The Local Galaxy Volume

***{Abstract** – In this segment of our "How far away is it" video book, we cover the local galaxy volume compiled by the Spitzer Local Volume Legacy Survey team.*

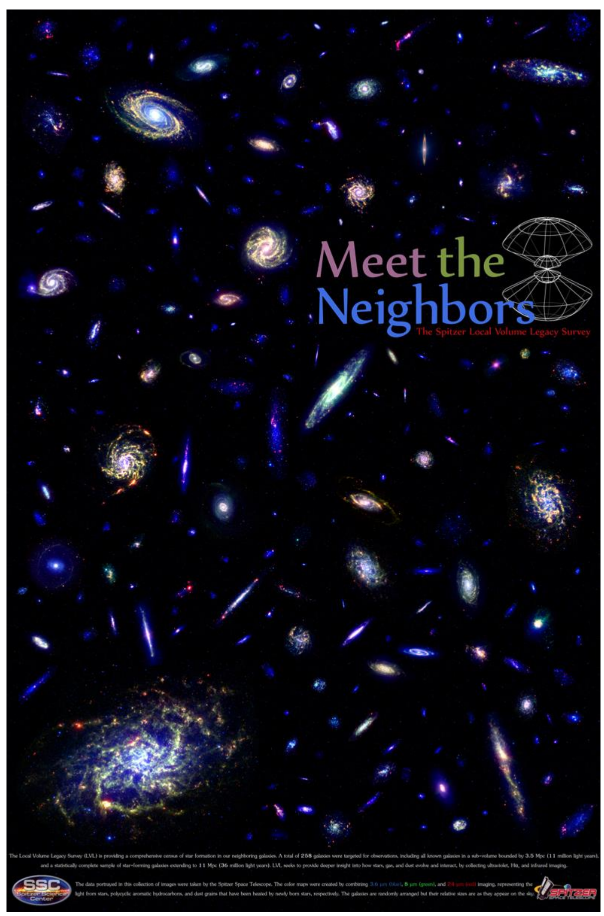
The survey covered 258 galaxies within 36 million light years. We take a look at just a few of them including: NGC 4214, Centaurus A, NGC 5128 Jets, NGC 1569, majestic M81, Holmberg IX, M82, NGC 2976,the unusual Circinus, M83, NGC 2787, the Pinwheel Galaxy M101, NGC 6503, the Fireworks Galaxy, M106, NGC 3344, NGC 4485, the Sombrero Galaxy M104 including Spitzer's infrared view, NGC 1512, the Whirlpool Galaxy M51, M74, M66, and M96. In addition, we cover the Density Wave theory that attempts to explain how spiral arms in spiral galaxies exist as they do.

*We end with a look at the tuning fork diagram created by Edwin Hubble with its description of spiral, elliptical, lenticular and irregular galaxies.***}**

Introduction

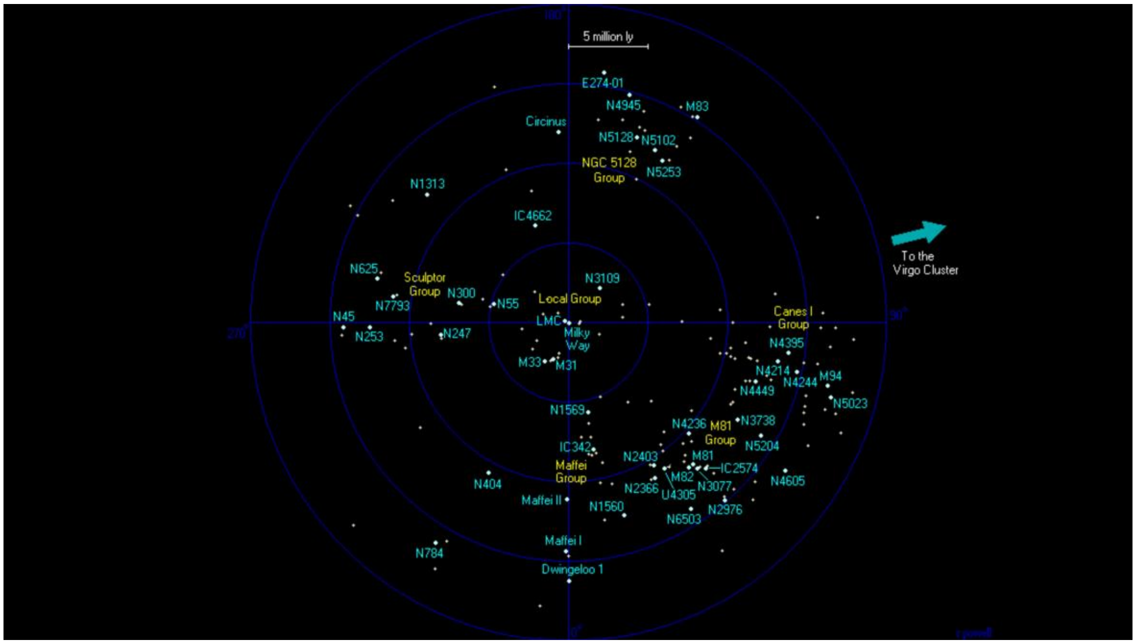
[Music: @00:00 Johann Pachelbel, "Canon in D"; from the album The Most Relaxing Classical Music, 1997**]**

The Local volume is the set of galaxies covered in the Local Volume Legacy survey or LVL, for short, conducted by the Spitzer team. It is a complete sample of 258 galaxies within 36 million light years. This montage of images shows the ensemble of galaxies as observed by Spitzer. The galaxies are randomly arranged but their relative sizes are as they appear on the sky.



[Additional info: The broad goal of LVL is to provide critical insight into two of the primary processes that shape the growth of galaxies: star formation and its interaction with the interstellar medium.**]**

Here we have the galaxies laid out by distance from us. We'll take a look at a number of them.

