2015 Update Script

Introduction

2015 marked the Hubble Space Telescope's 25th anniversary. To celebrate, they published a number of spectacular images. In this update:

- we'll see caverns carved out of dust by a new star;
- we'll see the Veil nebula expanding;
- and we'll see right through the Eagle nebula
- we'll look deep into the center of our galaxy
- and deep into the disk of the Andromeda galaxy
- we'll also check out a lonely galaxy on the edge of our local void

[We'll also update Gaia's progress, and take a look at a new way to calculate superclusters.**]**

The LHC at CERN reopened in 2015 after a two year upgrade. Both CERN and Hubble touched on Dark Matter over the past year, so we'll examine the evidence for Dark Matter and discuss a few of the possibilities for what this mysterious material might be.

But first, we'll start with what Hubble saw inside the Milky Way.

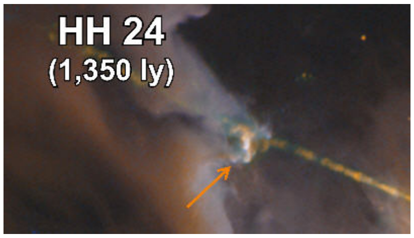
HH 24 - 1,350 ly [Music: *Tchaikovsky - Sleeping Beauty Waltz*]

Here we are zooming into the great Orion molecular cloud. As we enter the cloud, we see the jets from a central star that is hidden by gas and dust.

[These jets have carved an hourglass-shaped cavity in the near side of the nebula. The nebula provides a vivid example of a gas cloud shaped by stellar emission. When a star forms inside giant clouds of cool molecular hydrogen, some of the surrounding material collapses under gravity to form a rotating, flattened disk encircling the newborn star.

In the center of this Hubble image and partially obscured by a dark cloak of dust, a newborn star shoots twin jets of superheated material out into space in opposite directions along the star's rotation axis. The jets collide with the surrounding gas and dust and clear vast spaces, like a stream of water plowing into a hill of sand. These narrow energetic beams are streaking across space at over 160,000 km per hour and are expected to exist for only a few thousand years.

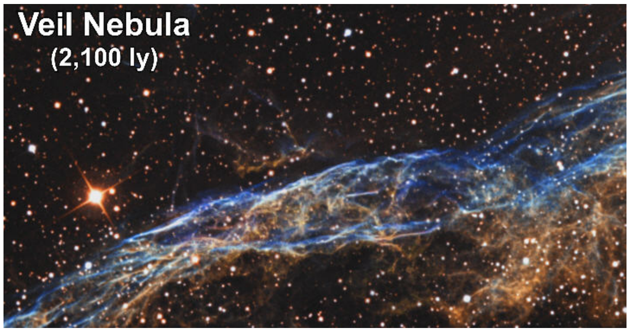
Shock fronts develop along the jets and heat the surrounding gas to thousands of degrees Centigrade. The shock fronts form Herbig-Haro (HH) objects as we covered in our segment on Star Birth Nebula. The prominent HH object shown in this image is HH 24.]



Veil Nebula

The Hubble Space Telescope is entering its 25th year in operation. Here it imaged three sections of the beautiful Veil Nebula in 1997. We saw those in our segment on Star Clusters and Supernova.

[Deriving its name from its delicate, draped filamentary structures, the Veil Nebula is one of the best-known supernova remnants. It formed from the violent death of a star twenty times the mass of the Sun that exploded about 8,000 years ago. This brightly colored cloud of glowing debris spans approximately 110 light-years.]



In 2015, Hubble took another look. Overlaying new images with new old, allows scientists to study how far the nebula has expanded since it was photographed over 18 years ago. Despite the nebula's complexity and distance from us, the movement of some of its delicate structures is clearly visible — particularly the faint red hydrogen filaments.

[In this image, one such filament can be seen as it meanders through the middle of the brighter features that dominate the image. The red color arises after gas is swept into the shock wave — which is moving at almost 1.5 million kilometers per hour! — and the hydrogen within the gas is excited by particle collisions right at the shock front itself.]

Eagle Nebula   6,500 ly

Hubble has also revisited the famous Eagle Nebula [M16] pillars, capturing the multi-colored glow of gas clouds, and wispy tendrils of dark cosmic dust. With these new images come better contrast and clearer views of the region.

In addition to this new visible-light image, Hubble has also produced an infrared image. Infrared penetrates much of the obscuring dust and gas and unveils newborn stars, hidden in the visible-light view.

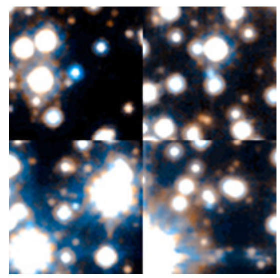
White Dwarfs in Galactic Bulge

Here we are zooming into the Milky Way's center 26,000 light-years away.

This is a small section of Hubble's view of the dense collection of stars crammed together in the galactic bulge.

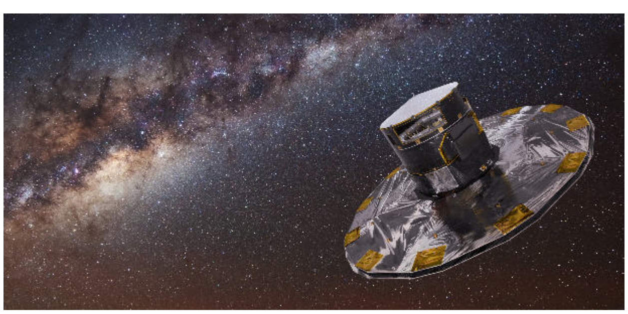
[Hubble uncovered extremely faint and hot white dwarfs. This is a sample of 4 out of the 70 brightest white dwarfs found.

White Dwarfs are the smoldering remnants of once-vibrant stars. They contain information about the stars that existed about 12 billion years ago that burned out to form these stars. Studying them can yield clues to our galaxy's construction processes - processes that happened long before the Earth and our sun formed.]



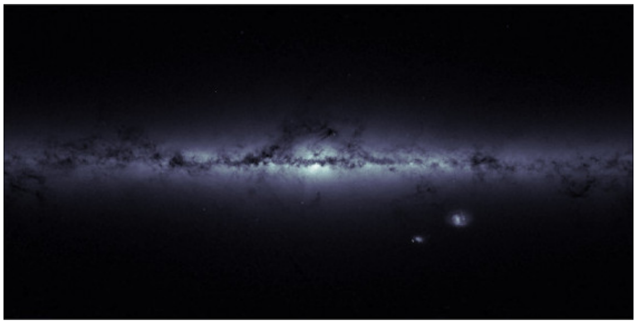
Gaia Update

Gaia is the ambitious mission to provide unprecedented positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars.



It has now accumulated about 340 billion positional or astrometric measurements, 68 billion brightness data points, and 6.7 billion spectra. [Each of these data points is associated with a celestial object that passed across the Gaia focal plane during a scan. A preliminary catalogue based on data from the first year of Gaia's observations is planned for release in mid-2016.]

This image, based on housekeeping data from ESA's Gaia satellite, portrays the outline of our Galaxy. It was obtained by plotting the total number of stars crossing Gaia's focal plane per second. This is a measure of the density of stars in the region that is being scanned.

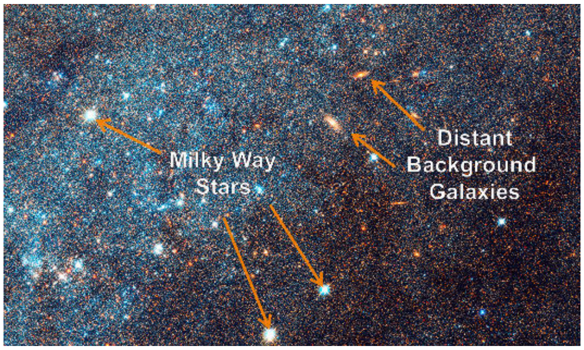


Andromeda – 2.5 mly [Music: *Liszt - Love Dream No 3 , Liebestraum***]**

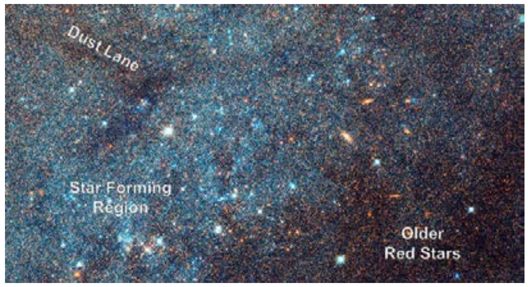
Now let's take a look at some of the developments outside the galaxy.

