OUTCOME 2.4: DISCOVER HOW THE UNIVERSE WORKS, EXPLORE HOW IT BEGAN AND EVOLVED, AND SEARCH FOR EARTH-LIKE PLANETS.

NASA's Astrophysics Division seeks to understand the birth of the universe, the extremes of space and time near black holes, and the dark energy that fills the entire universe. It is exploring the relationship between the smallest of subatomic particles and the vast expanse of the cosmos. Its missions reveal the diversity of planets and planetary system architectures in the Milky Way galaxy; pinpoint Earth-like, potentially life-supporting planets in other solar systems; and study stellar and planetary environments and what powers the most energetic galaxies. Astrophysics designs and launches space telescopes that work in conjunction with ground and airborne telescopes to exploit the full range of the electromagnetic spectrum to view the broad diversity of the objects in the universe.

NASA's Astrophysics missions have provided researchers with new ways of looking at the universe so that they can expand knowledge about cosmic origins and fundamental physics. The study of the universe benefits the Nation's scientific research community by focusing research and advanced technology developments on optics, sensors, guidance systems, and propulsion systems. Some of these new and improved technologies enable groundbreaking capabilities, which are then available to the civil and defense sectors.

Stunning images produced from Astrophysics' operating missions continue to inspire the public, revealing the beauty of the universe and the science behind those images. The striking images from these observatories also are educational tools to help spark student interest in science, technology, engineering, and mathematics and serve to prominently illustrate the role of the United States in scientific exploration. NASA provides the tools to translate the science for the classroom and other learning venues in ways that meet educator needs.

Providing National Scientific Capabilities for Astrophysics

NASA continues to develop the Nation's capabilities in support of this science objective by funding research and mission development performed by scientists and engineers at universities, research centers, private sector organizations, and NASA Centers. The vast majority of research awards also include funding for postdoctoral fellows, graduate students, and undergraduate students, thereby supporting the education and training of future scientists and engineers.

Programs and activities serving this goal in FY 2012 include:

- Basic technology development in detector systems and materials sciences;
- Postdoctoral and early career fellowships through the Einstein, Hubble, and Sagan Postdoctoral fellowships and the Roman Technology Early Career fellowships; and
- Presidential Early Career Award for Scientists and Engineers.

The establishment, operation, and maintenance of necessary facilities is critical to the Nation's scientific capabilities. In FY 2012, NASA provided:

- Operations centers for NASA's astrophysics spaceflight missions including the Hubble Space Telescope, Chandra X-ray Observatory, Spitzer Space Telescope, Fermi Gamma Ray Space

Telescope, Kepler Space Telescope, and other missions;
- Technology development including high contrast imaging testbeds at the Jet Propulsion Laboratory, X-ray mirror production facilities at the Goddard Space Flight Center, and the X-ray Calibration Facility at the Marshall Space Flight Center;
- Operation of data archives that capture all NASA astrophysics data and make it available to the science community and the public, including the Barbara Mikulski Archive for Space Telescopes, the High Energy Astrophysics Science Archive, and the Infrared Science Archive; and
- Operation of the Nation's scientific balloon facilities in Palestine, Texas, and McMurdo Base, Antarctica.

NASA requires that all funded research investigations publish their results in open, peer reviewed science literature, ensuring that data and knowledge are captured.

Each year, the Astrophysics Subcommittee of NASA's external advisory Science Committee evaluates the progress made by NASA toward each science objective. In FY 2012, the subcommittee found that expectations had been fully met by research results, which included those discussed below.

Reported Multi-Year Performance

Multi-Year Performance Goal 2.4.1.1: Provide national scientific capabilities through necessary skilled researchers and supporting knowledge base. (In support of objective 2.4.1: "Improve understanding of the origin and destiny of the universe, and the nature of black holes, dark energy, dark matter, and gravity.")

