2016 update

Introduction

2016 was another very good year for the expansion of our knowledge of the Universe.

Inside the Solar System we have:

- A solar flare
- Mars at opposition
- Juno reached Jupiter
- Rosetta ended

In the Milky Way we have:

- Major data from Gaia
- Updates on several nebula and star clusters
- A close look of the Crab Nebula pulsar
- The discovery of a new Magnetar

We'll go into what a magnetar is which will also lead us into a deep dive on how we used radio astronomy to piece together our galaxy's rotation curve.

Beyond the galaxy, we have some beautiful photographs of:

- Nebula inside orbiting galaxies
- The discovery of Eta Carina twins
- A skyrocket galaxy
- A report from a Great Observatories Survey that has changed the number of galaxies we believe exist in the Universe.

We'll end with a look at the Palomar Observatory and its new Zwicky Transit Facility that can cover the whole sky in 8 hours; compare one day to the next; and report differences of any kind. It's great for finding things like distance supernova to nearby asteroids.

We'll start with the Solar System and its center, the Sun.

Solar System **[Music: Tchaikovsky – String Quartet Andante cantabile]**

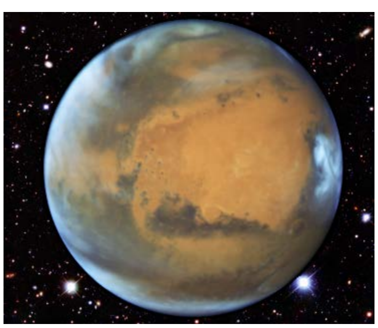
Solar Flare

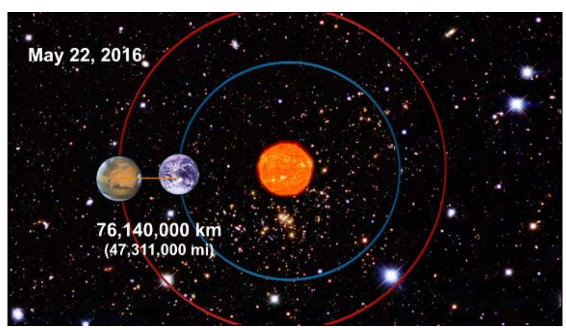
On April 17, 2016, an active region on the sun's right side released a mid-level solar flare, captured here by NASA's Solar Dynamics Observatory. The solar flare caused moderate radio blackouts. This video was captured in several wavelengths of extreme ultraviolet light and color-coded for easy viewing.

Mars in Opposition

On May 12, 2016, the Hubble Space Telescope captured this striking image of Mars. The planet was 80.5 million km (50 million miles) from Earth. **[**The photo reveals details as small as 30 to 50 km across (20 miles to 30 miles across). The large, dark region at far right is Syrtis Major Planitia, one of the first features identified on the surface of the planet by seventeenth century observers. Christiaan Huygens used this feature to measure the rotation rate of Mars. He found that a Martian day is about 24 hours and 37 minutes. Today we know that Syrtis Major is an ancient, inactive shield volcano. Late-afternoon clouds surround its summit in this view.**]**

This observation was made just a few days before Mars opposition on May 22, when the sun and Mars were on exact opposite sides of the Earth. This phenomenon is a result of the difference in orbital periods between Earth's and Mars' orbit. While Earth takes 365 days to travel once around the sun, Mars takes 687. As a result, Earth makes almost two full orbits in the time it takes Mars to make just one, resulting in a Martian opposition about every 26 months.





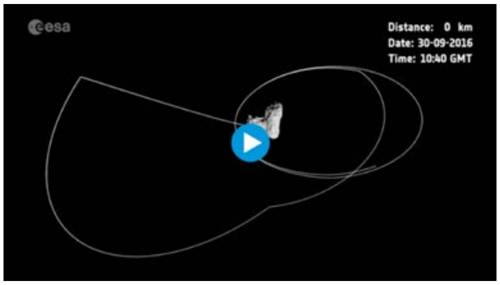
Jupiter - Juno Arrives

NASA's Juno spacecraft arrived at Jupiter on July 4 after a five-year journey. On Aug 27, it successfully completed the first, and closest of 36 planned orbital flybys. The spacecraft flu over the tops of Jupiter's clouds at a distance of just 4,200 kilometers (2,600 miles). This photograph is the first flyby data to be released. It was taken from a distance of 703,000 kilometers (437,000 miles).

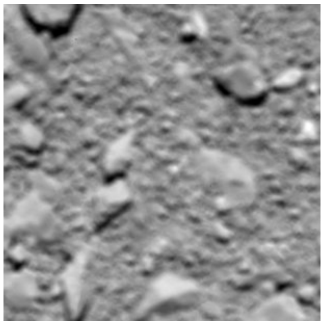
Juno is experiencing some propulsion and electronic difficulties. Hopefully, it will be fixed and continue to collect data on Jupiter's atmosphere, weather, magnetic fields and formation history until 2018. Then, the spacecraft is scheduled to plunge into Jupiter's atmosphere, taking measurements all the way in till it is crushed or burns up.

Rosetta Mission's End

The European Space Agency's historic Rosetta mission to the Comet 67P has concluded with a controlled impact onto the comet. The decision to end the mission was based on the inevitable: the Rosetta spacecraft was running out of power. Here's the collision course into the comet from an altitude of around 19 km.



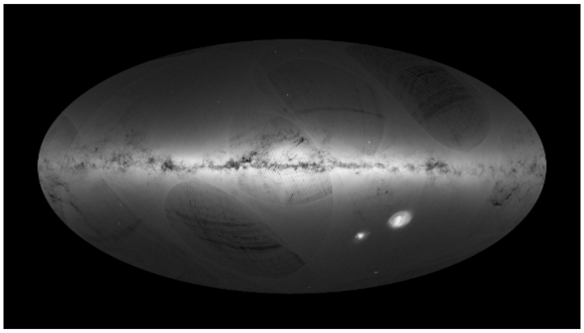
Rosetta targeted a region on the small lobe of the comet, close to a region of active pits. Pits are of particular interest because they play an important role in a comet’s activity. Transmissions continued up to the moment of impact. The comet is now beyond the orbit of Jupiter and heading for the Kuiper Belt. It will return with Rosetta’s wreckage on board in 2021.



