Physics of a Star

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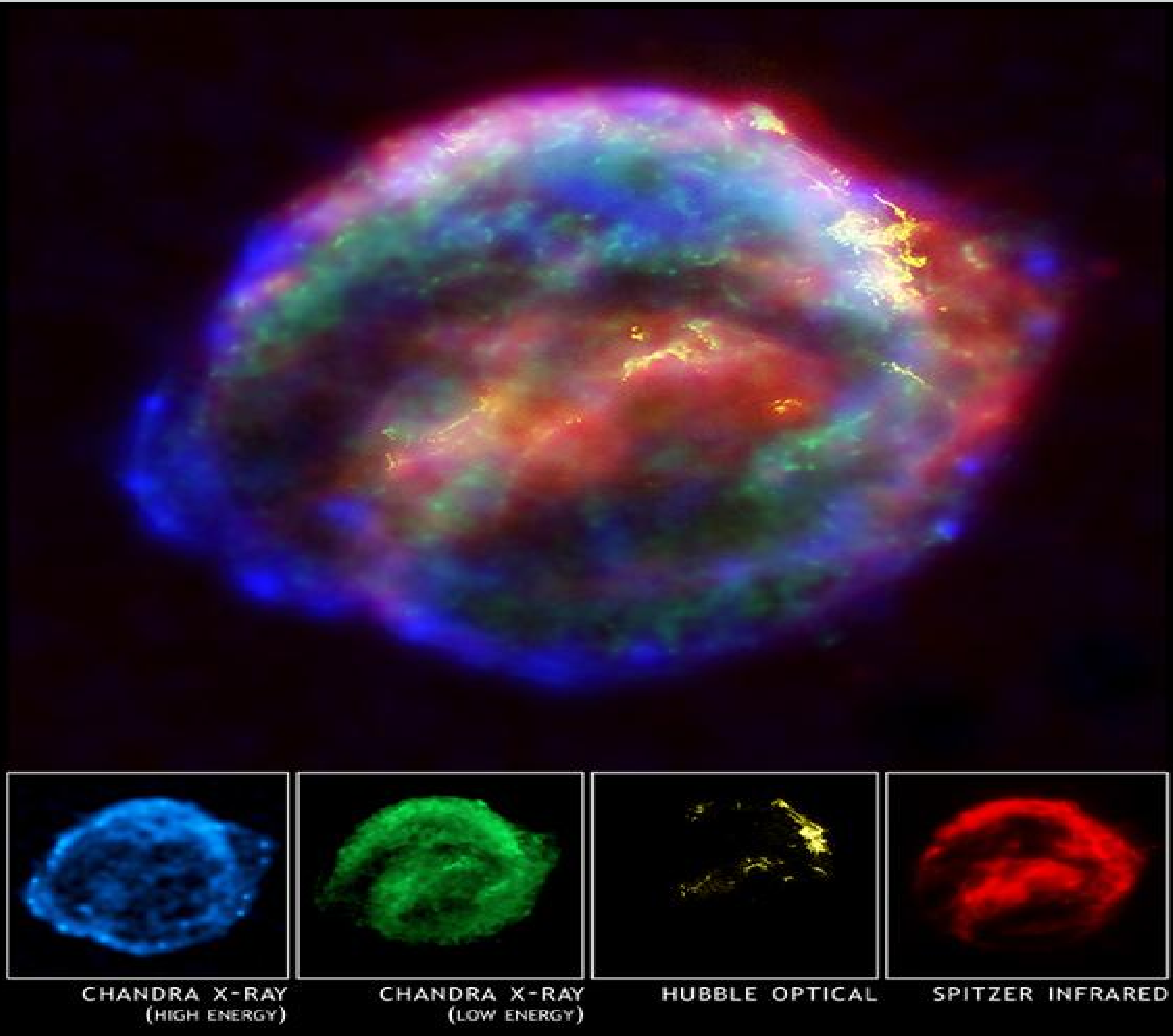
Early Star Life

- The Big Bang
  - Existence as we know started from a cataclysmic explosion that occurred approximately 13.798 billion years ago, setting in motion a chain of events that created our universe, galaxy, solar system, planet, and even the substances that we are made of.
  - The universe dramatically expanded, heated and cooled.
  - The universe is still expanding at an exponential rate.
  - The energy from the big bang was then converted into subatomic particles which combined into Hydrogen and other atomic gases.
  - The remnants of the big bang created molecular clouds called nebula and led to the formation of stars from dense stellar nurseries.

Molecular Clouds

- Molecular clouds can range from just a few light years to several hundred light years in diameter.
  - A light year is determined by the distance light can travel in a vacuum in one Julian year which is approximately 9.4605284×10^{15} meters
- Advancing technology in radio and infrared waves has made observations of clouds and star possible
- Isaac Newton and many others have debated the general concepts of star formation over many centuries.


