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

ASTROPHYSICS

Major Astrophysics milestones of the last year include:

- (List of examples below selected by APS)

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 2016 AS-16-1: *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 XX

Summary: (to be prepared by APS0

The items featured in this section are:

- (list of examples selected by APS --- typically 2 to 5 examples)

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Example 1

Andromeda Galaxy Scanned with High-Energy X-ray Vision.
NASA's Nuclear Spectroscopic Telescope Array, or NuSTAR, has captured the best high-energy X-ray view yet of a portion of our nearest large, neighboring galaxy, Andromeda. The space mission has observed 40 "X-ray binaries" -- intense sources of X-rays comprised of a black hole or neutron star that feeds off a stellar companion.

The results will ultimately help researchers better understand the role of X-ray binaries in the evolution of our universe. According to astronomers, these energetic objects may play a critical role in heating the intergalactic bath of gas in which the very first galaxies formed.

Andromeda, also known as M31, can be thought of as the big sister to our own Milky Way galaxy. Both galaxies are spiral in shape, but Andromeda is slightly larger than the Milky Way in size. Lying 2.5 million light-years away, Andromeda is relatively nearby in cosmic terms. It can even be seen by the naked eye in dark, clear skies.

Other space missions, such as NASA's Chandra X-ray Observatory, have obtained crisper images of Andromeda at lower X-ray energies than the high-energy X-rays detected by NuSTAR. The combination of Chandra and NuSTAR provides

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astronomers with a powerful tool for narrowing in on the nature of the X-ray binaries in spiral galaxies.

In X-ray binaries, one member is always a dead star or remnant formed from the explosion of what was once a star much more massive than the sun. Depending on the mass and other properties of the original giant star, the explosion may produce either a black hole or neutron star. Under the right circumstances, material from the companion star can "spill over" its outermost edges and then be caught by the gravity of the black hole or neutron star. As the material falls in, it is heated to blazingly high temperatures, releasing a huge amount of X-rays.

With NuSTAR's new view of a swath of Andromeda, NASA scientists are working on identifying the fraction of X-ray binaries harboring black holes versus neutron stars. That research will help them understand the population as a whole.

Reference: Wik et al. 2016, in preparation TO BE CHECKED

http://www.nasa.gov/feature/jpl/Andromeda-Galaxy-Scanned-with-High-Enrgy-X-ray-Vision

Example 2

NASA's Fermi Telescope Poised to Pin Down Gravitational Wave Sources

On Sept. 14, waves of energy traveling for more than a billion years gently rattled space-time in the vicinity of Earth. The disturbance, produced by a pair of merging black holes, was captured by the Laser Interferometer Gravitational-Wave Observatory (LIGO) facilities in Hanford, Washington, and Livingston, Louisiana. This event marked the first-ever detection of gravitational waves and opens a new scientific window on how the universe works.

Less than half a second later, the Gamma-ray Burst Monitor (GBM) on NASA's Fermi Gamma-ray Space Telescope picked up a brief, weak burst of high-energy light consistent with the same part of the sky. Analysis of this burst suggests just a 0.2-percent chance of simply being random coincidence. Gamma-rays arising from a black hole merger would be a landmark finding because black holes are expected to merge “cleanly,” without producing any sort of light.

Detecting light from a gravitational wave source will enable a much deeper understanding of the event. Fermi's GBM sees the entire sky not blocked by Earth and is sensitive to X-rays and gamma rays with energies between 8,000 and 40 million electron volts (eV). For comparison, the energy of visible light ranges between about 2 and 3 eV.

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With its wide energy range and large field of view, the GBM is the premier instrument for detecting light from short gamma-ray bursts (GRBs), which last less than two seconds. They are widely thought to occur when orbiting compact objects, like neutron stars and black holes, spiral inward and crash together. These same systems also are suspected to be prime producers of gravitational waves.

