Stars: The Stellar Death Cycle

What Happens when a Star Dies?

2024 OzSky "Classic" Star Safari

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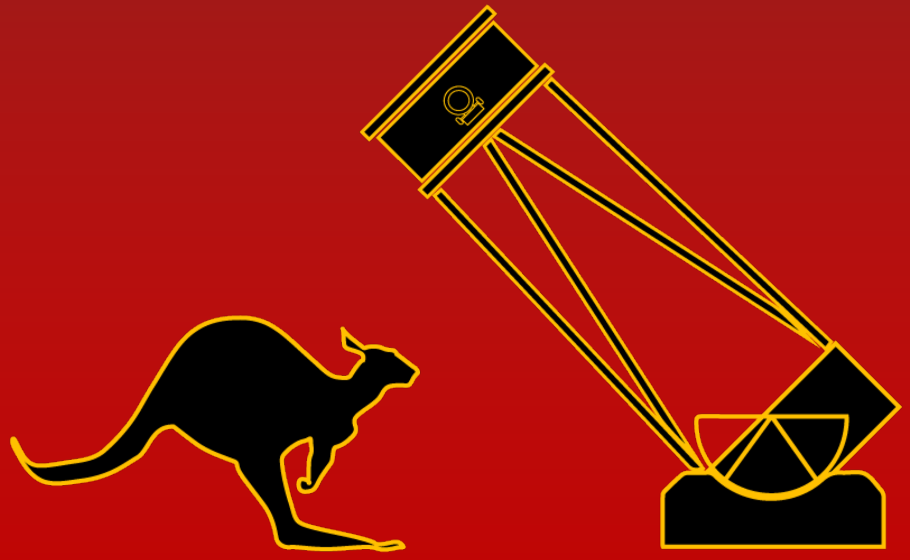

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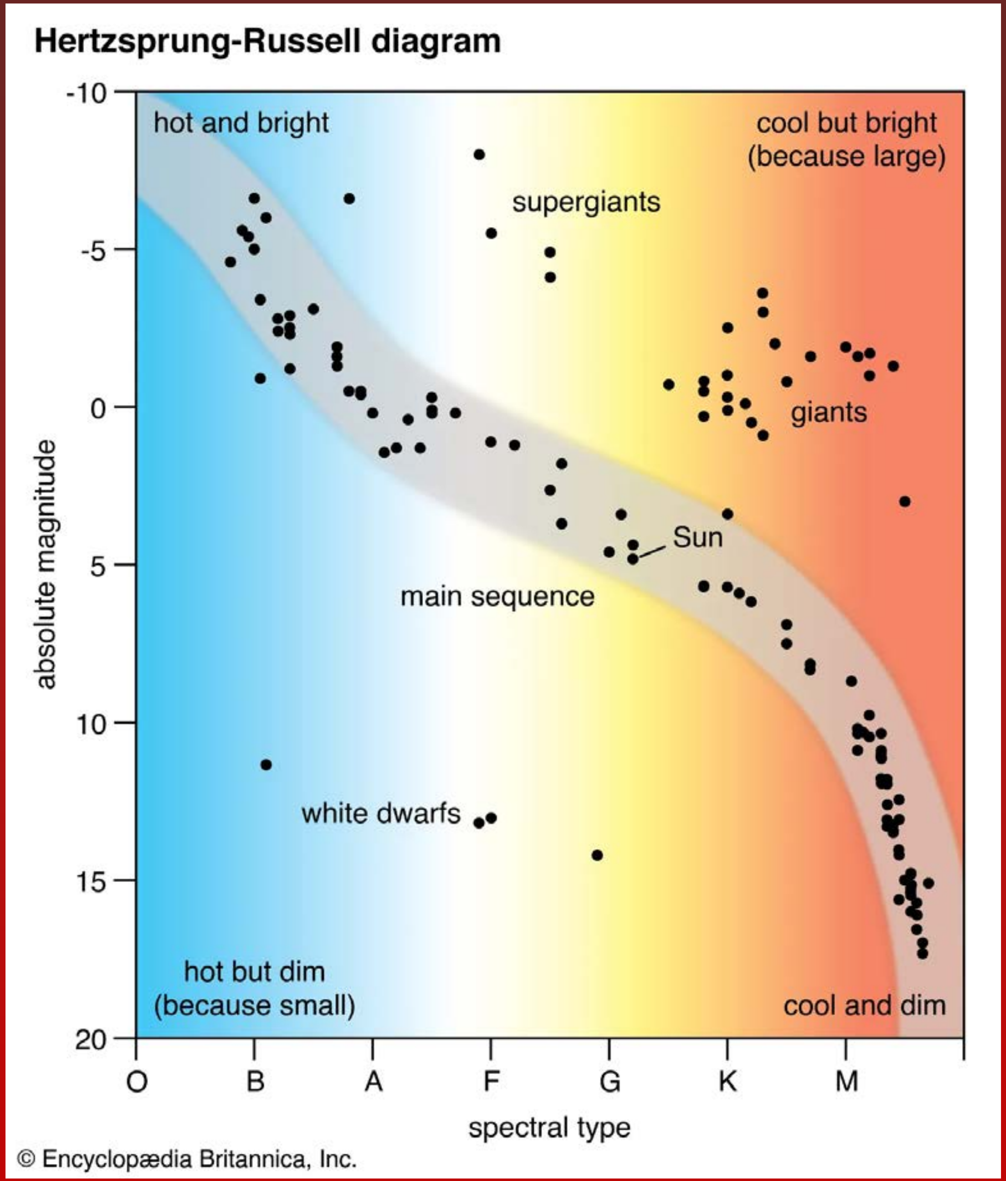
What Happens when a Star Dies?