CHANDRA X-RAY
(HIGH ENERGY)
CHANDRA X-RAY
(LOW ENERGY)
HUBBLE OPTICAL
SPITZER INFRARED

Molecular Clouds

Types of Nebula:

Dark Nebula
Planetary Nebula
Supernova Remnant
Diffuse Molecular Nebula

Molecular Clouds

Types of Nebula:

Dark Nebula

Dark nebula are usually so dense that they obscure light.

Horse Head

Molecular Clouds

Types of Nebula:

Planetary Nebula

Planetary nebula are stellar remnant clouds which contain glowing shells of ionized gases.

Cat's Eye Nebula

Molecular Clouds

Types of Nebulae:

Supernova Remnant

Supernova remnant clouds are the remains from the explosion of dying stars.

Crab Nebula

Molecular Clouds

Types of Nebula:

Diffuse Molecular Nebula

Stars are most commonly formed from nebula called diffuse molecular clouds.

Molecular Clouds
Accretion

- The birth of stars begins in nebula with the slow accumulation of dust, gas, and other materials left over from the universe's creation in a process known as accretion.

- The dust and elements of the cloud clump together into molecular cores, which become some of the densest matter of a nebula.

$$D=M/V$$

- This matter will continue to accumulate until a gravitational disturbance, like the pass of a star or other large body interferes with the materials collapse.

Molecular Clouds
Accretion

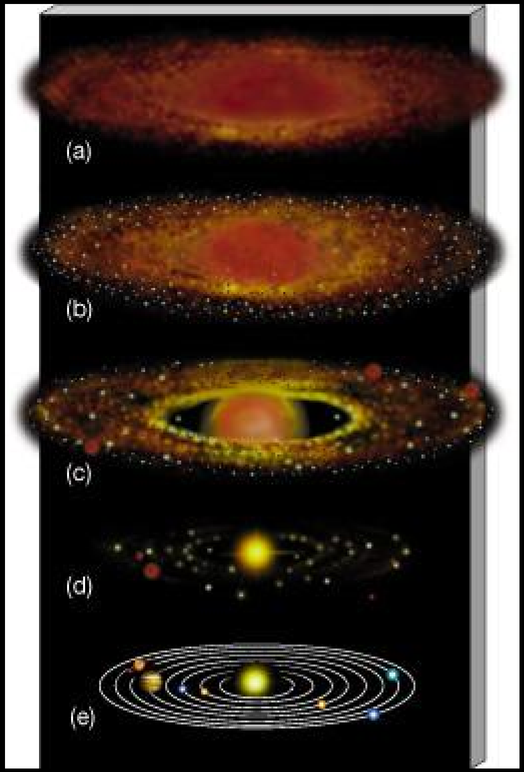
- Every point mass in the universe attracts every other point mass with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them (Hewitt, P. 2010).

The Inverse Square Law

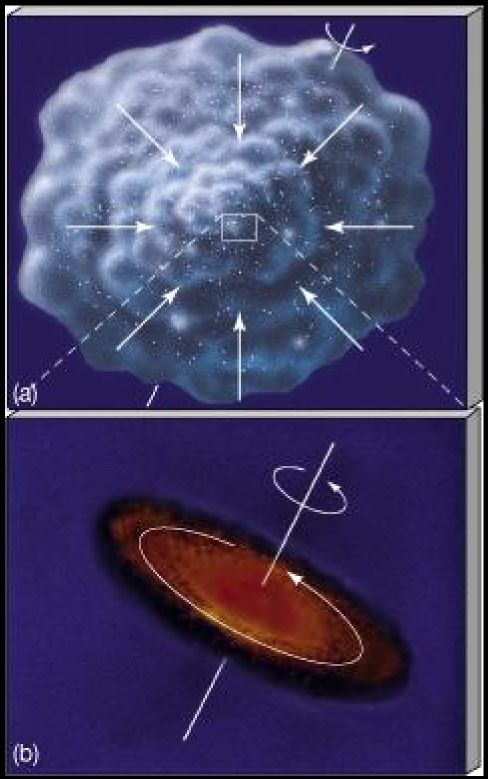
$$\frac{I_1}{(I_2)} = \frac{(d_2)^2}{(d_1)^2}$$

I_1 is the initial intensity of radiation, d_1 is the initial distance, and d_2 is the final distance, and I_2 is the final intensity.

Molecular Clouds
Accretion



Molecular Clouds
Accretion and Angular Momentum



Nebular Contraction (a) Conservation of angular momentum demands that a contracting, rotating cloud (a) must spin faster as its size decreases. (b) Eventually, the primitive solar system came to resemble a giant pancake. The large blob at the center would ultimately become the Sun.

Molecular Clouds
Gravitational Instability

- Stars are formed from gravitational collapse of a molecular cloud found at the center or in spiral arms of galaxies.
- As the gravitational force of the core increases it draws more of the surrounding particles inward and in addition increases in mass.
- The cores continue to collapse and become increasingly more dense.

