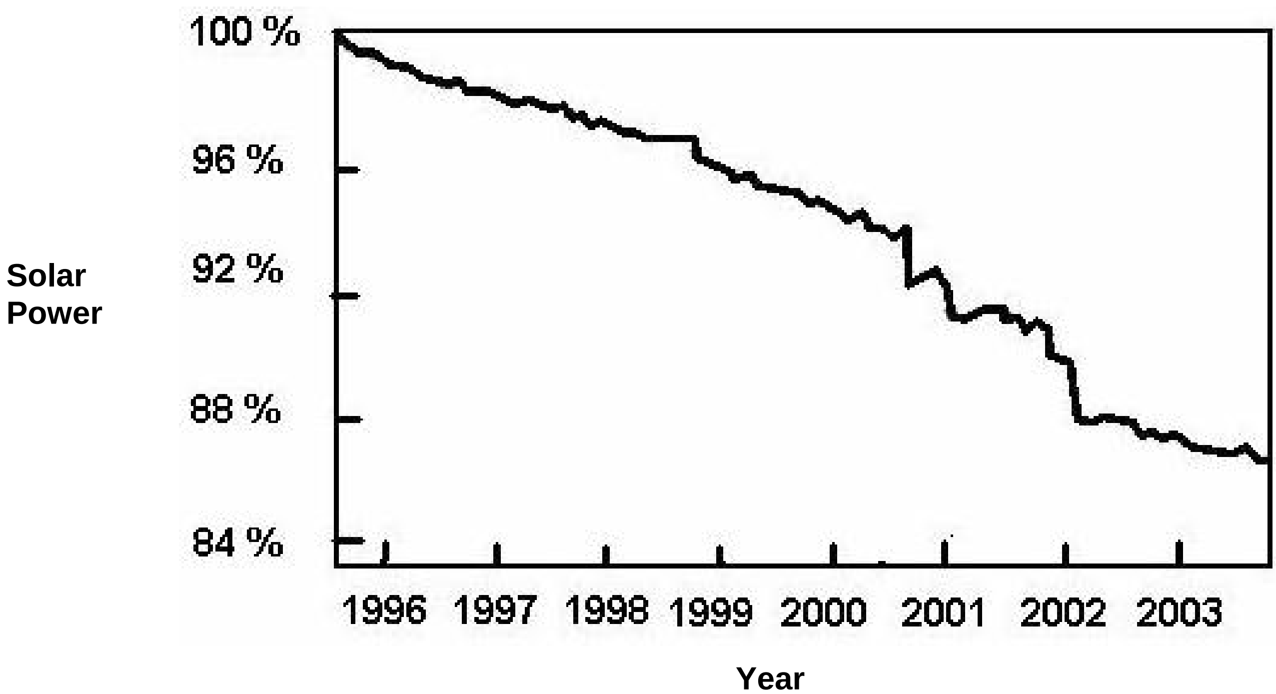


Problem 3 - The largest uncertainty is the strength of the next solar activity (sunspot) cycle. If it is stronger than the previous maximum between 2000-2001, the ISS altitude losses will be even larger in 2012-2014, and the ISS will be in extreme danger of re-entry before 2020.

The period after 2010, when the US losses access to space travel and has to rely on Russian low-capacity shuttles, will be a critical time for the ISS, and an intensely worrisome one for ISS managers.

Solar Activity and Satellite Power Declines

Soon after the first satellites were placed into orbit, engineers began to notice that the electrial power produced by solar panels to operate the satellites was slowly declining. Very careful studies of the way that solar cells worked in space soon came up with a culprit: Cosmic rays! Cosmic rays are very high-speed ions, protons and electrons that travel through space. Some are produced by the sun during solar flares, while others come from space beyond the solar systems itself. Cosmic rays are deflected by strong magnetic fields. Fortunately, Earth has a very strong magnetic field that shields us from most of these cosmic rays, but enough get through that they collide with solar panels and solar cells on satellites orbiting Earth. Over time, these fast-moving particles cause changes in solar cells, making them less able to generate the electricity they are supposed to when sunlight falls on them. Thanks to decades of study, engineers can make very accurate models of these cosmic rays effects and incorporate them into the design of satellite power systems. Below is an actual graph prepared by Dr. Paul Brekke, the Project Scientist for the Solar Heliospheric Observatory. It shows how fast the satellite's solar arrays have changed their power output since 1995.

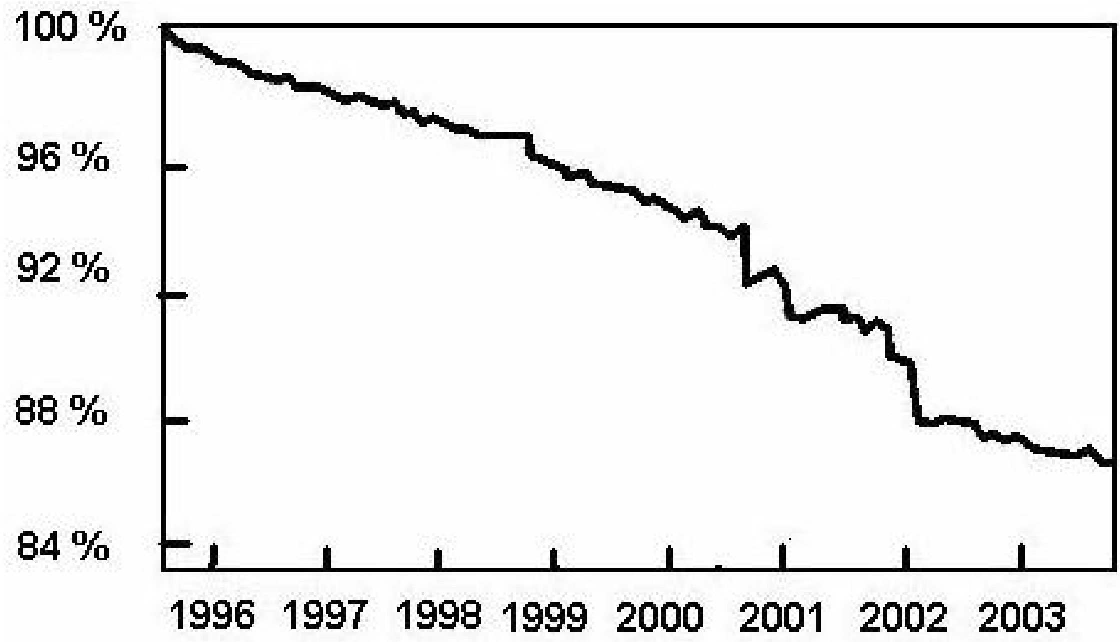


Question 1: By how much has the SOHO satellite power declined by 2002?

Question 2: Satellites often remain usable for 15 years. By what percentage will the electricity from the SOHO solar panels have declined by that time?

Question 3: The instruments on a satellite require 850 watts of power to operate. If a scientist wants her instrument to continue working for 15 years, how large should the satellite power supply be at the time of launch?

Question 4: The surface of a satellite has an area of 1000 square centimeters. The solar cells can generate about 0.03 watts per square centimeter. A) What is the total power available to the satellite by covering its surface with solar cells? B) If the satellite is to last 15 years, what is the maximum power that the instruments can draw and still work after 15 years?



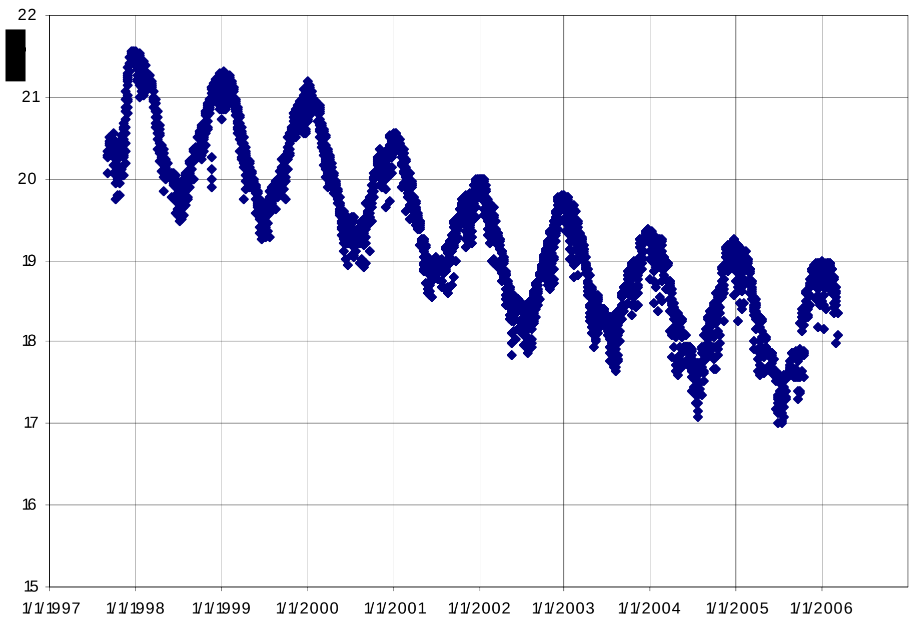
Question 1: By how much has the SOHO satellite power declined by 2002?
Answer: From the plot, the power has declined to 88% of its original 100% at launch.

Question 2: Satellites often remain usable for 15 years. By what percentage will the electricity from the SOHO solar panels have declined by that time? **Answer:** From the previous answer, the decline was 12% in 6 years, so after 15 years the decline will be (15/6) x 12% = 30%.

Question 3: The instruments on a satellite require 850 watts of power to operate. If a scientist wants her instrument to continue working for 15 years, how large should the satellite power supply be at the time of launch? **Answer:** From the previous answer, if the experiments need 850 watts to operate after 15 years, the solar panels have to be designed to produce 30% more than 850 watts at the start of the mission or (1.30) x 850 watts = 1105 watts.

Question 4: The surface of a satellite has an area of 1000 square centimeters. The solar cells can generate about 0.03 watts per square centimeter. A) What is the total power available to the satellite by covering its surface with solar cells? B) If the satellite is to last 15 years, what is the maximum power that the instruments can draw and still work after 15 years?
Answer:
A) The total power will be 3000 square cm x 0.03 watts per square cm = 90 watts.
B) Because the solar panels will degrade by 30% during the 15 years, this means that after 15 years you will only have 90 watts x 0.70 = 63 watts to run your instruments!!
Scientists typically take advantage of the surplus of energy at the start of a mission to run the most energy-consuming instruments, then shut them down one at a time until the satellite finally stops being a useful scientific instrument.

Satellite Power Loss - ACE



The Advanced Composition Explorer (ACE) satellite is located at the 'L1' point in the Earth-Sun system, which is located 1.5 million kilometers from Earth along a line that connects the center of the sun with the center of Earth. From this vantage point, it has an unobstructed, stable view of the sun, and the conditions in interplanetary space far from Earth's messy environment.

From this location, outside Earth's protective magnetic field, it receives a steady rain of high-energy 'cosmic ray' particles that strike the satellite's solar panels and cause a steady loss of electrical power over time as the solar panels are eroded by the nuclear impacts.

The graph above shows decline in solar panel current between September 1998 and February 2006. The periodic 'ups and down' cycle is caused by the seasonal changes in the orientation of the solar panels relative to the sun, since the satellite orbits in the orbital plane of Earth.

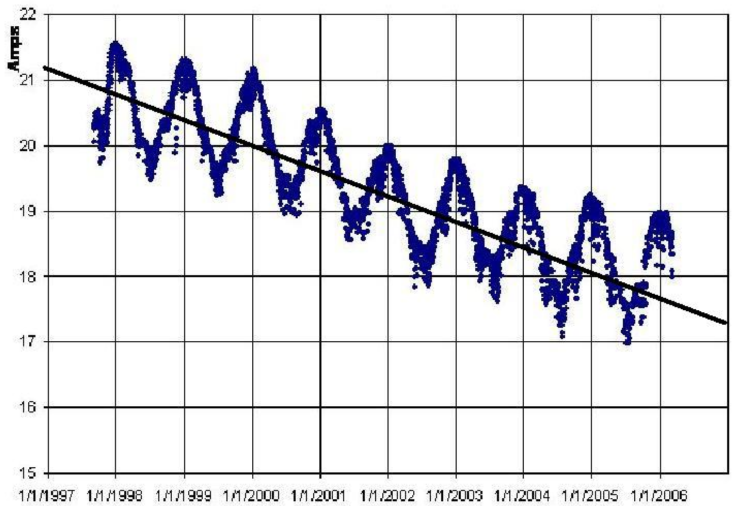
Problem 1 - Draw a line through the cycles that passes half-way between each of the maxima and minima of the curve.

Problem 2 - What is the slope of this line in Amperes/year?

Problem 3 - What is the percent change in the solar power in percent/year?

Problem 4 - What is the amperage of the solar panels by 1/1/2010?

Problem 1 - Draw a line through the cycles that passes half-way between each of the maxima and minima of the curve. Answer: **See below.**



Problem 2 - What is the slope of this line in Amperes/year?
Answer: Slope = (y2 - Y1) / (x2 - x1). Each horizontal division is 1 year so x2 - x1 = 10 years. The vertical change is from y1 = 21.1 to y2 = 17.3 or y2-y1 = -3.8 Amperes, so the slope is M = - 3.8/10 = **-0.38 amperes/year**.

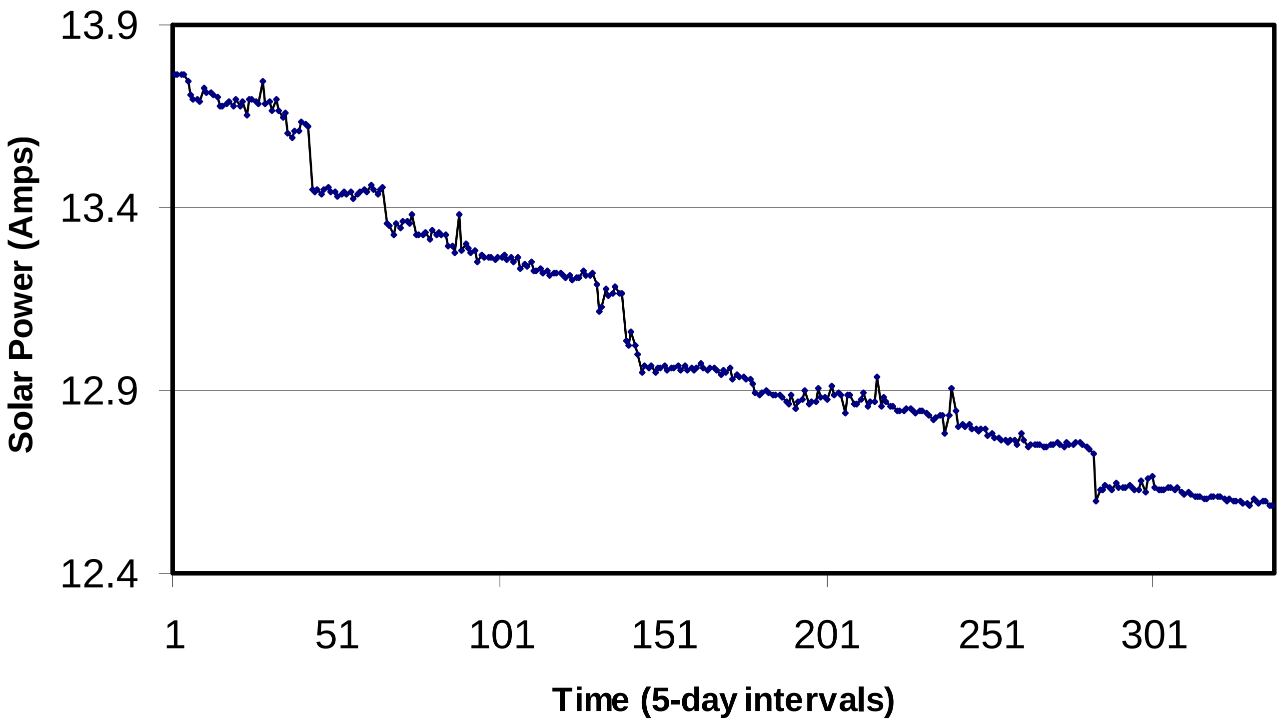
Problem 3 - What is the percent change in the solar power in percent/year?

Answer: Selecting the average value of the amperage over this time interval we have A = (17.3 + 21.1)/2 = 19.2 Amperes. Then the percent change is just
P = 100% x (-0.38/19.2) or **P = -2.0% / year**.

Problem 4 - What is the amperage of the solar panels by 1/1/2010?

Answer: The date 1/1/2010 is 13 years from the start of the data in the graph for which A = 21 amperes, so after 13 years it will be A = 21.0 - 0.38 (13) or **A = 16.1 amperes.**

Satellite Power Loss - WIND



The WIND satellite follows a complex orbit that takes it inside and outside Earth's magnetic field in order to obtain gas and magnetic field measurements on the solar wind and observe radio waves in the near-Earth environment. The graph above shows decline in solar panel current between its launch date on November 1, 1994 and July 6, 2006.

Problem 1 - What is the average slope of this amperage curve in amperes/year?

Problem 2 - What is the percent change in the solar power in percent/year?

Problem 3 - What is the amperage of the solar panels by 11/1/2010?

Problem 1 - What is the average slope of this amperage curve in amperes/year?

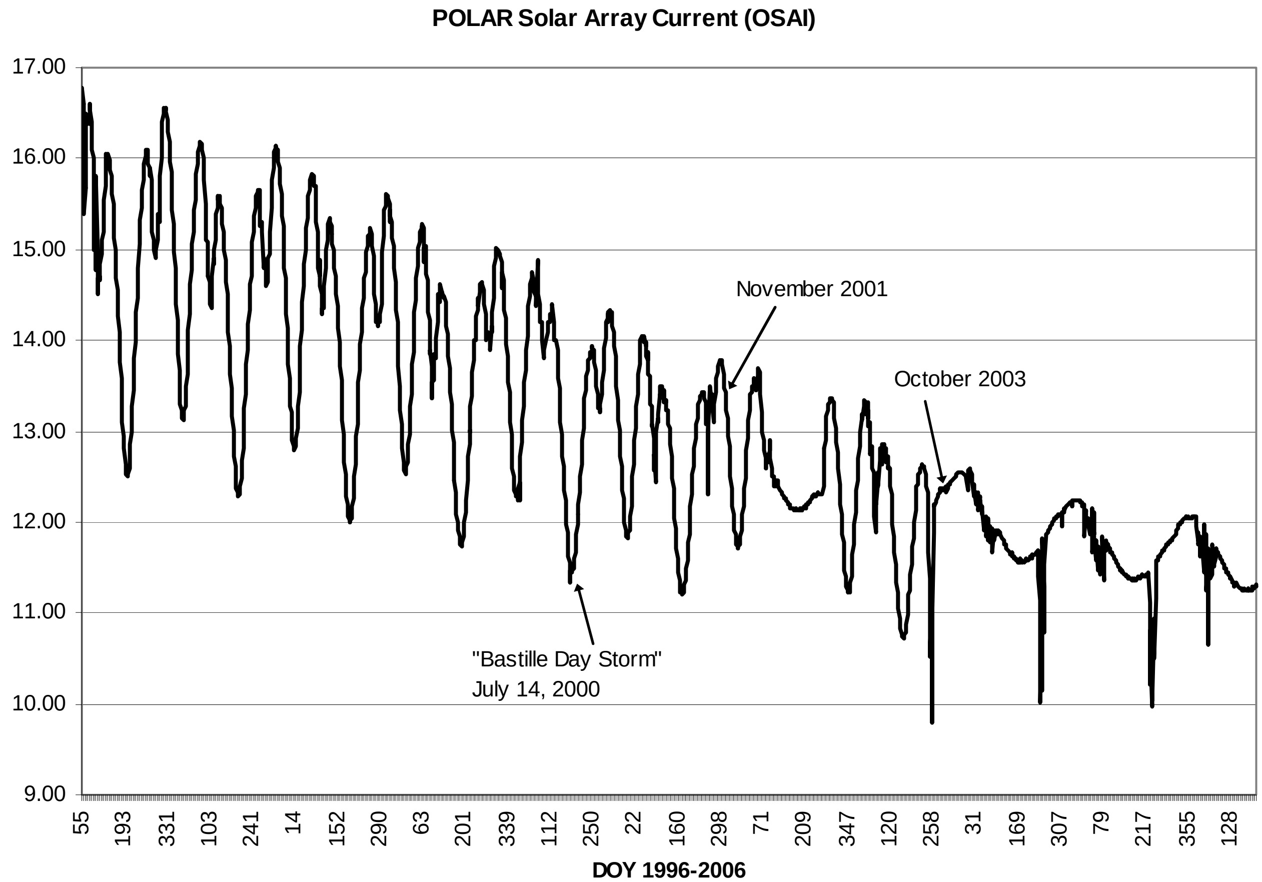
Answer: Slope = (y2 - y1) / (x2 - x1). For reasonable choices of the points (x1,y1) and (x2, y2) as for instance (1, 13.8) and (301,12.6). Next, the tie scale says that the intervals are in multiples of 5 days, so we get the points (5,13.8) and (1505,12.60 in units of days and amperes. Then the slope is just m = (12.6 - 13.8)/(1505 - 5)
M = -1.2/1500 and so, m = -0.0008 amperes/day. Converting this into amperes/year we get **m = -0.29 amperes/year**.

Problem 2 - What is the percent change in the solar power in percent/year?
Answer: The average amperage during this time is just (12.6 + 13.8)/2 = 13.2 amperes, so the average rate of change of the amperage is just P = 100% x (-0.29/13.2) so **P = -2.2%/year**.

Problem 3 - What is the amperage of the solar panels by 11/1/2010?

Answer: The number of years since 11/1/1994 is just 16, so the current loss from the aging panels is just A = 13.8 - 0.29 x 16 so **A = 9.2 amperes.**

Satellite Power Loss - Polar



The Polar satellite, launched on February 24, 1996 is located in a highly elliptical orbit that spends most of its time inside Earth's protective magnetic field (called the magnetosphere). The graph above shows the electrical current decline from the solar panels between February 24, 1996 ('55' on the horizontal axis) and May 8, 2006 ('128').

Problem 1 - What is the average slope of this amperage curve in Amperes/year?

Problem 2 - What is the percent change in the solar power in percent/year?

Problem 3 - What is the amperage of the solar panels by 1/1/2010?

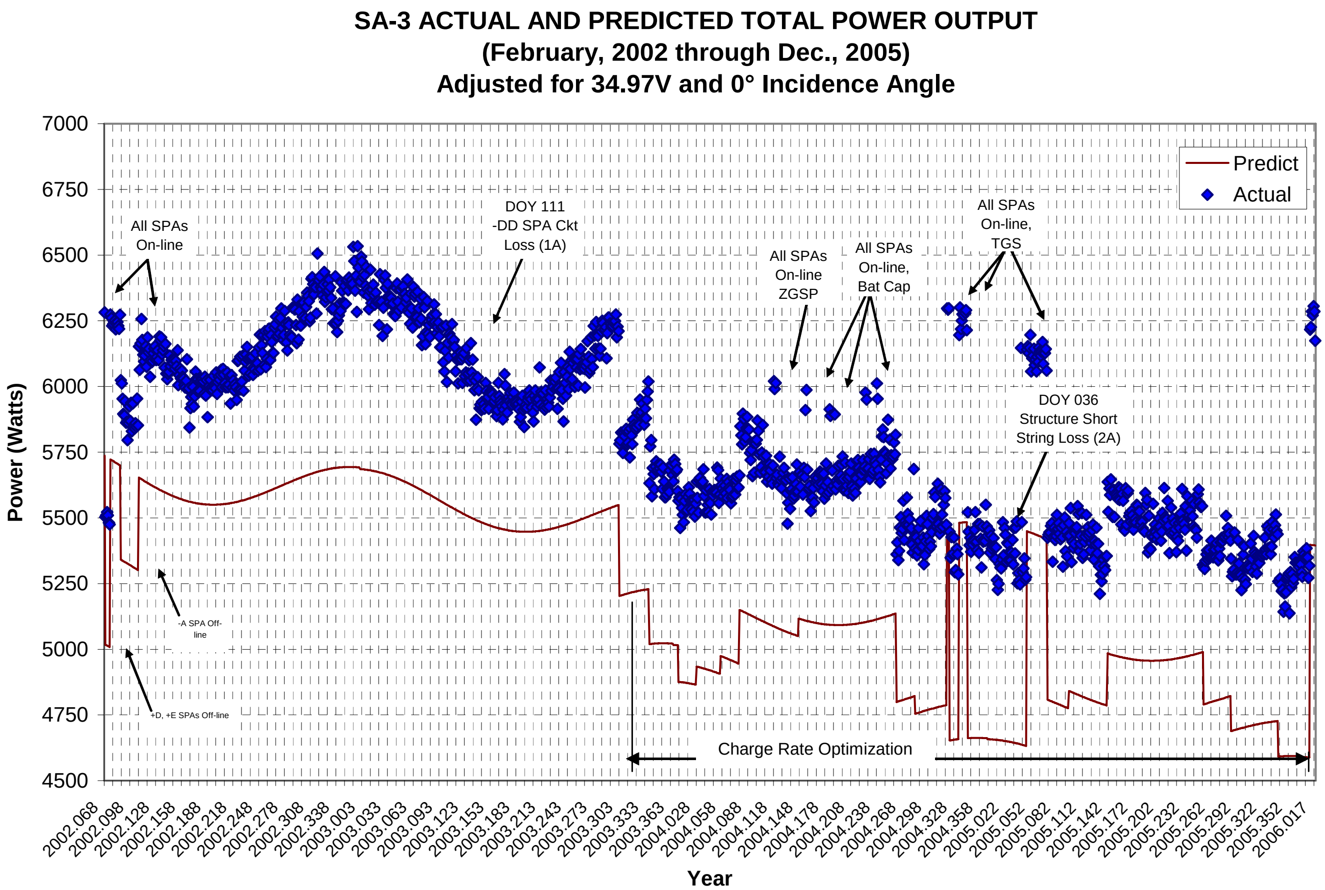
Problem 1 - What is the average slope of this amperage curve in Amperes/year?

Answer: Slope = (y2 - y1) / (x2 - x1). For reasonable choices of the points (x1,y1) and (x2, y2) as for instance (2/24/1996, 16.0) on the far-left and (5/8/2006,11.3). Next, we have to calculate the number of years between the given dates. This is about 2006.35-1996.15 or 10.2 years. Then the slope is just m = (11.3 - 16.0)/(10.2)
And so **m = -0.46 amperes/year**.

Problem 2 - What is the percent change in the solar power in percent/year?
Answer: The average amperage during this time is just (11.3 + 16.0)/2 = 13.7 amperes, so the average rate of change of the amperage is just P = 100% x (-0.46/13.7) so **P = -3.4%/year**.

Problem 3 - What is the amperage of the solar panels by 1/1/2010?

Answer: The number of years since 2/24/1996 is just 13.8, so the current loss from the aging panels is just A = 16.0 - 0.46 x 13.8 so **A = 9.7 amperes.**



The Hubble Space Telescope is located in a low-Earth orbit at an altitude of about 370 kilometers, with an orbit period of about 90 minutes. The constant impact of high-energy particles on the solar panels causes a steady decrease in the power output of these panels over time as the trend in the graph shows.

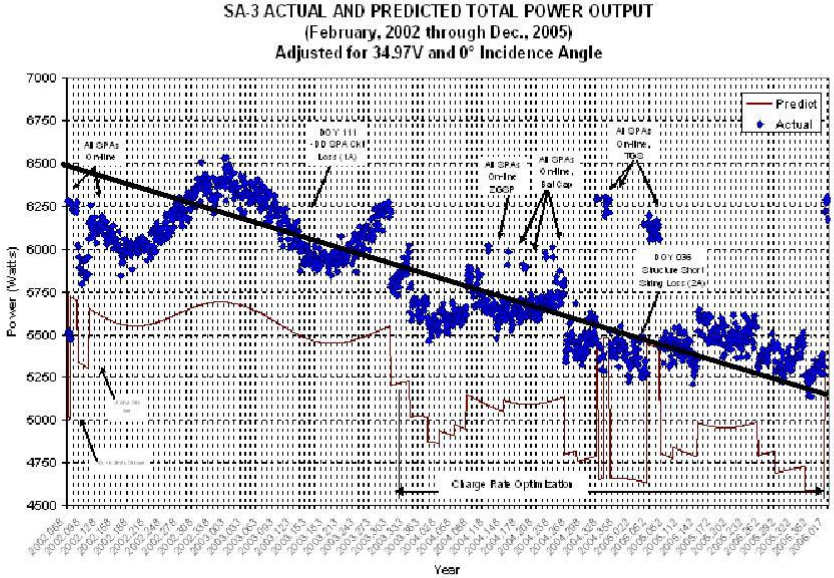
Problem 1 - Draw a line that passes through the middle of this curve from left to right.

Problem 2 - What is the average slope of this solar power curve in watts/year?

Problem 3 - What is the percent change in the solar power in percent/year?

Problem 4 - What is the wattage of the solar panels by 1/1/2015?

Problem 1 - Draw a line that passes through the middle of this curve from left to right.



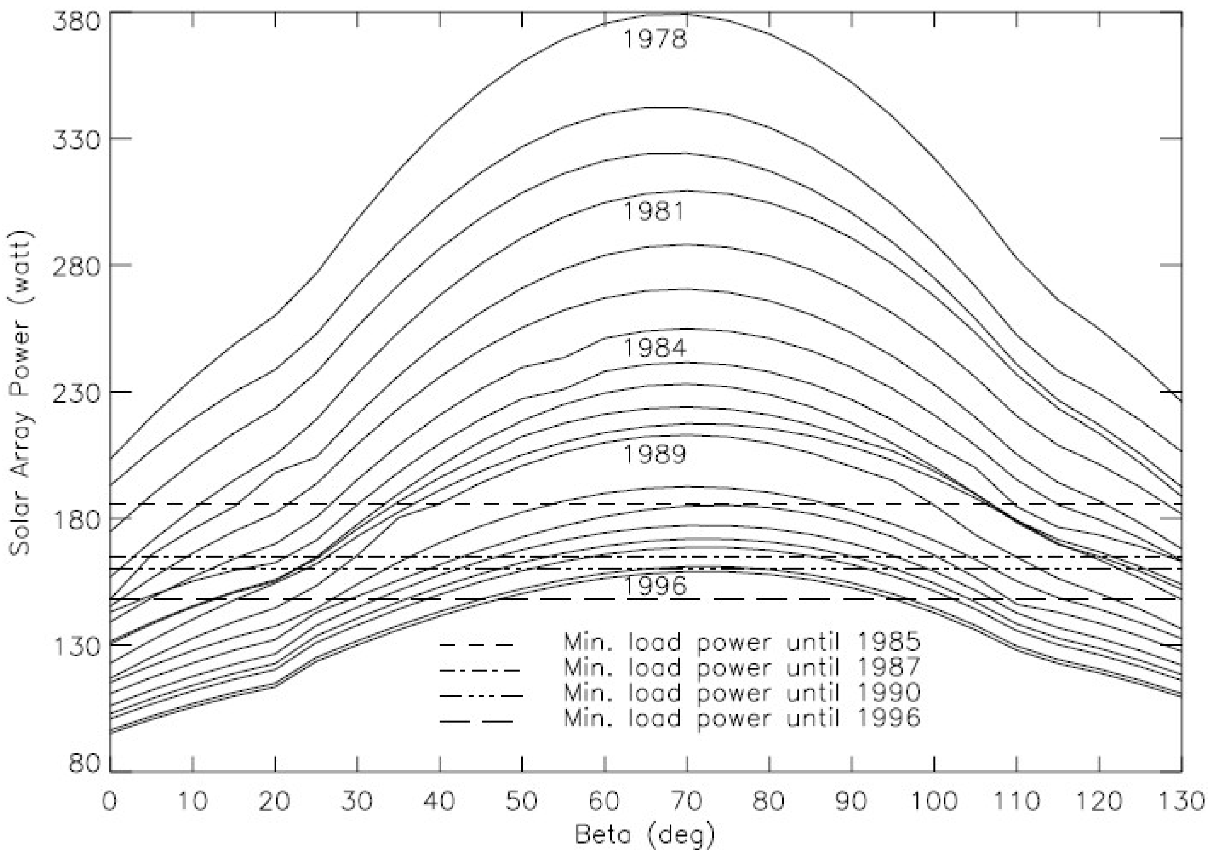
Problem 2 - What is the average slope of this solar panel power curve in watts/year?

Answer: Slope = (y2 - y1) / (x2 - x1). For reasonable choices of the points (x1,y1) and (x2, y2) as for instance (2002.068, 6500) on the far-left and (2006.017,5250). Next, we have to calculate the number of years between the given dates. This is about 2006.017-2002.068 or 3.9 years. Then the slope is just m = (5250-6500)/(3.9)
And so **m = -320 watts/year**.

Problem 3 - What is the percent change in the solar power in percent/year?
Answer: The average amperage during this time is just (6500+5250)/2 = 5875 watts, so the average rate of change of the power is just P = 100% x (-320/5875)
so **P = -5.4%/year**.

Problem 4 - What is the wattage of the solar panels by 11/1/2015?

Answer: The number of years since 2002.068 is just 12.9 years, so the power loss from the aging panels is just A = 6500 - 320 x 12.9 so **A = 2,372 watts.**



The International Ultraviolet Explorer (IUE) satellite was located in a geosynchronous Earth orbit within the outer magnetosphere. From 'geosynchronous orbit' at a distance of 42,164 km from the center of Earth, it was permanently located at the same equatorial longitude of Earth as Earth rotated once each 24-hours.

The above power curves were published in "IUE Spacecraft Operations:Final Report (ESA, 1997, SP-1215) and show the amount of power produced by the solar panels in terms of the orientation angle with respect to the sun (Beta).

Problem 1 - By how much did the maximum solar array power change between 1978 and 1996?

Problem 2 - What is the average slope of this power decline in watts/year?

Problem 3 - What is the percent change in the solar power in percent/year?

Problem 4 - Had the mission continued 5 more years beyond 1996 what would the wattage of the solar panels have been by the end of that time?

Problem 1 - By how much did the maximum solar array power change between 1978 and 1996? Answer: Over the 18 year span of time, the maximum wattage declined from 380 watts to about 160 watts.

Problem 2 - What is the average slope of this power decline in watts/year?

Answer: Slope = (y2 - y1) / (x2 - x1). Then the slope is just m = (160-380)/(18) so, **m = -12.2 watts/year**.

Problem 3 - What is the percent change in the solar power in percent/year?
Answer: The average amperage during this time is just (380+160)/2 = 270 watts, so the average rate of change of the power is just P = 100% x (-12.2/270)
so **P = -4.5%/year**.

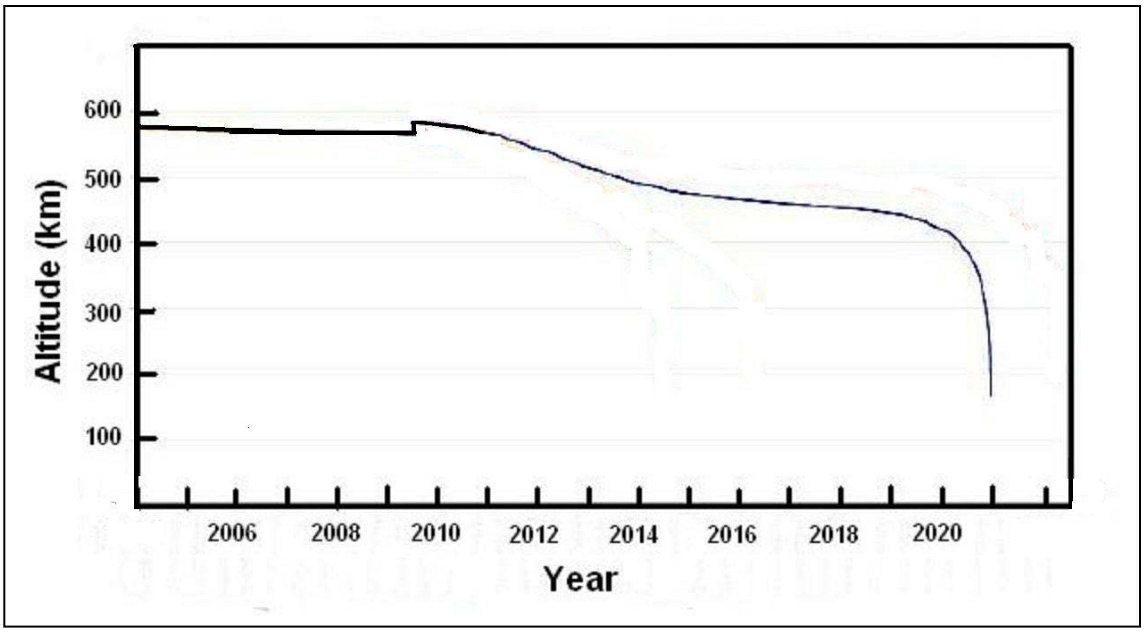
Problem 4 - Had the mission continued 5 more years beyond 1996 what would the wattage of the solar panels have been by the end of that time?

Answer: The number of years since 1978 is just 23, so the power loss from the aging panels was just A = 380 - 12.2 x 23 so **A = 99.4 watts.**

Satellite Drag and the Hubble Space Telescope

The Hubble Space Telescope was never designed to operate forever. What to do with the observatory remains a challenge for NASA once its scientific mission is completed in 2012. Originally, a Space Shuttle was proposed to safely return it to Earth, where it would be given to the National Air and Space Museum in Washington DC. Unfortunately, after the last Servicing Mission, STS-125, in May, 2009, no further Shuttle visits are planned. As solar activity increases, the upper atmosphere heats up and expands, causing greater friction for low-orbiting satellites like HST, and a more rapid re-entry.

The curve below shows the predicted altitude for that last planned re-boost in 2009 of 18-km. NASA plans to use a robotic spacecraft after ca 2015 to allow a controlled re-entry for HST, but if that were not the case, it would re-enter the atmosphere sometime after 2020.



Problem 1 – The last Servicing Mission in 2009 will only extend the science operations by another 5 years. How long after that time will the HST remain in orbit?

Problem 2 – Once HST reaches an altitude of 400 km, with no re-boosts, about how many weeks will remain before the satellite burns up? (Hint: Use a millimeter ruler.)

Problem 1 – The last Servicing Mission in 2009 will only extend the science operations by another 5 years. How long after that time will the HST remain in orbit?

Answer: The Servicing Mission will occur in 2009. The upgrades an gyro repairs will extend the satellite's operations by 5 more years, so if it re-enters after 2020 it will have about 6 years to go before uncontrolled re-entry.

Problem 2 – Once HST reaches an altitude of 400 km, with no re-boosts, about how many weeks will remain before the satellite burns up? (Hint: Use a millimeter ruler.)

Answer: Use a millimeter ruler to determine the scale of the horizontal axis in weeks per millimeter. Mark the point on the curve that corresponds to a vertical value of 400 km. Draw a line to the horizontal axis and measure its distance from 2013 in millimeters. Convert this to weeks using the scale factor you calculated. The answer should be about 50 weeks.

"HST science lifetime could potentially be limited by HST spacecraft orbital decay. Long-term orbit decay predictions are developed based on atmospheric models and solar flux predictions. All contributing combinations of solar flux strength and timing are run in order to bound the orbit decay predictions from a best case atmosphere to a worst case ("unkind") atmosphere. The predictions also consider the effects of Space Shuttle re-boost during HST Servicing Missions. The figure shows the model results for a worst case, 2-sigma high solar cycle (Cycle 24), followed by an early Cycle 25 of average intensity. Figure 3 depicts four curves for various shuttle re-boost scenarios. For the case of no further HST re-boost in any future servicing mission, the prediction is that HST will reenter the Earth's atmosphere in late 2013 or early 2014. The HST science program will cease approximately one year prior to re-entry due to loss of the precise attitude control capability required for science observing, as the atmospheric drag increases. The earliest expected end of the HST science program due to orbital decay is thus late 2012. Further information about this topic is contained in the accompanying Hubble Fact Sheet, entitled "HST Orbit Decay and Shuttle Re-boost." [From 'Expected HST Science Lifetime after SM4", HST Program Office; July 21, 2003]

The Hubble Space Telescope Re-entry

Because of friction with Earth's atmosphere, satellites in Low Earth Orbit below 600 kilometers, experience a gradual loss of orbit altitude over time. The lower the orbit, the higher is the rate of altitude loss, and it can be approximated by the formula:

$$T(h) = 0.012De^{0.025(h-150)}$$

where h is the altitude of the orbit in kilometers above Earth's surface, and T(h) is in days until re-entry. The variable, D, is called the ballistic coefficient and is a measure of how massive the satellite is compared to the surface area facing its direction of motion (in kilograms/meter^2).

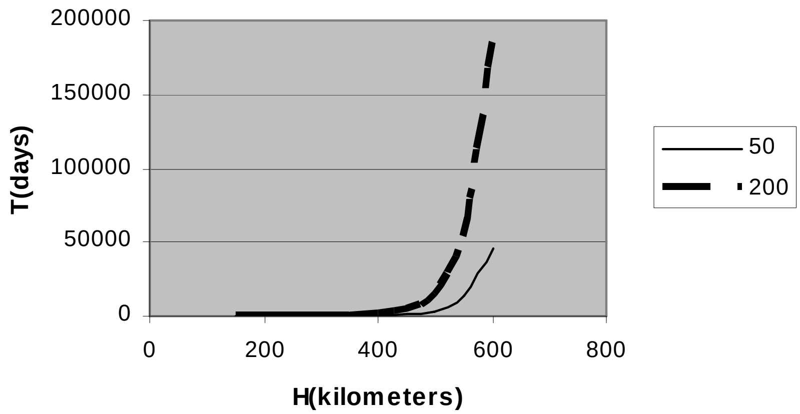
Problem 1 - Graph this exponential function for a domain of satellite orbits given by 150 kilometers $<$ h $<$ 600 kilometers for D = 50 kg/m^2 and D = 200 kg/m^2.

Problem 2 - Graph this function for the same domain and values for D as a log-linear plot: h vs log(T).

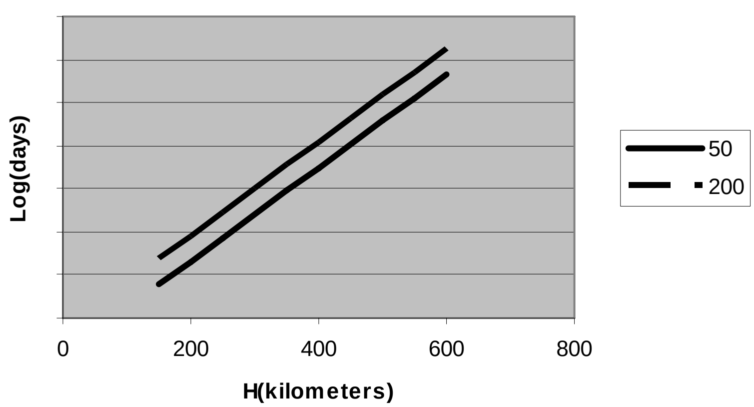
Problem 3 - What is the average slope of the function for D = 100 kg/m^2 within 5 kilometers of an altitude near A) 600 kilometers? B) 150 kilometers? C) How do you physically interpret these two rates?

Problem 4 - Suppose that the Hubble Space Telescope, D=11 kg/m^2, is located in an orbit with an altitude of 575 kilometers following the 're-boost' provided by the Space Shuttle crew during the last Servicing Mission in 2009. The Space Shuttle raised the orbit of HST by 10 kilometers. A) By what year would HST have re-entered had this re-boost not occurred? B) About when will the HST re-enter the atmosphere following this Servicing Mission?

Problem 1 - Graph this exponential function for a domain of satellite orbits given by 150 kilometers < h < 600 kilometers for D = 50 kg/m^2 and D = 200 kg/m^2 .



Problem 2 - Graph this function for the same domain and values for D as a log-linear plot: h vs log(T).



Problem 3 - Answer A) m = [T(605)-T(595)]/(605 - 595) so **m(600)= 2,312 days/km**.
B) m = [T(155)-T(145)]/(155 - 145) so **m(150)= 0.03 days/km**.
C) This means that at an altitude of 600 kilometers, increasing the altitude of the satellite by 1 kilometer means that the satellite re-enters 2,312 days (6.3 years later). At an altitude of 150 kilometers, you only gain an additional 0.03 days (43 minutes!) with the same orbit increase. This means that re-boosting a satellite when it is in the higher orbit makes a HUGE difference in the lifetime of the satellite.

Problem 4 - Answer: A) Before the re-boost, the altitude was 575 - 10 km = 565 km, in 2009, so T = 0.012(11)e(0.025 (565-150)) = 4,230 days or 11 years from 2009 so the reentry would have occurred **around 2020**. B) After the re-boost, the altitude was 575 km in 2009, so T = 0.012(11)e(0.025 (575-150)) = 5,432 days or 15 years from 2009 so the reentry occurs around **2024**.

Sunspots and Satellite Re-entry

Satellite technology is everywhere! Right now, there are over 1587 working satellites orbiting Earth. They represent over $160 billion in assets to the world's economy. In the United States alone, satellites and the many services they provide produce over $225 billion every year. But satellites do not work forever. Typically they have to be replaced every 10 to 15 years as new services are created, and better technology is developed. Satellites in the lowest orbits, called Low Earth Orbit (LEO) orbit between 300 to 1000 kilometers above the ground. Because Earth's atmosphere extends hundreds of kilometers into space, LEO satellites eventually experience enough frictional drag from the atmosphere that at altitudes below 300 km, they fall back to Earth and burn up. The table below gives the number of LEO satellites that re-entered Earth's atmosphere, and the average sunspot number, for each year since 1969.

Year	Sunspots	Satellites
2004	43	19
2003	66	31
2002	109	38
2001	123	41
2000	124	37
1999	96	25
1998	62	30
1997	20	21
1996	8	22
1995	18	20
1994	31	17
1993	54	28
1992	93	41
1991	144	40
1990	145	30
1989	162	45
1988	101	33
1987	29	13
1986	11	16
1985	16	17
1984	43	14
1983	65	28
1982	115	19
1981	146	32
1980	149	41
1979	145	42
1978	87	33
1977	26	18
1976	12	16
1975	14	15
1974	32	21
1973	37	14
1972	67	12
1971	66	19
1970	107	25
1969	105	26

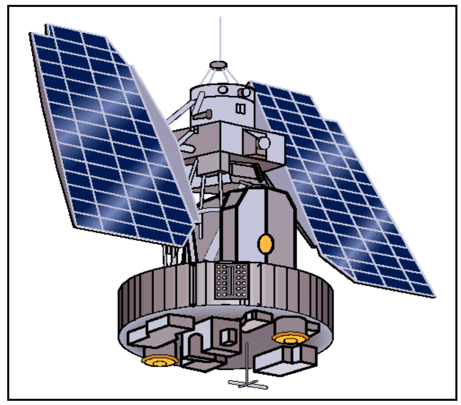


Figure: A typical weather satellite

Problem 1: On the same graph, plot the number of sunspots and decayed satellites (vertical axis) for each year (horizontal axis). During what years did the peaks in the sunspots occur?

