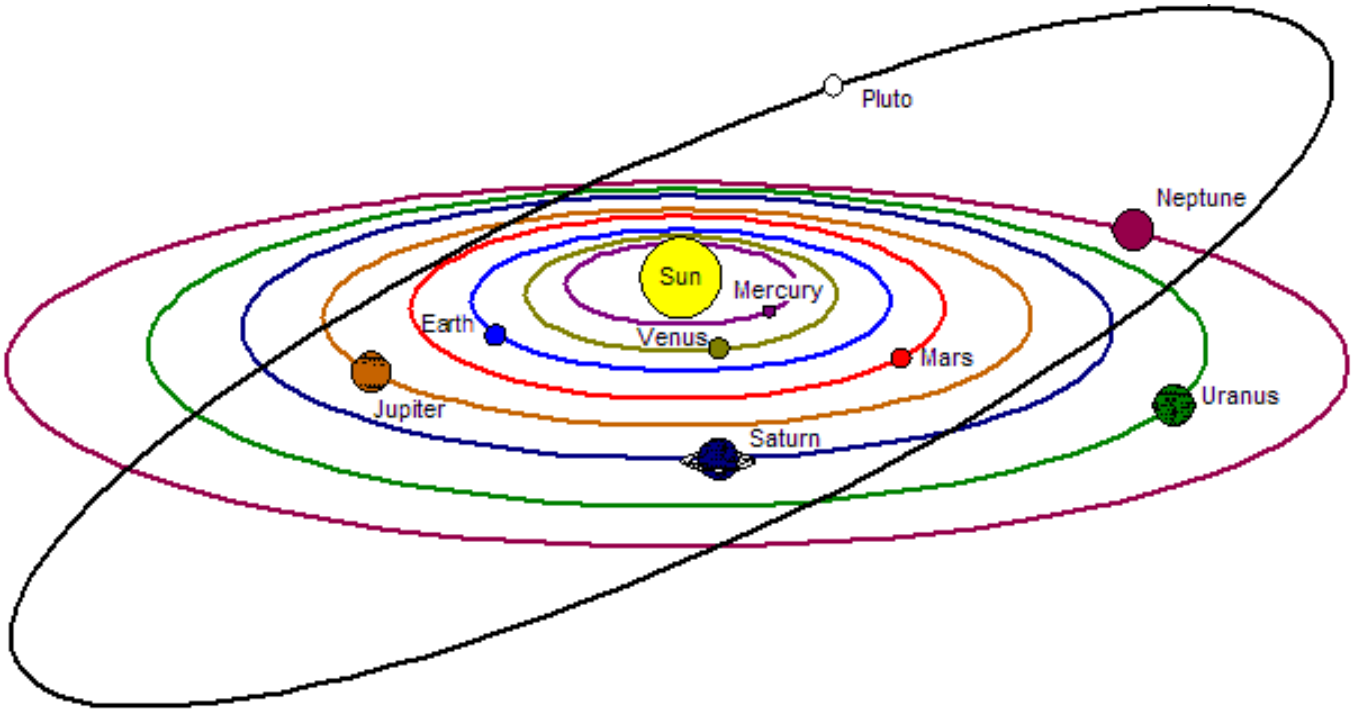
Lesson 05

The Sun

The Star at the Center of the Solar System

The accepted model of our solar system is the **Heliocentric Model**. ***"Sun in the center".***



Sun: The star at the center of the solar system.

- Yellow dwarf star
- 4.6 Billion Years old

The sun contains ~ **99.9% of the total mass** of the solar system. The Sun's mass is **700-times greater** than the combined mass of all other matter in the solar system.

FACTS ABOUT THE SUN

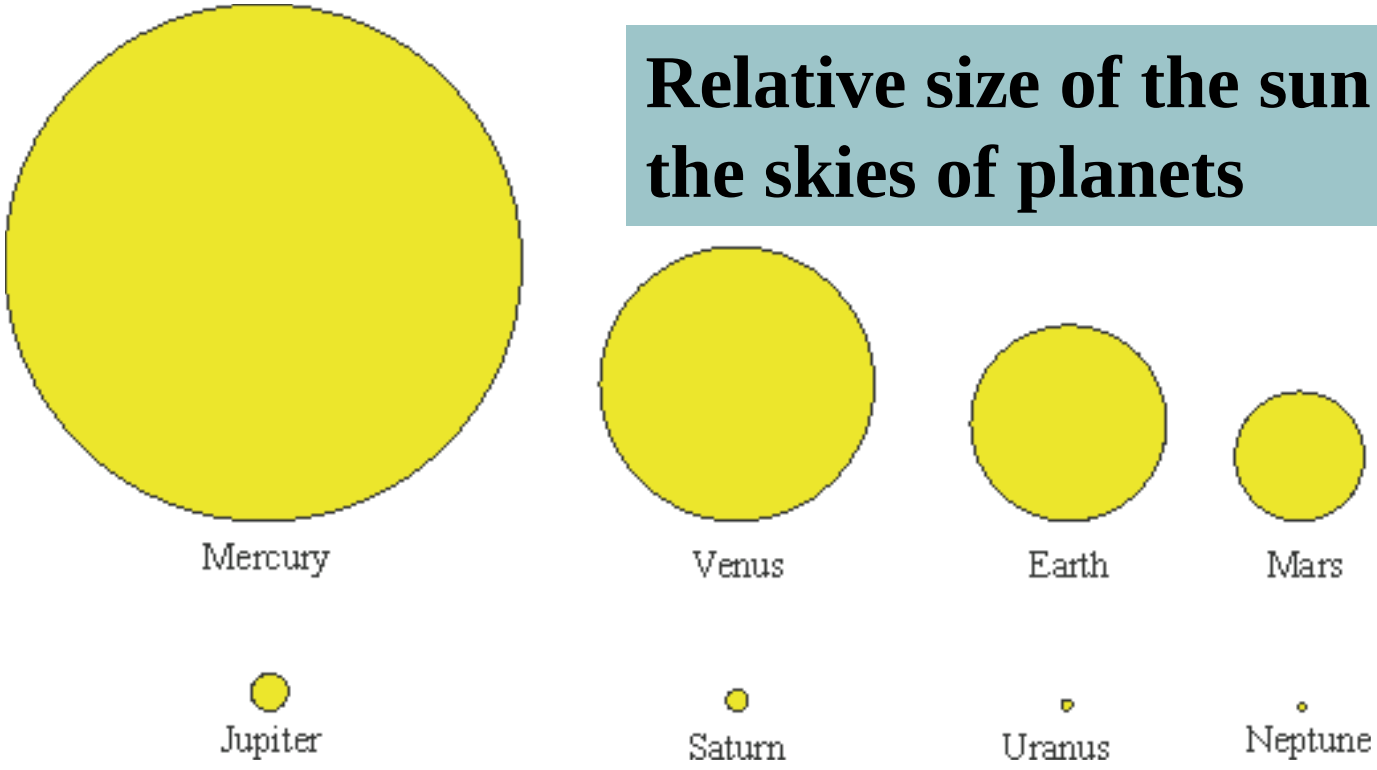
- ***Yellow dwarf star*** in the ***main sequence***
- Equatorial diameter = 140,000 km
- Solar mass = 2.0×10^{30} kg
- Rotational period = 24.5 days
- Surface temperature = 5800 Kelvin
- Core temperature = 15,000,000 Kelvin
- Luminosity: 3.85×10^{26} Watts
- Composition by mass (how much)

  71% hydrogen, 27% helium, 2% heavy elements
- Composition by atomic abundance (how many)

  92% hydrogen, 8% helium, <0.1% heavy elements

The closer the planet's orbit to the Sun, the larger and brighter the Sun appears in the daytime sky. The Sun appears to be very large in Mercury's sky because Mercury is the closest planet to the Sun. The Sun appears like a small dot in Neptune's sky because Neptune is very far away from the Sun in the outer solar system.

Relative size of the sun in the skies of planets

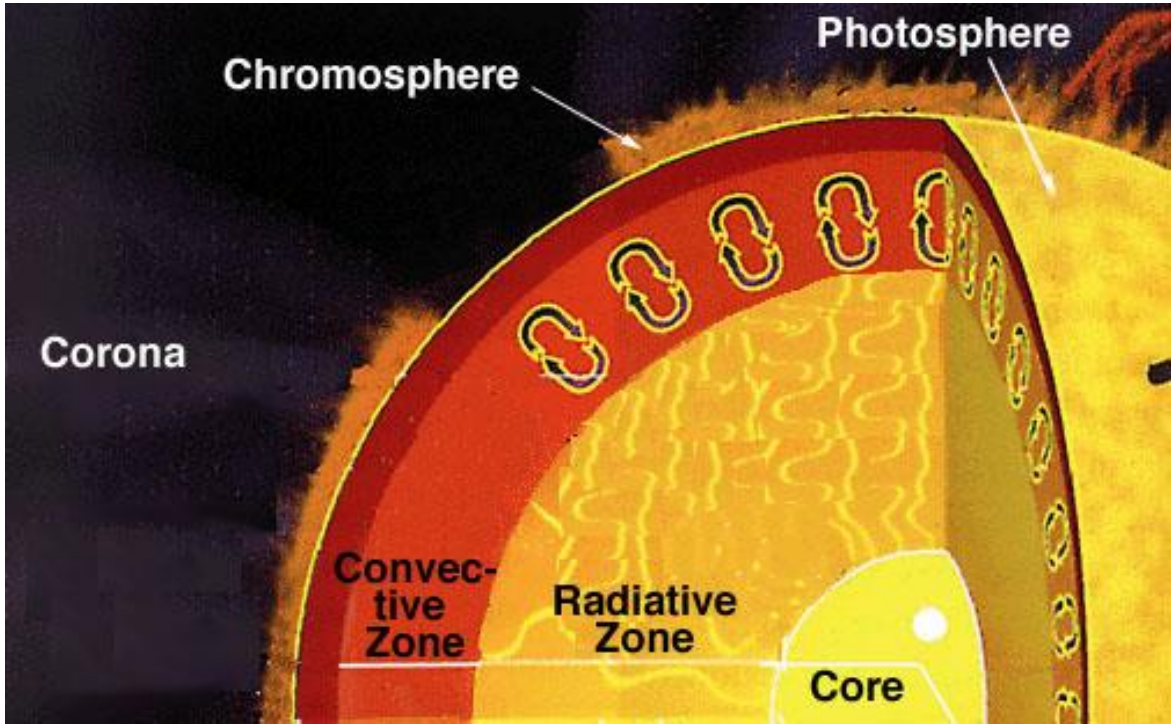


The Sun is a **yellow dwarf star** that is in the **main sequence** of its life cycle.

- Relatively a small star. Most stars in the Milky Way galaxy are much larger and more luminous.
- Yellow color at its photosphere is due to the Sun's surface temperature of 5800 kelvin.

Main sequence stars are those that **fuse** hydrogen atoms to form helium atoms in their cores. That is the source of the Sun's energy.

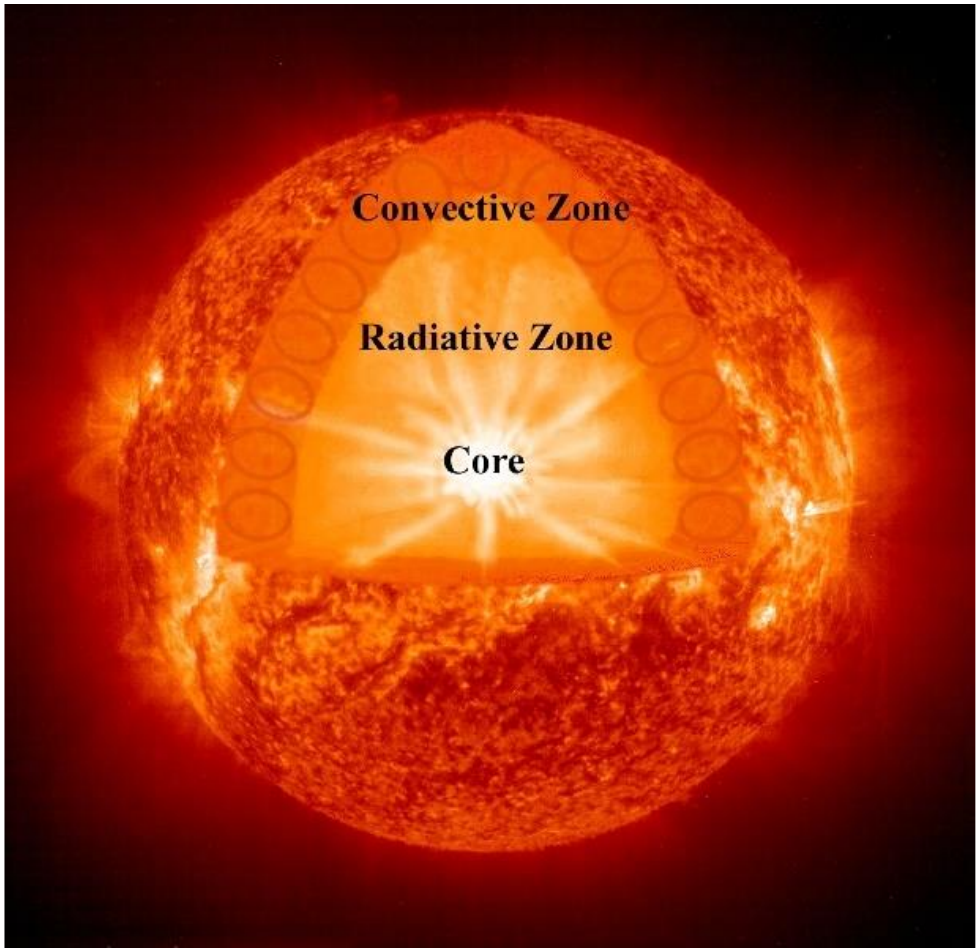
The **Sun** is not a simple large ball of luminous gas in space. The Sun's structure is complex with defined dynamic layers.



