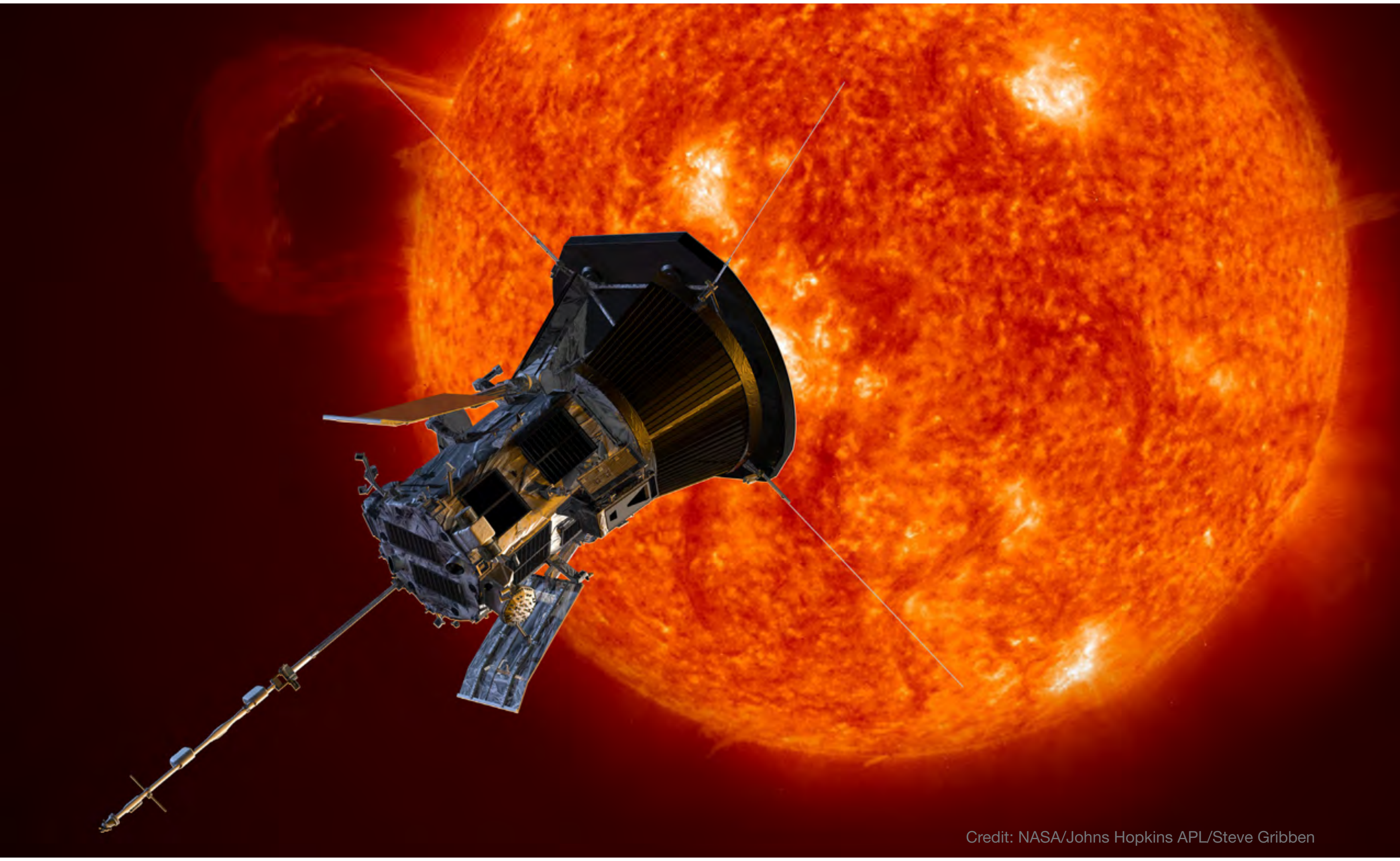
National Aeronautics and
Space Administration

Parker Solar Probe



A Mission to Touch the Sun

Press Kit • August 2018

www.nasa.gov

PARKER SOLAR PROBE

A Mission to Touch the Sun

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For more information about Parker Solar Probe, visit:
nasa.gov/solarprobe

Media Services Information

Pre-Launch News Briefings

Information about Parker Solar Probe pre-launch media events will be posted at:
nasa.gov/solarprobe

NASA TV Launch Coverage

NASA TV live launch coverage will begin at 3:15 a.m. EDT. For NASA TV downlink information, schedules and links to streaming video, visit *nasa.gov/nasatv*.

Audio only of the news conferences and launch coverage will be carried on the NASA "V" circuits, which may be accessed by dialing 321-867-1220, -1240, -1260 or -7135. On launch day, "mission audio," the launch conductor's countdown activities without NASA TV launch commentary, will be carried on 321-867-7135.

NASA Web Prelaunch and Launch Coverage

Prelaunch and launch day coverage of Parker Solar Probe will be available on the *NASA website*. Coverage will include live streaming and blog updates beginning at 3:15 a.m. EDT as the countdown milestones occur. On-demand streaming video and photos of the launch will be available shortly after liftoff. For questions about countdown coverage, contact the newsroom at 321-867-2468. You can follow countdown coverage on our launch blog at *https://blogs.nasa.gov/parkersolarprobe/*.

Parker Solar Probe Press Releases and Mission News

A link to all NASA Parker Solar Probe press releases and mission news can be found at:
https://www.nasa.gov/solarprobe

Multimedia Gallery

Parker Solar Probe images, high-definition video and animations can be found at:
https://svs.gsfc.nasa.gov/Gallery/ParkerSolarProbe.html

Parker Solar Probe Executive Summary

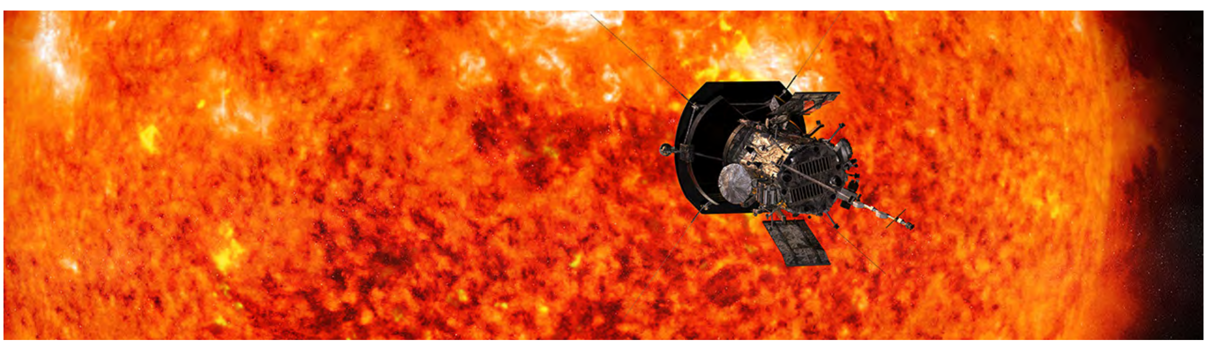
NASA's Parker Solar Probe mission will revolutionize our understanding of the Sun. The mission will "touch the Sun," flying directly through the solar corona, facing brutal heat and radiation conditions and providing unprecedented, close-up observations of the star we live with.

These observations will address unsolved science questions such as how the Sun's corona is heated and how the solar wind is accelerated. It will also benefit humans on the ground by making critical contributions to our ability to forecast major space weather events that impact life and technology on Earth. Such information can shed light not only on how the Sun drives the space environment in our own solar system, but also provide insight into other stars throughout the universe.

To unlock the mysteries of the corona, Parker Solar Probe will carry four instrument suites designed to study magnetic fields, plasma and energetic particles, and image the corona and solar wind. The mission will use seven Venus flybys over nearly seven years to gradually shrink its orbit around the Sun and complete a total of 24 close approaches. The spacecraft will come as close as about 3.8 million miles (6.2 million kilometers) to the Sun, well within the orbit of Mercury and will come closer to our star than any spacecraft has come before.

To perform these unprecedented investigations, the spacecraft and instruments are protected from the Sun's heat by a 4.5-inch-thick carbon-composite shield, which will withstand temperatures of nearly 2,500 degrees Fahrenheit.

Parker Solar Probe will launch no earlier than Aug. 11, 2018.



Artist's concept of NASA's Parker Solar Probe. The spacecraft will fly through the Sun's corona to trace how energy and heat move through the star's atmosphere.

