Our Moon and the Formation of Stars in the Milky Way

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Historical Observations of Moons

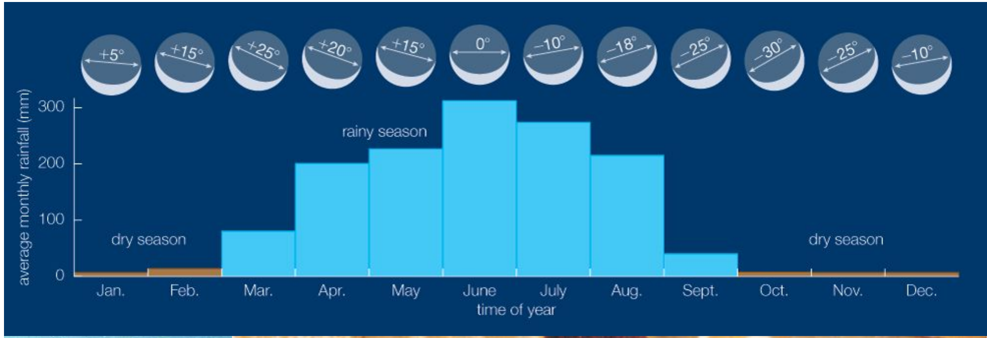
Astronomy was extremely important to ancient humans, mainly for timekeeping:

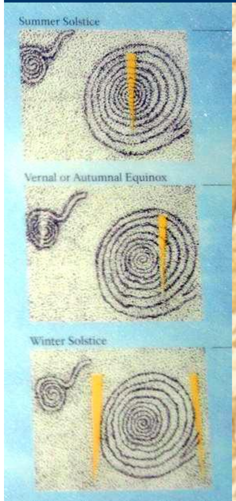
Month=time for Moon to complete cycle=time for Moon to go around Earth

year=time for seasons to complete cycle=time for Earth to complete revolution around Sun

week=1 day for each of 7 brightest objects in sky (Sun, Moon, 5 planets)

Used for religious and practical purposes.





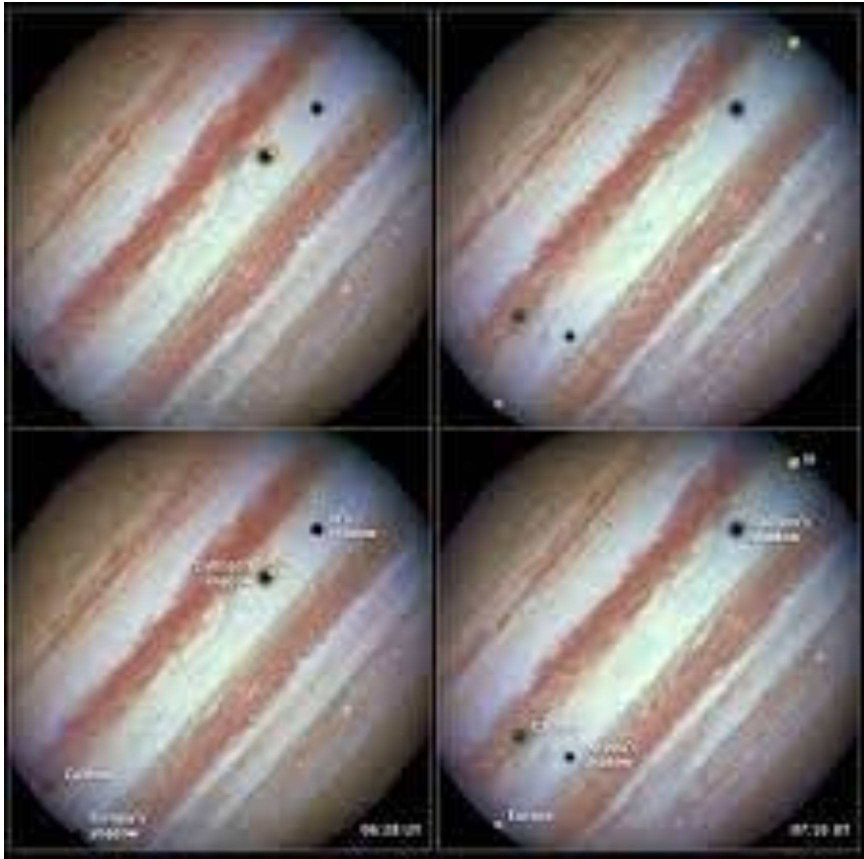
Historical Observations of Moons

Motion of objects in sky due to Earth's rotation→ objects in sky appear as bright, perfect circles moving in perfect circles. Predictable motion, same direction (east-west), no sign of stopping.

Ancient Greeks believed this perfect east-west circularity and "permanent" motion came from divine nature of sky.

All astronomical objects were then thought to be perfectly smooth spheres which move in circles by default (as things on Earth are stationary by default)

In the early 1600s Galileo began observations of objects in our solar system that would change our understanding of the Universe.



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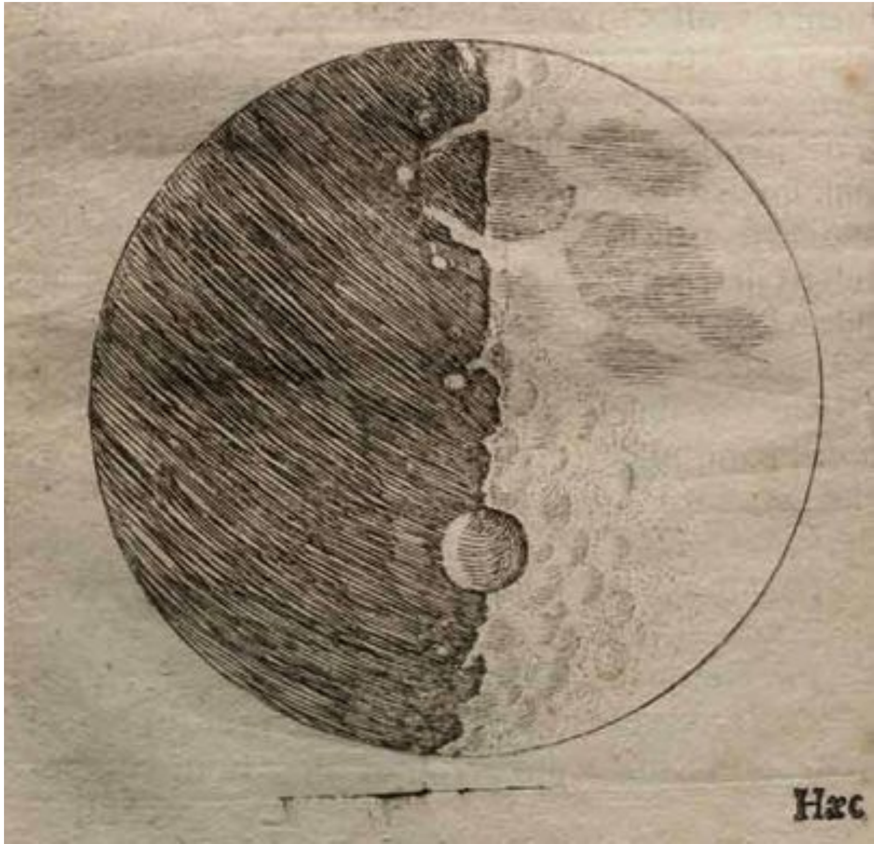