In "How Far Away is it" we covered the Andromeda galaxy as part of our Local Group. In 2015, the Hubble Space Telescope captured the sharpest and most detailed image ever taken of the galaxy. It shows over 100 million stars and thousands of star clusters embedded in a section of the galaxy's disc stretching across over 48,000 light-years. It traces the galaxy from its central galactic bulge on the left, where stars are densely packed together, across lanes of stars and dust to the sparser outskirts of its outer disc on the right.

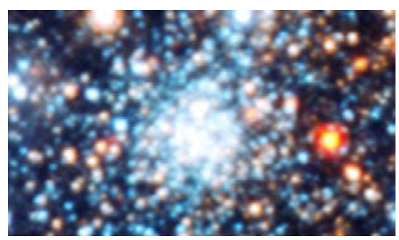
Zooming into the boxed field, we see some foreground Milky Way stars in the line of sight to Andromeda and a couple of distant spiral galaxies shining through Andromeda's disk.



The large groups of blue stars in the galaxy indicate star-forming regions in the spiral arms, whilst the dark silhouettes of obscured regions trace out complex dust structures. Underlying the entire galaxy is a smooth distribution of cooler red stars that trace Andromeda's evolution over billions of years.

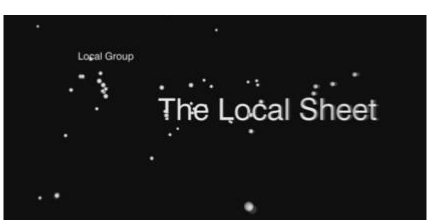


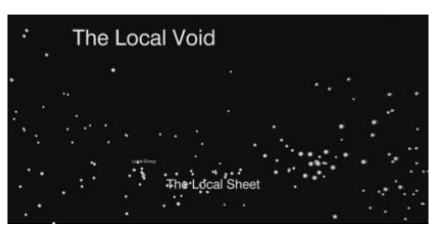
A large number of star clusters can be seen in this analysis of Andromeda. This 150 light-years across view of AP 14 and others like it are helping astronomers interpret the light from more distant galaxies that have a similar structure. **[**They discovered that, for whatever reason, nature creates star clusters with a consistent distribution from massive blue supergiants to small red dwarfs. This remains a constant across both the Andromeda and Milky Way galaxies, despite the fact that the clusters vary in mass by a factor of 10 and range in age from 4 million to 24 million years old.**]**



NGC 6503   18 mly

Astronomers have previously noticed that the Milky Way sits in a large, flat array of galaxies called the Local Sheet. This sheet of galaxies bounds a void called the Local Void. The void's size is not known. But it is at least 150 million light years wide and 230 million light years long. Its center is approximately 75 million light years from us.



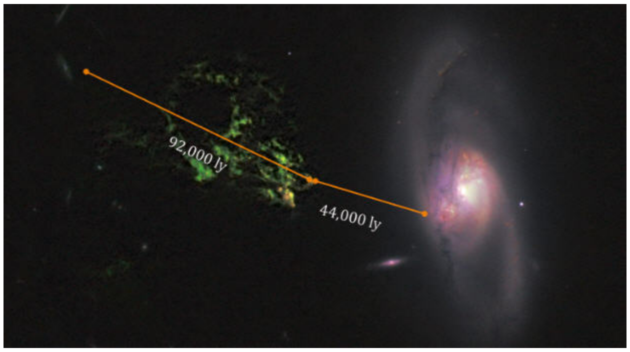


Hubble has taken a beautiful picture of NGC 6503, a lonely galaxy on the edge of this void. It spans some 30,000 light-years. In this image, bright red patches of gas can be seen scattered through its swirling spiral arms, mixed with bright blue regions that contain newly-forming stars, with dark brown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

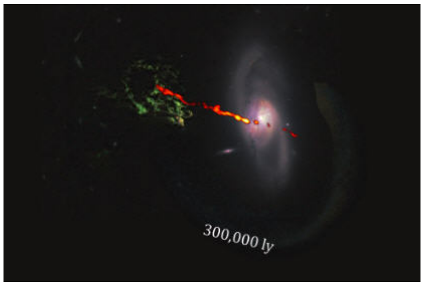
[By examining galaxies such as this one, astronomers have discovered that the emptiness of this region has quite an effect on the space around us. In fact, the Milky Way is being strongly pulled away from it by the gentle but relentless tug of other nearby galaxies.**]**

<u>Hanny's Voorwerp</u> – 65 mly

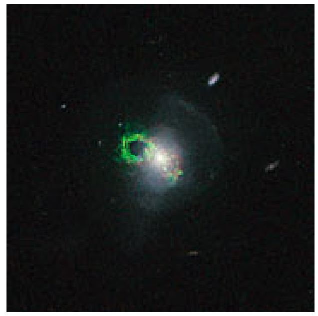
Hanny's Voorwerp is one of the strangest space objects ever seen. A mysterious, glowing green blob of gas is floating in space near a spiral galaxy (IC 2497). The object is so huge that it stretches from 44,000 light-years to 136,000 light-years from the galaxy's core.



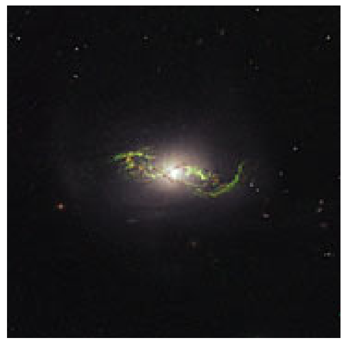
It turns out that it's part of a 300,000 light-years long tidal tail that wraps around IC 2497. Our current understanding is that this part of the tail was illuminated by a high energy beam created by matter falling into the galaxy's central black hole. Their unmistakable emerald hue is caused by ionized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



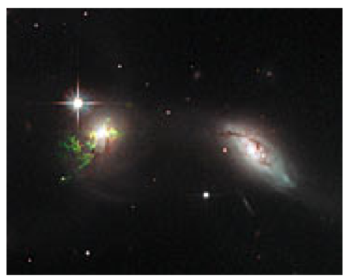
Here's a closer look at the Teacup galaxy. [2MASX J14302986+1339117 Redshift: 0.0852 = 1.05 bly]



This is NGC 5972. [Redshift: 0.0297 = 409 mly]



And here's UGC 11185. [Redshift: 0.0412 = 567 mly]



Here is a set of eight objects released by Hubble in 2015. These all have the same characteristics as Hanny's Voorwerp.

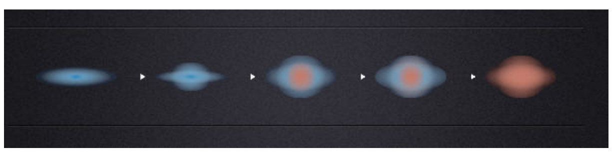
[Those featured here are (from left to right on top row) the Teacup (more formally known as 2MASX J14302986+1339117), NGC 5972, 2MASX J15100402+0740370 and UGC 7342, and (from left to right on bottom row) NGC 5252, Mrk 1498, UGC 11185 and 2MASX J22014163+1151237.]

[IC 2006 – [redshift 0.00461 = 63.5 mly]

This Hubble image shows an elliptical galaxy known as IC 2006. Massive elliptical galaxies like these are common in the modern Universe, where star formation is nearly non-existent. The question astronomers were trying to answer is how the once furious rates of star formation in galaxies like this came to an end.