The hydrogen gas that makes up the Sun is in the **plasma** state. The temperatures inside the sun and in its atmosphere are so hot that the gas atoms are ionized.

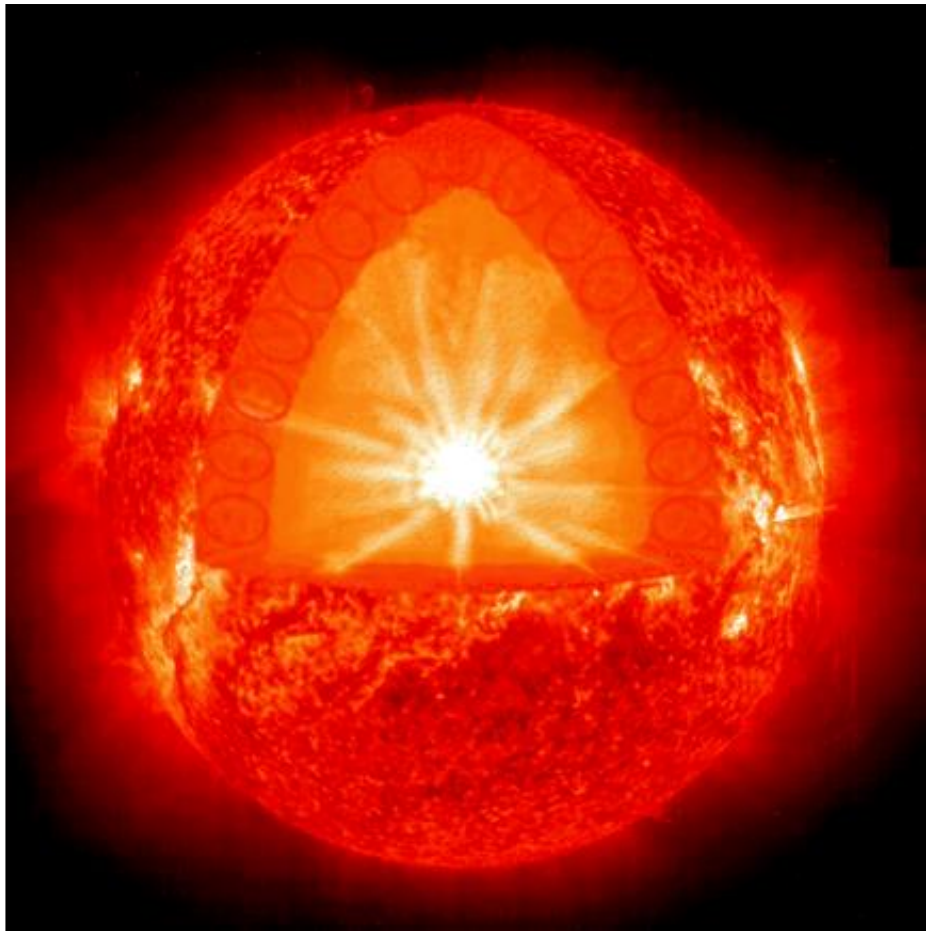
Core: The centermost region of the Sun's interior.

- The core is the Sun's powerhouse or nuclear reactor—the place where the Sun's heat/energy is generated.
- Temperature = 15,000,000 Kelvin



The core's temperature is astronomically hot because of the astronomical inward force of gravity crushing gases into a denser and denser confined space.

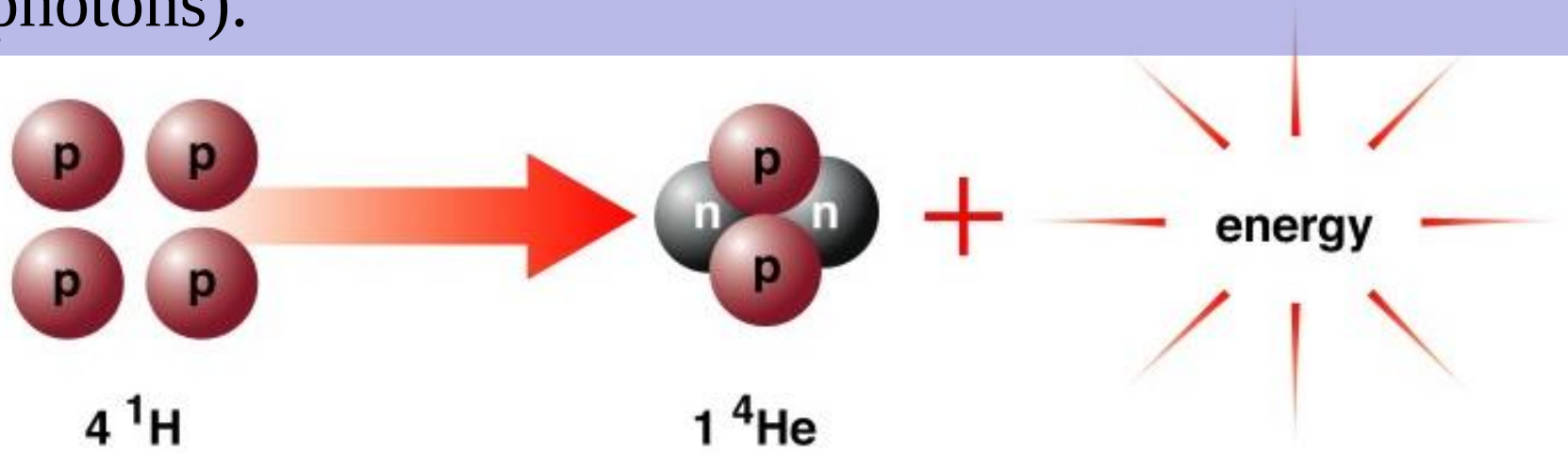
Nuclear fusion reactions happen in the core of the Sun. The astronomical heat and crushing inward pressure by gravity fuse four hydrogen atoms together to form one new helium atom.



The fusion reaction releases heat and high energy light in the form of gamma rays and x-rays.

That heat and light from the core is the energy of the Sun.

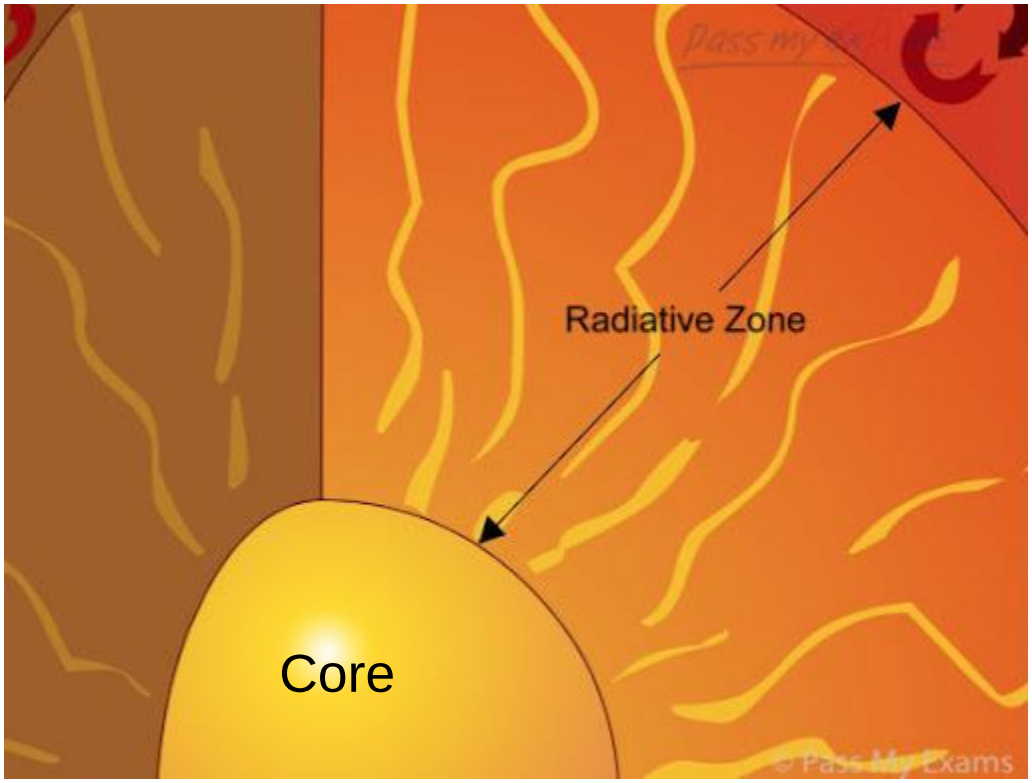
Four hydrogen atoms fuse together to become **one new helium atom**. The fusion reaction releases energy in the form of gamma and x-rays (high energy radiation and photons).



During fusion, a small amount of matter is converted to energy (**Einstein's Theory of Relativity**).

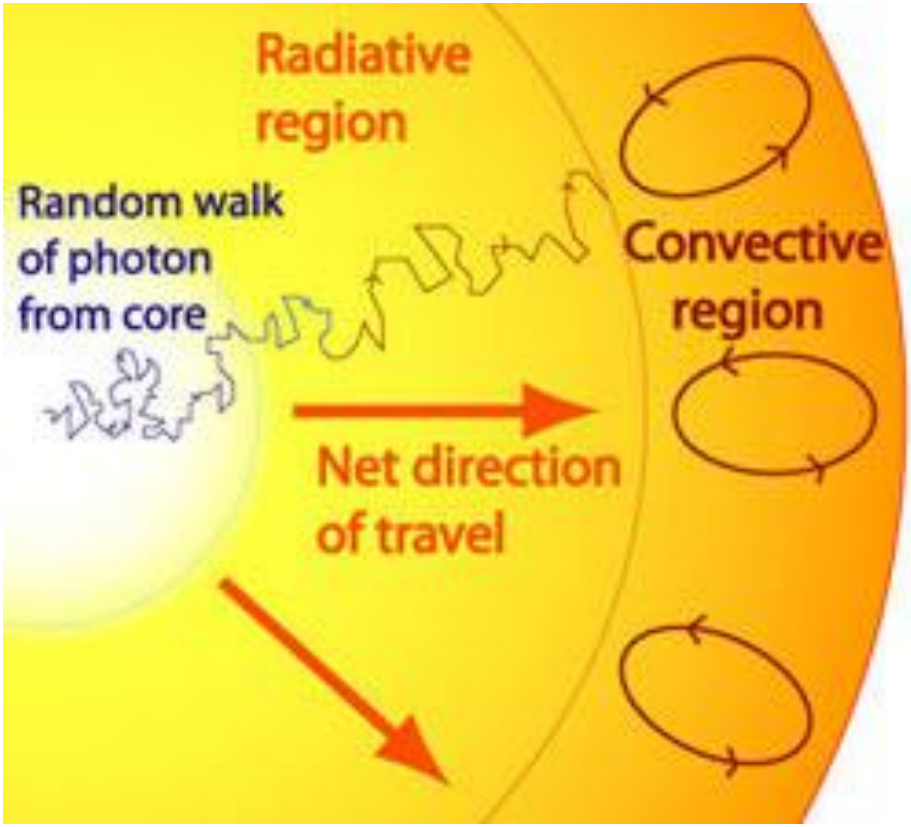
(The actual mechanism of this fusion reaction has multiple steps. For simplicity, they will not be shown.).

Radiative zone is the Sun's thickest layer. The gas molecules in the radiative zone are densely packed together



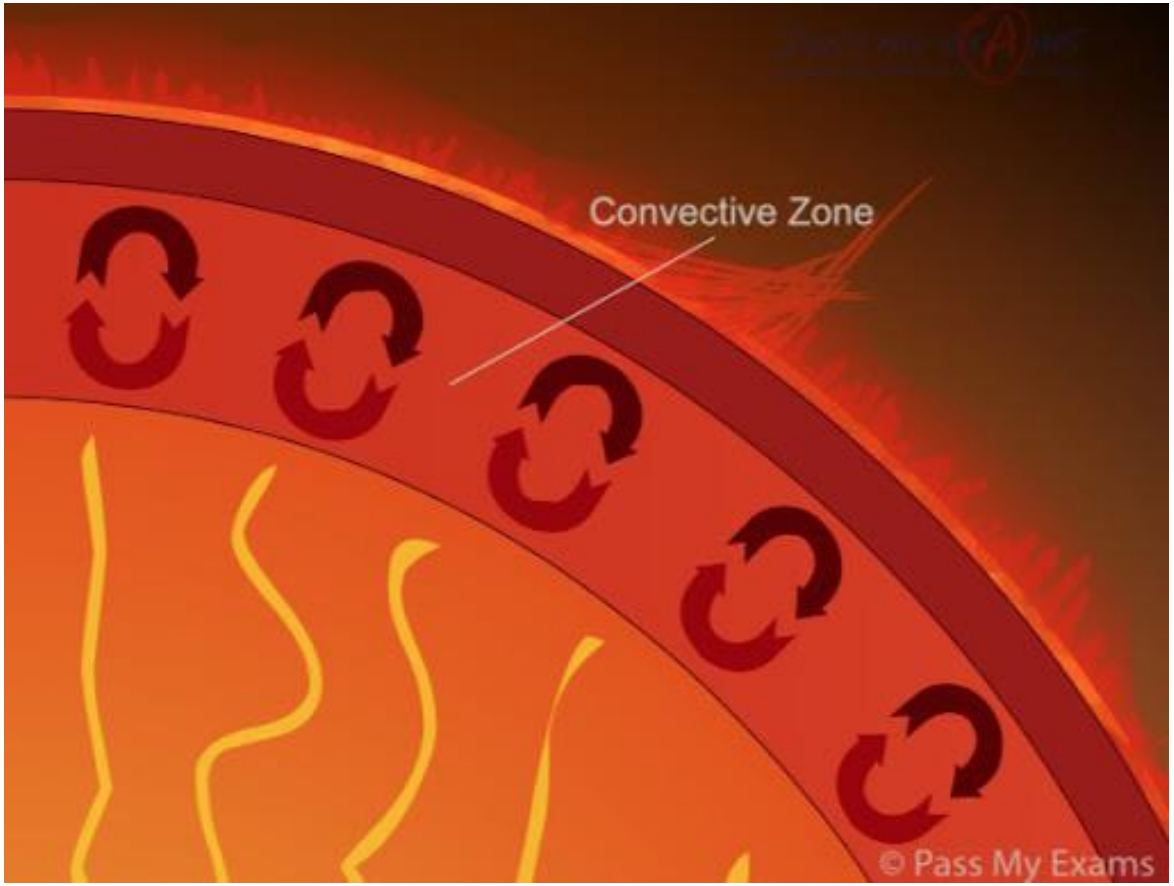
The photons of the light waves (gamma and x-rays) that were created in the core by fusion travel away from the core through the radiative zone. "Radiation transfer zone".