- It depends on the mass and type of star

The Hertzsprung-Russell diagram (HR diagram)



- The Hertzsprung-Russell diagram (HR diagram) is one of the most important tools in the study of stellar evolution. It plots the temperature of stars against their luminosity.
- Developed independently by Ejnar Hertzsprung (Danish) in 1911 and by Henry Norris Russell (USA) in 1913
- Depending on its initial mass, every star goes through specific evolutionary stages dictated by its internal structure and how it produces energy. Each of these stages corresponds to a change in the temperature and luminosity of the star, which can be seen to move to different regions on the HR diagram as it evolves.
- The majority of stars, including our Sun, are found along a region called the Main Sequence. Main Sequence stars vary widely in effective temperature, but the hotter they are, the more luminous they are; hence the main sequence tends to follow a band going from the top left of the diagram to the bottom right.
- Main sequence stars fuse hydrogen into helium within their cores. This is sometimes called "hydrogen burning" but you need to be careful with this term. "Burning" implies a combustion reaction with oxygen but the process within stellar cores is a nuclear reaction, not a chemical one. Our sun will spend about 10 billion years as a main sequence star.
- Other major groups of stars found on the H-R diagram are the giants and supergiants; luminous stars that have evolved off the main sequence, and the white dwarfs.

There are 3 main star types

- Dwarf Stars
- Main Sequence Stars
- Giant Stars

All star types come in many different colours, which generally correlates with temperature.

