2017 Review

Introduction

2017 was another very interesting year with a number of firsts. We detected our first asteroid from another star; a Type 1a Supernova companion survivor; a star collapse into a black hole without a supernova; a gravitationally lensed Type 1a Supernova; a non-elliptical early dead galaxy; colliding neutron stars; and visual confirmation of a gravitational wave.

Inside the Solar System we have:

- Jupiter picture
- Water vents on Europa
- A new Oort Cloud comet outside the orbit of Saturn

In and around the Milky Way we have:

- Gaia's view of the LMC
- A type 1a survivor
- A runaway star in the Orion Nebula
- A dark matter study in the Sculptor dwarf galaxy
- Zwicky Transient Facility first light

Beyond the galaxy:

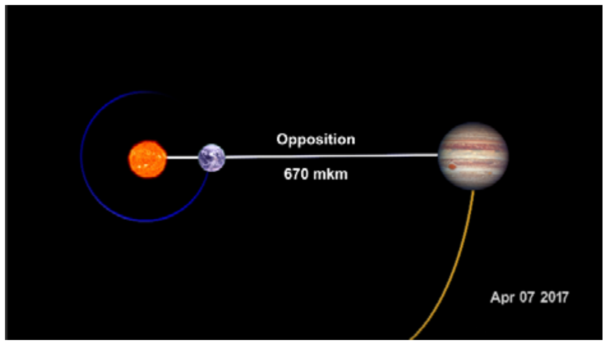
- Gravitationally lensed Type 1a Supernova
- A number of colliding galaxies
- An early dead galaxy with a twist
- Lots of new pictures of distant galaxy clusters

Plus a deeper look at Gamma-Ray Bursts and the gravitational wave from colliding neutron stars.

We'll start with a fantastic new Hubble picture of Jupiter.

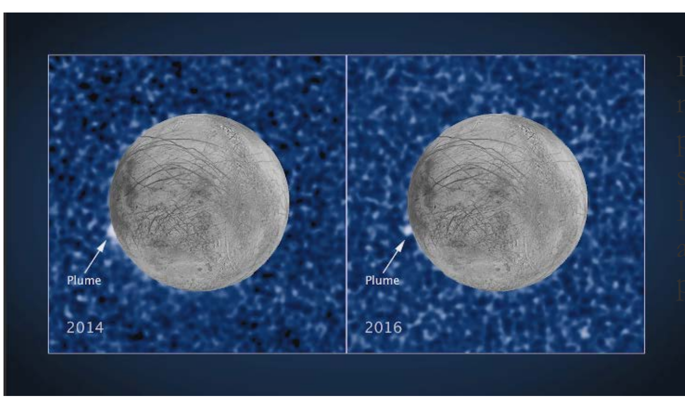
Jupiter in Opposition **[Music: Schubert - String Quintet]**

On April 7th Jupiter was in opposition with the hemisphere facing Earth fully illuminated by the Sun. [Opposition also marked the planet's closest approach to Earth about 670 million kilometers (416 million miles). This happens around once every 13 months. The next one is May 9th.]



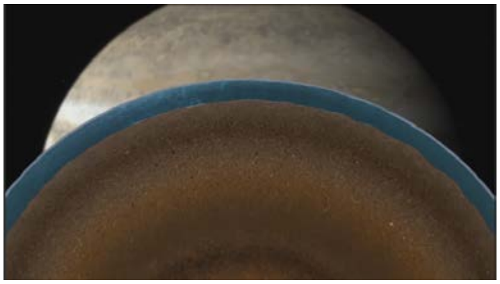
This Hubble image reveals the intricate, detailed beauty of Jupiter's clouds as arranged into bands. These bands are produced by air flowing in different directions at various latitudes. Lighter colored areas, called zones, experience high-pressure where the atmosphere rises. Darker low-pressure regions where air falls are called belts. Constantly stormy weather occurs where these opposing east-to-west and west-to-east flows interact.

Water Vents on Europa

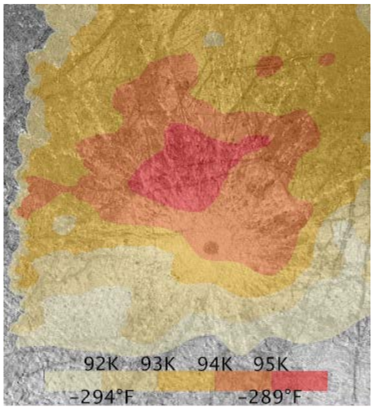


Recent Hubble observations of Jupiter's icy moon Europa have uncovered a probable plume of material erupting from the moon's surface. The plume went about 100 km above Europa's surface (that's 62 miles). It happened at the same location as a similar apparent plume erupted two years earlier.

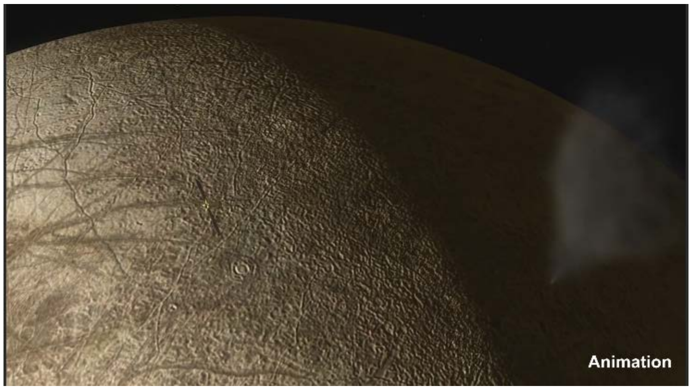
These plumes are consistent with the idea that Europa has an ocean of water under a thick layer of ice.



Although it is quite cold on the icy surface of the moon at 92 degrees Kalvin (that's -289 degrees Fahrenheit), other studies have found that there is an area of relatively warmer temperatures in the same region where the plumes are located. If there is a causal link between the plumes and the thermal anomaly, there could be geologic activity on Europa's surface that is producing the plumes. This would also provide the energy for life.

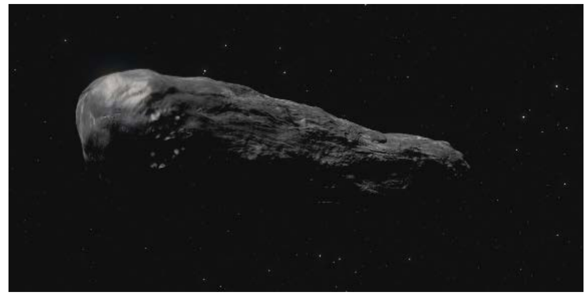


Given all this, a new mission has been funded to send a spacecraft called the Europa Clipper to Jupiter with the instruments needed to study Europa in greater detail. It is scheduled for launch in the 2020s.



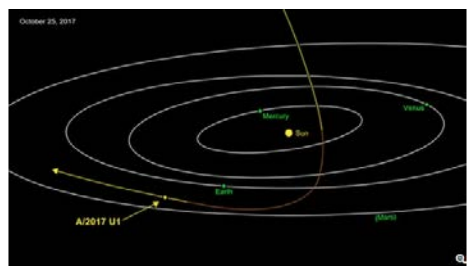
Interstellar Asteroid Enters Solar System

In October 2017, a team from the Pan-STARRS observatory in Hawaii detected a very unique object traveling on a hyperbolic path through our Solar System. Subsequent observations by a variety of telescopes, using spectroscopy and brightness curves found it to be a reddish-ray elongated asteroid tumbling lengthwise.