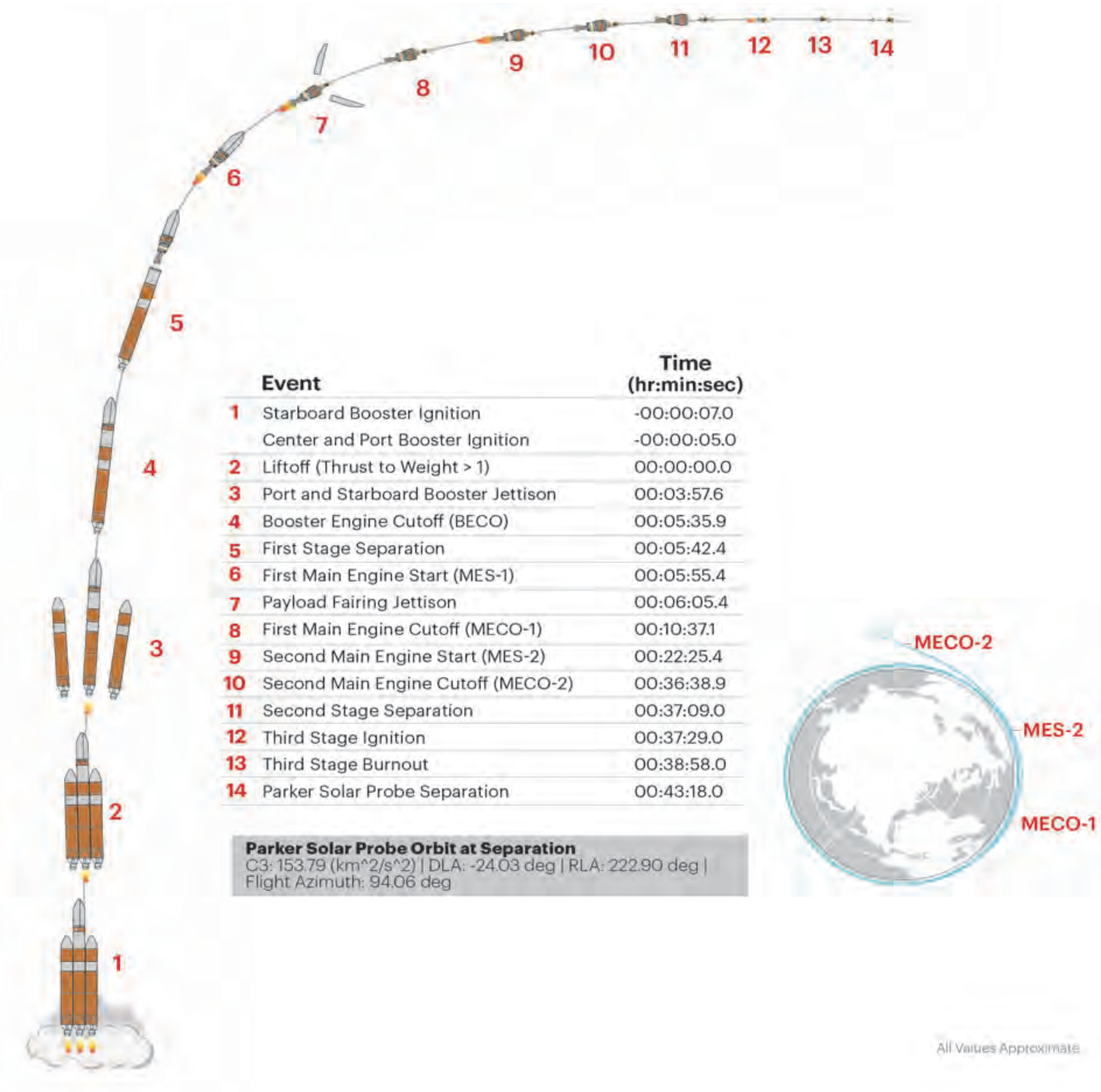
Credit: NASA/Johns Hopkins APL

Parker Solar Probe Mission Quick Facts

Launch Date:	Aug. 11, 2018 (Targeted)
Launch Site:	Space Launch Complex 37, Cape Canaveral Air Force Station
Launch Vehicle:	United Launch Alliance Delta IV Heavy rocket
Launch:	Targeted for 3:48 a.m. EDT (approximately 45-minute window)
Spacecraft Separation:	Targeted for approximately 36 minutes after launch
Orbit:	Elliptical orbit around the Sun at 3.4 degree inclination from the ecliptic plane
Orbital Period:	88 days for final orbits with closest approach
Mission Duration:	Baseline seven-year science mission
Operations:	The Johns Hopkins University Applied Physics Lab in Laurel, Maryland, will perform ground commanding, flight operations and data telemetry, as well as data processing and archiving.
Ground Data Passes:	Parker Solar Probe will transmit data via NASA's Deep Space Network.

Parker Solar Probe Flight Profile

Delta IV Heavy Launch Profile



	Event	Time (hr:min:sec)
1	Starboard Booster Ignition	-00:00:07.0
	Center and Port Booster Ignition	-00:00:05.0
2	Liftoff (Thrust to Weight > 1)	00:00:00.0
3	Port and Starboard Booster Jettison	00:03:57.6
4	Booster Engine Cutoff (BECO)	00:05:35.9
5	First Stage Separation	00:05:42.4
6	First Main Engine Start (MES-1)	00:05:55.4
7	Payload Fairing Jettison	00:06:05.4
8	First Main Engine Cutoff (MECO-1)	00:10:37.1
9	Second Main Engine Start (MES-2)	00:22:25.4
10	Second Main Engine Cutoff (MECO-2)	00:36:38.9
11	Second Stage Separation	00:37:09.0
12	Third Stage Ignition	00:37:29.0
13	Third Stage Burnout	00:38:58.0
14	Parker Solar Probe Separation	00:43:18.0

Parker Solar Probe Orbit at Separation
C3: 153.79 (km^2/s^2) | DLA: -24.03 deg | RLA: 222.90 deg | Flight Azimuth: 94.06 deg

Courtesy of United Launch Alliance

Parker Solar Probe Quick Facts: The Spacecraft

Mass: The mass of the spacecraft after fueling is about 1,400 pounds (635 kilograms). The heat shield, called the Thermal Protection System (TPS), weighs 160 pounds (73 kilograms).

Spacecraft Dimensions: The spacecraft is about 9.8 feet (3 meters) tall and about 3.3 feet (1 meter) in diameter below the cooling system. The Thermal Protection System is a little over 4.5 inches (11.43 centimeters) thick and has a diameter of about 7.5 feet (2.3 meters).

Solar Arrays: The two solar arrays are each about 3.7 feet (1.12 meters) long by 2.26 feet (0.69 meters) wide, for a total area of 17.2 square feet (1.6 square meters).

Power: Parker Solar Probe's solar arrays can produce 388 watts of power, depending on configuration—about enough to run a kitchen blender.

Antenna: The spacecraft has three types of antenna.

- One High-Gain Antenna (HGA) for downlinking high-rate science data
- Two Fan-beam Antenna to support command uplink and real-time health and status telemetry downlink during nominal operations
- Two Low-Gain Antenna (LGA) to support command uplink and real-time health and status telemetry downlink during contingency operations

Maximum Downlink Rate: The maximum downlink rate is 555 kilobits per second (kbps). The downlink time varies by orbit phase.

- During cruise phase, the spacecraft will transmit health and status telemetry to the ground three times per week.
- During the solar encounter phase, the spacecraft talks to Earth three times per week by transmitting a beacon tone which indicates spacecraft health and status.
- During the science data downlink period, the spacecraft will transmit high rate science data to the ground on a daily basis, from 10 to 24 hours per day.

Parker Solar Probe Quick Facts: The Journey

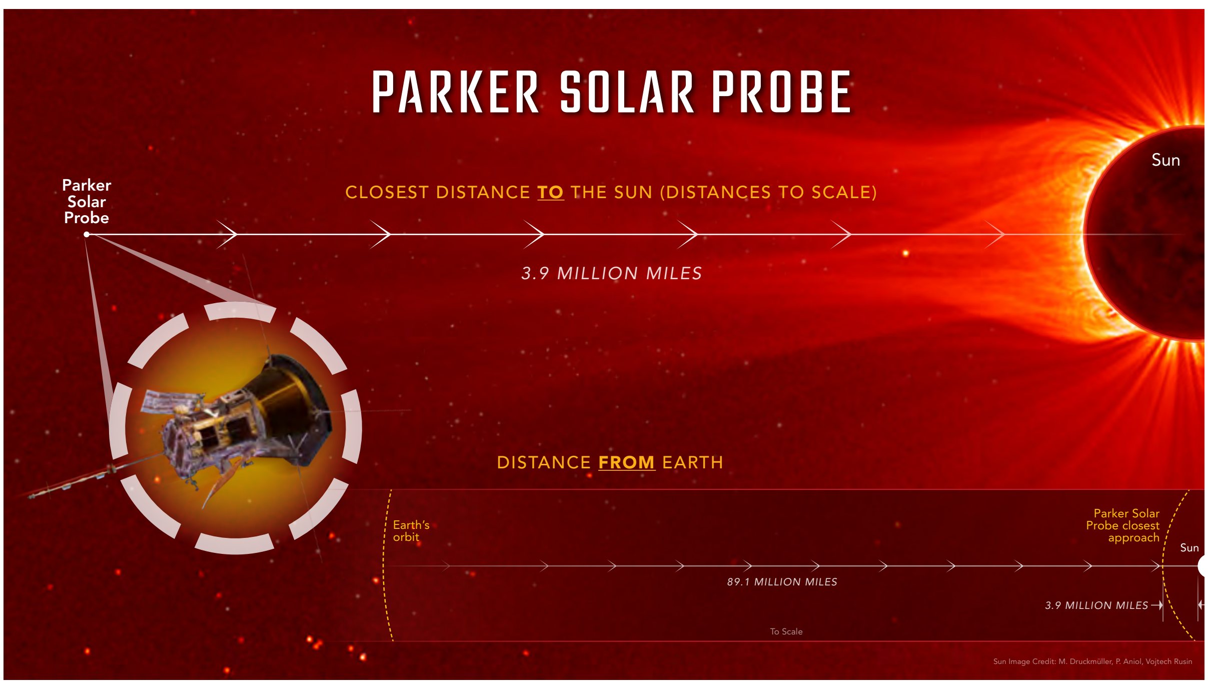
- Parker Solar Probe will reach its first close approach to the Sun three months after launch.

- Over seven years, the spacecraft will complete 24 orbits around the Sun and will encounter Venus seven times—each time performing a gravity assist maneuver to slow the spacecraft down so it can pass closer to the Sun.

- At its closest approach, the spacecraft will come within about 3.8 million miles of the Sun. If the distance between Earth and the Sun was the length of a football field, the spacecraft would be around 4 yards from the end zone.

- At closest approach, Parker Solar Probe will hurtle around the Sun at approximately 430,000 miles per hour—that's fast enough to get from Washington, D.C., to Tokyo in under a minute.

- While the front of Parker Solar Probe's heat shield will reach temperatures approaching 2,500° Fahrenheit at its closest approach to the Sun, the spacecraft's interior will remain near room temperature (about 85° Fahrenheit).



Parker Solar Probe Quick Facts: The Science

- Parker Solar Probe's observations from directly inside the corona will help scientists understand why the Sun's atmosphere is some hundreds of times hotter than its surface.
- The mission will provide unprecedentedly close observations of the solar wind—the constant outflow of solar material hurled from the Sun at a million miles per hour.
- Parker Solar Probe will also study how solar eruptions accelerate particles to such energies that they can pose a hazard for astronauts and technology in space.
- Understanding more about fundamental processes near the Sun will provide key information to better understand their effect on the space environment near Earth. Such space weather can change the orbits of satellites, shorten their lifetimes, or interfere with onboard electronics. The more we learn about what causes space weather—and how to predict it—the better we can protect the satellites we depend on.
- Understanding more about space weather also helps protect astronauts from dangerous radiation exposure during potential human space flight missions exploring the Moon and Mars.
- Our Sun is the only star that can be studied up close. Observing the star we live with sheds light on stars throughout the universe.
- Parker Solar Probe is the newest addition to NASA's heliophysics fleet—missions that study the vast interconnected system from the Sun to the space surrounding Earth and other planets to the farthest limits of the Sun's constantly flowing streams of solar wind. Parker Solar Probe provides key information about how the Sun drives this dynamic and complex system.

Parker Solar Probe's heat shield was installed on the spacecraft on June 27, 2018.

Credit: NASA/Johns Hopkins APL/Ed Whitman

Parker Solar Probe Mission Overview

Parker Solar Probe will travel through the Sun's atmosphere, closer to the surface than any spacecraft before it, facing brutal heat and radiation conditions—and ultimately providing humanity with the closest-ever observations of a star.

The Sun is the only star we can study up close. By studying the star we live with, we learn more about stars throughout the universe. Parker Solar Probe's primary science goals are to trace how energy and heat move through the solar corona and to explore what accelerates the solar wind as well as solar energetic particles.

The solar wind is the flow of ionized gases from the Sun that streams past Earth at speeds of more than a million miles per hour (500 km per second). Disturbances in the solar wind shake Earth's magnetic field and pump energy into the radiation belts, part of a set of changes in near-Earth space known as space weather. Space weather can change the orbits of satellites, shorten their lifetimes, or interfere with onboard electronics. The more we learn about what causes space weather—and how to predict it—the more we can protect the satellites we depend on.

The solar wind also fills up much of the solar system, dominating the space environment far past Earth. As we send spacecraft and astronauts further and further from home, we must understand this space environment just as early seafarers needed to understand the ocean.

Parker Solar Probe will use Venus' gravity during seven flybys over nearly seven years to gradually bring its orbit closer to the Sun. The spacecraft will fly close enough to the Sun to watch the solar wind speed up from subsonic to supersonic, and it will fly though the birthplace of the highest-energy solar particles. Parker Solar Probe will carry four instrument suites designed to study magnetic fields, plasma and energetic particles, and image the solar wind.