European Space Organization's Very Large Telescope and the Hubble Space Telescope have discovered that three billion years after the Big Bang, these galaxies still made stars on their outskirts, but no longer in their interiors. The quenching of star formation seems to have started in the cores of the galaxies and then spread to the outer parts.

This diagram illustrates this process. Galaxies in the early Universe appear at the left. The blue regions are where star formation is in progress and the red regions are the "dead" regions where only older redder stars remain and there are no more young blue stars being formed. The resulting giant spheroidal galaxies in the modern Universe appear on the right.



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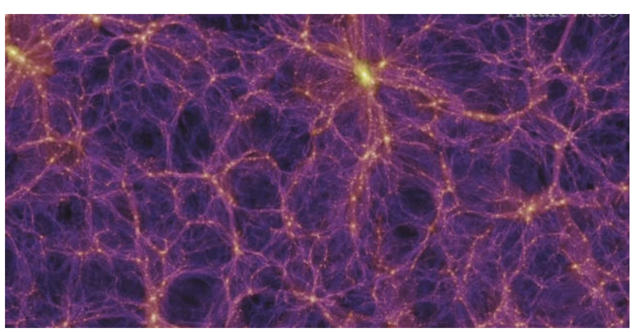
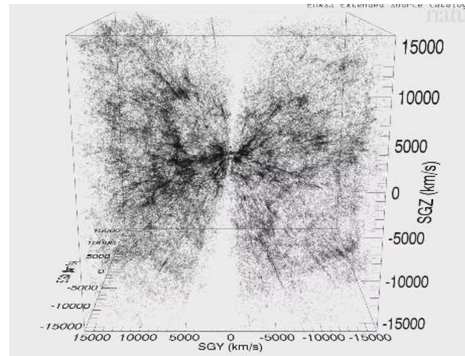
<u>Laniakea: Our home supercluster</u>

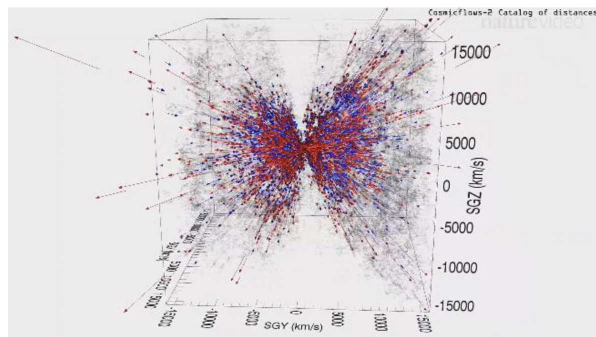
In our segment on the Cosmos in the "How far away is it" video book, we covered how, on the widest scale, the universe forms a web of galaxies surrounding great voids, and that the web filaments are galaxies grouped into superclusters.

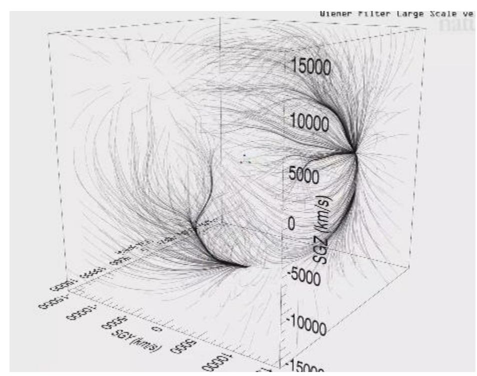


It has always been difficult for astronomers to determine where one supercluster ends and another begins. But now a team of astronomers have collected data on thousands of galaxies around us to understand their peculiar motion. You'll recall from our segment on "Local Superclusters" that the peculiar motion of an object is its motion less that part of its motion associated with the Hubble flow due to the expanding universe.

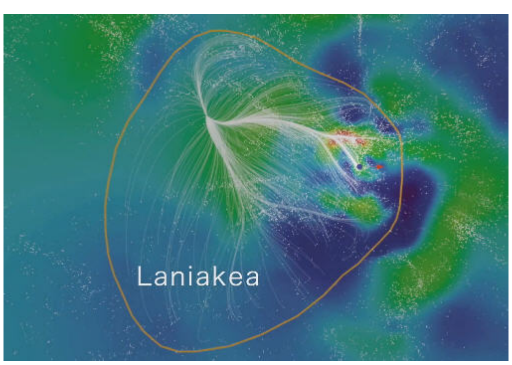


They used this data to identify which galaxies are moving towards us (shown in blue) and which galaxies are moving away from us (shown in red).





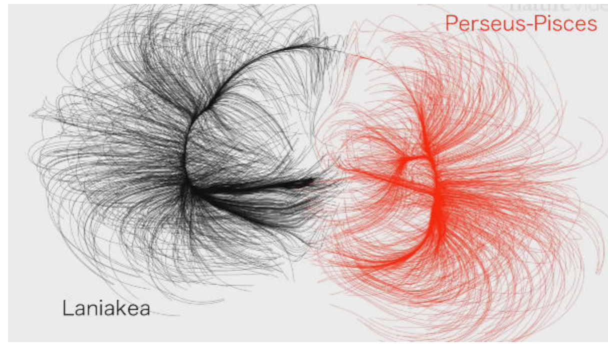
With this data, they were able to create a map of the paths galaxies are migrating along. These paths are called cosmic flows. Using this motion, they came up with a new way to map the distribution of matter in the universe.

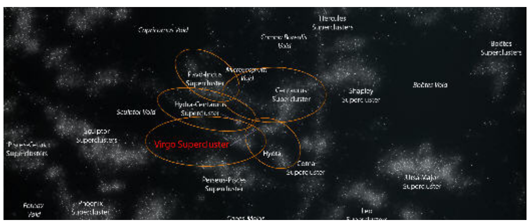


In our segment on the Virgo Supercluster, we counted the Virgo Galaxy cluster and a few hundred others as our local supercluster. But using this new technique we see that the Virgo Supercluster is part of a much larger structure that is 100 time larger and more massive. The astronomers who made this discovery have named this new supercluster "Laniakea" – Hawaiian for 'immeasurable heaven'.

For example here is an illustration of Laniakea and Perseus-Pisces an adjacent supercluster.

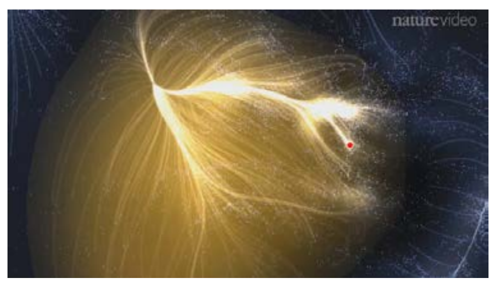
The boundary is where the supercluster objects are sharing apart like the North American Great Divide separates water flowing to the Atlantic Ocean from water flowing to the Pacific Ocean.





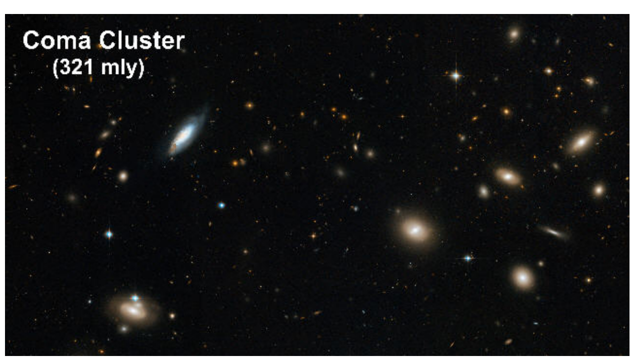
The Laniakea Supercluster encompasses 100,000 galaxies stretched out over 520 million light-years. It contains the Virgo, Hydra, Centaurus, Hydra-Centaurus, and Pavo-Indus previously identified superclusters.

In this view, the red dot shows our Milky Way's location in Laniakea.

