

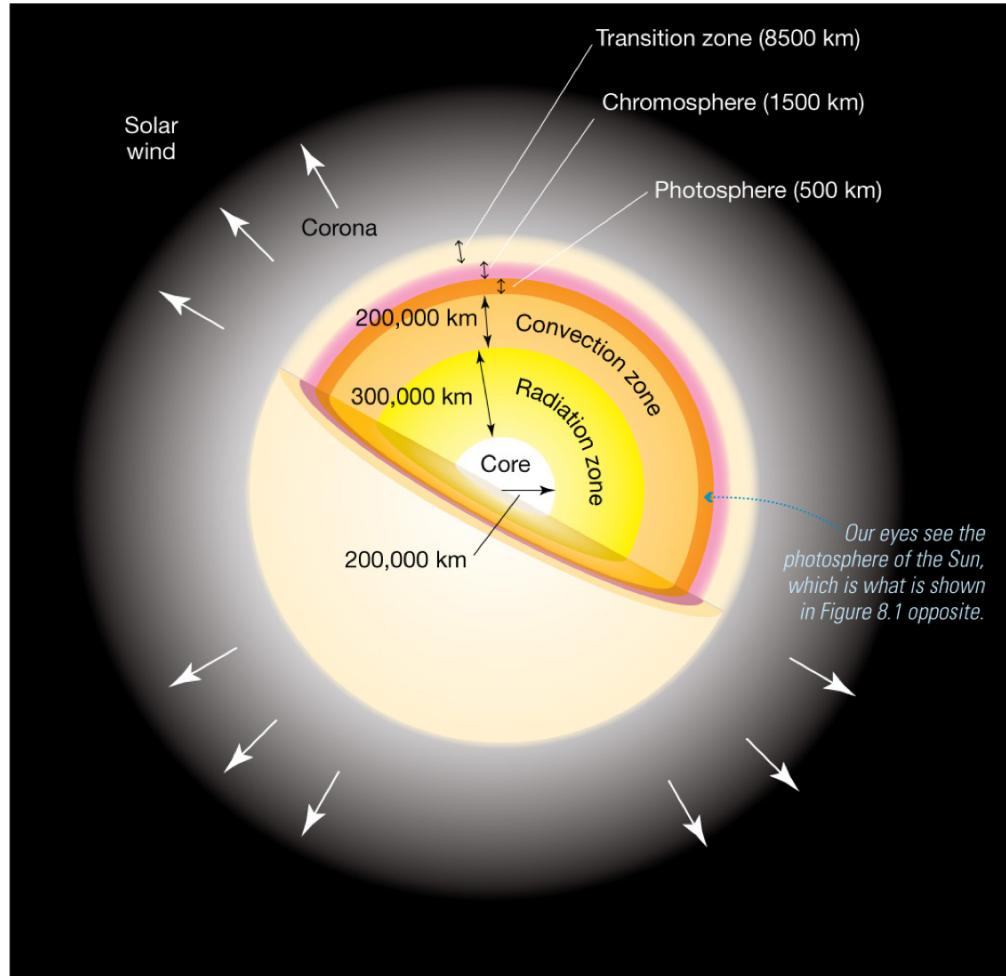
# Chapter 8: The Sun

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AST 1002

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# Properties of the Sun

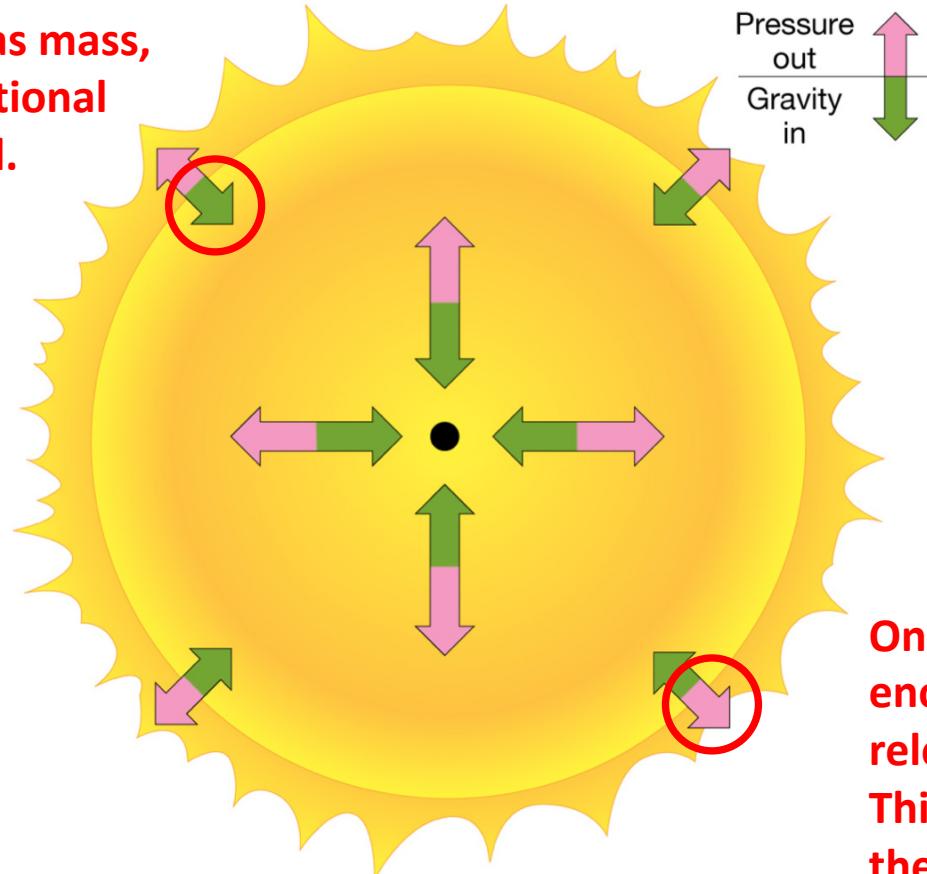


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- The Sun is a **star**: a collection of hot gas, mostly hydrogen, which emits light like a blackbody. The Sun is a fairly typical star for our solar system.
- The Sun rotates, but unlike the Earth, it orbits differently between the equator and the poles.
- The Sun has several layers to it:
  - The innermost layer, the **core**, is where the Sun produces its power via nuclear fusion.
  - The **radiation zone**, in which the gas is a plasma (a gas of charged particles) and only light can escape.
  - The **convection zone**, through which energy escapes.
  - The **photosphere**, where the light we see is physically generated.
  - The 3 outer layers, the photosphere, chromosphere, and corona, form the **solar atmosphere**.

