The Virgo Supercluster

***{Abstract** – In this segment of our "How far away is it" video book, we cover our local supercluster, the Virgo Supercluster.*

We begin with a description of the size, content and structure of the supercluster, including the formation of galaxy clusters and galaxy clouds. We then take a look at some of the galaxies in the Virgo Supercluster including: NGC 4314 with its ring in the core, NGC 5866, I Zwicky 18, the beautiful NGC 2841, NGC 3079 with is central gaseous bubble, M60, M100, M77 with its central supermassive black hole, NGC 3949, NGC 3310, NGC 4013, the unusual NGC 4522, NGC 4710 with its "X"-shaped bulge, NGC 1052, Hanny's Voorwerp*, NGC 3256 and NGC 4414. Then we continue with galaxy gazing with: NGC 1427A, NGC 3982, NGC 1300, NGC 5584, the dusty NGC 1316, NGC 4639, NGC 4319, NGC 3021 with is large number of Cepheid variables, NGC 3370, NGC 1309, and 7049.*

*At this point, we have enough distant galaxies to formulate Hubble's Law and calculate Hubble's Red Shift constant. From a distance ladder point of view, once we have the Hubble constant, and we can measure red shift, we can calculate distance. So, we add Red Shift to our ladder. We end with a review of the distance ladder now that Red Shift has been added.**}***

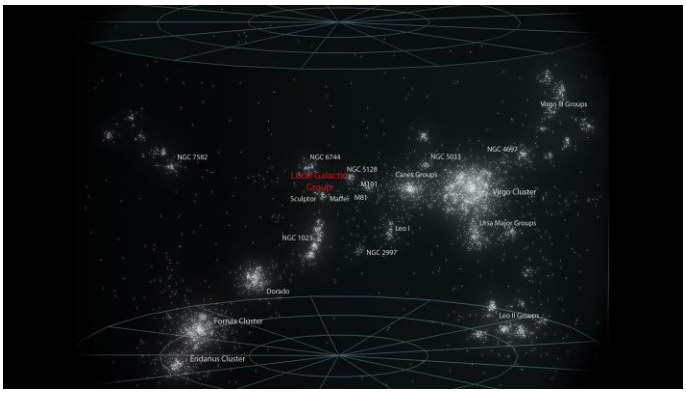
Introduction

> **[Music:** *Antonio Vivaldi: Four Seasons - Winter Concerto in F Minor – Largo; from the album The Most Relaxing Classical Music, 1997***]**

Superclusters are among the largest structures in the known Universe. The Virgo Supercluster, also known as the Local Supercluster, is 110 million light-years diameter. It contains 4,000 luminous galaxies, organized into 100 galaxy groups and galaxy clusters. The Virgo Supercluster's volume is approximately 7,000 times larger than our Local Group and 100 billion times larger than the Milky Way.

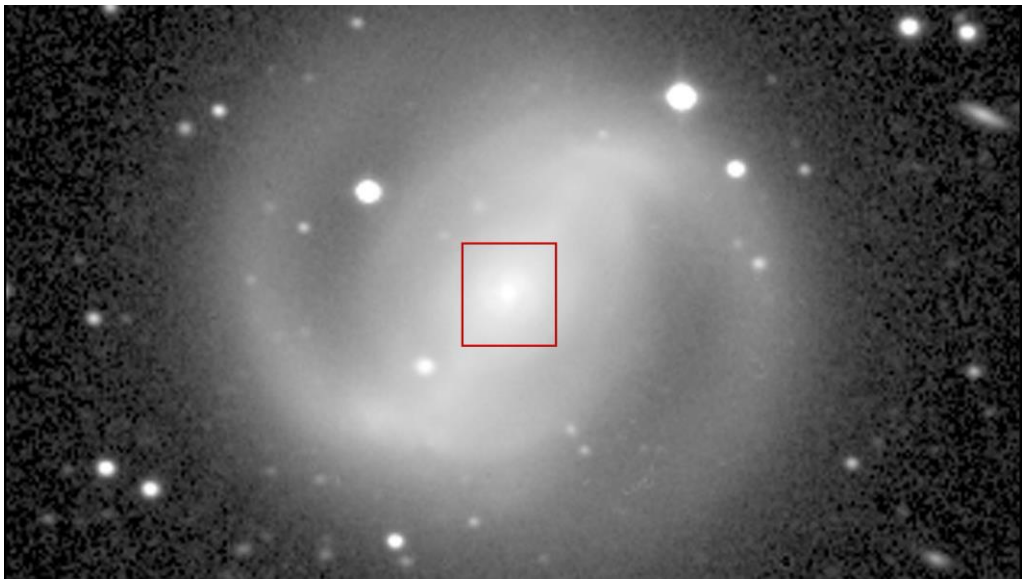
For the first time, we are at a distance where we can see that galaxies are not just evenly distributed throughout space.

In this picture, each galaxy is a point of light. And these points are crowded together into galaxy clusters. And these clusters are crowded together into galaxy clouds. And these clouds of galaxy clusters are grouped up into the supercluster. Let's take a look at some of the galaxies in the Virgo Supercluster.



NGC 4314 – 30 mly - 672 km/s

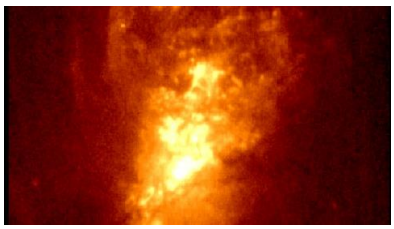
This ground-based image of the barred-spiral galaxy NGC 4314 was taken by the McDonald Observatory in Texas. It shows the entire galaxy, including the bar of stars bisecting the core and the outer spiral arms, which begin near the ends of this bar. That's normal enough.



But this Hubble image reveals clusters of infant stars that formed in a ring around the core. This close-up view by Hubble also shows other interesting details in the galaxy's core: dust lanes, a smaller bar of stars, dust and gas embedded in the stellar ring, and an extra pair of spiral arms packed with young stars. These details make the center resemble a miniature version of a spiral galaxy.

M77, NGC 1068 – 35 mly - 784 km/s

Messier 77 is a spiral galaxy containing a supermassive black hole. The X-ray images and spectra obtained using Chandra's Spectrometer show that a strong wind is being driven away from the center of the galaxy at a rate of about 1.6 million km/hr that's a million miles per hour. This wind is likely generated as surrounding gas is accelerated and heated as it swirls toward the black hole. A portion of the gas is pulled into the black hole, but some of it is blown away.