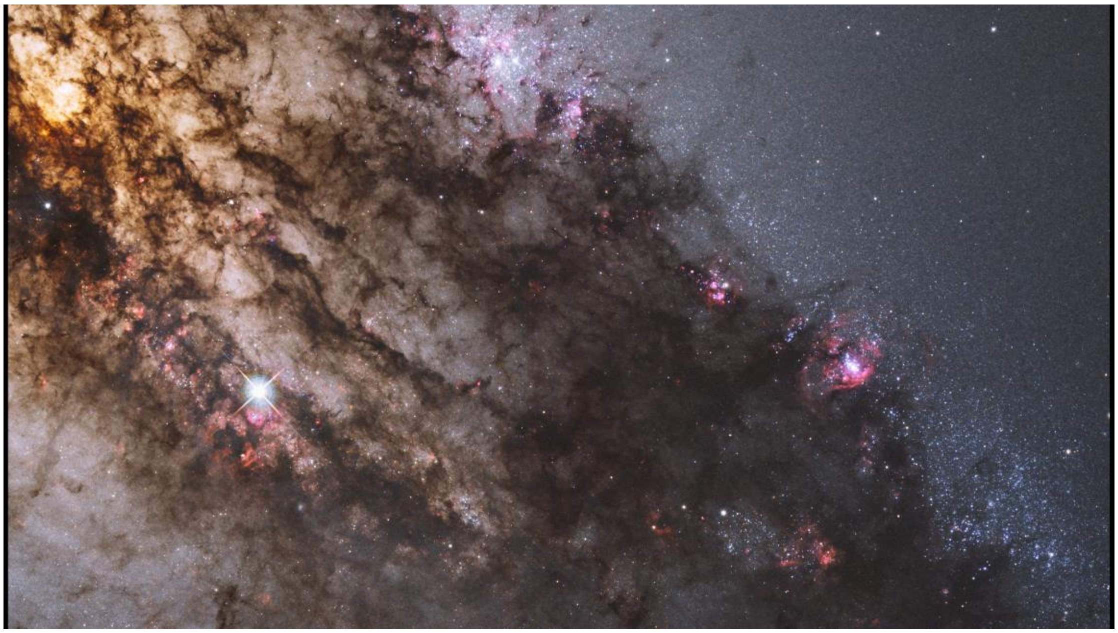


NGC 4214 – 10 mly

The dwarf galaxy NGC 4214 is ablaze with young stars and gas clouds. The galaxy's close proximity, combined with the wide variety of evolutionary stages among the stars, make it an ideal laboratory to research the triggers of star formation and evolution. Intricate patterns of glowing hydrogen formed during the star-birthing process, cavities blown clear of gas by stellar winds, and bright stellar clusters of NGC 4214 can be seen in this optical and near-infrared image.

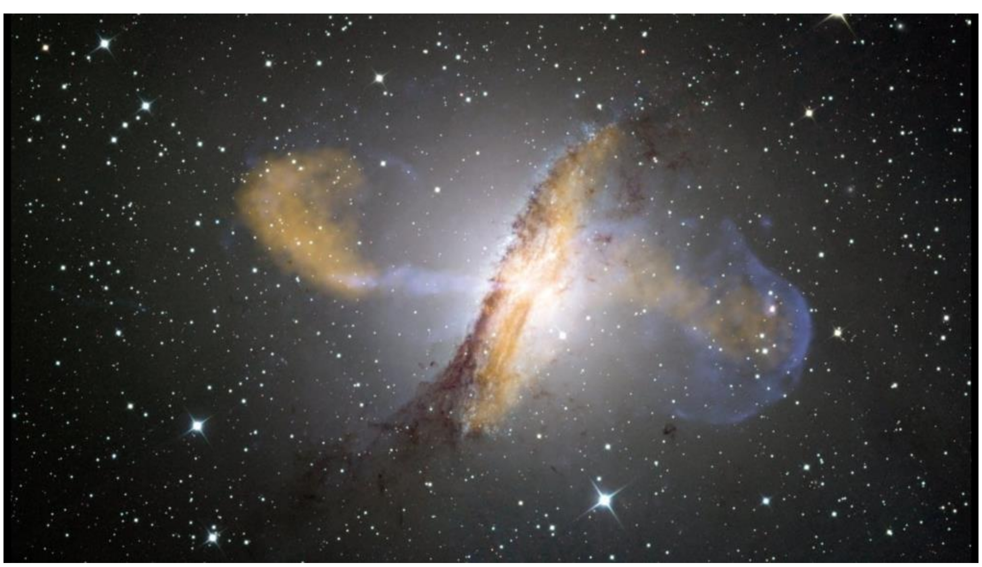
NGC 5128, Centaurus A – 11 mly

Resembling looming rain clouds on a stormy day, dark lanes of dust crisscross the giant elliptical galaxy Centaurus A. Hubble's panchromatic vision, stretching from ultraviolet through near-infrared wavelengths, reveals the vibrant glow of young, blue star clusters and a glimpse into regions normally obscured by the dust. warped shape of Centaurus A's disk of gas and dust is evidence for a past collision and merger with another galaxy. The resulting shockwaves cause hydrogen gas clouds to compress, triggering a firestorm of new star formation. These are visible in the red patches in this Hubble close-up.



At a distance of just over 11 million light-years, Centaurus A contains the closest active galactic nucleus to Earth. The center is home for a supermassive black hole that ejects jets of high-speed gas into space, but neither the supermassive black hole nor the jets are visible in this image.

But they are in this one. This Color composite image of Centaurus A reveals the lobes and jets emanating from the active galaxy's central black hole.