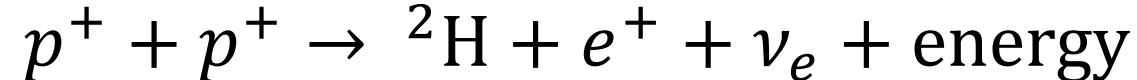
# Equilibrium in the Sun

The hydrogen gas in the sun has mass, and all that mass has a gravitational attraction, pulling itself inward.

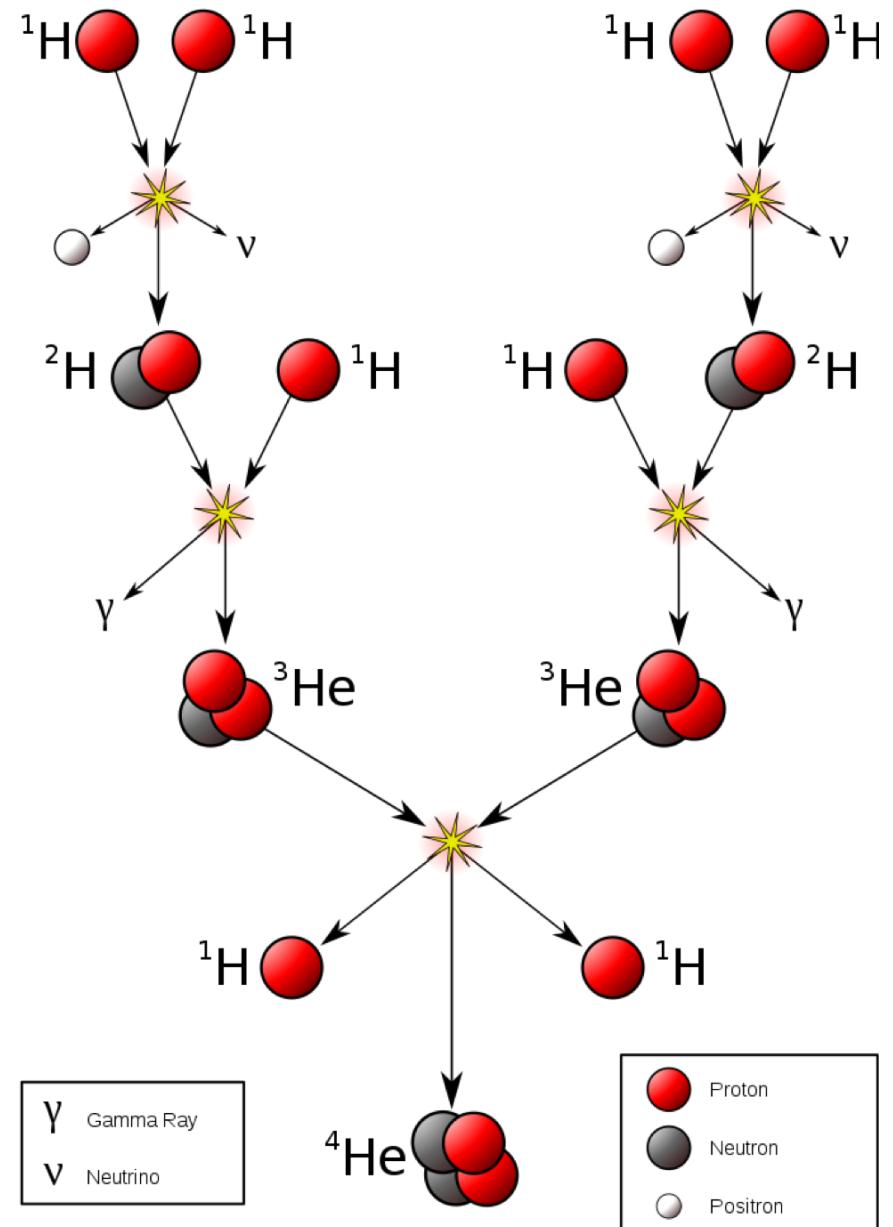


Once the hydrogen gets packed tightly enough, it can undergo fusion, releasing massive amounts of energy. This counteracts the gravity, keeping the Sun in equilibrium.

# Nuclear Fusion



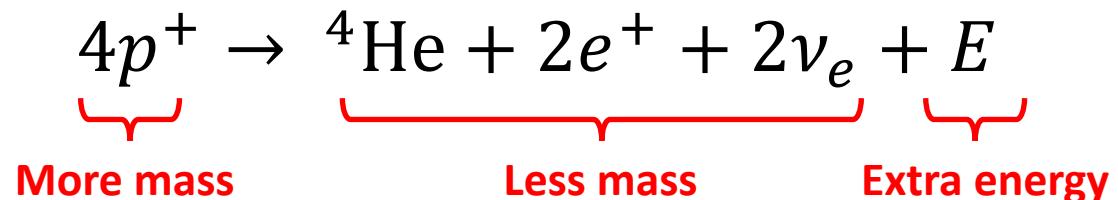
Overall:



# Nuclear Fusion Calculations

$$m_p = 1.6726 \times 10^{-27} \text{ kg}$$
$$m_{^4\text{He}} = 6.6442 \times 10^{-27} \text{ kg}$$
$$m_e = 9.11 \times 10^{-31} \text{ kg}$$
$$m_{\nu_e} = 0 \text{ (approximately)}$$

**Step 1:** Overall:



**Step 2:**  $\Delta m = 4m_p - (m_{^4\text{He}} + 2m_e + 2m_{\nu}) = 4.438 \times 10^{-29} \text{ kg}$

$\Delta$  = "Change in"

