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

ASTROPHYSICS

Over the past year, NASA's Astrophysics Division has continued its primary goal of addressing its three main science questions: How does the Universe work? How did we get here? Are we alone? These are some of humanity's oldest and most profound questions, and together they define an incredible range of astrophysical inquiry. Combined with the support of many ground-based observatories, and relying on the dedication and hard work of thousands of astronomers, over the past year NASA Astrophysics missions have continued to make incredible progress in answering these questions. This progress has come in the form of expansive surveys, systematic and exquisitely precise experiments, and startling and unexpected discoveries, all of which have provided humanity with a better understanding of the Universe we live in.

NASA's mission portfolio spans an incredible range of size, scope, and technologies. These missions employ the full range of astronomical messengers, from the highest energy photons all the way through the electromagnetic spectrum, as well as high-energy subatomic particles. Such a broad range of methodologies is needed to explore the full range and diversity of astrophysical objects and phenomenon, from observations of the smallest planets orbiting the smallest stars, to measurements of the geometry of the University itself.

NASA's achievements in astrophysics over the past year are as varied as they are impressive. Planck has made the most precise measurements to date of the geometry and inventory of the universe, measurements at a level of exquisite accuracy that would have been inconceivable only a few decades ago. NuSTAR is using its unprecedented sensitivity to high-energy X-rays to explore some most extreme objects in the universe: supermassive black holes thought to be located in the centers of nearly every galaxy in the universe, including our own. The insights from NuSTAR have been aided and abetted by observations from Chandra, XMM-Newton, and RXTE, all of which have provided insight into how these enigmatic objects feed and grow.

A key strength of NASA's portfolio is its broad wavelength sensitivity. This is essential for peering back in time, and for understand the panchromatic emission from galaxies and their central supermassive black holes. By combining the power of the great observatories (Hubble, Chandra, and Spitzer), and with the help of NASA-funded ground-based observatories, we are peering all the way back to beginning of the Universe, to the earliest stages of the assembly of the structure in the universe. We are reaching ever further back in time, identifying some of the first galaxies, thereby enabling us to reconstruct the story of how the universe has evolved since the Big Bang, ultimately producing the bewildering menagerie of galaxies we see in the sky today.

We need not launch observatories into space to avoid much of the delterious effects of the Earth's atmosphere: NASA's balloon and sounding rocket programs, as well as the SOFIA observatory, allow us to obtain measurements that would be impossible from the ground, without entering into orbit. Indeed, the CIBER experiment has shown that the smooth "infrared background light" of the Universe is brighter than we thought, causing us to rethink the origin of this enigmatic component of the night sky.

Finally, NASA is at the forefront of one of the most exciting revolutions in astronomy: the cataloging and characterization of planets orbiting other stars. Kepler continues to amaze: its compendium of confirmed planets now numbers over a thousand systems. Furthermore, Kepler continues to expand the range of known planet properties with the discovery of a planet with mass less than ten times that of the Earth. Simultaneously, a novel use of the Spitzer satellite is enabling the first measurement of the Galactic distribution of exoplanets. Finally, heroic observations with Hubble are providing some of the most detailed portraits of individual exoplanets to date.

Many of the achievements enabled by NASA's Astrophysics missions are only possible because they enable the study of the Universe well above the deleterious effects of the Earth's atmosphere, in the near-vacuum of space that is essentially transparent to almost all forms of radiation. However, exploiting this opportunity requires sustained and focused development of technology, including specialized detectors and electronics that can operate efficiently and reliably under conditions harsher and more varied than found anywhere on Earth. These challenges pose special technical problems that, once solved, lead to more broadly applicable technologies that benefit both the commercial and defense sectors.

