

Topic 14: Stellar Evolution



14.1 Messier and New General Catalogue (NGC)

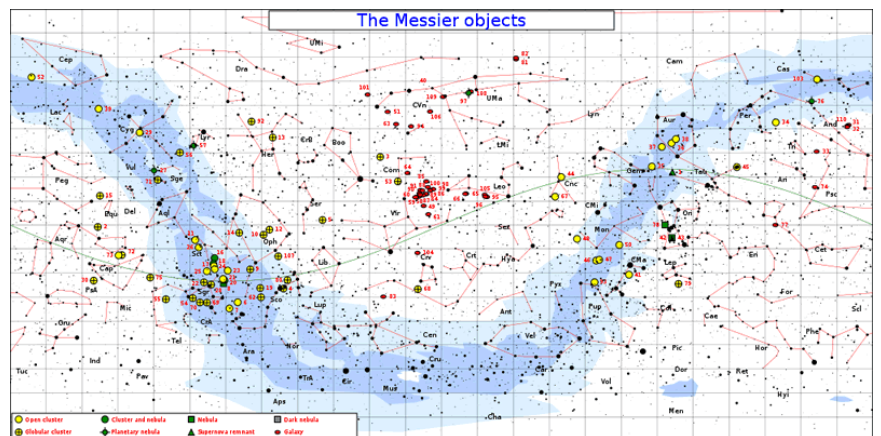


Messier Objects

The French astronomer Charles Messier was a comet hunter. He was fed up of discovering objects that initially looked like comets but weren't, so he published a catalogue which eventually contained 110 of these objects.

These objects are of immense importance to astronomers as they are nebula and galaxies.

The objects are prefixed as 'M' so the Crab Nebula in Taurus is M1. He was restricted by the objects he could see from France, making list limited by today's standards. It remains popular due to the length of time it has been around, as well as familiarity with the most common of these objects in it.



The New General Catalogue

The NGC is a list of galaxies, star clusters, emission nebulae and absorption nebulae catalogued by number.

Objects are prefixed with 'NGC' so the Crab Nebula is 'NGC 1952'.

It was published in 1888 by the Danish-Irish astronomer John Louis Emil Dreyer based on work by the Herschel trio of William, Caroline and John.

The first volume had over 1,000 objects in it. Numerous updates and corrections have been published since.

Today the 'Revised New General Catalogue and Index Catalogue' (NGC/IC) contains nearly 8,000 objects.

Catalogue.

No.	G. C.	J. H.	W. H.	Other Observers.	Right Ascension, altim.	Annual Proces- sion, altim.	North Polar Distance, altim.	Annual Proces- sion, altim.	Summary Description.	Notes
1	1	...	...	d'A	h m s 0 0 4	+ 3.07	63 43	-20.1	F, S, R, bet μ 11 and μ 14	
2	6246	...	...	Ld R*	0 0 6	3.07	63 40	20.1	vF, S, μ of G.C. 1	
3	5080	...	...	m 1	0 0 6	3.07	82 28	20.1	F, vR, R, also still	
4	5081	...	...	m 2	0 0 16	3.07	82 23	20.1	vF	
5	...	...	...	St XII	0 0 37	3.08	55 25.0	20.1	vF, vR, N = μ 13, 14	
6	...	...	...	Sw II	0 1 5	3.08	58 25.6	20.1	vF, vR, vK	
7	2	4004	...	...	0 1 14	3.07	120 41.2	20.1	vF, vL, mK, vgrhM	
8	5082	...	...	O Stars	0 1 17	3.08	66 59	20.1	vF, N in μ and	
9	5083	...	...	O Stars	0 1 27	3.08	67 0	20.1	F, R, μ 9, 10 of	
10	3	4015	...	...	0 1 28	3.08	124 58.9	20.1	F, vL, vR, vK	
11	...	...	...	St XII	0 1 29	3.08	55 19.9	20.1	vF, vR, vK, μ vF at μ	
12	4	1	III 808	...	0 1 34	3.07	86 10.2	20.1	vF, vL, vgrhM	
13	5	2	III 806	...	0 1 35	3.08	57 20.8	20.1	vF, vR, S at μ neb	
14	7	3	II 591	...	0 1 37	3.08	74 57.9	20.1	vF, vR, R, vgrhM	
15	5084	...	...	m 3	0 1 50	3.08	69 10	20.1	vF, vR, R, LM	
16	8 = 12	4 = 5	IV 15	...	0 1 52	3.08	63 3.0	20.1	vR, S, R, LM	*
17	...	...	...	Nu II	0 1 58	3.07	102 54.0	20.1	vF, vR, vR, D μ 1.9	
18	5085	...	...	Schultz	0 2 11	3.08	65 2.8	20.1	F, vR, vR, mK, h μ 1.9	*
19	...	...	...	Sw II	0 2 13	3.08	57 55.6	20.1	vF, vR, 3 vF at around	
20	6 = 5086	...	...	Ld R, Schultz	0 2 21	3.09	57 28.2	20.1	F, μ 10 at	
21	...	...	...	Sw II	0 2 25	3.08	57 34.1	20.1	vF, S, vR	
22	...	...	...	St XIII	0 2 36	3.08	62 56.9	20.1	vF, vR, R, hM, r	
23	9	...	III 147	...	0 2 41	3.08	64 51.0	20.1	3 S at μ neb	
24	10	3508	III 461	...	0 2 47	3.06	115 45.0	20.1	vF, vL, mK, vgrhM	
25	11	3509	...	...	0 2 57	3.05	147 48.2	20.1	vF, S, R	
26	5087	...	...	d'A	0 3 14	3.08	64 56.2	20.1	vF, vL, R, 2 F at μ	
27	...	...	...	Sw I	0 3 15	3.09	61 47.3	20.1	vF, vR, vR, D μ 1.9	
28	13	2510	...	...	0 3 25	3.03	147 46.4	20.1	vF, p of 2	
29	14	6	II 853	...	0 3 32	3.09	57 25.6	20.1	vR, vL, E μ	
30	5088	...	...	m 4	0 3 38	3.08	68 49	20.1	Neb μ 13	
31	15	2511	...	...	0 3 39	3.08	147 46.4	20.1	vF, S, R, f of 2	
32	16	...	...	J Schmidt	0 3 42	3.08	71 59.0	20.1	F (Ann. 1)	
33	5089	...	...	m 5	0 3 45	+ 3.07	87 6	-20.1	vF, vR, μ neb at	