Extra mass

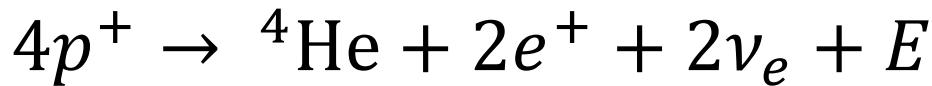
**Step 3:**

$$E = (\Delta m)c^2 = 3.994 \times 10^{-12} \text{ J}$$

Extra energy      Extra mass

Speed of light:  
 $c = 3 \times 10^8 \text{ m/s}$

# Nuclear Fusion in the Sun



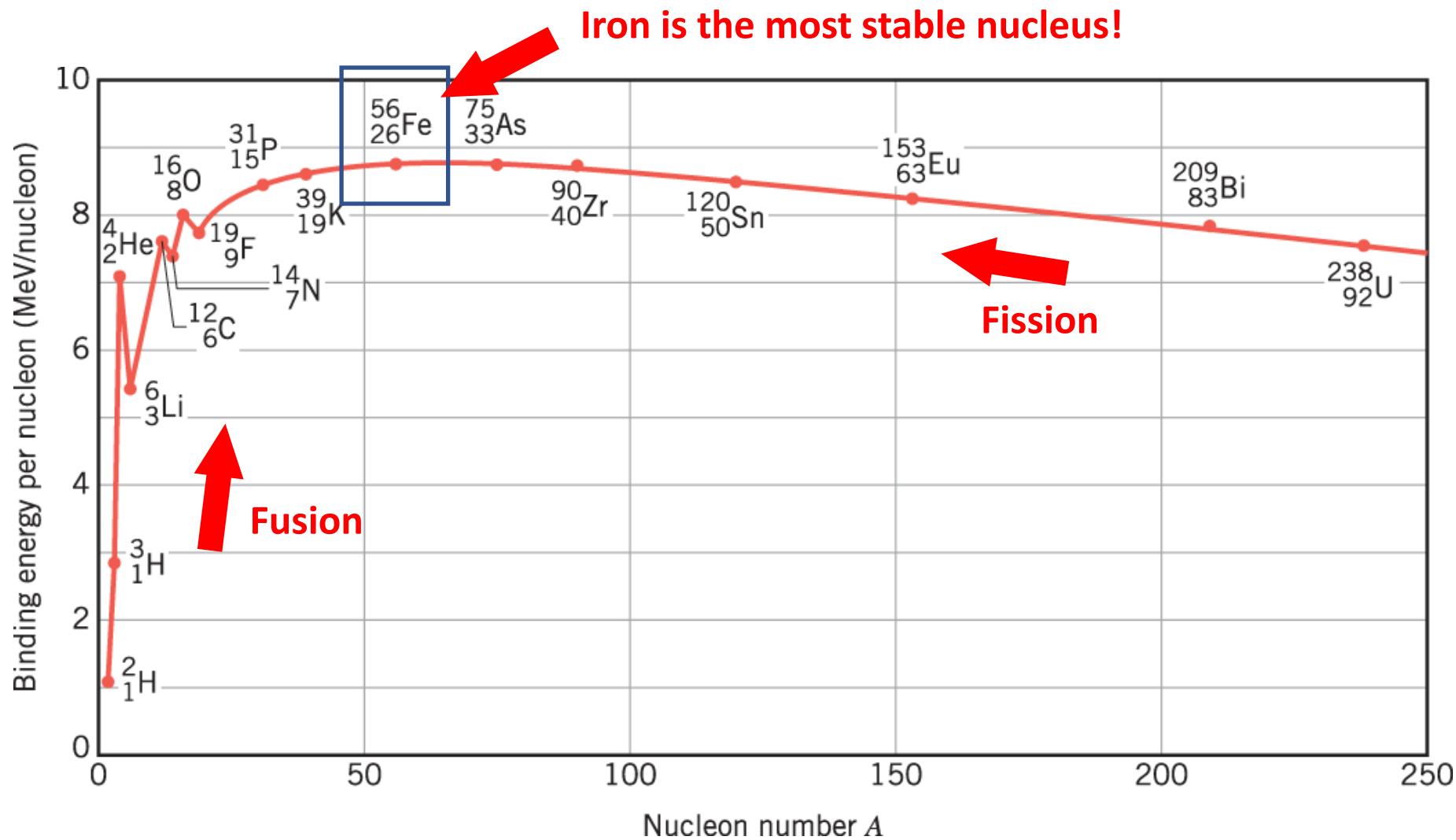
Occurs  $9.58 \times 10^{37}$  times every second

$$\frac{\text{Energy}}{\text{second}} = N * E = 3.828 \times 10^{26} \text{ J/s}$$