Surface of the Moon

The lunar surface is covered in geological features

Mare: large smooth areas that were recently covered in lava

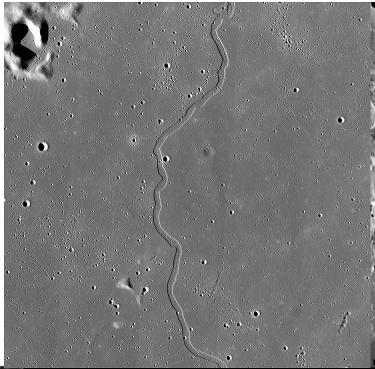
Highlands: Heavily cratered, rugged mountains

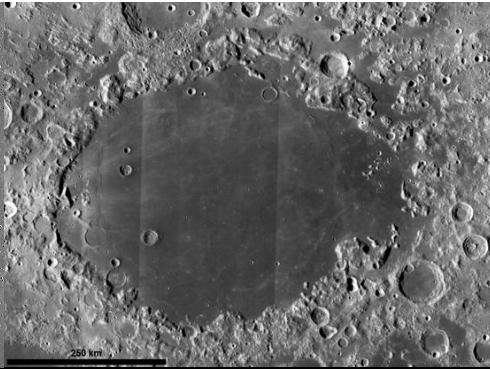
Rilles: meandering river-like features

New/sunken craters: Older craters have smoothed or interrupted edges

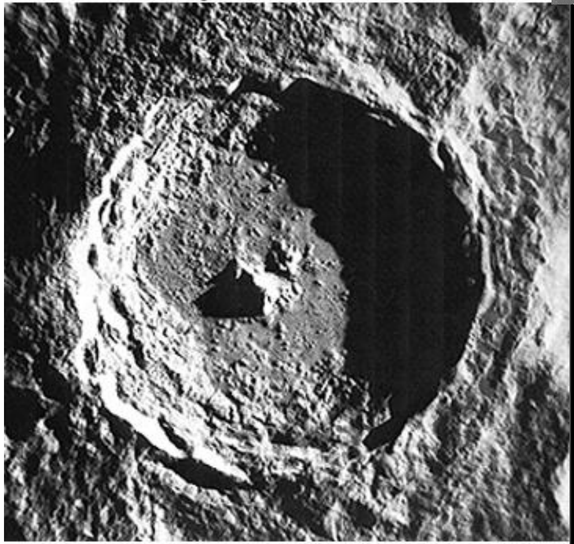
Craters w/central peak: a crater with a small mountain

Astronomers can use these features to reconstruct past events on the lunar surface





Tycho Crater



(NASA Lunar Orbiter image V-125M.)

Other Moons in Our Solar System

Terrestrial (inner) planets are smaller and rarely have moons– only Mars and Earth.

- Earth, ~8,000 miles:
  - 1 moon, ~2,000 miles
- Mars, ~4,000 miles:
  - 2 moons, largest ~17 miles

Jovian (outter) planets are much larger and usually have many moons:

- Jupiter, ~85,000 miles:
  - 53-79 moons, largest ~3,200 miles
- Saturn, ~72,000 miles:
  - 53-82 moons, largest ~3,200 miles
- Uranus, 32,000 miles:
  - 27 moons, largest ~900 miles
- Neptune, 30,000 miles:
  - 14 moons, largest ~1,600 miles

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Why is Earth's moon so large????

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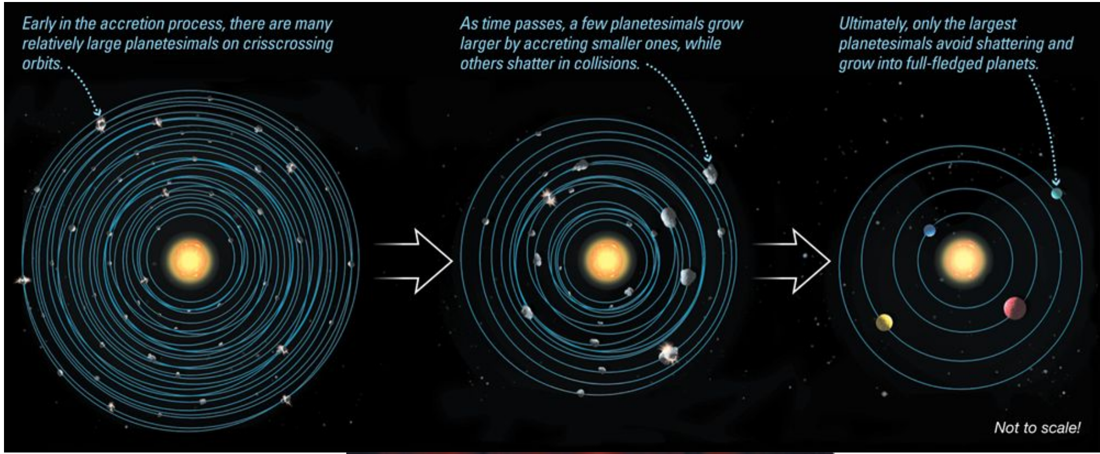
Formation of the Solar System