Scientists have sought these answers for more than 60 years, but the investigation requires sending a probe right through the 3 million degrees Fahrenheit heat of the corona. Today, this is finally possible with cutting-edge thermal engineering advances that can protect the mission on its dangerous journey. The spacecraft and instruments will be protected from the Sun's heat by a 4.5-inch-thick (11.43 cm) carbon-composite shield.

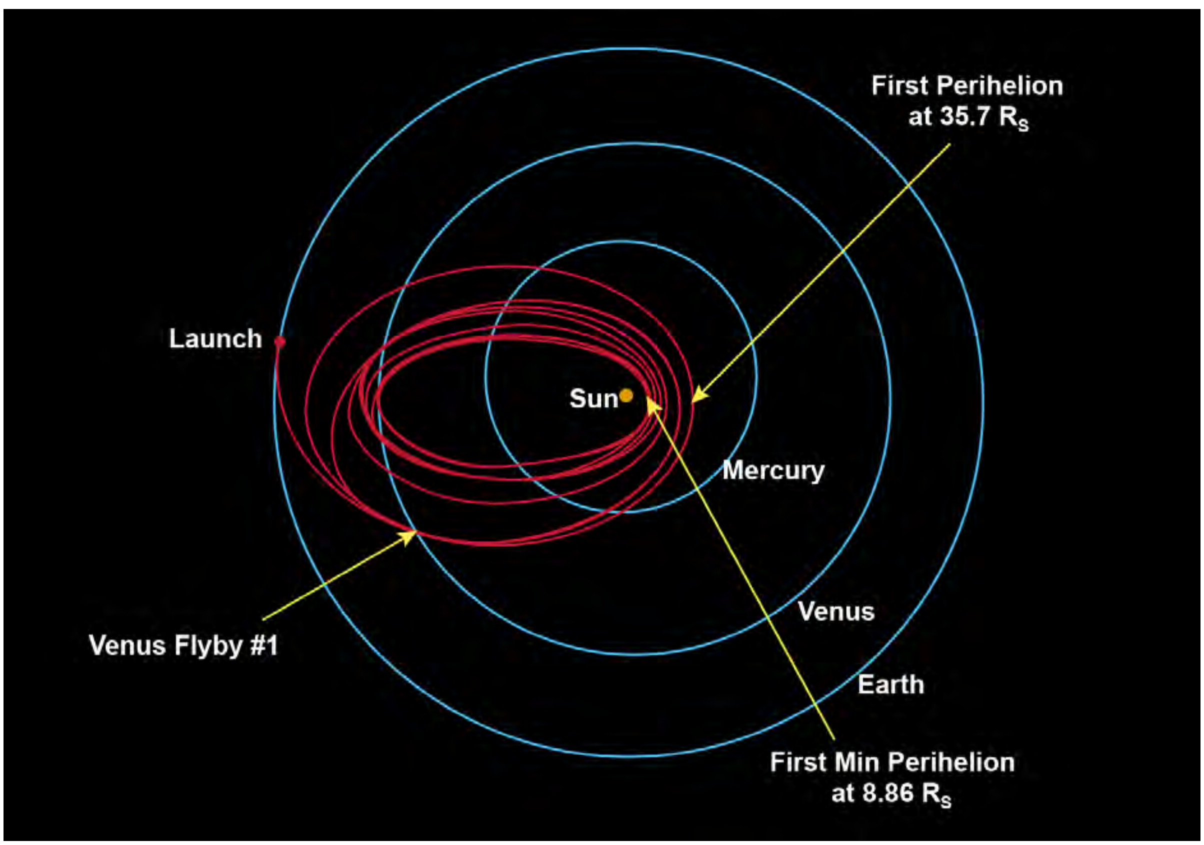
Mission Orbit

Parker Solar Probe will use Venus gravity assists during seven flybys over nearly seven years to gradually bring its orbit closer to the Sun. Its first Venus flyby is two months after launch, in late September 2018, and its first close approach to the Sun—already closer than any spacecraft has ever gone before—will occur three months after launch, in early November 2018.

On the final three orbits, Parker Solar Probe flies to within about 3.8 million miles of the Sun's surface. The current record-holder for a close solar pass, the Helios 2 spacecraft, was seven times farther away: Helios 2 came within 27 million miles of the Sun's surface in 1976. Mercury orbits about 36 million miles from the Sun on average, so it is nearly 10 times farther away than Parker Solar Probe's closest approach.

At closest approach, Parker Solar Probe hurtles around the Sun at approximately 430,000 mph (700,000 kph). That's fast enough to get from Philadelphia to Washington, D.C., in one second.

The spacecraft will be in an elliptical orbit around the Sun at 3.4 degree inclination from the ecliptic plane.



Data Path and Rate

Parker Solar Probe's data will be downlinked via NASA's Deep Space Network. Spacecraft health and status telemetry is processed and archived at the APL Mission Operations Center, or MOC. Science data is archived at the MOC and distributed to the instrument teams and general public via the Science Gateway.

The maximum downlink rate from the spacecraft is 555 kilobits per second (kbps). Downlink time varies by orbit phase.

- During cruise phase, the spacecraft will transmit health and status telemetry to the ground three times per week.
- During the solar encounter phase, the spacecraft talks to Earth three times per week by transmitting a beacon tone which indicates spacecraft health and status.
- During the science data downlink period, the spacecraft will transmit high rate science data to the ground on a daily basis, from 10 to 24 hours per day.

Parker Solar Probe Instruments

Parker Solar Probe carries four instrument suites designed to study magnetic fields, plasma and energetic particles, and image the solar wind.

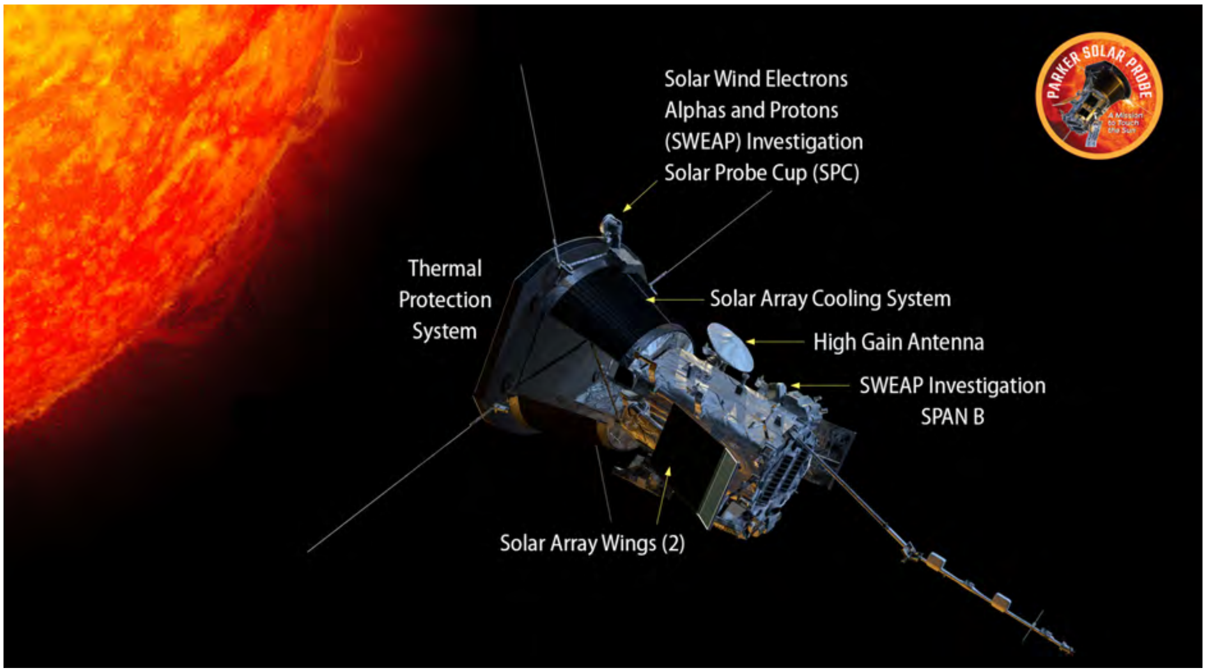
FIELDS:
Surveyor of the invisible forces, the FIELDS instrument suite captures the scale and shape of electric and magnetic fields in the Sun's atmosphere. FIELDS measures waves and turbulence in the inner heliosphere with high time resolution to understand the fields associated with waves, shocks and magnetic reconnection, a process by which magnetic field lines explosively realign. FIELDS was designed, built, and is operated by a team lead by the Space Sciences Laboratory at the University of California, Berkeley (principal investigator Stuart D. Bale).

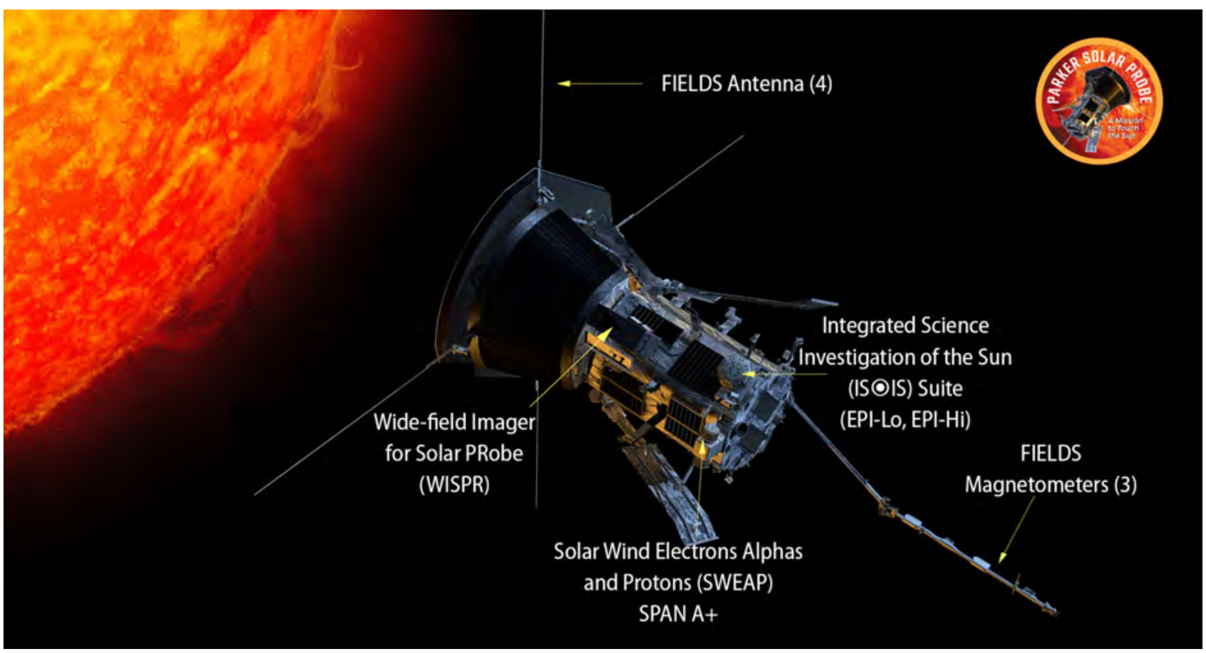
WISPR (Wide-Field Imager for Parker Solar Probe):
The Wide-Field Imager for Parker Solar Probe is the only imaging instrument aboard the spacecraft. WISPR looks at the large-scale structure of the corona and solar wind before the spacecraft flies through it. About the size of a shoebox, WISPR takes images from afar of structures like coronal mass ejections, or CMEs, jets and other ejecta from the Sun. These structures travel out from the Sun and eventually overtake the spacecraft, where the spacecraft's other instruments take in-situ measurements. WISPR helps link what's happening in the large-scale coronal structure to the detailed physical measurements being captured directly in the near-Sun environment. WISPR was designed and developed by the Solar and Heliophysics Physics Branch at the Naval Research Laboratory in Washington, DC (principal investigator Russell Howard), which will also develop the observing program.