FY11
Green
FY12
Green

NASA provides the skilled researchers and supporting astrophysics knowledge base necessary for the Nation's scientific capabilities. Efforts in support of this science objective include the Chandra X-ray Observatory, Hubble Space Telescope, Fermi Gamma Ray Space Telescope, Spitzer Space Telescope, Kepler Space Telescope, and other missions.

El Gordo: NASA's Chandra Finds Largest Galaxy Cluster in Early Universe

The largest galaxy cluster seen in the distant universe was found using NASA's Chandra X-ray Observatory and the National Science Foundation-funded Atacama Cosmology Telescope (ACT) in Chile.

Officially known as ACT-CL J0102-4915, the galaxy cluster was nicknamed "El Gordo" ("the big one" or "the fat one" in Spanish) by the researchers who discovered it. This cluster is located more than seven billion light years from Earth. This large distance means that it is being observed at a young age. Galaxy clusters, the largest objects in the universe that are held together by gravity, form through the merger of smaller groups or sub-clusters of galaxies. Because the formation process depends on the amount of dark matter and dark energy in the universe, clusters can be used to study these mysterious phenomena. Thus, El Gordo will provide an important link for understanding the content of the universe, essential to establishing its origin and ultimate fate. (Read more about this story.)

Giant Black Hole Kicked Out of Home Galaxy

Astronomers have found strong evidence that a massive black hole is being ejected from its

host galaxy at a speed of several million miles per hour. New observations from NASA's Chandra X-ray Observatory of the black hole, located in the middle of a galaxy about four billion light years away, suggest that it collided and merged with another black hole and received a powerful recoil kick from gravitational wave radiation. The kick occurs because more gravitational waves are being emitted in one direction. These new data support the idea that gravitational waves—ripples in the fabric of space first predicted by Albert Einstein but never detected directly—can exert an extremely powerful force, able to move a black hole with the mass of millions of Suns. Although likely to be rare, such ejections could mean that there are many giant black holes roaming undetected out in the vast spaces between galaxies. (Read more about this story.)

Fermi Observations of Dwarf Galaxies Provide New Insights on Dark Matter

There's more to the cosmos than meets the eye. About 80 percent of the matter in the universe is invisible to telescopes, yet its gravitational influence is manifest in the orbital speeds of stars around galaxies and in the motions of clusters of galaxies. Despite decades of effort, no one knows what this "dark matter" really is. WIMPs, or Weakly Interacting Massive Particles, represent a favored class of dark matter candidates. Some WIMPs may mutually annihilate when pairs of them interact, a process expected to produce gamma rays, the most energetic form of light.

NASA's Fermi Gamma Ray Space Telescope recently provided new clues. Using a novel technique where data from individual galaxies are analyzed jointly to boost the signal, the Fermi team examined roughly two dozen dwarf galaxies known to orbit the Milky Way. No gamma-ray signal consistent with the annihilations expected from four different types of commonly considered WIMP particles was found. For the first time, the results show that WIMP candidates within a specific range of masses and interaction rates cannot be dark matter. (Read more about this story.)

Update to Multi-Year Performance Goal	
FY13 Update	This performance goal remains the same in FY13.
FY14	This performance goal remains the same in FY14.

Reported Annual Performance					
AS-12-1: Demonstrate planned progress in understanding the origin and destiny of the universe, and the nature of black holes, dark energy, dark matter, and gravity. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.					
Contributing Theme:		Astrophysics			
Contributing Program(s):		Multiple Programs			
FY07	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**
7UNIV1 Green	**8AS01 Green**	**9AS1 Green**	**10AS01 Green**	**AS-11-1 Green**	**AS-12-1 Green**

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Planned Annual Performance	
FY13 Update	AS-13-1: Demonstrate planned progress in understanding the origin and destiny of the universe and the nature of black holes, dark energy, dark matter, and gravity. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.
FY14	AS-14-1: Demonstrate planned progress in understanding the origin and destiny of the universe and the nature of black holes, dark energy, dark matter, and gravity. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.

