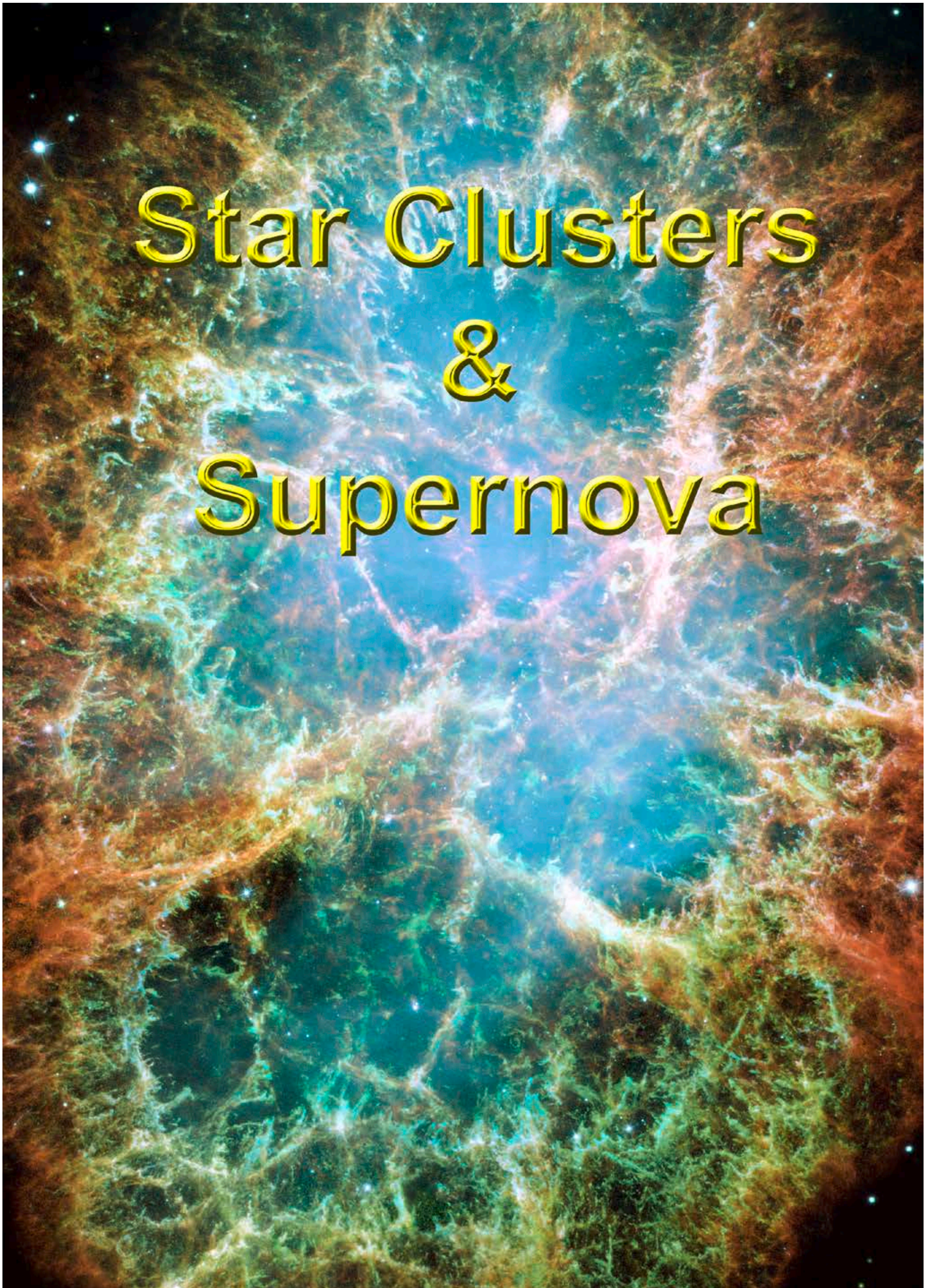

Star Clusters
&
Supernova

Star Clusters and Supernova

{***Abstract*** *– In this segment of our "How far away is it" video book, we cover Supernovae and star clusters.*

As we start Supernovae, we compare the magnitude of the exploding star that created the Helix Planetary Nebula with the explosion that created the Crab Nebula. We take the opportunity to describe the size and densities of White Dwarfs as compared to Neutron Stars. We also take a look at what the daytime sky might look like if Betelgeuse were to supernova.

We then cover the Neutron Star that that a star supernova leaves behind. We take a deep look at the Crab Nebula' Neutron star and cover the full spectrum view of the nebula from radio waves to x-rays. We then take a look at the beautiful Veil Nebula and the Cygnus Loop.

We then explain what a Type 1a Supernova is and how it works as a critically important standard candle. We show a binary star system with matter flowing through the L1 Lagrange point, and mention Subrahmanyan Chandrasekhar's solution to Einstein's equations. We then take a look at the amazing remnants of past supernova explosions scattered across our galaxy including: SN 1006, RCW 86, Tycho Supernova SN 1572, Cassiopeia A with its Light Echoes, RCW 103 with its Magnetar, Kepler's supernova SN 1604, N 63A, and Supernova 1987A. For RCW 103, we illustrate the impact on the Earth if it were Capella that went supernova. We conclude this section on SN with a look at how we find them with transient facilities like the Zwicky Transient Facility at the Palomar Observatory.

We continue on to Star Clusters by pointing out that there are two primary kinds of star clusters: open cluster and globular cluster. We visit some very beautiful open clusters including: the Pleiades, the Jewel Box (NGC 4755), Pismis 24 in NGC 6357, Terzan 5, NGC 6791, and the Quintuplet and Arches clusters. And then we visit some spectacular globular clusters including: 47 Tucanae, Omega Centauri, Terzan 5, M30 and M53.

We conclude by adding brightest globular clusters and Type 1a Supernova as key standard candle rungs on our distance ladder.}

[Music:** Bach, Johann Sebastian: Air 'on the G string'; Academy of St. Martin in the Fields – Sir Neville Marriner, 1974; from the album "The most relaxing classical album in the world…ever!"**]

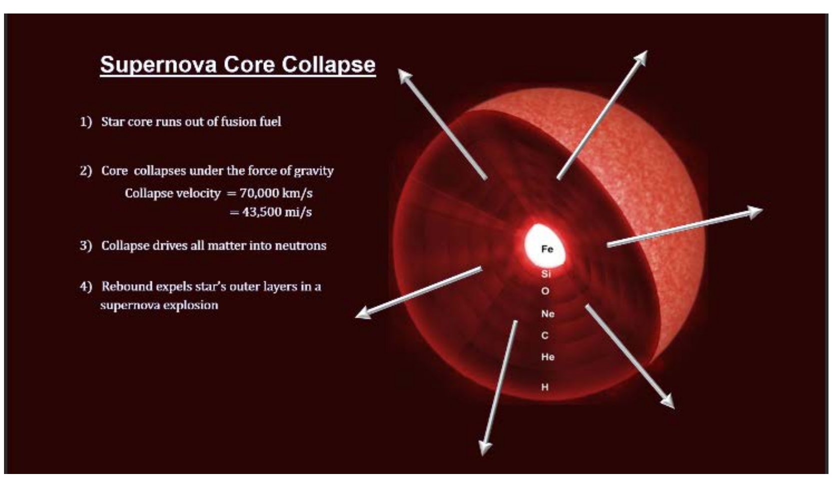
Supernovae

Welcome to our segment on supernovae and star clusters. These are two very important items for our distance ladder, and there're strikingly beautiful. We'll start with supernovae.

