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PAP – Pulsars and their Properties

Akshat Kapoor

Introduction

End of the Star's Lifecycle

At the end of the life cycle of a star, there are three possibilities. If the star has a mass that is approximately has the mass of 1-8 solar masses, then the star sheds its outer layer, i.e. the 'corona' and the star develops into a White Dwarf which has a size which is slightly bigger than the Earth.

If the star is more than 20 solar masses, then the core collapses into itself and it turns into a black hole, the gravity of which is infinite at the point of singularity.

Finally, if the size of the star is about 8 to 15 solar masses, i.e a medium sized star, then the star explodes into a supernova and leaves a core behind. This core collapses upon itself which due to the dominance of gravitational forces and the protons and electrons are compressed together to turn into neutrons. These neutrons are accumulated in a dense star known as the neutron star.

Neutron Stars

In 1934, two astronomers, Walter Baade and Fritz Zwicky, proposed the existence of a new form of star, the neutron star, which would be the end point of stellar evolution (the star does not evolve beyond this point) They noted: "... with all reserve we advance the view that a supernova represents the transition of an ordinary star into a neutron star, consisting mainly of neutrons. Such a star may possess a very small radius and an extremely high density." [1]

The Neutron stars have a diameter of about 10 miles and have a mass of about 1.4 times of the Sun. It also has very high density and due to this, it possesses a gravitational eld that is about 300 times that of the Earth. Neutron stars also have very intense magnetic elds - about 10^{12} times stronger than Earth's. [2]

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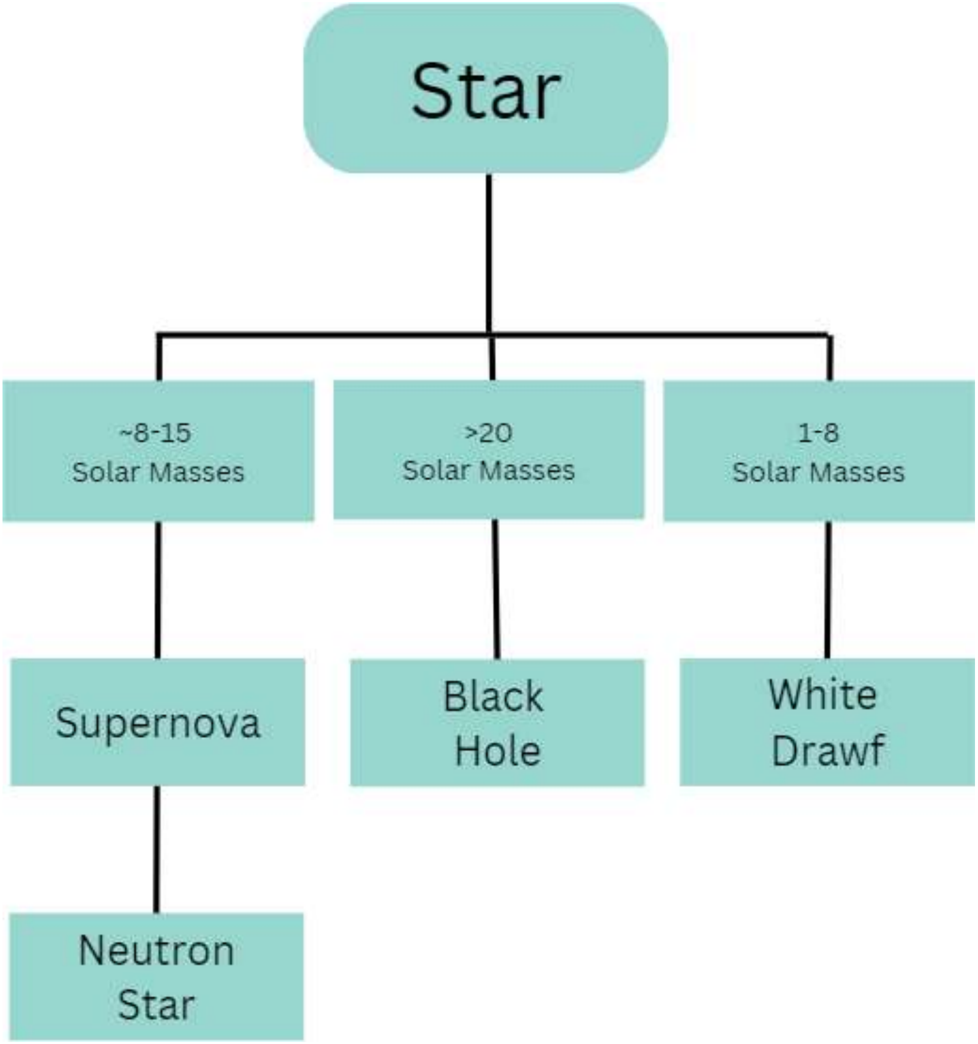