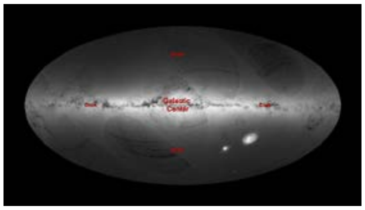
Milky Way

Gaia

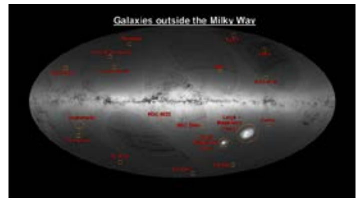
Moving out to the Milky Way, we have an update on Gaia, the spacecraft that’s recording information on over a billion stars. In 2016, Gaia produced the most detailed 3D map ever made of our Milky Way galaxy. It has pinned down the brightness and precise position on the sky of 1 billion, 142 million stars. This past year’s data release also includes the distances and the motions across the sky for more than two million stars. This map shows the density of stars observed by Gaia in each portion of the sky. Brighter regions indicate denser concentrations of stars, while darker regions correspond to patches of the sky where fewer stars are observed. The dark lines are artifacts of the collection process. They will disappear once more data has been collected.



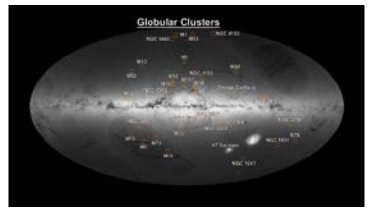
The image clearly shows the structure of our galaxy with its core, disk and halo. Darker regions across the Galactic Plane correspond to dense clouds of interstellar gas and dust that absorb starlight along the line of sight.



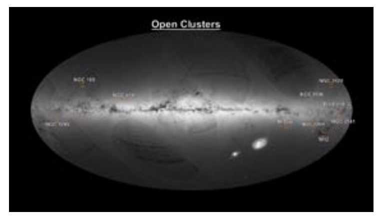
As Gaia rotates and captures the light from stars around us, it also see orbiting and local group galaxies. Several are visible in this image.



You may remember from our "How far away is it" segment on globular clusters that they are the backbone of our galaxy. A significant number of them are visible here. You can see them spread throughout the central part of the halo.



Open clusters are also visible. Not how they tend to occupy volumes closer to the galactic plane and are further out from the core than the globular clusters.



Trumpler 14 – 8,000 ly

Let's take a look at some of the Milky Way objects photographed by Hubble this past year. This image from Hubble shows a glittering open star cluster that contains a collection of some of the brightest stars seen in our Milky Way galaxy. Called Trumpler 14, it is located 8,000 light-years away in the Carina Nebula.

Because the cluster is only 500,000 years old, it has one of the highest concentrations of massive, luminous stars in the entire Milky Way. These blue-white stars are burning their hydrogen fuel so ferociously that they will explode as supernovae in just a few million years. The combination of outflowing stellar "winds" and, ultimately, supernova blast waves will carve out cavities in nearby clouds of gas and dust. These fireworks will kick-start the beginning of a new generation of stars in an ongoing cycle of star birth and death. **[**The small, dark knot left of center is a nodule of gas laced with dust, and seen in silhouette.**]**

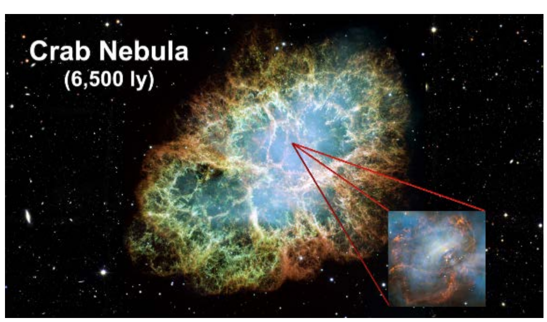
Bubble Nebula – 7,100 ly

Here is a 2016 photograph of the Bubble Nebula [NGC 7635]. It's a balloon-like bubble, 7 light-years across, being blown into space by a super-hot, massive star. The high-energy light is from the star BD +60°2522, an extremely bright, massive, and short-lived star that has lost most of its outer hydrogen and is now fusing helium into heavier elements. The star is about four million years old, and in 10 to 20 million years, it will likely detonate as a supernova. It is responsible for ionizing the entire region.

In this clip, a virtual camera flies through the foreground stars and approaches the central bubble imaged by Hubble. The three-dimensional perspective emphasizes the extended nature of the structure and the fact that the star is not located at the center. The computer model incorporates both scientific and artistic interpretation of the data. In particular, distances are significantly compressed.

Crab Nebula Pulsar PSR B0531+21 – 6,500 ly

At the center of the Crab Nebula, a pulsar blasts out pulses of radiation 30 times a second.



This Hubble image captures the region around the pulsar. It is centered on the region around the neutron star [the rightmost of the two bright stars near the center of this image] and the expanding filamentary debris surrounding it. Inside this shell is a blue glow that is radiation given off by electrons spiraling at nearly the speed of light in the powerful magnetic field around the pulsar. Bright wisps are moving outward from the star at half the speed of light to form an expanding ring. It is thought that these wisps originate from a shock wave that turns the high-speed wind from the pulsar into extremely energetic particles.

