Summer Project'25

Astral Trails

SESSION 2

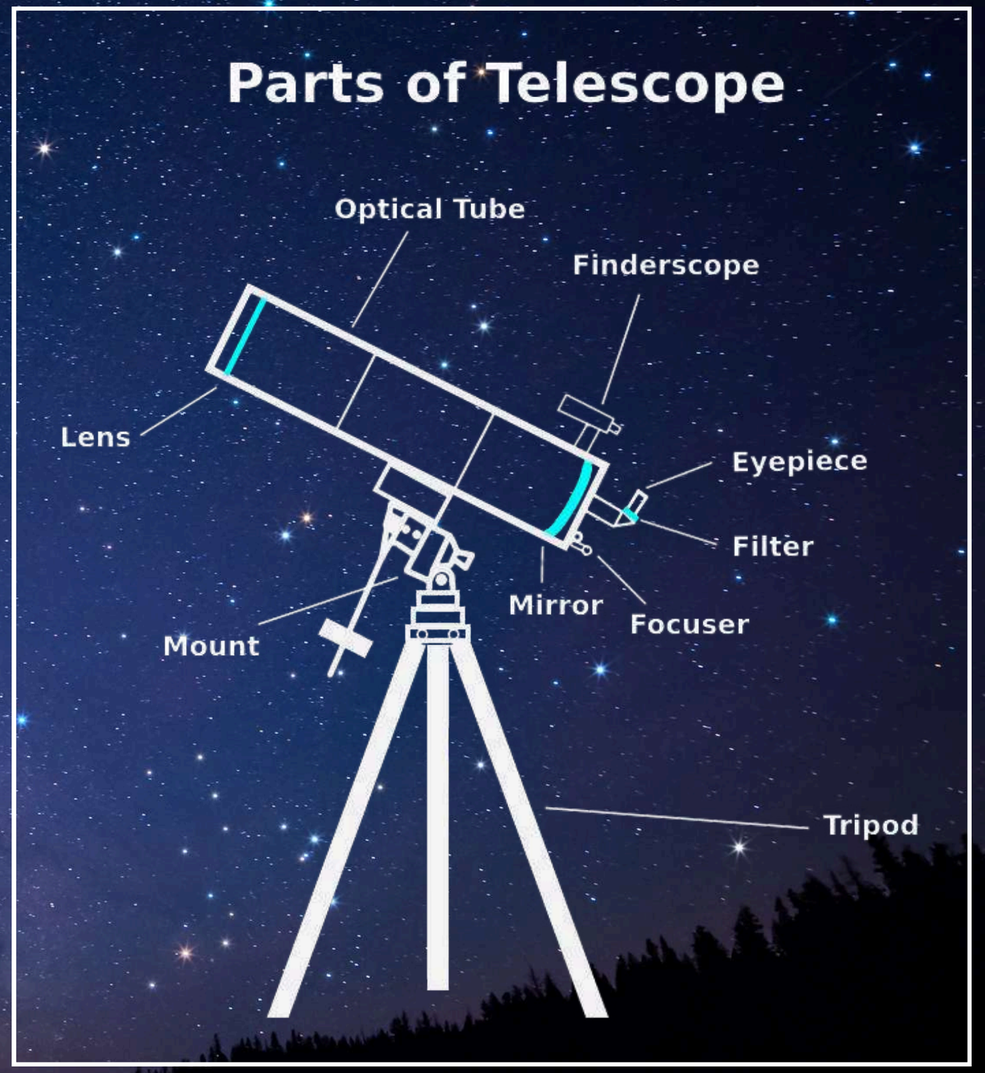
Observational Instruments

Tools used to observe objects and phenomena that occur in space:

- Telescopes:
  1. Optical Telescopes
  2. Radio Telescopes
  3. Space Based Telescopes
- Starshoot Autoguider
- Cameras

Telescopes

- Telescope magnifies distant objects using curved mirrors and lenses, based on refraction and reflection principles.
- Galileo Galilei, an Italian astronomer, was the first person to use a telescope for astronomical studies.



Types of optical telescopes

Reflecting

Refracting

Catadioptric

Types of optical telescopes

Newtonian

Cassegrain

Starshoot Autoguider

Camera

Radio Telescopes

- These employ the use of radio waves to peek into the night sky.
- Unlike optical telescopes, radio telescopes can be used in the daytime as well as at night.
- Due to the weak signals received, larger radio telescopes (antennas) along with sensitive devices are being built.
- India has its own radio observatory in the form of GMRT (Giant Metrewave Radio Telescope)

Parkes Solar Observatory

?

GMRT (Pune, Maharashtra)

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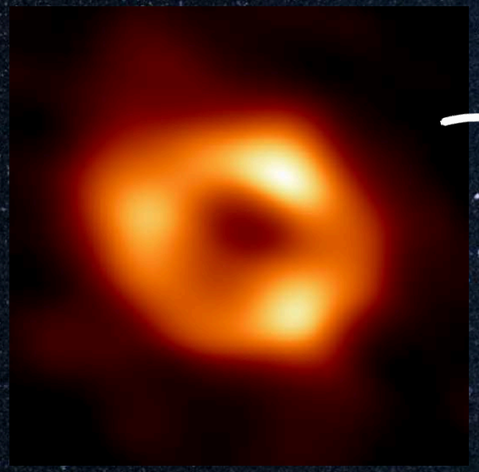
Parkes Solar Observatory



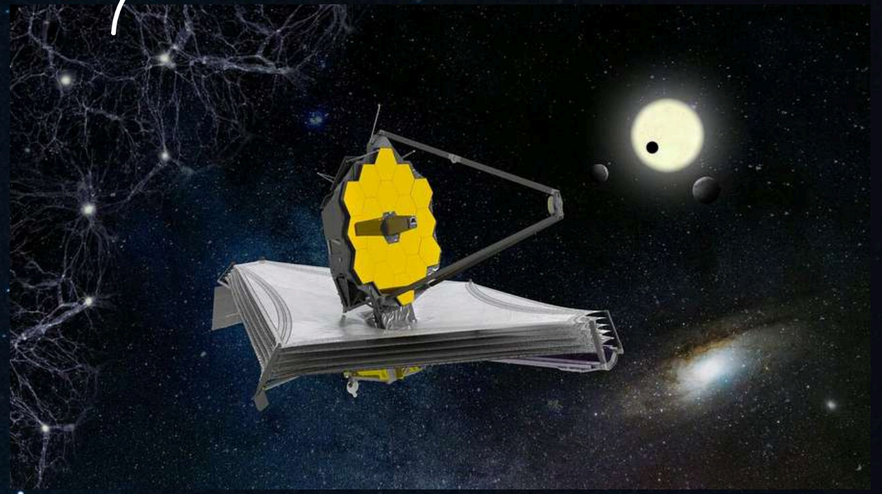
First Black Hole image taken using Radio Telescopes

GMRT (Pune, Maharashtra)

Space based Telescopes

- The main problem of ground based telescopes is the atmospheric interference in observations.
- For this, we put telescopes into the space to negate the same and get clear and crisp data across all wavelengths.
- Main examples of these are Hubble Space Telescope, James Webb Space Telescope etc.

JWST



AstroSat

Hubble

Telescopes

What’s a Telescope?

An optical instrument which uses mirrors or/and lenses or their combination used to obtain images of distant objects

History

Pre-Telescopic observatories: Machu Picchu and Stonehenge

History

- Galileo’s Telescope

Functions of a telescope

Collect the faint light coming from astronomical source
2. Focus the collected light into a point or image

More the aperture (light collecting area), more the amount of light entering

Components

Simply viewing the sky with a telescope and writing down descriptions is a very inefficient way

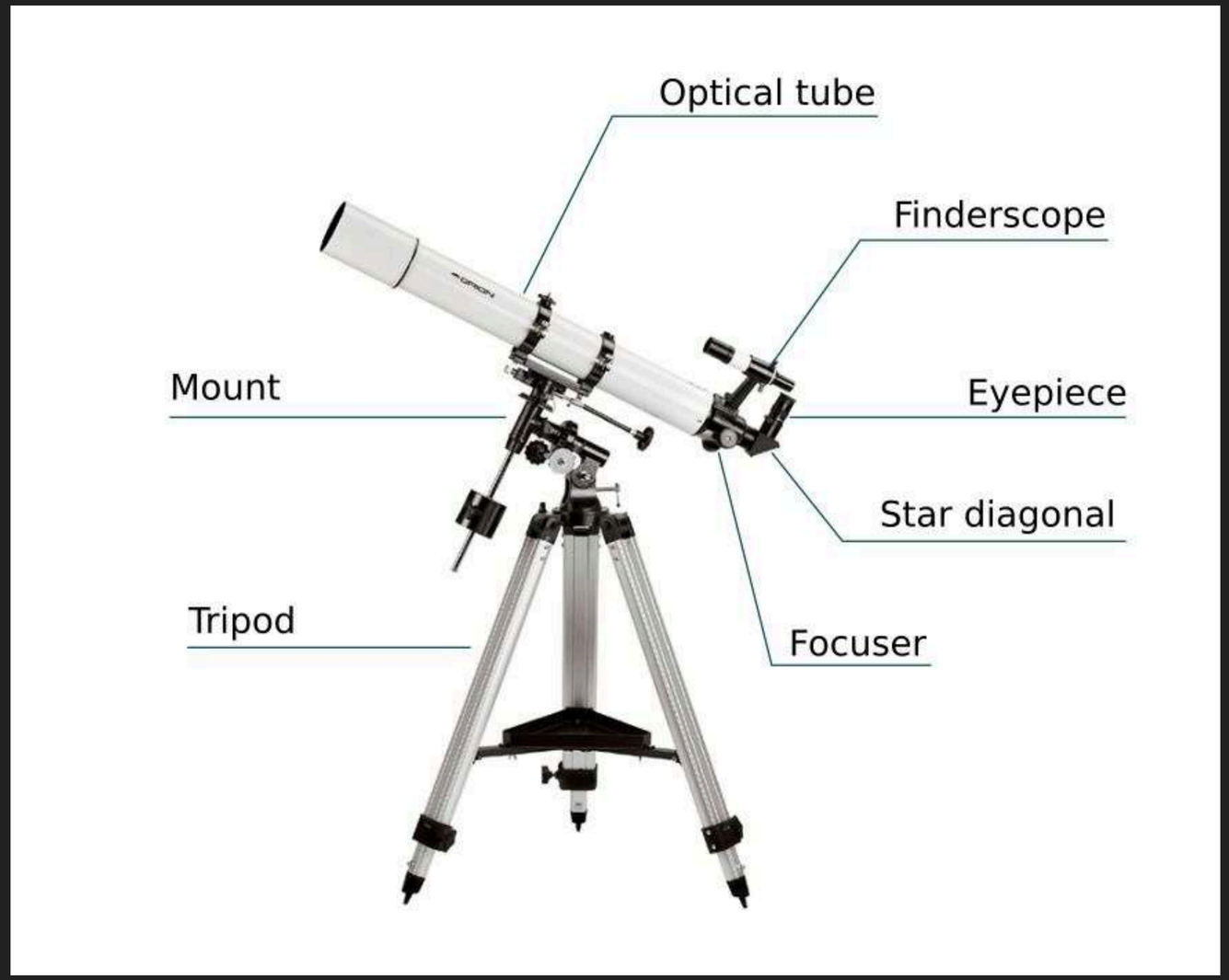
That is why modern telescopes usually involve some more components along with them

1. Telescope, which collects light
An instrument to sort incoming radiation by wavelength, as per need
A Detector, to record the observations

Types of telescopes: Based on wavelength of light they observe

1. X-ray telescopes
2. UV telescopes
3. Optical telescopes [Visible region]
4. Infrared telescopes
5. Submillimeter telescopes [Microwave region]
6. Radio telescopes