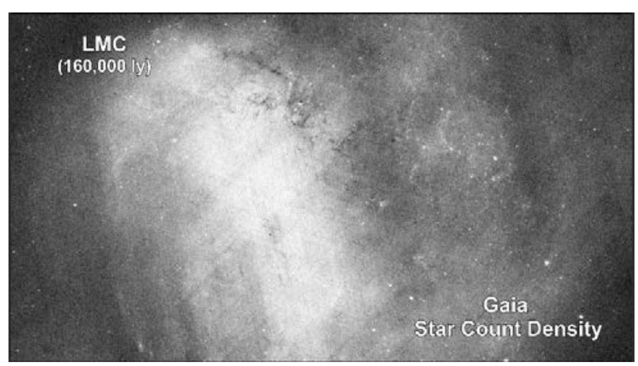
The object approached our solar system from almost directly "above" the ecliptic (that's the plane in space where the planets and most asteroids orbit the Sun). Its path indicates that it came from outside our Solar System. On Sept. 2, 2017 the small body crossed under the ecliptic plane just inside of Mercury's orbit and then made its closest approach to the Sun on Sept. 9. At that point (its perihelion) it was traveling 89 km/s (that's 55 miles/s) relative to the Sun. At that velocity, it is definitely not gravitationally bound to the Sun. [To see just how fast this is, Haley's Comet was going only 55 km/s (that's 34 miles/s) at its perihelion.**]**

Pulled by the Sun's gravity, the object made a hairpin turn under our solar system, passing under Earth's orbit on Oct. 14 at a distance of about 24 million kilometers (15 million miles) (that's 60 times our distance from the Moon). It has now shot back up above the plane of the planets and is speeding toward the constellation Pegasus.

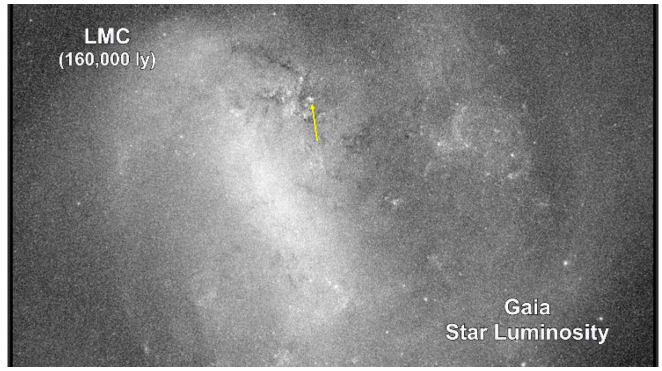


Gaia's View of the MC – 160 mly [Music: Puccini - Sister Angelica - Intermezzo]

Gaia continues its work creating a three-dimensional map of a billion stars with unprecedented positional and radial velocity measurements. A full data release is due in 2018. This past year, Gaia released 14 months' worth of data on the Large Magellanic Cloud (LMC), one of the nearest galaxies to our Milky Way. This image is based on stellar density. It shows the large scale distribution of stars in the LMC, clearly delineating the full extent of the spiral arms. It is peppered with bright dots; each representing a faint clusters of stars. [The stripes along the central bar are an artefact caused by Gaia's scanning procedure and will gradually decrease as more data is gathered.]



This image is based on the total luminosity. It is dominated by the brightest, most massive stars, which greatly outshine their fainter, lower-mass counterparts. In this view, the bar of the LMC is outlined in greater detail, alongside individual regions of star formation like the bubbling Tarantula Nebula.



Here are a few views in visible light from ground based telescopes.

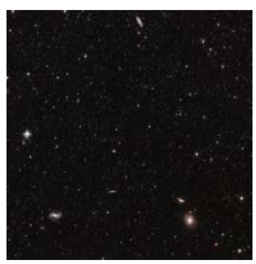
  

Dark Matter in the Sculptor Dwarf Galaxy - 285,000 ly

Here we zooming into the Sculptor Dwarf galaxy – an elliptical/spheroidal galaxy orbiting the Milky Way. In 2017, Gaia and Hubble provided datasets separated by 12 years that were used to measure the exact 3 dimensional motion of a small number of Sculptor's stars. The main goal was to examine the distribution of dark matter in a galaxy without a central bar like our own.

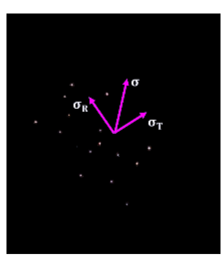
The current theory has it that dark matter is cold and only interacts with itself and visible matter via gravitational forces. Statistical simulations indicate that matter with these properties would clump into galaxies with the dark matter density being highest in the center. This peak density at the center is referred to as a dark matter cusp. But spheroidal galaxies like this don't have core dense center bars like our own. So the central question became "does this galaxy have a dark matter cusp even though it has no visible core?" If the answer is no, as expected by many, than we go back to the drawing board for figuring out dark matter.

126 stars were found in common in the two Hubble Pointings and the Gaia dataset. Using star distance, the researchers identified 91 of these stars that were actually inside Sculptor.



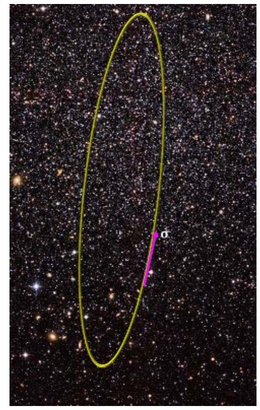
Using only those stars with the most accurate motion readings, brought the number down to 15 stars. **[**They found that the radial and tangential velocities were on the order of 11.5 and 8.5 km/s.**]** Over the 12 years, they would have traveled on average of only 6 ten thousandths of a light year in Sculptor's own reference frame.

Let
t = time = 12.3 years
d = distance star travels
σ = mean velocity within Sculptor's frame of reference
σ_T = mean transvers velocity = 8.5 km/s
σ_R = mean radial velocity = 11.5 km/s



Then
$\sigma = (\sigma_T^2 + \sigma_R^2)^{1/2}$
$= 14.3$ km/s
And
$d = \sigma t = (14.3 \text{ km/s})(12.3 \text{ years})$
$= 5{,}547{,}000{,}000$ km
$= 0.00059$ ly

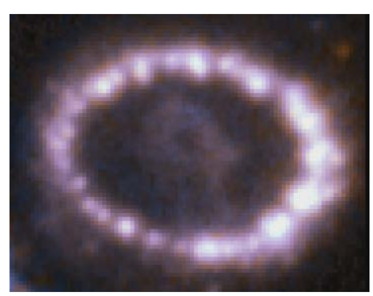
The results show that stars in the Sculptor Dwarf Galaxy move preferentially on elongated radial orbits. This indicates that the density of dark matter increases towards the center instead of flattening out. These findings are in agreement with the established dark matter model. But the data set is very small, and more is needed before a definite answer to our question can be reached.



New Era SN 1987A – 163,000 ly [Music: Bach - Concerto for Piano, Strings and Continuo]

Three decades ago, astronomers spotted one of the brightest exploding stars in more than 400 years. The titanic supernova, called 1987A (SN 1987A) in the Large Magellanic Cloud, blazed with the power of 100 million Suns for several months following its discovery **[**on Feb. 23, 1987**]**. A dense ring of gas around the supernova is glowing in optical light, and has a diameter of about one light-year. A flash of ultraviolet light from the explosion energized the gas in the ring, making it glow for decades. [The ring was created when the star was a red giant - around 20,000 years before the star exploded.]

This time-lapse video sequence of Hubble images show the effects of the shock wave from the supernova blast smashing into the ring. The ring begins to brighten as the shock wave hits it. [The ring is about one light-year across.] In the past few years, the ring's X-ray light has stopped getting brighter. And, the bottom left part of the ring has started to fade. These changes provide evidence that the explosion's blast wave has moved into the region beyond the ring. This represents the end of an era for this supernova. We expect to learn more about this new region as the blast wave impacts its contents.