Reported Annual Performance					
No annual performance goal in FY12.					
Contributing Theme:		Astrophysics			
Contributing Program(s):		Physics of the Cosmos			
FY07	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**
7UNIV2 Yellow	**8AS02 Green**	**None**	**10AS04 Green**	**None**	**None**

Planned Annual Performance	
FY13 Update	AS-13-2: Achieve mission success criteria for the Fermi Gamma-ray Space Telescope.
FY14	No annual performance goal in FY14.

Reported Annual Performance	
No annual performance goal in FY12 or trended performance.	
Contributing Theme:	Astrophysics
Contributing Program(s):	Physics of the Cosmos

Planned Annual Performance	
FY13 Update	No annual performance goal in FY13.
FY14	AS-14-2: Complete NuSTAR mission success criteria.

Reported Multi-Year Performance

Multi-Year Performance Goal 2.4.1.2: By 2015, launch at least one mission in support of objective 2.4.1.

FY11
Green
FY12
Green

The launch of satellites provides the data that is critical to meeting NASA's scientific objectives. NASA completed this performance goal this year by launching the Nuclear Spectroscopic Telescope Array (NuSTAR) on June 13, 2012. NuSTAR carries the first focusing telescopes to image the sky in the high-energy X-ray region of the electromagnetic spectrum. The result is an unmatched ability to study high-energy X-ray sources like black holes and super-dense dead stars. On September 12, NASA celebrated NuSTAR's first 100 days in operation.

Update to Multi-Year Performance Goal	
FY13 Update	No performance goal in FY13.
FY14	No performance goal in FY14.

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Reported Annual Performance					
AS-12-2: Complete the Nuclear Spectroscopic Telescope Array (NuSTAR) Launch Readiness Review.					
Contributing Theme:		Astrophysics			
Contributing Program(s):		Astrophysics Explorer			
FY07	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**
None	**None**	**None**	**10AS02 Green**	**AS-11-2 Green**	**AS-12-2 Green**
Planned Annual Performance					
FY13 Update	No annual performance goal in FY13.				
FY14	No annual performance goal in FY14.				

Reported Multi-Year Performance

Multi-Year Performance Goal 2.4.2.1: Provide national scientific capabilities through necessary skilled researchers and supporting knowledge base. (In support of objective 2.4.2: "Improve understanding of the many phenomena and processes associated with galaxy, stellar, and planetary system formation and evolution from the earliest epochs to today.")

FY11
Green
FY12
Green

NASA provides the skilled researchers and supporting astrophysics knowledge base necessary for the Nation's scientific capabilities. Efforts in support of this science objective include the Chandra X-ray Observatory, Hubble Space Telescope, Fermi Gamma Ray Space Telescope, Spitzer Space Telescope, Kepler Space Telescope, and other missions.

NASA's Hubble Shows Milky Way is Destined for Head-On Collision

NASA astronomers announced they can now predict with certainty the next major cosmic event to affect the Milky Way galaxy, Sun, and solar system: the titanic collision of the Milky Way galaxy with the neighboring Andromeda galaxy, predicted to happen four billion years from now. This finding was provided through painstaking NASA Hubble Space Telescope measurements of the motion of Andromeda. Also known as M31, Andromeda is now 2.5 million light years away but falling toward the Milky Way under the mutual pull of gravity between the two galaxies and the invisible dark matter that surrounds them both.

Although the galaxies will plow into each other, stars inside each galaxy are so far apart relative to their sizes that they will not collide with each other during the encounter. However, the stars will be thrown into different orbits around the new galactic center. Simulations show that Earth's solar system will probably be tossed much farther from the galactic core than it is today.

The universe is expanding and accelerating, but collisions between galaxies in close proximity to each other still happen because they are bound by the gravity of the dark matter surrounding them. The Hubble Space Telescope's deep views of the universe show such encounters between galaxies were more common in the past when the universe was smaller. (Read more about this story.)