SWEAP (Solar Wind Electrons Alphas and Protons Investigation):
The Solar Wind Electrons Alphas and Protons investigation, or SWEAP, gathers observations using two complementary instruments: the Solar Probe Cup, or SPC, and the Solar Probe Analyzers, or SPAN. The instruments count the most abundant particles in the solar wind—electrons, protons and helium ions—and measure such properties as velocity, density, and temperature to improve our understanding of the solar wind and coronal plasma. SWEAP was built mainly at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, and at the Space Sciences Laboratory at the University of California, Berkeley. The institutions jointly operate the instrument. The principal investigator is Justin Kasper from the University of Michigan

IS☉IS (Integrated Science Investigation of the Sun):
The Integrated Science Investigation of the Sun—IS☉IS, pronounced ee-sis and including the symbol for the Sun in its acronym—uses two complementary instruments in one combined scientific investigation to measure particles across a wide range of energies. By measuring electrons, protons and ions, IS☉IS will understand the particles' lifecycles—where they came from, how they became accelerated and how they move out from the Sun through interplanetary space. The two energetic particle instruments on IS☉IS are called EPI-Lo and EPI-Hi (EPI stands for Energetic Particle Instrument).

IS⊙IS is led by Princeton University in Princeton, New Jersey (principal investigator David McComas), and was built largely at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland, and Caltech, in Pasadena, California, with significant contributions from Southwest Research Institute in San Antonio, Texas, and NASA's Goddard Space Flight Center in Greenbelt, Maryland. The IS⊙IS Science Operations Center is operated at the University of New Hampshire in Durham.





NOTE: Spacecraft and Sun relative positions adjusted to better show instrument placement.
Credit: NASA/Johns Hopkins APL/Margaret Brown

Parker Solar Probe Mission Management

Parker Solar Probe is part of NASA's Living With a Star program to explore aspects of the Sun-Earth system that directly affect life and society.

The Living With a Star flight program is managed by the agency's Goddard Space Flight Center in Greenbelt, Maryland, for NASA's Science Mission Directorate in Washington. The Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, manages the mission for NASA. APL is designing and building the spacecraft and will also operate it.

NASA's Goddard Space Flight Center (Greenbelt, Md.):
- Living With a Star Program Management
- Project Oversight

Johns Hopkins University Applied Physics Lab (Laurel, Md.):
- Mission operations
- Management and technical engineering support for instrument and spacecraft development teams
- Science
- Education and public outreach
- Mission principal investigation
- Flight software
- Electronics
- Data archive

University of California, Berkeley:
- FIELDS instrument management
- SWEAP instrument joint operation

Naval Research Laboratory (Washington, D.C.):
- WISPR instrument management

Smithsonian Astrophysical Observatory (Cambridge, Mass.):
- SWEAP instrument joint operation

University of Michigan (Ann Arbor):
- SWEAP instrument principal investigation

Princeton University (N.J.):
- IS⊙IS instrument principal investigation

University of New Hampshire (Durham):
- IS⊙IS science operations

University of California, Los Angeles:
- HeliOSPP investigation management

NASA's Launch Services Program

NASA turns to the engineers and analysts in its Launch Services Program, or LSP, to send robotic spacecraft on their way for some of the most exciting and notable missions in the agency's history.

The program is based at NASA's Kennedy Space Center, Fla. and boasts a roster of engineers and technicians who specialize in all aspects of rocketry and spacecraft integration. LSP selects the appropriate launcher for a mission's spacecraft, in this case the United Launch Alliance Delta IV Heavy for Parker Solar Probe. Sometimes this selection process takes place years before the first launch opportunity. The program then provides oversight as the designs of the rocket and mission are integrated with each other.

As liftoff nears, teams oversee the launch vehicle's engineering and manufacture and its integration with the spacecraft. LSP conducts the countdowns for NASA's scientific missions and provides additional quality assurance along with other controls to ensure a successful mission.

Working with commercial rocket builders, planners have a number of rocket models to choose from, ranging from Delta IV Heavy used for Parker Solar Probe, to the workhorse Delta II rocket from United Launch Alliance, to the powerhouse Altas V, also from ULA. The catalog is growing with the addition of the Space X, Falcon 9 and Orbital ATK Antares rockets.

Because some spacecraft need to fly in a different kind of orbit, LSP operates several launch centers around the world. Cape Canaveral Air Force Station in Florida is adjacent to Kennedy Space Center and hosts launches to place spacecraft in orbits that remain close to the equator. Launching close to the equator allows Parker Solar Probe to utilize Earth's rotational velocity to help accelerate it into its final orbit. The LSP team goes to Vandenberg Air Force Base to run launches that require spacecraft to fly around the world in a north-to-south orbit, known as a polar orbit. LSP also conducts launches from Kwajalein in the Marshall Islands, Kodiak Island, Alaska and NASA's Wallops Flight Facility on Virginia's eastern Shore.

To learn more about LSP, rockets and
NASA missions go to:

http://www.nasa.gov/centers/kennedy/launchingrockets/index.html

Parker Solar Probe Program/Policy Management

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More information about NASA's Parker Solar Probe can be found online at:

www.nasa.gov/solarprobe

solarprobe.jhuapl.edu

What is the solar wind?

The solar wind is the Sun's constant outflow of magnetized solar material. It comprises a steady stream of particles blowing away from the Sun, blustering at 800,000 to five million miles per hour. The solar wind carries a million tons of matter into space every second (that's the mass of Utah's Great Salt Lake) and reaches well beyond the solar system's planets. The speed, density and magnetic fields associated with solar wind plasma affect Earth's magnetosphere, its protective magnetic shield in space, inducing space weather effects.

What is space weather?

Space weather describes the dynamic conditions in Earth's and other planets' near-space environments. Just as conditions on Earth vary place to place due to the weather, so too do space conditions, depending on solar activity. Space weather includes any and all conditions and events on the Sun, in the solar wind, in near-Earth space, and in our upper atmosphere that can affect space-borne and ground-based technological systems and through these, human life and society.

Modern society depends on a variety of technologies susceptible to the extremes of space weather. Strong electrical currents driven along the Earth's surface during space weather events may disrupt electric power grids and contribute to corrosion of oil and gas pipelines. Changes in the ionosphere during geomagnetic storms interfere with high-frequency radio communications and GPS navigation. During polar cap absorption events caused by hazardous solar proton events, radio communications can be compromised for commercial airliners on transpolar crossing routes. The sudden occurrence of energetic protons can pose a hazard to astronauts in space.

Today, airlines fly over 7,500 polar routes per year. These routes take aircraft to latitudes where satellite communication cannot be used, and flight crews must rely instead on high-frequency radio to maintain communication with air traffic control, as required by federal regulation. During certain space weather events, solar energetic particles spiral down geomagnetic field lines in the polar regions, where they increase the density of ionized gas, which in turn affects the propagation of radio waves and can result in radio blackouts.

What is the corona?

The corona is part of the Sun's atmosphere.

The Sun is not a solid nor a gas, but plasma—a superheated mix of electrically charged particles that stream along magnetic field lines. This plasma is tenuous and gaseous near the surface, but gets denser toward the Sun's core. The Sun's core is about 27 million degrees Fahrenheit, and the temperature cools dramatically toward the outer layers of

MIND-MELTING FACTS ABOUT THE SUN

MIND-MELTING FACTS

Temperature vs. Heat

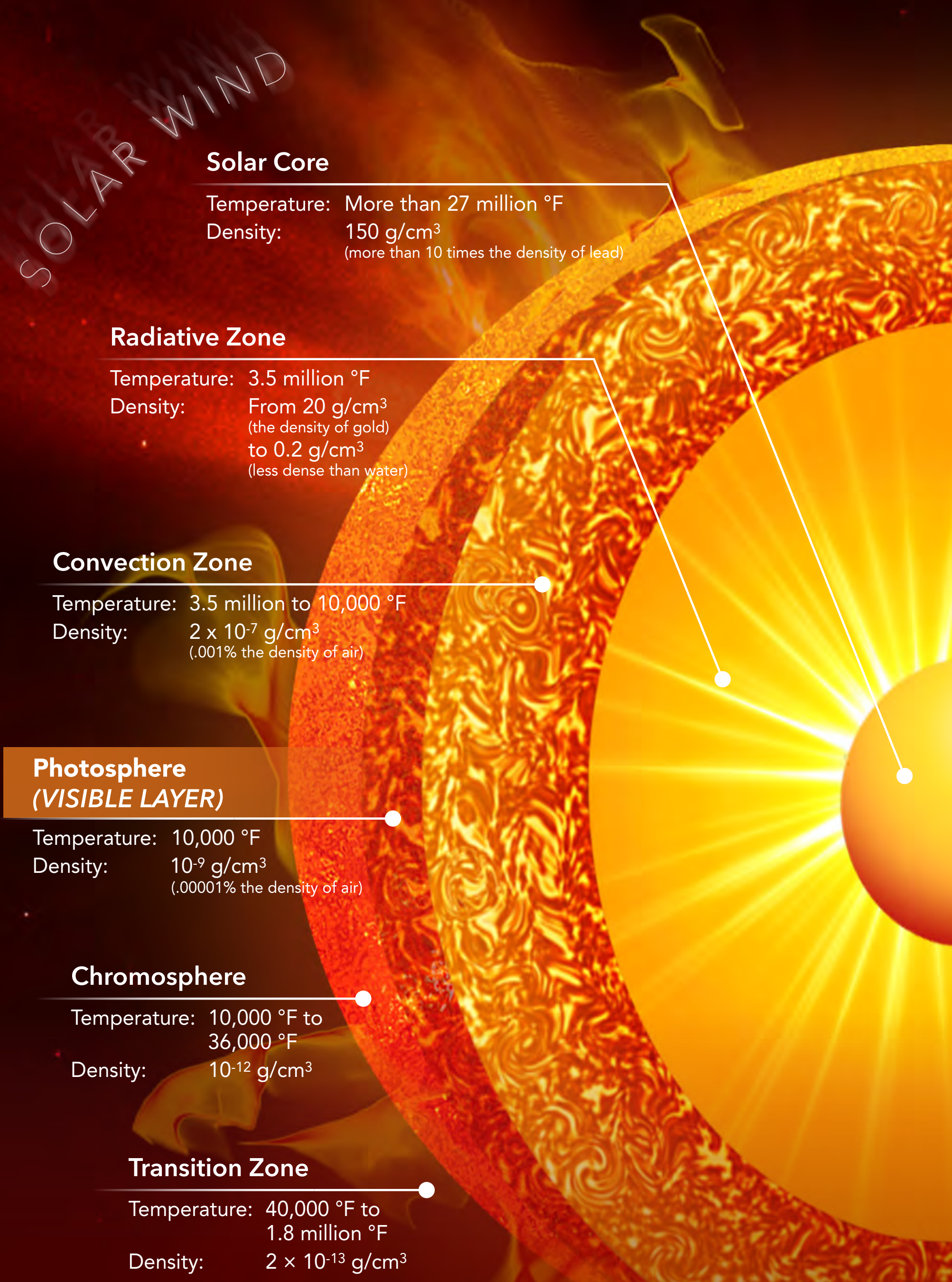
In space, the temperature can be thousands of degrees without "feeling hot." Why? *Temperature* measures how fast particles are moving, whereas *heat* measures the total amount of energy that they transfer. Since space is mostly empty, there are very few particles to transfer energy to your hand. Particles may be moving fast (high temperature), but if there are very few of them, they won't transfer much energy (low heat).