[It is interesting to note that supernova theory says that there should be a compact object formed at the center of the supernova -- either a neutron star or a black hole -- but no telescope has uncovered any evidence for one yet.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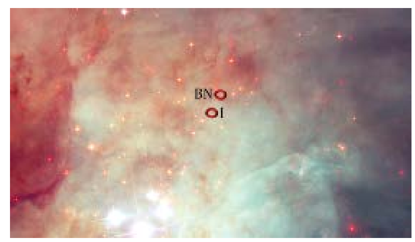
N103B – Type 1A Supernova Survivor – 160 mly

Most supernova explosions involve just one star. But Type 1a supernova involve a binary star system with a normal star and a white dwarf. But no one has ever found an exploding star's companion. In 2017, a group of astronomers used Hubble to study the remnant of the Type Ia supernova explosion [SNR 0509-68.7 — also] known as N103B located in the LMC where they may have finally found one.

Using the exploding star's remnant curved shock fronts, they located the center of the explosion and found a candidate star nearby. The star has the right temperature, luminosity and distance from the center of the original supernova explosion. Although this star is a reasonable contender for N103B's surviving companion, its status cannot be confirmed yet without a spectroscopic confirmation. The research is still ongoing.

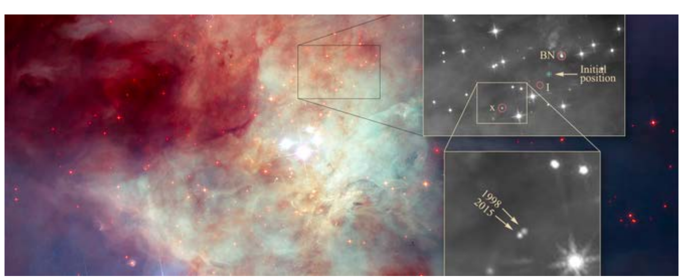
Runaway Star in the Orion Nebula – 1,344 ly

Here we are panning across the Kleinmann-Low nebula 1,300 light years away at the heart of the Orion Molecular Cloud. It is the most active star-forming region in Orion. Cloaked in dust, the stars in Kleinmann-Low are only visible in infrared light.



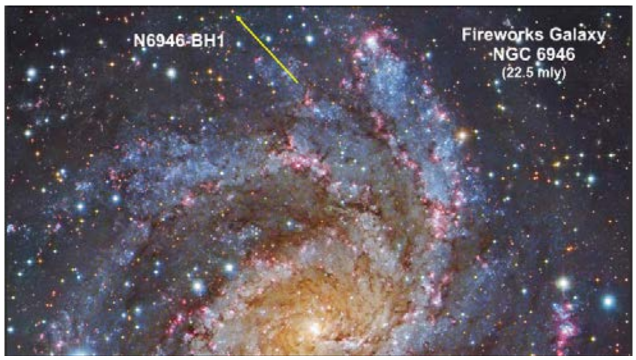
Decades ago, researchers found two stars — labeled BN, **[**for Becklin-Neugebauer**]**, and "I," for source I traveling at high speeds in opposite directions from each other. They traced both stars back 540 years to the same location. This suggested that they were part of a multiple-star system. But the duo's combined energy, which is propelling them outward, didn't add up. The researchers reasoned there must be at least one other star that took kinetic energy from the other two.

While searching for rogue planets and brown dwarfs among this turbulence, astronomers have found a star – labeled x for source x, moving at an unusually high speed — about 200,000 km per hour. That's almost 30 times the speed of most of Orion's stars. It's thought that this star might be the missing piece of the star system. If this is the missing star, it might shed light on just what caused the 3 star system to break apart in the first place in the year 1477.

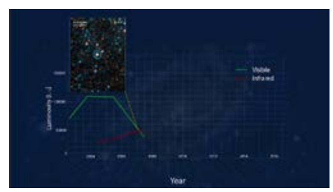


Star Collapses into a Black Hole – 22 mly

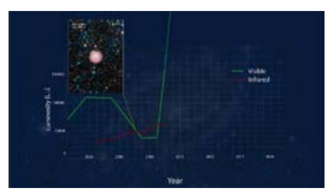
The Large Binocular Telescope (LBT for short) in Arizona was scanning the Fireworks Galaxy 22 million light years away looking for supernova candidates. [The galaxy is known for having large numbers of supernova explosions.] They examined the star named N6946-BH1 – a star 25 times more massive than our Sun. Stars that size usually end in a supernova explosion – leaving behind a neutron star or a black hole.



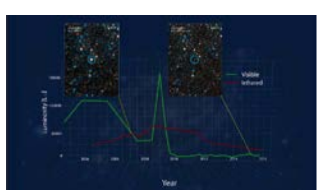
Here's a graph of the stars luminosity in visible and infrared light over time. In 2007, Hubble took this picture of the star.



In 2009, the star shot up in brightness to become over 1 million times more luminous than our sun for several months. The expectation was that it was about to supernova.



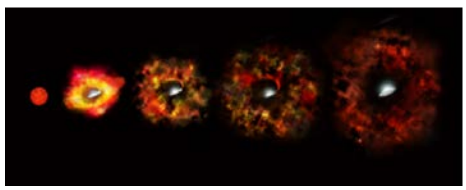
But it didn't. It just seemed to vanish, as seen in this image from 2015. After the LBT turned up the star, astronomers aimed the Hubble (for visible light) and Spitzer (for infrared light) space telescopes to see if the star was still there. All the tests came up negative. The star was no longer there. The researchers eventually concluded that the star must have become a black hole - without a supernova.



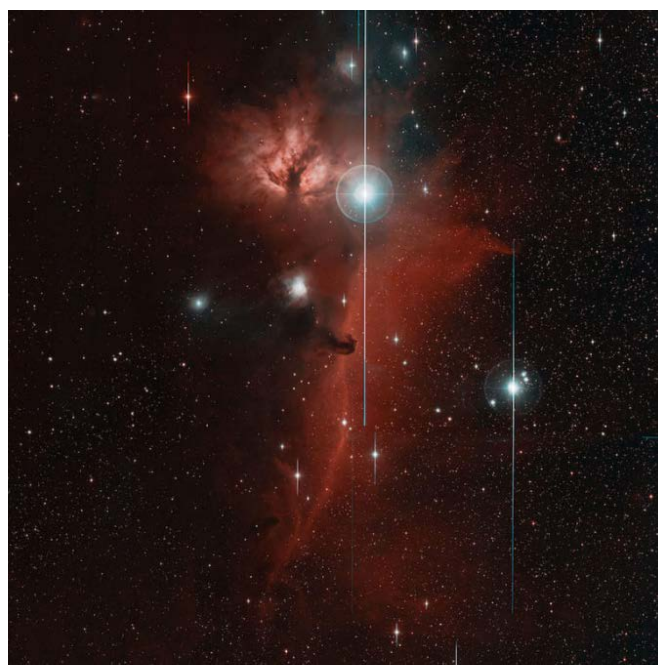
[This illustration shows the possible final stages in the life of a supermassive star that fails to explode as a supernova but instead implodes under gravity to form a black hole.

- The massive star evolves into a red supergiant.
- The outer envelope of the star is ejected and expands, producing a cold, red transient source surrounding the star.
- Gravity pulls the rest of the star to within its Schwarzschild radius creating a newly formed black hole.
- Some residual material falls into the black hole, as illustrated by the stream and the disk, potentially powering some optical and infrared emissions years after the collapse.

It has been estimated that up to 30% of all massive stars form black holes this way with the remaining 70% taking the supernova path.]



