A Star is born, and then….

The Life Cycle of a Star

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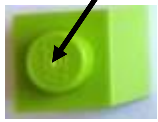
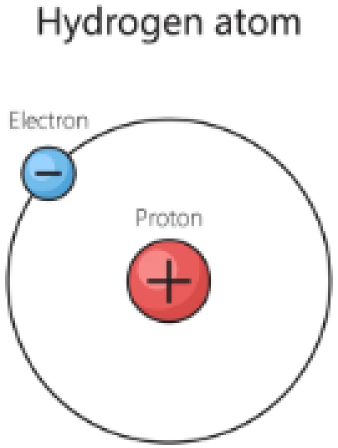
What is a Star?

- A star is a spheroid shaped collection of plasma that generates its own energy (light, heat, radiation).
- An example of a star is our own sun
- A galaxy is an organized collection of stars, planets and other material, held together by gravity. Our galaxy is the Milky Way. It is estimated that there are between 100 and 400 billion stars in our galaxy and there are between 100 billion and 200 billion galaxies in the universe.

Before we discuss stars, let’s talk about atoms

- Think of an atom as the smallest **building block** of our universe. A good analogy is Lego. Imagine that each Lego piece is an atom.
- Every atom has positively charged protons, negatively charged electrons and all but Hydrogen, have neutral neutrons. The protons and neutrons are in the atom’s centre (its nucleus).
- Let’s focus only on the protons in the nucleus
- The simplest/smallest/lightest atom is Hydrogen. The single connector on its Lego piece represents its 1 proton





Other larger atoms

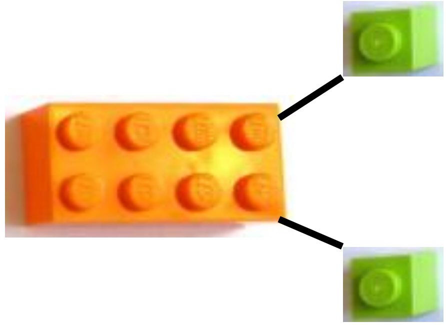
- The helium atom has 2 protons in its nucleus

- The carbon atom has 6 protons in its nucleus

- The oxygen atom has 8 protons in its nucleus

So what can we do with atoms?

1. Make a **molecule**. For example, we can combine 2 hydrogen atoms with 1 oxygen atom to make H_2O.



2. **Split (Fission)** an atom (e.g. a very big atom like Uranium – it has 92 protons). Under special conditions you can break apart its atomic nucleus and release a lot of energy (nuclear energy or nuclear bomb)

So what can we do with atoms?

3. **Fuse** atoms together. This is called a fusion reaction and it releases a lot of energy. This is what powers stars!!

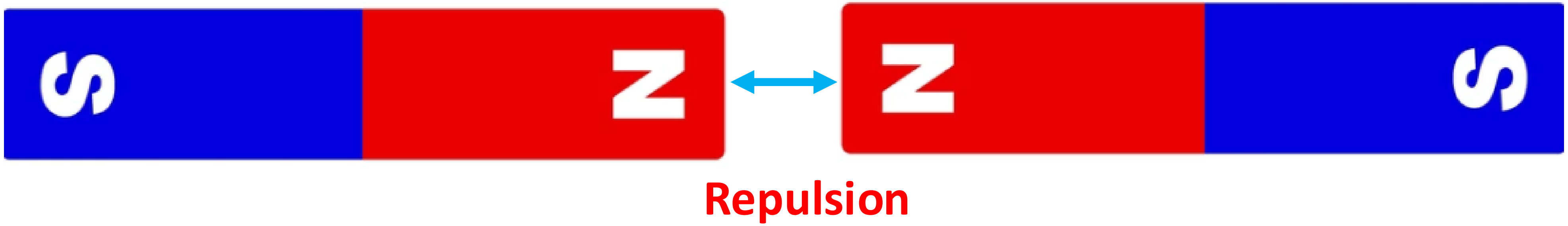
Two types of forces involved.

a) Strong Nuclear force – this is the strong force that holds protons and neutrons together in a nucleus. This helps the fusion reaction happen once smaller atoms are compressed together, at high speed

b) Coulomb “repulsive” force which makes it hard for protons to come close together since they have the same positive charge. A lot of heat and pressure are required to overcome this force to fuse atoms. This makes it difficult for fusion to happen.

