2018 Review

Introduction

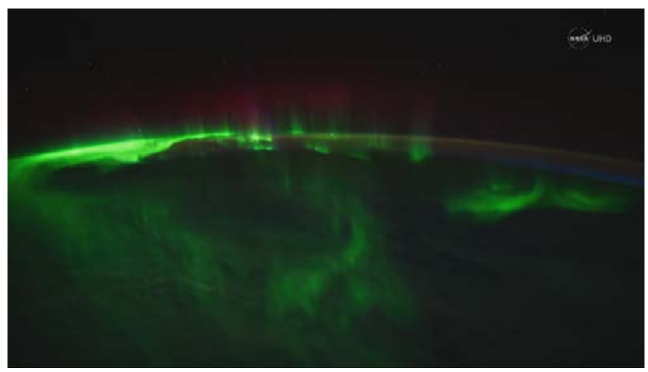
Hello and welcome to our 2018 review. As usual, it was another big year for expanding our understanding of the world around us. We really are living in an age of discovery.

In this review we'll see the northern lights on Saturn: a new asteroid landing close to Earth; the ghost of Cassiopeia; new information on the stars at the center of our galaxy; and more. We'll also cover the second GAIA data release on 1.7 billion stars. We'll then go beyond the galaxy to see a wide variety of galaxies and galaxy clusters. We'll see a single star 9 billion light years away.

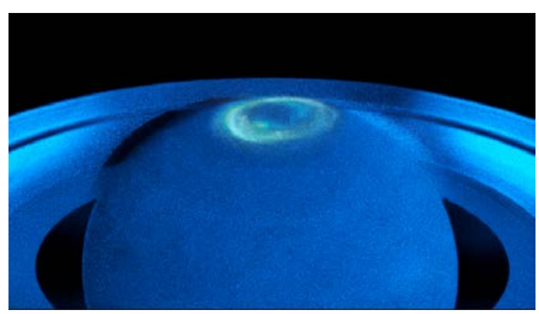
Our deep dive this year is a close look at Brown Dwarfs: what are they; how do they form; and where do they fit between high mass planets and low mass stars; and we'll take a look at a few of them. But first, we'll start close to home with Saturn's Northern Lights.

Saturn's Northern Lights

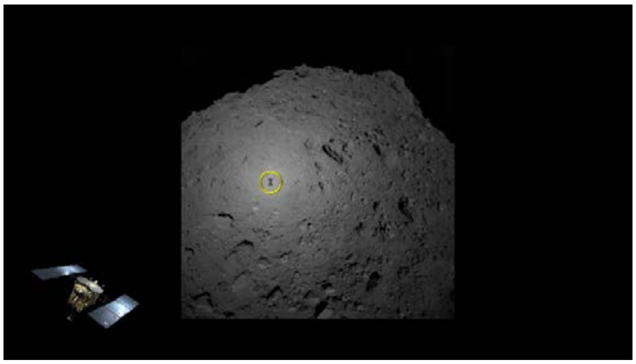
You'll recall that we covered Earth's Aurora Borealis in our segment on the Heliosphere. The magnetosphere routs solar wind charged particles to the poles that collide with the atmosphere there. The green and red colors are produced by excited oxygen and nitrogen atoms respectively. Magnetospheres and therefore auroras exist on other planets in our solar system as well.



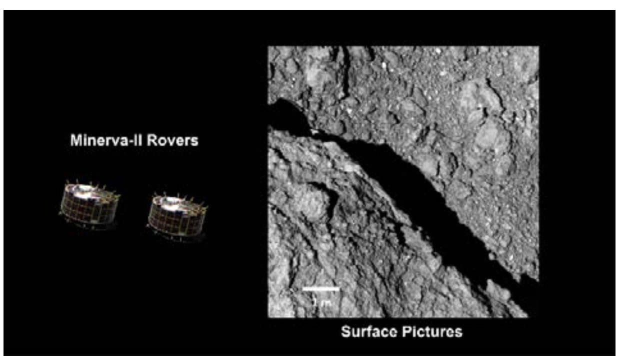
Astronomers using the Hubble Space telescope have taken a series of spectacular images featuring the fluttering auroras at Saturn's norther pole. The observations were taken in ultraviolet light and the resulting images from excited hydrogen atoms provide us with the most comprehensive picture so far of Saturn's northern aurora. The main image presented here is a composite of observations made of Saturn in early 2018 in the optical and of the auroras on Saturn's North Pole region, made in 2017.



Japan lands a probe on asteroid Ryugu



Here we see the near Earth asteroid 162173 Ryugu taken by the Japan Aerospace Exploration Agency spacecraft Hayabusa 2. It's a potentially hazardous asteroid discovered in 1999. It's approximately 1 kilometer or 6 tenths of a mile wide, and its mass is estimated to be around 450 million tons. The spacecraft was launched in 2014 and arrived at the asteroid on the 27th of June 2018. Here you can see the spacecraft's shadow on the asteroid



The mission includes four rovers that will land and explore the surface. By September 22, two of them had successfully touched down on Ryugu's surface. Their objective is to explore for the asteroid's minerals, water and organic matter in a bid to learn about the origin and evolution of the solar system. The mission is expected to return material from the asteroid to Earth by the end of 2020.

[62173 Ryugu is thought to be composed of mostly nickel and iron. Asteroids like Ryugu are interesting for several reasons, perhaps foremost because they are near the Earth and might, one day in the far future, pose an impact threat. In the nearer term, Ryugu is interesting because it may be possible to send future spacecraft there to mine it, thus providing humanity with a new source of valuable metals.**]**

IC 63 - The ghost of Cassiopeia - 550 ly

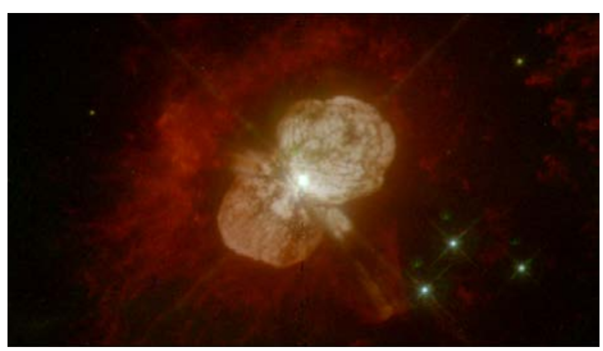
Gamma Cassiopeia is a blue-white subgiant variable star. It's 19 times more massive and 65 000 times brighter than our Sun. The radiation of Gamma Cassiopeia is so powerful that it even affects IC 63, sometimes nicknamed the Ghost of Cassiopeia that lies several light years away from the star.

The colors in the nebula showcase how it's affected by the powerful radiation from the distant star. The hydrogen within IC 63 is being bombarded with ultraviolet radiation from Gamma Cassiopeia, causing its electrons to gain energy which they later release as radiation — visible in red in this image. This makes IC 63 an emission nebula, but we also see the blue light reflected by dust particles in the nebula. So the Ghost of Cassiopeia is also a reflection nebula.

Serpens Nebula HBC 672 - 1,300 light-years

This beautiful stellar nursery is called the Serpens Nebula. It's a reflection nebula nearly 1,300 light-years away. In the upper right we have a young start named HBC 672. It's a Sun-like star surrounded by a debris ring of dust, rock, and ice. The disk is too small and too distant to be seen, even by Hubble. But its shadow is projected large upon the cloud in which the star was born. The presence of a shadow means that the disk is being viewed nearly edge-on. In this Hubble image, the feature—nicknamed the "Bat Shadow"—spans approximately 200 times the length of our solar system.

[Eta Carinae Outburst – 7,500 ly



About 170 years ago, astronomers witnessed a major outburst by Eta Carinae, one of the brightest known stars in the Milky Way galaxy. The blast unleashed almost as much energy as a standard supernova explosion. And yet Eta Carinae survived. An explanation for the eruption has eluded astrophysicists. However, light echoes from the 1840s explosion arriving here in recent years have given astronomers another look.

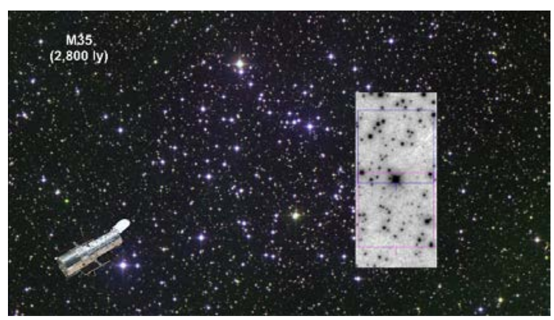
Here's a possible scenario for the powerful blast that fits the accumulated data.

1. Eta Carinae initially was a triple-star system. Two massive stars in the system are orbiting closely and a third is orbiting much farther away.
2. When the most massive of the close binary stars neared the end of its hydrogen burning life, it began to expand and dumps most of its matter onto its slightly smaller star.
3. The smaller star grew to about 100 solar masses. The donor star would have lost its hydrogen layers, exposing its hot helium core. The mass transfer alters the gravitational balance of the system, and the helium-core star moves farther away.
4. The helium-core star then interacts gravitationally with the outermost star, pulling it into the center.
5. Star C, moving inward, interacts with the extremely massive sibling, creating a disk of material around the giant star.
6. Eventually, the stars merge, producing an explosive event that ejects 10 times the mass of our Sun that forms the bipolar lobes of material. Meanwhile, the surviving companion, settles into an elongated orbit around the merged pair.]