Zwicky Transient Facility Sees First Light



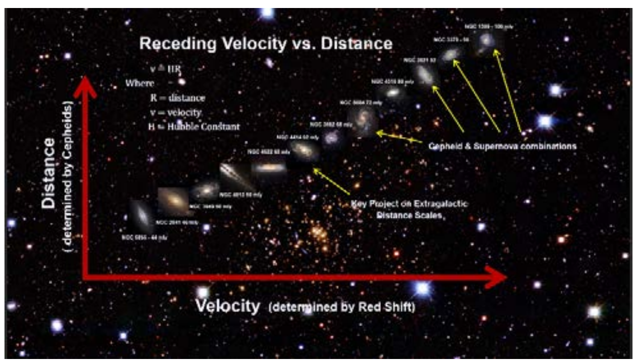
We covered Palomar Observatory's new Zwicky Transient Facility (ZTF for short) in our 2016 review. It's a robotic camera with the ability to capture hundreds of thousands of stars and galaxies in a single shot. In 2017, ZTF took its first image of the sky, an event astronomers refer to as "first light." This first-light image of Orion is a taste of what's to come.

Every night, ZTF will scan a large portion of the Northern sky, discovering objects that erupt, move or vary in brightness including asteroids, comets and supernovae. Each image is more than 24,000 by 24,000 pixels. 4 terabytes of data will be collected each night. ZTF's science survey phase is scheduled to begin in February, 2018.

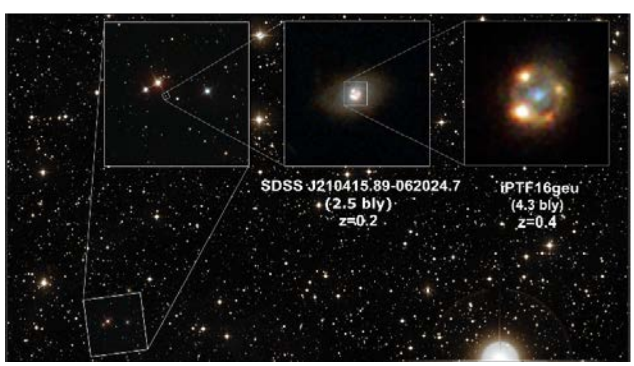
Gravitationally Lensed Type 1a SN – 2 bly & 4 bly

[Music: Mozart - Adagio for Violin and Orchestra]

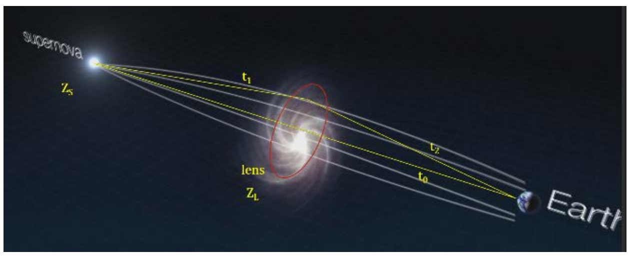
You may recall that we used redshift to determine a galaxy's receding velocity along with the inverse square law for standard candles like Cepheid Variables and Type 1a Supernova to determine a galaxy's distance. Combined, they gave us Hubble's Law and the Hubble Constant.



In 2017, a Swedish-led team of astronomers used the Hubble Space Telescope to analyze the multiple images of a gravitationally lensed type 1a supernova. This had never been done before. Here we see the lensing galaxy in the middle frame. It's over 2 billion light years away. The four images of the supernova can be seen in the right most frame. It originated over 4 billion light years away. **[**iPTF16geu was initially observed by the Palomar Transient Factory collaboration with the Palomar Observatory.**]**



These four images of the exploding star and the time difference in their light profiles can be used to measure the Hubble constant in a completely different way. Since the light travel times for the various images are unequal, intrinsic variations of the source would be observed at different times in the images. The time delay between the images is proportional to the difference in the light path lengths through the lensing galaxy's space-time, which in turn is proportional to one over the Hubble constant. So, by measuring redshifts and time delays, and by producing an accurate model for the lensing galaxy, the Hubble constant can be calculated. But measuring the lens properties of a galaxy billions of light years away is difficult. This is where most of the ongoing research is focused.



Let

$\Delta t = (t_1+t_2) - t_0$

Z_S = source redshift

Z_L = lensing galaxy redshift

φ_{lens} = gravitational lens mass model

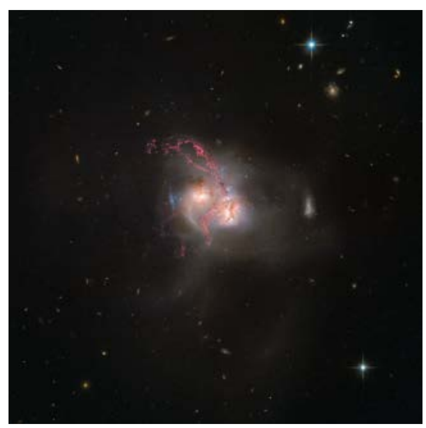
H_0 = Hubble constant

Then

$H_0 = Z_S Z_L \varphi_{lens} / \Delta t (Z_S - Z_L)$

Markarian 266 - 350 mly

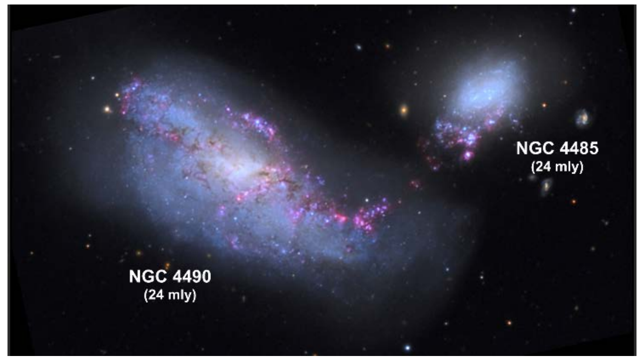
Here we are zooming into Markarian 266 (aka NGC 5256). The odd structure of this galaxy is due to the fact that it is not one galaxy, but two — in the process of a galactic collision. It is composed of two disc galaxies whose nuclei are currently just 13 000 light-years apart. Their constituent gas, dust, and stars are swirling together igniting newborn stars in bright star formation regions across the galaxy. In addition, each merging galaxy contains an active galactic nucleus, where gas and other debris are fed into supermassive black holes.



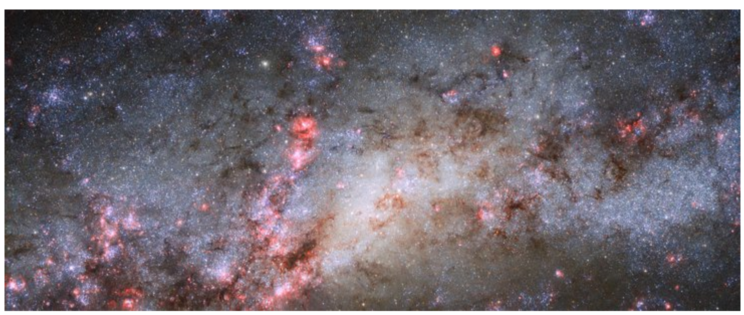
Interacting Galaxies NGC 4490 and NGC 4485 – 24 mly

Here we see NGC 4490 and NGC 4485. Together they form the system Arp 269. Over millions of years, their mutual gravitational attraction has dragged the two galaxies into each other. In this image, the two galaxies have moved through each other and are speeding apart again. But the galaxies are likely to collide once more (within a few billion years). 4490 was once a barred spiral galaxy, like the Milky Way. But now the outlying regions have been stretched out, resulting in its nickname - the Cocoon Galaxy.