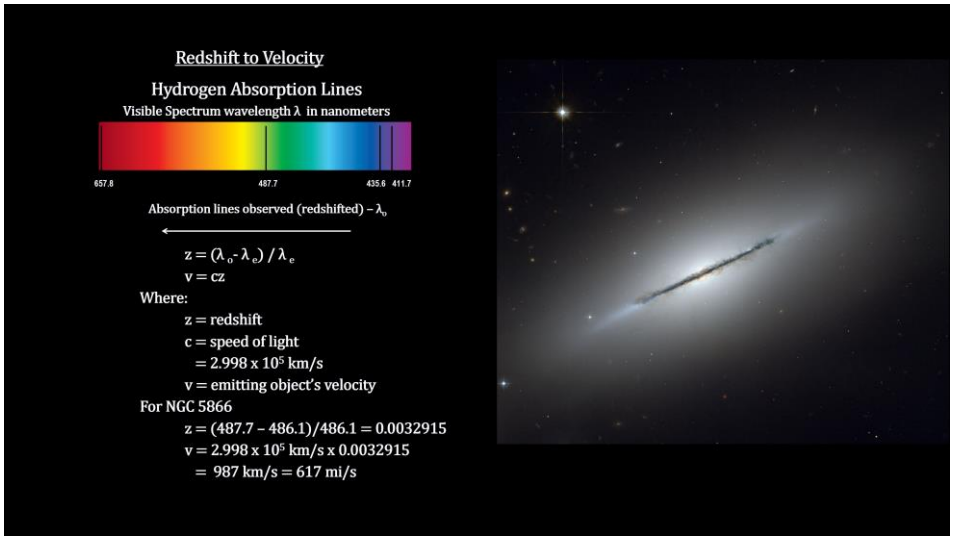
High energy X-rays produced by the gas near the black hole heat the ouflowing gas, causing it to glow at lower X-ray energies. These results help explain how an "average"-sized supermassive black hole can alter the evolution of its entire host galaxy.

Music: *Saint-Saëns: "The Carnival of the Animals - The Swan"; from the album he "Most Relaxing Classical Music" 1997*]

NGC 5866 – 45 mly – 987 km/s

This is a unique view of a galaxy tilted nearly edge-on to our line-of-sight. The image highlights the galaxy's structure: a subtle, reddish bulge surrounding a bright nucleus, a blue disk of stars running parallel to the dust lane, and a transparent outer halo. The dust lane is slightly warped compared to the disk of starlight. This warp indicates that NGC 5866 may have undergone a gravitational tidal disturbance in the distant past, by a close encounter with another galaxy.

We'll use this galaxy along with several others in the Virgo Supercluster to develop our final Cosmic Distance Ladder rung – Redshift. You may recall that we covered redshift in our segment on Planetary Nebula where we used the shift in hydrogen spectral lines to determine the radial velocity of a celestial object. NGC 5866's redshift [0.0032915] indicates that it is moving away from us at just under 1,000 km/s (that's 617 miles/s).



M100 – 50 mly – 1120 km/s

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

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

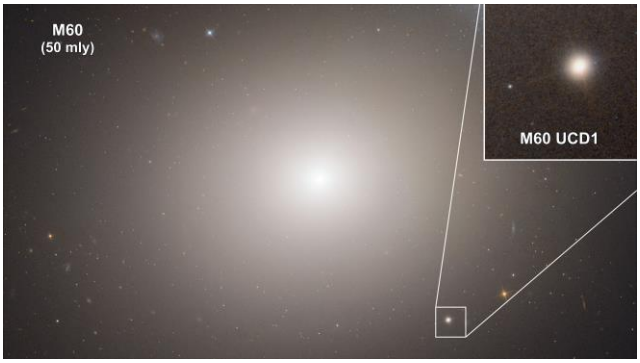
NGC 3949 – 50 mly – 1120 km/s

One of the ways we construct the form of our home Milky Way galaxy is to examine galaxies that are similar in shape and structure. Spiral galaxies like NGC 3949, pictured in this Hubble image, fit the bill. Like our Milky Way, this galaxy has a blue disk of young stars peppered with bright pink star-birth regions. In contrast to the blue disk, the bright central bulge is made up of mostly older, redder stars.

M60-UCD1 50 mly

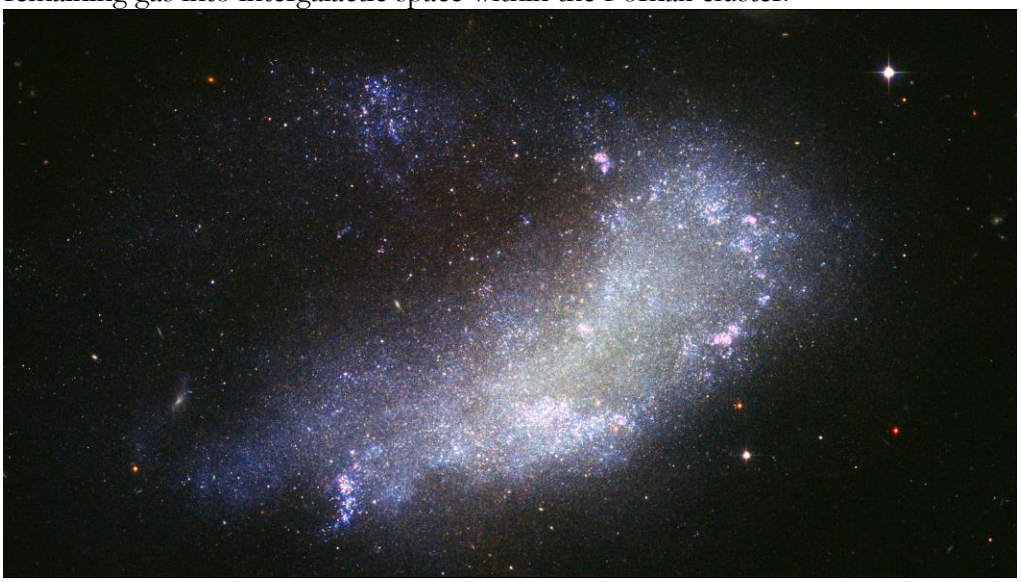
Here's a look at a pair of galaxies: NGC 4647 is the spiral galaxy in the upper right; M60 is the large elliptical galaxy. On the edge of M60, there is an Ultra-Compact galaxy known as M60-UCD1.

New Hubble observations have found a supermassive black hole with the mass of 20 million Suns at its center, making this tiny galaxy the smallest ever found to host such a black hole. M60-UCD1 is a tiny galaxy with a diameter of 300 light-years, containing some 140 million stars. This is 500 times smaller than the Milky Way, but its supermassive black hole is 5 times more massive than ours. This shows just how significant this black hole is and it leaves open the question about just how a black hole this large could have been created in the first place, given the small number of stars in its galaxy.



NGC 1427A – 50 mly

NGC 1427A is a bright dwarf irregular galaxy on the outskirts of the Fornax cluster. It is similar to the Large Magellanic Cloud orbiting our Milky Way. It is plunging headlong into the cluster at nearly 600 km/s (that's nearly 400 miles per second). 1427A will not survive long as an identif1able galaxy passing through the cluster. Within the next billion years, it will be completely disrupted, spilling its stars and remaining gas into intergalactic space within the Fornax cluster.



NGC 3310 – 55 mly

Most galaxies form new stars at a fairly slow rate, but members of a rare class known as "starburst" galaxies blaze with extremely active star formation. The galaxy NGC 3310 is forming clusters of new stars at a prodigious rate. There are several hundred star clusters visible in this image as the bright blue diffuse objects that trace the galaxy's spiral arms. Each of these star clusters represents the formation of up to about a million stars.