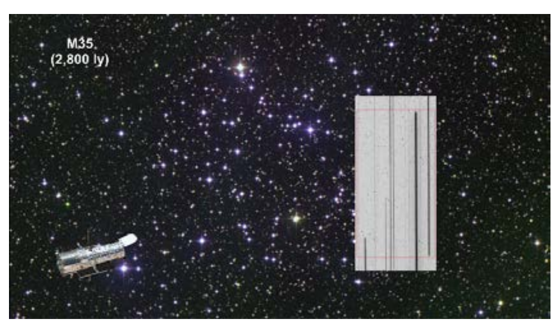
Spatial scanning

Driven by the need for better data during exoplanet transits across their sun, a technique that rotates the telescope during observations called Spatial Scanning was developed by the Hubble team.

The technique was demonstrated with a pilot program of spatial scanning observations of the open star cluster M35 in 2009. Normally, angles on the sky between objects as well as other information about each object were based on a static photograph. Telescope jitter and pixel saturation limited the amount and accuracy of the collected data.



By rotating the telescope during observations, each point image is replaced by a "trail" on the detector. The trails for all sources are parallel in the frame. We see that the light from each source is spread over a much larger number of pixels. Furthermore, each long trail provides thousands of separate position measurements in the cross-trail direction, one for each pixel traversed, thus averaging out the impact of single-pixel and local telescope jitter irregularities.



With spatial scans, Hubble can achieve measurement precision of a parallax angel of 40 micro arc seconds or better (10^{-6} arcsec). This translates into distance measurements as far as 80,000 light years away. This is close to what the GAIA satellite can do and has enabled Hubble to measure distances to stars out in the Milky Way's halo.

Parallax Distance

Let

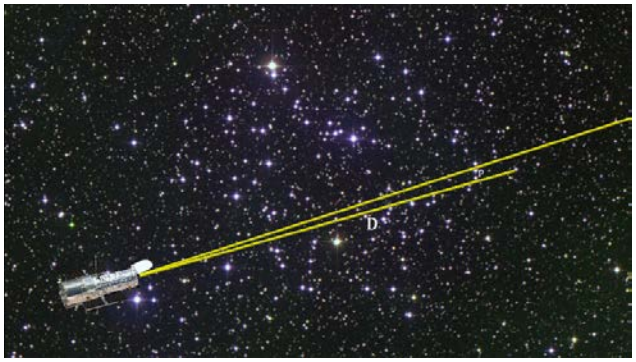
D = distance in parsecs
p = parallax angle in arcsec
d = distance in lightyears
k = light years in one parsec $= 3.26156$

With $p = 40 \times 10^{-6}$ arcsec

$D = 1/p = 1/40 \times 10^{-6} = 25{,}000$ parsecs

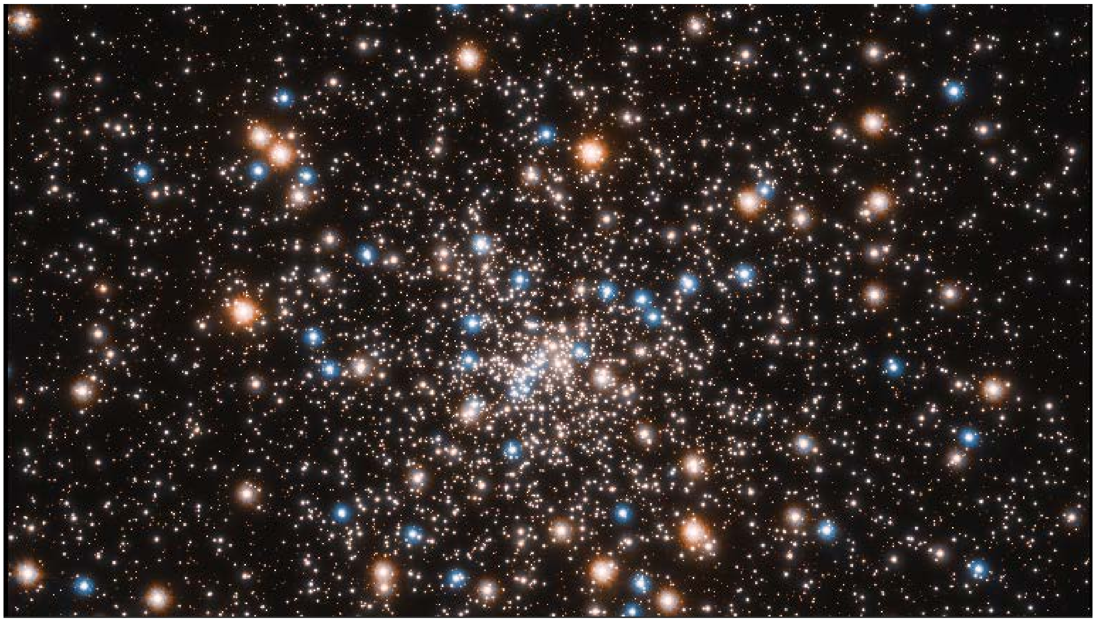
And

$d = 3.26156 \times 25000 = 81{,}539$ ly



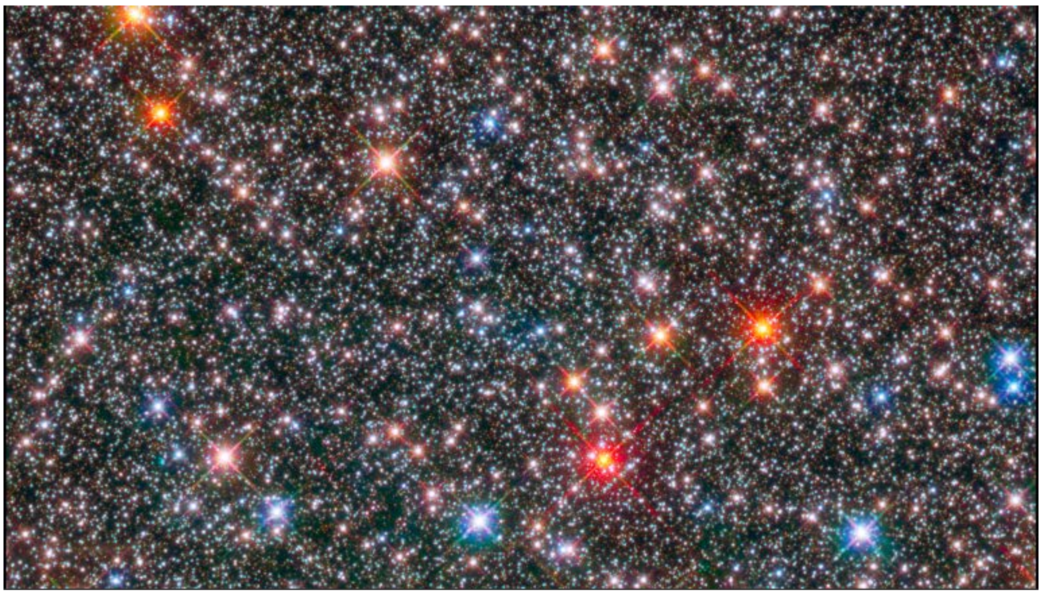
NGC 6397 – 7,800 LY

Globular star cluster NGC 6397 is one of the oldest objects in the universe. It's estimated to be 13.4 billion years old. It's also one of the closest such star clusters to Earth. In 2018, using the new special scanning based parallax data, astronomers have, for the first time, precisely measured the distance to globular star cluster NGC 6397. The new measurement sets the cluster's distance at 7,800 light-years, with just a 3 percent margin of error. This is significantly better than the Hertzsprung-Russel Diagram technique based on luminosities and star colors. The margin of error for H-R Diagram estimates ranges from 10 to 20 percent.



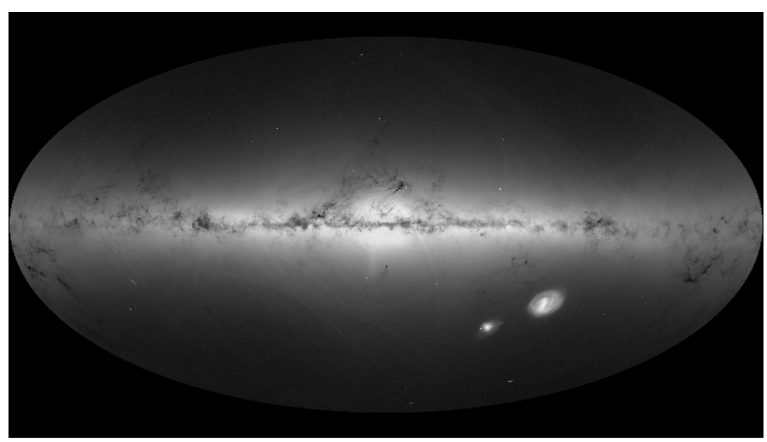
Milky Way Bulge Stars – 26000 ly

A nine year analysis of about 10,000 Sun-like stars in the Milky Way bulge reveals that our galaxy's hub is a dynamic environment of stars of various ages and compositions zipping around at different speeds. This supports the theory that the bulge formed later in the galaxy's lifetime, slowly evolving after the first generations of stars were born. In this scenario, some of the stars in the bulge might be younger, with their chemical composition enriched in heavier elements expelled from the death of previous generations of stars. And they should show a different motion compared to the older stars. This is exactly what the Hubble studies showed to be the case.