Star Formation and Forces That Must be Overcome

- Extrinsic Thermal Pressure
  - Due to the increasing pressure of collapse particles are energized and counteract gravitational force.
- Thermal Pressure sets the minimum mass that a cloud core must exceed in order to collapse under its own gravity.

$$\frac{dp}{dr} = -\frac{G\rho(r)M_{enc}(r)}{r^2},$$

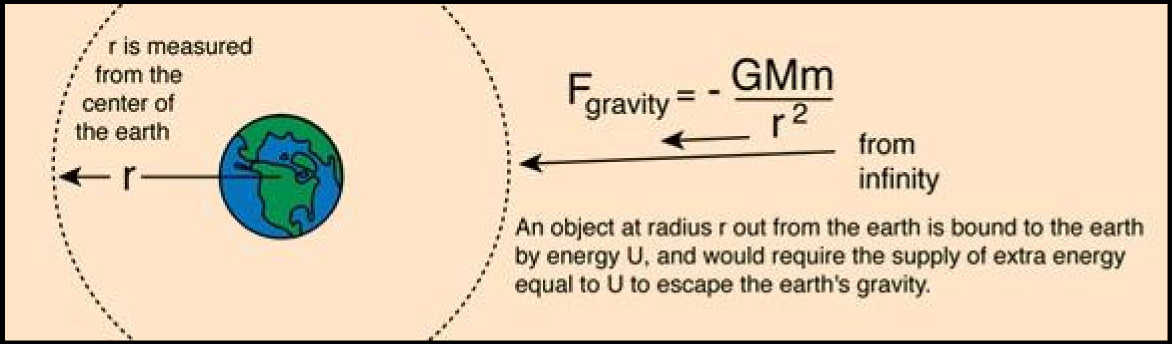
- Where G is equal to the gravitational constant, Menc is enclosed mass, r is the radius, p is pressure p (r) is the pressure of gas at r

Molecular Clouds
Gravitational Instability

- Areas of overly dense matter have a greater gravitational potential than that of the surrounding atomic gas causing what is known as gravitational instability. Gravitational potential or the energy needed to escape the gravitational pull is defined by:

U=(Gm1m2)/(r^2)

- Where G is the gravitational constant, m is the mass and r the radius.

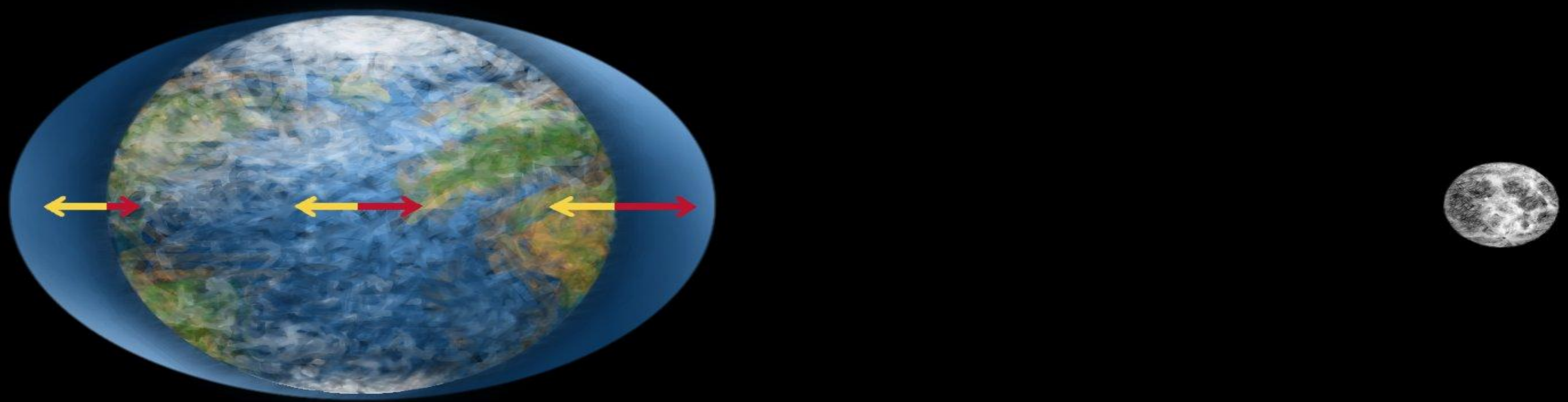


Star Formation and Forces That Must be Overcome

- <u>Turbulence</u>
- Turbulence in space is a random diffusion of material traveling at supersonic speeds that can exceed .2km-1.
- This random variation of velocity and pressure works against the gravitational force of collapse.
- Density fluctuations of stars can be influenced by these supersonic movements and by the energized particles. These fluctuations in density lead to limitations on star size and provides evidence that turbulent motions effect star growth (Puiu, T 2012).

Star Formation and Forces That Must be Overcome

- Tidal Force
- Tidal force depends upon the pull of one mass compared to that of the second mass and the distortion that occurs to each body.
- Tidal forces may be greater than that of the force of gravitational collapse acting upon the core, which will cause interference and can stop star formation.