NASA's Spitzer Detects Comet Seeding Primordial Planet

NASA's Spitzer Space Telescope has detected signs of cometary ices raining down on

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primordial 'planetessimals' (budding planets) in an alien solar system. This happened in this solar system several billion years ago. During that period, comets and other icy objects that were flung in from the outer solar system pummeled the primordial inner planets, generated huge clouds of dust and ice, scarred rocky planets and moons, and seeded them with water and organics that may have helped kick-start life.

Spitzer spotted a band of dust around nearby bright star, Eta Corvi, with the tell-tale signature of an obliterated giant comet. This is the first time that evidence for such a comet storm has been seen around another star. This dust band is close to Eta Corvi, where Earth-like worlds could exist, implying a collision took place between a planet and one or more comets. The Eta Corvi system is about a billion years old, which is about the right age for such an extraterrestrial hailstorm.

Earth's solar system has a similar region, known as the Kuiper Belt, where icy and rocky leftovers from planet formation linger. About four billion years ago, some 600 million years after the solar system formed, scientists think the Kuiper Belt was disturbed by a migration of the gas-giant planets Jupiter and Saturn. This jarring shift in the solar system's gravitational balance scattered the icy bodies in the Kuiper Belt, flinging the vast majority into interstellar space and producing cold dust in the belt. Some Kuiper Belt objects, however, were set on paths that crossed the orbits of the inner planets.

The resulting bombardment of comets lasted until 3.8 billion years ago. Some of these comets struck Earth, or were incinerated in the atmosphere, and are thought to have deposited water and carbon on this planet. This period of impacts might have helped life form by delivering its crucial ingredients. (Read more about this story.)

Update to Multi-Year Performance Goal	
FY13 Update	This performance goal remains the same in FY13.
FY14	This performance goal remains the same in FY14.

Reported Annual Performance					
AS-12-3: Demonstrate planned progress in understanding the many phenomena and processes associated with galaxy, stellar, and planetary system formation and evolution from the earliest epochs to today. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.					
Contributing Theme:	Astrophysics				
Contributing Program(s):	Multiple Programs				
FY07	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**
7UNIV6 Green	**8AS06 Green**	**9AS6 Green**	**10AS09 Green**	**AS-11-3 Green**	**AS-12-3 Green**

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Planned Annual Performance	
FY13 Update	AS-13-3: Demonstrate planned progress in understanding the many phenomena and processes associated with galaxy, stellar, and planetary system formation and evolution from the earliest epochs to today. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.
FY14	AS-14-3: Demonstrate planned progress in understanding the many phenomena and processes associated with galaxy, stellar, and planetary system formation and evolution from the earliest epochs to today. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.

Reported Multi-Year Performance

Multi-Year Performance Goal 2.4.2.2: Design and assemble the James Webb Space Telescope (JWST).

FY11
Yellow
FY12
Green

During FY 2012, the JWST Program successfully tested two of four science instruments, the Fine Guidance Sensor (FGS) and the Mid-Infrared Instrument (MIRI), in cryogenic vacuum conditions and qualified them for spaceflight and subsequently delivered them to NASA's Goddard Space Flight Center. The program also successfully completed the following significant and technically challenging developments and tests:

• Cryogenic vacuum testing on all flight primary mirrors to confirm precision optical shape under cryogenic conditions;
• Fabrication of the flight primary mirror backplane support structure, a very complex graphite-epoxy composite structure, to exacting shape necessary to hold the primary mirrors;
• The telescope tower, also a precision composite structure;
• Extensive modifications of the large vacuum Chamber A at the Johnson Space Center (JSC) to add, for the first time, cryogenic testing capabilities; and
• Fabrication of the critical center of curvature optical assembly, a critical element of precision testing of the flight optical system in JSC's Chamber A.

Update to Multi-Year Performance Goal	
FY13 Update	This performance goal remains the same in FY13.
FY14	This performance goal remains the same in FY14.