[The extreme tidal forces of their interaction have determined the shapes and properties of the two galaxies. Virtually no trace of its past spiral structure can be seen from our perspective, although its companion galaxy 4485 still clings on to its spiral arms. Star formation is also evident in the thin thread that connects the two galaxies: a bridge of stars created by the ancient crash, stretching over the 24,000 light-years that currently separate the pair.]



[This cosmic collision has created rippling patches of higher density gas and dust within both galaxies. The conditions there are ripe for star formation; the brilliant pockets of light seen here are dense clouds of ionized hydrogen, glowing as they are irradiated with ultraviolet light from nearby young, hot stars. This spectacular burst of new activity has led to NGC 4490's classification as a starburst galaxy.]



Interacting Galaxies NGC 1510 and NGC 1512 – 38 mly

Here we're zooming into the tiny galaxy NGC 1510 and its colossal neighbor NGC 1512. The large galaxy to the left in this image, is classified as a barred spiral. The tiny NGC 1510 to the right, on the other hand, is a dwarf galaxy. Despite their very different sizes, each galaxy affects the other through gravity, causing slow changes in their appearances.

[The bar in NGC 1512 acts as a cosmic funnel, channeling the raw materials required for star formation from the outer ring into the heart of the galaxy. This pipeline of gas and dust in NGC 1512 fuels intense star birth in the bright, blue, shimmering inner disc known as a circumnuclear starburst ring, which spans 2400 light-years.

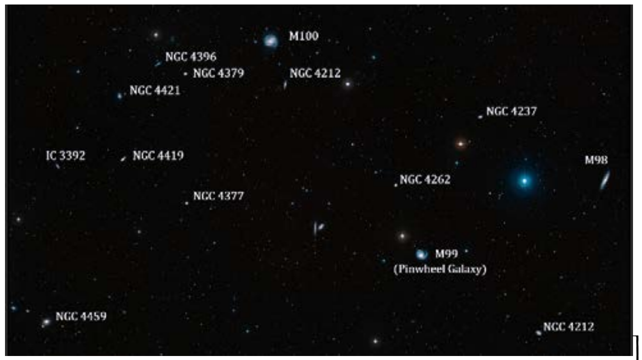
Both the bar and the starburst ring are thought to be at least in part the result of the gravitational forces between the two galaxies. The merger that has been going on for 400 million years. Together, the pair demonstrate how interactions between galaxies, even if they are of very different sizes, can have a significant influence on their structures, changing the dynamics of their constituent gas and dust and even triggering starbursts. Such interactions between galaxies, and galaxy mergers in particular, play a key role in galactic evolution.]

A Problem Galactic Pair – 55 mly

Here's an image of two galaxies: one is seen almost face-on and the other is seen edge-on. They were observed by Hubble in 2017 to celebrate its 27th year in orbit. In the face-on galaxy, we can see spiral arms and the blue patches of ongoing star formation and young stars. In the edge-on galaxy, we can see huge swathes of dust responsible for the mottled brown patterns. We also see a burst of blue to the left side of the galaxy indicating a region of extremely vigorous star formation.

Their galaxy centers are 35,000 light years apart. At their closest points, the galaxies are separated from each other by only around 7,000 light-years. Given this very close arrangement, astronomers are intrigued by the galaxies' apparent lack of any significant gravitational interaction. [The only indication of an interaction is a faint bridge of neutral hydrogen gas -- not visible in this image – that appears to stretch between them.] The long tidal tails and deformations in their structure that are typical of galaxies lying so close to each other are missing completely.

[As we zoom out from our puzzling pair to the wider Virgo Supercluster we can see M98, M99 (the Pinwheel Galaxy), and M100 along with a large number of other galaxies.



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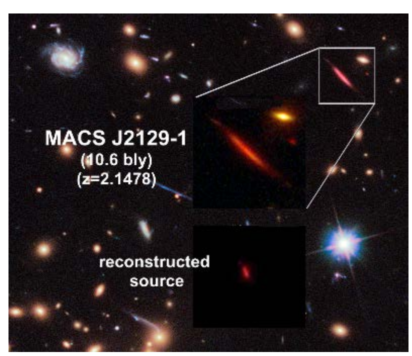
An Early Dead Galaxy – 5.5 bly

When the Universe was just three billion years old, half of the most massive galaxies were extremely compact and had already exhausted their fuel for star formation. A galaxy is said to be 'dead' when it stops creating new stars. They were elliptical and it is believed that they grew into the most massive local elliptical galaxies we see today through mergers with nearby galaxies. In 2017, while scanning a distant galaxy cluster, astronomers discovered the first example of a massive compact dead galaxy in the early universe that is not elliptical.

The foreground galaxy cluster has magnified the image of the more distant galaxy enabling a closer look than ever before. The dead galaxy is in fact a fast-spinning, disk-shaped galaxy. It has three times the mass of the Milky Way, but it's only half the size, and spinning more than twice as fast.

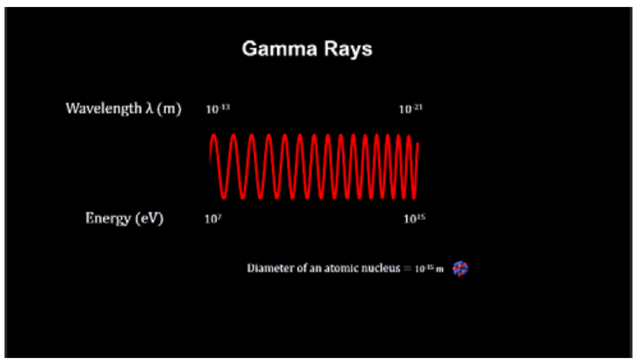


This is the first direct observational evidence that at least some of the earliest "dead" galaxies somehow evolve from a Milky Way-shaped disk into the giant elliptical galaxies we see today. How this could happen is not yet understood.

Gamma Ray Bursts [Tchaikovsky - String Sextet, Op 70, Souvenir de Florence II]

Gamma-ray bursts are the most energetic and luminous electromagnetic events in the Universe. They can release more energy in 10 seconds than our Sun will emit in its entire 10-billion-year expected lifetime! To understand these events, we need to take a closer look at gamma rays.

Gamma rays are the highest-energy form of light in the Universe. The wavelengths are smaller than the diameter of the typical atomic nucleus.



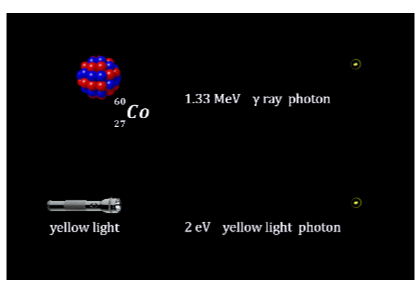
[Remember that a photon is created when a charged particle either changes energy states or is accelerated. Here on Earth, gamma rays are produced by the decay of radioactive elements and nuclear reactors via energy state changes, and by lightning accelerating electrons.] Here's an example of a Gamma ray photon created when an excited Cobalt atomic nucleus decays to a lower energy level. The gamma-ray photon has 640,000 times more energy than the yellow light photon. And this is a relatively low energy gamma ray.