Currently, gravitational wave observatories possess relatively blurry vision. This will improve in time as more facilities begin operation, but for the September event, dubbed GW150914 after the date, LIGO scientists could only trace the source to an arc of sky spanning an area of about 600 square degrees, comparable to the angular area on Earth occupied by the United States.

Less than half a second after LIGO detected gravitational waves, the GBM picked up a faint pulse of high-energy X-rays lasting only about a second. The burst effectively occurred beneath Fermi and at a high angle to the GBM detectors, a situation that limited their ability to establish a precise position. Fortunately, Earth blocked a large swath of the burst's likely location as seen by Fermi at the time, allowing scientists to further narrow down the burst's position.

The GBM team calculates less than a 0.2-percent chance random fluctuations would have occurred in such close proximity to the merger. Assuming the events are connected, the GBM localization and Fermi's view of Earth combine to reduce the LIGO search area by about two-thirds, to 200 square degrees. With a burst better placed for the GBM's detectors, or one bright enough to be seen by Fermi's Large Area Telescope, even greater improvements are possible

Reference: Connaughton et al. 2016, APJL, in press

http://www.nasa.gov/feature/goddard/2016/nasas-fermi-telescope-poised-to-pin-down-gravitational-wave-sources

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Example 3

NASA's Fermi Satellite Detects First Gamma-ray Pulsar in Another Galaxy

Researchers using NASA's Fermi Gamma-ray Space Telescope have discovered the first gamma-ray pulsar in a galaxy other than our own. The object sets a new record for the most luminous gamma-ray pulsar known.
The pulsar lies in the outskirts of the Tarantula Nebula in the Large Magellanic Cloud, a small galaxy that orbits our Milky Way and is located 163,000 light-years away. The Tarantula Nebula is the largest, most active and most complex star-formation region in our galactic neighborhood. It was identified as a bright source of

gamma rays, the highest-energy form of light, early in the Fermi mission. Astronomers initially attributed this glow to collisions of subatomic particles accelerated in the shock waves produced by supernova explosions.   It's now clear that a single pulsar, PSR J0540-6919, is responsible for roughly half of the gamma-ray brightness that was originally thought to have come from the nebula.

When a massive star explodes as a supernova, the star's core may survive as a neutron star, where the mass of half a million Earths is crushed into a magnetized ball no larger than Washington, D.C. A young isolated neutron star spins tens of times each second, and its rapidly spinning magnetic field powers beams of radio waves, visible light, X-rays and gamma rays. If the beams sweep past Earth, astronomers observe a regular pulse of emission and the object is classified as a pulsar.

Prior to the launch of Fermi in 2008, only seven gamma-ray pulsars were known. To date, the mission has found more than 160.

Reference: Ackermann et al. 2016, A&A, 586, 71

http://www.nasa.gov/feature/goddard/nasas-fermi-satellite-detects-first-gamma-ray-pulsar-in-another-galaxy

Example 4

Caught For The First Time: The Early Flash Of An Exploding Star
The brilliant flash of an exploding star's shockwave—what astronomers call the "shock breakout"—has been captured for the first time in the optical wavelength or visible light by NASA's planet-hunter, the Kepler space telescope.

Scientists analyzed light captured by Kepler every 30 minutes over a three-year period from 500 distant galaxies, searching some 50 trillion stars. They were hunting for signs of massive stellar death explosions known as supernovae.

In 2011, two of these massive stars, called red supergiants, exploded while in Kepler's view. The first behemoth, KSN 2011a, is nearly 300 times the size of our sun and a mere 700 million light years from Earth. The second, KSN 2011d, is roughly 500 times the size of our sun and around 1.2 billion light years away. Earth's orbit about our sun would fit comfortably within these colossal stars.

The steady gaze of Kepler allowed astronomers to see, at last, a supernova shockwave as it reached the surface of a star. The shock breakout itself lasts only about 20 minutes, so catching the flash of energy is an investigative milestone for astronomers. Supernovae like these — known as Type II — begin when the internal furnace of a star runs out of nuclear fuel causing its core to collapse as gravity takes over.