Major Astrophysics milestones of the last year include:

- The Planck Satellite has provided the most accurate measurements to date of the geometry and constituents of our Universe, providing the benchmark measurements of these properties that will be the standard for decades to come.
- Chandra, NuSTAR, XMM-Newton, and RXTE have used the highest energy radiation from black holes to dramatically improve our understanding of how these enigmatic objects feed, and how they eject matter as a by-product of their feeding.
- Hubble, Chandra, Spitzer, and Keck have allowed us to peer back in time to study the earliest collapsed systems, allowing us to identify galaxies from when the Universe was only a few percent of its current age, and identify a previously unknown population of young, massive, compact galaxies whose star-making phase ends early in the age of the universe.
- Data from the sounding rocket experiment CIBER has found that the smooth, infrared background light in the Universe is brighter than we thought, and indicates that this light likely comes from streams of stripped stars too distant to be seen individually.
- Kepler has increased its planet haul to over 1000 confirmed planetary systems, and measured the mass of the smallest planet to date: Kepler-138b, with a mass only one-tenth that of the Earth, or roughly the mass of Mars.
- Astronomers using Hubble have provided unprecedented insight into the detailed properties of exoplanets, from measuring the phase-resolved change in the temperature and water vapor content of hot, Jupiter-sized planet as it orbits its parent star, to detection of a immense cloud of hydrogen escaping from a Neptune-sized planet orbiting a nearby star.
- Spitzer measurements of a gravitational microlensing event containing a planetary perturbation, when compared with observations of the same event as seen from Earth, have provided one of the first measurements of the parallax and thus distance to a planetary system outside of our local solar neighborhood, thus paving the way for a measure of the Galactic distribution of exoplanets.

~~*[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*~~ GREEN~~*]*~~.

Summary: NASA missions continue to advance our knowledge of the underlying laws of nature involved in the birth of the universe, the properties of dark matter and dark energy that govern its evolution since the big bang, and the behavior of matter in the extreme gravity of black holes. New data released by the

Planck satellite represent the latest measurements of the cosmic microwave background, providing the best images yet of the universe when it was just 0.003 % of its current age. Although dark energy and dark matter completely dominate the composition of the universe today, their origin remains a profound mystery in astronomy that is, at best, incompletely understood by physicists. NASA has advanced investigations of the nature of dark matter through its gravitational influence, particularly the bending of light originally predicted by Einstein. Finally researchers using NASA observatories are investigating the properties of black holes, ranging in known sizes from a few times the mass of our sun to monster supermassive black holes found in the centers of galaxies, by studying their radiation across the electromagnetic spectrum. Such supermassive black holes can be spectacular; in fact the most luminous known galaxy, reported by the WISE satellite this year to be shining with the light of 300 trillion suns, appears to be lit up from a supermassive black hole gorging itself on gas falling in from the host galaxy [Tsai et al. 2015]. The fact that the light from this galaxy is 12.5 billion years old – about 90 % of the age of the universe - testifies that supermassive black holes play an integral role in how galaxies form and evolve throughout cosmic history.

Tsai, C.-W., et al., The Astrophysical Journal, 805, 15 (2015) – 4 citations

The items featured in this section are:

- Latest measurements of the early universe with the Planck satellite
- New measurements on the properties of dark matter by observing how its gravity bends light using data from Hubble and Chandra
- Properties of supermassive black holes from NuSTAR and Chandra

Planck Mission Explores the History of Our Universe

New data released by Planck, a European Space Agency mission in which NASA played a key role, are refining what we know about our Universe from precise measurements of the cosmic microwave background radiation. The data enable more precise measurements of matter, including dark matter, and how it is clumped together. One cosmic property appears to have changed as a result of the new 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 contains more than 1,500 images of clusters of galaxies, the largest catalog of this type ever made. In one of the first-of-its-kind efforts, the Planck team calculated the masses of these clusters by observing how the clusters bend background microwave light. The results refine mass estimates of galaxy clusters, which in turn improve our understanding of dark matter and dark energy.

Planck Collaboration, 2015, "Planck 2015 Results. I. Overview of Products and Scientific Results", arXiv 1502.01582 – 41 citations.

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

~~*[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 "megaflare" 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]~~GREEN.

