2024 Review

Introduction

2024 was another big year for Webb and Hubble as they and others continue to find new galaxies and more about galaxies and stars that we've seen before. We'll start with our last look at DART in our solar system. We'll cover new information on famous Milky Way celestial objects like the Horsehead, Little Dumbbell, and the Crab nebulae. Moving out to galaxies orbiting ours, we'll cover a super nova and brown dwarfs. Further out into our Local group, we'll take a closer look at Triangulum. We'll cover new information on galaxies tens of millions of light years away including the Cigar, Sombrero, Penguin, and others. We'll also see a protocluster, supernova, and black hole merger billions of lightyears away. And we'll see two galaxies that formed near the end of the Dark Ages. We'll end with coverage of Webbs first 2024 release. It showcases near- and mid-infrared portraits of 19 face-on spiral galaxies in the Virgo Supercluster.

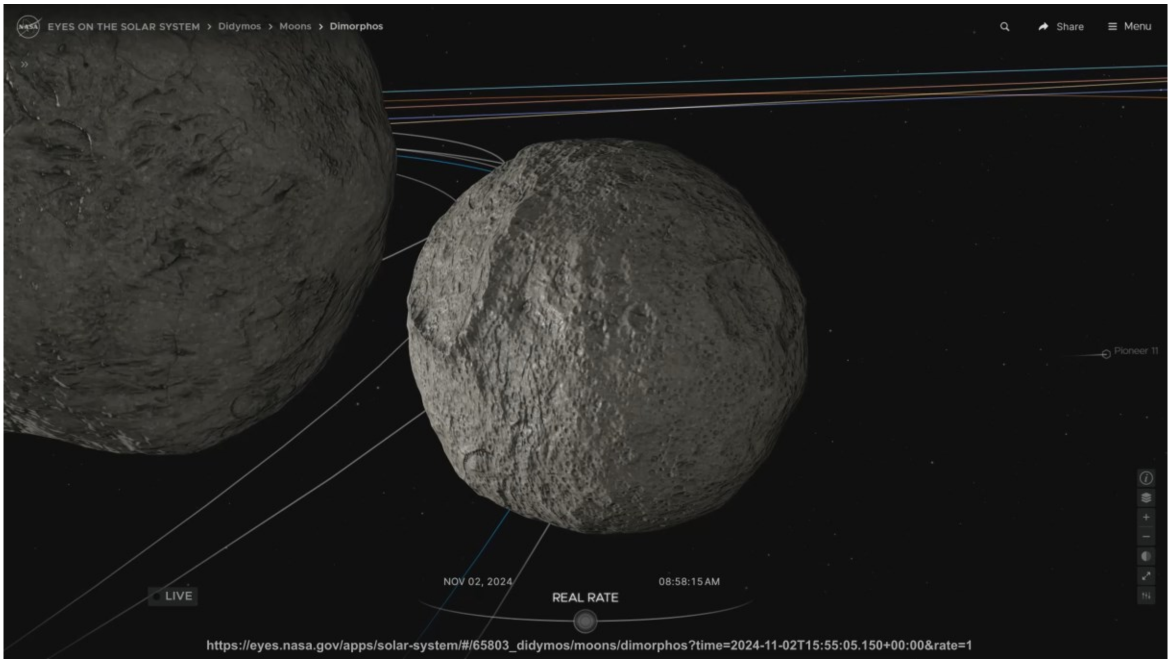
I trust you'll find it interesting and informative.

DART Update

Here's an update on the historic Double Asteroid Redirection Test (DART for short). The demonstration showed that a controlled impact could deflect a hazardous asteroid should one ever be on a collision course with Earth. A Jet Propulsion Lab study has shown that the shape of asteroid Dimorphos has changed and its orbit around Didymos has shrunk.

Before the impact, Dimorphos had a roughly symmetrical "oblate spheroid" shape – like a squashed ball that is wider than it is tall. It had a well-defined, circular orbit at a distance of about 1,189 meters from Didymos (that's 3,900 feet). Dimorphos took 11 hours and 55 minutes to complete one loop around Didymos.

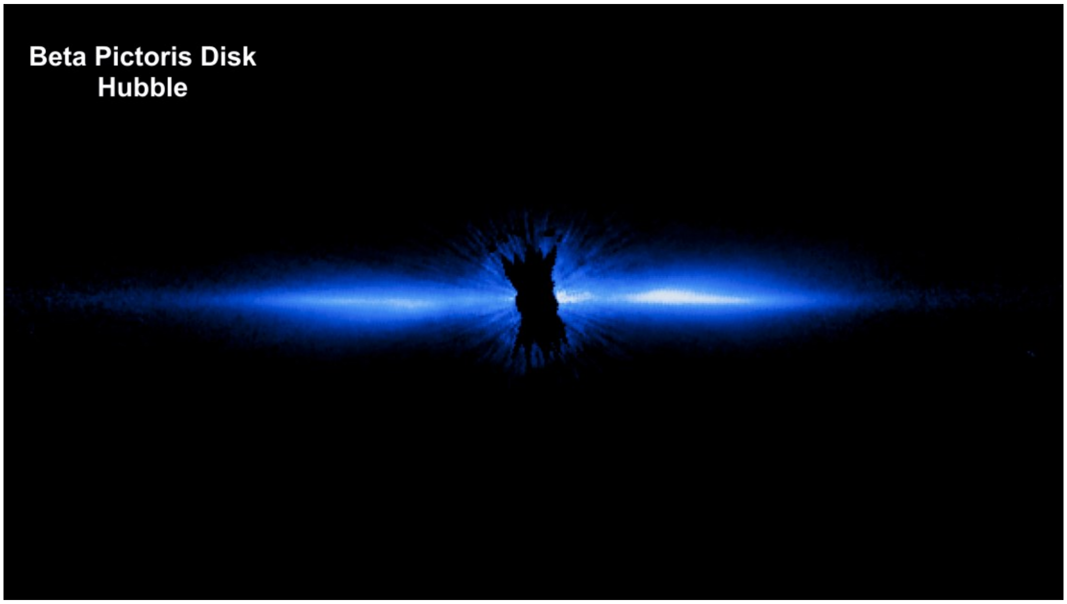
Now its orbit is no longer circular. Its orbital period is 33 minutes and 15 seconds shorter. And the entire shape of the asteroid has changed, from a relatively symmetrical object to a 'triaxial ellipsoid' – something more like an oblong watermelon.



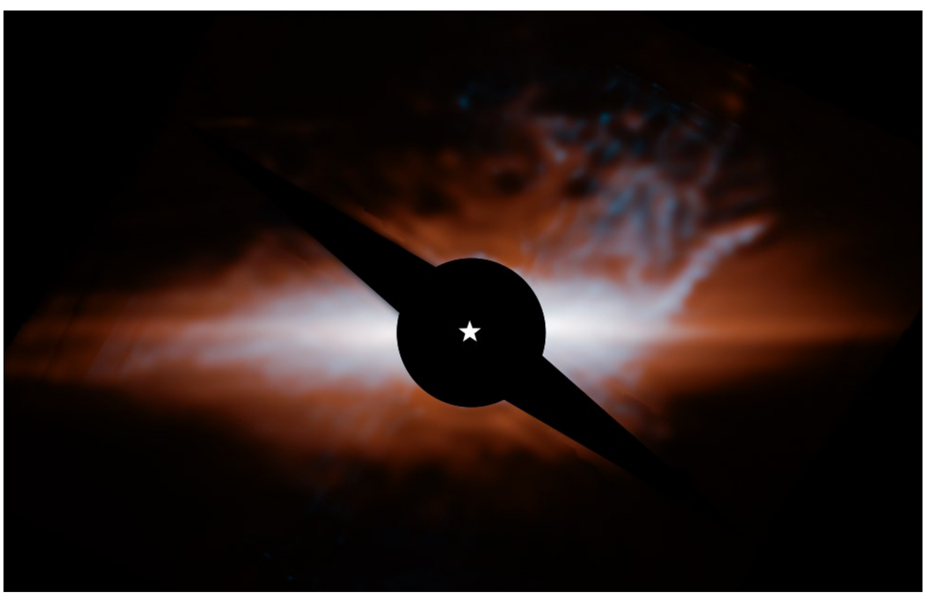
Beta Pictoris - 60 ly

Beta Pictoris is about 60 light-years away. It is one of the best-known examples of a star surrounded by a dusty debris disc. Observations done with ESO's Very Large Telescope, have proven the presence of a planet around the star. It has nine times Jupiter's mass.

Here's a detailed Hubble picture of a large, edge-on, gas-and-dust disk encircling the 20-million-year-old star. A coronagraph (the black circle and two small disks) has been used to block the light of the central star. The new visible-light Hubble image traces the disk in closer to the star to within about 1046 million km or 650 million miles of the star.



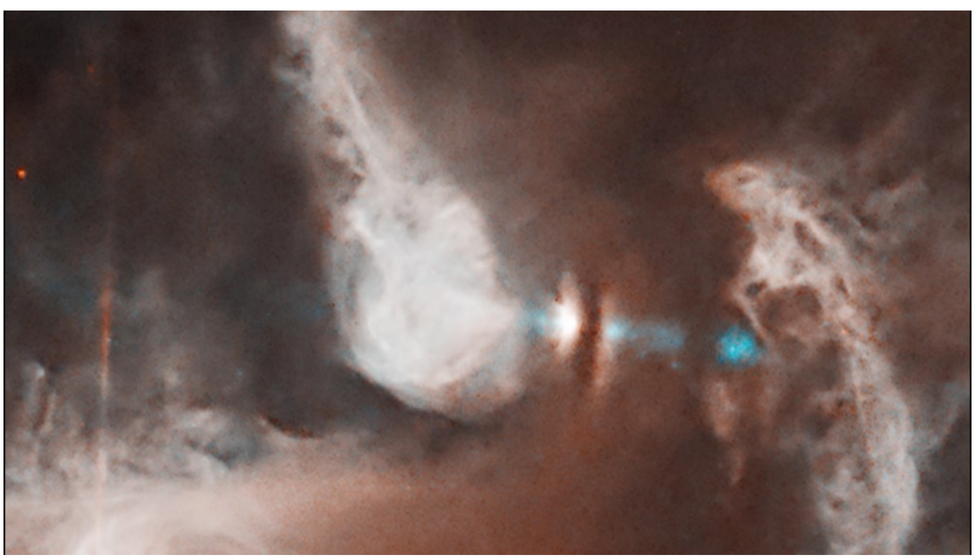
Here's the Webb Mid-Infrared image. Unexpectedly, Webb's infrared capabilities detected a new feature of the Beta Pic system: a curvy branch of dust that resembles the shape of a cat's tail. This tail extends from the southwest portion of the secondary debris disk and is estimated to span 16 billion km or 10 billion miles. The dust that forms the tail may be similar to the matter found on the surfaces of comets and asteroids in our solar system. Further analysis is required to understand the origins of the cat's tail, but collision between asteroids, comets, or planetesimals may be responsible.



FS Tau – 450 ly

FS Tau is a multi-star system made up of FS Tau A, the bright star-like object near the middle of the image, and FS Tau B (Haro 6-5B), the bright object to the far right that is partially obscured by a dark, vertical lane of dust. The young objects are surrounded by softly illuminated gas and dust. The system is only about 2.8 million years old, very young for a star system. FS Tau A is a T Tauri binary system, consisting of two stars orbiting each other. T Tauri protostars are not yet burning hydrogen, but they will in time.

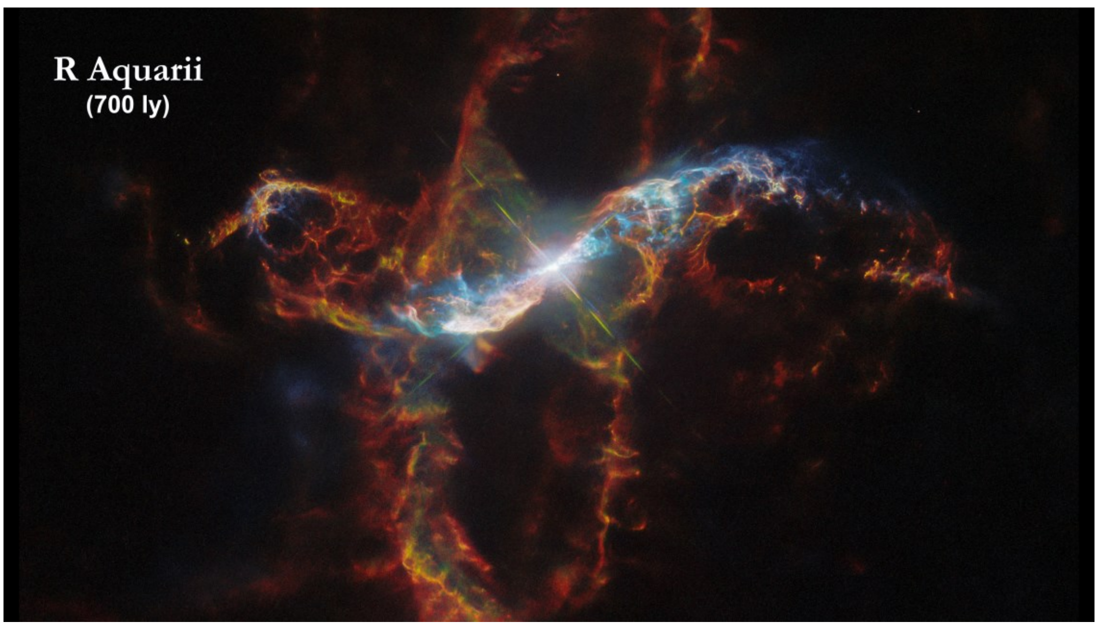
FS Tau B is a protostar surrounded by a protoplanetary disc that will eventually coalesce into planets. The thick dust lane, seen nearly edge-on, separates the illuminated surfaces of the disc. Protostars are known to eject fast-moving jets, and FS Tau B provides a striking example of this phenomenon. It is the source of an unusual asymmetric, double-sided jet, visible here in blue. Its asymmetrical structure may be because mass is being expelled from the object at different rates. The protostar is also classified as a Herbig-Haro object Haro 6-5B.



R Aquarii - 700 ly
Hubble first observed the star R Aquarii in 1990. It was resolved into two very bright stars separated by about 2.6 billion km (that's 1.6 billion miles). It belongs to a class of double stars called symbiotic stars. The primary star is an aging red giant and its companion is a compact white dwarf. The red giant primary star is over 400 times larger than our Sun. The star pulsates, changes temperature, and varies in brightness by a factor of 750 times over a roughly 390-day period. At its peak the star is nearly 5,000 times our Sun's brightness.

When the white dwarf star swings closest to the red giant along its 44-year orbital period, it gravitationally siphons off hydrogen gas. This material accumulates on the dwarf star's surface until it undergoes spontaneous nuclear fusion, making that surface explode like a gigantic hydrogen bomb. After the outburst, the fueling cycle begins again.

This outburst ejects geyser-like filaments shooting out from the core, forming loops and trails as the plasma emerges in streamers. The plasma is twisted by the force of the explosion and channeled upwards and outwards by strong magnetic fields. The outflow appears to bend back on itself into a spiral pattern. The plasma is shooting into space over 1.6 million Km/hr (that's a million mph). It's material can be traced out to at least or 24 times our solar system's diameter.



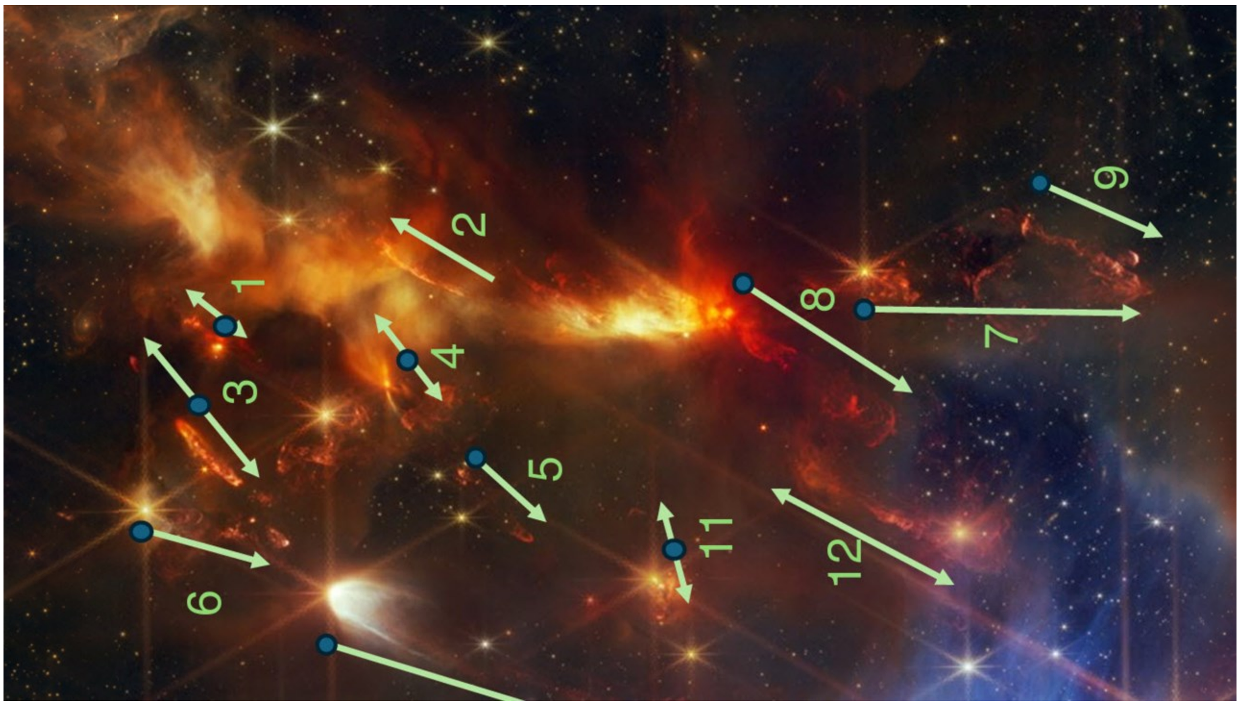
05 - Serpens Nebula – 1,300 ly

Here's a Webb Near-Infrared view of the Serpens nebula 1300 ly away. We covered the nebula's Bat Shadow in the 2020 Review. The Nebula is home to a particularly dense cluster of newly forming stars approximately 100,000 years old. Some of them will eventually grow to the mass of our Sun. To the right of the "Bat Shadow" there's an eye-shaped crevice. Astronomers think this could be gases of different densities layered on top of one another.

In this image, astronomers found a grouping of aligned protostar outflow jets within one small region at the top left corner. These jets are identified by the bright clumpy streaks in red. These are the shockwaves from the jet hitting surrounding gas and dust. Here, the red color represents the presence of molecular hydrogen and carbon monoxide.