The two supernovae matched up well with mathematical models of Type II explosions reinforcing existing theories. But they also revealed what could turn out to be an unexpected variety in the individual details of these cataclysmic stellar events.

Understanding the physics of these violent events allows scientists to better understand how the seeds of chemical complexity and life itself have been scattered in space and time in our Milky Way galaxy

Reference: Garnavich et al. 2016, ApJ, 820, 23

http://www.nasa.gov/feature/ames/Kepler/caught-for-the-first-time-the-early-flash-of-an-exploding-star

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 2016 AS-16-3: *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 XX

The items featured in this section are:

- (list of examples selected by APS --- typically 2 to 5 examples)
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Example 1

Hubble Team Breaks Cosmic Distance Record

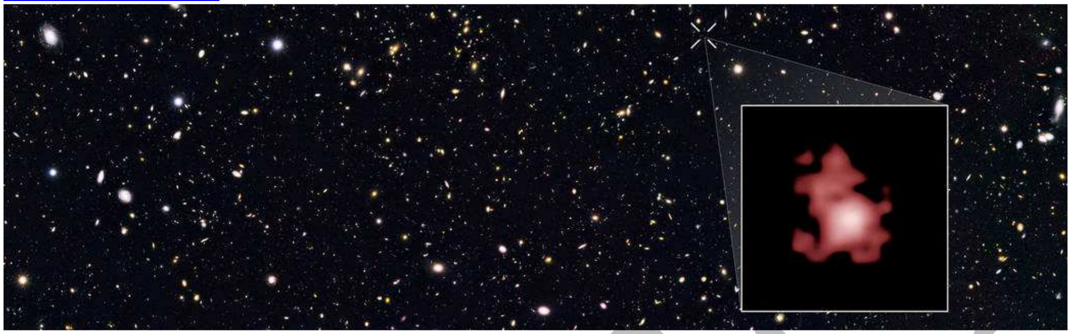
By pushing NASA's Hubble Space Telescope to its limits, an international team of astronomers has shattered the cosmic distance record by measuring the farthest galaxy ever seen in the universe. This surprisingly bright infant galaxy, named GN-z11, is seen as it was 13.4 billion years in the past, just 400 million years after the Big Bang. GN-z11 is located in the direction of the constellation of Ursa Major. We see GN-z11 at a time when the universe was only three percent of its current age.

This measurement provides strong evidence that some unusual and unexpectedly bright galaxies found earlier in Hubble images are really at extraordinary distances. Previously, the team had estimated GN-z11's distance by determining its color through imaging with Hubble and NASA's Spitzer Space Telescope. Now, for the first time for a galaxy at such an extreme distance, the team used Hubble's Wide Field Camera 3 to precisely measure the distance to GN-z11 spectroscopically by splitting the light into its component colors.

This observation takes astronomy into the realm of very distant objects, marking the very early universe, which will be the subject of intense study with the upcoming James Webb Space Telescope, on track for launch in 2018.

Reference: Oesch et al. 2016, ApJ, 819, 29

http://www.nasa.gov/feature/goddard/2016/hubble-team-breaks-cosmic-distance-record



This figure shows the location of galaxy GN-z11, which is the farthest galaxy ever seen. GN-z11 is located in the Big Dipper, in the direction of the constellation Ursa Major. The background picture is the GOODS North field of galaxies, and the inset marks the location of the young galaxy. GN-z11 is shown as it existed 13.4 billion years in the past, just 400 million years after the Big Bang, when the universe was only three percent of its present age.

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Example 2

Astronomers using NASA's Hubble Space Telescope have discovered that the universe is expanding 5 percent to 9 percent faster than expected. This surprising finding may be an important clue to understanding those mysterious parts of the universe that make up 95 percent of everything and don't emit light, such as dark energy, dark matter and dark radiation.