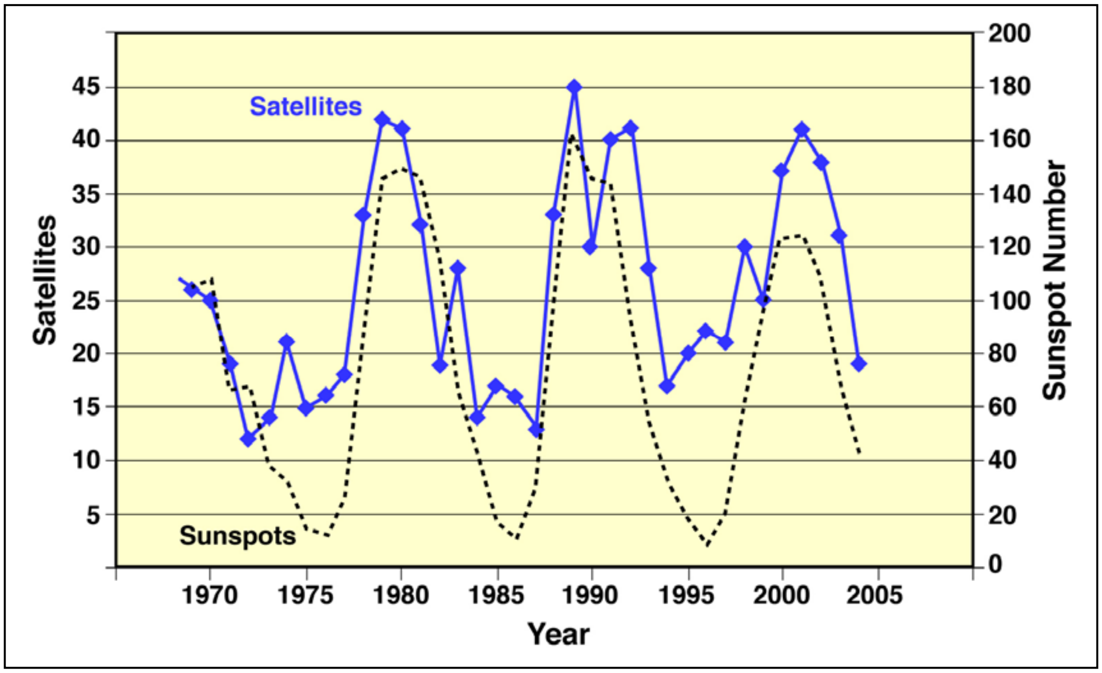
Problem 2: When did the peaks in the satellite re-entries occur?

Problem 3: Is there a correlation between the two sets of data?

Problem 4: If you are a satellite operator, should you be concerned about the sunspot cycle?

Problem 5: Do some research on the topic of how the sun affects Earth. Can you come up with at least two ways that the sun could affect a satellite's orbit?

Problem 6: Can you list some different ways that you rely on satellites, or satellite technology, during a typical week?



Problem 1: On the same graph, plot the number of sunspots (divided by 4) and decayed satellites for each year. During what years did the peaks in the sunspots occur? **Answer:** From the graph or the table, the 'sunspot maximum' years were 2000, 1989, 1980 and 1970.

Problem 2: When did the peaks in the satellite re-entries occur? **Answer:** The major peaks occurred during the years 2001, 1989, 1979 and 1969.

Problem 3: Is there a correlation between the two sets of data? **Answer:** A scientist analyzing the two plots 'by eye' would be impressed that there were increases in the satellite decays that occurred within a year or so of the sunspot maxima years. This is more easy to see if you subtract the overall 'trend' line which is increasing from about 10 satellites in 1970 to 20 satellites in 2004. What remains is a pretty convincing correlation between sunspots numbers and satellite re-entries.

Problem 4: If you were a satellite operator, should you be concerned about the sunspot cycle? **Answer:** Yes, because for LEO satellites there seems to be a good correlation between satellite re-entries near the times of sunspot maxima.

Problem 5: Do some research on the topic of how the sun affects Earth. Can you come up with at least two ways that the sun could affect a satellite's orbit? **Answer:** The answers may vary, but as a guide, space physicists generally believe that during sunspot maxima, the sun's produces more X-rays and ultraviolet light, which heat Earth's upper atmosphere. This causes the atmosphere to expand into space. LEO satellites then experience more friction with the atmosphere, causing their orbits to decay and eventually causing the satellite to burn-up. There are also more 'solar storms', flares and CMEs during sunspot maximum, than during sunspot minimum. These storms affect satellites in space, causing loss of data or operation, and can also cause electrical blackouts and other power problems.

Problem 6: Can you list some different ways that you rely on satellites, or satellite technology, during a typical week? **Answer:** Satellite TV, ATM banking transactions, credit card purchases, paying for gas at the gas pump, weather forecasts, GPS positions from your automobile, news reports from overseas, airline traffic management, tsunami reports in the Pacific Basin, long distance telephone calls, internet connections to pages overseas.

Cosmic Rays and Satellite Anomalies

Year	SSN	GCR	**R**	Year	SSN	GCR	**R**
1979	155	80	0.1	1992	94	64	0.0
1980	154	76	0	1993	54	96	0.3
1981	140	56	0.7	1994	29	104	0.9
1982	116	72	0.5	1995	17	112	0.8
1983	66	40	0.8	1996	8	116	0.6
1984	45	80	1.8	1997	21	116	0.3
1985	17	88	2.4	1998	64	120	0.2
1986	13	104	2.3	1999	93	104	0.2
1987	29	112	1.2	2000	119	72	0.3
1988	100	96	1.0	2001	110	64	0.3
1989	157	56	0.7	2002	104	72	0.2
1990	142	24	0.5	2003	63	64	0.1
1991	145	40	0.1				

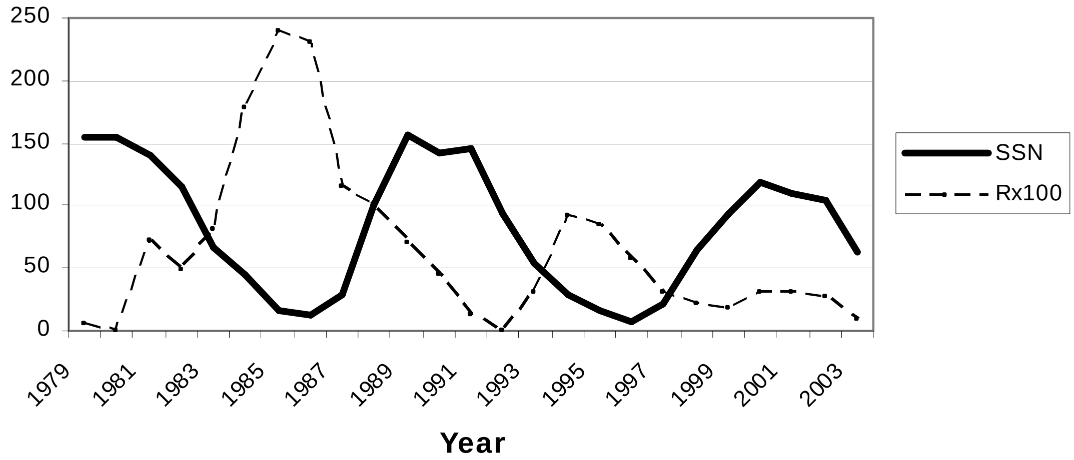
Satellite anomalies are conditions in which a satellite suddenly operates in a way not consistent with its commanded state, or where data has been temporarily corrupted. This can result in operator intervention to correct the problem. It can also cause serious damage to a satellite if the anomaly is too severe.

The table shown above is a summary of the anomaly logs from a collection of satellites published by Drs David Wilkinson and Joseph Allen in 1997. Their survey included 5,033 satellite anomalies that occurred between 1970-1997 and were reported by the operators of 259 satellites. The table summarizes the anomalies reported for 33 of these satellites that were located in geosynchronous orbit during the indicated years. The columns give the average sunspot number for each year (SSN) and the intensity of the cosmic rays detected by satellite instruments (GCR). The column indicated by 'R' is the rate of satellite anomalies for that year in units of anomalies per satellite per year. For example, in 1985 a single satellite would experience about 2 anomalies during that year.

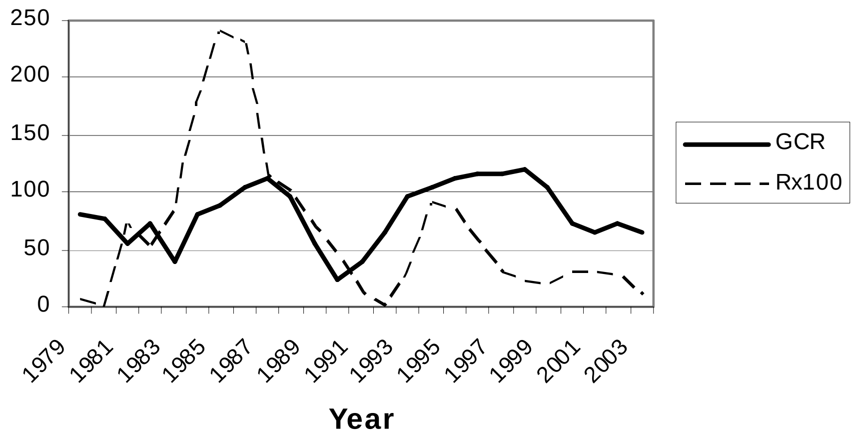
Problem 1 - Graph the quantity R and A) the Cosmic Ray rate, GCR, defined in the table, and B) The sunspot number for each year. (Hint: For convenience, plot 100xR on the same scale as sunspot number).

Problem 2 - From your graphs in Problem 3, does the average number of satellite anomalies each year correlate more closely with the number of sunspots or the cosmic ray rate?

Problem 1 - Graph the quantity R and A) the Cosmic Ray rate, GCR, defined in the table, and B) The sunspot number for each year.
Answer: A) Anomalies with sunspot counts:



B) Anomalies with Cosmic Ray Intensity:



Problem 2 - From your graphs in Problem 3, does the average number of satellite anomalies each year correlate more closely with the number of sunspots or the cosmic ray rate?

Answer: **The correlation appears to be the strongest with cosmic ray intensity because the peaks and valleys line up in time a bit better.**

Satellite Failures and Outages During Cycle 23

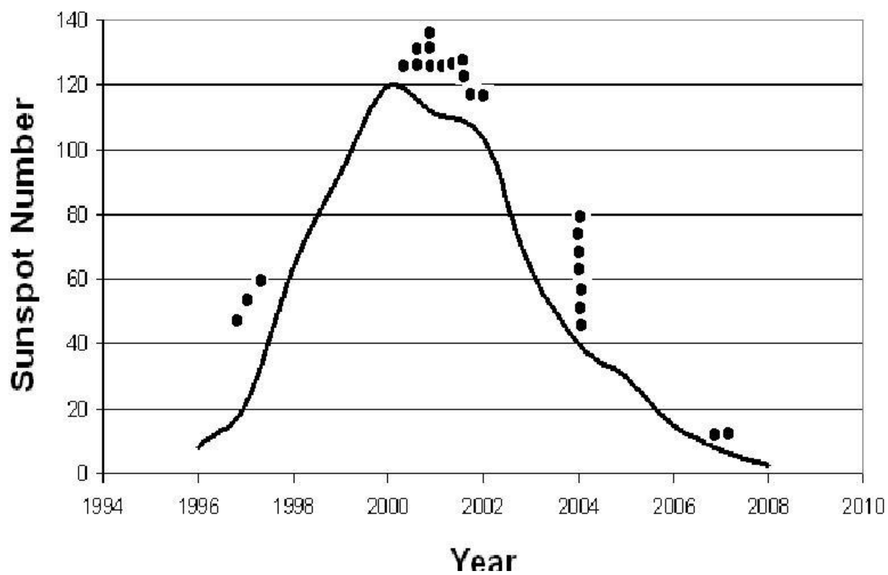
Event Date	AP*	SSN	SPE	Flare	Satellite	Condition
1-11-1997	------	7	---------	--------	Telstar-401	Satellite failure - Pointing/attitude
4-11-1997	------	23	72	--------	Tempo-2	Transponder loss
9-20-1997	46	14	---------	M1.7	Adeos-1	Main computer malfunction - GCR
3-21-2000	------	150	---------	M1.8	Hotbird-2	Loss of service for 9 hours
4-9-2000	137	108	55	M3.1	Brazilsat-A2	Loses TWTA
4-28-2000	------	124	--------	M7.8	Turksat-1C	ESD causes 55-minute service loss
7-15-2000	192	148	24,000	X5.7	GOES-8	Electron sensor problems- power
7-15-2000	192	148	24,000	X5.7	GOES-10	Data corruption
7-15-2000	192	148	24,000	M1.3	ASCA	Satellite Failure and reentry
8-27-2000	45	113	--------	--------	Solidaridad-1	Backup SCP fails
10-31-2000	41	111	---------	M4.4	Echostar-4	26/44 transponders lost
11-4-2000	78	130	---------	-------	Insat-2B	Service outage
9-6-2001	------	141	---------	M2.2	PAS-7	25% power loss
10-23-2001	105	143	24	X1.2	Echostar-6	Solar array string loss announced
12-7-2001	------	138	---------	M1.0	Arabsat-3A	Loss of transponders
10-25-2003	42	88	---------	--------	Adeos-2	Satellite Failure - Solar array malfunction
10-28-2003	252	165	29,500	X17.2	DRTS	Enters Safe Mode
10-28-2003	252	165	29,500	X17.2	FEDSAT	Magnetometer data corrupted
10-28-2003	252	165	29,500	X17.2	GOES-8	X-ray sensor disabled
10-30-2003	252	167	29,500	X10.0	INMARSAT	CPU outages and attitude errors
10-30-2003	252	167	29,500	X10.0	KODAMA	Goes into Safe Mode
10-30-2003	252	167	29,500	X10.0	DMSP F14	One microwave sounder damaged
9-23-2006	-----	8	---------	--------	Meteosat-8	SEU
12-5-2006	120	20	1,980	X9.0	GOES-13	X-ray imager damaged

The table gives a short list of the publicly-admitted satellite failures and outages during sunspot cycle 23 (1996-2008).

Problem 1 - The annual sunspot counts for Cycle 23 between 1996 and 2008 (inclusive) were as follows: [9,21,64,93,120,111,104,64,40,30,15,8,3]. How do the outages compare in time with the sunspot cycle? (Hint: Graph the sunspot cycle and then indicate on the graph when the outages occurred)

Problem 2 - Assuming that this list is complete, what is the probability that a satellite outage/failure will occur during a solar proton event?

Problem 1 - The annual sunspot counts for Cycle 23 between 1996 and 2008 (inclusive) were as follows: [9,21,64,93,120,111,104,64,40,30,15,8,3]. How do the outages compare in time with the sunspot cycle? (Hint: Graph the sunspot cycle and then indicate on the graph when the outages occurred) Answer: **The graph below shows the sunspot cycle (line) and dots representing the approximate dates of the outages. The outages can come at any time in the cycle, but are most common close to the peak of the cycle.**



Problem 2 - Assuming that this list is complete, what is the probability that a satellite outage/failure will occur during a solar proton event?

Answer: The total number of satellite outages is 24, of which 13 were reported during SPE events so the probability is 100% x 13/24 = **54%**.

Airline Travel and Solar Storm Radiation

In 1999, Dr. Sten Odenwald wrote a book called 'The 23rd Cycle: Learning to live with a stormy star" that described all of the ways that severe space weather events, called solar storms, can affect our satellite technology, our electrical power, and even the health of astronauts and airline passengers and crew.

Read the accompanying excerpt from his book, and answer the following questions based on the information in the excerpt.

Question 1: What topic is this part of the book describing?

Question 2: Describe how a solar storm is involved with this topic?

Question 3: What does the article identify as a possible risk for passengers?

Here is a short list of your radiation exposure at ground level each year, in terms of a unit of radiation dosage called the milliRem.

Radon gas in your basement ……………………160 milliRems per year
The ground under your feet……………………… 60
Nuclear reprocessing plants…………………… 40
Cosmic rays at sea level……………………..…… 38
Cosmic rays from high altitude city (Denver)….130
Medical imaging…………………………………. 30
Food and water………………………………….. 25

Question 4: If you add up the different exposures in the list above, what is your total dosage each year if you were living at sea level? Living at high altitudes in Denver?

Question 5: According to the information in the article, how much extra radiation exposure would a passenger receive in a 10-hour flight at 35,000 feet?

Question 6: How much extra radiation will an airline crew member receive during 900 hours per year of flying?

Question 7: Do you think the radiation risk from solar storms is a significant one? Present the evidence that demonstrates the size of the health risk, and the evidence that suggests that the health risk is minimal.

[*Answers provided in the back of the Space Weather Math book*]

Airline Travel and Solar Storms

Jet airliners fly at altitudes above 35,000 feet which is certainly not enough to get them into space, but it is more than enough to subject the pilots and stewardesses to some respectable doses when looked at over the course of their careers, and thousands of flights. A trip on a jet plane is often taken in a party-like atmosphere with passengers confident that, barring any unexpected accidents and food problems, they will return to Earth safely and with no lasting physical affects. But depending on what the Sun is doing, a solar storm can produce enough radiation to equal a significant fraction of a chest X-ray's dosage even at typical passenger altitudes of 35,000 feet. Airline pilots and flight attendants can spend over 900 hours in the air every year, which makes them a very big target for cosmic rays and anything else our Sun feels like adding to this mix. According to a report by the Department of Transportation, the highest dosages occur on international flights passing close to the poles where the Earth's magnetic field concentrates the particles responsible for the dosages.

Although the dosage you receive on a single such flight per year is very small, about one milliRem per hour, frequent fliers that amass over 100,000 miles per year would accumulate nearly 500 millirems each year. Airline crews who spend 900 hours in the air would absorb even higher doses, especially on polar routes. For this population, their lifetime cancer rate would be 23 cancers per 100 people. By comparison, the typical cancer rate for ground dwellers is about 22 cancers per 100. But the impact does not end with the airline crew. The federally recommended limit for pregnant women is 500 millirems per year. Even at these levels, about four extra cases of mental retardation would appear on average per 100,000 women stewardesses if they are exposed between weeks 8 to 15 in the gestation cycle. This is a time when few women realize they are pregnant, and when critical stages in neural system formation are taking place in the fetus.

Matthew H. Finucane, air safety and health director of the Association of Flight Attendants in Washington DC, has claimed that these exposure rates are alarming, and demands that the FAA to do something about it. One solution is to monitor the cabin radiation exposure and establish OSHA guidelines for it. If possible, he also wants to set up a system to warn crews of unusually intense bursts of cosmic radiation, or solar storm activity during a flight. Meanwhile, the European Aviation Agency is contemplating going even further. They want to issue standard dosimetry badges to all airline personnel so that their annual exposures can be rigorously monitored. This is a very provocative step to take, because it could have a rather chilling effect on airline passengers. It might also raise questions at the ticket counter that have never been dealt with before*, 'Excuse me, can you give me a flight from Miami to Stockholm that will give me less than one chest X-ray extra dosage?'* How will the traveler process this new information, given our general nervousness over simple diagnostic X-rays?

Consider this: during September 29, 1989, for example, a powerful X-ray flare caused passengers on high-flying Concord airliners to receive dosages equal to two chest X-rays per hour. At the end of the flight, each passenger had silently received hundreds of additional millirems added to their regular background doses. Still, these occasional dosages the average person receives while flying, compared to the dosages we might accumulate once we land at another geographic location, are rather inconsequential over a lifetime. Compared to the quality of life that we gain in exchange for the minor radiation exposure we risk, most people will grudgingly admit the transaction is a bargain. Statisticians who work with insurance companies often think in terms of the number of days lost to your life expectancy from a variety of causes. On this scale, smoking 20 cigarettes a day costs you 2200 days; being overweight by 15% costs you 730 days; and an additional 300 millirem per year over the natural background dose (about 250 milliRem) reduces your life expectancy by 15 days. "

[Dr. Sten Odenwald, 'The 23rd Cycle' Columbia University Press, 2000]

Hey! Who Turned Out the Lights?

Astronomers were busily tracking "Active Region 5395" on the Sun when suddenly it blasted-out a huge cloud of super-hot gas on March 10, 1989. Three days later, and seemingly unrelated to the solar blow-out, people around the world saw a spectacular, and entertaining, Northern Lights display. The distant solar storm 93 million miles away had silently set in motion a chain of events reaching from the Sun's fiery surface to the skies overhead. Most newspapers that reported this event thought that the spectacular aurora was the most newsworthy aspect of the storm. Seen as far south as Florida and Cuba, the most people in the Northern Hemisphere had never seen the Northern Lights dancing in their evening skies. But this particular explosion of matter and energy did much more than just dazzle and confuse the casual sky watcher as it painted the heavens with shifting colors and shapes.

At 2:45 AM on March 13, electrical currents created by the impact of this storm found their way into the electrical circuitry of the Hydro-Quebec Power Authority. Giant capacitors tried to regulate these currents but failed within a few seconds as automatic protective systems took them off-line one by one. Suddenly, the entire 9,500 megawatt output from Hydro-Quebec's La Grande Hydroelectric Complex began to waver. Power swings tripped the supply lines from the 2,000 megawatt Churchill Falls generation complex, and 18 seconds later, the entire Quebec power grid collapsed. The cascading of events lasted barely 97 seconds. It was much too fast for human operators to react, but it was more than enough time for 21,500 megawatts of badly needed electrical power to suddenly disappear from service.

For nine hours, large portions of Quebec were plunged into darkness. A thousand miles away, even Maryland, Virginia and Pennsylvania were affected as half of the capacitors in the Allegheny Power System went off-line. In many ways, it was a sanitized calamity. It was wrapped in a diversion of beautiful colors, and affected a distant population mostly while they slept. There were no houses torn apart, or streets flooded from powerful hurricanes. There was no dramatic TV News footage of waves crashing against the beach. There were no tornadoes cutting a swath of destruction through Kansas trailer parks.

The calamity passed without mention in the major metropolitan newspapers, yet six million people were affected as they awoke to find no electricity to see them through a cold Quebec wintry night. Some engineers from the major North American power companies were not so calm. They worried how this Quebec blackout could easily have escalated into a $6 billion catastrophe affecting most US East Coast cities. All that prevented 50 million people in the US from joining their Canadian friends in the dark were a few dozen heroic capacitors on the Allegheny Power Network. ***(Excerpted from the book "The 23rd Cycle". Author: Dr. Sten Odenwald)***

Problem 1 - If the solar storm took 3 days to travel 150 million kilometers to Earth, how fast was it traveling in kilometers per hour?

Problem 2 - How much time elapsed between the arrival of the storm at Earth, and the time when the Quebec power system failed?

Problem 3 - How long did the blackout continue?

Problem 4 - What kinds of severe problems could occur in a typical city during a blackout in the daytime? In the nighttime?

Answer Key

Problem 1 - 150 million kilometers / (3 x 24 hrs) = 2.1 million km/hour

Problem 2 - The electrical event began at 2:45 Am and lasted 97 seconds

Problem 3 - The Quebec Blackout lasted nine hours.

Problem 4 - Students may provide, and defend, a variety of answers to this question.

The 1859 Superstorm

On August 28, 1859 a massive solar storm caused spectacular aurora seen all over the globe. It was reported in all the major newspapers, poems were written about it, and famous artists painted its shapes and forms. It also caused severe problems with telegraph networks at the time, which lasted for many hours world-wide. Although scientists gave detailed reports of the changing forms of this vivid display, many ordinary citizens offered their own impressions of this event too. Below are two of these descriptions seen from two different locations.

Galveston, Texas:

August 28 as early as twilight closed, the northern sky was reddish, and at times lighter than other portions of the heavens. At 7:30 PM a few streamers showed themselves. Soon the whole sky from Ursa Major to the zodiac in the east was occupied by the streams or spiral columns that rose from the horizon. Spread over the same extent was an exquisite roseate tint which faded and returned. Stately columns of light reaching up about 45 degrees above the horizon moved westward. There were frequent flashes of lightning along the whole extent of the aurora. At 9:00 PM the whole of the streaking had faded leaving only a sort of twilight over the northern sky."

London, England.

"At 0:15 AM on August 28th the auroral light in the north assumed the form of a luminous arch, similar to daybreak, and in the southwest there was an intense glare of red covering a very large extent of the sky. At 00:20 AM streamers appeared; at 00:25 AM the streamers rose to the zenith and were tinged with crimson at their summits. At 00:45 AM frequent coruscations appeared in the aurora. At 01:20 AM the arch which had partially faded began to reform and the body of the light was very strong but not bright enough to read newspaper print. At 1:30 AM the light had begun to fade. By 2:00 AM the aurora was very indistinct."

A common problem scientists face when organizing observations from different laces around the world is that observers like to note when things happened by their local time. Scientists simplify these accounts by converting them into Universal Time., which is the local time in Greenwich, England also called Greenwich Mean Time (GMT). To make time calculations easier, UT is expressed in the 24-hour clock format so that 11:00 AM is written as 11:00, but times after noon are written, for example, as 1:00 PM is written as 13:00, and 10:00 PM is written as 22:00. Since London is very close to Greenwich, the times mentioned in the London account above are already in Universal Time and only need to be converted to the 24-hour format. For Galveston, Texas, its time is 5 hours behind UT so that to get the equivalent UT for Galveston, first convert the Galveston times to the 24-hour format, then add 5 hours.

Question 1 - From these two descriptions, can you extract the specific points of each narrative. What are their similarities?

Question 2 - From the sequences of events in each description, can you create a timeline for the aurora display that fits the most details?

Question 3 - Why was the aurora observed to reach closer to zenith in London than in Galveston?

Question 1: From these two descriptions, cam you extract the specific points of each narrative? What are their similarities? **Answer:** Here are the main points in each story with the similarities highlighted.

Story 1:

1. Display began at end of twilight with faint **reddish light in north**.
2. 7:30 PM (00:00 UT) **streamers began to appear**
3. Streamers of spiral columns filled eastern sky
4. Faint rose-colored light covered same eastern sky, fading and returning
5. Columns of light reached **45 degrees to zenith**, and moved westwards
6. Frequent **flashes of light along the whole aurora**
7. 9:00 PM (02:00 UT), the **aurora faded** and left a twilight glow in north.

Story 2:

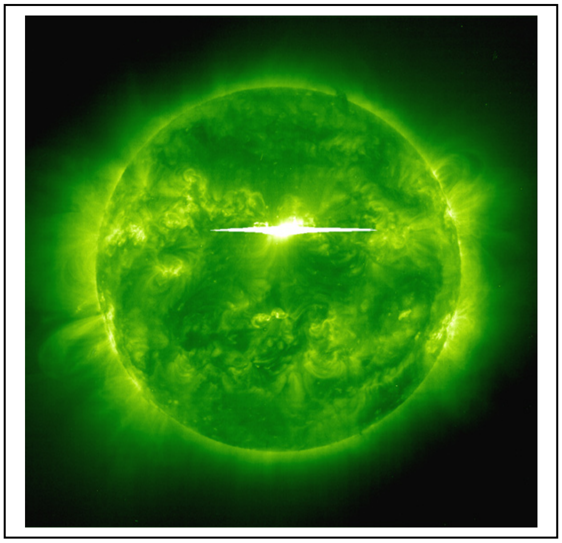
1. 00:15 AM (00:15 UT) - Luminous arch **appeared in northern** sky
2. 00:16 AM (00:16 UT) - Intense glare of red in southwest
3. 00:20 AM (00:20 UT) - **Streamers appeared**
4. 00:25 AM (00:25 UT) - Streamers **reached zenith** and were crimson at highest points
5. 00:45 AM (00:45 UT) - Frequent **coruscations appeared in aurora**
6. 01:20 AM (01:20 UT) - Arch begins to fade and reform
7. 01:30 AM (01:30 UT) - Aurora **begins to fade.**
8. 02:00 AM (02:00 UT) - Aurora very indistinct.

Similarities: Auroral light appeared in northern sky. Streamers appeared soon afterwards. The streamers expanded in the sky until they were nearly overhead from Galveston, and overhead in London. The aurora shapes showed activity in the form of flashes and movement (coruscations). Soon after this active phase, the aurora faded.

Question 2: From the sequences of events in each description, can you create a common timeline for the aurora display that fits the most details?
Answer: Each student might group the events differently because the eyewitness accounts are not detailed enough. Because this aurora is seen in the Northern Hemisphere, it is properly called the Aurora Borealis. Here is one way to organize the timeline:

“The aurora borealis started with a faint wash of reddish light in the north. A brilliant arch of light formed. Five minutes later, streamers began to appear which were crimson at their highest points above the horizon. Then, coruscations (waves) began to appear in the brightening red glow of the aurora with the streamers filling the entire eastern sky. The columns of light and streamers began to move westwards, and frequent flashes of light were seen along the aurora as the luminous arch of began to fade and reform. After an hour and fifteen minutes, the aurora began to fade away, leaving behind a twilight glow that persisted for another half-hour.”

Question 3 - Why was the aurora observed to reach closer to zenith in London than in Galveston? **Answer-** Because the aurora is a polar phenomenon, and London is at a higher latitude than Galveston. That means that the aurora will be seen higher in the northern sky from London than from Galveston.



On July 15, 2001 a solar storm was tracked from the Sun to Earth by a number of research satellites and observatories. This activity lets you perform time and day arithmetic to figure out how long various events lasted. This is a very basic process that scientists go through to study an astronomical phenomenon. The image to the left was taken by the TRACE satellite and shows the x-ray flare on the Sun.

Photo courtesy SOHO/NASA

The Story: On July 14, 2000, NASA's TRACE satellite spotted a major X5.7-class solar flare erupting at 09:41 from Active Region 9077. The flare continued to release energy until 12:31. At 10:18:27, radio astronomers using the Nancay radio telescope detected the start of a radio-frequency Type-I noise storm. This storm strengthened, and at 10:27:27, four moving radio sources appeared. Meanwhile, the satellite, GOES-10 detected the maximum of the x-ray light from this flare at 10:23. The SOHO satellite, located 92 million miles from the Sun, and 1 million miles from Earth, recorded a radiation storm from fast-moving particles, that caused data corruption at 10:41. The SOHO satellite's LASCO imager also detected the launch of a coronal mass ejection (CME) at 10:54. The CME arrived at the satellite at 14:17 on July 15. Then at 14:37 on July 15, the CME shock wave arrived at Earth and compressed Earth's magnetic field. The IMAGE satellite recorded the brightening of the auroral oval starting at 14:25. Aurora were at their brightest at 14:58. The aurora expanded to the lowest latitude at 17:35. By 20:00, Earth's magnetic field has slightly decreased in strength in the equatorial regions. By 16:47 on July 16, the IMAGE satellite recorded the recovery of Earth's magnetosphere to normal conditions. On January 12, 2001, the CME was detected by the Voyager I satellite located 63 AU from the Sun.

Problem 1 - From this information, create a time line of the events mentioned.

Problem 2 – How long did it take for the CME to reach Earth?

Inquiry: What other questions can you explore using this timing information?

Answer Key

Problem 1

July 14,

09:41 - X5.7-class solar flare
10:19 - Radio astronomers detect Type-I radio storm.
10:23 - GOES-10 detected the maximum of the x-ray light from this flare
10:27 - Four moving radio sources appeared on sun.
10:41 - SOHO satellite radiation storm and data corruption.
10:54 - SOHO sees launch of CME

July 15,

14:17 - CME shock wave arrived at Earth
14:25 – IMAGE satellite sees brightening of the auroral oval
14:58 - Aurora at brightest
17:35 – Aurora expand to lowest latitudes
20:00 - Earth's magnetic field has slightly decreased in strength

July 16

16:47 - IMAGE satellite recorded the recovery of Earth's magnetosphere

January 12, 2001, CME detected by Voyager I satellite 63 AU from the Sun.

Problem 2 - The CME was launched on July 14 at 10:54 and arrived at Earth on July 15 at 14:17. The elapsed time is 1 full day (24 hours) and the difference between 10:54 and 14:17 which is 14:17 – 10:54 = 13:77 – 10:54 = 3hours and 77-54 = 23 minutes. The total elapsed time is then 24h + 3h 23m = 27hours 23minutes.

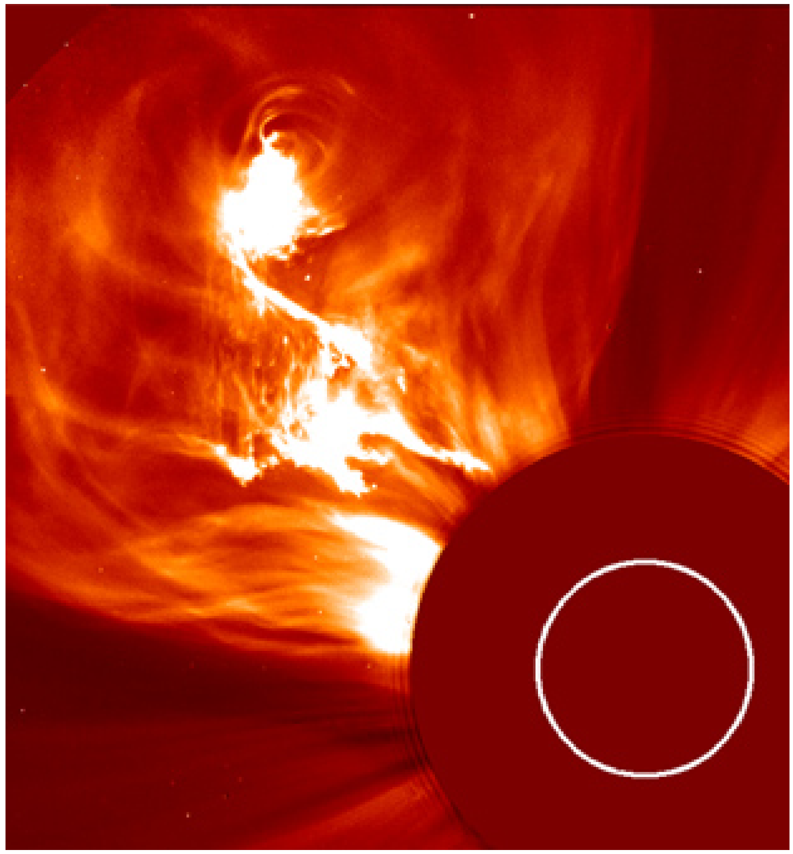
Inquiry – There are many possibilities, for example, how long did it take for the CME to reach Voyager in days? Hours? What was the speed of the CME as it traveled to Earth? How long after the flare did SOHO experience a radiation storm?

Solar Storm Timeline - Tabular

The sun is an active star that produces explosions of matter and energy. The space between the planets is filled with invisible clouds of gas that sometimes collide with Earth. Scientists call them Coronal Mass Ejections. They can travel at millions of miles per hour and carry several billion tons of gas called a plasma. When 'CMEs' collide with Earth, they produce the Northern Lights and magnetic storms.

In this exercise, you will examine one of these 'solar storm' events by examining a timeline of events that it caused.

The picture to the right was taken by the SOHO spacecraft showing a spectacular CME. The white circle is the size of the sun.



Solar Storm Timeline

Day	*Time*	*What Happened*
Tuesday	4:50 PM	Gas eruption on Sun
Thursday	3:36 AM	Plasma storm reaches Earth.
Thursday	5:20 AM	Storm at maximum intensity.
Thursday	5:35 AM	Auroral power at maximum.
Thursday	11:29 AM	Aurora power at minimum.
Thursday	2:45 PM	Space conditions normal

1) How much time passed between the solar gas eruption and its detection near Earth?

2) How long after the plasma storm reached Earth did the aurora reach their maximum power?

3) How long did the storm last near Earth from the time the plasma was detected, to the time when space conditions returned to normal?

<u>Extra for Experts!</u>

If the Earth is 150 million kilometers from the sun, how fast did the storm travel from the Sun in kilometers per hour? How long will the trip to Pluto take is Pluto is 40 times farther away from the sun than Earth?

Goal: Students will interpret a timeline table to extract information about a solar storm using time addition and subtraction skills.

Day	*Time*	*What Happened*
Tuesday	**4:50 PM**	**Gas eruption on Sun**
Thursday	**3:36 AM**	**Plasma storm reaches Earth.**
Thursday	**5:20 AM**	**Storm at maximum intensity.**
Thursday	**5:35 AM**	**Auroral power at maximum.**
Thursday	**11:29 AM**	**Aurora power at minimum.**
Thursday	**2:45 PM**	**Space conditions normal**

1) How much time passed between the solar gas eruption and its detection near Earth?
Answer: There are various ways to do this problem. You want to subtract the final time from the initial time so: (Tuesday 4:50 PM) – (Thursday, 3:36 AM) = (Thursday – Tuesday) + (3:36 AM – 4:50 PM) = 48 hrs – (4:50PM – 3:36AM) = 48h – 13h 14m = 34hours and 46minutes.

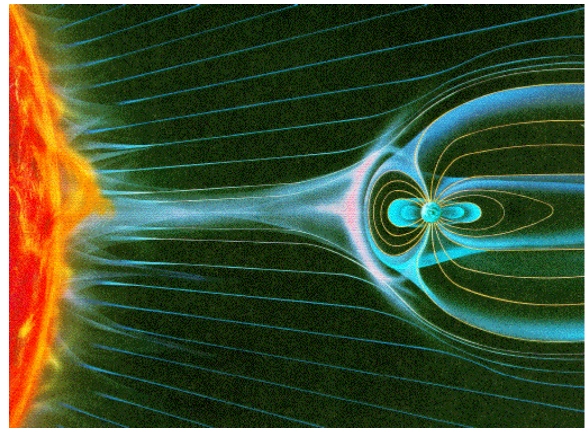
2) How long after the plasma storm reached Earth did the aurora reach their maximum power?
Answer: Storm arrived at 3:36 AM. Aurora at maximum at 5:35AM. Difference in time is 1 hour and 59 minutes.

3) How long did the storm last near Earth from the time the plasma was detected, to the time when space conditions returned to normal?
Answer: On Thursday, the storm started at 3:36 AM and ended at 2:45 PM, so the storm effects at Earth lasted from 03:36 to 14:45 so the difference is 14:45 – 03:36 = 11 hours and (45-36 =) 9 minutes.

Extra for Experts!
If the Earth is 150 million kilometers from the sun, how fast did the storm travel from the Sun in kilometers per hour? How long will the trip to Pluto take is Pluto is 40 times farther away from the sun than Earth?
Answer: The answer to Problem 1 is 34hours and 46minutes, which in decimal form is 34 + (46/60) = 34.8 hours with rounding. The speed is therefore 150 million km/34.8 hours or 4.3 million km/h. The trip to Pluto would take 40 x 34.8 hours = 1,392 hours or about 58 days. Note, the Space Shuttle is our fastest manned spacecraft and travels at about 27,000 km/h so it would take about 58 x (4.3 million/27,000) = 9,237 days to make this trip, which equals 25 years!!!! Of course, the Space Shuttle will be out of fuel and supplies within a week.

A solar flare as a violent explosion of magnetic energy on the sun. A Coronal Mass Ejection (CME) is a billion-ton cloud of gas exploding from the solar surface. Scientists can detect these 'solar storms' and measure how Earth's environment changes.

What scientists would like to learn is, how do you predict what will happen near Earth by looking at events taking place on the Sun, or in space?

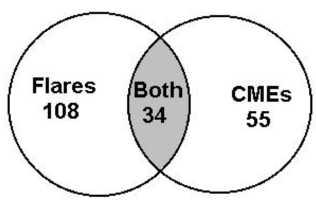


Storms from the Sun sometimes make their way to Earth. Space physicists try to predict what will happen when these storms arrive, and forecast their arrival.

Statistical data can be used to draw conclusions about cause-and-effect relationships, even though the details of the process are unknown.

Here's how to do it!

In 2000, 142 solar flares, and 89 Coronal Mass Ejections were spotted on the Sun. 34 flares happened at nearly the same time as CMEs. What percent of CMEs are not accompanied by solar flares?



$$\frac{89-34}{89} = 0.62$$

or 62 %

Now you try!

1) In the sample problem above, what percentage of solar flares do not happen during CMEs? A news reporter says that solar flares produce CMEs. Is this an accurate statement? Explain.

2) A NASA satellite called ACE measures changes in the magnetism of the gas flowing away from the sun. During 2000 it detects 56 severe magnetic changes. Another satellite called SOHO detects 55 CMEs of which 29 happen at the same time as the ACE disturbances. The IMAGE satellite detects aurora in the polar regions of Earth. A total of 63 bright Aurora are detected during the 56 ACE magnetic 'storms'. There are 31 cases where aurora are seen at the same time as the magnetic disturbances. a) What percentage of CMEs cause magnetic disturbances? b) What fraction of magnetic disturbances lead to major aurora on Earth?

3) Can CME's be reliably used to predict when the next Aurora will occur? Explain.

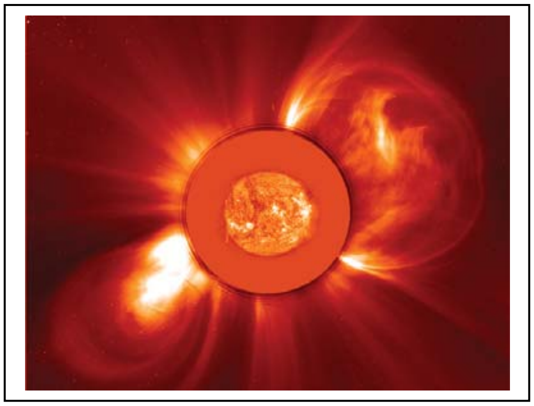
Answer Key

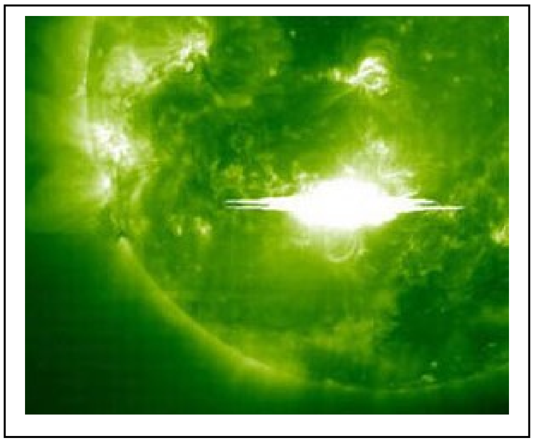
Problem 1 – There are a total of 108 solar flares spotted. If 34 happen at the same time as CMEs directed towards Earth are recorded, then there are 108-34 = 74 solar flares that happen when CMEs are not detected. This percentage is (74/100)x100% = 68 %, so 68% of all major solar flares do not produce CMEs. Most solar flares do not produce CMEs.

Problem 2 – A) Of the 55 CMEs directed towards Earth, 29 happen at the same time as severe disturbances seen by the ACE satellite, so the percentage is 53%. B) Of the 59 magnetic storms detected by the ACE satellite, 31 produce bright aurora seen by the IMAGE satellite, so (31/56)x100% = 55% of the magnetic disturbances produce strong aurora.

Problem 3 – Of the 55 CMEs heading towards Earth, 29 cause magnetic disturbances. But only 55% of the magnetic disturbances seen by the ACE satellite lead to strong aurora. SO, out of the CMEs detected, only (29/55) x (55/100) = 0.29 or 29% cause strong aurora. Most CMEs do not produce disturbances near earth, so the detection of a CME headed towards earth is not enough to help us reliably predict when strong aurora will happen.

Studying Solar Storms with Venn Diagrams



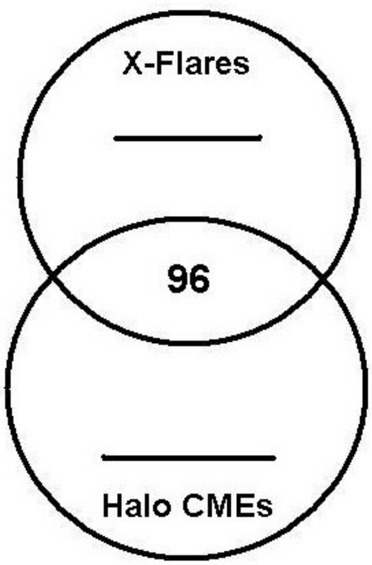


Solar storms come in two varieties:

Coronal Mass Ejections (CMEs) are clouds of gas ejected from the sun that can reach Earth and cause the Aurora Borealis (Northern Lights). These clouds can travel at over 2 million kilometers/hr, and carry billions of tons of matter in the form of charged particles (called a plasma). The picture to the left shows one of many CMEs witnessed by the SOHO satellite.

Solar Flares are intense bursts of X-ray energy that can cause short-wave radio interference on Earth. The picture to the left shows a powerful X-ray flare seen by the SOHO satellite on October 28, 2003.

Between 1996 and 2006, astronomers detected 11,031 coronal mass ejections (CMEs), and of these, 593 were directed towards Earth. These are called 'Halo CMEs' because the ejected gas surrounds the sun's disk on all sides and looks, like a halo around the sun. During these same years, astronomers also witnessed 122 solar flares that were extremely intense X-flares. Of these X-flares, 96 happened at the same time as the Halo CMEs.

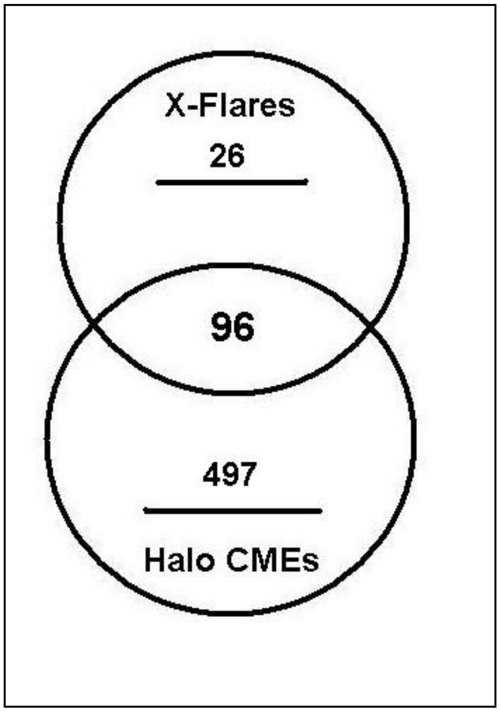


Problem 1 - From this statistical information, fill-in the missing numbers in the circular Venn Diagram to the left.

Problem 2 – What percentage of X-Flares also happened at the same time as a Halo CME?

Problem 3 – What percentage of Halo CMEs happened at the same time as an X-Flare?

Problem 4 – What percentage of all CMEs detected between 1996 and 2006 produced X-Flares?



Answer 1 - The total number of Halo CMEs is 593 and the total number of X-Flares is 122. The intersecting area of the two circles in the Venn Diagram shows the 96 events in which a Halo CME and X-Flare are BOTH seen together. The areas of the circles not in the intersection represent all of the X-flares that are not spotted with Halo CMEs (top ring) and all of the Halo CMEs that are not spotted with X-Flares (bottom ring).

The missing number in the X-Flare ring is just 122 – 96 = 26, and for the Halo CMes we have 593 – 96 = 497.

Answer 2 – The total number of X-Flares is 122 and of these only 96 occurred with a Halo CME, so the fraction of X-Flares is just 96/122 = 0.79. In terms of percentage, this represents 79 %.

Answer 3 – The total number of Halo CMEs is 593 and of these only 96 occurred with an X-Flare, so the fraction of Halo CMEs is just 96/593 = 0.16. In terms of percentage, this represents 16 %.

Answer 4 – There were 11,031 CMEs detected, and of these only 96 coincided with X-Flares, so the fraction is 96/11031 = 0.0087. In terms of percentage, this represents 0.87 % or less than 1 % of all CMEs.

Solar Storms: Odds, Fractions and Percentages

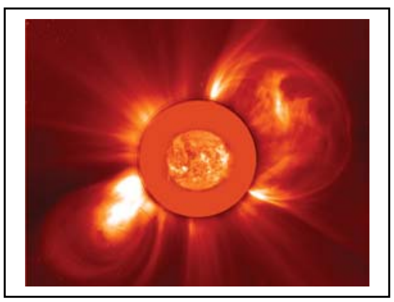
One of the most basic activities that scientists perform with their data is to look for correlations between different kinds of events or measurements in order to see if a pattern exists that could suggest that some new 'law' of nature might be operating. Many different observations of the Sun and Earth provide information on some basic phenomena that are frequently observed. The question is whether these phenomena are related to each other in some way. Can we use the sighting of one phenomenon as a prediction of whether another kind of phenomenon will happen?

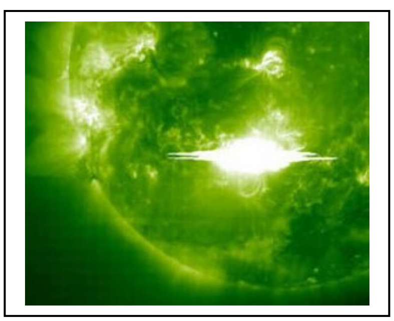
During most of the previous sunspot cycle (January-1996 to June-2006), astronomers detected 11,031 coronal mass ejections, (CME: Top image) of these 1186 were 'halo' events. Half of these were directed towards Earth.