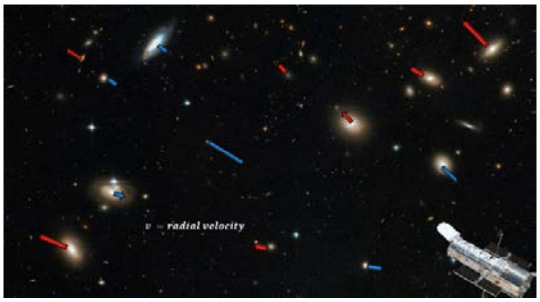


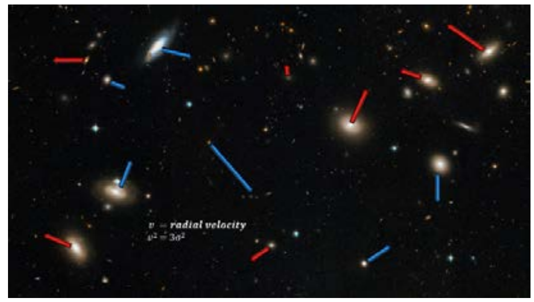
Dark Matter [Music: *Grieg - Peer Gynt - Death of Aase***]**

Until the early part of the 20th century it went without saying that the matter we see is most of the matter there is. That would be protons and neutrons with accelerating electrons creating the light we "see". But that came into question in the early 1930s when Fritz Zwicky, a Swiss astronomer out of Caltech, studied the Coma galaxy cluster 321 mly away with a thousand galaxies spanning 25 mly in diameter. He looked at it in a number of ways – two of which are very revealing. In one he used galaxy motion to calculate mass and in the other he used galaxy luminosity.

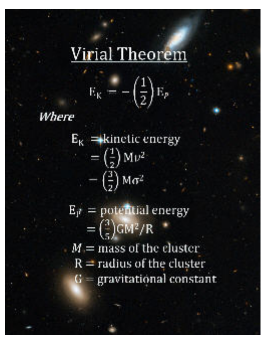


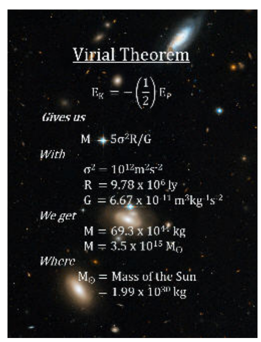
His processes are not precise, but they do provide ballpark figures for the mass of the cluster. For motion, he had the cluster galaxy's radial velocities from the Doppler shifts in the light we see. He then generalized them into their three dimensional velocity dispersion statistical equivalent.



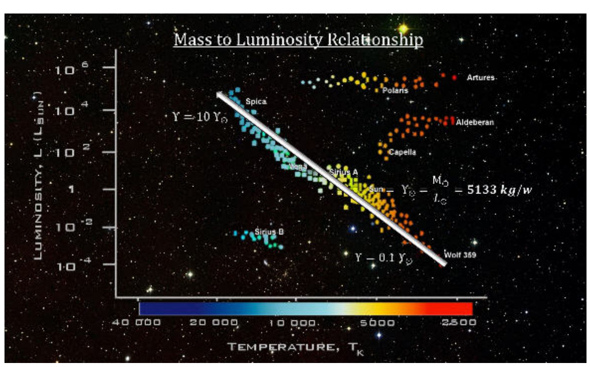


This galaxy motion gives us the kinetic energy of the cluster. Zwicky used the well understood virial theorem that has the kinetic energy of a system equal to ½ its gravitational potential energy. This allows us to solve for the mass of the cluster. This is the mass as measured by its gravitational effects.

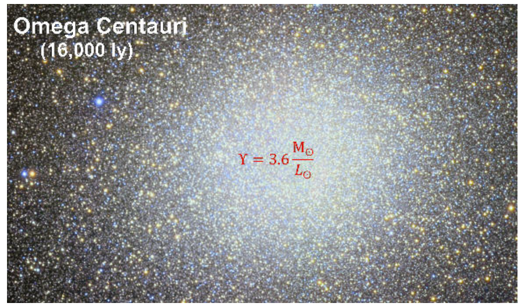


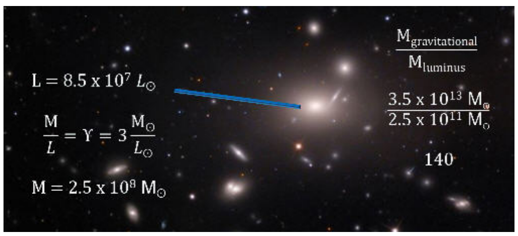


The second way he calculated the cluster's mass was to use the cluster's luminosity. You may recall from our discussion of the Hertzsprung-Russel diagram in our "How Far Away is it" segment on "Distant Stars" that there is a relationship between a star's mass and its luminosity. We can use that relationship to estimate the mass of groups of stars by measuring their luminosity.



We use the mass to light ratio of the sun as the base for comparisons. For example, the Omega Centauri globular star cluster has a mass to light ratio of 3.6.



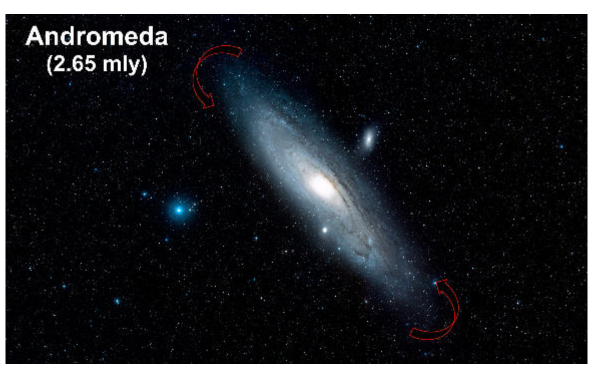


Zwicky measured the luminosity of the average galaxy in the Coma Cluster. Using a mass to light ratio of 3, he calculated its mass. When he multiplied the average times the 1,000 galaxies in the cluster, he came out with a number that was over a 100 time less than the mass calculated via the virial theorem based on gravity. In other words, the motion of the galaxies in the cluster indicated a mass that was over 100 times the mass from luminous matter.

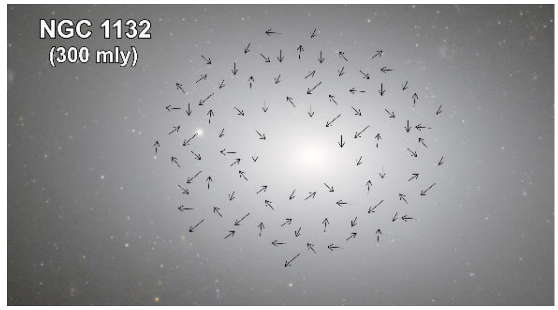
Zwicky concluded that either the laws of gravity as we know them (Newton's and Einstein's) did not work for volumes as large as the Coma Cluster, or the luminous matter is only a very small part of the total matter in the cluster. He called the rest of the matter – 'dark matter', and suggested that gravitational lensing would help quantify this dark matter. In the 1930s, nobody believed him.

Galaxy Rotation Curves [Music: *Mendelssohn - Symphony No 3 Scottish IV Adagio***]**

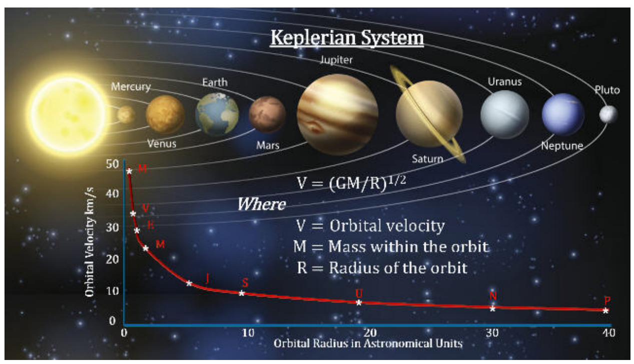
Fast forward to the 1970s. Attention was focused on an anomaly associate with the velocity of stars orbiting spiral galaxies. Resolving the velocities of individual stars in distance galaxies is not feasible, but in spiral galaxies, where all the stars in the disk are rotating in the same direction, a good aggregate estimate is possible.



With elliptical galaxies, the motion of stars around the center are chaotic. So we have no velocity data to use and therefore no anomalies to identify.