Star Formation and Forces That Must be Overcome

- Magnetic Fields

- Magnetic fields are not able to completely counter the force of gravity alone, they are speculated to have some influence on star formation.

- Unfortunately, there is not enough data to properly understand the importance of magnetic fields in countering the gravitational forces. They may however damper rotational forces (Jsureshcfa 2011).

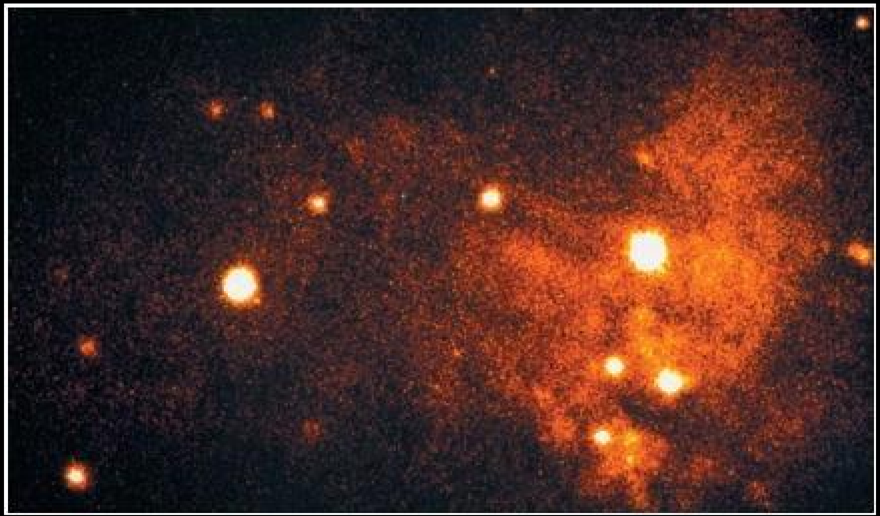
Light Generation

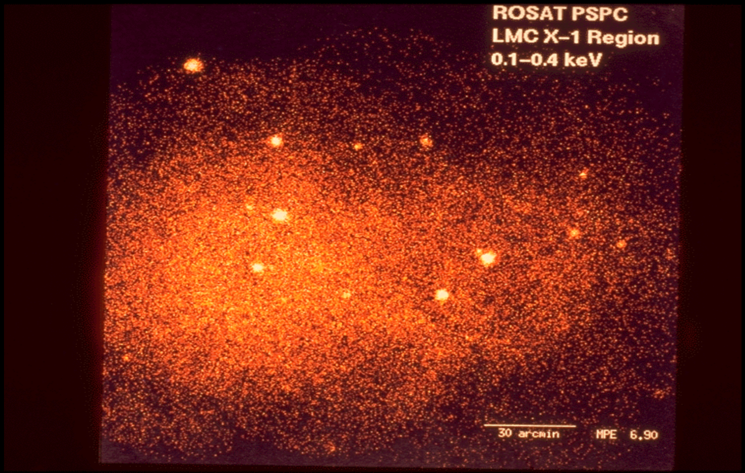
- In order for a star to begin to generate its own light, the core temperature has to reach 10,000,000 degrees Kelvin, at which point fusion reactions begin.
- At this point, the solar winds that are produced will push away the remaining debris.
- A star then becomes a hot ball of gas, with hydrogen fusing into helium at its core (Mihos.)

Binary Systems

- Unlike our solar system, in which we have one star, many stars are formed in multiple systems, usually in binary systems.
- In such cases, two stars will orbit a common center of mass. The brighter,
  or larger of the two stars is referred to as the Primary star, and the smaller,
  or less bright of the two stars is referred to as the secondary or companion
  star.
- Binary stars can be put into four different classifications: visual binaries, spectroscopic binaries, eclipsing binaries, and astrometric binaries. It is important to note that any binary star system can fall into more than one classification (Millis).

Binary Systems





- Images of an X-ray binary system, LMC X-1.
- In this type of system, x-rays are produced when matter from the donor star, usually a normal star in it's main sequence, falls onto an older, more dense star, possibly a black hole or white dwarf.
- 80% of all stars in our galaxy are part of a binary system.

Angular Momentum

- One of the main reasons that stars evolve in binary systems is because there is so much angular momentum in a particular molecular cloud.
- "Angular momentum is the product of a body's rotational inertia and rotational velocity about a particular axis. For an object that is small compared with the radial distance, it is the product of mass, speed, and radial distance of rotation" (Hewitt, P 2010).
- Because there is so much excess angular momentum that cannot be decreased into a single star, this problem is solved by distributing the excess angular momentum into binaries, and even clusters of stars.