14.2 Bayer System for Naming Stars

On star maps, brighter stars appear as a larger dot and smaller stars as a smaller dot.

Stars are labelled according to their brightness. The system that astronomers use is the Bayer Designation, named after the German astronomer Johann Bayer who in 1603 catalogued stars by using the Greek alphabet to represent their brightness where Alpha is the brightest, Beta the next brightest etc.

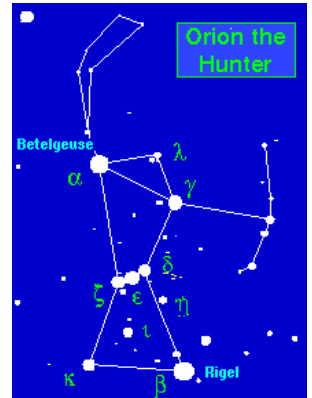
With this system the brightest star in Orion is Alpha Orionis.

When Bayer had used all the 24 letters he started using lower case Latin letters.

It is in use today but has been amended over time by the International Astronomy Union.

Some criticism of the system is that it does not take into account changes in the brightness of stars due to variability or that the Alpha star is sometimes not the brightest star. Changes in constellation boundaries have led to some confusion. The top right star of the square of Pegasus is Alpha Andromedae.

Amongst other ways to label stars are Flamsteed numbers which number stars by their brightness.



14.3 Radiation Pressure vs Gravity in a Main Sequence Star

14.4 Changes in Radiation Pressure-Gravity Balance (Sun-like Stars)

A stellar nebula is a massive, interstellar cloud of dust, hydrogen, helium, and plasma that serves as a nursery for star formation. Gravity causes dense regions within these clouds to collapse, heat up, and form new stars.



For nuclear fusion to occur, both nuclei must have sufficiently high kinetic energy to overcome the electrostatic repulsion between protons

The conditions required to achieve this are:

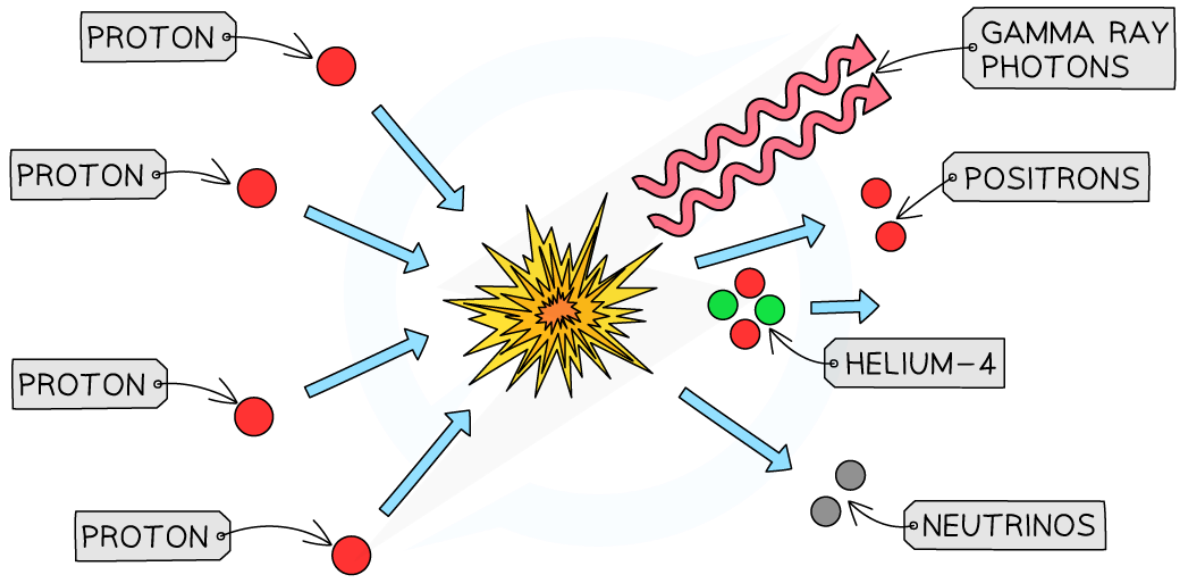
- Very high temperature (on the scale of 100 million Kelvin)
- Very high pressure and density

Four hydrogen nuclei (protons) are fused into one helium nucleus, producing two gamma-ray photons, two neutrinos and two positrons

- Massive amounts of energy are released
- The momentum of the gamma-ray photons results in an outward acting pressure called radiation pressure

Once the core temperature of a star reaches millions of degrees and the fusion of hydrogen nuclei to helium nuclei begins

- The protostar's gravitational field continues to attract more gas and dust, increasing the temperature and pressure of the core
- With more frequent collisions, the kinetic energy of the particles increases, increasing the probability that fusion will occur
- Eventually, when the core becomes hot enough and fusion reactions can occur, they will begin to produce an outward radiation pressure which balances the inward pull of gravity



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Protostars

[Sometimes known as a PMS (pre-main-sequence star)]

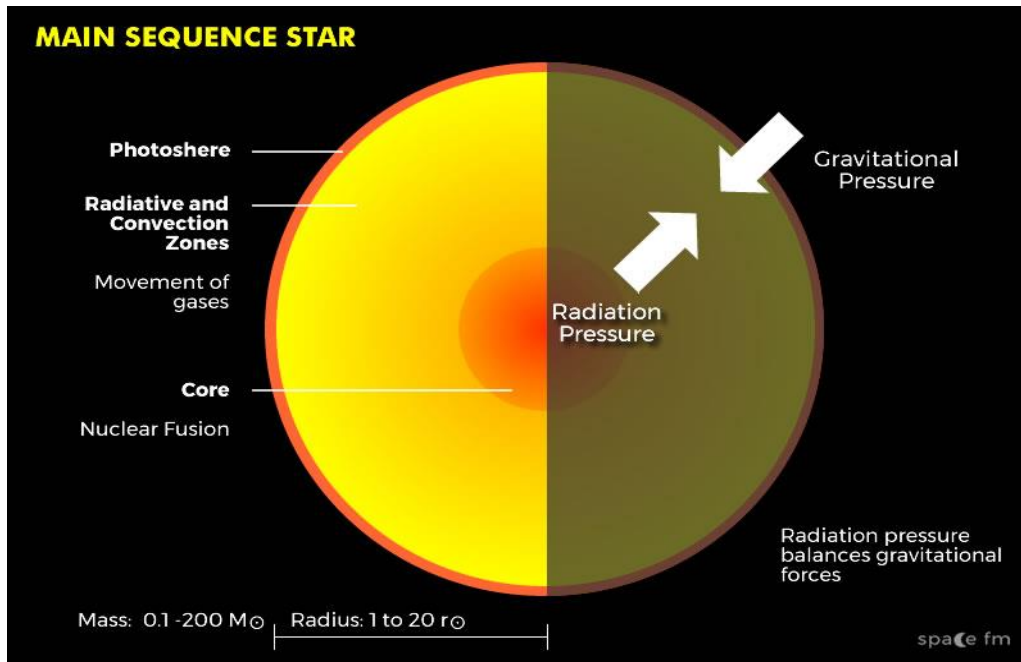
Once the core temperature of a star reaches millions of degrees kelvin and the fusion of hydrogen nuclei to helium nuclei begins

- The protostar's gravitational field continues to attract more gas and dust, increasing the temperature and pressure of the core
- With more frequent collisions, the kinetic energy of the particles increases, increasing the probability that fusion will occur
- Eventually, when the core becomes hot enough and fusion reactions can occur, they will begin to produce an outward radiation pressure which balances the inward pull of gravity

Gravity pulls inward while radiation pressure pushes outward (from nuclear fusion).