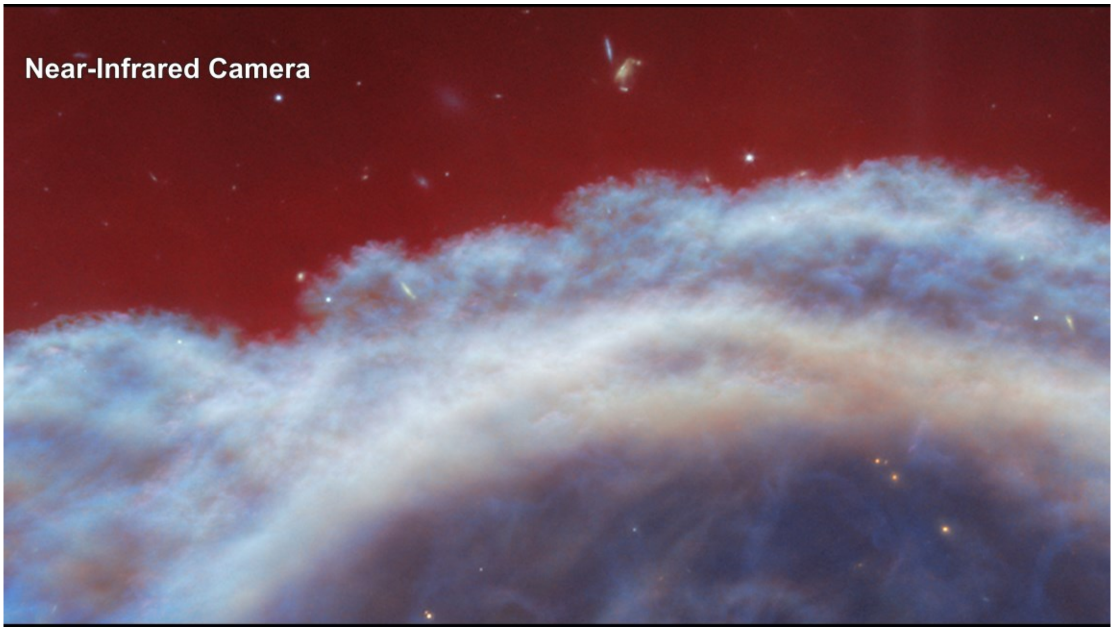
Typically, these objects have varied orientations within one region. Here, however, they are slanted in the same direction, to the same degree. The probability that this alignment is random is extremely small (on the order of 10 to the minus 4). 20 outflows were analyzed.

This in turn suggests that the 16 aligned protostars, which seem to be at similar evolutionary stages based on their outflow dynamics, 17 formed at similar times with a similar spin inherited from a single local cloud filament. This constitutes new evidence for the long-standing theory that stars form from collapsing molecular clouds.

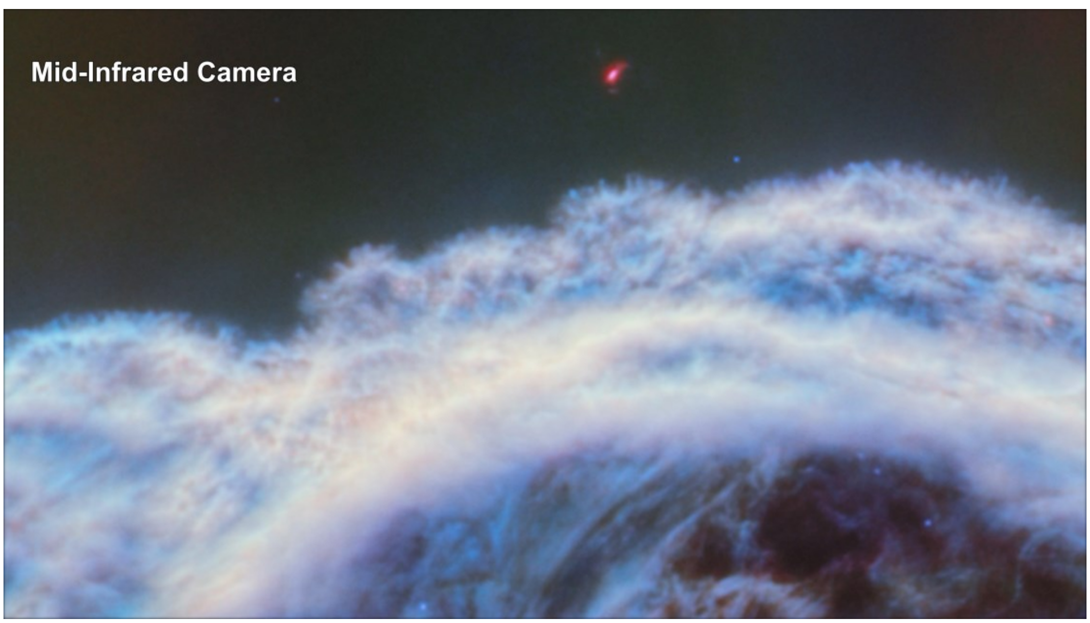


Horsehead Nebula – 1,300 ly

Here we are zooming into the well-known Horsehead Nebula for a closer look at a small section at the very top. The clouds are seen up close, showing thick, whitish streaks and dark voids, as well as textured, patterns of dust and gas. This is the Mid-InfraRed camera view.



This second view was taken by the Mid-Infrared camera. You can see the stars dim and the details around the dust and gas are significantly improved.



Little Dumbbell Nebula M76 – 3,400 ly

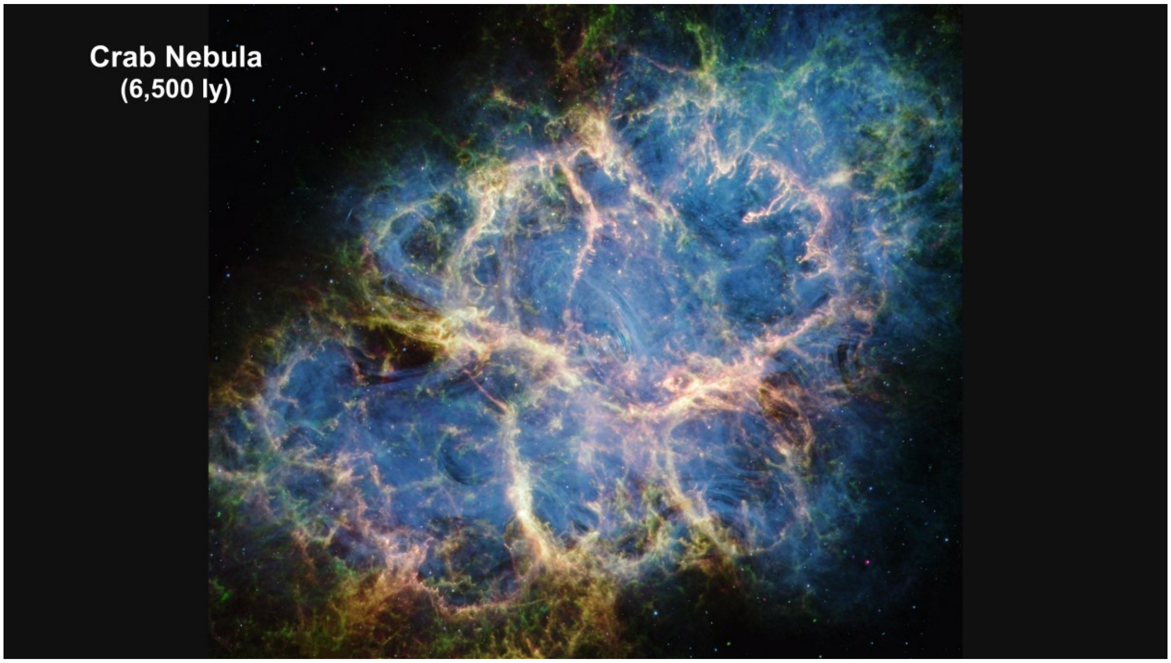
The Hubble Space Telescope launched on the 24th of April 1990, 34 years ago. Over those years, Hubble has made 1.6 million observations of over 53,000 astronomical objects. In celebration of its 34th anniversary, Hubble released this image of the Little Dumbell Nebula 3,400 ly away. It is classified as a planetary nebula. You may recall from our coverage in the 'How far away is it' video book that a planetary nebula is unrelated to planets. It has the name 'planetary' because astronomers in the 1700s, using low-power telescopes, thought this type of object resembled a planet.

This one is composed of a ring, seen edge-on as the central bar structure, and two lobes on either side of the ring. Before the star burned out, it ejected the ring of gas and dust. The primary star is collapsing to form a white dwarf. It is one of the hottest stellar remnants known, at 120,000 degrees Celsius. That's 24 times our Sun's surface temperature. Ultraviolet radiation from the super-hot star is causing the gases to glow. The red color is from nitrogen, and blue is from oxygen.

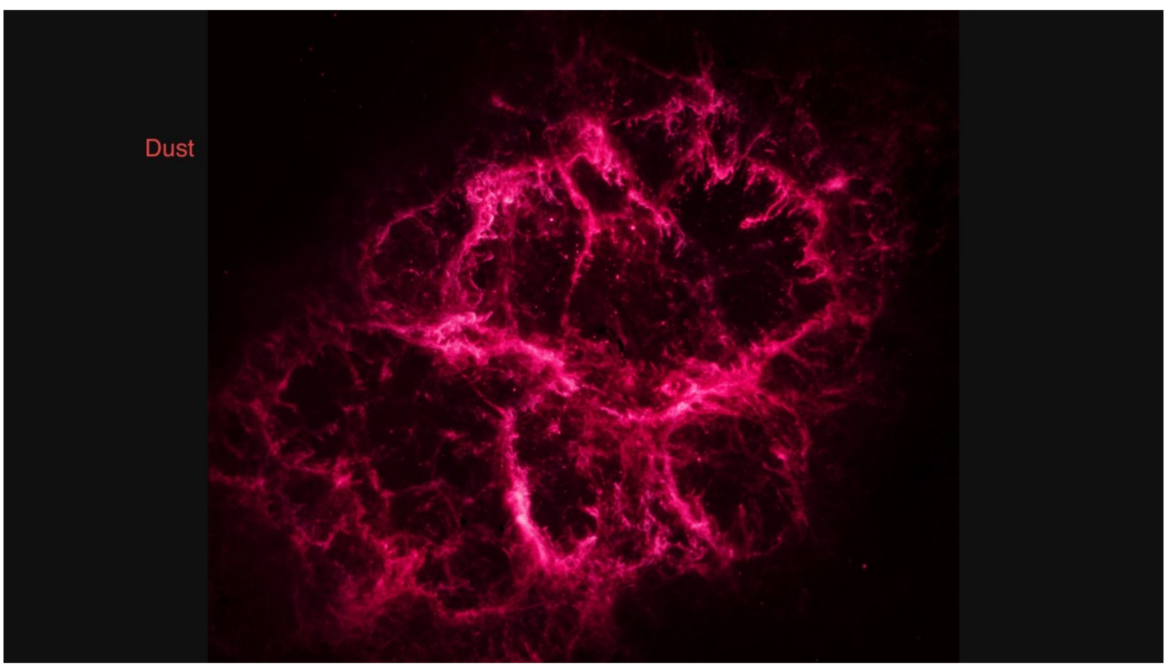
Planetary nebula dissipate rapidly. This one will vanish in about 15,000 years.

Crab Nebula – 6,500 ly

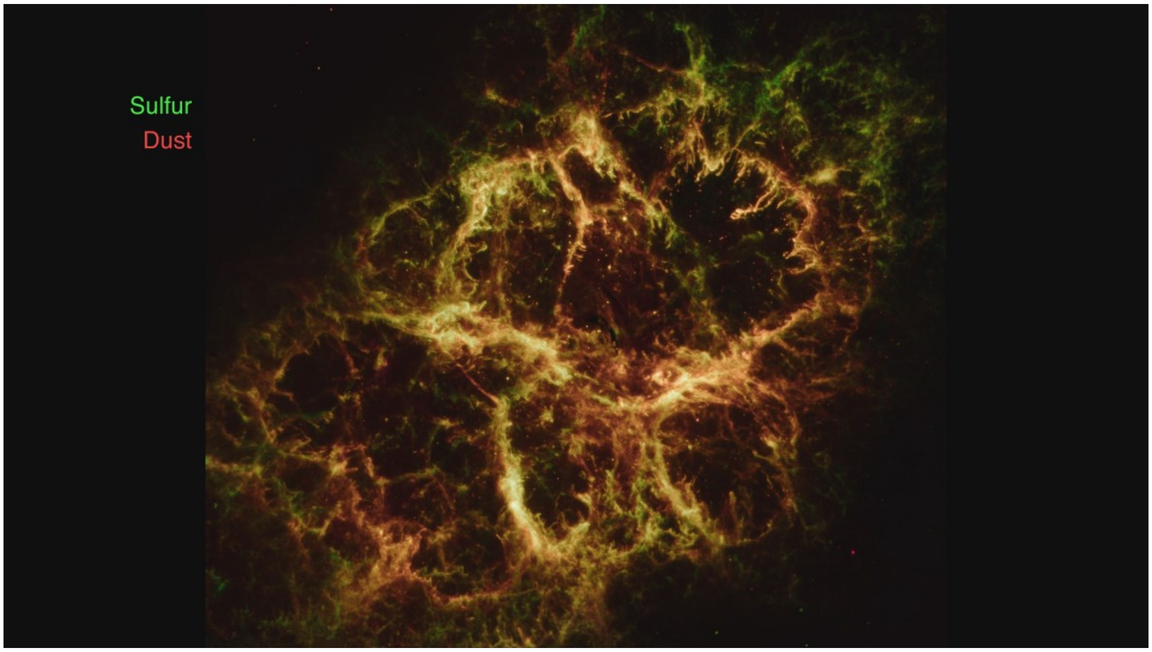
Here's another Webb near and mid-infrared camera look at the Crab Nebula - the result of a core-collapse supernova. The explosion itself was seen on Earth in 1054 CE and was bright enough to view during the daytime. The much fainter remnant observed today is an expanding shell of gas and dust, and outflowing wind powered by a pulsar. This study is designed to clarify the nebula's history.



For the first time, the images and data collected by Webb enabled a research team to isolate the dust emission within the Crab and map it in high resolution. By mapping the warm dust emission with Webb, and combining it with the Herschel Space Observatory's data on cooler dust grains, the team created a well-rounded picture of the dust distribution. Represented as fluffy magenta material, the dust grains form a cage-like structure that is most apparent toward the lower left and upper right portions of the remnant. The outermost filaments contain relatively warmer dust, while cooler grains are prevalent near the center.



Filaments of dust are also threaded throughout the Crab's interior and sometimes coincide with regions of doubly ionized sulfur (sulfur III) colored in green. Yellow-white mottled filaments, which form large loop-like structures around the supernova remnant's center, represent areas where dust and doubly ionized sulfur overlap.



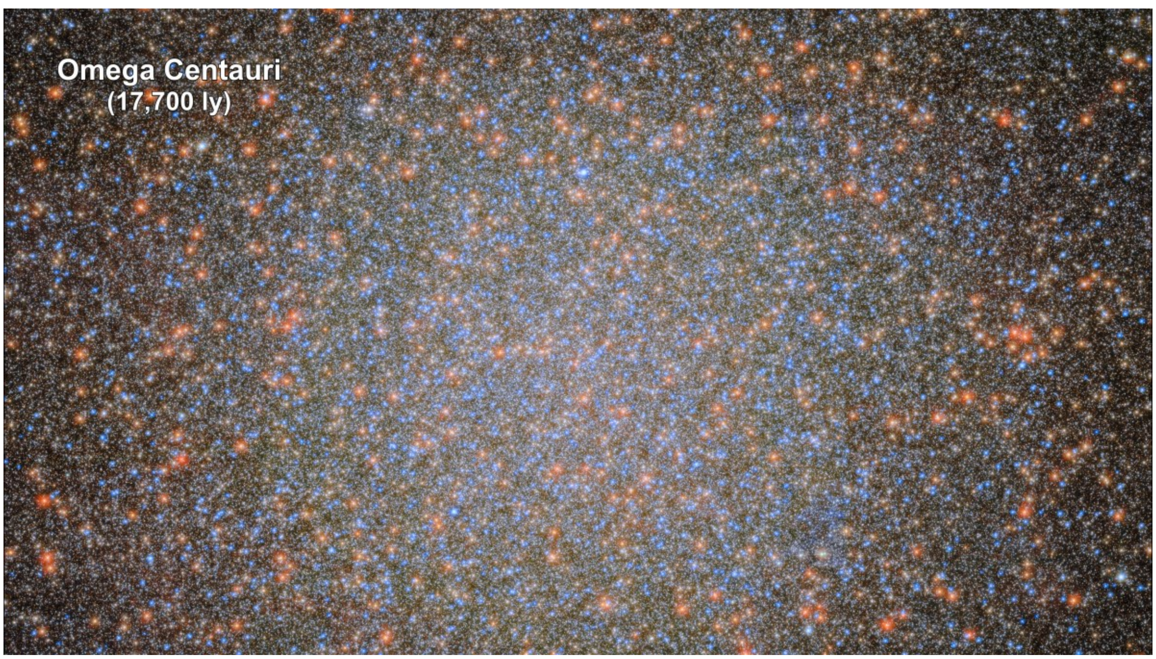
The dust's cage-like structure helps constrain some, but not all of the synchrotron emission represented in blue. The emission resembles wisps of smoke, most notable toward the Crab's center. The thin blue ribbons follow the magnetic field lines created by the Crab's pulsar.

Combined with the dust, and then the sulfur, we get the full view.

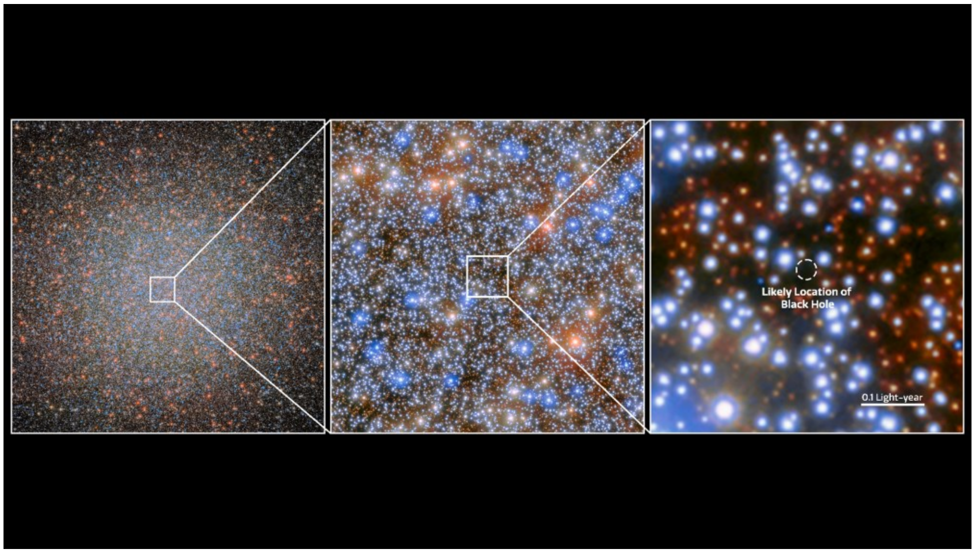
IMBH in Omega Centauri - 17,700 ly

In the "How Fast Is It" video book, we covered how rare and how hard it is to find Intermediate Mass Black Holes (IMBH for short). In 2024, an international team of astronomers used more than 500 images from Hubble — spanning two decades of observations — to search for evidence of an IMBH. They used the 'stars orbiting an invisible point' technique like the one we used to find Sagittarius A* at the center of our galaxy by following the motion of fast-moving stars in the innermost region of the globular star cluster Omega Centauri, with its 10 million stars 17,700 light-years away. This is the largest-known globular cluster in the Milky Way with a diameter of roughly 150 light-years.