The Solar "Surface"

The Sun does not have a solid "surface". The layer you can see, called the **photosphere**, is just the layer that emits the most light in the visible part of the electromagnetic spectrum. In fact, there are three layers on top of it, but the visible light they emit is too faint to see. Except during a total solar eclipse, when the corona can be seen by the naked eye!

The Puzzle of Coronal Heating

As you walk away from a fire, you expect the temperature to go down. The Sun is quite different: the **corona**, the outermost layer of the Sun, is hotter than the layers immediately below it! Exactly how the corona gets so hot is a major unsolved puzzle in heliophysics.



Solar Core

Temperature: More than 27 million °F
Density: 150 g/cm³
(more than 10 times the density of lead)

Radiative Zone

Temperature: 3.5 million °F
Density: From 20 g/cm³
(the density of gold)
to 0.2 g/cm³
(less dense than water)

Convection Zone

Temperature: 3.5 million to 10,000 °F
Density: 2×10^{-7} g/cm³
(.001% the density of air)

Photosphere
(VISIBLE LAYER)

Temperature: 10,000 °F
Density: 10^{-9} g/cm³
(.00001% the density of air)

Chromosphere

Temperature: 10,000 °F to 36,000 °F
Density: 10^{-12} g/cm³

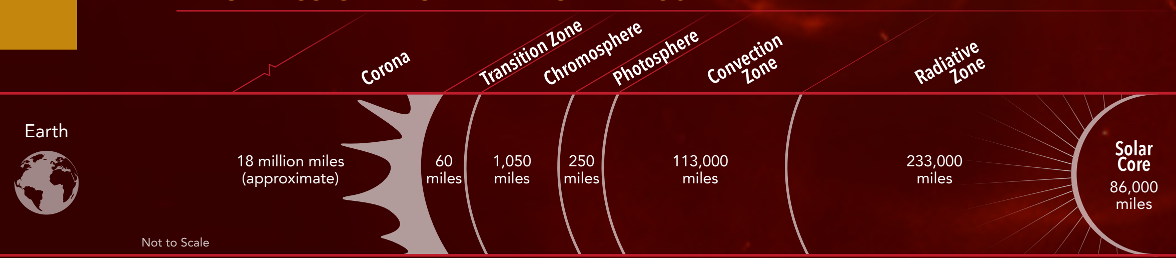
Transition Zone

Temperature: 40,000 °F to 1.8 million °F
Density: 2×10^{-13} g/cm³

Corona
(THE SUN'S OUTER ATMOSPHERE)

Temperature: Average 2-5 million °F
Density: 10^{-16} g/cm³

THICKNESS OF EACH LAYER OF THE SUN



For more information, please visit:
nasa.gov/sunearth

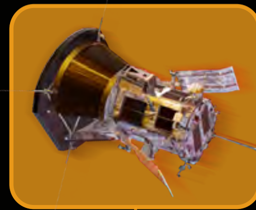
the Sun. The middle layer of the Sun, called the convection zone, is 3.5 million degrees Fahrenheit. At the very surface, the Sun is 10,000 degrees Fahrenheit.

The Sun's corona reaches temperatures up to several million degrees Fahrenheit, which is 200 to 500 times hotter than the solar surface below. Because the Sun produces its energy and heat in its center, scientists would typically expect that the Sun's surface—closer to the core—would be hotter than the atmosphere above. The corona's extremely high temperatures mean that there must be other mechanisms at work heating the solar atmosphere. We know that the energy is stored in the dynamic magnetic fields of the Sun, which constantly stir up the photosphere and release energy into the solar atmosphere. The precise details of how, when, and where that energy release occurs are still under investigation.

Solar Wind and Corona Timeline

PARKER SOLAR PROBE LAUNCH

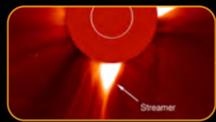
A mission to travel directly through the Sun's corona, providing up-close observations on what heats the solar atmosphere and accelerates the solar wind.



2018

Slow Solar Wind and Helmet Streamers

Using observations from the joint ESA/NASA Solar and Heliospheric Observatory, Neil R. Sheeley Jr. and colleagues identify puffs of slow solar wind emanating from helmet streamers – bright areas of the corona that form above magnetically active regions on the photosphere. Exactly how these puffs are formed is still not known.



1995

The Sun's Poles

Ulysses, a joint NASA-ESA mission, becomes the first mission to fly over the Sun's north and south poles. Among other findings, Ulysses found that in periods of minimal solar activity, the fast solar wind comes from the poles, while the slow solar wind comes from equatorial regions.

1990

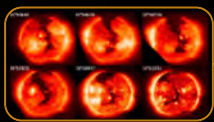
Nanoflares May Heat the Corona

Eugene Parker proposes that frequent, small eruptions on the Sun – known as nanoflares – may heat the corona to its extreme temperatures. The nanoflare theory contrasts with the wave theory, in which heating is caused by the dissipation of Alfvén waves.

1988

Fast Wind from Coronal Holes

Images from Skylab, the U.S.'s first manned space station, identify that the fast solar wind is emitted from coronal holes – comparatively cool regions of the corona where the Sun's magnetic field lines open out into space.



1973

The Slow and Fast Solar Wind

NASA's Mariner 2 spacecraft observes the solar wind, detecting two distinct 'streams' within it: a slow stream travelling at approximately 215 miles per second, and a fast stream at 430 miles per second.

1962

Solar Wind Detected

The Soviet satellite Luna 1, the first spacecraft to leave geocentric orbit, measures the solar wind directly for the first time, confirming key parts of Parker's theory.

1959

The First Theory of the Solar Wind

Eugene Parker connects the hot corona with the solar wind in a rigorous mathematical theory. According to the theory, heat pressure from the million-degree corona forces it to expand outward in all directions, forming a solar wind that drags the Sun's magnetic field lines deep into space.

1958

A Solar Wind Made of Particles

Building on Kepler's hypothesis from 400 years before, Cuno Hoffmeister (and later Ludwig Biermann) proposes that the Sun emits a steady stream of charged particles that push the ions in the comet tails always away from the Sun.

1943

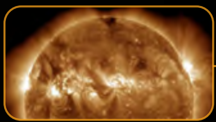
A New Heating Mechanism

Swedish physicist Hannes Alfvén proposes the existence of a new kind of wave forming in electrically conducting fluids. So-called Alfvén waves revealed a previously overlooked mechanism for heat and energy to be transferred on the Sun.

1942

The Coronal Heating Problem

Swedish astronomer Bengt Edlen detects highly ionized iron in the corona, indicating a temperature of 1.8 million degrees Fahrenheit. Edlen's findings created the coronal heating problem: Why is the corona so much hotter than the Sun's surface?



1842

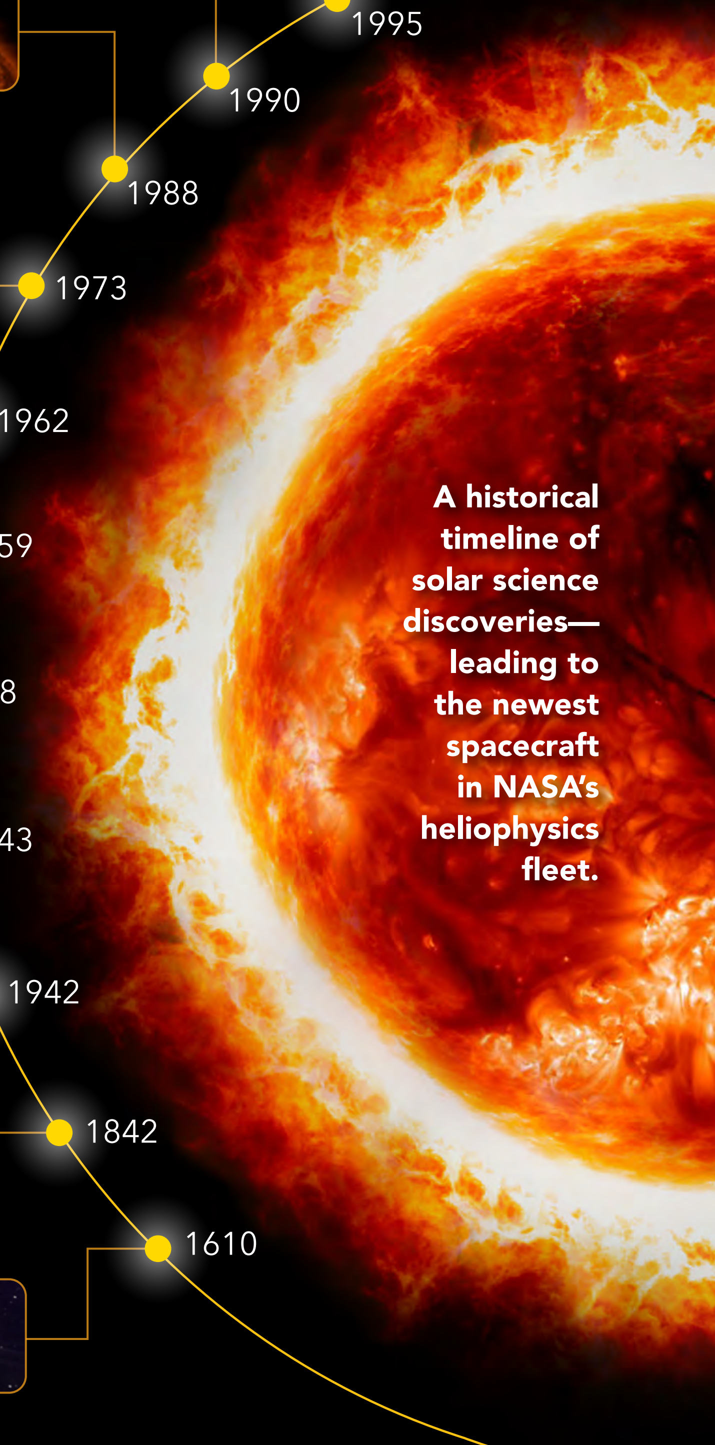
The Corona as the Sun's Atmosphere

English astronomer Francis Baily observes a total solar eclipse and suggests that the hazy 'corona' outlining the Sun is its atmosphere.

1610

Comet Tails in the Wind

Johannes Kepler observes comet tails and hypothesizes that they are blown by pressure from sunlight – a solar breeze.



A historical timeline of solar science discoveries— leading to the newest spacecraft in NASA's heliophysics fleet.

Parker Solar Probe Mission Overview

https://go.nasa.gov/2JLdMBG

July 20, 2018

NASA Prepares to Launch Parker Solar Probe, a Mission to Touch the Sun

Early on an August morning, the sky near Cape Canaveral, Florida, will light up with the launch of Parker Solar Probe. No earlier than Aug. 6, 2018, a United Launch Alliance Delta IV Heavy will thunder to space carrying the car-sized spacecraft, which will study the Sun closer than any human-made object ever has.