Luminosity,  $L$       Watts,  $W$

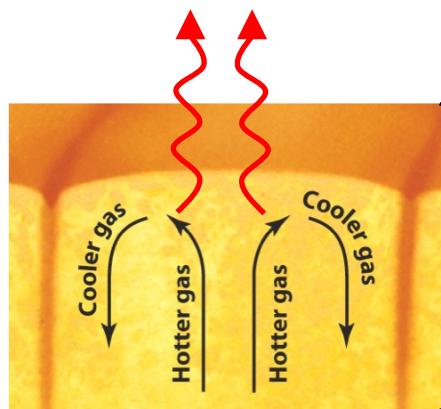
$E = 3.994 \times 10^{-12} \text{ J}$

# Fission vs. Fusion



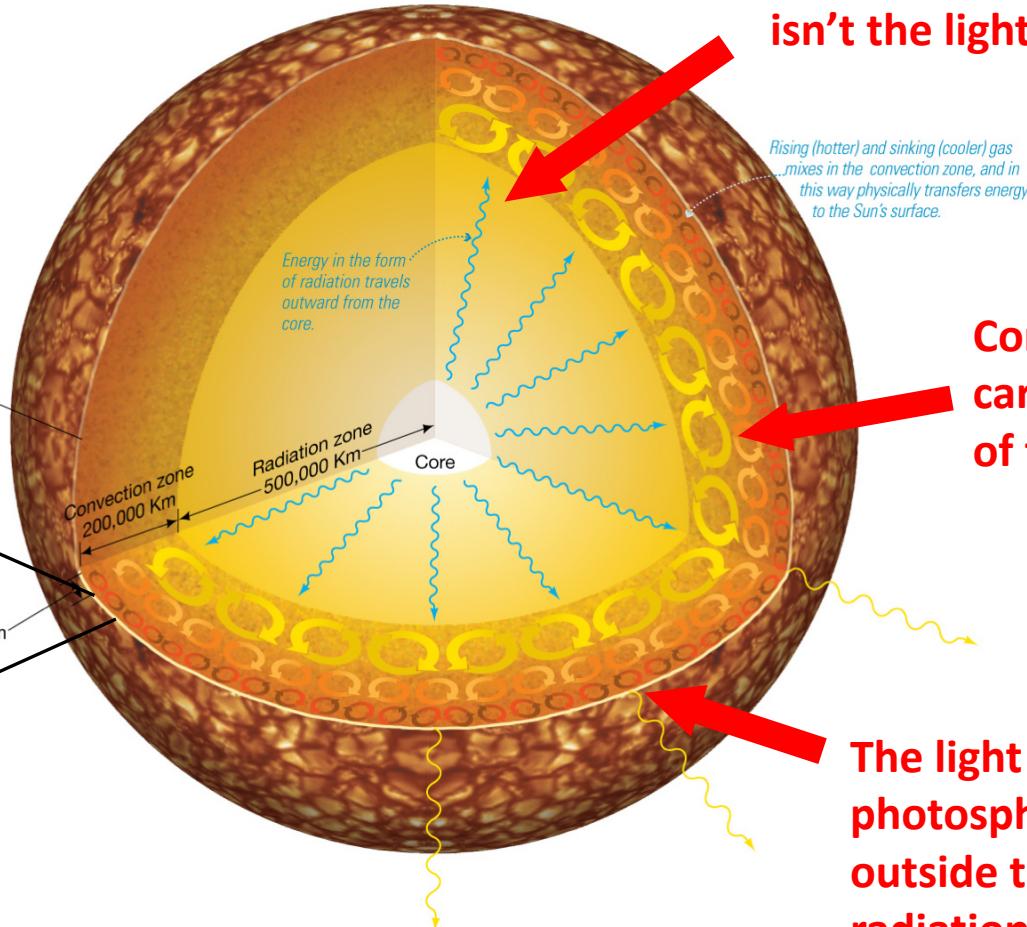
# Radiation vs. Convection Zones

Heat leaves hot gas at top of convection cycle, then cool gas drops.



Outer-most convection cycles (just under photosphere) form “granules.”

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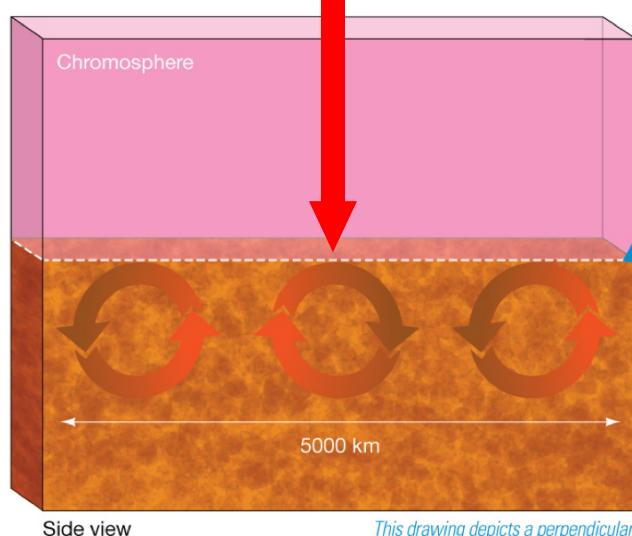
The radiation in the radiation zone isn't the light that escapes the Sun.

Convection cycles progressively carry energy up to the surface of the Sun.

The light we see comes from the photosphere, which is a thin layer just outside the convection zone. This radiation is at a much lower energy.

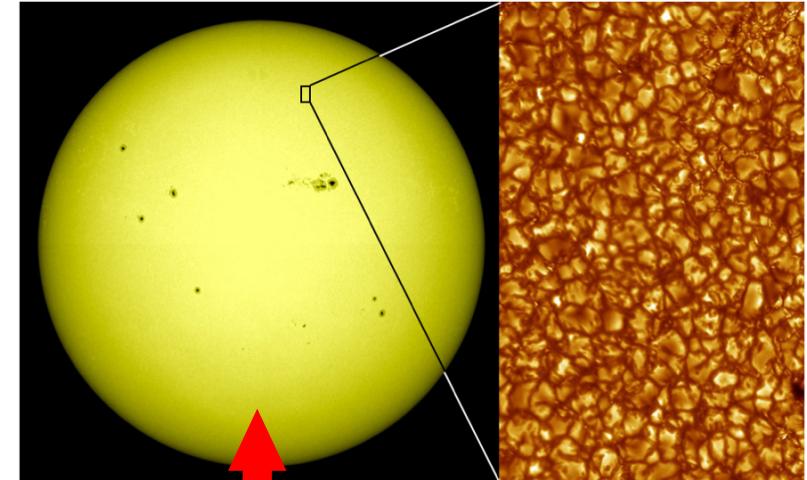
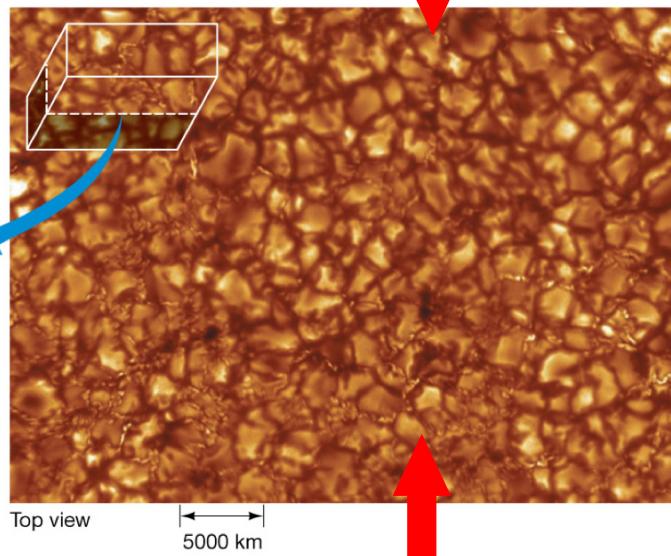
# Granules

The boundary is the photosphere.