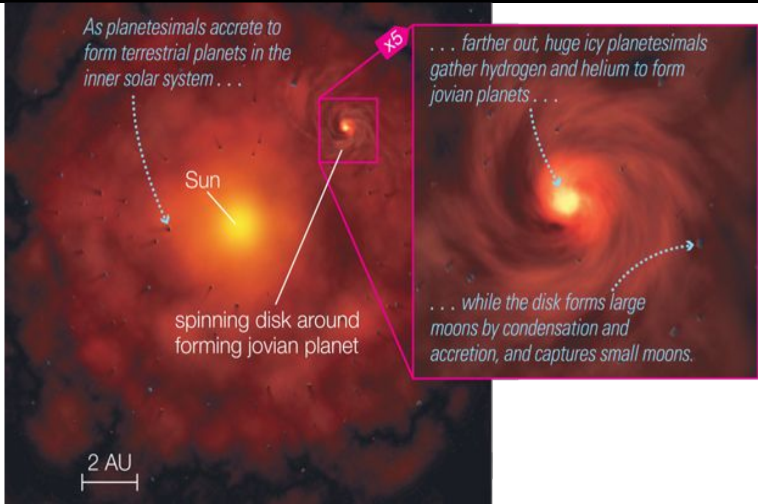
1) Begin with huge cloud of gas, dust
2) Various processes cause cloud to become disk-shaped (“accretion disk”), increase in density
   a) Center extremely dense, hot→ protostar
3) Tiny flecks of dust begin to collide, stick together in disk, forming pebbles→ pebbles to huge rocks→ huge rocks to planetesimals
4) Almost all material in inner solar system used up to make planets



Inner planet formation basically stops here

5) Further from the protostar/Sun, huge ice crystals form→ outer planets larger
6) Outer planet grows so large, it creates its own accretion disk *within the Sun’s*!
7) Just as in larger Sun accretion disk, “moonetesimals” orbit the large planet, colliding with each other
8) Moons in outer planets are leftover accretion disk pieces! Larger planet=larger disk=larger and more moons

Also Saturn’s rings!

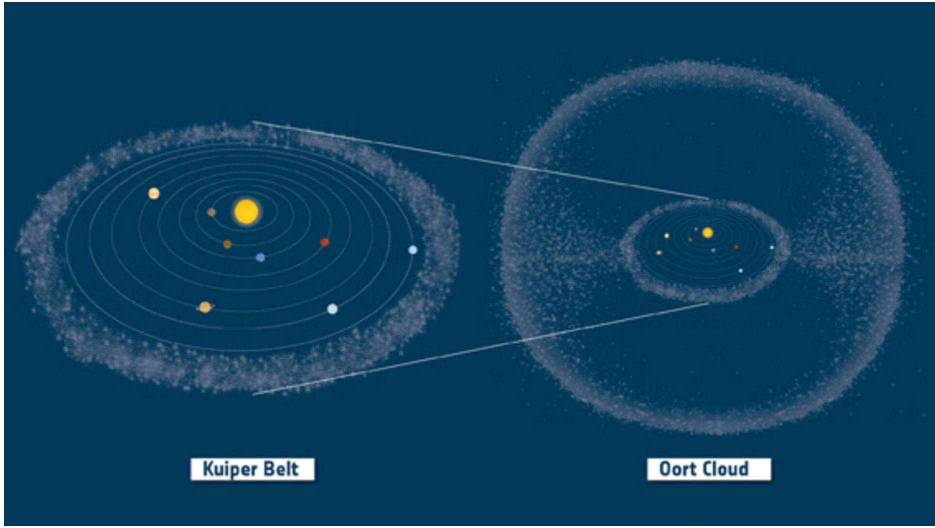


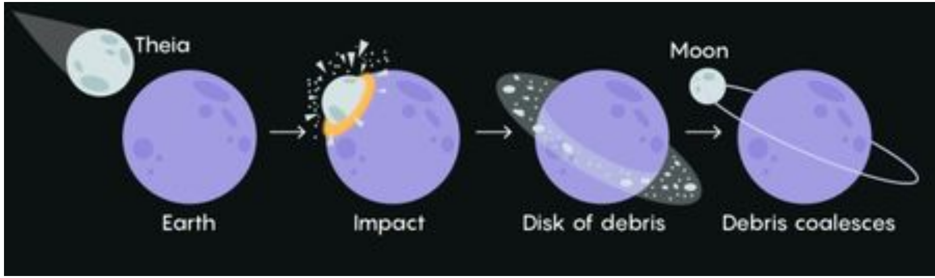
Formation of the Moon

Without accretion disk, how do inner planets get moons at all?

1) Satellite Capture:
   Still some leftover chunks from planet formation→ these can have chaotic orbits, stray into inner solar system→ small ones can be slowed and captured by inner planets gravity. Explains Mars, but not Earth's huge moon

2) Giant Impact:
   Even when planetesimals collide and stick, debris is made. This debris can sometimes be gravitationally captured by the new planet→ ancient Earth would have had rings similar to Saturn for a short time→ rings condense into our Moon.
   - Apollo missions confirm Moon is made of material very similar to the outer layers of the Earth
   - Also possible the Moon was formed from the debris of several smaller collisions





Stellar Birth and Molecular Clouds

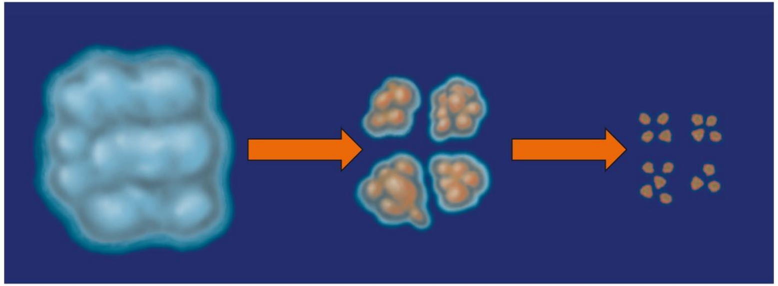
Confusingly, to create hot stars you first need very cold gas! For gas clouds to collapse, individual atoms/molecules need to lose energy so that gravity can move them. This energy is usually given off as light.

Problem; the hotter the gas, the harder it is to release the heat as light!

Molecular bonds in the gas allow light to be released more easily. Once these form the cooling is rapid, causing the cloud to collapse under its own gravity. As it does, the cloud fragments.

Some regions of the cloud get dense enough that the molecules cannot radiate heat properly; these places become “proto-stars” (and eventually stars).