NGC 4013 – 60 mly

[Music: *Mascagni: "Intermezzo"; Philharmonia Orchestra - from the album "The Most Relaxing Classical Music" 1988***]**

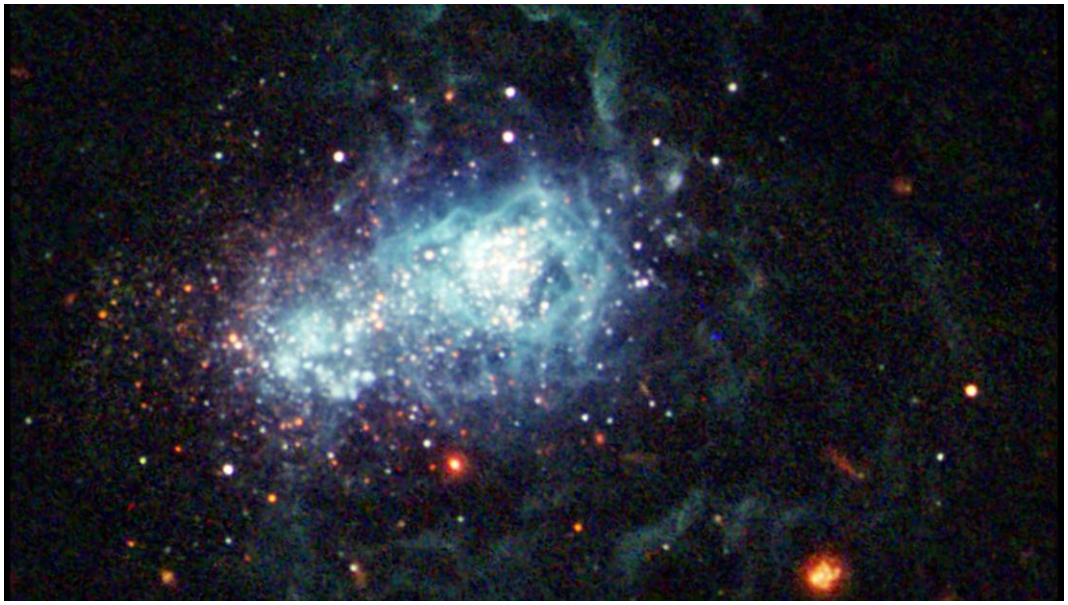
NGC 4013 is a spiral galaxy, similar to our own Milky Way. This Hubble picture reveals, with exquisite detail, huge clouds of dust and gas extending along, as well as far above, the galaxy's main disk. Viewed pole-on, it would look like a nearly circular pinwheel. Even at 55 million light-years, the galaxy is larger than Hubble's field of view, and the image shows only a little more than half of the object.

[Additional info: When light passes through a volume containing small particles, it becomes fainter and redder. By studying the color and the amount of light absorbed by these distant clouds in NGC 4013, astronomers can estimate the amount of matter in them. Individual clouds contain as much as one million times the amount of mass in our Sun.**]**

I Zwicky 18 – 60 mly

I Zwicky 18 is classified as a dwarf irregular galaxy and is much smaller than our Milky Way. The concentrated bluish-white knots embedded in the heart of the galaxy are two major starburst regions where stars are forming at a significant rate. The wispy blue filaments surrounding the central starburst regions are bubbles of gas that have been blown away by stellar winds and supernovae

explosions from a previous generation of stars. This gas is now heated by intense ultraviolet radiation from hot, young stars. Besides the bluish-white young stars, white-reddish stars also are visible. These stars are thought to be around 10 billion years old.

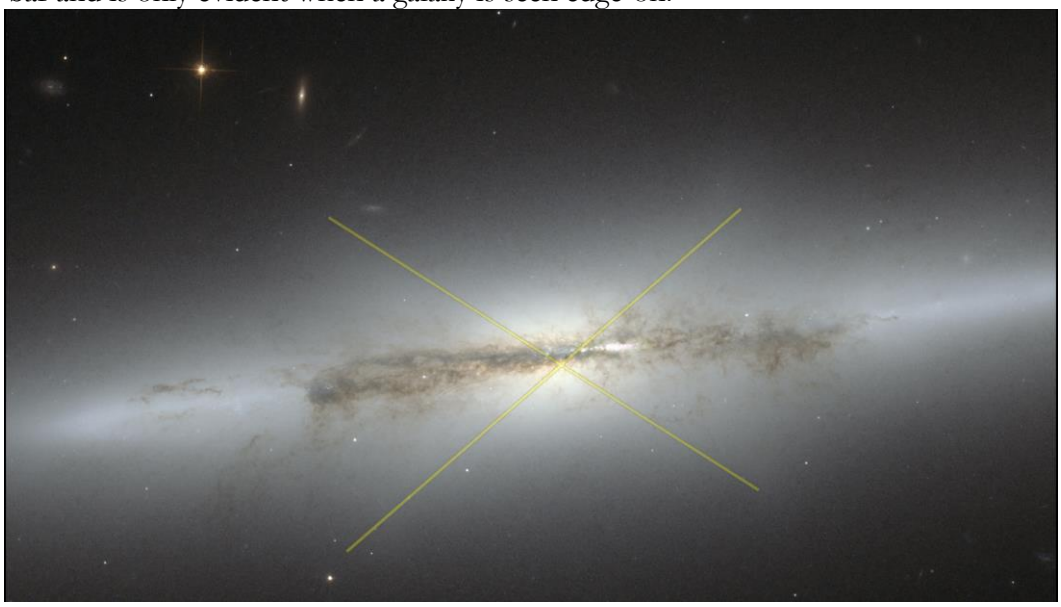


NGC 4522 – 60 mly – 1336 km/s

NGC 4522 is a spectacular example of a spiral galaxy that is currently being stripped of its gas content by its strong central winds. Scientists estimate that the galaxy is moving at more than 6 million miles per hour. A number of newly formed star clusters that developed in the stripped gas can be seen in the Hubble image. The picture highlights the dramatic state of the galaxy with an especially vivid view of the ghostly gas being forced out of its center. Bright blue pockets of new star formation can be seen to the right and left of center.

NGC 4710 – 60 mly

Here we are zooming into NGC 4710 in the Virgo Cluster. This magnificent giant galaxy is tilted nearly edge-on to our view from Earth. This perspective allows astronomers to easily distinguish the central bulge of stars from its pancake-flat disk of stars, dust, and gas. When staring directly at the center of the galaxy, one can detect a faint, ethereal "X"-shaped structure. Such a feature, which astronomers call a "boxy" or "peanut-shaped" bulge, is due to the vertical motions of the stars in the galaxy's bar and is only evident when a galaxy is seen edge-on.



NGC 1316 – 60 mly

NGC 1316 is one of the brightest ellipticals in the Fornax galaxy cluster. The Hubble Space Telescope enabled uniquely accurate measurements of a class of red star clusters inside the galaxy. Astronomers conclude that these star clusters constitute clear evidence of the occurrence of a major collision of two spiral galaxies that merged together a few billion years ago to shape NGC 1316 as it appears today.