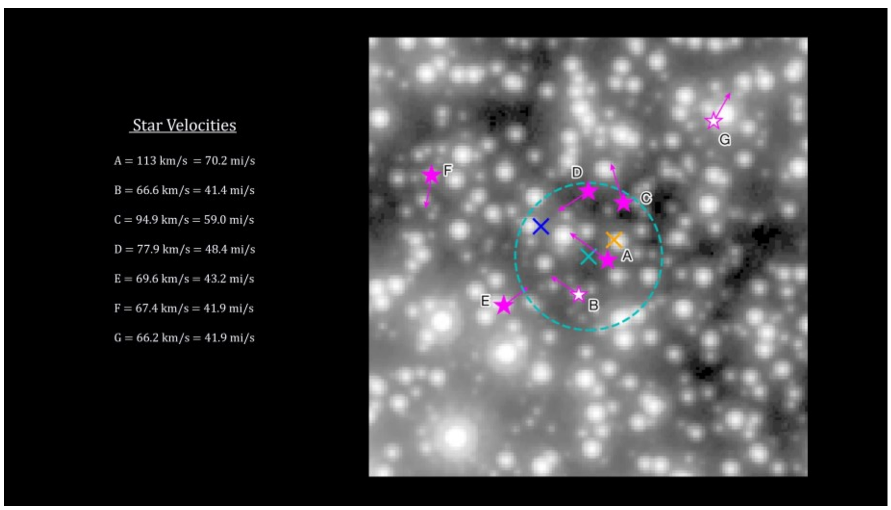
They measured the velocities for 1.4 million stars, and discovered seven near the center that are moving so fast that they would normally be escaping the cluster. But they're not. The most likely explanation is that a very massive object is gravitationally pulling on these stars and keeping them close to the center. The only object that can be so massive is a black hole, with a mass of at least 8,200 times that of our sun. That would make it an Intermediate Mass Black Hole.



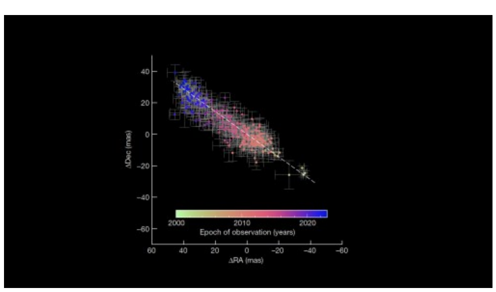
This image includes three panels. The first image at left shows the globular cluster Omega Centauri. The second image shows the details of the central region of this cluster, with a closer view of the individual stars. The third image shows the location of the IMBH candidate in the cluster.

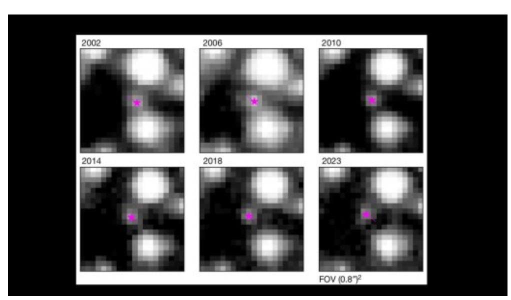


Here we have a closeup showing the movement directions and velocities of the 7 stars. Star A is the fastest and closest to the [IMBH] Black Hole at the center.



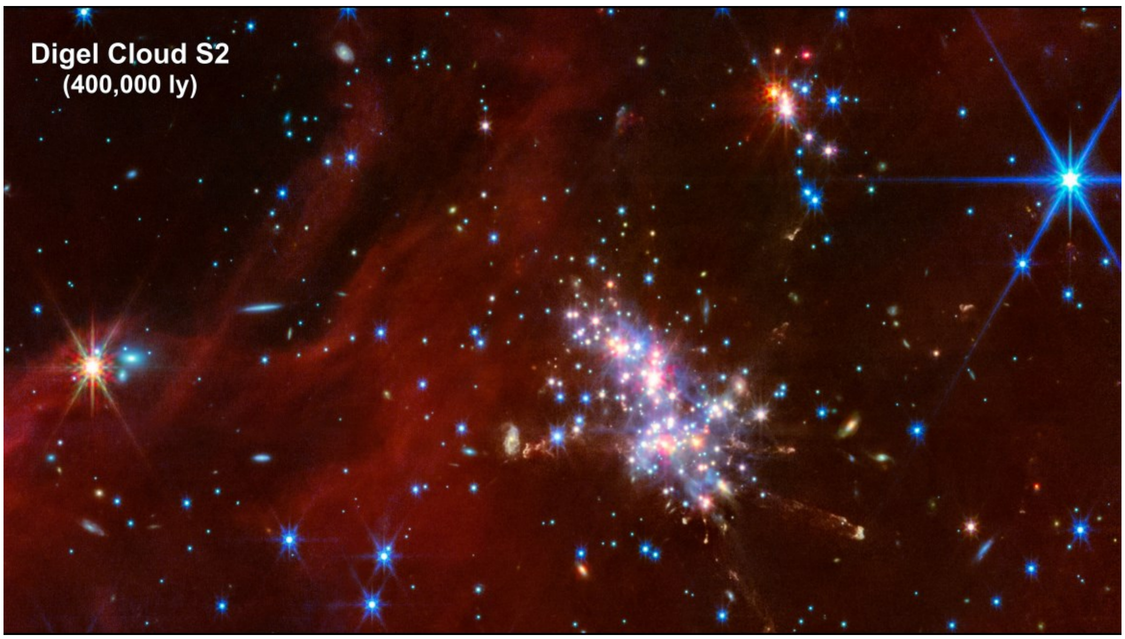
Here's a closer look at star A's motion. Doppler shift gives us the radial motion at each point in time as angular motion and distance to the star gives us the proper motion across the sky. The motion is orbital around the unseen central object. You'll note the change in the star's directions over the years. This deep analysis was done for all 7 stars.





Digel Cloud 2S – 40,000 ly

Webb has observed the very outskirts of our Milky Way galaxy. Known as the Extreme Outer Galaxy, this region is located more than 58,000 light-years from the Galactic center. For comparison, Earth is approximately 26,000 light-years from the center. The Digel Cloud 2S, shown here, is one of areas examined. It contains star clusters undergoing bursts of star formation. Some of the details include such as very young protostars and distinctive nebular structures. Several of these young stars are emitting extended jets of material from their poles. To the main cluster's top right is a sub-cluster of stars. Scientists previously suspected this subcluster was there, but has now been confirmed with Webb.

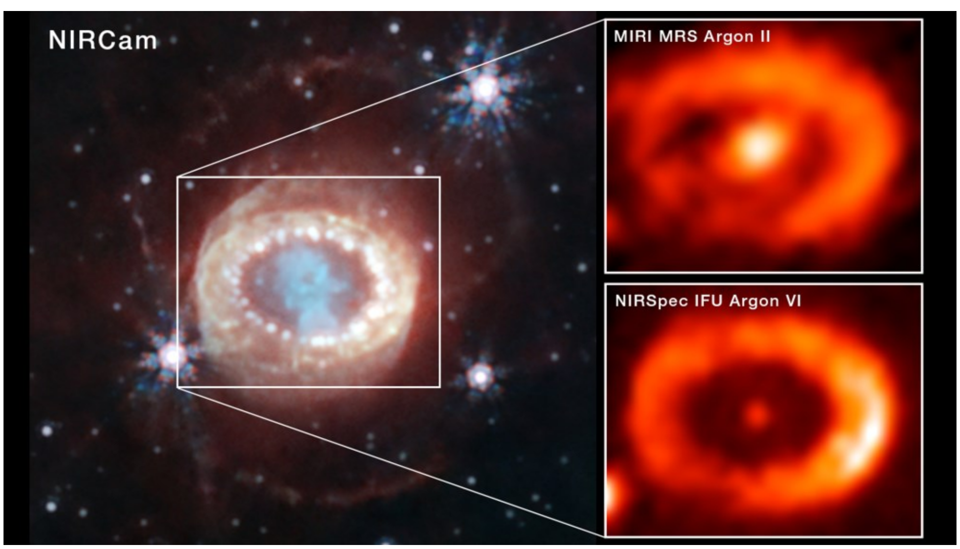


SN 1987A - 163,000 ly

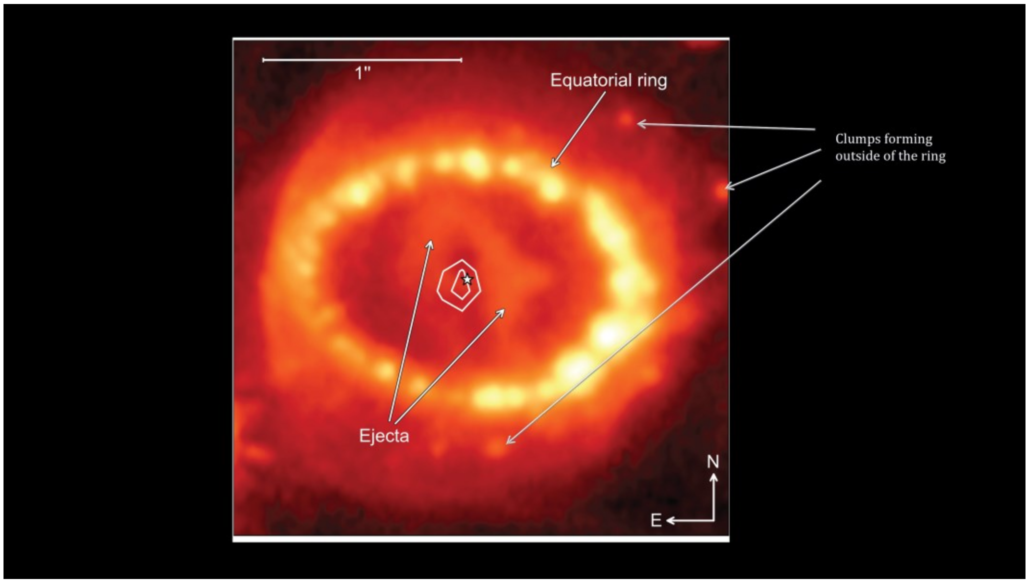
Here we're zooming in on a Supernova we covered in the 'Star Clusters and Supernova' chapter of the "How Far Away Is It" video book. Thirty-seven years ago, astronomers spotted one of the brightest exploding stars in more than 400 years named SN 1987A. It was the first supernova that could be seen with the naked eye since Kepler's Supernova was observed in 1604. This new one radiated with the power of 100 million Suns for several months following its discovery. A 10-second burst of neutrinos observed just before the supernova implied that a neutron star or black hole was formed in the explosion. Evidence for such a compact object has long been sought.

Here's Webb's Near-Infrared Camera image on the left. It highlights the object's central structure. The ring is expanding by several thousands of km/s. That's over a thousand miles per second. The blue region is the densest part of the clumpy ejecta, containing heavy elements like carbon, oxygen, magnesium, and iron, as well as dust. The bright 'ring of pearls' is the result of the collision of the ejecta with a ring of gas ejected around 20,000 years before the explosion.

The top image on the right features the data from the Mid-Infrared Instrument. Its spectral analysis shows a strong signal due to ionized argon and weak lines of ionized sulphur from the center of the ejected material that surrounds the original site of the supernova. The bottom image depicts data from the Near Infrared Spectrograph at shorter wavelengths. It found even more heavily ionized chemicals. Of particular interest is the five times ionized argon. That's argon atoms that have lost 5 of their 18 electrons due to high-energy radiation in the center of the remnant, illuminating an almost point-like region in the center. The most likely source is believed to be a neutron star because the computed masses are insufficient for producing a black hole.



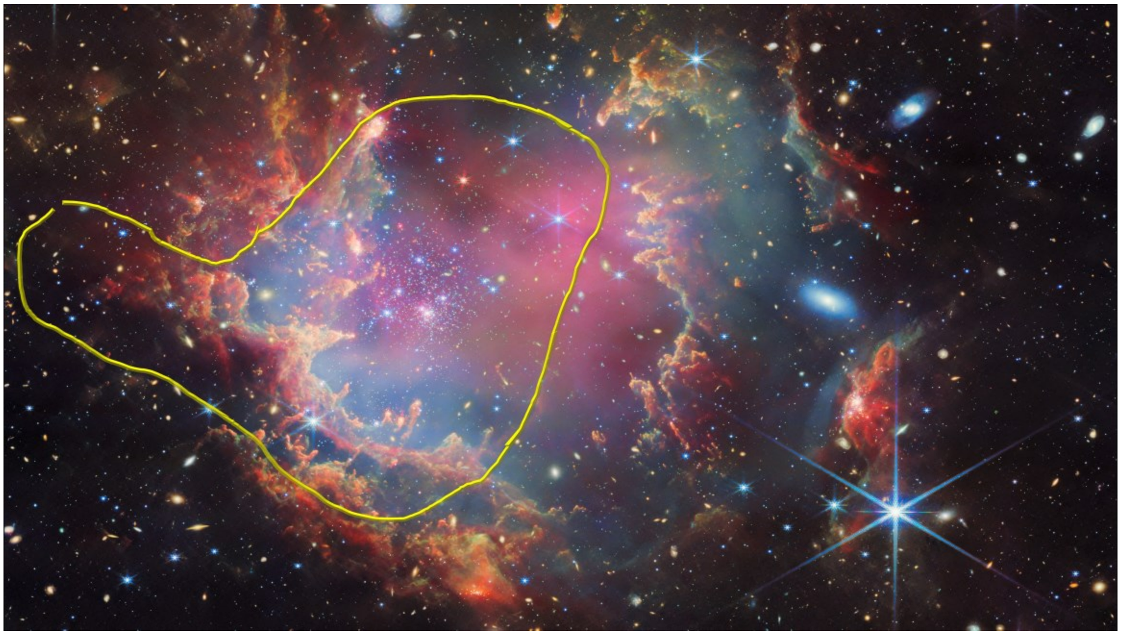
The Webb team used the Medium Resolution Spectrograph mode of the mid-infrared instrument that forms a spectrum at each pixel, allowing analysts to see spectroscopic differences across the object. This is the first time that the effects of high energy emission from the young neutron star have been detected. In this view, we see spots exterior to the ring, with diffuse emission surrounding them. These are the locations of supernova shocks hitting more exterior material from the progenitor star. The outer ejecta is illuminated by X-rays from the collision, while the inner ejecta is powered mainly by radiation from the neutron star.



Young Brown Dwarfs – 200,000 ly

Here's the star cluster NGC 602 on the outskirts of the Small Magellanic Cloud. The local environment of this cluster is a close to what existed in the early Universe, with very low amounts of elements heavier than hydrogen and helium.

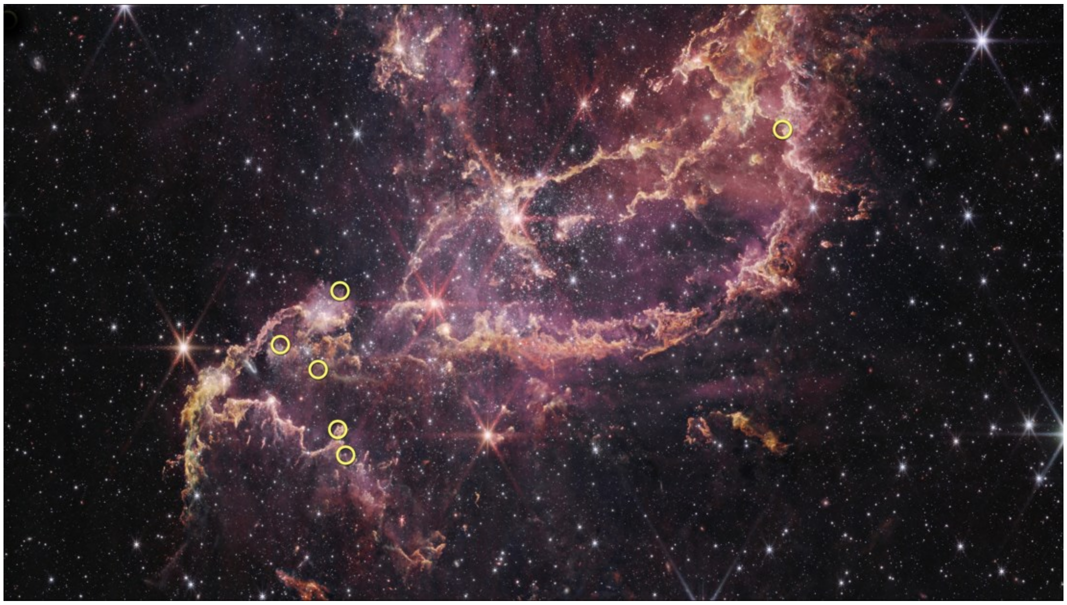
An international team of astronomers used Webb to individually resolve 64 candidate brown dwarfs with masses ranging from 50 to 84 time the mass of Jupiter scattered across the left side of the nebula. Their spatial distribution indicates that they appear collocated with the nebula's pre-main-sequence stars. Until now, we've known of about 3000 brown dwarfs, but they all exist inside our own galaxy.



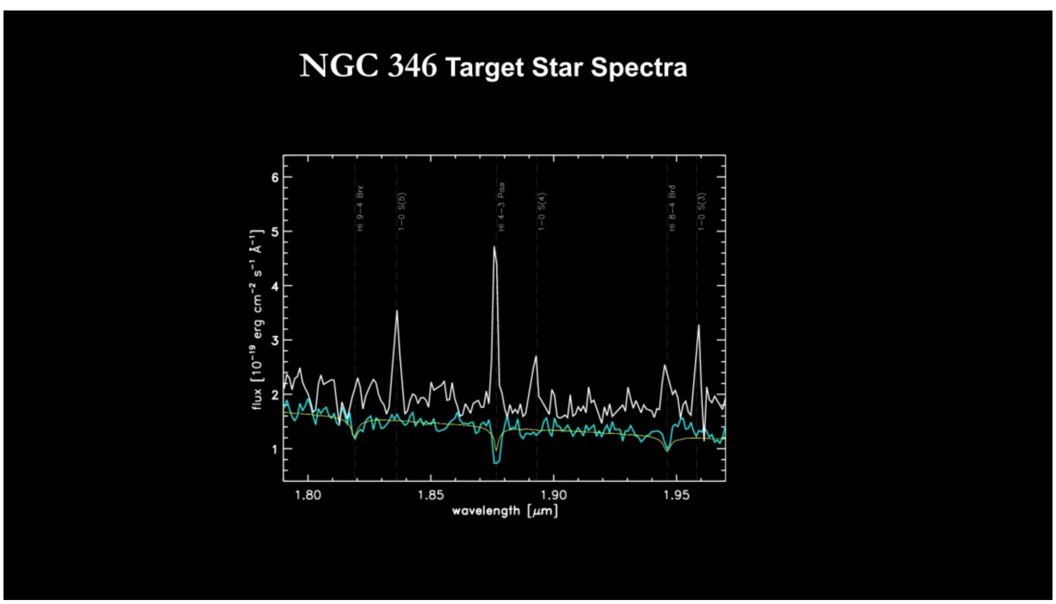
NGC 346 - 200,000 ly
In their final formation stages, after dissipating most of the envelope of dust and gas in which they formed, Sun-like stars still have a mostly gaseous disk from which they continue to accrete while the star contracts until hydrogen ignites in the core. It is in these disks that planetary systems form. In nearby star-forming regions, the accretion disks are short-lived, with decay timescales of around 2 million years.