GAIA Data Release 2 (DR2)

The second Gaia data release was made public on 25 April 2018 and includes the position and brightness of 1.7 billion stars, as well as the parallax, proper motion and color of more than 1.3 billion stars. It also includes the surface temperature of more than 100 million stars, and the amount of dust between us and 87 million stars. There are also more than 500,000 variable stars like Cepheids, [and the position of over 14,000 known Solar System objects – most of them asteroids –] included in the release.



It also includes the radial velocity of more than seven million stars. This video shows how 7 million stars will move during the next 800,000 years. We then zoom in by a factor of three to visualize the details.

[Kepler Space Telescope Retires

After nine years in deep space collecting data on exoplanets, the Kepler space telescope has run out of fuel and ceased science operations. Kepler leaves a legacy of more than 2,600 planet discoveries from outside our solar system. In fact, we now think that there are billions of planets out there – more planets even than stars.

The most recent analysis of Kepler's discoveries concludes that 20 to 50 percent of the stars visible in the night sky are likely to have small, possibly rocky, planets similar in size to Earth, and located within the habitable zone of their parent stars. That means they're located at distances from their parent stars where liquid water – a vital ingredient to life as we know it – might pool on the planet surface.]

NGC 3344 – 20 mly

This beautiful bared spiral galaxy is about half the size of the Milky Way. Astronomers estimate that two-thirds of all spiral galaxies have a bar structure at its center. That including our own Milky Way. The swirling spiral arms are the birthplace of new stars. Their high temperatures make them shine blue. Clouds of dust and gas distributed through the spiral arms — glowing red in this image — are reservoirs of material for even more stars. The bright stars on the left are Milky Way stars in the line of sight to NGC 3344.

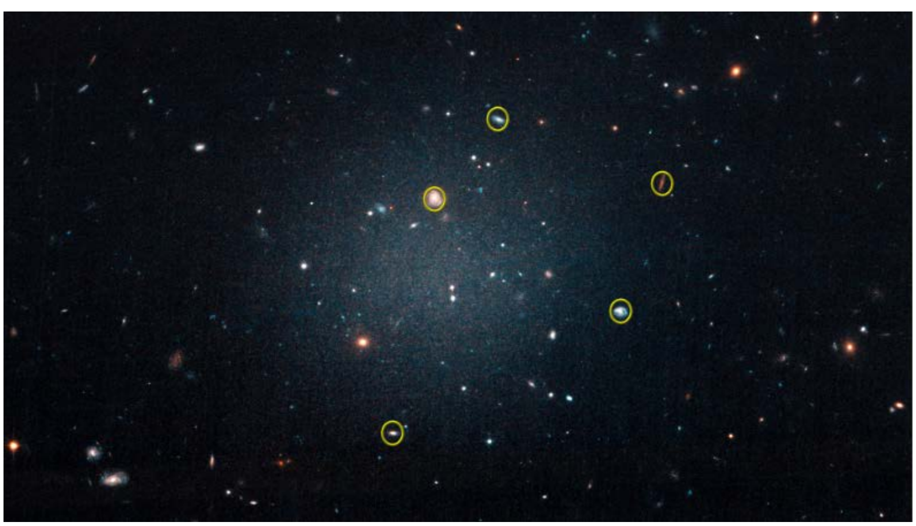
M100 in Focus – 55 mly

This is a 1993 image of the grand-design spiral galaxy M100 taken with Hubble's Wide Field/Planetary Camera 1, which was part of an original suite of instruments launched aboard Hubble in 1990. Because of a manufacturing flaw, the galaxy appears blurred because it cannot be brought into a single focus.

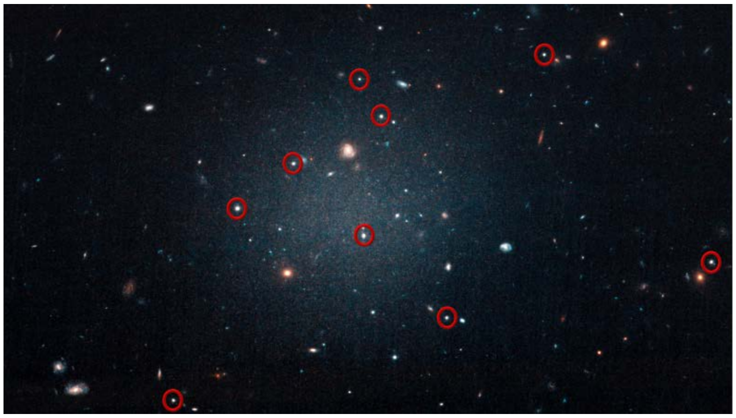
In celebration of the 25th anniversary of the first astronaut mission to service the Hubble Space Telescope in orbit, a comparison photo made by Hubble's Wide Field Camera 3 was released. The improvement was both critically important for Hubble's science mission, it made for significantly better pictures.

NGC 1052-DF2 – 65 mly

Here's a very interesting galaxy. It is as large as our Milky Way, but it contains only 1/200th the number of stars. Given the object's large size and faint appearance, astronomers classify it as an ultra-diffuse galaxy. Note the galaxies behind it and further away. This is literally a see-through galaxy.



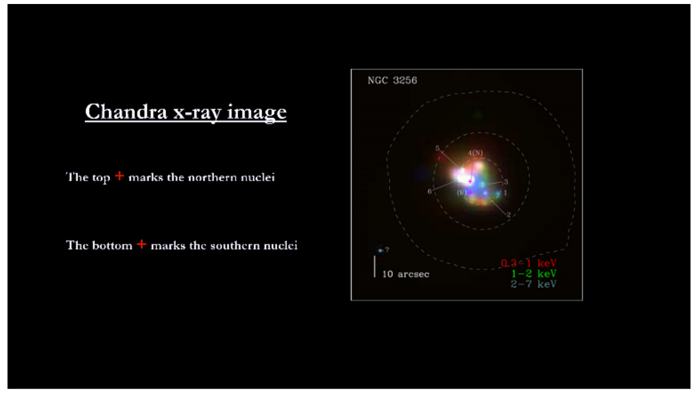
Current dark matter theory has it that galaxies form around dark matter. So, researchers were surprised when they discovered that this galaxy has hardly any dark matter at all. Measuring the motions of 10 giant globular clusters, astronomers found their velocities to be consistent with the estimated mass of the visible matter. There was no need to assume the presence of dark matter. Astronomers have competing theories about how this could happen. It goes to show you that we still have a lot to learn.



NGC 3256 – 100 mly

Here we are zooming to NGC 3256. It is approximately the same size as our Milky Way and bears the marks of its past galactic collision in the extended luminous tails that sprawl out around the galaxy. These are thought to have formed around 500 million years ago during the initial encounter between the two galaxies, which today form just one. These tails are studded with young blue stars. It is believed that their birth was triggered by the collision. The brightness in the center of the galaxy makes it a starburst galaxy, host to vast amounts of infant stars born into groups and clusters.

As well as being lit up by over 1000 bright star clusters, the central region is home to crisscrossing threads of dark dust and a large disc of molecular gas spinning around two distinct nuclei — the relics of the two original galaxies. It takes an x-ray telescope to spot the second nuclei. In a few hundred million years, their nuclei will merge.



NGC 1277 - 240 mly

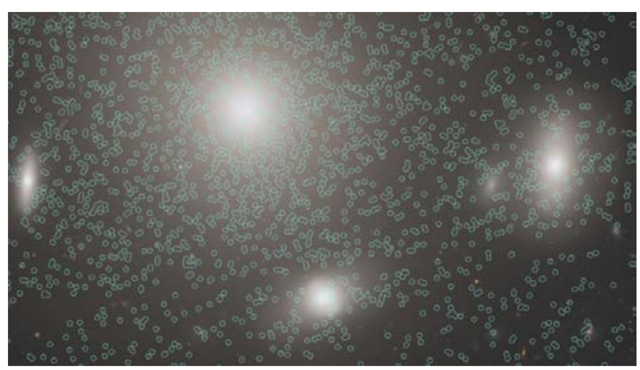
Here we have the relatively nearby Perseus Galaxy Cluster. It is one of the most massive objects in the known universe, containing thousands of galaxies immersed in a vast cloud of hot gas. It's moving away from us at over 5,000 km/s m (that's almost 2,000 miles/s).

Inside this galaxy cluster, Hubble discovered a very old and rare galaxy moving through the cluster at 3.2 million km per hour (that's 2 million miles per hour). It is though that NGC 1277 has remained essentially unchanged for the past 10 billion years. The evidence that this is the case lies in the ancient globular star clusters that swarm around it. Massive galaxies like this one tend to have both newer blue and older red globular clusters. Red ones are believed to have formed as their galaxies are formed. Blue ones are brought in later as the galaxy merges with others. However, NGC

1277 is almost entirely lacking in blue globular clusters. One explanation is that, because, that it cannot merge with other galaxies to collect stars or pull in gas to fuel star formation.