Parts of a Telescope

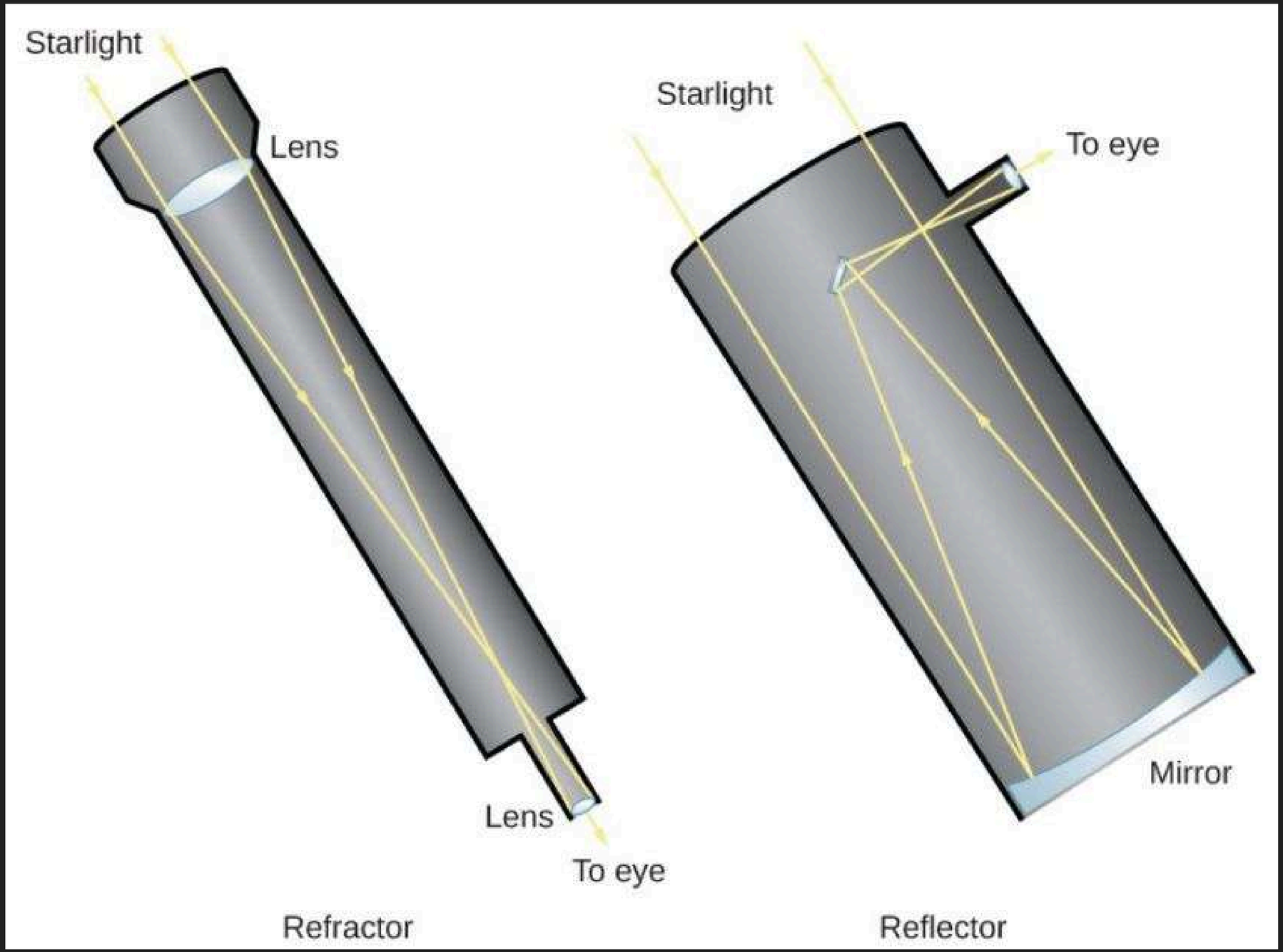


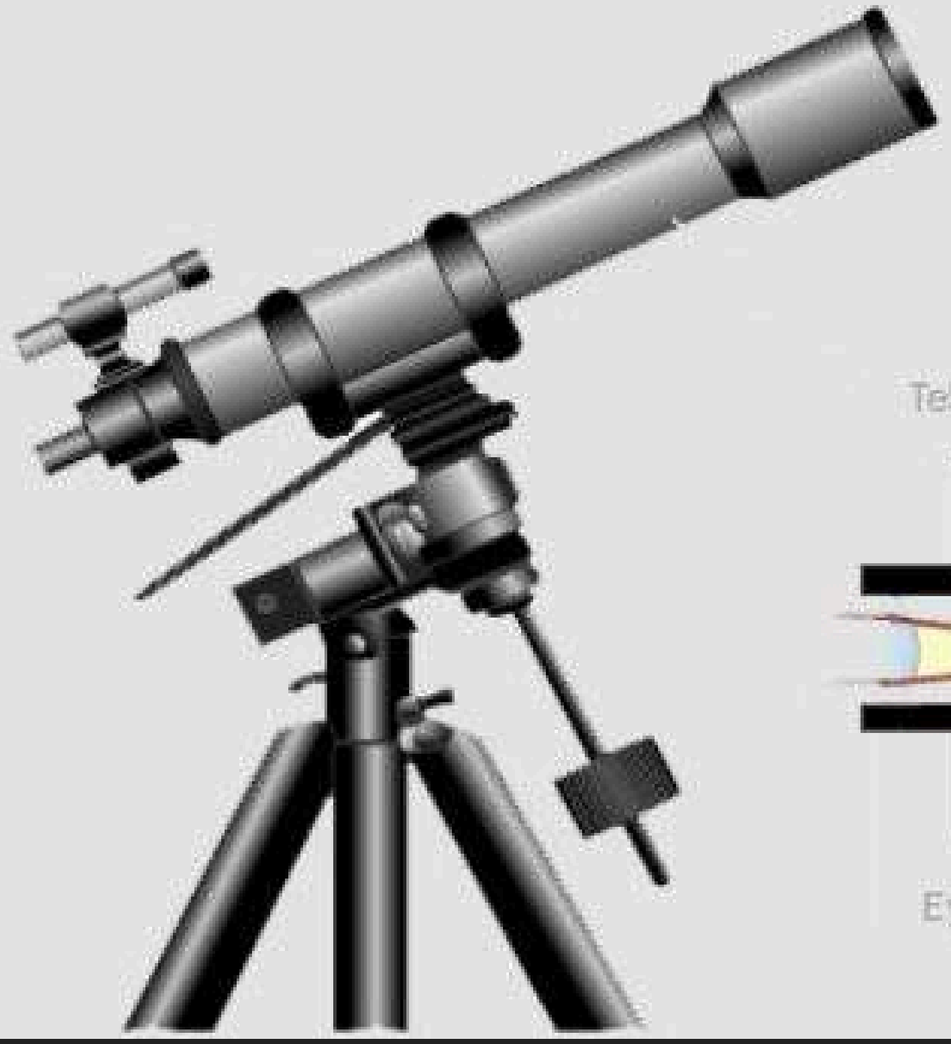
- Minimum 2 lenses/mirrors
- Varying sizes of eyepieces

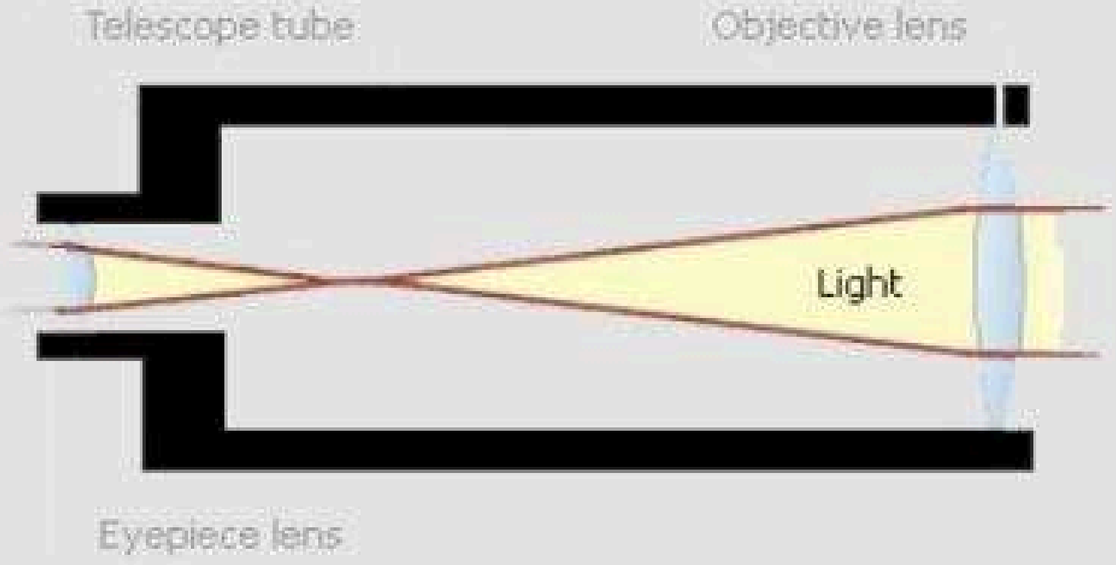

CELESTRON
AstroMaster 130

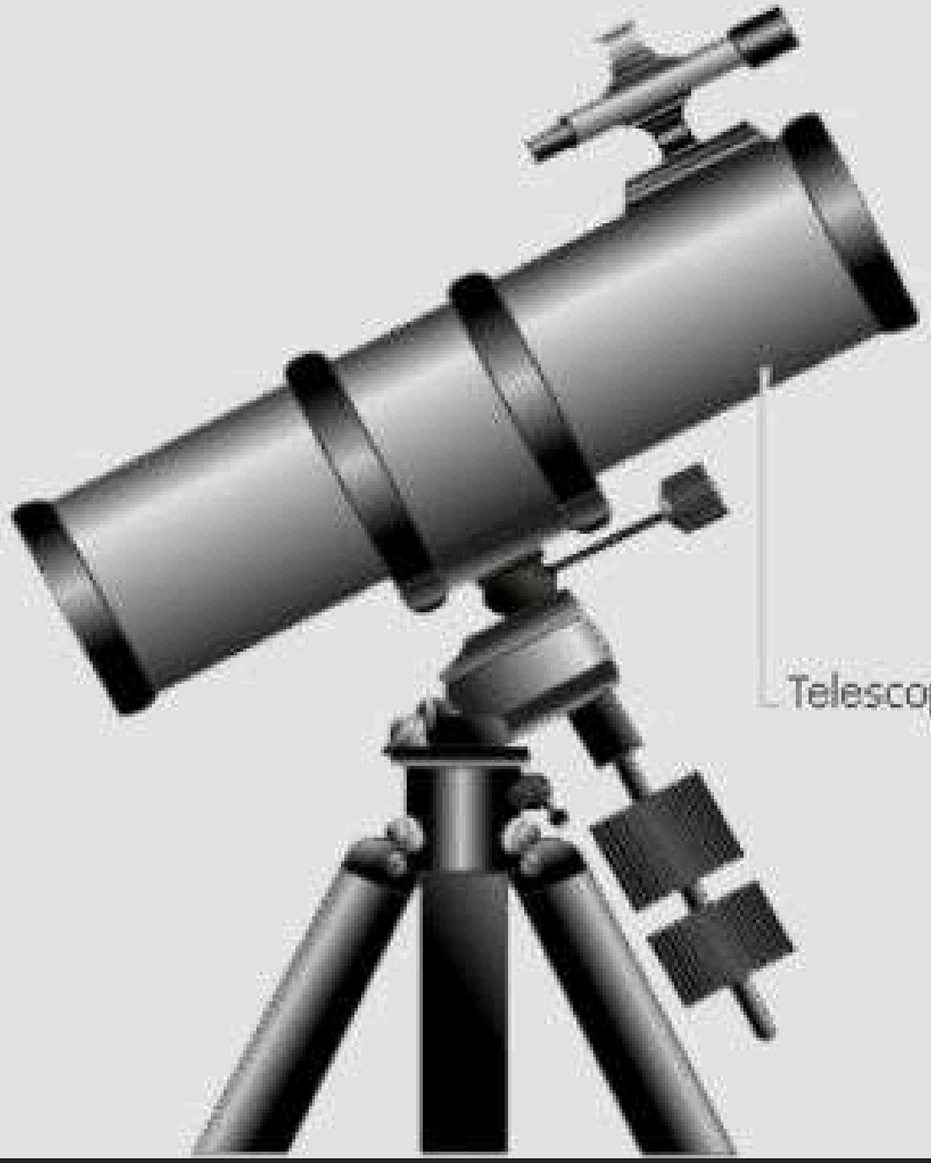
Types of telescopes

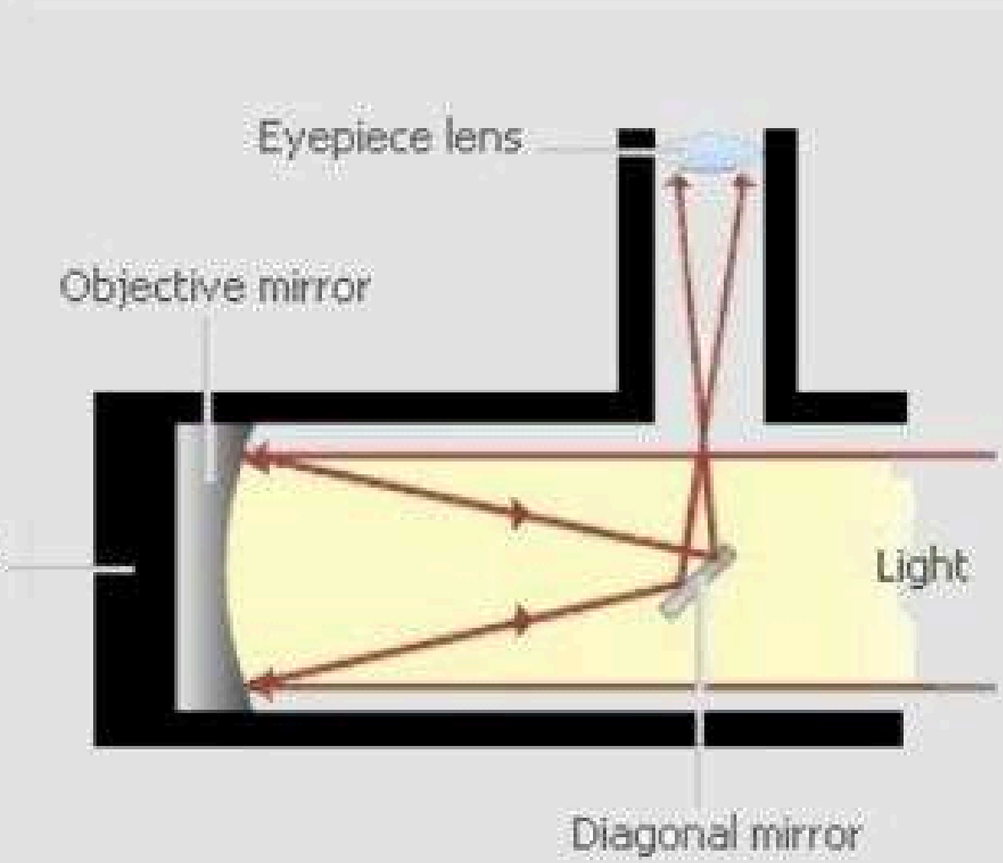
- Refracting Telescope: Uses lenses
- Reflecting Telescope: Uses mirrors
- Catadioptric Telescope: Combination of mirrors and lenses