Summary: Over the past year, astronomers used NASA space missions to obtain unprecedented observations that shed new light on the nature of planets, stars, and galaxies in the Universe. In a true example of Carl Sagan's famous quote, "We are Made of Star Stuff", new infrared capabilities from NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) showed that the amount of dust generated through the process of stellar death is enough to make thousands of Earth like planets. The sites of all star formation, star clusters, were also the target of new multi-wavelength observations by the Hubble Space Telescope. In one study, astronomers used ultraviolet imaging to uncover newborn stellar remnants - white dwarfs - and showed that the clock of stellar evolution can be used to directly measure the timescale of gravitational relaxation. White dwarfs were also the target of a remarkable observation by the Fermi/Large Area Telescope. For the first time, researchers observed gamma ray emission from the surfaces of white dwarfs undergoing stellar eruptions (novae). Astronomers now believe that these common outbursts always produce gamma rays, the most energetic form of light. Numerous other studies by NASA missions contributed to a breakthrough year of scientific discoveries in our Milky Way galaxy and nearby galaxies.

Looking beyond our Galaxy, NASA's space missions continued to push studies of the distant Universe to new extremes. Both the Spitzer and Hubble telescopes teamed up with the 10-meter ground-based Keck Observatory to see the light from a galaxy that was emitted when the Universe was just 5% of its current age. EGS-zs8-1 is now the record holder for the most distant galaxy known in the Universe, and gives us a glimpse of what the Universe's earliest conditions were. Astronomers also combined the power of these telescopes with natural cosmic lenses called galaxy clusters. The clusters produce a warp in space-time, and the light from distant background objects can be magnified and multiply lensed as it passes through the cluster. In one example, astronomers used Hubble to find a galaxy that was intrinsically much smaller and fainter than what they could see in the absence of the lens. The observations shed light on how galaxies grow from small objects in the early Universe to the beautiful large and organized systems we see today. Other observations of galaxy clusters by the Chandra X-ray Observatory showed that the growth of massive galaxies containing supermassive black holes can be halted in some cases. The effect is caused by the cycling of gas with different temperatures from the outer halos to the inner regions.

This summary contains only a few examples of the exciting science from NASA's Astrophysics program as it relates to the origin and evolution of planets, stars and galaxies in the Universe.
~~*[Summary of this section here]*~~