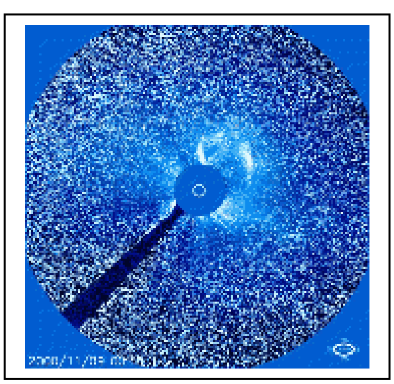
During the same period of time, 95 solar proton events (streaks in te bottom image were caused by a single event) were recorded by the GOES satellite network orbiting Earth. Of these SPEs, 61 coincided with Halo CME events.

Solar flares (middle image) were also recorded by the GOES satellites. During this time period, 21,886 flares were detected, of which 122 were X-class flares. Of the X-class flares, 96 coincided with Halo CMEs, and 22 X-class flares also coincided with 22 combined SPE+Halo CME events. There were 6 X-flares associated with SPEs but not associated with Halo CMEs. A total of 28 SPEs were not associated with either Halo CMEs or with X-class solar flares.

From this statistical information, construct a Venn Diagram to interrelate the numbers in the above findings based on resent NASA satellite observations, then answer the questions below.







1 - What are the odds that a CME is directed towards Earth?

2 - What fraction of the time does the sun produce X-class flares?

3 - How many X-class flares are not involved with CMEs or SPEs?

4 - If a satellite spotted both a halo coronal mass ejection and an X-class solar flare, what is the probability that a solar proton event will occur?

5 - What percentage of the time are SPEs involved with Halo CMEs, X-class flares or both?

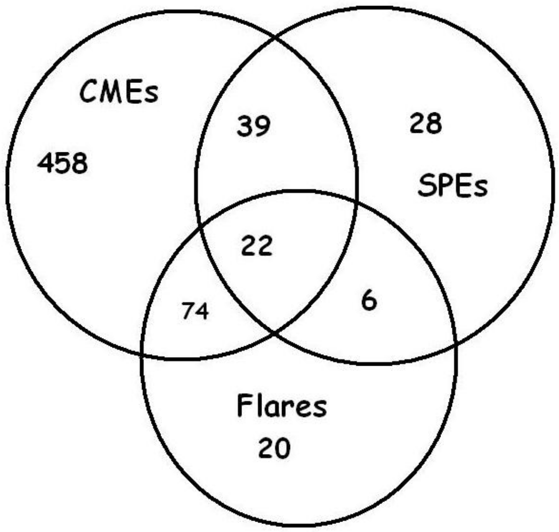
6 - If a satellite just spots a Halo CME, what are the odds that an X-class flare or an SPE or both will be observed?

7 - Is it more likely to detect an SPE if a halo CME is observed, or if an X-class flare is observed?

8 - If you see either a Halo CME or an X-class flare, but not both, what are the odds you will also see an SPE?

9 - If you observed 100 CMEs, X-class flares and SPEs, how many times might you expect to see all three phenomena?

Answer Key



Venn Diagram Construction.

1. There are 593 Halo CMEs directed to Earth so 593 = 74 with flares + 39 with SPEs + 22 both SPEs and Flares + 458 with no SPEs or Flares..

2. There are 95 SPEs. 95 = 39 with CMEs + 6 with flares + 22 with both flares and CMEs + 28 with no flares or CMEs

3. There are 122 X-class flares. 122 = 74 With CMEs only + 6 with SPEs only + 22 both CMEs and SPEs + 20 with no CMEs or SPEs.

1 - What are the odds that a CME is directed towards Earth? 593/11031 = 0.054 **odds = 1 in 19**

2 - What fraction of the time does the sun produce X-class flares? 122/21886 = **0.006**

3 - How many X-class flares are not involved with CMEs or SPEs? 122 - 74 - 22 - 6 = **20.**

4 - If a satellite spotted BOTH a halo coronal mass ejection and an X-class solar flare, what is the probability that a solar proton event will occur? 22/(74+22) = **0.23**

5 - What percentage of the time are SPEs involved with Halo CMEs, X-class flares or both?
100% x (39+22+6 / 95) = **70.1 %**

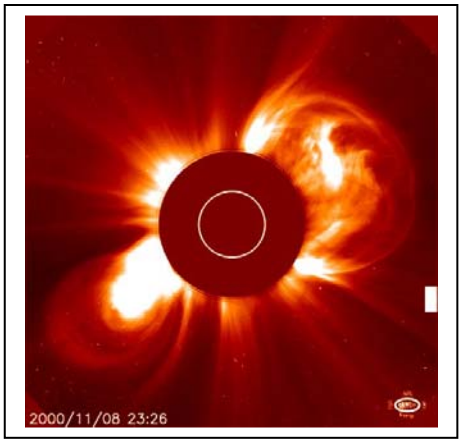
6 - If a satellite just spots a Halo CME, what are the odds that an X-class flare or an SPE or both will be observed?
39+22+74 / 593 = 0.227 so the odds are 1/0.227 or about **1 in 4.**

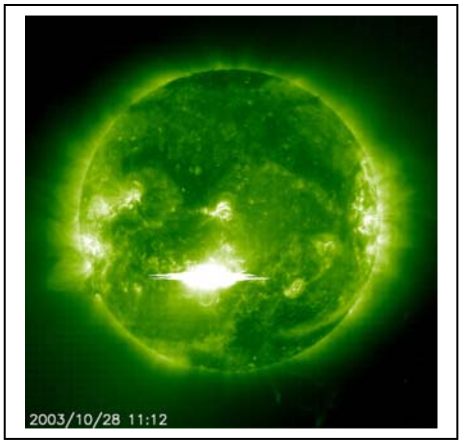
7 - Is it more likely to detect an SPE if a halo CME is observed, or if an X-class flare is observed?
(6+22)/95 = 0.295 or 1 out of 3 times for X-flares
(39+22)/95 = 0.642 or 2 out of 3 for Halo CMEs
It is more likely to detect an SPE if a Halo CME occurs by 2 to 1.

8 - If you see either a Halo CME or an X-class flare, but not both, what are the odds you will also see an SPE?
39+6 / 95 = 0.50 so the odds are 1/0.50 or **2 to 1 .**

9 - If you observed 100 CMEs, X-class flares and SPEs, how many times might you expect to see all three phenomena?

100 x 22/(95+122+593) = **3 times**





The sun produces two basic kinds of storms; coronal mass ejections (SOHO satellite: top left) and solar flares (SOHO satellite: bottom left). These are spectacular events in which billions of tons of matter are launched into space (CMEs) and vast amounts of electromagnetic energy are emitted (Flares). A third type of 'space weather storm' can also occur.

Solar Proton Events (SPEs) are invisible, but intense, showers of high-energy particles near Earth that can invade satellite electronics and cause serious problems, even malfunctions and failures. Some of the most powerful solar flares can emit these particles, which streak to Earth within an hour of the flare event. Other SPE events, however, do not seem to arrive at Earth until several days latter.

Here is a complete list of Solar Proton Events between 1976-2005: http://umbra.nascom.nasa.gov/SEP/

Here is a complete list of coronal mass ejections 1996 - 2006: http://cdaw.gsfc.nasa.gov/CME_list/

Between January 1, 1996 and June 30, 2006 there were 11,031 CMEs reported by the SOHO satellite. Of these, 1186 were halo events. Only half of the halo events are actually directed towards Earth. The other half are produced on the far side of the sun and directed away from Earth. During this same period of time, 90 SPE events were recorded by GOES satellite sensors orbiting Earth. On the next page, is a list of all the SPE events and Halo CMEs that corresponded to the SPE events. There were 65 SPEs that coincided with Halo CMEs. Also included is the calculated speed of the CME event.

From the information above, and the accompanying table, draw a Venn Diagram to represent the data, then answer the questions below.

Problem 1: A) What percentage of CMEs detected by the SOHO satellite were identified as Halo Events? B) What are the odds of seeing a halo Event? C) How many of these Halo events are directed towards Earth?

Problem 2: A) What fraction of SPEs were identified as coinciding with Halo Events? B) What are the odds that an SPE occurred with a Halo CME? C) What fraction of all halo events directed towards earth coincided with SPEs?

Problem 3: A) What percentage of SPEs coinciding with Halo CMEs are more intense than 900 pFUs? B) What are the odds that, if you detect a 'Halo- SPE', it will be more intense than 900 pFUs?

Problem 4: A) What percentage of Halo-SPEs have speeds greater than 1000 km/sec? B) What are the odds that a Halo-SPE in this sample has a speed of > 1000 km/sec?

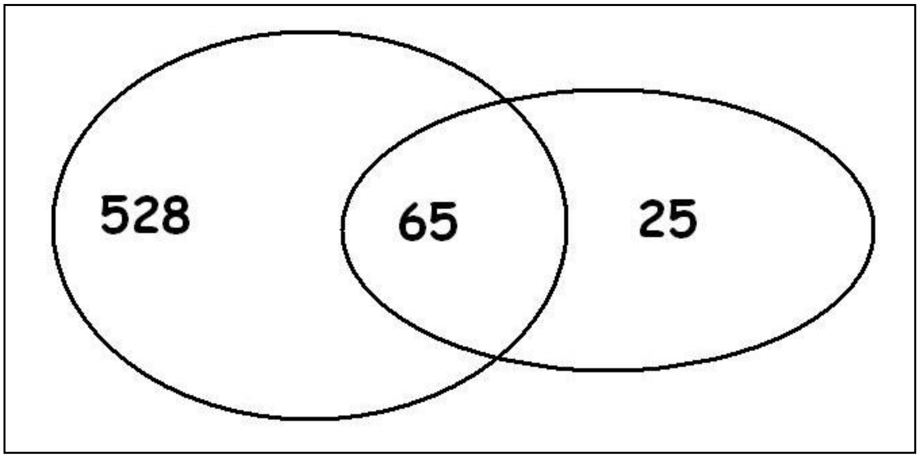
Problem 5: From what you have calculated as your answers above, what might you conclude about SPEs and CMEs? How would you use this information as a satellite owner and operator?

Data Tables showing dates and properties of Halo CMEs and Solar Proton Events.

Date	CME Speed (km/s)	SPE (pfu)
November 4, 1997	785	72
November 6, 1997	1556	490
April 20, 1998	1863	1700
May 2, 1998	938	150
May 6, 1998	1099	210
May 3, 1999	1584	14
June 1, 1999	1772	48
June 4, 1999	2230	64
February 18, 2000	890	13
April 4, 2000	1188	55
June 6, 2000	1119	84
June 10, 2000	1108	46
July 14, 2000	1674	24000
July 22, 2000	1230	17
September 12, 2000	1550	320
October 16, 2000	1336	15
October 25, 2000	770	15
November 8, 2000	1738	14800
November 24, 2000	1289	940
January 28, 2001	916	49
March 29, 2001	942	35
April 2, 2001	2505	1100
April 10, 2001	2411	355
April 15, 2001	1199	951
April 18, 2001	2465	321
April 26, 2001	1006	57
August 9, 2001	479	17
September 15, 2001	478	11
September 24, 2001	2402	12900
October 1, 2001	1405	2360
October 19, 2001	901	11
October 22, 2001	618	24
November 4, 2001	1810	31700
November 17, 2001	1379	34
November 22, 2001	1437	18900
December 26, 2001	1446	779

Date	CME Speed (km/s)	SPE (pfu)
January 8, 2002	1794	91
January 14, 2002	1492	15
February 20, 2002	952	13
March 15, 2002	957	13
March 18, 2002	989	19
March 22, 2002	1750	16
April 17, 2002	1240	24
April 21, 2002	2393	2520
May 22, 2002	1557	820
July 15, 2002	1151	234
August 14, 2002	1309	24
August 22, 2002	998	36
August 24, 2002	1913	317
September 5, 2002	1748	208
November 9, 2002	1838	404
May 28, 2003	1366	121
May 31, 2003	1835	27
June 17, 2003	1813	24
October 26, 2003	1537	466
November 4, 2003	2657	353
November 21, 2003	494	13
April 11, 2004	1645	35
July 25, 2004	1333	2086
September 12, 2004	1328	273
November 7, 2004	1759	495
January 15, 2005	2861	5040
July 13, 2005	1423	134
July 27, 2005	1787	41
August 22, 2005	2378	330

Note: Solar Proton Event strengths are measured in the number of particles that pass through a square centimeter every second, and is given in units called Particle Flux Units or PFUs.



Problem 1: Answers: A) 1186/11031 = **11%** B) 1 / 0.11 = **1 chance in 9** C) From the text, only half are directed to Earth so 1186/2 = **593 Halos**.

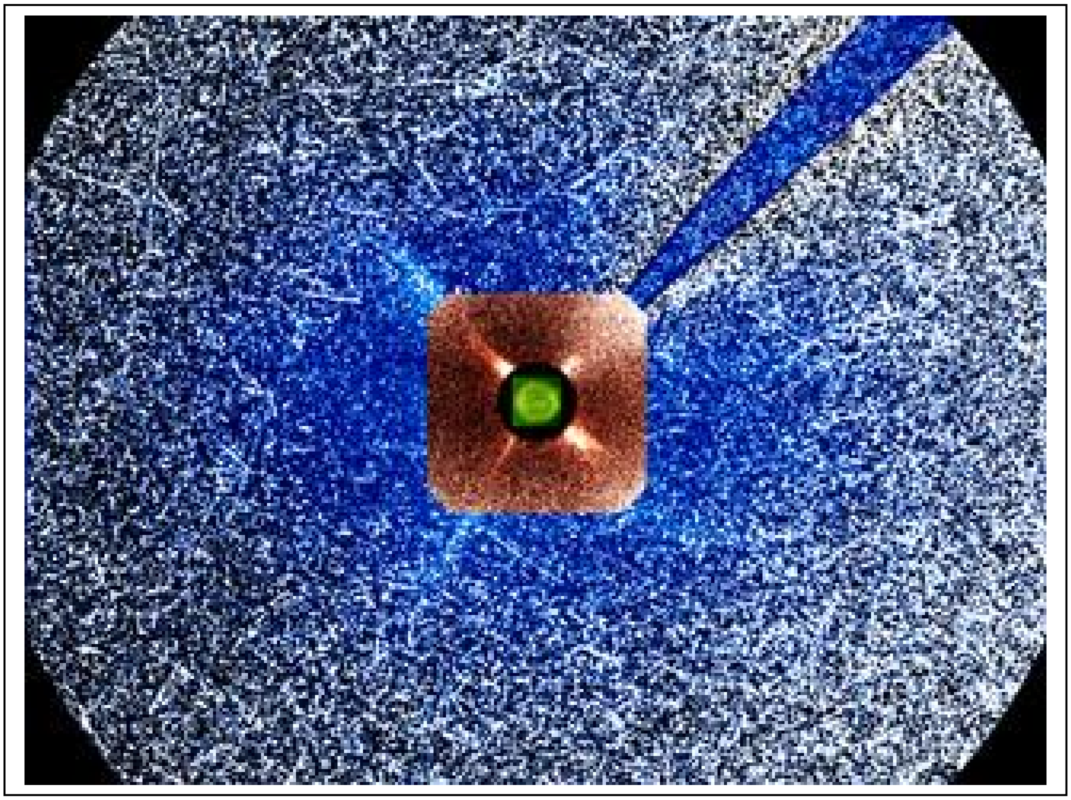
Problem 2: Answers: A) 65 table entries / 90 SPEs = **72%** B) 1 / 0.72 = 1 chance in 1.38 or about **2 chances in 3** C) 65 in Table / (528+65) Halos = **11%**

Problem 3: Answers: A) From the table, there are 12 SPEs out of 65 in this list or 12/65 = **18 %** B) 1 / 0.18 = **1 chance in 5**.

Problem 4: Answers: A) There are 50 out of 65 or 50/65 = **77%** B) 1 / 0.77 = 1 chance in 1.3 or **2 chances in 3**.

Problem 5: From what you have calculated as your answers above, what might you conclude about Solar Proton Events and CMEs? How would you use this information as a satellite owner and operator?

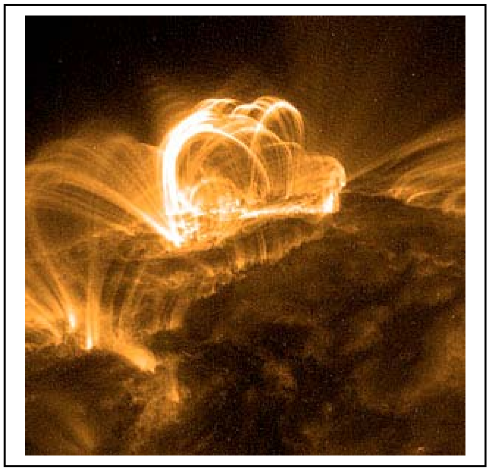
A reasonable student response is that Halo CMEs occur only 11% of the time, and of the ones directed towards Earth only 1 out of 9 coincide with SPEs. However, in terms of SPEs, virtually all of the SPEs coincide with Halo events (2 out of 3) and SPEs are especially common when the CME speed is above 1000 km/sec. As a satellite owner, I would be particularly concerned if scientists told me there was a halo CME headed towards Earth AND that it had a speed of over 1000 km/sec. Because the odds are now 2 chances out of 3 that an SPE might occur that could seriously affect my satellite. I would try to put my satellite in a safe condition to protect it from showers of high-energy particles that might damage it.



The January 20, 2005 solar proton event (SPE) was by some measures the biggest since 1989. It was particularly rich in high-speed protons packing more than 100 million electron volts (100 MeV) of energy. Such protons can burrow through 11 centimeters of water. A thin-skinned spacesuit would have offered little resistance, and the astronaut would have been radiation poisoned, and perhaps even killed.

The above image was taken by the SOHO satellite during this proton storm. The instrument, called LASCO, was taking an image of the sun in order for scientists to study the coronal mass ejection (CME) taking place. Each of the individual white spots in the image is a track left by a high-speed proton as it struck the imaging CCD (similar to the 'chip' in your digital camera). As you see, the proton tracks corrupted the data being taken.

The high-speed particles from these proton storms also penetrate satellites and can cause data to be lost, or even false commands to be given by on-board computers, causing many problems for satellite operators.



The Sun is an active star, which produces solar flares (F) and explosions of gas (C). Astronomers keep watch for these events because they can harm satellites and astronauts in space. Predicting when the next storm will happen is not easy to do. The problems below are solved by writing out all of the possibilities, then calculating the probability of the particular outcome!

Solar flare photo courtesy TRACE/NASA

1 – During a week of observing the sun, astronomers detected 1 solar flare (F). What was the probability (as a fraction) that it happened on Wednesday?

2 – During the same week, two gas clouds were ejected (C), but not on the same days. What is the probability (as a fraction) that a gas cloud was ejected on Wednesday?

3 – Suppose that the flares and the gas clouds had nothing to do with each other, and that they occurred randomly. What is the probability (as a fraction) that both a flare and a gas cloud were spotted on Wednesday? (Astronomers would say that these phenomena are uncorrelated because the occurrence of one does not mean that the other is likely to happen too).

Answer Key

1 – Answer: There are only 7 possibilities:

F X X X X X X   X X X F X X X   X X X X X X F
X F X X X X X   X X X X F X X
X X **F** X X X X   X X X X X F X

So the probability for any one day is **1/7.**

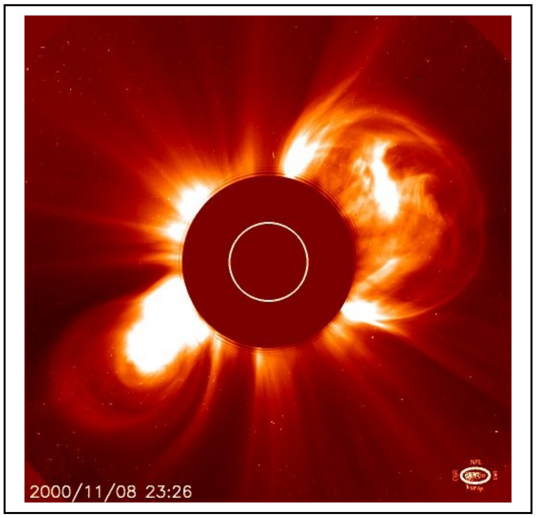
2 – Here we have to distribute 2 storms among 7 days. For advanced students, there are 7! / (2! 5!) = 7 x 6 / 2 = 21 possibilities which the students will work out by hand:

C C X X X X X   X C **C** X X X X   X X **C** C X X X   X X X C C X X
C X **C** X X X X   X C X C X X X   X X **C** X C X X   X X X C X C X
C X X C X X X   X C X X C X X   X X **C** X X C X   X X X C X X C
C X X X C X X   X C X X X C X   X X **C** X X X C   X X X X C C X
C X X X X C X   X C X X X X C   X X X X C X C
C X X X X X C   X X X X X C C

There are 6 possibilities (in red) for a cloud appearing on Wednesday (Day 3), so the probability is **6/21.**

3 – We have already tabulated the possibilities for each flare and gas cloud to appear separately on a given day. Because these events are independent of each other, the probability that on a given day you will spot a flare and a gas cloud is just 1/7 x 6/21 or 6/147. This is because for every possibility for a flare from the answer to Problem 1, there is one possibility for the gas clouds.

There are a total of 7 x 21 = 147 outcomes for both events taken together. Because there are a total of 1 x 6 outcomes where there is a flare and a cloud on a particular day, the fraction becomes (1 x 6)/147 = **6/147.**



The Sun is an active star that produces solar flares (F) and explosions of gas (C). Astronomers keep watch for these events because they can harm satellites and astronauts in space. Predicting when the next storm will happen is not easy to do. The problems below are solved by writing out all of the possibilities, then calculating the probability of the particular outcome!

Photo of a coronal mass ejection courtesy SOHO/NASA.

Problem 1 – During a particularly intense week for solar storms, three flares were spotted along with two massive gas cloud explosions. Work out all of the possible ways that 3 Fs and 2 Cs can be separately distributed among 7 days. Examples include C C X X X X X and F F F X X X X.

What is the probability (as a fraction) that none of these events occurred on Friday?

Inquiry: Does the probability matter if we select any one of the other 6 days?

Answer Key

1 – Here we have to distribute 2 cloud events (C) among 7 days. For advanced students, there are 7! / (2! 5!) = 7 x 6 / 2 = 21 possibilities which the students will work out by hand, in this case starting with Monday as the first place in the sequence:

C C X X **X** X X	X C C X **X** X X	X X C C **X** X X	X X X C C X X
C X C X **X** X X	X C X C **X** X X	X X C X C X X	X X X C **X** C X
C X X C **X** X X	X C X X C X X	X X C X **X** C X	X X X C **X** X C
C X X X C X X	X C X X **X** C X	X X C X **X** X C	X X X X C C X
C X X X **X** C X	X C X X **X** X C		X X X X C X C
C X X X **X** X C			X X X X **X** C C

Next, we have to distribute 3 flares (F) among 7 days. There will be 7! / (3! 4!) = (7 x 6 x 5) /(3 x 2) = 35 possibilities as follows:

F F F X **X** X X	F X X F F X X	X F F F **X** X X	X X F F F X X
F F X F **X** X X	F X X F **X** F X	X F F X F X X	X X F F **X** F X
F F X X F X X	F X X F **X** X F	X F F X **X** F X	X X F F **X** X F
F F X X **X** F X	F X X X F F X	X F F X **X** X F	X X F X F F X
F F X X **X** X F	F X X X F X F	X F X F F X X	X X F X F X F
F X F F **X** X X	F X X X **X** F F	X F X F **X** F X	X X F X **X** F F
F X F X F X X		X F X F **X** X F	X X X F F F X
F X F X **X** F X		X F X X F F X	X X X F F X F
F X F X **X** X F		X F X X F X F	X X X F **X** F F
		X F X X **X** F F	X X X X F F F

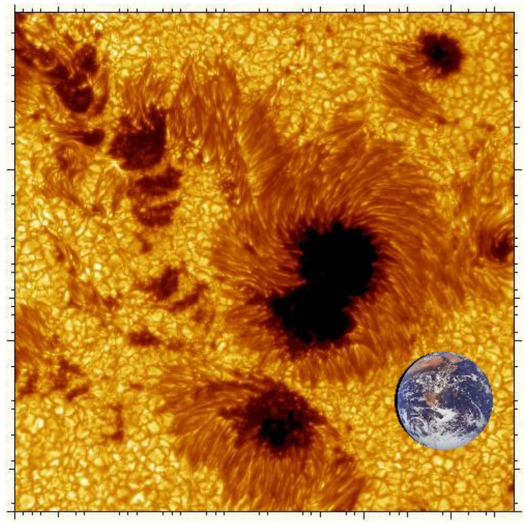
For each cloud event (21 possibilities) there are 35 possibilities for flare events, so the total number of arrangements is 21 x 35 = 735. Friday is the fifth location in each sequence.

The number of sequences of cloud events in which no cloud appears in the fifth slot is highlighted in red. There are 15 possibilities. For the solar flares, there are 20 possibilities, so because these are independent, the total number is 15 x 20 = 300. So, the probability that there will be no solar storms on Friday is 300/735

Inquiry – Students may redo the calculation for any of the other days. The resulting probability should always be 300/735. This is because the events are not correlated with any particular day, so the day choice is random as well.

Sunspots are a sign that the Sun is in a stormy state. Sometimes these storms can affect Earth and cause all kinds of problems such as satellite damage and electrical power outages. They can even harm astronauts working in space.

Scientists use many different kinds of measurements to track this stormy activity. In this exercise, you will learn how to use some of them!



This sunspot is as big as Earth!

Looking at sequences of numbers can help you identify unusual events that depart from the average trend.

Here's how to do it!

An astronomer counts sunspots for 5 days and gets the following sequence:
149, 136, 198, 152, 145

Maximum = 198
Minimum = 136
Mean = (149+136+198+152+145)/5 = 156
Median = 149

Find the maximum, minimum, mean and median of each sequence.

1) Number of Sunspots

241	240	243	229	268	335	342	401	325	290	276	232	214

2) Number of Solar Flares

5	7	13	8	9	14	9	13	16	6	14	15

3) Aurora Power (measured in billions of watts!)

171.2	122.2	219.4	107.9	86.2	112.4	76.2	39.8	153.9

Answer Key

Problem 1 - Maximum= 401, minimum=214;
Ordered = 214, 229 ,232 ,240, 241, 243 ,268, 276, 290, 325, 335 ,342, 401
Median = 268
Mean = 264

Problem 2 - Maximum= 16, minimum= 5
Ordered = 5, 6, 7, 8, 9, 9, 13, 13, 14, 14, 15
Median = 9
Mean = 10

Problem 3 - Maximum = 219.4; minimum=39.8
Ordered = 39.8 ,76.2 ,86.2 ,107.9 ,112.4, 122.2, 153.9, 171.2, 219.4
Median = 112.4
Mean = 121.0

Solar Flares and the Sunspot Cycle

Year	C-class	M-class	X-class
1996	76	4	1
1997	288	20	3
1998	1198	96	14
1999	1860	170	4
2000	2265	215	17
2001	3107	311	20
2002	2319	219	12
2003	1315	160	20
2004	912	122	12
2005	578	103	18
2006	150	10	4
2007	73	10	0
2008	8	1	0

Solar flares are the most dramatic explosions on the sun, which have been known for some time. An average-sized flare can release more energy in a few hours than thousands of hydrogen bombs exploding all at once.

Solar flares do not happen randomly, but like many other solar phenomena follow the rise and fall of the sunspot cycle.

The table to the left is a tally of the number of C, M and X-class flares identified during each year of the previous sunspot cycle.

Problem 1 - During the entire sunspot cycle, how many solar flares occur?

Problem 2 - What percentage of solar flares during an entire sunspot cycle are A) C-class? B) M-class? C) X-class?

Problem 3 - During a single week, how many flares of each type would the sun produce during A) Sunspot maximum in the year 2001? B) Sunspot minimum during the year 1996?

Problem 4 - During sunspot maximum, what is the average time in hours between flares for, A) C-class? B)M-class? and C) X-class? (Hint: 1 year = 8,760 hours)

Problem 5 - Do as many flares occur in the time before sunspot maximum (1996-2000) as after sunspot maximum (2002-2008) for A) C-class? B) M-class? C) X-class?

Problem 1 - During the entire sunspot cycle, how many solar flares occur?
Answer: The sum of all the flares in the table is **15,715**.

Problem 2 - What percentage of solar flares during an entire sunspot cycle are A) C-class? B) M-class? C) X-class?
Answer: A) C-class = 100% x (14149/15715) = **90%**
B) M-class = 100% x (1441/15715) = **9%**
C) X-class = 100% x (14149/15715) = **1%**

Problem 3 - During a single week, how many flares of each type would the sun produce during A) Sunspot maximum in the year 2001? B) Sunspot minimum during the year 1996?
Answer: A) C-type = 3107/52 = **60**
M-type = 311/52 = **6**
X-type = 20/52 = **0.4**

B) C-type = 76/52 = **1.4**
M-type = 4/52 = **0.08**
X-type = 1/52 = **0.02**

Problem 4 - During sunspot maximum, what is the average time in hours between flares for, A) C-class? B)M-class? and C) X-class? (Hint: 1 year = 8,760 hours)
Answer: C-class = 1 year/3107 flares x (8760 hours/year) = **2.8 hours/flare**.
M-class = 1 year/311 flares x (8760 hours/year) = **28 hours/flare**. (1 day)
X-class = 1 year/20 flares x (8760 hours/year) = **438 hours/flare**. (18 days)

Problem 5 - Do as many flares occur in the time before sunspot maximum (1996-2000) as after sunspot maximum (2002-2008) for A) C-class? B) M-class? C) X-class?

Answer: Between 1996-2000 there were 6,231 and between 2001-2008 there were 6,046 so although the numbers are nearly the same, there were slightly fewer flares after sunspot maximum.

Note: In statistics, the sampling error is n = $(6231)^{1/2}$ = 79, so the range of random variation for 1996-2000 is between 6231+79 and 6231-79 or [6151, 6310] for 2002-2008 we have $(6046)^{1/2}$ = 78, so the range of random variation for 2002-2008 is between 6046+78 and 6046-78 or [5968, 6124]. Because of this sampling uncertainty, the counts between each side of solar maximum are statistically similar. They do not differ by more than 3-sigma (3x78 = 234) which means they are the same to better than 98% certainty.

Table of Fast CMEs between 1996 - 2006

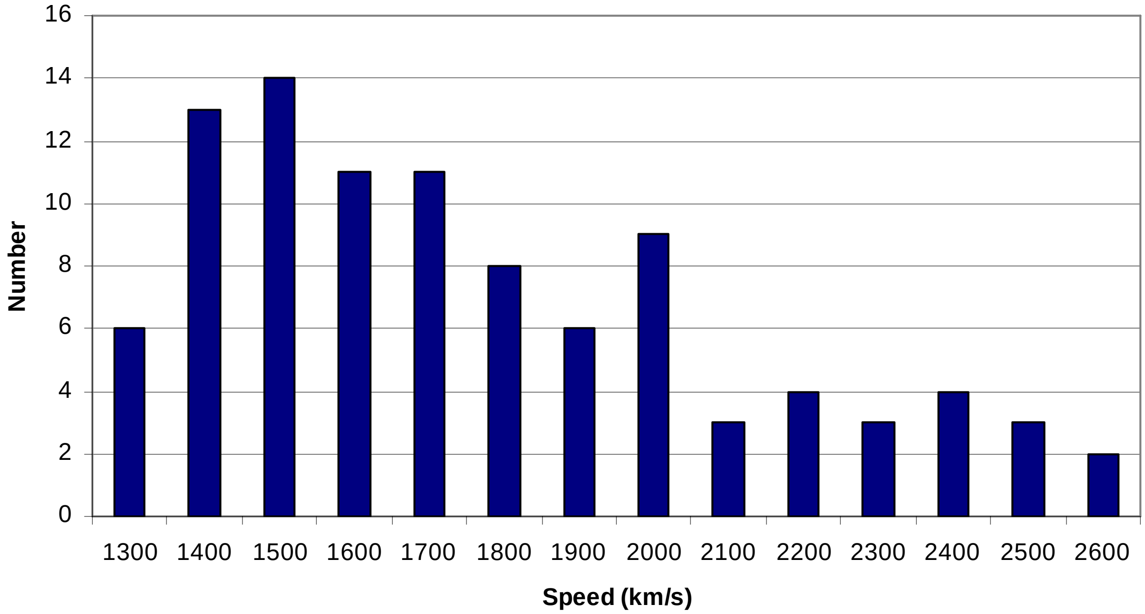
Year	Month	Speed	Year	Month	Speed	Year	Month	Speed	Year	Month	Speed
2004	11	3387	2002	7	2047	1999	6	1772	2001	10	1537
2005	1	2861	2003	11	2036	2004	11	1759	2005	7	1527
2003	11	2657	2003	10	2029	2002	3	1750	2003	11	1523
2000	5	2604	2005	1	2020	1998	12	1749	2001	1	1507
2003	11	2598	2003	11	2008	2002	9	1748	2001	12	1506
2005	1	2547	2004	11	2000	2001	6	1701	1998	11	1505
2005	7	2528	1998	3	1992	2002	10	1694	1999	4	1495
2000	11	2519	2005	7	1968	1999	5	1691	2002	1	1492
2001	4	2465	2002	7	1941	2005	5	1689	2003	10	1484
2003	10	2459	2005	8	1929	2005	6	1679	2001	4	1475
2001	4	2411	2005	9	1922	2000	7	1674	2005	7	1458
2001	9	2402	2002	8	1913	2005	9	1672	2004	7	1444
2002	4	2393	2005	9	1893	2003	11	1661	2001	11	1443
2005	8	2378	2005	9	1866	2005	7	1660	2001	11	1437
2005	9	2326	2002	11	1838	2002	7	1636	2001	8	1433
2002	7	2285	2003	5	1835	1998	4	1618	2002	3	1429
2005	9	2257	2003	6	1813	2005	8	1600	2005	7	1423
2003	11	2237	2001	11	1810	2000	5	1594	2001	6	1407
2001	12	2216	2005	8	1808	2002	8	1585	2001	10	1405
2002	7	2191	1998	6	1802	1999	5	1584	1998	3	1397
2002	10	2115	1998	11	1798	2001	8	1575	2001	4	1390
2005	7	2115	2002	1	1794	2002	5	1557	1999	7	1389
2005	1	2094	2005	7	1787	1997	11	1556	1998	4	1385
2003	6	2053	2000	5	1781	2000	9	1550	2005	9	1384
2005	1	2049	2001	12	1773	2005	7	1540	2005	2	1380

Coronal Mass Ejections (CMEs) are billion-ton clouds of gas that can leave the solar surface at many different speeds as shown in the table above. This table gives the speeds of the 100-fastest CMEs seen during the last sunspot cycle between 1996-2008.

Problem 1 - Create a histogram of the CME speeds using bins that are 100 km/sec wide over the domain of speeds [1300, 2600].

Problem 2 - What is the: A) Average speed? B) Median speed? C) Mode speed?

Problem 3 - If the transit time to Earth is 42 hours for a CME traveling at a speed of 1,000 km/s, to the nearest hour, what is A) the range of speeds spanned by this complete sample of 100 CMES? B) The average transit time of a CME?



Problem 1 - Create a histogram of the CME speeds using bins that are 100 km/sec wide over the domain of speeds [1300, 2600]. Answer: See above.

Problem 2 - What is the: A) Average speed? B) Median speed? C) Mode speed?
Answer: A) The average speed is found by adding all 100 speeds and dividing by 100. The answer is **<V> = 1,851 km/sec**. B) The median speed is the speed for which half of the CME speeds are below and half are above the value. The table is ranked from fastest to slowest so CME #50 will be close to the median speed for this 'even' numbered set. **Vm = 1,773 km/sec**. C) The mode speed is the most frequently occurring speed in the sample which is **V = 2,115 km/sec**.

Problem 3 - If the transit time to Earth is 42 hours for a CME traveling at a speed of 1,000 km/s, to the nearest hour, what is A) the range of speeds spanned by this complete sample of 100 CMES? B) The average transit time of a CME?

Answer: A) The range is from 1,380 to 3,387 km/sec B) so by scaling we get 42 x (1000/1380) = 30 hours for the slowest and 42 x (1000/3387) = 12 hours. the average transit time is T = 42 x (1000/1851) = **23 hours**.

Table of Event Frequencies for Cycle 23

	Flares (Class)			SPEs (pfu)				Halo
	C	M	X	10	100	1000	10000	CMEs
1996	76	4	1	1	1	0	0	1
1997	288	20	3	1	1	0	0	5
1998	1198	96	14	5	2	1	0	29
1999	1860	170	4	8	2	2	1	42
2000	2265	215	17	6	3	0	1	48
2001	3107	311	20	8	5	2	1	41
2002	2319	219	12	7	3	2	0	30
2003	1315	160	20	2	1	1	1	21
2004	912	122	12	3	1	1	1	87
2005	578	103	18	2	1	3	0	110
2006	150	10	4	0	1	1	0	33
2007	73	10	0	0	0	0	0	11
2008	8	1	0	0	0	0	0	12

The term 'solar storm' can refer to many different kinds of energetic phenomena including solar flares, Solar Proton Events (SPEs) and coronal mass ejections (CMEs). Solar flares are the most well-known, and are classified according to their x-ray power as C, M or X, with X being the most powerful. SPEs are classed according to the number of protons that pass through a surface area per second at Earth's orbit in units of particle Flux Units (pFUs). SPEs with 10,000 pFUs or higher can be deadly to astronauts not properly shielded. The table above gives the number of flares detected during each year of the previous solar activity cycle

Problem 1 - During sunspot maximum in 2001, what was the average number of hours you would have to wait between A) each of the three classes of X-ray flares? Each of the four classes of SPEs? And C) Each of the Halo CMEs? (Hint: There are 8,760 hours in 1 year)

Problem 2 - Assuming that Halo CMEs and X-class flares occur randomly over the year, what is the probability that during 2001 you will see both a Halo CME and an X-class flare on the same day?

Problem 1 - During sunspot maximum in 2001, what was the average number of hours you would have to wait between A) each of the three classes of X-ray flares? Each of the four classes of SPEs? and C) Each of the Halo CMEs? (Hint: There are 8,760 hours in 1 year)

Answer: From the table we have

	Flares (Class)			**SPEs (pfu)**				Halo
	C	M	X	10	100	1000	10000	CMEs
2001	3107	311	20	8	5	2	1	41

A) C-class flares: 8760 hours /3107 flares = **2.8 hours.**
M-class flares: 8760 / 311 = **28 hours = 1 day**
X-class flares: 8760 / 20 = **438 hours = 18 days**

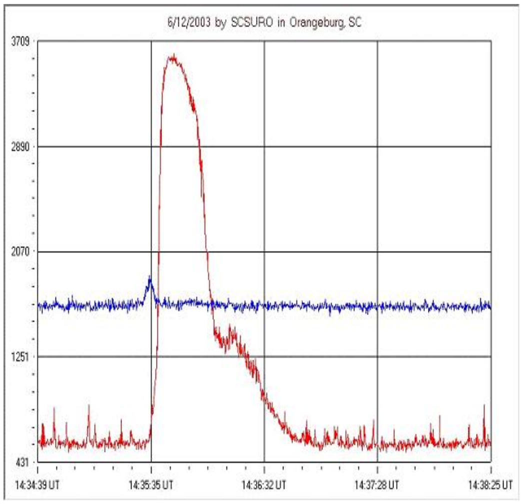
B) 10 pFU: 8760/8 = **1,095 hours = 1.5 months**
100 pFU: 8760/5 = **1,752 hours = 2.5 months**
1000 pFU: 8760/2 = **4,380 hours = 6 months**
10000 pFU: 8760/1 = **8,760 hours = 1 year**

C) Halo CME: 8760 / 41 = **214 hours or 9 days**.

Problem 2 - Assuming that Halo CMEs and X-class flares occur randomly over the year, what is the probability that during 2001 you will see both a Halo CME and an X-class flare on the same day?

Answer: During this year there were 20 X-class flares and 41 Halo CMEs. Each day the probability is 20/365 = 1/18 that an X-class flare will occur, and 41/365 = 1/9 that a Halo CME will occur. The probability is then P(Halo) x P(Xflare) = 1/18 x 1/9 = **P(both) = 1/162** = 0.006 that both will happen on the same day.

Halo CMEs and Radio Bursts



Solar radio burst detected by the Radio Jove network on 6/12/2003.

When energy is explosively released on the sun, powerful bursts of radio waves can be emitted. These travel towards Earth and can be detected with radio telescopes and other radio-energy receivers.

Although solar flares and coronal mass ejections (CMEs) emit radio bursts at some point in their evolution, these radio signals can be invaluable in determining whether hazardous clouds of plasma are moving towards Earth. This is because CMEs can be seen from Earth even though they are on the far side of the sun and not a hazard. Fortunately, radio bursts can be detected from CMEs launched from the front side of the sun.

A tally of data was assembled for the 23rd sunspot cycle that included days during which solar flares, Halo CMEs and radio bursts occurred. Because there were a number of days for which satellites and ground radio telescopes were not reporting data, only those days for which data was available for all three phenomena were included in the statistical sample.

During the 23rd sunspot cycle (1996-2008) a total of 465 Halo-type CMEs were observed by the SOHO satellite. Of these, 153 were associated with Type-II or Type IV radio bursts. The total number of detected radio bursts during this time was 403. During this same period, a number of X and M-class solar flares were detected. 107 coincided with Halo CMEs that also coincided with radio bursts, leaving 46 Halo events with radio bursts that did not coincide with solar flares. Also, 70 Halo events coincided with solar flares but not radio bursts. Among the remaining solar flares, 107 coincided with radio bursts but no Halo CMEs, and there were 143 radio bursts that did not coincide with either solar flares or Halo CMEs. There were 380 flares not associated with Halo CMEs or radio bursts.

Problem 1 - If Halo CMEs = H, radio bursts = R, and solar flares = F, create a Venn Diagram that presents the numerical data for the numbers of events in each logical partition.

Problem 2 - Of the CMEs that coincide with X and M-class solar flares A) what percentage produce radio bursts? B) What percentage do not produce radio bursts?

Problem 3 - If an astronomer detected a radio burst and a flare, what is the probability that no Halo CME is involved?

Problem 1 - If Halo CMEs = H, radio bursts = R, and solar flares = F, create a Venn Diagram that presents the numerical data for the numbers of events in each logical partition.

Problem 2 - Of the CMEs that coincide with X and M-class solar flares A) what percentage produce radio bursts? B) What percentage do not produce radio bursts?
Answer: There are 107 + 70 = 177 CMEs that also coincide with solar flares of class X or M.

A) CME/flare and Radio bursts = 100% x (107/177) or **60%**
B) CME/flare but not Radio bursts = 100% x (70/177) or **40%**

Problem 3 - If an astronomer detected a radio burst and a flare, what is the probability that no Halo CME is involved?

Answer: There are 107 cases where a radio burst + flare occur, and 107 cases where a radio burst+flare+Halo CME occur for a total of 214 flare events. The probability is then 100% x (107 no Halo/ 214) = **50%**

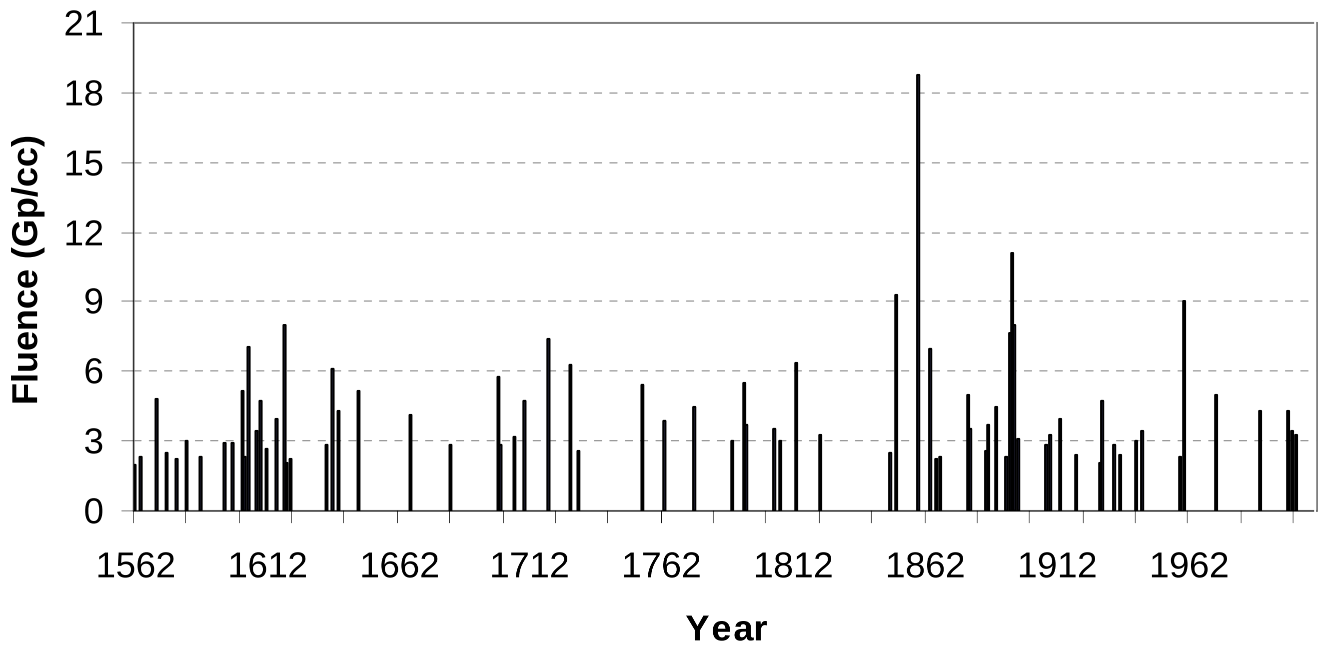
Radio burst archives:

Learmonth Observatory **http://www.ips.gov.au/Solar/3/9**

Zurich Archive of Radio Burst Spectrograms **http://helene.ethz.ch/rapp/archive/form_nf.html**

Greenbank Solar Radio Burst Spectrometer **http://gbsrbs.nrao.edu/**

NASA WAVES Satellite **http://lep694.gsfc.nasa.gov/waves/waves.html**



In 1976, Dr. Robert McCracken at the University of Aldlaide studied ice cores from Greenland and Antarctica and discovered chemical anomalies in the atmospheric composition of the element beryllium. He later correlated these 'spikes' in the normal abundance with solar proton events. The above graph shows the intensities of these SPEs between 1562 - 2003. The SPE intensity, called the fluence, is given in terms of the total number of particles it delivered to one cubic centimeter (cc) of the atmosphere in units of 1 billion particles/cc (1 Gp/cc) .

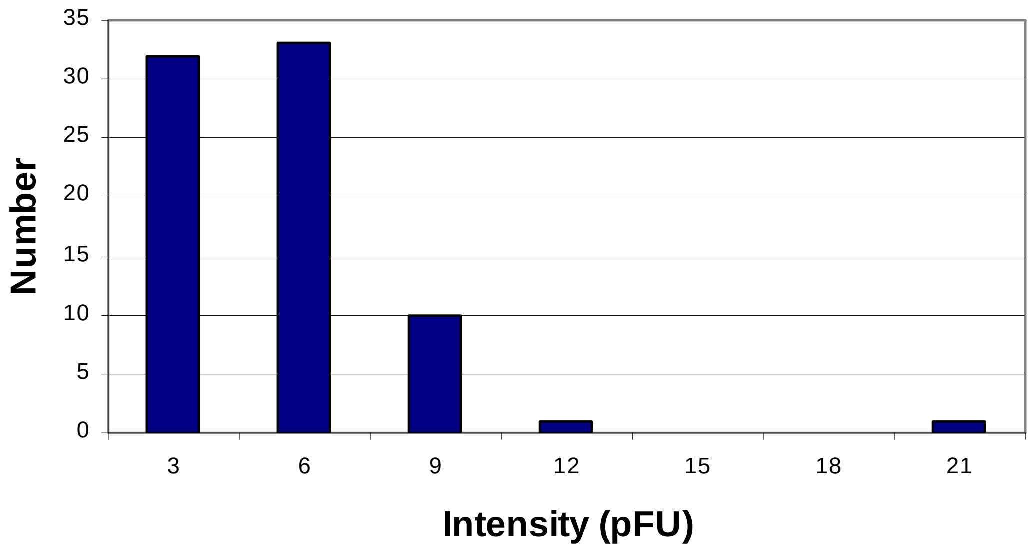
Problem 1 - Create a histogram by counting the number of SPEs with intensities in the following bin intervals: [0.1,3.0]; [3.1,6.0]; [6.1,9.0]; [9.1,12.0]; [12.1,15.0]; [15.1,21.0]

Problem 2 - A solar physicist detects an SPE. What is the probability, in percent, that it will be more intense than 6 Gp/cc?