NOTE: STARS FORM IN CLUSTERS



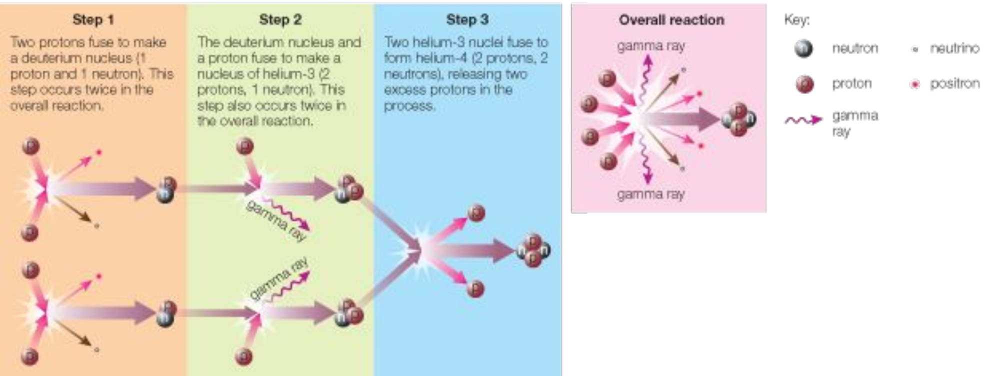
Star Formation

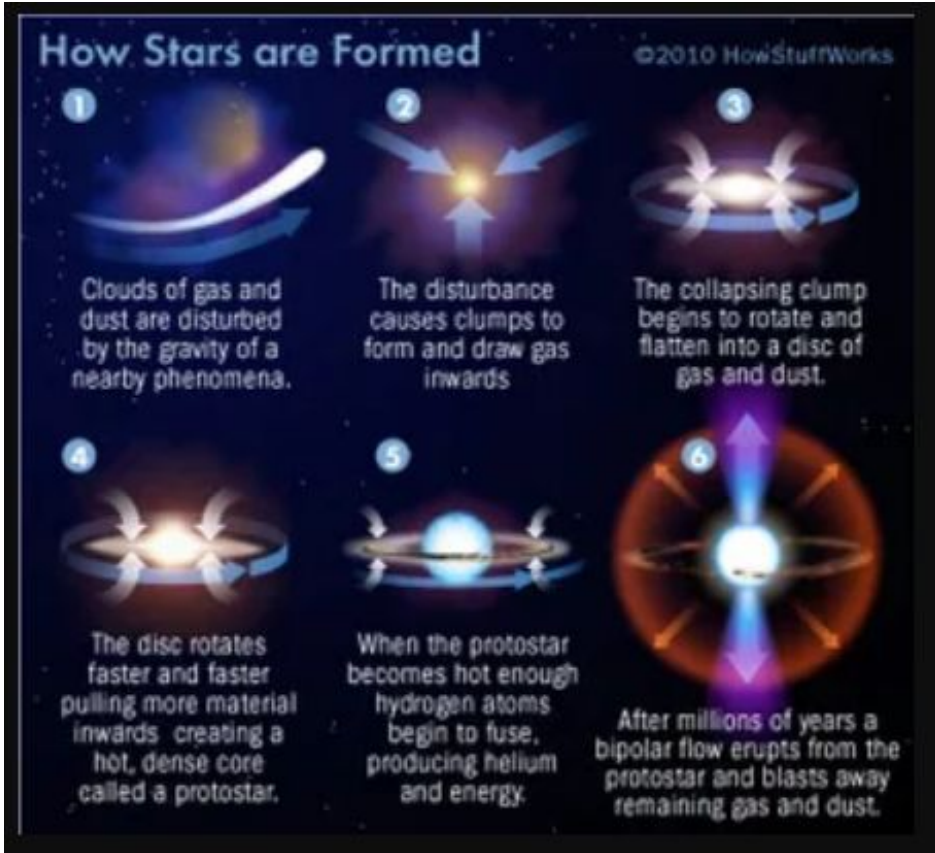
Early astronomers knew the Sun released immense amounts of energy. But it wasn't until the 1900s we understood where it came from.

Stars are self-regulating nuclear reactors!

1) Gravity pulls material inward, increasing pressure/temperature at the core
2) This increases the rate of nuclear reactions
3) This increases outward pressure from continuous nuclear explosions(!!!!!!!!)
4) This pushes material outward and reduces pressure/temperature at the core

Hydrogen Fusion by the Proton–Proton Chain





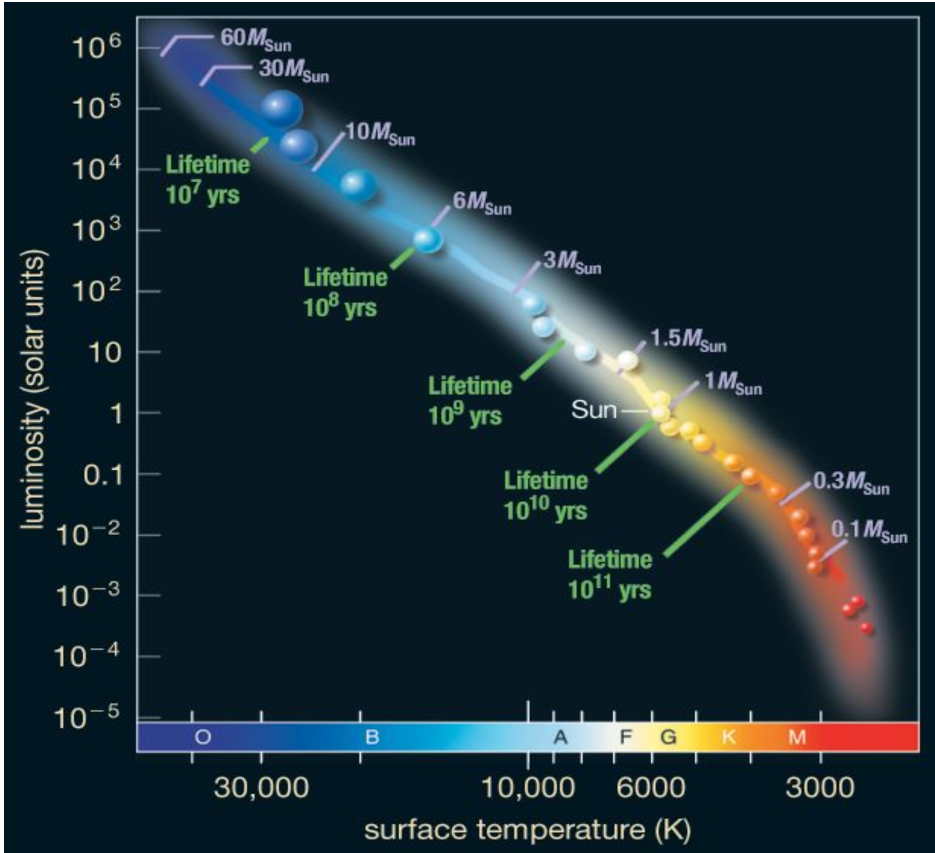
Stars and Color

Almost everything about a star can be determined from its birth mass:

More mass→more gravity→more pressurized core→faster nuclear reactions→hotter surface→color

Stellar mass determines fuel supply AND burning rate→stellar lifespan

The vast majority of the life of any star is spent burning hydrogen at its center. While it does this it is said to be on the “Main Sequence”; because size, brightness, and temperature are all determined from the stellar mass, we can make a graph of temperature (or color) vs brightness! All stars begin their lives at some place on this line.