Probing the formation and evolution of the earliest galaxies

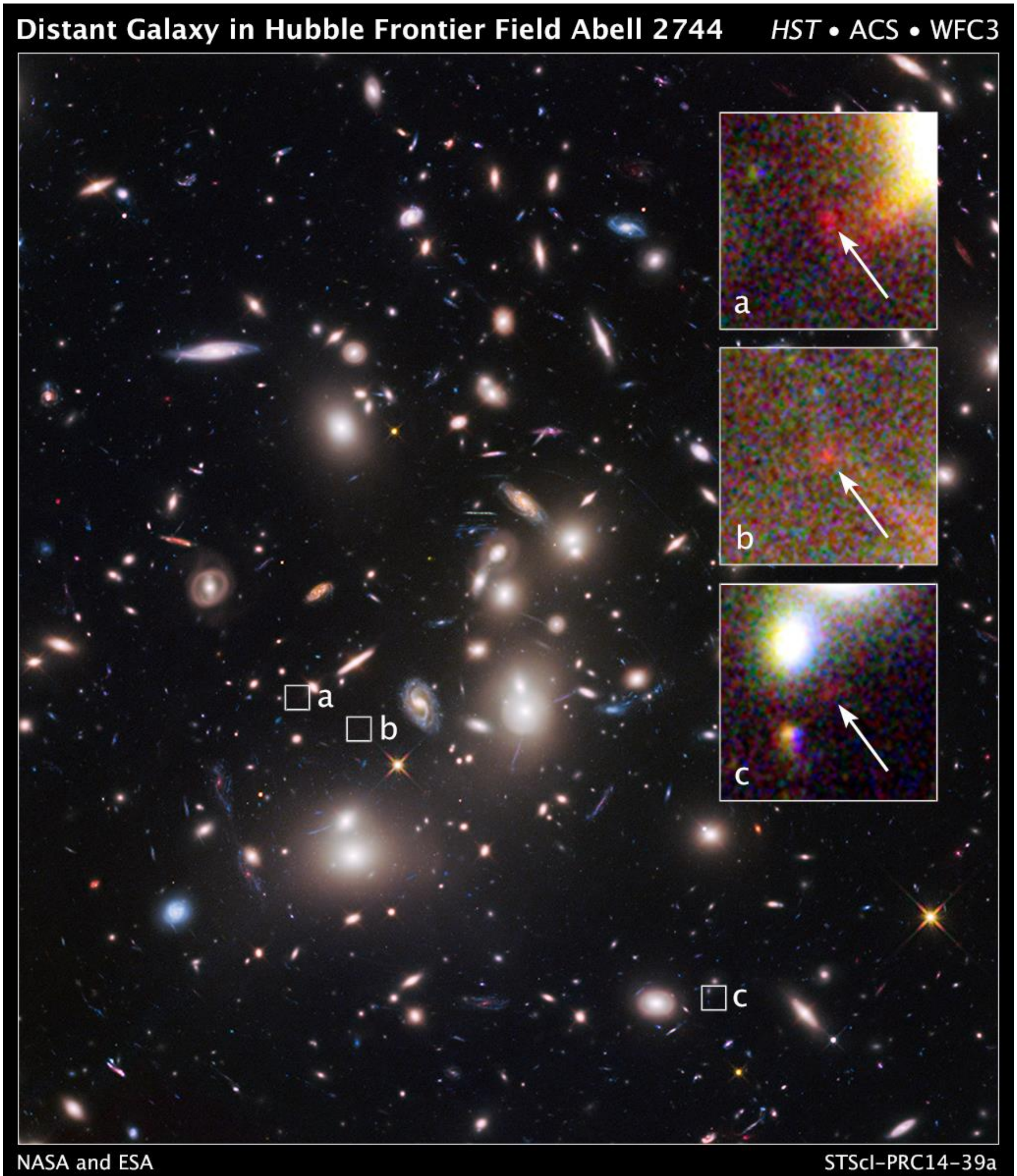
Discovering extremely distant galaxies and characterizing their properties is a major goal in astrophysics over the next decade. NASA's telescopes allow us to view these objects as they were when the Universe was extremely young, and these observations provide crucial insights into the physics of galaxy formation and evolution. For example, NASA's Hubble and Spitzer space telescopes were used in combination with supporting observations from the Keck telescope to set a new galaxy distance record (Oesch et al. 2014). These observations pushed back the frontier of galaxy exploration to a time when the Universe was only 5 percent of its present age of 13.8 billion years. This allowed astronomers to view this galaxy as it was when it was only about 100 million years old. Another study took advantage of the magnifying effect of a mammoth cluster of galaxies to discover one of the smallest and faintest distant galaxies ever seen by astronomers, seen when the Universe was only 500 million years old (Zitrin et al. 2014). The tiny galaxy was detected as part of the Frontier Fields program, an ambitious three-year effort, begun in 2013, that teams Hubble with NASA's other Great Observatories — the Spitzer Space Telescope and the Chandra X-ray Observatory — to probe the early universe by studying large galaxy clusters. Massive clusters have such strong gravitational fields that they can bend light from galaxies far behind them, an effect called gravitational lensing. This makes distant galaxies appear brighter and larger, allowing astronomers to study tiny, faint galaxies in the young Universe that would otherwise be beyond the reach of our existing telescopes. This helps us understand how the physical processes important for shaping galaxy formation may have been different at these early epochs. New research has also made progress in illuminating how and why young galaxies stop making stars, and transition from gas rich, rapidly star forming spiral galaxies into “red and dead” galaxies composed only of aging stars (Sell et al. 2014). Researchers using the Hubble Space Telescope and Chandra X-ray Observatory have uncovered young, massive, compact galaxies whose star-making phase is ending early. This new study reveals that galaxy mergers may be able to drive gas to such high densities that a bonanza of intense star formation results. 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.