Problem 3 - About how strong were the 5 most intense SPEs detected after 1962.

Problem 4 - The radiation exposure in milliRems for a shielded astronaut inside a space craft can be estimated using the conversion that 1 Gp/cc = 10 milliRem. About how many milliRems of exposure would have occurred for each of the 5 SPEs since 1965?

Problem 1 - Create a histogram by counting the number of SPEs with intensities in the following bin intervals: [0.1,3.0]; [3.1,6.0]; [6.1,9.0]; [9.1,12.0]; [12.1,15.0]; [15.1,21.0]
Answer: Depending on how well the graph can be read, students should get numbers that are close to the following exact count:
[0.1,3.0]; N=32
[3.1,6.0]; N = 33
[6.1,9.0]; N = 10
[9.1,12.0]; N = 1
[12.1,15.0]; N= 0
[15.1,21.0]; N = 1



Problem 2 - A solar physicist detects an SPE. What is the probability, in percent, that it will be more intense than 6 Gp/cc?
Answer: The total number of SPEs in the data is 32+33+10+1+1 = 77. The number that are stronger than 6 Gp/cc is 12, so the probability is 100% x (12/77) = **16%**

Problem 3 - About how strong were the 5 most intense SPEs detected after 1962.
Answer: **18.8 (1859); 11.1 (1895); 9.3 (1851); 7.7 (1894) and 7.4 (1719)**

Problem 4 - The radiation exposure in milliRems for a shielded astronaut inside a space craft can be estimated using the conversion that 1 Gp/cc = 10 milliRem. About how many milliRems of exposure would have occurred for each of the 5 SPEs since 1965?

Answer: From the graph, the SPEs had intensities of about 5, 4, 4, 3, 3 Gp/cc so the radiation levels would have been **50, 40, 40, 30 and 30 milliRem** during the several hours of the storm. Note the natural ground level rate is 350 milliRem / year.

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	5											5	5		4			4					
2											2	4					3						
3																							
4						6				19							2					4	
5				3									2										4
6													8			2			2				3
7									3				11		2	5			9				
8												3	8	3									3
9	4			6					9	7		4	3	3						5			
10		5		4													3						
11										2													
12																							
13						3																	

Note: The columns indicate the corresponding sunspot cycles from 1 to 23. The calendar year for 'Year 1' for each cycle is as follows:1755, 1765, 1775, 1785, 1798, 1810, 1823, 1833, 1843, 1856, 1867, 1878, 1889, 1901, 1913, 1923, 1933, 1944, 1954, 1964, 1975, 1986, 1996

The table above gives the intensity of Solar Proton Events (SPEs) detected since 1751 (Cycle 1) through the end of the last sunspot cycle in 2008 (Cycle 23). An SPE is an intense burst of high-energy protons from the sun that reach Earth traveling at nearly the speed of light. The data for Cycle 1 - 22 were obtained by Dr. Robert McCracken in a study of ice cores from Greenland and Antarctica, which recorded the atmospheric changes caused by the most intense SPEs during each year.

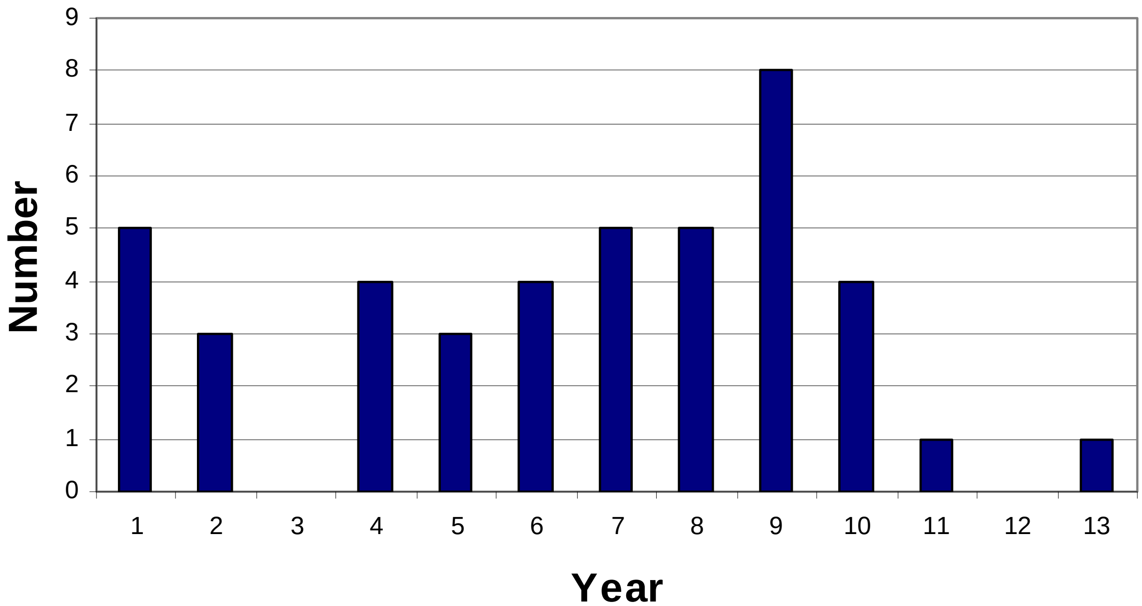
Although the ice core data was assembled chronologically as a continuous record of events since 1562, the above table folds the intensity of SPEs each year by the year of the sunspot cycle in which the SPE was recorded. The calendar year for 'Year 1' in the far-left column is given in the legend for the table.

Problem 1 - Create a histogram that tallies the number of SPEs occurring in each of the 13 years of the sunspot cycle. What is the total number of SPEs recorded for the 23 sunspot cycles?

Problem 2 - For each year in the average sunspot cycle, what is the percentage of SPEs that one expects to find?

Problem 3 - Which year of the sunspot cycle has the greatest historical percentage of SPEs?

Problem 1 - Create a histogram that tallies the number of SPEs occurring in each of the 13 years of the sunspot cycle. What is the total number of SPEs recorded for the 23 sunspot cycles?



Answer: **Total = 43**

Problem 2 - For each year in the average sunspot cycle, what is the percentage of SPEs that one expects to find?

Answer:

Year	Number	Percent
1	5	12
2	3	7
3	0	0
4	4	9
5	3	7
6	4	9
7	5	12
8	5	12
9	8	19
10	4	9
11	1	2
12	0	0
13	1	2

Problem 3 - Which year of the sunspot cycle has the greatest historical percentage of SPEs?
Answer: **Year 9.**

Cosmic Rays and the Sunspot Cycle

Year	SSN	Flux	Year	SSN	Flux	Year	SSN	Flux
1950	84	93	1970	105	86	1990	142	76
1951	69	94	1971	67	88	1991	146	80
1952	31	95	1972	69	98	1992	94	86
1953	14	96	1973	38	96	1993	55	94
1954	4	98	1974	34	100	1994	30	96
1955	38	100	1975	15	97	1995	18	98
1956	142	98	1976	13	99	1996	9	99
1957	190	94	1977	27	100	1997	21	99
1958	185	80	1978	93	96	1998	64	100
1959	159	84	1979	155	90	1999	93	96
1960	112	82	1980	155	89	2000	120	88
1961	54	84	1981	140	84	2001	111	86
1962	38	88	1982	116	88	2002	104	88
1963	28	92	1983	67	80	2003	64	86
1964	10	96	1984	46	90	2004	40	86
1965	15	98	1985	18	92	2005	30	94
1966	47	98	1986	13	96	2006	15	96
1967	94	93	1987	29	98	2007	8	98
1968	106	90	1988	100	94	2008	3	100
1969	106	88	1989	158	84			

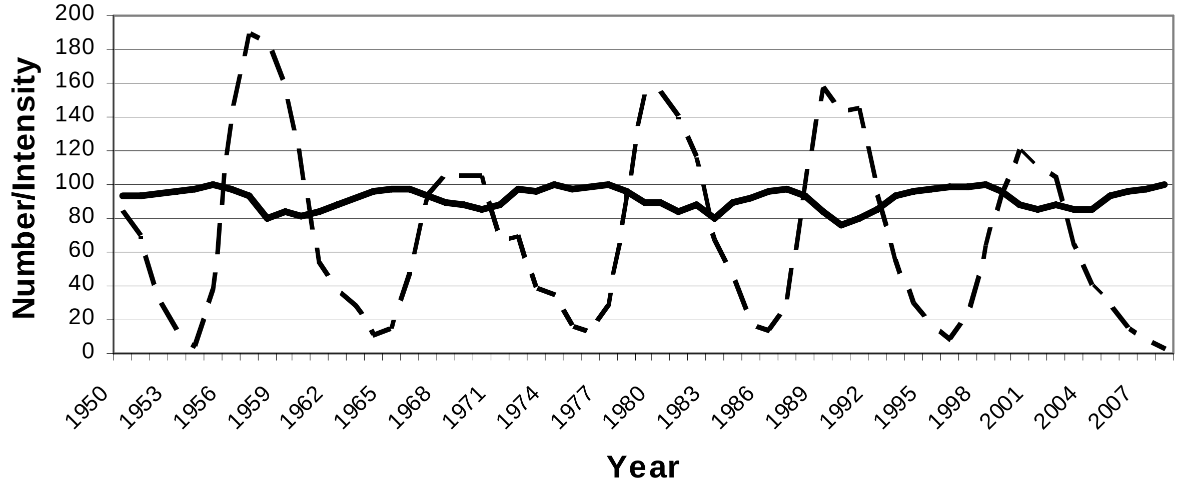
Cosmic rays are high-energy particles that enter our solar system from distant sources in the Milky Way galaxy and beyond. These particles are a radiation hazard for satellite electronics and for astronauts exposed to them for prolonged periods of time. The table above presents the intensity of the cosmic rays measured by instruments located in Climax, Colorado during the period from 1950 to 2008, along with the annual sunspot counts.

Problem 1 - On the same graph, plot the sunspot numbers and the cosmic ray intensities.

Problem 2 - What do you notice about the relationship between cosmic rays and sunspots?

Problem 3 - If you were planning a 1-year trip to Mars, what time would you make your journey relative to the sunspot cycle?

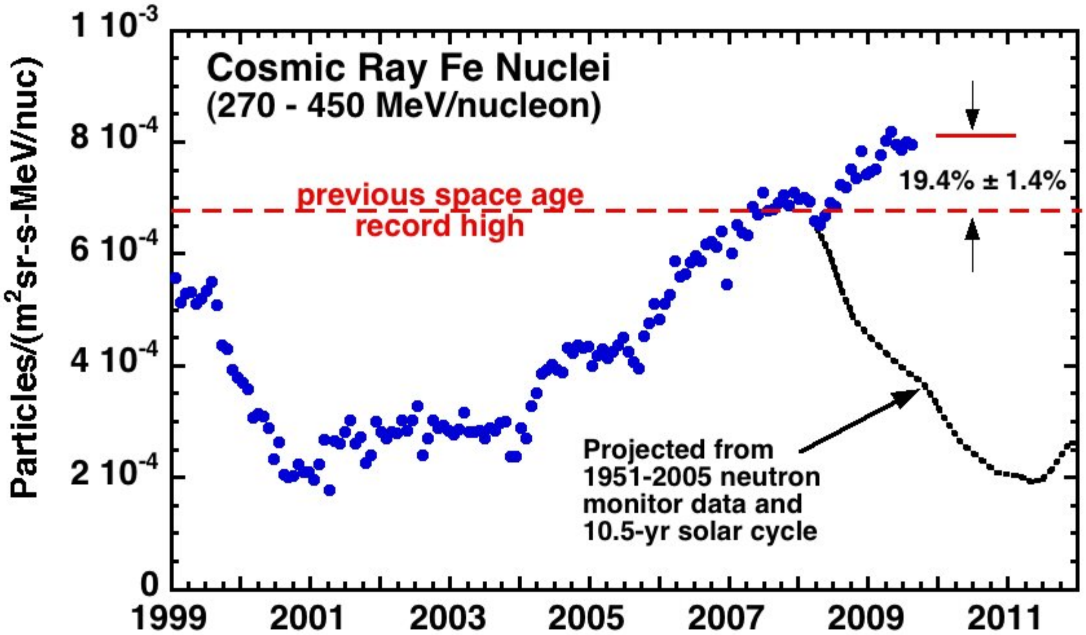
Problem 1 - On the same graph, plot the sunspot numbers and the cosmic ray intensities. Answer: **See below.**



Problem 2 - What do you notice about the relationship between cosmic rays and sunspots?
Answer: **When the sunspot number is highest, the cosmic ray intensity is lowest. The sunspot number peaks (maxima) match up with the cosmic ray valleys (minima).**

Problem 3 - If you were planning a 1-year trip to Mars, what time would you make your journey relative to the sunspot cycle?
Answer: **You would probably want to make the journey during sunspot maximum conditions when the cosmic ray intensity is lowest. This will reduce your total accumulated radiation dosage during the 1-year trip by 20%.**

Cosmic Ray Variations in the Inner Solar System



Energetic iron nuclei counted by the Cosmic Ray Isotope Spectrometer on NASA's ACE spacecraft reveal that, during the period from 2008-2010, cosmic ray levels have jumped 19% above the previous Space Age high.

Cosmic rays are charged, high-energy particles that can be affected by magnetic fields. During times when the sun is most active, called sunspot maximum, the solar magnetic field carried by the solar wind is more intense than during sunspot minimum. In the region of the solar system interior to the asteroid belt, this effect causes cosmic ray intensities to be lowest during sunspot maximum, and highest during sunspot minimum. The 'normal' end of the previous sunspot cycle, Number 23, should have been in 2008, however the prolonged 'minimum' has lasted until 2010, causing the cosmic ray intensity to continue to climb after 2008.

Problem 1 - If the sunspot minimum had lasted until 2011, making it the cycle with the longest period of spotless days since 1700, what would the ACE cosmic ray intensity have been at that time?

Problem 2 - What is the percentage change in the cosmic ray intensity between sunspot maximum and sunspot minimum from 2001 to 2008 ?

Problem 3 - The fluence of cosmic rays is the number of particles passing through a 1 meter^2 area in one second. If the fluence of the cosmic rays at sunspot minimum is 0.1 particles/m^2/sec, how many cosmic rays will pass through the surface area of a cylindrically-shaped spacecraft with a height of 10 meters and a radius of 3 meters in one year? (1 year = 31 million seconds).

Problem 1 - If the sunspot minimum had lasted until 2011, making it the cycle with the longest period of spotless days since 1700, what would the ACE cosmic ray intensity have been at that time? Answer: From the graph, and extending the dots linearly to the upper right corner, the intensity would have been about 0**.00095 particles/m^2/str/sec/MeV**

Problem 2 - What is the percentage increase in the cosmic ray intensity between sunspot maximum and sunspot minimum from 2001 to 2008?
Answer: Minimum = 0.00067 Maximum = 0.0002 so the change is 100% x (0.00067 - 0.0002)/0.0002 or **235%**

Problem 3 - The fluence of cosmic rays is the number of particles passing through a 1 meter^2 area in one second. If the fluence of the cosmic rays at sunspot minimum is 0.1 particles/m^2/sec, how many cosmic rays will pass through the surface area of a cylindrically-shaped spacecraft with a height of 10 meters and a radius of 3 meters in one year? (1 year = 31 million seconds).

Answer: The area of the spacecraft is $A = \pi R^2 h = 3.14 \times (3)^2 \times 10 = 283$ meters^2

The total cosmic ray count would be $N = 0.1 \times (283) \times (31,000,000) =$ **8.8×10^8 cosmic rays.**

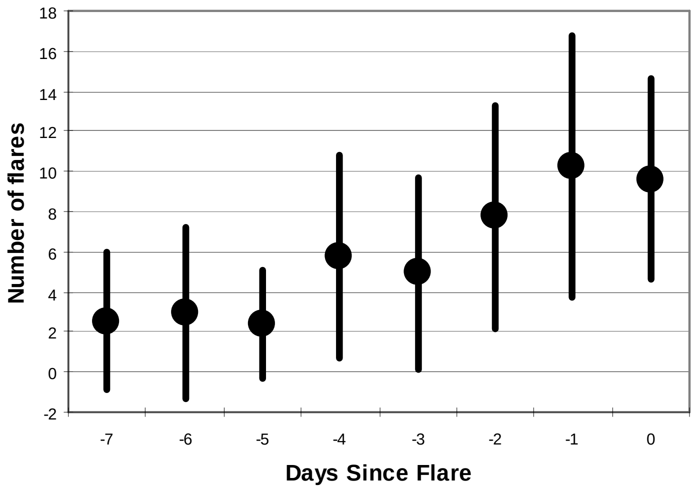
Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
-7	**0**	8	**0**	1	0	5	7	0	0	**0**	**0**	**0**	7	**0**	**0**	9	**0**	**0**	4	11	2	0	3	4	2
-6	**0**	15	2	2	0	8	3	0	0	**0**	**0**	**0**	5	**0**	**0**	13	**0**	**0**	6	7	0	4	0	2	7
-5	**0**	8	3	1	0	8	7	2	0	0	0	**0**	1	0	2	5	6	2	4	5	0	2	0	2	1
-4	0	8	3	2	11	6	15	14	10	6	0	0	3	1	9	16	8	4	11	8	0	2	0	6	1
-3	1	13	4	0	7	3	8	4	12	0	0	0	11	1	13	15	6	3	7	6	0	3	1	5	0
-2	1	12	14	9	8	8	12	18	15	0	0	1	10	3	15	13	15	7	6	8	2	9	0	6	2
-1	3	9	11	30	5	9	10	12	14	8	9	6	15	3	14	22	14	8	6	10	18	6	0	3	12
0	5	15	8	20	2	19	13	11	6	7	6	6	16	7	9	14	11	12	10	5	16	7	1	6	8

The table above gives the number of C and M-class flares recorded in the 7 days just before the eruption of an X-class flare from the solar surface. On Day-0 the X-class flare appeared. We would like to know if there is some way to predict whether an X-class flare will occur based on the amount of solar activity during previous days leading up to the X-class flare.

Problem 1 - For each day, what is the average number of C and M-class flares recorded?

Problem 2 - Graph the average number of flares versus the number of days prior to the X-class flare event. What do you notice about the data?

Problem 3 - A statistical measure of the possible range in a measured value is the 'sigma' or 'standard deviation'. For a given day, subtract the average value from each of the 25 events. Next compute the square of this difference and sum these squared quantities. Finally, divide the sum by (25-1) = 24 and take the square root of the answer. The most likely range of the measurement, A, (1-sigma) is then A +s and A-s. Compute the sigma for each day, and add 'error bars' to your graph to show the possible range of values due to statistical sampling.



Problem 1 - For each day, what is the average number of C and M-class flares recorded? Answer: **See the dots plotted on the graph above, and column 2 of the table below.**

Problem 2 - Graph the average number of flares versus the number of days prior to the X-class flare event. What do you notice about the data? Answer: **See the table below, column 2, for the averages. These are found by summing the total number of flares each day, N, and dividing by 25 'events'. The trend is that there is an increasing number of flares as you get closer to the day of the X-class flare.**

Day	Average	N	Sigma
-7	3	63	3
-6	3	74	4
-5	2	59	3
-4	6	144	5
-3	5	123	5
-2	8	194	6
-1	10	257	7
0	10	240	5

Problem 3 - A statistical measure of the possible range in a measured value is the 'sigma' or 'standard deviation'. For a given day ,subtract the average value from each of the 25 events. Next compute the square of this difference and sum these squared quantities. Finally, divide the sum by (25-1) = 24 and take the square root of the answer. The most likely range of the measurement, A, (1-sigma) is then A +s and A-s. Compute the sigma for each day, and add 'error bars' to your graph to show the possible range of values due to statistical sampling. Answer: See graph above. Example, Day -7, Average = 3. Sum = $(0-3)^2 + (8-3)^2 + (0-3)^2 + (1-3)^2 + \ldots = 280.3$, sigma = (280.3/24) = 3.4, so the error bar for day -7 should extend from 3-3.4 = -0.4 to 3+3.4 = 6.4.

M-flares as Predictors of X-flares

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
-7		2		0	0	0	2	0		0					4			2			2	2	0	0	0	0		0
-6		5	0	1	0	1	1	0		0					0			2			1	2	0	0	0	0		0
-5		3	1	0	0	0	0	0		0	0	0			0	0	0	4	2	0	0	1	0	0	0	0		0
-4	0	3	0	0	0	0	4	0	7	0	0	0		0	0	0	0	2	1	0	2	1	0	0	0	0	0	0
-3	0	4	0	0	2	0	2	0	5	1	0	0	1	0	1	0	1	3	0	0	1	0	0	1	1	1	1	0
-2	0	1	3	0	2	0	2	0	2	5	0	0	2	0	0	0	1	2	3	0	0	0	0	0	0	0	0	0
-1	1	1	5	4	1	0	4	1	4	2	0	0	7	2	1	0	0	4	3	1	0	0	3	1	0	1	1	0
0	0	2	4	6	0	4	0	4	0	0	1	2	3	2	2	0	1	1	0	2	1	0	2	0	0	0	0	2

The table above lists the number of M-class flares that occurred on the sun in the 7 days preceding the appearance of an X-class flare for 28 separate solar events.

Problem 1 - For each day, what is the average number of M-class flares that occurred?

Problem 2 - What is the variance (sigma) for the average value during each day?

Problem 3 - Graph the average number of M-class flares counted for each day including the range determined by 1-sigma error bars.

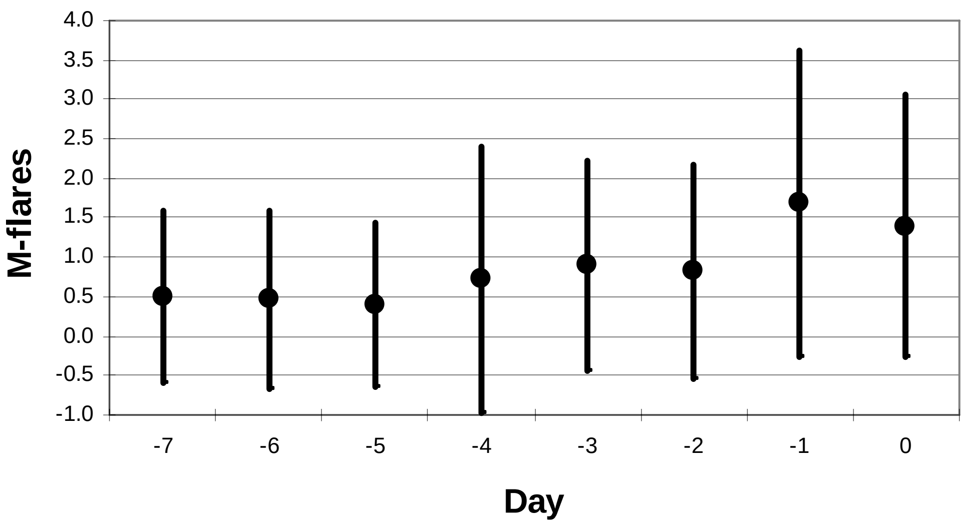
Problem 4 - Is the M-flare activity a good predictor of whether an X-class flare will occur or not?

Problem 1 - For each day, what is the average number of M-class flares that occurred? Answer: **See table below.**

Problem 2 - What is the variance (sigma) for the average value during each day? Answer: **See table below.**

Day	Average	Sigma
-7	0.5	1.0
-6	0.5	1.1
-5	0.4	1
-4	0.7	1.6
-3	0.9	1.3
-2	0.8	1.3
-1	1.7	1.8
0	1.4	1.6

Problem 3 - Graph the average number of M-class flares counted for each day including the range determined by 1-sigma error bars. Answer: **See below.**



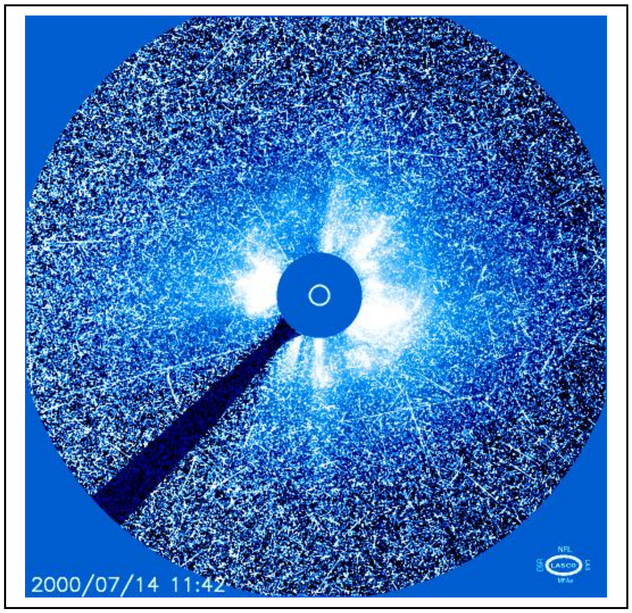
Problem 4 - Is the M-flare activity a good predictor of whether an X-class flare will occur or not? **Answer: The averages show a weak trend upwards, but the 1-sigma error bars are so large that the apparent trend is not statistically significant. All of the daily averages are within 1-sigma of each other.**

Solar Proton Event Energy Release

Time (hrs)	Intensity (Counts)
0	40
4	10000
8	40000
12	35000
16	33000
20	25000
24	20000
28	15000
32	12000
36	10000
40	8000
44	6000
48	5000
52	4000
56	3000
60	2500
64	2200
68	2000
72	1500
76	1200
80	1000
84	600
88	400
92	250
96	200
100	180

The SOHO satellite is capable of measuring the intensity of high-energy protons emitted during a SPE using the Celias Proton Monitor developed by solar physicists the University of Maryland. The table on the left gives the recorded intensity for an SPE detected on April 21, 2002 which had a peak intensity of 2,520 pFU.

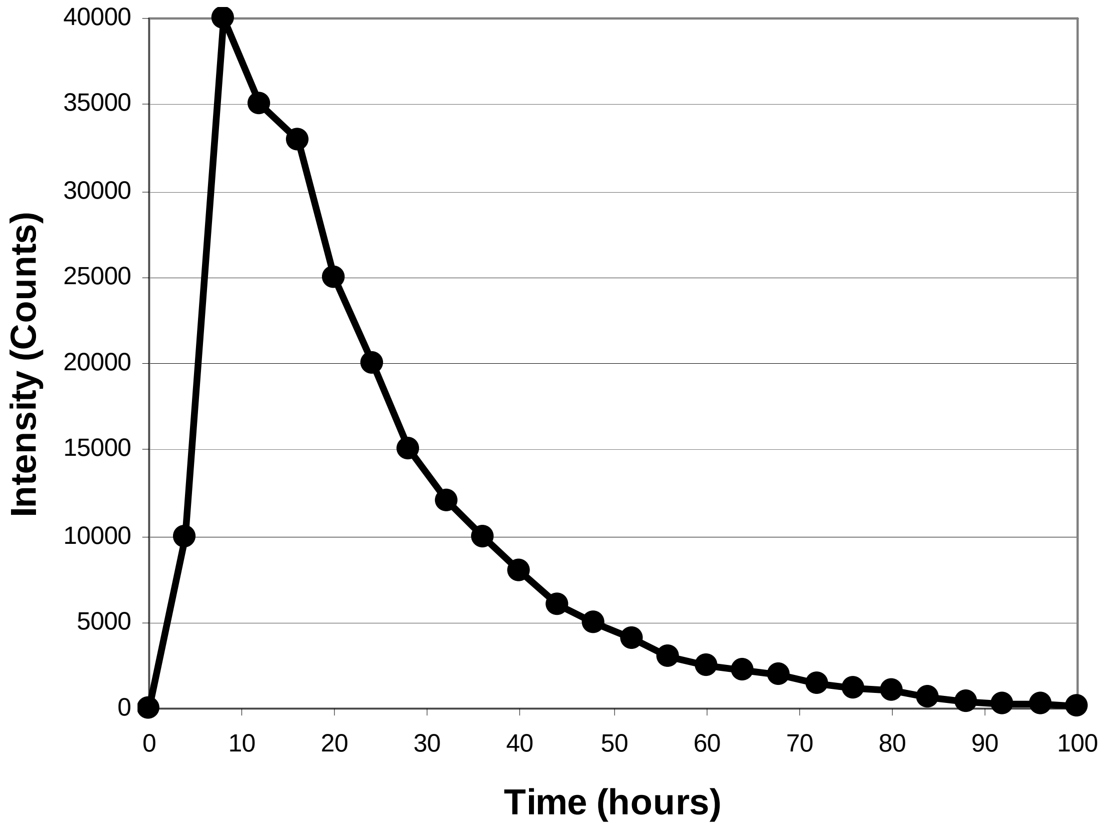
The figure below shows the result of an SPE on the imaging electronics of the SOHO satellite located 150 million kilometers from the sun. The white dots and streaks are caused by the high-energy protons striking the pixels and causing data errors.



Problem 1 - Graph the time history of the emission from this Solar Proton Event.

Problem 2 - The ground-level normal background radiation dosage is about 0.05 milliRem/hour. Suppose that for an astronaut working inside a shielded spacecraft that the peak radiation dosage from this event was 10 milliRem/hour. How long after the start of this SPE will the radiation dosage fall below normal levels?

SPE light curve Courtesy University of Maryland SOHO/Celias Proton Monitor
http://umtof.umd.edu/pm/flare/flare_figs.HTML



Problem 1 - Graph the time history of the emission from this Solar Proton Event.
Answer: **See above.**

Problem 2 - The ground-level normal background radiation dosage is about 0.05 milliRem/hour. Suppose that for an astronaut working inside a shielded spacecraft that the peak radiation dosage from this event was 10 milliRem/hour. How long after the start of this SPE will the radiation dosage fall below normal levels?

Answer: Peak counts = 40,000 which equals 10 milliRem, so for 0.05 milliRem we have the proportion 0.05/10 x 40000 = 200 counts. This level occurs **96 hours after the start of the storm, so you have to wait nearly 3 days!**

Guides for Predicting Space Weather

Near-Earth Missions

Astronauts working in the International Space Station, and satellite systems operating within geosynchronous orbit, all rely on accurate predictions of today's space weather and expectations for the conditions in the near future.

The primary data that drives these forecasts involve research satellite systems at L1 (ACE, SOHO, SDO) in Earth-orbit (GOES), along with ground-based monitors that keep track of solar surface conditions, and the state of Earth's magnetic field.

Basic Resources You Will Need:

SWAC-Space Weather Action Center http://sunearthday.nasa.gov/swac/data.php
Media Viewer http://sunearth.gsfc.nasa.gov/spaceweather/FlexApp/bin-debug/index.html#
SWPC-Space Weather Prediction Center http://www.swpc.noaa.gov/

Space Conditions Now:

For humans, the most important forecast that you want to make will be about solar flares and solar proton events. SWPC provides a quick-look status table at the top of their page. Ranges near the top of their 5-point scale will be reasons for concern that require immediate action to reduce radiation exposure. The GOES Solar X-ray Flux graph will indicate whether there have been any recent M or X-class flares, which require no direct human action since the actual x-rays from the flares are well-shielded and not harmful. X-class flares can, however, occur close to the same time as solar proton events, which can be very harmful, and even lethal. There is no good correlation between flare class and SPE strength, so every solar flare of class M or X may be followed by an SPE whose particles would arrive within an hour of the X-flare detection time. Also at this time, satellites may experience a number of operation anomalies, so care must be taken during M and X-flares to monitor satellite and spacecraft operations. Strong M and X-flares also cause ionospheric changes that affect GPS ground accuracy.

The SWPC and SWAC can also be checked for current geomagnetic conditions by monitoring the Kyoto Dst

http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/presentmonth/index.html

and Kp indices, **http://www.swpc.noaa.gov/rt_plots/kp_3d.html** and by checking the ACE 'Bz' magnetometer readings at

http://www.swpc.noaa.gov/ace/MAG_7d.html.

The Kp bar graph will indicate disturbed geomagnetic conditions (Kp > 7) by showing the previous 3-6 hour measurements (previous two bars). Dst will indicate whether a storm is beginning through the Sudden Storm Commencement 'positive spike' signal that begins shortly before the main geomagnetic storm arrives, leading to very negative Dst values below -100 nT. The ACE 'Bz' measurement will become large and negative (< -10 nT) about 30-45 minutes before a storm commences on Earth. Geomagnetic disturbances can affect ground-based power grids, and can cause satellite attitude changes if the satellite is relying on magnetometers to sense orientation. Geomagnetic storms also set into motion a chain of events leading to increases in spacecraft charging events, electric discharges, and 'killer electrons' that can cause operational anomalies, and even damage under severe conditions.

Space Conditions in the Next Few Days:

Successful predictions of local space weather conditions within the next few days depend on a detailed knowledge of solar surface conditions. Solar flare forecasts are provided by SWPC in their '3-day forecast' at **http://www.swpc.noaa.gov/forecast.htmlLong-term Trends:** page. Look in Section III for the 3-day probabilities for X and M-class flares and SPE. Alternatively, check whether there are any Active Regions (sunspots) present using daily images at the SWAC **Space Weather Media Viewer**.

Also view the SOHO/MDI magnetograms to check on the magnetic complexity of these regions, and the professional write-up and classification on the SWPC Solar Region Summary page at **http://www.swpc.noaa.gov/ftpdir/latest/SRS.txt**. If the active regions show a classification of alpha or beta, the probability of a significant solar flare is low, but if the classification is gamma or delta, the probability is higher.

The SOHO/LASCO images on the SWEAC Media Viewer or the current synoptic image archive at will indicate whether a coronal mass ejection has occurred. Only the halo events are potentially geomagnetically important, but only those that are Earth-directed. Backside halo events are of no concern. To distinguish whether a halo CME is front-side and potentially directed at earth, check for the detection of a radio burst at the SWPC page **http://www.swpc.noaa.gov/ftpdir/lists/radio/radio_bursts.txt**. If a burst was detected at the time of the halo event, then there is a high probability it will reach earth. The speed of the CME can be determined from the succession of SOHO/LASCO images and compared to tabulated values for CME speeds to get a prediction for the number of transit hours to Earth.

Also check the SWPC, Space Weather Alerts archive **http://www.swpc.noaa.gov/alerts/archive.html** to look at the alerts posted for the previous 7 days based on a professional assessment of potential hazards.

Check list:

1) Solar active regions with gamma or higher classification
2) Halo CME eruption in the past day and determine speed and arrival time
3) Radio burst to discriminate between back-side halo and Earth-directed halo CME
4) Geomagnetic Kp and Dst indices indicating disturbed geomagnetic conditions

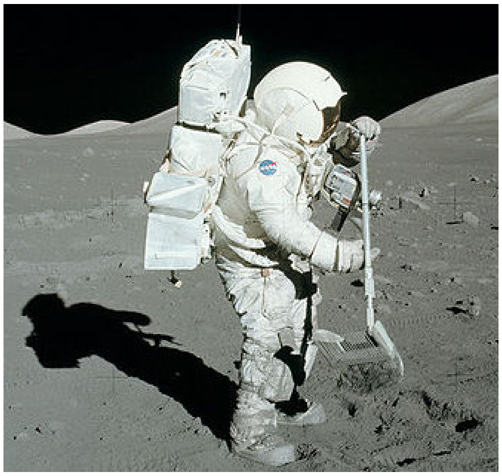
Long-term Trends:

These have more to do with what part of the sunspot cycle you are in. Generally, during the sunspot-minimum years, there is a low risk for M and X-flares, solar proton events and CMEs of all types. By the time you are 2-years from sunspot maximum, the monthly risk for strong geomagnetic storms and X or M-class solar flares increases significantly, and remains high for most of the years after sunspot maximum. Although cosmic ray fluxes are highest during sunspot minimum, activities deep within Earth's geomagnetic field are shielded from most of the high-energy particles so radiation exposure is fairly low. During sunspot maximum, lower fluxes of cosmic rays will lessen the cumulative radiation exposure for activities within Earth's magnetosphere, especially in low-earth orbit (e.g. ISS).

Check list:

1) Determine current year of the sunspot cycle
2) Within 2 years of sunspot minimum cosmic rays high, CME and flare probabilities low
3) Within 2 years of sunspot maximum cosmic rays low, CME and flare probabilities high

Missions to the Moon



The transit phase is short enough that cosmic rays are not a significant risk factor. It is expected that the 2-3 day journey will not be scheduled during a period when a known solar active region is producing flares or CMEs. If scheduling does not permit launching during a quiet period, magnetically complex regions on the sun will need to be monitored and the NOAA/SEC space weather indices monitored for indications that a solar flare event has a hightened probability. If a halo CME has been launched, and/or an x-ray flare of class M or X detected, astronauts must prepare for the arrival of high-energy particles within the hour. They must return from EVAs and seek out shielded regions in the spacecraft for a duration that could last several hours or days. Radiation monitors will indicate when the storm event has passed. During the event, computers and other critical digital electronics must also be monitored for signs of data corruption and false-commands. For long-duration stays on the moon, shielding must be available for astronauts either in a landed spacecraft, or beneath lunar regolith in a habitation module.

<u>Basic Resources You Will Need</u>:

SWAC-Space Weather Action Center http://sunearthday.nasa.gov/swac/data.php
Media Viewer http://sunearth.gsfc.nasa.gov/spaceweather/FlexApp/bin-debug/index.html#
SWPC-Space Weather Prediction Center http://www.swpc.noaa.gov/

<u>Space Conditions Now:</u>

For humans, the most important forecast that you want to make will be about solar flares and solar proton events. SWPC provides a quick-look status table at the top of their page. Ranges near the top of their 5-point scale will be reasons for concern that require immediate action to reduce radiation exposure. The GOES Solar X-ray Flux graph will indicate whether there have been any recent M or X-class flares, which require no direct human action since the actual x-rays from the flares are well-shielded and not harmful. X-class flares can, however, occur close to the same time as solar proton events, which can be very harmful, and even lethal. There is no good correlation between flare class and SPE strength, so every solar flare of class M or X may be followed by an SPE whose particles would arrive within an hour of the X-flare detection time.

Space Conditions in the Next Few Days:

Successful predictions of local space weather conditions within the next few days depend on a detailed knowledge of solar surface conditions. Solar flare forecasts are provided by SWPC in their '3-day forecast' at **http://www.swpc.noaa.gov/forecast.htmlLong-term Trends:** page. Look in Section III for the 3-day probabilities for X and M-class flares and SPE. Alternatively, check whether there are any Active Regions (sunspots) present using daily images at the SWAC **Space Weather Media Viewer**.

Also view the SOHO/MDI magnetograms to check on the magnetic complexity of these regions, and the professional write-up and classification on the SWPC Solar Region Summary page at **http://www.swpc.noaa.gov/ftpdir/latest/SRS.txt**. If the active regions show a classification of alpha or beta, the probability of a significant solar flare is low, but if the classification is gamma or delta, the probability is higher.

Because the moon has no magnetic field, magnetic storms caused by halo CMEs are not relevant, however ,halo CMEs can cause solar proton events which will be hazardous to lunar activities. The SOHO/LASCO images on the SWEAC Media Viewer or the current synoptic image archive at will indicate whether a coronal mass ejection has occurred. Only the halo events are potentially important, but only those that are Earth-directed. Backside halo events are of no concern. To distinguish whether a halo CME is front-side and potentially directed at earth, check for the detection of a radio burst at the SWPC page **http://www.swpc.noaa.gov/ftpdir/lists/radio/radio_bursts.txt**. If a burst was detected at the time of the halo event, then there is a high probability it will reach the moon. The speed of the CME can be determined from the succession of SOHO/LASCO images and compared to tabulated values for CME speeds to get a prediction for the number of transit hours to Earth.

Also check the SWPC, Space Weather Alerts archive **http://www.swpc.noaa.gov/alerts/archive.html** to look at the alerts posted for the previous 7 days based on a professional assessment of potential hazards.

Check list:

1) Solar active regions with gamma or higher classification
2) Halo CME eruption in the past day and determine speed and arrival time
3) Radio burst to discriminate between back-side halo and Earth-directed halo CME
4) Geomagnetic Kp and Dst indices indicating disturbed geomagnetic conditions

Long-term Trends:

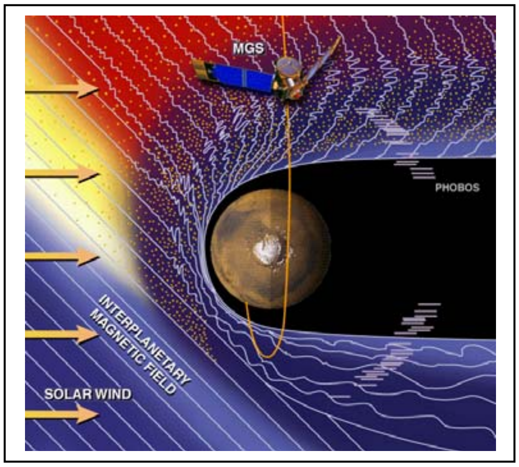
These have more to do with what part of the sunspot cycle you are in. Generally, during the sunspot-minimum years, there is a low risk for M and X-flares, solar proton events and CMEs of all types. By the time you are 2-years from sunspot maximum, the monthly risk for strong geomagnetic storms and X or M-class solar flares increases significantly, and remains high for most of the years after sunspot maximum. Cosmic ray fluxes are highest during sunspot minimum, and unlike Earth, activities on the lunar surface are **not** shielded from most of the high-energy particles so radiation exposure is fairly high and constant. During sunspot maximum, high fluxes of cosmic rays are considerably lower, but shielding will still be required to reduce overall cumulative exposure.

Check list:

1) Determine current year of the sunspot cycle
2) Within 2 years of sunspot minimum cosmic rays high, CME and flare probabilities low
3) Within 2 years of sunspot maximum cosmic rays low, CME and flare probabilities high

Images courtesy NASA/Apollo and National Space Society (LUNOX The NASA/JSC "LUNOX" proposal from 1993) http://www.nss.org/settlement/moon/LUNOX.html

Missions to Mars



These are long-duration journeys outside Earth's magnetic field. Cosmic rays are a constant background contributing to a steady increase in human dosages. More access to CME plasma will occur as the orbits traverse a lager volume of space through which CMEs are known to travel. As the spacecraft distance from Earth increases, astronauts will be less and less able to rely on the vantage points provided by earth-based satellite observations of the sun (SOHO etc) to help forecast upcoming events unless they bring similar imaging technology with them.

Basic Resources You Will Need:

SWAC-Space Weather Action Center http://sunearthday.nasa.gov/swac/data.php
Media Viewer http://sunearth.gsfc.nasa.gov/spaceweather/FlexApp/bin-debug/index.html#
SWPC-Space Weather Prediction Center http://www.swpc.noaa.gov/

These resources provide information about space weather conditions from the vantage point of Earth. To use for Mars forecasting, the location of Mars in its orbit relative to the position of Earth must be determined and allowed-for. In the following discussions, we assume that Mars is located in the same orbital quadrant as Earth.

Mars lacks a magnetosphere, so there will be no need to forecast the equivalent of geomagnetic storms. Only solar flares, solar proton events and cosmic rays are relevant hazards. On the surface of Mars, the dilute atmosphere provides modest shielding from some of the solar proton event particles, but secondary particles produced by the air showers can still elevate the total radiation dosage for space suited astronauts on the surface.

Space Conditions Now:

The prediction for X and M-class solar flares follows those steps used for Earth space weather forecasting. These have no direct human health consequences. The forecasting of these flare events is to anticipate solar proton events, which will have a larger human impact since mars has no large-scale magnetic field to provide even modest shielding from some of the high-energy particles. As for earth space weather forecasting, all X-class flares should be considered as potential warning for solar proton showers which may arrive at Mars within an hour or so after the x-ray flare emission arrives.

Space Conditions in the Next Few Days:

Successful predictions of local space weather conditions within the next few days depend on a detailed knowledge of solar surface conditions. Solar flare forecasts are provided by SWPC in their '3-day forecast' at **http://www.swpc.noaa.gov/forecast.htmlLong-term Trends:** page. Look in Section III for the 3-day probabilities for X and M-class flares and SPE. Alternatively, check whether there are any Active Regions (sunspots) present using daily images at the SWAC **Space Weather Media Viewer**.

Also view the SOHO/MDI magnetograms to check on the magnetic complexity of these regions, and the professional write-up and classification on the SWPC Solar Region Summary page at **http://www.swpc.noaa.gov/ftpdir/latest/SRS.txt**. If the active regions show a classification of alpha or beta, the probability of a significant solar flare is low, but if the classification is gamma or delta, the probability is higher.

Because Mars has no magnetic field, magnetic storms caused by halo CMEs are not relevant, however, halo CMEs can cause solar proton events which will be hazardous to lunar activities. The SOHO/LASCO images on the SWEAC Media Viewer or the current synoptic image archive at will indicate whether a coronal mass ejection has occurred. Only the halo events are potentially important, but only those that are Mars-directed. Backside halo events are of no concern. To distinguish whether a halo CME is front-side and potentially directed at Mars, check for the detection of a radio burst at the SWPC page **http://www.swpc.noaa.gov/ftpdir/lists/radio/radio_bursts.txt**. If a burst was detected at the time of the halo event, by measurements made at Earth, then there is a high probability it will reach mars some hours after it is detected at Earth through its inevitable geomagnetic effects. The speed of the CME can be determined from the succession of SOHO/LASCO images and compared to tabulated values for CME speeds to get a prediction for the number of transit hours to mars.

Also check the SWPC, Space Weather Alerts archive **http://www.swpc.noaa.gov/alerts/archive.html** to look at the alerts posted for the previous 7 days based on a professional assessment of potential hazards.

Check list:

1) Solar active regions with gamma or higher classification
2) Halo CME eruption in the past day and determine speed and arrival time
3) Radio burst to discriminate between back-side halo and Mars-directed halo CME
4) Geomagnetic Kp and Dst indices indicating disturbed geomagnetic conditions have reached Earth and the CME is likely in transit to Mars.

Long-term Trends:

These have more to do with what part of the sunspot cycle you are in. Generally, during the sunspot-minimum years, there is a low risk for M and X-flares, solar proton events and CMEs of all types. By the time you are 2-years from sunspot maximum, the monthly risk for strong geomagnetic storms and X or M-class solar flares increases significantly, and remains high for most of the years after sunspot maximum. Cosmic ray fluxes are highest during sunspot minimum, and unlike Earth, activities on the lunar surface are **not** shielded from most of the high-energy particles so radiation exposure is fairly high and constant. During sunspot maximum, high fluxes of cosmic rays are considerably lower, but shielding will still be required to reduce overall cumulative exposure.

Check list:

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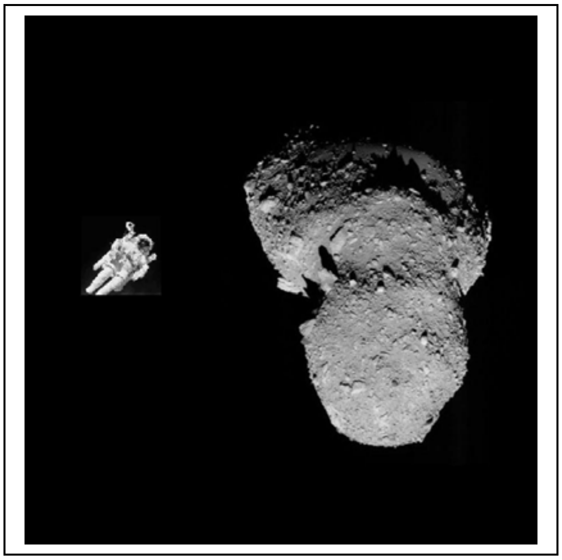
Asteroid Missions



Asteroids have no atmosphere or magnetic fields so space weather conditions for astronauts exploring these bodies is essentially that of open space.