Morgan Keenan Star Colour and Temperature Table

Class	Effective temperature[1][2]	Vega-relative chromaticity[3][4][a]	Chromaticity (D65)[5][6][3][b]	Main-sequence mass[1][7] (solar masses)	Main-sequence radius[1][7] (solar radii)	Main-sequence luminosity[1][7] (bolometric)	Hydrogen lines	Fraction of all main-sequence stars[8]
O	≥ 30,000 K	blue	blue	≥ 16 $M_\odot$	≥ 6.6 $R_\odot$	≥ 30,000 $L_\odot$	Weak	~0.00003%
B	10,000–30,000 K	blue white	deep blue white	2.1–16 $M_\odot$	1.8–6.6 $R_\odot$	25–30,000 $L_\odot$	Medium	0.13%
A	7,500–10,000 K	white	blue white	1.4–2.1 $M_\odot$	1.4–1.8 $R_\odot$	5–25 $L_\odot$	Strong	0.6%
F	6,000–7,500 K	yellow white	white	1.04–1.4 $M_\odot$	1.15–1.4 $R_\odot$	1.5–5 $L_\odot$	Medium	3%
G	5,200–6,000 K	yellow	yellowish white	0.8–1.04 $M_\odot$	0.96–1.15 $R_\odot$	0.6–1.5 $L_\odot$	Weak	7.6%
K	3,700–5,200 K	light orange	pale yellow orange	0.45–0.8 $M_\odot$	0.7–0.96 $R_\odot$	0.08–0.6 $L_\odot$	Very weak	12.1%
M	2,400–3,700 K	orange red	light orange red	0.08–0.45 $M_\odot$	≤ 0.7 $R_\odot$	≤ 0.08 $L_\odot$	Very weak	76.45%

- This table is a development of the Harvard Table which was created by Annie Jump Cannon.
- The table shows the general correlation between colour, surface temperature and luminosity.
- There are numerous sub classes within each spectral colour class.
- Our own Sun is a G2V type star. There are 9 Categories of "G" type stars. "G" type stars comprise 7.6% of all stars in the Universe, which is the 3rd most populated spectral class, behind "M" with 76.45% and "K" with 12.1%.

Star Size and Mass

- Stars come in many different sizes and weights. A star changes size over the course of its life.

- Star mass is measured relative to the mass of our own Sun, which is classed as “1” Solar Mass.

- The lightest known stars are red dwarfs. EBLM J0555-57Ab, which is about 600 light years away, is the current record holder for the star with the least mass. It is slightly smaller than Saturn and has about 6.4% the mass of the sun (0.064 solar masses) or about 70 times the mass of Jupiter.

- R136a1 currently holds the record as the most massive known star. It's more than 265 times the mass of the Sun. It is in the Tarantula Nebula.

Star Size and Mass

- The smallest known star is a Neutron Star (CXOU J085201.4-461753) with a diameter of 1.2km, but it is only recently discovered and very little is known about it.

- The second smallest known star by size is PSR B0943+10. It is a Pulsar / Neutron Star 2,000 light years from Earth in the direction of the constellation of Leo. It was discovered at Pushchino in December 1968. It has a diameter of 2.6km, yet it has a mass of 1.5 Solar Masses.

- The largest star is named Stephenson 2-1 with a radius 2,150 times that of the Sun. That's 1.5 billion km in diameter, or roughly 10 billion times the volume of the Sun. If it was placed at the center of our Solar System, its photosphere would engulf the orbit of Saturn. The Sun is incredibly small compared to it, and by comparison the Earth is basically a speck of dust.

- However, a great deal of controversy exists regarding the size of this star. Due to its proximity to a cluster of other massive red supergiant stars and other factors, it's hard to get a good measure of it. In fact, this star might not turn out to be largest and might end up being beaten by what is currently the second-largest known star.

- The second largest star, UY Scuti is a variable hypergiant with a radius around 1,700 times larger than the radius of the Sun. To put that in perspective, the volume of almost 5 billion Suns could fit inside a sphere the size of UY Scuti. Despite its huge size it only has a mass of 7 to 10 Solar masses.

Star Size Comparison

As with most stages in a star's life, the post-main sequence events are primarily dependent on its mass.

When small to medium stars die !