A Coulomb Force Analogy

- Have you ever played with bar magnets?
- If you try to push the North ends of 2 bar magnets together, they repel each other.
- This is like trying to push two protons together, as they both have the same charge (positive)



Examples of Man-Made Fusion Reactions

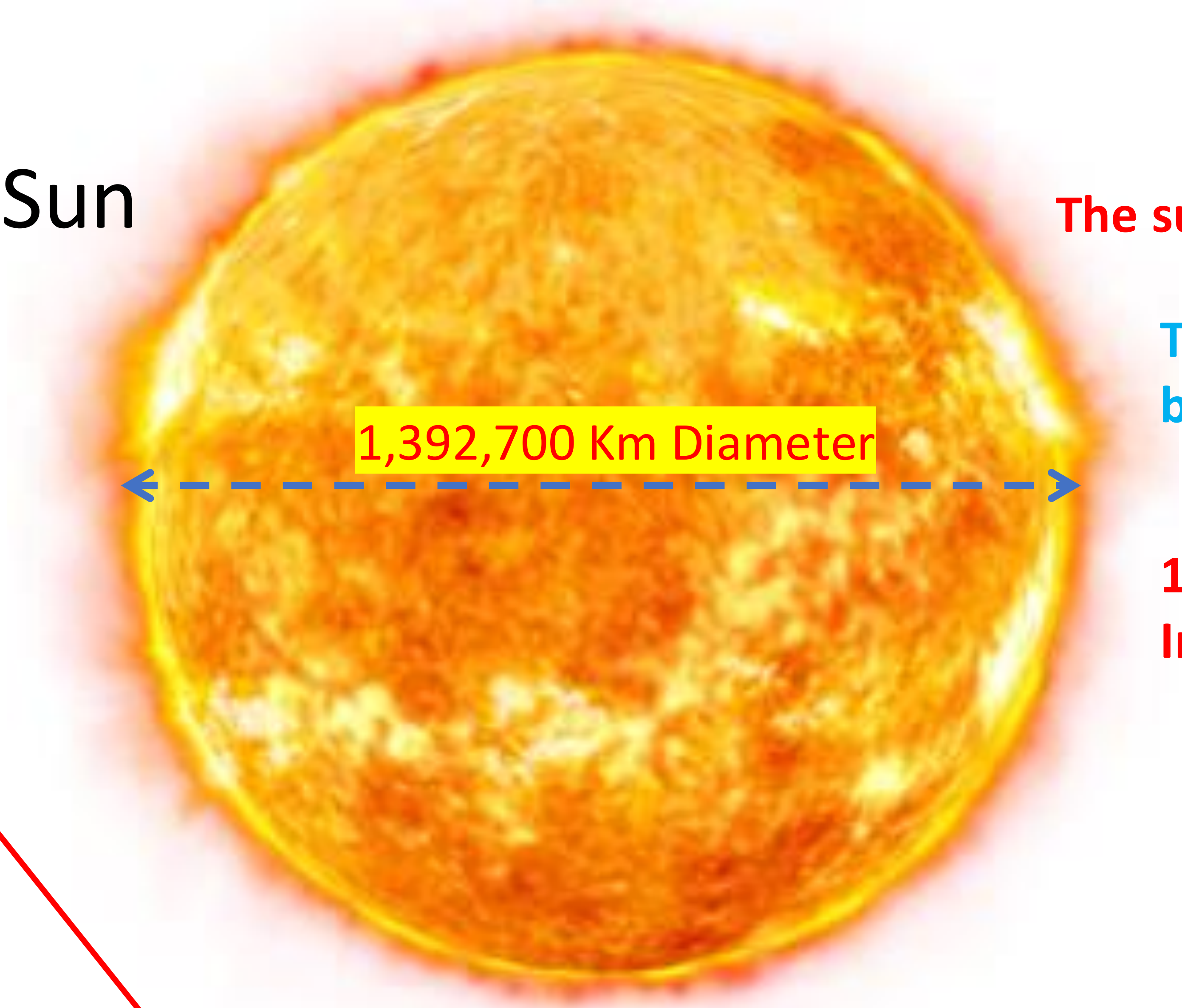
Hydrogen bomb

- Original “atomic” bombs used in WWII were fission (atom splitting) nuclear bombs.
- Later the “hydrogen” (fusion) bomb was developed, tested but not used in warfare to date. Much more powerful than atomic bomb