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Bright parts are slightly bluer than dark parts



Diameter of the Sun  
is 1.4 million km

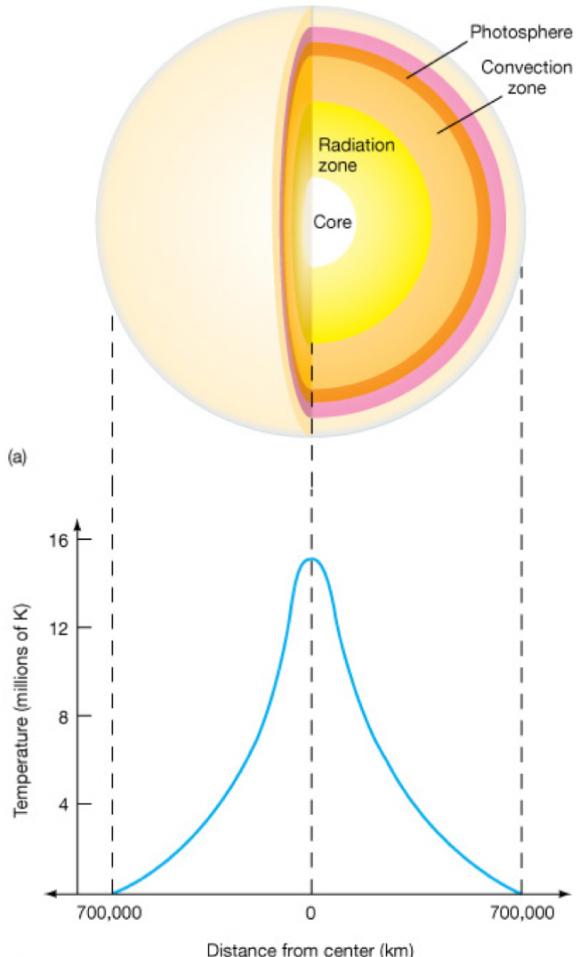


Granules are 1000km in size

Granules are produced by convection, the same as bubbles in boiling water.

[https://www.youtube.com/watch?v=W\\_Scoj4HqCQ](https://www.youtube.com/watch?v=W_Scoj4HqCQ)

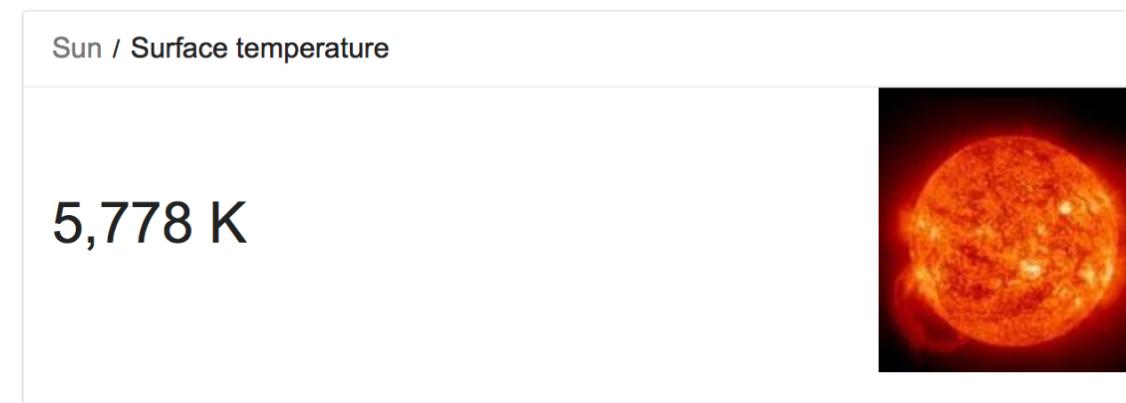
# Temperature of the Sun



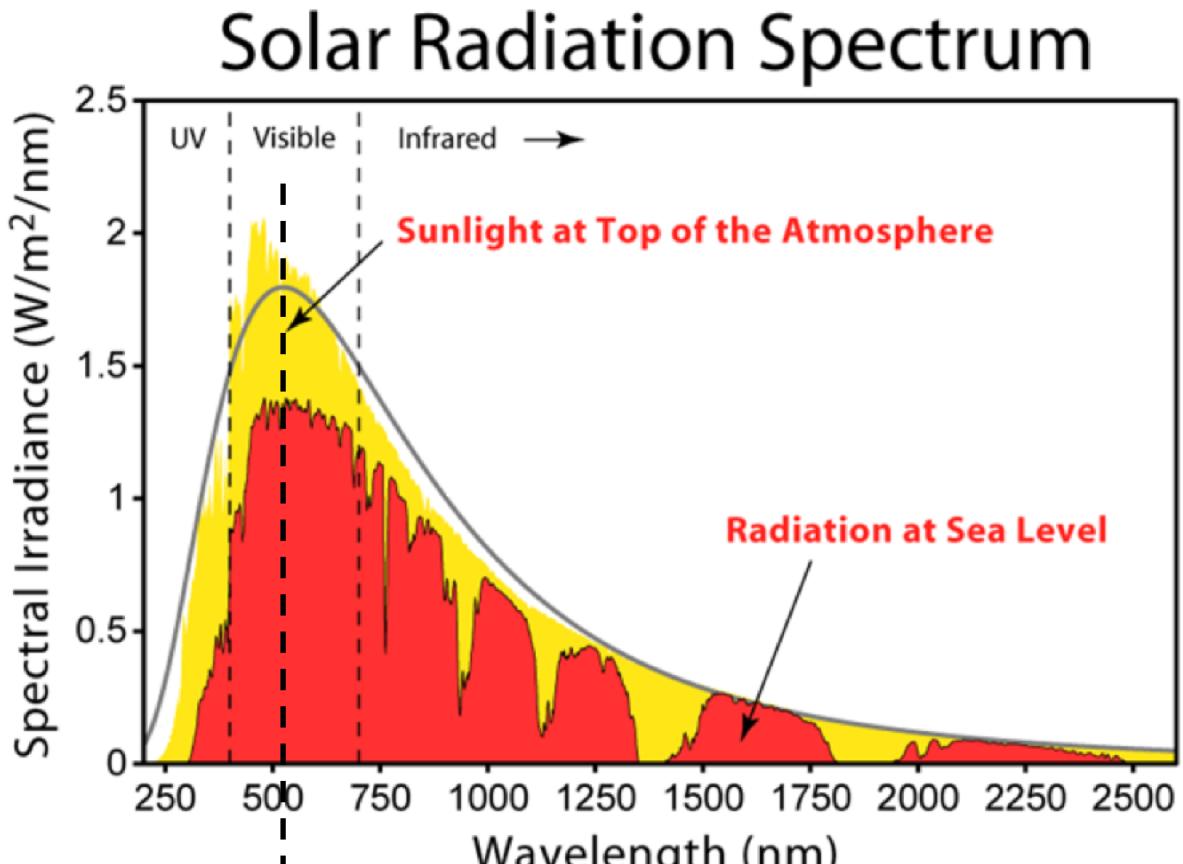
The Sun is a blackbody, so the brightness and color of light we see is determined by temperature.

The photosphere is the visible part of the Sun, which is what acts as the blackbody.

The “temperature of the Sun” is the temperature of the photosphere! This is around 5800K.