Mass and size are dependent on how much material there is to make and develop a star and how undisturbed it is from interstellar winds.

A protostar may evolve over 100,000 years.



Main Sequence:

[Balance between gravity and radiation pressure. Stable.]

Main sequence stars are the majority population of stars we observe. These are between brighter and hotter white stars and dimmer and cooler red stars. Our Sun is somewhere in the middle.

Stars can sit on the main sequence from 8% mass of our Sun to over 40%. Stars up to 1.5 times the mass of our Sun fuse hydrogen atoms to form helium. Above that they start using carbon, nitrogen and carbon to help do the same.

A hotter star will burn its materials sooner and will have a shorter life whereas a cooler star will burn slower and have a longer life.

Red Dwarfs are abundant throughout the universe. They are stable and considered to be candidates for exoplanets capable of sustaining life.

They are known as low mass stars, some have 8% the mass of our sun. This amount of mass is needed to start nuclear fusion in its core. They are considered to be denser however. Because of this they can burn their energy for a very long time.

Brown Dwarfs are known as 'failed stars'. Like other stars they accrete gas but do not get to a level where they start nuclear fusion because they have not built up enough mass and density. They glow a dim red/brown at first and are thought to cool down. Although we know of many brown dwarfs, they are considered difficult to find although they do emit x-rays and radio signals. Not strictly a star.

Between the boundary of very large gas giants and small stars and between roughly 10 to 80 Jupiter masses that of Jupiter. Typically, the smaller stars are 8% of the mass of the Sun so they do not reach this critical mass.

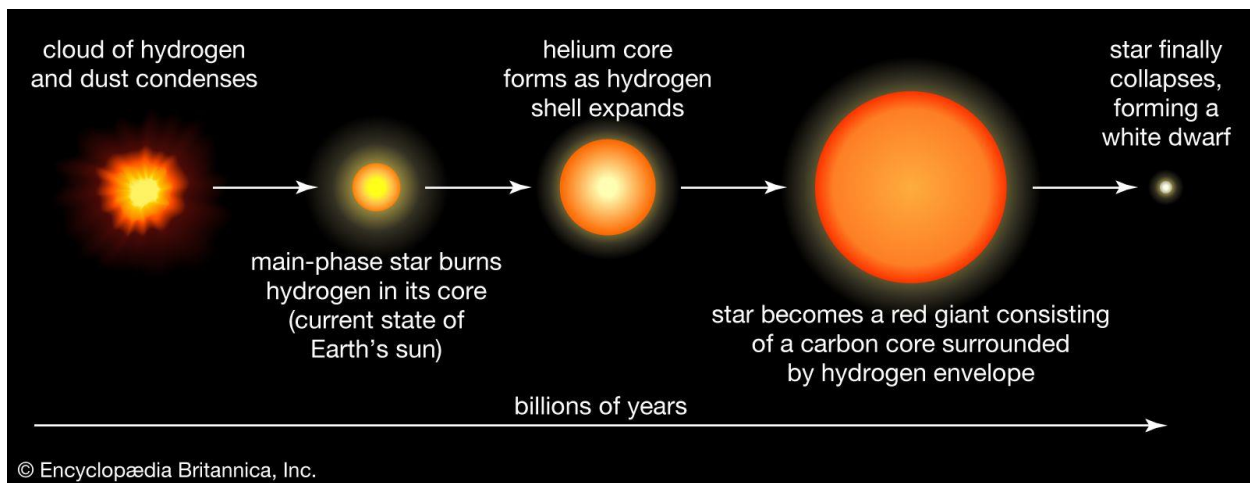
Red Giant Phase

Hydrogen runs out → Fusion slows → Gravity collapses the core → Outer layers expand]

A star exhausting its hydrogen slows its rate of fusion and lacks outward pressure to offset the outward pressure needed to maintain its size. This increases its size until it starts consuming heavier elements.

Typically, up to a thousand times larger than the Sun. Cooler stars of class K, M, S, and C.

Several hundred million of years in this stage



Over its lifetime as it swells to a red giant these same forces keep it together but when it shrinks to a white dwarf and no longer fuses, different forces are at work.

The outer layers of the star are expelled to form a **planetary nebula**.