Photons of the gamma and x-rays do the "***random walk***" through the **radiative zone** as they move outward. Photons collide with hydrogen gas atoms as they flow outward through the radiative zoen. The atoms absorb the photons, become excited, then the atoms release the photons again.

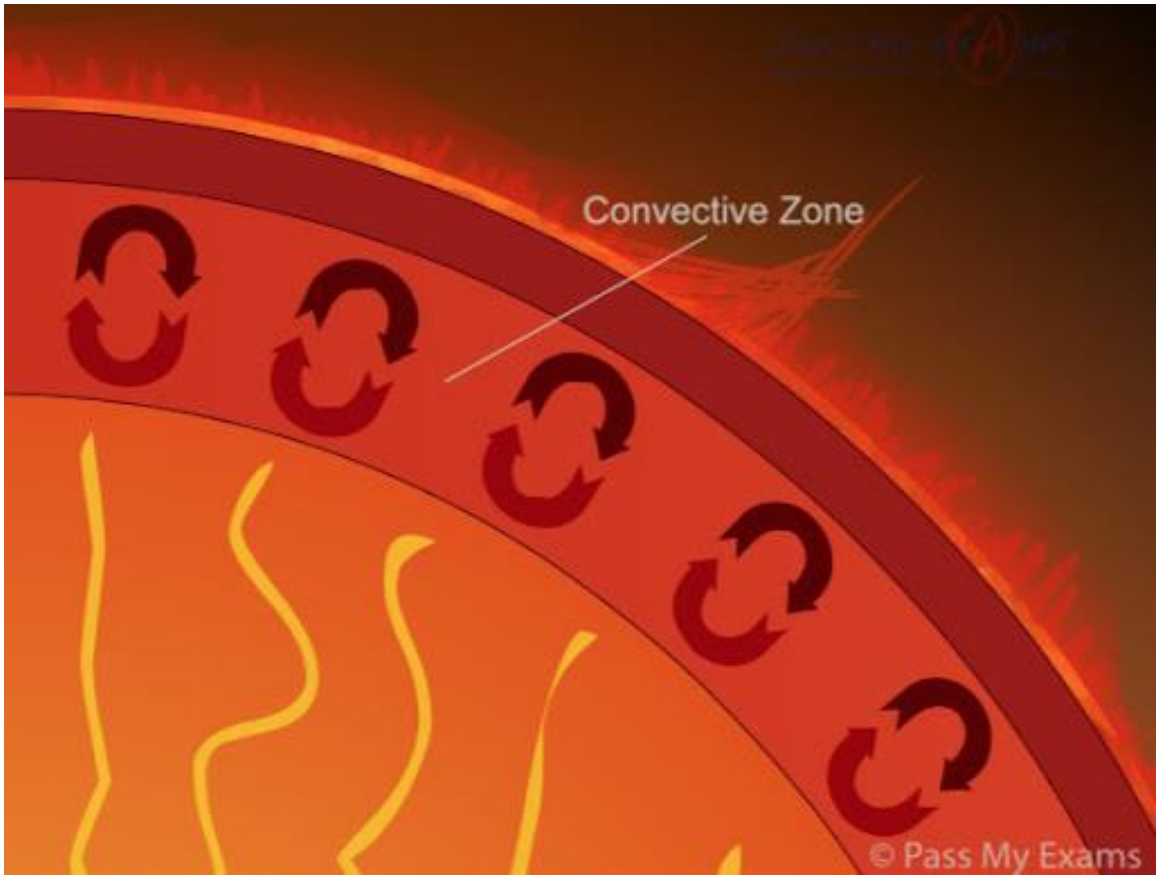


Photons can be absorbed and emitted tens of millions of times as the light energy moves through the radiative zone. It can take 100,000 to 200,000 years to pass through the radiative zone because it is a thick zone densely packed with hydrogen.

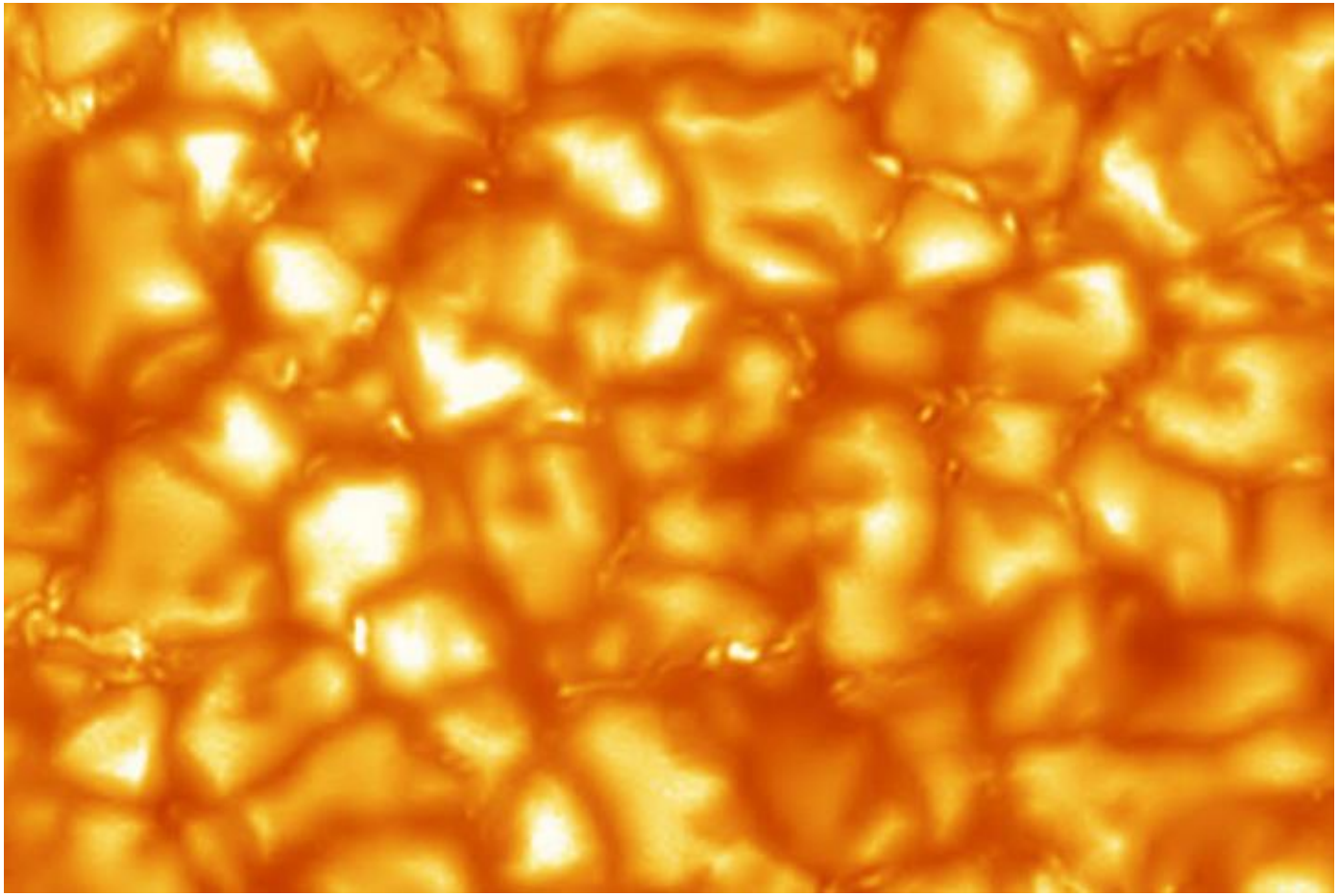
Convective zone is the active layer of sun atop of the radiative zone. **Convection** means *up-and-down circulation that moves heat and energy*. The heat and energy from the radiative zone enters into the convective zone and the circulation of hydrogen gas carries the energy.



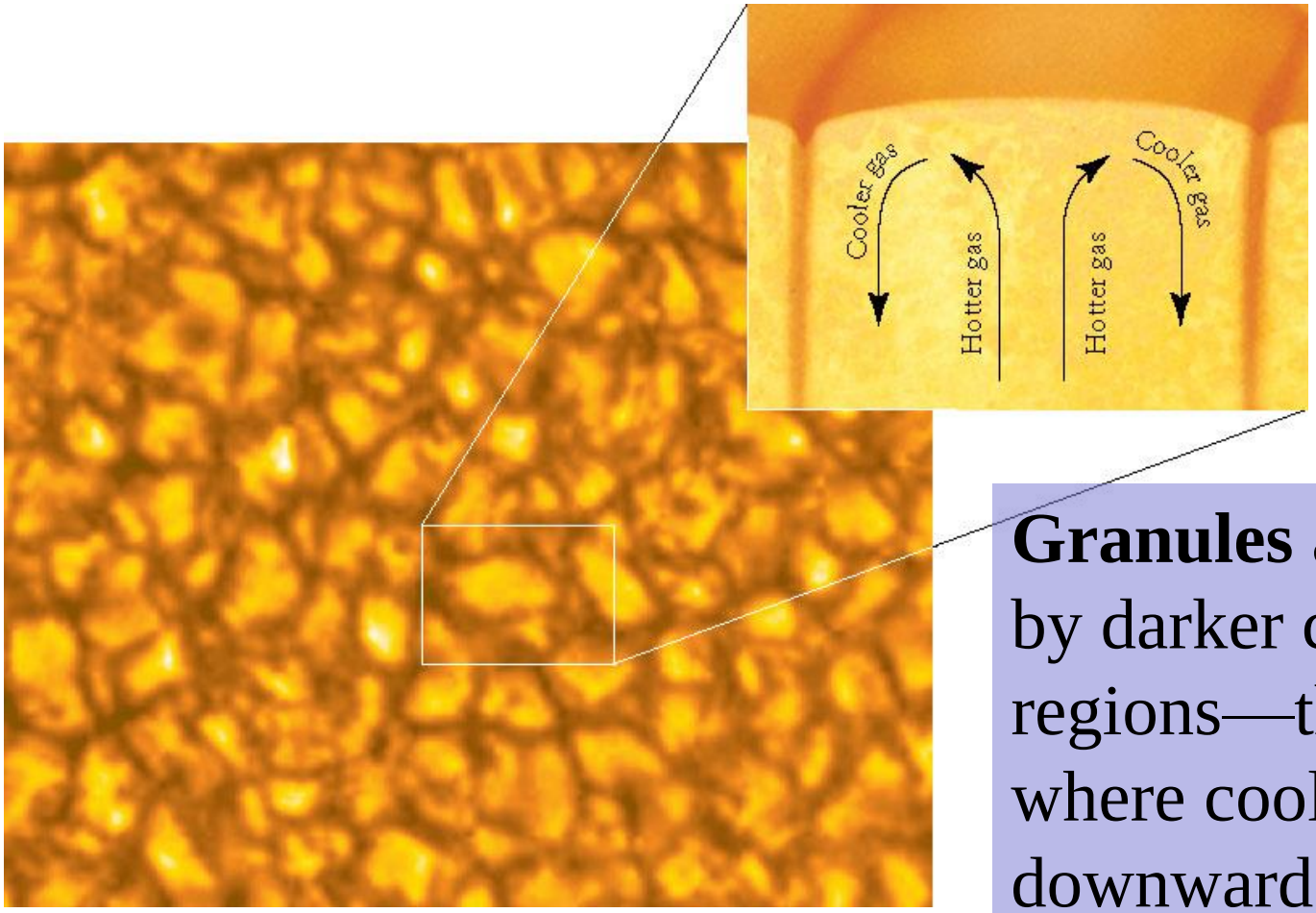
Very hot gases at the bottom of the convective zone flow upward to the top of the convective zone. The gases release heat and energy into the photosphere layer above the convective zone, the gases cool in temperature, and sink downward. This is a continuous process.



Photosphere is the visible yellow surface layer of the Sun. The photosphere is not smooth, but rather bumpy bubbly with **granulation**.
Temperature: 5800 kelvin



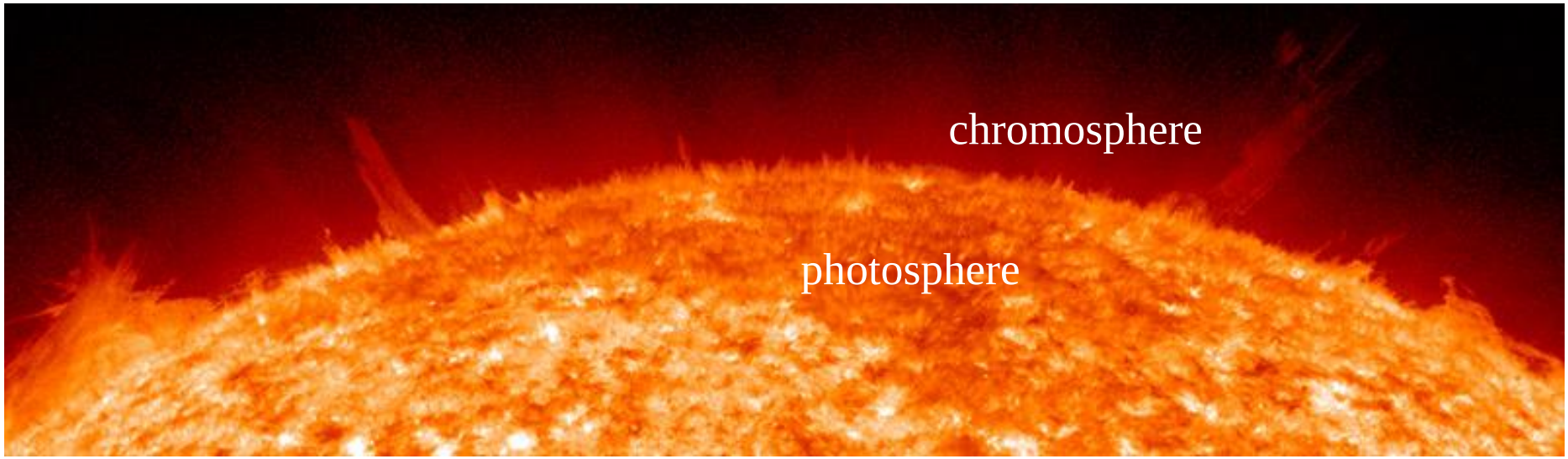
Granules are the bubble-like brighter regions—top of the convection currents where hot gases are rising and releasing heat.