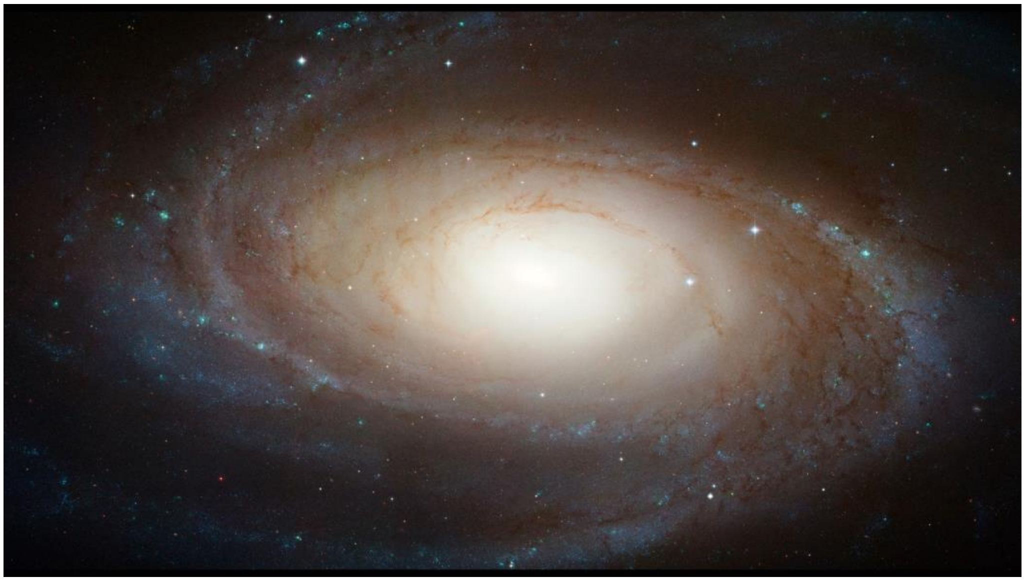


NGC 1569 – 11 mly

This image showcases the brilliant core of one of the most active galaxies in our local neighborhood. The entire core is 5,000 light-years wide. NGC 1569 sparkles with the light from millions of newly formed young stars. It is pumping out stars at a rate that is 100 times faster than the rate observed in our Milky Way Galaxy. This frenzied pace has been almost continuous for the past 100 million years.

M81 – 11.6 mly

This beautiful galaxy is tilted at an oblique angle on to our line of sight, giving us a "birds-eye view" of this "grand design" spiral galaxy. It is similar to our Milky Way, but this favorable view provides a better picture of the typical architecture of spiral galaxies. The spiral arms, which wind all the way down into the nucleus, are made up of young, bluish, hot stars formed in the past few million years. A number of sinuous dust lanes also wind all the way into the nucleus of M81. The galaxy's central bulge is significantly larger than the Milky Way's bulge. A black hole of 70 million solar masses resides at the center. This is about 15 times the mass of the Milky Way's black hole. Hubble research shows that the size of the central black hole in a galaxy is proportional to the mass of a galaxy's bulge.



Holmberg IX – 12 mly

> **[Music:** @04:54 Mozart: Flute Quartet in G major; from the album Meditation: Classical Relaxation, 2010**]**

This loose collection of stars is actually a dwarf irregular galaxy, called Holmberg IX. It resides just off the outer edge of M81. Holmberg IX is of the so-called Magellanic type of galaxy, as its size and irregularity in structure are similar to the Small Magellanic Cloud. A close encounters with M81 may have triggered the newer star formation that has occurred. By understanding how Holmberg IX was formed, scientists hope to understand their role as building blocks for large galaxies.

M82 – 12 mly

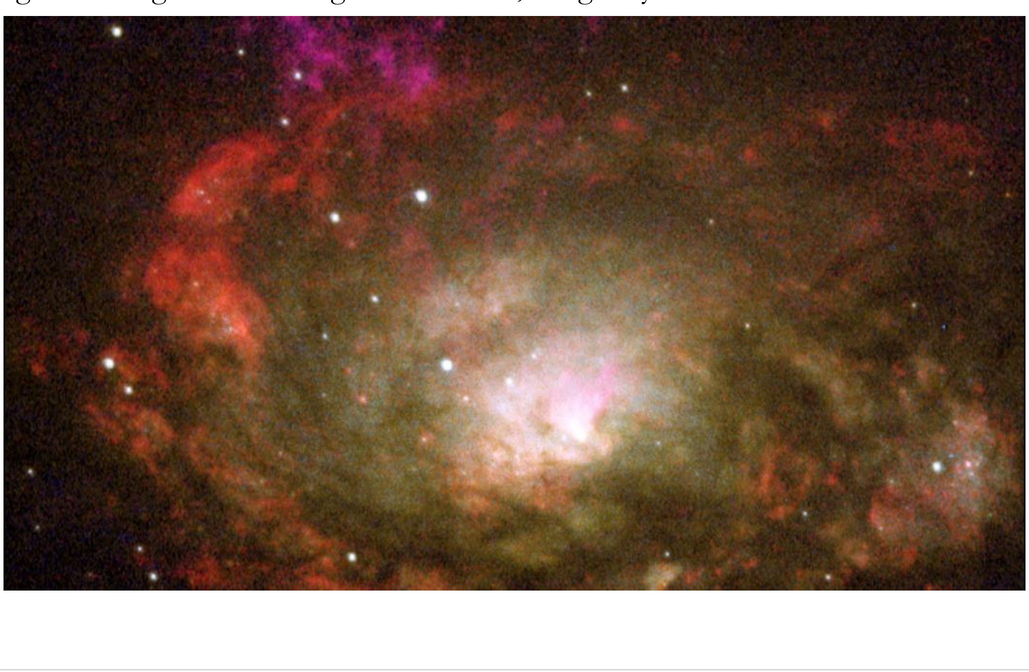
Here we are zooming into M82. The galaxy is remarkable for its bright blue disk, webs of shredded clouds, and fiery-looking plumes of glowing hydrogen blasting out of its central regions.Throughout the galaxy's center, young stars are being born 10 times faster than they are inside our entire Milky Way Galaxy. A huge concentration of young stars has carved into the gas and dust at the galaxy's center. The fierce galactic superwind generated from these stars compresses enough gas to make millions of more stars. Young stars are crammed into tiny but massive star clusters. These, in turn, congregate by the dozens to make the bright patches, or "starburst clumps," in the central parts of M82. The clusters in the clumps can only be distinguished in the sharp Hubble images. Most of the pale, white objects sprinkled around the body of M82 that look like fuzzy stars are actually individual star clusters about 20 light-years across that contain up to a million stars each.

