

2015 Astrophysics Division input for Government Performance and Results Act (GPRA) Modernization Act (GPRAMA) review by Astrophysics Subcommittee

ASTROPHYSICS

(From 2014 GPRAMA Document, as an example)

NASA leads the Nation and the world on a continuing journey to answer some of the most profound questions that touch the hearts of all humanity: How does the Universe work? How did we get here? Are we alone? The scope of astrophysics is truly breathtaking, ranging from the birth of the universe and the development of stars and galaxies over cosmic time, to the search for life on planets around other stars. Often in cooperation with ground-based observatories, NASA Astrophysics missions exploit the full range of the electromagnetic spectrum and the physics of high-energy subatomic particles to understand the broad diversity of objects in the universe.

NASA's Astrophysics missions explore the most extreme physical conditions of the universe and study the building blocks of our own existence at the most basic level: the space, time, matter, and energy that create the Universe we live in. We seek to understand how the universe has evolved since the Big Bang, producing the magnificent night sky we see today, as well as the planet we live on and all the chemical elements which sustain life. To do this, NASA's telescopes explore the origin and evolution of the galaxies, stars and planets that make up our universe. The most distant galaxies we have found were formed when the universe was only a few percent of its present age. NASA's telescopes have observed the formation of chemical elements in stars and the formation of new planetary systems within our galaxy.

NASA is leading humankind on a voyage of unprecedented scope and ambition, seeking to discover and study planets orbiting other stars, and to explore whether they could harbor life. NASA's astrophysics missions, in conjunction with ground-based telescopes, have already confirmed the existence of over 900 extrasolar planets and have discovered more than 2700 new candidates. Of even greater interest, we are now finding that there are many small, rocky extrasolar planets where liquid water could exist.

NASA astrophysics missions afford opportunities for studying the cosmos from the near-vacuum of space which, unlike the Earth's atmosphere, is transparent to nearly all forms of radiation. Exploiting these opportunities requires the development of specialized detectors and electronics that can operate efficiently and reliably under conditions harsher and more varied than found anywhere on Earth. Astrophysical observations from space present special technical problems in sensitivity and stability that, once solved, lead to more broadly applicable technologies that benefit both the commercial and defense sectors.

The fantastic and inspiring imagery and data provided by Astrophysics Missions is the basis for much of NASA Science Technology Engineering and Mathematics education and outreach work. Deep-space images reveal stars forming in glowing clouds, black holes at the core of galaxies, and vast fields of ancient galaxies, which intrigue students, teachers and the public. Space telescopes observe at many wavelengths that give us insight into the history of the universe, and our place in it. Hundreds of planets have been discovered in orbit around distant stars, with thousands more to be confirmed. All this NASA research aims to answer the enduring question, "Are we alone?" NASA's education and public outreach work translates scientific discoveries into classroom-useable forms that meet the needs of K-12 educators who are preparing the next generation of scientists, engineers, and innovators.

Major Astrophysics milestones of the last fiscal year include:

- Observations with NuSTAR reveal that spectral features observed in X-rays allow determination of the spin rates for supermassive black holes.....
- The Hubble eXtreme Deep Field (XDF) is the deepest image ever taken, revealing galaxies that were formed when the universe was only 0.5 billion years old.

- [The Wide-field Infrared Survey Explorer \(WISE\) has discovered a pair of stars that constitute the third-closest star system to the sun, the nearest star system discovered since 1916.](#)
- [The Kepler mission has discovered for the first time multiple planets that are orbiting a pair of stars.](#)

[In addition, the SOFIA airborne infrared observatory is now beginning science operations and exciting new scientific results can be expected in the near future.](#)

[\[Overall Summary here\]](#)

Strategic Objective 1.6: Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars.

Multiyear Performance Goal 1.6.2: *Demonstrate progress in probing the origin and destiny of the universe, including the nature of black holes, dark energy, dark matter, and gravity.*

Annual Performance Indicator: FY 2015 AS-15-1: *Demonstrate planned progress in probing the origin and destiny of the universe, including the nature of black holes, dark energy, dark matter, and gravity.*

The NASA Astrophysics Subcommittee graded the Division's progress in this area to be [\[enter rating color here\]](#).

Summary: [\[Summary of this section here\]](#)

Here are the specific citations and more details about each of the results cited above:

NASA's Chandra Detects Record-Breaking Outburst from Milky Way's Black Hole

Astronomers have observed the largest X-ray flare ever detected from the supermassive black hole at the center of the Milky Way galaxy. This event, detected by NASA's Chandra X-ray Observatory, raises questions about the behavior of this giant black hole and its surrounding environment. Astronomers made the unexpected discovery while using Chandra to observe how Sgr A* would react to a nearby cloud of gas known as G2. On Sept. 14, 2013, Haggard and her team detected an X-ray flare from Sgr A* 400 times brighter than its usual, quiet state. This "megafare" was nearly three times brighter than the previous brightest X-ray flare from Sgr A* in early 2012. After Sgr A* settled down, Chandra observed another enormous X-ray flare 200 times brighter than usual on Oct. 20, 2014. The researchers have two main theories about what caused Sgr A* to erupt in this extreme way. The first is that an asteroid came too close to the supermassive black hole and was torn apart by gravity. The debris from such a tidal disruption became very hot and produced X-rays before disappearing forever across the black hole's point of no return, or event horizon. A second theory is that the magnetic field lines within the gas flowing towards Sgr A* could be tightly packed and become tangled. These field lines may occasionally reconfigure themselves and produce a bright outburst of X-rays.