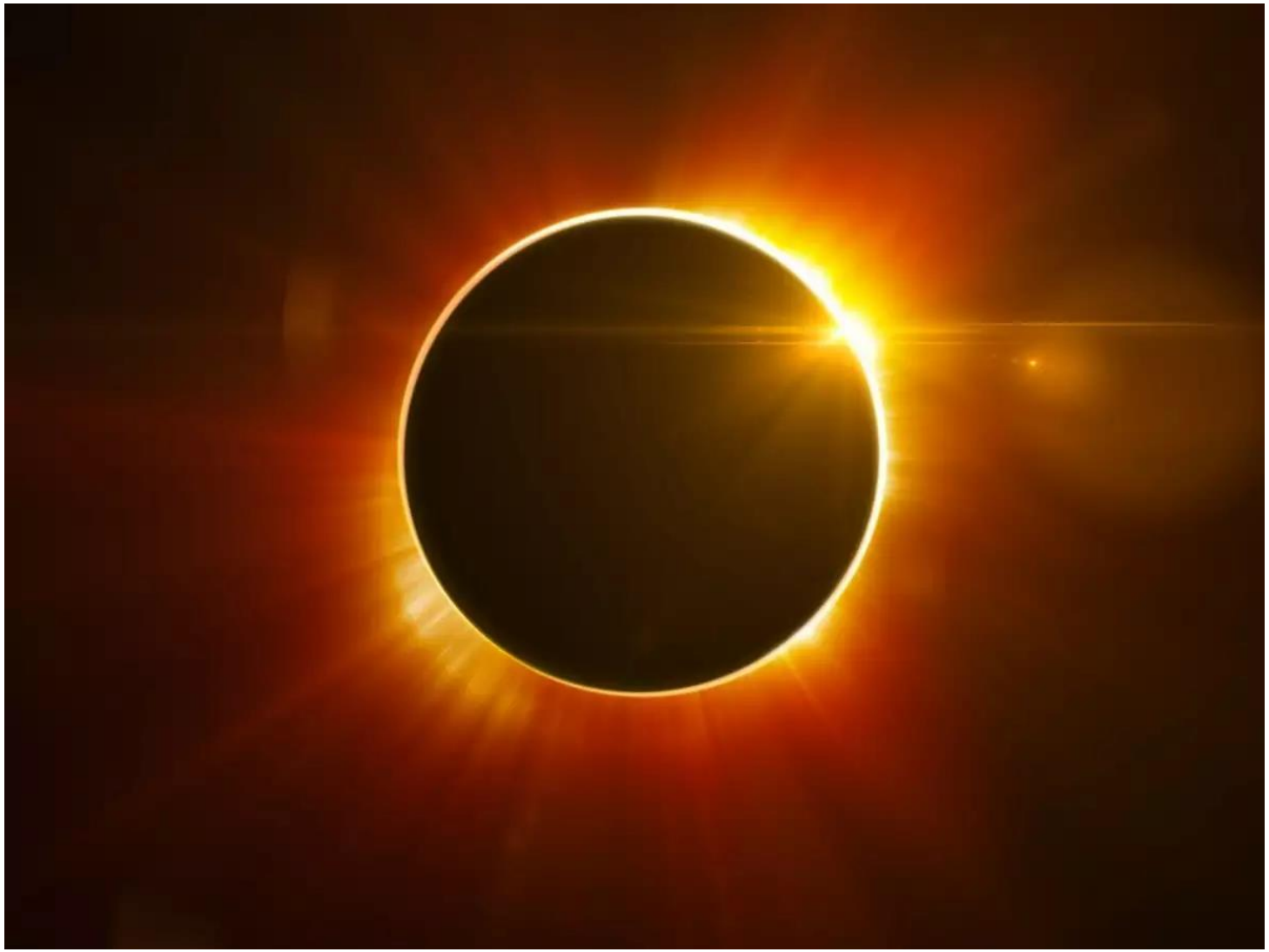
Granules are surrounded by darker cooler regions—the places where cooler gases sink downward after they released heat.

Chromosphere: ~200 km thick; the hazy reddish lower atmosphere of the sun. It lies just above the **photosphere**.

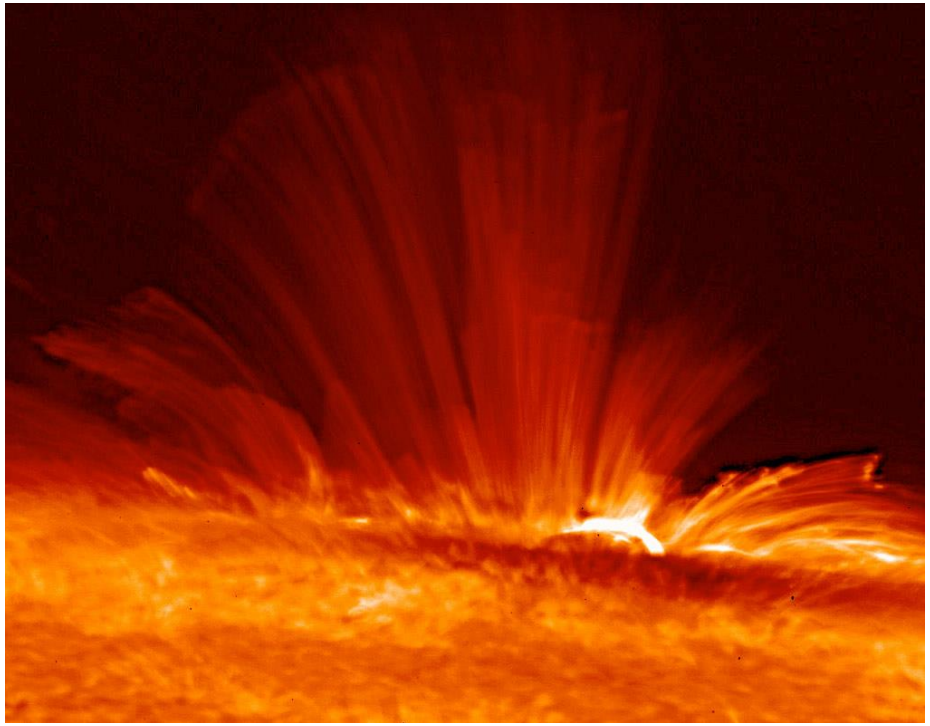
- Contains **spicules**—small narrow jets of very hot gases shooting upward out of the photosphere.
- Temperature ~ 6000-20,000 K



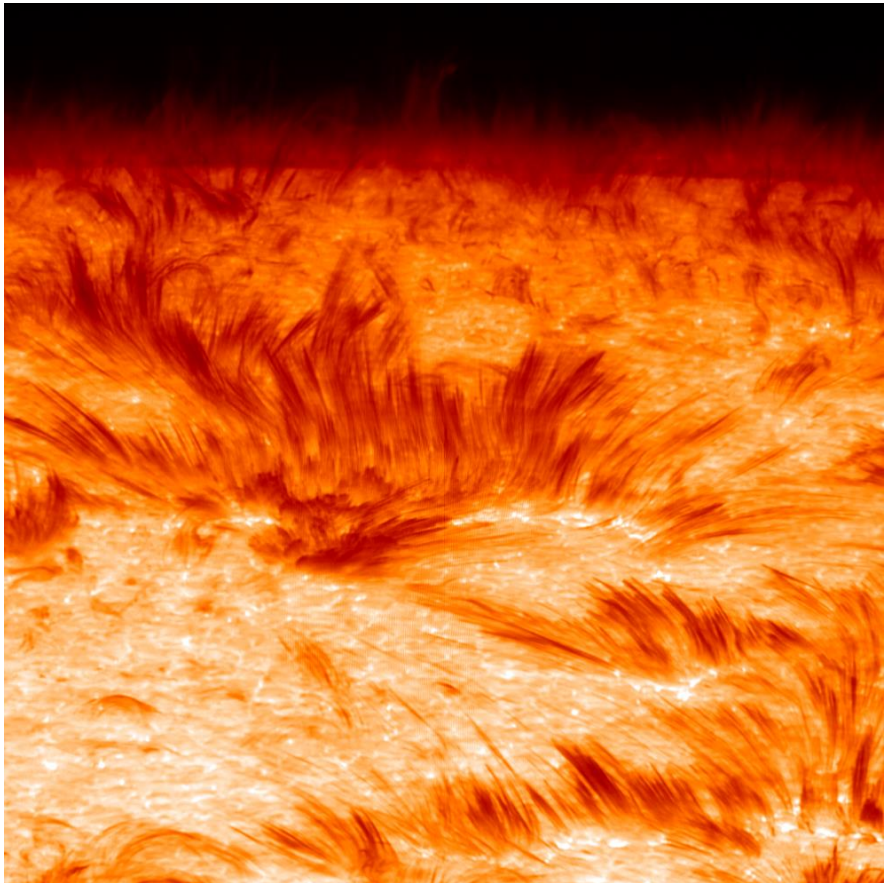
The chromosphere is the red glowing fuzzy ring seen during an annular solar eclipse.



Close-up view of a small cluster of spicules in the chromosphere



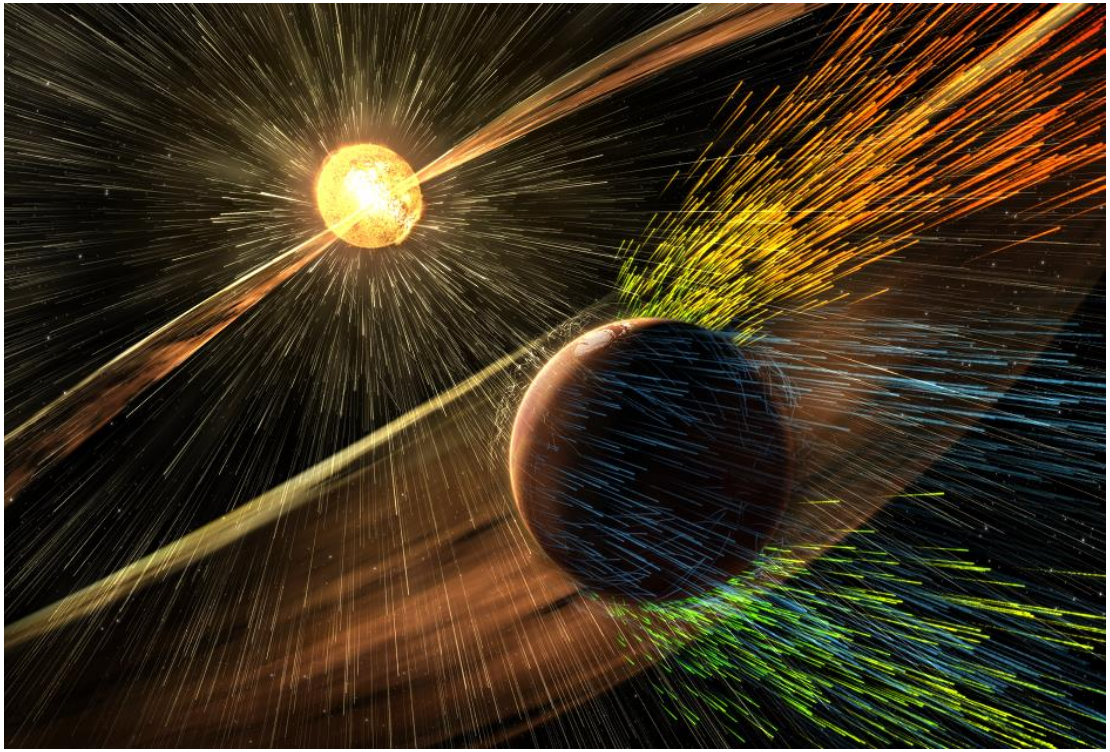
Spicules are the dark upward curving jets of very hot gas.