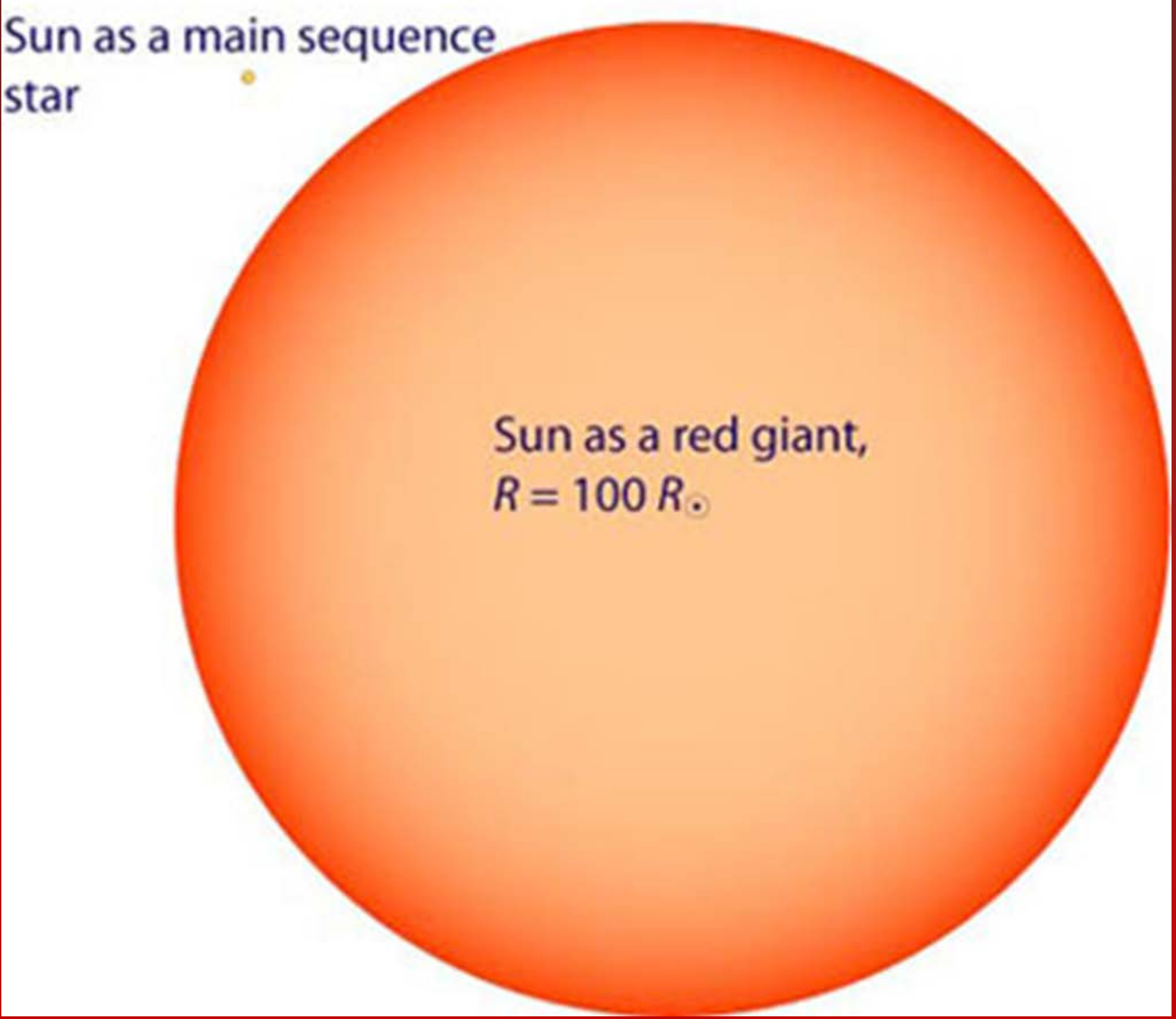
- We define small to medium stars as having less than 1.4 Solar masses. This is a limit dictated by the laws of physics as to how small they can be and undergo this death cycle. It is known as the Chandrasekhar Limit.