Stars and Color

The insides of stars are not well-mixed; if they run out of hydrogen in the core, more doesn't just fall in.

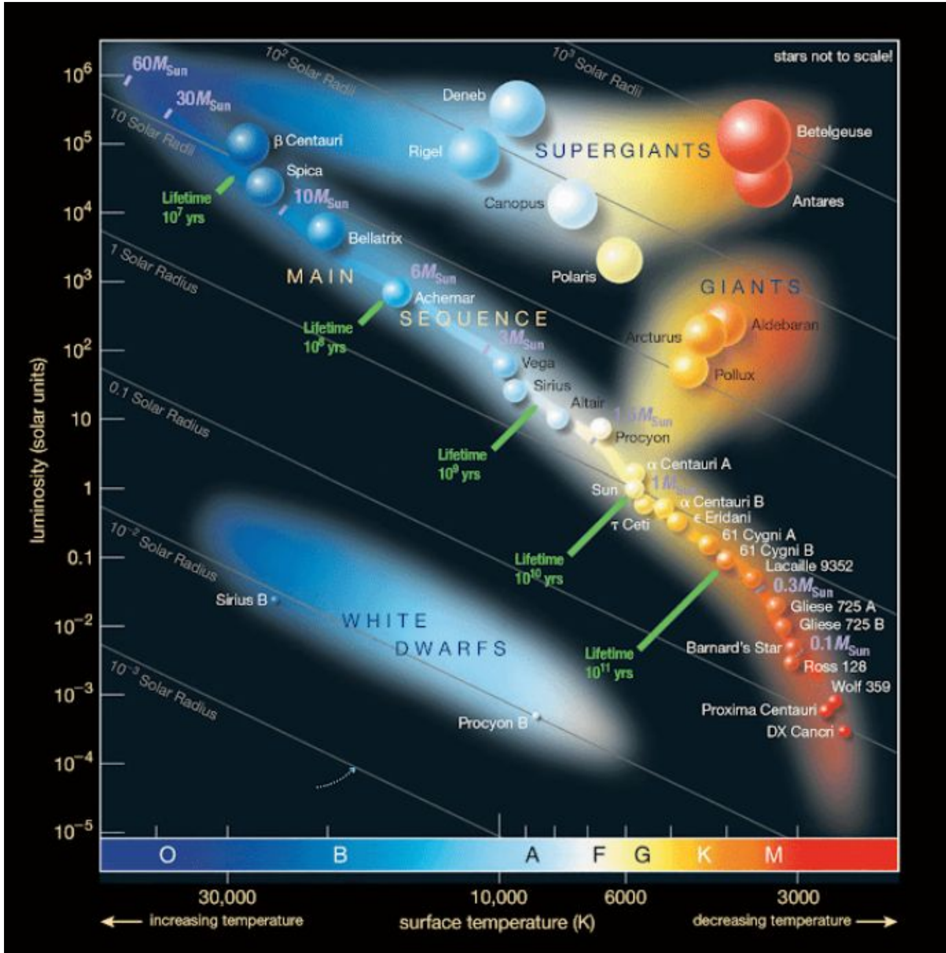
What happens? Depends on mass (again!)

If the stars total mass is not enough to immediately begin fusing helium, the temperature *outside the core* may become hot enough to burn hydrogen!

This "shell burning" is faster and hotter than burning hydrogen in the core; it causes the core to contract and the outer layers to separate, "puffing up" the star.

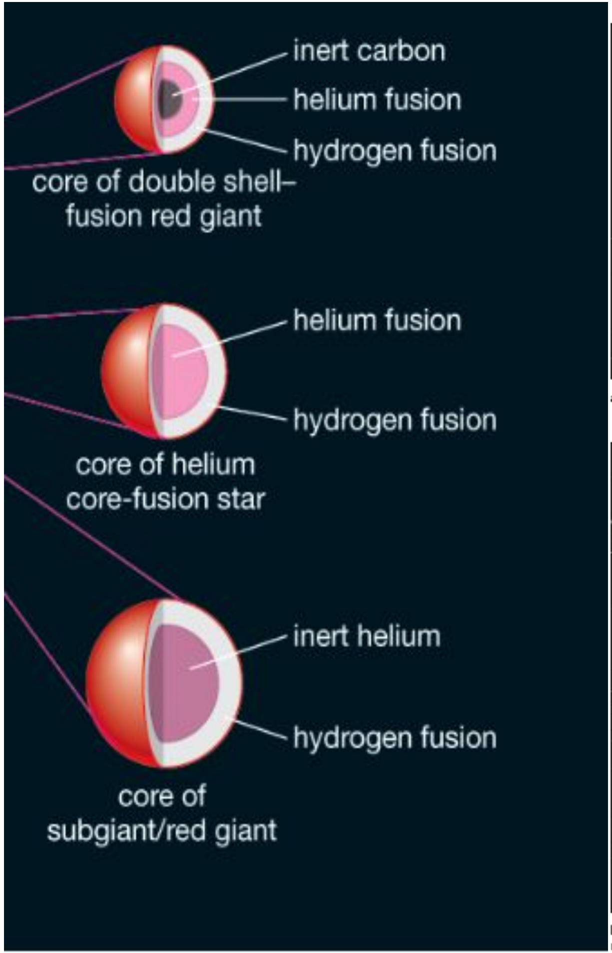
The star has left the Main Sequence and entered the giant/supergiant phase

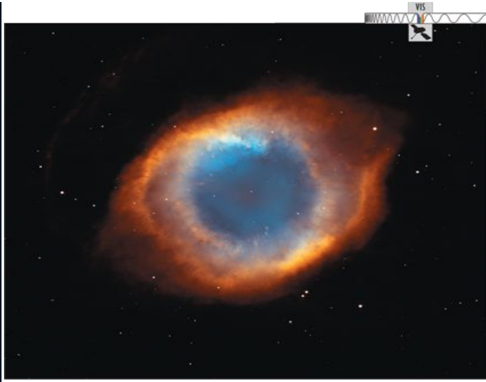
Even though the core is hotter and denser than ever, the outer layers actually cool and inflate. During this phase of the stars life, the surface and core of the star often do opposite things!