Upper Limit Mass Formations

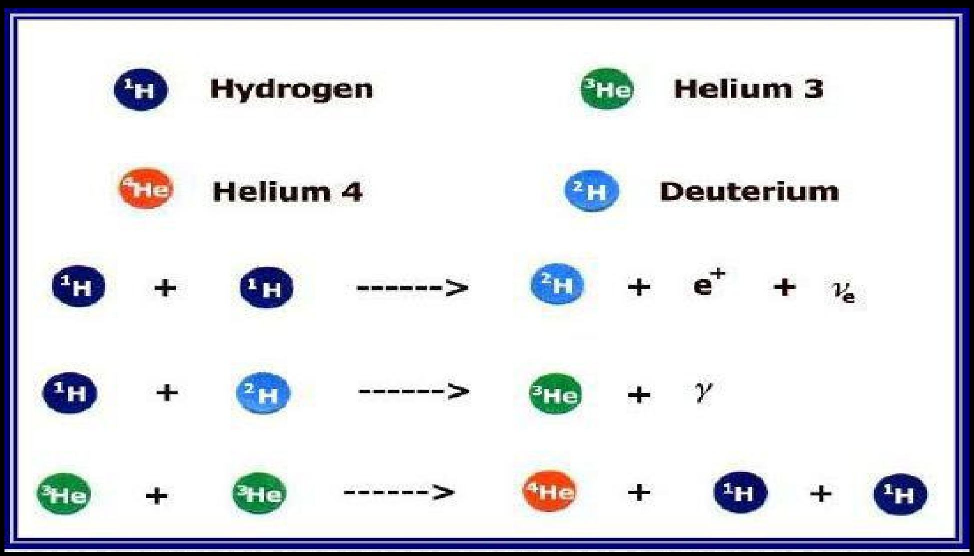
- A long-standing question that is of some interest is whether or not there is an upper-limit to the mass formations of stars.
- One of the main things to consider with this question, is whether or not the size of the molecular clouds in which the star is formed plays a role in determining how big the star can get.
- According to research done by the University of Michigan, there may be an upper limit to the mass of a star, that is close to 120-200 times bigger than our sun (Cain, 2005).
- The fact that we still don't know for sure what the upper limit to the mass of a star is, shows that our knowledge and understanding of stars and how they are formed is somewhat limited.

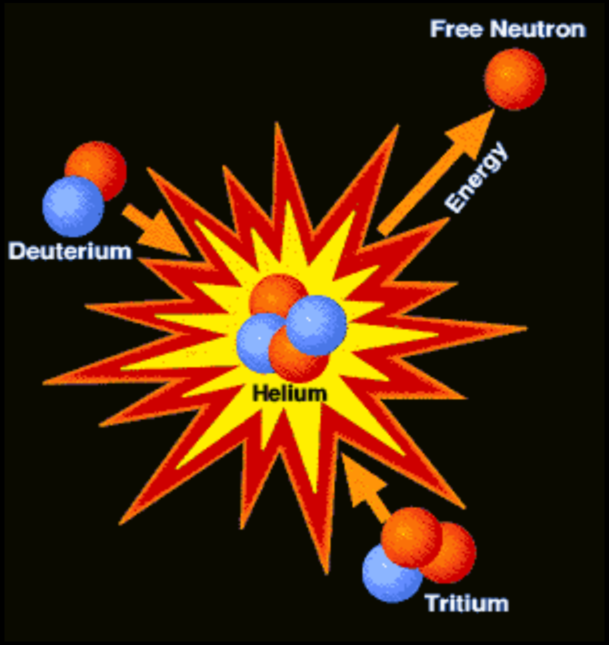
Middle Life
Fusion Reactions of Cores

- The main phase of a stars life is called the "main sequence".
- The equilibrium of this process is the battle of the gravity and the gas pressure, this battle between the two is a big part of how stars live and die.
- Once they achieve nuclear fusion, the star begins to shed light into the universe for billions of years to try and make up for the heat and light energy that it has lost.
- While this is occurring, the star is gaining density, pressure and heat. The core begins to increase and contract, due to the battle of gas and gravity occurring throughout the entire life of the star.