Fusion Energy

- If we can use fusion reaction to create energy this would be the ultimate clean power source.
- On Dec 5/22, the National Ignition Facility produced more energy in a fusion reaction than energy inputted. Powerful laser ignition.

The Sun



The sun is 4.6 billion years old

The sun has about 5 billion years of fuel left

1,300,000 earths could fit Inside the sun

The Earth

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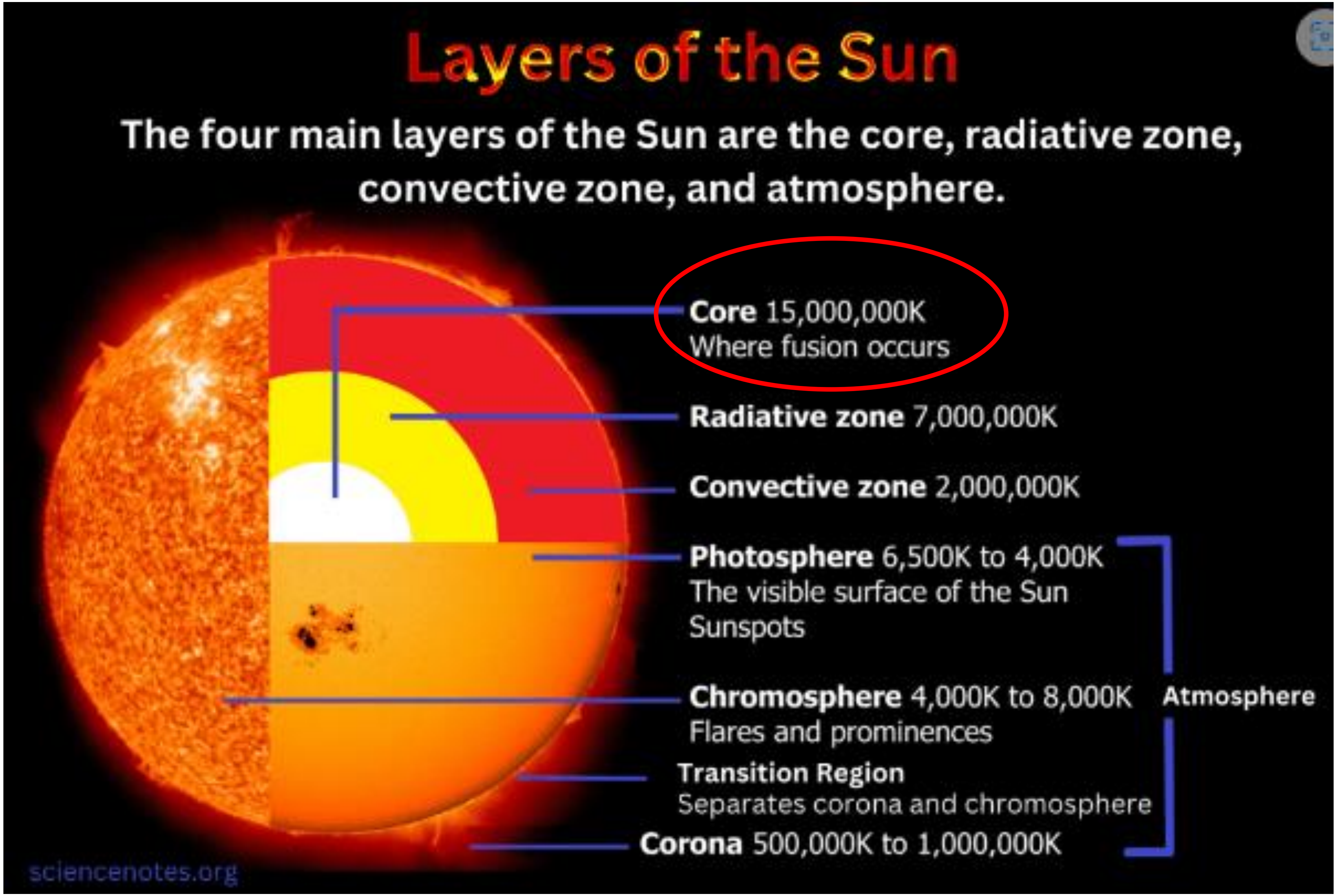
1,989,000,000,000,000,000,000,000,000,000 kilograms