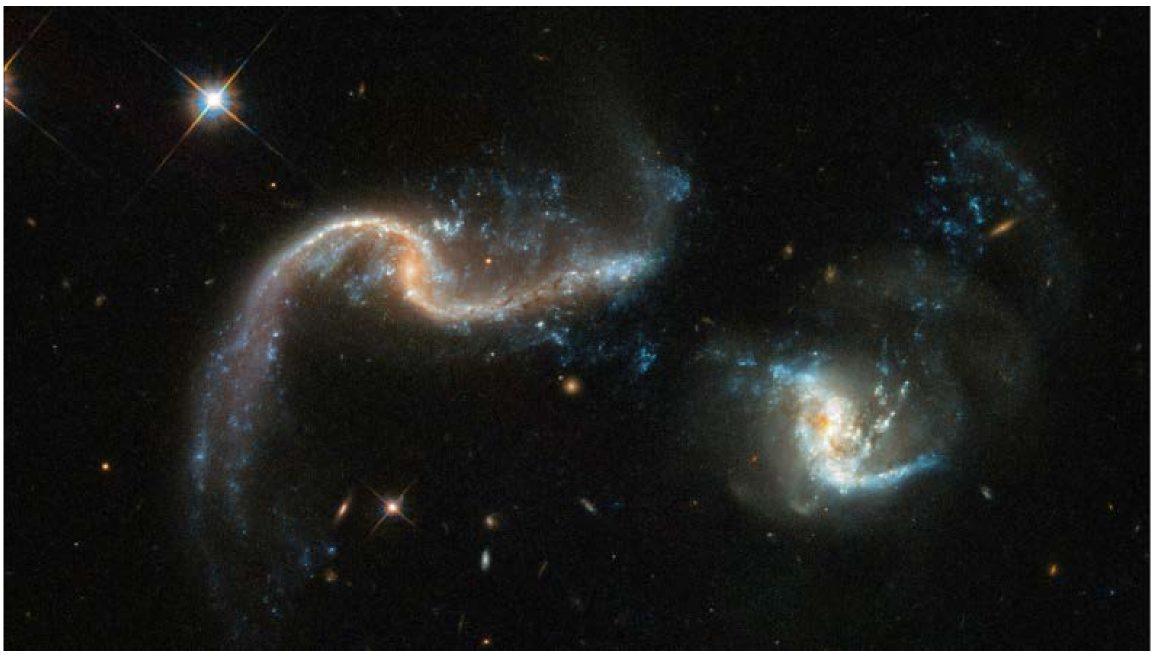
Coma Galaxy Cluster Star Clusters – 300 mly

Here we are zooming into the immense Coma cluster of over 1,000 galaxies, located 300 million light-years from Earth. It contains thousands of globular star clusters (circled in green). Hubble was used to do a comprehensive survey of the Coma's globular star clusters. They found over 22,000 of them (circled in green). They found globular clusters scattered in space between the galaxies - ripped from their home galaxies by near-collisions with other galaxies. Astronomers will use the globular cluster field for mapping the distribution of matter and dark matter in the Coma galaxy cluster.



Arp 256 – 350 mly

Here we see a pair of barred spiral galaxies that have just begun a merger. Though their nuclei are still separated by a large distance, the shapes of the galaxies are significantly distorted. For example, the galaxy on the left contains very pronounced tidal tails — long, extended ribbons of gas, dust and stars. The bright blue areas are stellar nurseries. These vigorous bursts are triggered by the massive gravitational interactions, which stir up interstellar gas and dust out of which stars are created. The galaxies in this system will continue their merger for millions of years, before finally becoming a single galaxy.



[Abell 1758N – 3 bly

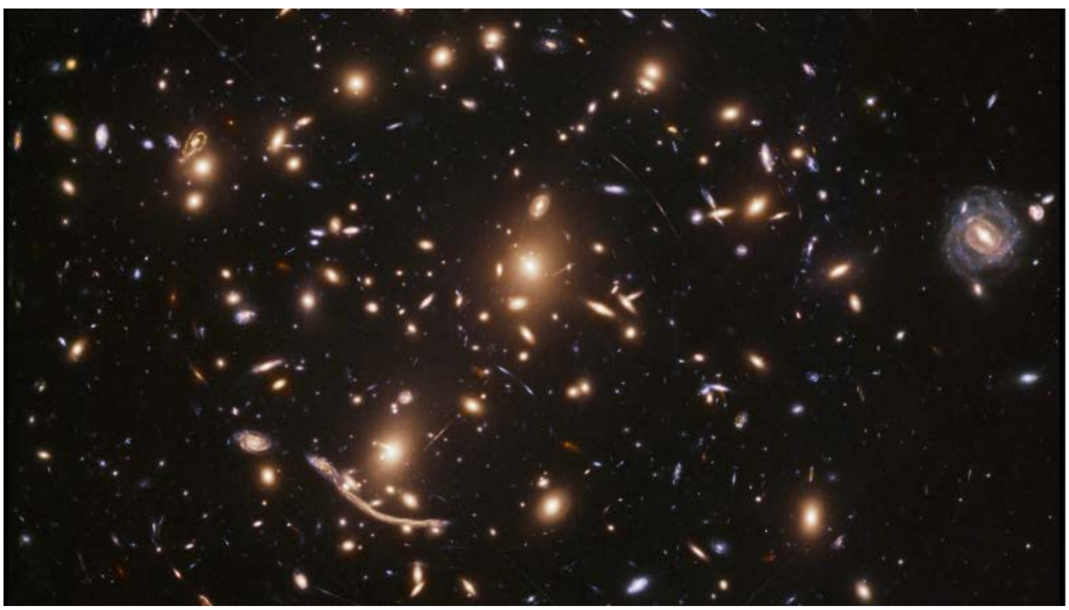
The Abell 1758 galaxy cluster has two concentration of galaxies some 2.4 million light-years apart. These components are known as A1758N (North) and A1758S (South). In this Hubble image only the northern structure of the cluster is visible. You can see that A1758N is itself split into two sub-structures, known as East and West that are in the early stages of a collision with each other. Collisions such as this one are the most energetic events in the Universe apart from the Big Bang itself.]

Abell 370 – 4 bly

This image shows the massive galaxy cluster Abell 370 embedded in the middle of a field of nearly 8,000 galaxies flung across space and time.

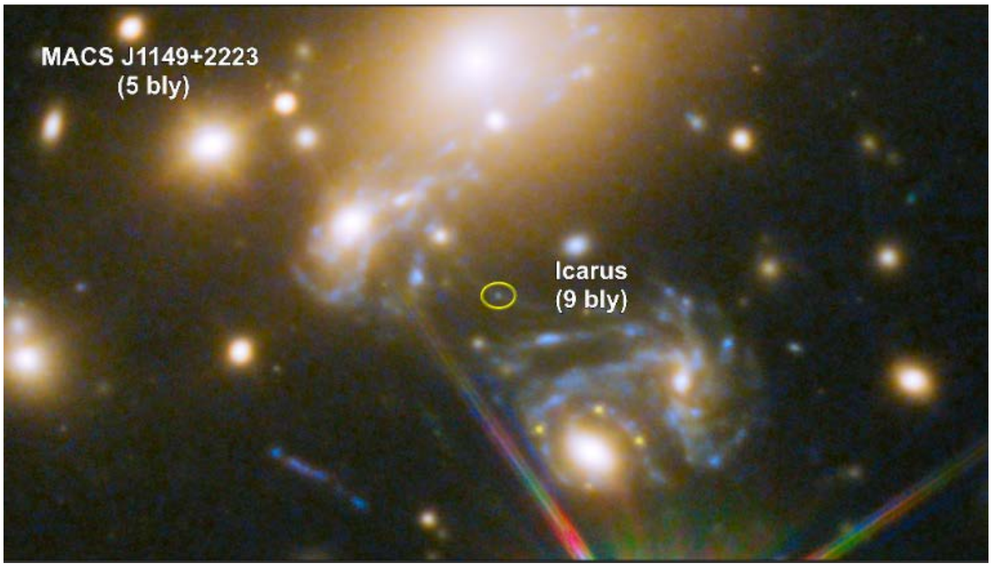
Hubble is mapping regions previously observed by the Spitzer Space Telescope. The two telescopes are working together to detect and study some of the universe's earliest galaxies. Spitzer imaged a much larger area of the sky than Hubble but could not measure the distances to the galaxies it observed. Hubble, in a major survey, is now coming back to the full area of sky covered by Spitzer, to measure the distances to thousands of galaxies.

Astronomers anticipate that the survey will yield new insights into when the most massive and luminous galaxies formed and how they are linked to dark matter, and how the dynamics of the clusters influence the galaxies in and around them.



Icarus – 9 bly

This foreground galaxy cluster 5 billion light years away is acting as a gravitational lens for more distant objects. As we zoom in we can see the star nicknamed Icarus – 9 billion light years away. This is the farthest individual star ever seen. The colors of the light coming from this object, showed that it was a blue supergiant star. This type of star is much larger, more massive, hotter, and possibly hundreds of thousands of times intrinsically brighter than our Sun.



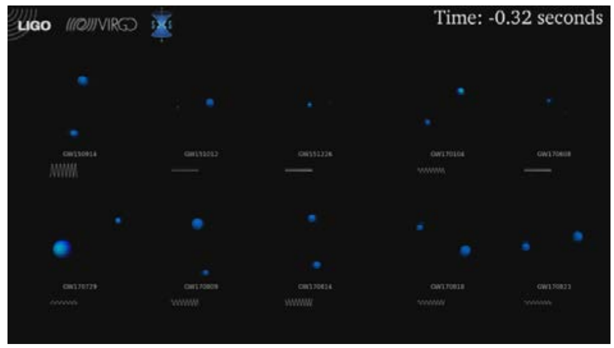
Hubble Deep Ultraviolet

Astronomers using Hubble's ultraviolet capabilities have captured one of the largest panoramic views of the distant universe. The field features approximately 15,000 galaxies, most of which are forming stars. Hubble is literally tracking the birth of stars over the last 11 billion years back to the cosmos' busiest star-forming period, which we think happened about 3 billion years after the big bang. The light from distant star-forming regions in remote galaxies started out as ultraviolet. However, the expansion of the universe has shifted the light into infrared wavelengths. By comparing images of star formation in the distant and nearby universe, astronomers glean a better understanding of how nearby galaxies grew from small clumps of hot, young stars long ago.