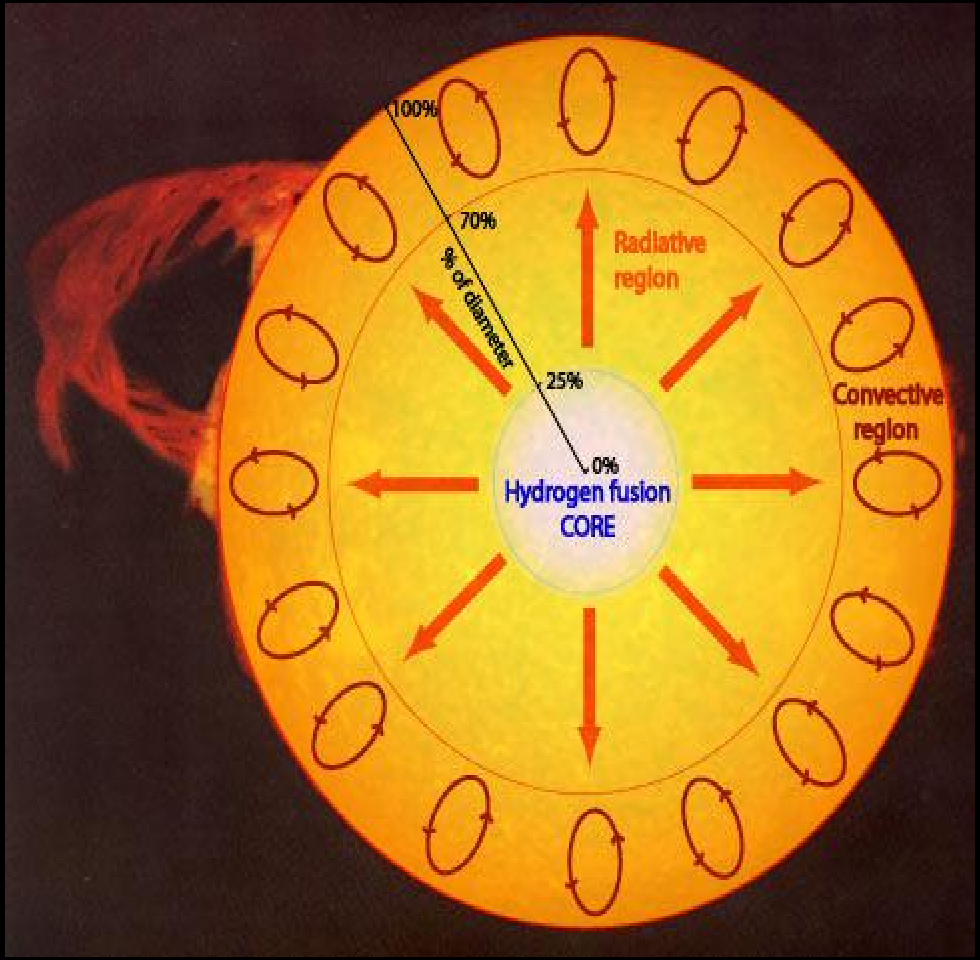
Mass into Energy

- Light atoms combine with heavier atoms and form fusion and that is how stars create their energy (H + He)