Low Mass Stars

The core continues to contract and heat, the outer layers continue to expand and cool, leaving us with a *white dwarf* and planetary nebula (NOTE: doesn't actually have to do with planets). The star has reached the end of its life.





a Helix Nebula. The central white dot is the hot white dwarf.

b Butterfly Nebula. The hot white dwarf is hidden in the dark ring of dust at the center.

High Mass Stars

High mass stars can easily be thousands of times brighter than the Sun. Their extreme surface temperatures cause them to look white or blueish as opposed to yellow/red.

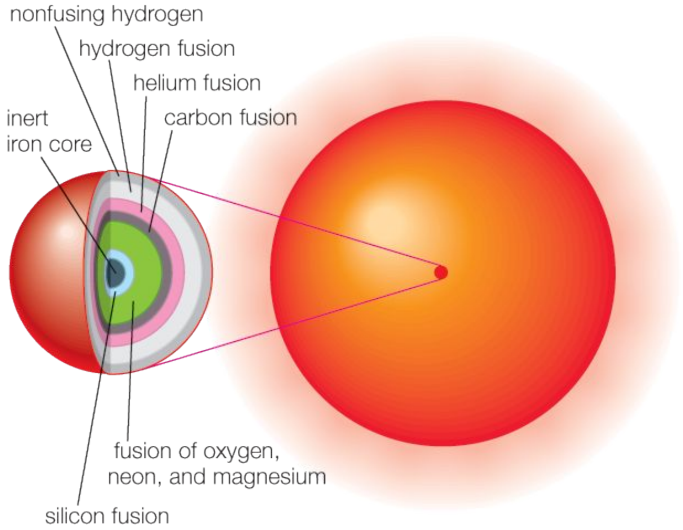
They can also burn heavier nuclear fuel, and have multiple giant/supergiant phases. However, they burn it all quickly, making them short lived.

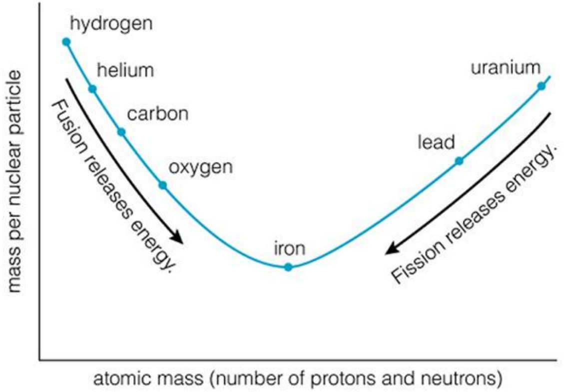
Low mass stars die when they reach a fuel too heavy to burn. Can a star with more mass always just move to a new fuel?

NO!!!

No matter how massive the star, it will die shortly after fusing iron.

Fusion works against gravity by releasing more energy than it takes to start the reaction. But elements more massive than iron take *more energy to start fusing* than you get out. This starts a runaway process.





The Fate of Stars

Once the star begins fusing iron, each reaction allows gravity to compress the star *further* instead of creating outward pressure.

Usually:
Contraction→increased reaction rate→expansion→decreased reaction rate

When fusing iron:
Contraction→increased reaction rate→increased contraction→increased reaction rate!!

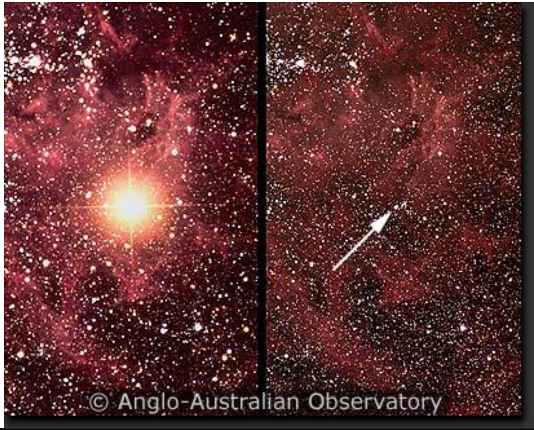
The star rapidly collapses as the iron fusion rate increases.

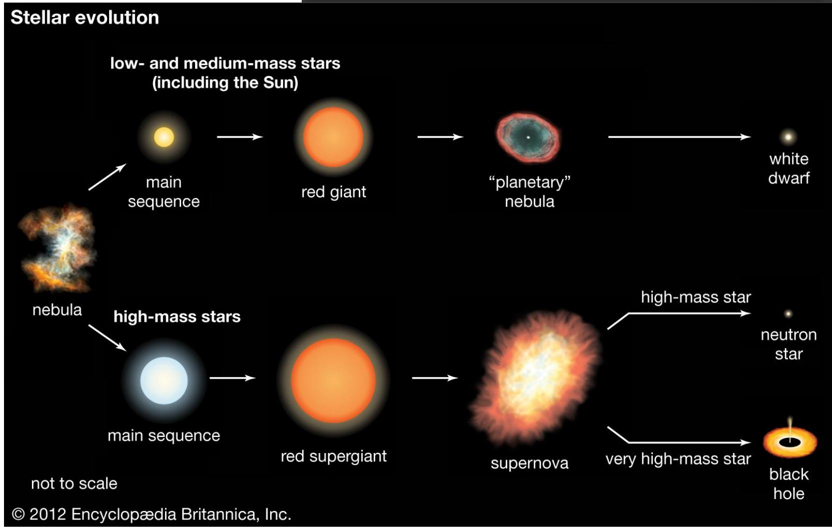
Core becomes so hot/pressurized that electrons are shoved into protons, and in only seconds the star goes from hundreds of time the size of the Sun to the size of a city. The energy released causes an explosion called a supernova, one of the brightest phenomenon in the Universe. During these few seconds, heavy elements like gold and uranium are made.