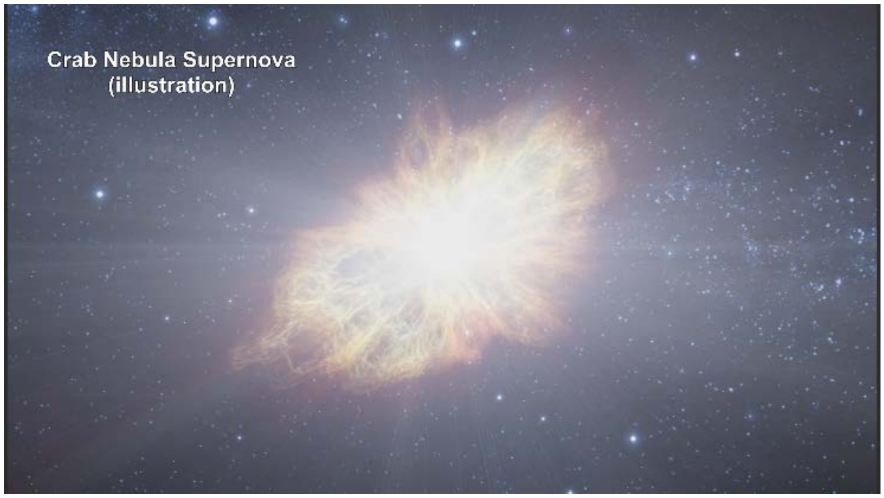
You'll recall that Planetary Nebulae are the result of a star exploding at the end of its life. This is the expected end for the Sun and most stars less than 5 times the mass of the Sun.

The star left behind at the end is called a white dwarf. The typical white dwarf is around the mass of the Sun but packed into a star about the size of the Earth. It's so dense that a spoonful of it would weigh several tons here on Earth.

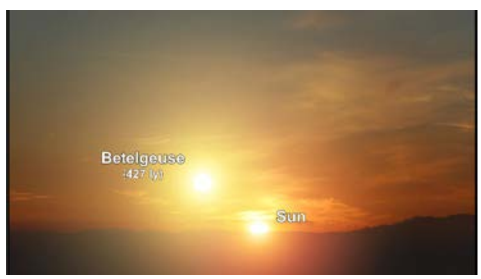
For massive red supergiant stars, a different end is in store. They undergo a core collapse when their nuclear fusion runs out of fuel. At that point, the star can no longer sustain the core's volume against its own gravity. The collapse happens in seconds reaching velocities of 70,000 km/s (that's over 43,000 mi/s). A rebound causes the violent expulsion of the outer layers of the star resulting in a supernova.



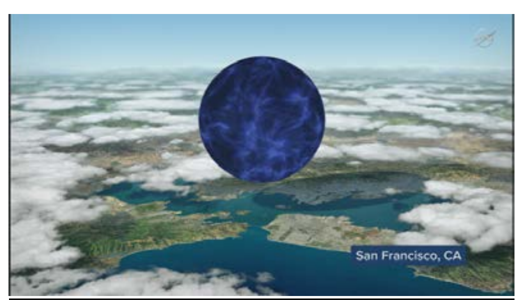
The supernova is billions of times larger than Planetary nebula explosions. A supernova may shine with the brightness of 11 billion suns! The total energy output can be as much as the total output of the sun during its entire 13 billion year lifetime!



Here's what the daytime sky might look like if and when Betelgeuse over 400 light years away supernovas.

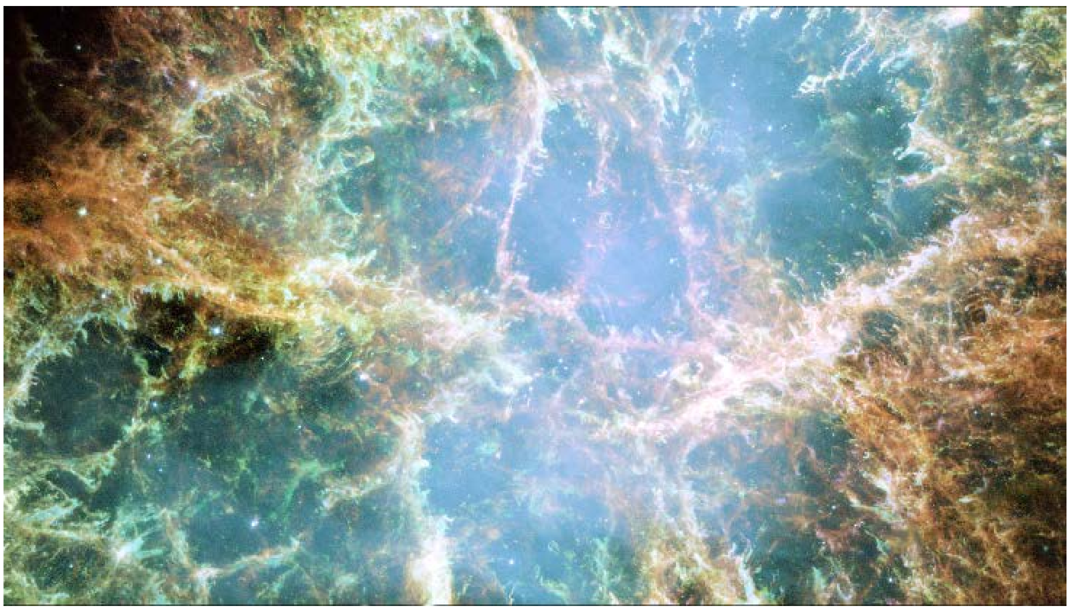


The star left behind at the end is called a neutron star because it is made entirely of neutrons. The typical neutron star is around one and a half times the mass of the Sun but packed into a star with a diameter of around 20 km (that's 12 and a half miles). It's so dense that a spoonful of it would weigh 10 million tons!

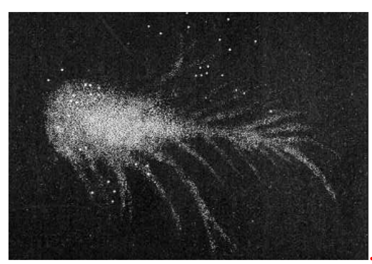


Crab Nebula - 6,500 light-years

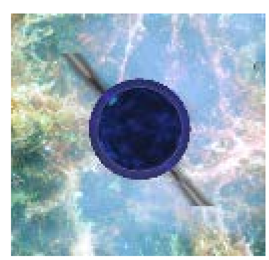
The debris left behind from a supernova is called the Supernova Remnant. These remnants can form spectacular nebulae, millions of times larger than Planetary Nebula. The Crab Nebula is a good example. The remnant is 6 light years wide and expanding at 1,500 km/s (that's 930 mi/s). The orange filaments are the tattered remains of the star and consist mostly of hydrogen.