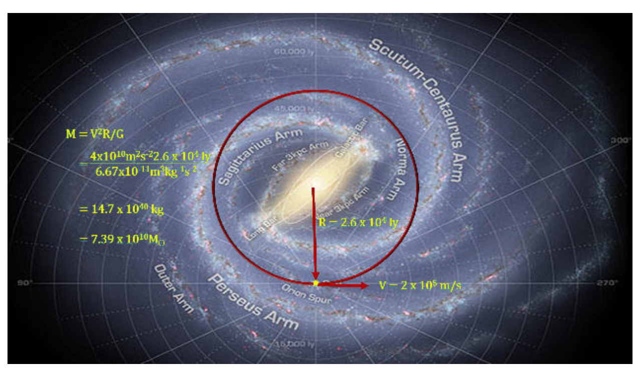


To see how the velocities give us a measure of mass, we'll start with our solar system. Here's the 'rotation curve' we get when we map the velocity of the planets orbiting the Sun. Because the Sun has 99% of all the matter in the system, the mass within any orbit will be relatively fixed at the Sun's mass. Therefore, the further away from the central mass we get, the weaker the gravitational pull and the slower the orbital velocity. The model is call Keplerian because it follows Kepler's laws for orbital motion.

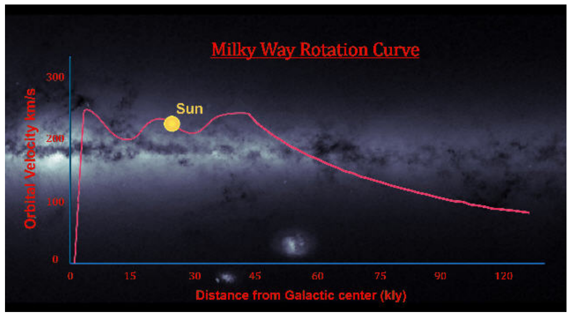


Now a galaxy is much more complex than a solar system. The mass within increasing orbital volumes is not fixed like it is in solar systems. As you move out from the center of a galaxy, there is considerable mass added in addition to the mass of the central bulge.

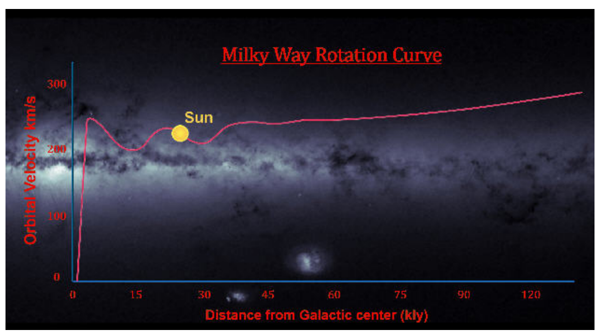
This is because of the large number of stars, dust and gas in the galaxy's disk. For instance, it is estimated that the mass of the central bulge of the Milky Way is 20 billion solar masses. We saw in our segment on the Milky Way that the velocity of the sun around the center of the galaxy is 200 km/s and its distance from the center is 26,000 ly. So the mass of the galaxy interior to the Sun's orbit is approximately 74 billion solar masses – a good deal more than the bulge itself.



But at the outer edges of the disk, the star density drops off dramatically. In the 1970s, everyone expected to see rotation curves that look like this.



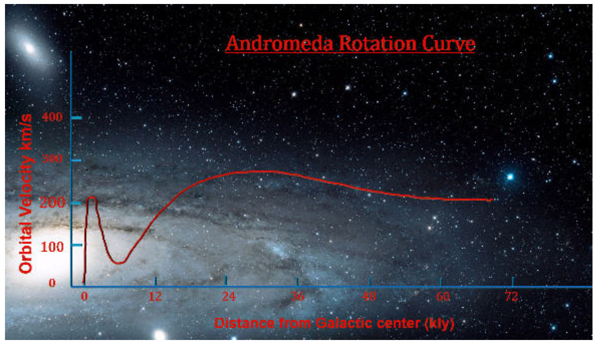
But in 1975, an American astronomer Vera Rubin published 'galaxy rotation curves' for the Milky Way and a number of other galaxies that showed a remarkable result. Where the velocities were expected to fall off, they remained relatively constant.



If our current theory of gravity holds up over galactic distances, then this curve tells us that our model of the Milky Way is missing something. In order for objects far from the center of the Galaxy to be moving faster than predicted, there must be significant additional mass far from the Galactic Center exerting gravitational pulls on those stars. This means that the Milky Way must include an unseen component that is very massive and much larger than the galaxy's visible disk. In other words – dark matter.

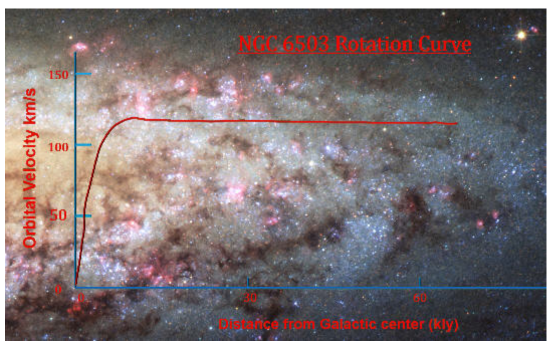
[In 2015, a team of Swedish astronomers reported that a detailed study of the motion of stars near the central part of the galaxy indicate that dark matter also exists inside the galactic disk. In this image, the blue dots represent stars moving towards us (blue shifted) and the red dots represent stars moving away from us (red shifted). The spherically symmetric blue halo illustrates the dark matter distribution.]

Here's Vera Rubin's measurements of the velocity curve for Andromeda.

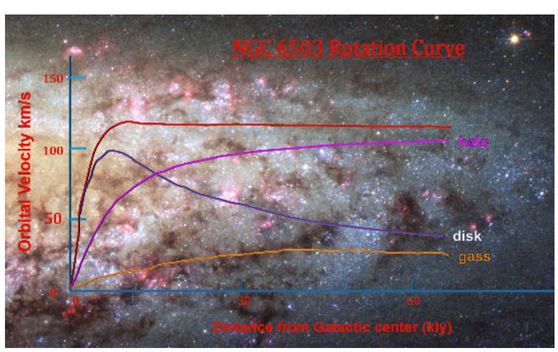


NGC 6503 Rotation Curve

And here's the rotation curve for NGC 6503 (the galaxy on the edge of the local void that we covered earlier).



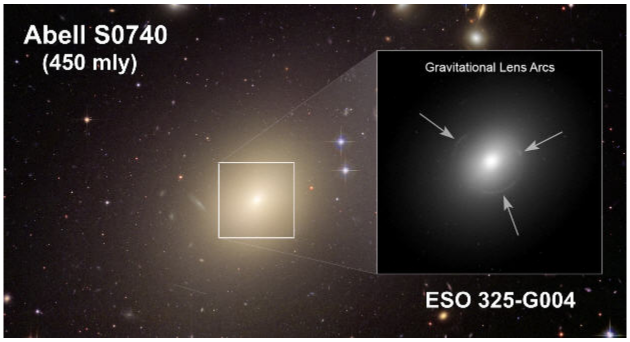
Using accurate and high resolution emission lines from neutral hydrogen, astronomers modelled the mass distribution of this galaxy. They used the mass to light ratio in the visible disk, the galaxy's core radius and the circular velocity of the halo. The study found the contribution to the rotation curve of three types of matter (gas, luminous matter and dark matter). These galaxy rotation curves show that the dark matter contribution becomes dominant with increasing distance from the galactic center.