In 2024, Hubble and Webb examined the massive star-forming cluster NGC 346 in the Small Magellanic Cloud orbiting the Milky Way 200,000 ly away. What's interesting about this cluster is that it has a relative lack of heavier elements. This makes it a nearby proxy for stellar environments similar to conditions in the early distant universe.

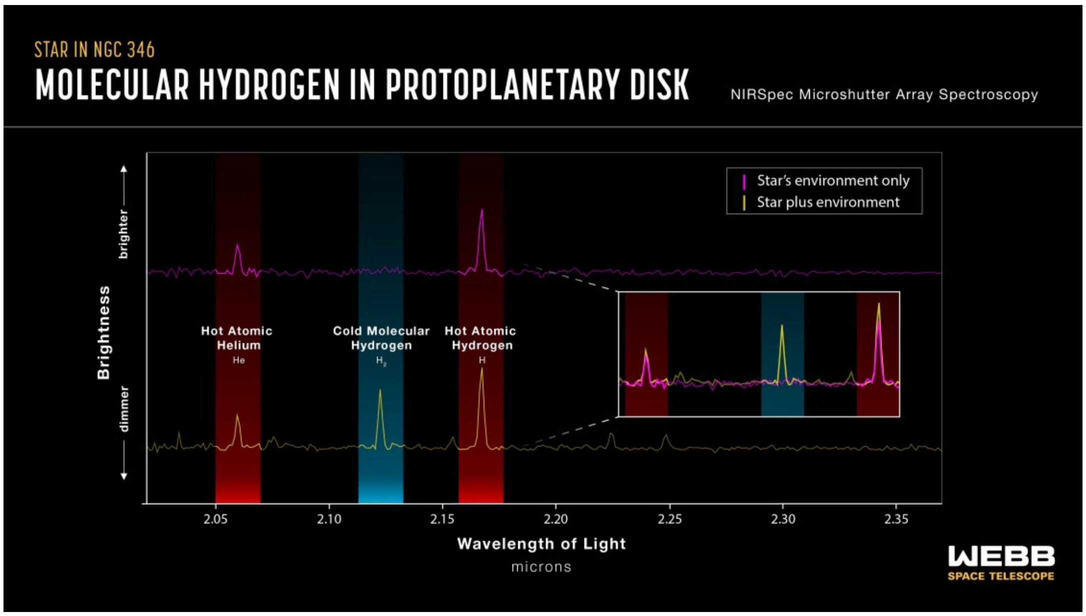
The team found thousands of stars that appear to accrete at higher rates and for times exceeding 30 million years. Here are 6 of the 10 stars examined in the study.



With Webb, scientists have the first-ever spectra of forming Sun-like stars and their immediate environments in a nearby galaxy.



This graph shows a spectrum of one of the target stars. On the bottom left in yellow, this graph highlights spectral fingerprints of hot atomic helium, cold molecular hydrogen, and hot atomic hydrogen. On the top left in magenta, it shows a spectrum slightly offset from the star that includes only light from the background environment. This second spectrum lacks a spectral line of cold molecular hydrogen. On the right is the comparison of the top and bottom lines. This comparison shows a large peak in the cold molecular hydrogen coming from the star but not its nebular environment. Also, atomic hydrogen shows a larger peak from the star. This indicates the presence of a protoplanetary disk immediately surrounding the star.

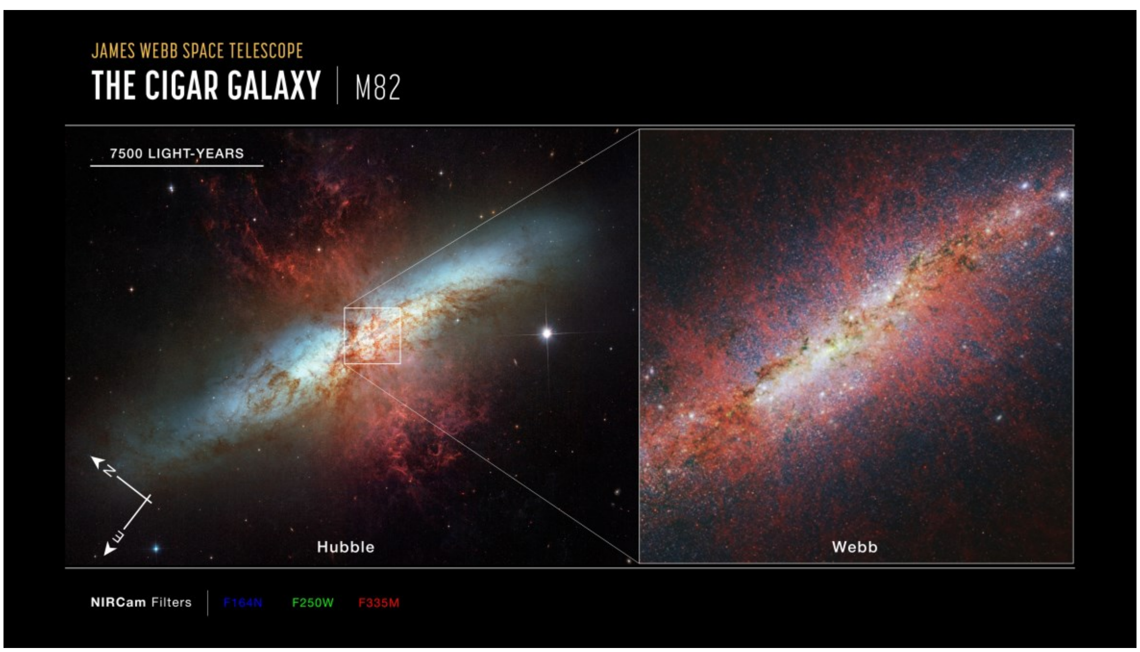


But these findings tell us that new stars can indeed form large planets even in the early Universe when there were no heavy element around.

The Cigar Galaxy M82 – 12 mly

We covered this Hubble image of the starburst galaxy M82 (aka the Cigar Galaxy) 12 mly away in the How Far Away Is It video book. It's called a starburst galaxy because of the extremely rapid star formation at its core. It's creating stars 10 times faster than the Milky Way. The clumpy tendrils represented in red can be seen extending above and below the plane of the galaxy. These gaseous streamers are a galactic wind rushing out from the core of the starburst.

Now a team of scientists is using Webb's Near-Infrared camera to examine the core of the galaxy to better understand how it is forming these stars and how this extreme activity is affecting the galaxy as a whole. One area of focus for this research team was understanding how this galactic wind, which is caused by the rapid rate of star formation and subsequent supernovae, is being launched, and how is it influencing its surrounding environment.



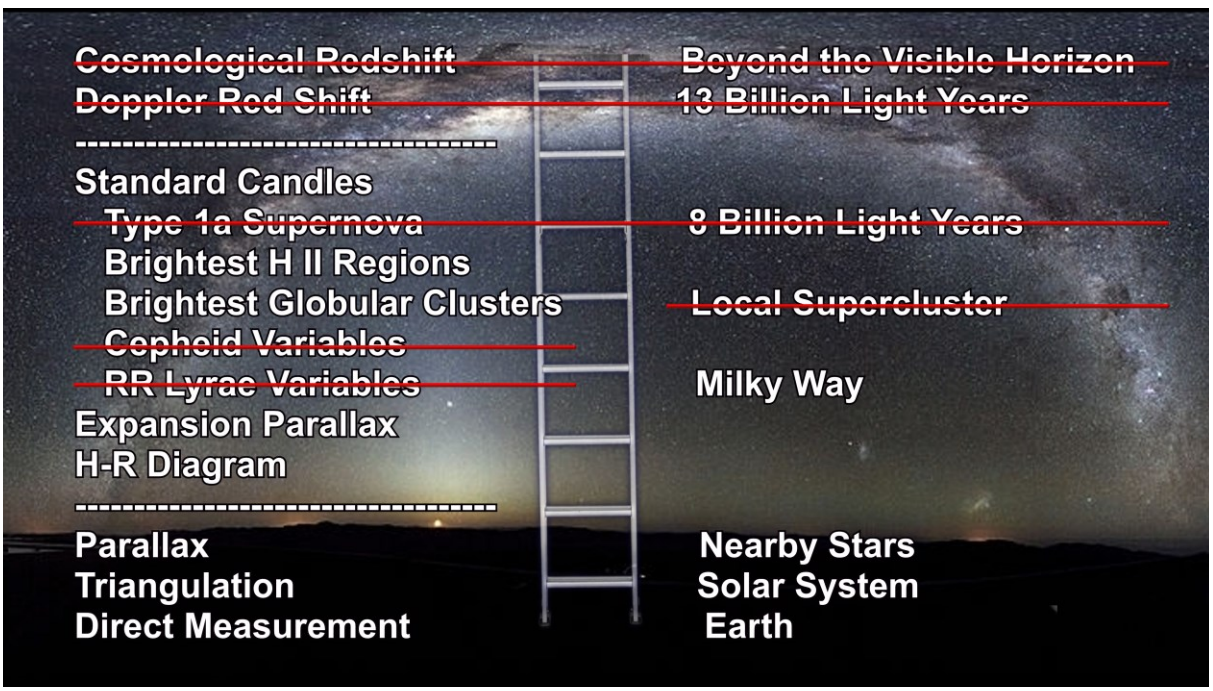
By resolving a central section of M82, scientists have been able to examine where the wind originates, and gain insight into how hot and cold components interact within the wind. Looking closer toward the center, we see small specks in green that represent concentrated areas of iron, most of which came from supernova explosions. Small patches that appear red signify regions where molecular hydrogen is being lit up by the radiation from nearby young stars.

This image uses shorter wavelengths that distinguish small, bright compact sources. Every single white dot in this image is either a star or a star cluster. This granularity enables astronomers to acquire an accurate count of all the star clusters in this galaxy. This knowledge can help us understand the different phases of star formation and the timelines for each stage.

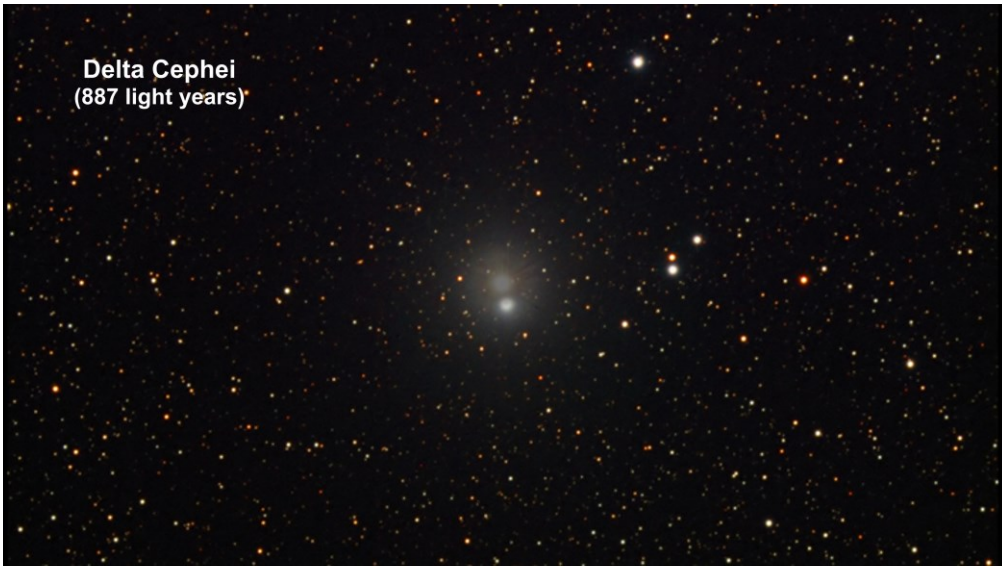
In the near future, the team will have spectroscopic observations of M82 from Webb ready for their analysis, as well as complementary large-scale images of the galaxy and its wind. So, we will be visiting this galaxy again soon.

Cepheid Variable Check – NGC 5468 - 130 mly

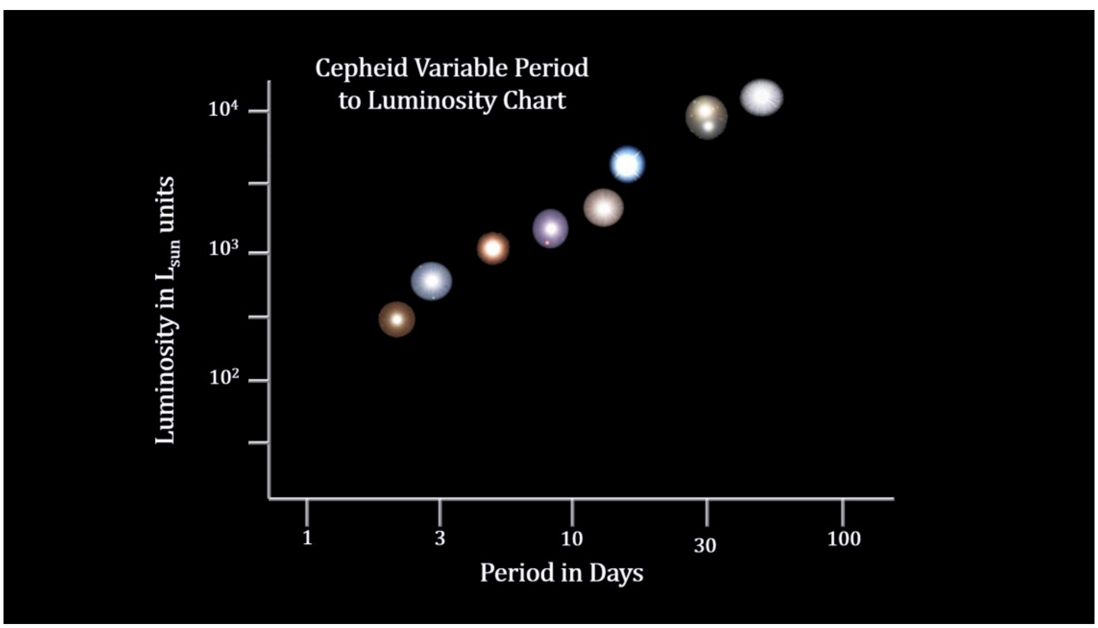
In the "How Far Away Is It" video book, we built the Cosmic Distance Ladder, step by step from direct measurement to parallax to standard candles including Cepheid Variables and Type 1a Supernovae up to Redshift. But as late as the early 1900s, cepheid variable stars were not considered a standard candle. So, there was no calibrating rung on the ladder to establish the distances to Type 1a supernova. There was no good way to know how far away celestial objects were beyond our Milky Way galaxy.



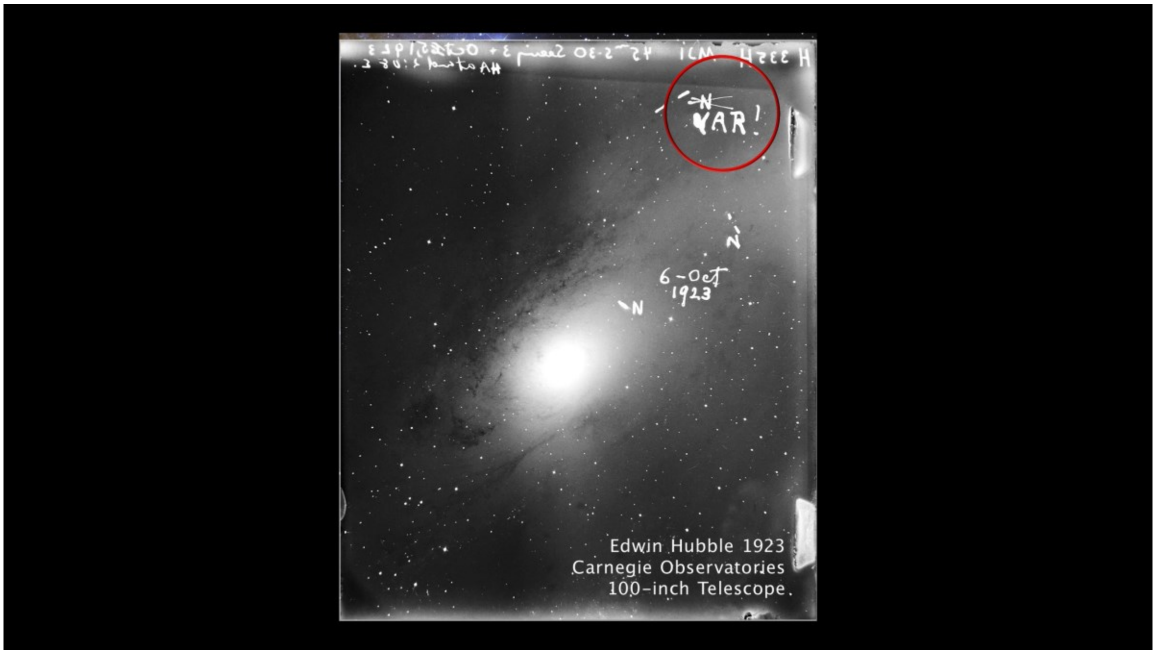
Most stars have some variability in their luminosity. Even our sun varies on an 11 year cycle of sun spots. But Cepheid variability is caused by regular pulsation in the outer layers of the star.



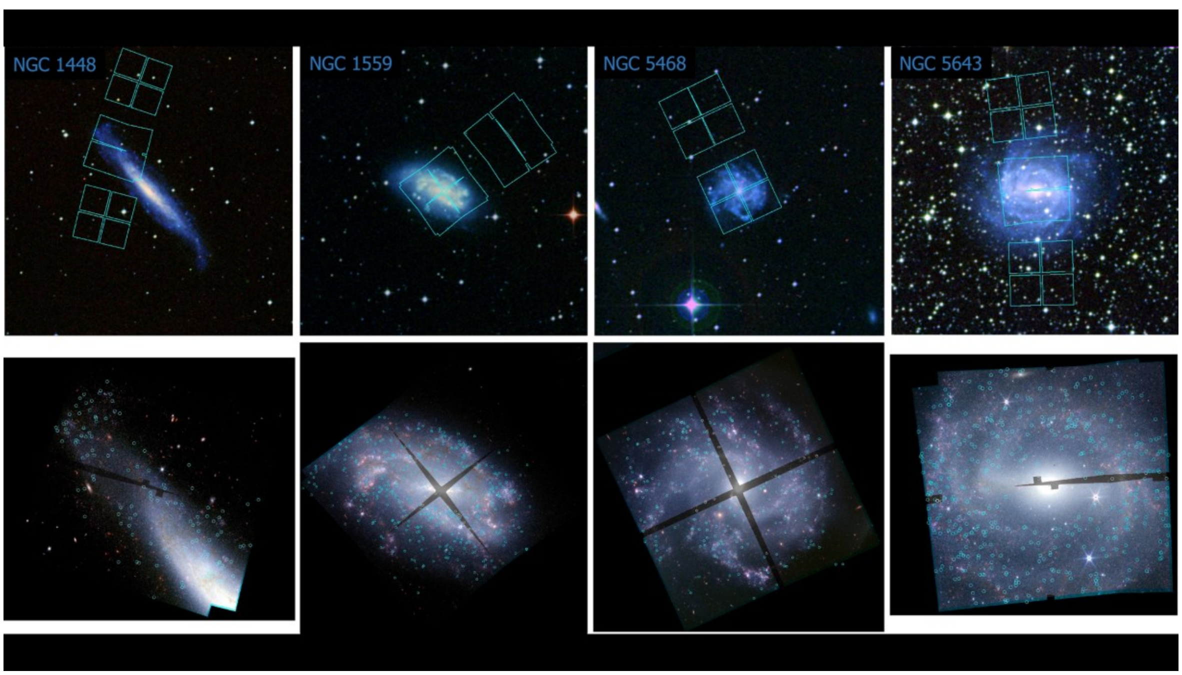
In the late 19th and early 20th century, Henrietta Leavitt, an American astronomer, worked meticulously to plot Cepheid luminosity cycle periods against luminosity. She found that the period of these stars varied in proportion to their absolute brightness. Leavitt's discovery made Cepheid stars true standard candles and changed the world of astronomy forever.