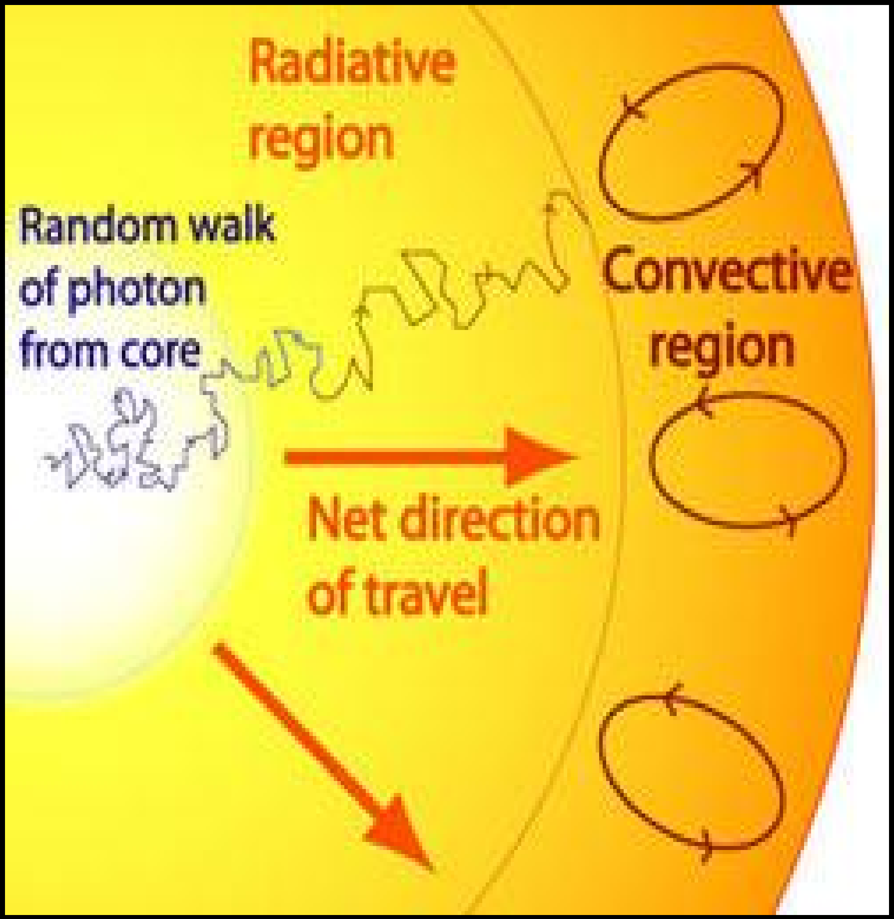


Regions of a Main Sequence Star



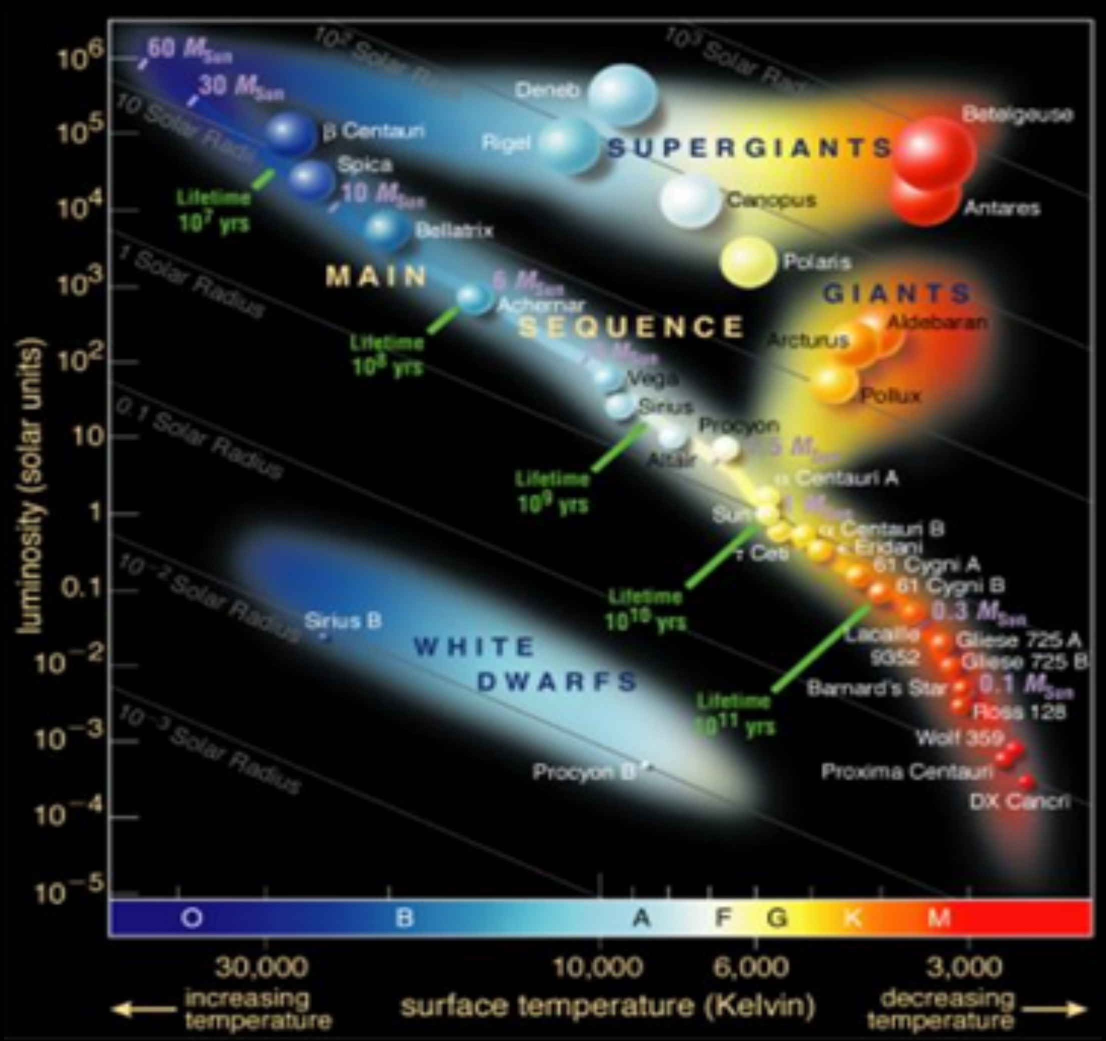
- The Core - where high energy fusion reactions occur.
- The Radiative Zone - The areas outside of where these primary energy producing reactions are taking place.
- The Convective Zone - a less dense area of hot gas where the radioactive processes that drove the photons out of the Radiative Zone are less important.

Photons Random Walk



- Photons begin their life as high energy gamma rays produced by the stars powerful fusion reaction.
- Photons are constantly being produced in the form of gamma-rays and are colliding with other particles, often electrons, that are being cast off by fusion processes.
- It can take about 200,000 years for photons to escape to the Radiative Zone