Photon Energy

$E = hf = hc/\lambda$

Where

E = energy
f = frequency
λ = wavelength
c = speed of light = 3×10^8 m/s
h = Plank's Constant = 4.14×10^{-15} eV-s
$hc = 1.24 \times 10^{-6}$ eV-m



For Cobalt γ ray photon, $\lambda = 9.3 \times 10^{-13}$ m

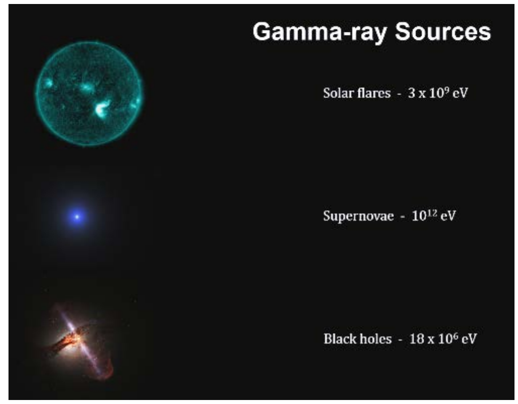
$E = 1.24 \times 10^{-6}$ eV-m$/9.3 \times 10^{-13}$ m
$= 1.33 \times 10^6$ eV

For a yellow light photon, $\lambda = 6.0 \times 10^{-7}$ m

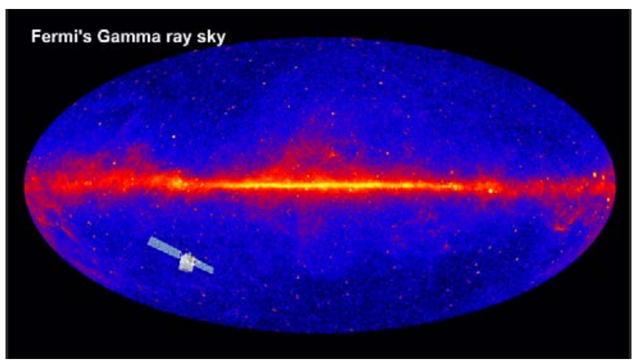
$E = 1.24 \times 10^{-6}$ eV-m$/6.0 \times 10^{-7}$ m
$= 2.07$ eV

1.33×10^6 eV / 2.07 eV = 640,000

Other sources are extreme conditions in our Milky Way and other galaxies. Some are generated by transient events, such as solar flares and supernovas. Others are produced by steady sources like supermassive black holes at galaxies' centers. [We have seen 3 billion eV gamma-rays from solar flares. Supernova remnants crashing into gas and dust clouds are thought to generate trillion eV gamma-rays. And matter falling into a black hole can generate 18 million eV gamma rays.]



Since June 2008, the Fermi Gamma-ray Space Telescope has been scanning the entire sky for gamma rays every three hours. Here's an all sky map as seen by Fermi. [The map is oriented with the center of the Milky Way at their center and the plane of our galaxy oriented horizontally across the middle.] The brightest gamma-ray light is shown in yellow and progressively dimmer gamma-ray light is shown in red and blue. We see that the plane of the Milky Way is bright in gamma rays. Above and below the bright band, much of the gamma-ray light comes from outside of our galaxy.

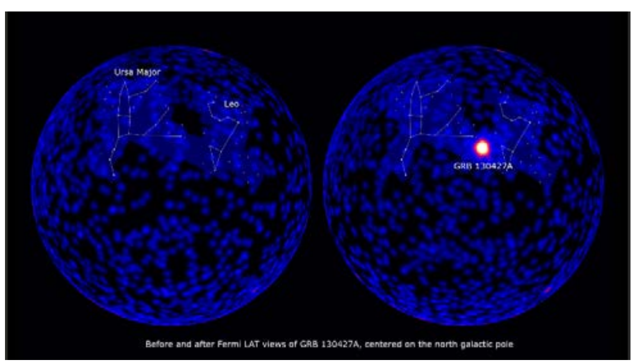


Here's a full spectrum composite image of the Cassiopeia A supernova remnant. [Radio data from the Very Large Array is orange. Infrared data from Spitzer is red. Visible light data from Hubble is yellow. X-ray data from Chandra is blue and green. And Gamma ray data from Fermi is magenta.] Note the strong gamma ray emission area on the right. Gamma ray energies up to 7 TeV were measured here. But the energy from sources such as these spread out in all directions and weaken in intensity according to our familiar inverse square law.

But Gamma Ray Bursts (GRBs for short) first spotted in the 1960s are focused and remain intense even as they move across the cosmos. Lasting anywhere from a few milliseconds to several minutes, they shine hundreds of times brighter than a typical supernova and about a million trillion times brighter than our Sun.

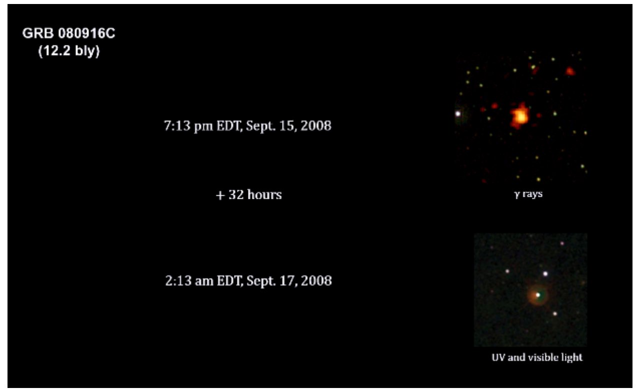
[Here's a recent burst of gamma rays from a star 3.7 billion light-years away. The initial emissions were picked up by the Fermi Gamma-ray Space Telescope in low Earth orbit. It produced the second brightest optical flash ever detected from a gamma ray burst.

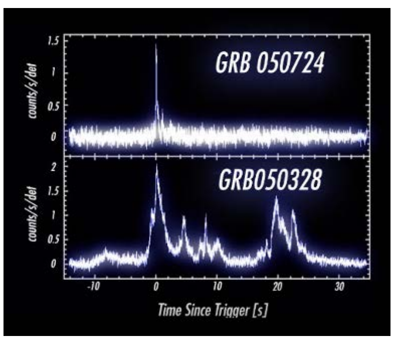
It is interesting to note that the energy of these incoming particles is far greater than anything we have ever been able to create in our man made accelerators - including the large collider at CERN that found the Higgs Boson.



Given their nature as extremely high energy photons, there aren't any absorption spectral lines in gamma ray radiation because there are no energy level changes in atoms in the gas the photons pass through with that kind of energy. But when Gamma Ray events are followed by optical radiation with spectral lines, redshift and therefore distance to the Gamma ray event can be calculated.]

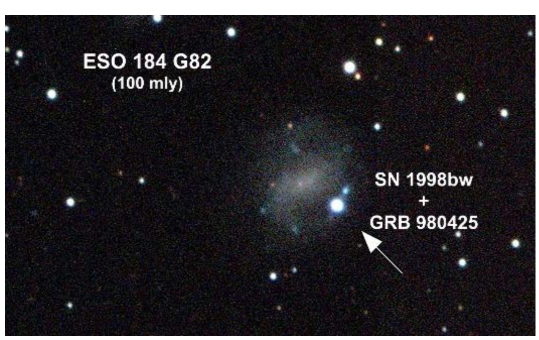
Here's the furthest and most powerful GRB ever detected. It occurred 12.2 billion light-years away as determined by visible afterglows seen by the European Southern Observatory in Chile. With the distance known, the strength of the blast can be calculated. This blast exceeded the power of approximately 5900 type 1a supernovae, **[**and the gas funneled out during the initial event was accelerated to no less than 99.9999 percent of the speed of light. The burst lasted for 23 minutes, almost 700 times as long as the two-second average for high energy GRBs.**]**





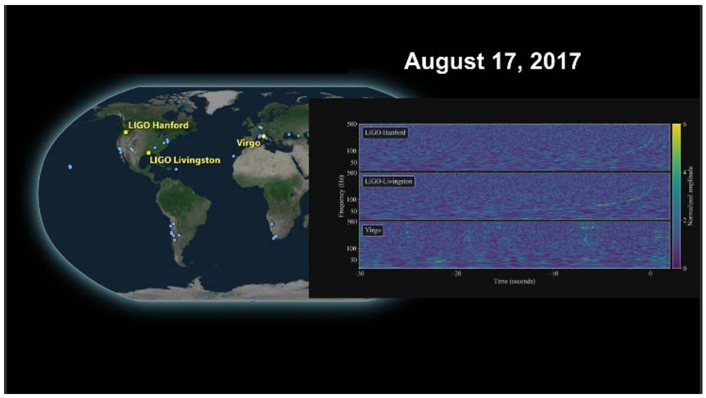
By the late 90s, 10 GRBs had been observed. This was enough to distinguish two distinct types: short (usually around a second or less); and long (usually around 30 seconds to a couple of minutes).