Layers of the Sun
The four main layers of the Sun are the core, radiative zone, convective zone, and atmosphere.
Core 15,000,000K
Where fusion occurs
Radiative zone 7,000,000K
Convective zone 2,000,000K
Photosphere 6,500K to 4,000K
The visible surface of the Sun
Sunspots
Chromosphere 4,000K to 8,000K
Flares and prominences
Transition Region
Separates corona and chromosphere
Corona 500,000K to 1,000,000K
Atmosphere
sciencenotes.org

What Powers the Sun

- The sun's is composed of 74.9% hydrogen (**but not as gas**). This is the fuel for the sun.
- In the core of the sun, hydrogen atoms (1 proton each) 

under very high temperatures and pressures, **fuse** together to make the

heavier atom called **helium** (2 protons) 

The high core temperature makes the hydrogen atoms smash together fast and the high core pressure pushes the hydrogen together with a lot of force

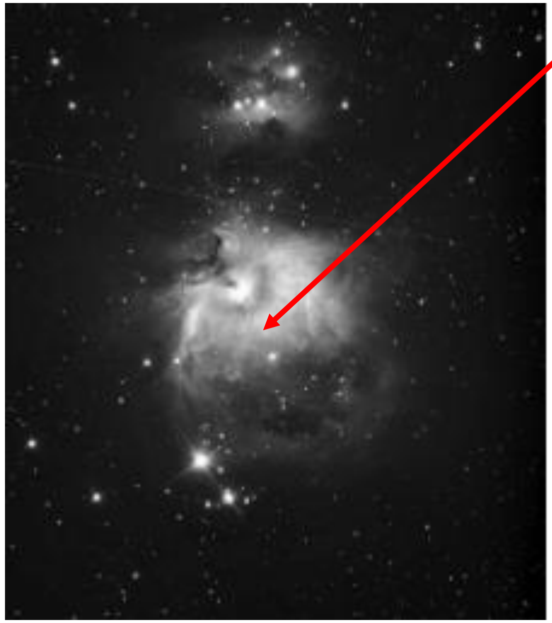
- **In the process, a small amount of mass is left over** and this excess mass is converted into **energy.**
- Einstein said that Mass and Energy are related by his equation

  $E = MC^2$

If you want to fuse larger atoms, it takes a lot more heat/pressure since **more protons** (**much bigger bar magnets !!!!**)

The Birth of a Star

- Stars are born in a Nebula. A Nebula is a collection of gases and dust. To birth stars, the nebula must have hydrogen gas.
- A good example is in the Orion constellation. Through a small telescope you will see a fuzzy/cloudy area called the **Orion nebula**



The Orion nebula has hydrogen, dust and young stars

A Birth of a Star

- Over a period of time, the gases in a nebula will start to move closer together, drawn by gravity.
- This clump of gas will start to collapse due to gravity and heat up in the centre due to the pressure of its gravity. This star shaped blob is called a **Protostar**. More gases are drawn to the Protostar due to the building gravity.
- A **star** if formed when the core of the Protostar is high enough in temperature and pressure to "ignite" the fusion reaction. The star now starts to produce its own energy, radiation and light.
- The larger the initial cloud of gas/protostar, the larger the star