Citation: [\[need citation\]](#)

url: <http://www.nasa.gov/press/2015/january/nasa-s-chandra-detects-record-breaking-outburst-from-milky-way-s-black-hole>

NASA, ESA Telescopes Give Shape to Furious Black Hole Winds

NuSTAR and ESA's XMM-Newton telescope are showing that fierce winds from a supermassive black hole blow outward in all directions -- a phenomenon that had been suspected, but difficult to prove until now. This discovery has given astronomers their first opportunity to measure the strength of

these ultra-fast winds and prove they are powerful enough to inhibit the host galaxy's ability to make new stars. In the new study, astronomers determined PDS 456, an extremely bright black hole known as a quasar more than 2 billion light-years away, sustains winds that carry more energy every second than is emitted by more than a trillion suns. NuSTAR and XMM-Newton simultaneously observed PDS 456 on five separate occasions in 2013 and 2014. The space telescopes complement each other by observing different parts of the X-ray light spectrum: XMM-Newton views low-energy and NuSTAR views high-energy. Previous XMM-Newton observations had identified black-hole winds blowing toward us, but could not determine whether the winds also blew in all directions. XMM-Newton had detected iron atoms, which are carried by the winds along with other matter, only directly in front of the black hole, where they block X-rays. The scientists combined higher-energy X-ray data from NuSTAR with observations from XMM-Newton. By doing this, they were able to find signatures of iron scattered from the sides, proving the winds emanate from the black hole not in a beam, but in a nearly spherical fashion. With the shape and extent of the winds known, the researchers could then determine the strength of the winds and the degree to which they can inhibit the formation of new stars. Astronomers think supermassive black holes and their home galaxies evolve together and regulate each other's growth. This latest report demonstrates a supermassive black hole and its high-speed winds greatly affect the host galaxy. As the black hole bulks up in size, its winds push vast amounts of matter outward through the galaxy, which ultimately stops new stars from forming.

Citations: *[need citation]*

url: <http://www.nasa.gov/jpl/nustar/nasa-esa-telescopes-give-shape-to-furious-black-hole-winds>

NASA's WISE Spacecraft Discovers Most Luminous Galaxy in Universe

A remote galaxy shining with the light of more than 300 trillion suns has been discovered using data from NASA's Wide-field Infrared Survey Explorer (WISE). The galaxy is the most luminous galaxy found to date and belongs to a new class of objects recently discovered by WISE -- extremely luminous infrared galaxies, or ELIRGs. The brilliant galaxy, known as WISE J224607.57-052635.0, may have a behemoth black hole at its belly, gorging itself on gas. Supermassive black holes draw gas and matter into a disk around them, heating the disk to roaring temperatures of millions of degrees and blasting out high-energy, visible, ultraviolet, and X-ray light. The light is blocked by surrounding cocoons of dust. As the dust heats up, it radiates infrared light. Immense black holes are common at the cores of galaxies, but finding one this big so "far back" in the cosmos is rare. Because light from the galaxy hosting the black hole has traveled 12.5 billion years to reach us, astronomers are seeing the object as it was in the distant past. The black hole was already billions of times the mass of our sun when our universe was only a tenth of its present age of 13.8 billion years. The new study outlines three reasons why the black holes in the ELIRGs could have grown so massive. First, they may have been born big. In other words, the "seeds," or embryonic black holes, might be bigger than thought possible. The other two explanations involve either breaking or bending the theoretical limit of black hole feeding, called the Eddington limit. When a black hole feeds, gas falls in and heats up, blasting out light. The pressure of the light actually pushes the gas away, creating a limit to how fast the black hole can continuously scarf down matter. If a black hole broke this limit, it could theoretically balloon in size at a breakneck pace. Black holes have previously been observed breaking this limit; however, the black hole in the study would have had to repeatedly break the limit to grow this large. More research is needed to solve this puzzle of these dazzlingly luminous galaxies. Knowing these objects' true hefts will help reveal their history, as well as that of other galaxies, in this very crucial and frenzied chapter of our cosmos.

Citation: <http://arxiv.org/abs/1410.1751>

url: <http://www.nasa.gov/press-release/nasas-wise-spacecraft-discovers-most-luminous-galaxy-in-universe>

NASA's RXTE Satellite Decodes the Rhythm of an Unusual Black Hole

Astronomers have uncovered rhythmic pulsations from a rare type of black hole 12 million light-years away by sifting through archival data from NASA's Rossi X-ray Timing Explorer (RXTE) satellite. The signals have helped astronomers identify an unusual midsize black hole called M82 X-1, which is the brightest X-ray source in a galaxy known as Messier 82. Most black holes formed by dying stars are modestly-sized, measuring up to around 25 times the mass of our sun. And most large galaxies harbor monster, or supermassive, black holes that contain tens of thousands of times more mass. By going over past RXTE observations, the astronomers found specific changes in brightness that helped them determine M82 X-1 measures around 400 solar masses. As gas falls toward a black hole, it heats up and emits X-rays. Variations in X-ray brightness reflect changes occurring in the gas. The most rapid fluctuations happen near the brink of the black hole's event horizon, the point beyond which nothing, not even light, can escape. Astronomers call these rhythmic pulses quasi-periodic oscillations, or QPOs. For stellar black holes, astronomers have established that the larger the mass, the slower the QPOs, but they could not be sure what they were seeing from M82 X-1 was an extension of this pattern. When we study fluctuations in X-rays from many stellar-mass black holes, we see both slow and fast QPOs. For every three pulses from one member of a QPO pair, its partner pulses twice. By analyzing six years of RXTE data, the team located X-ray variations that reliably repeat about 5.1 and 3.3 times a second, a 3:2 relationship. The combined presence of slow QPOs and a faster pair in a 3:2 rhythm sets a standard scale allowing astronomers to extend proven relationships used to determine the masses of stellar-mass black holes.

Citation: Dheeraj et al., 2014, Nature, 513, 74 (A 400-solar-mass black hole in the galaxy M82)

url: <http://www.nasa.gov/press/2014/august/nasas-rxte-satellite-decodes-the-rhythm-of-an-unusual-black-hole>

NASA's Hubble, Chandra Find Clues that May Help Identify Dark Matter

Using observations from NASA's Hubble Space Telescope and Chandra X-ray Observatory, astronomers have found that dark matter does not slow down when colliding with itself, meaning it interacts with itself less than previously thought. Researchers say this finding narrows down the options for what this mysterious substance might be. Researchers used Hubble and Chandra to observe these space collisions. Specifically, Hubble was used to map the distribution of stars and dark matter after a collision, which was traced through its gravitational lensing effect on background light. Chandra was used to detect the X-ray emission from colliding gas clouds. The team found that, like the galaxies, the dark matter continued straight through the violent collisions without slowing down much. This means dark matter does not interact with visible particles and flies by other dark matter with much less interaction than previously thought. Had the dark matter dragged against other dark matter, the distribution of galaxies would have shifted.