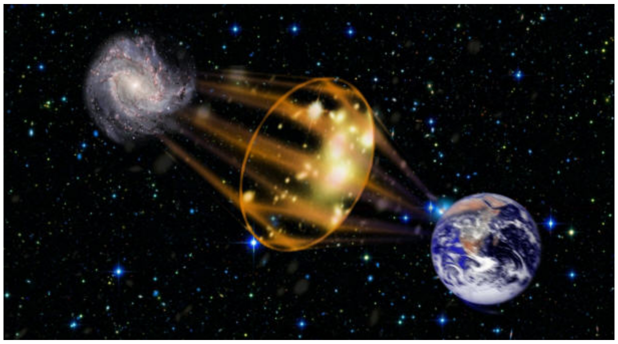
Back to galaxy clusters

Gravitational Lensing

With this new understanding about the possibility and impact of dark matter, astronomers turned their attention back to galaxy clusters like the one studied by Zwicky in 1936. Back then, Zwicky suggested that gravitational lensing could be used to better understand dark matter. We first mentioned gravitational lensing in our "How Far Away Is It" "Local Superclusters" segment where we covered an Einstein Ring.



[In our "How fast is it" "General Relativity II" segment we showed how gravity in a galaxy cluster bends the light that travels through it on its way here.



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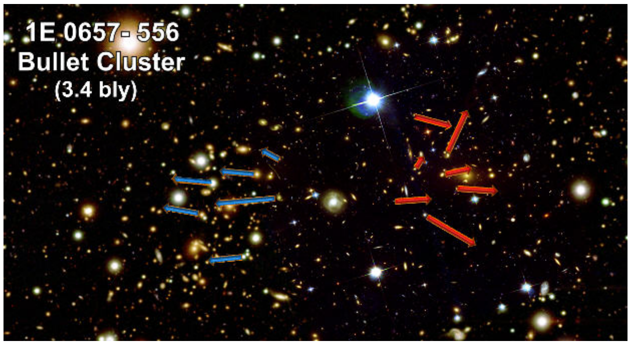
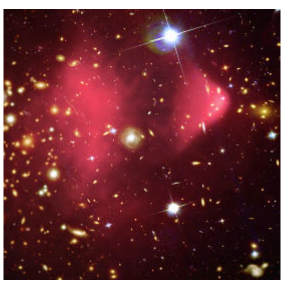
Bullet cluster - 3.4 bly



Our case in point is the galaxy cluster 1E 0657-556, also known as the "bullet cluster." The virial motion of its galaxies indicates that a collision has occurred. Two massive clusters have passed through each other millions of years ago and the member galaxies are now flying apart.

If we zoom in a bit closer, we can see the telltale arcs of more distant galaxies lensed by the gravity of the bullet cluster. Counting the lensed objects and the estimated amount of light bending involved for each one, a map of the areas containing most of the mass of the cluster can be superimposed on the visible image. We have used blue to indicate the locations where the vast majority of the matter must be located in order to get the observed lensing.

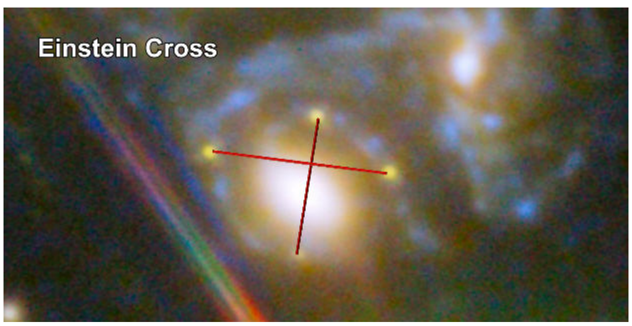


Here we have the cluster's hot x-ray emitting gas detected by the Chandra X-ray observatory. The two pink clumps contain most of the "normal," matter – sometimes referred to as baryonic matter or matter made up of protons and neutrons. The bullet-shaped clump on the right is the hot gas from one cluster, which passed through the hot gas from the other larger cluster during the collision.

When we superimpose the dark, baryonic and visible components of the cluster's mass we get the full picture. The galaxies and the dark matter have traveled a great deal further than the gas. This indicates that the galaxies and dark matter in the two colliding clusters did not interfere with each other. In other words, they passed through each other without slowing down. On the other hand, during the collision, the gas clouds were slowed by a drag force, similar to air resistance. This combination had the effect of separating the gas from the dark matter. This separation is considered to be direct evidence that dark matter exists. Measurement indicate that galaxy clusters on average have 85% dark matter, 14% intergalactic gas, and only 1% stars.

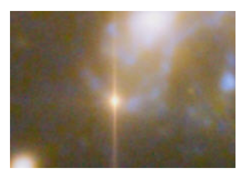
Gravitationally lensed supernova

In 2014, a team of astronomers found a supernova in this galaxy cluster [MACS J1149+2223] over 5 billion light years away.

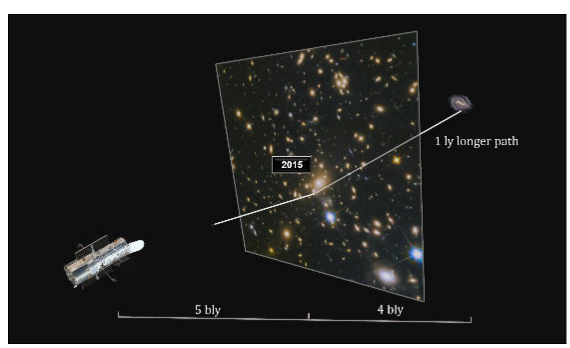


The supernova actually happened in a galaxy 4 billion light years behind this cluster – making it 9 billion light years away. The huge mass of the foreground galaxy and the cluster bent the light from the distant supernova - creating four separate images of the same explosion. The images are arranged around an elliptical galaxy in a formation known as an Einstein cross – because he was the one who predicted this phenomena.

Following this discovery, astronomers modeled several possible gas and dark matter distributions in the galaxy cluster. Each model predicted that another image of this supernova will appear in the cluster, but they had different time estimates ranging from 2015 through 2025. In December 2015 it appeared.



For the first time in history, the time and location of a supernova was accurately predicted. We actually saw the supernova happen. Instead of detecting a flash in the sky and turning telescopes to its location, we had the telescopes already focused on the correct area and recorded the event from beginning to end. This was powerful evidence for dark matter.



[The supernova has been nicknamed Refsdal in honor of Norwegian astronomer Sjur Refsdal, who, in 1964, first proposed using time-delayed images from a lensed supernova to study the expansion of the Universe.]

[In 2015, astronomers using observations from the Hubble Space Telescope and the Chandra X-ray Observatory published a 72 galaxy cluster study on how dark matter behaves when the clusters collide. The results, show that dark matter interacts with itself even less than previously thought.

This narrows down the options for what this mysterious substance might be. Particle physics theorists have to keep looking, but they now have a smaller set of unknowns to work with when building their models.

Dark matter could potentially have rich and complex properties, but these latest results rule out interactions that create a strong frictional force. That would cause dark matter to slow down during collisions and it doesn't.

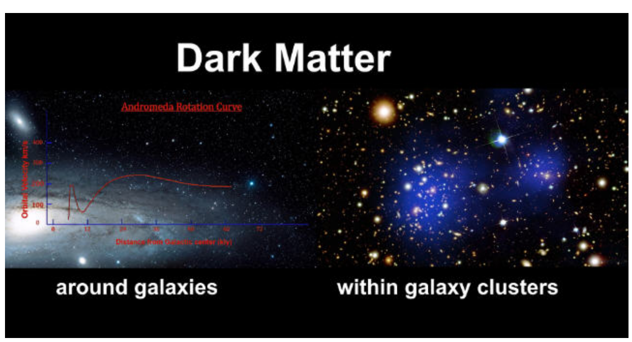
The clusters shown here are, from left to right and top to bottom: MACS J0416.1–2403, MACS J0152.5-2852, MACS J0717.5+3745, Abell 370, Abell 2744 and ZwCl 1358+62.