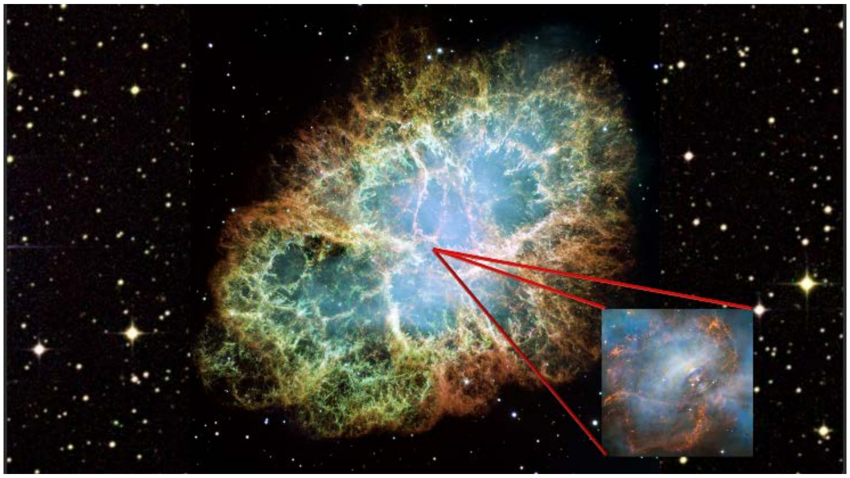
Japanese and Chinese astronomers recorded this event nearly 1,000 years ago in 1054. It got its name because of its appearance in a drawing made by Irish astronomer William Parsons in 1844.



The supernova's remnant neutron star is rotating like a lighthouse. It is ejecting twin beams of radiation that appear to pulse 30 times a second due to the star's extremely fast rotation rate. This kind of neutron star is called a **Pulsar**.



Pulsar PSR B0531+21



This Hubble image captures the region around the pulsar 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.

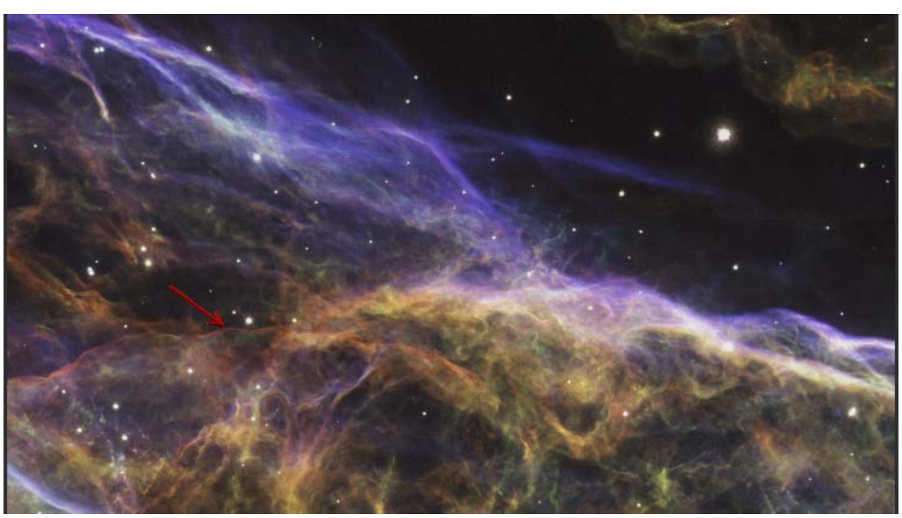
Veil Nebula – 1,500 light years

So let's take a look at some of the fantastic celestial remnants of stars destroyed by supernovae explosions photographed by the Hubble Space Telescope.

This Veil Nebula is the shattered remains of a supernova that exploded some 5-10,000 years ago. We are zooming into sections of the Veil Nebula photographed by Hubble in 1997. This series of images provides beautifully detailed views of the delicate, wispy structure resulting from this cosmic explosion.

In 2015, Hubble took another look. Overlaying new images with the 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.

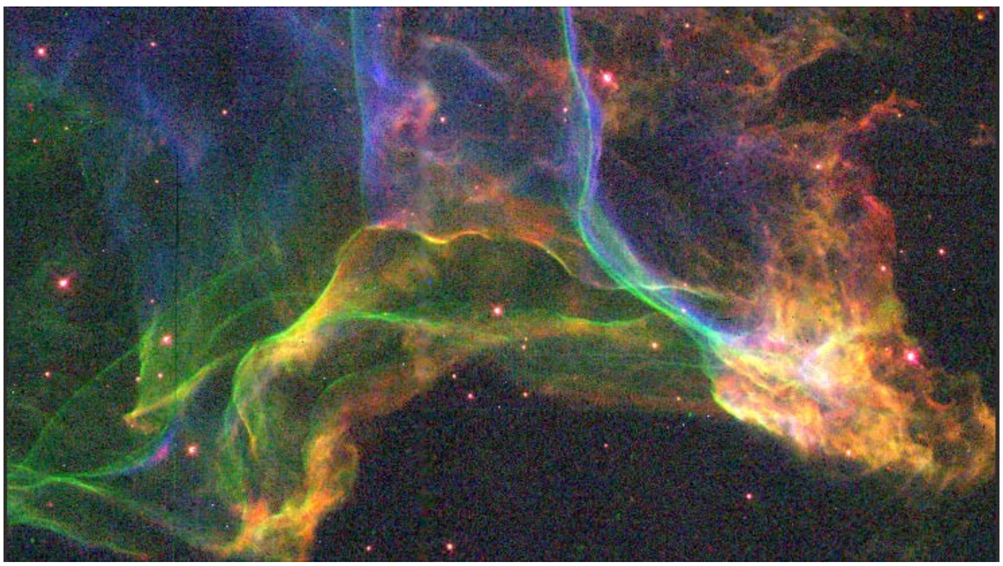
[In this image, one such filament can be seen as it meanders through the middle of the brighter features that dominate the image. The red color arises after gas is swept into the shock wave — which is moving at almost 1.5 million kilometers per hour! — and the hydrogen within the gas is excited by particle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



<u>Cygnus Loop</u> – 2,500 light years

The Veil Nebula is part of a larger nebula known as the Cygnus Loop. The Cygnus Loop marks the edge of a bubble-like, expanding blast wave from a colossal stellar explosion which occurred about 15,000 years ago. This image shows a small portion of this nebula.

[Additional info: In this image the supernova blast wave, which is moving from left to right across the field of view, has recently hit a cloud of denser than average interstellar gas. This collision drives shock waves into the cloud that heats interstellar gas, causing it to glow.**]**



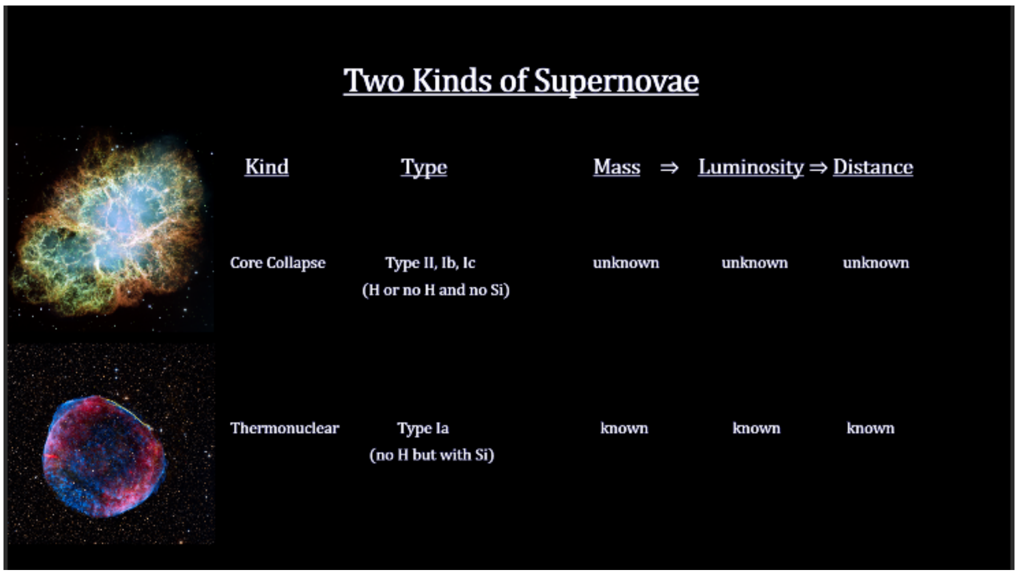
Although only a few stars per century in our Galaxy will end their lives in this spectacular way, these explosions are responsible for making some of the chemical elements heavier than iron in the Universe.