How do Stars Evolve

- The smaller the star, the longer the lifespan. There is less pressure/lower core temperatures in smaller stars and this means that they use their fuel more slowly (like a small, fuel efficient car)
- The smallest stars can last > 1 Trillion years while the largest stars may only last a few millions years.
- A star’s colour indicates its temperature. The hotter the star, the larger it is. Red stars are the smallest/coolest*

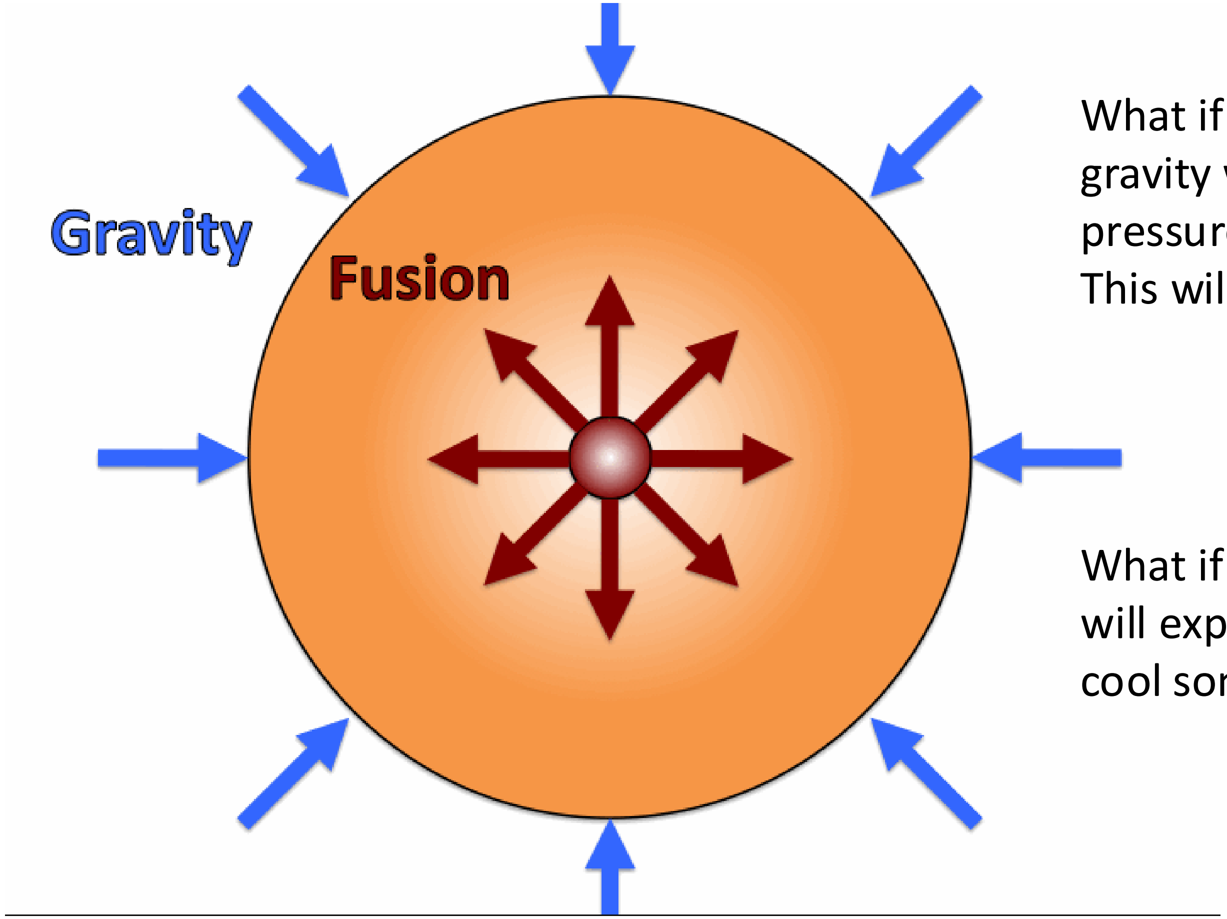

The Colors of Stars
From Hottest to Coldest
hottest
BLUE
Rigel
25,000 K
BLUE-WHITE
Sirius
10,000 K
YELLOW
Sun
6,000 K
ORANGE
Aldebaran
4,000 K
RED
Antares
3,000 K
coldest

How will our Sun Evolve

- Our sun is a medium sized star. It has been fusing hydrogen into helium for the last 4.6 billion years.
- Over this time, the helium has been building up in the sun’s core causing the core to get denser. This has increased the rate of fusion, causing the sun to get hotter and brighter (about 40%).
- In another billion years, the sun will be so hot that it will evaporate the earth’s oceans!!!