# The Sun as a Blackbody



$$b = 2.9 \times 10^6 \text{ nm} \cdot \text{K}$$

Wein's Law:

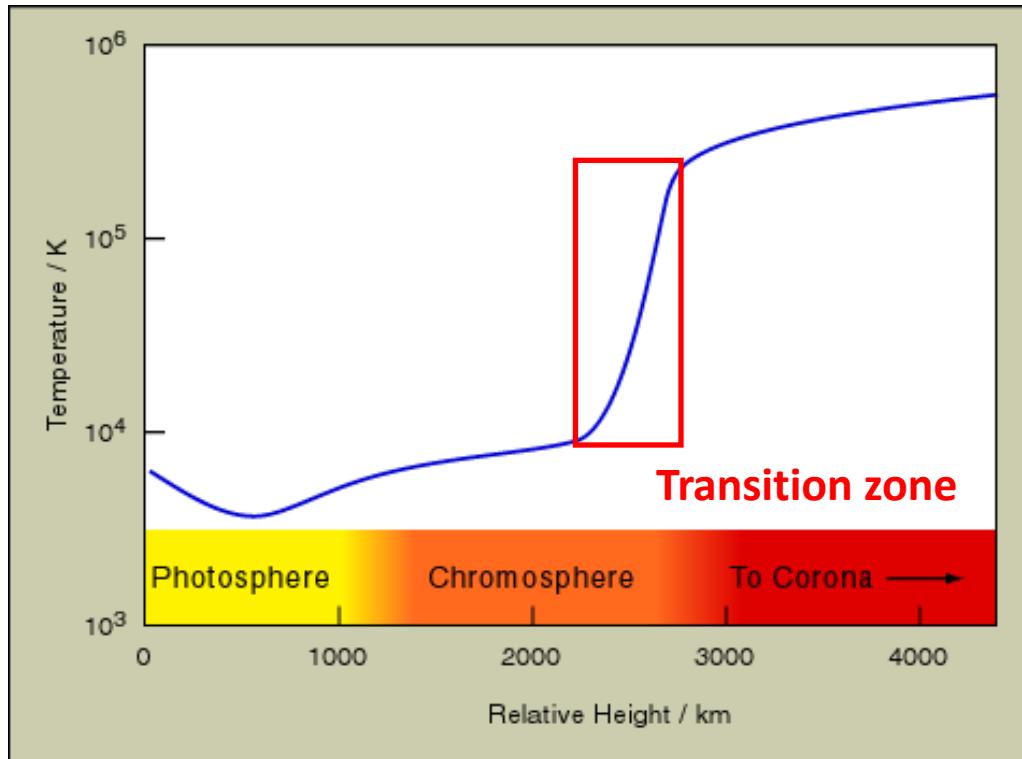
$$\lambda_{\max} = \frac{b}{T}$$

$$T = \frac{b}{\lambda_{\max}} = 5800\text{K}$$

Temperature of the blackbody,  
and therefore temperature of the  
photosphere

# Solar Atmosphere

Atmosphere contradicts temperature trend

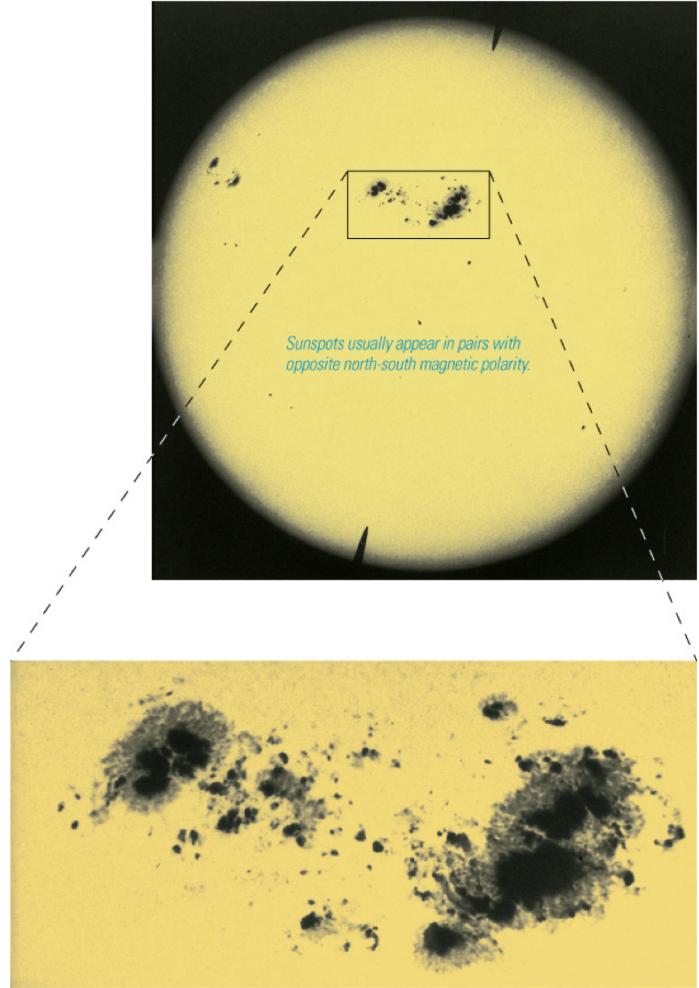


2<sup>nd</sup> Law of Thermodynamics:  
Heat flows from hot to cold, never from cold to hot.