- When the core runs out of hydrogen fuel, it will contract under the weight of gravity. Some hydrogen fusion will occur in the upper layers. As the core contracts, it heats up. This causes the outer layers to expand. As they expand, the radius of the star will increase, and it will become a red giant.

- The radius of our Sun when it enters the red giant phase will be just beyond Earth's current orbit. At some point after this, the core will become dense enough to cause the helium to fuse into carbon. When the helium fuel runs out, the core will expand and cool. The outer layers will expand and eject material that will collect around the dying star to form a planetary nebula.

- Finally, the core will cool into a white dwarf and then eventually into a black dwarf. The entire process to white dwarf stage will take a few billion years. The Universe isn’t old enough for any black dwarfs to have formed.

Comparison in size of Sun as a Main Sequence star and as A Red Giant



White Dwarf Stars

- A white dwarf star generally has a size roughly equal to the Earth, but has a mass equal to the Sun.
- A teaspoon of White dwarf star material would weigh about 15 tonnes.
- Sirius “B” and Rigel “B” are two of the better known White Dwarf stars we observe in amateur telescopes.

Planetary Nebula

- A planetary Nebula is the ejected material from the death of a red giant that is illuminated by the newly formed White Dwarf Star at it's centre.

- Planetary Nebula vary in diameter from less than 1 light year to about 10 light years (most are < 5 LY).

- The apparent size viewed from Earth depends on the size of the Nebula and it's distance.

- By the time the planetary nebula has expanded beyond about 5 light years, it becomes too diffuse and it is too dim to be detected with Earth based telescopes, although there are a couple of exceptions.

The Helix Nebula (NGC 7293)

- Located in Aquarius
- Visual magnitude = 7.6
- Apparent Size = 25’
- Actual Size = 2.87 LY
- Distance = 650 LY

The Cat's Eye Nebula (NGC 6543, Caldwell 6)

- Located in Draco
- Visual magnitude = 8.2
- Apparent Size = 23” x 17”
- Actual Size = 5.0 LY
- Distance = 3,000 LY

The Eskimo Nebula (NGC 2392 , Caldwell 39)

- Located in Gemini
- Visual magnitude = 9.2
- Apparent Size = 47” x 43”
- Actual Size = .68 LY
- Distance = 4,000 LY

The Ring Nebula (M57, NGC 6720)

- Located in Lyra
- Visual magnitude = 8.8
- Apparent Size = 76” x 56”
- Actual Size = 1.3 LY
- Distance = 2,000 LY

The Eight-Burst Nebula (NGC 3132, Caldwell 74)

- Located in Vela
- Visual magnitude = 9.4
- Apparent Size = 84” x 53”
- Actual Size = 0.4 LY
- Distance = 2,000 LY
- Also known as the Southern Ring Nebula

When Medium to Large Stars Die

- Medium to large size stars we can define as larger than 1.4 solar masses and less than 10 solar masses.

- When the core runs out of hydrogen, these stars fuse helium into carbon just like the Sun. However, after most of the helium undergoes fusion, their mass is enough to fuse carbon into heavier elements such as oxygen, neon, silicon, magnesium, sulfur and iron. Once the core has turned to iron, it can no longer burn.

- The star collapses by its own gravity and the iron core heats up. The core becomes so tightly packed that protons and electrons merge to form neutrons. In less than a second, the iron core, which is about the size of Earth, shrinks to a neutron core with a radius of about 10 kilometers.

- The outer layers of the star fall inward on the neutron core, thereby crushing it further. The core heats to billions of degrees and explodes in a supernova event, thereby releasing large amounts of energy and material into space.

- The shock wave from the supernova can initiate star formation in other interstellar clouds. The remains of the core form a neutron star and the ejected material forms a supernova remnant (SNR).

Neutron Stars

- A neutron star generally has a size of roughly 10km to 20km in diameter with a mass between 1 and 2 solar masses

- A teaspoon of Neutron star material would weigh about 1 billion tonnes.