Terzan 5 – 19,000 ly

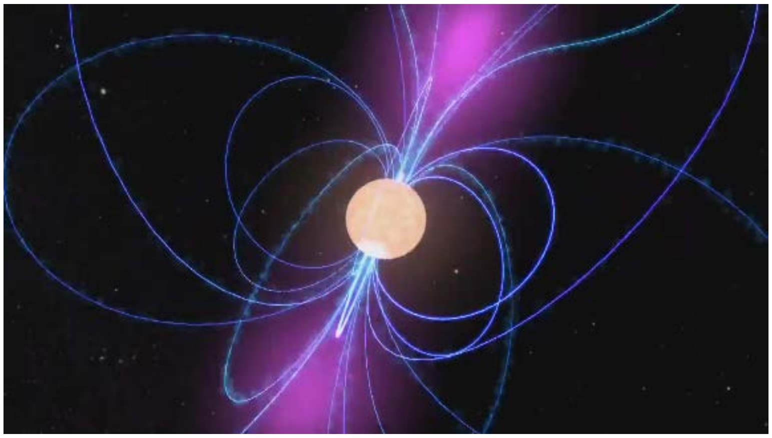
This stellar system resembles a globular cluster, but it's like no other cluster known. A team of astronomers found that there are two distinct kinds of stars in Terzan 5 which not only differ in the elements they contain, but also have an age-gap of roughly 7 billion years. The ages of the two populations indicate that the star formation process in Terzan 5 was not continuous, but was dominated by two distinct bursts of star formation. While the properties of Terzan 5 are uncommon for a globular cluster, they are very similar to the stellar populations which can be found in the galactic bulge. These similarities lead us to believe that Terzan 5 is relic of galaxy formation, representing one of the earliest building blocks of the Milky Way.

Milky Way Core – 26,000 ly

Zooming into the center of our galaxy, Hubble reveals a rich tapestry of more than half a million stars in core's nuclear star cluster. This is the most massive and densest star cluster in our galaxy. Astronomers estimate that about 10 million stars in this cluster are too faint to be captured in the image. The distance between stars in this region is around ½ of a light year.

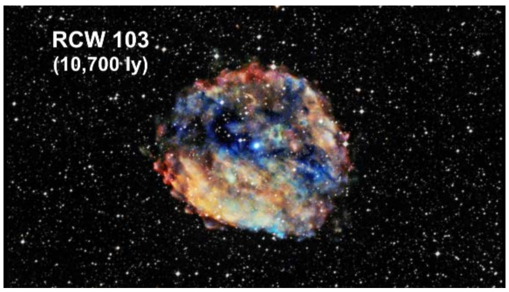
<u>Magnetars</u> **[Music: Gounod - Faust - Ballet Music II Adagio]**

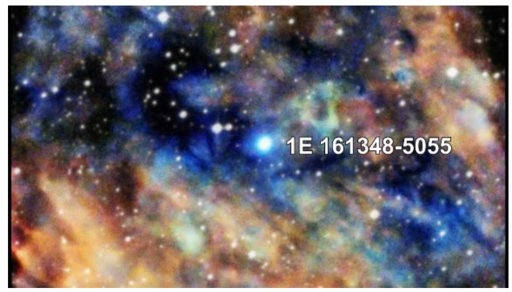
Our last inside the Milky Way object is a magnetar. A magnetar is a spinning neutron star with an intense magnetic field. Magnetic field strength is measured in units called gauss. A refrigerator magnet is around 50 gauss. MRI's use up to 70,000 gauss. A magnetar's field strength is a thousand trillion gauss – enough to tear atoms apart a 1000 km away. Only around one in ten neutron stars start out as a magnetars. We do not yet know what makes their magnetic fields so strong. But it looks like they don't last long. They settle into normal neutron star status after around 10,000 years.



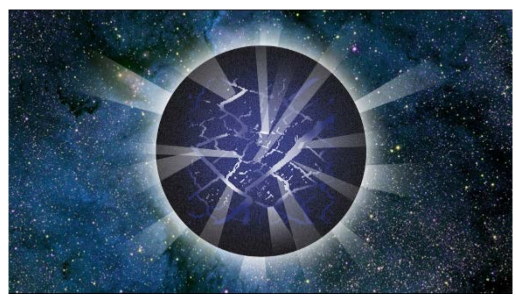
RCW 103 Magnetar – 10,700 ly

On June 22, 2016, an instrument aboard NASA's Swift telescope captured the release of a short burst of X-rays from 1E 1613, a star in the middle of the supernova remnant RCW 103, indicating that it may be a magnetar. Seeking to investigate further, astronomers had the Chandra X-ray Observatory and other telescopes follow up with observations of their own. They confirmed that 1E 1613 has the properties of a magnetar, making it the 30th magnetar ever discovered.





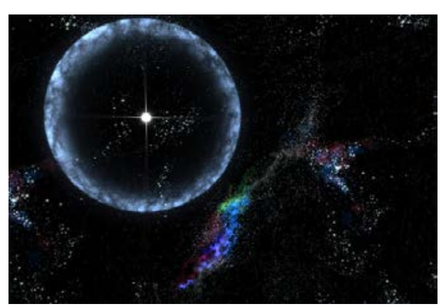
One of the most fascinating aspects of magnetars is how they can have starquakes - earthquakes, but on stars. When neutron stars form, they can have a crust on the outside, surrounding the matter inside. This crust of neutrons can crack, like the tectonic plates on Earth. As this happens, the magnetar releases a blast of radiation like the solar flare we saw earlier, but millions of times stronger.



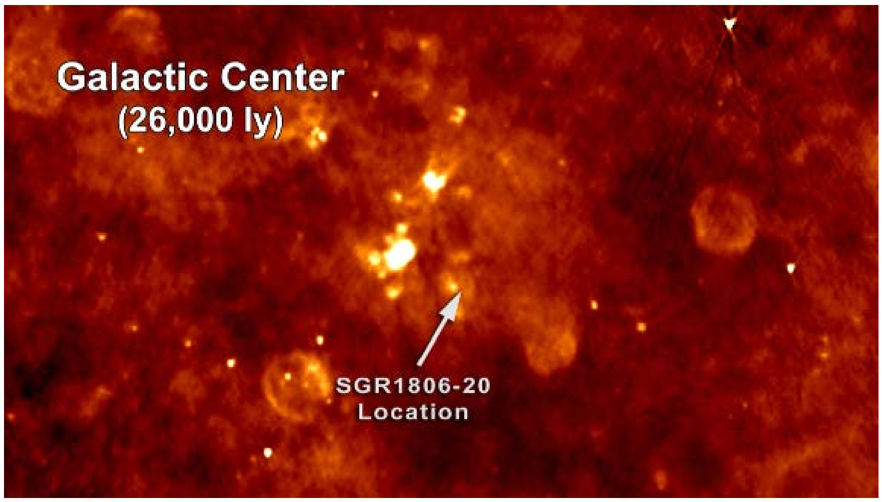
[Additional Info: According to x-ray starquake seismology, the curst is around 1 km thick.**]**