The inverse-square law will reduce the energy and particle fluxes from solar flares and solar proton events. Coronal mass ejection plasma and magnetic fields will also be slightly more diluted through expansion.

Basic Resources You Will Need:

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Media Viewer http://sunearth.gsfc.nasa.gov/spaceweather/FlexApp/bin-debug/index.html#
SWPC-Space Weather Prediction Center http://www.swpc.noaa.gov/

These resources provide information about space weather conditions from the vantage point of Earth. To use for asteroid forecasting, the location of the asteroid in its orbit relative to the position of Earth must be determined and allowed-for. In the following discussions, we assume that the asteroid is located in the same orbital quadrant as Earth.

Asteroids lack a magnetosphere, so there will be no need to forecast the equivalent of geomagnetic storms. Only solar flares, solar proton events and cosmic rays are relevant hazards. The conditions are those of open space.

Space Conditions Now:

The prediction for X and M-class solar flares follows those steps used for Earth space weather forecasting. These have no direct human health consequences. The forecasting of these flare events is to anticipate solar proton events, which will have a larger human impact since mars has no large-scale magnetic field to provide even modest shielding from some of the high-energy particles. As for Earth space weather forecasting, all X-class flares should be considered as potential warning for solar proton showers which may arrive at the asteroid within an hour or so after the x-ray flare emission arrives.

Space Conditions in the Next Few Days:

Successful predictions of local space weather conditions within the next few days depend on a detailed knowledge of solar surface conditions. Solar flare forecasts are provided by SWPC in their '3-day forecast' at **http://www.swpc.noaa.gov/forecast.htmlLong-term Trends:** page. Look in Section III for the 3-day probabilities for X and M-class flares and SPE. Alternatively, check whether there are any Active Regions (sunspots) present using daily images at the SWAC **Space Weather Media Viewer**.

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Because asteroids have no magnetic fields, magnetic storms caused by halo CMEs are not relevant, however, halo CMEs can cause solar proton events which will be hazardous to lunar activities. The SOHO/LASCO images on the SWEAC Media Viewer or the current synoptic image archive at will indicate whether a coronal mass ejection has occurred. Only the halo events are potentially important, but only those that are asteroid-directed. Backside halo events are of no concern. To distinguish whether a halo CME is front-side and potentially directed at the asteroid, check for the detection of a radio burst at the SWPC page **http://www.swpc.noaa.gov/ftpdir/lists/radio/radio_bursts.txt**. If a burst was detected at the time of the halo event, by measurements made at Earth, then there is a high probability it will reach the asteroid some hours after it is detected at Earth through its inevitable geomagnetic effects. The speed of the CME can be determined from the succession of SOHO/LASCO images and compared to tabulated values for CME speeds to get a prediction for the number of transit hours to mars.

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Check list:

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2) Halo CME eruption in the past day and determine speed and arrival time
3) Radio burst to discriminate between back-side halo and asteroid-directed halo CME
4) Geomagnetic Kp and Dst indices indicating disturbed geomagnetic conditions have reached Earth and the CME is likely in transit to the asteroid.

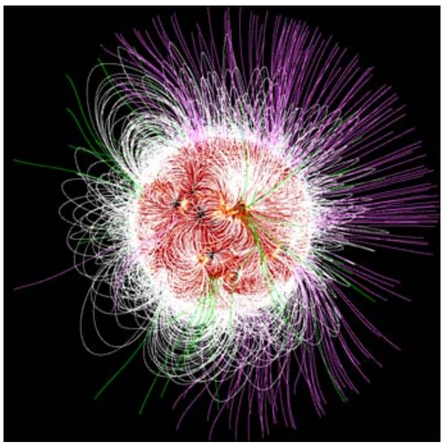
<u>Long-term Trends:</u>

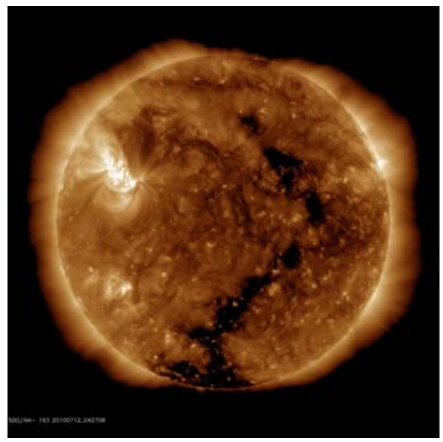
These have more to do with what part of the sunspot cycle you are in. Generally, during the sunspot-minimum years, there is a low risk for M and X-flares, solar proton events and CMEs of all types. By the time you are 2-years from sunspot maximum, the monthly risk for strong geomagnetic storms and X or M-class solar flares increases significantly, and remains high for most of the years after sunspot maximum. Cosmic ray fluxes are highest during sunspot minimum, and unlike Earth, activities on the asteroid surface are **not** shielded from most of the high-energy particles so radiation exposure is fairly high and constant. During sunspot maximum, high fluxes of cosmic rays are considerably lower, but shielding will still be required to reduce overall cumulative exposure.

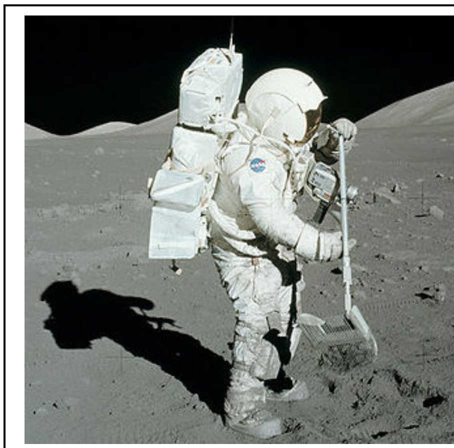
Check list:

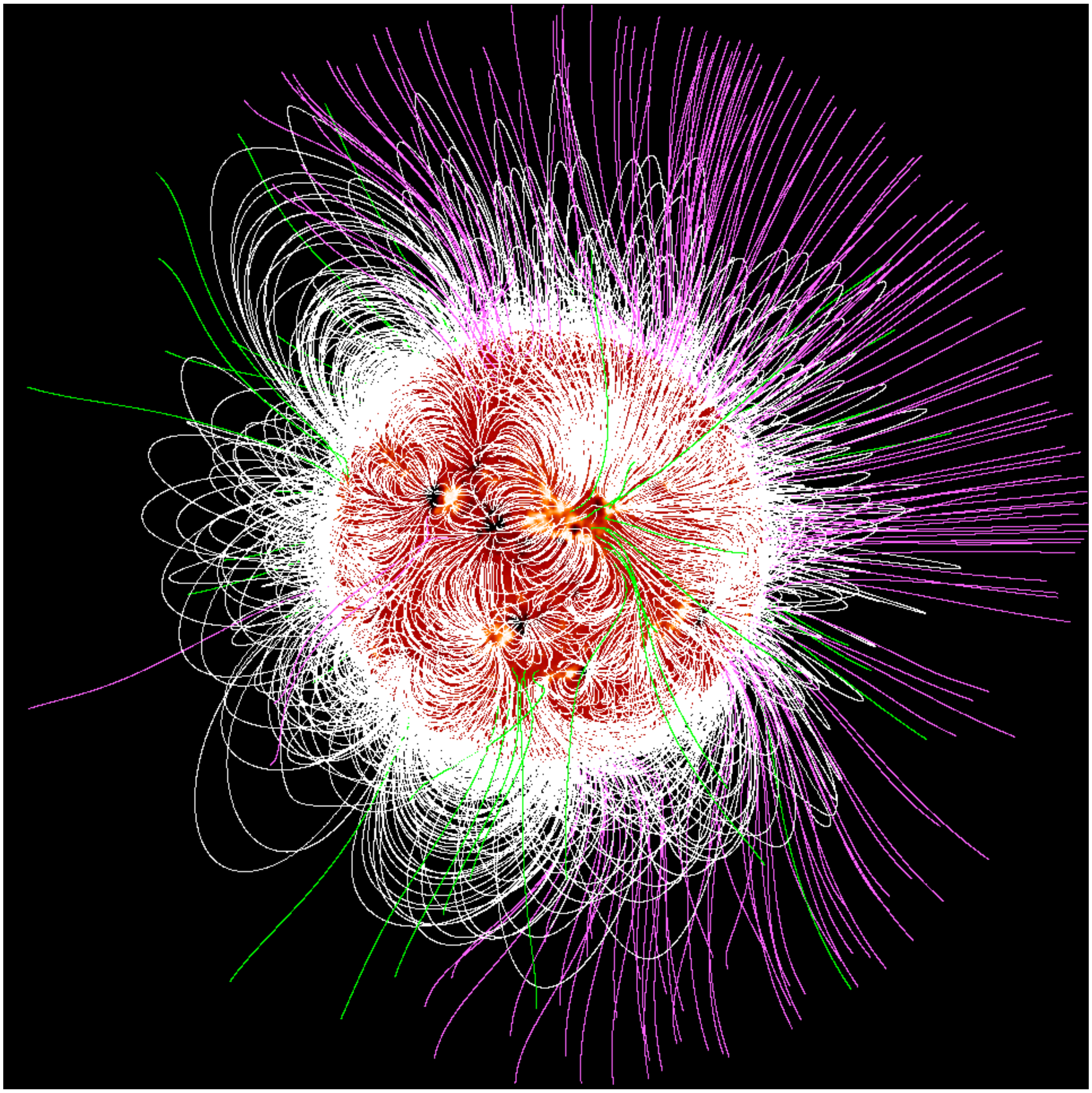
1) Determine current year of the sunspot cycle
2) Within 2 years of sunspot minimum cosmic rays high, CME and flare probabilities low
3) Within 2 years of sunspot maximum cosmic rays low, CME and flare probabilities high

A Gallery of Space Weather Imagery



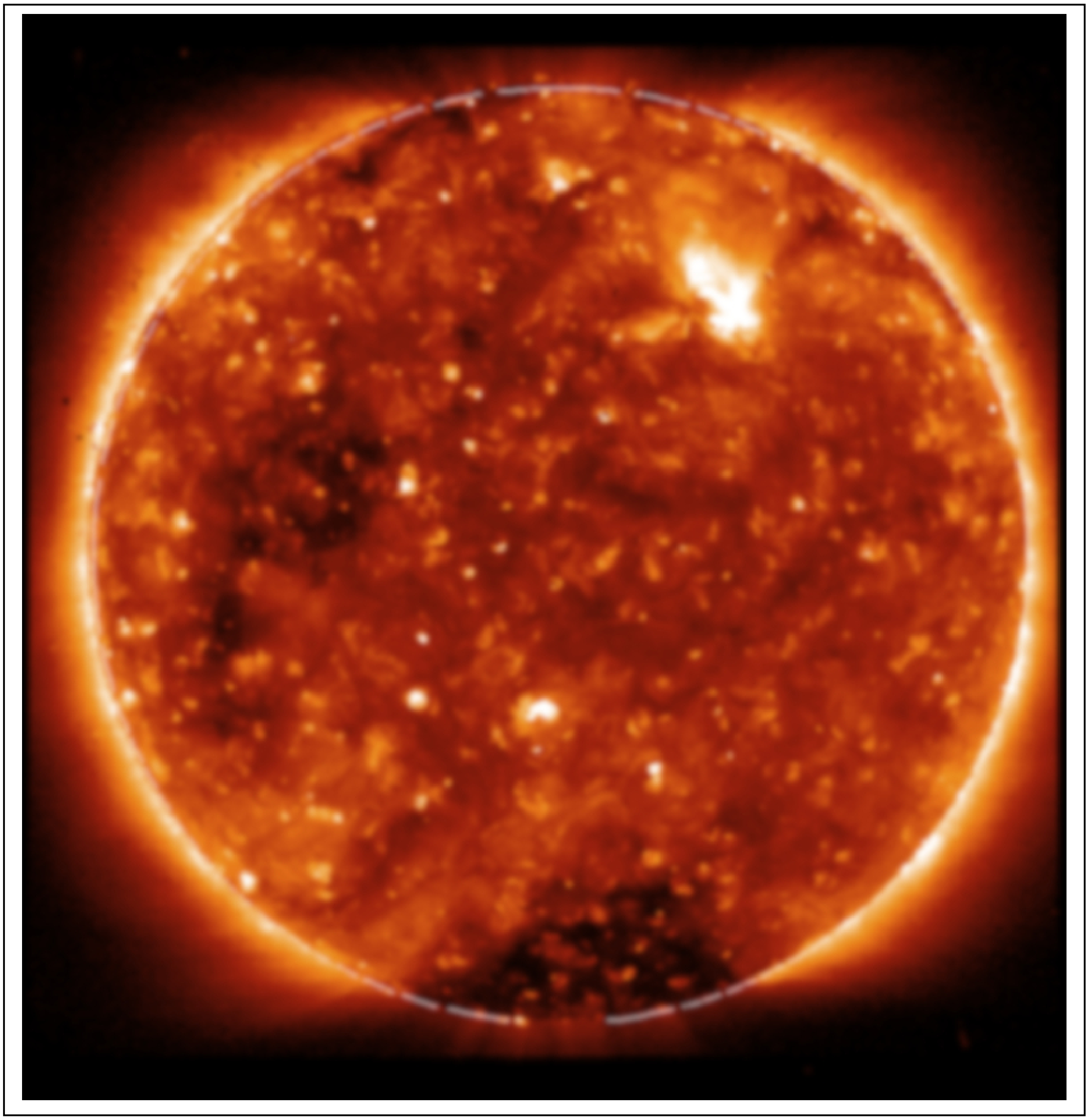






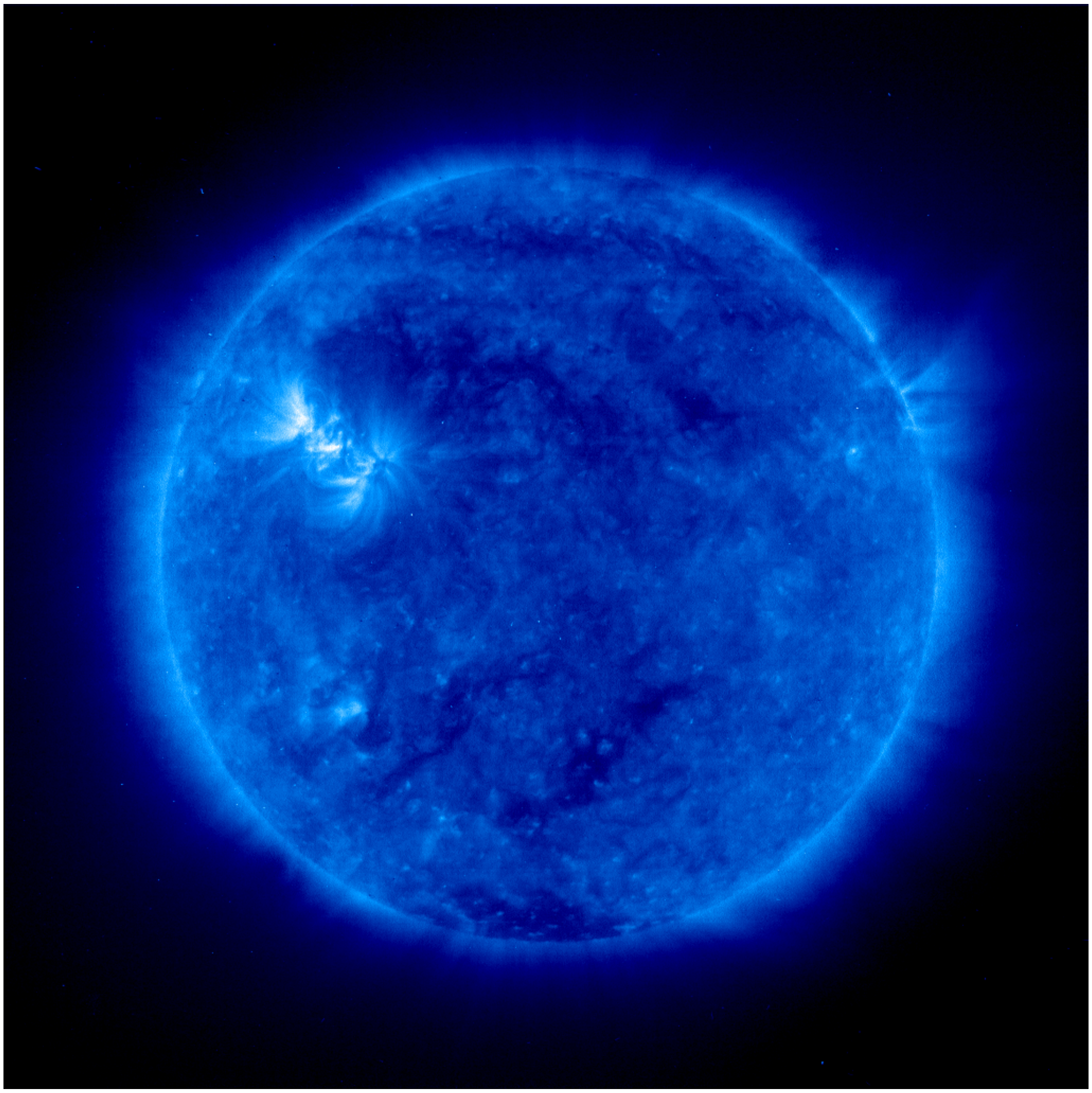
The Solar Magnetic Field

The above model was generated using one of the most advanced computer models of the solar corona in the World. It was produced at the Lockheed Martin Solar and Astrophysics Laboratory by solar astronomers Drs Markus Aschwanden, Marc DeRosa and Carolus Schrijver. This model reproduces the structure of the solar coronal magnetic field as it appeared on 21 October 2000



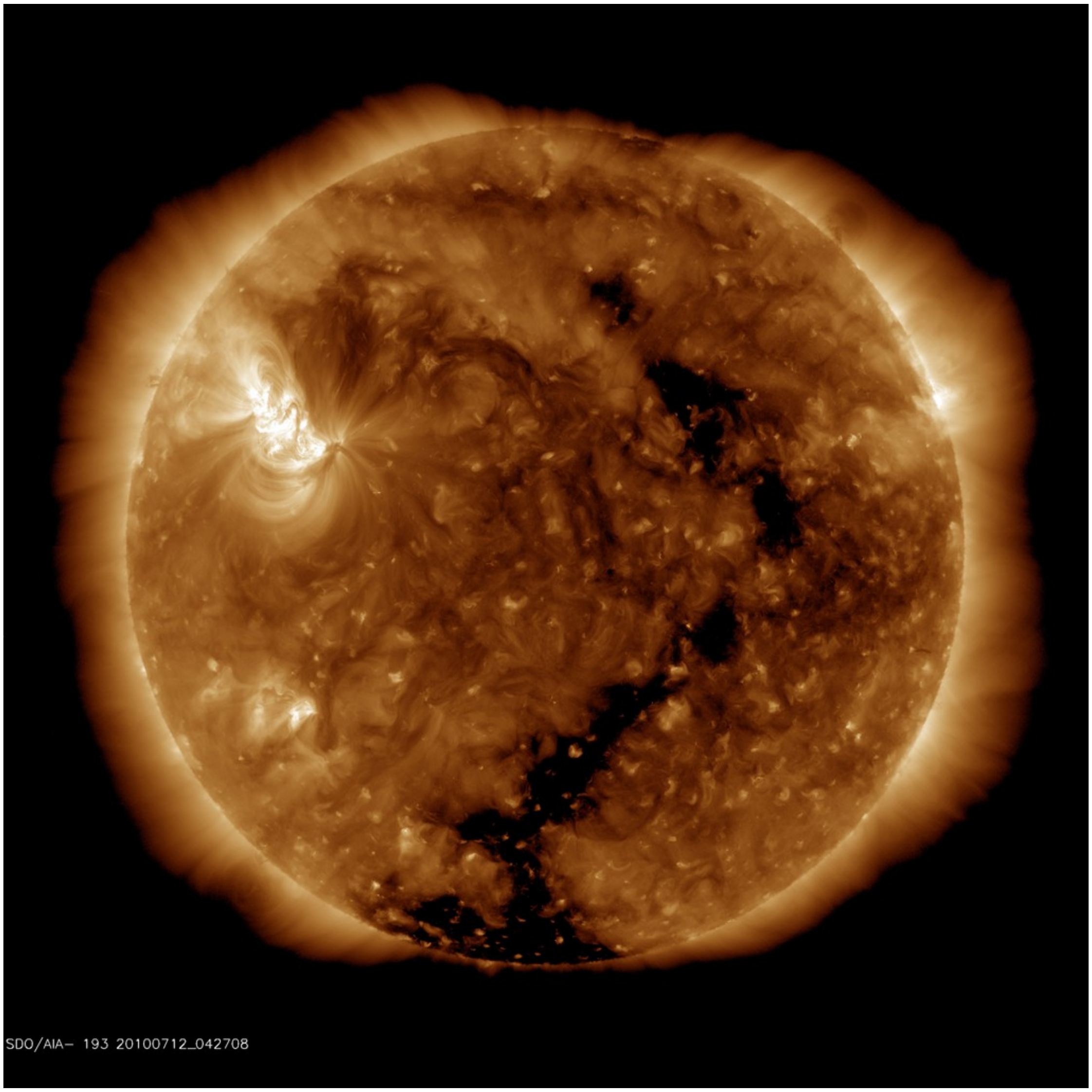
X-ray Image of the Sun

This image of the X-ray emissions from the sun was taken on April 3, 2009 by the Hinode satellite. It shows the locations of plasma heated to over 1 million C in the inner corona. The bright spots are flare-like regions above the solar photosphere where tangled magnetic fields are releasing energy. The entire surface is freckled by thousands of these spots of energy at all times during the sunspot cycle, and may be the source of energy heating the corona itself.



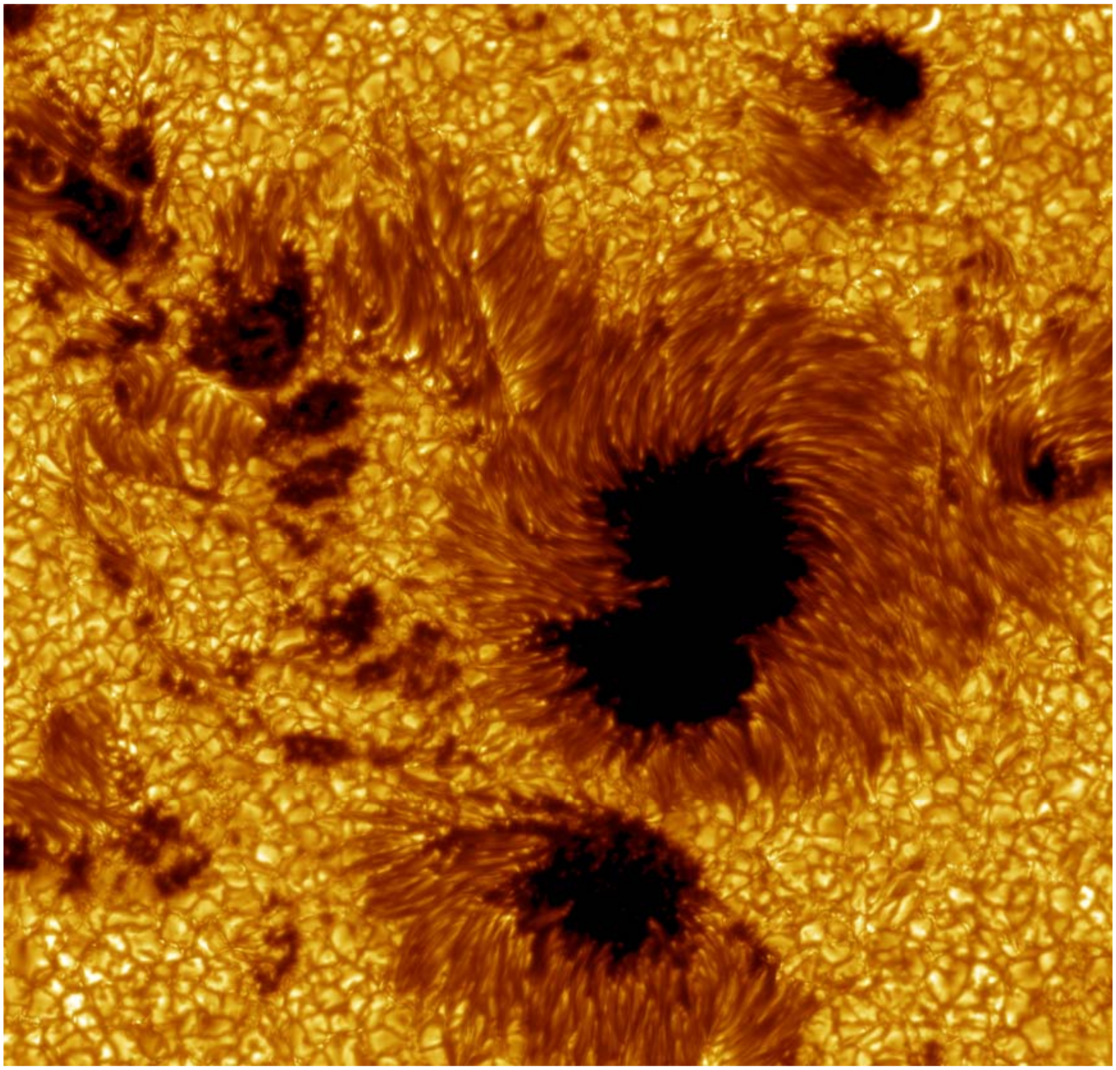
Ultraviolet Image of the Sun

UV image showing the prominent active region AR 1087 taken by the SOHO/EIT camera at 171 Angstroms on July 12, 2010. It shows the location of an active region with its spectacular magnetic field.



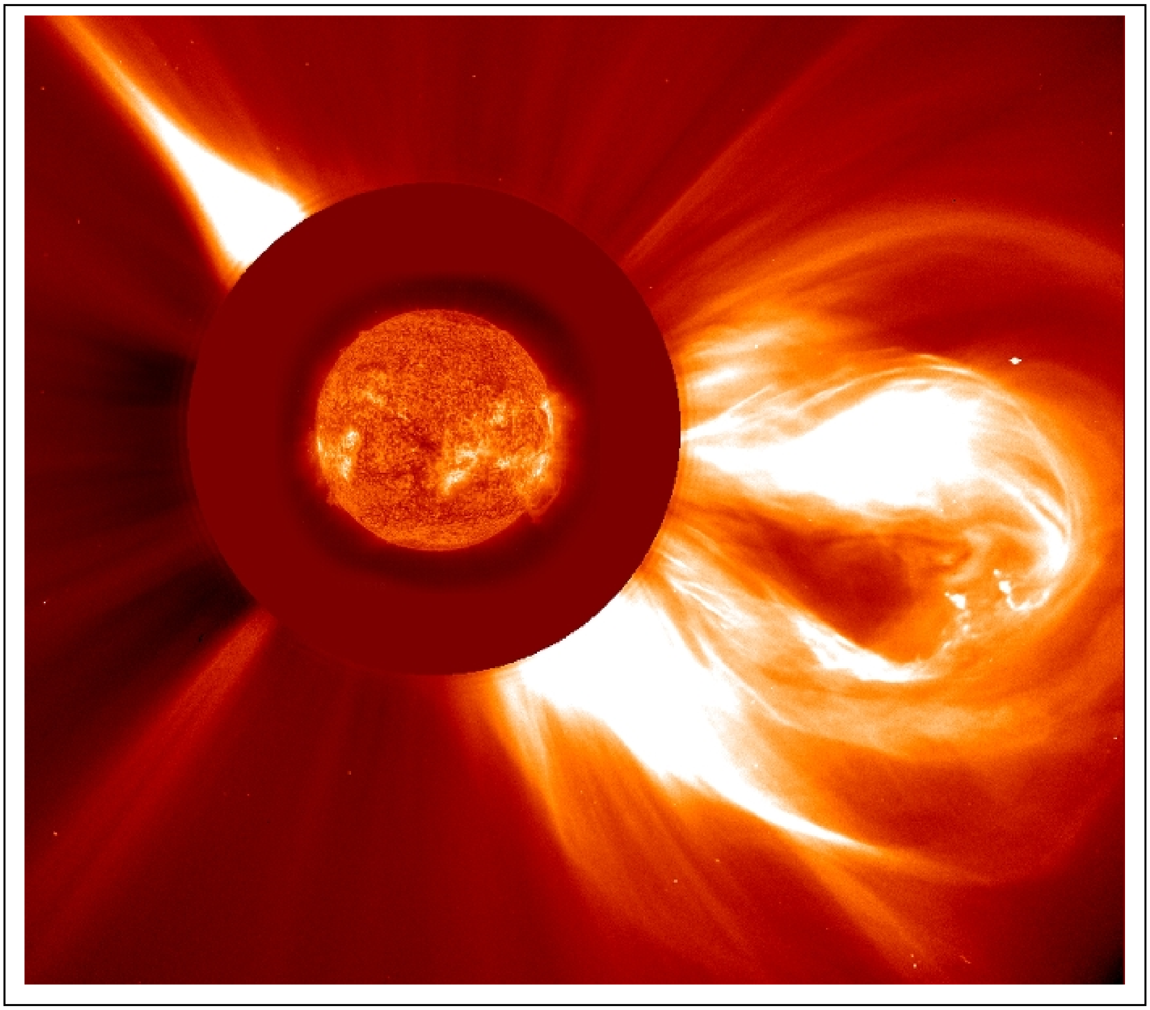
Coronal Hole

A coronal hole seen by the Solar Dynamics Observatory AIA imager on July 12, 2010 at 193 Angstroms. The corona consists of plasma heated to over 1 million degrees C, which emits copious amounts of X-ray light. The magnetic fields mostly close back upon the surface, keeping these plasmas close to the sun (gold colored areas). However, some regions of magnetic field open out into the interplanetary medium so that the hot plasma can escape. The result is the dark X-ray poor regions known as coronal holes. These are also the origins for high-speed solar wind streams that can produce magnetic storms on Earth if our planet in its orbit happens to be located within these zones.



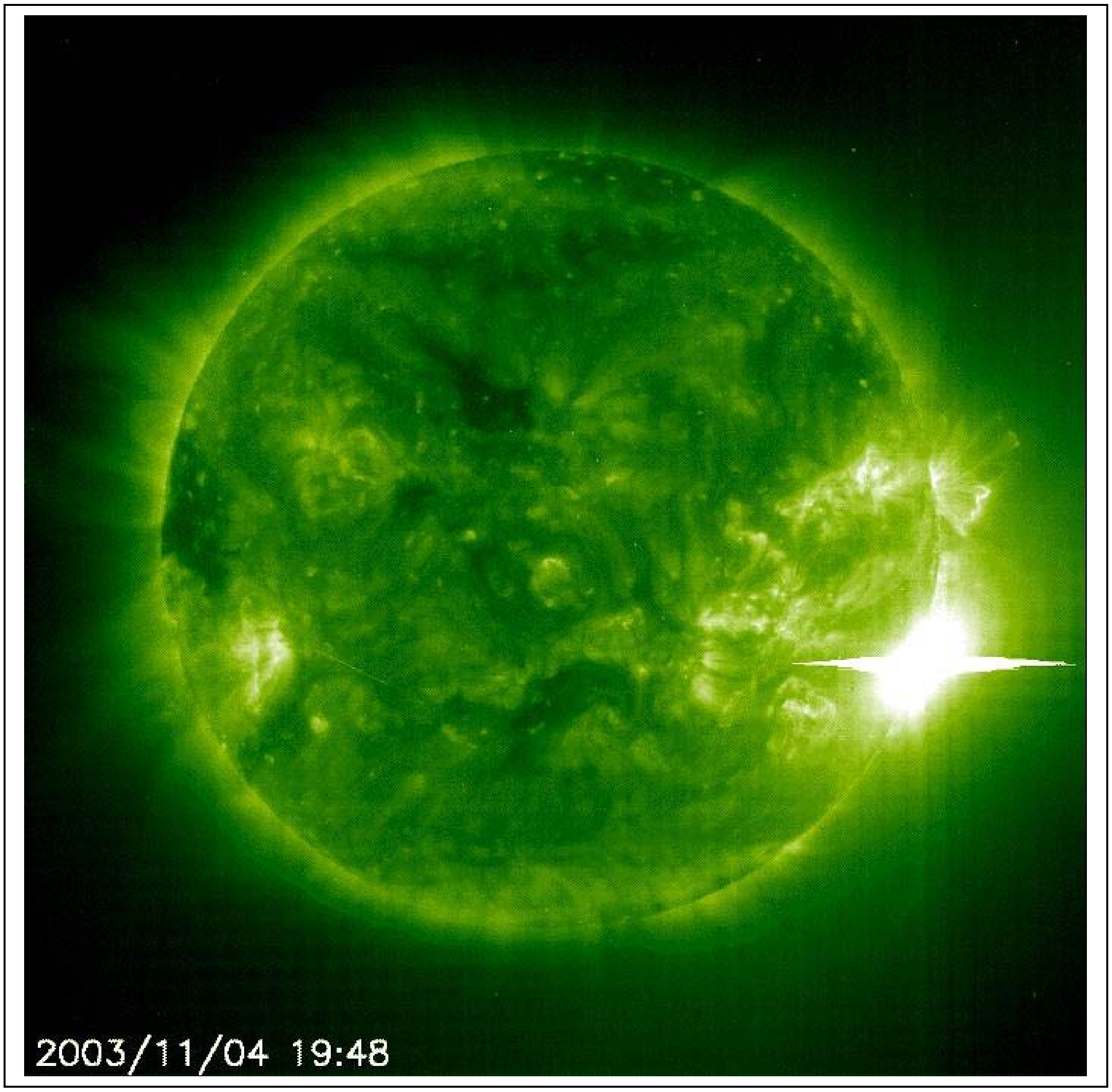
Sunspot Details

Active region AR10030 (July 15, 2002) imaged with the 1-meter, Swedish Vacuum Telescope. Granulation cells on the solar photosphere are clearly seen, along with details within the penumbras (light areas) and umbras (dark areas) of several sunspots. (Royal Swedish Academy of Sciences Institute for Solar Physics: Göran Scharmer) http://www.solarphysics.kva.se/



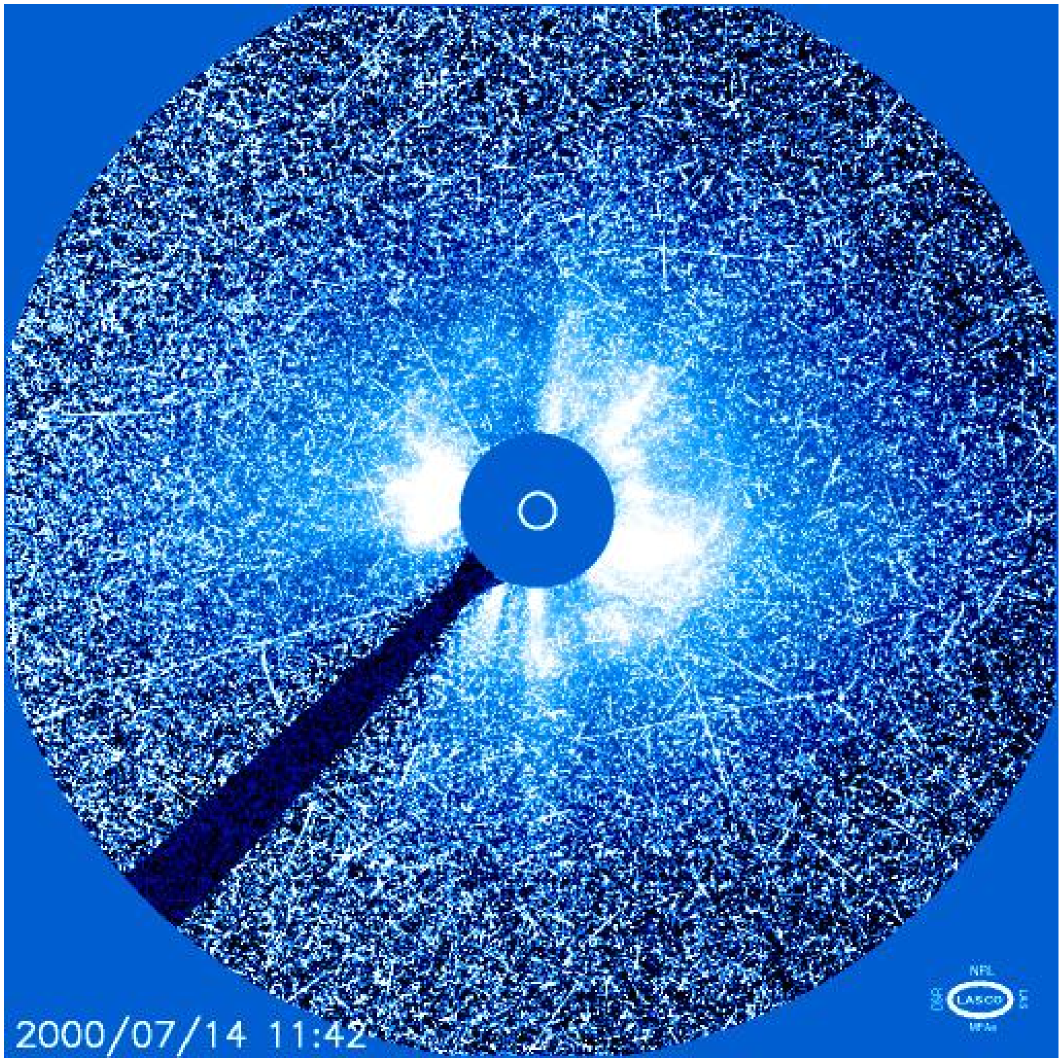
Coronal Mass Ejection

A dramatic Coronal Mass Ejection imaged by the SOHO/LASCO instrument. Ejected from the solar surface, these enormous clouds of plasma and magnetic fields can travel several million kilometers an hour and contain billions of tons of matter. Although this 'CME' is headed away from Earth's direction, of the many thousands of CMEs produced each sunspot cycle, hundreds can be aimed towards Earth and when they arrive, cause spectacular geomagnetic disturbances ,which can be seen as aurora.



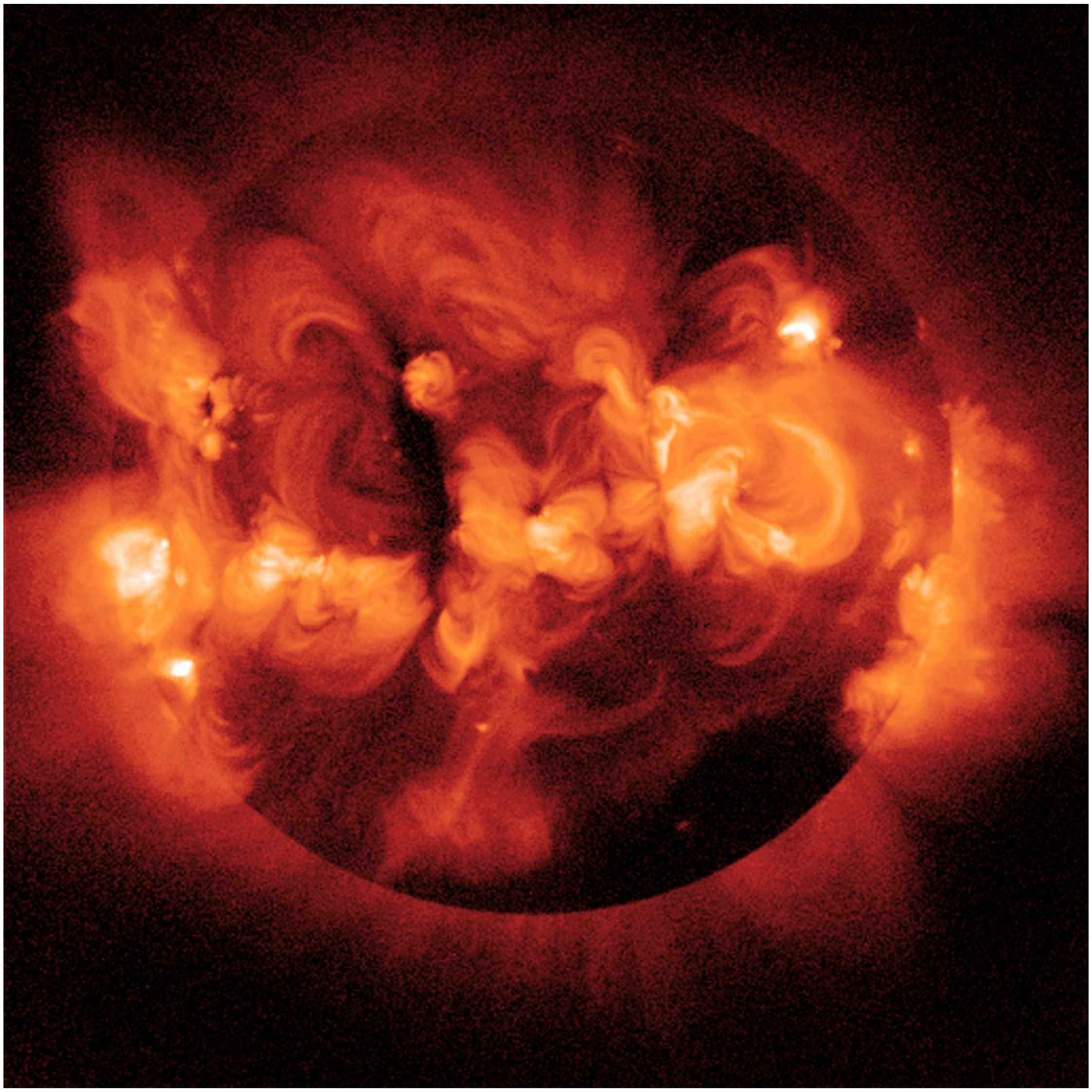
Solar Flare

This enormous solar flare on November 4, 2003 caught by the SOHO / EIT imager was one of the largest solar flares seen in the last 50 years, and classified as 'X28'. The x-ray energies heated up the upper atmosphere of Earth for hours, causing satellites to alter their orbits due to atmospheric drag.



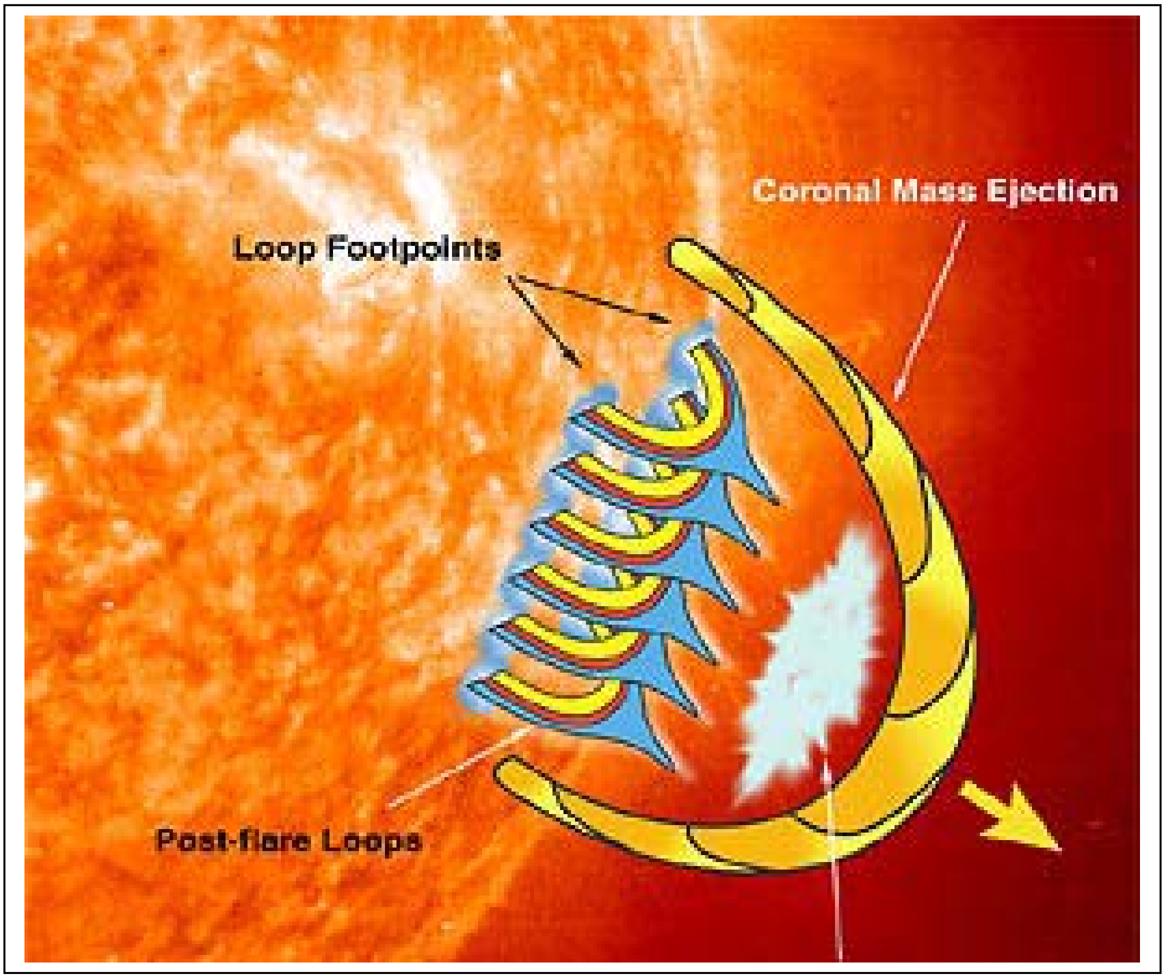
Solar Proton Event

This Solar Proton Event during the Bastille Day storm July 14, 2000 caused streaks in the imaging system on the SOHO satellite. Similar particle effects can cause satellite anomalies as critical memory locations are temporarily corrupted, causing false commands to be recorded by Earth-orbiting satellites. Just as for your home computer, satellite computers often have to be 're-booted' to correct these temporary problems.



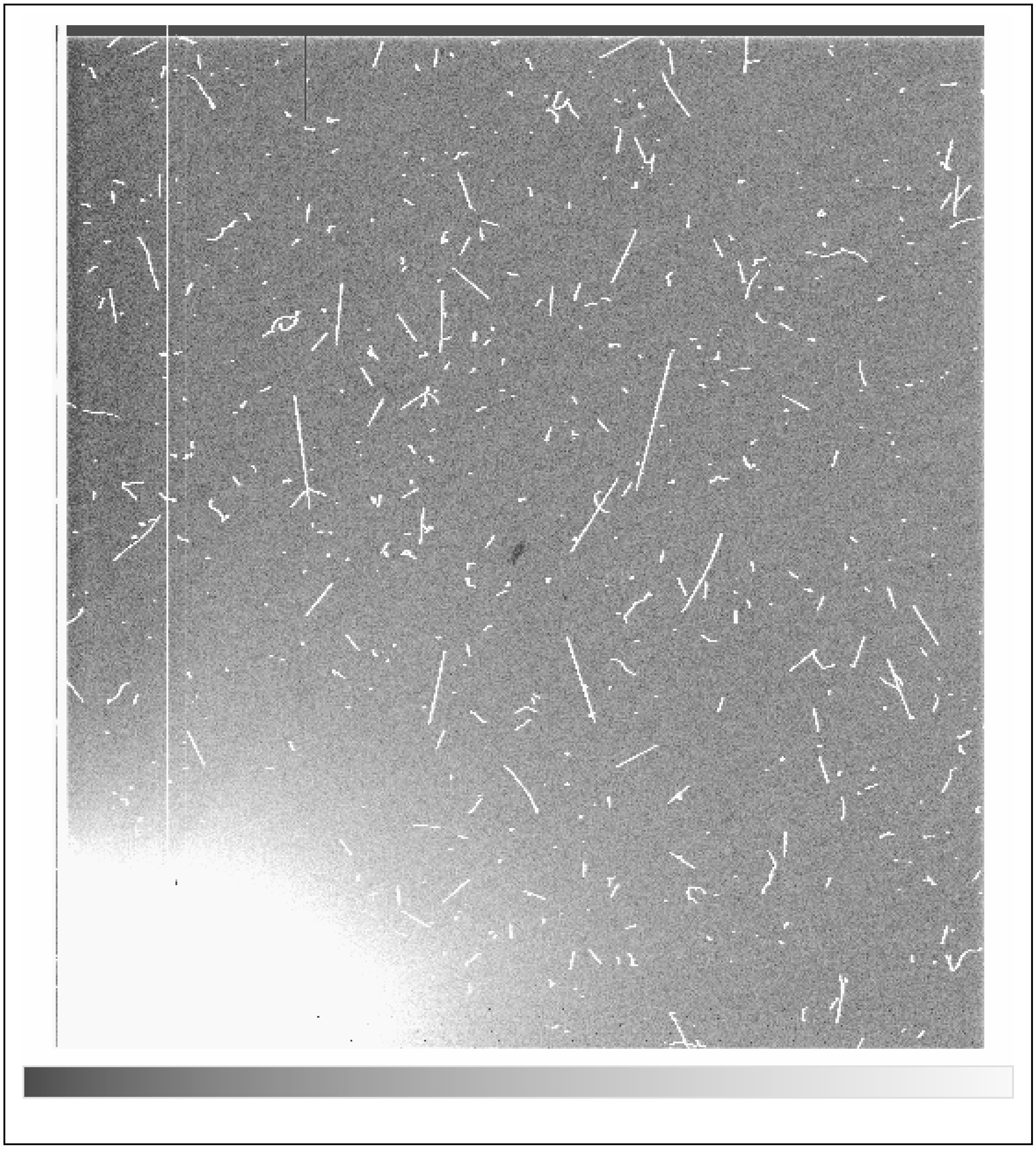
Solar Corona in X-rays

Complex coronal structures images by the Yohkoh satellite during sunspot maximum reveal a complex corona whose structure is dramatically affected by active regions on the solar surface.