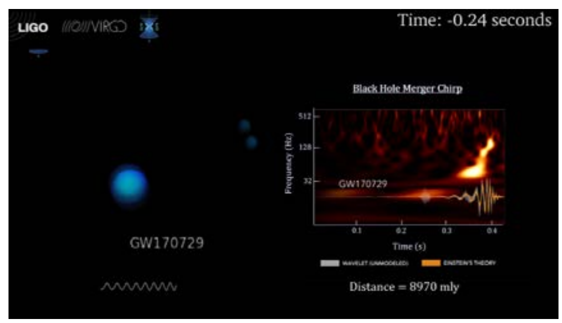
[LIGO

In 2018, LIGO and VIRGO gravitational-wave detectors published new results from two Observing runs in 2017. Four new black hole mergers were announced. The LIGO and Virgo collaborations have now confidently detected gravitational waves from a total of 10 stellar-mass binary black hole mergers and one merger of neutron stars.

This is a visualization of the merging black holes that LIGO and Virgo have observed so far. The video shows numerically relative calculations of the black holes' horizons above the emitted gravitational waves during the final few orbits of the black holes as they spiral inwards, merge and ring down.



As the horizons of the black holes spiral together and merge, the emitted gravitational waves increase in amplitude and frequency like a 'chirp'. Here we see the Chirp for the 4 new events. GW170729 is the furthest ever observed at nearly 9 billion light years away. Note that the actual wave and the wave predicted by general relativity are included. Einstein's theory was found to be consistent with the data.



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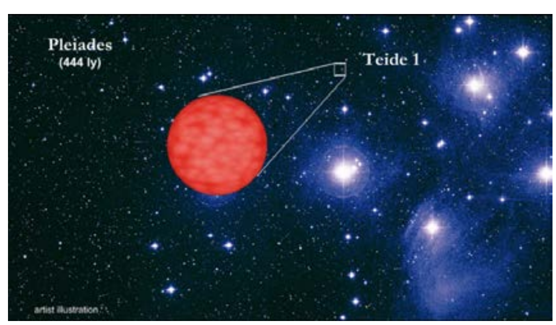
Brown Dwarfs

Brown Dwarf Teide 1 – 444 ly

Brown dwarfs were predicted to exist as far back as the mid-1960s. But because they do not shine in visible light, they are very hard to find. The first one ever actually found was Teide 1 in the Pleiades open star cluster in 1995.



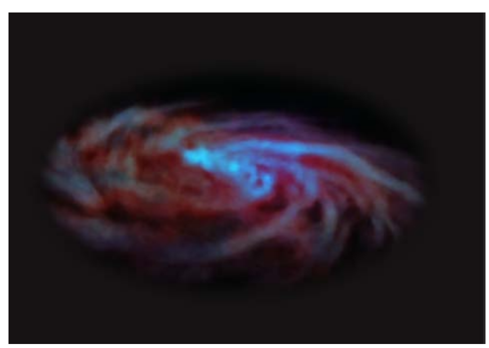
Brown Dwarf Rho-Oph 102 – 400 ly

Here we're zooming into the brown dwarf Rho-Oph 102, in the Rho Ophiuchi star-forming region. Its position is marked by the crosshairs. Recent studies indicate that this brown dwarf might be in the process of forming a terrestrial planet in a debris disk surrounding it.

Brown Dwarf Formation

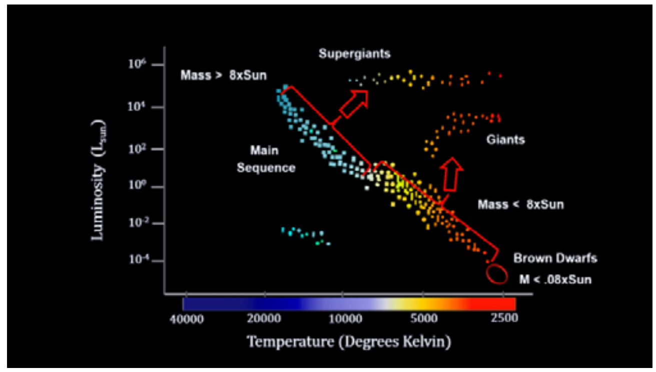
It is generally considered that brown dwarfs are formed just like regular stars. With the key difference being that they do not wind up with enough mass to trigger hydrogen fusion like main sequence stars do. Stars form inside concentrations of cold interstellar gas and dust known as molecular clouds. [These regions are extremely cold with temperature around 10 to 20 K, just above absolute zero.] The process begins when the denser parts of the cloud collapse under their own gravity. [These clumps typically have masses around 10 to 50 solar masses.] Angular momentum turns the cloud into a rotating disk with the center forming into a protostar. The whole process takes about 10 million years.

At first, the protostar has about 1% of its final mass. But the envelope of the star continues to grow as infalling material is accreted. Densities and temperatures rise dramatically. This continues until either the cloud material is exhausted and we have a brown dwarf, or [after a few million years,] thermonuclear fusion begins in its core and we have a young star. You can see why brown dwarfs are sometimes referred to as 'failed stars'.

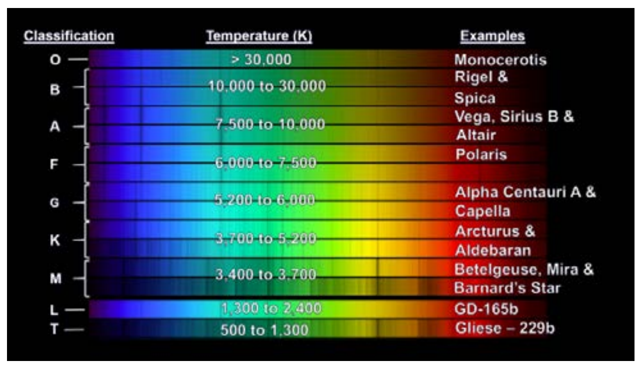


[At that point, a strong stellar wind is produced which stops the in fall of new mass. Its mass is fixed, and its future evolution is set.]

On an H-R diagram, we put brown dwarfs below the low mass red stars. And, because they do not burn hydrogen, they never grow to giant stars and explode. Brown dwarfs only shine in infrared light, so they are hard to find. And by the way, they are not brown.



Two new stellar classifications have been added to cover these objects. Spectral Class L represents the larger mass brown dwarfs and may include some low mass red dwarfs. Spectral Class T will be the lower mass brown dwarfs.

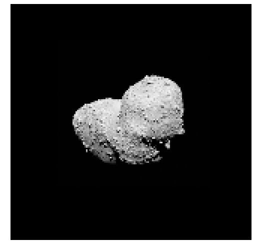


Effects of Increasing Mass

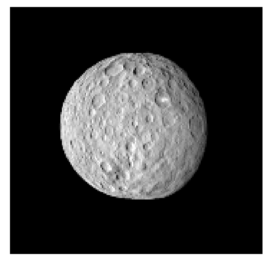
Planets on the other hand, form from the debris disks around forming stars. And yet, because giant planets don't burn hydrogen, brown dwarfs have more in common with them than they do with stars. To understand how we distinguish a brown dwarf from a low mass star or from a high mass planet, we'll examine the effects of increasing mass on celestial objects starting with rocks.

A rock maintain its shape and size due to the molecular bonding of its material. Gravity plays no role in the size or shape of the object. An asteroid like Steins [5.9 km or 3.7 miles in diameter] is a good example of this (as is any solid object on Earth).

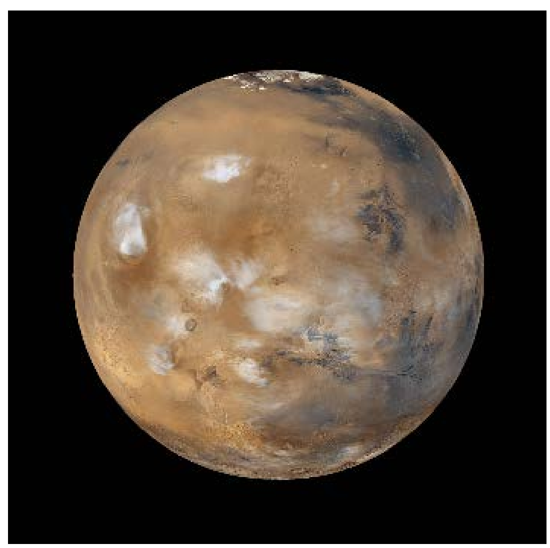
As we increase the mass of an object, the first transition is reached when the mass produces a gravitational force strong enough to hold together a “rubble pile”. The near Earth rubble-pile asteroid Itokawa [350 km or 217 miles in diameter; 9.39 x 10^{20} kg] is a good example of this. It contains a number of objects with different densities.