[Additional info: We'll cover other sources for the elements around us in subsequent chapters. Many elements, such as copper, mercury, gold, iodine and lead that we see around us here on Earth today were forged in these violent events billions of years ago: Supernovae, merging neutron stars, hypernovae, etc. The expanding shells of supernova remnants were mixed with other material in the Milky Way and became the raw material for new generations of stars and planets. That's why we are 'star dust', as Carl Sagan pointed out in his Cosmos series back in the 80s.**]**

*[**Music:** Puccini, Giacomo: Preludio Sinfonico; Radio-Symphonie-Orchester Berlin and Riccardo Chailly; from the album "Puccini Without Words", 2006]*

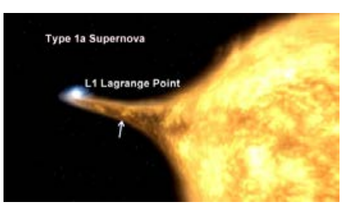
Type Ia Supernova

The luminosity of a supernova depends on the mass of the star. If we knew the mass, we'd have ourselves another standard candle, one that shines hundreds of thousands of times brighter than Cepheid Variables. But for most explosions across the cosmos, we don't have that information. But there is one scenario where we do. It is called a **Type Ia Supernova**. It is based on a particular binary star setup, and it is recognizable via light profiles and spectral analysis.



Here's how it works:

1) A massive red giant star has a small stellar companion.



2) Mass flows from the giant to the dwarf through the L1 Lagrange point. You'll remember Lagrange points from our discussion on Jupiter in the segment on our Solar System.

3) The mass of the dwarf star increases.

4) Once the mass of the smaller star reaches a critical level, its ability to hold off collapsing under the force of gravity ends. The result is a total collapse inside a few seconds. This creates the supernova explosion that rips the smaller star to pieces.

The critical mass needed for this explosion was calculated to be 1.44 solar masses by Subramanian Chandrasekhar in 1930 on a ship on the way from India to England to begin graduate study in physics at Cambridge University! The Chandra space telescope is named after this great physicist.

$$M_{Limit} = 2.13(hc/2\pi G)^{3/2} \times (\mu_e m_H)^{-2}$$
$$= 1.44\ M_{sun}$$

Where:

M_{Limit} = Chandrasekhar limit = maximum star mass that can be supported by electron degeneration pressure

h = Planck's constant

c = speed of light

G = Newton's gravitational constant

μ_e = average molecular weight per electron

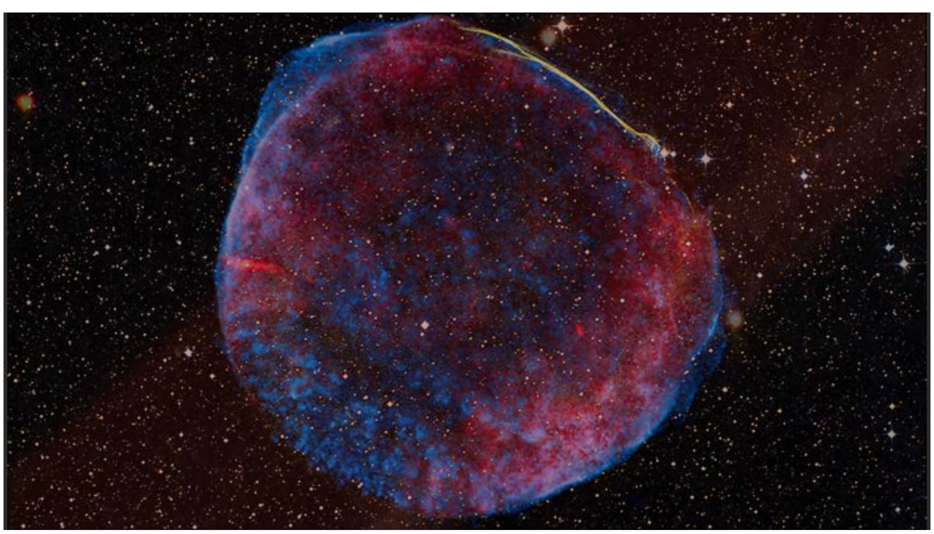
m_H = mass of the hydrogen atom

M_{sun} = Mass of the sun

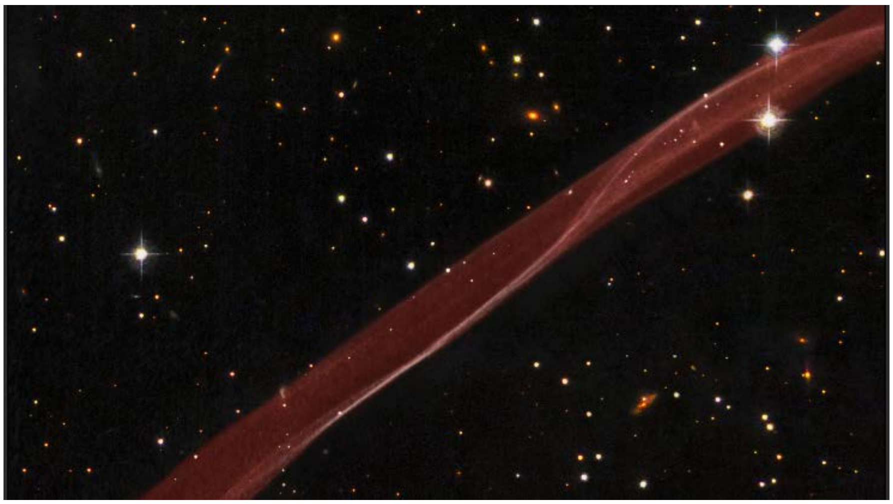
Type 1a supernovae provide a candle as accurate as Cepheid variables but with the advantage that they can be seen clearly at much larger distances. [Because we know the mass of a Type Ia supernova, we know the luminosity. This has made them very important standard candles and one of the most reliable distance measurements. They are thought to provide a distance measurement approaching 5% accuracy over vast distances. They are even used to help find out if the expansion of our Universe is accelerating or decelerating.]