SGR 1806-20 – 50,000 ly

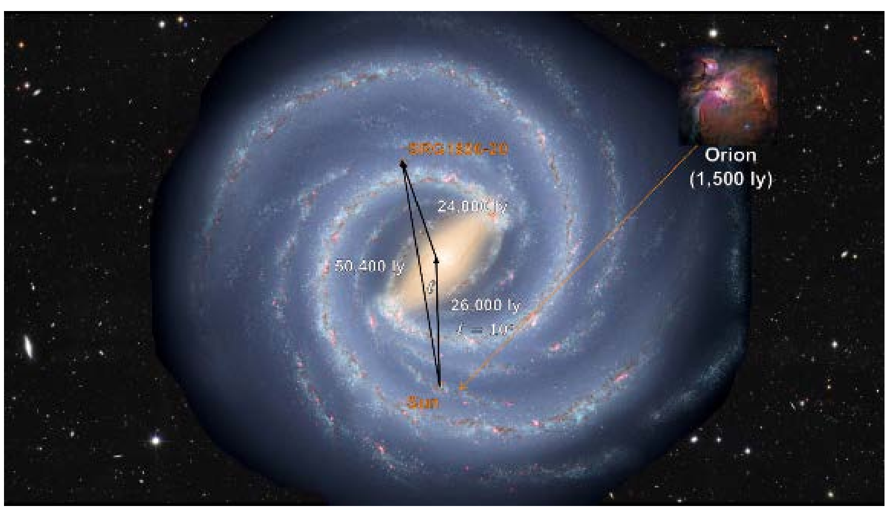
In fact, in 2004, the most powerful starquake ever recorded came from a magnetar called SGR 1806-20. In a tenth of a second, one of these starquakes released more energy than the Sun gives off in 100,000 years. This wasn't a supernova. It was a cm wide crack on the magnetar's surface. The Swift satellite, which was designed and built to detect gamma-ray bursts, not only saw this blast but was so flooded with energy its detectors completely saturated. This enormous wave of energy was so powerful it partially ionized the Earth's upper atmosphere, and it made our magnetic field ring like a bell.



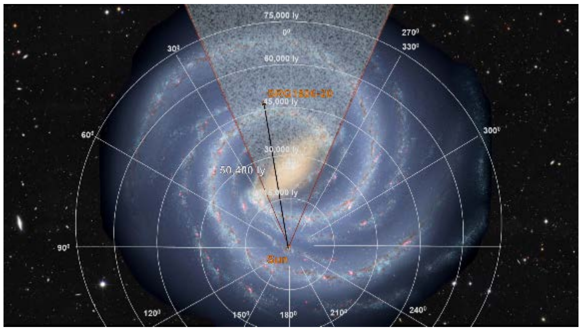
And all of this came from an event on the other side of the galaxy. This is an image of the galactic core. The magnetar is located far behind it and cannot be seen because of the density of stars and dust in the core.



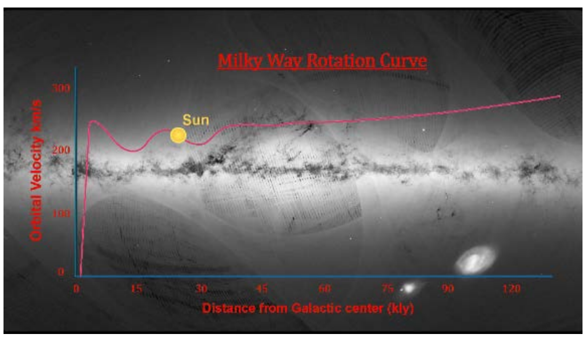
Compare that to the distance to the Orion Molecular Cloud Complex 1,500 light years away. It's a little disturbing to find out that a cm wide crack in a magnetar's crust can impact our atmosphere from so far away.



Milky Way Rotation Curves **[Music: Schubert - Symphony No 6 - The Little]**



To understand how we calculate that the magnetar SGR 1806-20 is 45,000 light years away, deep inside the 'hidden zone',



we need to take a look at how kinematic distance calculations and radio astronomy were used to develop the Milky Way Rotation Curve that we discussed in our 2015 update on Dark Matter.

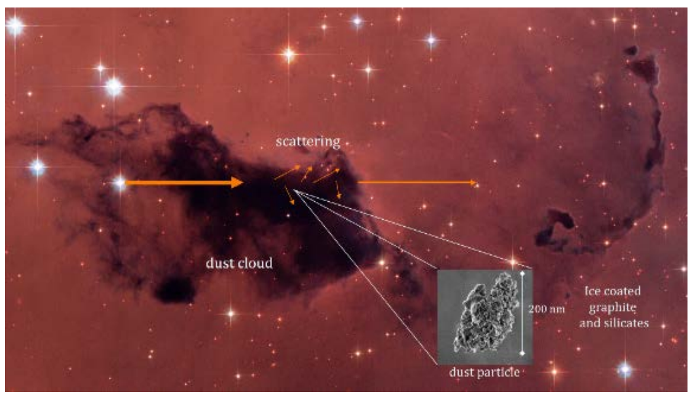
The best way to map out the rotation curve for the galaxy's disk is to measure the orbital velocities and distances of gas clouds and star forming regions across the galaxy. These are the HI, HII, and molecular clouds we covered in our segment on "Star Birth Nebula". These are the best objects to analyze for three reasons:

1) They trace out the spiral arms like we see here with Andromeda;
2) We can see them clearly at great distances using radio astronomy; and
3) There is a good way to calculate their distance for the inner part of the galaxy.

Spitzer image at 24-microns shows how gas and dust clouds trace Andromeda's spiral arms

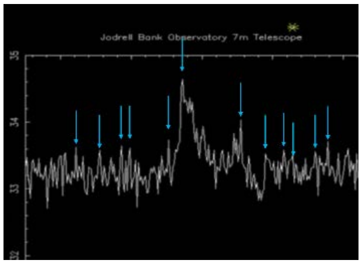
We need radio astronomy because stars are not good candidates for building a galaxy wide map. This is because we cannot see stars in the plane of the galaxy's disk beyond 6000 light years due to the dust in the interstellar medium. The dust absorbs and scatters the light that passes through it. The further the light has to travel, the more of this dust it encounters, and the dimmer it gets. This is called extinction.