NGC 4414 – 62 mly

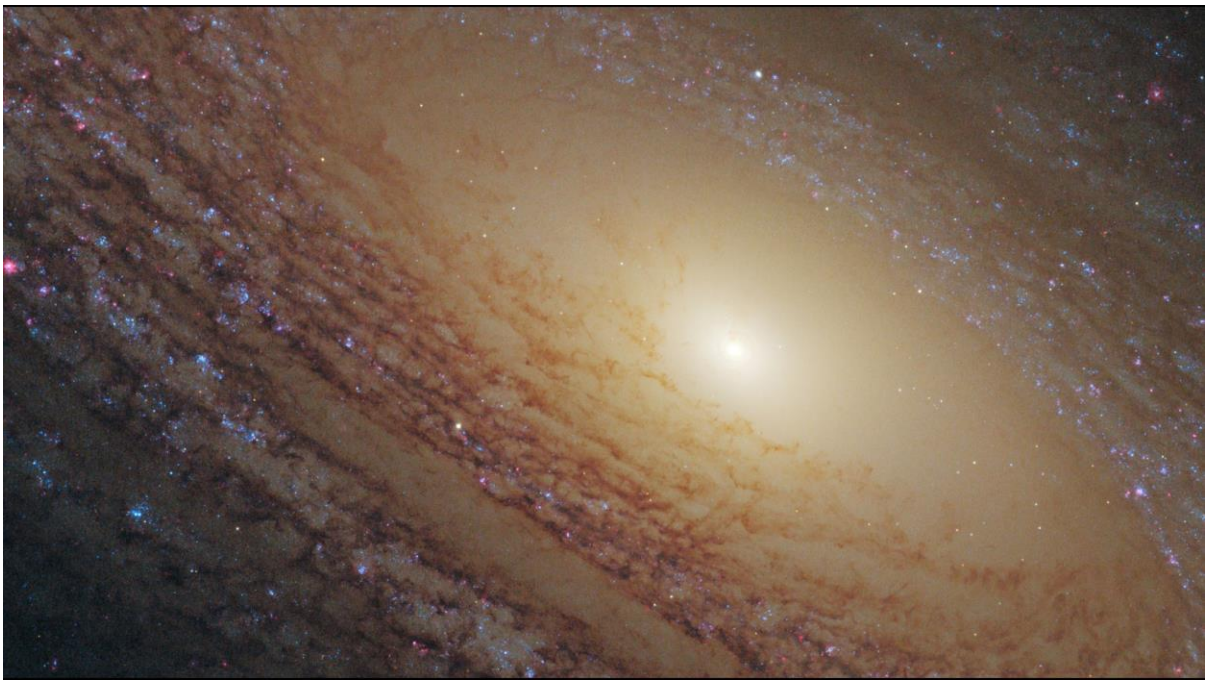
In 1995, the majestic spiral galaxy NGC 4414 was imaged by the Hubble as part of the Key Project on Extragalactic Distance Scales. An international team observed this galaxy on 13 different occasions over the course of two months. Based on their discovery and careful brightness measurements of Cepheid variable stars in NGC 4414, the Key Project astronomers were able to make an accurate determination of the distance to the galaxy - 62 million light-years.

NGC 1300 – 62 mly

The Hubble telescope captured a display of starlight, glowing gas, and silhouetted dark clouds of interstellar dust in this image of the barred spiral galaxy NGC 1300 - a prototypical barred spiral galaxy. Blue and red supergiant stars, star clusters, and star-forming regions are well resolved across the spiral arms, and dust lanes trace out fine structures in the disk and bar.

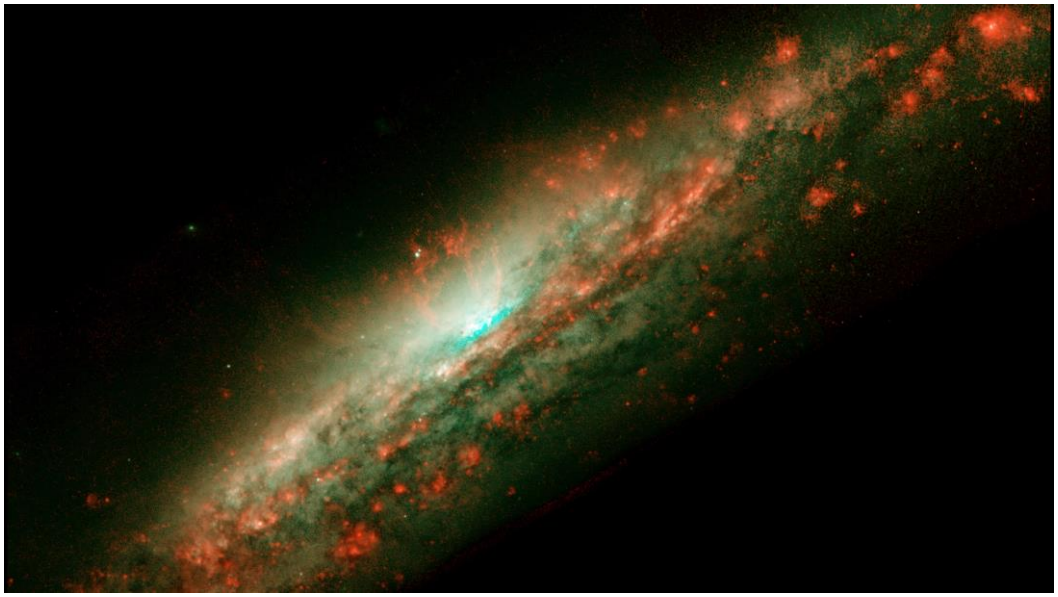
NGC 2841 – 65 mly

Hubble reveals a majestic disk of stars and dust lanes in this view of the spiral galaxy NGC 2841. A bright cusp of starlight marks the galaxy's center. Spiraling outward are dust lanes that are silhouetted against the population of whitish middle-aged stars. Much younger blue stars trace the spiral arms. Notably missing are pinkish emission nebulae indicative of new star birth. It is likely that the radiation and supersonic winds from fiery, super-hot, young blue stars cleared out the remaining gas, and hence shut down further star formation in the regions in which they were born.

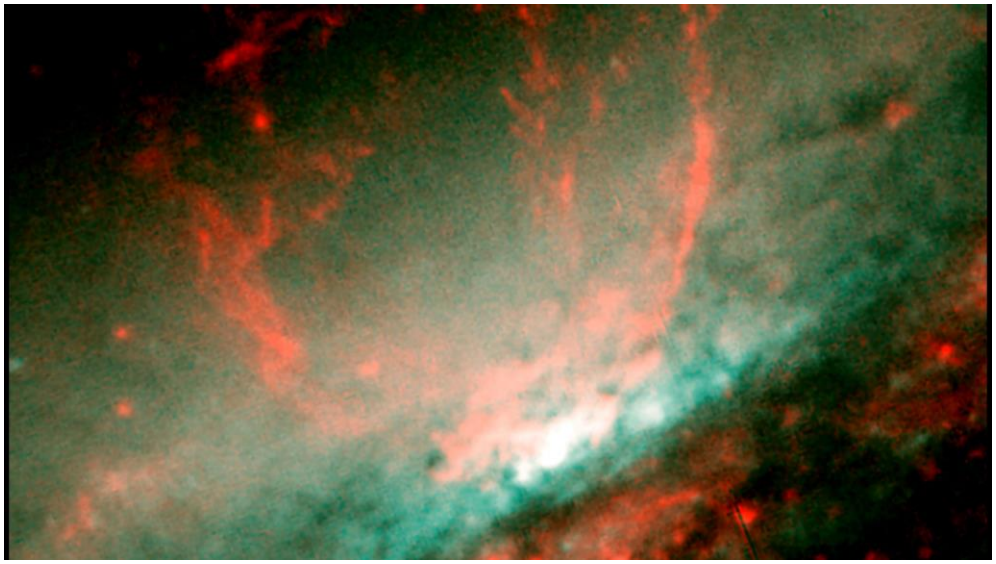


NGC 3079 – 65 mly

This picture shows a bubble in the center of the galaxy's disk. The structure is more than 3,000 light-years wide and raises 3,500 light-years above the galaxy's disk.