For example, it was Edwin Hubble's 1923 discovery of a Cepheid variable in the Andromeda cloud that proved Andromeda was its own galaxy 2.5 millions of light years outside our galaxy. Now, the Hubble Space Telescope has been measuring cepheid variables for 30 years to establish the Hubble constant for the Universe's current expansion rate.



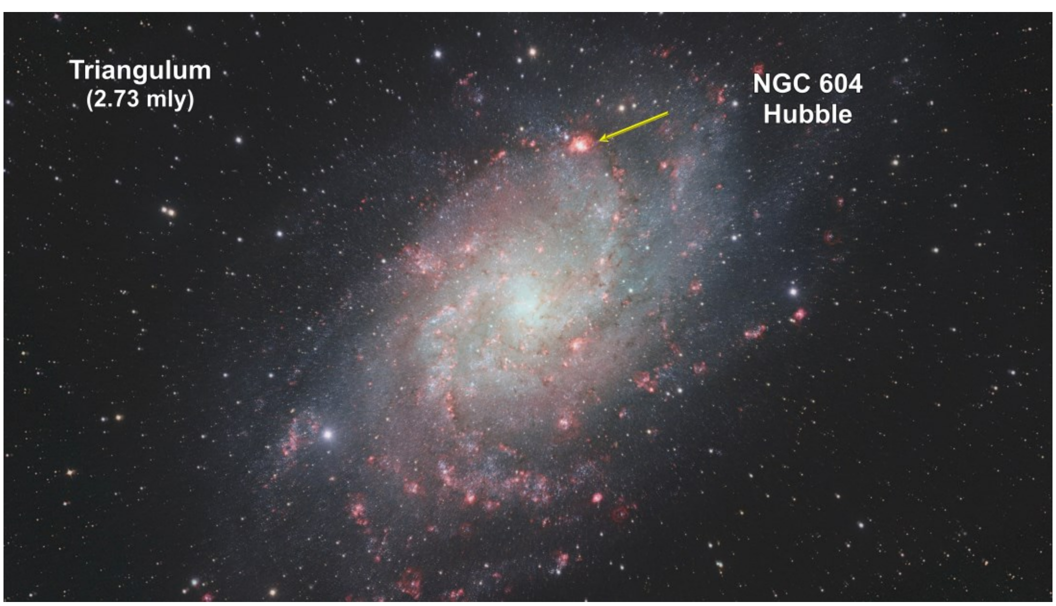
The Webb telescope is now being used to double check the Hubble results. The new Webb observations include five host galaxies with eight Type Ia supernovae containing a total of 1,000 Cepheids.



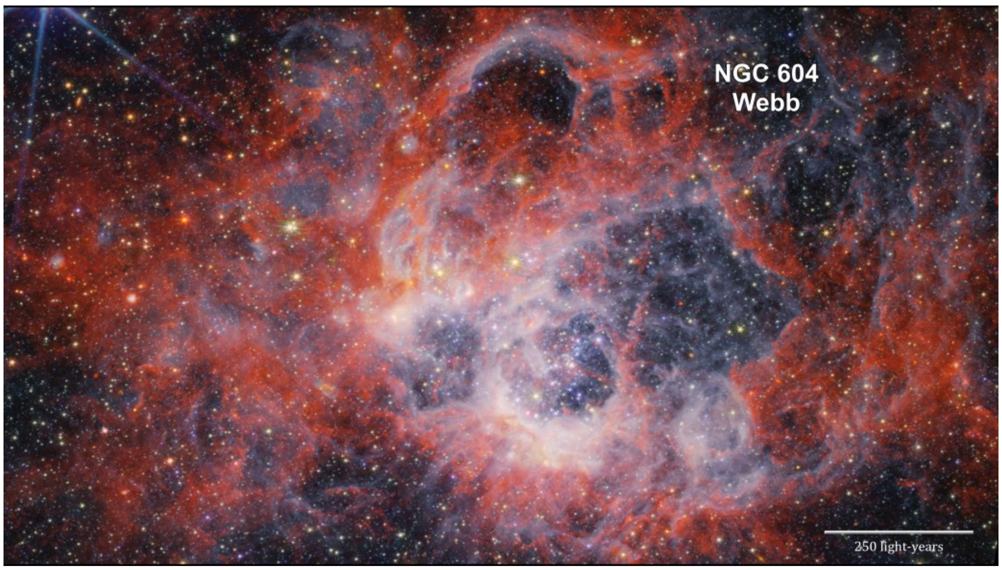
NGC 54 68 a 130 million light-years away, is one of them. It's the farthest galaxy where Cepheids have been well measured. This covers the entire range of the Cepheid rung on the cosmic distance ladder. These Webb observations verify the accuracy of the earlier Hubble measurements.

NGC 604 in Triangulum – 2.73 mly

Here we are zooming into the Triangulum galaxy 2.73 million lightyears away. It's the third largest galaxy in our local group. In the 'How Far Away Is It' video book, we covered this galaxy and the star forming region NGC 604 located in one of its outer arms. This is the Hubble image.



This Webb Near-Infrared Camera image shows how stellar winds from bright, hot young stars carve out cavities in surrounding gas and dust. The bright orange streaks signify the presence of carbon-based molecules known as polycyclic aromatic hydrocarbons. As you travel further from the immediate cavities of dust where the star is forming, the deeper red signifies molecular hydrogen. This cooler gas is a prime environment for star formation. Hydrogen ionized by ultraviolet radiation appears as a white and blue glow.



This image shows how large clouds of cooler gas and dust glow in mid-infrared wavelengths. This region contains more than 200 of the hottest, most massive kinds of stars, all in the early stages of their development. Some of the stars seen in this image are red supergiants—stars that are cool but very large, hundreds of times the diameter of our Sun. The blue tendrils of material signify the presence of the hydrocarbons.

Sombrero galaxy - 28 mly

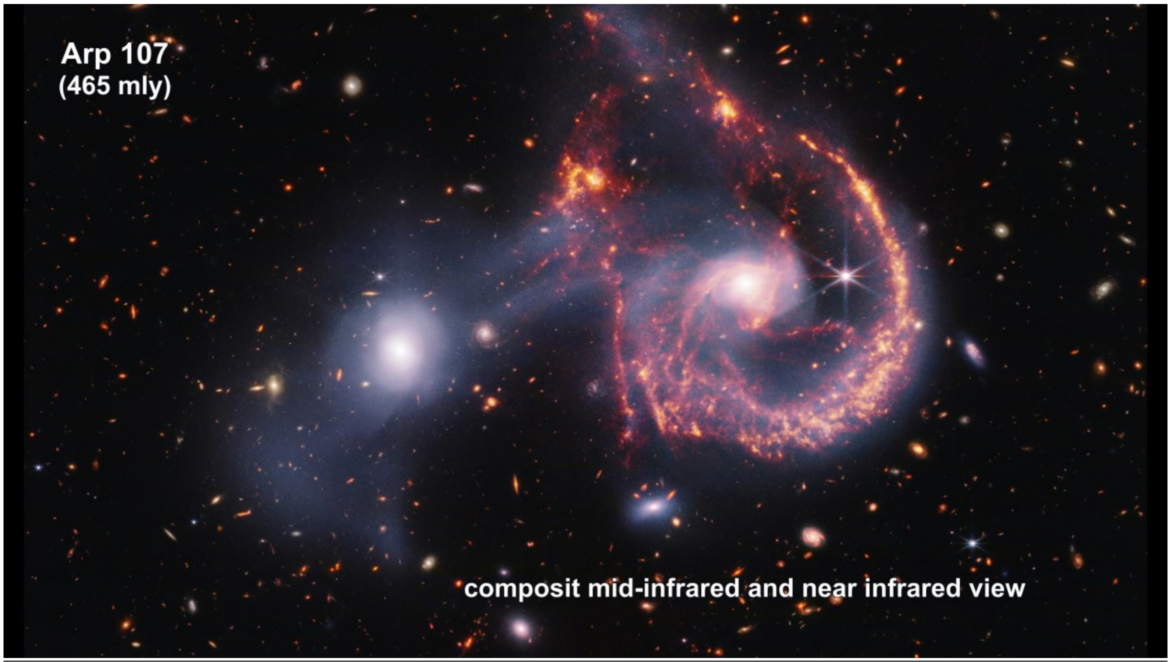
Here's Hubble's image the Sombrero galaxyM104, [Messier 104] taken in 2003. The galaxy's hallmark is a brilliant white, bulbous core encircled by the thick dust lanes comprising the spiral structure of the galaxy. As seen from Earth, the galaxy is tilted nearly edge-on. The galaxy is 50,000 light-years across. Hubble easily resolves M104's rich system of globular clusters, estimated to be nearly 2,000 in number - 10 times as many as orbit our Milky Way galaxy. The ages of the clusters are similar to the clusters in the Milky Way, ranging from 10-13 billion years old.

Here's the view from Spitzer's infrared camera in 2005. It highlights the bright, smooth ring of dust circling the galaxy. Spitzer's full view shows the disk is warped, which is often the result of a gravitational encounter with another galaxy. The clumpy areas spotted in the far edges of the ring indicate young star-forming regions.

This is the image from Webb taken in 2024. It reveals the smooth inner disk of the galaxy. The mid-infrared light highlights the gas and dust that are part of star formation taking place within the Sombrero Galaxy's outer disk. Embedded in the bright core of M104 is a smaller disk, which is tilted relative to the large disk. X-ray emission suggests that there is material falling into the compact core, where a 1-billion-solar-mass black hole resides.

Arp 107 is located 465 million light-years

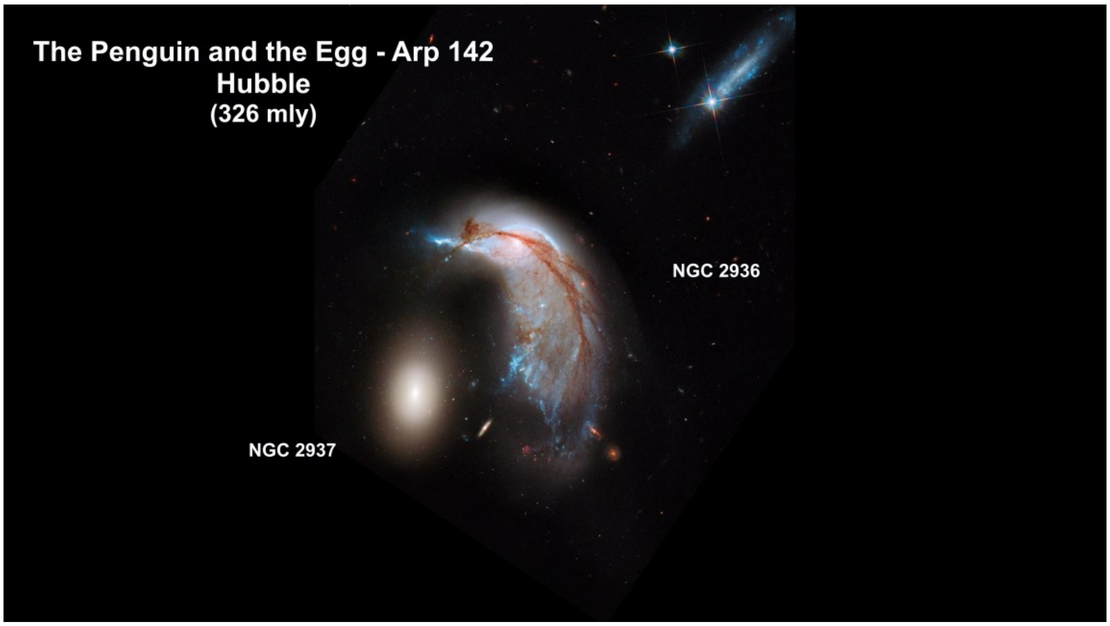
This is the interacting galaxy pair named Arp 107. They collided hundreds of millions of years ago. The smaller elliptical galaxy had an off-center collision instead of a direct hit. This significantly disturbed the spiral arms of the larger galaxy. The image is a composite, combining observations from Webb's Mid-InfraRed Instrument and its Near-InfraRed Camera. The near infrared highlights the stars within both galaxies, and the connection between them: a transparent, white bridge of stars pulled from both galaxies during their passage through each other. The orange-red highlights star-forming regions and dust.



This mid-infrared image highlights the supermassive black hole at the center of the large spiral galaxy. The bright nucleus contains an accreting supermassive black hole, which makes this a Seyfert galaxy.

The Penguin and the Egg - Arp 142 – 326 mly

This is the Hubble image of Arp 142, nicknamed the Penguin and the Egg, taken in 2013. We first covered this system in the Colliding Galaxies chapter of the "How Far Away Is It" video book.

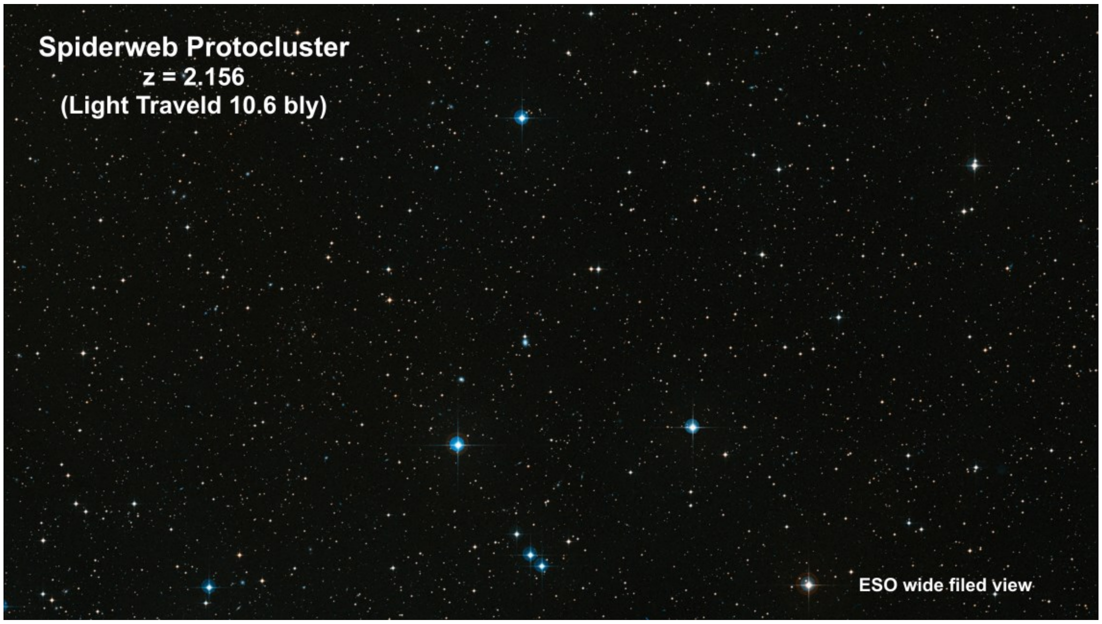


This new near-infrared image from Webb was taken in 2024 to mark the telescopes second year in operation. The two interacting galaxies made their first pass through each other between 25 and 75 million years ago. The event triggered new star formation in the Penguin with about 100 to 200 stars forming per year. By comparison, our Milky Way galaxy [which is not interacting with a galaxy of the same size] forms roughly six to seven new stars per year.

This is a combined near and mid infrared instruments image. The Penguin's galactic center looks like an eye set within a head, and the galaxy has prominent star trails that take the shape of a beak, backbone, and fanned-out tail. A faint, but prominent dust lane extends from its beak down to its tail. Despite the Penguin appearing far larger than the Egg, these galaxies have approximately the same mass. The oval Egg is filled with old stars, and little gas and dust, which is why it has maintained a compact oval shape.

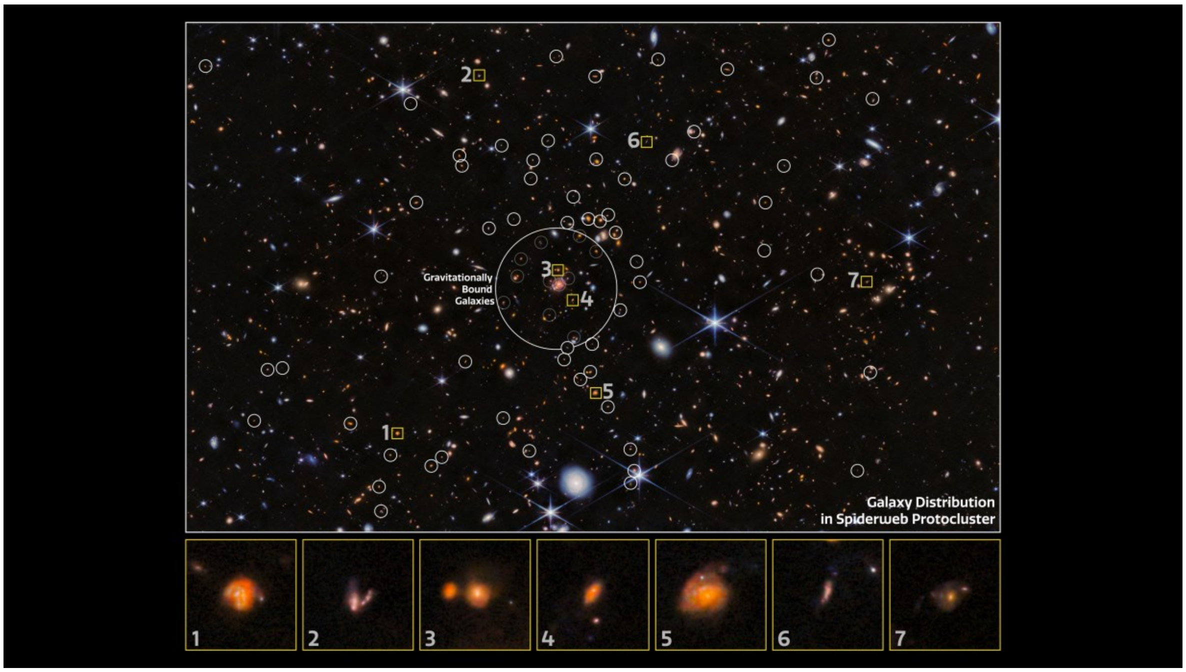
Spiderweb Protocluster – z = 2.156

Here's a wide field view of the protocluster around the Spiderweb galaxy from the European Southern Observatory. It's 10.6 bly away. The light that we see in the image shows galaxies at a time when the Universe was only 3 billion years old. Most of the mass in the protocluster does not reside in the galaxies, but in the gas known as the intracluster medium. Because of the mass of the gas, we know that the protocluster is in the process of becoming a massive cluster held together by its own gravity.