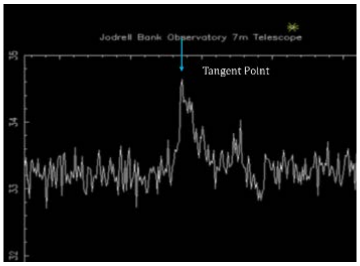
[Additional info: The dust is made of thin, highly flattened flakes of graphite and silicate (that's carbon and rock-like minerals) coated with water ice. Each dust flake is roughly the size of the wavelength of blue light or smaller. The dust is probably formed in the cool outer layers of red giant stars and dispersed in the red giant winds and planetary nebulae. It wasn't until we could measure the amount of dust between us and the stars that we could accurately use standard candles to determine how far away they were. It was the astronomer Robert Trumpler who first quantified this phenomenon in the 1930s.**]**



But gas clouds radiate radio waves. And radio waves pass through dust particles untouched because their wavelength is much larger than the size of these particles. We can see these clouds all across the galaxy, including the hidden area behind the central bulge. What's more, the hydrogen in these regions emit a spectral line in the radio frequency band. And this spectral line exhibits Doppler shifts enabling us to measure the cloud's radial velocity relative to us.

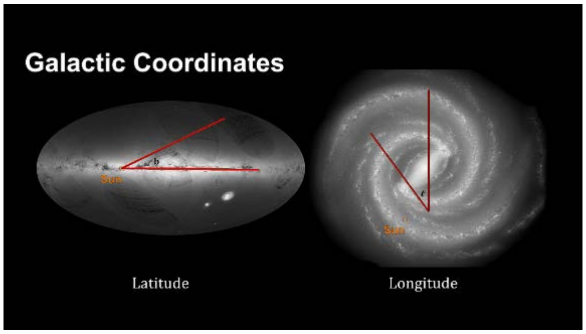
In this line of sight reading, we see a number of peaks. Each one represents a cloud. The peaks have different frequencies because the clouds have different radial velocities. The maximum peak is from a cloud that's radial velocity is close to its total orbital velocity. **[Additional info:** In particular, in HI regions, neutral hydrogen has one at 21 cm from neutral hydrogen, and in HII regions, carbon monoxide has one at 2.6 and 1.3 mm.**]**





Kinematic Distance

We can use the Doppler shift of dust clouds to find the kinematic distance to the object and calculate how fast it is rotating around the center of the galaxy. Kinematic distance is the distance to an object based on its motion. When analyzing motion, we always start with a coordinate system. For the galaxy, we measure latitude as the angel up or down from the galactic plane, and we measure longitude as the horizontal angle from the line connecting us to the galactic center.



[Additional Info: Motion around the galactic center is generally circular, but all stars, including our own, have orbits that are perturbed by the presence of other stars. To calculate a baseline motion we use a Local Standard of Rest (LSR) based on the average motion of all the stars in our vicinity. It is currently set at 220 km/s (V_0) at 26,100 ly (R_0) from the center. In addition, based on several Palomar Observatory Sky Surveys, we are 65.2 light years above the galactic plane.**]**

In order to convert this radial velocity information into rotational velocity and distance from the center of the galaxy, we use a technique called the Tangent Point Method. First, we take a line of sight look for clouds. Having found one, we adjust the longitude to get the maximum radial velocity based on the Doppler shift. This will mark the clouds closet approach to the center. At this tangent point, a line to the center will be perpendicular to the line of sight. Here, the radial velocity of the cloud will be equal to its rotational velocity around the center of the galaxy. We can calculate its distance from the center and its distance from us with a little trigonometry.

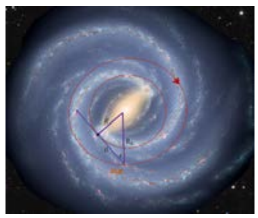
Kinimatic Distance

$R = R_0 \boldsymbol{sin}(\ell)$

$d = R_0 \boldsymbol{cos}(\ell)$

Where

R = object's distance to center
R_0 = Sun's distance to center
d = distance to the object
ℓ = galactic longitudinal angle

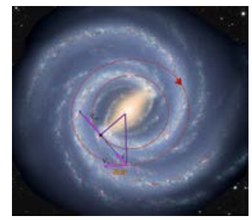


Kinimatic Distance

$V_r = V_m + V_s \boldsymbol{sin}(\ell)$

Where

V_r = rotaional velocity of object
V_m = measured radial velocity of object
V_s = rotaional velocity of the Sun
ℓ = galactic longitudinal angle



So for clouds closer to the center than we are, we can scan the sky, bit by bit and create a map of the rotation velocity and distance for the inner galaxy. This map can then be used to find distances to all the clouds and the stars they contain as long as they are closer to the center of the galaxy than we are.

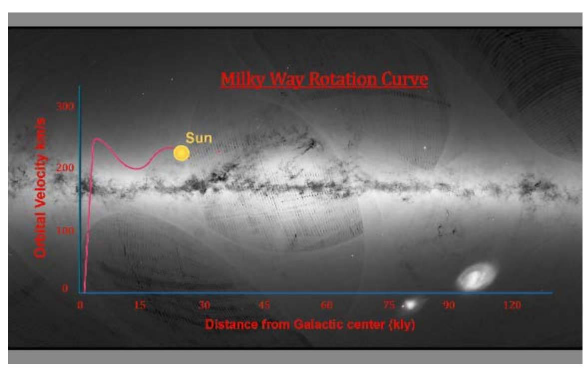
[Additional Info: In the inner Galaxy ($r < R_0$), this orbital radius corresponds to two distances from us along the line of sight called the near and the far kinematic distances, located on either side of the tangent point. This ambiguity can be resolved in several ways including the width of the 21 cm line. Dust in the interstellar medium widens the line. The more dust traversed, the wider the line. This can then be used to choose the near distance (if it's narrow) or far distance (if it's wide).**]**