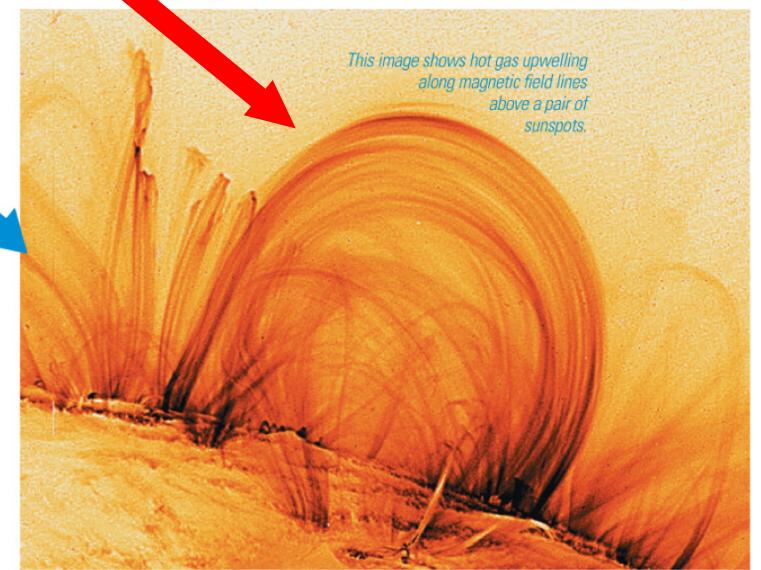
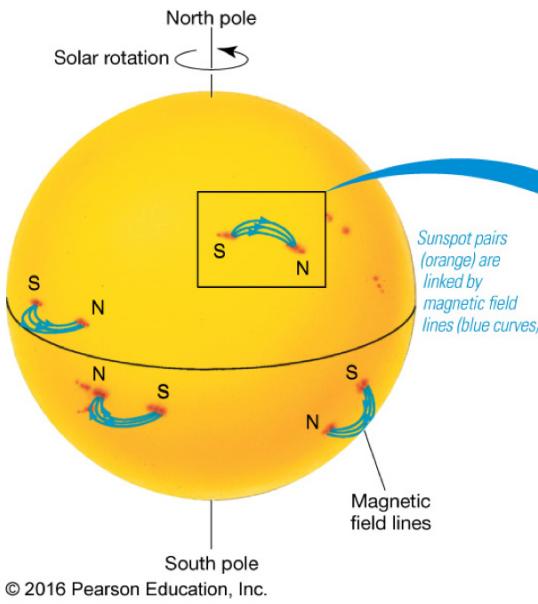


Coronal heating problem!  
Possible solution: magnetic recombination

# Sunspots

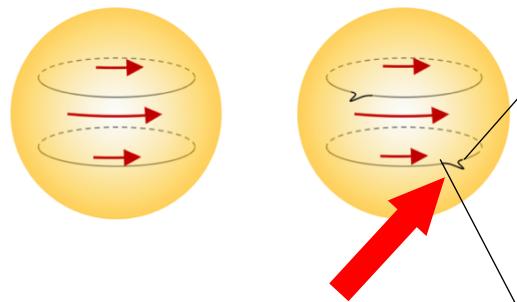
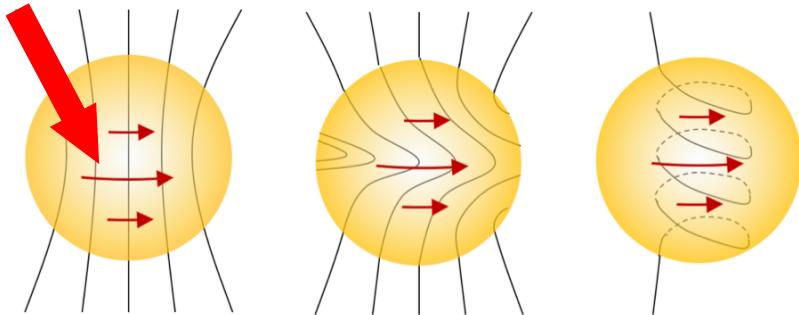


These looping magnetic fields are known as “prominences”