Citation:

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

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

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



Zitrin et al. 2014, ApJ, 793, 12 (“A Geometrically Supported z ~ 10 Candidate Multiply Imaged by the Hubble Frontier Fields Cluster A2744”)

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 heftiest 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/#.VW3RqkhgNAQ

NASA Rocket Experiment Finds the Universe Brighter than we t~~T~~hought

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*

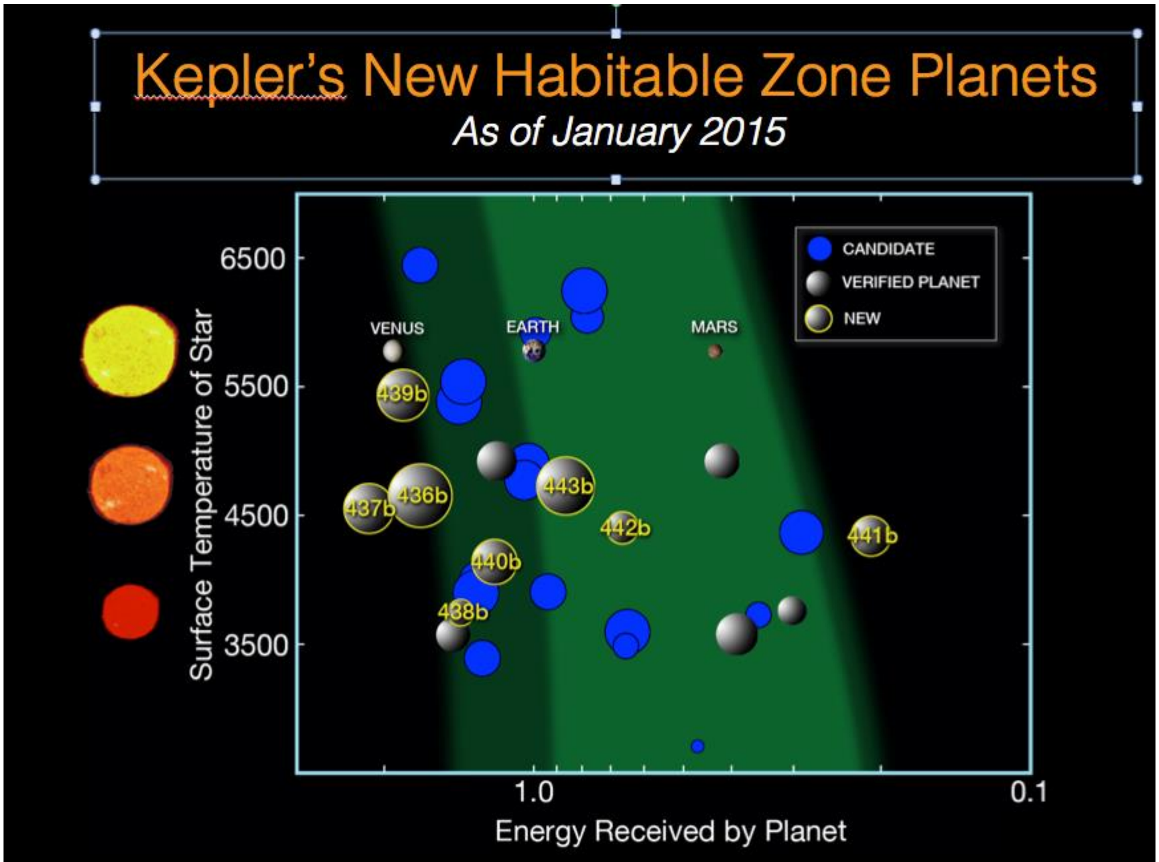
The NASA Astrophysics Subcommittee graded the Division's progress in this area to be ~~**[rating here]**~~ **GREEN.**

Summary: *[Summary of this section here]*

To do.

The items featured in this section are:

- NASA's Kepler mission reached a milestone of 1,000 confirmed planets, discovered two new Earth-sized planets in the habitable zones of their stars, and discovered the first planet smaller than the Earth with both a measured radius and mass, the Mars-mass exoplanet Kepler-138b.
- The Hubble Space Telescope measured the variations in the temperature and water abundance of the bizarre world WASP-43b as it orbits its parent star over the course of its 19 hour orbital period, and detected an enormous cloud of hydrogen escaping from the warm, Neptune-sized planet GJ 436b.
- A unique application of NASA's Spitzer Space Telescope, when combined with data from a telescope on the ground, has allowed it to find and pinpoint the location of a remote gas planet about 13,000 light-years away, making it one of the most distant planets known.