NGC 2976 – 12

NGC 2976 does not look like a typical spiral galaxy. In this view of the galaxy's inner region, there are no obvious spiral arms. Dusty filaments running through the disk show no clear spiral structure. Although the gas is centrally concentrated, the galaxy does not have a central bulge of stars. What look like grains of sand in the image are actually individual stars. Studying the individual stars allowed astronomers to determine their color and brightness, which provided information about when they formed.

Circinus Galaxy – 13 mly

This galaxy is called Circinus. Much of the gas in its disk is concentrated in two specific rings — a larger one 1,300 light-years wide, and a previously unseen ring 260 light-years wide. Both rings are home to large amounts of gas and dust as well as areas of major "starburst" activity. At the center of the starburst rings is the supermassive black hole that is accreting surrounding gas and dust. The black hole and its accretion disk are expelling gas out of the galaxy's disk and into its halo. The detailed structure of this gas is seen as magenta-colored streamers extending towards the top of the image. near the plane of our own Milky Way Galaxy, the Circinus galaxy is partially hidden by intervening dust along our line of sight. As a result, the galaxy went unnoticed until 1999.



M83, the Southern Pinwheel – 15 mly

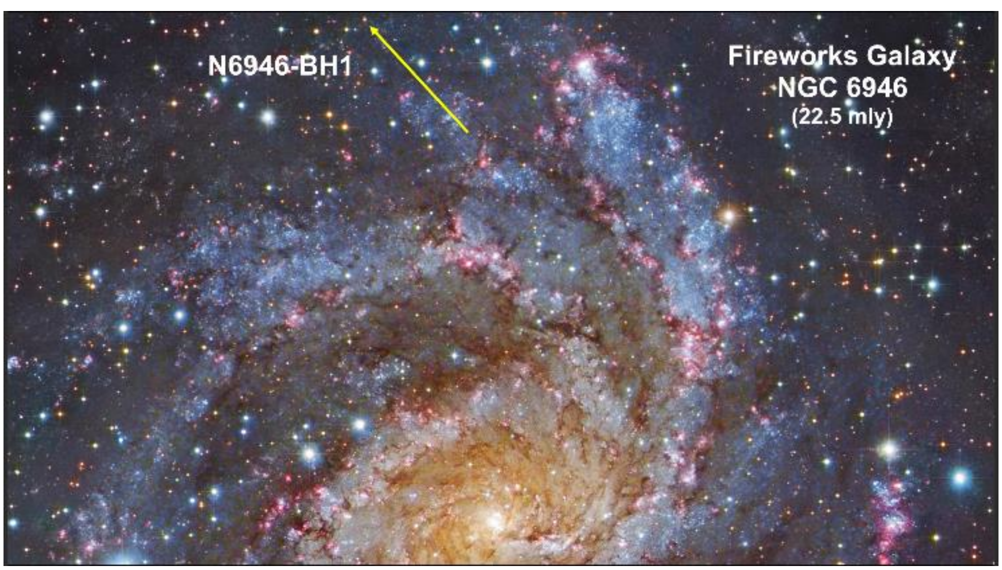
Nicknamed the Southern Pinwheel, M83 is undergoing more rapid star formation than our own Milky Way galaxy, especially in its nucleus. This Hubble close-up has captured hundreds of young star clusters, ancient swarms of globular star clusters, and hundreds of thousands of individual stars, mostly blue supergiants and red supergiants. The remains of about 60 supernova blasts can be seen in the image.

NGC 6503 18 mly

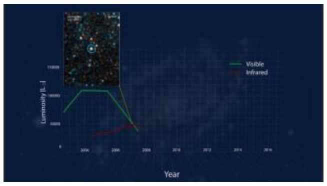
Hubble has taken a beautiful picture of NGC 6503. It spans some 30,000 light-years. In this image, bright red patches of gas can be seen scattered through its swirling spiral arms, mixed with bright blue regions that contain newly-forming stars, with dark brown dust lanes snaking across the galaxy's bright arms and center.

NGC 3344 – 20 mly
This beautiful bared spiral galaxy is about half the size of the Milky Way. Astronomers estimate that two-thirds of all spiral galaxies have a bar structure at its center. That including our own Milky Way. The swirling spiral arms are the birthplace of new stars. Their high temperatures make them shine blue. Clouds of dust and gas distributed through the spiral arms — glowing red in this image — are reservoirs of material for even more stars. The bright stars on the left are Milky Way stars in the line of sight to NGC 3344.

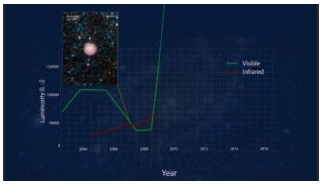
Fireworks Galaxy – 22 mly
The Large Binocular Telescope (LBT for short) in Arizona was scanning the Fireworks Galaxy 22 million light years away looking for supernova candidates. [The galaxy is known for having large numbers of supernova explosions.] They examined the star named N6946-BH1 – a star 25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



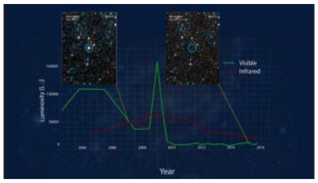
Here's a graph of the stars luminosity in visible and infrared light over time. In 2007, Hubble took this picture of the star.



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.



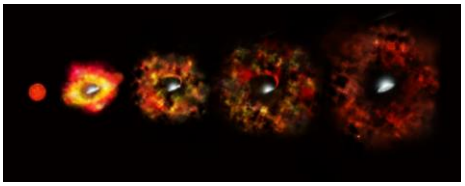
But it didn't. It just seemed to vanish, as seen in this image from 2015. After the LBT turned up the star, astronomers aimed the Hubble (for visible light) and Spitzer (for infrared light) space telescopes to see if the star was still there. All the tests came up negative. The star was no longer there. 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.