14.5 Electron Pressure vs Gravity in a White Dwarf

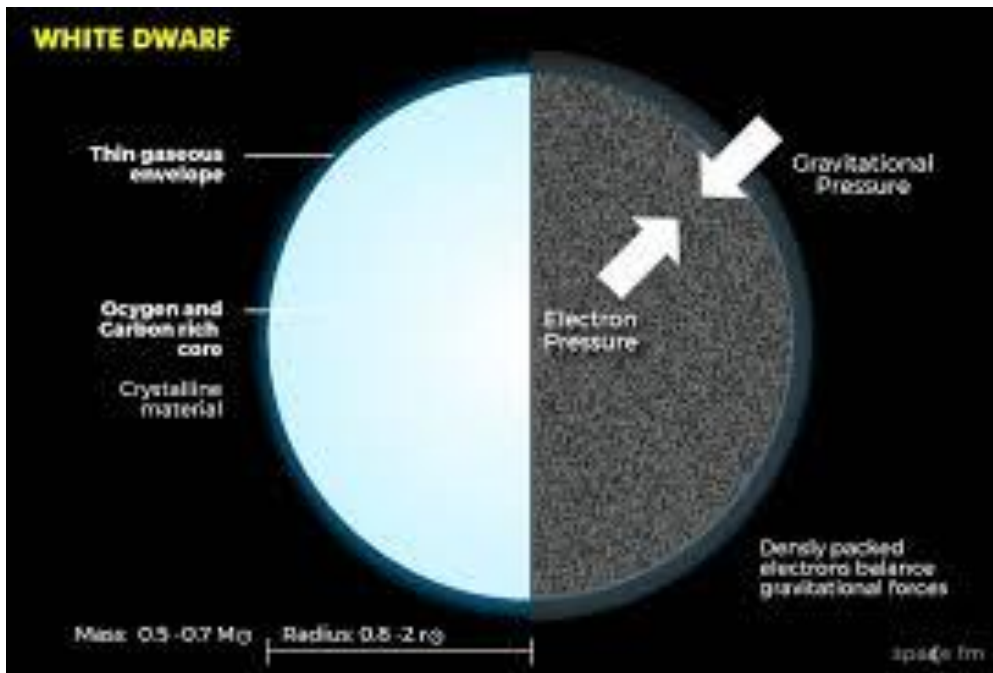
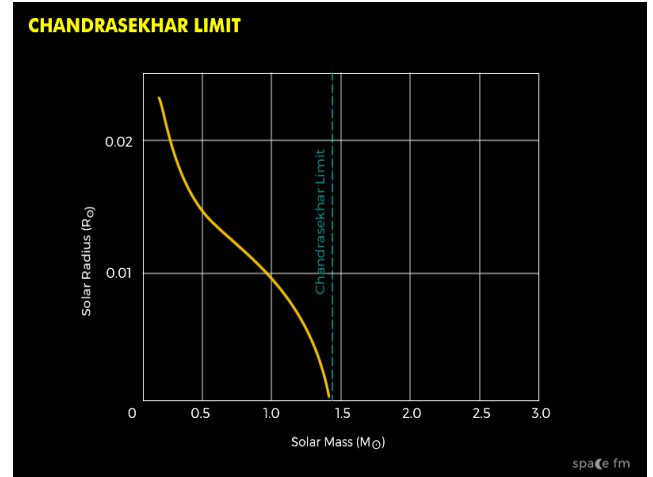
14.8 Chandrasekhar Limit

White dwarf

The core of the former star and is now a crystallised structure of oxygen and carbon, densely packed with electrons.

Whereas before the electrons were free to move around now they are restricted in their movement. The strong gravity means electrons are more compact. This is called electron degeneracy pressure and keeps the white dwarf stable.

Astrophysicist Subrahmanyan Chandrasekhar realised that the higher mass a white dwarf is, the more dense it becomes and so the smaller it is. A white dwarf can be no more than 1.4 solar masses. This is called the **Chandrasekhar Limit**.