It was thought that long- duration bursts came from imploding stars collapsing into black holes. These are referred to as super-luminous supernovae or hypernovae or collapsars. This theory was confirmed in 1998 when GRB 980425 was also found to be SN 1998bw in a spiral galaxy [ESO 184-G82] a 100 mly away. But there has never been any confirmation that short bursts come from merging neutron stars. That is until August 17, 2017.

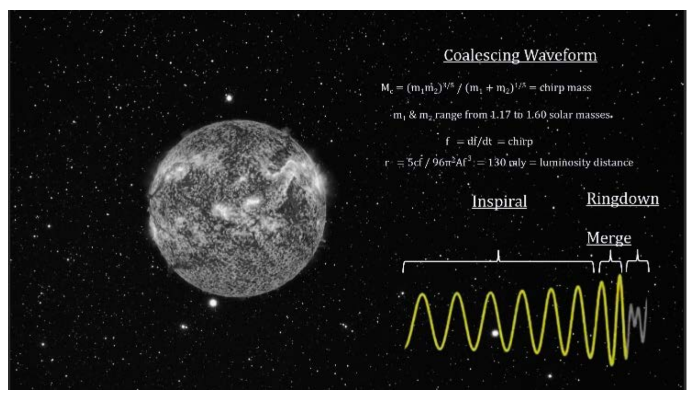


Merging Neutron Stars Gravitational Waves

On August 17, 2017, a gravitational wave, traveling at the speed of light, swept across the two LIGO interferometers and the new Virgo interferometer in Italy. The wave was named GW 170817.

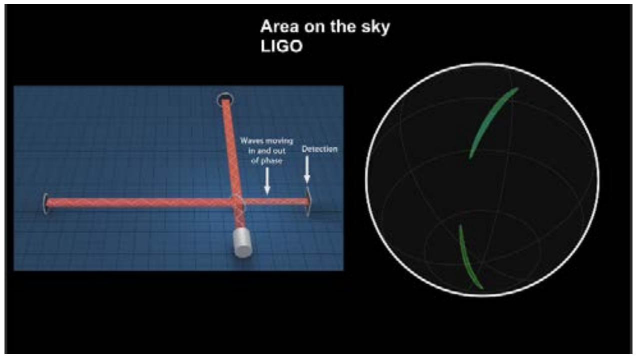


You may remember from our segment on gravitational waves, that the interferometer waveform amplitude, frequency and change in frequency (called its chirp) give us a measure of the merging objects' mass and distance. This waveform indicated that the masses fit the profile for neutron stars, and that the luminosity distance to the source was around 130 mly. [This was a dramatic departure from the norm. All previous gravitational waves were from merging black holes billions of light years away.]

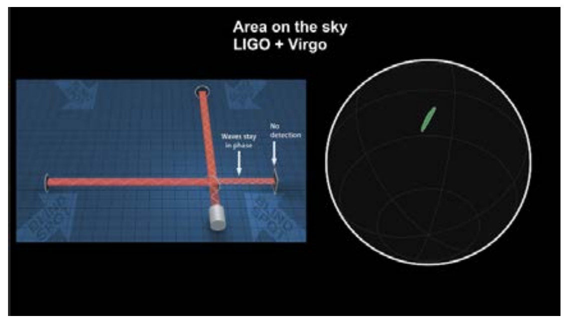


[We infer the component masses of the binary to be in the range 1.17–1.60 M⊙, with the total mass of the system 2.74M⊙. The source had a luminosity distance of 130 mly, the closest and most precisely localized gravitational-wave signal yet.]

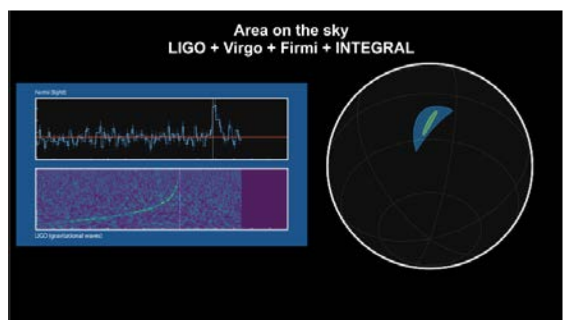
Location analysis from LIGO limited the direction of the event to two long swaths of sky.



As you may have noticed, the Virgo interferometer in Italy did not trigger on the event. This indicates that the angle of impact was one of the four that would not be seen by an interferometer because the instrument's arms are impacted in exactly the same way at exactly the same time. This allowed us to narrow the source's location on the sky considerably.

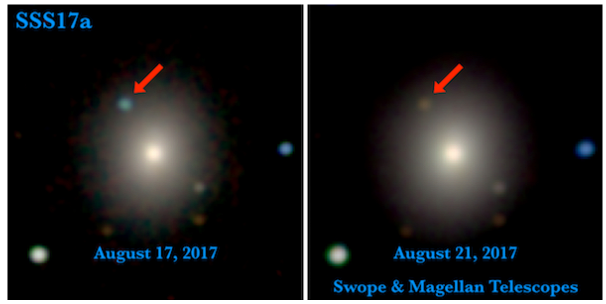


1.7 seconds after Ligo triggered, the Fermi Gamma-ray Burst Detector registered γ-ray burst GRB 170817A in an area of the sky that overlaps the area identified by LIGO and Virgo. [But as we have covered earlier, we get no distance information from gamma rays.] Simultaneous detection by ESA's INTEGRAL satellite helped narrow down the gamma ray sources possible area of the sky completely consistent with the gravitational wave origin.

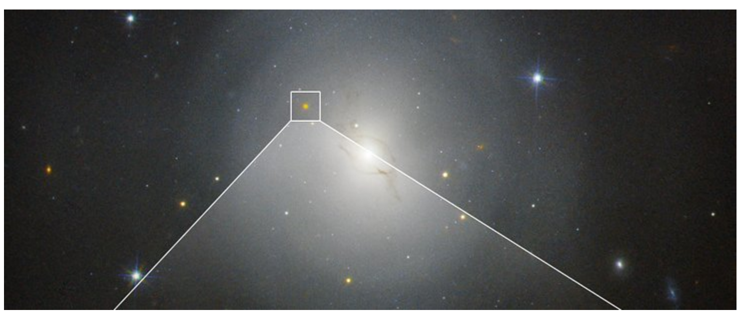


But there are a number of candidate galaxies for the neutron star collision in this area – all at various distances from Earth. But galaxy NGC 4993, 130 mly away, looked like a good candidate.

Alerts when out to all observatories across the plant and in orbit, that a simultaneous gravitational wave and gamma ray burst had been detected in this area of the sky. Within hours, ground based telescopes observed optical and near-infrared images of a bright light and named it SSS17a. Redshift data indicated that it was indeed coming from NGC 4993. Four days later it had faded significantly.



Over the next six days, Hubble captured images of the galaxy in visible and infrared light. Here's an image of the new bright object that faded noticeably over that time period. This all represents powerful evidence that GW170817, GRB 170817A, and SSSS17a are indeed caused by the same event – the merger of two neutron stars. [The combining of gravitational wave detection with electromagnetic detection, gives us a whole new avenue of astronomical study.]