On July 20, 2018, Nicky Fox, Parker Solar Probe's project scientist at the Johns Hopkins University Applied Physics Lab in Laurel, Maryland, and Alex Young, associate director for science in the Heliophysics Science Division at NASA's Goddard Space Flight Center in Greenbelt, Maryland, introduced Parker Solar Probe's science goals and the technology behind them at a televised press conference from NASA's Kennedy Space Center in Cape Canaveral, Florida.

"We've been studying the Sun for decades, and now we're finally going to go where the action is," said Young.

Our Sun is far more complex than meets the eye. Rather than the steady, unchanging disk it seems to human eyes, the Sun is a dynamic and magnetically active star. The Sun's atmosphere constantly sends magnetized material outward, enveloping our solar system far beyond the orbit of Pluto and influencing every world along the way. Coils of magnetic energy can burst out with light and particle radiation that travel through space and create temporary disruptions in our atmosphere, sometimes garbling radio and communications signals near Earth. The influence of solar activity on Earth and other worlds are collectively known as space weather, and the key to understanding its origins lies in understanding the Sun itself.

"The Sun's energy is always flowing past our world," said Fox. "And even though the solar wind is invisible, we can see it encircling the poles as the aurora, which are beautiful—but reveal the enormous amount of energy and particles that cascade into our atmosphere. We don't have a strong understanding of the mechanisms that drive that wind toward us, and that's what we're heading out to discover."

That's where Parker Solar Probe comes in. The spacecraft carries a lineup of instruments to study the Sun both remotely and in situ, or directly. Together, the data from these state-of-the-art instruments should help scientists answer three foundational questions about our star.

One of those questions is the mystery of the acceleration of the solar wind, the Sun's constant outflow of material. Though we largely grasp the solar wind's origins on the Sun, we know there is a point—as-yet unobserved—where the solar wind is accelerated to supersonic speeds. Data shows these changes happen in the corona, a region of the Sun's atmosphere that Parker Solar Probe will fly directly through, and scientists plan to use Parker Solar Probe's remote and in situ measurements to shed light on how this happens.

Second, scientists hope to learn the secret of the corona's enormously high temperatures. The visible surface of the Sun is about 10,000 F—but, for reasons we don't fully understand, the corona is hundreds of times hotter, spiking up to several million degrees F. This is counterintuitive, as the Sun's energy is produced at its core.

"It's a bit like if you walked away from a campfire and suddenly got much hotter," said Fox.

Finally, Parker Solar Probe's instruments should reveal the mechanisms at work behind the acceleration of solar energetic particles, which can reach speeds more than half as fast as the speed of light as they rocket away from the Sun. Such particles can interfere with satellite electronics, especially for satellites outside of Earth's magnetic field.

To answer these questions, Parker Solar Probe uses four suites of instruments.

The FIELDS suite, led by the University of California, Berkeley, measures the electric and magnetic fields around the spacecraft. FIELDS captures waves and turbulence in the inner heliosphere with high time resolution to understand the fields associated with waves, shocks and magnetic reconnection, a process by which magnetic field lines explosively realign.

The WISPR instrument, short for Wide-Field Imager for Parker Solar Probe, is the only imaging instrument aboard the spacecraft. WISPR takes images from of structures like coronal mass ejections, or CMEs, jets and other ejecta from the Sun to help link what's happening in the large-scale coronal structure to the detailed physical measurements being captured directly in the near-Sun environment. WISPR is led by the Naval Research Laboratory in Washington, D.C.

Another suite, called SWEAP (short for Solar Wind Electrons Alphas and Protons Investigation), uses two complementary instruments to gather data. The SWEAP suite of instruments counts the most abundant particles in the solar wind—electrons, protons and helium ions—and measures such properties as velocity, density, and temperature to improve our understanding of the solar wind and coronal plasma. SWEAP is led by the University of Michigan, the University of California, Berkeley, and the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts.

Finally, the IS☉IS suite—short for Integrated Science Investigation of the Sun, and including ☉, the symbol for the Sun, in its acronym—measures particles across a wide range of energies. By measuring electrons, protons and ions, IS☉IS will understand the particles' lifecycles—where they came from, how they became accelerated and how they move out from the Sun through interplanetary space. IS☉IS is led by Princeton University in New Jersey.

Parker Solar Probe is a mission some sixty years in the making. With the dawn of the Space Age, humanity was introduced to the full dimension of the Sun's powerful influence over the solar system. In 1958, physicist Eugene Parker published a groundbreaking scientific paper theorizing the existence of the solar wind. The mission is now named after him, and it's the first NASA mission to be named after a living person.

Only in the past few decades has technology come far enough to make Parker Solar Probe a reality. Key to the spacecraft's daring journey are three main breakthroughs: The cutting-edge heat shield, the solar array cooling system, and the advanced fault management system.

"The Thermal Protection System (the heat shield) is one of the spacecraft's mission-enabling technologies," said Andy Driesman, Parker Solar Probe project manager at the Johns Hopkins Applied Physics Lab. "It allows the spacecraft to operate at about room temperature."

Other critical innovations are the solar array cooling system and on-board fault management systems. The solar array cooling system allows the solar arrays to produce power under the intense thermal load from the Sun and the fault management system protects the spacecraft during the long periods of time when the spacecraft can't communicate with the Earth.

Using data from seven Sun sensors placed all around the edges of the shadow cast by the heat shield, Parker Solar Probe's fault management system protects the spacecraft during the long periods of time when it can't communicate with Earth. If it detects a problem, Parker Solar Probe will self-correct its course and pointing to ensure that its scientific instruments remain cool and functioning during the long periods when the spacecraft is out of contact with Earth.

Parker Solar Probe's heat shield—called the thermal protection system, or TPS—is a sandwich of carbon-carbon composite surrounding nearly four and half inches of carbon foam, which is about 97% air. Though it's nearly eight feet in diameter, the TPS adds only about 160 pounds to Parker Solar Probe's mass because of its lightweight materials.

Though the Delta IV Heavy is one of the world's most powerful rockets, Parker Solar Probe is relatively small, about the size of a small car. But what Parker Solar Probe needs is energy—getting to the Sun takes a lot of energy at launch to achieve its orbit around the Sun. That's because any object launched from Earth starts out traveling around the Sun at the same speed as Earth—about 18.5 miles per second—so an object has to travel incredibly quickly to counteract that momentum, change direction, and go near the Sun.

The timing of Parker Solar Probe's launch—between about 4 and 6 a.m. EDT, and within a period lasting about two weeks—was very precisely chosen to send Parker Solar Probe toward its first, vital target for achieving such an orbit: Venus.

"The launch energy to reach the Sun is 55 times that required to get to Mars, and two times that needed to get to Pluto," said Yanping Guo from the Johns Hopkins Applied Physics Laboratory, who designed the mission trajectory. "During summer, Earth and the other planets in our solar system are in the most favorable alignment to allow us to get close to the Sun."

The spacecraft will perform a gravity assist to shed some of its speed into Venus' well of orbital energy, drawing Parker Solar Probe into an orbit that—already, on its first pass—carries it closer to the solar surface than any spacecraft has ever gone, well within the corona. Parker Solar Probe will perform similar maneuvers six more times throughout its seven-year mission, assisting the spacecraft to final sequence of orbits that pass just over 3.8 million miles from the photosphere.

"By studying our star, we can learn not only more about the Sun," said Thomas Zurbuchen, the associate administrator for the Science Mission Directorate at NASA HQ. "We can also learn more about all the other stars throughout the galaxy, the universe and even life's beginnings."

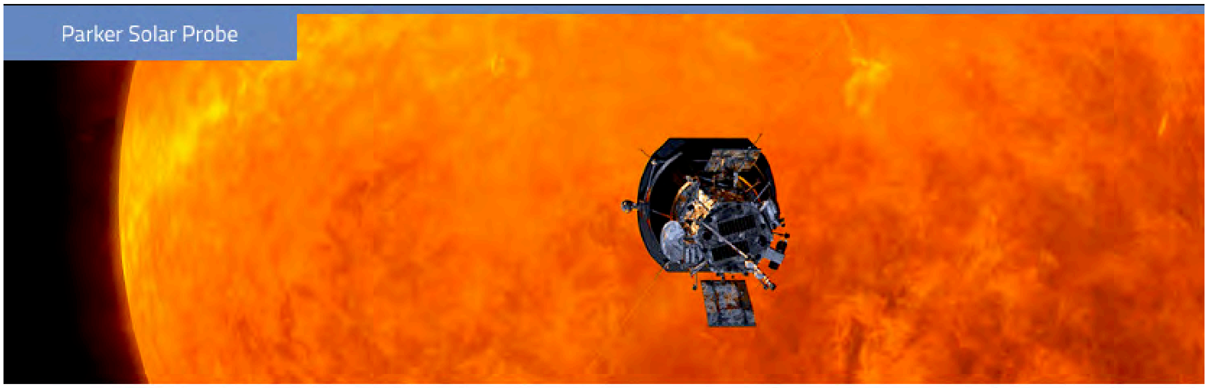
Parker Solar Probe is part of NASA's Living with a Star Program, or LWS, to explore aspects of the Sun-Earth system that directly affect life and society. LWS is managed by NASA's Goddard Space Flight Center in Greenbelt, Maryland, for the Heliophysics Division of NASA's Science Mission Directorate in Washington. Johns Hopkins APL manages the Parker Solar Probe mission for NASA. APL designed and built the spacecraft and will also operate it.

Banner image: Illustration of NASA's Parker Solar Probe leaving Earth. Credit: NASA/Johns Hopkins APL/Steve Gribben

By Sarah Frazier
NASA's Goddard Space Flight Center, Greenbelt, Md.
Last Updated: July 20, 2018

Parker Solar Probe Engineering

https://go.nasa.gov/2JDv3MV



July 19, 2018

Traveling to the Sun: Why Won't Parker Solar Probe Melt?

This summer, NASA's Parker Solar Probe will launch to travel closer to the Sun, deeper into the solar atmosphere, than any mission before it. If Earth was at one end of a yard-stick and the Sun on the other, Parker Solar Probe will make it to within four inches of the solar surface.

Inside that part of the solar atmosphere, a region known as the corona, Parker Solar Probe will provide unprecedented observations of what drives the wide range of particles, energy and heat that course through the region—flinging particles outward into the solar system and far past Neptune.

Inside the corona, it's also, of course, unimaginably hot. The spacecraft will travel through material with temperatures greater than a million degrees Fahrenheit while being bombarded with intense sun light.

So, why won't it melt?

Parker Solar Probe has been designed to withstand the extreme conditions and temperature fluctuations for the mission. The key lies in its custom heat shield and an autonomous system that helps protect the mission from the Sun's intense light emission, but does allow the coronal material to "touch" the spacecraft.

The Science Behind Why It Won't Melt

One key to understanding what keeps the spacecraft and its instruments safe, is understanding the concept of heat versus temperature. Counterintuitively, high temperatures do not always translate to actually heating another object.

In space, the temperature can be thousands of degrees without providing significant heat to a given object or feeling hot. Why? Temperature measures how fast particles are moving, whereas heat measures the total amount of energy that they transfer. Particles may be moving fast (high temperature), but if there are very few of them, they won't transfer much energy (low heat). Since space is mostly empty, there are very few particles that can transfer energy to the spacecraft.