Starlight
Lens
Lens
To eye
Refractor
Starlight
To eye
Mirror
Reflector

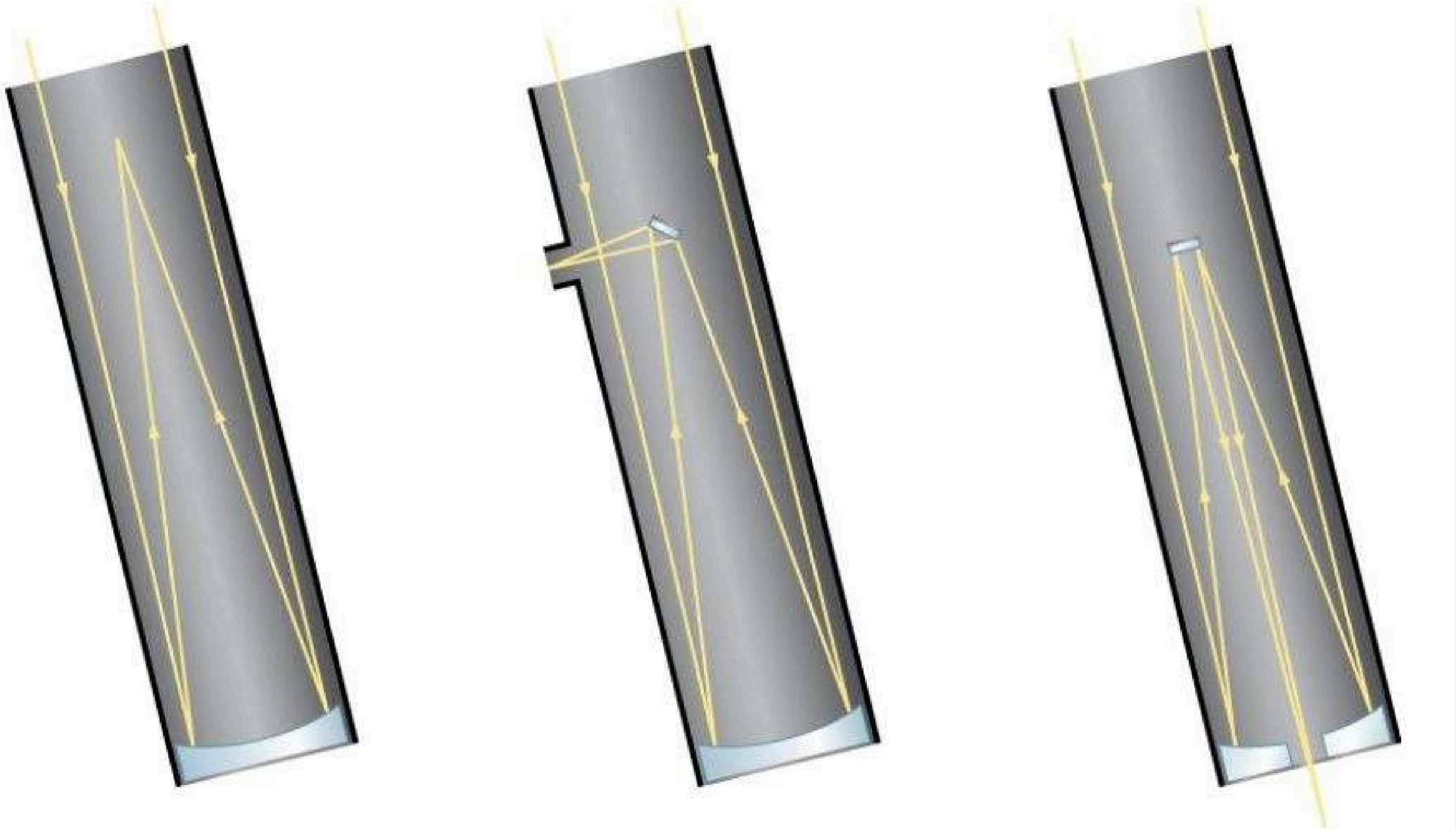



Telescope tube
Objective lens
Light
Eyepiece lens


Telescope tube


Eyepiece lens
Objective mirror
Light
Diagonal mirror

A Problem with Refractors

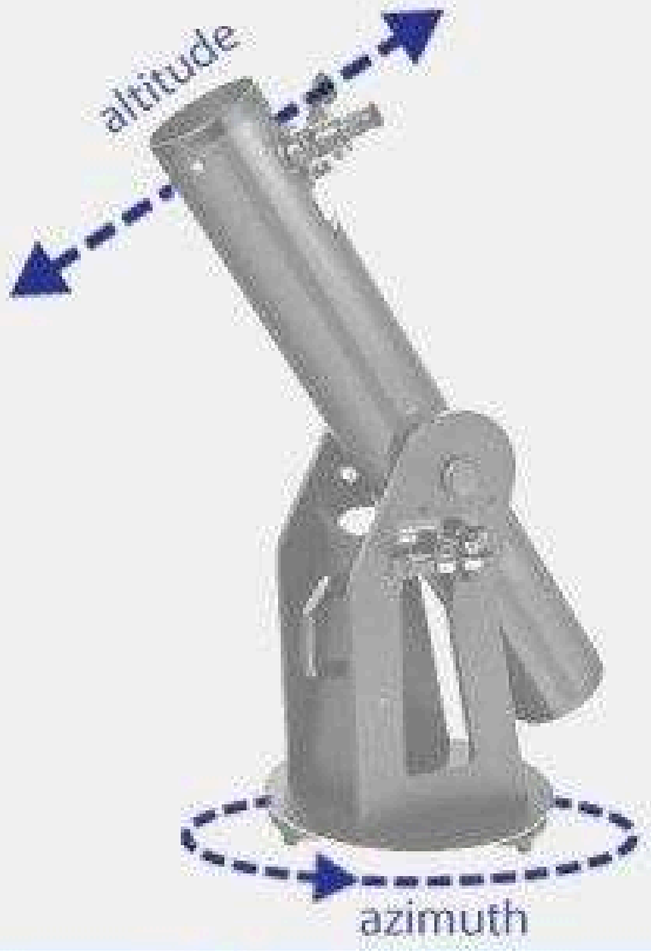

Prime focus
Newtonian focus
Cassegrain focus

Telescope Mounts

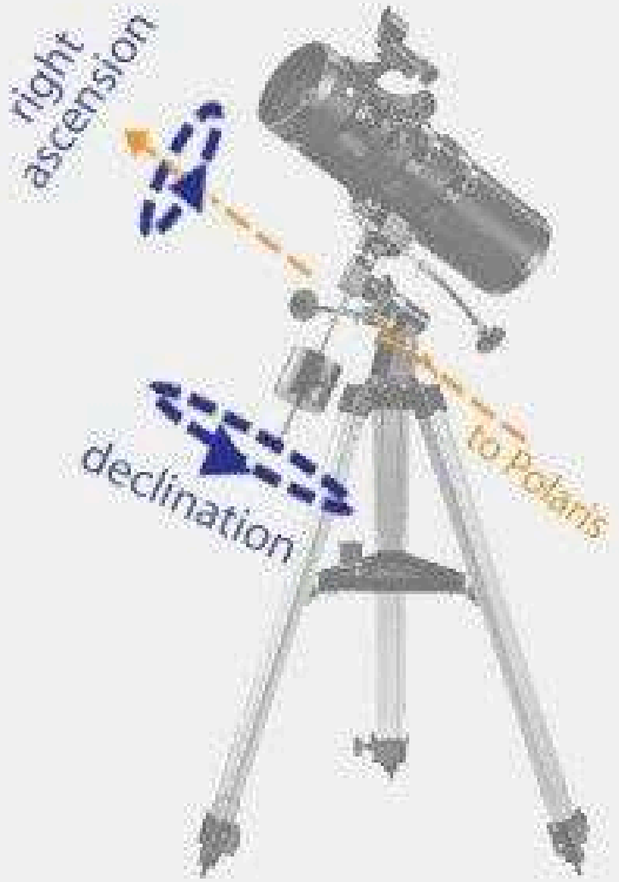
Alt-Azimuth: Aligned with local zenith
Equatorial: Aligned with polar axis and requires a heavy counter-weight

Comparison of Mount Types

Alt-Az



Dobsonian



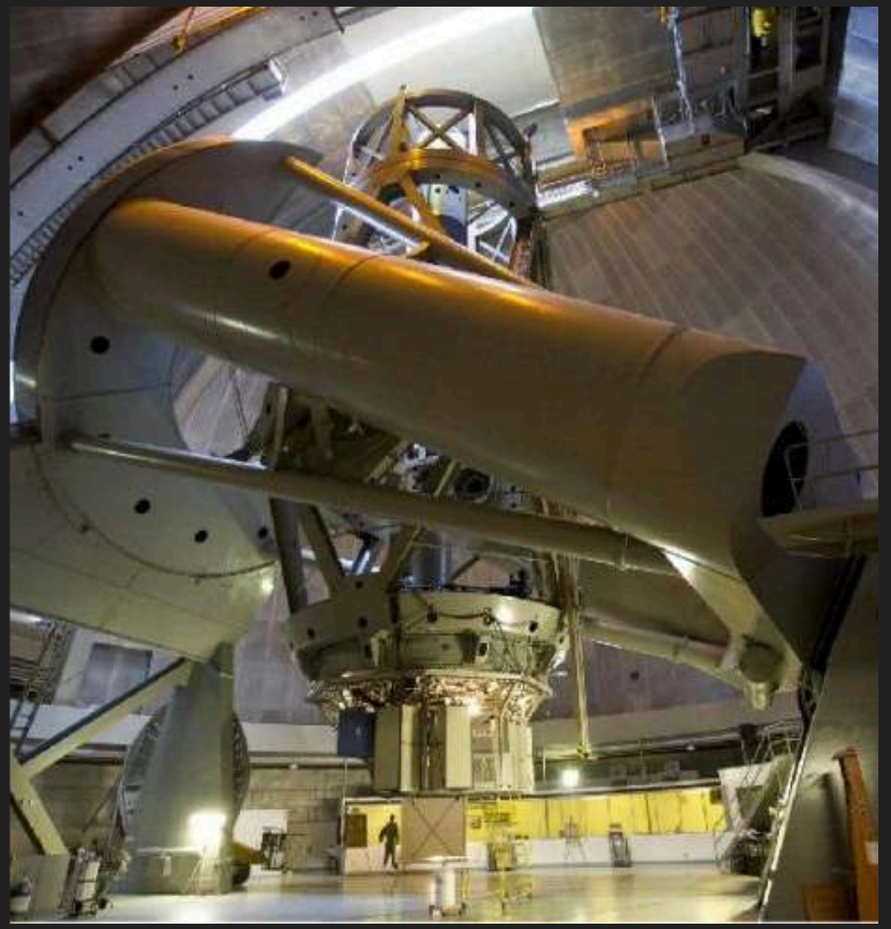
Equatorial

A good telescope?

The key characteristic of a telescope is the aperture of the main mirror or lens

Magnification is not one of the criteria on which to base your choice of a telescope. The magnification of the image is done by a smaller eyepiece, so the magnification can be adjusted by changing eyepieces

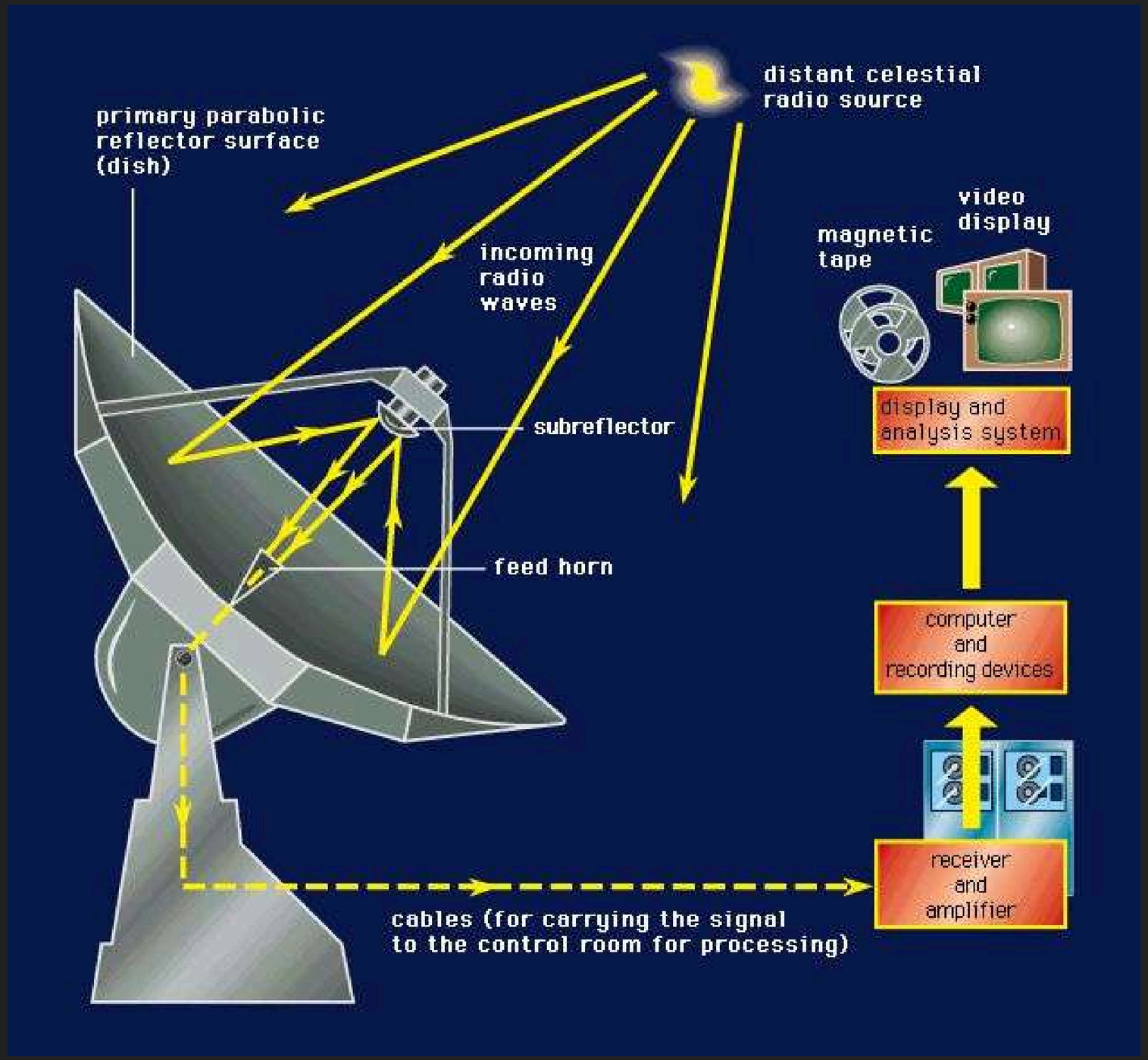
A sturdy and stable mount is essential



Radio Telescopes

Radio waves are not something which can be heard
They can produce current in conductors (metal antenna or something similar)
Radio waves are reflected by conducting surfaces