Citation: *[Need citation]*

url: <http://www.nasa.gov/press/2015/march/nasa-s-hubble-chandra-find-clues-that-may-help-identify-dark-matter>

Kepler and Swift Capture Rare, Early Moments of Baby Supernovae

Astronomers are studying measurements taken by NASA's Kepler and Swift spacecraft of newborn supernova to better understand what sparks these world-shattering stellar explosions. Type Ia supernovae are particularly fascinating, as they can serve as a lighthouse for measuring the vast distances across space. A better understanding of the differences among Type Ia explosions will help

us improve our knowledge of dark energy, a mysterious force that appears to be accelerating cosmic expansion. Type Ia supernovae explode with similar brightness because the exploding object is always a white dwarf, the Earth-sized remnant of a star like the sun. A white dwarf can go supernova by merging with another white dwarf or by pulling too much matter from a nearby companion star, causing a thermonuclear reaction and blowing itself to smithereens. Kepler and Swift have found supporting evidence for both star-pulverizing scenarios. Astronomers are working to determine the percentage of supernovae produced by each one.

Citation: Yi Cao et al., 2015, Nature 521, 328 (A strong ultraviolet pulse from a newborn type Ia supernova)

Oiling et al., 2015, Nature 521, 332 (No signature of ejecta interaction with a stellar companion in three type Ia supernovae)

url: <http://www.nasa.gov/ames/kepler/nasa-spacecraft-capture-rare-early-moments-of-baby-supernovae>

NASA X-Ray Telescopes Find Black Hole May be a Neutrino Factory

The giant black hole at the center of the Milky Way may be producing mysterious particles called neutrinos. If confirmed, this would be the first time that scientists have traced neutrinos back to a black hole. The evidence for this came from three NASA satellites that observe in X-ray light: Chandra, Swift, and NuSTAR. "We now have the first evidence that an astronomical source -- the Milky Way's supermassive black hole -- may be producing these very energetic neutrinos." Because neutrinos pass through material very easily, it is extremely difficult to build detectors that reveal exactly where the neutrino came from. The IceCube Neutrino Observatory, located under the South Pole, has detected 36 high-energy neutrinos since the facility became operational in 2010. By pairing IceCube's capabilities with the data from the three X-ray telescopes, scientists were able to look for violent events in space that corresponded with the arrival of a high-energy neutrino here on Earth. In addition, several neutrino detections appeared within a few days of flares from the supermassive black hole that were observed with Swift and NuSTAR. Scientists think that the highest energy neutrinos were created in the most powerful events in the universe like galaxy mergers, material falling onto supermassive black holes, and the winds around dense rotating stars called pulsars. The team of researchers is still trying to develop a case for how Sagittarius A* might produce neutrinos. One idea is that it could happen when particles around the black hole are accelerated by a shock wave, like a sonic boom, that produces charged particles that decay to neutrinos. This latest result may also contribute to the understanding of another major puzzle in astrophysics: the source of high-energy cosmic rays. Since the charged particles that make up cosmic rays are deflected by magnetic fields in our galaxy, scientists have been unable to pinpoint their origin. The charged particles accelerated by a shock wave near Sgr A* may be a significant source of very energetic cosmic rays.

Citation:
Bai et al., 2014, Phys. Rev. D, 90, 063012 ("Neutrino lighthouse at Sagittarius A*")

url: <https://www.nasa.gov/centers/marshall/news/news/releases/2014/14-169.html>

Planck Mission Explores the History of Our Universe

Hot gas, dust and magnetic fields mingle in a colorful swirl in a new map of our Milky Way galaxy, which is part of a new and improved data set from Planck, a European Space Agency mission in which NASA played a key role. The new data are now available publicly, include observations made during the entire mission. The Planck team says these data are refining what we know about our

universe, making more precise measurements of matter, including dark matter, and how it is clumped together. Other key properties of our universe are also measured with greater precision, putting theories of the cosmos to ever more stringent tests.

One cosmic property appears to have changed with this new batch of data: the length of time in which our universe remained in darkness during its infant stages. A preliminary analysis of the Planck data suggests that this epoch, a period known as the Dark Ages that took place before the first stars and other objects ignited, lasted more than 100 million years or so longer than thought. Specifically, the Dark Ages ended 550 million years after the Big Bang that created our universe, later than previous estimates by other telescopes of 300 to 400 million years. Research is ongoing to confirm this finding.

The Planck data also support the idea that the mysterious force known as dark energy is acting against gravity to push our universe apart at ever-increasing speed. The new Planck catalog of images now has more than 1,500 clusters of galaxies observed throughout the universe, the largest catalog of this type ever made. A new analysis by the Planck team of more than 400 of these galaxy clusters gives us a new look at their masses, which range between 100 to 1,000 times that of our Milky Way galaxy. In one of the first-of-its-kind efforts, the Planck team obtained the cluster masses by observing how the clusters bend background microwave light. The results narrow in on the overall mass of hundreds of clusters, a huge step forward in better understanding dark matter and dark energy.

[Need citation]

url: <http://www.nasa.gov/jpl/planck-mission-explores-the-history-of-our-universe>

Multiyear Performance Goal: 1.6.3: *Demonstrate progress in exploring the origin and evolution of the galaxies, stars, and planets that make up the universe.*

Annual Performance Indicator: FY 2015 AS-15-3: *Demonstrate planned progress in exploring the origin and evolution of the galaxies, stars, and planets that make up the universe.*

The NASA Astrophysics Subcommittee graded the Division's progress in this area to be *[insert rating color here]*