M106 – 23.5 mly

Here's the magnificent spiral galaxy M106. It is a class of galaxy called a Seyfert galaxy. Seyfert galaxies account for about 10% of all galaxies and are some of the most intensely studied objects in astronomy, as they are thought to be powered by the same phenomena that occur in quasars, although they are closer and less luminous than quasars. These galaxies have supermassive black holes at their centers which are surrounded by accretion discs of in-falling material. The accretion discs are believed to be the source of the observed ultraviolet radiation.

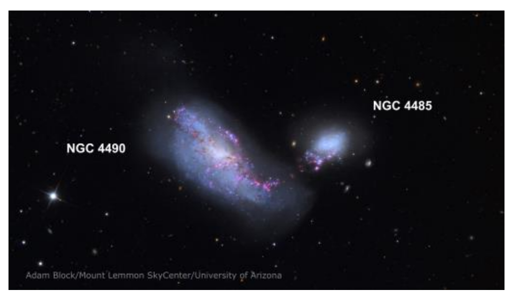
NGC 2787 – 24 mly

Tightly wound, almost concentric, arms of dark dust encircle the bright nucleus of galaxy NGC 2787. This lens-shaped galaxy shows little or no evidence of any grand spiral arms. Also visible in the image are about a dozen globular clusters hovering around the galaxy. What appear to be stars are, in fact, gravitationally bound families of 100,000's of ancient stars orbiting the center of NGC 2787.

NGC 4485 – 25 mly

The irregular galaxy NGC 4485 shows all the signs of having been involved in a collision with another galaxy. The right side of the galaxy is ablaze with star formation, shown in the large number of young blue and pinkish star berth nebulas. The left side, however, looks intact. It contains hints of the galaxy's previous spiral structure, which, at one time, was undergoing normal galactic evolution.

Here's the other colliding galaxy NGC 4490. The two galaxies sideswiped each other millions of years ago and are now 24,000 light-years apart. The gravitational tug-of-war between them created rippling patches of higher-density gas and dust within both galaxies.



<u>Pinwheel Galaxy M101 – 25 mly</u>

Here we are zooming into the Pinwheel galaxy, M101. This is the largest and most detailed photo of a spiral galaxy that has ever been released from Hubble. The galaxy's portrait is actually composed of 51 individual Hubble exposures, in addition to elements from images from ground-based photos. The giant spiral disk of stars, dust, and gas is 170,000 light-years across or nearly twice the diameter of our galaxy. M101 is estimated to contain at least one trillion stars. Approximately 100 billion of these stars could be like our Sun in terms of temperature and lifetime.

<u>Sombrero Galaxy M104 – 28mly</u>

This is the Sombrero galaxy. The galaxy's hallmark is a brilliant white, bulbous core encircled by the thick dust lanes comprising the spiral structure of the galaxy. It is 50,000 light-years across. M104's rich halo system of nearly 2,000 globular clusters is 10 times as many as orbit our Milky Way galaxy. 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.

Here's what it looks like in inferred from Spitzer.

NGC 1512 – 30mly

NGC 1512 is a barred spiral galaxy spanning 70,000 light-years. The galaxy's core is unique for its stunning 2,400 light-year-wide circle of infant star clusters, called a "circumnuclear" starburst ring.

In this view of the center of the magnificent barred spiral galaxy NGC 1512, Hubble's broad spectral vision reveals the galaxy at all wavelengths from ultraviolet to infrared. The colors (which indicate differences in light intensity) map where newly born star clusters exist in both "dusty" and "clean" regions of the galaxy.

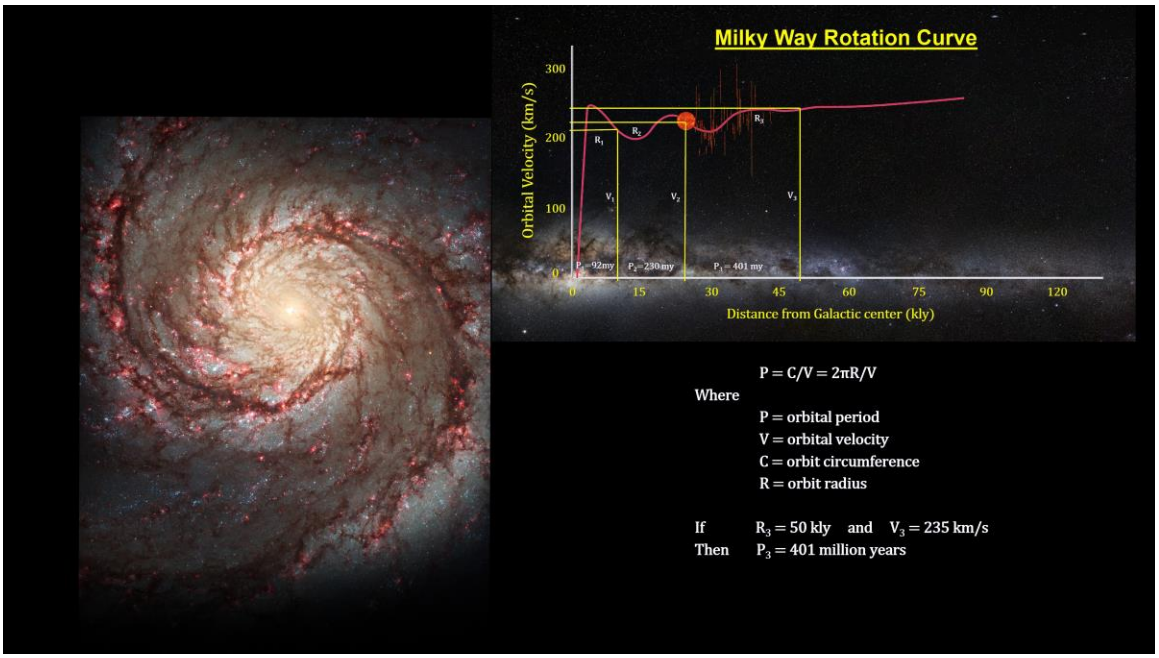
Whirlpool Galaxy M51 – 31 mly

*[**Music:** @17:14 Schubert: Impromptu in A-Flat; Pianist Evelyne Dubourg; from the album Meditation: Classical Relaxation, 2010]*