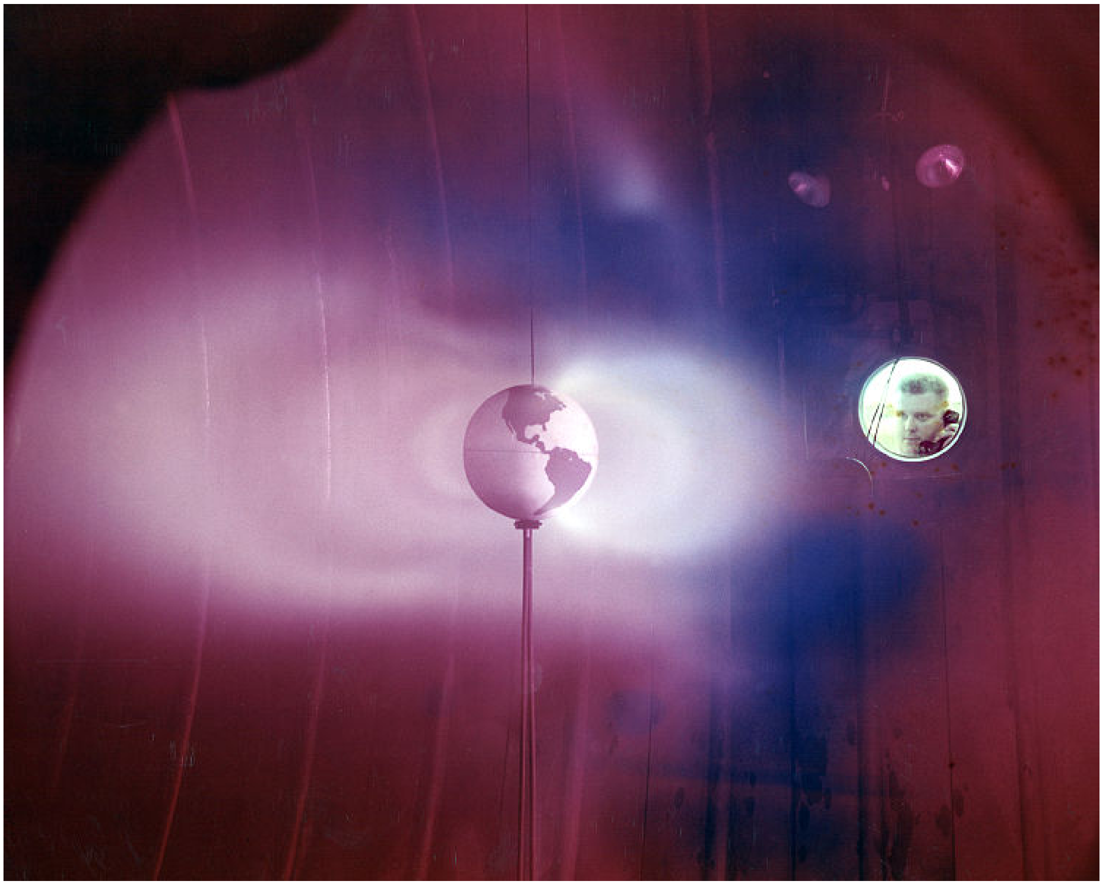
Model of a Solar Flare

A sketch of a solar flare and coronal mass ejection (NASA/RHESSI) shows the many detailed parts of the magnetic phenomenon, including an unstable 'hedgerow' of magnetic loops whose explosive reconnection causes overlying magnetized plasma to be ejected as a coronal mass ejection. The entire process lasts only a few minutes, but spans millions of square kilometers of surface area. The energy release can exceed thousands of hydrogen bombs released simultaneously.



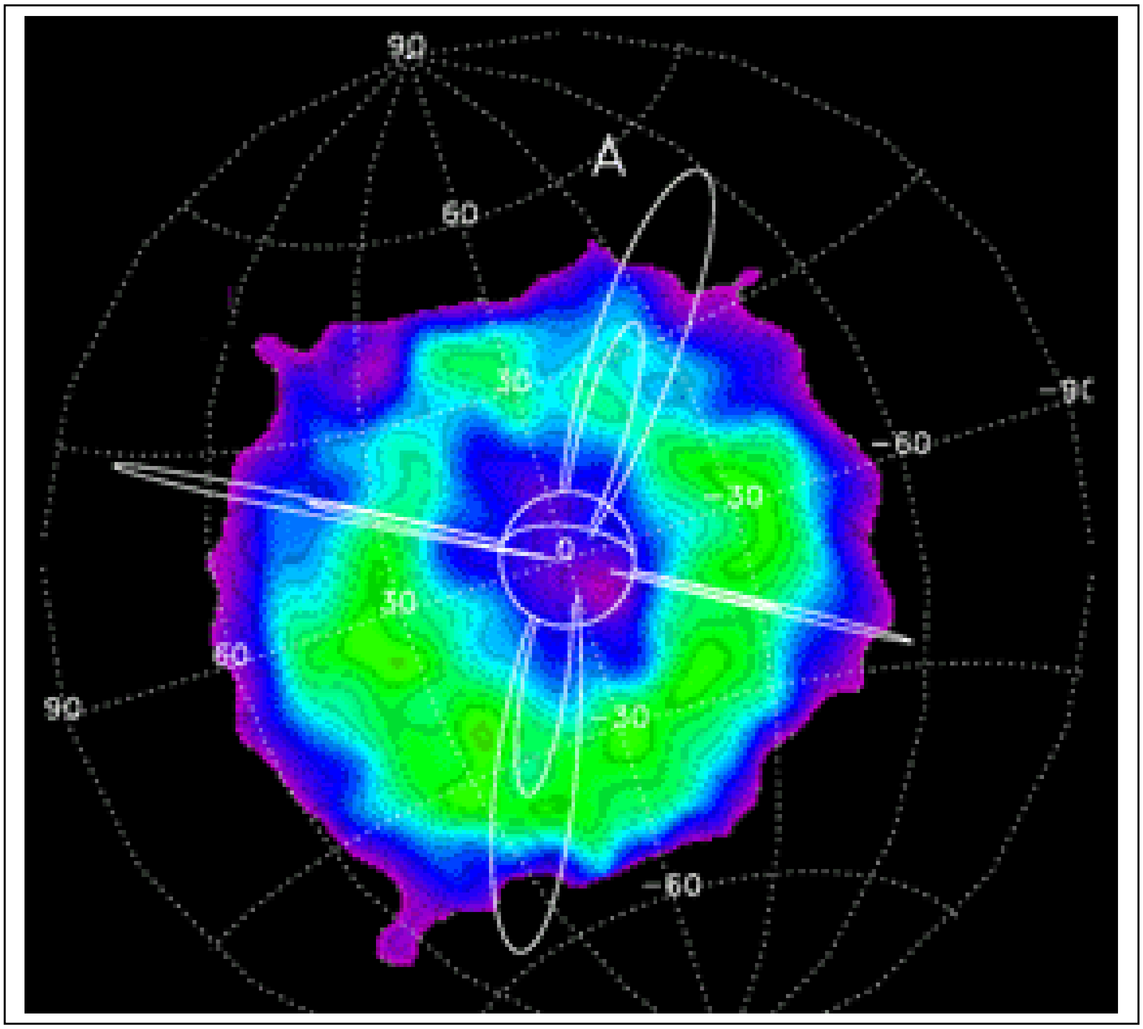
Cosmic Ray Tracks

A one-hour image taken with the shutter closed on the Mt Hopkins MMT telescope in Arizona showing numerous cosmic ray hits and tracks in the CCD detector in the Red Channel Spectrograph. A similar pattern of tracks can affect computer memory, causing satellites to misbehave. (Smithsonian Astrophysical Observatory: http://www.mmto.org/)



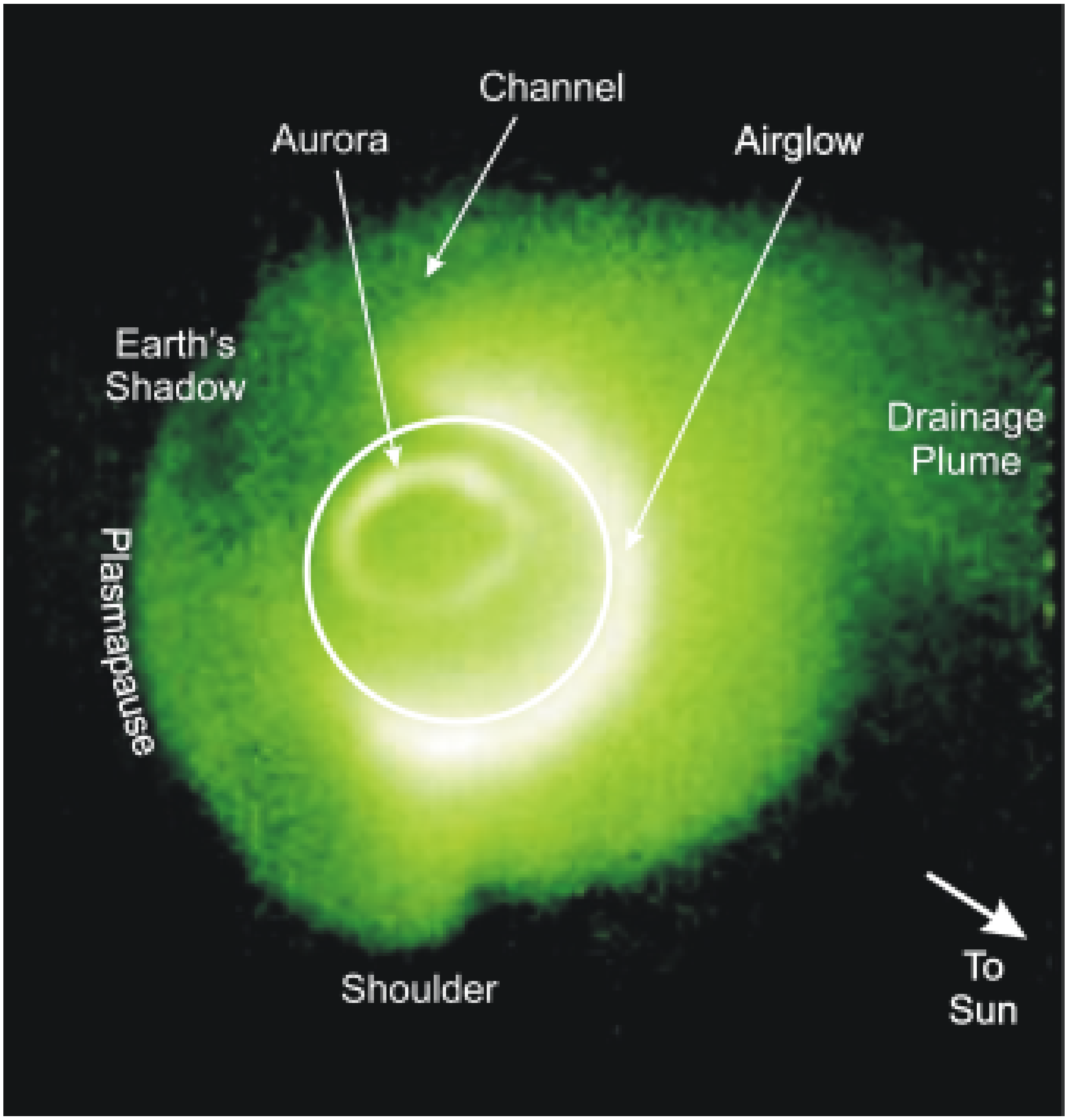
Simulated Van Allen Belts

Simulated Van Allen Belts generated by a plasma thruster in Tank #5 of the Electric Propulsion Laboratory at the Lewis Research Center, Cleveland Ohio, now John H. Glenn Research Center at Lewis Field. Charged particles follow the magnetic field of the modeled Earth in a manner analogous to the way that high-energy electrons and protons are trapped within Earth's van Allen belts.



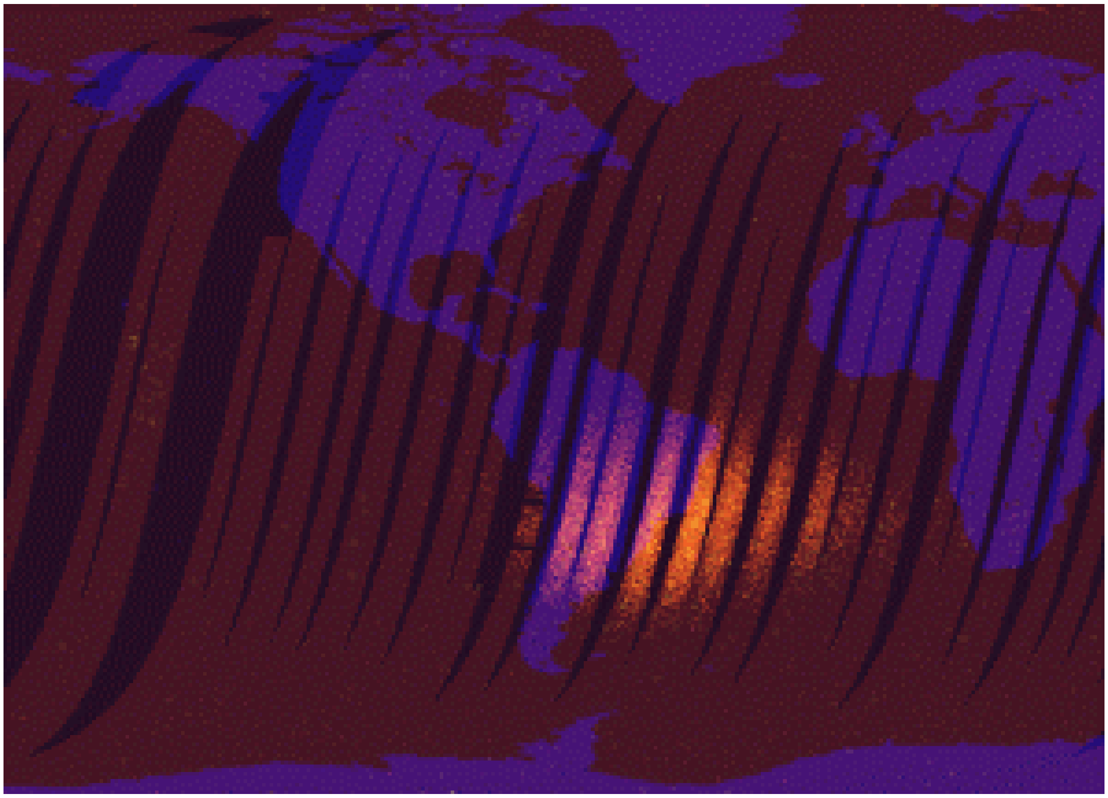
The Ring Current

This image shows energetic neutral atom (ENA) emissions from the Earth's ring current, as seen with the High Energy Neutral Atom (HENA) on NASA's IMAGE spacecraft. The false color indicates the intensity of the ENA emissions. This image was acquired at 21:18 UT on 9 June 2000 during the recovery stage of a geomagnetic storm that began on 8 June. The view is toward Earth's north pole from an altitude of 5 Earth radii. The relative size and position of the Earth are indicated by the white circle. Pairs of representative field lines (extending to 4 and 8 Earth radii respectively) are shown at (clockwise from top) local midnight, dusk, noon, and dawn.



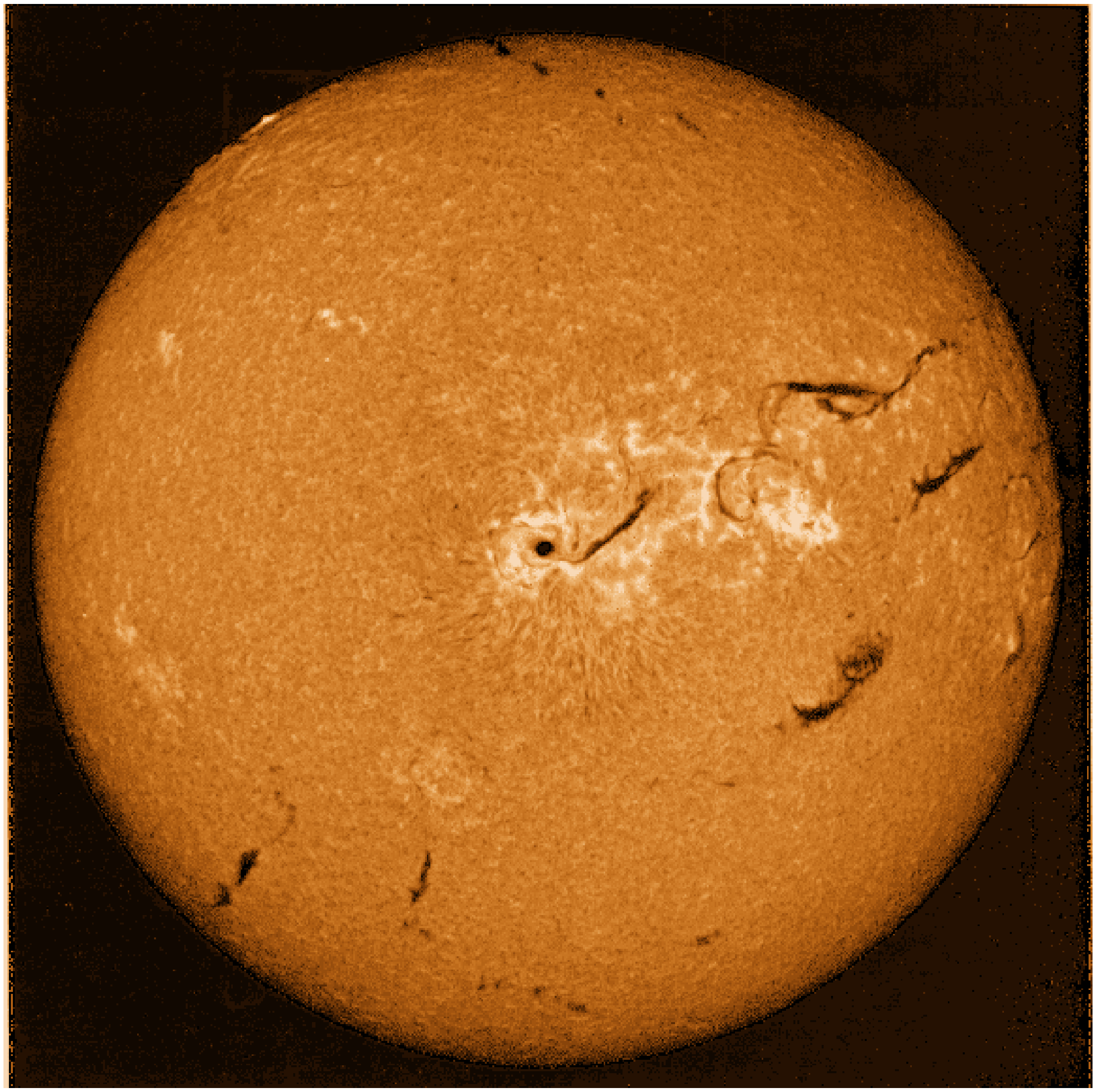
The Plasmasphere

Earth's plasmasphere at 30.4 nm. This image from the Extreme Ultraviolet Imager on the IMAGE satellite was taken at 07:34 UTC on 24 May 2000, at a range of 6.0 Earth radii from the center of Earth and a magnetic latitude of 73 N. The Sun is to the lower right, and Earth's shadow extends through the plasmasphere toward the upper left. The bright ring near the center is an aurora, and includes emissions at wavelengths other than 30.4 nm. (Courtesy B.R. Sandel, IMAGE/EUI)



South Atlantic Anomaly

This map was created by specially processing MISR "dark" data taken between 3 February and 16 February 2000, while the cover was still closed. Data from the red band of the most forward-looking MISR camera were geographically projected over a map of Earth's land areas. The South Atlantic Anomaly (SAA) is a region of unusually high proton levels. Because proton "hits" even in the SAA are relatively infrequent, each picture element of the map shows the most extreme "outliers" resulting from proton hits, rather than the average of all observations.



H-Alpha Sun

H-alpha image of the sun taken in the light from hydrogen atoms reveals many details not visible in ordinary 'white light' photographs. The dark filaments are cool dense plasma within prominences seen against the hotter solar surface. Also visible are the white areas called plagues where solar energy diverted from sunspots finally reaches the surface. (Courtesy National Solar Observatory/Sacramento Peak)

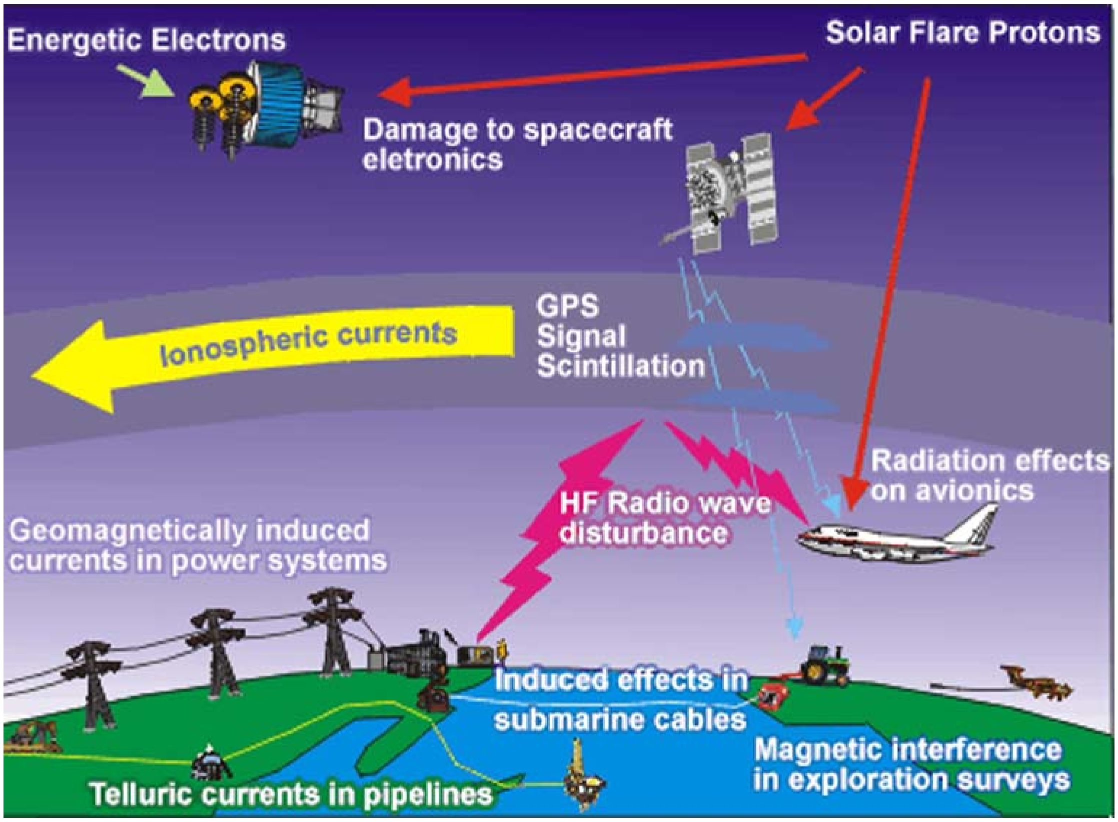
Global Positioning System (GPS III) Satellite

One of 30 other satellites orbiting Earth within the van Allen belts, this constellation forms the backbone of the high-precision position sensing system now commonly found in cars to give us accurate directions. By measuring the arrival times of radio signals from 4 GOPS satellites, the position of a GPS receiver can be determined on the surface of Earth to an accuracy of a few meters. During solar storms, however, this accuracy degrades to tens or even hundreds of meters for several hours at a time. (Lockheed Martin)

Geomagnetic Storm Induced Transformer Damage

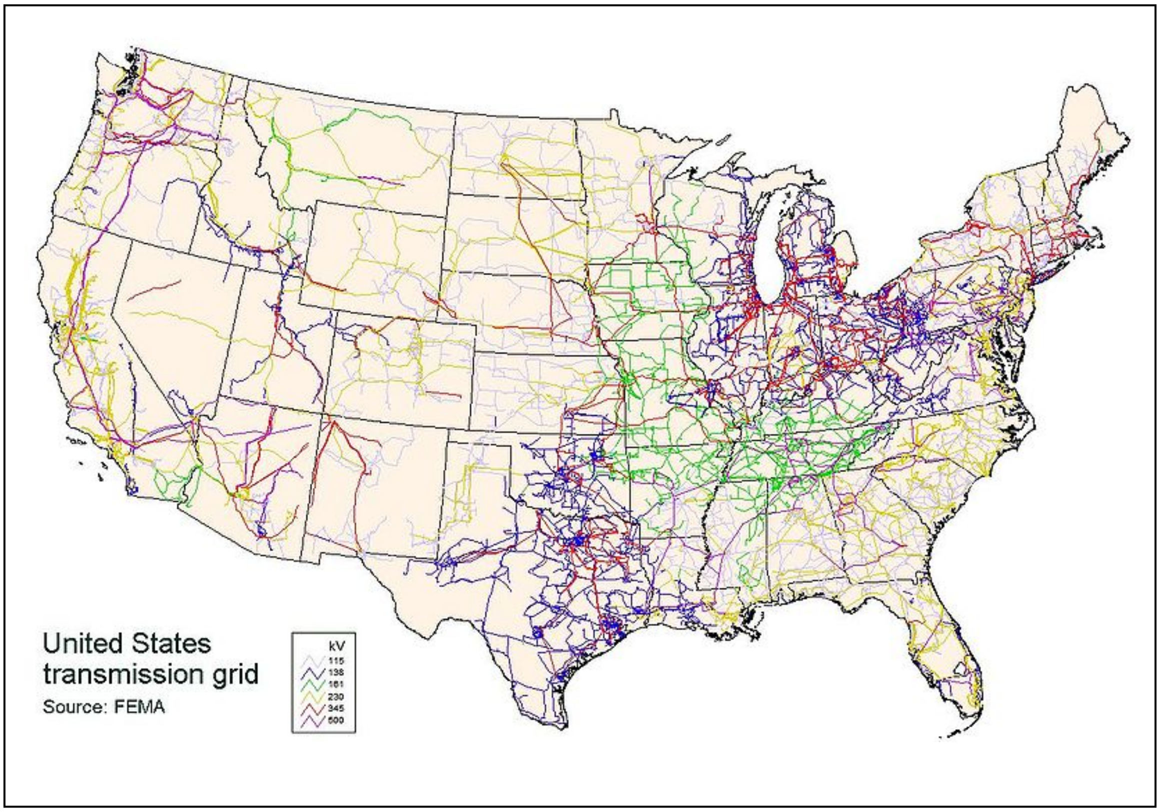
Transformer Damage

Transformer damage from March 1989 'Quebec Blackout' storm caused by ground currents .These currents flow up the 'ground wire' of transformers and can temporarily raise the core temperatures to over 300 C, causing burn out and explosive coolant evaporation. The added currents also cause the metal core elements to vibrate violently and deform.



Space Weather Effects

There are many technological systems affected by space weather conditions. This figure shows a few of them. (Courtesy: Dr. David Boteler; Canadian National Resources Council http://sst.rncan.gc.ca/rrnh-rran/proj3_e.php)



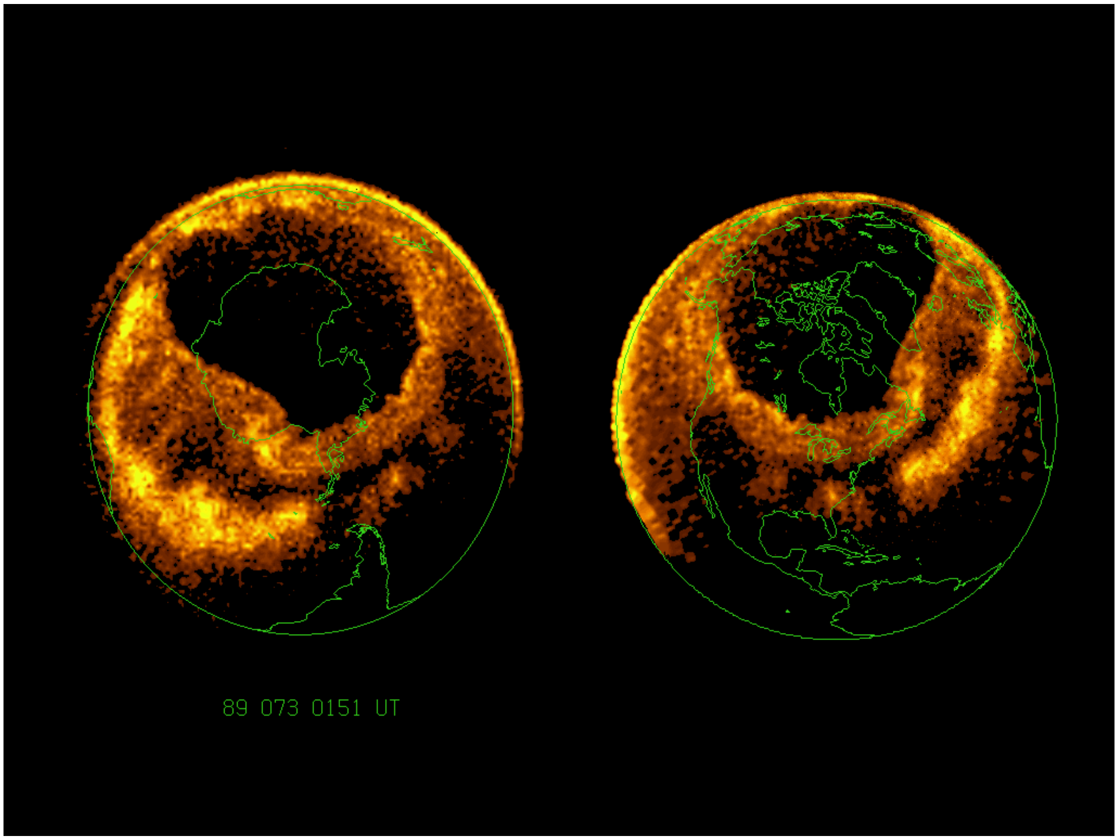
The US Power Grid

This enormous roadway for electrical power contains thousands of expensive transformers and a variety of different power line systems to move electricity from generation stations to distant users. This grid can be affected by geomagnetic storms because of the ground currents that can find their way into the grid through the transformers. This destabilizes the precise load-supply balances across the grid and can cause it to 'collapse;' in a blackout condition.

There are 5,400 electric power plants across the country. Every day, some 12,000 megawatt-hours of electricity flow across this grid to power our homes and industries. A typical US home consumes about 12,000 kilowatt-hours each year. About 80% is produced by burning fossil fuels.

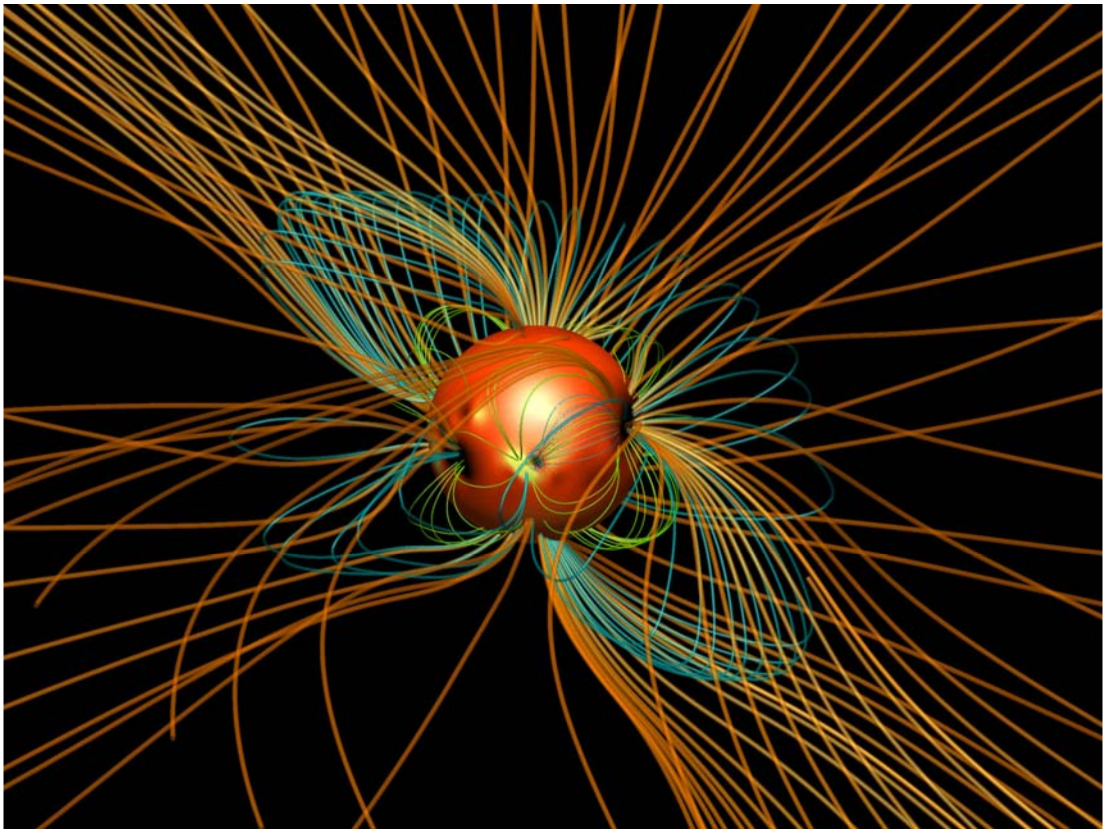
Aurora from Space

Astronaut Don Pettit took this image during Expedition 6 to the ISS in 2003. The International Space Station (ISS) orbits at nearly the same height as many aurora, sometimes passing over them, and sometimes right through them. Still, the auroral electron and proton streams pose no direct danger to the ISS. From orbit, Pettit reported that changing aurora appeared to crawl around like giant green amoebas. Over 300 kilometers below, the Manicouagan Impact Crater can be seen in northern Canada.



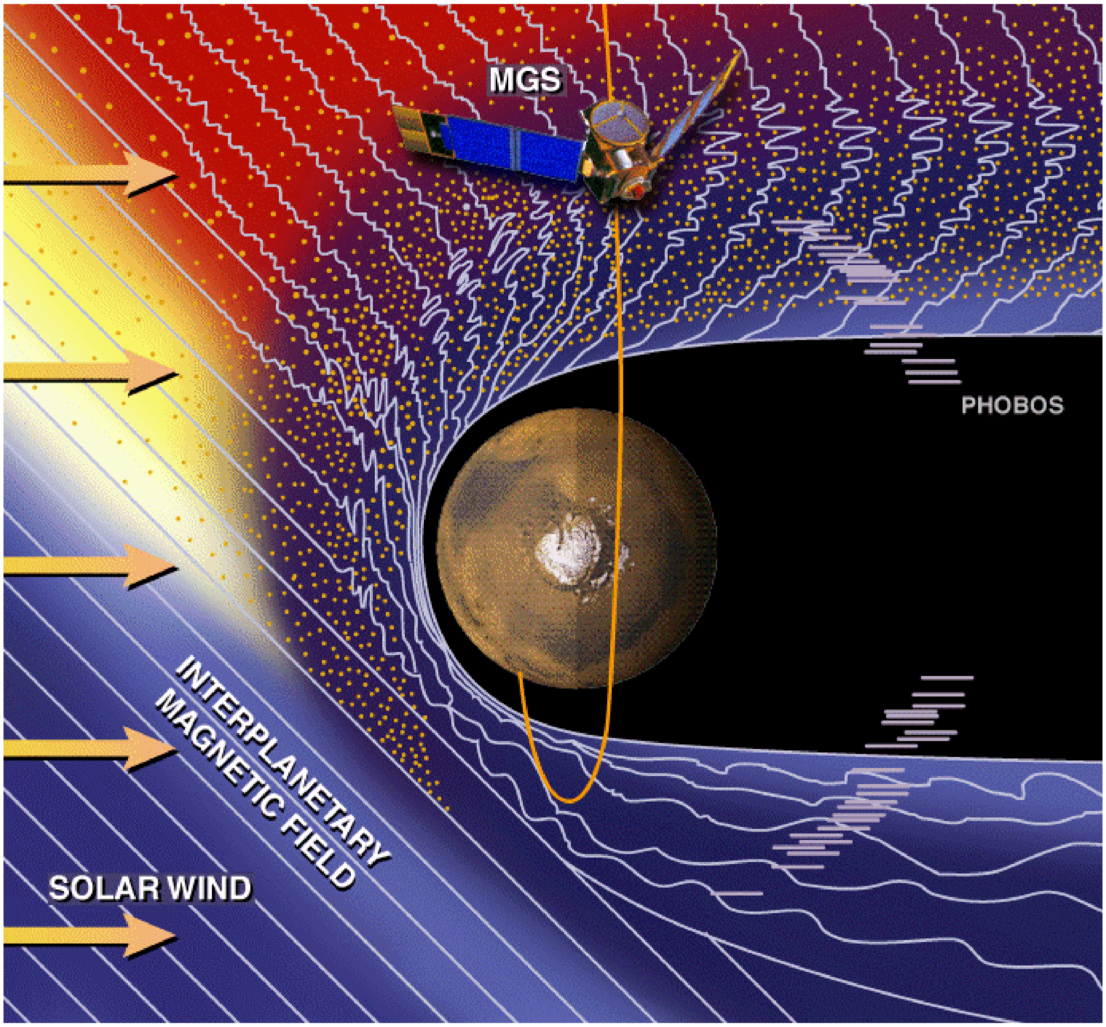
Auroral Ovals over the Poles

Dynamics Explorer satellite image of the aurora from space. The left image is an extremely large aurora that occurred 14 March 1989 at 0151 UT over the southern polar regions and the right image is a re-mapping of that image along magnetic field lines to the northern polar regions. This is a close approximation of what the auroral oval probably looked like if DE-1 had been over the northern hemisphere at this time.



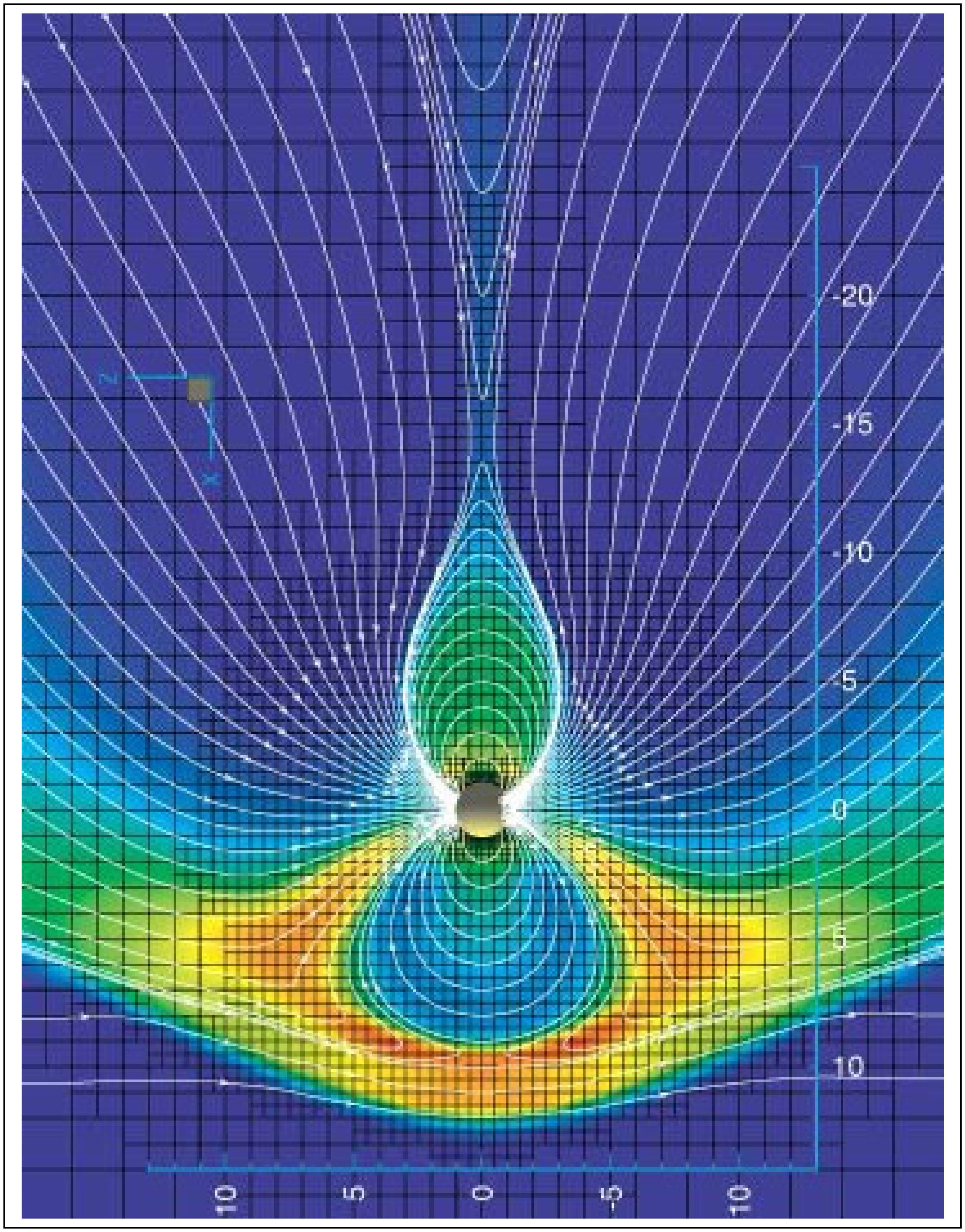
Solar Magnetic Field

This image is the result of a detailed mathematical model of the solar magnetic field. It shows how some of the magnetic field lines from the solar surface connect back upon the surface where sunspots are located, but other field lines reach far into interplanetary space. These open field lines originate in coronal holes, and provide magnetic pathways for high-energy solar plasma to flow out into the solar system. (Darren de Zeeuw; U. Michigan; Center for Space Environment Modeling)
http://aoss.engin.umich.edu/pages/space/Space_Weather



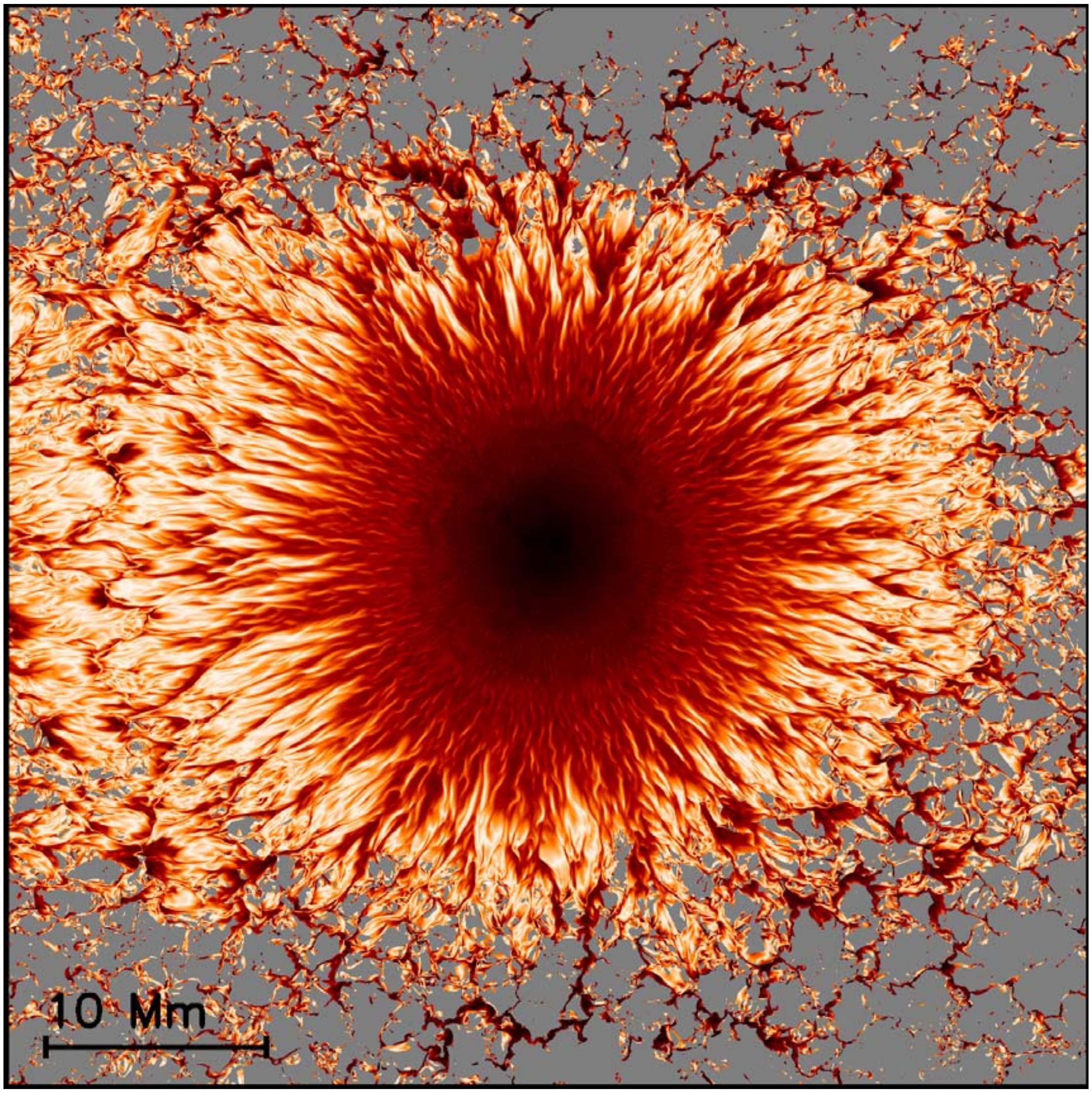
Solar Wind and Mars

This model shows what happens to the solar wind as it passes-by the planet Mars. The plasma is bunched-up in a shock front on the sun-side of the planet, compressing the tenuous atmosphere. The magnetic lines of force in the solar wind drape across the planet's atmosphere to form a comet-like shape. Measurements made by orbiting satellites can monitor the boundaries of this mare-solar plasma as the satellites move in and out of the boundary areas.