A radio-reflecting telescope consists of a concave metal reflector (called a dish), analogous to a telescope mirror
The radio waves collected by the dish are reflected to a focus, where they can then be directed to a receiver and analyzed
Furthers methods like interferometry can be applied


distant celestial
radio source
primary parabolic
reflector surface
(dish)
incoming
radio
waves
video
display
magnetic
tape
display and
analysis system
subreflector
feed horn
computer
and
recording devices
receiver
and
amplifier
cables (for carrying the signal
to the control room for processing)

Resolution

Resolution refers to precision of details present in image

Depends on size of telescope; Large apertures produce sharper images

Measured in units of arcseconds

1 arcsecond = 1/3600 degree

$\sin\alpha = 138/D$

Adaptive Optics

One of the clearest images of Jupiter taken from ground based telescope

Advanced Stellar Phenomena

Pulsars, Neutron Stars, Magnetars & Black Holes

LINKS

- https://youtu.be/oLoLey75i2k?si=XhPCxdbKNkCIFink
- https://youtu.be/tWsWcWAcK2U?si=T8AdeKON3s98Krlp
- https://youtu.be/jRPjgKs-aw4?si=Mh1Kcc5PcpCPwr5I
- https://youtu.be/e-P5IFTqB98?si=mOzqtGlCrvBYVBdI
- https://youtu.be/4rTv9wvvat8?si=G36O03JtUb2-ZHsd

Basic Structure of Stars

Mass governs a star's temperatUre, luminosity, and diameter.

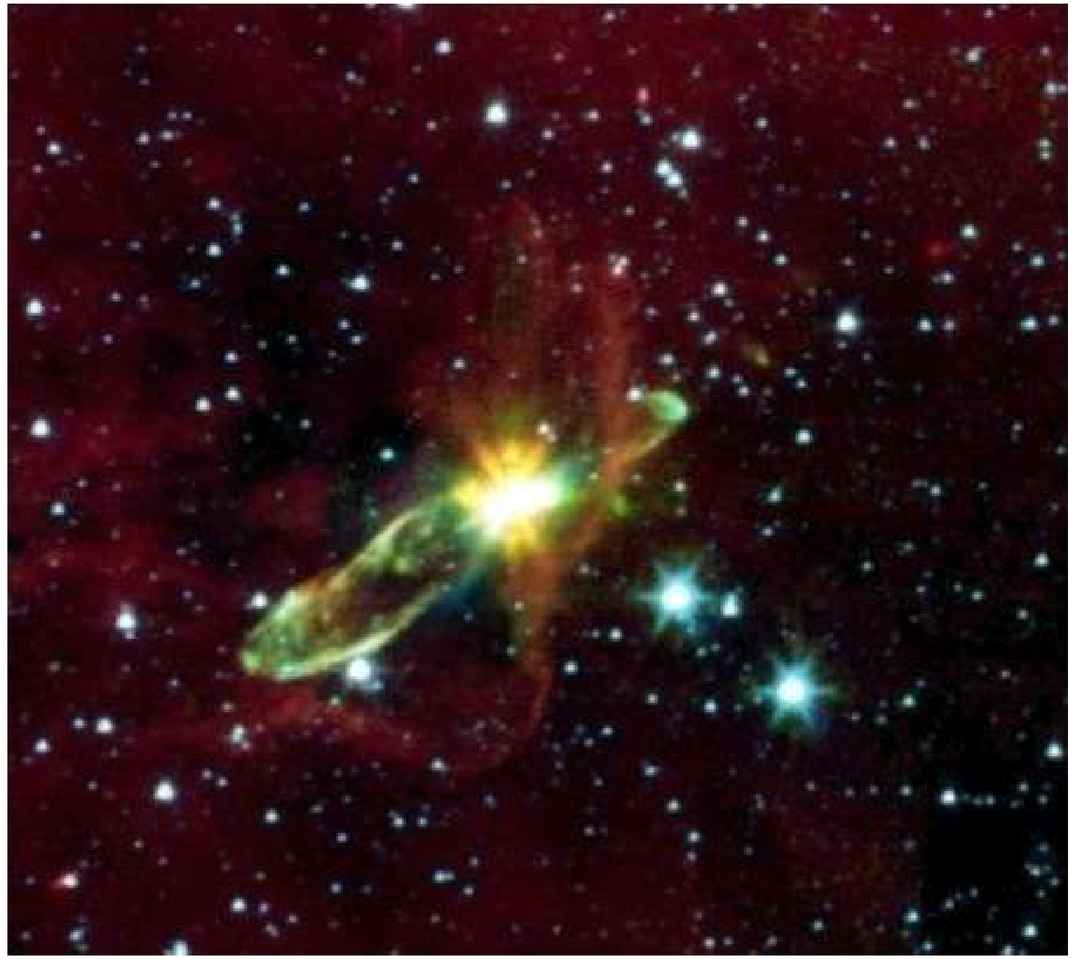
Mass Exects:
The more massive the star, the greater the force of gravity towards its center of mass (the core).

As a result, a star needs to be hotter and denser to counteract its own gravity.
The balance between gravity squeezing inward and outward pressure is maintained by heat due to nuclear reactions and compression.

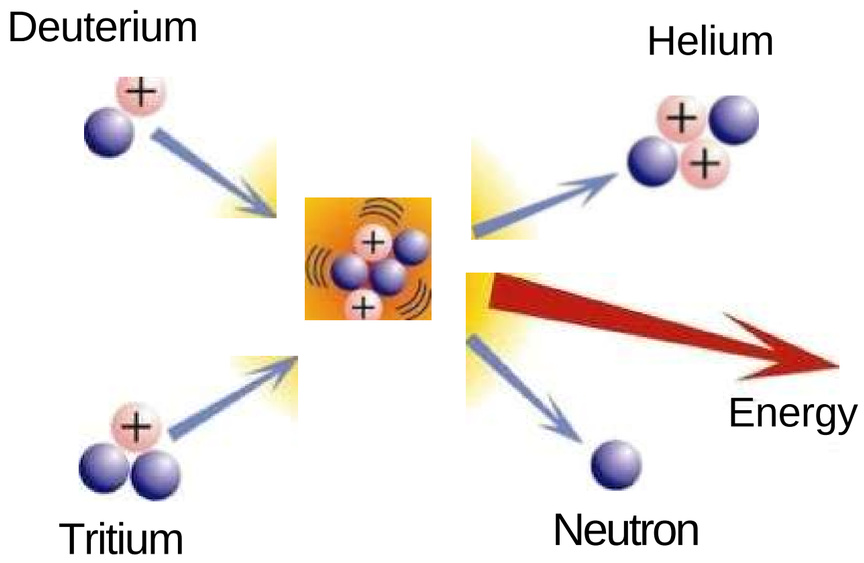
Stellar Evolution

Star formation

The formation of a star begins with a cloud of interstellar gas and dust called a nebula.
Provided the cloud is bip enough, it will begin collapsing in on itself as a result of gravity.
As it continues to contract, its rotational forces it into a disk shape with a hot and dense center.
This is called a protostar.



Stellar Evolution

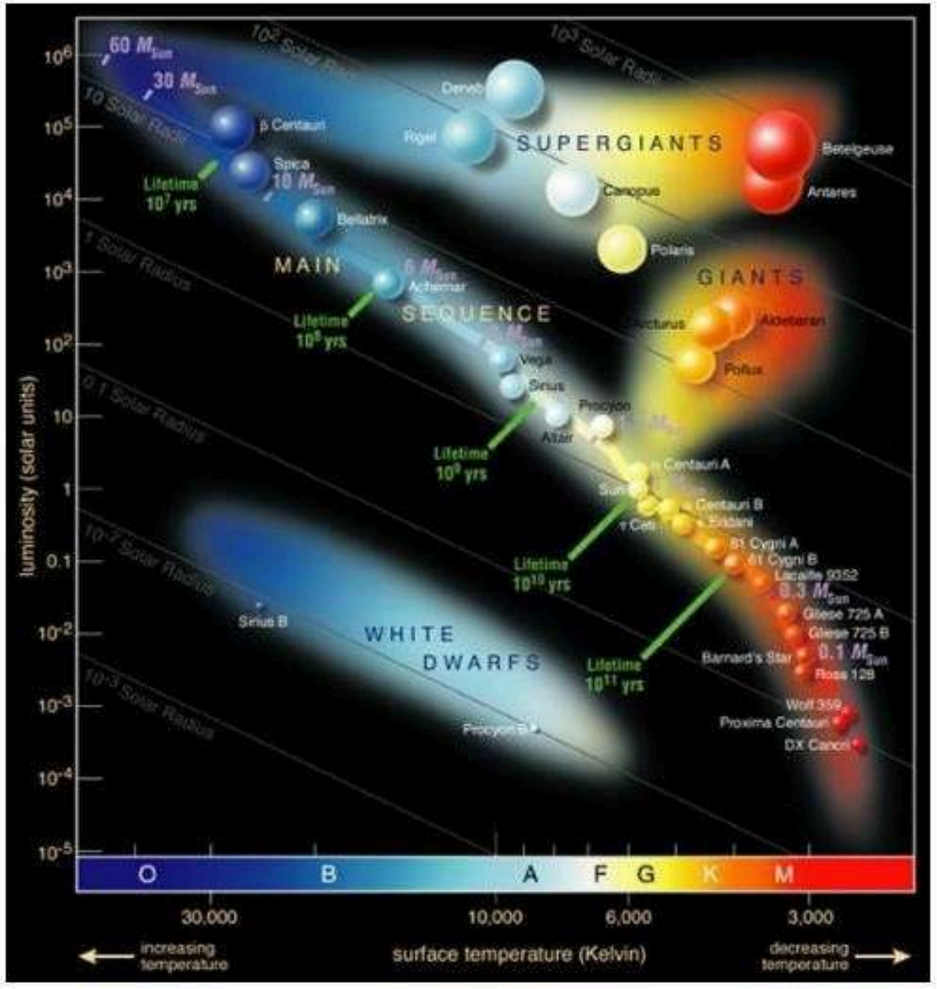


Fusion Begins.

When the temperature at the core of the protostar becomes hot enough, nuclear fusion reactions begin.

- The first fusion reactions always begin with the conversion of hydrogen into helium.
  Once this happens, the star becomes stable and it takes its place along the main sequence according to its mass.

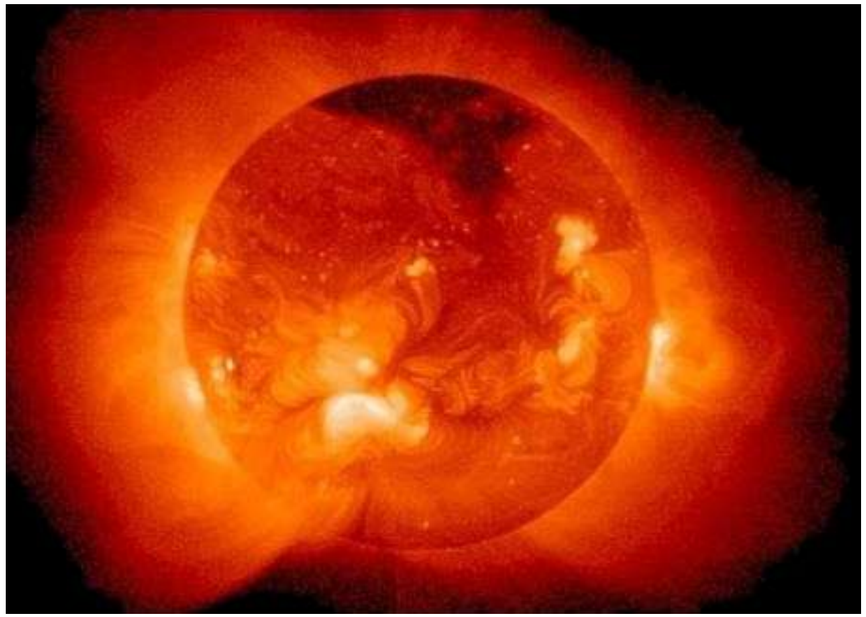
Stellar Evolution



Stellar Evolution

- Life Cycles of medium—low mass stars.

A star like the Sun will gradually become more luminous because the core density and temperature rise slowly and increase the reaction rate.
It takes about zo billion years for a star like the Sun to convert all of the hydrogen in its core to helium.