]

What is Dark Matter? [Music: *Ravel - Pavane pour une infante défunte*]

We have just seen two kinds of evidence for dark matter: One from galaxy rotation curves for dark matter around spiral galaxies and the other from gravitational lensing for galaxy clusters. Both leave us with only two possibilities:

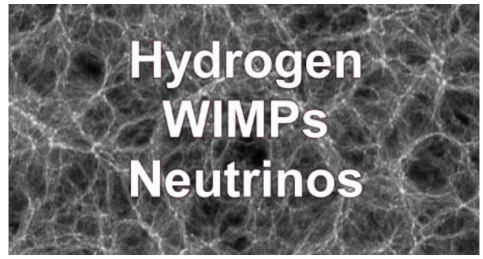
- either our current theory of gravity just doesn't extend to galaxies and/or galaxy clusters,
- Or most of the universe is made up of one or more unknown substances that interact with normal matter via gravity but not much else.



A tremendous amount of research is actively trying to find out what this stuff is. Here are some of the possibilities:

- Hydrogen
- Weakly interacting massive particles(WIMPs)
- Neutrinos

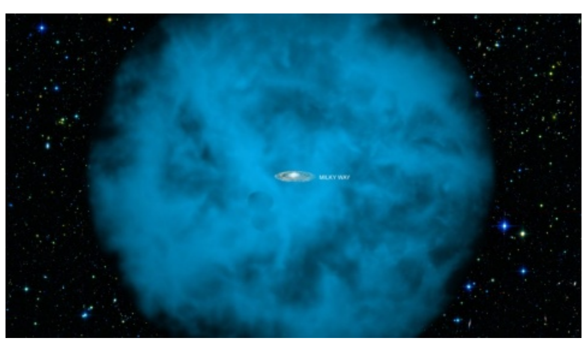
Let's take a quick look at each of these.



Hydrogen

Here's a European Southern Observatory artist's representation of the distribution of dark matter around the Milky Way galaxy.

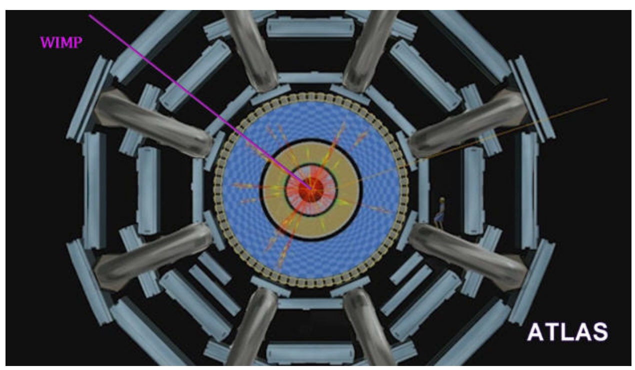
You may recall form our 'How far away is it' segment on the Milky Way that in September 2012, Chandra found evidence that the Milky Way Galaxy is embedded with a large amount of hot gas in the halo. Counting this vast amount of gas, the mass of the halo is estimated to equal the mass of the stars in the galaxy. This could be the solution for star orbital speeds and might be the answer for spiral galaxy dark matter. It could not be the answer for galaxy clusters, but then again, it doesn't have to be.



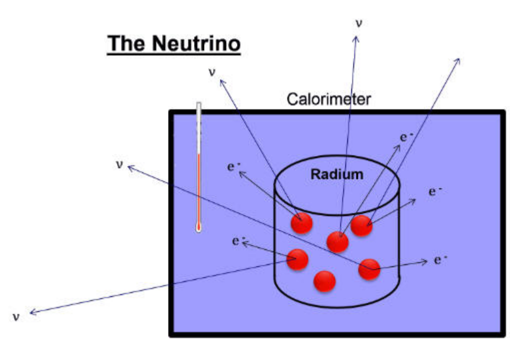
WIMPs

Another possibility is the existence of a new set of extended Standard Model particles. There are a variety of theories that predict weakly interacting massive particles (WIMPs).

In late 2015, the Large Hadron Collider at CERN came back on line after a two year upgrade. It can now reach 13 TeV, almost double the collision energy before the upgrade. At this level it might be enough to produce a WIMP. Of course the particle would not be detected because it wouldn't interact with any layer of the detector. However, it would carry away energy and momentum, so physicists could infer their existence from the amount of energy and momentum "missing" after a collision.

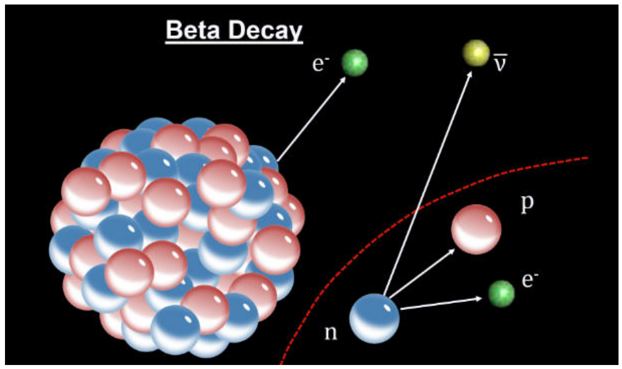


You may remember from our 'How small is it' "Elementary Particles" segment that this is exactly the same way Ellis and Wooster found the Neutrino back in 1927.



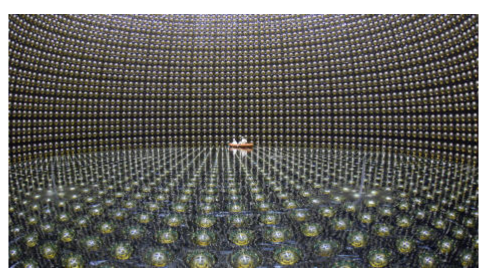
Neutrinos

This brings us to the last possibility we'll cover. In our discussion on elementary particles, we found that the neutrino is a critical component in many nuclear reactions.

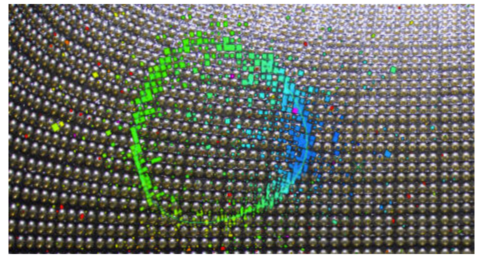


Over the life of the universe, countless numbers have been produced. And the detection of solar neutrinos and neutrinos from SN 1987A marked the beginning of neutrino astronomy. Over the life of the universe, countess numbers have been produced. They are over a billion times more abundant than the electrons, protons and neutrons that make up stars, planets and people. But are there enough of them to account for the dark matter in galaxy clusters. Neutrino astronomy is trying to discover the answer to this question.

Today we have built amazing neutrino detectors such as the Super-Kamiokande in Japan to better understand these fundamental but elusive particles. The Super-Kamiokande is located 1,000 meters underground in a Japanese mine. It contains a lake holding 50,000 tons of ultra-pure water surrounded by an inner detector with over 11,000 photomultiplier tubes that flash when struck by a photon created by a neutrino interaction with the water.

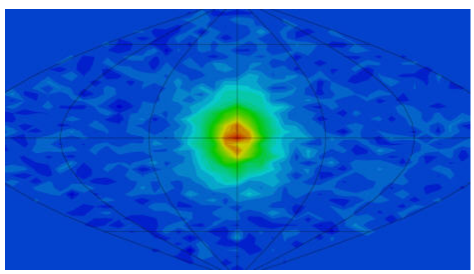


The speed of light in water is slower than the speed of light in a vacuum. A neutrino interaction with the electrons or nuclei of water can produce a charged particle that moves faster than the speed of light in water. This creates a cone of light known as Cherenkov radiation. This is the optical equivalent of a sonic boom. The Cherenkov light is projected as a ring on the wall of the detector and recorded by the photomultipliers.



[The Sun sends about 65 billion neutrinos per square centimeter our way every second. That's a lot of neutrinos. And almost all of them pass right on through the earth and out the other side. Trillions of neutrinos are passing through your body every second.

This figure shows the sun as observed by Super-Kamiokande.