The team made the discovery by refining the universe's current expansion rate to unprecedented accuracy, reducing the uncertainty to only 2.4 percent. The team made the refinements by developing innovative techniques that improved the precision of distance measurements to faraway galaxies.

The improved Hubble constant value is 45.5 miles per second per megaparsec. (A megaparsec equals 3.26 million light-years.) The new value means the distance between cosmic objects will double in another 9.8 billion years.

This refined calibration presents a puzzle, however, because it does not quite match the expansion rate predicted for the universe from its trajectory seen shortly after the Big Bang. Measurements of the afterglow from the Big Bang by NASA's Wilkinson Microwave Anisotropy Probe (WMAP) and the European Space Agency's Planck satellite mission yield predictions which are 5 percent and 9 percent smaller for the Hubble constant, respectively.

There are a few possible explanations for the universe's excessive speed. One possibility is that dark energy, already known to be accelerating the universe, may be shoving galaxies away from each other with even greater — or growing — strength.

Another idea is that the cosmos contained a new subatomic particle in its early history that traveled close to the speed of light. Such speedy particles are collectively referred to as "dark radiation" and include previously known particles like neutrinos. More energy from additional dark radiation could be throwing off the best efforts to predict today's expansion rate from its post-Big Bang trajectory.

The boost in acceleration could also mean that dark matter possesses some weird, unexpected characteristics. Dark matter is the backbone of the universe upon which galaxies built themselves up into the large-scale structures seen today.

And finally, the speedier universe may be telling astronomers that Einstein's theory of gravity is incomplete.

This Hubble Space Telescope image shows one of the galaxies in the survey to refine the measurement for how fast the universe expands with time, called the Hubble constant.

Credits: NASA, ESA and A. Riess (STScI/JHU)

Reference: Riess et al. 2016, ApJ, in press TO BE CHECKED

http://www.nasa.gov/feature/goddard/2016/nasa-s-hubble-finds-universe-is-expanding-faster-than-expected

Example 3

NASA's Great Observatories Weigh Massive Young Galaxy Cluster

Astronomers have used data from three of NASA's Great Observatories to make the most detailed study yet of an extremely massive young galaxy cluster. This rare cluster, which is located 10 billion light years from Earth, weighs as much as 500 trillion suns. This object has important implications for understanding how these megastructures formed and evolved early in the universe.

The galaxy cluster called IDCS J1426.5+3508 (IDCS 1426 for short), is so far away that the detected light is from when the universe was roughly a quarter of its current age. It is the most massive galaxy cluster detected at such an early age. First discovered by the Spitzer Space Telescope in 2012, IDCS 1426 was observed using the Hubble Space Telescope and the Keck Observatory to determine its distance. Observations from the Combined Array for Millimeter Wave Astronomy indicated it was extremely massive. New data from the Chandra X-ray Observatory confirm the galaxy cluster mass and show that about 90% of the mass of the cluster is in the form of dark matter, a mysterious substance detected so far only through its gravitational pull on normal matter composed of atoms.

Galaxy clusters are the largest objects in the Universe bound together by gravity. Because of their sheer size, scientists think it should take several billion years for them to form. The distance of IDCS J1426 means astronomers are observing it when the Universe was only 3.8 billion years old, implying that the cluster is seen at a very young age.

The data from Chandra reveal a bright knot of X-rays near the middle of the cluster, but not exactly at its center. This overdense core has been dislodged from the cluster center, possibly by a merger with another developing cluster 500 million years prior. Such a merger would cause the X-ray emitting, hot gas to slosh around like wine in a glass that is tipped from side to side.

Aside from this cool core, the hot gas in the rest of the cluster is very smooth and symmetric. This is another indication that IDCS 1426 formed very rapidly. In addition, astronomers found possible evidence that the amount of elements heavier than hydrogen and helium in the hot gas is unusually low. This suggests that this galaxy cluster might still be in the process of enriching its hot gas with these elements as supernovae create heavier elements and blast them out of individual galaxies.