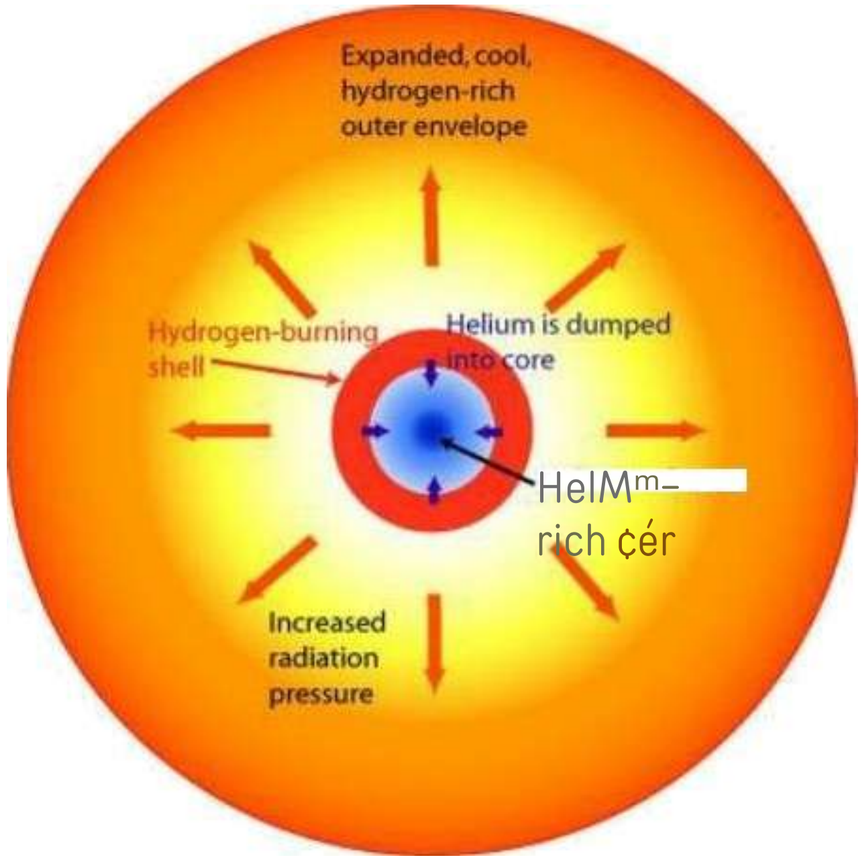


Stellar Evolution

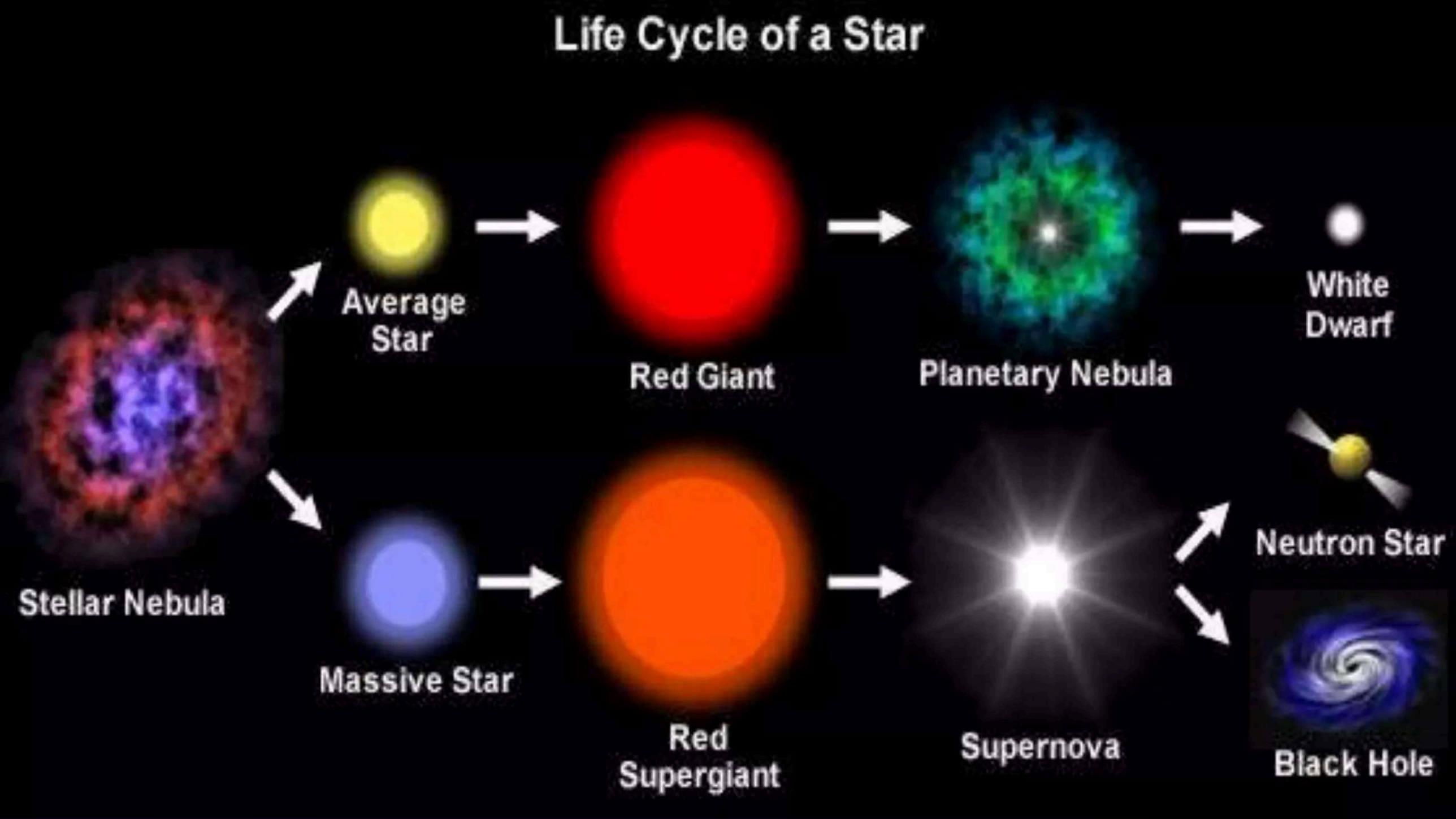
Red Giant Phase

Once a star begins burning helium in its core, it grows to become a red giant.

Red giants are so large because hydrogen continues to react in a thin layer at the edge of the helium core. The energy produced in this layer forces the outer layers of the star to expand.

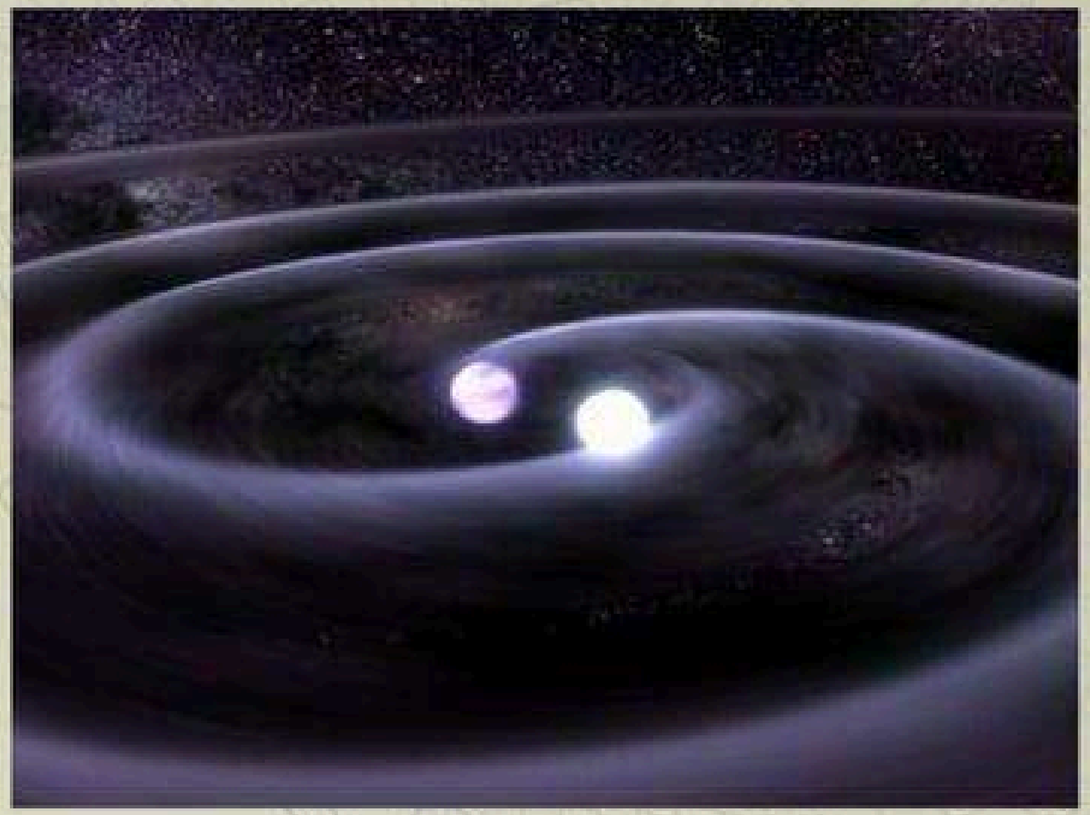


I fydragen Shell ßurning on the Red Gian t Branch


Life Cycle of a Star
Stellar Nebula
Average Star
Red Giant
Planetary Nebula
White Dwarf
Massive Star
Red Supergiant
Supernova
Neutron Star
Black Hole

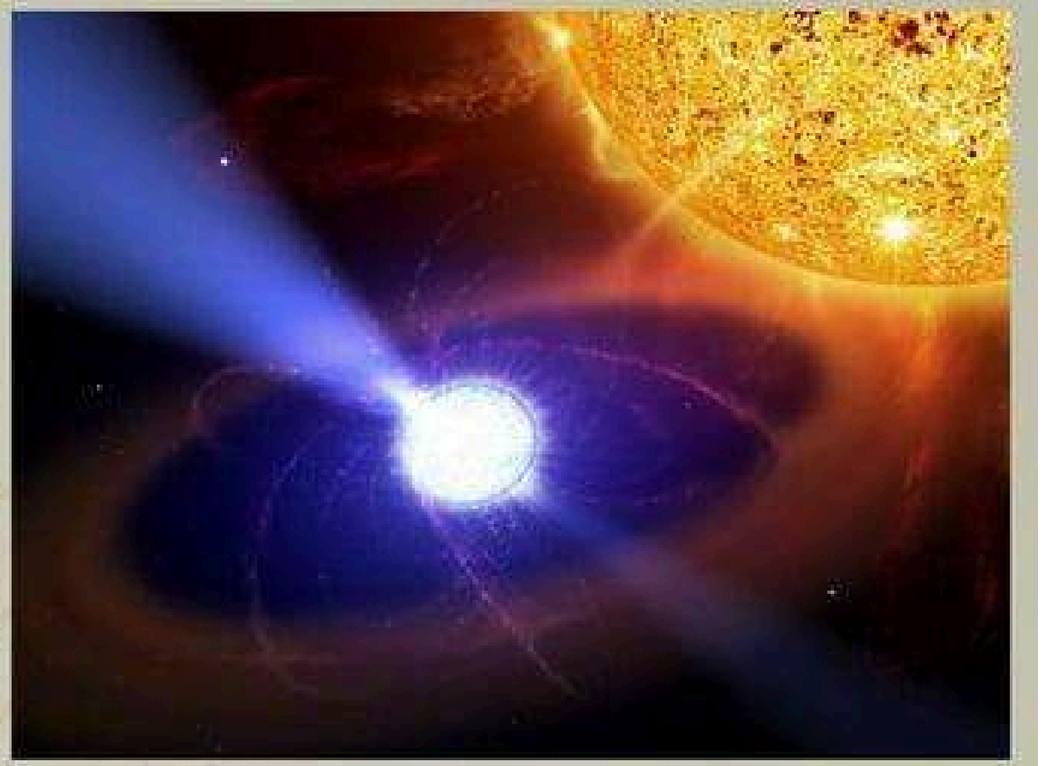
White Dwarfs

Definition: The remnant of a star that has collapsed, having an extremely dense state with no empty space between its atoms, but not reaching the extremely dense state of a neutron star or black hole.



- They are burned-out cores.
- Extremely low hydrogen.
- Carbon and oxygen.
- *Electron degeneracy pressure.*

White Dwarfs



- Very dense (mass ≈ *Sun's* mass).

- Very small (size ≈ *The Earth's* size).