Figure 1: What can happen at the end of a star's life-cycle

Pulsars

'Pulsar', or a 'Pulsating Star' is a highly magnetized rotating neutron star that emits beams of electromagnetic radiation out of its magnetic poles. [3]

Types of Pulsars

Pulsars can be divided on two basis. Firstly, they can be divided on the basis of the number of oscillations and secondly, one the basis of their orientation with other stars. On the basis of oscillations, Pulsars can be further divided into two types: 'Millisecond Pulsars' and 'Normal Pulsars'. In a similar fashion, on the basis of orientations, pulsars can again be divided into two types: 'Binary Pulsars' and 'Regular Pulsars' (also, 'Normal Pulsars'; not to be confused with Oscillatory Normal Pulsars) It is also to be noted, that a binary pulsar can be a millisecond or a normal pulsar, and similarly a regular pulsar can be a millisecond or a normal pulsar.

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Oscillation based classification

As discussed above, on the basis of oscillation, pulsars can be divided into two categories: 'Millisecond Pulsars' and 'Normal Pulsars' Millisecond pulsars, as the name suggests oscillate multiple times a second, thus oscillating on millisecond basis. They tend to have an oscillatory period of less than 10 milliseconds. They are also referred to as 'Recycled Pulsars' since millisecond pulsars tend to be older pulsars which have been sped up with the accretion of matter while being in a binary system. While normal pulsars, are those pulsars which rotate about 1-2 times per second.

Orientation based classification

On the basis on orientation, pulsars are further classified as: 'Binary Pulsars' and 'Regular Pulsars' Again, as the name suggests binary pulsars are those pulsars which are pulsars which are in a companionship with another star, which usually tend to white dwarfs or neutron stars. One peculiar case to be noted, where a pulsar was in a binary companionship which was the double pulsar PSR J0737-3039 [4] On the other end, when pulsars exist alone, they are known as 'Regular Pulsars'

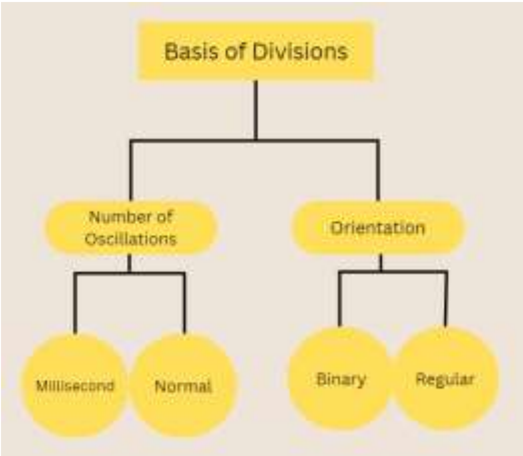

Figure 2: Types of Pulsars

Properties of Pulsars

Physical and Chemical properties

Oscillation

One of the most common and well known (as well as easily observable properties) of a pulsar is its oscillatory motion along its axis. This rotation is caused due to electrons and protons. Since, these electrons and protons their own electric fields, they tend to dampen the electric field of the neutron star causing it to oscillate. Hence, the star begins to oscillate between the positives and negatives.