Evidence for other massive galaxy clusters at early times has been found, but none of these matches IDCS 1426 with its combination of mass and youth. The mass determination used three independent methods: a measurement of the mass needed to confine the hot X-ray emitting gas to the cluster, the imprint of the cluster's gaseous mass on the cosmic microwave background radiation, and the observed

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distortions in the shapes of galaxies behind the cluster, which are caused by the bending of light from the galaxies by the gravity of the cluster.

Reference: Brodwin et al. 2016, ApJ, 817, 122

http://www.nasa.gov/mission_pages/chandra/nasas-great-observatories-weigh-massive-young-galaxy-cluster.html

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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 2016 AS-16-6: *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 **XX**

The items featured in this section are:

- (list of examples selected by APS --- typically 2 to 5 examples)
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Example 1

Hubble Directly Measures Rotation of Cloudy 'Super-Jupiter'

Astronomers using NASA's Hubble Space Telescope have measured the rotation rate of an extreme exoplanet by observing the varied brightness in its atmosphere. This is the first measurement of the rotation of a massive exoplanet using direct imaging, a unique technique to explore the atmospheres of exoplanets and to measure their rotation rates.

The planet, called 2M1207b, is about four times more massive than Jupiter and is dubbed a "super-Jupiter." It is a companion to a failed star known as a brown dwarf, orbiting the object at a distance of 5 billion miles. By contrast, Jupiter is approximately 500 million miles from the sun. The brown dwarf is known as 2M1207. The system resides 170 light-years away from Earth.

Hubble's image stability, high resolution, and high-contrast imaging capabilities allowed astronomers to precisely measure the planet's brightness changes as it spins. The researchers attribute the brightness variation to complex clouds patterns in the planet's atmosphere. The new Hubble measurements not only verify the presence of these clouds, but also show that the cloud layers are patchy and colorless.

Astronomers first observed the massive exoplanet 10 years ago with Hubble. The observations revealed that the exoplanet's atmosphere is hot enough to have "rain" clouds made of silicates: vaporized rock that cools down to form tiny particles with sizes similar to those in cigarette smoke. Deeper into the atmosphere, iron droplets are forming and falling like rain, eventually evaporating as they enter the lower levels of the atmosphere.

The super-Jupiter is so hot that it appears brightest in infrared light. Astronomers used Hubble's Wide Field Camera 3 to analyze the exoplanet in infrared light to explore the object's cloud cover and measure its rotation rate. The planet is hot because it is only about 10 million years old and is still contracting and cooling. For comparison, Jupiter in our solar system is about 4.5 billion years old.

The planet, however, will not maintain these sizzling temperatures. Over the next few billion years, the object will cool and fade dramatically. As its temperature decreases, the iron and silicate clouds will also form lower and lower in the atmosphere and will eventually disappear from view.

Scientists have also determined that the super-Jupiter completes one rotation approximately every 10 hours, spinning at about the same fast rate as Jupiter.

This super-Jupiter is only about five to seven times less massive than its brown-dwarf host. By contrast, our sun is about 1,000 times more massive than Jupiter. This is a very good clue that the 2M1207 system we studied formed differently than our own solar system. The planets orbiting our sun formed inside a circumstellar disk through accretion. But the super-Jupiter and its companion may have formed throughout the gravitational collapse of a pair of separate disks.

This study demonstrates that Hubble and its successor, NASA's James Webb Space Telescope, will be able to derive cloud maps for exoplanets, based on the light we receive from them. Indeed, this super-Jupiter is an ideal target for the Webb telescope, an infrared space observatory scheduled to launch in 2018. Webb will help astronomers better determine the exoplanet's atmospheric composition and derive detailed maps from brightness changes with the new technique demonstrated with the Hubble observations.