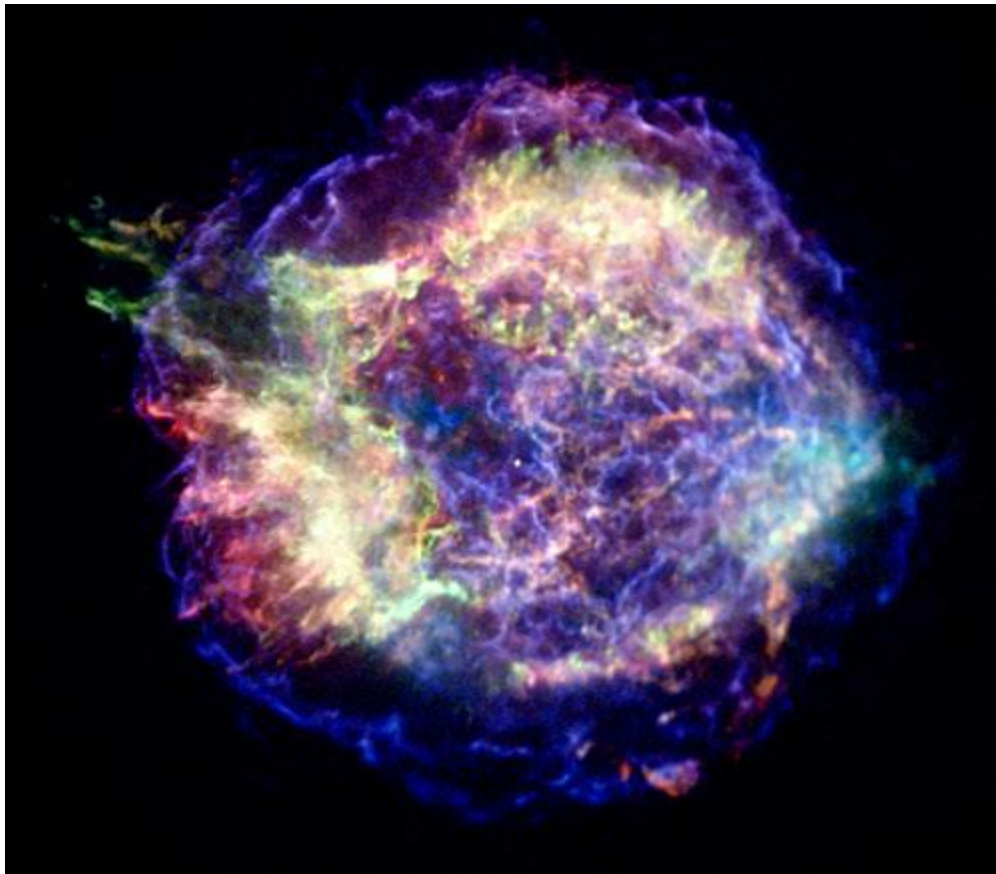
14.6 Radiation Pressure-Gravity Balance in High-Mass Stars

Similar to Sun-like stars but with **more dramatic changes**:

- **Main Sequence**: Gravity & radiation pressure balanced.
- **Red Supergiant**: Fusion of heavier elements up to iron.
- **Supernova**: Gravity overcomes pressure → Core collapses, outer layers ejected.
- **Neutron Star / Black Hole**: Final state depends on mass.

Supergiant Stars are rare stars with high luminosity and among the largest stars. They consume fuel at a fast rate, burning its elements until it reaches iron before destroying itself in a supernova.

Hyper Giants are very rare stars with strong luminosities that burn fuel at an increased rate. They are unstable and vulnerable to losing mass blown by interstellar winds.



14.7 Neutron Pressure vs Gravity in a Neutron Star

There are two types of formation of a neutron star.

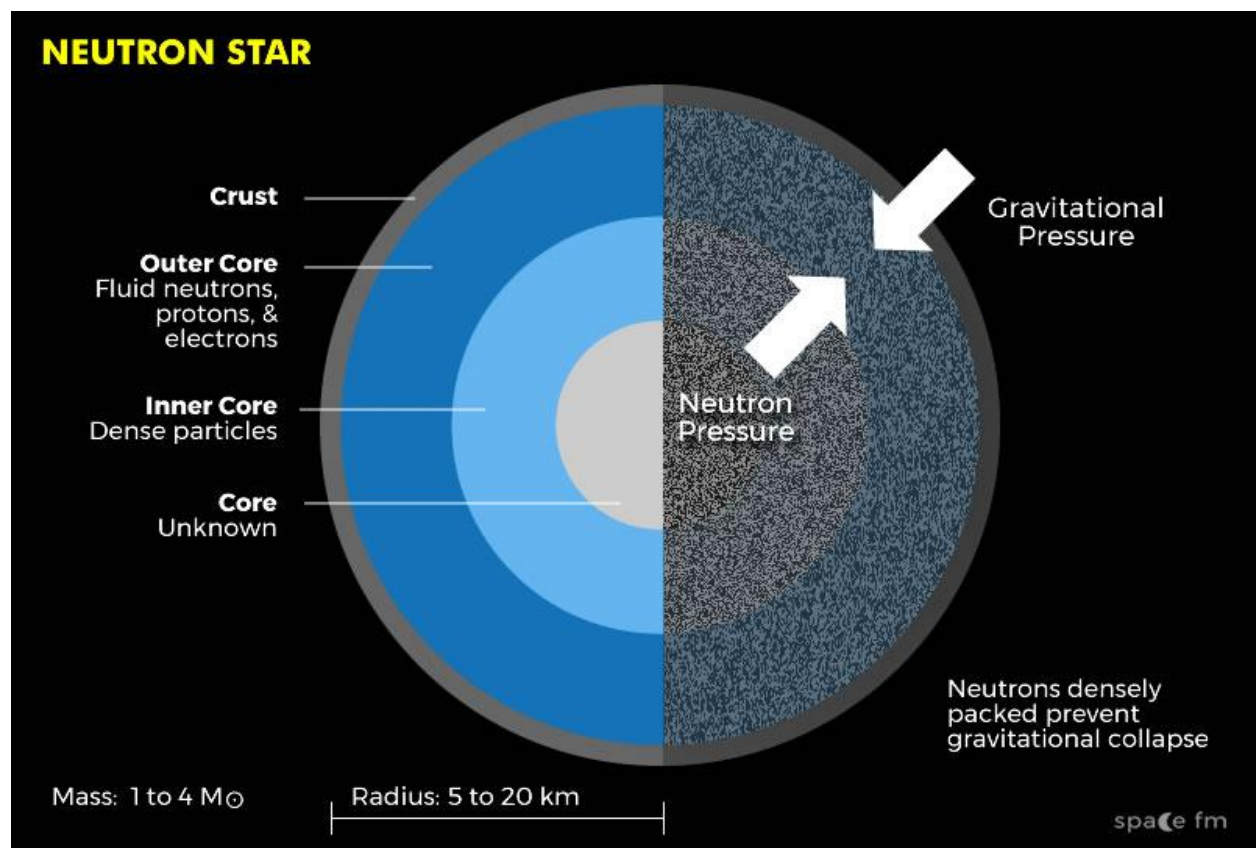
- A star between 4 and 25 solar masses will grow to a red super giant and explode as a supernova, leaving a neutron star smaller than the size of Earth.
- A white dwarf that cannot contain its mass through electron degeneracy pressure and exceeds 1.4 solar masses will become a neutron star