SN 1006 – 7,000 light years

Just over a thousand years ago, the stellar explosion known as supernova SN 1006 was observed. It was brighter than Venus and visible during the day for weeks. The brightest supernova ever recorded on Earth, this spectacular light show was documented in China, Japan, Europe, and the Arab world. Ancient observers were treated to this celestial fireworks display without understanding its cause or implications. We now understand that SN 1006 was a Type 1a supernova.



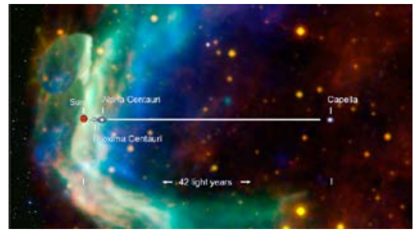
In 1976, the first detection of exceedingly faint optical emission of the supernova remnant was reported. A tiny portion of this filament is revealed in detail by this Hubble observation. The twisting ribbon of light corresponds to locations where the expanding blast wave from the supernova is now sweeping into very tenuous surrounding gas. The size of the remnant implied that the blast wave from the supernova had expanded at nearly 32 million km/hr (or 20 million miles per hour) every hour for over 1,000 years.



RCW 86 - 8,000 light-years

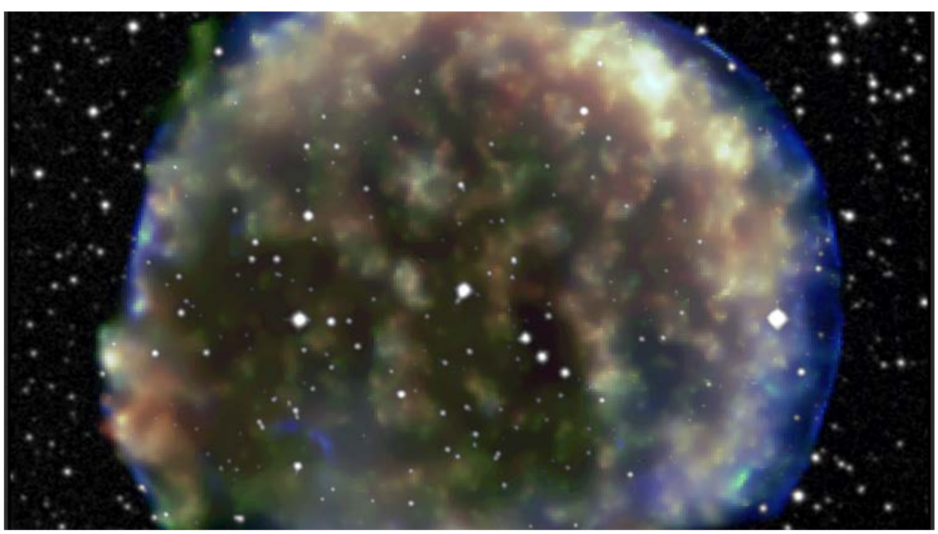
The Chinese witnessed this supernova event in 185 A.D., documenting a mysterious "guest star" that remained in the sky for eight months. This combined visible light and X-ray image shows the interstellar gas that has been heated to millions of degrees by the passage of the shock wave from the supernova.

RCW 86 is approximately 85 light-years in diameter. If it were the star Capella, the shock wave would be tearing us apart right now.



Tycho Supernova SN 1572 - 9,800 light-years

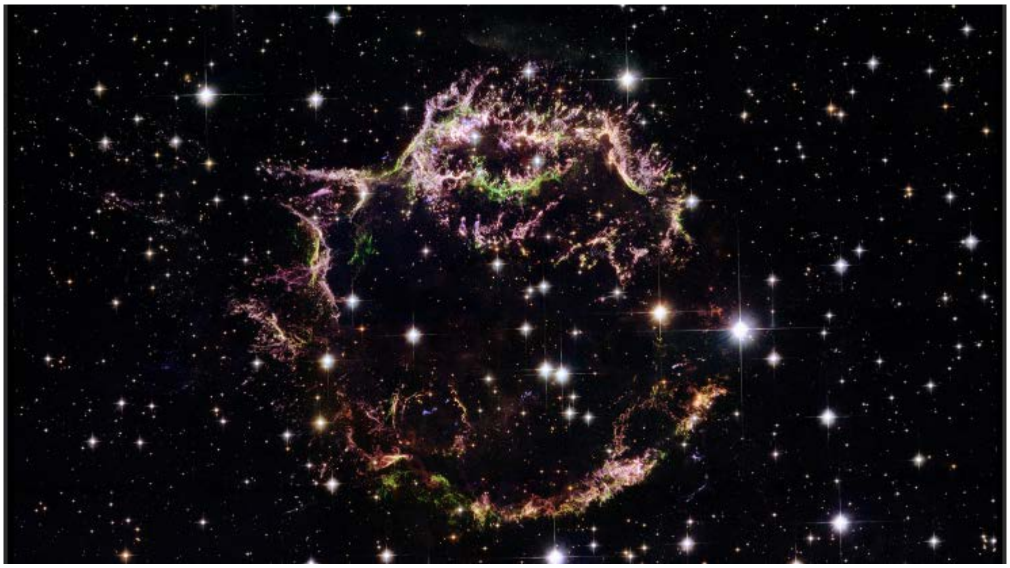
Here we are zooming into the surviving companion star to a titanic supernova explosion witnessed in the year 1572 by the great Danish astronomer Tycho Brahe. On November 11, 1572, Tycho Brahe noticed a star in the constellation Cassiopeia that was as bright as the planet Jupiter. No such star had ever been observed at this location before. It soon equaled Venus in brightness. For about two weeks the star could be seen in daylight. At the end of November it began to fade and change color, from bright white to yellow and orange to faint reddish light, finally fading away from visibility in March 1574.



Tycho's meticulous record of the brightening and dimming of the supernova now allows us to identify its "light signature" as that of a Type 1a supernova. Tycho Brahe's supernova was very important in that it helped 16th-century astronomers abandon the idea of the immutability of the heavens.

Cassiopeia A - 10,000 light-years

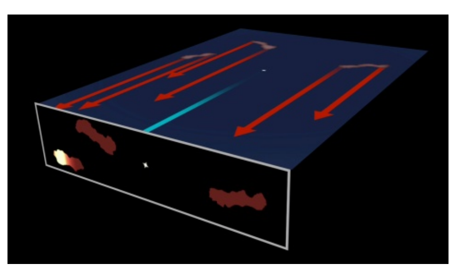
These supernova star's shredded remains are called Cassiopeia A, or "Cas A" for short. Cas A is the youngest known supernova remnant in our Milky Way Galaxy. The light from this exploding star reached Earth in the late 1600s.



This photo shows the upper rim of the supernova remnant's expanding shell. The colors highlight parts of the debris where chemical elements are glowing. The dark blue fragments, for example, are richest in oxygen; the red material is rich in sulfur. [The star that created this colorful show was a big one, about 15 to 25 times more massive than our Sun.]

These Spitzer Infrared Space Telescope images show shifting patterns of glowing dust beyond the remnant itself. These changes are so fast that they indicate motion at the speed of light!

These are **light echoes** just like what we saw with the star Monocerotis. The light from a supernova can take hundreds of years to reach surrounding dust clouds. Following the arrows of light it's clear we'll see the supernova flash first. The light echoing off of the dust clouds will arrive later - at various times, delayed by hundreds of years from the original flash.