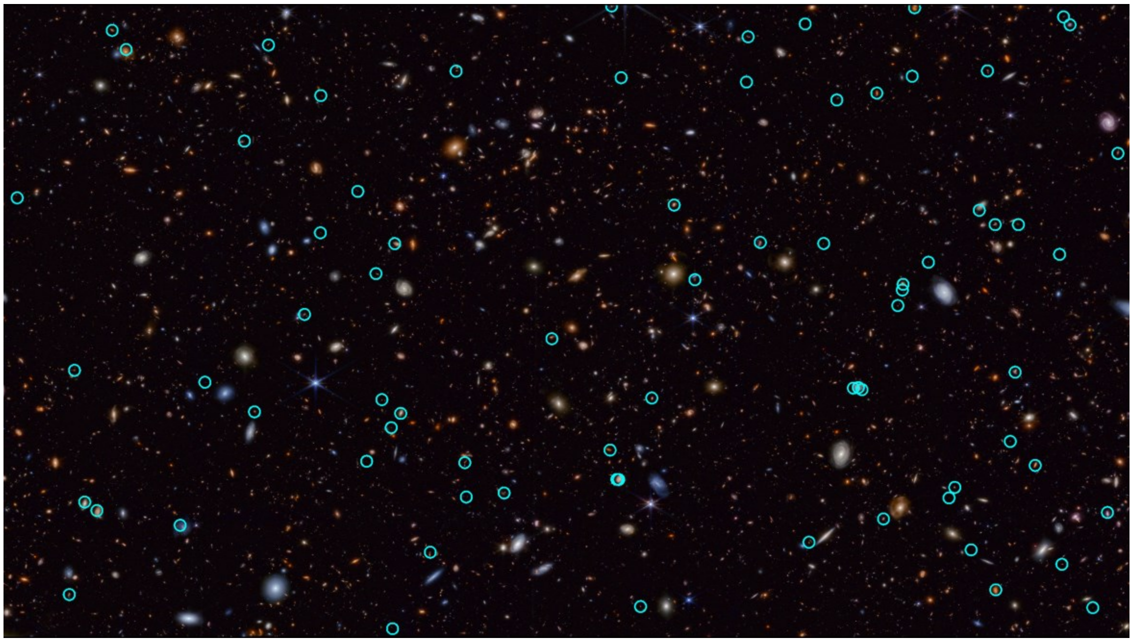
Using Webb's infrared capabilities, an international team of astronomers have found new galaxies in the Spiderweb protocluster. Infrared radiation passes more freely through cosmic dust than visible light, which is scattered by the dust. They found that the gravitational interactions in these dense regions are not as important as previously thought.

This annotated image shows the galaxy distribution in the Spiderweb protocluster. The galaxies are annotated by white circles, and the collection of gravitationally-bound galaxies is identified in the center of the image. A selection of these galaxies is featured as individual close-ups at the bottom of the image.

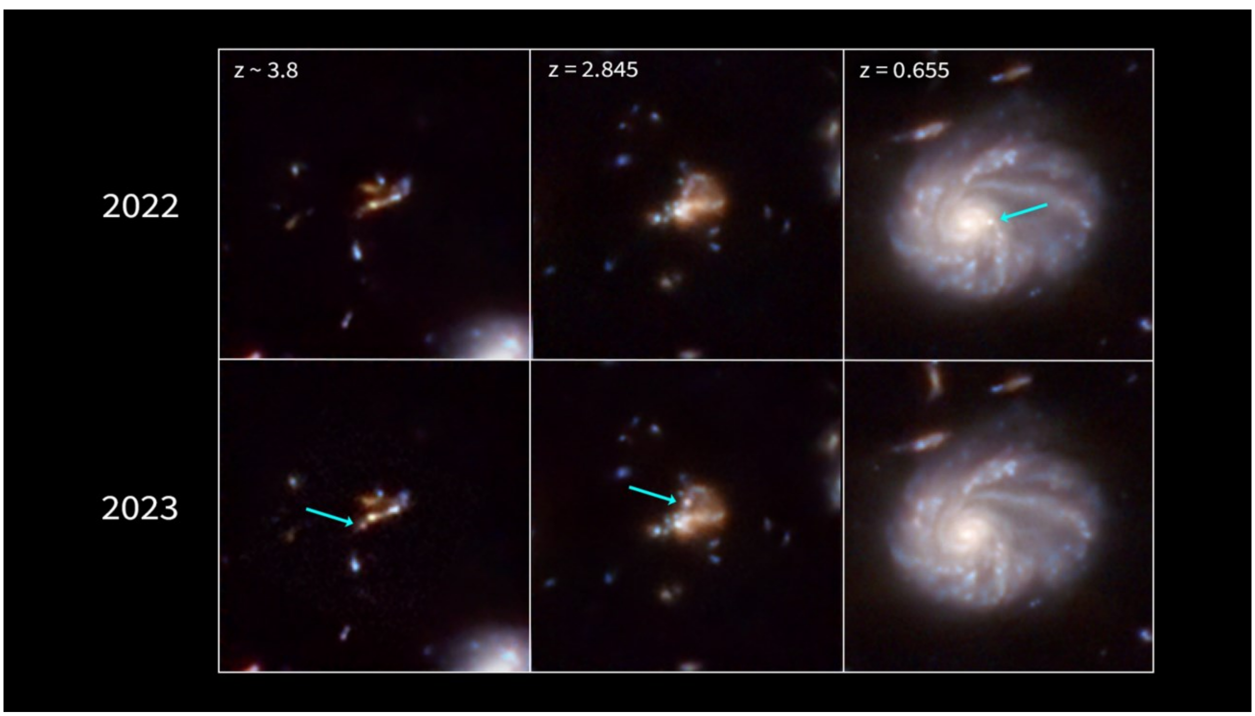


JADES Supernovae Survey – z = 3.6

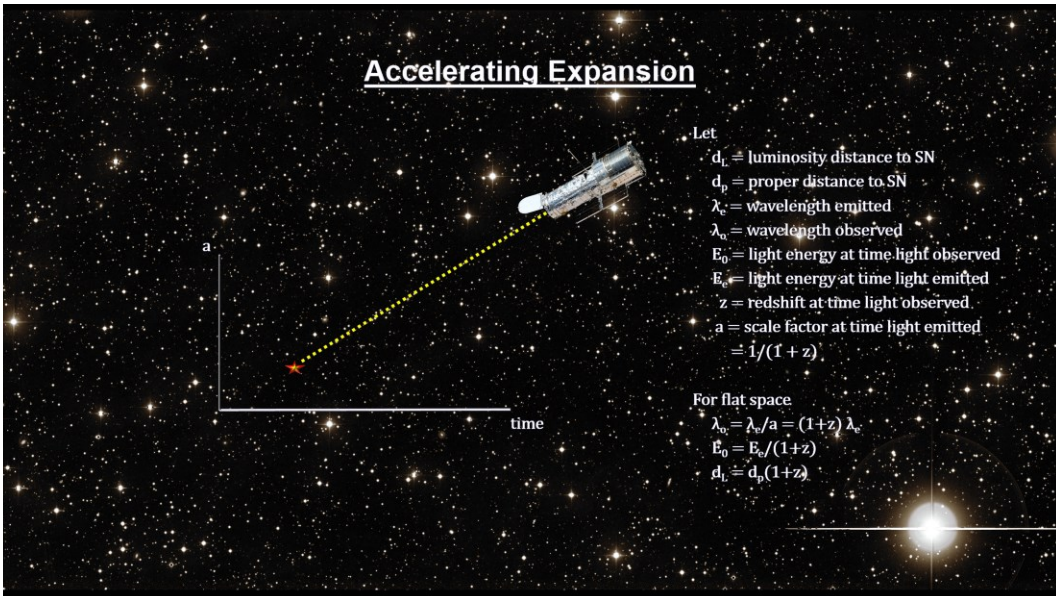
Here's a study of the GOODS South Field looking for supernovae. A team using Webb data has identified 10 times more supernovae in the early universe than were previously known. The team analyzed imaging data obtained as part of the Advanced Deep Extragalactic Survey (JADES for short) program. In all, they uncovered around 80 supernovae in a patch of sky about the thickness of a grain of rice held at arm's length. To Prior to Webb's launch, only a handful of supernovae had been found above a redshift of 2. That's 10.4 bly away. The JADES sample contains many supernovae that exploded even further in the past, with redshifts up to 3.6 – 1.5 billion light years further away.



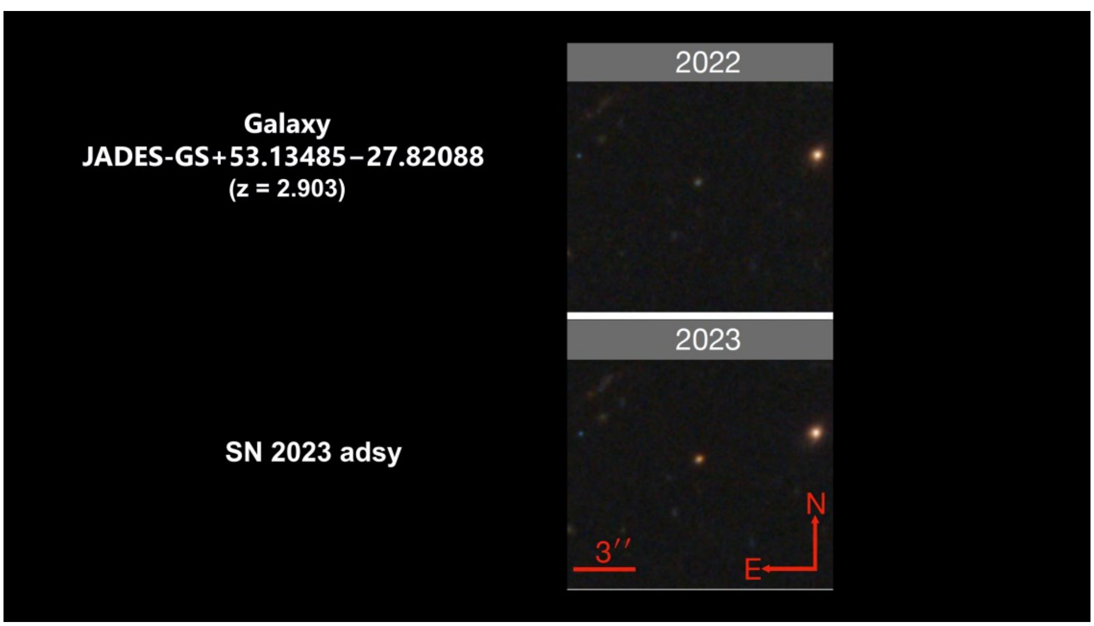
To discover the supernovae, the team compared multiple images taken up to one year apart and looked for sources that disappeared or appeared in those images. These objects that vary in observed brightness over time are called transients. The team is trying to identify whether distant supernovae are fundamentally different from or very much like what we see in the nearby universe.



Of particular interest are standard candle Type Ia supernovae used to measure the expansion rate of the universe. We covered this in the "How Far" and "How Old" video books. The question is 'Do Type Ia supernovae at high redshifts have the same intrinsic brightness, regardless of distance?' This is critically important, because if their brightness varies with redshift, they would not be reliable markers for measuring the expansion rate.



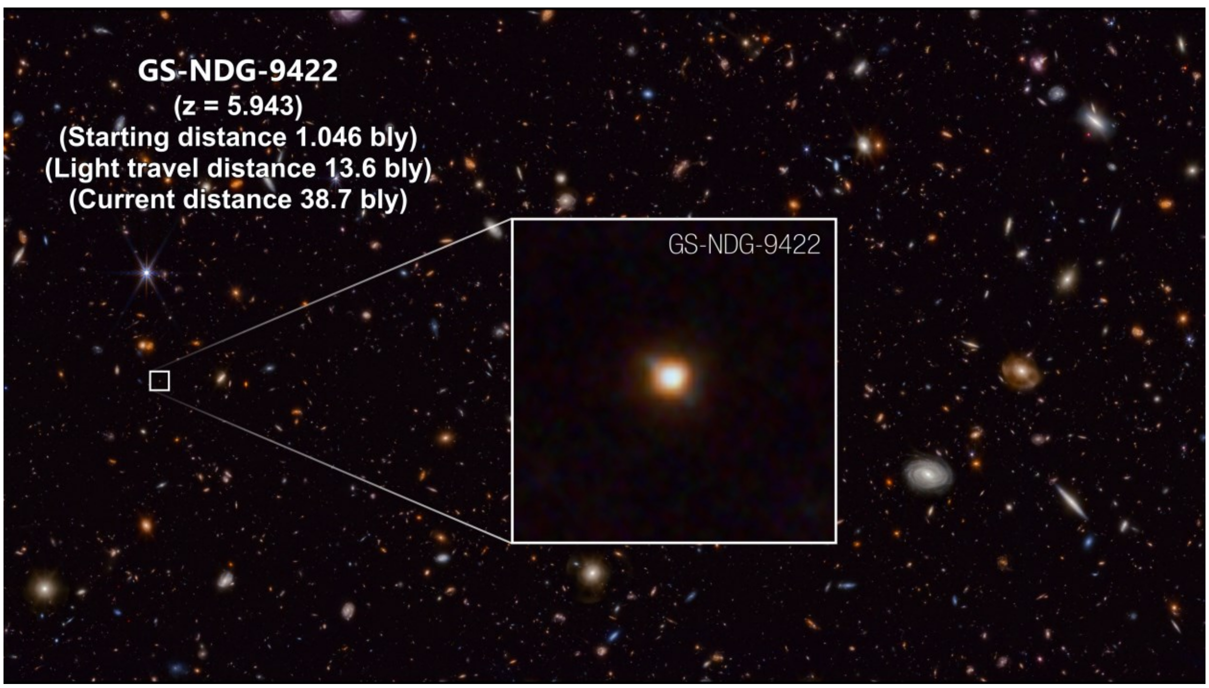
The team identified one at a redshift of 2.903. The light from this explosion took 11.5 billion years to reach us. The previous distance record was z=1.95 (1.2 bly closer). This new JADES supernova showed no evidence that Type Ia brightness changes with redshift. So, for now, Type Ia supernova-based theories about the universe's expansion rate and its ultimate fate remain intact.



GS-NDG-9422 – z = 5.9

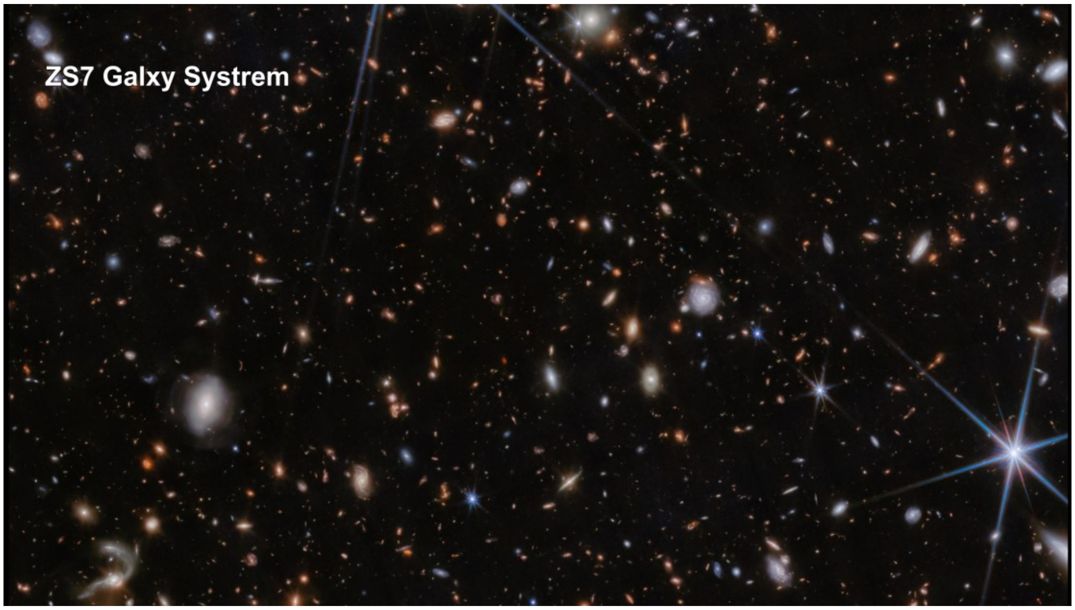
Here's Webb image of galaxy GS-NDG-9422. Light from this galaxy took 13.64 billion years to reach us. The galaxy has an odd light signature, which astronomers attribute to its gas outshining its stars. Formed approximately one billion years after the big bang, it may be a missing-link phase of galactic evolution between the universe's first stars and familiar, well-established galaxies.

In the local universe, typical hot, massive stars have a temperature ranging between 40,000 to 50,000 degrees Celsius. This galaxy has stars hotter than 80,000 degrees! The research team suspects that the galaxy is in the midst of a brief phase of intense star formation inside a cloud of dense gas that is producing a large number of massive, hot stars. The gas cloud is being hit with so many photons from these stars that it is shining more brightly than the stars themselves.

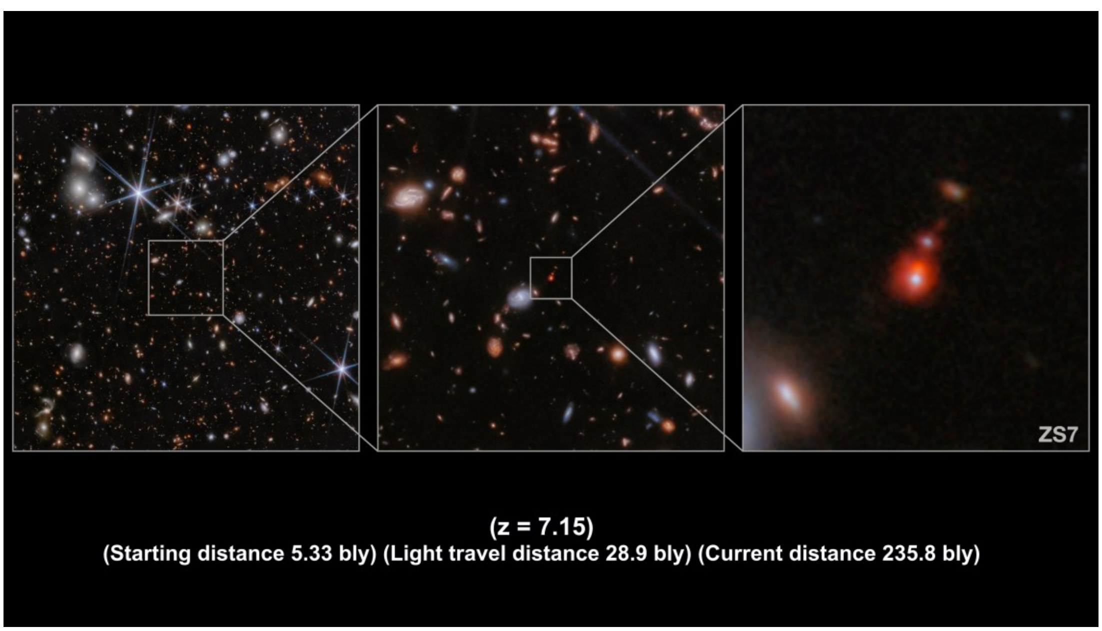


Black Hole Merger z = 7.15

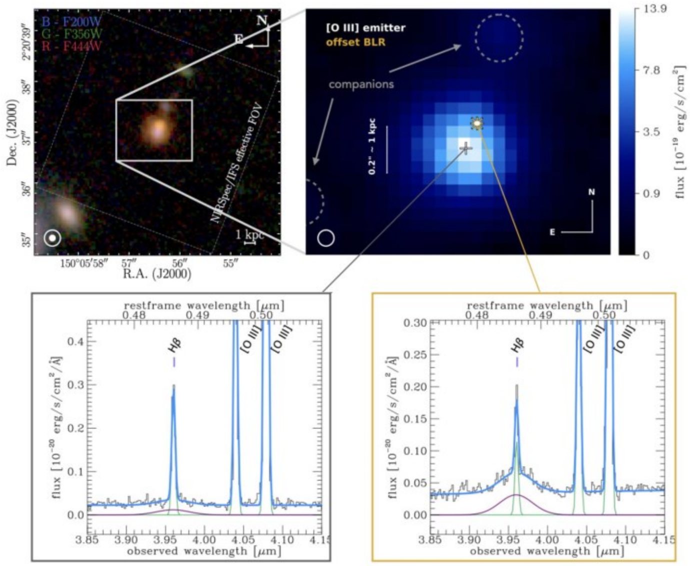
This image shows the environment containing the galaxy system ZS7 from the James Webb Space Telescope PRIMER program as seen by Webb's near-infrared camera. Recent studies have found a large number of Active Galactic Nuclei (AGN for short) associated with moderately massive black holes with redshifts greater than 5. New research using Webb's Spectrographic capabilities has found evidence of an ongoing merger of two galaxies along with their massive black holes much further away than that.