These stars are compressed so much that they are composed entirely of neutrons (made from combined electrons and protons)

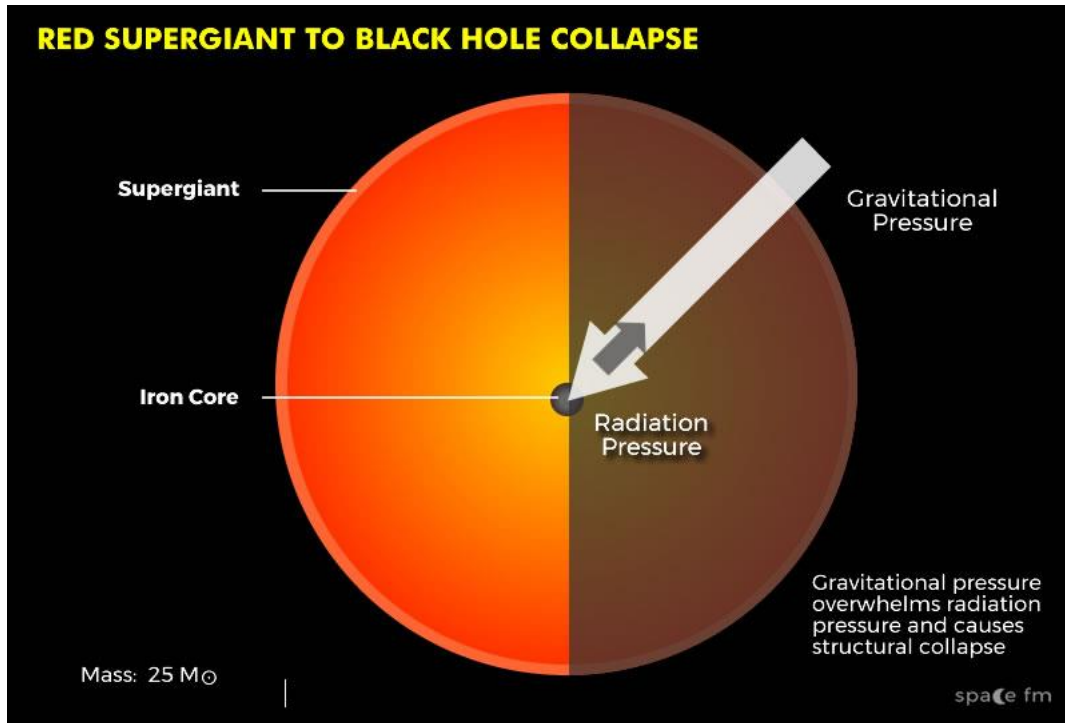
Neutron stars rotate rapidly after formation, typically spinning between fractions of a second and half a minute.

We can detect this because they emit radio pulses, and the ones we detect are known as pulsars.

Radio astronomy has also detected brightness and temperature from neutron stars, and astronomers have used x-ray astronomy to detect them when matter from companion stars falls onto neutron stars.



14.11 Evidence for Black Holes



Black Holes

No astronomer has ever seen a black hole, largely because there is too much material surrounding it and also because it is black as the name suggests.

Most astronomers accept they exist but there is a lot about them that we don't know. [So there is no direct evidence for them]

When a very large star explodes, the mass condenses so much that it collapses in on itself. The gravity is still present.