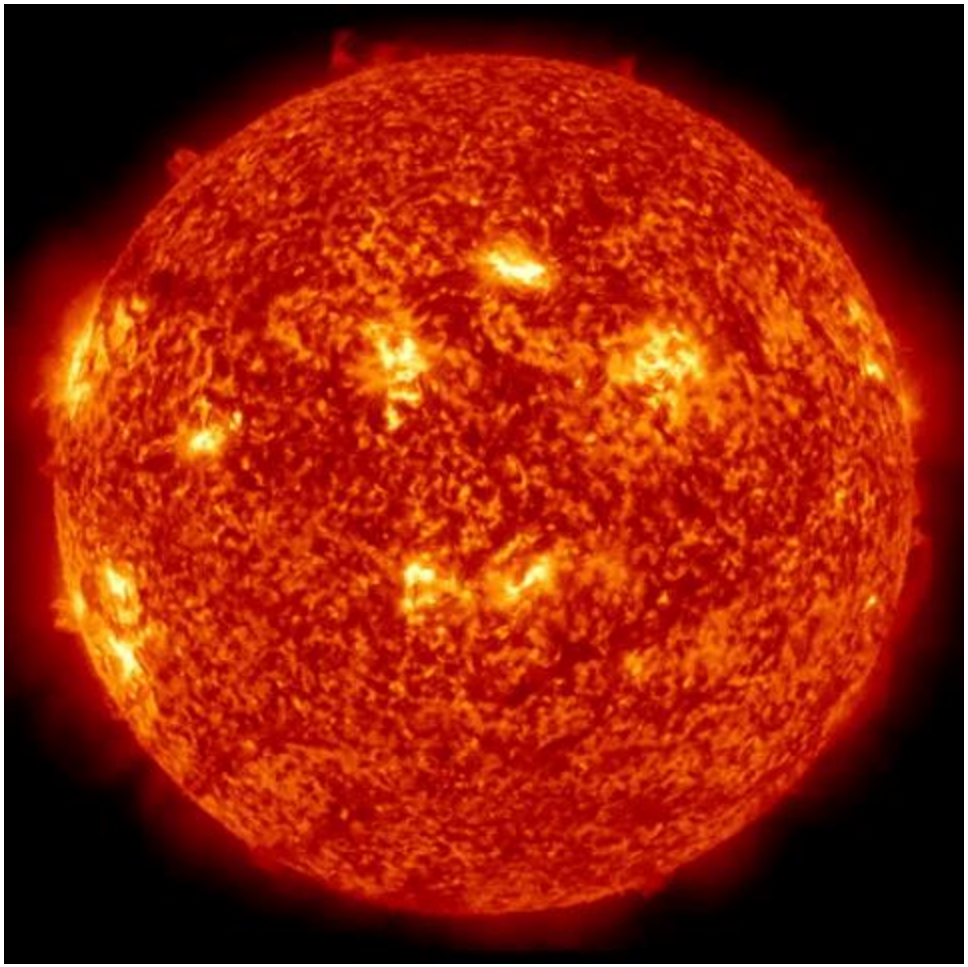
Corona: The aura of plasma that surrounds the sun—the sun's extensive and very thin outermost atmosphere. The corona extends millions of kilometers away from the surface of the sun. Visible as wispy waves of gas during a total solar eclipse

Temperature of the corona is > 2,000,000 Kelvin.

The **solar wind** is the constant streaming flow of energetic charged particles and electrons that are discharged outward from the corona into space.



The **solar wind** radiates outward from the corona and sweeps across the planets, comets, and other object in our solar system. The particles in the solar wind move hundreds of thousands to millions of km/hr.

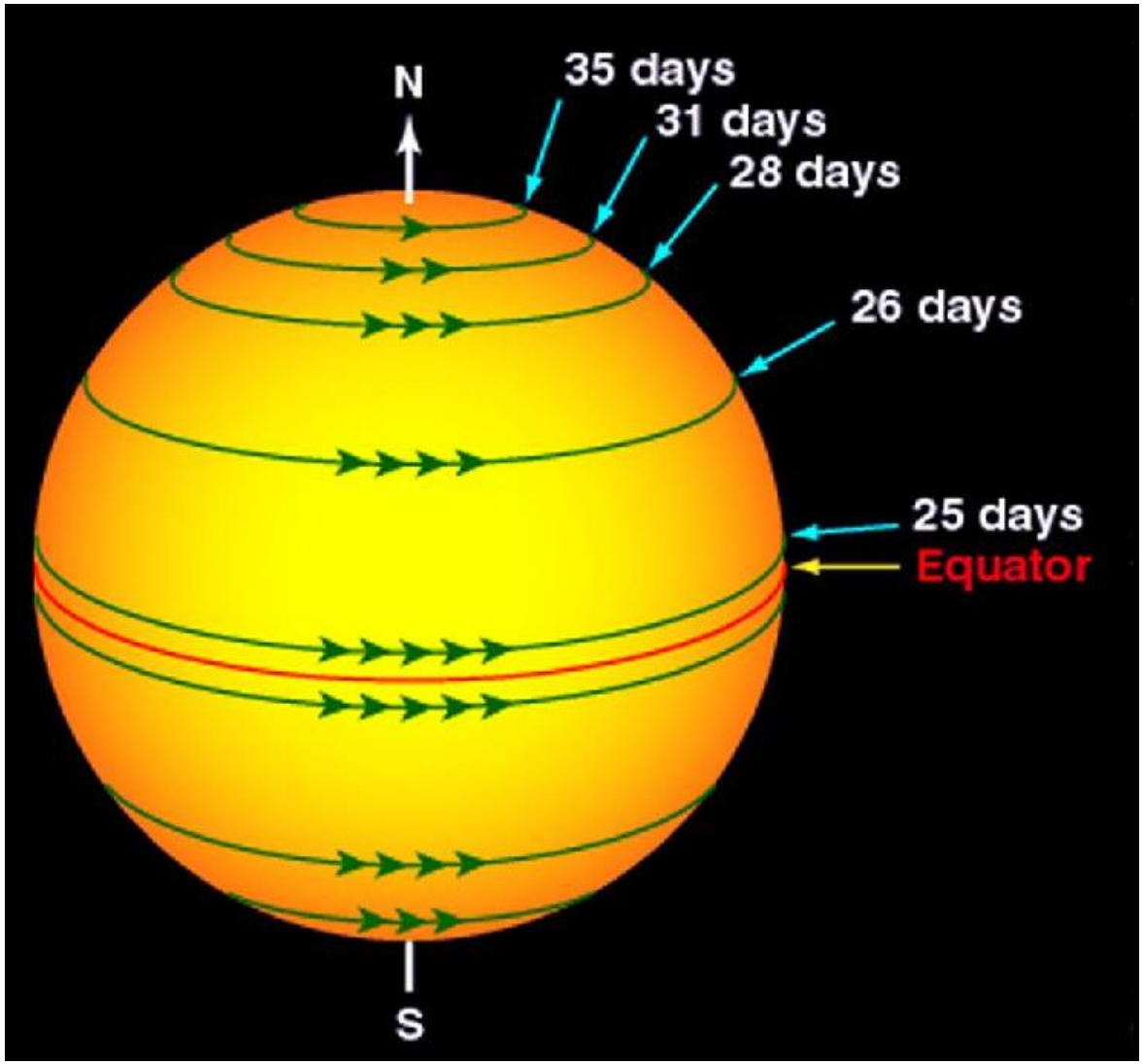


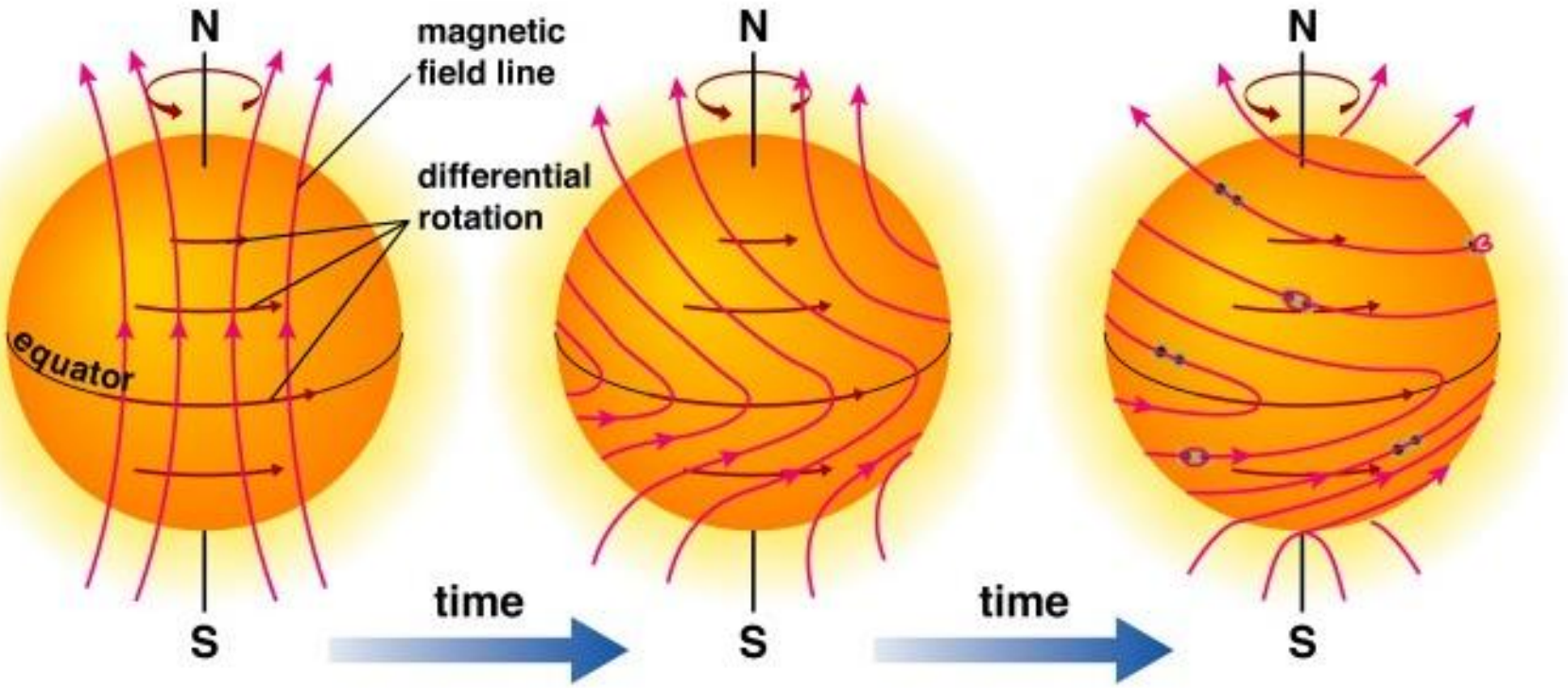
The bulk of the Sun rotates once every 24.5 Earth days. The sun is not a rigid solid, so different zones of the sun rotate at different rates.

Faster rotation at the equator and slower rotation at the poles.

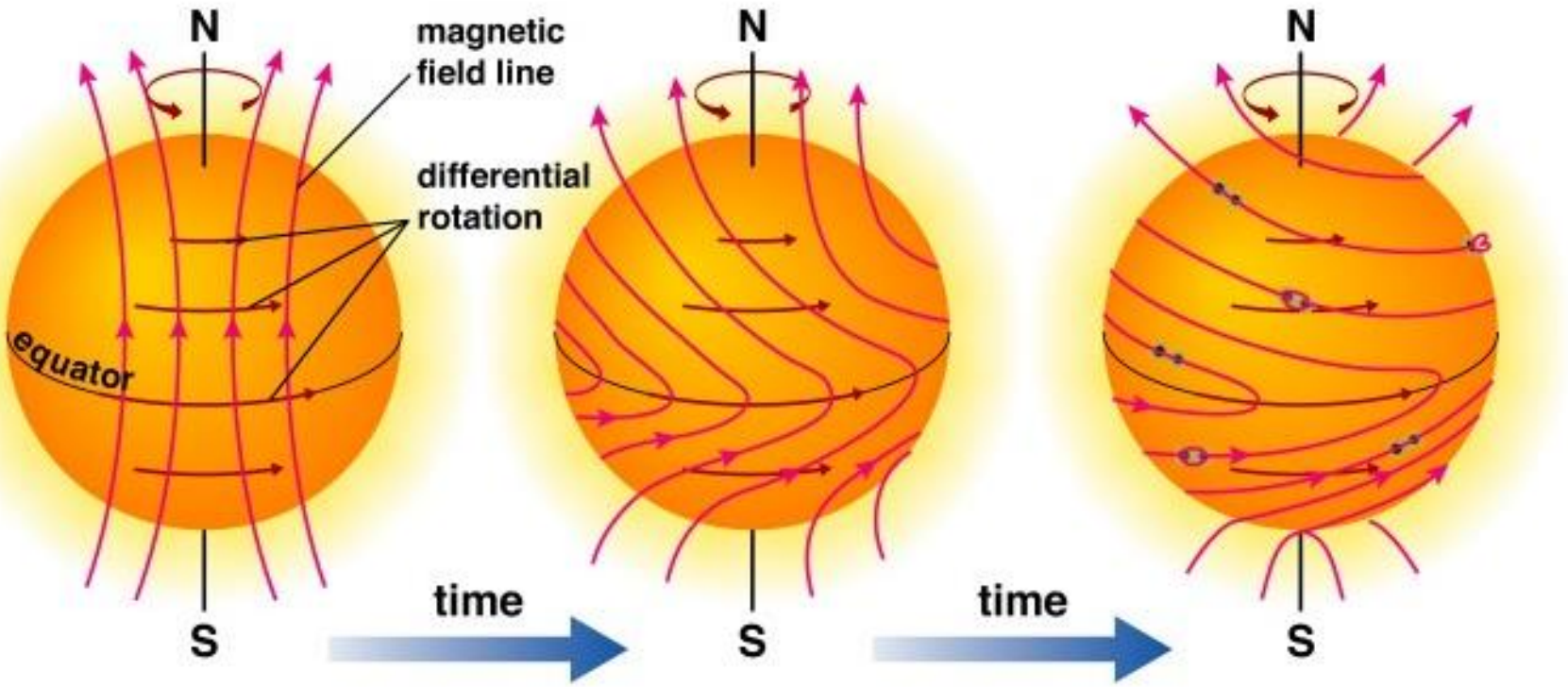
The animation of the Sun's rotation is sped up many times.

The **differential rotation**. of the Sun's mass as a function of latitude away from the Sun's equator.