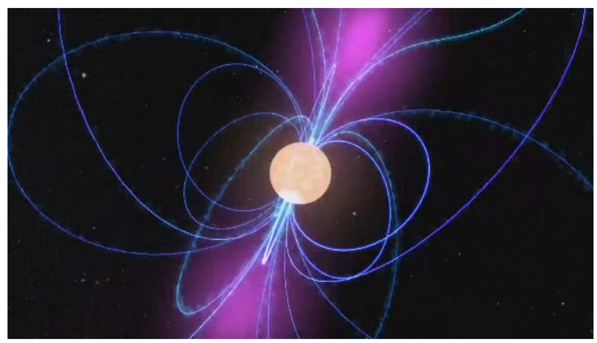


So we're not seeing the dust move, we're seeing the light from the supernova move through the dust. It's Spitzer that can detect this brief boost in the thermal infrared glow.

> **[Music:** *Bach, Johann Sebastian: Herz und Mund und Tat und Leben, Cantata BWV 147 - Arr. Guillermo Figueroa - 10. Jesu, Joy of Man's Desiring, Orpheus Chamber Orchestra, from the album "Baroque – The Essentials, 2018***]**

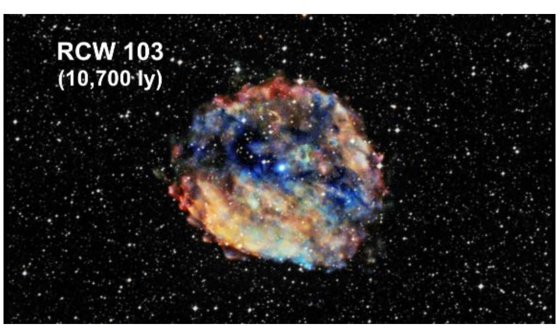
Magnetars

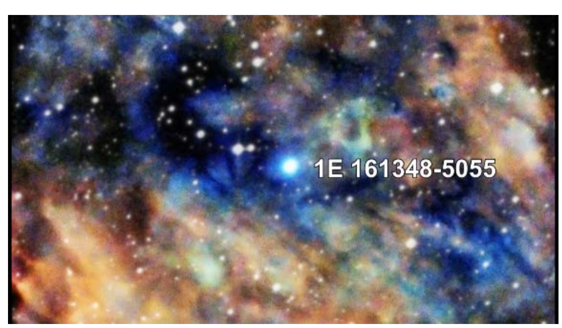
A magnetar is a spinning neutron star with an intense magnetic field. Magnetic field strength is measured in units called gauss. A refrigerator magnet is around 50 gauss. MRI's use up to 70,000 gauss. A magnetar's field strength is a thousand trillion gauss – enough to tear atoms apart a 1000 km away. 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

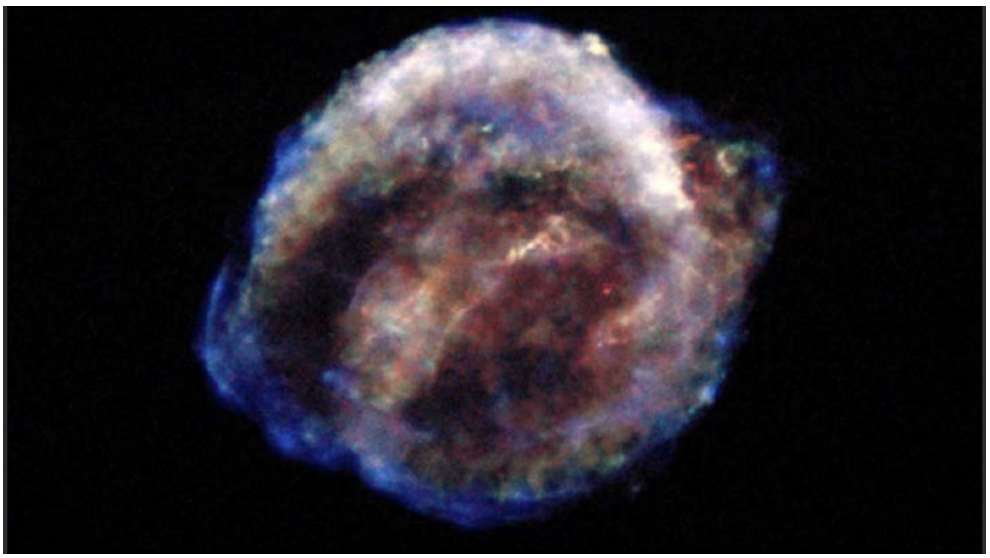
On June 22, 2016, an instrument aboard NASA's Swift telescope captured the release of a short burst of X-rays from 1E 1613, a star in the middle of the supernova remnant RCW 103, indicating that it may be a magnetar. Seeking to investigate further, astronomers had the Chandra X-ray Observatory and other 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.





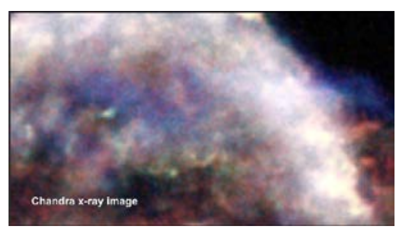
Kepler's supernova SN 1604 - 13,000 light-years

Four hundred years ago, sky watchers, including the famous astronomer Johannes Kepler, were startled by the sudden appearance of a "new star" in the western sky, rivaling the brilliance of the nearby planets. **[**When a new star appeared alongside Jupiter, Mars, and Saturn on Oct. 9, 1604, observers could only use their eyes to study it. The telescope would not be invented for another four years.**]**

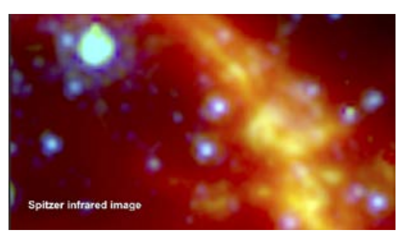


Modern-day astronomers examine the remnant in

In X-rays, that show regions of very hot gas.



In infrared radiation, that shows heated microscopic dust particles that have been swept up by the supernova shock wave.



And in visible light, that reveals where the supernova shock wave is slamming into the densest regions of surrounding gas.

You can see the value of going beyond visible light. Hubble's visible light image doesn't 'see' the full nature of the supernova remnant. The X-ray and infrared cameras do.

[Additional info: The combined image unveils a bubble-shaped shroud of gas and dust that is 14 light-years wide and is expanding at 4 million miles per hour. Observations from each telescope highlight distinct features of the supernova remnant, a fast-moving shell of iron-rich material from the exploded star, surrounded by an expanding shock wave that is sweeping up interstellar gas and dust at more than 22 million miles per hour, like an interstellar tsunami.**]**

N 63A – 160,000 light years

A violent and chaotic-looking mass of gas and dust is seen in this Hubble Space Telescope image of a nearby supernova remnant denoted N 63A.

Many of the stars in the immediate vicinity of N 63A are extremely massive. It is estimated that the progenitor of the supernova that produced the remnant seen here was about 50 times more massive than our own Sun.