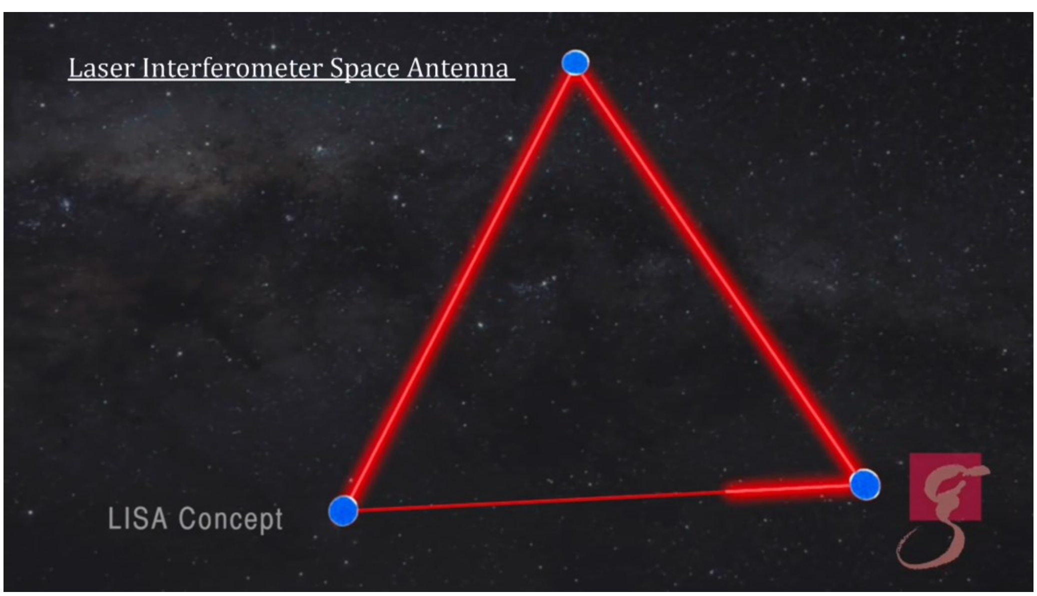
The program team found galaxy ZS7 along with very dense high velocity gas in the vicinity of a black hole, as well as hot and highly ionized gas illuminated by the energetic radiation typically produced by black hole accretion disks. The galaxy and its black holes have a redshift of 7.15. Light from this galaxy took 28.9 billion years to reach us. The team was able to spatially separate the two black holes and determined that one of the two has a mass that is 50 million times the mass of the Sun. The mass of the other one is likely similar, although it is harder to measure because this second black hole is surrounded by dense gas. In this image, ionized hydrogen emission is orange and the doubly ionized oxygen emission is dark red.



One of the ways to detect a black hole is to analyze the radiation created by their accretion disks. In this case, Webb's spectrograph focused on the emission lines of hydrogen and oxygen. Both of these spectra presented a double peak feature. This double peak is caused by the rotation of the accretion disk. As the disk rotates, light from the portion of the disk rotating toward us is shifted toward the blue spectrum, while light on the portion of the disk rotating away from us is redshifted.

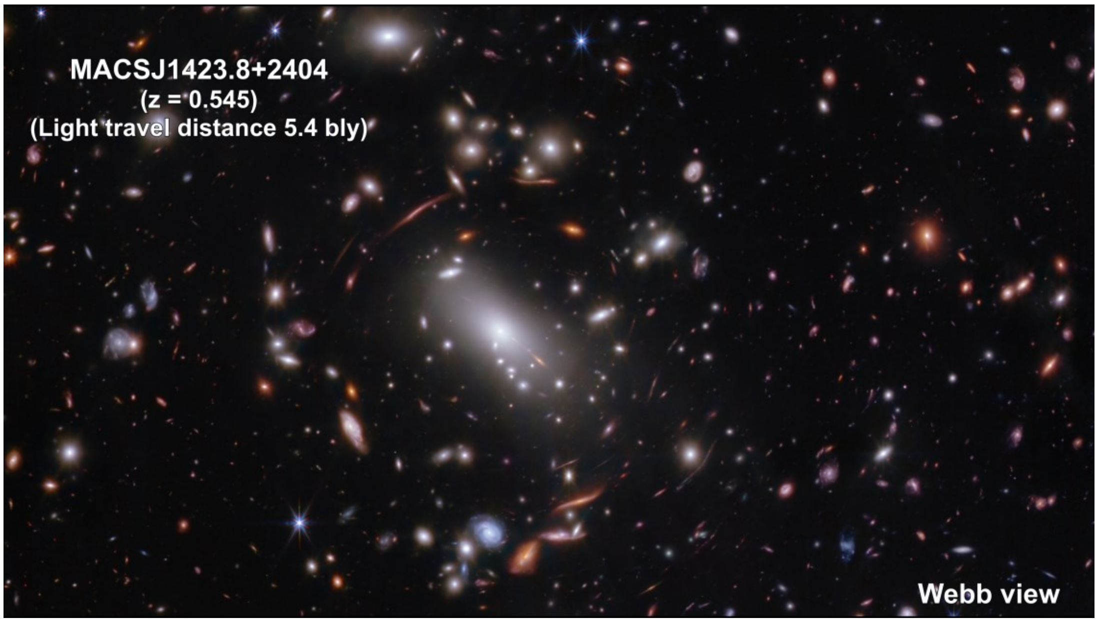


This finding may be relevant for estimates of the rate and properties of gravitational-wave signals from the early universe that may will be detected by future observatories like LISA.

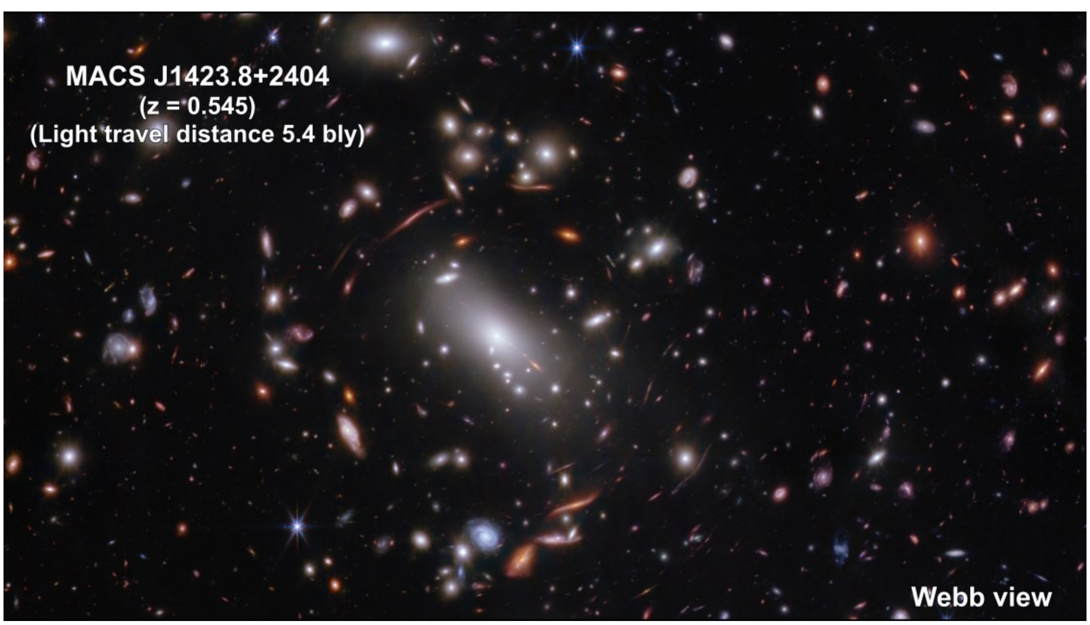


Firefly Sparkle – 13.1 bly

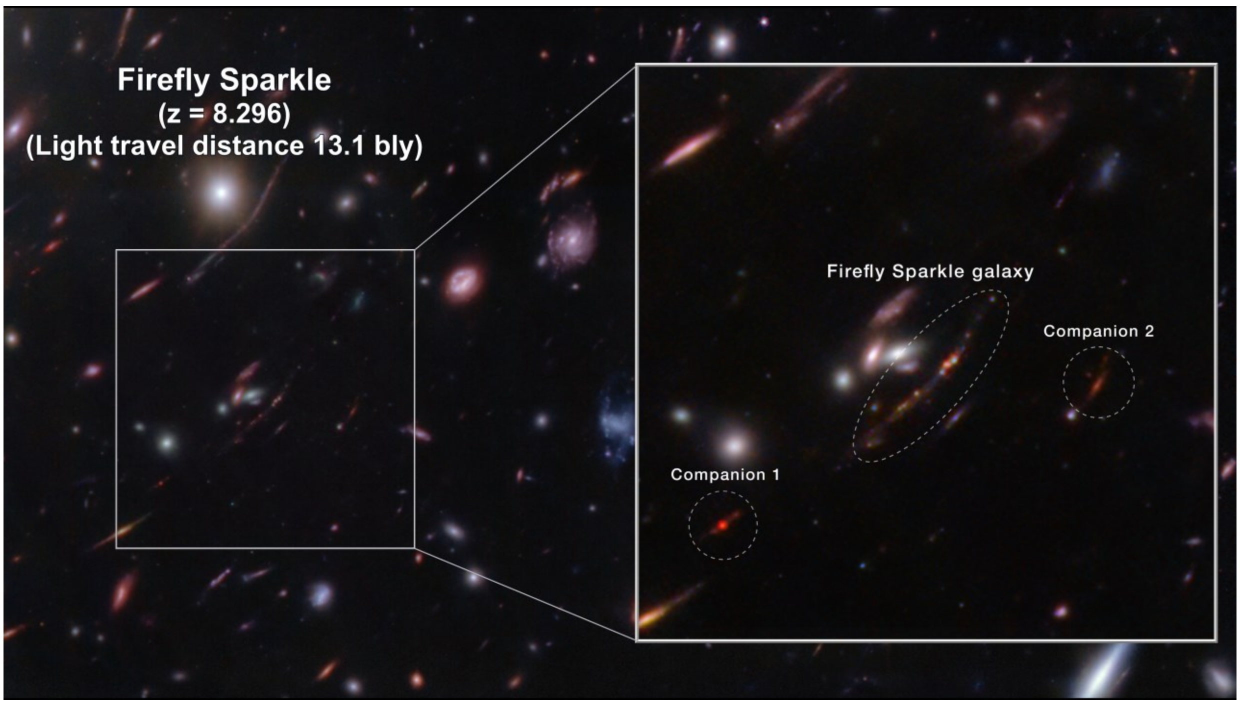
Here's a view of the galaxy cluster MACS J1423.8 taken by Hubble in 2010. Light from this cluster traveled 5.4 billion lightyears to get here. Note the large central elliptical galaxy at the center.



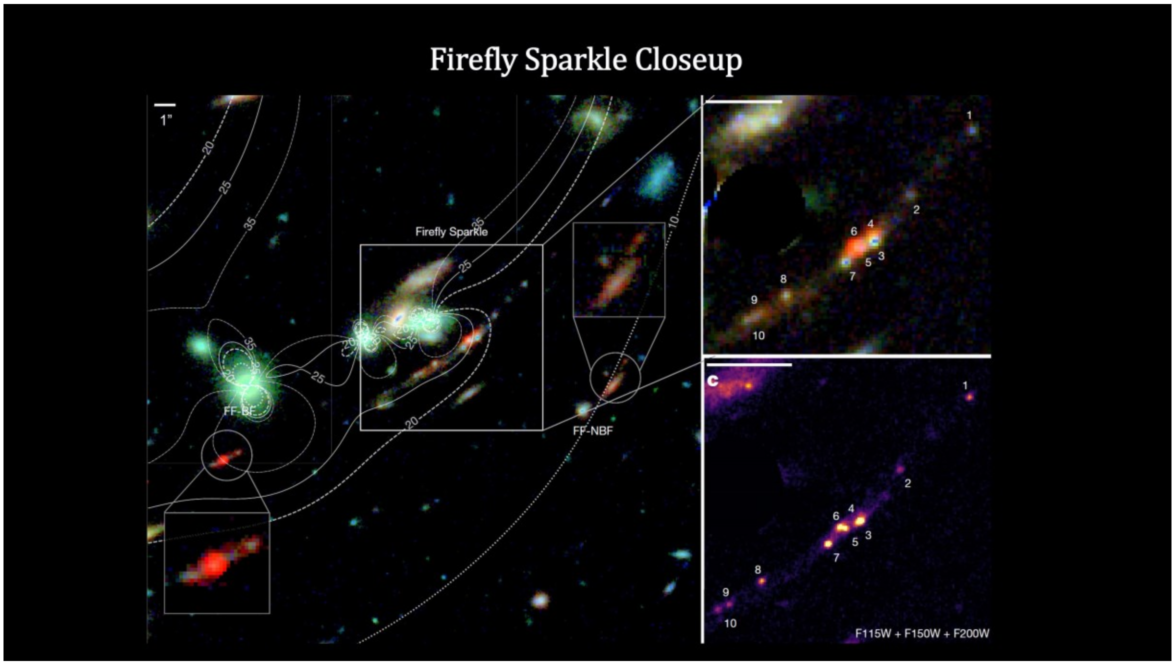
Here's the Webb view taken in 2024 by the Canadian Unbiased Cluster Survey (CANUCS). They revisited the field using Webb's infrared capabilities. They used the cluster as a gravitational lens to find a galaxy that existed 600 million years after the Big Bang.



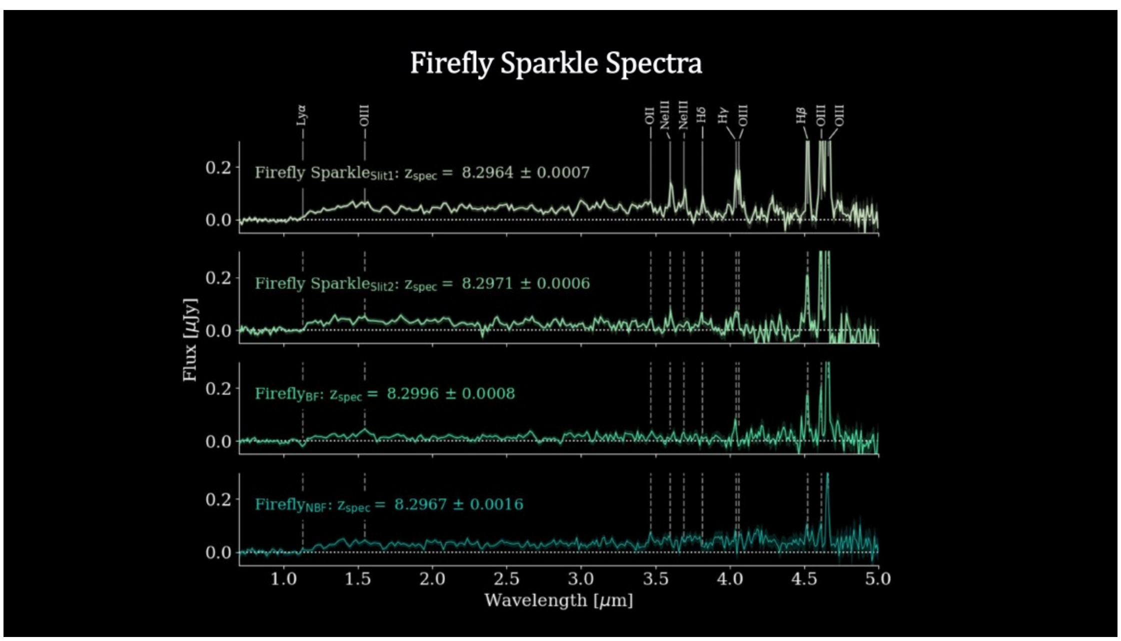
Nicknamed the Firefly Sparkle, its redshift is 8.296. The light we see traveled 13.1 billion lightyears. Its mass is similar to what our Milky Way galaxy's mass might have been at the same stage of development. Since the image of the galaxy is warped into a long arc, the researchers easily picked out 10 distinct star clusters, which are emitting the bulk of the galaxy's light. They are represented here in shades of pink, purple, and blue. Each of these clusters show different phases of star formation. Note that Firefly Sparkle has two neighbors: Firefly-Best Friend [at z = 8.2996] and Firefly-New Best Friend [at z = 8.2967].



Here's an image of the full field with the three galaxies. The white contours show the lines of lensing magnifications that range from 15, up to 40. The 10 star clusters are highlighted on the right. Firefly Sparkle is only 6500 light-years away from its best friend, and 42000 light-years away from its new best friend. All three would fit inside the Milky Way.