The corona through which Parker Solar Probe flies, for example, has an extremely high temperature but very low density. Think of the difference between putting your hand in a hot oven versus putting it in a pot of boiling water (don't try this at home!)—in the oven, your hand can withstand significantly hotter temperatures for longer than in the water where it has to interact with many more particles. Similarly, compared to the visible surface of the Sun, the corona is less dense, so the spacecraft interacts with fewer hot particles and doesn't receive as much heat.

That means that while Parker Solar Probe will be traveling through a space with temperatures of several million degrees, the surface of the heat shield that faces the Sun will only get heated to about 2,500 degrees Fahrenheit (about 1,400 degrees Celsius).

The Shield That Protects It

Of course, thousands of degrees Fahrenheit is still fantastically hot. (For comparison, lava from volcano eruptions can be anywhere between 1,300 and 2,200 F (700 and 1,200 C) And to withstand that heat, Parker Solar Probe makes use of a heat shield known as the Thermal Protection System, or TPS, which is 8 feet (2.4 meters) in diameter and 4.5 inches (about 115 mm) thick. Those few inches of protection mean that just on the other side of the shield, the spacecraft body will sit at a comfortable 85 F (30 C).

The TPS was designed by the Johns Hopkins Applied Physics Laboratory, and was built at Carbon-Carbon Advanced Technologies, using a carbon composite foam sandwiched between two carbon plates. This lightweight insulation will be accompanied by a finishing touch of white ceramic paint on the sun-facing plate, to reflect as much heat as possible. Tested to withstand up to 3,000 F (1,650 C), the TPS can handle any heat the Sun can send its way, keeping almost all instrumentation safe.

The Cup that Measures the Wind

But not all of the Solar Parker Probe instruments will be behind the TPS.

Poking out over the heat shield, the Solar Probe Cup is one of two instruments on Parker Solar Probe that will not be protected by the heat shield. This instrument is what's known as a Faraday cup, a sensor designed to measure the ion and electron fluxes and flow angles from the solar wind. Due to the intensity of the solar atmosphere, unique technologies had to be engineered to make sure that not only can the instrument survive, but also the electronics aboard can send back accurate readings.

The cup itself is made from sheets of Titanium-Zirconium-Molybdenum, an alloy of molybdenum, with a melting point of about 4,260 F (2,349 C). The grids that produce an electric field for the Solar Probe Cup are made from tungsten, a metal with the highest known melting point of 6,192 F (3,422 C). Normally lasers are used to etch the gridlines in these grids—however due to the high melting point acid had to be used instead.

Another challenge came in the form of the electronic wiring—most cables would melt from exposure to heat radiation at such close proximity to the Sun. To solve this problem, the team grew sapphire crystal tubes to suspend the wiring, and made the wires from niobium.

To make sure the instrument was ready for the harsh environment, the researchers needed to mimic the Sun's intense heat radiation in a lab. To create a test-worthy level of heat, the researchers used a particle accelerator and IMAX projectors—jury-rigged to increase their temperature. The projectors mimicked the heat of the Sun, while the particle accelerator exposed the cup to radiation to make sure the cup could measure the accelerated particles under the intense conditions. To be absolutely sure the Solar Probe Cup would withstand the harsh environment, the Odeillo Solar Furnace—which concentrates the heat of the Sun through 10,000 adjustable mirrors—was used to test the cup against the intense solar emission.

The Solar Probe Cup passed its tests with flying colors—indeed, it continued to perform better and give clearer results the longer it was exposed to the test environments. "We think the radiation removed any potential contamination," Justin Kasper, principal investigator for the SWEAP instruments at the University of Michigan in Ann Arbor, said. "It basically cleaned itself."

The Spacecraft That Keeps its Cool

Several other designs on the spacecraft keep Parker Solar Probe sheltered from the heat. Without protection, the solar panels—which use energy from the very star being studied to power the spacecraft—can overheat. At each approach to the Sun, the solar arrays retract behind the heat shield's shadow, leaving only a small segment exposed to the Sun's intense rays.

But that close to the Sun, even more protection is needed. The solar arrays have a surprisingly simple cooling system: a heated tank that keeps the coolant from freezing during launch, two radiators that will keep the coolant from freezing, aluminum fins to maximize the cooling surface, and pumps to circulate the coolant. The cooling system is powerful enough to cool an average sized living room, and will keep the solar arrays and instrumentation cool and functioning while in the heat of the Sun.

The coolant used for the system? About a gallon (3.7 liters) of deionized water. While plenty of chemical coolants exist, the range of temperatures the spacecraft will be exposed to varies between 50 F (10 C) and 257 F (125 C). Very few liquids can handle those ranges like water. To keep the water from boiling at the higher end of the temperatures, it will be pressurized so the boiling point is over 257 F (125 C).

Another issue with protecting any spacecraft is figuring out how to communicate with it. Parker Solar Probe will largely be alone on its journey. It takes light eight minutes to reach Earth—meaning if engineers had to control the spacecraft from Earth, by the time something went wrong it would be too late to correct it.

So, the spacecraft is designed to autonomously keep itself safe and on track to the Sun. Several sensors, about half the size of a cell phone, are attached to the body of the spacecraft along the edge of the shadow from the heat shield. If any of these sensors detect sunlight, they alert the central computer and the spacecraft can correct its position to keep the sensors, and the rest of the instruments, safely protected. This all has to happen without any human intervention, so the central computer software has been programmed and extensively tested to make sure all corrections can be made on the fly.

Launching Toward the Sun

After launch, Parker Solar Probe will detect the position of the Sun, align the thermal protection shield to face it and continue its journey for the next three months, embracing the heat of the Sun and protecting itself from the cold vacuum of space.

Over the course of seven years of planned mission duration, the spacecraft will make 24 orbits of our star. On each close approach to the Sun it will sample the solar wind, study the Sun's corona, and provide unprecedentedly close up observations from around our star—and armed with its slew of innovative technologies, we know it will keep its cool the whole time.

Banner image: Illustration of Parker Solar Probe circling the Sun. Credit: NASA/JHUAPL

By Susannah Darling
NASA Headquarters, Washington
Last Updated: July 26, 2018

Parker Solar Probe Science – Coronal Heating

https://go.nasa.gov/2An4JHI

Sun

July 27, 2018

NASA's Parker Solar Probe and the Curious Case of the Hot Corona

Something mysterious is going on at the Sun. In defiance of all logic, its atmosphere gets much, much hotter the farther it stretches from the Sun's blazing surface.

Temperatures in the corona—the tenuous, outermost layer of the solar atmosphere—spike upwards of 2 million degrees Fahrenheit, while just 1,000 miles below, the underlying surface simmers at a balmy 10,000 F. How the Sun manages this feat remains one of the greatest unanswered questions in astrophysics; scientists call it the coronal heating problem. A new, landmark mission, NASA's Parker Solar Probe—scheduled to launch no earlier than Aug. 11, 2018—will fly through the corona itself, seeking clues to its behavior and offering the chance for scientists to solve this mystery.

From Earth, as we see it in visible light, the Sun's appearance—quiet, unchanging—belies the life and drama of our nearest star. Its turbulent surface is rocked by eruptions and intense bursts of radiation, which hurl solar material at incredible speeds to every corner of the solar system. This solar activity can trigger space weather events that have the potential to disrupt radio communications, harm satellites and astronauts, and at their most severe, interfere with power grids.

Above the surface, the corona extends for millions of miles and roils with plasma, gases superheated so much that they separate into an electric flow of ions and free electrons. Eventually, it continues outward as the solar wind, a supersonic stream of plasma permeating the entire solar system. And so, it is that humans live well within the extended atmosphere of our Sun. To fully understand the corona and all its secrets is to understand not only the star that powers life on Earth, but also, the very space around us.

A 150-year-old mystery

Most of what we know about the corona is deeply rooted in the history of total solar eclipses. Before sophisticated instruments and spacecraft, the only way to study the corona from Earth was during a total eclipse, when the Moon blocks the Sun's bright face, revealing the surrounding, dimmer corona.

The story of the coronal heating problem begins with a green spectral line observed during an 1869 total eclipse. Because different elements emit light at characteristic wavelengths, scientists can use spectrometers to analyze light from the Sun and identify its composition.

But the green line observed in 1869 didn't correspond to any known elements on Earth. Scientists thought perhaps they'd discovered a new element, and they called it coronium. solar eclipse photographed 21 Aug 2017.

Not until 70 years later did a Swedish physicist discover the element responsible for the emission is iron, superheated to the point that it's ionized 13 times, leaving it with just half the electrons of a normal atom of iron. And therein lies the problem: Scientists calculated that such high levels of ionization would require coronal temperatures around 2 million degrees Fahrenheit—nearly 200 times hotter than the surface.

For decades, this deceptively simple green line has been the Mona Lisa of solar science, baffling scientists who can't explain its existence. Since identifying its source, we've come to understand the puzzle is even more complex than it first appeared.

"I think of the coronal heating problem as an umbrella that covers a couple of related confusing problems," said Justin Kasper, a space scientist at the University of Michigan in Ann Arbor. Kasper is also principal investigator for SWEAP, short for the Solar Wind Electrons Alphas and Protons Investigation, an instrument suite aboard Parker Solar Probe. "First, how does the corona get that hot that quickly? But the second part of the problem is that it doesn't just start, it keeps going. And not only does heating continue, but different elements are heated at different rates." It's an intriguing hint at what's going on with heating in the Sun.

Since discovering the hot corona, scientists and engineers have done a great deal of work to understand its behavior. They've developed powerful models and instruments and launched spacecraft that watch the Sun around the clock. But even the most complex models and high-resolution observations can only partially explain coronal heating, and some theories contradict each other. There's also the problem of studying the corona from afar.

We may live within the Sun's expansive atmosphere, but the corona and solar plasma in near-Earth space differ dramatically. It takes the slow solar wind around four days to travel 93 million miles and reach Earth or the spacecraft that study it—plenty of time for it to intermix with other particles zipping through space and lose its defining features. animated illustration of corona

Studying this homogenous soup of plasma for clues to coronal heating is like trying to study the geology of a mountain, by sifting through sediment in a river delta thousands of miles downstream. By traveling to the corona, Parker Solar Probe will sample just-heated particles, removing the uncertainties of a 93-million-mile journey and sending back to Earth the most pristine measurements of the corona ever recorded.

"All of our work over the years has culminated to this point: We realized we can never fully solve the coronal heating problem until we send a probe to make measurements in the corona itself," said Nour Raouafi, Parker Solar Probe deputy project scientist and solar physicist at the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland.

Traveling to the Sun is an idea older than NASA itself, but it's taken decades to engineer the technology that makes its journey possible. In that time, scientists have determined exactly what kinds of data—and corresponding instruments—they need in order to complete a picture of the corona and answer this ultimate of burning questions.

Explaining the corona's secrets

Parker Solar Probe will test two chief theories to explain coronal heating. The outer layers of the Sun are constantly boiling and roil with mechanical energy. As massive cells of charged plasma churn through the Sun—much the way distinct bubbles roll up through a pot of boiling water—their fluid motion generates complex magnetic fields that extend far up into the corona. Somehow, the tangled fields channel this ferocious energy into the corona as heat—how they do so is what each theory attempts to explain.