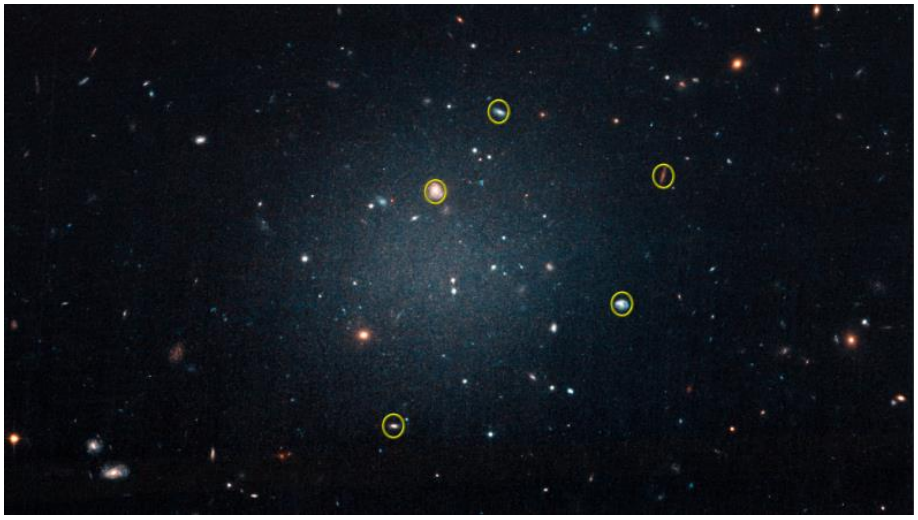
This is a close-up view of the bubble. Gaseous filaments at the top of the bubble are whirling around in a vortex and are being expelled into space. Eventually, this gas will rain down upon the galaxy's disk where it may collide with gas clouds, compress them, and form a new generation of stars.



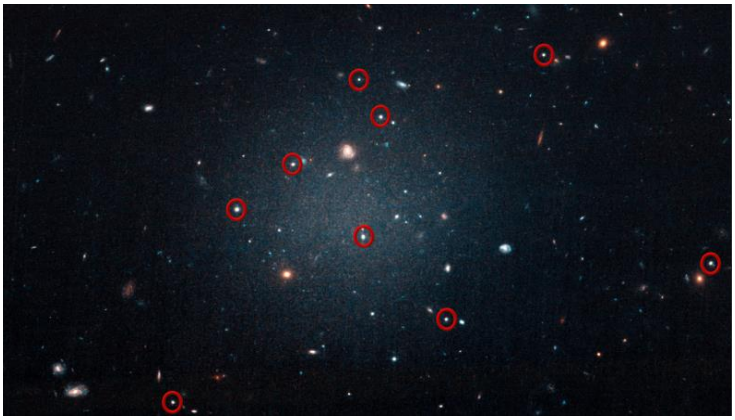
NGC 1052-DF2 – 65 mly

> **[Music:** *Puccini - Le Villi - Opera in 2 Acts _ Act 1 – Prelude; Radio-Symphonie-Orchester Berlin and Riccardo Chailly; from the album "Puccini Without Words" 2006*]

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

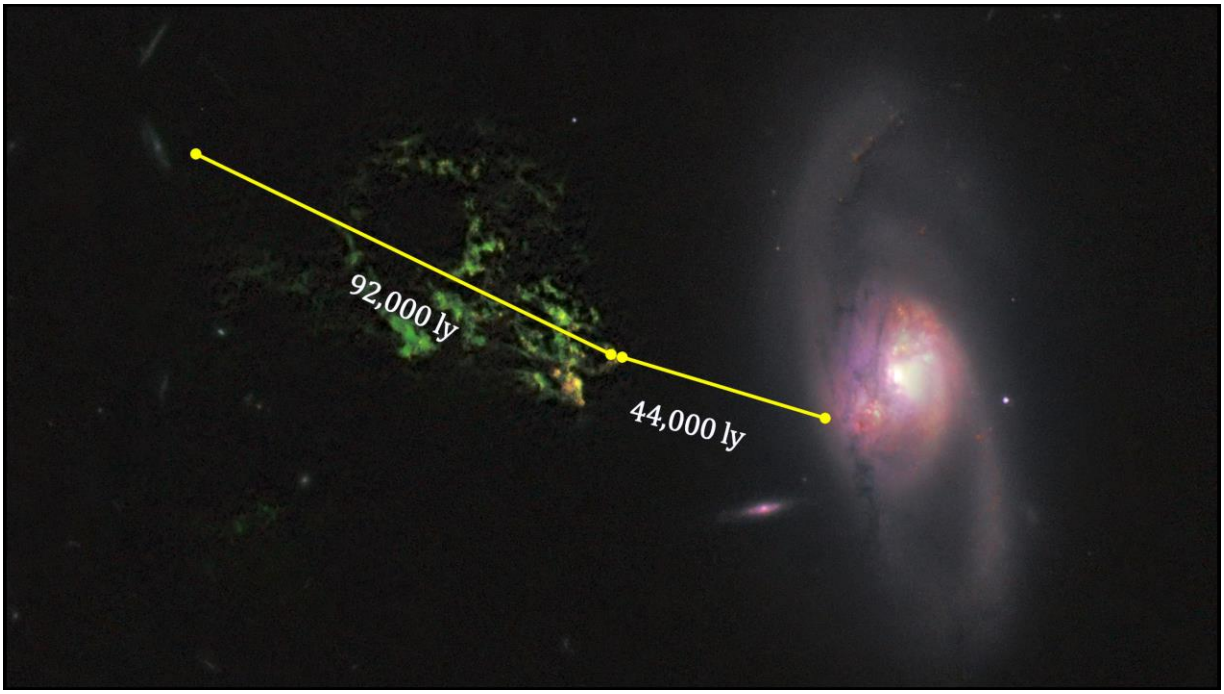


Current dark matter theory has it that galaxies form around dark matter. So, researchers were surprised when they discovered that this galaxy has hardly any dark matter at all. Measuring the motions of 10 giant globular clusters, astronomers found their velocities to be consistent with the estimated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

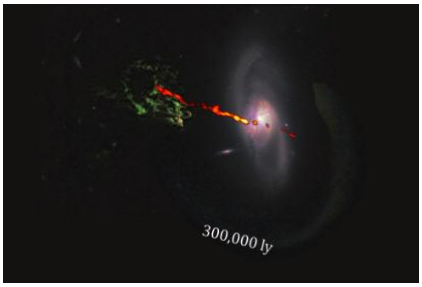


Hanny's Voorwerp – 64 mly

Hanny's Voorwerp is one of the strangest space objects ever seen. A mysterious, glowing green blob of gas is floating in space near a spiral galaxy (IC 2497). The object is so huge that it stretches from 44,000 light-years to 136,000 light-years from the galaxy's core.