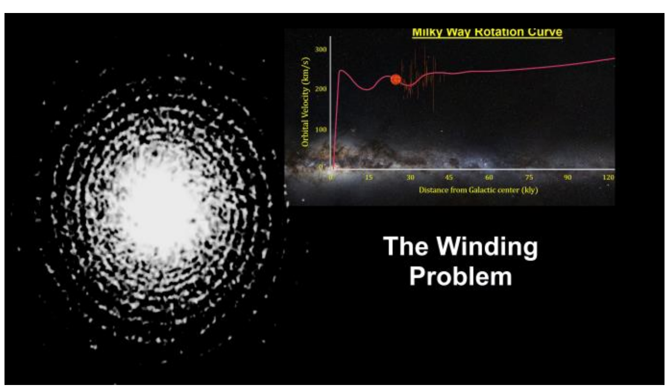
Here's a deep dive into the Whirlpool galaxy, M51. These images of the Whirlpool galaxy highlight the attributes of a typical spiral galaxy, including graceful, curving arms, pink star-forming regions, and brilliant blue strands of star clusters.

Spiral Arms – Density Waves

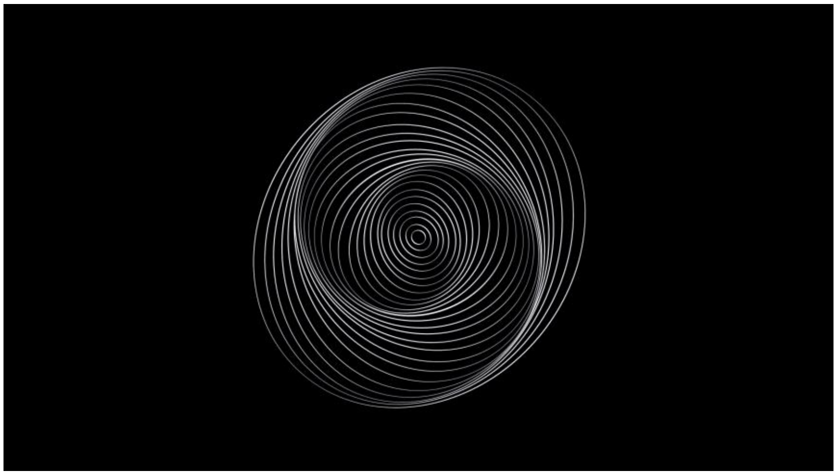
In the early days, when knowledge of spiral arms around galaxies was relatively new, astronomers thought that they were made of material and orbited the center of their galaxy just like stars, dust and gas. Our whirlpool galaxy is a good model for this. But as star motion within galaxies became better understood, we found that the stars nearer the center have a much shorter orbital period than the stars further way from the center. For example, in our Milky Way, stars near the central bulge can complete a revolution around the central bulge in around 90 million years. Out here 26,000 ly away it takes 230 million years. And in the outskirts it can take over 400 million years.



It followed that if the spiral arms were rotating with the stars, its structure would be lost in just a few rotations. You can see in this simulation that even after just one rotation, the arms would change significantly with the inner galaxy areas being stretched more than the outer galaxy areas. In astronomical terms, we would see spiral arm structure disappear in short order. But, from all we see from spiral galaxies of all ages, the spiral arm structure does persist over billions of years. This disconnect is called the 'Winding Problem". Clearly, the spiral arms do not rotate with the stars, dust and gas.

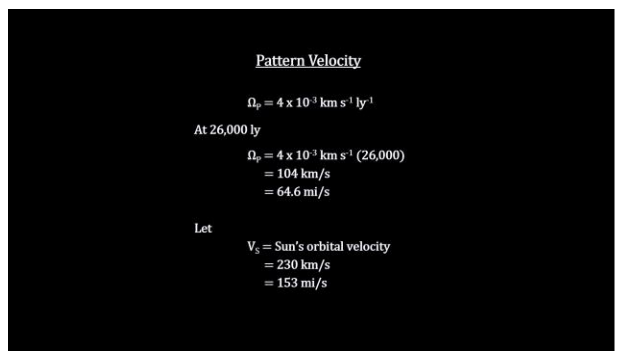


The density wave theory was proposed by C.C. Lin and Frank Shu in the mid-1960s to explain the spiral arm structure of spiral galaxies. The theory holds that spiral arms are not material in nature, but instead made up of areas of greater density. The stars, gas and dust in a galaxy move around the center in elliptical orbits. If we simply assume that an orbit's major axis shifts slightly as the distance from the center goes up, we can reconstruct the spiral arms as we see them in real galaxies.

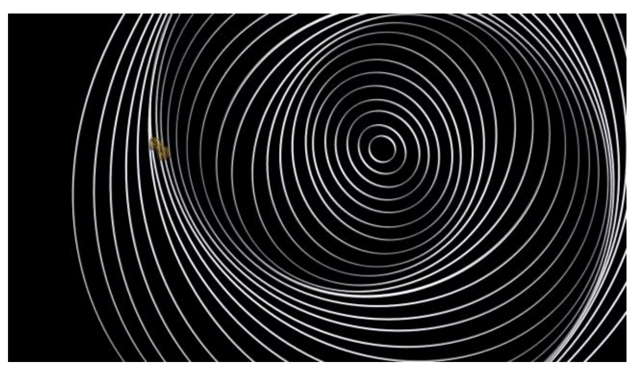


Lin and Shu, examining magnetic fields, gas distributions and star velocities, showed that this kind of grand design spiral pattern could persist indefinitely if the pattern also rotated, but with the outer portion of the arms rotating faster than the inner portions.