A Model of Earth's Magnetic Field

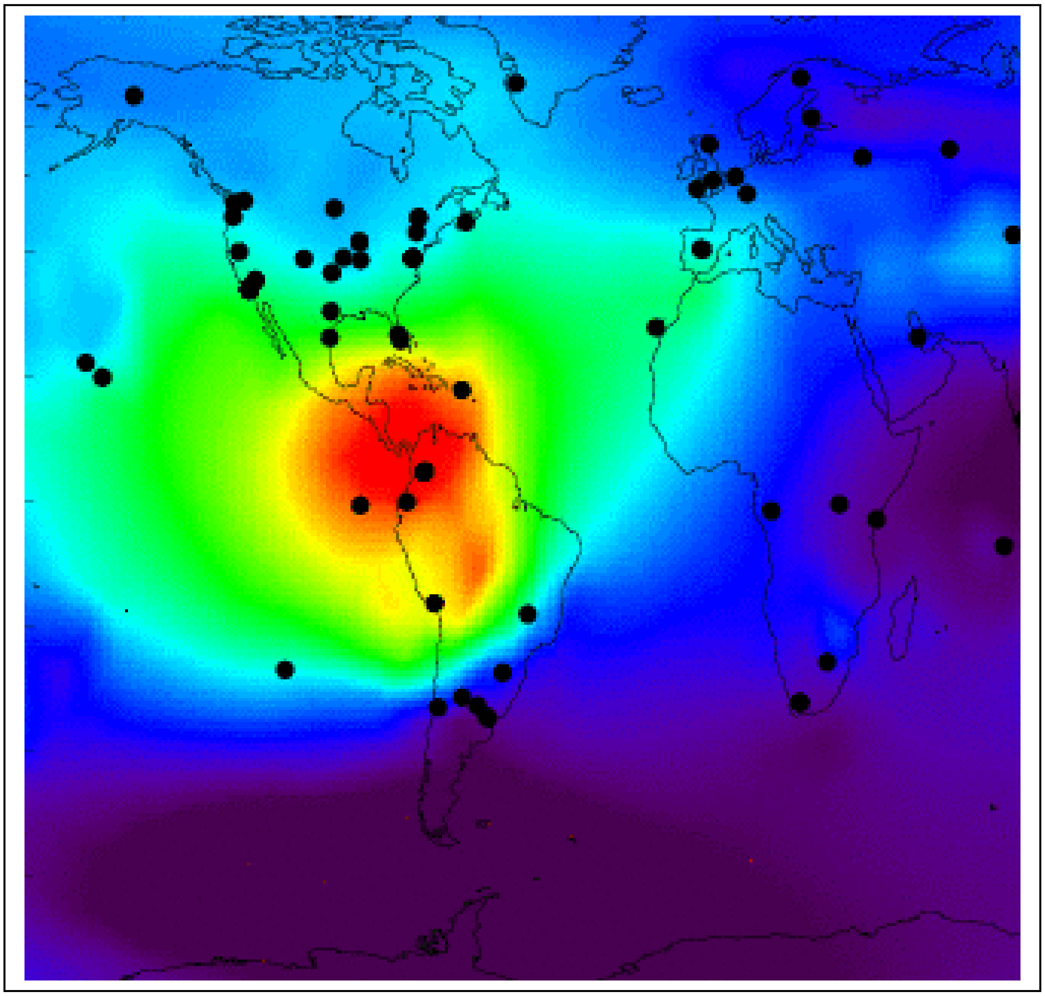
This mathematical model of Earth's magnetic field shows many essential features including the bow shock (lower orange regions) and the van allen radiation belts (closed loops) and the magnetotail (top lines in V-shape extending out of page).



Mathematical Model of a Sunspot

The interface between a sunspot's umbra (dark center) and penumbra (lighter outer region) shows a complex structure with narrow, almost horizontal (lighter to white) filaments embedded in a background having a more vertical (darker to black) magnetic field. Farther out, extended patches of horizontal field dominate. For the first time, NCAR scientists and colleagues have modeled this complex structure in a comprehensive 3D computer simulation, giving scientists their first glimpse below the visible surface to understand the underlying physical processes. © *UCAR, image courtesy Matthias Rempel, NCAR*

http://www.ucar.edu/news/releases/2009/sunspots.jsp



Global Positioning System Errors

This map shows the calculated density of electrons in Earth's ionosphere, and locations where changes in this density will cause GPS radio signals to experience rapid changes in time. This 'scintillation' leads to significant reductions in position accuracy at the surface, especially during solar storms when errors as high as 100 meters can occur for several minutes at a time. The map shows a region over Central America where position measurements may be inaccurate. Global maps of ionospheric total electron content (TEC) are produced in real-time by mapping GPS observables collected from ground stations. These maps are produced to test real-time data acquisition, monitoring facilities, and mapping techniques. The mapping can provide accurate ionospheric calibrations to navigation systems. These maps are also used to monitor ionospheric weather, and to nowcast ionospheric storms that often occur responding to activities in solar wind and Earth's magnetosphere as well as thermosphere. This map is produced by NASA/JPL. (http://iono.jpl.nasa.gov/latest_rti_global.html

Web Resources in Space Weather Studies

Space Weather Action Center

This NASA resource provides a simplified data-access page to dozens of real-time images and data monitors across NASA missions. Students may use this resource to practice their space weather forecasting skills, and submit their findings.

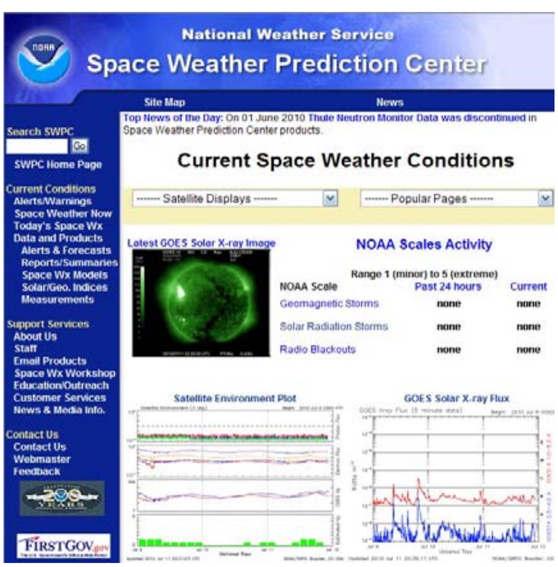
http://sunearthday.nasa.gov/swac/

Space Weather Media Viewer

A NASA resource that provides real-time images of the solar surface from a variety of NASA satellites and wavelengths. The images can be selected from a menu bar, and magnified to show surface details and active regions. There is also additional information provided about what is being seen at each wavelength, and links to the mission education pages and other resources.

http://sunearth.gsfc.nasa.gov/spaceweather/FlexApp/bin-debug/index.html#

Space Weather Prediction Center



This is a professional space weather resource provided by NOAA that serves as a quick-look resource for assessing the current state of space weather. The many supplementary resources and archives allow students and researchers to look at historical space weather data extending decades before the current era and access sunspot counts, imagery and data plots that show the changing space weather conditions on decade, annual, daily and hourly timescales.

http://www.swpc.noaa.gov/

Spaceweather.com

This is an informal space weather resource that presents the daily space weather conditions,geomagnetic indices, sunspot counts and flare forecasts, along with news briefs on space weather-related topics and links to amateur photographs of aurora. You can also use the archive feature to revisit past web pages to January 2001. This is a quick way to find significant solar storm episodes.

www.spaceweather.com

Space Weather & Human Impacts

This is an informational website that discusses the many ways that space weather can affect humans, and covers all technological and health issues. Also featured is an archive of newspaper stories between 1851-1923.

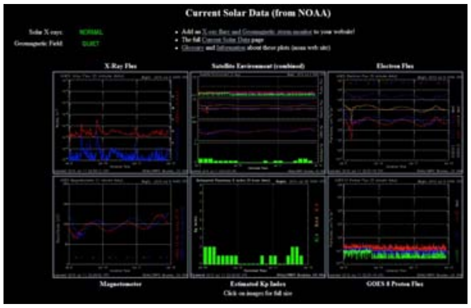
www.solarstorms.org

Space Weather Monitors

The Space Weather Monitor program at the Stanford Solar Center is an education project to build and distribute inexpensive ($350) ionospheric monitors to students around the world. The monitors detect solar flares and other ionospheric disturbances. Two versions of the monitor exist - one simple and low-cost, named SID, and one research quality, called AWESOME.

http://sid.stanford.edu

Current Solar Data



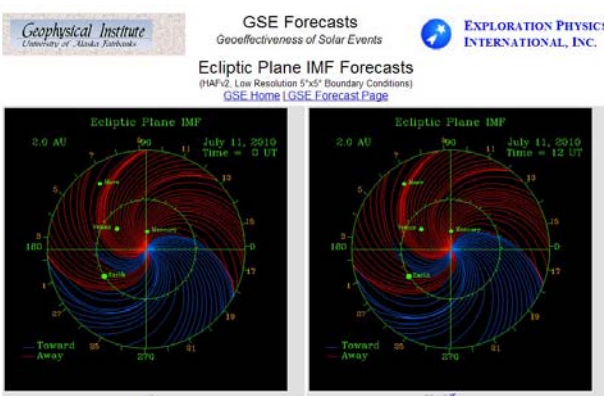
This resource was developed by a Ham radio operator as a convenient quick guide to solar and ionospheric conditions that affect radio signal propagation. It mostly keeps track of conditions that could lead to solar flares using NASA and NOAA data resources.

http://www.n3kl.org/sun/noaa.html

Community Coordinated Modeling Center

This is a research-grade resource that allows you to run actual science-based models to forecast currsnt geophysical and solar conditions. The 'Instant Runs' link features specific space weather models
http://ccmc.gsfc.nasa.gov/modelweb/

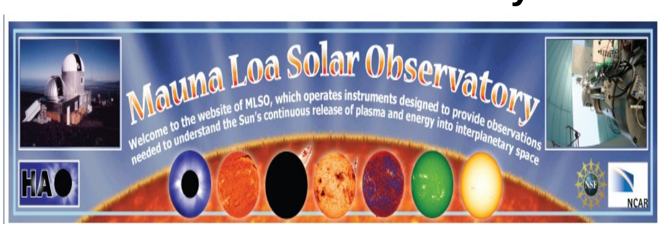
Geophysical Institute Solar IMF model



These science-grade models feature professional solar wind models that run every 15 minutes after the hour based on data inputs from satellites. They show the orientation of the interplanetary magnetic field (IMF) superimposed on the orbits and current locations of the inner planets.

http://gse2.gi.alaska.edu/recent/ecimf.html

Mauna Loa Solar Observatory



This resource shows images of the sun taken every day using a variety of ground and space-based imaging systems.

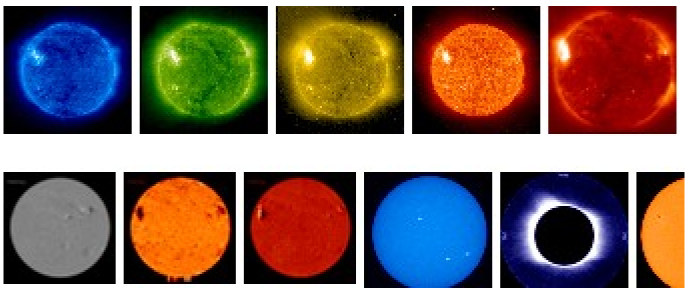
http://mlso.hao.ucar.edu/cgi-bin/mlso_homepage.cgi

Big Bear Solar Observatory

Provides daily solar activity reports and flare alerts under the 'Data' tab.

http://www.bbso.njit.edu/

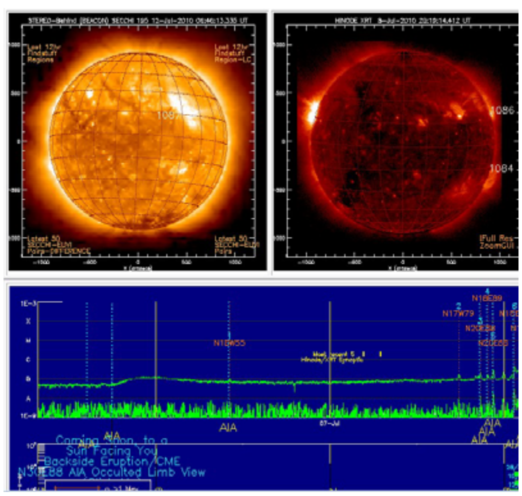
Solar Data Analysis Center



This NASA resource features a variety of real-time and archival images of the sun at the present time. A great resource from which to explore the multi-wavelength face of our nearest star!!

http://umbra.nascom.nasa.gov/images/latest.html

SolarSoft Latest Events Archive



Lists the major solar flares that have happened in the last few weeks, their dates and times, classification plus many archival pages showing solar flare information since 2002. A great resource from which to study the sun during the sunspot cycle, and learn about today's state of activity.

http://www.lmsal.com/solarsoft/latest_events_archive.html

A Catalog of Known Space Weather Impacts Reported in Newspapers:1850-2004

Exerpted from "Newspaper Reporting of Space Weather: The end of a Golden Age? Sten Odenwald, American Geophysical Union Journal of Space Weather, 2007, v. 5.

Human Impacts

The most common reporting often involved very detailed accounts of what the aurora looked like and where they were spotted. Currently, only some of these reports have any scientific value because of the heterogeneity of the observations. Sometimes the date and local time were mentioned, but usually not. The most interesting historical accounts of lasting value are the ones that cover the various human and technological impacts of the various storm events. These 141 commentaries are sufficiently brief that I will present complete excerpts in this section, classified according to the type of impact. The excerpts are complete for the five newspapers that are the primary focus of this paper, but also include accounts from additional newspapers for selected storm events in the sample.

Each quotation is referenced to a specific newspaper using the following code BG = Boston Globe, BS = Baltimore Sun, BT = The Bismark Tribune, CT = Chicago Tribune, FD = Fairbanks Daily News, FT = Florida Times Union, HW = Harper's Weekly, KS = Kansas City Evening Star, LA = Los Angeles Times, LT = Louisville Times, MG = Montreal Gazette, MH = Miami Herald, NO = New Orleans Daily Picayune, NY = New York Times, OH = Omaha Herald, PI = Philadelphia Inquirer, SN = Savannah Morning News, WP = Washington Post.

People Amazed

Both ancient and modern reports mention how amazed observers were of the colors and movement of the aurora. Curiously, this very basic response is so obvious that reporters often fail to cite the dimensions of this reaction in their stories. Some of these reports do suggest a large scale impact.

1- "Paris - During the evening it was warm enough to sit out of doors along the boulevards, and gossip would have had its swing had not a splendid aurora polaris, to use the latest expression, come to furnish a subject of conversation and curiosity, and to direct attention from the topics of the day…Nearly everyone fancied that it was the reflection of a vast incendiary beyond les Invalides, or toward Autruil,…It was not equal, however ,to the grand aurora of 1870, and conversation turned upon recollections of the three October nights when the sky was blood-red from horizon to horizon." (NY, 2-29-1872, p. 2)

2- "Dinner tables all over [Plainfield, NJ] were deserted and the people stood in shivering groups on lawns and sidewalks watching nature's masterpiece" (NY, 2-14-1882, p.1)

3- "…half of New York seemed to be out of bed watching the skies .Attractive as the aurora or northern lights always are, seldom if ever were they viewed with greater interest or by larger numbers than on Sunday night." (NY, 4-18-1882, p.5)

4- "The phenomenon was seen as far south as Vienna, and in Holland crowds awaiting the birth of Princess Juliana's baby cheered is as a lucky omen" (NY, 1-26-1938, p. 25)

5- "Washington area residents jammed telephone circuits to the Weather Bureau and newspapers last night following a spectacular display of aurora borealis…The phenomena, which originates in the Arctic region, was also observed as far south as Miami." (WP, 11-13-1960, p. A1)

6- "It was hardly the end of the world but many Chicago residents who bombarded newspapers, radio and television stations, and police departments with calls last night were startled by the splashes of green and yellow lights in the northern sky" (CT, 7-6-1974, p. F3)

People Afraid

Fear of the aurora borealis, officially called auroraphobia by psychologists, is a common if not rampant visceral reaction to seeing the blood-red and fiery colors of aurora. The vast majority of legends and folklore consider aurora to be bad omens or portends of wars or cold weather.

7- "Mr. Hood was told by one of the partners of the North=west Company, that he 'once saw the coruscations of the Aurora Borealis so vivid and low, that the Canadians fell on their faces and began praying and crying, fearing they should be killed." (Salem Gazette, 9-11-1832, p.2)

8- "Several *Paddies* in Boston at the time of the late Aurora Borealis, though the day (or night) of judgment had come, and fell upon their knees and went to praying vehemently." (Barre Gazette, 2-10-1837, p.2)

9- "…Several old women were nearly frightened to death, thinking it announced the end of the world, and immediately took to saying their prayers. A fat old citizen tremblingly stated that this was the avant courier of a dreadful epidemic, like the cholera of 1833, whilst a French gentleman pooh-poohed, and gravely assured us this was the well known sign of revolution in Paris, requesting us to make a note of the date of the month." (NO, 8-30-1859, p. 5)

10- "The Columbus Statesman (newspaper) says that a young lady, aged about sixteen, of considerable intelligence and prepossessing appearance, is now residing with the Sheriff of Ottawa County, preparatory to her removal to the lunatic asylum, having become insane from viewing the aurora borealis a short time ago, which she was induced to believe betokened the approaching end of the world." (HW, 10-8-1859, p. 647)

11- "Cleveland, OH - The electrical condition which produced the extraordinary auroral display last night, more or less seriously effected (sic) a great many persons here, particularly those troubled with nervous disorders. The Rev O. L. Blinkey, pastor of the Prospect Street Methodist Episcopal Church, was prostrated in his pulpit while praying, by what was first supposed to be paralysis .Ladies fainted in the churches during the services, and people who were out of doors as well as in complain generally of strangely oppressive sensations similar to those attendant upon an earthquake." (NY, 4-18-1882, p.5)

12- "Peasants in outlying country fled, thinking judgment day had arrived." (NY, 3-11-1926, p. 1)

13- "The aurora borealis, rarely seen in Southern or Western Europe ,tonight spread fear in parts of Portugal and lower Austria ,while thousands of Britons were brought running into the streets in wonderment" (FT, 1-26-1938, p.1)

14- "Superstitious folks of the Scottish lowlands shook their heads and declared the northern lights always spelled an ill-omen for Scotland" (NY, 1-26-1938, p. 25)

15- "The aurora borealis - northern lights - put on a spectacular display in the Chicago area last night, causing many residents to call The Tribune to seek information or to report that they had seen plane crashes, flying saucers, sky rockets, and balloons." (CT, 10-7-1960, p.1)

16- "…Most of the callers thought it was probably a missile fired from Vandenberg Air Force base or something like that…but there were a couple of callers who said they were afraid we were being invaded or something" (LA, 3-14-1989, p.2)

17- "Confused sky watchers jammed police lines with reports of falling debris from the space shuttle Discovery after spotting northern lights for the first time", (MG, 3-15-1989, p.A3)

Brilliance

Aurora are generally faint, but on occasion 'superluminal' aurora have occurred. The most frequent accounts involve the 1859, 1882, 1860 and 1921 aurora.

18- "The Brightness of the Sky was so very great that the smallest Print might plainly be discern'd. But as to the Cause of this Phenomenon, notwithstanding the Lights, we are altogether in the dark" (Pennsylvania Gazette, 11-12-1730, p. 1)

19- "On the night of August 1 [sic] we were high up on the Rocky Mountains .sleeping in the open air. A little after midnight we were awakened by the auroral light, so bright that one could easily read common print. Some of the party insisted that it was daylight and began the preparation of breakfast. The light continued until morning, varying in intensity in different parts of the heavens, and slowly changing position." (Rocky Mountain News, 9-17-1859, p. 3)

20- "Sept. 2nd, between 2 and 3 A.M., the aurora displayed itself in greater splendor than it did on the 28th .Many persons were awakened from their slumbers by the intense light which entered their chambers." (AJS, Article XXIV; Item 19)

21- "The light was equal to that of daybreak, but was not sufficient to eclipse the light of the stars. The sea reflected the color, and appeared as if of blood." (AJS, Article XXIV, Item 31)

22- "Singular as it may appear, a gentleman actually killed three birds with a gun this morning about 1 o'clock - a circumstance which perhaps never had its like before, and may never happen again. The birds were killed while the beautiful aurora borealis was at its height, and being a very early species - larks - were no doubt deceived by the light appearance of everything and came forth innocently supposing it was day." (The Pittsfield Sun, 9-22-1859, p.1)

23- "At Omaha on Friday evening the aurora was very brilliant, the illumination rendering the night almost as bright as day. At St. Paul the sky was of blood-red color…Cheyenne reports the illumination as that point last night as bright as day." (PE, 11-20-1882, p.1)

24- "…While it was at the brightest, a paper might have been read in the open streets. The city was bathed in the blood-red light which streamed down from the firmament and painted the silent, deserted streets and structures. The effect was beautiful in the extreme and entranced those who saw it." (NY, 4-18-1882, p.5)

25- "Petersburgh, VA - The display of the aurora borealis last night was one of the most magnificent sights ever witnessed here, and lasted until 4 o'clock this morning. The light resembled a great conflagration, and was so brilliant that the street lamps could easily have been dispenced (sic) with" (NY, 4-18-1882, p.5)

26- "Until after midnight crowds stood in Broadway watching the phenomenon…Even the intense lights of the electric signs along Broadway could not dim the brilliance of the flaring skies." (NY, 5-15-1921, p.1)

27- "The aurora…was bright enough to be visible from Washington itself - despite the brightness of the city's own lights" (WP, 5-27-1967, p. B3)

28- "…Although not visible in the New York area, the aurora was so brilliant over Europe that it aroused fears of conflagrations" (NY, 2-12-1958, p.16)

False Fires

Among the oldest interpretations involve false-fires in distant towns (Ostia ca 74 AD). This interpretation is still quite alive, and has surfaced as recently as 1981 in reports from Kern County, California.

29- "The Aurora Borealis has lately been unusually bright at the North .The Boston fire companies recently turned out to quench one of them ,under the impressions we suppose that the town was on fire. They couldn't reach it." (Vermont Gazette, 8-3-1830, p.4)

30- "Between 7 and 8 o'clock Wednesday evening, we had quite a brisk alarm of fire. Bells rang in various parts of the town (Philadelphia), and the cry was given in that deep, determined and startling tone, which informs the practiced ear that he who utters it is satisfied that he has reason for his clamor." (Rhode-Island Republican, 2-1-1837, p.2)

31- "...according to another account, the city firemen were led a chase more energetic than agreeable in the deep snow, after supposed fires. The northern and eastern portions of the heavens were lit up by a deep crimson glow like the reflections of an immense fire - and the bells rung, and away went men and boys to look at it, or extinguish it. But when they arrived at the jumping off place at the North End, the fire was as far off as ever." (New Bedford Mercury, 1-27-1837, p. 2)

32- "The consternation in the metropolis was very great, thousands of persons were running in the direction of the supposed awful catastrophe. The engines belonging to the Fire Brigade stations in Baker street, Farringdon street, Watiing street, Waterloo road, and likewise those belonging to the West of England station, in fact every fire engine in London, were horsed and galloped after the supposed scene of destruction, with more than ordinary energy, followed by carriages, horsemen and vast mobs." (Newport Mercury, 10-19-1839, p. 1)

33- "..The watchmen were much alarmed at the colored light with which the southern part of the sky was covered, which gave rise to the belief hat a small village about three leagues south of Santiago was on fire. This seems to be the first time that a polar light has been seen at Santiago." (AJS, Article XI, Item15)

34- "A traveler who happened to be in Leichestershire at the time found the inhabitants of a certain village gazing intently at the phenomenon…The traveler was rather taken aback, but found upon inquiry that the villagers all believed the red light in the sky to be the reflection of Paris on fire…" (HW, 1870, v 12/17, p.819)

35- "Hundreds of persons in this city [New York] started on a run for the West Side thinking there was a big fire over in New Jersey. When they reached the river, however, and the light was as far away as ever, and they for the first time noticed the white auroral streamers, the more ignorant became afraid...Many thought it was a sign that the world was coming to an end." (NY, 2-14-1892, p. 1)

36- "Bostonians thought all Cambridge was afire, and the Boston Fire Department actually got in readiness to respond to a call to save the Harvard University buildings." (NY, 2-14-1892, p. 1)

37- "Residents along the New Jersey coast generally attributed the glow in the sky to the prevalence of forest fires in the interior of the state." (NY, 2-14-1892, p. 1)

38- "The whole fire department of Salzburg was called out last night to quench the northern lights. It was the first time the aurora borealis had ever been seen here and so many alarms were turned in from all parts of Salzburg that the bewildered firemen thought the whole city was simultaneously in flames and helped to increase the panic by dashing about in all directions." (NY, 3-11-1926, p. 1)

39- "The tocsin was sounded at 4 o'clock this morning in the village of Musiege in Haute Savoie, bringing out the fire brigade and all the villagers, who saw immense flames rising to the sky above a neighboring village. They dashed to the rescue, but upon arriving at the spot they found the villagers asleep and no fire. Then they discovered that nature had played a joke .A beautiful aurora borealis hovering over the village had given the impression from afar of a huge conflagration. The villagers chaffed the fireman, asking them to extinguish the aurora borealis." (NY, 2-26-1927, p. 15)

40- "United States forest officials at Descanso, forty miles east of here [San Diego] were routed out of bed early today by reports of a 'great fire in the back country" .They found it was only the aurora borealis, last seen here in February 1888." (NY, 1-23-1938, p. 29)

41- Hamilton Bermuda - The sky was brilliantly lighted with dark red streamers, flashing like searchlights. Many persons thought the light was caused by a ship afire at sea... Steamship agents took the precaution of checking with wireless stations to learn if there had been any SOS calls. " (NY, 1-26-1938, p. 25)

42- "It was only the Aurora Borealis on the blink again that kept fireman dashing about much of Europe into the early morning hours today." (Louisville Times, 1-26-1938, p1)

43- "In Sofia Bulgaria…there was a flaming track of fire in the heavens and in several places in the provinces, and even in Sofia, fire brigades were called out. A less brilliant display was seen in Yugoslavia" (NY, 3-26-1940, p.18)

44- "Telephone lines to police, fire departments and newspapers were clogged as hundreds inquired as to the cause of the brilliant glow. Most thought it was a huge fire in the distance" (BG, 2-11-1958, p.1)

45- "One firehouse reported that even rookie firemen were calling in, confessing they'd 'never seen it before and figured it must be fire'. (WP, 11-14-1960, p A3)

46- "Dozens of calls were received at the Globe .Some thought it was the reflection of a five-alarm fire in Malden .A Navy veteran compared it to the hues cast by burning tankers torpedoed on the Atlantic during World War II." (BG, 11-13-1960, p.1)

47- "The unusual southerly display of the aurora borealis Sunday night colored skies along the eastern edge of California, causing a flood of calls to police and prompting one Fire Department to send out firefighters in search of a blaze…The Kern County Fire Department sent a unit to a reported fire in the Caliente area but learned the glow was not a fire, a dispatcher said." (LA, 4-13-1981, p. 1)

48- "In Brownsville Texas, the southernmost city in the continental United States, police Sgt .Rudy Limas said, 'People say they're seeing something red or orange in color in the sky, like a fire'" (PI, 3-14, p.17A)

Telegraph Service

The advent of the electric telegraph by Joseph Henry in 1830 and perfected by Samuel F.B. Morse in ca 1838, was followed by the recognition that it could be affected by magnetic storms once the telegraph network had reached a large-enough geographic capacity. In 1848, Carlo Matteucci (1811 - 1868) the Director of Telegraphs in Pisa observed the iron armatures of the electric telegraph connecting Pisa and Florence behave in an unexpected manner during a brilliant aurora on November 17, 1848. The electromagnets remained powered even without the battery attached. This behavior ceased once the aurora dimmed. This effect was extensively reported by newspapers during the August-September, 1859 storm. It would be repeated in telegraph systems around the world for the next 100 years, during which time extensive citations of interruptions in telegraph service can be found. The longest disruption probably involved the January 26, 1938 storm which caused disruptions for a ' few days'.

49- "During the splendid aurora borealis of Monday evening very singular phenomena were noticed on the telegraph wires…Strong magnetic currents seemed to pass from the ground into the wires, at times so powerful as to overcome the batteries on the line, and reverse the magnetic poles, making queer work, and causing some perplexity among the operators. The magnetic currents were evidently joining in the merry dance of their brilliant partners in the sky." (Weekly Eagle, 10-2-1851, p.2)

50- "On the 19 of February, 1852, there was a brilliant display of the northern aurora, and while it continued the telegraph lines were singularly affected; on the Boston and Montreal lines the batteries were disconnected and messages sent wholly by the auroral current." (The Farmer's Cabinet, 9-28-1858, p.2)

51- "The Manager of the Electric telegraph Company in Glasgow, Scotland, states that the transmission of intelligence over the wires was suspended in consequence of an aurora borealis, which prevailed at the time." (Barre Patriot, 1-14-1853, p. 1)

52- "The atmosphere was so strongly impregnated with electricity that communication was kept up for some time with New York, Boston and Montreal over the Western Union telegraph wires without the use of a battery" (CT, 5-29-1877, p. 2)

53- "It very seriously affected the workings of the telegraph lines both on the land and in the sea, and for three hours from 9 AM until noon telegraph business east of the Mississippi and north of Washington was at a stand-still…While no great damage was done, there was very much annoyance by reason of the delay in the transmission of business, and at 4 o'clock, when the trouble seemed to have ceased entirely, every instrument and every operator was busy in rushing off the accumulated business' (NY, 11-17-1882, p.1)

54- "Telegraph and telephone lines in the British Isles and throughout all northern Europe have been seriously interrupted by the great magnetic storm which virtually paralyzed wire transmission in the United States Saturday night and Sunday" (MH, 5-17-1921, p. 2)

55- "Slow transmission of market transactions between Wall Street and London was caused by the magnetic disturbance yesterday morning." (NY, 10-16-1926, p. 11)

56- "Telegraphic communications throughout the United States - including the Associated Press network of 300,000 miles of leased wires, have caught the dickens during the last couple of days. The static was so intense that when operators sent out such a phrase as 'diplomatic sources' the words arrived as 'awgxvm kvkpvaqvu'. (Florida Times Union, 1-26-1938, p.1)

57- "A crippling blow to telegraph service for five hours on a day when the lines are bogged down with Easter messages" (NY, 3-25-1940, p. 1)

Cables

The strongest geomagnetic storms can generate ground currents, which when coupled to long conductors, can induce electric fields from 1 to 10 volts/km. This leads to, potentially, thousands of volts on sub-ocean or ground telegraph and telephone cables.

58- "The underground wires and cables seemed to be as seriously affected as the land lines…The electric disturbances also prevented service over the Mexican and Cuban cables as well as the Atlantic cables" (NY, 11-17-1882, p.1)

59- "Officials of the cable companies, in describing the effect on the cables beneath fathoms of ocean, declared that one enterprise that ordinarily received from twenty-five to thirty cables every day had received only one up to late last night." (NY, 3-23-1920, p. 13)

60- "Three of the eight transatlantic cables owned by Western Union were affected by earth currents accompanying the aurora…Two of these were in full operation again, but the third, although not entirely out of commission, was not back to normal…the cost of repairing even a small fault in a cable in deep water would reach $200,000.." (NY, 5-18-1921, p. 12)

Navigation Errors

The fact that magnetic storms could affect compass needles was first shown by Gellibrand (1634), in his treatise "*A Discourse mathematical on the Variation of the Magnetical Needle together with its admirable Diminution lately discovered*" and later studied in detail by Anders Celcius (1701-1744) and his student Olof Hiorter (1696-1750) who in 1741 uncovered a correlation between magnetic 'activity' and auroral sightings near Uppsala, Sweden and London.

Navigation errors caused by magnetic storms are the simplest to identify and should be the most direct impact of severe space weather events. Identifying reports of actual instances during which compass bearings were affected is, however, a challenge. The most likely documentation might be expected from the numerous ships logs recorded daily during the 1800's by the thousands of ships that annually plied the oceans. Identifying these reports would be a monumental, and extraordinarily tedious, process. There are, however, scattered newspaper reports from 1837 (Olmstead, 1837) that claim that compasses were, indeed, actually affected by magnetic storm events producing deviations as high as 10 degrees in a few hours- deviations easily detected by maritime systems.

61- "The magnetic needle shifted its position more than a degree in the course of five minutes, and the common focus was supposed to be about the pole of the dipping needle." (The Pittsfield Sun, 11-26-1835, p. 2)

62- "As usual in brilliant exhibitions of the Aurora Borealis, the Magnetic Needle was exceedingly disturbed…It often moved 30 minutes in three seconds .Its entire range was nearly six degrees." (Connecticut Courant ,11-25-1837, p. 2)

63- "During the Great Auroral Display of September 2, 1859, the disturbances of the magnetic needle were very remarkable…At Toronto, in Canada, the declination of the needle changed nearly four degrees in half an hour." (Harper's New Monthly Magazine June 1869, vol. XXXIX, p. 12)

64- "Generally the magnetic disturbances are too small to be noticed with an ordinary compass; but sometimes the deviations amount to several degrees, vastly to the discernment of any unlucky surveyor who may happen to be running a farm-line at the time - for aurora occur by day as of ten as by night" (NY, 10-23-1872, p. 4)

65- "A magnetic storm, sweeping in from stellar space and bringing two huge sunspots to the sun's surface, played strange tricks yesterday across a wide part of the earth as compass needles on ships at sea trembled erratically, teletype machines tapped messages that had no meaning, and short-wave communications between the United States and Europe went into a temporary 'blackout'…' (NY, 2-3-1946, p.26)

66- "Brussels, Sept. 23 (AP), Budget Minister Joseph Merlot today said 'abnormal weather conditions and the aurora borealis' might have put the instruments out of order on the Sabena airlines plane that crashed near Cander (sic), N.F, killing 26 persons." (LA, 9-24-1946, p.4)

Weird Sounds

There have been persistent accounts of aurora causing audible sounds that could be perceived by observers under certain conditions. Often dismissed as a sympathetic reaction to seeing moving fire in the sky, there may be situations in which sounds can occur. The easiest to understand are sounds produced by 'aurora' in which technology is used as a transducer. Ground currents can be exceptionally strong and infiltrate themselves into telephone and radio systems. Although not directly associated with aurora, ‘whistlers’ can be detected on long-wave systems under proper conditions.

67- "An observer informs us that he distinctly heard the sound which not infrequently accompany this phenomenon, a slight flapping sound, in quick succession like that made by the waving of heavy drapery.", (Republican Star, 5-3-1831, p.3)

68- "The telephone lines of the Metropolitan Telephone Company also refused to work during the greater part of the day…People who attempted to use the telephone lines heard a buzzing, ringing noise, rather than any well-defined sound..." (NY, 11-17-1882, p.1)

69- "A dispatch from Albany states that during the continuance of the aurora at that place a peculiar rustling noise was plainly heard at the telephones…" (NY, 2-14-1892, p. 1)

70- "In lonely northern districts, where other noises do not interrupt, particularly brilliant polar lights that appear to flash low to the ground are said to be accompanied by a swishing and crackling sound. " (NY, 5-15-1921, p.1)

71- "Operators of the local wireless station (Berezov, Tobolsk Province Siberia) report that while watching the aurora borealis they heard melodic sounds. The sounds rose and fell in consonance with the fluctuations of the aurora" (NY, 10-5-1927, p. 24)

Air Travel

All reports of impacts to air travel involve some aspect of space weather affecting radio communications systems. In one instance, however, auroral interference with magnetic navigation was suggested as a contributing cause to a fatal crash on September 23, 1946.

72- "Some pilots on landing said that they had relayed messages from one plain to another; thus a plane some distance away from the airport would make contact with another plane near the airport and notify the field that the farther plane was coming in" (NY, 3-25-1940, p. 1)

73- "Long-range radio communications have been so seriously disrupted by the aurora borealis that transatlantic planes have in many cases been seriously delayed, according to airline reports yesterday. Thirteen planes operated by major transocean airlines were held up during the day. Six Europe-bound planes were stalled in Gander, Newfoundland, and seven west-bound ones in Shannon, Eire." (NY, 3-27-1946, p. 13)

74- "The first trans-Atlantic plane to break through an almost complete blackout of radio communications caused by the aurora borealis since March 22 arrived at La Guardia Field at 5 P.M. (E.S.T.) March 27. The plane which arrived was a liner from Paris. It had been held at Shannon Airport, Eire, 15 hours. Officials at La Guardia Field said unusual radio conditions would continue, although they are not expected to be severe." (Christian Science Monitor, 3-29-1946, p.13)

75- "Long-range radio communications have been so seriously disrupted by the aurora borealis in the last few days that trans-Atlantic planes have in many cases been seriously delayed, according to airline reports yesterday. Thirteen planes operated by major transocean airlines were held up during the day .Six Europe-bound planes were stalled in Gander, Newfoundland, and seven westbound ones at Shannon, Eire." (NY, 3-27-1946, p. 13)

76- "Brussels, Sept. 23 (AP), Budget Minister Joseph Merlot today said 'abnormal weather conditions and the aurora borealis' might have put the instruments out of order on the Sabena airlines plane that crashed near Cander (sic), N.F, killing 26 persons." (LA, 9-24-1946, p.4)

77- "Yesterday's blackout…paralysed (sic) Dorval airport, delaying flights" (MG, 3-14-1989, p.1)

Rail Service

Impacts to rail service invariably involve problems with electric signaling equipment, however, in one instance ground currents may have been involved in an actual power failure in 1903.

78- "In Geneva, all the electrical street cars were brought to a sudden standstill, and the unexpected cessation of the electric current caused consternation at the generating works, where all efforts to discover the cause were fruitless" (NY, 11-2-1903, p. 7)

79- "It may have contributed to a short circuit in the New York Central signal system, followed by a fire in the Fifty-seventh Street signal tower." (NY, 5-17-1921, p. 1)

80- "Brewster NY - A fire which destroyed the Central New England Railroad station, here, Saturday night, was caused by the Aurora Borealis, in the opinion of the railroad officials. Telegraph Operator Hatch says he was driven away from his instrument by a flare of flame which enveloped the switchboard and ignited the building. The loss was $6,000" (NY, 5-17-1921, p. 1)

81- "The sunspot which caused the brilliant Aurora on Saturday night and the worst electrical disturbances in memory on the telegraph systems was credited with an unprecedented thing at 7:04 o'clock yesterday morning, when the entire signal and switching system of New York Central railroad below 125th Street was put out of operation, followed by a fire in the control tower at Fifty-seventh Street and Park Avenue…While all outgoing and incoming trains were stopped, the Fire Department extinguished the fire in the tower, but not until residents of many Park Avenue apartment houses were coughing and choking from the suffocating vapors which spread for blocks." (NY, 5-16-1921, p.2)

82- "The phenomenon was also the cause of delay to express trains on the L.N.F.R. Manchester-Sheffeld line. At 7:48 PM, the signaling apparatus in both the parallel Woodhead Tunnels was found to be out of order. The working of the trains through the tunnels was stopped. An official said that the failure was apparently due to the electrical disturbances caused by the Aurora Borealis." (LT, 1-27-1938, p. 2)

Voltages

A common complaint involves the detection of unusually large voltages and currents on telegraphic systems. The presumed mechanism has ground currents invading open ‘one-line’ telegraph circuits, which can produce 200-700 Volts. The most intense event occurred during the 1921 geomagnetic storm when voltages exceeding 1,000 volts were reported, and electric field strengths in the range of 20 Volts/km cited (Kappenman, 2004). During the 1989 Quebec blackout, electric fields of 1.7 Volts/km were detected for 20seconds at the station near Louvincourt (Bolduc, 2002). During the August 4, 1972 event, a strength of 7.4 Volts/km was measured at the Meanook Magnetic Observatory near Edmonton, Alberta. (Space Weather Canada, 2006).

83- "An electric lamp attached to a St. Paul wire made a brilliant illumination without the use of a battery" (CT, 11-18-1882, p.2)

84- "The telegraph system of this country has, since Friday morning last, been disturbed in a way that far exceeds anything of the kind that has ever happened before…The electric storm commenced on Thursday, but reached its climax on Friday morning (November 17) between 10 and 11 a.m. The currents measured over 50 milliamperes, which is five times greater than the ordinary working currents." (Nature, 11-23-1882, p. 82)

85- "…at its climax [October 31, 1903] there were 675 volts of electricity - enough to kill a man - in the wires without the batteries attached…" (NY, 11-1-1903, p.1)

86- "During the height of the electrical disturbance the measuring instruments in the telegraph offices in this city [New York] registered the presence on the wires of upward of 500 volts of electric current from the unknown source" (NY, 9-26-1909, p.12)

87- "The electrical disturbance was so marked that wire traffic chiefs at the Chesapeake and Potomac telephone headquarters reported that meters registered more than 1,000 volts…" (NY, 5-16-1921, p. 1)

88- "The Consolidated Edison System reported that at the height of the trouble Sunday morning "voltage dips" of 1,500 volts were recorded at its three main generator stations in Brooklyn and the Bronx. The dips, a spokesman explained, represented power loss in the strength of electrical power being generated" (NY, 3-26-1940, p.18)

89- "Postal Telegraph officials said they had not seen anything like this in twenty-five years. The current of the electrical disturbance in the earth measured from 200 to 400 volts, they said" (NY, 3-25-1940, p. 1)

90- "From Newfoundland came reports that magnetism from the aurora has caused the voltage in electric circuits to vary in a range of 320 volts. Utility companies in many parts of the United States reported similar disruptions." (NY, 2-11-1958, p.62)

91- "The telephone company reported the cosmic display caused more than usual havoc this time .Voltage meters all over the system suddenly shot up..trouble lights flashed on" (BG, 2-11-1958, p1)

92-"The Alaskan power utilities are completing a north-south tie linking the coastal power grid centered on Anchorage, with the interior one based at Fairbanks. Auroral-induced fluctuations have already been recorded in the tie linking a coal-burning power plant at the Healy mine near Alaska Range and Fairbanks." (NY, 2-4-1986, p.C3)

<u>Weather</u>

The relationship between auroral sightings and weather has a long history, but is mostly folkloric and cannot be dated to determine their origins. Newspaper reports of aurora in the 1700's already seem eager to make this connection, but apparently not for the first time.

93- "On the evening of the 17th instant, a very bright Aurora Borealis rendered the northern part of the heavens luminous…The 15th and 16th were cold days, the wind generally from the north-east.."(The Boston Patriot, 7-17-1814)

94- "The weather to-day has been very cold for the season. Brilliant auroral displays are apt to be followed by cold weather and frosts, and this instance is no exception. For ZA week past the press at the West has alluded to the show of Northern Lights, and at the same time to extraordinarily cold weather." (Rochester Advertiser, 9-2-1859, p.2)

95- "Thus far it remains uncertain whether the earth as a whole is warmer or colder; but there is a slight balance of probability in favor of the former supposition, the greater activity of the solar surface when the spots are most numerous, probably ore than compensating for the diminution of luminous area." (NY, 7-16-1873, p. 4)

96- "The humidity of the atmosphere, which has been so apparent for several weeks, has resulted in a density most favorable to electrical phenomena .An aurora borealis was the first evidence of the overcharging of the atmosphere with electrical fluid." (NY,11-18-1882, p.1)

97- "Sir Oliver Lodge and Sir Norman Lockyer were interviewed on the matter (of the telegraph interference) and agreed in attributing the cause to sun spots and an increase in solar activity, which would also account for the unusual wet season now being experienced.", (NY, 11-2-1903, p.7)

98- "The ionospheric disturbances, a reaction from storms on the sun, have prevented proper reflection of radio waves .The weather here, meantime, continued unseasonably warm…With the beginning of rain during the afternoon the mercury started to fall." (NY, 3-27-1946, p.13)

<u>Politics - Warfare</u>

Although the earliest accounts suggest that the aurora were omens for wars, the practical consequence seems to be in providing additional light with which to change the outcome of a particular battle. Recently, however, the short-wave radio interruptions produced communication blackouts during which time important information could not be transmitted.

99- "Owing to unfavorable static conditions, in the North Atlantic, which have handicapped wireless communication between this country and Germany, the German

Government for some time has found it practically impossible to send messages here without having them pass first into the hand of the British censors in London…Germany may thus remain isolated from the rest of the world for several weeks. It has been estimated that the static disturbances now occurring often increase the wireless distance between Nauen and Sayville by the equivalent of 2,000 miles." (NY, 5-25-1915, p3)

100- "At the radio station in the Brooklyn Navy Yard, information as to the effect of the freakish electrical show on the wireless operation was refused on the ground that all information of any character regarding wireless operation had to be furnished through official channels at Washington" (NY, 5-9-1918,, p. 9)

101- "Seven or eight German airplanes made a raid over England last night. Eleven persons were known to have been killed and forth-six injured in the metropolitan district…There was a remarkable display of the auroras borealis last night, and it is believed by many that this furnished conditions under which the air raiders could work more effectively than under a clear star-lit sky." (NY, 3-9-1918, p. 3)

102- "The aurora borealis was blamed today by scientists for the failure of President Coolidge's speech a the International Oratorical Contest last night to get out through the air to radio listeners…The engineers looked for the cause but could find no mechanical trouble. " (NY, 10-17-1926, p. 3)

103- "Korean war news began flowing again last night after a blackout for half a day…This made possible resumption of Korean war coverage from General MacArthur's headquarters." (NY, 8-20-1950, p. 5)

104- "The United Press quoted University of Chicago scientists as calling the cosmic ray shower the greatest ever recorded…The Admiralty speculated today that cosmic disturbances caused a full-scale naval alarm for a British submarine feared missing. The submarine Acheron due to report her position at 10:05 A.M. (5:05 A. M. Eastern standard time) while on an Arctic trial, failed to make radio contact…Four hours later Acheron was heard from and the search was abandoned." (NY, 2-25-1957, p.L21)

105- "Sunspots delayed accounts of the Allied landing today (September 3) in Italy. Wireless technicians attributed to the spots the faulty transmission from the Mediterranean area to the United States. Dispatches piled up beside the operators as they tried various wave lengths in an effort to get through." (NY, 9-4-1943, p.2)

106- "Radio Free Europe said yesterday that its engineers found no indication the Kremlin had resumed jamming it or its sister station, Radio Liberty, to block reports on demonstrations in the Soviet Union…Radio Free Europe spokesman Bob Redlich said that an effect similar to jamming could have been caused by recent increases in solar activity, which can hamper radio reception." (BS, 3-15-1989, p.4A)

Radio Reception

Radio transmissions via short-wave are severely disrupted by changes in the ionospheric D-layer during solar flares, causing shortwave fade-outs. During geomagnetic storms, particle precipitation enhances electron density in the E and F-layers over large geographic regions, and ionospheric currents cause plasma irregularities, which lead to radio wave scattering. These problems became increasingly severe after ca 1930 when higher-frequency broadcasting technology became more commonplace, supplanting the older long-wave systems that were popular between 1905 and 1929.