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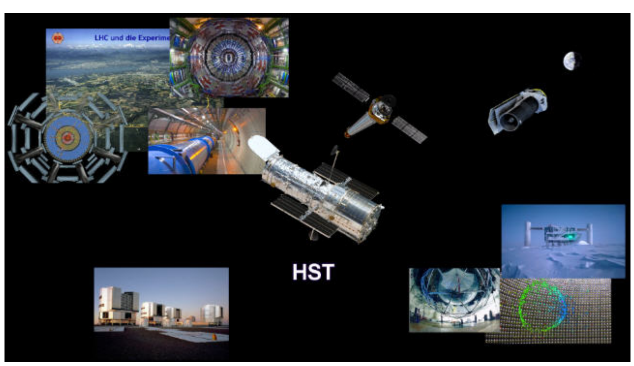
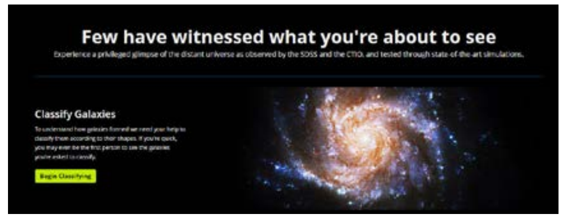
With so much of the scientific community searching for an answer, we can expect to know if neutrinos, WIMPS, hydrogen, new gravitational theories or something else can explain the movement of stars around galaxies, and galaxies around clusters. Hopefully, there will be news to report on this topic in the 2016 update.



Credits

Before listing all the sources I used to make this 2015 update, I'd like to point to two websites you might find interesting.

One is Galaxy Zoo. It's a site where you help with over a million cataloged Hubble galaxy the images. Hanny's Voorwerp was found by Dutch schoolteacher Hanny van Arkel. The name is Dutch for Hanny's object.



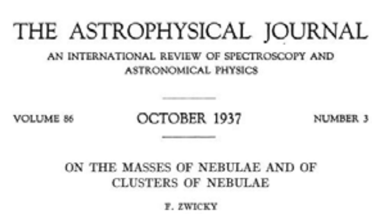
http://www.galaxyzoo.org/

Amazing Space, Hubble Site's sister site, is launching a new look and feel. Amazing Space takes users on a journey of astronomical discovery through the nearby and distant cosmos from the combined perspectives of the Hubble Space Telescope and its successor, the James Webb Space Telescope. Take a look.

http://amazingspace.org/

Here are two articles worth reading.

This is Fritz Zwicky's 1939 paper that first introduces the idea of dark matter needs more math.


THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 86 OCTOBER 1937 NUMBER 3

ON THE MASSES OF NEBULAE AND OF CLUSTERS OF NEBULAE

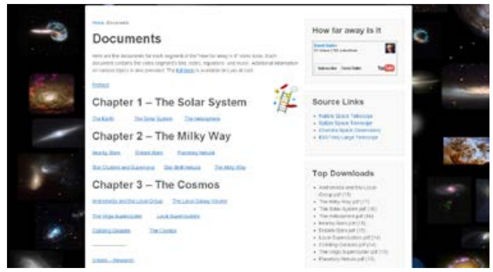
F. ZWICKY

http://adsabs.harvard.edu/abs/1937ApJ....86..217Z

The second paper is a recent article by Vera Rubin that you'll find easier to read.

http://www.phys.ufl.edu/courses/phy3101/spring08/2006_Physics_Today_Vera_Rubin_vol59no12p8_9.pdf

And don't forget, every video segment on the How Far Away Is It YouTube channel, including this one, has a document with the text, pictures, links and notes located on howfarawayisit.com/documents.



Here are the links to the Hubble and other locations where I found the information contained in this 2015 update. These are the places where you can go to find out learn more. Thank you for watching.

Gaia Update

http://sci.esa.int/gaia/
http://sci.esa.int/gaia/56123-counting-stars-with-gaia/

Veil Nebula

http://hubblesite.org/newscenter/archive/releases/2015/29/

http://www.spacetelescope.org/news/heic1520/?lang

Eagle Nebula

http://www.spacetelescope.org/news/heic1501/

Star Birth Nebula HH 24

http://hubblesite.org/newscenter/archive/releases/2015/42/
http://www.spacetelescope.org/images/heic1526b/

White Dwarfs in Galactic Bulge

http://hubblesite.org/newscenter/archive/releases/2015/38/image/a/

http://www.spacetelescope.org/images/opo1116a/

Andromeda

http://hubblesite.org/newscenter/archive/releases/2015/02/image/a/

http://www.spacetelescope.org/news/heic1502/

http://hubblesite.org/newscenter/archive/releases/2015/18/image/j/

NGC 6503

http://www.spacetelescope.org/news/heic1513/

Local Void

http://www.clues-project.org/misc/clues-obsmovies/observations.html

Hanny's Voorwerp

http://www.spacetelescope.org/news/heic1507/

IC 2006

http://www.spacetelescope.org/news/heic1508/

http://www.spacetelescope.org/images/heic1508b/

Laniakea: Our home supercluster

https://www.youtube.com/watch?v=rENyyRwxpHo

http://www.nature.com/nature/journal/v513/n7516/full/nature13674.html

http://dx.doi.org/10.1038/nature13674
http://www.nature.com/news/earth-s-ne...

NGC 5139

http://www.peripatus.gen.nz/astronomy/objNGC5139.html

Omega Centauri with mass/light ratio

https://www.cta-observatory.ac.uk/?page_id=1254

Coma cluster

http://www.britannica.com/topic/Coma-cluster

https://ned.ipac.caltech.edu/level5/Biviano/Biviano3_3.html

http://www.astro.caltech.edu/~george/ay21/eaa/eaa-comacluster.pdf

http://spiff.rit.edu/classes/phys440/lectures/gal_clus/gal_clus.html

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http://www.teachastronomy.com/astropedia/article/Mass-to-Light-Ratios

Mass to light ratio

http://file.scirp.org/Html/7-7500789_23061.htm#Figure 1

Galaxy Rotation Curves

http://www.spacetelescope.org/images/heic0804a/

http://www.tlgzl.com/gunessistemi/

Solar System picture

http://www.ifa.hawaii.edu/~barnes/ast626_97/pcmw.html

Milky Way mass

http://www1.ynao.ac.cn/~jinhuahe/know_base/astro_objects/MilkyWay.htm#MWrotation_curve

Milky Way rotation curves

http://pages.uoregon.edu/jimbrau/astr123/Notes/Chapter23.html

Milky Way Rotation Curve

http://earthsky.org/space/dark-matter-in-the-inner-milky-way

https://www.e-education.psu.edu/astro801/content/l8_p8.html

http://www.universetoday.com/115241/a-new-look-at-dark-matter-is-the-milky-way-less-of-a-behemoth-than-previously-thought/

https://inspirehep.net/record/805890/plots

NGC 6503 Rotation Curve

http://file.scirp.org/Html/7-7500789_23061.htm#Figure_1

Bullet cluster

http://hubblesite.org/newscenter/archive/releases/2006/39/

http://chandra.harvard.edu/photo/2006/1e0657/more.html#1e0657_lens_ill

Chandra Bullet Cluster images

http://chandra.harvard.edu/photo/2006/1e0657/animations.html#1e0657_bullett_anim

Supernova - Refsdal

http://www.spacetelescope.org/images/heic1525a/

http://www.spacetelescope.org/news/heic1505/

http://frontierfields.org/2014/02/25/meet-the-frontier-fields-macs-j1149-52223/

Nature of Dark Matter

http://pages.uoregon.edu/jimbrau/astr123/Notes/Chapter23.html

http://spacetelescope.org/images/heic0701a/

http://www.spacetelescope.org/news/heic1506/

https://www.youtube.com/watch?v=PznhzHOtr_Y

Dark Matter distribution

http://chandra.harvard.edu/press/12_releases/press_092412.html

CERN

http://home.cern/about/updates/2015/11/lhc-collides-ions-new-record-energy

LHC collides ions at new record energy

http://home.cern/about/physics/dark-matter

Neutrinos

http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html

Music

Tchaikovsky - Sleeping Beauty Waltz

Liszt - Love Dream No 3 , Liebestraum

Grieg - Peer Gynt - Death of Aase

Mendelssohn - Symphony No 3 Scottish IV Adagio

Ravel - Pavane pour une infante défunte