Stars Temperature and Type

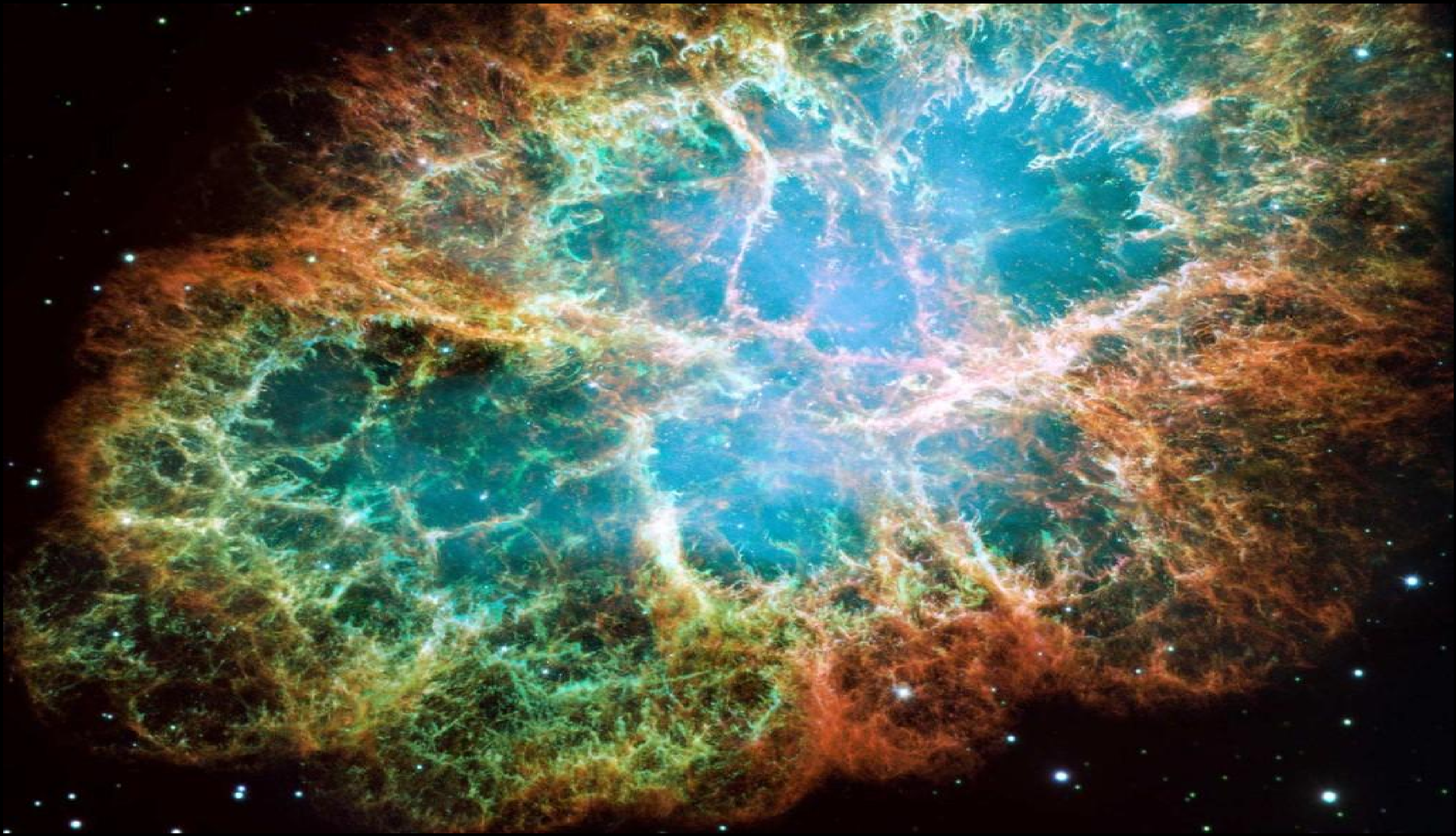


- There are 7 color categories of stars, O, B, A, F, G, K and M, with O types being the hottest and bluest with temperatures ranging from 25,000 - 50,000 degrees Kelvin to less than 3,500 K in M class stars .

- The hottest stars emit high intensity, short wavelengths of light that appear on the blue end of our visible light spectrum, while cooler stars emit light that falls closer to red in our spectrum of visible light.

Super Nova

- This is the Explosive death of a Star
- Often results in the star obtaining the brightness of 100 million suns for a short time.
- They leave behind black holes



The Crab Nebula, which exploded as a supernova in 1054, was visible during the day for nearly two years.

Differences Between Fusion Reactions and Size

- Fusion is the process where two or more nuclei combine to form an element with a higher atomic number. This is how stars get their power.

- The size of a star depends on how strong the inward pull of gravity is and how much outward push of energy (fusion) is.

Late Life/ Death
Energy Depletion

- As the temperature in the shell of the star increases, the outer layers expand.
- It tries to keep the heat of the core from escaping into space. Once this occurs, the star is considered a "Red Giant".
- No one is really certain on what happens after this occurs, but no matter how big or how small, the star will eventually run out of fuel.

Late Life/ Death
Electron Degeneracy

- Quantum mechanics of cold particles in a box
- Electron degeneracy pressure
- Structure of white dwarfs

Late Life/ Death
Red Dwarfs

- Red dwarfs are very faint, small stars, approximately one tenth the mass and diameter of the Sun.
- They burn very slowly and have estimated lifetimes of 100 billion years.
- Proxima Centauri and Barnard's Star are red dwarfs.

Late Life/ Death
White Dwarfs

- White dwarfs are very hot stars, that are in their final stages of a stars life cycle.
- White dwarfs have a mass similar to that of the sun, but only 1% of the sun's diameter; approximately the diameter of the earth.
- The surface temperature of a white dwarf is 8000 degrees Celsius or more.
- White dwarfs are the shrunken remains of normal stars, whose nuclear energy supplies have been used up.