Summary: *[Summary of this section here]*

Chandra Observatory Finds Cosmic Showers Halt Galaxy Growth

Using Chandra astronomers have found that the growth of galaxies containing supermassive black holes can be slowed down by a phenomenon referred to as cosmic precipitation. Cosmic precipitation is not a weather event. Rather, it is a mechanism that allows hot gas to produce showers of cool gas clouds that fall into a galaxy. Researchers have analyzed X-rays from more than 200 galaxy clusters, and believe that this gaseous precipitation is key to understanding how giant black holes affect the growth of galaxies. The study looked at some of the largest known galaxies lying in the middle of galaxy clusters. These galaxies are embedded in enormous atmospheres of hot gas. This hot gas should cool and many stars should then form. However, observations show that something is hindering the star birth. The answer appears to lie with the supermassive black holes at the centers of the large galaxies. Under specific conditions, clumps of gas can radiate away their energy and form cool clouds that mix with surrounding hot gas. Some of these clouds form stars, but others rain onto the supermassive black hole, triggering jets of energetic particles that push against the falling gas and reheat it, preventing more stars from forming. This cycle of cooling and heating creates a feedback

loop that regulates the growth of the galaxies. Voit and his colleagues used Chandra data to estimate how long it should take for the gas to cool at different distances from the black holes in the study. Using that information, they were able to accurately predict the "weather" around each of the black holes. They found that the precipitation feedback loop driven by energy produced by the black hole jets prevents the showers of cold clouds from getting too strong. The Chandra data indicate the regulation of this precipitation has been going on for the last 7 billion years or more. While a rain of cool clouds appears to play a key role in regulating the growth of some galaxies, the researchers have found other galaxies where the cosmic precipitation had shut off. The intense heat in these central galaxies, possibly from colliding with another galaxy cluster, likely "dried up" the precipitation around the black hole.

Citation: *[insert citation here]*

URL: <http://www.nasa.gov/press/2015/march/nasa-s-chandra-observatory-finds-cosmic-showers-halt-galaxy-growth>

Hubble Finds Extremely Distant Galaxy Through Cosmic Magnifying Glass

Peering through a giant cosmic magnifying glass, NASA's Hubble Space Telescope has spotted one of the farthest, faintest, and smallest galaxies ever seen. The diminutive object is estimated to be over 13 billion light-years away. This new detection is considered one of the most reliable distance measurements of a galaxy that existed in the early universe, said the Hubble researchers. They used two independent methods to estimate its distance. The galaxy appears as a tiny blob that is only a small fraction of the size of our Milky Way galaxy. But it offers a peek back into a time when the universe was only about 500 million years old, roughly 3 percent of its current age of 13.7 billion years. Astronomers have uncovered about 10 other galaxy candidates at this early era. But this newly found galaxy is significantly smaller and fainter than most of those other remote objects detected to date, and will help us understand how galaxies and the universe have evolved over time. These clusters are so massive that their gravity deflects light passing through them, magnifying, brightening, and distorting background objects in a phenomenon called gravitational lensing. These powerful lenses allow astronomers to find many dim, distant structures that otherwise might be too faint to see. In this new discovery, the lensing power of the mammoth galaxy cluster Abell 2744, nicknamed Pandora's Cluster, produced three magnified images of the same galaxy. Each magnified image makes the galaxy appear as much as 10 times larger and brighter than it would look without the intervening lens. An analysis of the distant galaxy shows that it measures merely 850 light-years across, 500 times smaller than the Milky Way, and is estimated to have a mass of only 40 million suns. The galaxy's star formation rate is about one star every three years (one-third the star formation rate in the Milky Way). Although this may seem low, given its small size and low mass, the tiny galaxy is in fact rapidly evolving and efficiently forming stars. Galaxies such as this one are probably small clumps of matter that are starting to form stars and shine light, but they don't have a defined structure yet. Therefore, it's possible that we only see one bright clump magnified due to the lensing, and this is one possibility as to why it is smaller than typical field galaxies of that time.

Citation: *[Need citation]*

URL: <http://hubblesite.org/newscenter/archive/releases/galaxy/2014/39/full/>

Fast Evolution of Youthful Compact Galaxies

Researchers using NASA's Hubble Space Telescope and Chandra X-ray Observatory have uncovered young, massive, compact galaxies whose star-making phase is ending early. The firestorm of star birth has consumed much of the gaseous fuel needed to make future generations of stars, and the powerful stellar winds of the newly born stars have blown away any remaining fuel. Now the stellar

birth phase is over for these gas-starved galaxies, and they are on track to possibly becoming so-called "red and dead galaxies," composed only of aging stars. Astronomers have debated for decades how massive galaxies rapidly evolve from active star-forming machines to star-starved graveyards. Previous observations of these galaxies reveal geysers of gas shooting into space at up to 2 million miles an hour. Astronomers have suspected that powerful monster black holes lurking at the centers of the galaxies triggered the gaseous outflows and shut down star birth by blowing out any remaining fuel. Now an analysis of 12 merging galaxies at the end of their star-birthing frenzy is showing that the stars themselves are turning out the lights on their own star-making party, with their own outflows of gaseous fuel. This happened when the universe was a little less than 7 billion years old, half its current age.

Citation: Sell et al., 2014, MNRAS 441, 3417 (Massive compact galaxies with high-velocity outflows: morphological analysis and constraints on AGN activity)

URL: <http://www.nasa.gov/content/goddard/partys-over-for-these-youthful-compact-galaxies>

NASA's Chandra Observatory Identifies Impact of Cosmic Chaos on Star Birth

The same phenomenon that causes a bumpy airplane ride, turbulence, may be the solution to a long-standing mystery about stars' birth, or the absence of it, according to a new study using data from NASA's Chandra X-ray Observatory. Galaxy clusters are the largest objects in the universe, held together by gravity. These behemoths contain hundreds or thousands of individual galaxies that are immersed in gas with temperatures of millions of degrees. This hot gas, which is the heaviest component of the galaxy clusters aside from unseen dark matter, glows brightly in X-ray light detected by Chandra. Over time, the gas in the centers of these clusters should cool enough that stars form at prodigious rates. However, this is not what astronomers have observed in many galaxy clusters. Prior studies show supermassive black holes, centered in large galaxies in the middle of galaxy clusters, pump vast quantities of energy around them in powerful jets of energetic particles that create cavities in the hot gas. Chandra, and other X-ray telescopes, have detected these giant cavities before. The latest research provides new insight into how energy can be transferred from these cavities to the surrounding gas. The interaction of the cavities with the gas may be generating turbulence, or chaotic motion, which then disperses to keep the gas hot for billions of years. "Any gas motions from the turbulence will eventually decay, releasing their energy to the gas. But the gas won't cool if turbulence is strong enough and generated often enough." The evidence for turbulence comes from Chandra data on two enormous galaxy clusters named Perseus and Virgo. By analyzing extended observation data of each cluster, the team was able to measure fluctuations in the density of the gas. This information allowed them to estimate the amount of turbulence in the gas. These results support the "feedback" model involving supermassive black holes in the centers of galaxy clusters. Gas cools and falls toward the black hole at an accelerating rate, causing the black hole to increase the output of its jets, which produce cavities and drive the turbulence in the gas. This turbulence eventually dissipates and heats the gas. While a merger between two galaxy clusters may also produce turbulence, the researchers think that outbursts from supermassive black holes are the main source of this cosmic commotion in the dense centers of many clusters.