Forces that control a star – a **balancing** act

“Hydrostatic Equilibrium”

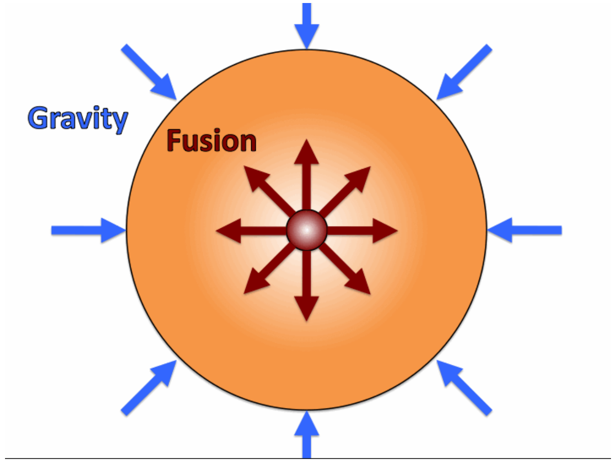


What if the Fusion reaction slows down? then gravity will compress the star. This increased pressure on the core will increase its temperature. This will increase the rate of fusion

What if the Fusion reaction speeds up? then the core will expand. With this decreased pressure, the core will cool somewhat and this slows the Fusion reaction.

The Hydrogen in the sun's core starts to run out!!!

- With the fusion reaction slowing, gravity will start to compress the sun



- This increases the core temperature and heats up the layer surrounding the core, to the level that hydrogen can fuse there.
- The heat radiates to the outer layers causing them to expand **(perhaps far enough to engulf the earth???).**

The End of the Sun

- The outer layers continue to expand. Although the sun's core temperature is high, the sun has expanded so greatly such that its average temperature goes down. It starts to turn into a **red giant**.
- Eventually the core compresses so much so that helium atoms (2 protons) can fuse into carbon (6 carbons).
- This reaction doesn't yield as muc  rgy as hydrogen fusion. 
- Once helium runs out, the core compresses more but conditions are never hot enough to fuse carbon (only in stars 8x the size of the sun), so the sun's core starts to shrink into a **very dense** "white dwarf" star with surrounding, expanded outer layers. The sun will go black after a long time (maybe a trillion years) and become a black dwarf (invisible). A pair of dice made from a white dwarf would weigh the same as an SUV vehicle
- All stars up to and including Blue-White stars, will end up as white dwarfs

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Planetary Nebula – no planet involved!!

- If a star is **larger** than the sun (like Sirius), then at white dwarf stage it will emit radiation which will excite the gases in the outer layers, giving rise to beautiful colours. This is called a planetary nebula.

Spirograph Nebula

Cat’s Eye Nebula


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What Happens to giant stars when fuel gone?

- “Blue” giant stars are much hotter and larger than our sun (sun’s core only 15 million degrees)
- At 8x the mass of our sun, carbon (6 protons) can fuse to make Neon (10), Sodium (11) and Magnesium (12).
- Even higher mass stars:
  - 1 billion degree core – Neon fuses to Oxygen (16) and Magnesium
  - 1.5 billion degree core – Oxygen fuses to Silicon (14)
  - 2 – 3 billion degree core – Silicon fuses to Iron (26)