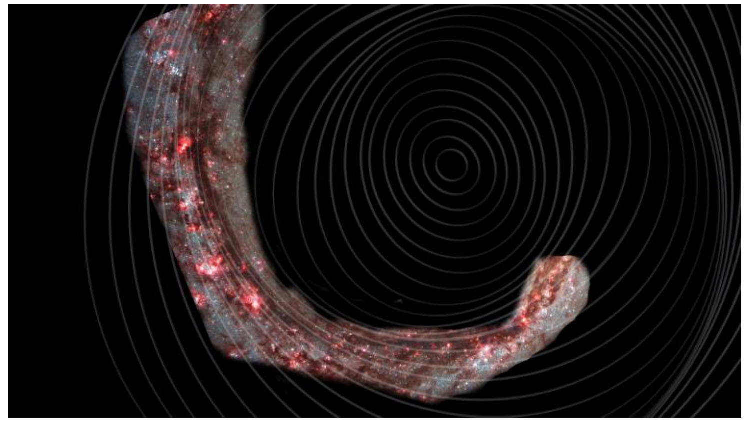
By their calculations, a typical pattern velocity is around .004 km s^{-1} ly^{-1}. That is the velocity of the pattern goes up .004 km/s for each ly the pattern location is from the center. For our star 26,000 ly from the center of the Milky Way, we have a pattern velocity for the Orion Spur at around a hundred km/s or 65 mi/s. Our velocity around the center is more than twice that much. I expect we'll be leaving the Orion spur in a few million years.



Here's a look at a gas cloud orbiting around the galaxy in the spiral patten's frame of reference. As it approaches a spiral arm, it gets compressed as the orbiting molecules withing the cloud move closer to each other. This compression effect is thought to trigger cloud collapse. This in turn creates new stars. The most massive blue stars don't burn long enough to make it through the spiral arm before they run out of hydrogen fuel and supernova.



That explains why we only see these giant blue stars in the trailing edge of spiral arms. Normal yellow and lower mass red stars exist for much longer and exit the spiral arm and orbit the galaxy for billions of years. It's important to note that just how these spiral arm structures form in the first place is still unknown.



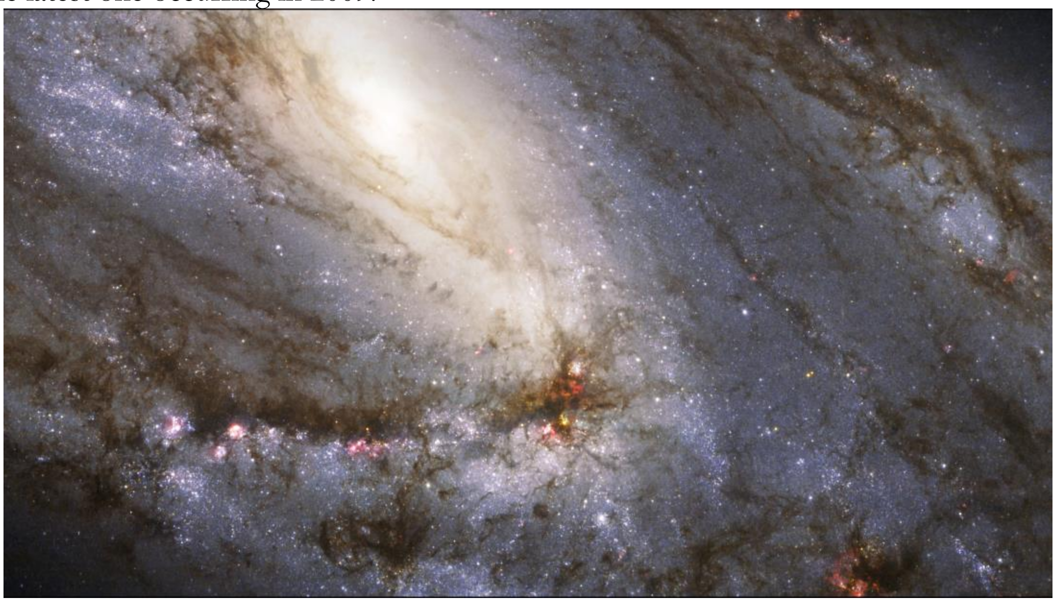
M74 – 32 mly

*[**Music:** @22:51 Tchaikovsky: Suite No. 1 - Intermezzo; from the album Meditation: Classical Relaxation, 2010]*

Here we are zooming into Messier 74, a stunning example of a "grand-design" spiral galaxy that is viewed by Earth observers nearly face-on. It's perfectly symmetrical spiral arms emanate from the central nucleus and are dotted with clusters of young blue stars and glowing pink H II regions of ionized hydrogen Tracing along the spiral arms are winding dust lanes that also begin very near the galaxy's nucleus and follow along the length of the spiral arms.

M66 – 35 mly

Here's a deep look into M 66, the owner of unusually asymmetric spiral arms which seem to climb above the galaxy's main disc and a displaced nucleus. Astronomers believe that M66's once orderly shape has most likely been distorted by the gravitational pull of its two neighbors. M66 boasts a remarkable record of supernovae explosions. The spiral galaxy has hosted three supernovae since 1989, the latest one occurring in 2009.