Citation: Zhuravleva et al., 2014, Nature 515, 7525 (Turbulent heating in galaxy clusters brightest in X-rays)

URL: <https://www.nasa.gov/press/2014/october/nasa-s-chandra-observatory-identifies-impact-of-cosmic-chaos-on-star-birth/#.VW3RqkhgNAO>

NASA Rocket Experiment Finds the Universe Brighter than we Thought

A NASA sounding rocket experiment has detected a surprising surplus of infrared light in the dark space between galaxies, a diffuse cosmic glow as bright as all known galaxies combined. The glow is thought to be from orphaned stars flung out of galaxies. The findings redefine what scientists think of as galaxies. Galaxies may not have a set boundary of stars, but instead stretch out to great distances,

forming a vast, interconnected sea of stars. Observations from the Cosmic Infrared Background Experiment, or CIBER, are helping to settle a debate on the origins of this background infrared light in the universe, previously detected by NASA's Spitzer Space Telescope: Whether it comes from these streams of stripped stars too distant to be seen individually, or from the first galaxies to form in the universe. During the CIBER flights, the cameras launch into space, then snap pictures for about seven minutes before transmitting the data back to Earth. Scientists masked out bright stars and galaxies from the pictures and carefully ruled out any light coming from more local sources, such as our own Milky Way galaxy. What's left is a map showing fluctuations in the remaining infrared background light, with splotches that are much bigger than individual galaxies. The brightness of these fluctuations allows scientists to measure the total amount of background light. To the surprise of the CIBER team, the maps revealed a dramatic excess of light beyond what comes from the galaxies. The data showed that this infrared background light has a blue spectrum, which means it increases in brightness at shorter wavelengths. This is evidence the light comes from a previously undetected population of stars between galaxies. Light from the first galaxies would give a spectrum of colors that is redder than what was seen.

Citation:

Bock et al. 2014, Science, 346, 732 ("On the origin of near-infrared extragalactic background light anisotropy")

URL: <http://www.nasa.gov/press/2014/november/nasa-rocket-experiment-finds-the-universe-brighter-than-we-thought>

Astronomers Set New Galaxy Distance Record

The discovery of an exceptionally luminous galaxy more than 13 billion years in the past, using the combined data from NASA's Hubble and Spitzer space telescopes, and the Keck I 10-meter telescope at the W. M. Keck Observatory in Hawaii, enabled astronomers to push back the cosmic frontier of galaxy exploration to a time when the universe was only 5 percent of its present age of 13.8 billion years. These observations confirmed it to be the most distant galaxy currently measured, setting a new record. The galaxy existed so long ago, it appears to be only about 100 million years old. The galaxy, EGS-zs8-1, was originally identified based on its particular colors in images from Hubble and Spitzer and is one of the brightest and most massive objects in the early universe. Measuring galaxies at these extreme distances and characterizing their properties is a main goal of astronomers over the next decade. The observations see EGS-zs8-1 at a time when the universe was undergoing very important changes: the hydrogen between galaxies was transitioning from an opaque to a transparent state. These new Hubble, Spitzer, and Keck observations together also pose new questions. They confirm that massive galaxies already existed early in the history of the universe, but that their physical properties were very different from galaxies seen around us today. Astronomers now have very strong evidence that the peculiar colors of early galaxies seen in the Spitzer images originate from a very rapid formation of massive, young stars, which interacted with the primordial gas in these galaxies.

Citation:

Oesch et al., 2014, ApJ, 786, 19 ("The Most Luminous $z \sim 9-10$ Galaxy Candidates Yet Found: The Luminosity Function, Cosmic Star-formation Rate, and the First Mass Density Estimate at 500 Myr")

URL: <http://www.spitzer.caltech.edu/news/1760-ssc2015-01-Astronomers-Set-a-New-Galaxy-Distance-Record>

NASA'S SOFIA Finds Missing Link Between Supernovae and Planet Formation

Using NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA), an international scientific team discovered that supernovae are capable of producing a substantial amount of the material from

which planets like Earth can form. “Our observations reveal a particular cloud produced by a supernova explosion 10,000 years ago contains enough dust to make 7,000 Earths.” The research team used SOFIA’s airborne telescope and the Faint Object InfraRed Camera for the SOFIA Telescope, FORCAST, to take detailed infrared images of an interstellar dust cloud known as supernova remnant Sagittarius A East, or SNR Sgr A East. The team used SOFIA data to estimate the total mass of dust in the cloud from the intensity of its emission. The investigation required measurements at long infrared wavelengths in order to peer through intervening interstellar clouds and detect the radiation emitted by the supernova dust. Astronomers already had evidence that a supernova’s outward-moving shock wave can produce significant amounts of dust. Until now, a key question was whether the new soot- and sand-like dust particles would survive the subsequent inward “rebound” shock wave generated when the first, outward-moving shock wave collides with surrounding interstellar gas and dust. “The dust survived the later onslaught of shock waves from the supernova explosion, and is now flowing into the interstellar medium where it can become part of the ‘seed material’ for new stars and planets. These results also reveal the possibility that the vast amount of dust observed in distant young galaxies may have been made by supernova explosions of early massive stars, as no other known mechanism could have produced nearly as much dust.

Citation:

Lau et al., Science, 348, 413 (“Old supernova dust factory revealed at the Galactic center”)

URL: <http://www.nasa.gov/press/2015/march/nasa-s-sofia-finds-missing-link-between-supernovae-and-planet-formation>

Multiyear Performance Goal: 1.6.4: *Demonstrate progress in discovering and studying planets around other stars and exploring whether they could harbor life*

Annual Performance Indicator: FY 2015 AS-15-6: *Demonstrate planned progress in discovering and studying planets around other stars and exploring whether they could harbor life*

The NASA Astrophysics Subcommittee graded the Division’s progress in this area to be **[rating here]**.