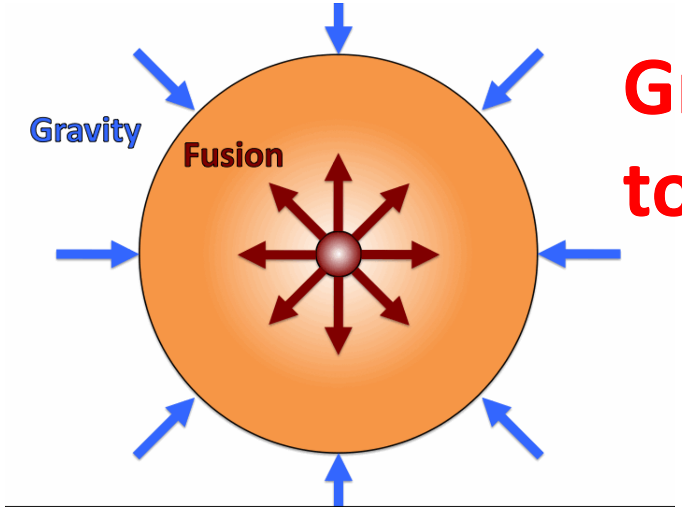
At 20x our sun’s size, a star fuses Helium for 1 Million years, Carbon for a thousand years, Neon for 1 year, Oxygen for 1 month and **Silicon for 1 day!**

Example: Betelgeuse

- Located in Orion constellation. It is usually the 10th brightest star in the night sky, even though 600 light years away. 1.2 billion Kms wide (our sun is 1.4 million kms wide)
- Likely started as a blue super giant
- Just like the sun, as it fused heavier atoms, the core heated up. The heat from the core radiated out and caused the outer layers to expand. It became a red super giant.
- One day it will explode as a supernova!!!

The Curse of Iron!!!

- Fusing atoms gives energy for the star, until it fuses silicon into iron
- Iron doesn't produce energy when it fuses, it absorbs energy!!
- Once iron forms in the core, the star is doomed as it has no energy source.



Gravity Starts to Win!!

Core shrinks and heats up but no fusion happens this time

The Future Death of Betelgeuse

- The shrinking iron core exerts tremendous gravity
- The core collapses from several hundred kms to a few km, in a fraction of a second.
- The outer layers get drawn in hard/fast towards the core, heating up and compressing.
- A massive shock wave emits from the core collapse, as well as a huge number of high energy neutrinos. These neutrinos carry away 99% of the star's energy (more than the energy produced by our sun in its **entire lifetime**)
- The compressed/dense outer layers absorb the shock wave and neutrinos, which causes them to explode in a massive Supernova explosion.

Black Hole

- Further core contraction continues until the star's core is reduced to a very small size (a black hole, black because not even light can escape its gravity)
- Almost every galaxy has a black hole at its centre. They direct many of the activities (star destruction, formation, etc..)

One of the first recorded images of a black hole

What Happens in a Supernova?

- The extreme high temperatures (about 100 billion degrees) and pressures of the supernova explosion, allow very high energy fusion reactions to occur in just a few seconds. This is called **Supernova Nucleosynthesis**.
- All the heavier elements (higher number of protons) are formed this way.