[Additional info: Such a massive star has strong stellar winds that can clear away its ambient medium, forming a wind-blown bubble. The supernova that formed N 63A is thought to have exploded inside the central cavity of such a wind-blown bubble. Color filters were used to sample light emitted by sulfur (shown in red), oxygen (shown in blue), and hydrogen (shown in green).**]**

[Music: *Bizet, Georges: Entracte to Act III from "Carman"; Orchestre National de France / Seiji Ozawa, 1984; from the album "The most relaxing classical album in the world…ever!"***]**

Supernova 1987A – 163,000 light years

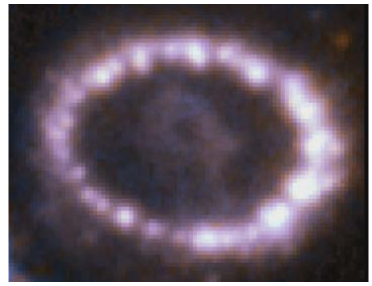
Three decades ago, astronomers spotted one of the brightest exploding stars in more than 400 years. The titanic supernova, called 1987A (SN 1987A) blazed with the power of 100 million Suns for several months following its discovery **[**on Feb. 23, 1987**]**.

Here we have an archival photographic plate of the star before it exploded next to one where it had.

A dense ring of gas around the supernova is glowing in optical light, and has a diameter of about one light-year. A flash of ultraviolet light from the explosion energized the gas in the ring, making it glow for decades. [The ring was created when the star was a red giant - around 20,000 years before the star exploded.]

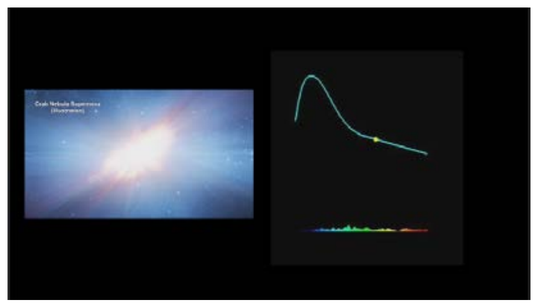
This time-lapse video sequence of Hubble images show the effects of the shock wave from the supernova blast smashing into the ring. The ring begins to brighten as the shock wave hits it. [The ring is about one light-year across.]

In the past few years, the ring's X-ray light has stopped getting brighter. And, the bottom left part of the ring has started to fade. These changes provide evidence that the explosion's blast wave has moved into the region beyond the ring. This represents the end of an era for this supernova. We expect to learn more about this new region as the blast wave impacts its contents.

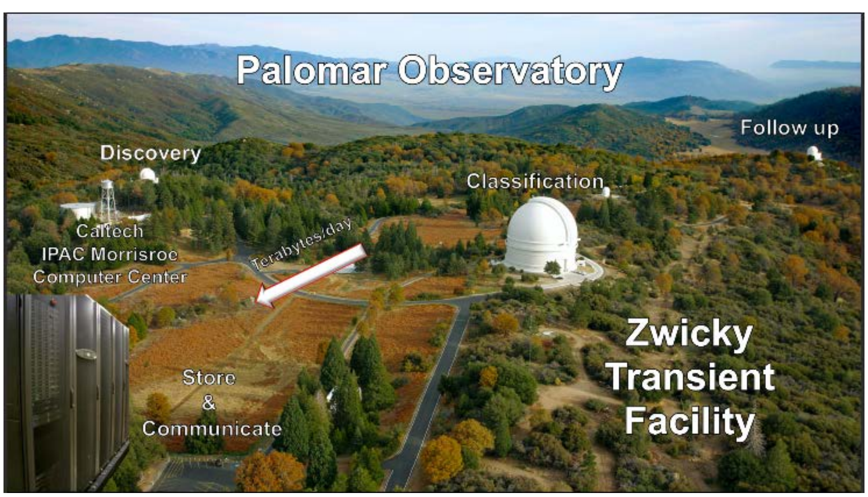


<u>Finding Supernovae</u>

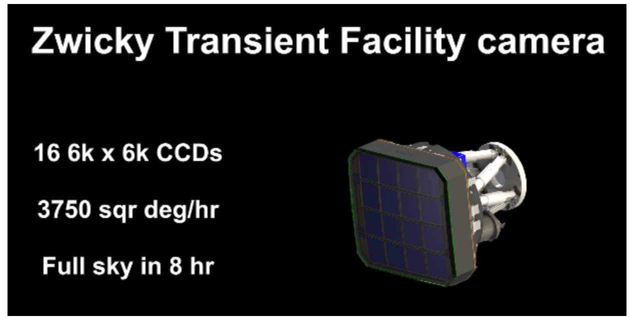
The key to understanding supernovae behavior is to examine its early light profile. But, because these explosions are transient events without location foreknowledge. We haven't analyzed very many from their earliest minutes.



But modern astronomy has new facilities to rapidly identify transient events and communicate them around the globe in real time. One of these is the new Zwicky Transient Facility (ZTF for short) at the Palomar Observatory in Southern California, operated by Caltech.



Every night, ZTF will a large portion of the Northern sky, discovering objects that erupt, move or vary in brightness including asteroids, comets and supernovae. Each image is more than 24,000 by 24,000 pixels. 4 terabytes of data will be collected each night.



This new facilities and others like it will greatly improve our chances for finding Supernovae very early in their explosive stage.

Star Clusters

There are two kinds of clusters:

Open clusters: usually a few hundred young stars lightly bound by gravity.

And **Globular clusters**: like this one, hundreds, sometimes hundreds of thousands of older stars tightly bound by gravity.

[Additional info: A few of the nearest clusters such as Pleiades are close enough for their distances to be measured using parallax. A Hertzsprung–Russell Diagram can be plotted for these clusters which has absolute values known on the luminosity axis. Then, when a similar diagram is plotted for a cluster whose distance is not known, the position of the main sequence can be compared to that of the first cluster and the distance estimated. This can then be compared to Cepheid variables found in the cluster to improve the accuracy of the H-R diagram process itself.**]**

Open Clusters

Pleiades - 456 light years

The Pleiades or Seven Sisters is an open cluster of extremely luminous blue stars. And it is one of the nearest star clusters to Earth. It is one of only a few open clusters whose distance can be measured via parallax.

Jewel Box – 6,500 light years

This image is a "close-up' view of the Jewel Box cluster taken by Hubble.

Several very bright, pale blue supergiant stars, a solitary ruby-red supergiant and a variety of other brilliantly colored stars are visible in the image, as well as many much fainter ones, often with intriguing colors. The huge variety in brightness exists because the brighter stars are 15 to 20 times the mass of the Sun, while the dimmest stars are less than half the mass of the Sun.

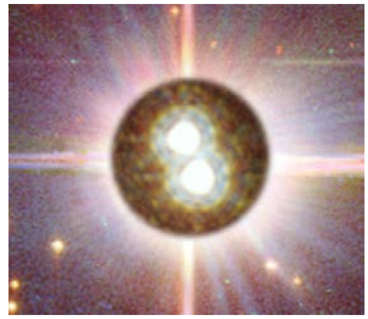
Trumpler 16 – 7,500 ly

The image shows a pair of colossal stars, WR 25 and Tr16-244, located within the open cluster Trumpler 16. This cluster is embedded within the Carina Nebula, an immense cauldron of gas and dust that lies approximately 7500 light-years from Earth. WR 25 is the brightest, situated near the center of the image. The neighboring Tr16-244 is the third brightest, just to the upper left of WR 25. The second brightest, to the left of WR 25, is not in the cluster. It's a low mass star located much closer to the Earth.