$R = R_0 \boldsymbol{sin}(\ell) V(r) / (V_m + V_s \boldsymbol{sin}(\ell))$

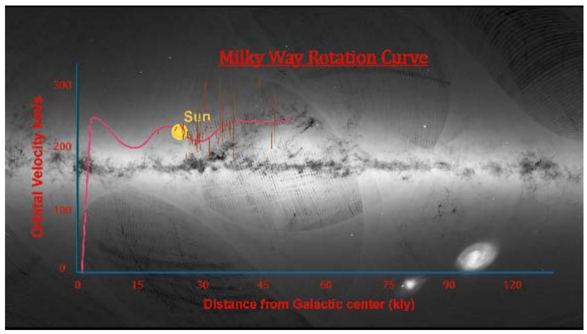
$d = R_0 \boldsymbol{cos}(\ell) \pm (R^2 - R_0^2 \boldsymbol{sin}^2(\ell))^{1/2}$

Where

R = *object's distance to center*
d = *our distance to the object*
R_0 = *Sun's distance to center* = 26,100 ly
V_m = *measured radial velocity of the object*
V_s = *rotational velocity of the Sun* = 220 km/s
$V(r)$ = *galaxy rotation curve velocity*
ℓ = *galactic longitude*



For clouds further out from the center of the galaxy than we are, there are no tangent points. For these, we have to use weaker methods for determining distance and rotational velocity. We then do a best fit line from the collected data. Here is a graphic superimposed on our galaxy curve that indicates the accuracy of methods used to provide the included data points. The vertical lines through each point represent the range of possible velocities for any given distance. Notice that these lines are quite long once we are dealing with distances beyond 1 astronomical unit.



[Reproduced from Clemens (1985), Ap. J. 295, 422.]

For magnetar SGR1806-20, a number of astronomers have connected it to the giant molecular cloud Westerhout 31. Its longitude is 10^0. Using the rotation curve, it is estimated to be around 45,000 light years away – give or take 5 thousand light years.

$$R = R_0 \sin(\ell) V(r) / (V_m + V_s \sin(\ell)) = 17{,}100 \text{ ly}$$

$$d = R_0 \cos(\ell) \pm (R^2 - R_0^2 \sin^2(\ell))^{1/2} = 45{,}682 \text{ ly}$$

Where

R = *object's distance to center*

d = *our distance to the object*

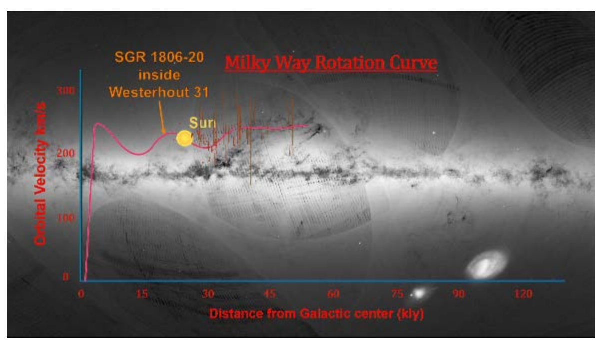
R_0 = *Sun's distance to center* = 26,100 ly

V_m = *measured radial velocity of the object* = 20 km/s

V_s = *rotational velocity of the Sun* = 220 km/s

$V(r)$ = *galaxy rotation curve velocity* = 220 km/s

ℓ = *galactic longitude* = 10°



Galaxies **[Music: Puccini - Tosca - Recondita armonia - concealed harmony]**

NGC 248 – 200,000 ly
Hubble captured two nebulas inside the Small Magellanic Cloud, situated so as to appear as one. Intense radiation from the brilliant central stars is heating hydrogen in each of the nebulas, causing them to glow red.

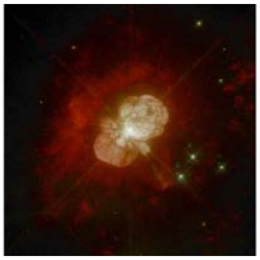
This is part of a study to understand how interstellar dust is different in galaxies that have a far lower supply of heavy elements. The Small Magellanic Cloud has between a fifth and a tenth of the amount of heavy elements that the Milky Way does. Because it is so close, astronomers can study its dust in great detail, and learn about what dust was like earlier in the universes' history.

R136 – 170,000 ly

Astronomers using the unique ultraviolet capabilities of the Hubble Space Telescope have identified nine monster stars with masses over 100 times the mass of the Sun in the star cluster R136. This makes it the largest sample of very massive stars identified to date. The detected stars are not only extremely massive, but also extremely bright. Together these nine stars outshine the Sun by a factor of 30 million.

Eta Carinae Twins

Eta Carinae, the most luminous stellar system ever seen, is best known for an enormous eruption in the mid-19th century that hurled an amount of material at least 10 times the sun's mass into space. Still shrouded by this expanding veil of gas and dust, Eta Carinae is the only object of its kind known in our galaxy.

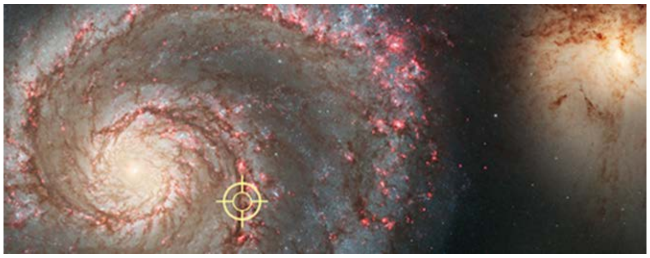


[Additional info: Astronomers estimate that the more massive star has about 90 times the sun's mass, while the smaller companion may exceed 30 solar masses. Stars as massive as this one are always rare, but they have tremendous impact on the chemical and physical evolution of their host galaxy. These stars produce and distribute large amounts of the chemical elements vital to life and eventually spread them into their surroundings when they explode as supernovae.**]**