NASA's Kepler Marks 1,000th Exoplanet Discovery, Uncovers More Small Worlds in Habitable Zones, and discovers a Mars-size Planet Orbits Distant Star

Kepler made significant progress this year towards its objective of measuring eta-Earth. The mission continues to identify new transiting planets in the prime mission field and released the first catalog based on four full years of data. Over 500 new planet candidates were added to the public archive bringing the total count to more than 4,000. The catalog includes the first terrestrial-size planets orbiting in the habitable zone of G-type stars. Revised estimates of eta-Earth for M-type stars indicate that the closest potentially habitable planet is likely to be within 5pc of the Sun. Over 1,000 of Kepler's candidates have now been confirmed either by dynamical measurements or statistical validation. Among these are twelve newly verified habitable zone planets. Kepler-438b is the first confirmation of an Earth-size (1.1 R_e) planet in the habitable zone of an M-type star. Dynamical analyses of radial velocity and transit timing variation measurements have yielded mass determinations of terrestrial-sized exoplanets resulting in valuable additions to the exoplanet mass-radius diagram in a region of parameter space that was previously void of measurements. In particular, Kepler-138b is a Mars-size exoplanet that is about one tenth the mass of Earth as determined from transit timing analysis. The mass-radius diagram is yielding information about compositional diversity of terrestrial-sized planets. The K2 mission is healthy and has reported on the confirmation of over 20 planets discovered in its first observing campaign, including super-earths orbiting stars within 50 pc.

Relevant Papers:

Planetary Candidates Observed by Kepler. VI. Planet Sample from Q1--Q16 (47 Months)
Mullally, F. et al. 2015 ApJS 217 31

A Nearby M Star with Three Transiting Super-Earths Discovered by K2
Crossfield, I. et al. 2015 ApJ 804 10

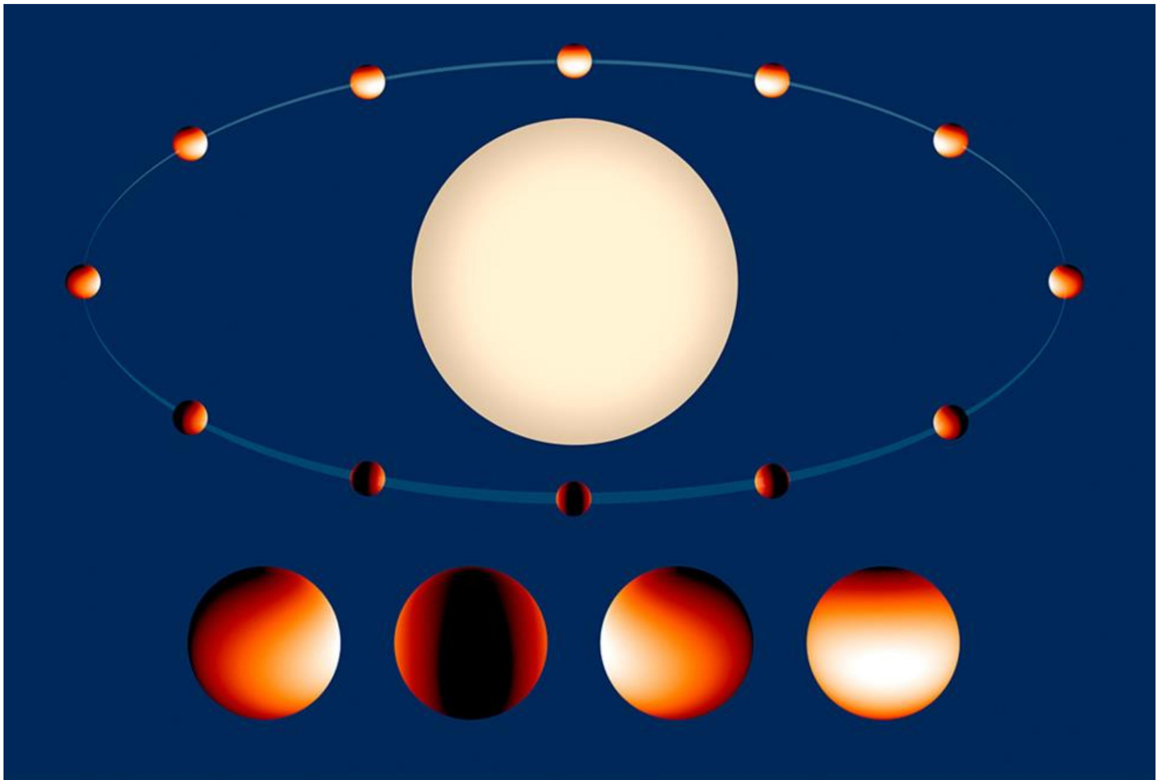
NASA's Kepler Space Telescope continuously monitored more than 150,000 stars beyond our solar system, and to date has offered scientists an assortment of more than 4,000 candidate planets for further study -- the 1,000th of which was recently verified. Using Kepler data, scientists reached this millenary 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 Torres et al., 2015, ApJ 800, 9924 ("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