In the end, we are left with a stellar core of pure neutrons; a neutron star

OR

For the most massive of stars, the strength of gravity after the final contraction has no known counteracting force, and a black hole forms.





Milky Way

Galaxies are huge collections of stars and gas. Their strong gravity helps hold the gas that stars eject, leading to a relatively closed system. But these systems can collide and merge, changing the galaxies shape.

Galaxies have two major types:

Elliptical: spherical or elongated spheres, not rotating, usually very few blue stars, usually older

Spirals: disk-shaped, rotating, usually more blue stars, usually younger

The MW is a “barred spiral”

Milky Way

Spiral galaxies consist of 3 major parts:

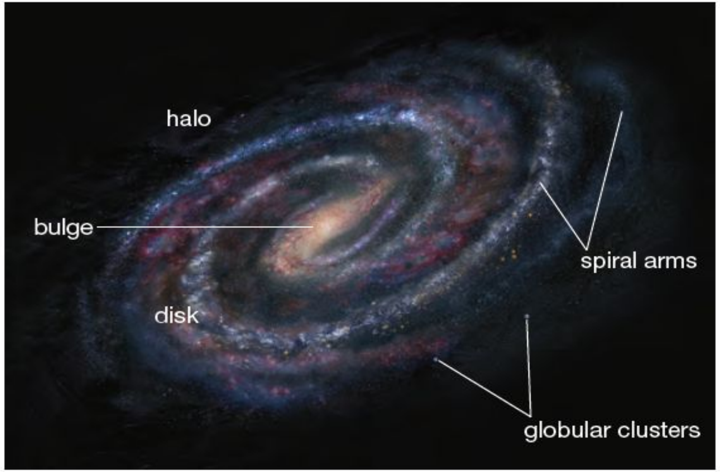
Bulge/bar: this inner region has high stellar density and is permeated by hot gas. Depending on galaxy type, some disks have a "bar"

Disk: This is the part most people think of as the whole galaxy. It is filled with knots of bright young stars and characterized by spiral "arms"

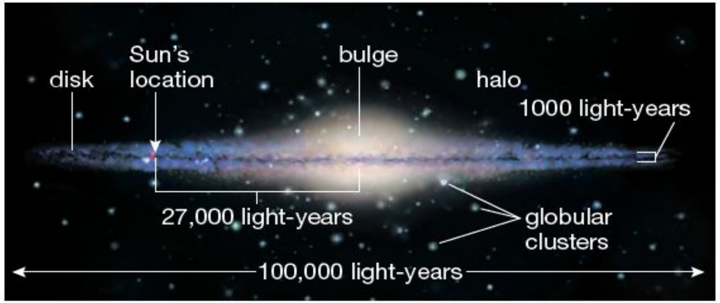
The bulge and disk contain the majority of the stars

Halo: This seemingly mostly empty area around the galaxy is marked by old stars. It is roughly spherical in shape, and much larger in extent than the disk.

The halo contains the majority of the hot gas (and metals)



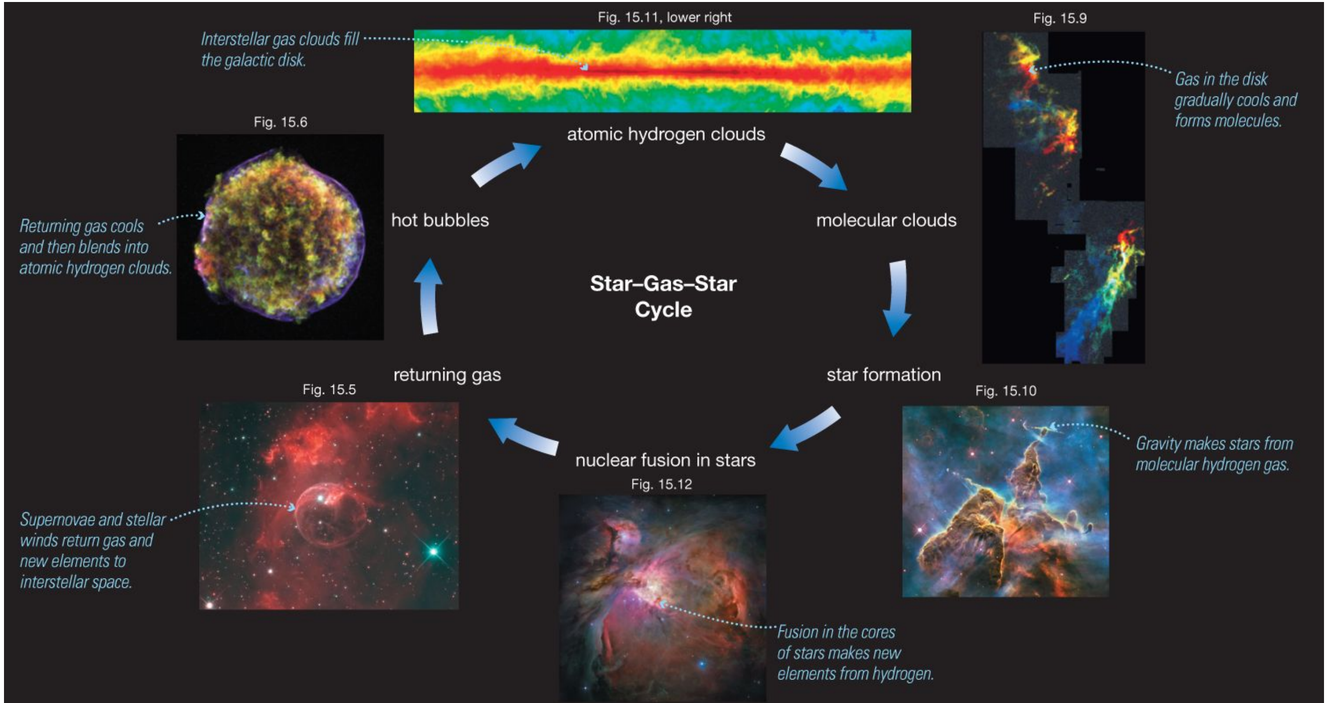
a Artist's conception of the Milky Way viewed from the outside.



b Edge-on schematic view of the Milky Way.

Star Formation in the Milky Way

Some astronomers think of galaxies as machines that repeatedly turn gas into stars. When a star has a supernova or becomes a planetary nebula, most of the gas leaves the immediate region. But in a galaxy, gravity is strong enough (and gas thick enough) to hold this gas in the disk, where is used to form stars *again*. This leads to a gradual build-up of metals in the galaxy.