Here's a small portion of the rough-and-tumble neighborhood of swirling dust and gas near the star. This close-up view shows only a three light-year-wide portion of the entire Eta Carina Nebula, which has a diameter of over 200 light-years. Dramatic dark dust knots and complex structures are sculpted by the high-velocity stellar winds and high-energy radiation from the ultra-luminous variable Eta Carinae. **[Additional info:** This image shows a region in the Carina Nebula between two large clusters of some of the most massive and hottest known stars. The filamentary structure is caused by turbulence in the circumstellar gas, which in turn was caused by several stars shedding their outer layers. Cold gas mixes with hot gas, leaving a veil of denser, opaque material in the foreground. The chemical elements in the surroundings create a potential reservoir for new star formation. Areas in the brightest parts of the image at the top show elephant-trunk shaped dust clouds that may form into embryonic solar systems.**]**

Galaxy surveys have not found any Eta twins, underscoring its rarity. But, in a 2015 survey released in 2016, five potential Eta twins were found 4 Virgo Supercluster galaxies. This is one of them. These five objects mimic the optical and infrared properties of Eta Carinae, indicating that each very likely contains a high-mass star buried in five to 10 solar masses of gas and dust. Further study will let astronomers more precisely determine their physical properties.

[M51 – 23 mly]



Kiso 5639 - 82 mly

A firestorm of star birth is lighting up one end of this dwarf galaxy Kiso 5639. The galaxy is shaped like a flattened pancake, but because it is tilted edge-on to our view, it resembles a skyrocket, with a brilliant blazing head and a long, star-studded tail. Kiso 5639 is a rare, nearby example of elongated galaxies that occur in abundance at larger distances, where we observe the universe during its earlier epochs. Observations of the early universe, such as Hubble's Ultra Deep Field, reveal that about 10 percent of all galaxies have these elongated shapes, and are collectively called "tadpoles." But studies of the nearby universe have turned up only a few of these unusual galaxies, including this one. **[Additional info:** Hubble uncovered several dozen clusters of stars in the galaxy's star-forming head, which spans 2,700 light-years across.

These clusters have an average age of less than 1 million years. Star clusters in the rest of the galaxy are between several million to a few billion years old. Giant holes are peppered throughout the galaxy's starburst head. These cavities are due to numerous supernova detonations that have carved out cavities of rarified superheated gas.**]**

NGC 4696 – 150 mly **[Music: Grieg - Piano Concerto, Op 16 II Adagio]**

New observations from Hubble have revealed the intricate structure of the galaxy NGC 4696 in greater detail than ever before. Astronomers have found that each of the dusty filaments has a width of about 200 light-years, and a density some 10 times greater than the surrounding gas. These filaments knit together and spiral inwards towards the centers supermassive black hole that's flooding the galaxy's inner regions with energy, heating the gas, and creating streams of heated material. It appears that these hot streams of gas bubble outwards, dragging the filamentary material with them as they go. The galaxy's magnetic field is also swept out with this bubbling motion, constraining and sculpting the material within the filaments.

[Additional info: Understanding more about filamentary galaxies such as NGC 4696 may help us to better understand why so many massive galaxies near to us in the Universe appear to be dead; rather than forming newborn stars from their vast reserves of gas and dust, they instead sit quietly, and are mostly populated with old and aging stars. This is the case with NGC 4696. It may be that the magnetic structure flowing throughout the galaxy stops the gas from creating new stars.**]**

Deep Sky Census

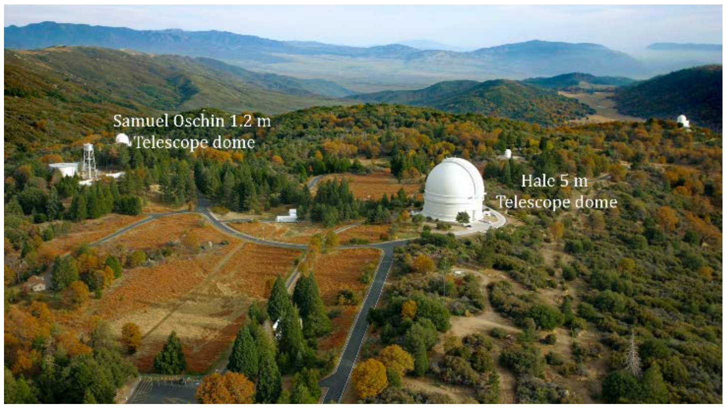
This Hubble Space Telescope view reveals thousands of galaxies stretching back into time across billions of light-years of space. The image covers a small portion of a large galaxy census called the Great Observatories Origins Deep Survey (GOODS), and it sheds light on just how many galaxies there are in the Universe. You may recall that the Hubble Deep Field and Ultra Deep Field views provided an estimate of 200 billion.

But recent studies by the GOODS team found that, in order for the small size of the older galaxies to add up to the mass of the larger galaxies in existence today, there must have been an additional one trillion 800 billion of them in the early Universe.

Unfortunately, the vast majority of these are too faint and too far away to be seen with present-day telescopes. But the James Webb Space Telescope, due for launch in 2018, should be able to see them.

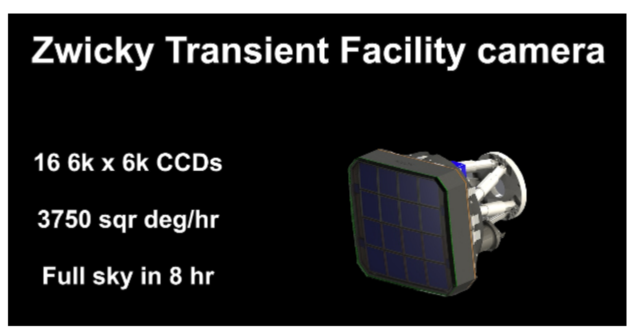
Palomar

Our final piece for 2016 is on the Palomar Observatory in Southern California, operated by Caltech. I had the opportunity to visit the observatory this past summer.