Summary: *[Summary of this section here]*

[\(From 2014, as an example\)](#)

[Summary: Dramatic progress in our understanding of the census and properties of exoplanets continues, highlighted by many new discoveries from NASA’s Kepler mission. Furthermore, observations using the Hubble and Spitzer Space Telescopes continue to contribute to our understanding of exoplanet properties, while discoveries from ground-based surveys demonstrate NASA’s broad and fruitful exoplanet portfolio. Finally, citizen science discoveries demonstrate the impact of NASA’s outreach efforts.](#)

[Kepler has dramatically increased the total number of known planets while simultaneously broadening the diversity of known planetary systems in our Galaxy. This past year, Kepler announced an additional 461 new planet candidates, bringing the total Kepler haul to 2,700 total planets. The Kepler sample continues to expand to include ever-smaller planets, including several planets with sizes smaller than Mercury. Kepler continued its progress toward its primary mission objective of measuring the frequency of habitable planets orbiting sun-like stars. In particular, four of the new planet candidates are less than twice the size of Earth and orbit in their sun’s “habitable zone,” the region in the planetary system where liquid water might exist on the surface of a planet. Kepler also discovered two new planetary systems that include three super-Earth-size planets in the habitable zone. Overall, these are the smallest such planets in the habitable zone discovered so far. Kepler has also quantified the frequency of potentially habitable planets around smaller stars for the first time. Kepler Mission results resulted in 219 peer-reviewed articles on exoplanets, and 188 peer-reviewed articles on stellar astrophysics \(January 2012 – July 2013\).](#)

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[Of course, NASA's progress toward the understanding of exoplanets systems extends well beyond Kepler. NASA-funded astronomers using ground-based telescopes have, for the first time, spotted planets orbiting sun-like stars in a crowded cluster of stars. The findings offer the best evidence yet planets can sprout up in dense stellar environments. Data from the Hubble Space Telescope has revealed a cobalt blue color for one planet and uncovered a rogue orbit for another, whereas data from the Spitzer Space Telescope has uncovered evidence of dramatic weather on "Hot Jupiters." Finally, a joint effort of amateur astronomers and scientists using Kepler data has led to the first reported case of a planet orbiting a double-star that, in turn, is orbited by a second distant pair of stars.](#)

[The items featured in this section are:](#)

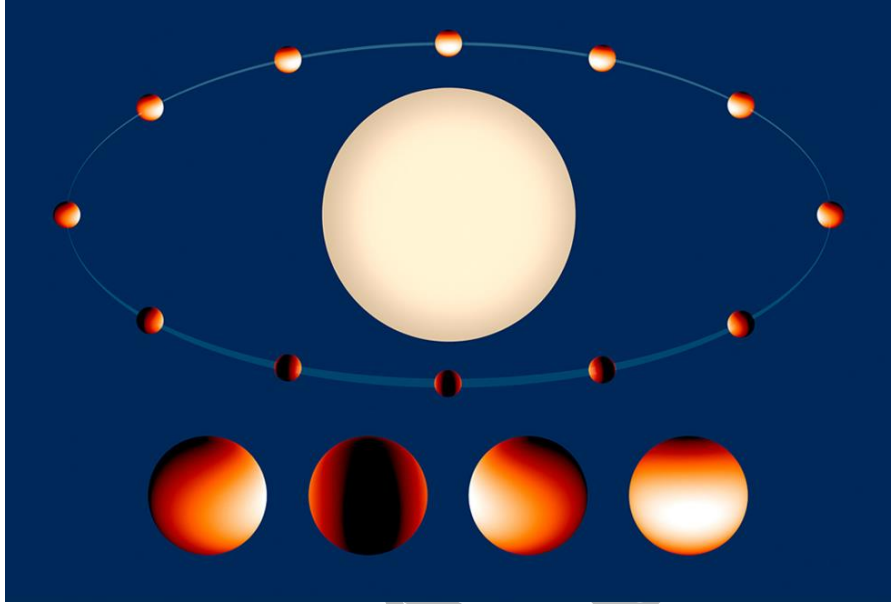
- [NASA's Kepler mission dramatically broadens the exoplanet census: many new planets, including sub-Mercury-sized planets and the smallest habitable-zone planets detected to date.](#)
- [First Planets Found Around Sun-Like Stars in a Cluster](#)
- [Citizen Scientists Discover Four-Star Planet with NASA Kepler](#)
- [Characterizing other worlds: Hubble Finds a Cobalt Blue Planet and Spitzer Finds Big Weather on Hot Jupiters](#)
- [NASA's Hubble Reveals Rogue Planetary Orbit For Fomalhaut b](#)

NASA's Kepler Marks 1,000th Exoplanet Discovery, Uncovers More Small Worlds in Habitable Zones.

NASA's Kepler Space Telescope continuously monitored more than 150,000 stars beyond our solar system, and to date has offered scientists an assortment of more than 4,000 candidate planets for further study -- the 1,000th of which was recently verified. Using Kepler data, scientists reached this millenary milestone after validating that eight more candidates spotted by the planet-hunting telescope are, in fact, planets. The Kepler team also has added another 554 candidates to the roll of potential planets, six of which are near-Earth-size and orbit in the habitable zone of stars similar to our Sun. Three of the newly-validated planets are located in their distant suns' habitable zone, the range of distances from the host star where liquid water might exist on the surface of an orbiting planet. Of the three, two are likely made of rock, like Earth. Two of the newly validated planets, **Kepler-438b** and **Kepler-442b**, are less than 1.5 times the diameter of Earth. Kepler-438b, 475 light-years away, is 12 percent bigger than Earth and orbits its star once every 35.2 days. Kepler-442b, 1,100 light-years away, is 33 percent bigger than Earth and orbits its star once every 112 days. Both Kepler-438b and Kepler-442b orbit stars smaller and cooler than our Sun, making the habitable zone closer to their parent star, in the direction of the constellation Lyra.