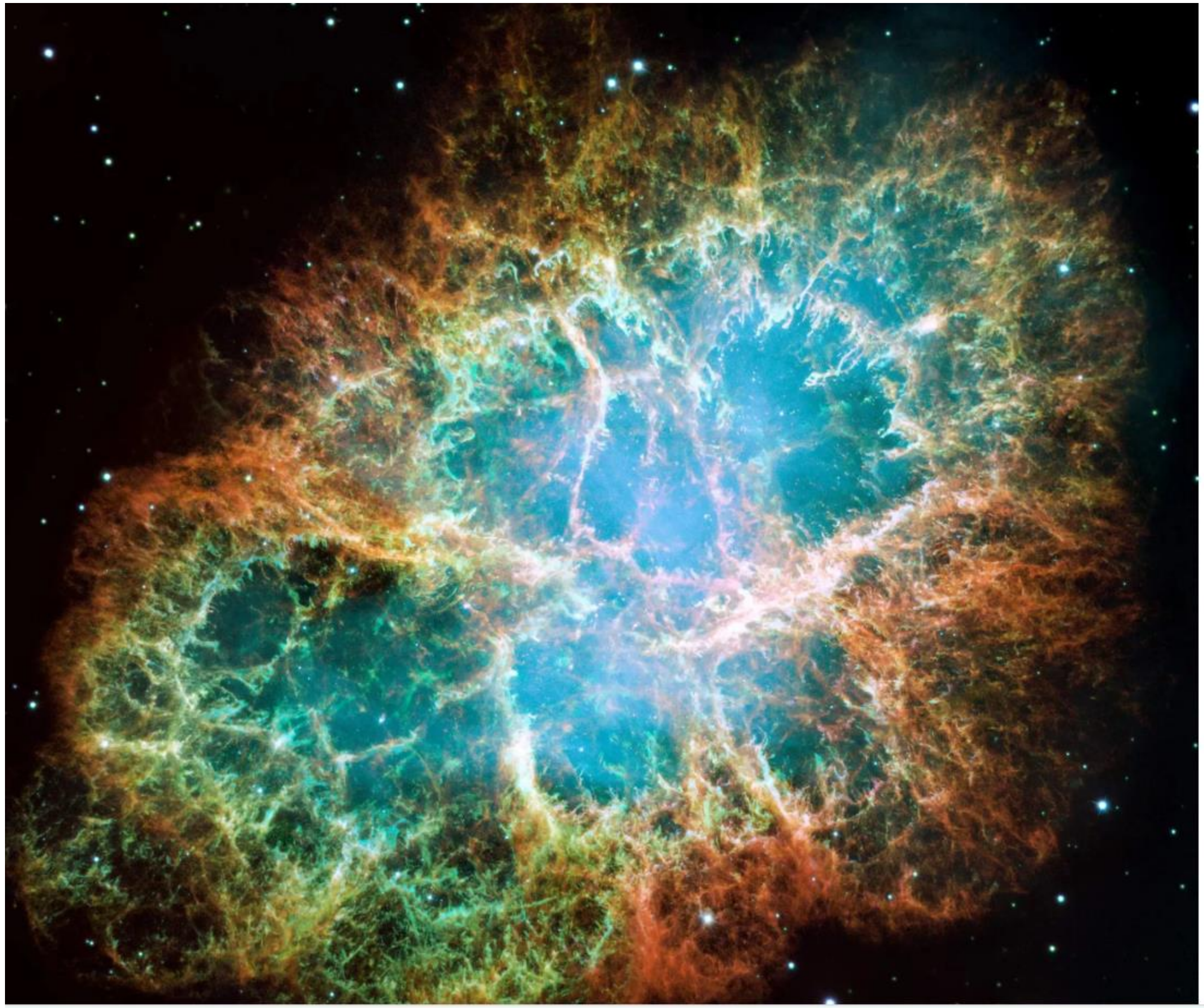
We are Stardust!!!

- In its infancy, the universe was mostly Hydrogen, with a little helium
- All the heavy elements that comprise the earth and our bodies, came from a supernova explosion.
- **Calcium** in our bones
- **Phosphorus** in our DNA
- **Iron** in our hemoglobin, to transport oxygen to our cells
- *All these elements were formed in the supernova of a red supergiant, about 5 billion years ago.*

Neutron Star

- If a star is a Blue Giant (not as large as Betelguise), it will still undergo a supernova but its core will stop collapsing before it reaches the black hole stage
- Composed almost entirely of neutrons and extremely dense (a teaspoon of a neutron star material weighs 10 million tons)
- Rotates at high speed (fastest is 716 times per second)
- Can emit beams of electromagnetic radiation in measurable, periodic pulses (a pulsar).
- Like white dwarf, they eventually run out of energy (no fusion)

Remnant of a Super Nova: Crab Nebula



Crab Nebula Image from Hubble telescope

Remnants of SuperNova that Chinese astronomers observed in 1054 AD.

This new “ghost star” was visible in daytime sky for 3 weeks

Supernova star became a neutron star. It is at the centre of the Crab Nebula. Crab Nebula is 6 light year across and can be observed in Taurus constellation, 6,500 light Years away.

Look for the Orion Constellation!!

- Is visible in the night sky this time of year.

Betelguese – red super giant

Orion Nebula

Rigel – Blue supergiant

Questions???