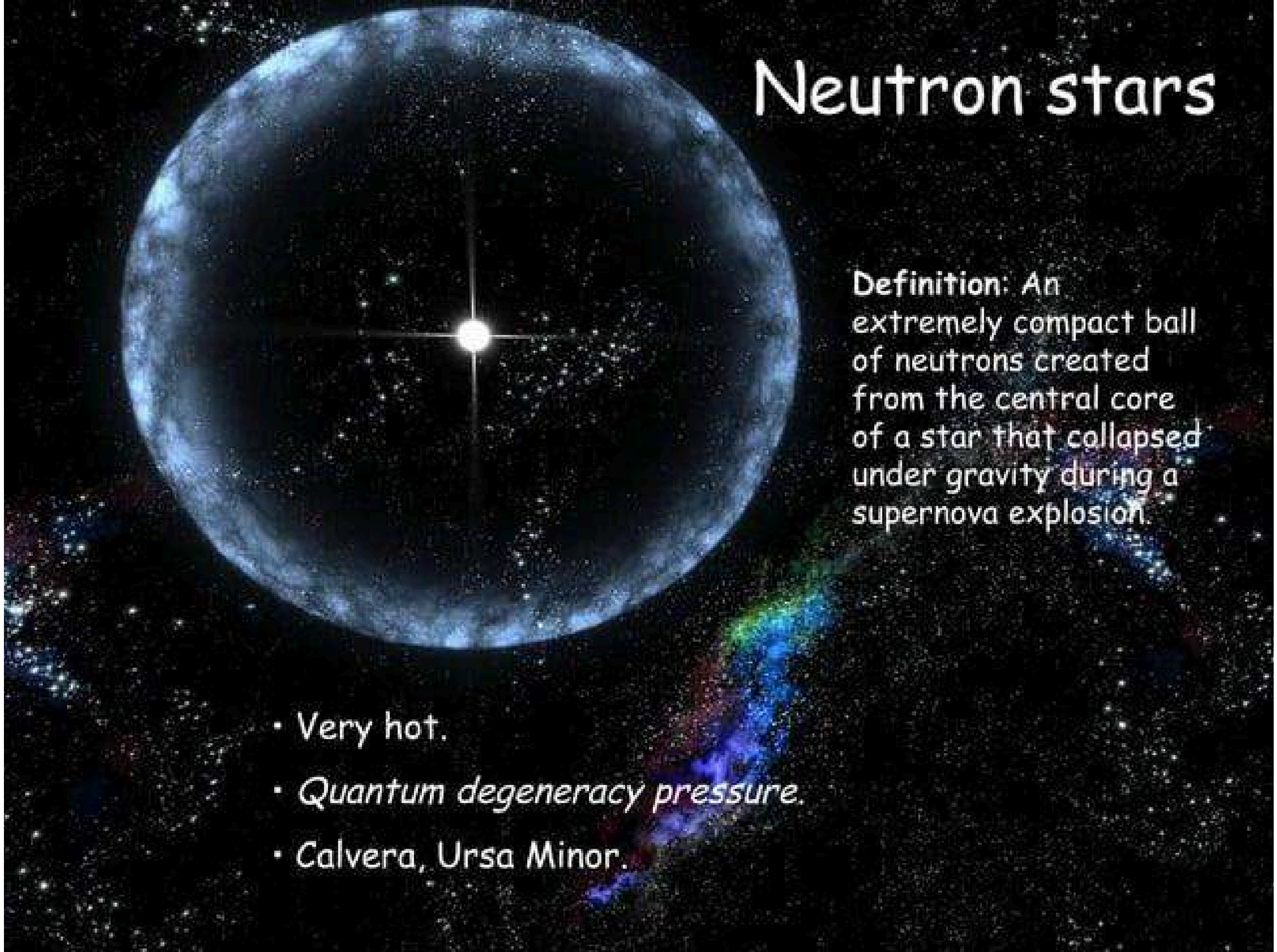
- Faint[1] luminosity.

- *Sirius B* is the nearest.

- Over 97% of the stars in the *Milky Way*.

[1]Faint: not strong

Neutron stars



Definition: An extremely compact ball of neutrons created from the central core of a star that collapsed under gravity during a supernova explosion.

- Very hot.
- *Quantum degeneracy pressure.*
- Calvera, Ursa Minor.

Neutron stars

- Extremely small.
- Extremely high mass.

- Protons + electrons → Neutrons
- Blinking radiation → *Pulsars*
- Non-spinning → Normal neutron stars
- Very high pressure.

Pulsar “Pulsating Star”

- ✓ are rotating/ spinning neutron stars
- ✓ discovered in late 1967 by graduate student Jocelyn Bell Burnell and Anthony Hewish as radio sources that blink on and off at a constant frequency
- ✓ initially referred to as LGM1, now called PSR B1919+21
- ✓ Like a ship in the ocean that sees only regular flashes of light, we see pulsars "turn on and off" as the beam sweeps over the Earth.

How do they form?

- It is a remnant of supernova explosion.
- Hence, they were known to us as the neutron star, specifically “rotating neutron star”.

What Makes it Pulse?

- pulsars appear to pulse because they rotate!
- we see pulsars "turn on and off" as the beam sweeps over the Earth.

Why does a Pulsar spin so fast?

- A supermassive star when compressed into a neuron star, its gravity is also compressed making it spins faster.

How dense are Pulsars?

- Pulsars are very dense.
- Its mass is 4 to 8 times greater than the sun.

What makes them light?

- They undergo the process called accretion.
- they grabs on electron to other atomic fields and flings them into space in high speed emitting radiation.
- This form is called the beam of light.

How do we classify pulsars?

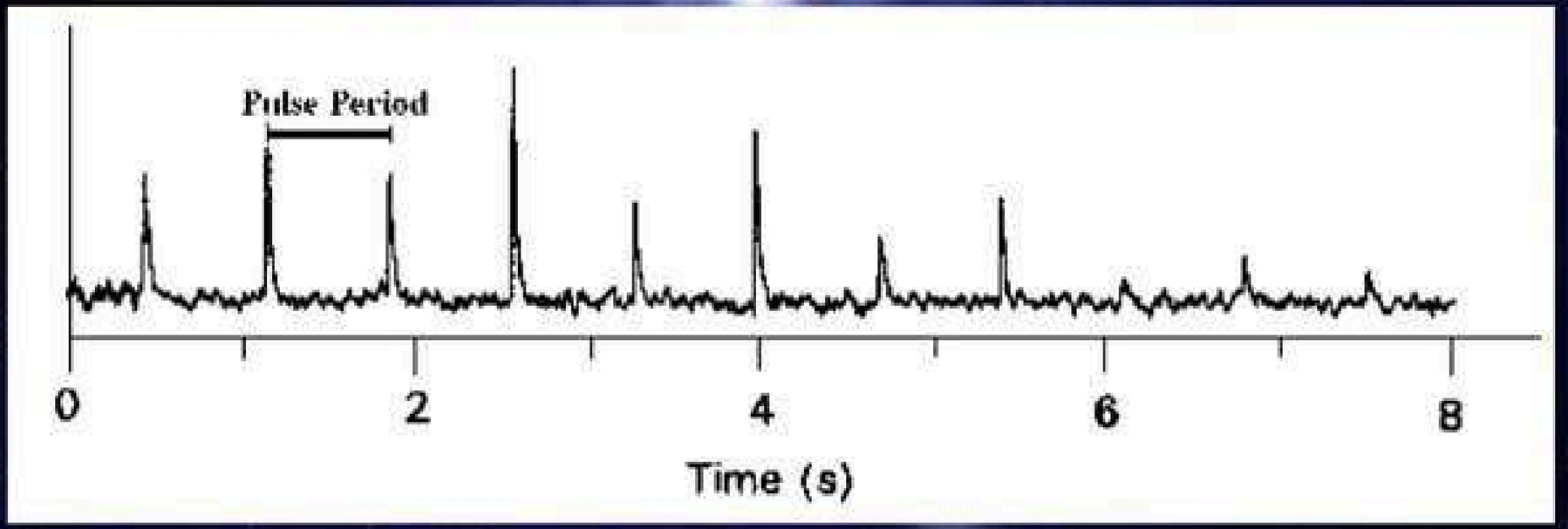
- They can be classified into two;
- spin-powered pulsars- indicates that the source of energy is from the rotation of the neutron star.
- accretion-powered pulsars- the source of energy came from the accumulated material around the neutron star.

How about the types of Pulsar?

Those with periods of a few milliseconds and whose periods are changing very slowly are called the *millisecond pulsars*. The remainder are simply called the "ordinary pulsars".

How was the Pulse interval of the Pulsar?

- The time interval between consecutive pulses is called the pulsar's *period*.



- It is observed that the highest frequencies of a pulse arrive at a telescope slightly before the lower frequencies.
- Due to intersellar medium.
- Its pulse will also weakens as time passes by or they may already undetectable.

Can we actually see Pulsars through our naked eyes?

No! they are discovered using optical, X-ray and gamma-ray telescopes.

Parkes radio telescope (the star of the film "The Dish"). The enormous Arecibo radio telescope in Puerto Rico, the Green Bank telescopes in America, the Molonglo telescope in Australia and the Jodrell Bank telescope in England.

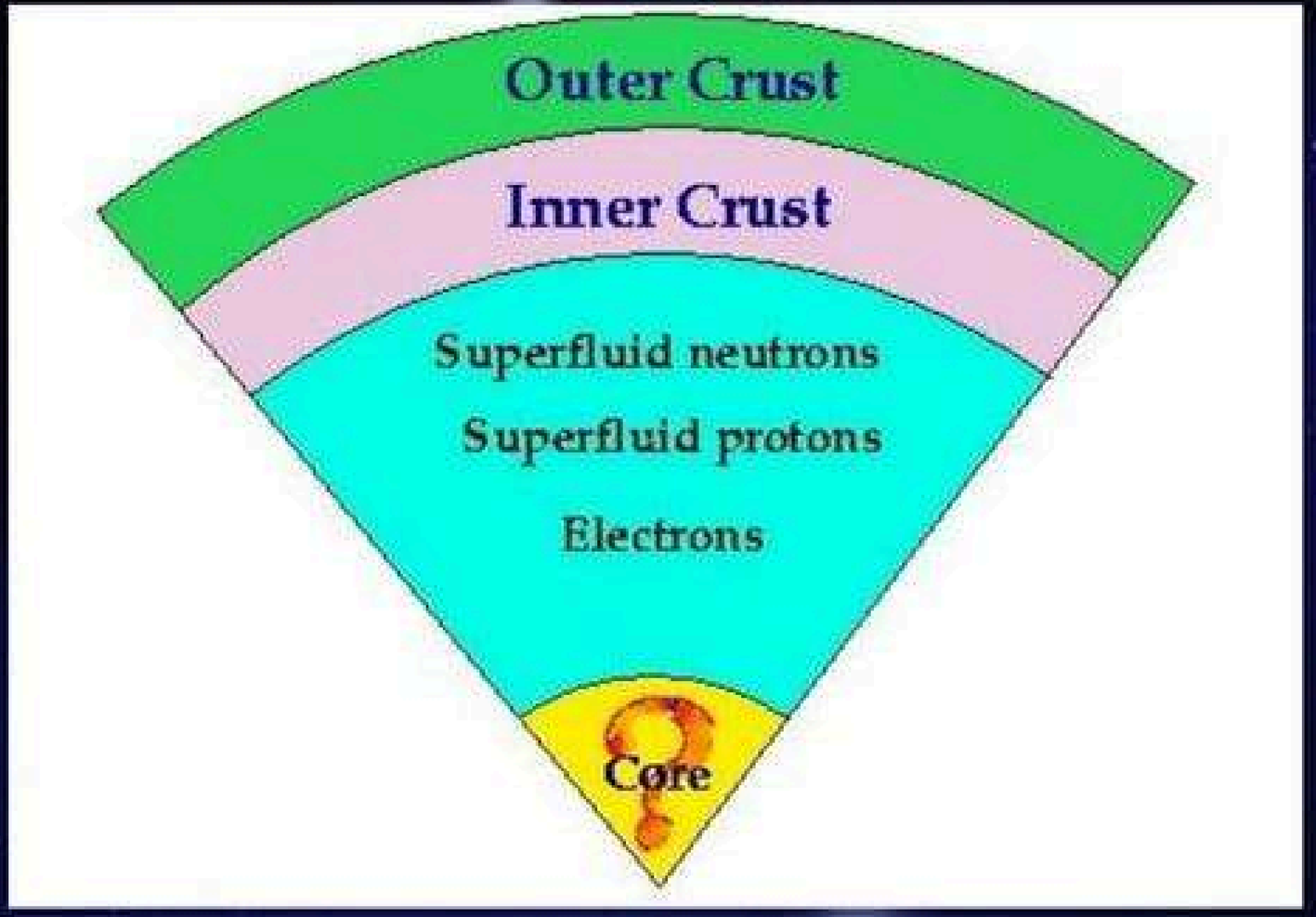
Why would it be undetectable?

- Pulsars either stay at one place or may transfer from one place to another.
- The fastest pulsar can escape to a galaxy and will never come back.

Do Pulsars orbit?

- Yes they do! Some Pulsars came in pair some are loner.
- When they come in pair or in binary system, the pulsar will orbit its pair or the other way around.