[Hubble also found indications that the material being ejected by the explosion was moving as fast as one-fifth of the speed of light. And heavy elements like gold and platinum were included in the material. Theoretically the merger of two neutron stars would produce these heavy elements. This was solid confirmation of the theory – a theory with cosmological implications.]

A Trip through the Deep Field

We'll finish our 2017 review with a trip through the Ultra Deep Field. This visualization traverses the CANDELS Ultra Deep Survey (UDS) field to showcase the varied appearances of galaxies and their three-dimensional distribution. The sequence features a dense cluster of galaxies about 6 billion light-years away and extends to galaxies at more than twice that distance. The changes seen in galaxies during the fly-through illustrate the changes in galaxy structure and appearance over billions of years of cosmic history.

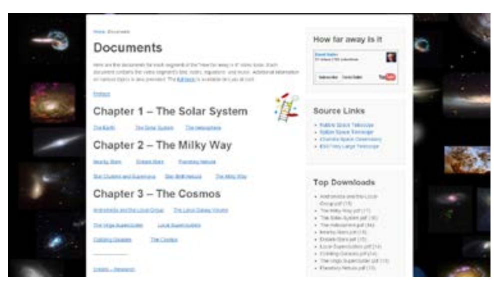
CANDELS is one of the largest projects ever done with the Hubble Space Telescope. Astronomers and visual artists extracted over 26,000 galaxies from the Hubble UDS images and created a computer model based on the measured and estimated properties.

Credits

Here are the links to Hubble sites, whitepapers and other locations where I found the information contained in this 2017 review. These are also the places where you can begin to do your own research.

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.



Jupiter in Opposition
http://www.spacetelescope.org/news/heic1708/?lang
https://svs.gsfc.nasa.gov/12021 (the video)

Water Vents on Europa
http://hubblesite.org/news_release/news/2017-17
http://hubblesite.org/video/947/news_release/2017-17 (video)
https://www.jpl.nasa.gov/missions/europa-clipper/

Interstellar Asteroid Enters Solar System

https://www.space.com/38580-interstellar-object-spotted-comet-asteroid-mystery.html
http://www.eso.org/public/videos/eso1737c/ (the video)
https://www.nasa.gov/feature/jpl/small-asteroid-or-comet-visits-from-beyond-the-solar-system

Gaia's View of the Large Magellanic Cloud

http://sci.esa.int/gaia/

Dark Matter in the Sculptor Dwarf Galaxy - 285,000 ly

http://sci.esa.int/gaia/59807-sculptor-dwarf-galaxy/
http://www.spacetelescope.org/videos/heic1719a/ (Sculptor zoom)
http://www.spacetelescope.org/static/archives/releases/science_papers/heic1719/heic1719a.pdf
https://briankoberlein.com/2014/07/08/still-dark/
https://www.nature.com/articles/s41550-017-0322-y

New Era for Supernova 1987A – 163,000 ly

https://www.cfa.harvard.edu/news/image-info/2017-08/1
http://hubblesite.org/news_release/news/2017-08
http://hubblesite.org/video/934/news_release/2017-08

N103B – Type 1A Supernova Survivor

http://www.spacetelescope.org/news/heic1706/?lang
http://www.spacetelescope.org/news/heic1707/?lang

Runaway Star in the Orion Nebula – 1,344 ly

http://www.spacetelescope.org/news/heic1705/?lang
http://hubblesite.org/news_release/news/2017-11

Star Collapses into a Black Hole

http://hubblesite.org/news_release/news/2017-19

Zwicky Transient Facility Sees First Light

https://astronomynow.com/2017/11/15/zwicky-transient-facility-opens-its-eyes-to-the-volatile-cosmos/

Gravitationally Lensed Type 1a Supernova

http://www.spacetelescope.org/news/heic1710/?lang
http://www.spacetelescope.org/static/archives/releases/science_papers/heic1710/heic1710a.pdf (whitepaper 1 – note Palomar)
http://xxx.lanl.gov/pdf/astro-ph/9709059v1 (whitepaper 2)
https://arxiv.org/pdf/1607.00017v2.pdf
http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?db_key=AST&bibcode=1964MNRAS.128..307R&letter=.&classic=YES&defaultprint=YES&whole_paper=YES&page=307&epage=307&send=Send+PDF&filetype=.pdf

Markarian 266 - 350 mly

http://www.spacetelescope.org/videos/heic1720a/

Interacting Galaxies NGC 4490 and NGC 4485 – 24 mly

http://www.spacetelescope.org/news/heic1716/?lang
http://skycenter.arizona.edu/gallery/Galaxies/NGC4490
http://annesastronomynews.com/annes-image-of-the-day-interacting-galaxies-ngc-4490-4485/

Interacting Galaxies NGC 1510 and NGC 1512 – 38 mly

http://www.spacetelescope.org/news/heic1712/?lang

A Problem Galactic Pair – 55 mly

http://www.spacetelescope.org/images/heic1709a/

An Early Dead Galaxy

http://hubblesite.org/news_release/news/2017-26
https://www.nature.com/articles/nature22388.epdf?author_access_token=MlZ_lPvhYlc_R5ccAxov-NRgN0jAjWel9jnR3ZoTv0NUZP2ljDiBrMgiODwJe2EFgIhH06gUd8mG3Rh1N5VjNxFcXjn_HPifl6LJzNM8tfuXmAiR2HYzWb1twYyzZjx4

A Trip through the Deep Field

https://www.youtube.com/watch?v=SUyDcyHpFhc&feature=push-u&attr_tag=pBVZ9LEYfWBLL31y-6

Gamma Ray Bursts

https://science.nasa.gov/ems/12_gammarays
https://www.cfa.harvard.edu/~loeb/PhyTod.pdf
https://www.sciencedaily.com/releases/2009/02/090219141458.htm
https://www.symmetrymagazine.org/article/june-2015/seeing-in-gamma-rays
https://www.youtube.com/watch?v=q-ZQBlWdlAY
https://www.youtube.com/watch?v=g5Nu7vDfCOg
https://www.nasa.gov/feature/goddard/2017/nasas-fermi-sees-gamma-rays-from-hidden-solar-flares
http://www.constellation-guide.com/cassiopeia-a/
https://www.eurekalert.org/pub_releases/2014-10/uos-fti102714.php
https://arxiv.org/pdf/1511.00309.pdf
http://science.sciencemag.org/content/329/5993/817
https://www.youtube.com/watch?v=CPGSuCC9alM
https://imagine.gsfc.nasa.gov/science/objects/bursts1.html

https://upload.wikimedia.org/wikipedia/commons/thumb/7/7e/SN_1998bw.jpg/1200px-SN_1998bw.jpg
https://apod.nasa.gov/apod/ap020228.html

Neutron Star Merger Gravitational Waves

http://www.spacetelescope.org/news/heic1717/?lang
https://www.ligo.org/detections/GW170817.php
https://www.youtube.com/watch?v=EtIkOjq0_50
https://www.youtube.com/watch?time_continue=56&v=WoDCPTLgxh4
https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.119.161101
https://www.nasa.gov/press-release/nasa-missions-catch-first-light-from-a-gravitational-wave-event
https://www.ligo.caltech.edu/page/press-release-gw170817
https://www.youtube.com/watch?time_continue=27&v=wCWgl7OzvUk
https://www.theguardian.com/science/2017/oct/16/astronomers-witness-neutron-stars-collide-global-rapid-response-event-ligo?CMP=fb_gu
https://www.youtube.com/watch?time_continue=46&v=V6cm-0bwJ98

Music

Schubert - String Quintet, Op 163

Puccini - Sister Angelica – Intermezzo

Bach - Concerto for Piano, Strings and Continuo

Mozart - Adagio for Violin and Orchestra

Tchaikovsky - String Sextet, Op 70, Souvenir de Florence II