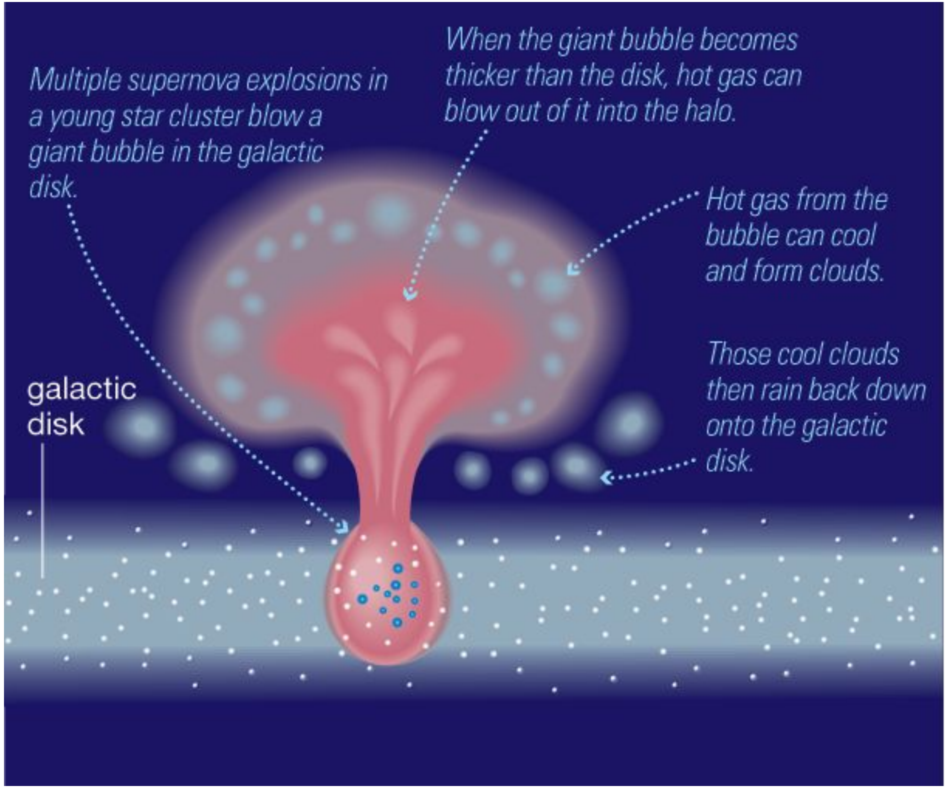
Star Formation in the Milky Way

In the same regions we find neutron stars and black holes, we often also find huge bubbles of hot gas extending above and below the MW disk. Stars tend to form in groups, at similar times. Then the most massive stars in a group also have supernova at similar times!

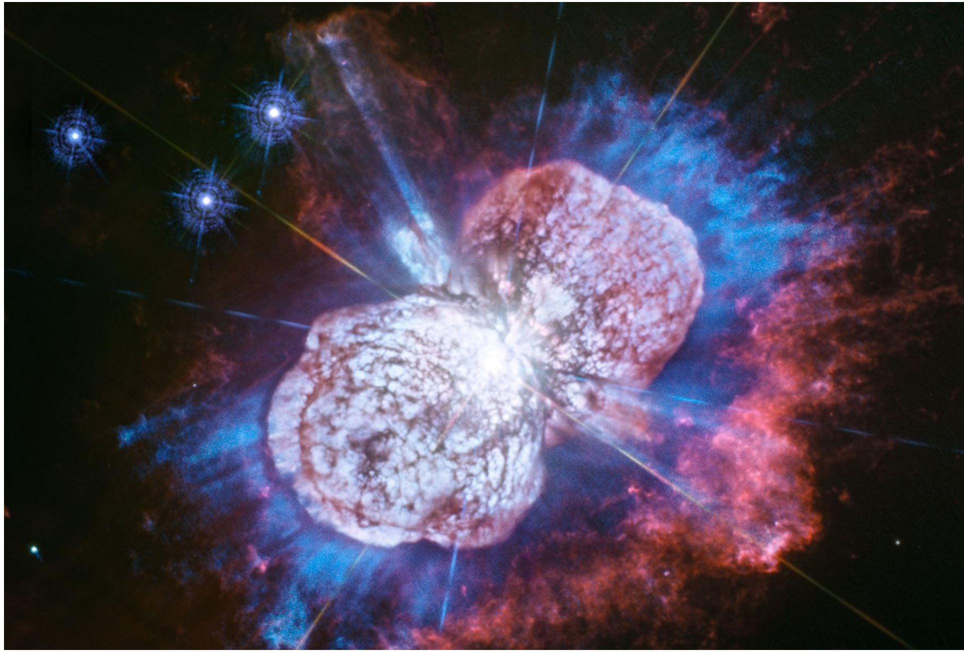
The explosions from these merge together within the group to form a single super hot bubble. If the bubble becomes so large it extends past the disk, it causes a “blow out”.

Much like volcanoes on Earth can explode and form dense clouds that cool and rain down, so too can galaxies!

As this gas falls back to the disk and cools, it forms stars. These stars bob up and down and contribute to the thickness of the disk.



Eta Carinae

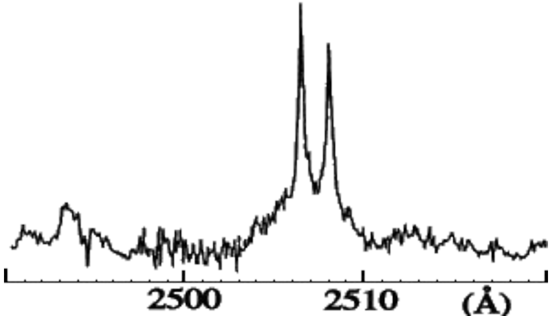


Outline of stellar life generally accurate, but the Universe is big; there are some weird situations.

Eta Carinae is a massive star (or collection of 2-3 stars) in the Milky Way. Combined, they are over 5 million times brighter than the Sun.

The largest star initially had a mass of 150-250M_{sun}. But in 1873, it experienced the Great Eruption, during which 30M_{Sun} superhot material were ejected by the largest star. This created the Homonculus Neblua. The event roughly resembled a supernova, but the star remains!

Eta Carinae fluctuates in brightness, and has highly unusual UV emission, being called a “dichromatic UV laser”.



Scientists are still studying the system today to uncover details about the history of eruptions.