It appears to pull in any material in the vicinity. Once matter goes past the boundary of a black hole (called the event horizon) it cannot escape back out again; not even light can escape which travels at 300,000 kilometres a second.

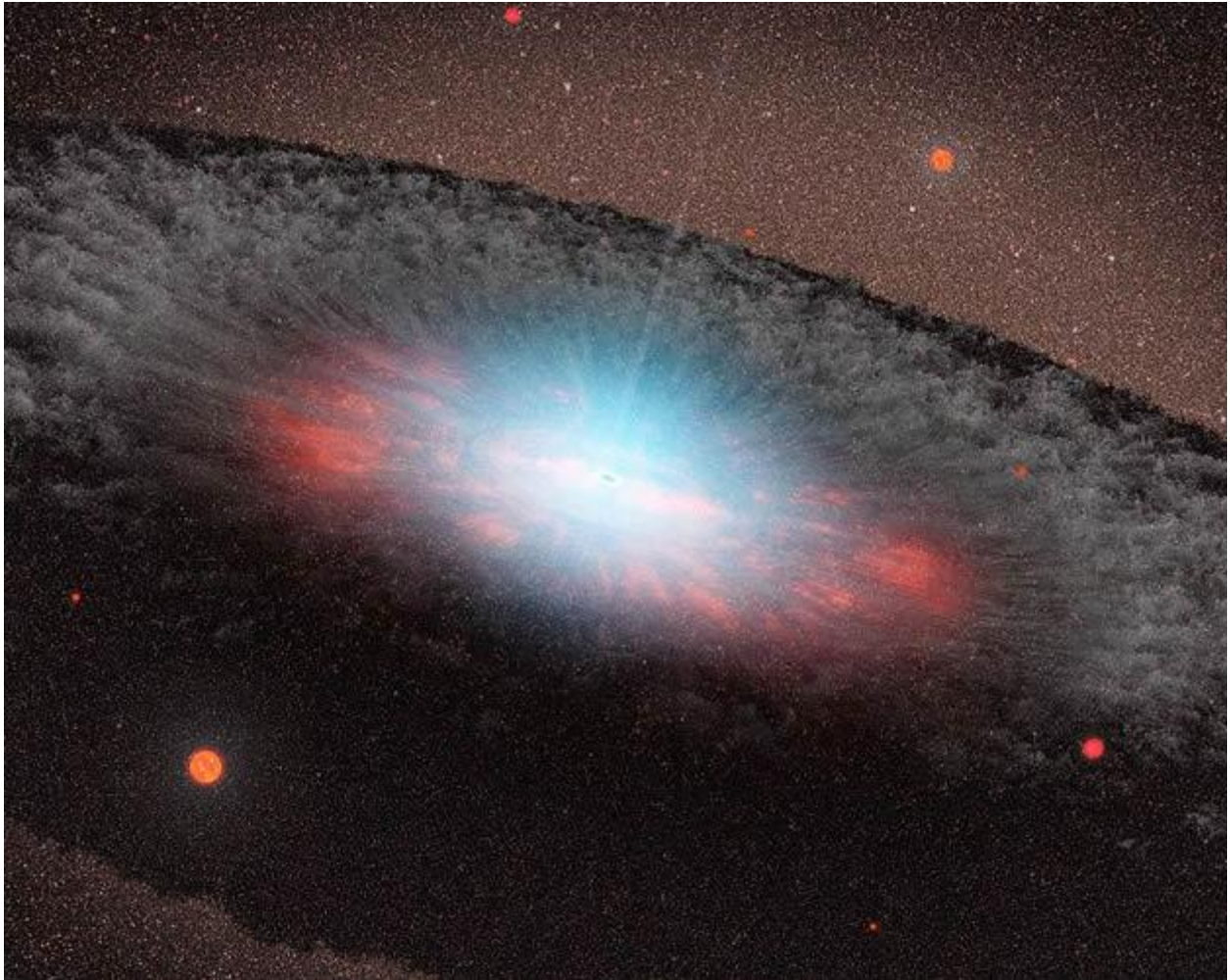
Evidence from black holes comes from binary stars that get their solar material pulled into the hole. This often forms an accretion disc of matter circling the area. It orbits so fast it is hot enough to give off x-rays and gamma ray bursts which we can measure.

The black hole forces such a gravitational force on these particles it can push them light years away, perpendicular to the disc in the form of particle jets travelling near to the speed of light.

It is thought that most galaxies have a super massive black hole in their centre.

Evidence:

- **X-ray emissions:** From accretion disks (e.g., Cygnus X-1).
- **Gravitational lensing:** Warping of light by black holes.
- **Orbital motion of nearby stars:** Observing stars orbiting an **invisible** object (e.g., Sagittarius A* in the Milky Way).



14.9-10 Stellar Evolution