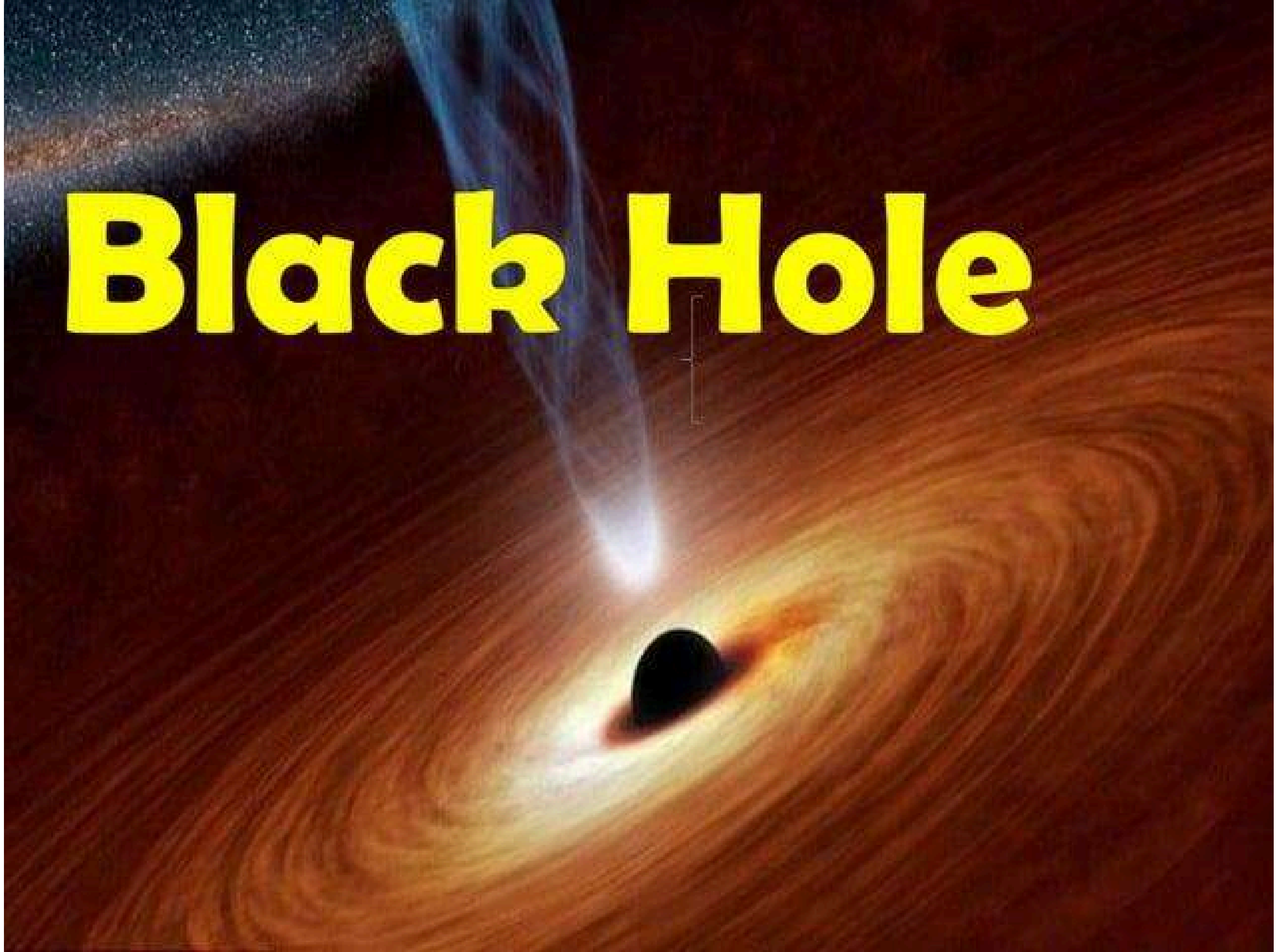
How about the structure of the Pulsar?



The interior structure of a neutron star consists of iron, neutron rich nuclei and electrons in the outer crust. The inner crust contains neutron rich nuclei, free superfluid neutrons and electrons and the interior, superfluid neutrons, superfluid protons and electrons. The makeup of the core is unknown.

So what have we learnt? The observations of pulsars tell us that:

- they are far away
- they are very small
- they are very dense
- they can orbit other objects
- they were probably born in supernova explosions
- they are travelling very fast through space
- the time between pulses is extremely regular although they are slowing down very slightly.


Black Hole

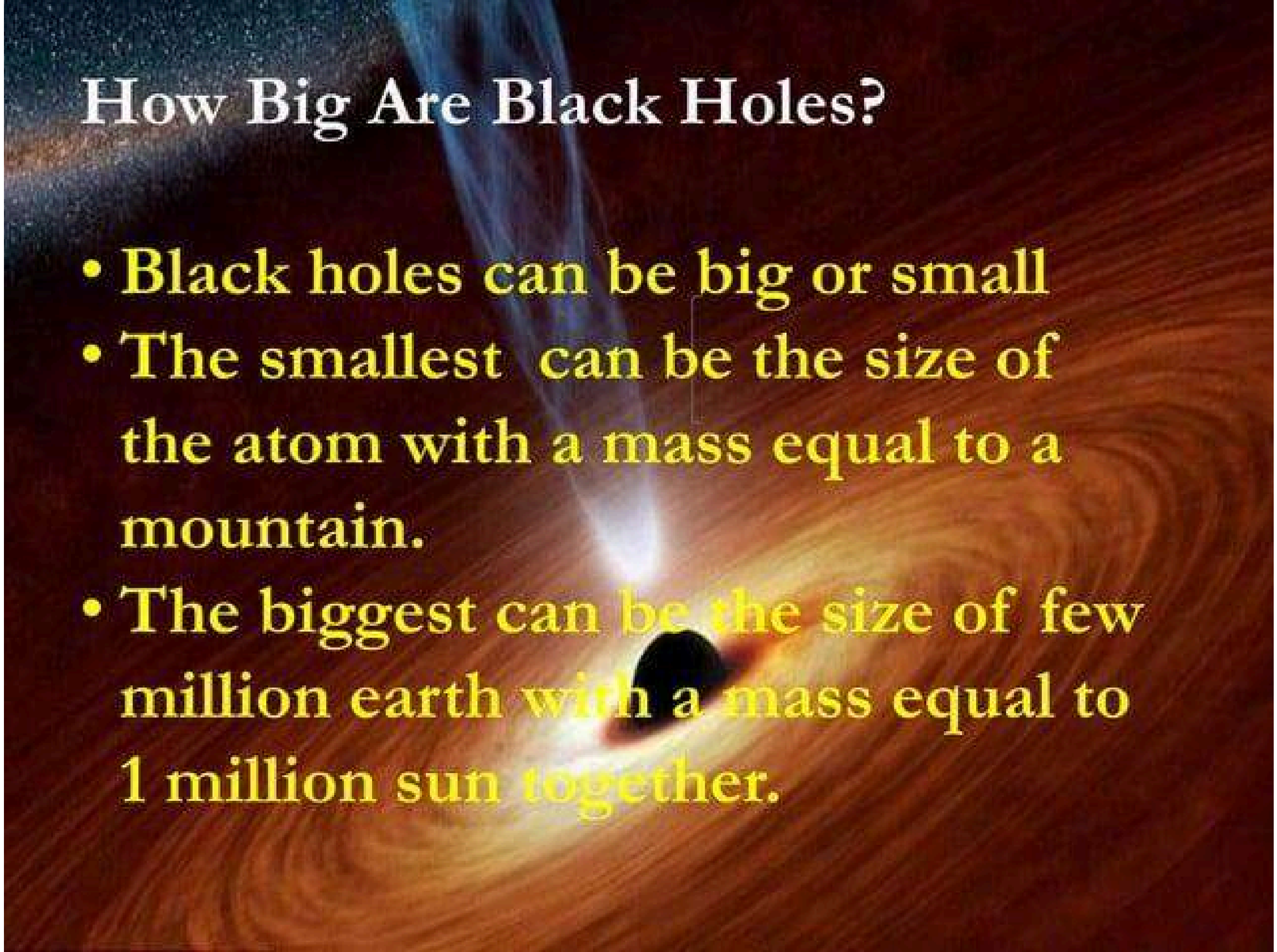
What is a Black Hole?

- a place in space where gravity pulls so much that even light can not get out
- They are invisible
- has extreme density
- Albert Einstein first predicted black holes in 1916 with his general theory of relativity.
- The term "black hole" was coined in 1967 by American astronomer John Wheeler, and the first one was discovered in 1971.

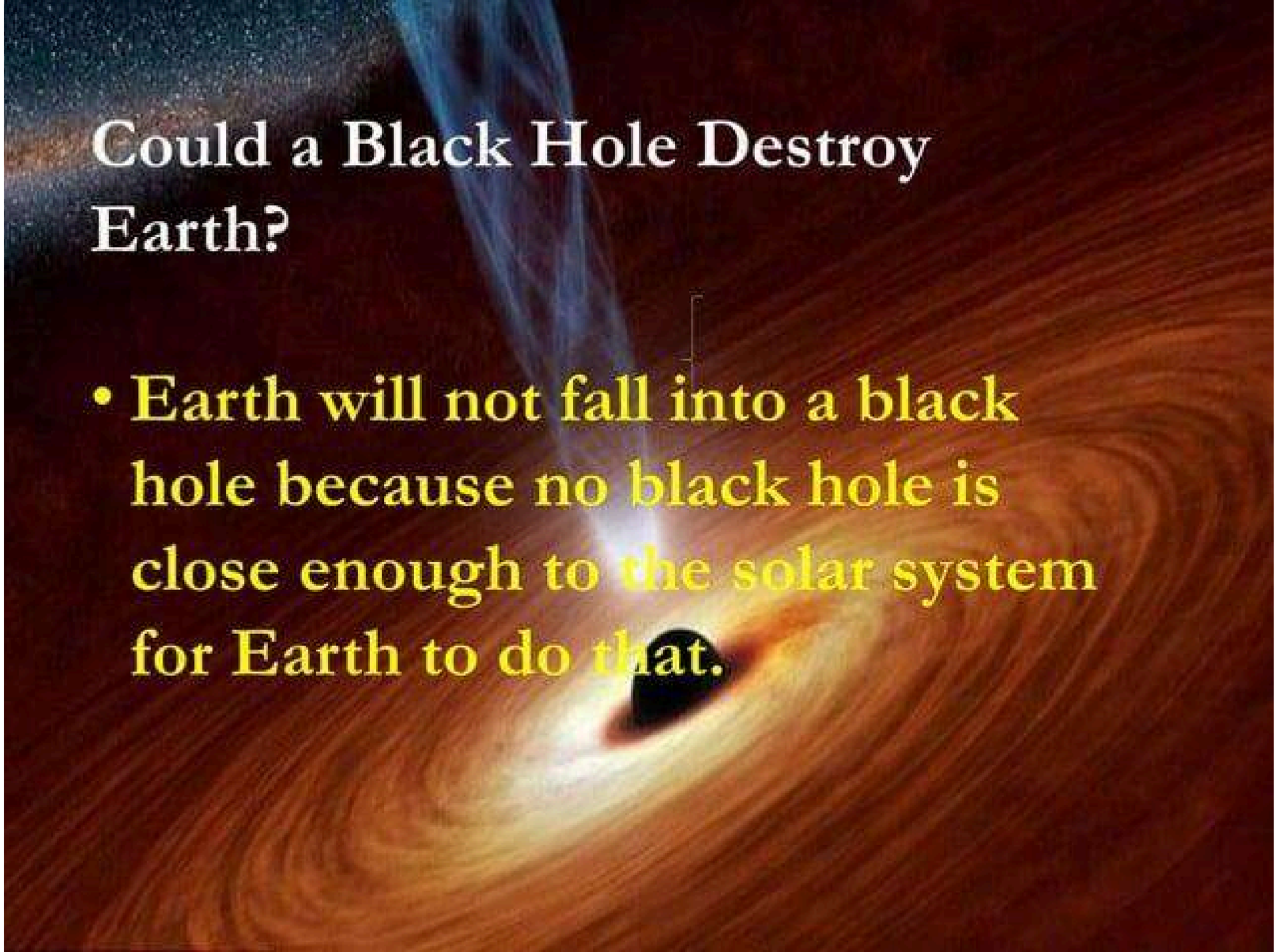
How Do Black Holes Form?

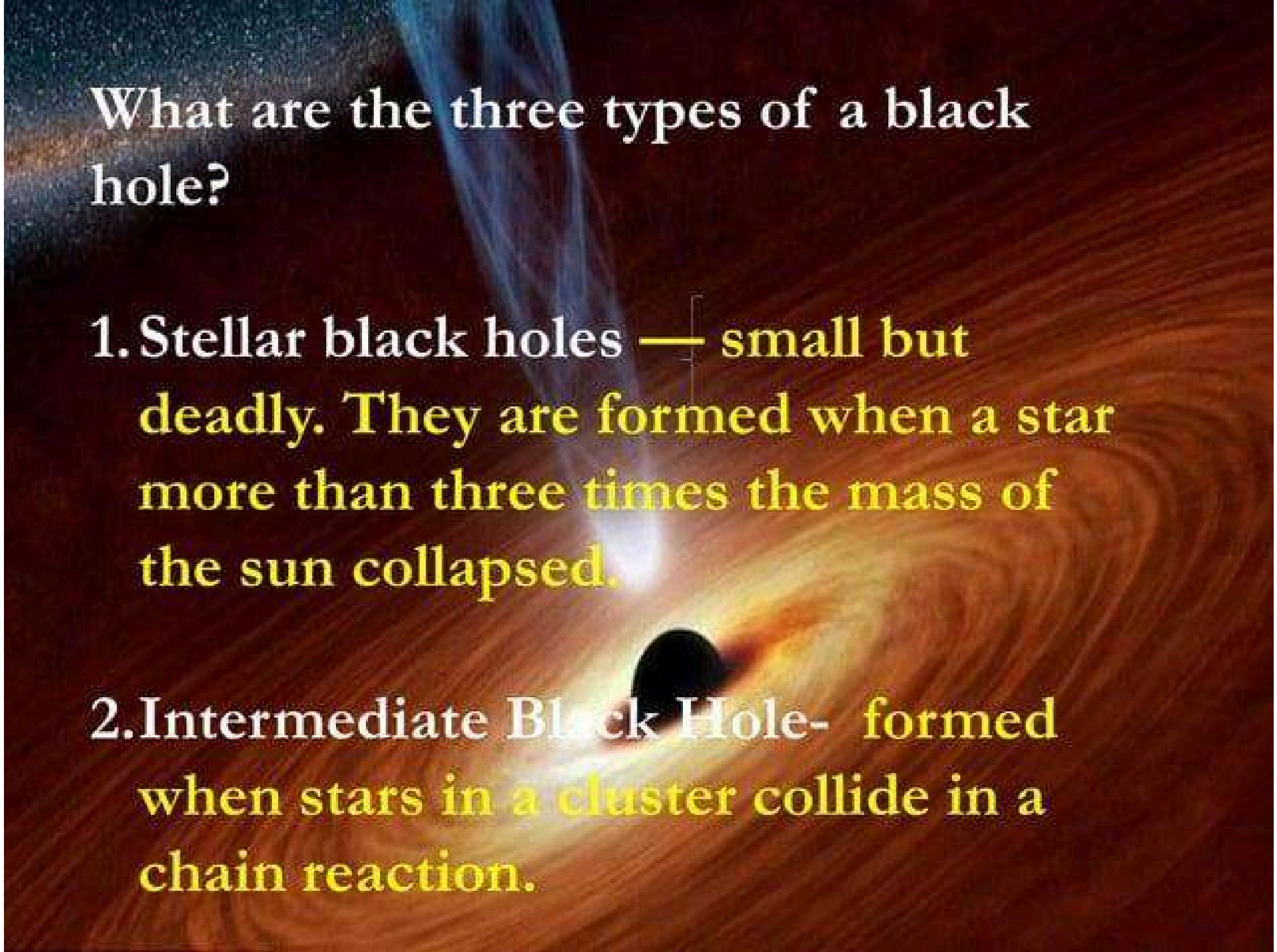
- Stellar black holes form when the center of a very massive star collapses in upon itself. This collapse also causes a supernova, or an exploding star, that blasts part of the star into space.