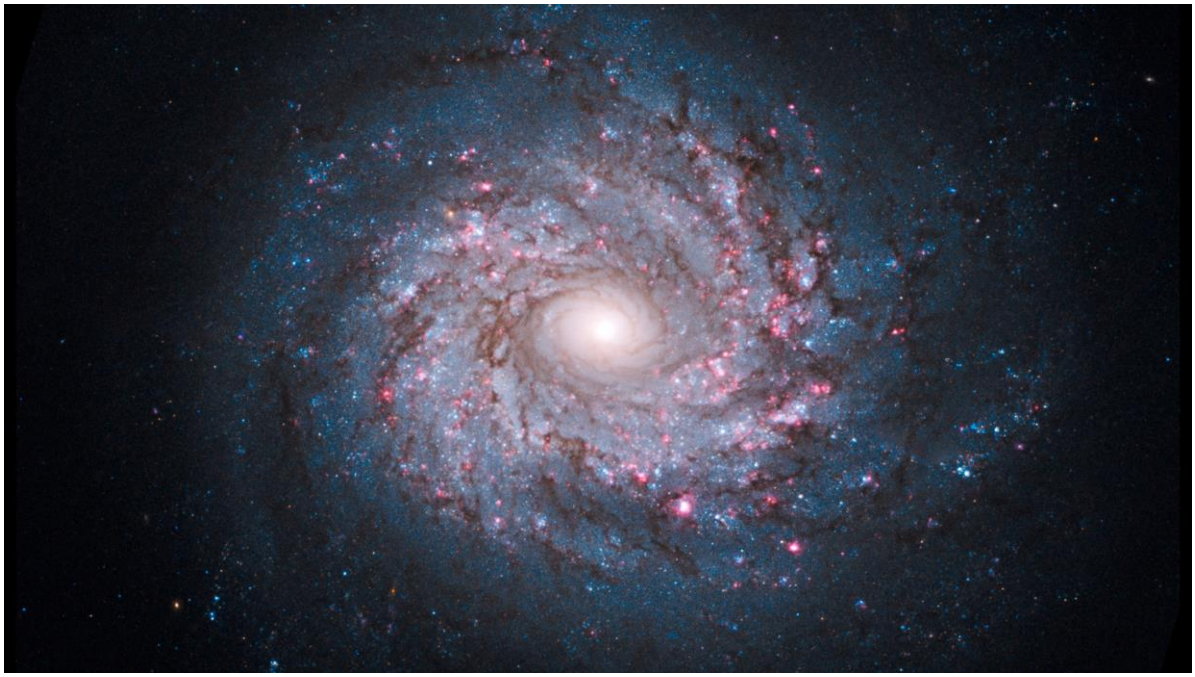


It turns out that it's part of a 300,000 light-years long tidal tail that wraps around IC 2497. Our current understanding is that this part of the tail was illuminated by a high energy beam created by matter falling into the galaxy's central black hole. Their unmistakable emerald hue is caused by ionized oxygen, which glows green.



NGC 3982 – 70 mly

Though the universe is full of spiral galaxies, no two look exactly the same. NGC 3982 is striking for its rich tapestry of star birth, along with its winding arms. The arms are lined with pink star-forming regions of glowing hydrogen, newborn blue star clusters, and obscuring dust lanes that provide the raw material for future generations of stars.



NGC 5584 – 70 mly

NGC 5584 contains Cepheid variables and one recent Type 1a supernova. As you know, we use these two standard candles as reliable distance markers to measure the universe's expansion rate. NGC 5584 was one of the eight galaxies astronomers studied to measure this rate. In total, the project analyzed more than 600 Cepheid variables, including 250 in NGC 5584.

NGC 4639 – 75 mly **[Music:** Schubert - Andante con moto (from Symphony No. 8); from the album "Meditation: Classical Relaxation", 1991**]**

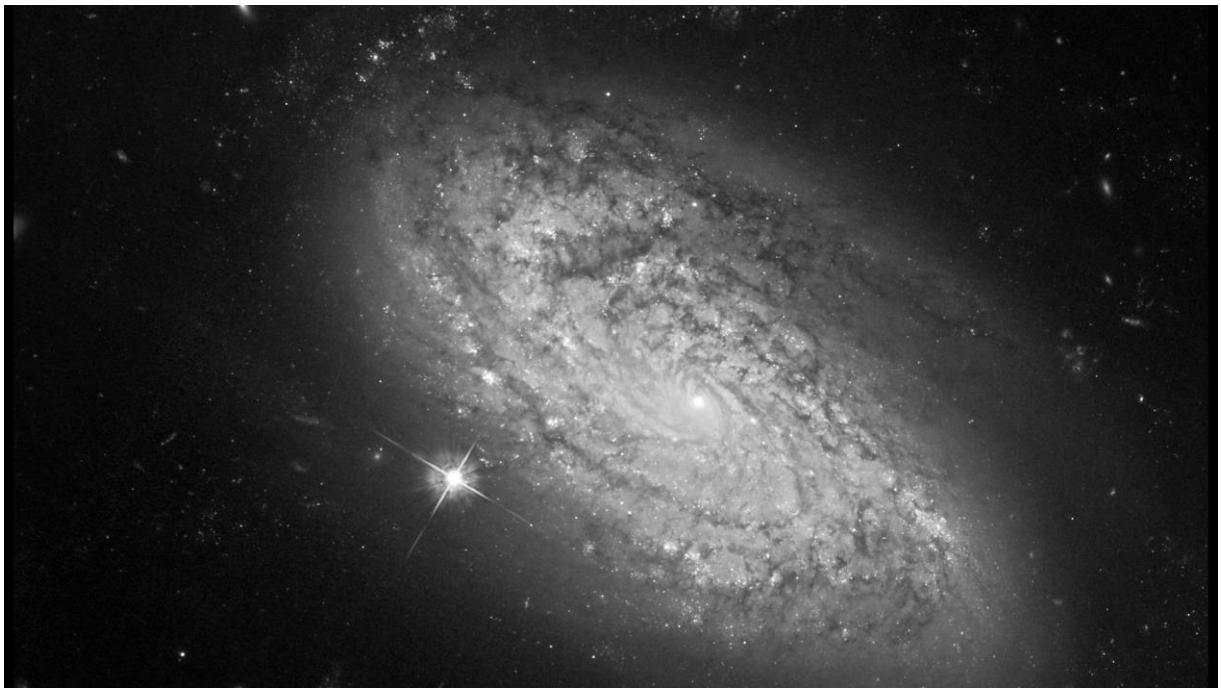
This Hubble image shows NGC 4639, a spiral galaxy located 78 million light-years away in the Virgo cluster of galaxies. The blue dots in the galaxy's outlying regions indicate the presence of young stars. Among them are older, bright Cepheids stars. After using Cepheids to calculate the distance to NGC 4639, the team compared the results to the peak brightness measurements of SN 1990N, a type 1a supernova located in the galaxy. Once again, Type 1a supernovae were found to be reliable standard candles.