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

URL: http://planetquest.jpl.nasa.gov/news/200



Characterizing Extreme Worlds with Hubble: NASA's Hubble MapsMapping the Temperature and Water Vapor on an Extreme Exoplanet, and Discovering a "Behemoth" Bleeding Atmosphere Around a Warm Neptune

The Hubble Space telescope continues to make unprecedented measurements allowing us to characterize extreme worlds.

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. Scientists combined two previous methods of analyzing exoplanets in an unprecedented technique to study the atmosphere of the bizzare planet WASP-43b. 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. Astronomers have By combing these methods, they were able to map 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.

Also using the Hubble Space Telescope, scientists have discovered an immense cloud of hydrogen dubbed bleeding from the GJ 436b. 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. 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: Kreidberg et al., 2014, ApJL, 793, L27 ("A Precise Water Abundance Measurement for the Hot Jupiter WASP-43b"

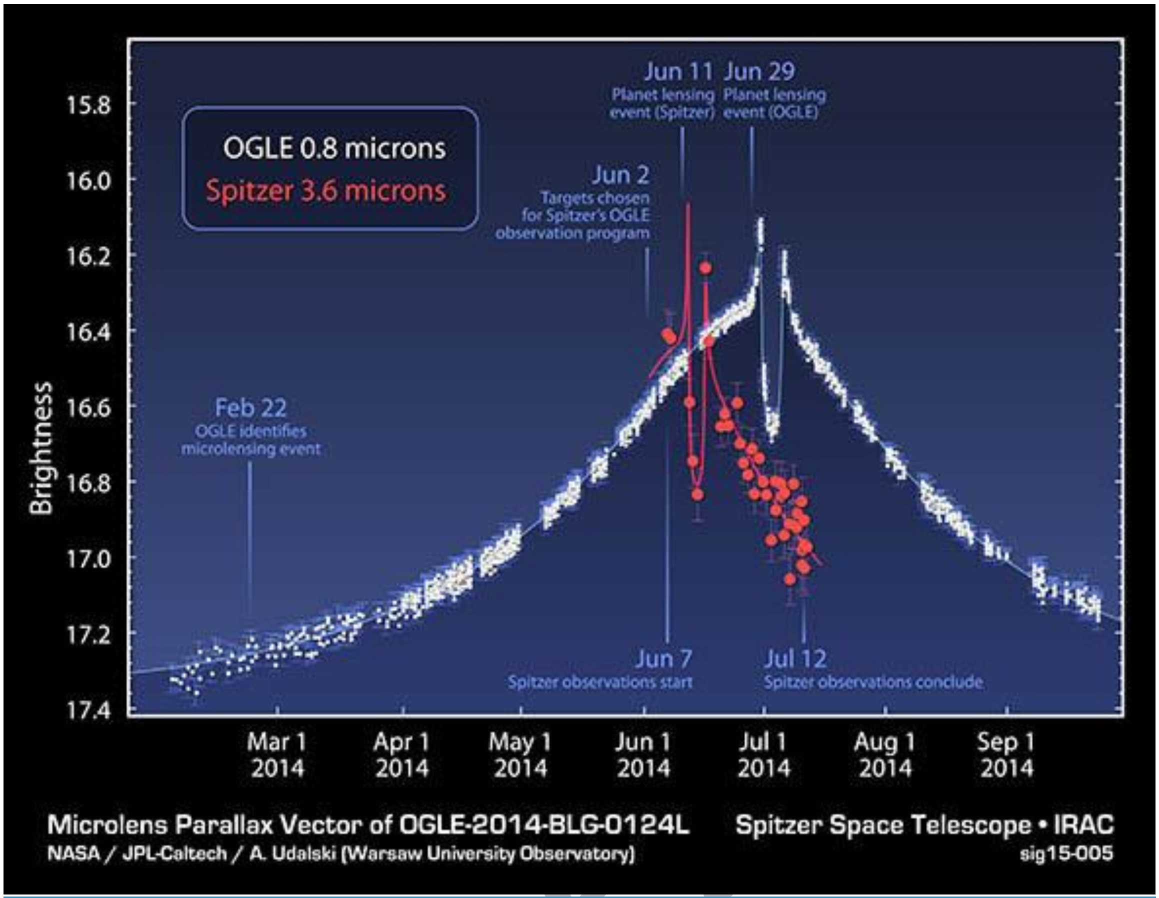
url: http://www.nasa.gov/press/2014/october/nasas-hubble-maps-the-temperature-and-water-vapor-on-an-extreme-exoplanet