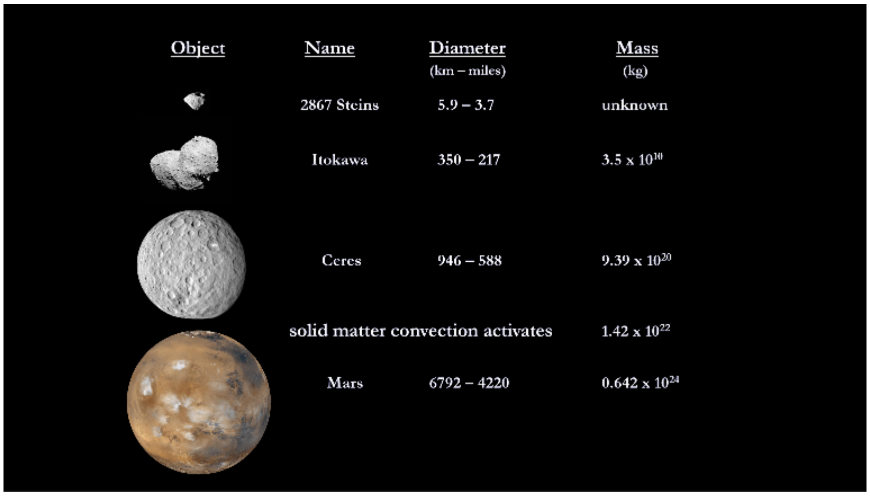
As we continue to add mass, the force of gravity will at some point exceed the material strength of the body, and force the object to take a more spherical shape. For materials with the strength and density of stony asteroids the critical mass is around 580 thousand trillion metric tons. [That’s 5.8 x 10^{20} kg. A diameter would be around 800 km or around 500 miles]. Ceres [with a mass of 9.39 x 10^{20} kg] is a good example of this. It’s large enough to be named a dwarf planet.



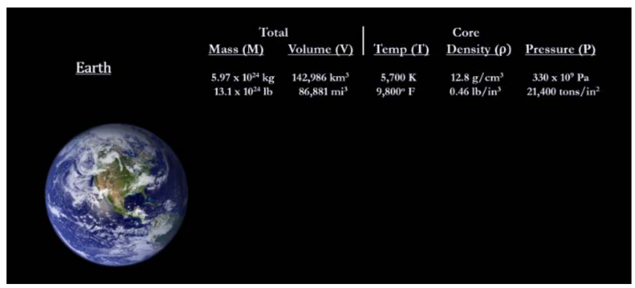
While becoming spherical is perhaps the most obvious outward sign of increasing mass, the interior of the body begins to undergo geophysical transitions as the mass increases. One is the transition to bodies large enough to sustain convection in their interiors. Convection is the process by which less dense material rises and more dense material sinks. Solid matter convection activates somewhere around 14 million trillion metric tons. [1.42 x 10^{22} kg with a diameter around 5000 km] The planet Mars is a good example of this. [0.642 x 10^{24} kg and a diameter of 6792 km]



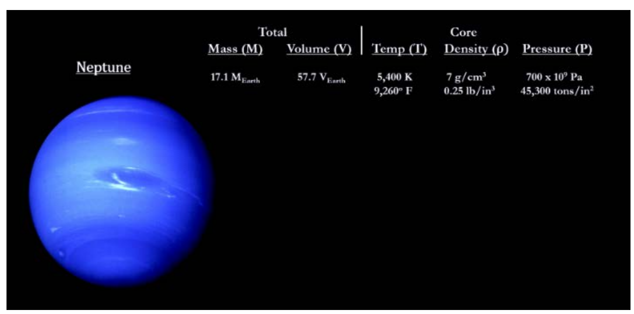
[At a diameter of around 3000 km for a terrestrial body – the average gravitational energy per atom exceeds 1~eV, which is the typical energy of chemical reactions. A body this size has sufficient gravitational energy to substantially modify the initial chemical composition of its initial materials.]

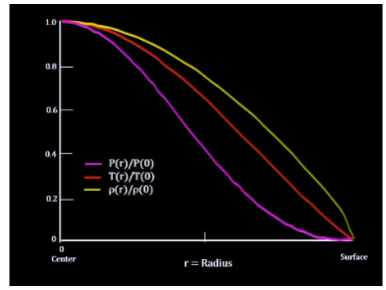


On Earth, convection in the mantel creates tectonic plate movement. We'll use Earth as our first baseline. The pressure and temperatures of the Earth's iron core are estimates based on the melting temperature of iron under great pressure. Since solar systems are made up mostly of Hydrogen and Helium with only small amounts of heavier elements like iron, there is insufficient solid matter to create terrestrial planets much larger than the Earth.



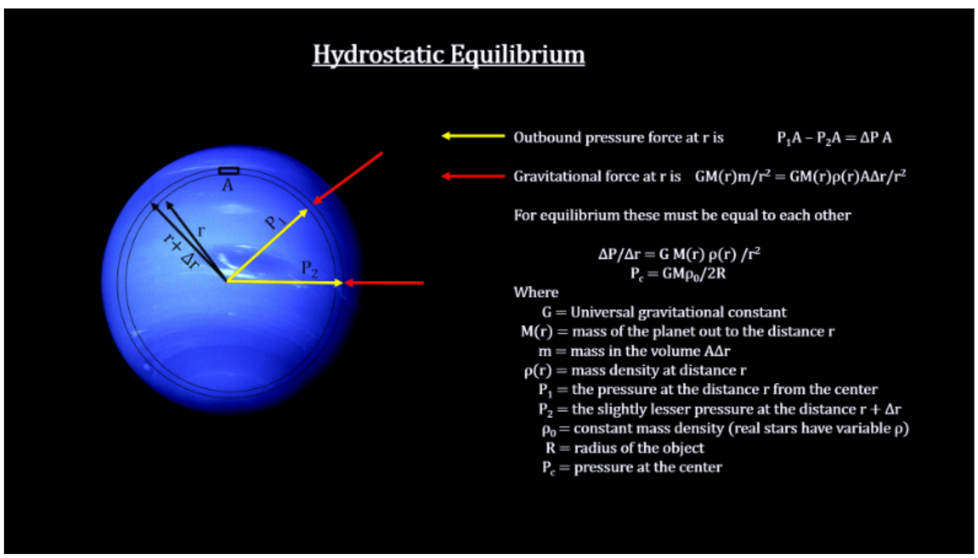
And there isn't another significant qualitative change in the relation between pressure and gravity until we reach masses greater than 11 times the mass of the Earth. So we'll switch to giant gas planets like Neptune. It's 17 times more massive than the Earth but almost 60 times larger. Its core is less dense and cooler, but it has more than twice the pressure.



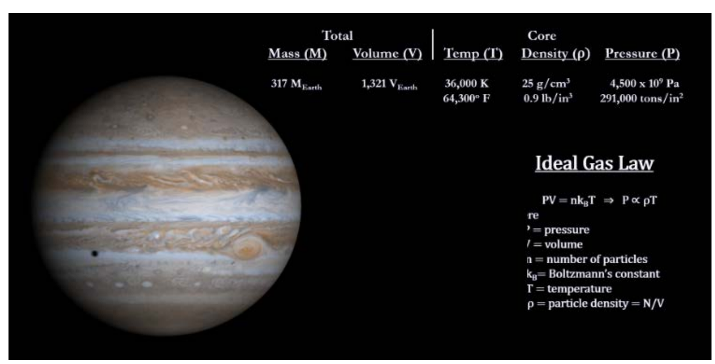


Planets like these experience strong gravitational forces pushing the mass inward. The deeper into the planet we go, the greater the pressure, - the greater the temperature - and the greater the mass density. The extremes all exist at the center, so we'll focus on planetary cores.

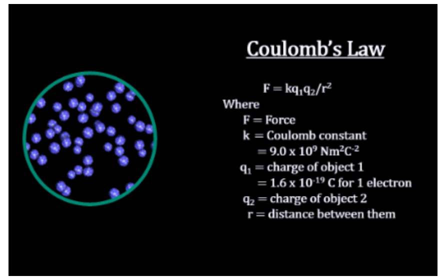
The high temperatures in the interior create significant kinetic energy within the gas that creates pressure forces pushing outward. The planet takes on a volume that equalizes these two forces at each and every distance from the center. We say that the planet is in Hydrostatic Equilibrium. This provides information about the pressures felt in a gas giant's core as a function of its mass.



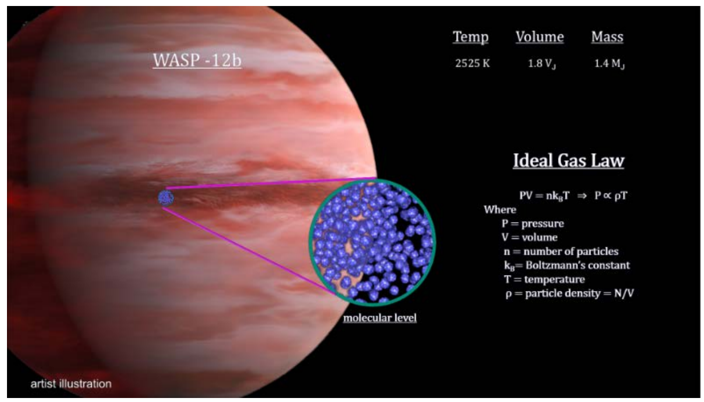
Now if we add mass to the planet, the particle density and the interior temperature will increase according to the laws of thermodynamics. At 10,000 degrees Kalvin, the electrons are stripped from their protons and form a free electron gas. The ideal gas formula still holds and shows that the rise in temperature increases the outward pressure. As a result, the planet's volume grows. Jupiter is 18 times more massive than Neptune and 23 time larger. [Its core is 3 and a half times denser, 6 and a half times hotter, with 6 and a half time the pressure.]



Here is a look at what's happening at the electron level. The electrons are bouncing off each other. It's the electromagnetic force of negative charge to negative charge repulsion that causes the bounce. This is called the Coulomb force. You can see from Coulomb's Law that the force gets very large when the distance between electrons gets very small. This is the same force that prevents your hands from going through each other when you clap.