Reported Annual Performance					
JWST-12-1: Begin integration of James Webb Space Telescope (JWST) flight optics into Optical Telescope Element (OTE).					
Contributing Theme:		James Webb Space Telescope			
Contributing Program(s):		James Webb Space Telescope			
FY07	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**
7UNIV4 Green	**8AS04 Green**	**9AS4 Green**	**10AS06 Green**	**JWST-11-1 Green**	**JWST-12-1 White**
Why this APG was not achieved: The JWST Program replanning process resulted in a schedule revision that changed the milestone reflected in the FY 2012 measure. In the final review of the updated performance plan, NASA inadvertently missed correcting this measure to reflect the replan. The JWST Program continues to be on-track to complete its revised plan.					

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Planned Annual Performance	
FY13 Update	JWST-13-1: Deliver James Webb Space Telescope Near Infrared Camera to Integrated Science Instrument Module (ISIM) Integration and Test.
FY14	JWST-14-1: Complete JWST Spacecraft Critical Design Review.
Comments	The JWST Program replan rearranged milestones in the schedule, moving some earlier and delaying others. The FY 2013 and FY 2014 APGs reflect the changed milestone schedule resulting from the JWST Program's replan. The JWST Program has rescheduled the integration of the flight optics into the Optical Telescope Element (see APG JWST-12-1) for a forthcoming fiscal year.

Reported Multi-Year Performance

Multi-Year Performance Goal 2.4.2.3: Develop and operate an airborne infrared astrophysics observatory.

FY11
Green
FY12
Green

NASA and the German Aerospace Center, Deutsches Zentrum fur Luft- und Raumfahrt (DLR), are developing the Stratospheric Observatory for Infrared Astronomy (SOFIA), an airborne observatory that will complement the Hubble, Spitzer, and Herschel space telescopes. The plan is to demonstrate SOFIA's full operational capability in 2014. The SOFIA Program has begun science flights during development to test and upgrade the instruments as needed. During FY 2012, the SOFIA Program completed the Early Science campaign, which began in FY 2011, and resulted in more than two dozen peer-reviewed papers based on the science results. The team then began preparing for Cycle 1 science observations by completing system upgrades, including observatory upgrades, and announcing General Observer investigations (totaling about 200 community science hours) evaluated by U.S.- and German-chartered peer-reviewed panels. The program also selected both the second-generation instrument upgrade proposal and the first full class of Airborne Astronomy Ambassadors: 26 U.S. and six German educators chosen to participate in Cycle 1 flights as partners and astronomers as part of a larger education, outreach, and enrichment program.

Update to Multi-Year Performance Goal	
FY13 Update	This performance goal remains the same in FY13.
FY14	This performance goal remains the same in FY14.

Reported Annual Performance					
AS-12-4: Initiate the Stratospheric Observatory for Infrared Astronomy (SOFIA) Segment 3 Aircraft modifications and upgrades.					
Contributing Theme:		Astrophysics			
Contributing Program(s):		Cosmic Origins			
FY07	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**
None	**None**	**9AS5 Yellow**	**10AS07 Yellow**	**AS-11-4 Green**	**AS-12-4 Green**

Planned Annual Performance	
FY13 Update	AS-13-4: Complete the Systems Requirement Review (SRR) for the initial second generation Stratospheric Observatory for Infrared Astronomy (SOFIA) instrument.
FY14	AS-14-5: Conduct Stratospheric Observatory for Infrared Astronomy (SOFIA) science flights to provide a minimum of 330 research hours.

Reported Multi-Year Performance

Multi-Year Performance Goal 2.4.3.1: Provide national scientific capabilities through necessary skilled researchers and supporting knowledge base. (In support of objective 2.4.3: "Generate a census of extra-solar planets and measure their properties.")

FY11
Green
FY12
Green

NASA provides the skilled researchers and supporting astrophysics knowledge base necessary for the Nation's scientific capabilities. Efforts in support of this science objective include the Chandra X-ray Observatory, Hubble Space Telescope, Fermi Gamma Ray Space Telescope, Spitzer Space Telescope, Kepler Space Telescope, and other missions.