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Given below are some neutron star oscillatory modes:

- Pressure (p) modes: Driven by pressure.
- Fundamental (f) mode: The first p-mode. Also known as the Kelvin mode. Gravity (G) modes: Driven by buoyancy.
- Inertial (i) modes: Driven by rotation.
- Magnetic (Alfven) modes: Driven by the magnetic force. Spacetime (w) modes: Need dynamical space-time.
- Shear (s,t) modes: Driven by elastic forces in the crust. Super fluidity: The system becomes a multi- fluid.
- Tkachenko modes: Driven by tension of super fluid.

Radiation and Energy

The neutron stars are highly energetic in nature due to their tendency to rotate. Besides, they also possess strong dipolar magnetic fields. In Pacini's paper (Pacini 1967) [1], he mentioned that a rapidly rotating neutron star could provide energy for the surrounding nebula (which later led to the discovery of crab pulsar).

Pulsar beams

Another characteristic feature of the pulsars is the beams ejected from its polar ends. These beams are a result of rotational energy of a pulsar (neutron stars). This rotational energy and a strong magnetic field generates an electrical field which results in the acceleration of protons and electrons on the surface, leading to the creation of this beam.These beams are in the shape of a cone whose tip originates at the magnetic polar ends of the stars.

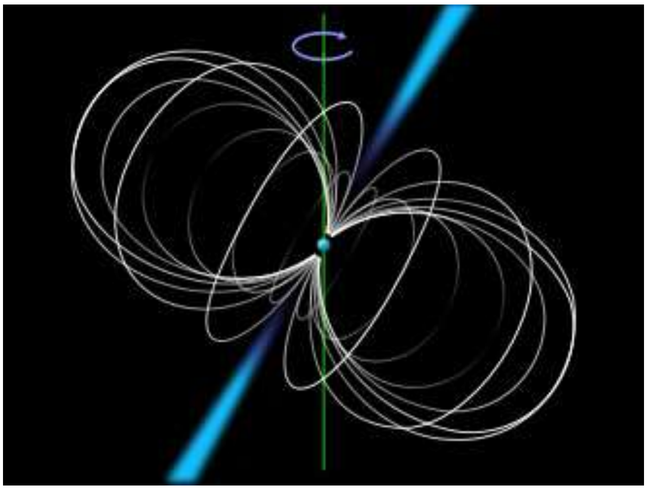

Figure 3: Beams from a binary star [5]

Luminosity

Luminosity is an intrinsic property of radio pulsars related to the properties of the magneto-spheric plasma and the beam geometry, and inversely proportional to the observing

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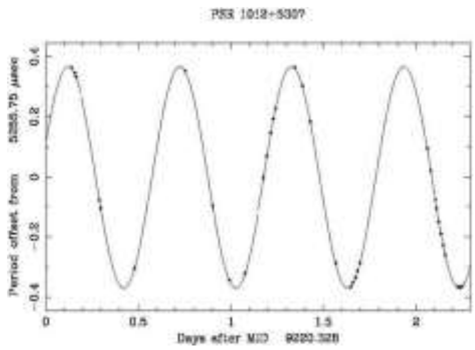
frequency. In traditional models, luminosity has been considered as a function of the spin parameters of pulsars [6]