Citation: Guillermo et al., 2015, ApJ 800, 24 ("Validation of 12 Small Kepler Transiting Planets in the Habitable Zone")

URL: <http://www.nasa.gov/press/2015/january/nasa-s-kepler-marks-1000th-exoplanet-discovery-uncovers-more-small-worlds-in>



NASA's Hubble Maps the Temperature and Water Vapor on an Extreme Exoplanet

A team of scientists using NASA's HST has made the most detailed global map yet of the glow from a turbulent planet outside our solar system, revealing its secrets of air temperatures & water vapor. Hubble observations show the exoplanet, WASP-43b, is no place to call home. It is a world of extremes, where seething winds howl at the speed of sound from a 3,000-degree-Fahrenheit "day" side, hot enough to melt steel, to a pitch-black "night" side with plunging temperatures below 1,000 degrees Fahrenheit. Astronomers have mapped the temperatures at different layers of the planet's atmosphere and traced the amount and distribution of water vapor. First discovered in 2011, WASP-43b is located 260 light-years away. The planet is too distant to be photographed, but because its orbit is observed edge-on to Earth, astronomers detected it by observing regular dips in the light of its parent star as the planet passes in front of it. As a hot ball of predominantly hydrogen gas, there are no surface features on the planet, such as oceans or continents that can be used to track its rotation. Only the severe temperature difference between the day and night sides can be used by a remote observer to mark the passage of a day on this world. The planet is about the same size as Jupiter, but is nearly twice as dense. The planet is so close to its orange dwarf host star that it completes an orbit in just 19 hours. The planet also is gravitationally locked so that it keeps one hemisphere facing the star. This was the first time astronomers were able to observe three complete rotations of any planet, which occurred during a span of four days. Scientists combined two previous methods of analyzing exoplanets in an unprecedented technique to study the atmosphere of WASP-43b. They used spectroscopy, dividing the planet's light into its component colors, to determine the amount of water and the temperatures of the atmosphere. By observing the planet's rotation, the astronomers also were able to precisely measure how the water is distributed at different longitudes. In order to understand how giant planets form astronomers want to know how enriched they are in different elements. The team found that WASP-43b has about the same amount of water as we would expect for an object with the same chemical composition as our Sun, shedding light on the fundamentals about how the planet formed.

Citation: Kreidberg et al., 2014, ApJL, 793, L27 ("A Precise Water Abundance Measurement for the Hot Jupiter WASP-43b")

url: <http://www.nasa.gov/press/2014/october/nasas-hubble-maps-the-temperature-and-water-vapor-on-an-extreme-exoplanet>

NASA's Hubble Sees a "Behemoth" Bleeding Atmosphere Around a Warm Exoplanet

Astronomers using NASA's Hubble Space Telescope have discovered an immense cloud of hydrogen dubbed "The Behemoth" bleeding from a planet, named GJ 436b, orbiting a nearby star. The enormous, comet-like feature is about 50 times the size of the parent star. The hydrogen is evaporating from a warm, Neptune-sized planet, due to extreme radiation from the star. This phenomenon has never been seen around an exoplanet so small. It may offer clues to how other planets with hydrogen-enveloped atmospheres could have their outer layers evaporated by their parent star, leaving behind solid, rocky cores. Hot, rocky planets such as these, known as Hot-Super Earths, and roughly the size of Earth, were discovered by the Convection Rotation and Planetary Transits (CoRoT) and NASA's Kepler space telescope. Hot Super-Earths could be the remnants of more massive planets that completely lost their thick, gaseous atmospheres to the same type of evaporation. Evaporation such as this may have happened in the earlier stages of our own solar system, when the Earth had a hydrogen-rich atmosphere that dissipated over 100 to 500 million years. If so, the Earth may previously have sported a comet-like tail.

Citation: Ehrenreich et al., 2015, Nature, 522, 459 (A giant comet-like cloud of hydrogen escaping the warm Neptune-mass exoplanet GJ 436b)

url: <http://www.nasa.gov/feature/goddard/hubble-sees-a-behemoth-bleeding-atmosphere-around-a-warm-exoplanet>

Mars-size Planet Orbits Distant Star

Researchers using NASA's Kepler mission data have measured the mass of a Mars-size exoplanet that is about one tenth the mass of Earth. Called Kepler-138b, it is the first exoplanet smaller than Earth to have both its mass and size measured. This significantly extends the range of planets with measured densities. To determine a planet's mass, astronomers typically measure the minuscule movement of the star caused by the gravitational tug of an orbiting planet. For planets the mass of Earth detecting such a tiny tug is extraordinarily challenging with current technology. Fortunately, when a star hosts multiple planets that orbit closely together, scientists have developed another way to get at the planets' masses. A team of astronomers was able to measure the mass of all three planets in this system by precisely observing the times each planet passed in front of, or transited, the star Kepler-138. Each time a planet transits a star it blocks a small fraction of the star's light, allowing astronomers to measure the size of the planet. This is how the Kepler spacecraft has detected thousands of planets around other stars. By measuring both the mass and size of an exoplanet, scientists can calculate the density and infer the bulk composition to determine if a planet is predominantly made of rock, water or gas. Tiny Kepler-138b's density is consistent with a rocky composition like Earth or Mars, but further observations are needed before astronomers can definitively say that it is a rocky world. Kepler-138b is the innermost of three planets that orbit Kepler-138, a star less than half the size of our sun and roughly 30 percent cooler. The Kepler-138 system is located about 200 light-years from Earth in the direction of the constellation Lyra. The outer two planets, Kepler-138c and Kepler-138d, are approximately the size of Earth. Kepler-138c is likely to be rocky, whereas Kepler-138d is less dense and cannot be made of the same mix of material as Earth. All three planets orbit too close to their star for liquid water to exist on the surface and support life, as we know it.