~~**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



NASA's Spitzer Spots Planet Deep Within Our Galaxy

NASA's Spitzer Space Telescope has teamed up with a telescope on the ground to find a remote gas planet about 13,000 light-years away, making it one of the most distant planets known. The discovery demonstrates that Spitzer -- from its unique perch in space -- can be used to help solve the puzzle of how planets are distributed throughout our flat, spiral-shaped Milky Way galaxy. Are they concentrated heavily in its central hub, or more evenly spread throughout its suburbs? The discovery combined data from the ground-based OGLE survey with the data from Spitzer. OGLE searched for planets using a technique called mirolensing, which occurs when one star happens to pass in front of another, and its gravity acts as a lens to magnify and brighten the more distant star's light. If that foreground star happens to have a planet in orbit around it, the planet might cause a blip in the magnification. Astronomers are using these blips to find and characterize planets tens of thousands of light-years away in the central bulge of our galaxy, where star crossings are more common. Our sun is located in the suburbs of the galaxy, about two-thirds of the way out from the center. The microlensing technique as a whole has yielded about 30 planet discoveries so far, with the farthest residing about 25,000 light-years away. Of the approximately 30 planets discovered with microlensing so far, roughly half cannot be pinned down to a precise location. The result is like a planetary treasure map lacking in X's. That's where Spitzer can help out, thanks to its remote Earth-trailing orbit. Spitzer circles our sun, and is currently about 128 million miles (207 million kilometers) away from Earth. That's farther from Earth than Earth is from our sun. When Spitzer watches a microlensing event simultaneously with a telescope on Earth, it sees the star brighten at a different time, due to the large distance between the two telescopes and their unique vantage points. This technique is generally referred to as parallax. This time delay between viewing of the event by OGLE and Spitzer was used to calculate the distance to the star and its planet. Knowing the distance allowed the scientists also to determine the mass of the planet, which is about half that of Jupiter.

This technique will ultimately provide the only way to learn about the distribution of planets in the Galaxy.

Citation: Udalski, A., et al. 2015, ApJ, 799, 237 ("Spitzer as a Microlens Parallax Satellite: Mass Measurement for the OGLE-2014-BLG-0124L Planet and its Host Star.")

url: http://www.spitzer.caltech.edu/news/1746-feature15-05-NASA-s-Spitzer-Spots-Planet-Deep-Within-Our-Galaxy