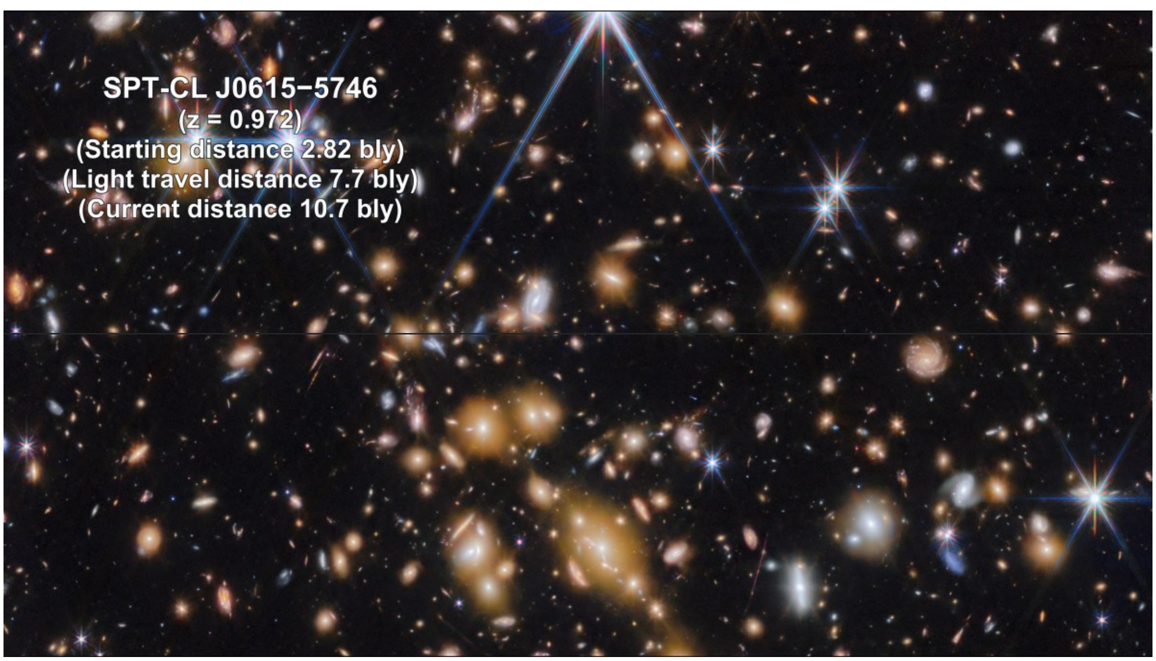
Here's the spectra for two slits of the Firefly Sparkle, along with those of its nearby two companions. Strong emission lines and a Lyman break in all the spectra unambiguously determine the redshifts of all the components.



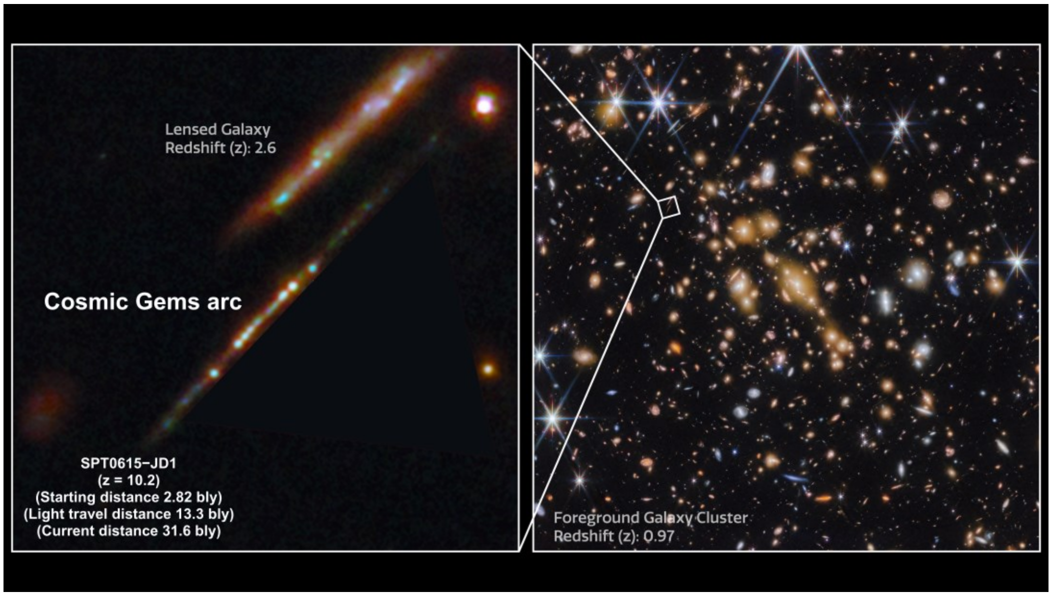
Cosmic Gems Arc – 13.2 bly

In our Milky Way we see ancient globular clusters of stars, which are bound by gravity and have survived for billions of years. These are old relics of intense star formation in the early Universe, but it is not well understood where and when these clusters formed.

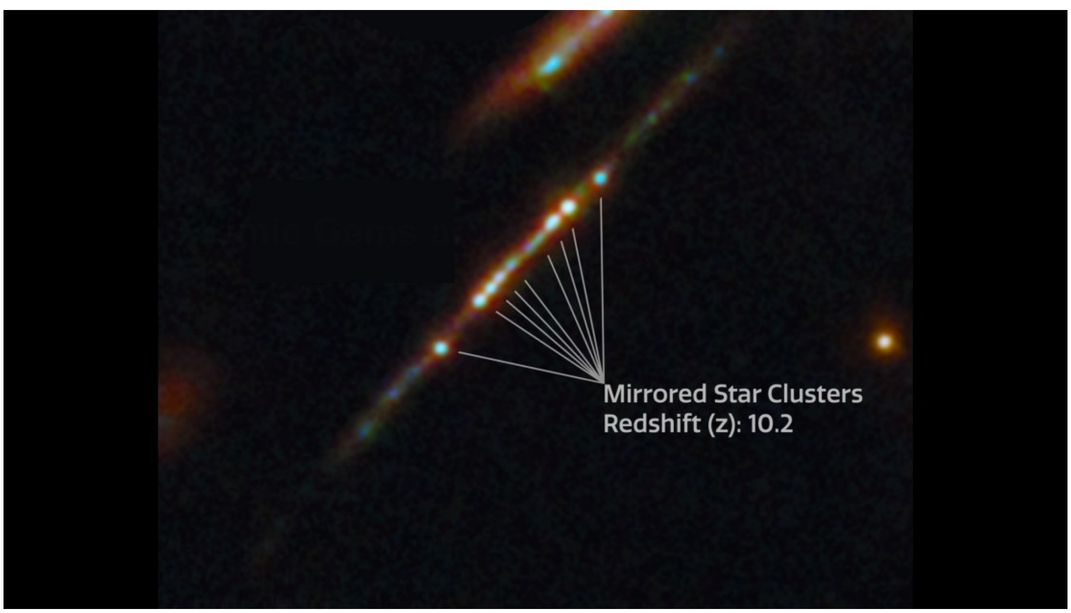
Here's a galaxy cluster 7.7 billion light years away first photographed by the Hubble Space Telescope.



It is gravitationally lensing more distant young galaxies that are distorted into arcs. One of these arcs, named the Cosmic Gems arc, is 13.3 billion light years away.



An international team of astronomers have used Webb to discover gravitationally bound star clusters in the arc. There are 5 of them with an additional 4 mirrored images. They are massive, dense, and located in a very small region of their galaxy, where they contribute the majority of the ultraviolet light coming from their entire galaxy. This is providing researchers with an excellent view of the early stages of a process that may go on to form globular clusters like M53.



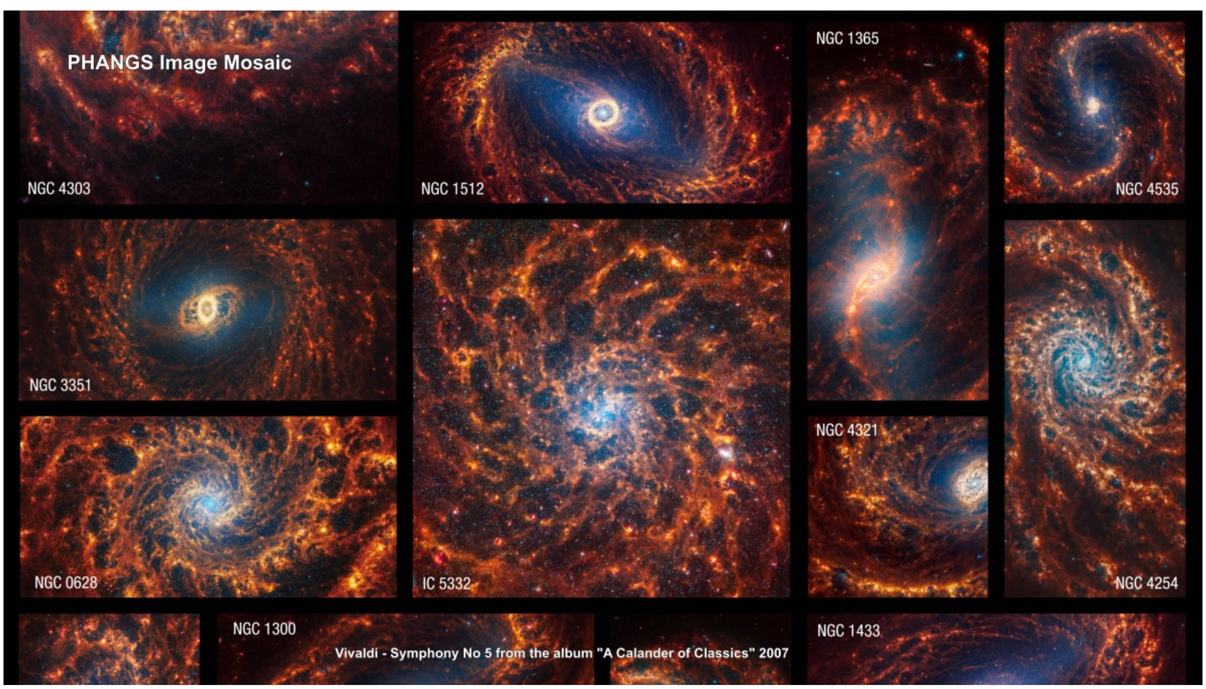
Ending Galaxy Array

We'll end our 2024 review with coverage of Webbs first 2024 release. It showcases near- and mid-infrared portraits of 19 face-on spiral galaxies in the Virgo Supercluster. They show stars, gas, and dust on the smallest scales ever observed beyond our own galaxy. [These Webb images are part of a large, long-standing project, the Physics at High Angular Resolution in Nearby Galaxies program or PHANGS for short.]

Webb's Near-Infrared Camera captured millions of stars in these images, which show up in blue tones. If you follow each of the galaxy's clearly defined arms, with all their stars, to their centers, you'll find old star clusters and active supermassive black holes.

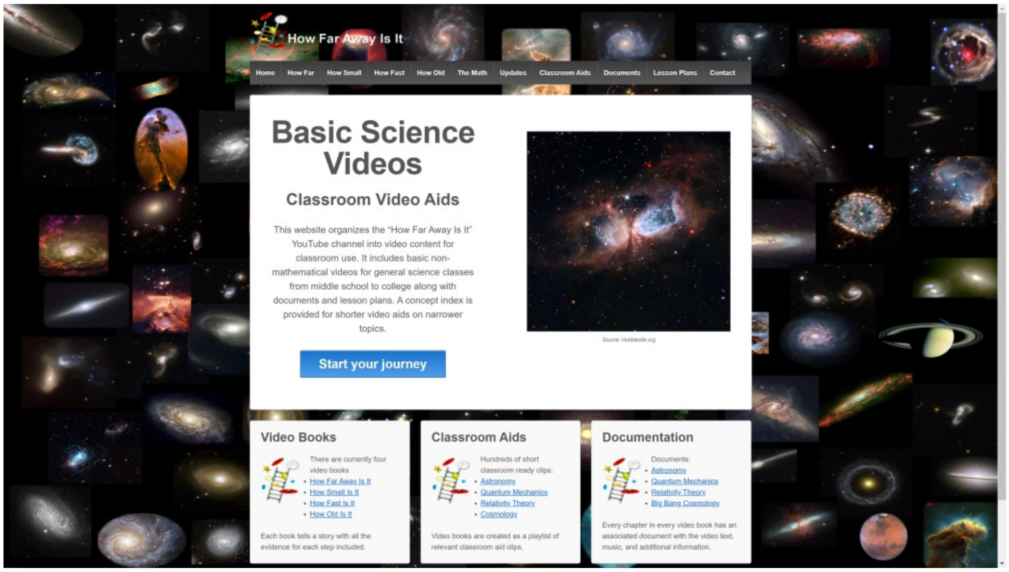
Some stars are spread throughout the spiral arms, but others are clumped tightly together in star clusters. The telescope's Mid-Infrared Instrument data highlights glowing dust, showing us where it exists behind, around, and between the stars. It also spotlights stars that haven't yet fully formed. The spiral arms' extended regions of gas also reveal details that show up in red and orange.

Evidence shows that galaxies grow from inside out. Star formation begins at galaxies' cores and spreads along their arms, spiraling away from the center. The farther a star is from the galaxy's core, the more likely it is to be younger. In contrast, the areas near the cores are populations of older stars. The galaxy cores that are awash in pink-and-red diffraction spikes may indicate an active supermassive black hole or saturation from bright star clusters toward the center.



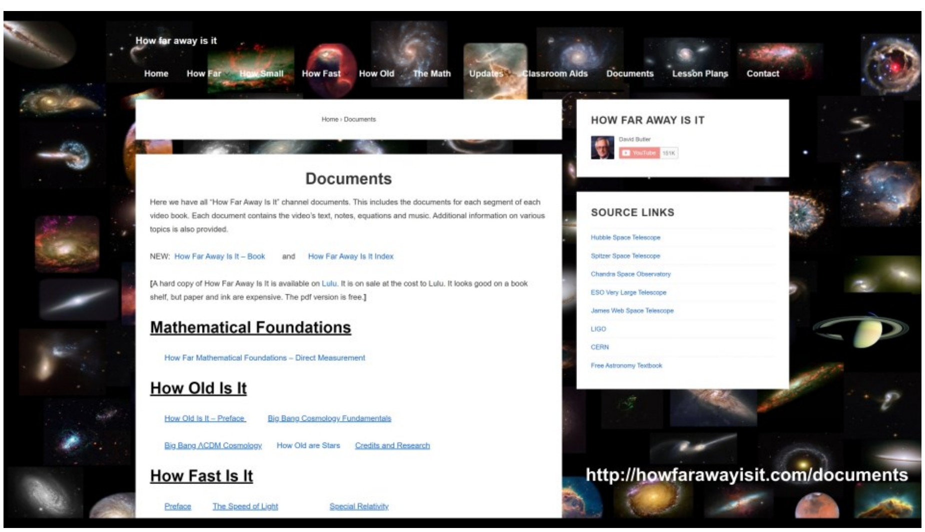
Credits and Research

Here are the links to Hubble and Webb sites, whitepapers, and other locations where I found the information contained in this 2024 review. These are also the places where you can begin to do your own research.



https://howfarawayisit.com/

And don't forget. Every video has a document on the howfarawayisit.com website containing all the text and pictures. Download and translate as needed. In closing, I want to thank Jonathan Onstead for his excellent editing. And I want to thank everyone for all the great comments and questions posted on my videos. I read them all. Keep them coming, and thanks for watching.



http://howfarawayisit.com/documents/

DART Update
https://www.jpl.nasa.gov/news/nasa-study-asteroids-orbit-shape-changed-after-dart-impact/
https://eyes.nasa.gov/apps/solar-system/#/65803_didymos/moons/dimorphos?time=2024-11-02T15:55:05.150+00:00&rate=1

Beta Pictoris - 60 ly
https://hubblesite.org/contents/media/images/2015/06/3490-Image.html
https://webbtelescope.org/contents/media/images/2024/101/01HKAHK9XJKKR4MFFSST52K2BY?news=true
https://www.eso.org/public/images/eso1024d/

FS Tau – 450 ly
https://esahubble.org/images/heic2406a/

R Aquarii - 700 ly
https://hubblesite.org/contents/news-releases/2024/news-2024-021.html

Serpens Nebula – 1,300 ly
https://webbtelescope.org/contents/news-releases/2024/news-2024-115.html
https://stsci-opo.org/STScI-01J0PNXVZGGSKMR1SVVD48M1PE.pdf

Horsehead Nebula – 1,300 ly
https://esawebb.org/news/weic2411/?lang

Little Dumbbell Nebula M76 – 3,400 ly
https://esahubble.org/news/heic2408/?lang

Crab Nebula – 6,500 ly
https://webbtelescope.org/contents/news-releases/2024/news-2024-120.html#heading-full-article
https://iopscience.iop.org/article/10.3847/2041-8213/ad50d1

IMBH in Omega Centauri - 17,700 ly
https://hubblesite.org/contents/news-releases/2024/news-2024-015.html
https://www.nature.com/articles/s41586-024-07511-z/figures/3

SN 1987A - 163,000 ly
https://esawebb.org/news/weic2404/?lang
https://www.science.org/doi/10.1126/science.adj5796

Young Brown Dwarfs – 200,000 ly
https://esawebb.org/news/weic2425/?lang

https://iopscience.iop.org/article/10.3847/1538-4357/ad779e

NGC 346 200,000 ly
https://webbtelescope.org/contents/news-releases/2024/news-2024-135.html

Digel Cloud 2S – 40,000 ly
https://esawebb.org/images/weic2422a/

The Cigar Galaxy M82 – 12 mly
https://esawebb.org/news/weic2410/?lang
https://arxiv.org/abs/2401.16648

Cepheid Variable Check – NGC 5468 - 130 mly
https://webbtelescope.org/contents/news-releases/2024/news-2024-108.html
https://iopscience.iop.org/article/10.3847/2041-8213/ad1ddd

NGC 604 in Triangulum – 2.73 mly
https://webbtelescope.org/contents/news-releases/2024/news-2024-110.html

Sombrero galaxy - 28 mly

https://hubblesite.org/contents/media/images/2003/28/1415-Image.html
https://www.jpl.nasa.gov/images/pia07899-spitzer-spies-spectacular-sombrero/
https://webbtelescope.org/contents/media/images/2024/137/01JCGMPWZ9NE1M4RHXSAQ36DH6
https://webbtelescope.org/contents/media/images/2024/137/01JCGK31M1TXEW8T7PEHHVDDC9

Arp 107 is located 465 million light-years

https://esawebb.org/news/weic2423/?lang

The Penguin and the Egg - Arp 142 – 326 mly

https://webbtelescope.org/contents/news-releases/2024/news-2024-124.html#heading-full-article

Spiderweb Protocluster – z = 2.156
https://esawebb.org/images/weic2428a/
https://www.eso.org/public/images/eso2304b/

JADES Supernovae Survey – z = 3.6
https://webbtelescope.org/contents/news-releases/2024/news-2024-122.html
https://arxiv.org/abs/2406.05089

GS-NDG-9422 – z = 5.9
https://webbtelescope.org/contents/news-releases/2024/news-2024-133.html

Black Hole Merger z = 7.15
https://esawebb.org/news/weic2413/?lang
https://academic.oup.com/mnras/article/531/1/355/7671512?login=false

Firefly Sparkle – 13.1 bly
https://www.nature.com/articles/s41586-024-08293-0
https://esawebb.org/news/weic2429/?lang

Cosmic Gems Arc – 13.2 bly
https://esawebb.org/news/weic2418/?lang
https://www.nature.com/articles/s41586-024-08293-0

Ending Galaxy Array
https://esawebb.org/news/weic2403/?lang

Music

Rachmaninoff - Symphony No. 2 Adagio: Sofia Philharmonic Orchestra, Emil Tabakov: from the album Sergei Rachmaninoff: Symphony No 2 in E minor, 2011

Svendsen - Romance in G: Miklos Szenthelyi: from the album Meditation – Classical Relaxation, 2010

Vivaldi - Symphony No 5: from the album "A Calander of Classics" 2007

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

⇒ → ± ⊙ ∞ ↛ ∃ ∄ ∈ ∉ ∬ ∫ ≅ ≥ ≤ ≈ ≠ ≡ √ ∛ ~ ∝ ħ ÷