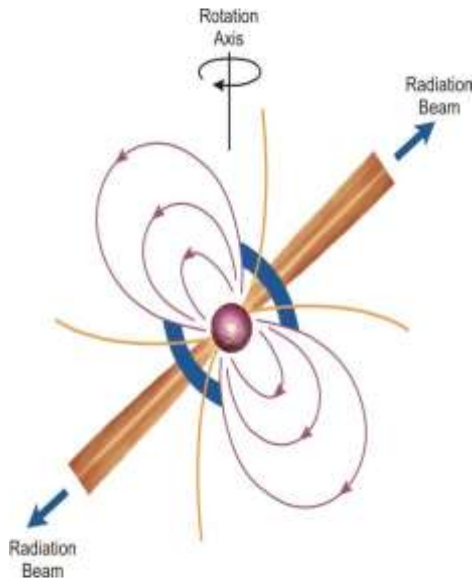
Magnetic Field

Magnetic fields in Pulsars are generally dipolar in nature. These magnetic fields are also involved in the ejection of beams from the magnetic ends of the pulsars. Often, the magnetic field is not aligned with the spin axis, so those beams of particles and light are swept around as the star rotates [7]

Density and Size

As discussed above, pulsars and neutron stars are extremely dense in nature. We can think of them as the entire mass of our Sun, compressed into an area as big as a city like Paris or New York. Pulsars have a density of 10^{14} g/cm^3. For a reference, it can be said that pulsars are 1000x denser than water.





(a) (b)

Figure 4: Left: Graph depicting oscillations in pulsars [9] Right: Oscillation in Pulsars [8]

Observational Properties

Identification of pulsars using physical versus observational properties:

While it is of common knowledge of how pulsars are identified, there are two possible explanations for the source of the oscillatory motion that were discussed during the early months of this discovery. The first explanation offered explained that these pulsars might be showing this property due to the oscillation of a condensed star (for example: The neutron star).

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The second explanation offered said that the mentioned property can be present due to a rapidly orbiting binary system In 1966, shortly before the discovery, Melzer and Thorne showed that a white dwarf star could have a resonant periodicity of about 10 seconds, for radial oscillation in the fundamental mode. [1]

Some notable pulsars

- The first radio pulsar "CP 1919" (now known as PSR B1919+21), with a pulse period of 1.337 seconds and a pulse width of 0.04-second, was discovered in 1967.
- The first binary pulsar, PSR 1913+16, whose orbit is decaying at the exact rate predicted due to the emission of gravitational radiation by general relativity
- The brightest radio pulsar, the Vela Pulsar. The first millisecond pulsar, PSR B1937+21
- The brightest millisecond pulsar, PSR J0437-4715 The first X-ray pulsar, Cen X-3
- The first accreting millisecond X-ray pulsar, SAX J1808.4-3658 The first pulsar with planets, PSR B1257+12
- The first pulsar observed to have been affected by asteroids: PSR J0738-4042
- The first double pulsar binary system, PSR J0737-3039
- The shortest period pulsar, PSR J1748-2446ad, with a period of about 0.0014 seconds or 1.4 milliseconds (716 times a second).
- The longest period neutron star pulsar, PSR J0901-4046, with a period of 75.9 seconds
- The longest period pulsar, at 118.2 seconds, as well as the only known example of a white dwarf pulsar, AR Scorpii.
- The pulsar with the most stable period, PSR J0437-4715
- The first millisecond pulsar with 2 stellar mass companions, PSR J0337+1715
- PSR J1841-0500, stopped pulsing for 580 days. One of only two pulsars known to have stopped pulsing for more than a few minutes.
- PSR B1931+24, has a cycle. It pulses for about a week and stops pulsing for about a month. One of only two pulsars known to have stopped pulsing for more than a few minutes.
- Swift J0243.6+6124 most magnetic pulsar with $1.6x10^{13}$G.
- PSR J1903+0327, a 2.15 ms pulsar discovered to be in a highly eccentric binary star system with a Sun-like star.

PSR J2007+2722, a 40.8-hertz 'recycled' isolated pulsar was the first pulsar found by volunteers on data taken in February 2007 and analyzed by distributed computing project Einstein@Home. PSR J1311-3430, the first millisecond pulsar discovered via gamma-ray pulsations and part of a binary system with the shortest orbital period.[3]

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