Reference: Zhou et al. 2016, ApJ, 818, 176

https://www.nasa.gov/feature/goddard/2016/hubble-directly-measures-rotation-of-cloudy-super-jupiter

Example 2

NASA K2 finds newborn planet around young star

Astronomers have discovered the youngest fully formed exoplanet ever detected. The discovery was made using NASA's Kepler Space Telescope and its extended K2 mission, as well as the W. M. Keck Observatory on Mauna Kea, Hawaii. Exoplanets are planets that orbit stars beyond our sun.

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The newfound planet, K2-33b, is a bit larger than Neptune and whips tightly around its star every five days. It is only 5 to 10 million years old, making it one of a very few newborn planets found to date.

Planet formation is a complex and tumultuous process that remains shrouded in mystery. Astronomers have discovered and confirmed roughly 3,000 exoplanets so far; however, nearly all of them are hosted by middle-aged stars, with ages of a billion years or more. For astronomers, attempting to understand the life cycles of planetary systems using existing examples is like trying to learn how people grow from babies to children to teenagers, by only studying adults. The newborn planet will help astronomers better understand how planets form, which is important for understanding the processes that led to the formation of Earth.

The first signals of the planet's existence were measured by K2. The telescope's camera detected a periodic dimming of the light emitted by the planet's host star, a sign that an orbiting planet could be regularly passing in front of the star and blocking the light. Data from the Keck Observatory validated that the dimming was indeed caused by a planet, and also helped confirm its youthful age.

Infrared measurements from NASA's Spitzer Space Telescope showed that the system's star is surrounded by a thin disk of planetary debris, indicating that its planet-formation phase is wrapping up. Planets form out of thick disks of gas and dust, called protoplanetary disks, that surround young stars.

A surprising feature in the discovery of K2-33b is how close the newborn planet lies to its star. The planet is nearly 10 times closer to its star than Mercury is to our sun, making it hot. While numerous older exoplanets have been found orbiting very tightly to their stars, astronomers have long struggled to understand how more massive planets like this one wind up in such small orbits. Some theories propose that it takes hundreds of millions of years to bring a planet from a more distant orbit into a close one -- and therefore cannot explain K2-33b, which is quite a bit younger.

There are two main theories that may explain how K2-33b wound up so close to its star. It could have migrated there in a process called disk migration that takes hundreds of thousands of years. Or, the planet could have formed "in situ" -- right where it is. The discovery of K2-33b therefore gives theorists a new data point to ponder.

Rereference: David et al. 2016, Nature, in press

http://www.jpl.nasa.gov/news/news.php?feature=6539

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Example 3

NASA's Spitzer Confirms Closest Rocky Exoplanet

Using NASA's Spitzer Space Telescope, astronomers have confirmed the discovery of the nearest rocky planet outside our solar system, larger than Earth and a potential gold mine of science data.

Dubbed HD 219134b, is the closest exoplanet to Earth to be detected transiting, or crossing in front of, its star and, therefore, perfect for extensive research. Webb and future large, ground-based observatories are sure to point at it and examine it in detail.

Only a small fraction of exoplanets can be detected transiting their stars due to their relative orientation to Earth. When the orientation is just right, the planet's orbit places it between its star and Earth, dimming the detectable light of its star. It's this dimming of the star that is actually captured by observatories such as Spitzer and can reveal not only the size of the planet but also clues about its composition.

HD 219134b was first sighted by the HARPS-North instrument and a method called the radial velocity technique, in which a planet's mass and orbit can be measured by the tug it exerts on its host star. The planet was determined to have a mass 4.5 times that of Earth, and a speedy three-day orbit around its star.

Spitzer followed up on the finding, discovering the planet transits its star. Infrared measurements from Spitzer revealed the planet's size, about 1.6 times that of Earth. Combining the size and mass gives it a density of 3.5 ounces per cubic inch (six grams per cubic centimeter) -- confirming HD 219134b is a rocky planet.

Reference:Motalebi et al., A&A, in press TO BE CHECKED

http://www.spitzer.caltech.edu/news/1792-ssc2015-02-NASA-s-Spitzer-Confirms-Closest-Rocky-Exoplanet

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