NGC 4319 – 80 mly

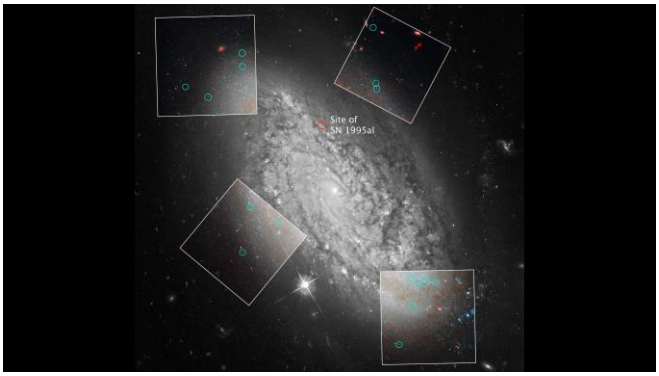
This Hubble image shows the inner region of NGC 4319. The unusually dark and misshapen dust lanes in the galaxy's inner region are evidence of a disturbance, probably caused by an earlier interaction with another galaxy.

NGC 3021 -90 mly

This galaxy was one of several hosts of recent type 1a supernovae observed by astronomers.



In the 1930s, Edwin Hubble made precise measurements of Cepheid variable stars in this galaxy, highlighted by green circles in the four inset boxes. These Cepheids are used to calibrate the supernova that was observed in the galaxy in 1995.



NGC 3370 – 90 mly

In 1994, NGC 3370 hosted a type 1a supernova designated SN 1994ae. This stellar outburst briefly outshone all of the tens of billions of other stars in its galaxy. Although supernovae are common, with one exploding every few seconds somewhere in the universe, this one was special. This supernova was one of the nearest and best observed supernovae since the advent of modern, digital detectors.

NGC 1309 – 100 mly

NGC 1309 is one of about 200 galaxies that make up the Eridanus galactic group. It was home to type 1a supernova SN 2002fk. Its light reached Earth in September 2002. It also contains a number of Cepheid variables resolved by the Hubble Space Telescope. And, once again, the type 1a was shown to be an excellent standard candle.

NGC 7049 – 100 mly

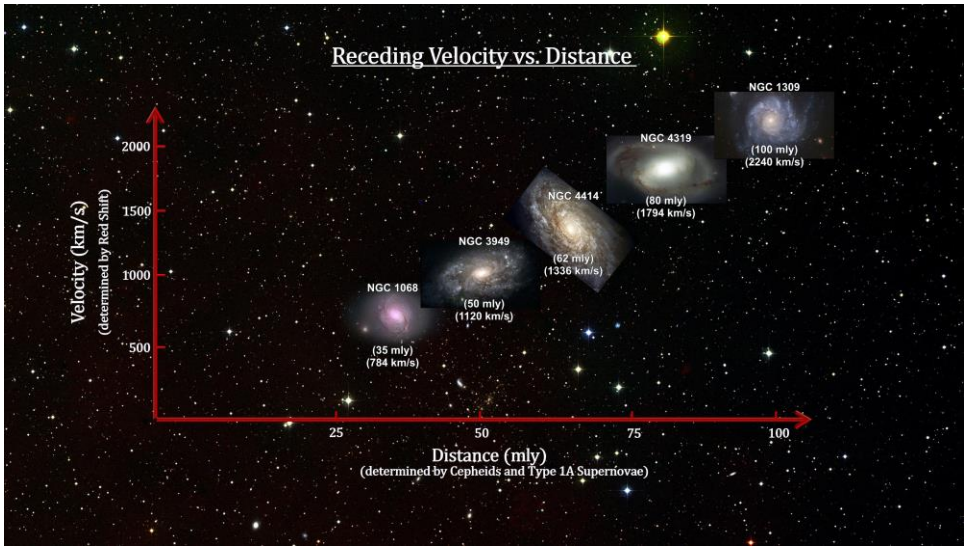
NGC 7049 is the brightest of a cluster of galaxies, called Brightest Cluster Galaxies or BCG for short. Typical BCGs are some of the oldest and most massive galaxies. **[**The globular clusters in NGC 7049 are seen as the sprinkling of small faint points of light in the galaxy's halo.**]**

Hubble' Law

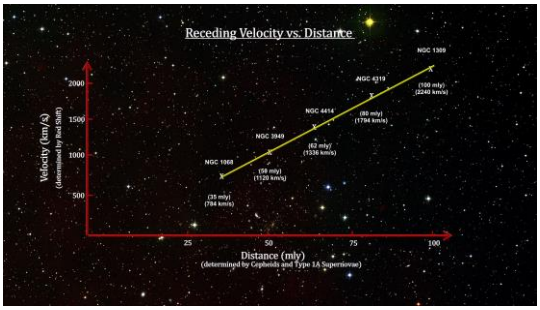
In 1923, after finding the V1 Cepheid variable in Andromeda, and determining that Andromeda was an entire galaxy over two million light years from our own, he turned his sights on other spiral and elliptical 'nebula' and found that they were galaxies as well. In his studies of these galaxies, he mapped their radial velocity as determined by the shift in spectral lines against their distance from us.

He found what we see here in the Virgo Supercluster.

- NGC 1068 is 35 mly away and receding at 784 km/s.
- NGC 3949 is 50 mly away and receding at 1120 km/s.
- NGC 4414, a galaxy studied by the Key Project on Extragalactic Distance Scales is 62 mly away and receding at 1336 km/s.
- NGC 4319, a galaxy with both Cepheid variables and Type 1a Supernova is 80 mly and receding at 1792 km/s.
- And NGC 1309, also a galaxy with both Cepheid variables and Type 1a Supernova is 100 mly away and receding at 2244 km/s.



He found that, except for a few near-by Local Group galaxies, all the spectra shifts were to the red. All the galaxies were moving away from us. And more than that, he found that the further away from us they are, the faster they are moving away from us. And even more than that, he found that the relationship between velocity and distance is linear – the graph is a straight line!



The equation is simple. The receding velocity of a galaxy is equal to the slope of the line (a constant) times the distance the galaxy is away from us. Today that constant is known as the Hubble Constant and the equation is known as Hubble's Law.