NASA's Kepler Mission Redefines the Population of Extra-solar Planets

The Kepler mission made major strides this past year in its census of extra-solar planets. It identifies planet candidates by measuring dips in the brightness of more than 150,000 stars to search for planets crossing in front of, or transiting, their stars. The Kepler science team requires at least three transits to verify a signal as a planet candidate. Further analysis or ground-based observations are required to confirm discoveries of planets.

Kepler's count of candidate planets increased by more than a thousand during FY 2012, and stood at over 2,300 as of December. The largest part of this increase arises from the greater number of small planets discovered: over 900 are smaller than twice Earth's diameter, and over 200 are Earth-sized. Kepler results to date show that Neptune-sized planets are much more common than Jupiter-sized ones, a result that must be accounted for by all future planet formation theories. More than 500 Kepler planet candidates to date are found in a multi-planet system, which is defined as two or more planets circling the same host star. Kepler's count of candidate multi-planet systems is so large that no other explanation can account for it: almost all Kepler multi-planet candidates must be true planets. (Read more about this story.)

NASA's Kepler Discovers Superlative Exoplanets

The Kepler mission has confirmed its first planet in the "habitable zone," the orbital region around a star where temperatures allow liquid water to exist on a planet's surface. Ten additional planet candidates near Earth size have been found in habitable zones and are awaiting confirmation. Candidates require follow-up observations using other telescopes to verify that they are actual planets.

The newly confirmed planet, Kepler-22b, at 600 light years distance, is the smallest yet found to orbit in the middle of the habitable zone of a star similar to the Sun. The planet is about 2.4 times the radius of Earth. While it is larger than Earth, its orbit of 290 days around a Sun-like star resembles that of Earth. The planet's host star belongs to the same class as the Sun, a "G-type," although it is slightly smaller and cooler. Scientists do not yet know if Kepler-22b has a predominantly rocky, gaseous, or liquid composition, but its discovery is a step closer to finding Earth-like planets. (Read more about this story.)

Using data from NASA's Kepler mission, astronomers announced the discovery of three new double-star planet systems: Kepler-16, Kepler-34, and Kepler-35. These findings establish that such "two sun" planets are not rare exceptions, but may in fact be common, broadening the hunting ground for systems that could support life. All three new planets are gaseous and Saturn-sized. Kepler-16b orbits a Sun-like star and its red dwarf companion

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	star every 229 days, while the two stars orbit each other every 41 days. Kepler-34b orbits its two Sun-like stars every 289 days, and the stars orbit one another every 28 days. Kepler-35b orbits its smaller and cooler host stars every 131 days, and the stellar pair orbit each other every 21 days. (Read more about Kepler 16b and Kepler 34 and 35).

Update to Multi-Year Performance Goal	
FY13 Update	This performance goal remains the same in FY13.
FY14	This performance goal remains the same in FY14.

Reported Annual Performance					
AS-12-5: Demonstrate planned progress in generating a census of extra-solar planets and measuring their properties. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.					
Contributing Theme:		Astrophysics			
Contributing Program(s):		Multiple Programs			
FY07	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**
7UNIV7 Green	**8AS07 Green**	**9AS7 Green**	**10AS10 Green**	**AS-11-5 Green**	**AS-12-5 Green**
Planned Annual Performance					
FY13 Update	AS-13-5: Demonstrate planned progress in generating a census of extra-solar planets and measuring their properties. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.				
FY14	AS-14-6: Demonstrate planned progress in generating a census of extra-solar planets and measuring their properties. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.				

Reported Annual Performance					
No annual performance goal in FY12.					
Contributing Theme:		Astrophysics			
Contributing Program(s):		Exoplanet Exploration			
FY07	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**
7UNIV8 Green	**8AS08 Green**	**9AS8 Green**	**None**	**None**	**None**
Planned Annual Performance					
FY13 Update	AS-13-6: Achieve mission success criteria for the Kepler mission.				
FY14	No annual performance goal in FY14.				