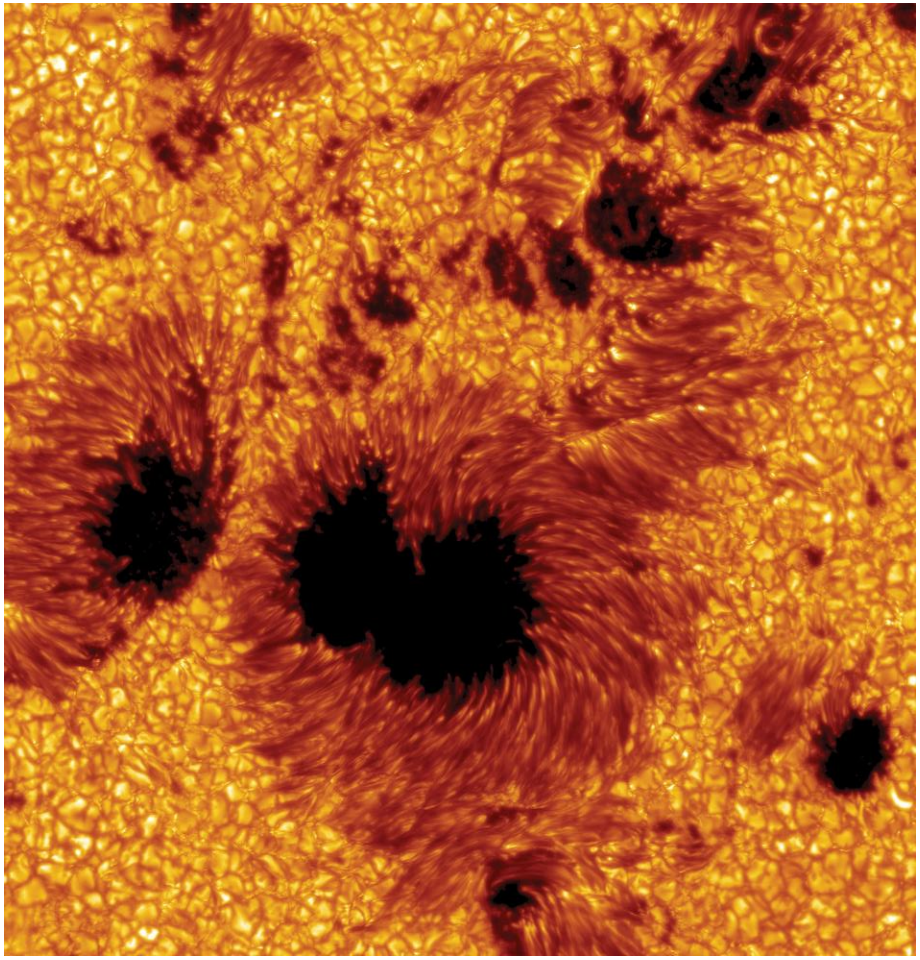


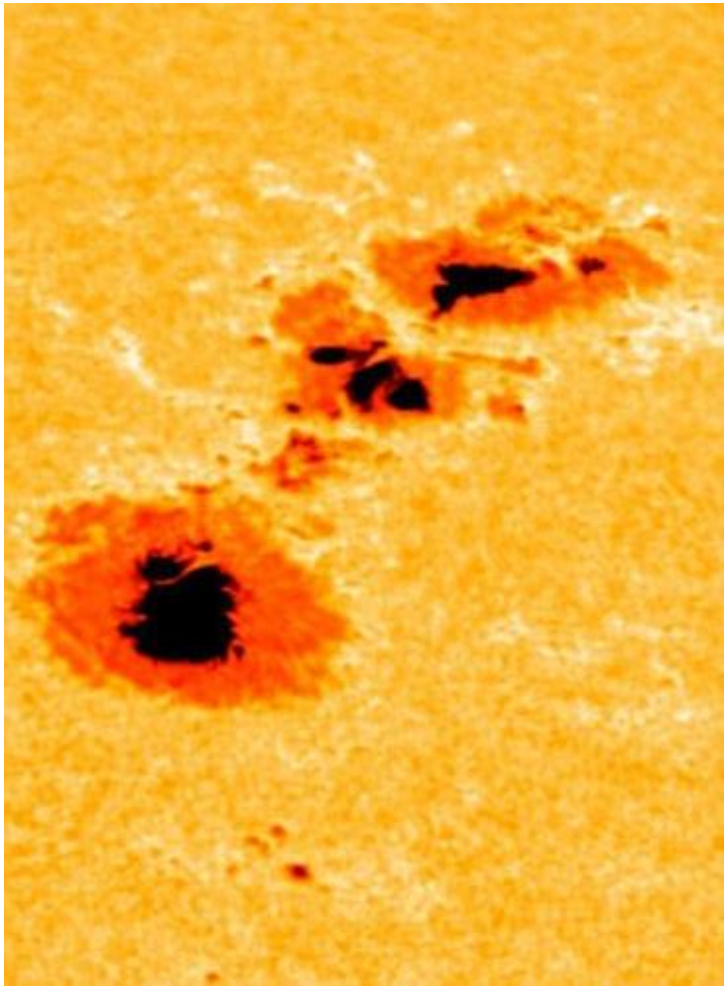
The different rotation speeds cause the flowing plasma (ionized gases and electrons) to swirl into whirlpools. The magnetic fields (magnetic forces) created by the swirls and whirlpools twist and bend around each other.

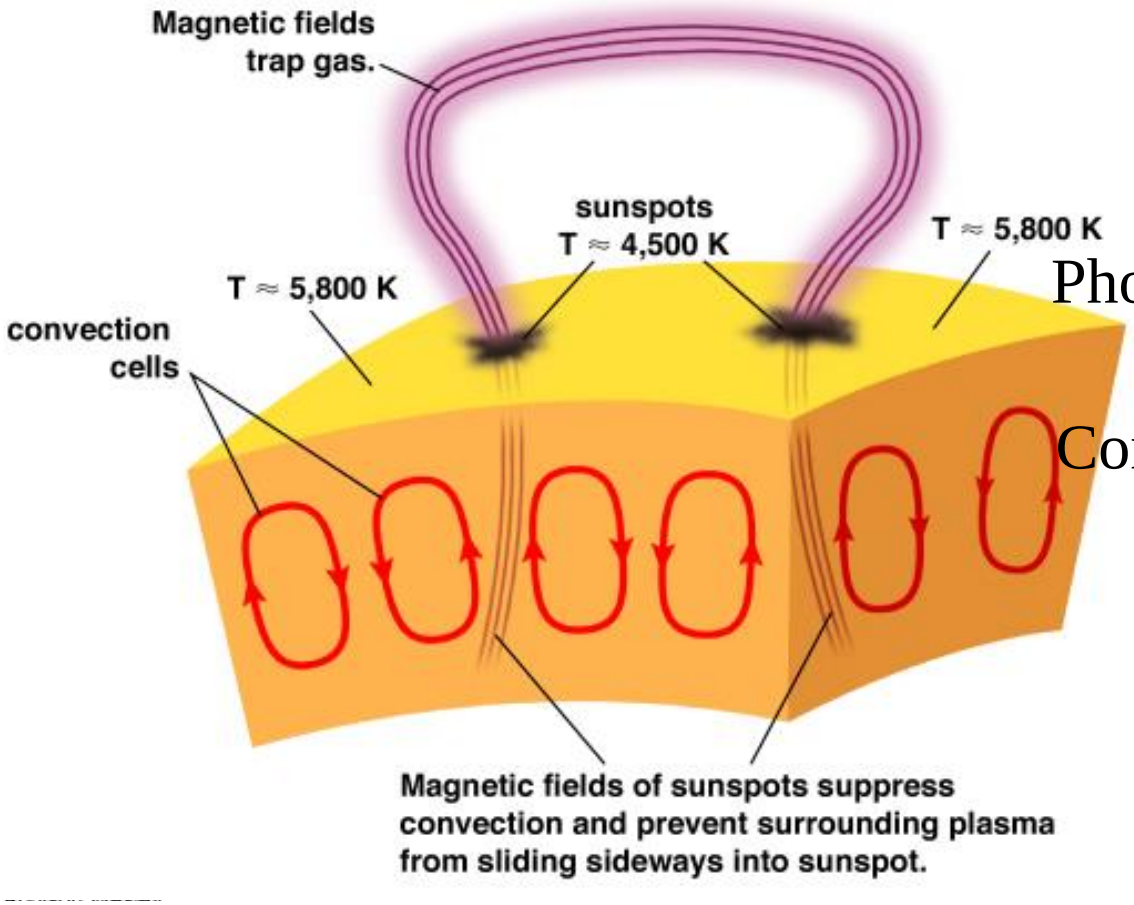


These extreme twists and bends in the magnetic fields as they pass through the photosphere and chromosphere create sunspots and the great solar storms such as loop prominences, solar flares, and coronal mass ejections.

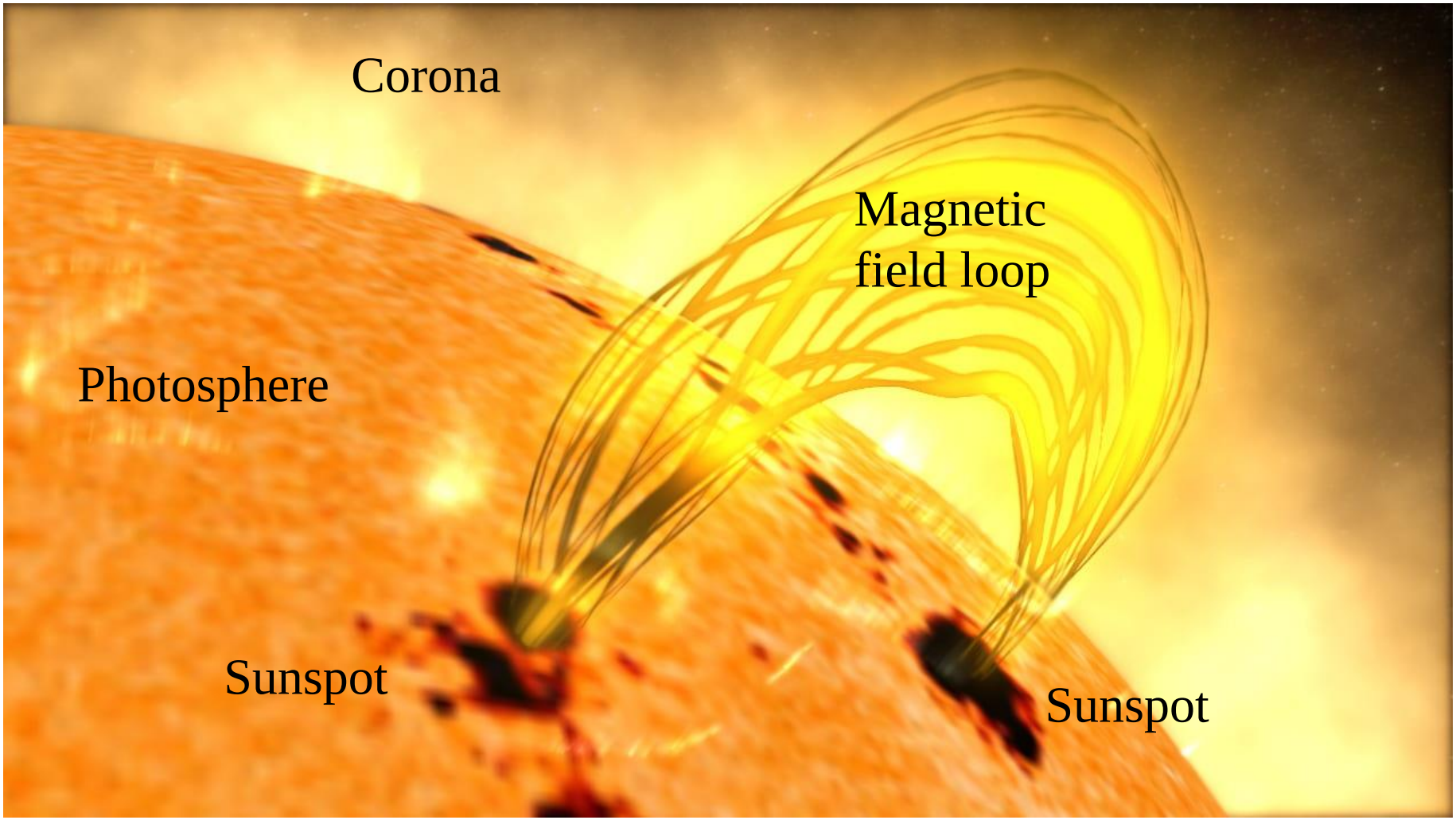
Sunspots are the dark, cooler regions on the photosphere. They appear as black. Sunspots tend to occur in pairs or clusters.







The looping magnetic fields prevent hot gases from the convective zone to rise into the photosphere, creating a dark to black cooler regions that form sunspots.