- Neutron stars are the fastest known rotating bodies in the Universe, spinning at 42,960 revolutions per minute *(or 716 times per second).*

Supernova Remnants

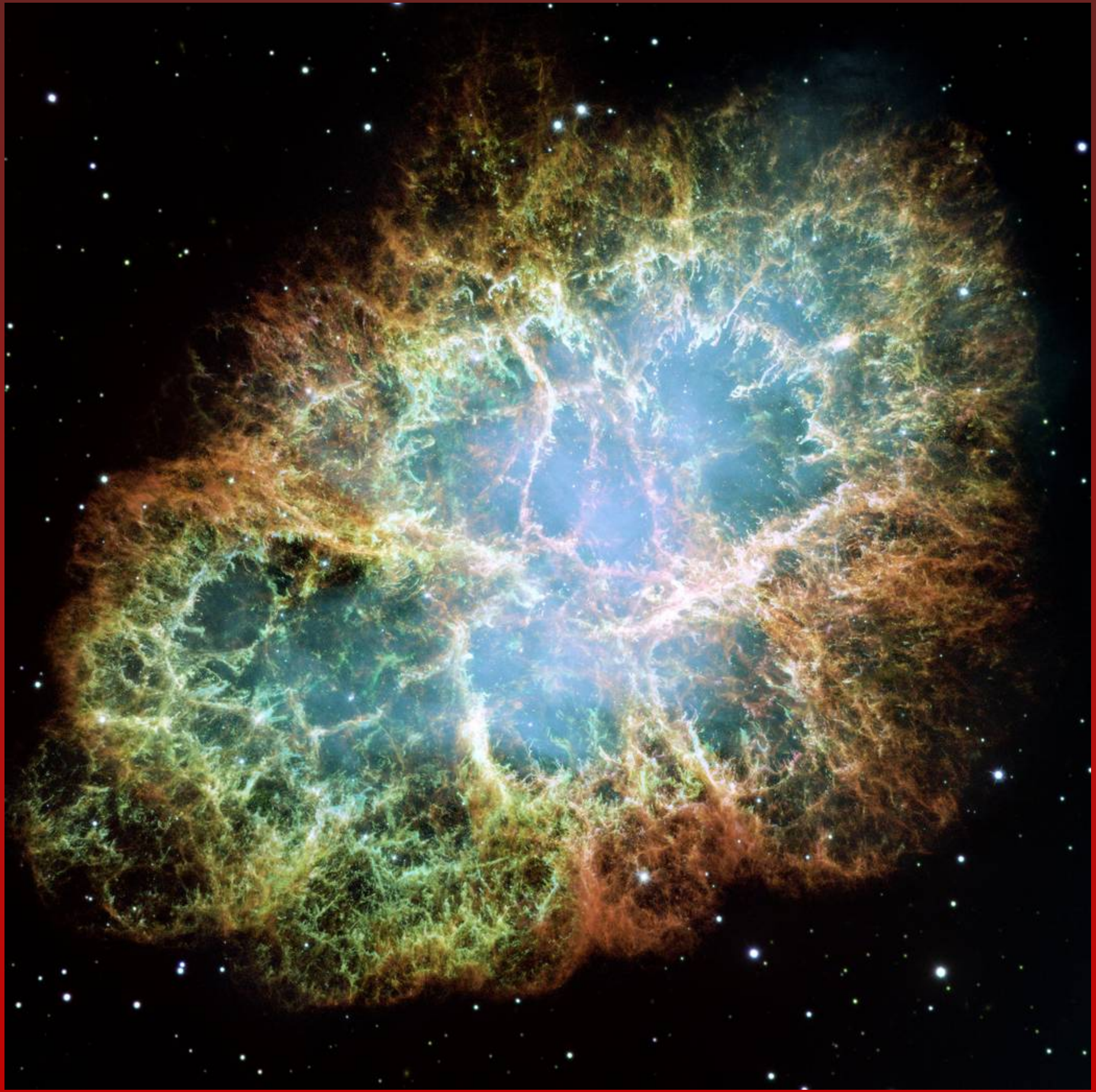
- A supernova remnant (SNR) is the ejected material from the death of a medium to large mass star that has undergone a supernova explosion.