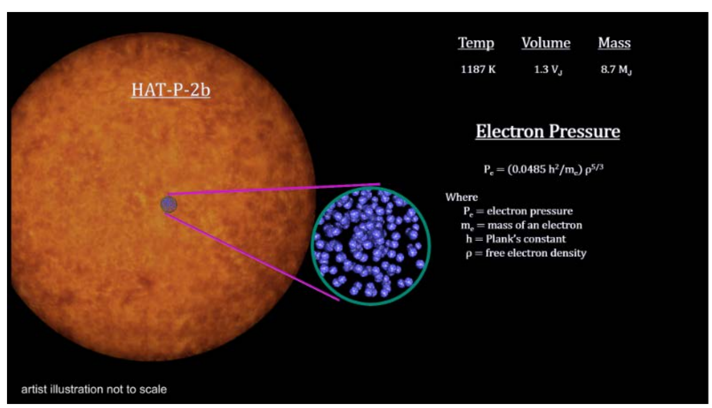


Now let's add enough mass to get to the size of the exoplanet WASP -12b. It's the largest exoplanet discovered to date. At the electron level we see the density of the hydrogen atoms is going up at the same time that the atoms are moving faster – that's their temperature going up. It's the faster movement that creates the increase in outward pressure that counters the increased inward gravitational pressure. WASP -12b is only 40% more massive than Jupiter, but it has almost twice the volume.

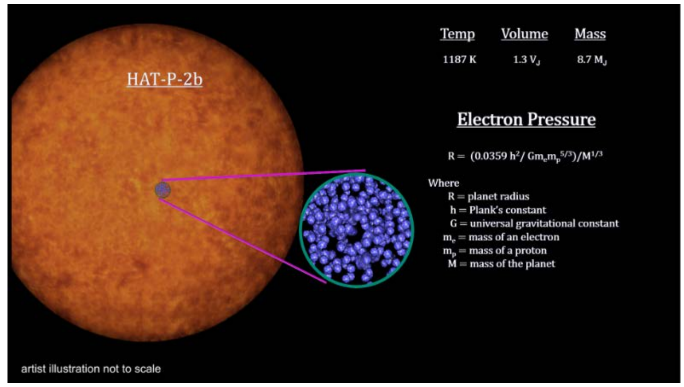


But as we continue to add mass, the inward gravitational forces begin to overwhelm the outward coulomb forces. The matter density prevents the electrons from moving. Therefore, increases in temperature slow down. Outward thermal pressure does not go up to meet the added inward pressure caused by the added mass. The gas is said to have become degenerate. The laws of Quantum Mechanics starts to overtake the laws of thermodynamics. The Pauli Exclusion Principle - that no two electrons can occupy the same quantum state comes into play. Based on this principle, an outward pressure is created that prevents a total collapse.

It's called electron pressure. For our purposes, it is important to note that it is temperature independent. It depends only on the matter density. Electron pressure is extremely powerful. It takes a mass almost 1500 Jupiters to create a gravitational force that exceeds it. It is the force that keeps white dwarf stars from collapsing.

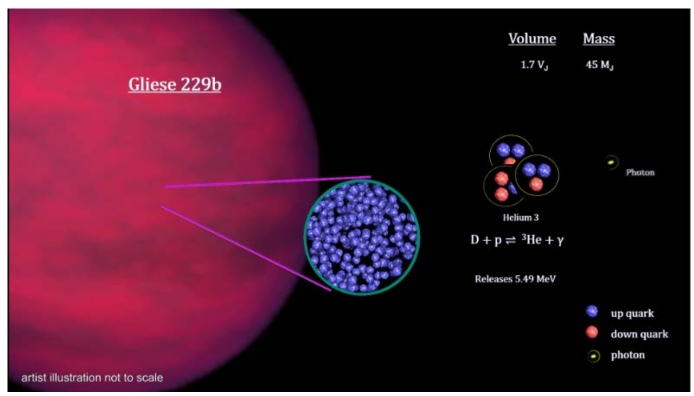


As this effect becomes dominant, adding matter causes the planet to increase its mass density but shrink in size. This would happen at around 10 Jupiter masses. The maximum size depends the planet's composition. We see that a pure hydrogen planet would have a maximum radius almost three times the maximum radius of a pure helium planet. HAT-P-2b is one of the most massive planets known so far. It has 6 times the mass of Wasp-12b, but its 30 percent smaller.



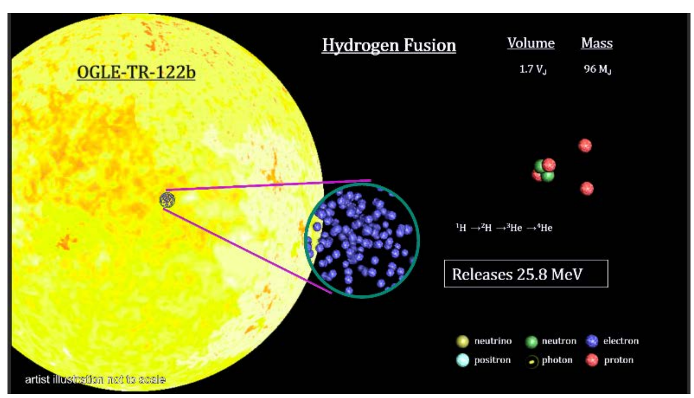
As we continue to add mass, the planet creates densities much greater than lead. The core becomes so hot and dense that, at around 11 to 16 Jupiter masses, it starts to fuse deuterium. [For every deuterium atom there are over 100 billion to a trillion hydrogen atoms.]At this point, it begins to shine in inferred wavelengths. We no longer have a 'planet'.

We have a 'Brown Dwarf'. Gliese 229b is a brown dwarf. Being larger than HAT-P-2b tells us that it contains a smaller amount of heavier elements. It's 70% larger than Jupiter, but has 45 times its mass. The deuterium burning can go on for up to 50 million years. It's important to note that at these masses, celestial objects cannot fuse hydrogen or lithium, and the thermal forces created by the deuterium burning are not enough to break the hold created by electron pressure.

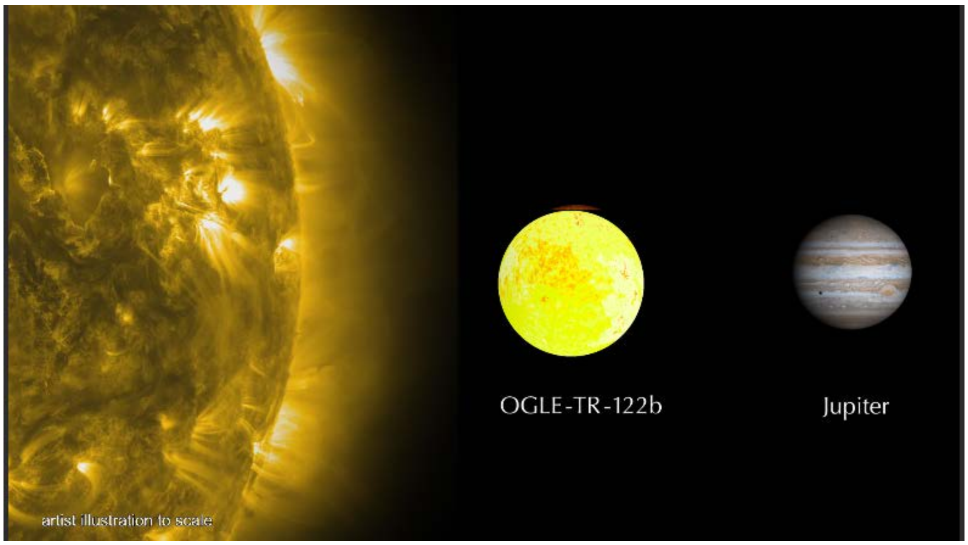


To get a star, we simply have to add more mass. Here's OGLE-TR-122b. It's one of the smallest known stars. It's around 96 Jupiter masses but with only a 16% larger radius. The conditions in the core are so extreme that hydrogen fusion begins. That's what makes it a true star.

Hydrogen fusion creates so much energy that it breaks out of the electron pressure quantum state and goes back into the thermodynamic realm. More mass will make it bigger and burn hotter – like our Sun. One measurable effect is that early on in a star's hydrogen burning life, it burns away all of its lithium. This gives us a way to distinguish brown dwarfs from a low mass stars. Brown dwarfs have lithium in their atmosphere and stars don't.

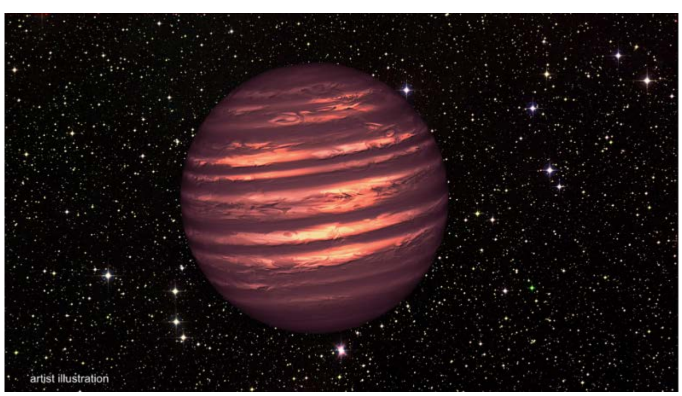


So we that distinguishing Brown Dwarfs from stars is easier than distinguishing them from planets. [Ideally, one would distinguish between two types of celestial objects based on their inherent characteristics and not on the circumstances of their creation. After all, an objects formation history may not always be discernable. For example, star interactions can separate a gas giant planet from its solar system leaving it all alone. If we spotted it, how could we determine if it was a high mass planet or a low mass brown dwarf?]