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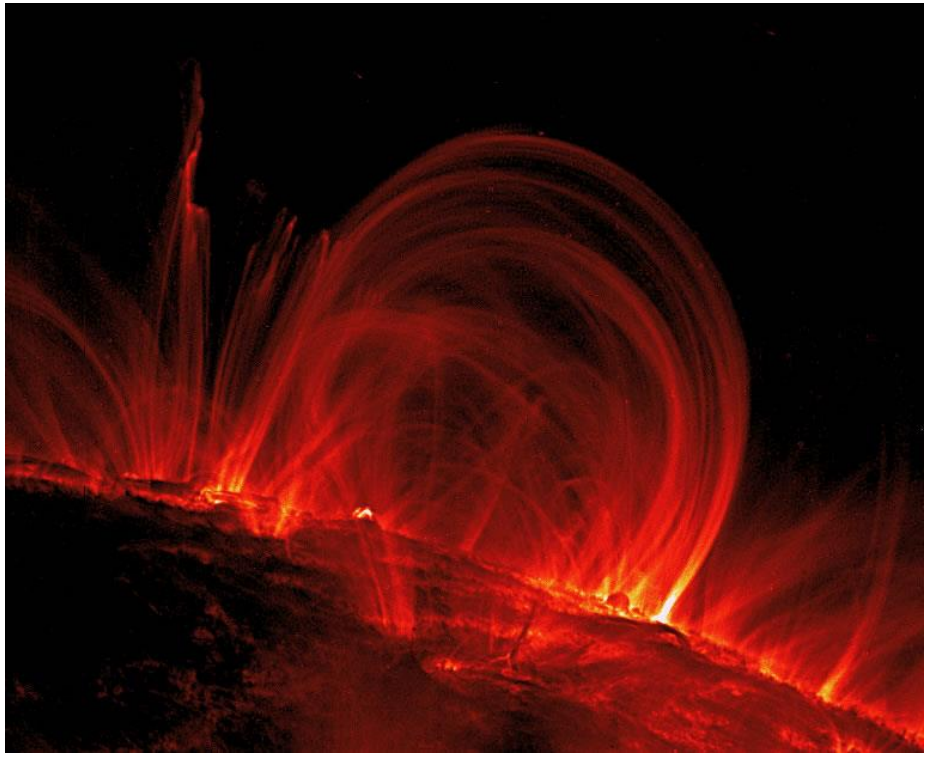
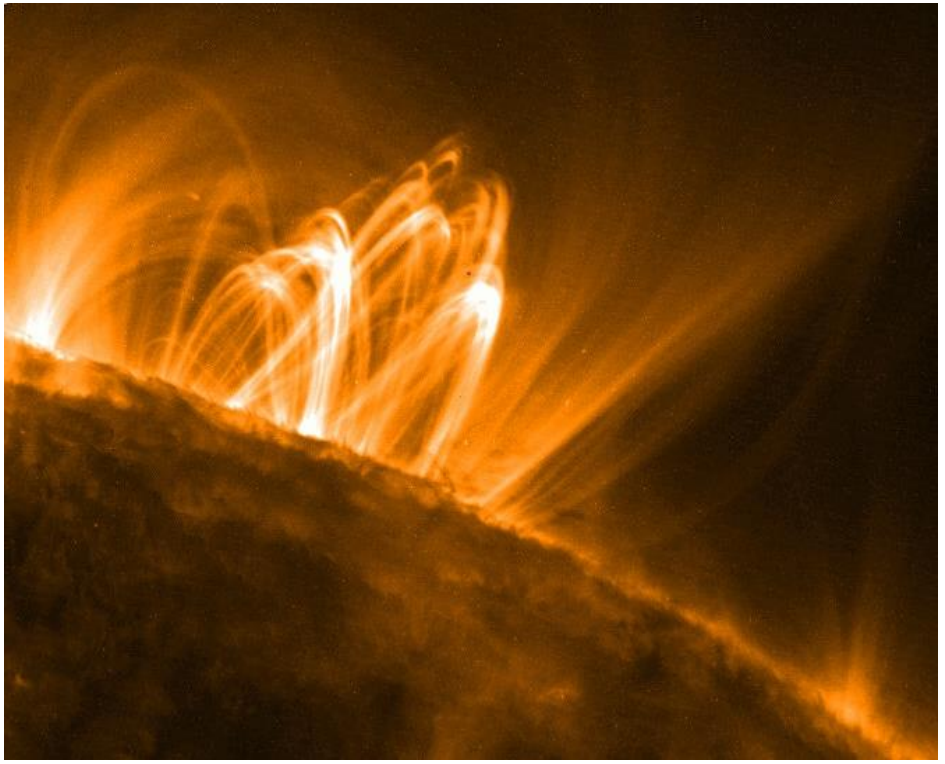
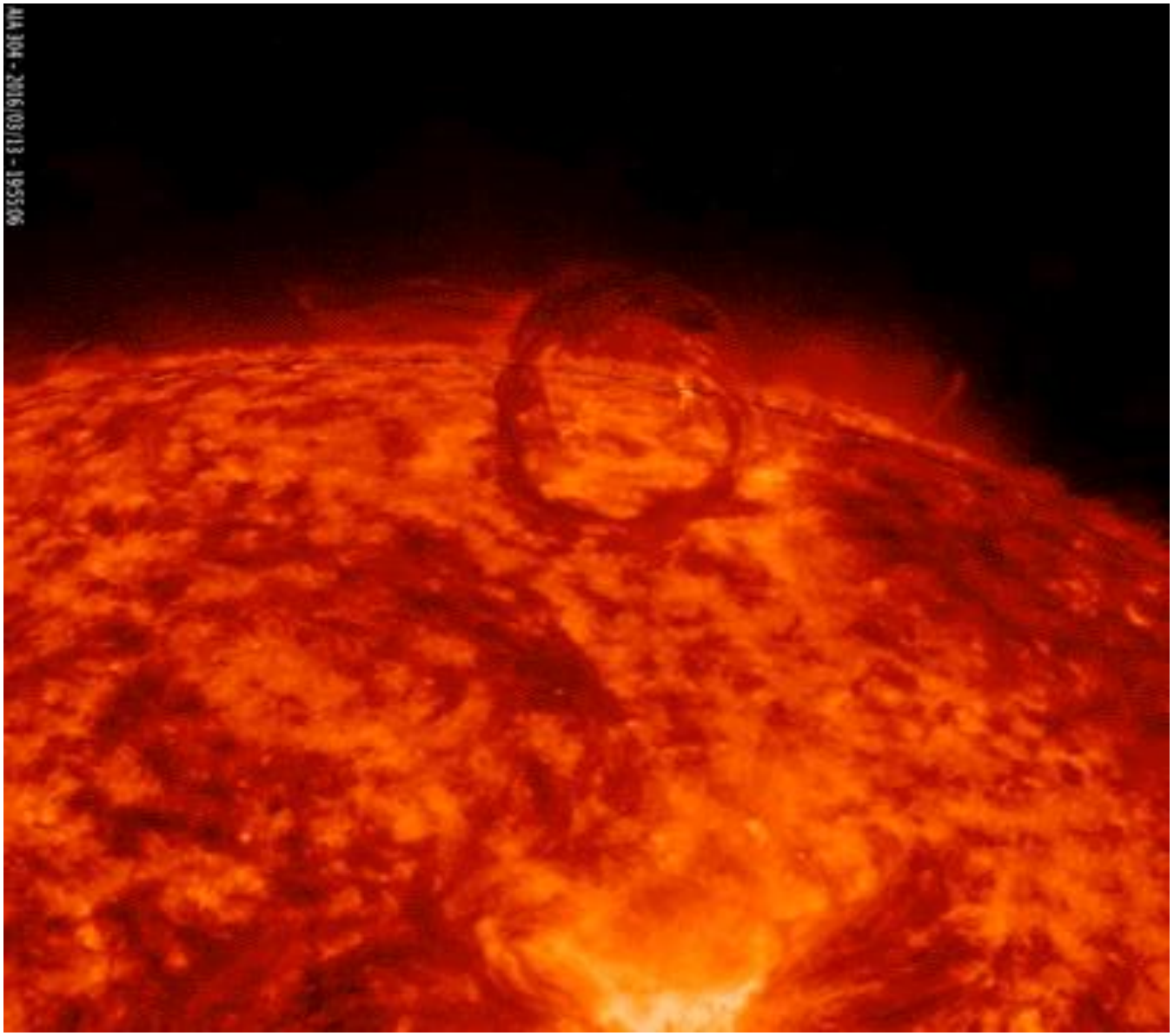




A **loop prominence** is an arcing type of solar flare. The jets of hot gases follow the curved magnetic forces. Gases flow upwards thousands of km over the Sun's surface, then curve down to return.

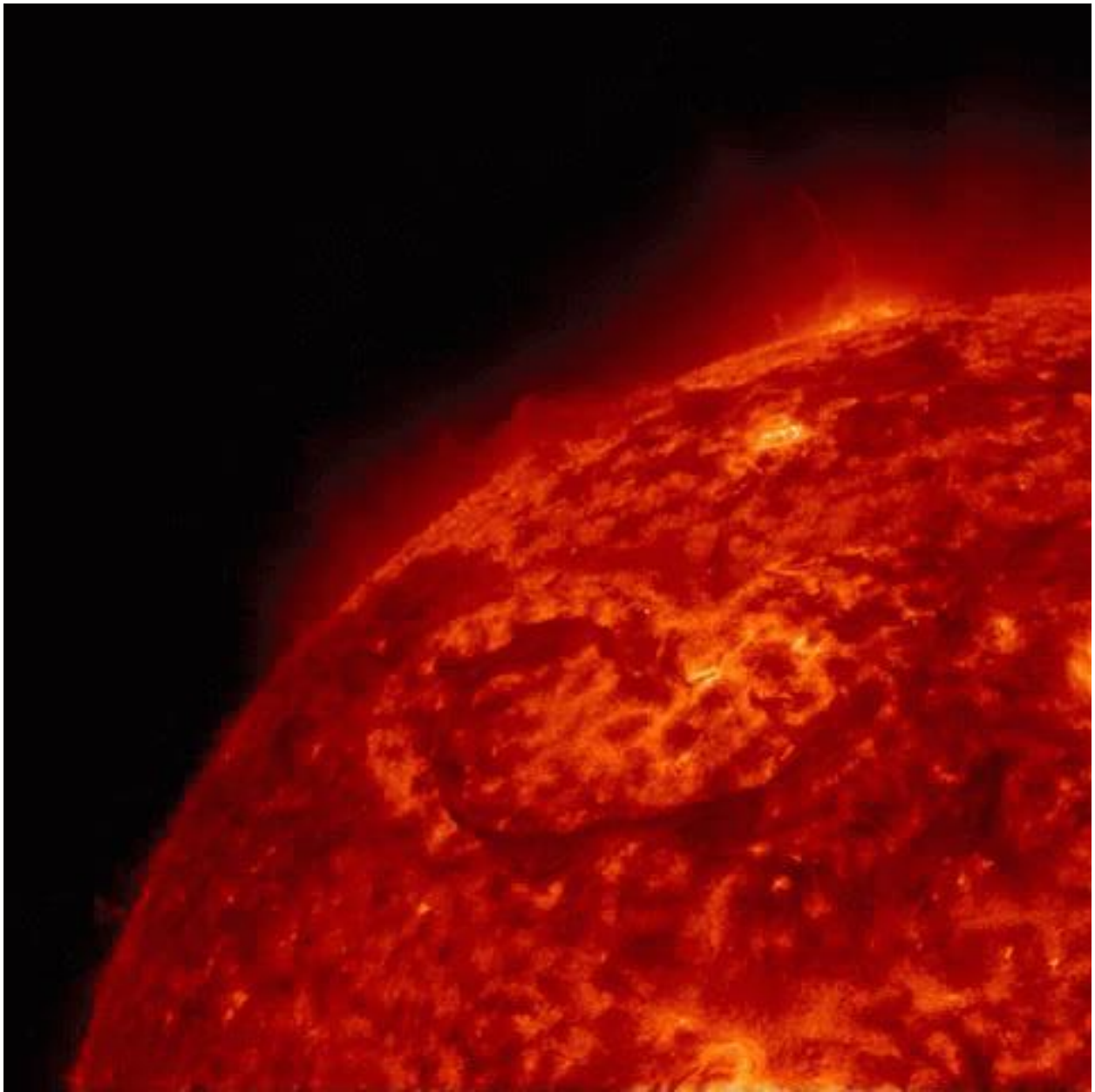
Giant loop prominence erupting from the Sun's surface

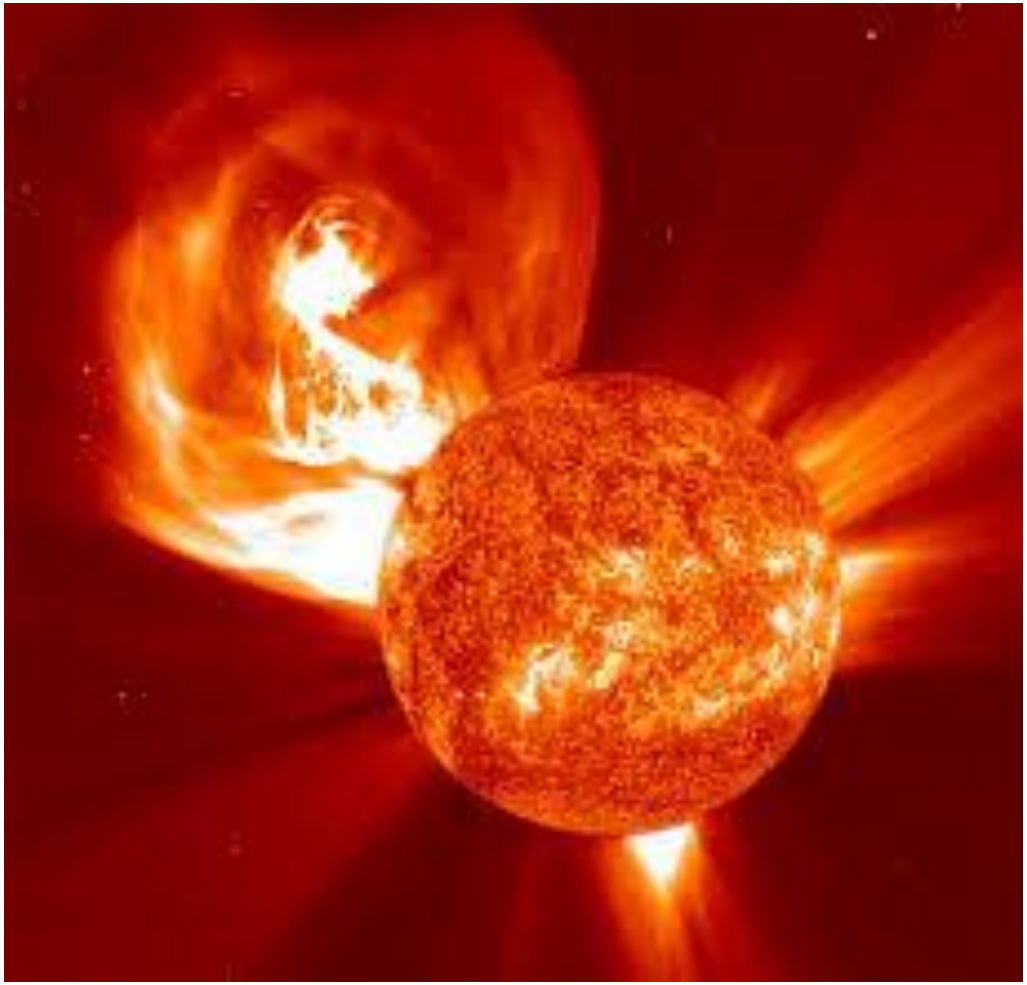
Giant loop prominence erupting from the Sun's surface.