Citation: Jontof-Hutter, D., et al. 2015, Nature, 522, 321-323 (The mass of the Mars-sized exoplanet Kepler-138 b from transit timing)

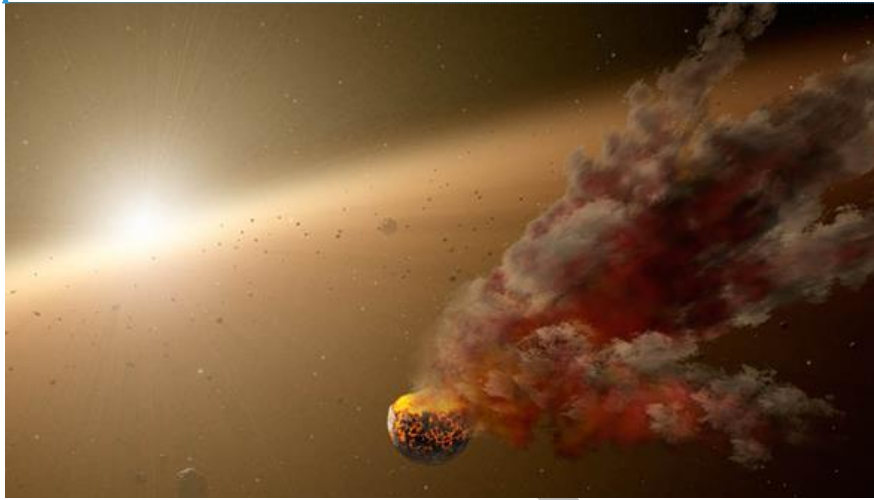
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[NASA's Spitzer Telescope Witnesses Asteroid Smashup](#)

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[NASA's Spitzer Space Telescope has spotted an eruption of dust around a young star, possibly the result of a smashup between large asteroids. This type of collision can eventually lead to the formation of planets. Scientists had been regularly tracking the star, called NGC 2547-ID8, when it surged with a huge amount of fresh dust between August 2012 and January 2013. While dusty aftermaths of suspected asteroid collisions have been observed by Spitzer before, this is the first time scientists have collected data before and after a planetary system smashup. The viewing offers a glimpse into the violent process of making rocky planets like ours. In the new study, Spitzer set its heat-seeking infrared eyes on the dusty star NGC 2547-ID8, which is about 35 million years old and lies 1,200 light-years away in the Vela constellation. Previous observations had already recorded variations in the amount of dust around the star, hinting at possible ongoing asteroid collisions. In hope of witnessing an even larger impact, which is a key step in the birth of a terrestrial planet, the astronomers turned to Spitzer to observe the star regularly. Beginning in May 2012, the telescope began watching the star, sometimes daily. A dramatic change in the star came during a time when Spitzer had to point away from NGC 2547-ID8 because our sun was in the way. When Spitzer started observing the star again five months later, the team was shocked by the data they received. A very thick cloud of dusty debris now orbits the star in the zone where rocky planets form. As the scientists observe the star system, the infrared signal from this cloud varies based on what is visible from Earth. For example, when the elongated cloud is facing us, more of its surface area is exposed and the signal is greater. When the head or the tail of the cloud is in view, less infrared light is observed. By studying the infrared oscillations, the team is gathering first-of-its-kind data on the detailed process and outcome of collisions that create rocky planets like Earth. The team is continuing to keep an eye on the star with Spitzer. They will see how long the elevated dust levels persist, which will help them calculate how often such events happen around this and other stars. And they might see another smashup while Spitzer looks on.](#)

[Citation: Meng, H., et al. 2015, ApJ, 805, 77 \(PLANETARY COLLISIONS OUTSIDE THE SOLAR SYSTEM: TIME DOMAIN CHARACTERIZATION OF EXTREME DEBRIS DISKS\)](#)

[url: http://www.spitzer.caltech.edu/news/1696-ssc2014-06-NASA-s-Spitzer-Telescope-Witnesses-Asteroid-Smashup](http://www.spitzer.caltech.edu/news/1696-ssc2014-06-NASA-s-Spitzer-Telescope-Witnesses-Asteroid-Smashup)

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Can Planets Be Rejuvenated Around Dead Stars?

For a planet, this would be like a day at the spa. After years of growing old, a massive planet could, in theory, brighten up with a radiant, youthful glow. Rejuvenated planets, as they are nicknamed, are only hypothetical. But new research from NASA's Spitzer Space Telescope has identified one such candidate, seemingly looking billions of years younger than its actual age. How might a planet reclaim the essence of its youth? Years ago, astronomers predicted that some massive, Jupiter-like planets might accumulate mass from their dying stars. As stars like our sun age, they puff up into red giants and then gradually lose about half or more of their mass, shrinking into skeletons of stars, called white dwarfs. The dying stars blow winds of material outward that could fall onto giant planets that might be orbiting in the outer reaches of the star system. Thus, a giant planet might swell in mass, and heat up due to friction felt by the falling material. This older planet, having cooled off over billions of years, would once again radiate a warm, infrared glow. The new study describes a dead star, or white dwarf, called PG 0010+280. An undergraduate student serendipitously discovered unexpected infrared light around this star while searching through data from NASA's Wide-field Infrared Survey Explorer, or WISE. Follow-up research led them to Spitzer observations of the star, taken back in 2006, which also showed the excess of infrared light. At first, the team thought the extra infrared light was probably coming from a disk of material around the white dwarf. In the last decade or so, more and more disks around these dead stars have been discovered -- around 40 so far. The disks are thought to have formed when asteroids wandered too close to the white dwarfs, becoming chewed up by the white dwarfs' intense, shearing gravitational forces. Other evidence for white dwarfs shredding asteroids comes from observations of the elements in white dwarfs. White dwarfs should contain only hydrogen and helium in their atmospheres, but researchers have found signs of heavier elements -- such as oxygen, magnesium, silicon and iron -- in about 100 systems to date. The elements are thought to be leftover bits of crushed asteroids, polluting the white dwarf atmospheres. But the Spitzer data for the white dwarf PG 0010+280 did not fit well with models for asteroid disks, leading the team to look at other possibilities. Perhaps the infrared light is coming from a companion small "failed" star, called a brown dwarf -- or more intriguingly, from a rejuvenated planet.

Citation: Xu, S. et al. 2015, *Astrophysical Journal*, 806, L5 (A YOUNG WHITE DWARF WITH AN INFRARED EXCESS)

url: <http://www.spitzer.caltech.edu/news/1772-feature15-07-Can-Planets-Be-Rejuvenated-Around-Dead-Stars>

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