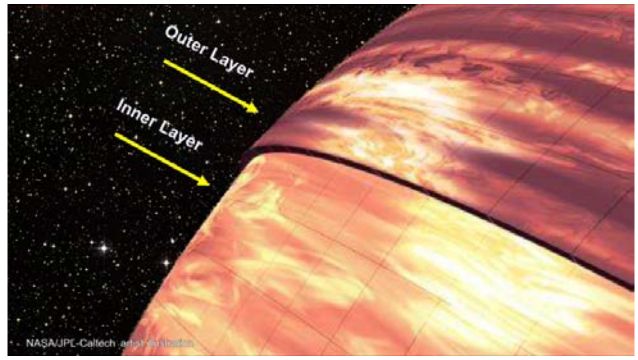


2MASSJ22282889-431026 – 35 ly

Let's take a closer look at what one of these brown dwarfs look like. Astronomers using the Spitzer and Hubble space telescopes have probed the stormy atmosphere of a brown dwarf just 35 ly away. It has a probable atmosphere making it a good example of the planet like characteristics of brown dwarfs.

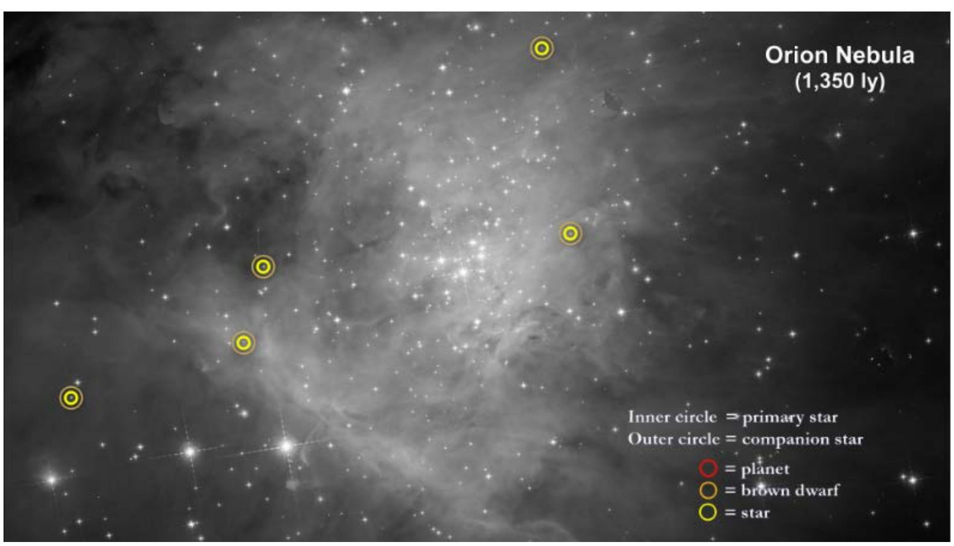


The probe's results revealed offset layers of material as indicated in the diagram. For example, the large, bright patch in the outer layer has shifted to the right in the inner layer. These variations are the result of different layers or patches of material swirling around the brown dwarf in windy storms as large as the Earth itself. We find that brown dwarf atmospheres can be similar to Jupiter's except that instead of raining ammonia, brown dwarfs rain molten iron droplets.



Substellar Objects in the Orion Nebula – 1,350 ly

In a deep survey for small, faint objects in the Orion Nebula, astronomers using the Hubble Space Telescope have uncovered the largest known population of brown dwarfs sprinkled among newborn stars. In the process, they also found some very massive planets. Here are some of the combinations they found. These are brown dwarfs orbiting stars. Here's a planet orbiting a brown dwarf. Here's a brown dwarf orbiting another brown dwarf. And here we see two giant planets orbiting each other without a star. Surveys like these indicate that brown dwarfs may be among the most common objects in our Milky Way galaxy.



NGC 1333 Brown Dwarfs – 1,000 ly

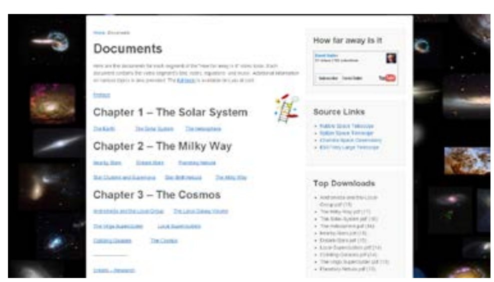
We'll end with a look at NGC 1333. It's a stellar nursery that has also been found to harbor an unusually high number of brown dwarfs. Some of them are at the very low end of the mass range for such objects – in other words, not much heavier than Jupiter. The James Webb Space Telescope, due to launch in 2021 will be used to learn more about these dim cousins to the cluster's bright newborn stars.

Minimum credit line: T.A. Rector/University of Alaska Anchorage, H. Schweiker/WIYN and NOAO/AURA/NSF

Credits

Here are the links to Hubble sites, whitepapers and other locations where I found the information contained in this 2018 review. These are also the places where you can begin to do your own research. I want to also thank Jonathan Onstead for his great help editing this video. And don't forget, every How Far Away Is It video, including this one, has a document with the text, pictures, links and notes located on howfarawayisit.com/documents.

Thanks for watching.



Saturn's Northern Lights
https://www.spacetelescope.org/news/heic1815/?lang
https://www.spacetelescope.org/images/heic1814b/

Japan lands a probe on asteroid Ryugu
https://astronomynow.com/2018/09/24/japans-hayabusa2-lands-to-rovers-on-asteroid/
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https://www.youtube.com/watch?v=cbwZUvXBfI4
https://commons.wikimedia.org/wiki/User:Tomruen
https://science.nasa.gov/asteroid-ryugu-hayabusa2

IC 63 - The ghost of Cassiopeia - 550 ly
https://www.spacetelescope.org/news/heic1818/?lang

Serpens Nebula HBC 672 - 1,300 light-years
http://hubblesite.org/news_release/news/2018-40

Eta Carinae Outburst – 7,500 ly
http://hubblesite.org/news_release/news/2018-33
http://hubblesite.org/video/1170/news_release/2018-33

Spatial scanning
http://iopscience.iop.org/article/10.1088/0004-637X/785/2/161/meta

NGC 6397 – 7,800 LY
http://hubblesite.org/news_release/news/2018-24

Milky Way Bulge Stars – 26000 ly
http://hubblesite.org/news_release/news/2018-01

GAIA Data Release 2 (DR2)
https://www.cosmos.esa.int/web/gaia/data-release-2
https://www.youtube.com/watch?v=wcW1coBGETo

Kepler Space Telescope Retires
https://www.nasa.gov/press-release/nasa-retires-kepler-space-telescope-passes-planet-hunting-torch
https://www.youtube.com/watch?v=xId3_Eifd44

NGC 3344 – 20 mly
https://www.spacetelescope.org/news/heic1803/?lang

M100 in Focus – 55 mly
http://hubblesite.org/image/4272/news_release/2018-48

NGC 1052-DF2 – 65 mly
https://www.spacetelescope.org/videos/heic1806a/

NGC 3256 – 100 mly
https://www.spacetelescope.org/news/heic1811/?lang
http://iopscience.iop.org/article/10.1088/0004-637X/806/1/126

NGC 1277 - 240 mly
http://hubblesite.org/news_release/news/2018-17
http://hubblesite.org/image/2500 (Perseus Cluster)

Coma Galaxy Cluster Star Clusters – 300 mly
http://hubblesite.org/video/1188/news_release/2018-44

Arp 256 – 350 mly
https://www.spacetelescope.org/news/heic1805/?lang

Abell 1758N – 3 bly
https://www.spacetelescope.org/news/heic1801/?lang

Abell 370 – 4 bly
http://hubblesite.org/news_release/news/2018-39
http://hubblesite.org/image/4229/news_release/2018-39
https://www.spacetelescope.org/news/heic1816/?lang

Icarus – 9 bly
http://hubblesite.org/news_release/news/2018-13

Hubble Deep Ultraviolet
http://hubblesite.org/news_release/news/2018-35

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https://www.ligo.caltech.edu/news/ligo20181203
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Brown Dwarfs

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https://www.space.com/23798-brown-dwarfs.html
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https://www.youtube.com/watch?v=mkktE_fs4NA
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https://www.eso.org/public/news/eso0507/
http://webbtelescope.org/articles/30?collection_name=Science_News
https://www.youtube.com/watch?v=ImrqjPeIows
http://adsbit.harvard.edu/cgi-bin/nph-iarticle_query?bibcode=1996EM%26P...75...17Z&db_key=AST&page_ind=2&plate_select=NO&data_type=GIF&type=SCREEN_GIF&classic=YES
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http://annesastronomynews.com/brown-dwarfs-may-host-rocky-earth-like-planets/
http://www.astro.sunysb.edu/aevans/AST205/notes/ast205-planetstructures2.pdf

Music

TBD

Greek letters:
- α β γ δ ε ζ η θ ι κ λ μ ν ξ ο π ρ σ τ υ φ χ ψ ω
- Α Β Γ Δ Ε Ζ Η Θ Ι Κ Λ Μ Ν Ξ Ο Π Ρ Σ Τ Υ Φ Χ Ψ Ω

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