- Supernova remnants develop in 3 stages through the interstellar material, which can take tens of thousands of years. They can span thousands of light years across because of this.

- The Crab Nebula (M1) is the resulting supernova remnant from a supernova event in 1054AD. This means it is still in it's very early stages of development, which means it is still fairly small (about 10 LY across) and easily visible in amateur telescopes.

- By comparison the Gum Nebula spans over 2 constellations (Vela and Puppis) and 36° of sky. It is several thousand light years across and over 1,000 light years deep. Because it is so diffuse, it requires a medium to large amateur telescope to see. The Gum Nebula is the result of a Supernova explosion over 1,000,000 years ago.

The Crab Nebula (M1, NGC 1952)



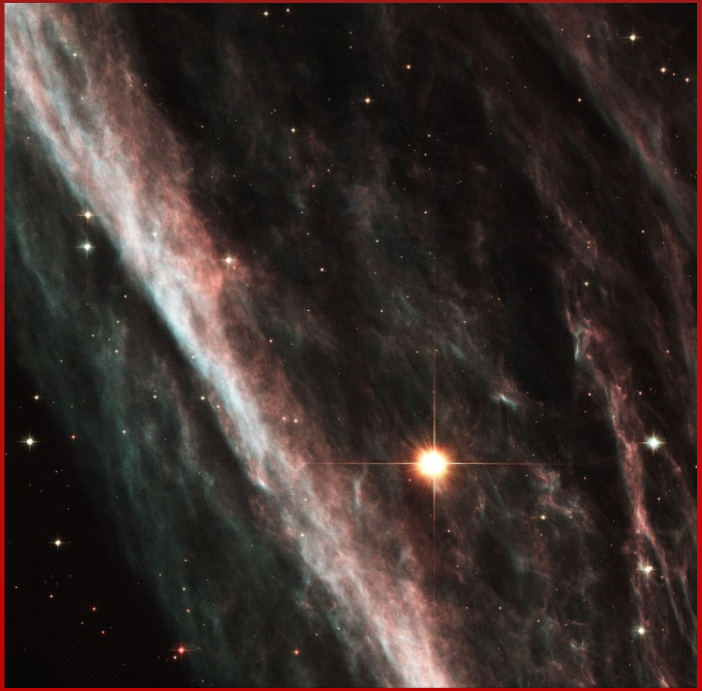
- Located in Taurus
- Visual magnitude = 4.4
- Apparent Size = 6’ x 4’
- Actual Size = 10 LY
- Distance = 6,500 LY
- Approximate Age = 968 Years

The Cygnus Loop (includes the Veil Nebula)

- Located in Cygnus
- Visual magnitude = 9.2
- Apparent Size = 3°
- Actual Size = 120 LY
- Distance = 2,500 LY
- Approximate Age = 20,000 Years
- Several Catalogue numbers including:
  - NGC 6992, 6995, 6960 plus several others
  - Caldwell 33 and 34

The Gum Nebula *(includes the Vela Supernova Remnant)*

- Located in Vela and Puppis
- Visual magnitude = generally very dim, brighter parts ~12.0
- Apparent Size = 36°
- Actual Size = >1,000 LY
- Distance = 1,500 LY
- Approximate Age = 1,000,000 Years
- Multiple catalogue designations including "The Pencil Nebula" NGC 2736



When Massive Stars Die

- Massive size stars are defined as larger than 10 solar masses.
- Having fused hydrogen to helium, these stars fuse helium into carbon just like the Sun. However, after the helium is gone, their mass is enough to fuse carbon into heavier elements such as oxygen, neon, silicon, magnesium, sulfur and iron.
- Once the core has turned to iron, it can no longer ‘burn’. The star collapses by its own gravity and the iron core heats up. The core becomes so tightly packed that protons and electrons merge to form neutrons.
- In less than a second, the iron core, which is about the size of Earth, shrinks to a neutron core and continues to contract, forming a black hole.