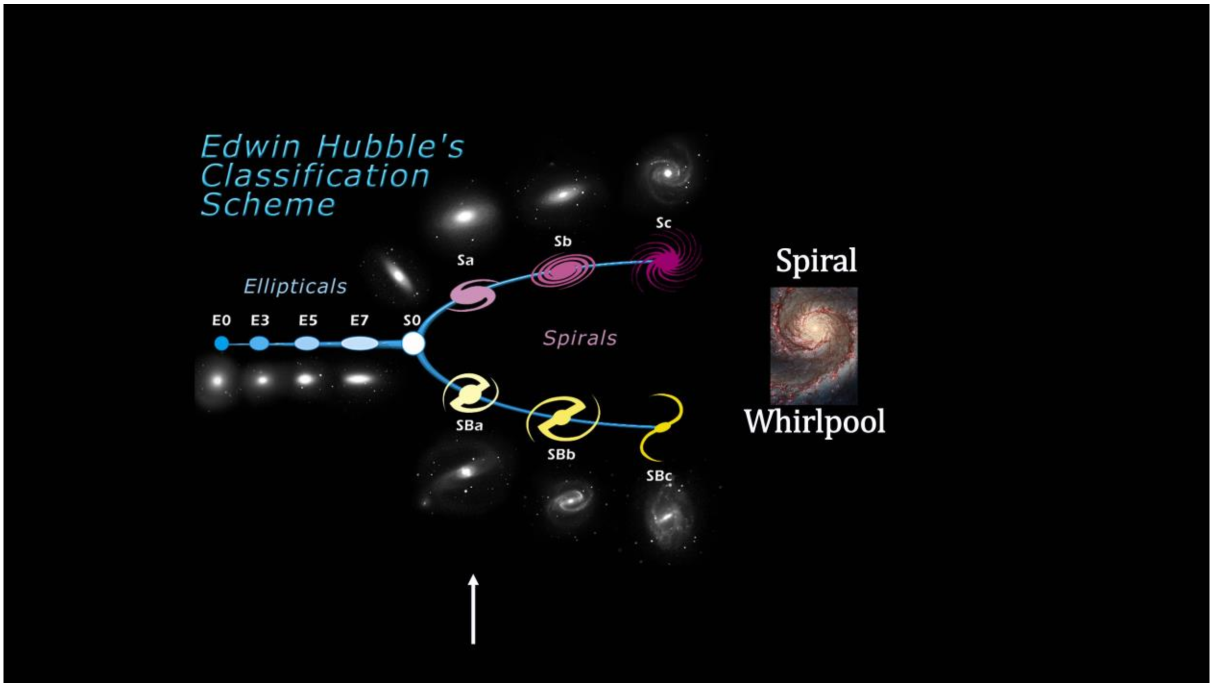


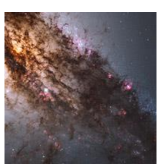
M96 – 35 mly

M96's core is also displaced from the galactic center. Its gas and dust are distributed asymmetrically and its spiral arms are ill-defined. But this portrait, taken with the ESO's Very Large Telescope, shows that imperfection can be beautiful. The galaxy's core is compact but glowing, and the dark dust lanes around it move in a delicate swirl towards the nucleus. And the spiral arms, patchy rings of young blue stars, are like necklaces of blue pearls. Its graceful imperfections likely result from the gravitational pull from nearby galaxies. spans some 100,000 light-years in diameter — about the size of our Milky Way.

Galaxy classifications

In 1926, there were enough galaxies known for Edwin Hubble to create a morphological classification scheme. This is his diagram. His students called it the “Hubble tuning-fork”. scheme divides galaxies into 3 broad classes based on their visual appearance.





Elliptical galaxies have smooth, featureless light distributions and appear as ellipses in images like Centaurus A. They are denoted by the letter E, followed by an integer n representing their degree of ellipticity on the sky.

Spiral galaxies consist of a flattened disk, with stars forming a spiral structure, and a central concentration of stars known as the bulge like the Whirlpool galaxy. They are given the symbol S or SB if it has a bar core followed by a letter a through c. The spiral arm structure becomes more open from a to c; the amount of dust and young stars decreases from a to c; and the central bulge of the galaxy decreases in size relative to the disc size from a to c.

Lenticular galaxies also consist of a bright central bulge surrounded by an extended, disk-like structure but, unlike spiral galaxies, the disks of lenticular galaxies have no visible spiral structure and are not actively forming stars in any significant quantity. NGC 2787 is an example of these. They are designated S0.

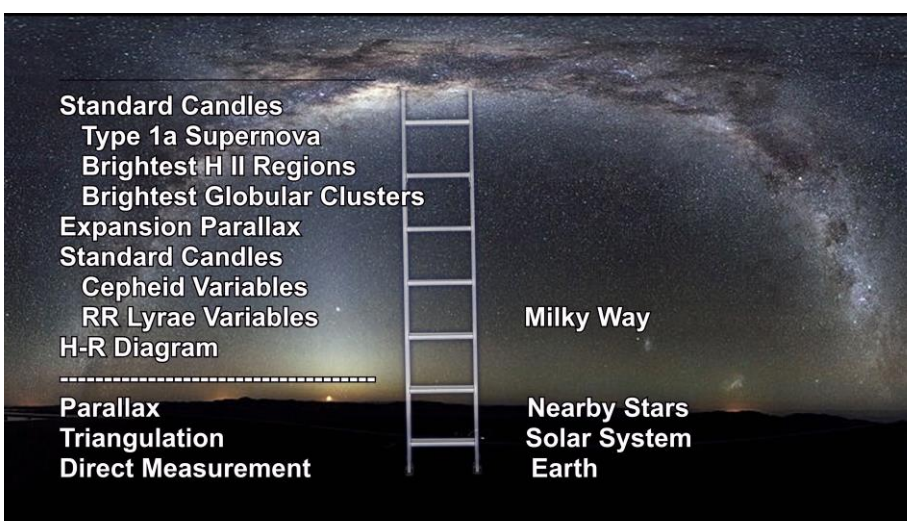
These broad classes can be extended to enable finer distinctions of appearance and to encompass other types of galaxies, such as **irregular galaxies**, which have no obvious regular structure (either disk-like or ellipsoidal). The Large Magellanic Cloud is an excellent example of this.

Since then, others have added characteristics such as Bars, Rings, and Spiral arm characteristics.

Distance Ladder

[Additional info: We've seen a wide variety of shapes and sizes as we toured the Local Volume of stars studied by the Spitzer LVL team. In each galaxy, it was not to hard to find at least one Cepheid Variable, RR Lyrae Variable, Type 1a Supernova, Bright HII and/or Globular cluster. Star spectra and the H-R diagram were also useful for red supergiants which are abundant in many of these galaxies. These were used to calculate galaxy distances.**]**

We lost parallax when we went beyond the nearby stars. But, so far, the rest of our distance ladder has taken us through the local group and the local volume. But at the outer reaches, RR Lyrae variables leave our list. They are just not bright enough to be seen well beyond 20 million light years. But Cepheids, H II Regions, Globular Clusters, and Type 1a Supernova are still going strong. They will take us well into the Virgo Supercluster, our next segment.



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 ÷