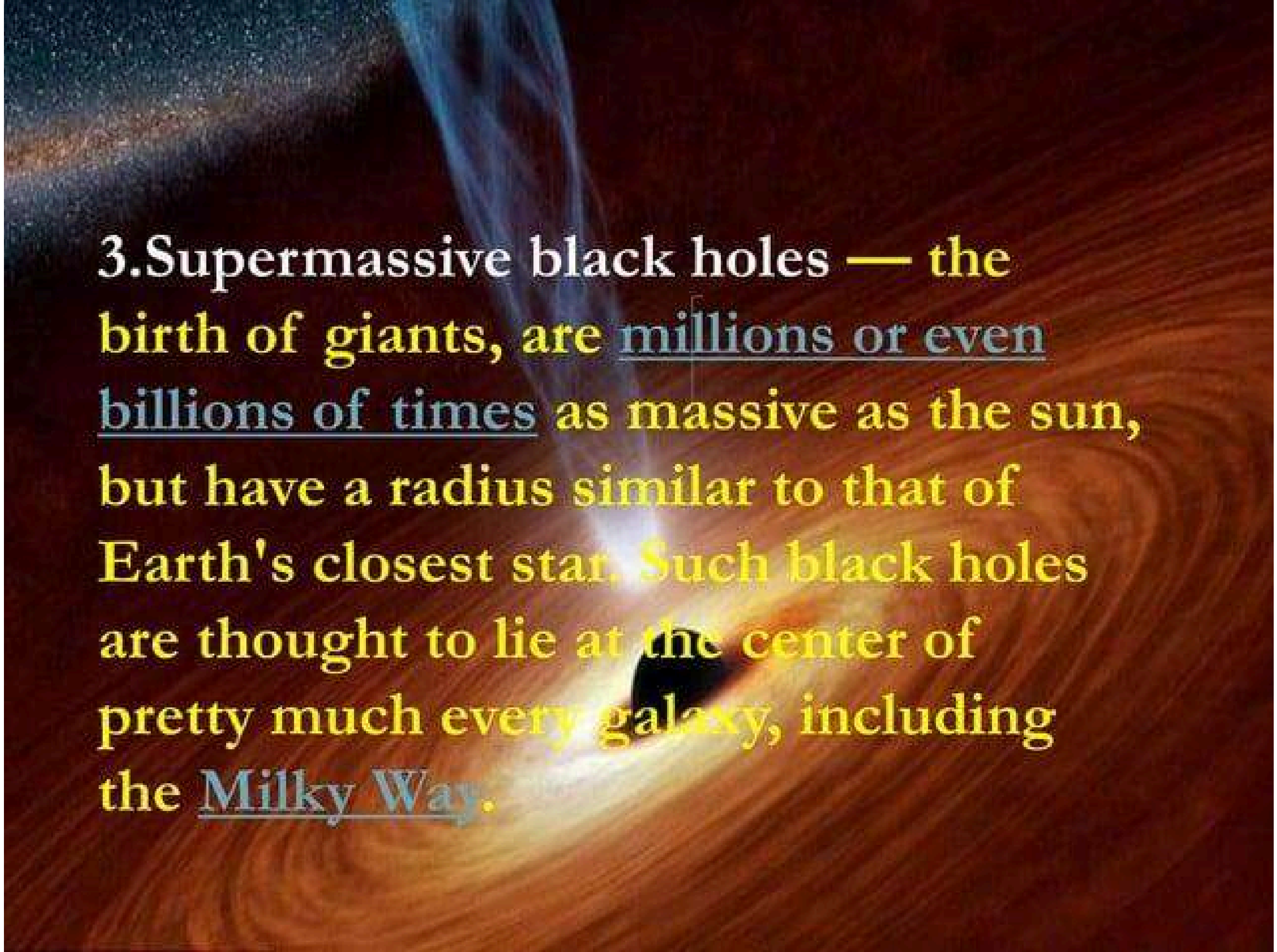
- Scientists think supermassive black holes formed at the same time as the galaxy they are in.

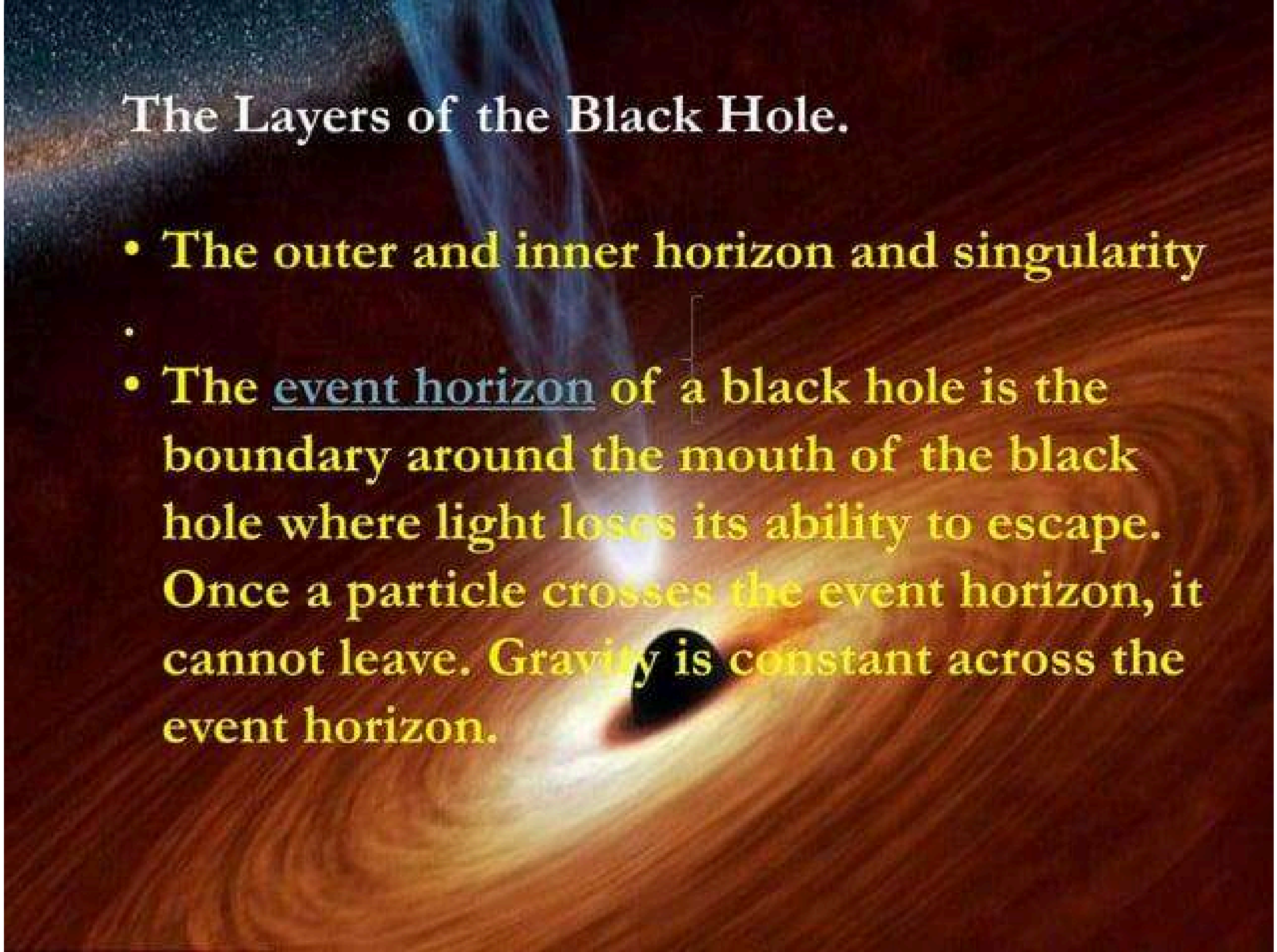

How Big Are Black Holes?
• Black holes can be big or small
• The smallest can be the size of the atom with a mass equal to a mountain.
• The biggest can be the size of few million earth with a mass equal to 1 million sun together.

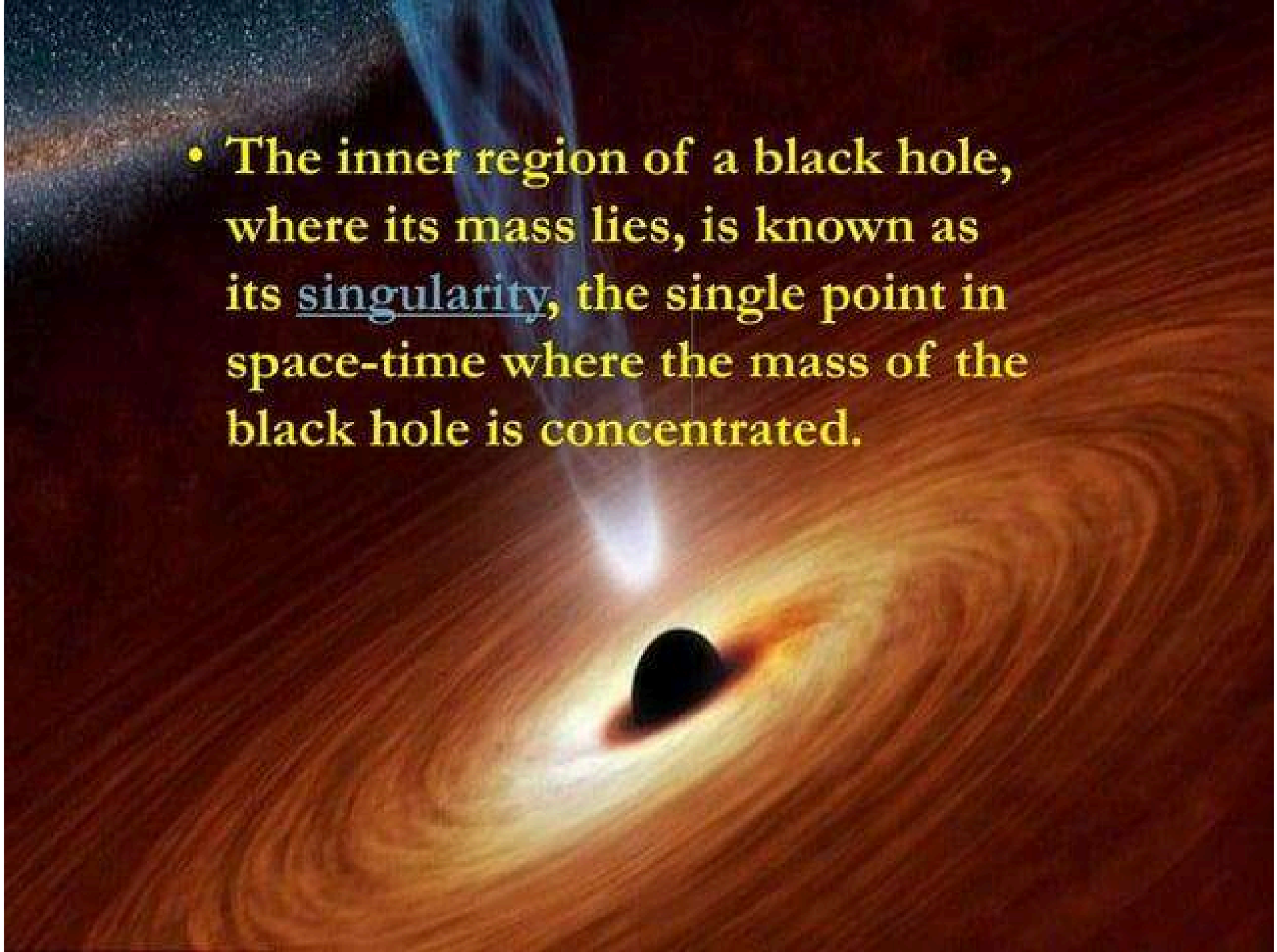

If Black Holes Are "Black," How Do Scientists Know They Are There?
• Scientists can study stars to find out if they are flying around, or orbiting, a black hole.
• When a black hole and a star are close together, high-energy light is made


Could a Black Hole Destroy Earth?
• Earth will not fall into a black hole because no black hole is close enough to the solar system for Earth to do that.


What are the three types of a black hole?
1. Stellar black holes — small but deadly. They are formed when a star more than three times the mass of the sun collapsed.
2. Intermediate Black Hole- formed when stars in a cluster collide in a chain reaction.


3.Supermassive black holes — the birth of giants, are millions or even billions of times as massive as the sun, but have a radius similar to that of Earth's closest star. Such black holes are thought to lie at the center of pretty much every galaxy, including the Milky Way.


The Layers of the Black Hole.
• The outer and inner horizon and singularity
•
• The event horizon of a black hole is the boundary around the mouth of the black hole where light loses its ability to escape. Once a particle crosses the event horizon, it cannot leave. Gravity is constant across the event horizon.


• The inner region of a black hole, where its mass lies, is known as its singularity, the single point in space-time where the mass of the black hole is concentrated.