Hubble's Law

$$v = H_0 d$$

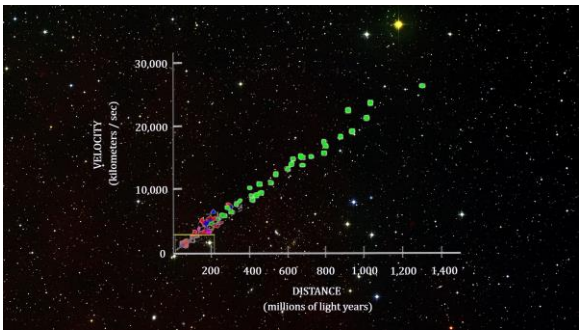
Where:

v = galaxy's velocity

d = distance to the galaxy

H_0 = The Hubble Constant

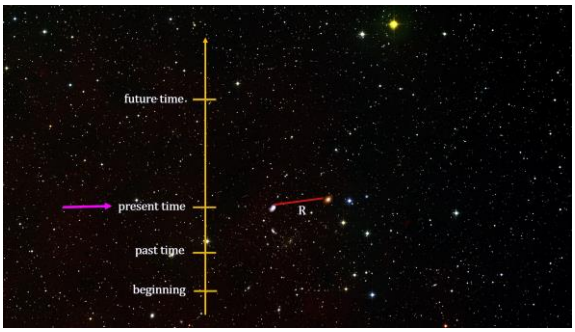
If we measure the redshift of a galaxy, we can determine its receding velocity, and knowing its receding velocity, this equation tells us how far away it is. This gives us a new rung on our cosmic distance ladder called 'Redshift'. The accuracy of this rung depends entirely on the value of the Hubble Constant. That's why it's one of the most studied numbers in astronomy and cosmology.

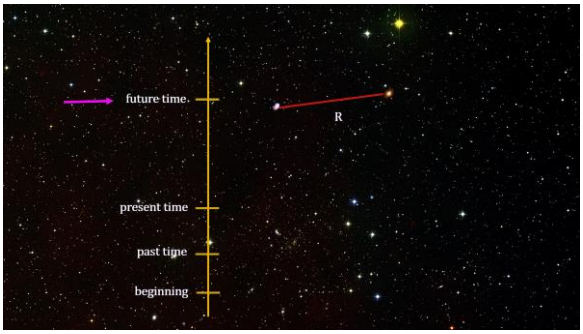


This constant has been refined over time, and the distances used to see how far it holds has increased by orders of magnitude with our modern ability to determine distances with space telescopes like Hubble analyzing Type 1a Supernova out to billions of light years. The box at the lower left shows the region that Hubble probed.

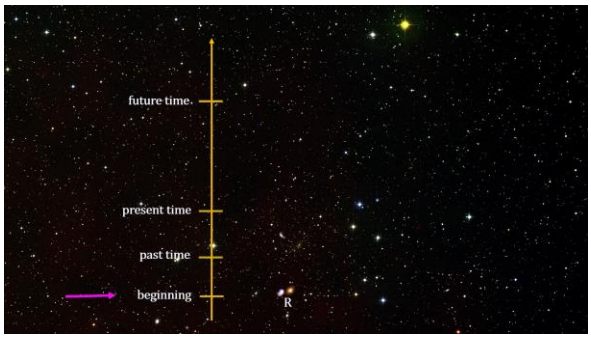
The current best value for the Hubble Constant using this approach is 22.4 km/s/mly plus or minus 3.2 (that's around 13 miles/sec per million-light-years) [70 km/s/MPc ± 10]. That is, the receding velocity of a galaxy goes up by 22.4 km/s for each additional million light years away from us it is.

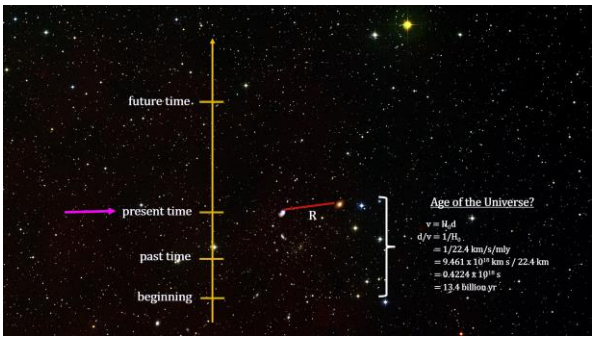
This slow and steady movement of galaxies away from us is called the Hubble Flow.





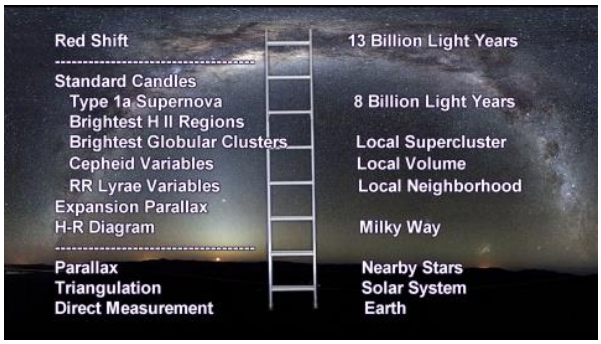
This Hubble Flow where galaxies are getting further away with time also implies that in the past, they were closer together. It follows that we can ask "How long would it take a galaxy to reach its current distance from us given its current velocity?" That's simply the distance divide by the velocity or one over the Hubble Constant – 13.4 billion years. That's the age of the Universe! We'll see later, in our chapter on the Cosmos, that the Hubble Constant turned out to not be constant over large enough times and distances. In modern cosmology it is called the Hubble Parameter and it gives us a slightly larger age for the Universe around 13.8 billion years.





Distance Ladder

Direct Measurements, Triangulation, and Parallax took us across Earth, the Solar System and nearby stars. We added expansion parallax for planetary nebula and a number of powerful standard candles that were verified against stars that could be measured via parallax. This took us all the way across the Milky Way and into our local Supercluster – the Virgo Supercluster.



Here, Cepheid variables confirmed the accuracy of type 1a supernova as an excellent standard candle. This is critical because, even with the Hubble Space Telescope, we can't see Cepheid stars much further than 100 million light years. But we can see type 1a supernova out to 8 billion light years. In addition, Cepheids and type 1a's have given us Red Shift as a way to tell distance. This rung is only limited by what is visible and we'll see in later segments, we can see out to around 13 billion light years.

Here we have just seen a few of the galaxies in the vast Virgo Supercluster. But Virgo is only one of millions of superclusters in the observable Universe. In the next segment, we'll take a look at our local group of superclusters and introduce a new way to measure supercluster boundaries with Laniakea being the one we are in.

Music:

@00:00 Antonio Vivaldi: Four Seasons - Winter Concerto in F Minor – Largo; from the album "The Most Relaxing Classical Music", 1997

@03:17 Saint-Saëns: "The Carnival of the Animals - The Swan"; from the album "The Most Relaxing Classical Music" 1997

@08:37 Mascagni: "Intermezzo"; Philharmonia Orchestra - from the album "The Most Relaxing Classical Music" 1988

@15:27 Puccini - Le Villi - Opera in 2 Acts _ Act 1 – Prelude; Radio-Symphonie-Orchester Berlin and Riccardo Chailly; from the album "Puccini Without Words" 2006

@18:31 Schubert - Andante con moto (from Symphony No. 8); from the album "Meditation: Classical Relaxation", 1991

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

$\Rightarrow \rightarrow \pm \odot \infty \nrightarrow \exists \nexists \in \notin \iint \int \cong \geq \leq \approx \neq \equiv \surd \sqrt[3]{} \sim \propto \hbar \div$