107- "Curiously, however, the disturbance that tied up the land wires seemed to strengthen the signals of wireless apparatus, which were unusually clear during the period of heaviest land wire disturbance" (The Bismark Tribune, 5-17-1921, p. 8)

108- "Magnetic storms hovering over the Atlantic are bothering the radio engineers who are striving to pick up European programs for rebroadcasting in America…Last Sunday Lady Astor spoke in London and was heard with remarkable clearness as her words crossed the sea on the American Telephone and Telegraph circuit for rebroadcasting over WABC's system. A half hour later the WEAF-WJZ network with WOR linked into the hook-up tried to rebroadcast from Holland, but the bombardment of the magnetic storms ruined the clarity…Twice last week WEAF-WJZ's attempts to relay European programs in this country were defeated by magnetic storms, which attached the programs coming from England and Germany and made it impossible to pick up on this side of the ocean." (NY, 3-2-1930, p. 133)

109- "A virtually complete blanking of short-wave communication between the United States and Europe, and partial disturbances of service to South America" (NY, 3-25-1940, p. 1)

110- "During the day, thousands of Brooklyn Dodger fans expressed themselves forcibly when a broadcast of the game with the Pittsburg Pirates at Pittsburg went off the air with the score 0-0…while Red Barber was broadcasting the story of the game over WOR. The broadcast was inaudible for fifteen minutes and when it resumed the Pirates had piled up four runs. Thousands of Brooklyn followers meanwhile had telephoned the station and displayed little satisfaction with the explanation that the sun was to blame." (NY, 9-19-1941, p.25)

111- "Electrical disturbances during the day affected transatlantic short-wave radio channels, disrupting traffic almost completely." (NY, 9-19-1941)

112- "RCA technical men reported no effect on television during the height of the magnetic storm" (NY, 9-20-1941, p.19)

113- "Radio listeners heard some spicy and unscheduled telephone conversations yesterday and the trouble was laid to the current magnetic storm caused by sun spots…WAAT during the first period, was broadcasting a program of recorded songs by Bing Crosby, when a conversation between two men was interjected suddenly and quite clearly into the background…A few minutes later the trouble was back, this time with a mysterious conversation between two girls who were talking about a 'blind' date." (NY, 9-20-1941, p.19)

114- "…the Columbia Broadcasting System yesterday reported that the sun spots had caused an almost complete blackout in radio reception of overseas short-wave broadcasts for the second consecutive day." (NY, 2-8-1946, p.18)

115- "Radio and TV listeners and viewers spent a hectic three hours as their sets blanked out, changed stations, or went completely haywire" (BG, 2-11-1958, p1)

116- "The aurora was accompanied by an electric storm that ended all radio communications between the United States and other countries and that disrupted telephone, teletype and electric circuits." (NY, 2-11-1958, p.62)

117- "Solar radiation bombarding the earth's atmosphere at speeds of 3,000 feet a second caused magnetic storms around the world that washed out radio communications" (NY, 11-14-1960, p.14)

118- "One monitoring station reported that short wave radio contact between New York and London was all but impossible" (CT, 11-16-1960, p.16)

119- "Scientists at the National Oceanic and Atmospheric Administration reported that the solar flare had already caused some effects on Earth, including some radio blackouts." (NY, 7-16-2000 p. 21)

Crime

Any documented reports of criminal activity almost certainly involve collateral issues not directly caused by the aurora or flares. Only one rather humorous example has been found to date.

120- "Last evening, while Charles F. Krebs stood outdoors admiring the aurora borealis, the money-drawer was taken from his saloon, and all the cash it contained, to the amount of between $3 and $4, stolen." (CT, 5-30-1877, p. 10)

Electric Shocks

Related to the very large voltages and currents reported during some exceptional storms have been reports of humans actually being shocked and injured by currents flowing in telegraph wires. In the instance of the September 25, 1909 event, a telegraph operator in Lulea, Sweden actually experienced a severe shock that paralyzed her hand (Stenquist, 1914). A similar injury may have befallen Frederick Royce during the 1859 storm. There are no actual reports of shocks having actually electrocuted someone, especially after 1909 when these types of accounts suddenly disappeared from being newsworthy. Possibly technological solutions to this problem made such events rare.

121- "…The effect was different than that of Aug. 28th. There was an intensity of current which gave a severe shock when testing…" (AJS, Article XIL, Item 5)

122- "…During the auroral display, I was calling Richmond, and had one hand on the iron plate. Happening to lean towards the sounder, which is against the wall, my forehead grazed a ground wire. Immediately I received a very severe electric shock, which stunned me for an instant. An old man who was sitting facing me, and but a few feet distant, said that he saw a spark of fire jump from my forehead to the sounder." (AJS, Article XIL, Item 6)

Ozone and the Atmosphere

Aurora and solar flares cause considerable upper atmosphere changes, but there are no documented mechanisms in which these effects can reach the surface. One specific account in Versailles in 1859 can probably be dismissed as a statistical fluctuation seen under the 'streetlamp' of the 1859 storm. Meanwhile, recent studies by

Thomas et al. (2007) have suggested that a considerable reduction occurred in the ozone layer during this storm.

123- "Regular observations were made at Versailles on the amount of ozone in the atmosphere. During the auroras of Aug 28th and Sept. 2, the quantity of ozone was decidedly greater than usual." (AJS, Article XXXV, Item 4)

124- "At Springfield…during the display of August 28th…The electrotype plates at the office of the 'Republican' at that place were so seriously affected by the aurora, that they could not be printed from during the continuance of the phenomenon" (Prescott, 1860)

Equipment fires

Telegraph systems 'over charged' by ground currents are frequently seen to produce sparks, so it is not surprising to hear of the occasional fire. Frequent mentions of this appear in the 1859, 1882 and 1921 storms, indeed, during the 1921 storm a telegraph office in Karlstad, Sweden was actually burned to the ground.

125- "…On the Albany and Springfield circuit, a flash passed across from the break key of the telegraph apparatus to the iron frame, the flame of which was about half the size of an ordinary jet of gas. It was accompanied by a humming sound similar to a heavy current passing between two metal points almost in contact. The heat was sufficient to cause the smell of scorched wood and paint to be plainly perceptible" (AJS, Article XII, Item 3)

126- "The switch-board in the Western Union (telegraph) office here ignited half a dozen times. Several instruments were melted. The duplex and quadruplex wires were rendered useless, and only one wire out of fifteen between Chicago and New York was in operation by noon…Reports from offices all over the Northwest told of damaged switch-boards and melted keys". (CT, 11-18-1882, p.2)

127- "The storm reached as far as Augusta Kentucky .Wires were worked here to Columbus and St Louis without batteries at this end. The wires were very heavily charged, a flame appearing when the contact was broken" (CT, 11-18-1882, p.2)

128- "The switch board in the Western Union Telegraph office there [Chicago] was set on fire several times and much damage was done to the telegraph apparatus. From Milwaukee a report comes that the volunteer electric current was at one time strong enough to light up an electric lamp" (Savanna Morning News, 11-18-1882, p.1)

129- "The switch board here (Chicago) was on fire a dozen times during the forenoon, and half a dozen keys of the instruments were melted by the current" (Kansas City Evening Star, 11-18-1882, p. 1)

130- "It was reported to the Western Union office in New York that the switch in the Springfield Mass. Office was set on fire." (NY, 4-18-1882, p.5)

131- "President Newcomb Carlton of the Western Union Telegraph Company said yesterday that the magnetic disturbance accompanying the aurora borealis on Sunday morning had blown out fuses, injured electrical apparatus and done other things which had never been caused by any ground and ocean currents known in the past" (NY, 5-17-1921, p. 1)

132- "The disturbance was reported by cable to have burned out a telephone station in Sweden." (NY, 5-17-1921, p. 1)

133- "East and west long distance telephone traffic for the entire country is handled through the switchboard here [Washington DC]. Nothing went through last night…High voltage caused by atmospheric electricity coming in on the wires burns out our fuses as fast as we replace them, the wire chief said" (The Kansas City Star, 5-15-1921, p.1)

134- "The disturbance is believed to have caused a fire which destroyed a telephone exchange at Karlstad, a Swedish town about 160 miles west of Stockholm." (Miami Herald, 5-17-1921, p. 2)

135- "Some of the strange results of the magnetic bombardment included the burning out near Bangor Maine of lightning arrestors that Western Union engineers had thought were immune to anything but lightning...(including) the complete fusing at Neche, North Dakota of the Fargo-to-Winnipeg cable." (NY, 3-26-1940, p.18)

Electricity Outages

Outright electrical outages or blackouts are, fortunately, very rare. The earliest event occurred in Geneva on October 31, 1903. The most famous occurred in Quebec on March 14, 1989 affecting over 3 million people. The most recent occurred in southern Sweden during the 2003 'Halloween' storm when the city of Malmö, Sweden suffered from a power blackout that affected 50,000 customers (Pulkkinen, 2004). All these events are attributable to excessive ground currents.

136- "The motors furnishing the electricity for the telegraph wires acted strangely throughout the period, it was reported at the Western Union offices. Just how the electricity in the air operated to interfere with the electrical apparatus could not be explained, but the effect was to change continually the quality of the current" (NY, 5-9-1918, p.9)

137- "Delivery of 195,000 of yesterday's Gazette around Montreal after a power failure shut down the presses. The Gazette had to borrow the press at La Presse in a different part of the city that still had power" (MG, 3-12-1989, p.A3)

138- "Hydro-Quebec is blaming yesterday's massive power failure on the stars. Officials at the utility are citing a magnetic storm - touched off by an explosion on ths sun and marked by a spectacular display of the northern lights - as the main culprit in the third province-wide blackout in less than a year….Yesterday's blackout closed schools and businesses ,kept the Metro shut down during the morning rush hour and paralyzed Dorval airport, delaying flights .It cost Quebec businesses tens of millions of dollars as it stalled production, idled workers and spoiled products." (MG, 3-14-1989, p.1)

139- "No major problems were reported at Montreal hospitals because they are powered by emergency generators in the event of a blackout .Still ,the Montreal Children's Hospital cancelled elective surgery, "We didn't want to be in a situation where everything goes black for a few minutes before the generator goes on", said Dr .Nicholas Steinmetz, the hospital's executive director…Roger Dufor, director of security at St. Luc Hospital said that for about a half-hour, three or four patients in intensive care had to have air pumped into their lungs manually when a back-up generator powering the respiratory machines failed briefly." (MG, 3-14-1989, p.A3)

140- "The General Motors car-assembly plant in Boisbraid lost production of $6.4 million worth of automobiles…The Montreal Stock Exchange, located in Place Victoria, was forced to operate on emergency power…most trades had to be completed manually…Sidbec-Dosco, Inc., a Quebec-owned steel company…estimated yesterday's production loss at between $500,000 and $1.5 million, "All the steel that was already on the line in the hot rolling mills is scrap"… Cascades ,Inc., a pulp and paper company based in Kingsey Falls, said the power shutdown would cost his company between $200,000 and $300,000…the amount doesn't include salaries." (MG, 3-14-1989, p.A3)

141- "...the utility consortium that serves most of Pennsylvania, New Jersey and Maryland, said that monitors had detected unusual intermittent electric currents in the earth and that if the currents became sustained the utilities would reduce long-distance transmission of electricity." (NY, 6-6-1991, p.A16)

A Selection of Newspaper Reprints: 1850-1923

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NYT, September 10, 1898

ANNOYING AURORA BOREALIS.

Many Telegraph Wires Are Disabled for a Time by a Daylight One.

CHICAGO, Ill., Sept. 9.—For an hour and a half this afternoon the Western Union Telegraph lines were disabled by a daylight aurora borealis. At least, that is what the telegraph officials say, and the weather man corroborates them. At 2:30 o'clock strange shocks began to be felt upon the wires. These shocks came in waves of increasing violence. After this had lasted several minutes, the wires would work for a time as though there was nothing the matter. Then the shocks would recommence and work would be delayed again. Inquiry showed the same effect as far east as Buffalo, west beyond Omaha, and south to Tennessee. Washington said that it worked the wires to Georgia with difficulty.

A Western Union official said: " We have had trouble with the Aurora Borealis before, and it has been noticed that the weather was always as it is to-day. The shocks registerad a force of 280 volts upon some of our lines. The trouble is widespread."

Strange to say, the telephone lines were not affected. Forecaster Cox said: " The Aurora was very strong, and if the day had not been cloudy it could easily have been seen."

NYT November 2, 1903

ELECTRIC PHENOMENA IN PARTS OF EUROPE.

Telephone and Street Car Services Suspended in Switzerland for Half an Hour on Saturday.

LONDON, Nov. 1.—Scientists attribute the magnetic disturbance of yesterday to sunspots. The worst effects of the phenomena appear to have been experienced in France. Berlin was not affected, and apparently neither Austria, Italy, nor Denmark suffered.

In Switzerland, however, there occurred a most strange phenomena. The telephone service ceased suddenly and remained suspended for half an hour, while the telegraphs were rendered unintelligible and useless. In Geneva all the electrical street cars were brought to a sudden standstill, and the unexpected cessation of the electric current caused consternation at the generating works, where all efforts to discover the cause were fruitless.

The Meteoroligical Office reports a magnetic storm, accompanied by aurora borealis. In several parts of Ireland and Scotland. The telegraphic disturbance was one of the most extraordinary on record. Late this morning, before it had been settled where the disturbances originated, although Siberia was strongly suspected, slight seismic disturbances were reported from the Riviera.

Sir Oliver Lodge and Sir Norman Lockyer were interviewed on the matter, and agreed in attributing the cause to sun spots and an increase in solar activity, which would also account for the unusual wet season now being experienced.

The Atlanta Constitution, November 1 and 2, 1903

SPOTS ON SUN CAUSE TROUBLE

Strange Phenomenon in France and Switzerland.

Magnetic Disturbance Caused Street Cars To Stand Still and Telephones and Telegraphs Made Useless—Scientists Say Sun Spots Did It.

London, November 1.—Scientists attribute the magnetic disturbance of yesterday to sun spots. The worst effects of the pehnomena appear to have been experienced in France, but Berlin was not affected, and apparently neither Australia, Italy, nor Denmark suffered. In Switzerland, however, there occurred a strange phenomenon. The telephone service ceased suddenly and remained suspended for half an hour, while the telegraphs were rendered useless. In Geneva all the electric street cars were brought to a sudden standstill, and the unexpected cessation of the electric current caused consternation at the generating works, where all efforts to discover the cause were fruitless.

The meteorological office reports a magnetic storm, accompanied by aurora borealis in several parts of Ireland and Scotland. The telegraphic disturbance was one of the most extraordinary on record.

WIRES CHARGED BY LIGHTNING

Aurora Borealis Puts Telegraph Companies Out of Business.

Chicago, Ills., October 31.—Serious electrical disturbances, said to be due to the aurora borealis, caused great inconveniences to telegraph and telephone companies today. Telegraph wires in all directions from Chicago felt the effect, in some localities causing a total cessation of business.

The disturbance lasted eight hours. At its climax there were 675 volts of electricity—enough to kill a man—in the wires without the batteries attached. An hour later the trouble had virtually disappeared.

"It was the worst electrical disturbance in thirty-five years," said Chief Operator J. E. Pettit, of the Postal Telegraph Company. "At times there were no workable wires in any direction and the cable service was seriously affected both on the Atlantic and Pacific."

Los Angeles Time, May 25, 1915

AURORA BOREALIS HALTS WIRELESS TO GERMANY.

[BY A. P. NIGHT WIRE.]

NEW YORK, May 24.—Wireless communication between the United States and Germany has been severely handicapped and probably will continue so until about July 1 by the static conditions prevailing in the North Atlantic at this time of the year.

The electrical activities of the aurora borealis, accompanied by electrical storms over the wireless routes, are the cause of the difficulty, it is explained, and may be expected to continue several weeks. This means that until normal conditions again prevail uncensored communication between Germany and the outside world will be limited.

The news agencies meantime have been obliged to depend upon London for regular transmission of the daily German War Office statement.

Chicago Daily Tribune, May 16, 1921

BOREALIS CAUSE, SUN SPOTS, WILL DIMINISH TODAY

Washington, D. C., May 15.—Interruption of telegraphic communication by electrical influences, if due to the presence of spots on the sun as set forth in the Brashear theory, will pass away within forty-eight hours, naval observatory officials here believe.

The present spot or group of spots on the face of the sun, estimated by naval observatory officials at 94,000 miles in length and 21,000 in latitude, was nearest the earth last night and today through rotation of the sun was moving away from the solar meridian.

Observatory officials said today that disregarding the decreasing effect of the spots on the earth's electrical currents through the usual breaking up of the spots, the regular rotation of the sun on its axis would, within a few days, carry the spots so far from the earth as to make their influence negligible.

The theory that the Aurora Borealis, or northern lights, which send "earth currents" through telegraphic wires, interrupting communication, result from sun spots, was advanced by Dr. John A. Brashear, the late Pittsburgh astronomer.

The theory has never definitely been accepted, the officials asserted, but the fact that spots on the sun usually are accompanied by electrical disturbances has resulted in almost general acceptance of the theory.

The spots present on the sun and which were visible to the naked eye today, with the use of smoked glass, were first photographed at the naval observatory last Monday, when the rotation of the sun brought that side of the solar body within view.

HURTS WIRES, NOT WIRELESS.

New York, May 15.—The remarkably powerful electrical disturbance of the aurora borealis last night, which severely disorganized transcontinental telegraph and telephone communication, disappeared today, permitting normal resumption of traffic.

The phenomenon, while seriously affecting land wires, apparently had little effect on trans-Atlantic wireless communication.

The Washington Post, May 8, 1918

Bel[illegible]d, an Aurora Borealis Glows I[illegible] Northern Sky; Startles Capital

A remarkable manifestation of the aurora borealis, remarkable in that it was so far south and so late in the season, was observed in this city last night. Shortly after 9 o'clock brilliant, dancing, wavering lights appeared in the north and northwest heavens and continued intermittently until well after midnight. The celectial phenomena attracted the attention of weather bureau officials, who described it as one of the most unusual sights that this city has ever known.

Stretching across about 30 degrees of the northern zenith, the lights flared in bursts of red and purple and streaks of gold and white. They glowed for three or four minutes at times, and again showed in fitful flashes of only seconds' duration. They glared at times and caused a report throughout the city that there was an immense fire to the north.

Telegraph wires were seriously affected. The electricity partially responsible for the appearance of the lights overcharged the wires throughout the Northwest and was responsible for extremely poor service, although the atmospheric conditions appeared to be ideal.

"This poor service," said Dr. H. C. Frankenfield, in charge of the weather bureau, "points plainly to the appearance of the aurora borealis. It is very rare that the 'northern lights' are seen as far south as this, and especially at this time of the year.

Officials of the Western Union Telegraph Company confirmed the statement of the weather bureau expert that their service had been impaired by the phenomena.

When the lights first showed in the northern heavens householders began telephoning to find out what was happening.

A number of persons called up the police to find out whether Baltimore was on fire, and finally led the police to ascertain for themselves the cause of the lights. Numerous others were convinced that the lights came from searchlights planted by the government to guard the city from air attacks. This delusion became quite general, despite the fact that the lights were diffused and not in a long, single strip, such as would be thrown from a searchlight lens.

The supercharged telegraph wires felt the effect of the aurora borealis' visit for several hours after the lights disappeared.

Dispatches from New York, Boston, Duluth, Memphis and other points told of gorgeous displays witnessed by citizens. At Duluth the lights took the form of an eagle with pinions spread.

At San Antonio, Tex., two army officers believing a camp on fire sped away for hours over the prairie in an automobile. Chicago thought the city burning. At Norfolk fears were entertained that ships were burning or that coast timber was ablaze. In all places people were much excited.

Chicago Daily Tribune, Feb 14, 1892

IT IS SEEN IN THE WEST.

Red Lights Illumine the Northern Heavens and Make an Imposing Display.

NORTHFIELD, Minn., Feb. 13.—[Special.]—A marvelous sight was witnessed in the heavens between 6 and 7 o'clock tonight. The northern part became tinged with a fiery red and this increased until at 6:30 it extended from the zenith to the north horizon. It was so strong that the snow and houses had a peculiar hue and the country was lit up for a long distance. Later white streamers sprang from the zenith, giving the sky a peculiarly corrugated appearance.

TUSCOLA, Ill., Feb. 13.—[Special.]—From 6 to 7 o'clock this evening a grand display was witnessed in the northern heavens. They assumed a beautiful pink appearance and at frequent intervals streaks of light would flash upward through the vapory mass in all the colors of the rainbow. Many timid people were alarmed.

GALESBURG, Ill., Feb. 13.—[Special.]—A magnificent display of aurora borealis, the finest for many years, is visible here tonight, nearly filling the entire northern hemisphere with a fiery red, traversed by changing columns of white.

CHAMPAIGN, Ill., Feb. 13.—[Special.]—The Northern heavens afforded sky-gazers excellent observation this evening. A large part of it was of solid red, and at intervals streaked with lines of white. The auroral display was the finest ever seen here.

DANVILLE, Ill., Feb. 13.—[Special.]—The aurora borealis was brilliant at 6 o'clock this evening. It was the first display for years. The sky had such a deep unbroken crimson hue that many persons ran up and down the principal streets looking for a fire. The light disappeared shortly after 7 o'clock.

DUBUQUE, Ia., Feb. 13.—[Special.]—There was a magnificent display of the aurora borealis this evening. The northern sky was colored deep red with flashing streamers of light shooting upward. Nothing of the kind has been seen here before for many years.

LYONS, Ia., Feb. 13.—At 6:10 o'clock tonight was witnessed the most wonderful exhibition of northern light ever seen in this section of the country. From east to west the northern sky was illuminated by an immense half circle flaming upward nearly to the zenith.

CEDAR RAPIDS, Ia., Feb. 13.—About 7 o'clock this evening local astronomers were given the most beautiful sight ever witnessed in this section. For a few minutes the heavens were scarlet and then striped with light. Suddenly the stripes moved west, while the scarlet background moved east by north. Then there was inky darkness with flashes of light.

Chicago Daily Tribune, June 14, 1890

THE GREAT MAGNET OF THE SKY.

Effect of Solar Energy in Disturbing the Magnetism of the Earth.

New York *Sun:* It is no new idea that the earth is a huge magnet, having its north and south poles of magnetism and its lines of force along which the magnetic energy manifests itself. Analogy would suggest that the other planets are also great magnets, and there is more than mere analogy to support the idea that the sun is beyond comparison the mightiest magnet of them all. It has been known for many years that the influence of the sun upon the magnetism of the earth is most pronounced and powerful at those times when the surface of the solar globe is most agitated by disturbing forces. Sun spots and their related phenomena are the visible manifestation of the activity of these forces.

The fact that one of the most conspicuous manifestations of the effect of solar energy in disturbing the magnetism of the earth is shown in extensive displays of the aurora borealis may be responsible for the new widespread belief that the weather is directly influenced by disturbances in the sun. It seems quite natural to conclude that if, as has often occurred, a violent outburst in the sun is instantly followed by a brilliant electrical display in the earth's atmosphere, the atmospheric influence of the solar energy may go further and be instrumental in the production of storms. But if the sun exercises such an influence its manifestations are either so uncertain or so slight that no conclusive proof of its existence has yet been obtained. Recently, however, observations have been made which may possibly throw new light upon this very interesting question, and which at any rate present the sun in a very formidable shape to the imagination. M. Charles Lagrange of the Brussels Observatory has arrived at the conclusion, based upon an extensive series of observations and experiments relating to the daily, annual, and secular variations of the magnetic needle, that the sun, being charged with electricty, has become a magnet as a result of its rotation upon its axis, and that the earth, being also electrified, and having in like manner become a magnet, is under the direct influence of the sun, within whose enormous magnetic field it is moving. M. Lagrange proceeds to explain how the magnetic axis of the earth, which does not correspond exactly with the axis of rotation, may have been formed under the influence of the sun, and how it is caused to retrograde by virtue of the earth's rotation in the sun's magnetic field. From the phenomena of the daily variation of the magnetic needle he concludes that the sun electrifies the earth by radiation and produces a system of electrical currents, principally in the atmosphere, by means of which the observed variations are produced. The point of maximum potential, from which the currents diverge, always follows the sun in its daily circuit through the heavens.

The significance of M. Lagrange's conclusions with reference to the weather is to be found in his statement that the earth's attraction on the atmosphere is composed of two elements: gravitation, which is constant, and the attraction of the layer of electricity covering the surface of the globe, which is variable and dependent upon the sun. In this way he offers an electro-magnetic theory of the formation of centers of barometric depression, and their movement toward the poles and from west to east. If this theory should turn out to be substantially correct, then it would be easy to understand how, and to what extent, the sun affects the weather.

The manner in which the sun holds the earth with the resistless grasp of gravitation is a familiar picture to the mind, but this idea of its magnetic power over our globe is somewhat novel and proportionately startling, for it conveys a greater sense of our helplessness. We know the gravitative energy of the sun to a nicety, and it never varies. But its electric influence depends largely upon its own condition, which is subject to the most violent and tremendous vicissitudes. Moreover, there is evidence that the sun's electric power, or whatever that force may be by which it excites the magnetism of the earth, extends equally to other planets. When the sun is most intensely agitated the vast globe of Jupiter is covered with unwonted spots and belts, and its great equatorial bands flush fiery red.

When a comet comes into the solar system there is a beautiful exhibition of a power of the sun which is certainly not gravitation, nor an effect of radiant light or heat as we know them, but which is probably an expression of electric energy. The appearance of the comet's tail, while it is yet far from the sun, is the first evidence that the visitor from space is affected by its approach toward the solar orb. At first the tail is barely visible, but as the comet draws nearer it increases in size and brightness until, at last, as it swings around the sun at close quarters, its blazing train sweeps away a hundred million miles. In this field of the sun, into which a comet cannot venture without thus attesting the far-reaching power of the wonderful governing body at its center, our little globe circles, and its inhabitants cannot be too thankful that the great magnet around which they revolve is not more erratic in the manifestations of its power.

Los Angeles Times, September 26, 1909

AURORA BOREALIS.

ELECTRICAL CURRENTS STOP TELEGRAPHIC COMMUNICATION.

[ASSOCIATED PRESS DAY REPORT.]

CHICAGO, Sept. 25.—Violent electrical earth currents, believed to emanate from the aurora borealis, today disturbed the telegraph service over the entire country, and for a time stilled the ticking of the instruments in the offices of the great telegraph companies.

While the drift of the currents noticeable in cities from San Francisco, Seattle, Omaha, through Chicago, Cleveland and Pittsburgh to New York apparently was to the east, its strength was little more pronounced in one section of the country than another.

The currents first were felt about 5 o'clock in the morning and increased in intensity for two hours, reaching the heaviest wave at 7:10 a.m., when all the telegraph activities were at a standstill.

The force of the disturbance was so great that fuses were blown out and resistance lamps lighted up brilliantly.

Shortly after 7 o'clock the currents began to subside and intermittent service was resumed. The conditions at 9 o'clock were fast becoming normal.

Prof. David Cuthbertson, in charge of the local Weather Bureau, declared the phenomenon was due to the aurora borealis, which, he said, always accompanied a high pressure in atmospheric conditions.

No reports have been received by the local Weather Bureau from north of Nebraska. The center of the magnetic storm, the Weather Bureau declares, is in Manitoba.

NEW YORK, Sept. 25.—For nearly three hours today the telegraph, telephone and cable service of the eastern portion of the United States was interrupted by a severe electrical storm, which generally accompanies a display of the aurora borealis.

The disturbance was first manifested east of New York at 6:50 a.m., temporarily preventing the operation of most of the cables and telegraph wires. The magnetic influence moved rapidly westward, and disappeared, so that by 9:40 a.m., communication was again established.

During the height of the electrical disturbance, the measuring instruments in the telegraph offices in this city registered the presence on the wires of upward of 500 volts of electricity from an unknown disturbance.

The disturbance continued intermittently throughout the day. The principal trouble was with the cable lines.

CURRENT WORKS WIRES.

[ASSOCIATED PRESS NIGHT REPORT.]

CINCINNATI, Sept. 25.—Telegraph business in Cincinnati today was seriously hampered by peculiar earth currents.

In the Western Union office an experiment was conducted by cutting off the batteries and working a single wire between Cincinnati and St. Louis by the power of this earth current. The plan worked all right as long as the earth current lasted, but it was not feasible for general work, as the current was too unsteady.

SPRING WEATHER AT OGDEN.

[ASSOCIATED PRESS NIGHT REPORT.]

OGDEN (Utah) Sept. 25.—Unusual meteorological conditions prevail in this part of Utah.

The weather has suddenly changed from the frost conditions of autumn to that of balmy spring, although the sky has not been overcast and all signs of storm have been absent for ten days.

Local electricians and wire chiefs at the telegraph and telephone offices report heavy electrical disturbances, which are causing much wire trouble.

Western Union wire chiefs attribute the "earth currents" to the aurora borealis, which is now visible, illuminating the northern heavens to the zenith with streams of white light.

The heavy electrical wave was first felt in the local offices at 5 o'clock this morning.

The Atlanta Constitution, May 8, 1918

Two Officers Chase Aurora Borealis Thinking It Fire

Vivid Northern Lights Seen as Far South as Tampa. Wire Service Is Interrupted.

Tampa, Fla., March 7.—For the first time in the present generation the aurora borealis was visible in the northern sky from Tampa tonight. There was a vivid red glow, as if a great fire was raging. One report had it that Dade City, a town forty miles to the north, was a-fire, but Dade City reported the same glow far to the north.

San Antonio, Texas, March 7.—Visibility of the aurora borealis here tonight for the first time in many years, caused an exciting ride for two army officers who saw the red glow in the north, suspected a fire at one of the army camps, hired an automobile, and speed out into the country seven miles before giving up the chase. The aurora was visible for nearly an hour.

Washington, March 7.—Brilliant lights in the sky over the capital tonight brought a large part of the population into the streets to observe what was thought to be a big fire. It was the aurora borealis, and officials of the naval observatory said the display was the best they ever had seen in this latitude.

Duluth, Minn., March 7.—The most elaborate display of the aurora borealis ever seen in Duluth appeared tonight. The lights took the form of an eagle with full spread wings.

New York, March 7.—The aurora borealis was observed by thousands of persons here tonight. The phenomena was visible from 8 o'clock until 11 o'clock, when apparently it reached its maximum of brilliancy. The long streamers from the arch were well tinted, a vivid red predominating. Telegraph and telephone communication north and east of New York suffered considerable interruption by reason of the phenomenon, while wires running south from Washington were hampered, but to a less extent shortly before 11 o'clock.

Telephone messages to the Constitution from various points in Georgia Thursday night reported the intense glow of the Aurora Borealis in the northern sky.

A message from Rome, Ga., reported that many citizens there thought the glow was caused from a great forest fire.

Although the sky was overcast by clouds in the vicinity of Atlanta a number of people called over the telephone to say that they had noted a display of lights in the north.

NYT February 3, 1919

RED ARTILLERY SHELLS PETROGRAD, SEIZED IN REVOLT

FIGHT REDS BY LIGHT OF AURORA BOREALIS

American and British Troops Again Repulse Attack on Dvina River Front.

ARCHANGEL, Feb. 1, (Associated Press.)—While they have succeeded in capturing the Shenkursk and Taresevo sectors, the Bolsheviki are still unable to make any impression on the American and allied lines on the Dvina sector near Tulgas. For the second time within a week a night attack by the enemy there was repulsed by the Americans and the Scotch.

The latest attack occurred early Friday. The Bolsheviki stormed the upper Tulgas, but met with severe resistance from the American patrol, who, however, withdrew, giving their artillery a clean sweep of the village. The Americans killed twenty of the Bolsheviki and wounded twenty, and also took seven prisoners. The allied patrols on the Taresevo sector moved southward twelve miles without encountering the enemy.

The indications are that the Bolsheviki are not following the Americans on their line of retreat here, but are moving in the direction of the Dvina in an effort to cut off the Dvina and Vaga forces at a point north of the junction point of the two rivers.

Last night's fighting was carried out under a clear sky and in cold weather. During the fighting the Northern Lights flamed spectacularly.

NYT, May 25, 1915

GERMANY IS CUT OFF BY BREAK IN WIRELESS

Electrical Disturbances in the North Atlantic Sever Direct Communication—Allies Censor Cables

Owing to unfavorable static conditions in the North Atlantic, which have handicapped wireless communication between this country and Germany, the German Government for some time has found it practically impossible to send messages here without having them pass first into the hands of the British censors in London. The belief was expressed yesterday that the present conditions would continue until about July 1. The activities of the aurora borealis and severe electrical storms over the wireless routes are responsible for the situation. Germany may thus remain isolated from the rest of the world for several weeks, unless the censors see fit to permit its messages to go over the cables which are controlled by the Allies.

It was learned yesterday that the wireless station at Sayville, L. I., the receiving station of the Atlantic Communication Company, the German wireless concern, has been cut off entirely from the German sending station at Nauen, Germany, on several occasions during the past two weeks. The situation is about the same at Tuckerton, N. J., from which the wireless messages to Germany are sent.

It has been estimated that the static disturbances now occurring often increase the wireless distance between Nauen and Sayville by the equivalent of 2,000 miles, a handicap which even the powerful equipment has been unable to overcome. Four operators have worked simultaneously at Sayville receiving a single message. By picking up fragments and patching them together a few messages have been received, but as a rule the result has been not at all satisfactory.

Germany had to fall back upon her wireless plants in order to transmit news and official or diplomatic messages through a channel not controlled by her enemies when the German-owned Atlantic cable was cut at the beginning of the war. The Sayville station became the distributing centre, and the messages were thence transmitted by neutral cable or telegraph to all parts of the world. In that way Germany managed to send uncensored messages to her diplomatic representatives in neutral countries, and the German War Office statements were distributed uncensored. At present the news agencies must depend upon London for transmission of the daily German War Office statements.

Chicago Daily Tribune, September 10, 1898

AURORA STOPS THE KEYS.

ELECTRICAL FREAKS OF NATURE INTERFERE WITH THE TELEGRAPH.

Wires All Over the United States East of the Rocky Mountains Made Useless by Strange Ground Currents—Phenomena Accompanied by High Barometric Pressure—Their Occurrence at This Time of the Year Considered Remarkable.

Telegraph wires over all the United States east of the Rocky Mountains refused to work yesterday between 11 a. m. and 4 p. m., during which time an electrical disturbance similar to that sometimes occasioned by the aurora borealis was in progress. The effect on the wires was much like that of an electric storm, except that the current was a "ground" current. The disturbance came in waves, which were about as strong in one part of the United States as another. Had the aurora occurred at night Chicago probably would have been treated to the most brilliant atmospheric display in years.

As far as could be ascertained last night, the electrical potential of the disturbance was not recorded by any instrument in Chicago. The Chicago Weather bureau has no instruments for recording magnetic disturbances. Professor A. A. Michelson of the department of physics of the University of Chicago said that as far as he knew no record had been made of the disturbance at the university.

The last disturbance of the kind occurred about three months ago. It was much less severe than that of yesterday. Both are regarded as being unusual, owing to the time of year. Telegraph wires over large areas of the United States are frequently affected in the months of April and November, but disturbances in September are rare.

Worst at 3 O'Clock.

At 3 p. m. there was not a telegraph wire working east of Pittsburg or Buffalo. Atlanta and Augusta, Ga., reported their lines north to Washington out of service. After 4 o'clock the magnetic display ceased altogether and the wires worked as well as before.

At the local weather office there was no knowledge of the disturbance except what was furnished by the newspapers. Forecast Official Wood thought there might be some connection between the unusually high barometric pressure and the magnetic waves, which usually accompany each other. The whole United States and that part of Canada covered by the weather service showed remarkable barometric conditions.

The cold wave had submerged practically the entire country. At Cheyenne, Wyo., the coldest point in the United States, the mercury fell to 32 degrees. Even in Texas a cold northeast wind was rapidly sending the mercury down. At Duluth the minimum temperature was 48 degrees.

North of the Canadian line the temperature was higher than in the northern United States. At Medicine Hat, the starting point of cold waves, the mercury reached 60 degrees, while 250 miles north, at Edmonton, it was eight degrees warmer. These peculiar conditions undoubtedly had some relation to the electrical condition of the atmosphere, Mr. Wood believes, though, neither depended on the other.

Rains Throughout Corn Belt.

Rain fell throughout the corn belt and at Green Bay and Grand Haven. The rains appeared to be moving eastward, and may bring showers to Chicago today. The local forecast was for a fair day and stationary temperature, however.

An official of the Western Union Telegraph company said in the evening regarding the electrical display of the afternoon:

"It was the most general disturbance the wires have had in a long time. They worked so slowly as to be almost useless. The disturbance did not appear to affect any one part of the United States more than another. I do not think it was noticed west of the Rockies, however. It appeared in waves, which manifested themselves at irregular intervals. We are used to milder disturbances of this sort, but this one was remarkably general and severe. We seldom are troubled by the aurora during September."

Forecast Official Wood said:

"No one knows the cause of those disturbances. They can be recorded and observed, but it is speculation to say what causes them. Evidently there is some relation between them and the high barometric pressue that always accompanies them."

New York Times, March 9, 1918

GERMAN AIR RAIDERS KILL 11 IN LONDON

46 Wounded by Bombs Dropped from Airplanes in Thursday Night's Attack.

AURORA AIDS THE GERMANS

Sky Brighter Than in Moonlight—Only Two of Seven or Eight Machines Reach the City.

LONDON, March 8.—Seven or eight German airplanes made a raid over England last night. Two of them reached London and dropped bombs in the north, northeast, northwest, and southwest districts of the city.

Eleven persons are known to have been killed and forty-six injured in the metropolitan district. It is feared that at least six bodies are still buried in wreckage.

An official report says:

"The latest police reports state that eleven were killed and forty-six injured in last night's airplane raid. It is feared that, in addition to the above, six bodies are still buried in the wreckage of houses. All the casualties occurred in London."

The raid is thus described in an earlier official report:

"Last night's air raid appears to have been carried out by seven or eight enemy airplanes, of which two reached London. The first two raiders approached the Isle of Thanet at about 10:55 P. M., and proceeded up the Thames estuary. Both were turned back before reaching London.

"Meanwhile a third raider came across the Essex coast at 11:20 P. M. and steered west. At 11:45 P. M. it was reported over East London. A few minutes later it dropped bombs on the southeastern and northeastern districts. At 11:50 P. M. the fourth raider, which had also come in across Essex, dropped bombs to the north of London and then proceeded south across the capital, dropping its remaining bombs on the northern district between 12:20 and 12:30 A. M. The remaining enemy machines, all of which came across the Essex coast, were turned back before they reached London.

"A certain amount of damage was caused to residential property in London. Several houses have been demolished."

Greatest Damage in Northwest.

The greatest damage in London was inflicted in the northwestern section, where four bombs demolished several houses. All the damage and casualties in this district were confined to two parallel streets, although, as usual, windows were broken for a radius of several blocks. A single raider appeared over this area. Hundreds of persons were just preparing to desert their homes, most of which are three-story buildings, for the more substantial shelter of the two nearby subways when the bombs began to fall.

The first bomb made a square hit on a three-story dwelling of concrete and brick, crashing through two floors before it exploded. While the police, special constables, and volunteer rescuers were busy there three more bombs fell in the neighborhood in quick succession. Ambulances arrived speedily, and, notwithstanding the confusion, the rescuers worked effectively under the anti-aircraft barrage, which was continued for twenty minutes after the bombing of this district.

Several persons were killed by the destruction of private houses in northeastern London. The house of a vicar was partially wrecked, but the clergyman escaped. He is a special constable and had left home for duty when the warning came a few minutes before the explosion which damaged his residence. The vicar worked throughout the night, assisting his wounded and homeless neighbors.

A bomb which fell in a northern suburb destroyed two houses and damaged the windows of every residence in the street. Doors were wrenched from the hinges and chimneys collapsed. Not far away a dance was in progress. It was not interrupted, although the roar of the guns almost drowned out the music.

Rescuers Work All Night.

Rescuers, who included Red Cross women, continued into the daylight hours to pull living persons from the wreckage of their homes. In one district two aged women clinging to each other were dug out alive, while at midday an elderly man was brought out suffering only from bruises. He had been buried with his wife and daughter who had been extricated earlier and who had thought him dead. As he was placed in an ambulance the onlookers cheered.

Several of the rescued persons still clung to frightened dogs and cats, while one woman carried a cage in which was a live canary. The woman had been caught in a basement when the upper floors of her house crashed down. A heavy beam protected her and her pet.

The hero of one neighborhood is a youth who borrowed a steel helmet to protect him from shrapnel and rescued his two elderly sisters and their maid after twelve hours' hard work.

The raid has demonstrated the fact that German aviators no longer depend upon moonlight. It was the first time the enemy had attempted a night raid over London when there was no moon. The stars were out, however, and there was little wind.

Londoners were taken by surprise when the warning signals were sounded. The theatres were just closing. The streets were soon cleared. The warning to avoid danger from shrapnel was generally heeded, everyone taking cover. For a time the gun fire was heavy.

There was a remarkable display of the aurora borealis last night, and it is believed by many that this furnished conditions under which the air raiders could work more effectively than under a clear, star-lit sky. Watchers on the Kent coast said that just before they heard the raiders approaching the whole northern sky became illuminated, in bands of red and white light which shone over the sea with far more powerful effect than the full moon. Then, as if to accentuate the brightness by contrast, the skies to the southward toward France and the English Channel grew pitch dark.

Another feature of the night was the strong breeze, which most persons believed hindered the operations of the hostile airplanes. Those who watched from high points the spectacle of the searchlights and gun flashes wondered how the enemy could face the wind and cold.

NASA Educational Resources Featuring Space Weather

Sun-Earth Day: Technology Through Time

Developed for NASA's Sun-Earth Day program of national and international education in solar and sun-earth connection science, these short essays cover a diverse range of topics related to the history and science behind space weather forecasting and solar observations from Ancient Egypt to the 21st Century. The theme for 2010 was 'Magnetic Storms'. All 71 back issues are available from the archive link. (http://sunearthday.gsfc.nasa.gov/2010/TTT/71.php)

IMAGE: Ask the Space Scientist

Hundreds of frequently asked questions about the sun, earth and space weather covering nearly all popular questions about solar storms, aurora, and the human impacts of space weather. (http://image.gsfc.nasa.gov/poetry/ask/askmag.html)

THEMIS: Exploring Magnetism

A series of 4 workbooks that describe all aspects of Earth's magnetic field and its often stormy conditions with many hands-on lab exercises designed to investigate magnetic storms using real-time NASA data (http://ds9.ssl.berkeley.edu/themis/classroom.html):

- Exploring Magnetism
- Magnetism and Electromagnetism
- Space Weather
- Earth's Magnetic Personality

Space Math @ NASA

In addition to hundreds of separate math problems covering nearly all aspects of astronomy and space science, there are 9 books that support space weather (http://spacemath.gsfc.nasa.gov/books.html):

- Solar Math
- Radiation Math
- Magnetic Math
- Northern Lights and Solar Sprites
- Exploring Earth's Magnetic Field
- The Classroom Magnetometer Lab
- Tracking a Solar Storm
- Solar Storms and You!
- The Northern Lights

SOHO Space Weather Monitor

Today's solar surface seen from many different wavelengths using ground-based and space-based imaging systems.
(http://sohowww.nascom.nasa.gov/spaceweather/)

Cosmicopia

An informational resource that covers many topics in astronomy, space science and space weather issues. **(**http://helios.gsfc.nasa.gov/weather.html)

NASA Integrated Space Weather Analysis System

A sophisticated, professional space weather system that runs on a computer.
(http://iswa.gsfc.nasa.gov/iswa/iSWA.html)

Hinode Education

This website provides a variety of resources that communicate the various aspects of solar science and space weather impacts including separate resource pages on (http://solarb.msfc.nasa.gov/for_educators/learn/):

- The Human Impacts of Space Weather
- Solar History Timeline
- All About Flares
- Solar Flare Forecasting

YouTube Video Programs:

- *Solar Storms: A talk with Sten Odenwald*
  http://www.youtube.com/watch?v=DSfAI6_7bjU
- *The Hinode Satellite*
  http://www.youtube.com/watch?v=06jygaYE5eY
- *The 1989 Blackout*
  http://www.youtube.com/watch?v=KqXtwAZFfUQ
- *Real World: Space Weather*
  http://www.youtube.com/watch?v=82_ppwzqLoQ

Scientific American (August, 2008): *Bracing for a Solar Superstorm*

This semi-technical article describes an historic 'superstorm' that occurred in September 1859, and what might happen should such an event re-occur in the modern era.

AGU Quarterly Journal of Space Weather

A professional journal covering many research topics in space weather science (http://www.agu.org/journals/sw/).

Recent Newspaper Headlines

- Out of control, Galaxy-15 'Zombisat' caused by solar storm, April 5, 2010
- Congress approves 'space weather' power grid legislation, June 2010

Books and Reports

- 'The 23rd Cycle; Learning to live with a stormy star'
  http://www.amazon.com/23rd-Cycle-Sten-Odenwald/dp/0231120796/ref=tmm_pap_title_0
- NAS Report: Severe space weather events, September, 2008
  (http://books.nap.edu/openbook.php?record_id=12507&page=R1)

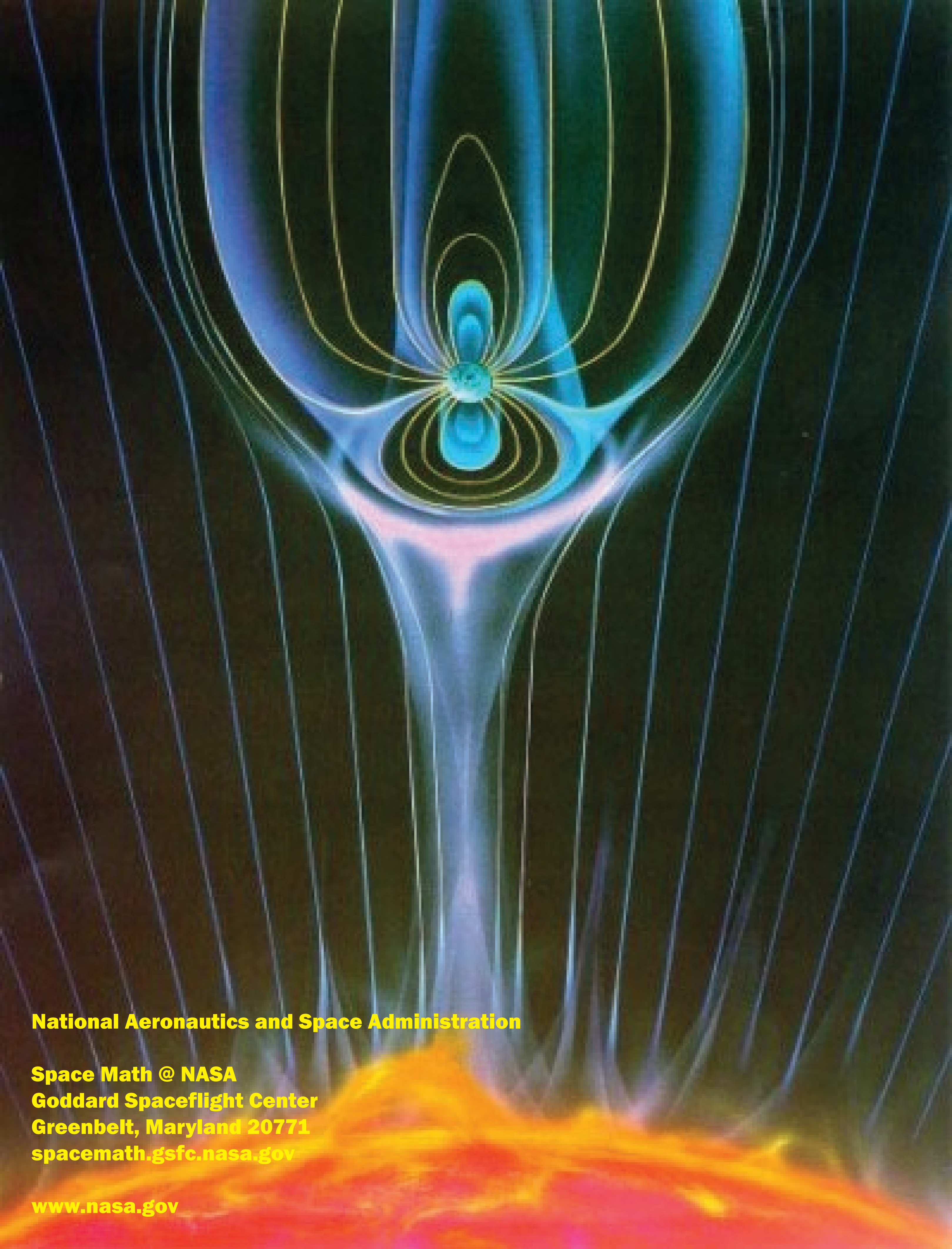
TV, Video and Planetarium Programs

- *Blackout!* (20 minute program, produced by IMAGE Project) Available through NASA-CORE. To order a copy, contact: Request Coordination Center, Code 633, Goddard Space Flight Center, 301) 286-6695 (Email) request@nssdc.gsfc.nasa.gov

CDroms

These are available through NASA-CORE or from the individual missions.

- IMAGE: *Space Weather: Exploring the Sun-Earth Connection*
- THEMIS: *Exploring Magnetism*
- STEREO: *The Sun and Space Weather: Multimedia presentations*
- SOHO: *The Dynamic Sun*



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