Pismis 24 - 8,000 light-years

The small open star cluster Pismis 24 lies in the core of the large emission nebula NGC 6357. We'll cover emission nebula in another segment on the Milky Way. The brightest object in the picture is designated Pismis 24-1. It was once thought to weigh as much as 200 times the mass of the sun.

However, the high-resolution Hubble Space Telescope images of the star show that it is really two stars orbiting one another.



[Music: *Rachmaninov, Sergei: Rhapsody on a Theme of Paganini – Variation 18; Cecile Ousset (Piano), City of Birmingham Symphony Orchestra / Sir Simon Rattle, 1984; from the album "The most relaxing classical album in the world…ever!"***]**

Trumpler 14 – 8,000 ly

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.

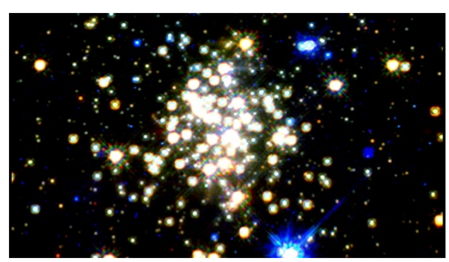
Because the cluster is only 500,000 years old, it has one of the highest concentrations of massive, luminous stars in the entire Milky Way. These blue-white stars are burning their hydrogen fuel so ferociously that they will explode as supernovae in just a few million years. The combination of outflowing 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.**]**

NGC 6791 – 13,300 light years

NGC 6791 is one of the oldest and largest open clusters known. It is 10 times larger than most open clusters and contains roughly 10,000 stars. **[**It is unusual in that it contains a large number of White Dwarf binary star systems.**]**

Quintuplet Cluster & Arches Cluster - 25,000 light-years

Penetrating 25,000 light-years of obscuring dust and stars, Hubble uses infrared to provide the clearest view yet of a pair of the largest young clusters of stars in our Milky Way galaxy. They are located less than 100 light-years from the very center of the Galaxy. Having the equivalent mass greater than 10,000 stars like our sun, the monster clusters are ten times larger than typical young star clusters scattered throughout the galaxy. Arches cluster is so dense, over 100,000 of its stars would fill a spherical region that only contains 5 stars in our local neighborhood.



Globular Clusters

47 Tucanae – 15,000 light years

47 Tucanae is one of the densest globular clusters in the Southern Hemisphere containing around a million stars. Multiple Hubble photos of this region allowed astronomers to track the "beehive swarm" motion of stars. Using Doppler shifts and proper motion measurements, precise velocities were obtained for nearly 15,000 stars in this cluster.

This has provided astronomers with the best observational evidence to date that globular clusters sort out stars according to their mass, governed by a gravitational billiard ball game between stars. Heavier stars slow down and sink to the cluster's core, while lighter stars pick up speed and move across the cluster to its periphery.

Omega Centauri - 16,000 light-years

Omega Centauri is among the biggest and most massive of some 200 globular clusters in the Milky Way. Hubble snapped this panoramic view of a colorful assortment of 100,000 stars residing in the crowded core of a giant star cluster that contains nearly 10 million stars. All of the stars in the image are cozy neighbors. The average distance between any two stars in the cluster's crowded core is only about a third of a light-year, roughly 13 times closer than our Sun's nearest stellar neighbor, Alpha Centauri.

Terzan 5 – 19,000 ly

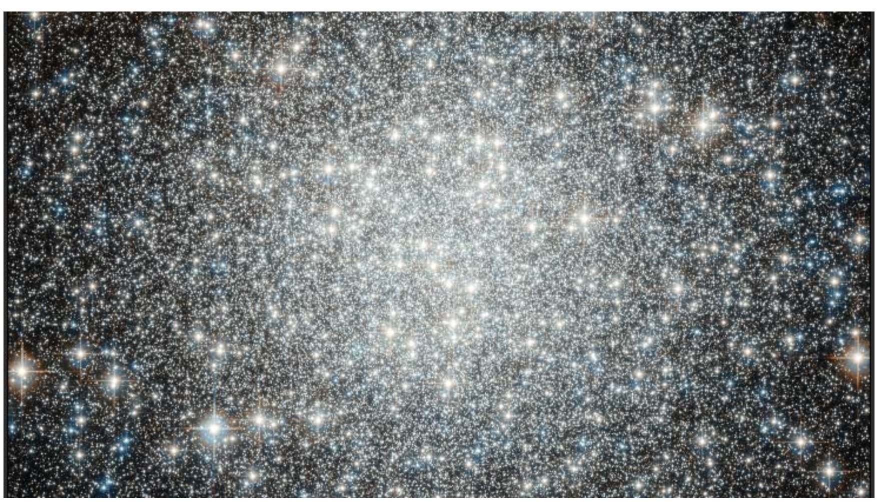
This stellar system resembles a globular cluster, but it’s like no other cluster known. A team of astronomers found that there are two distinct kinds of stars in Terzan 5 which not only differ in the elements they contain, but also have an age-gap of roughly 7 billion years. The ages of the two populations 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.

Globular Cluster M30 - 28,000 light-years

Globular cluster M 30 is a dense swarm of several hundred thousand stars. It's about 90 light-years across.

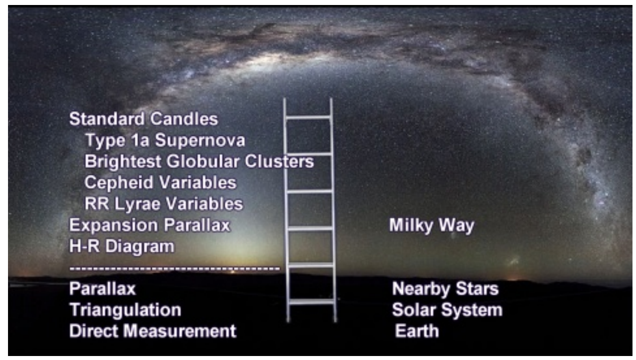
M53, NGC 5024 – 60,000 ly

Thousands and thousands of brilliant stars make up this globular cluster. Bound tightly by gravity, the cluster is roughly spherical and becomes denser towards its center. [There are over 150 of these enormous spherical clusters in the Milky Way. Because globular clusters are much older than open clusters, they are generally expected to contain more old red stars and fewer massive blue stars. But Messier 53 has an unusually large number of a type of star called blue stragglers. Stars in a globular cluster are expected to form around the same time, but blue stragglers appear to be brighter and younger than the rest. Although their precise nature remains unknown these unusual objects are probably formed by collisions between stars in the crowded centers of globular cluster.]



Distance Ladder

In previous segments, we have used parallax to verify and calibrate the H-R Diagram (aka Spectroscopic Parallax) and standard candles like Cepheid and RR Lyrae Variables. These standard candles then enabled distance measurements far beyond what can be done with parallax. In this segment, we saw how to calculate the luminosity of Type 1A Supernovae. And, although globular star clusters come in a variety of sizes and magnitudes, it appears that the brightest clusters have a similar luminosity. Astronomers used the Cepheids and other known standard candles to verify and calibrate these two new standard candle rungs on our cosmic distance ladder – Type 1a Supernovae and the brightest globular clusters.



Supernovae and Planetary Nebula are about star death. In our next segment, we'll be covering star birth nebula like this one – the Orion Nebula as seen by the Zwicky Transient Facility.