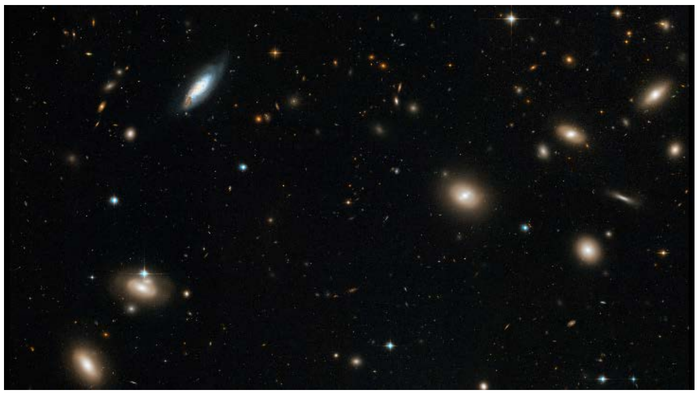


Palomar is playing a significant role in modern 'time domain astronomy' that studies how astronomical objects change with time – including everything from distant supernova to nearby asteroids. A transient facility is a complex combination of telescopes, fast wide angle cameras, and rapid computer based spectrographic analysis for detecting and communicating these changes. The Palomar Transient Factory attached to the Samuel Oschin telescope has been doing this for years – producing millions of publicly available images.

Now, a new facility named the Zwicky Transient Facility will see first light here in 2017. Its new camera will be able to examine nearly the entire sky in 8 hours. Its enormous 47 degree footprint, makes it one of the most efficient cameras ever developed for mapping the sky.



The facility was named after the famous astronomer Fritz Zwicky who, you may recall from our 2015 update, was the first to discover Dark Matter. In the 1930s, he persuaded Caltech to build a telescope at Palomar that could capture large numbers of galaxies in a single wide-angle photograph. They did, and that's what he used to study the Coma Cluster where he found the first evidence for Dark Matter.



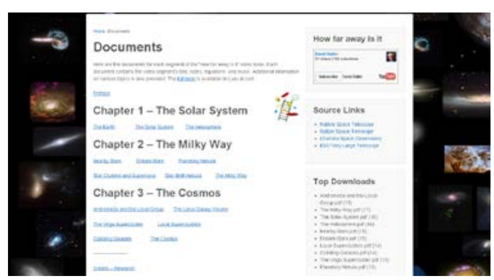
We'll check back in on his namesake's successes in our 2017 update.

Credits

Here are the links to Hubble and other locations where I found the information contained in this 2016 update. These are the places where you can go to learn more.

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

Thank you for watching.



Solar Flare

http://svs.gsfc.nasa.gov/12224

Mars

http://hubblesite.org/news_release/news/2016-15
https://www.youtube.com/watch?v=NXbCNAIIAxw

Jupiter

https://www.youtube.com/channel/UC-9b7aDP6ZN0coj9-xFnrtw
http://www.space.com/33883-juno-makes-closest-jupiter-flyby.html
https://www.youtube.com/watch?v=oi0bWpOeD54
https://www.youtube.com/watch?v=XpsQimYhNkA
http://hubblesite.org/news_release/news/2016-33

Rosetta

http://www.esa.int/Our_Activities/Space_Science/Rosetta/Mission_complete_Rosetta_s_journey_ends_in_daring_descent_to_comet

Gaia

http://sci.esa.int/gaia/58135-gaia-s-second-anniversary-marked-by-successes-and-challenges/

Trumpler 14

http://hubblesite.org/image/3693/news_release/2016-03

Bubble Nebula

http://hubblesite.org/news_release/news/2016-13

Crab Nebula Neutron Star

http://hubblesite.org/news_release/news/2016-26

Terzan 5

http://www.spacetelescope.org/news/heic1617/?lang

Milky Way Core

http://hubblesite.org/news_release/news/2016-11

Magnetars

http://phys.org/news/2016-08-magnetars.html
http://phys.org/news/2016-08-magnetars.html#jCp
https://www.eso.org/public/images/potw1341a/
https://www.youtube.com/watch?v=-q6QNDNDyhU
http://chandra.harvard.edu/photo/2016/rcw103/
http://www.slate.com/blogs/bad_astronomy/2012/12/27/cosmic_blast_magnetar_explosion_rocked_earth_on_december_27_2004.html
http://www.space.com/30263-paul-sutter-on-why-magnetars-are-scary.html
http://www.bu.edu/galacticring/kolpak_2003.pdf
http://iopscience.iop.org/article/10.1086/303807/fulltext/33968.text.html
http://galaxymap.org/drupal/node/170
http://iopscience.iop.org/article/10.1088/0004-637X/785/1/63
https://arxiv.org/pdf/0905.0723v1.pdf
https://arxiv.org/pdf/astro-ph/0503171.pdf
http://www.redorbit.com/news/space/483130/nasa_sees_hidden_structure_of_neutron_star_in_starquake/
https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=10144

Galaxy Rotation Curve

http://www.astronomynotes.com/ismnotes/s2.htm
http://spiff.rit.edu/classes/phys230/lectures/ism_dust/ism_dust.html
http://ircamera.as.arizona.edu/astr_250/Lectures/Lecture_22.htm
http://pasj.asj.or.jp/v65/n6/650118/table3.html#table:01

Radio Astronomy

http://proftimobrien.com/tag/radio-astronomy/

NGC 248

http://hubblesite.org/image/3970/news_release/2016-42

R136

http://www.spacetelescope.org/news/heic1605/?lang

Eta Carinae Twins

http://hubblesite.org/news_release/news/2016-01

Kiso 5639

http://hubblesite.org/news_release/news/2016-23

NGC 4696

http://www.spacetelescope.org/images/heic1621a/

Deep Sky Census

http://hubblesite.org/news_release/news/2016-39

Zwicky Transient Facility

https://imagine.gsfc.nasa.gov/science/objects/xray_transients2.html

https://www.spacetelescope.org/images/opo0904a/

http://www.astro.caltech.edu/ptf/PTFEPO.html

http://www.astro.caltech.edu/palomar/homepage.html

http://skyserver.sdss.org/dr5/en/proj/advanced/skysurveys/poss.asp

Music

Tchaikovsky – String Quartet

Grieg – Piano Concerto Op 16

Schubert – Symphony No 6 – The Little

Puccini – Concealed Harmony – Tosca

Gounod – Ballet Music II - Faust