One theory proposes electromagnetic waves are the root of the corona's extreme heat. Perhaps that boiling motion launches magnetic waves of a certain frequency—called Alfvén waves—from deep within the Sun out into the corona, which send charged particles spinning and heat the atmosphere, a bit like how ocean waves push and accelerate surfers toward the shore.

Another suggests bomb-like explosions, called nanoflares, across the Sun's surface dump heat into the solar atmosphere. Like their larger counterparts, solar flares, nanoflares are thought to result from an explosive process called magnetic reconnection. Turbulent boiling on the Sun twists and contorts magnetic field lines, building up stress and tension until they explosively snap—like breaking an over-wound rubber band—accelerating and heating particles in their wake.

The two theories aren't necessarily mutually exclusive. In fact, to complicate matters, many scientists think both may be involved in heating the corona. Sometimes, for example, the magnetic reconnection that sets off a nanoflare could also launch Alfvén waves, which then further heat surrounding plasma.

The other big question is, how often do these processes happen—constantly or in distinct bursts? Answering that requires a level of detail we don't have from 93 million miles away.

"We're going close to the heating, and there are times Parker Solar Probe will co-rotate, or orbit the Sun at the same speed the Sun itself rotates," said Eric Christian, a space scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland, and member of the mission's science team. "That's an important part of the science. By hovering over the same spot, we'll see the evolution of heating."

Uncovering the evidence

Once Parker Solar Probe arrives at the corona, how will it help scientists distinguish whether waves or nanoflares drive heating? While the spacecraft carries four instrument suites for a variety of types of research, two in particular will obtain data useful for solving the coronal heating mystery: the FIELDS experiment and SWEAP.

Surveyor of invisible forces, FIELDS, led by the University of California, Berkeley, directly measures electric and magnetic fields, in order to understand the shocks, waves and magnetic reconnection events that heat the solar wind.

SWEAP—led by the Harvard-Smithsonian Astrophysical Observatory in Cambridge, Massachusetts—is the complementary half of the investigation, gathering data on the hot plasma itself. It counts the most abundant particles in the solar wind—electrons, protons and helium ions—and measures their temperature, how fast they're moving after they've been heated, and in what direction.

Together, the two instrument suites paint a picture of the electromagnetic fields thought to be responsible for heating, as well as the just-heated solar particles swirling through the corona. Key to their success are high-resolution measurements, capable of resolving interactions between waves and particles at mere fractions of a second.

Parker Solar Probe will swoop within 3.9 million miles of the Sun's surface—and while this distance may seem great, the spacecraft is well-positioned to detect signatures of coronal heating. "Even though magnetic reconnection events take place lower down near the Sun's surface, the spacecraft will see the plasma right after they occur," said Goddard solar scientist Nicholeen Viall. "We have a chance to stick our thermometer right in the corona and watch the temperature rise. Compare that to studying plasma that was heated four days ago from Earth, where a lot of the 3D structures and time-sensitive information are washed out."

This part of the corona is entirely unexplored territory, and scientists expect sights unlike anything they've seen before. Some think the plasma there will be wispy and tenuous, like cirrus clouds. Or perhaps it will appear like massive pipe cleaner-like structures radiating from the Sun.

"I'm pretty sure when we get that first round of data back, we'll see the solar wind at lower altitudes near the Sun is spiky and impulsive," said Stuart Bale, University of California, Berkeley, astrophysicist and FIELDS principal investigator. "I'd lay my money on the data being much more exciting than what we see near Earth."

The data is complicated enough—and comes from multiple instruments—that it will take scientists some time to piece together an explanation for coronal heating. And because the Sun's surface isn't smooth and varies throughout, Parker Solar Probe needs to make multiple passes over the Sun to tell the whole story. But scientists are confident it has the tools to answer their questions.

The basic idea is that each proposed mechanism for heating has its own distinct signature. If Alfvén waves are the source of the corona's extreme heat, FIELDS will detect their activity. Since heavier ions are heated at different rates, it appears that different classes of particles interact with those waves in specific ways; SWEAP will characterize their unique interactions.

If nanoflares are responsible, scientists expect to see jets of accelerated particles shooting out in opposite directions—a telltale sign of explosive magnetic reconnection. Where magnetic reconnection occurs, they should also detect hot spots where magnetic fields are rapidly changing and heating the surrounding plasma.

Discoveries lie ahead

There is an eagerness and excitement buzzing among solar scientists: Parker Solar Probe's mission marks a watershed moment in the history of astrophysics, and they have a real chance of unraveling the mysteries that have confounded their field for nearly 150 years.

By piecing together the inner workings of the corona, scientists will reach a deeper understanding of the dynamics that spark space weather events, shaping conditions in near-Earth space. But the applications of this science extend beyond the solar system too. The Sun opens a window into understanding other stars—especially those that also exhibit Sun-like heating—stars that could potentially foster habitable environments but are too far to ever study. And illuminating the fundamental physics of plasmas could likely teach scientists a great deal about how plasmas behave elsewhere in the universe, like in clusters of galaxies or around black holes.

It's also entirely possible that we haven't even conceived of the greatest discoveries to come. It's hard to predict how solving coronal heating will shift our understanding of the space around us, but fundamental discoveries such as this have the capacity to change science and technology forever. Parker Solar Probe's journey takes human curiosity to a never-before-seen region of the solar system, where every observation is a potential discovery.

"I'm almost certain we'll discover new phenomena we don't know anything about now, and that's very exciting for us," Raouafi said. "Parker Solar Probe will make history by helping us understand coronal heating—as well as solar wind acceleration and solar energetic particles—but I think it also has the potential to steer the direction of solar physics' future."

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Parker Solar Probe Science – Solar Wind

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Parker Solar Probe and the Birth of the Solar Wind

This summer, humanity embarks on its first mission to touch the Sun: A spacecraft will be launched into the Sun's outer atmosphere.

Facing several-million-degree Fahrenheit temperatures, NASA's Parker Solar Probe—named after Eugene Parker, the University of Chicago physicist who first predicted the solar wind's existence—will directly sample solar particles and magnetic fields in an attempt to resolve some of the most important questions facing the field of solar science today. Among those questions: What is the origin of the solar wind and how is it accelerated to speeds of up to 1.8 million miles per hour?

The solar wind fills our entire solar system. When gusts of solar wind arrive at Earth, they can set off dazzling aurora—but also expose astronauts to radiation, interfere with satellite electronics, and disrupt communications signals like GPS and radio waves. The more we understand the fundamental processes that drive the solar wind, the more we can mitigate some of these effects.

In 1958, Parker developed a theory showing how the Sun's hot corona—by then known to be millions of degrees Fahrenheit—is so hot that it overcomes the Sun's gravity. According to the theory, the material in the corona expands continuously outwards in all directions, forming a solar wind. A year later, the Soviet spacecraft Luna 1 detected solar wind particles in space, and three years after that, the observations were confirmed by NASA's Mariner 2 spacecraft.

All those years ago, Mariner 2 detected two distinct streams of solar wind: a slow stream travelling at approximately 215 miles per second and a fast stream zipping through space at twice that speed. Then, in 1973, the origins of the fast solar wind were identified. X-ray images of the corona taken from Skylab—the U.S.'s first manned space station—revealed that the fast wind spews from coronal holes, which are dark, comparatively cool regions on the Sun.

“The slow solar wind is, in many respects, a larger mystery,” said Jim Klimchuk, solar physicist at NASA’s Goddard Space Flight Center in Greenbelt, Maryland. “It offers great promise for revealing fundamental new understanding.”

The origins and acceleration mechanisms of the slow solar wind remain mysterious. It is a matter of a decades-long fierce debate between scientists.

But we’re not without clues. NASA’s Ulysses mission, launched in 1990 to fly around the Sun’s poles, observed that during periods of minimum solar activity, the slow solar wind is confined to the Sun’s equator—right where Parker Solar Probe will fly. As the solar cycle progresses toward its maximum, the structure of the solar wind changes from two-distinct regimes—fast at the poles and slow at the equator—to a mixed, inhomogeneous flow.

The debate about the origins of the slow solar wind hinges on a distinction between what’s known as the closed and open corona. The closed corona refers to regions of the Sun where its magnetic field lines are closed—that is, connected to the solar surface at both ends. Bright helmet streamers—large loops that form over magnetically active regions, shaped like a knight’s pointy helmet—are one such example. The plasma, or ionized gas, travelling along the closed loops of a helmet streamer is for the most part confined to the area near the Sun.

The open corona, on the other hand, refers to regions where the magnetic field lines anchor to the Sun at only one end, stretching out into space on the other, thus creating a highway for solar material to escape into space. Coronal holes—the cooler regions at the source of the fast solar wind—are the habitat of open field lines.

By the time the slow solar wind leaves the solar corona, it is also flowing on open magnetic field lines, as that’s the only way to get so far from the Sun. But theories differ on whether it started off there, or was instead born on closed field lines only to switch to open field lines somewhere along the way.

The expansion factor theory, for example, claims the slow solar wind originates on open field lines, just like the fast wind. Its (comparatively) slow speed results from the expanding path it takes on its way out of the corona, as magnetic field lines skirt the borders of helmet streamers. Just as water coursing through a pipe slows to a trickle as the pipe expands, plasma traveling along these widening magnetic paths slows down, forming the slow wind.

Other theories claim the slow solar wind originates on closed field lines and later switches to open field lines. Accordingly, the slow wind forms when the open field lines from coronal holes bump into the closed field lines at the edges of helmet streamers, explosively rewiring themselves in an event called magnetic reconnection. Like a train changing tracks after the operator flips a switch, the plasma formerly on the streamer’s closed field lines suddenly finds itself on an open field line, where it can escape out to space.

The idea that slow solar wind plasma was once on closed field lines is supported by evidence that it once faced the kinds of extreme heating we know happens there.

“It’s not about the temperature of the plasma when we measure it; it’s about the temperature history of that plasma,” said Aleida Higginson, a University of Michigan research scientist working at Goddard. “We can tell that the slow solar wind was much hotter in the past.” In addition, the particular mix of elements that make up the slow solar wind matches well with those seen in the closed corona—but not with plasma that we know has always been on open field lines.

Current efforts to test these theories by spacecraft near Earth are stymied by the great distance between their measurements and the solar wind’s origins (a lot can happen in 93 million miles). The key is getting close up, tracing the solar wind back to its source—and Parker Solar Probe will do just that.

“If we can measure the slow solar wind, and find it comes from the boundary between open and closed magnetic fields, then that supports the idea that magnetic reconnection gives rise to the slow solar wind,” Klimchuk said.

Parker Solar Probe’s instruments will collect downstream evidence of magnetic reconnection—a tell-tale sign that the closed-field-to-open-field theory is at play. Specific kinds of reconnection twist the resulting magnetic field in different ways, and Parker’s instruments will measure the twists in these fields early on, before they have had much time to be distorted. In addition, close-up images of the nascent solar wind will tell us how coronal structures evolve as they propagate outward. This will help us answer a long-standing question whether the solar wind is a continuous or intermittent flow.

For scientists who crave data to test their theories, accurate measurements of the solar corona’s magnetic fields will be invaluable. “That’s why Parker’s mission is so important,” Higginson said. “It all traces back to understanding the detailed magnetic structure on the Sun.”

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Banner image: The solar wind blows past Earth in this illustration. Credits: NASA’s Goddard Space Flight Center/Scientific Visualization Studio/Greg Shirah

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