Solar Flares are very large jets of plasma and gas that erupt from the surface of the sun. They are more energetic and powerful than loop prominences. They blast free from the magnetic fields and shoot into space.

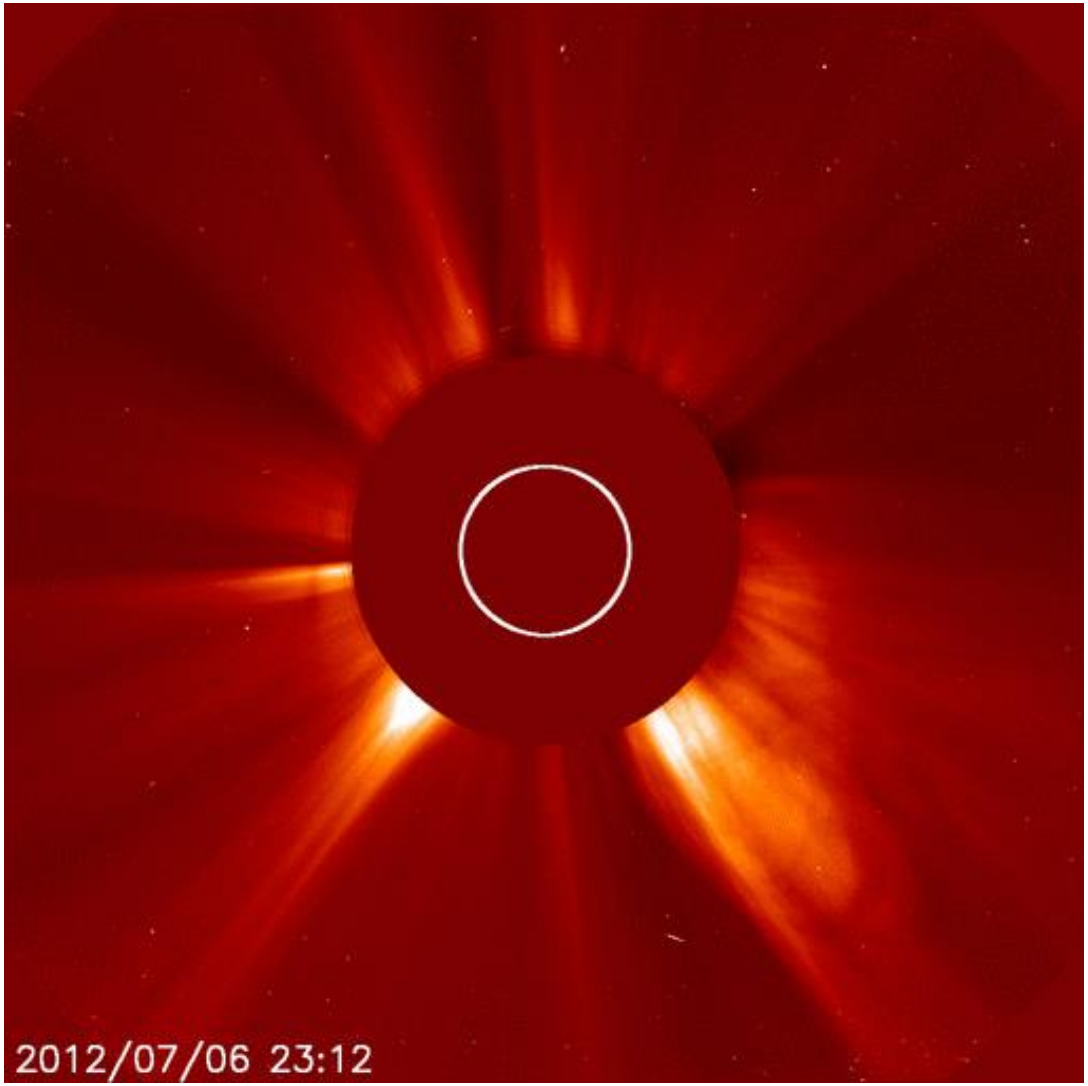
Solar flare erupting from the Sun's surface.





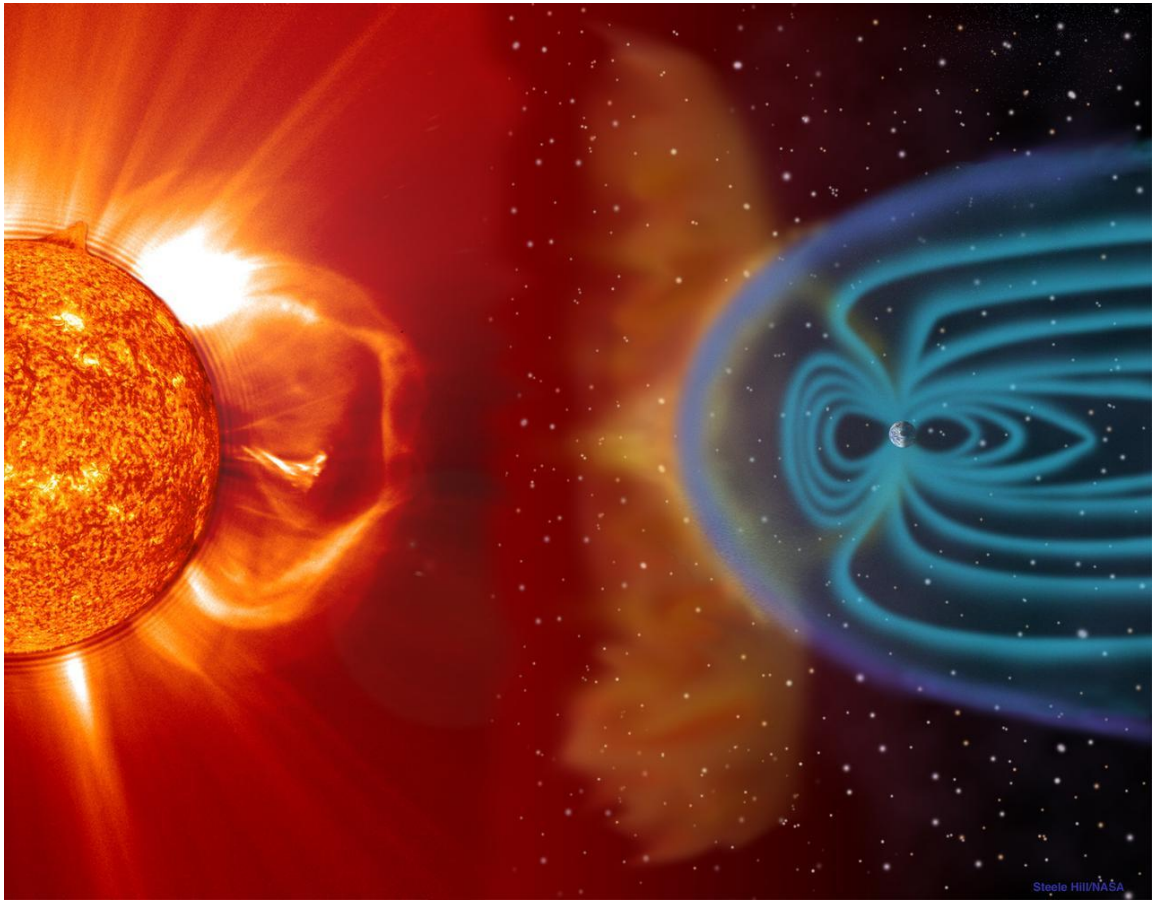
Coronal mass ejection is the largest and most powerful solar storm created when massive amounts of plasma and gases are discharged by turbulent magnetic storms from the Sun's surface and corona.

The powerful particle winds in from the coronal mass ejections move at millions of km/hr outward and can shock a planet's magnetic field causing **geomagnetic storms** that last for days or weeks.

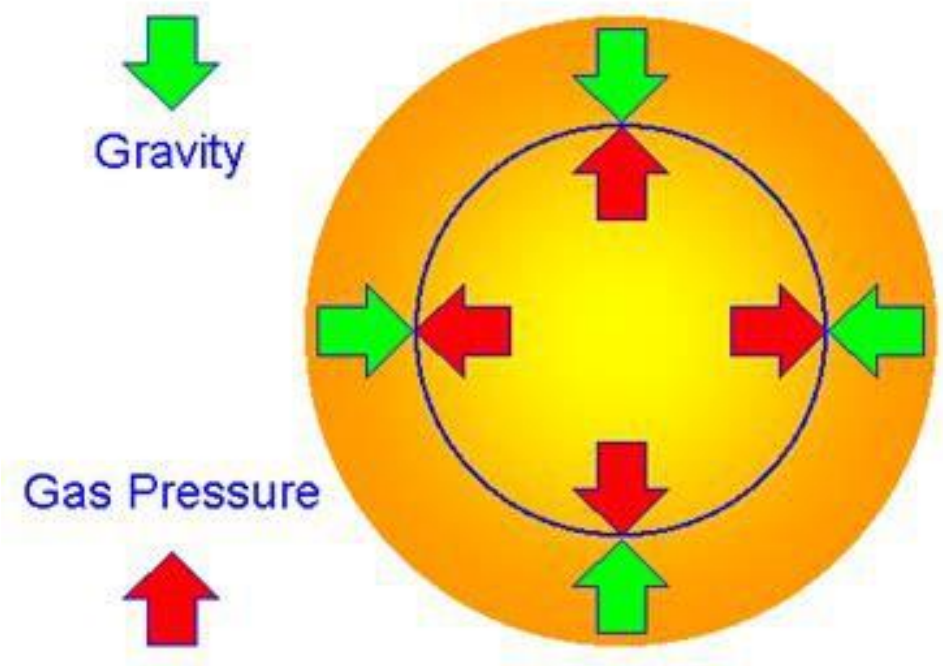


Coronal mass ejection over a time of 2 hours**.** The veil of gases and jets are the corona and the solar wind.

Earth's **magnetic field (Van Allen Belts)** protect earth from the constant solar wind and the occasional particle blasts from coronal mass ejections. The magnetic field (an invisible force), blocks and deflects the particles around the Earth.

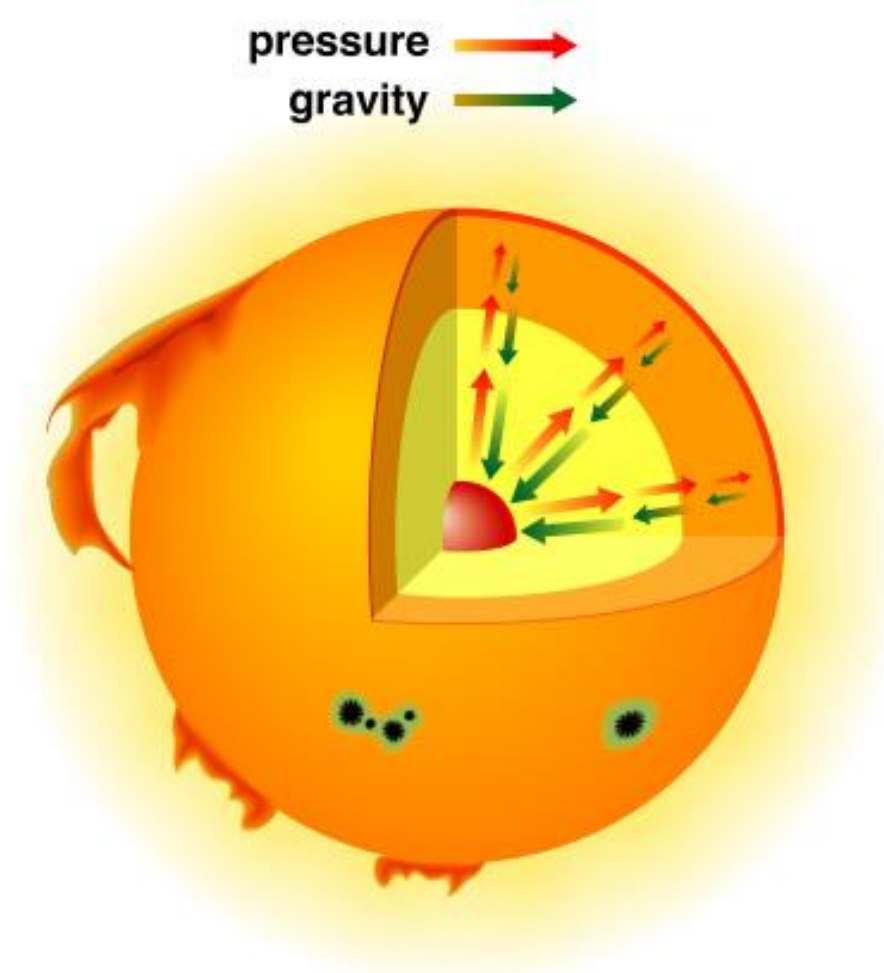


The **Aurora Borealis** and **Aurora Australis** (northern lights and southern lights) form when charged particles from solar flares or coronal mass ejections flow downward through the Earth's magnetic field into the upper atmosphere. The energy excites the atmosphere gases, causing them to glow.



The Sun, and all other **main sequence stars**, keep a constant size and diameter because of a process called **hydrostatic equilibrium** (translates to "not changing water balance")

The inward crushing **force of gravity** pulling the Sun's gases towards the Sun's core is exactly balanced (equal an opposite) by the **outward push force** created by the hydrogen fusion reactions in the Sun's core.



The heat and energy created in the Sun's core causes the gases in the Sun's interior to expand and move outward through the radiative zone. That outward pushing counterbalances the inward force of gravity trying to pull the mass of the Sun inward to the core.

If the fusion reaction rate slows, gravity would be the stronger force, the star would contract or collapse inward until the pressure is reestablished. The star's size and diameter would be smaller.