Pulsars

- A pulsar is a highly magnetized rotating neutron star that emits beams of electromagnetic radiation out of its magnetic poles.

- Neutron stars emit high-energy beams from their north and south magnetic poles. When these beams are pointed toward Earth and flash across us as the neutron star rotates, we see pulses. Astronomers named these beasts *pulsars*.

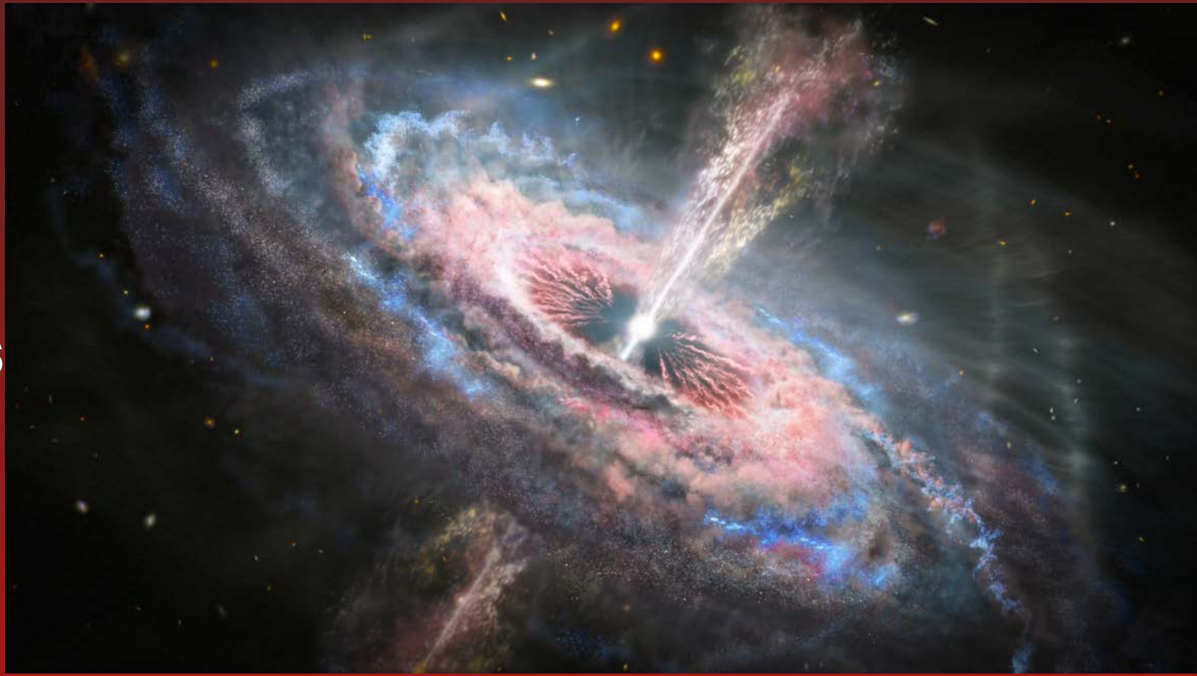
- Most neutron stars are observed as pulsars. So, all pulsars are neutron stars, but not all neutron stars are necessarily pulsars.

Vela Pulsar

Quasars

- A quasar is an extremely luminous active galactic nucleus, powered by a supermassive black hole, with mass ranging from millions to tens of billions of solar masses, surrounded by a gaseous accretion disc.

- The radiant energy of quasars is enormous; the most powerful quasars have luminosities thousands of times greater than that of a galaxy such as the Milky Way.



Artistic Impression of a Quasar

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