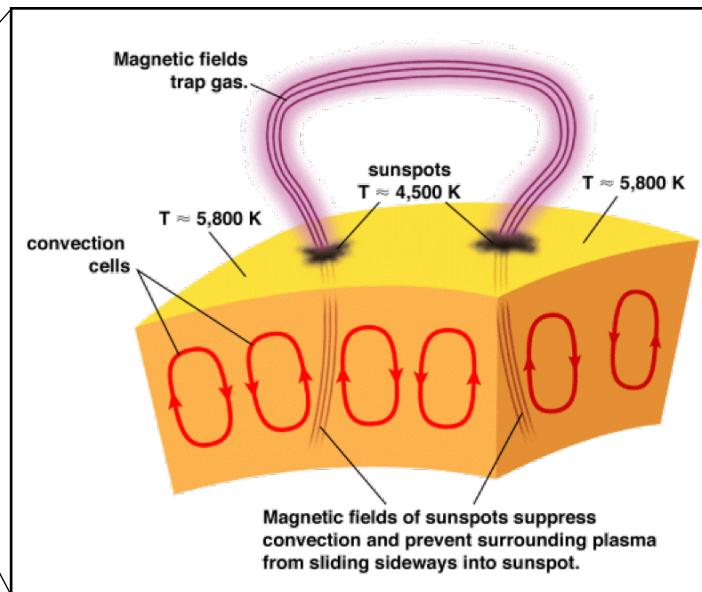


# Magnetic Reconnection

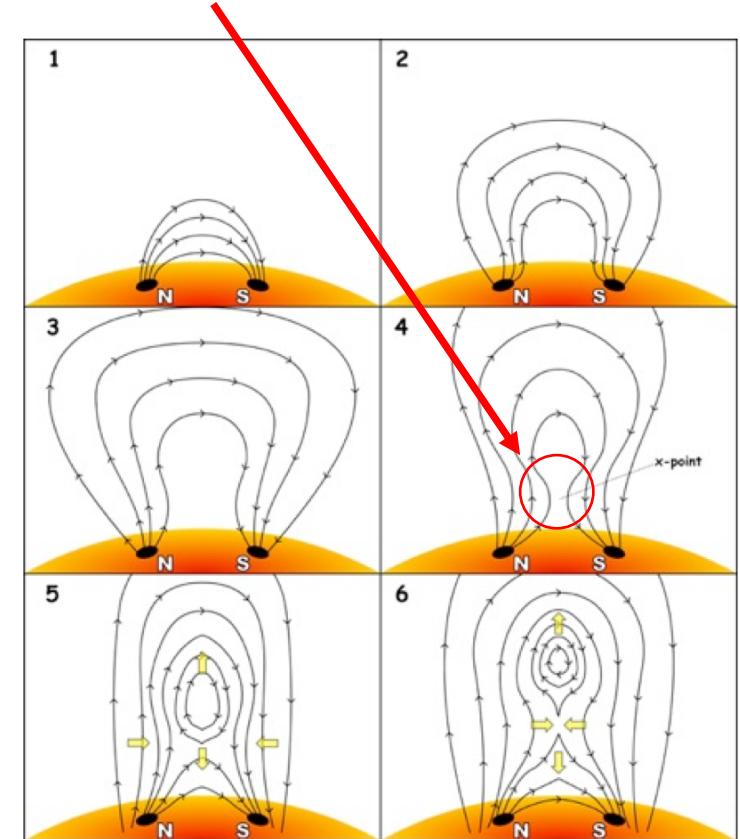
Equator rotates faster than poles



Magnetic loops develop kinks that poke out of Sun's surface

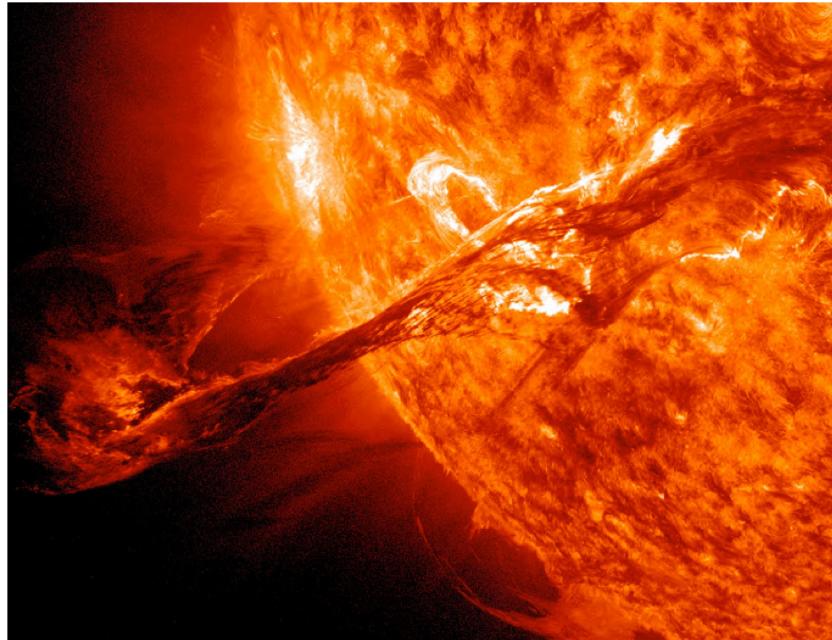


Reconnection point

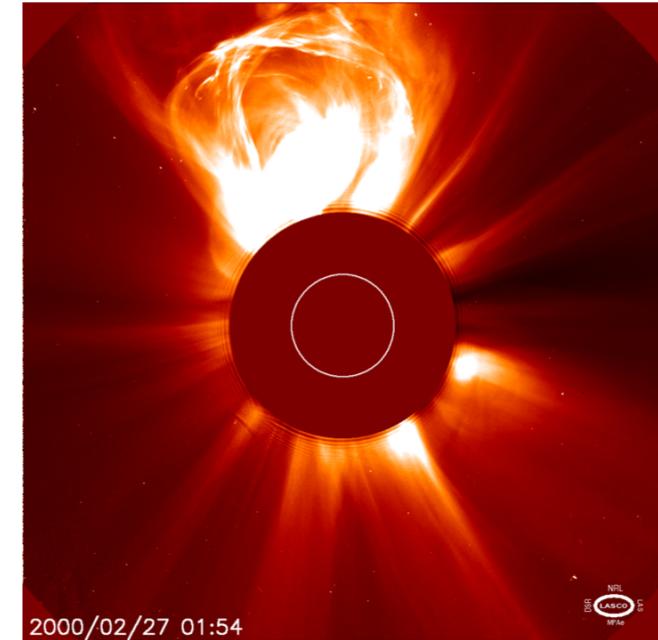


Massive energy released when magnetic fields reconnect, carried to corona to heat it.

# Solar Flares vs. Coronal Mass Ejections



In a solar flare, prominence is still trapped by Sun's magnetic field

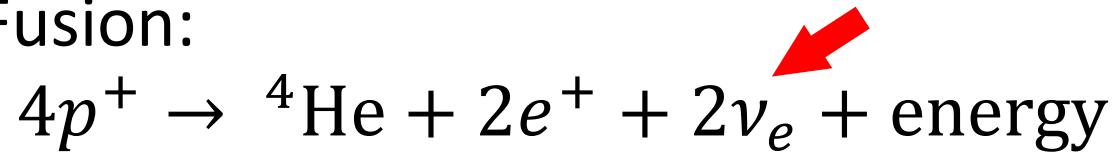


In a coronal mass ejection, prominence is energetic enough to escape Sun's magnetic field

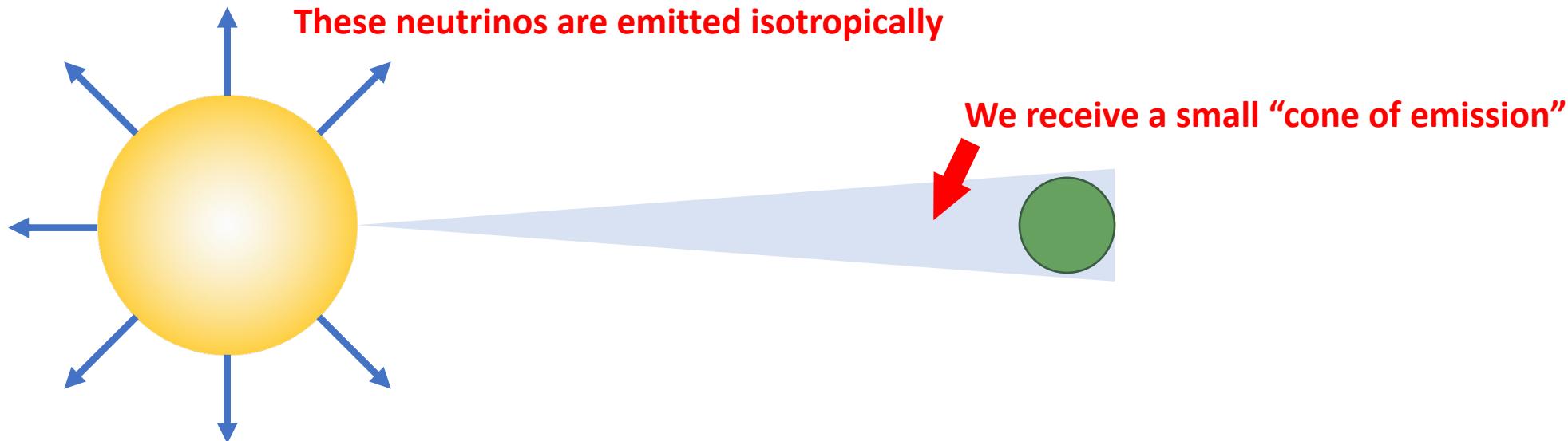
Difference between flares and CME's: <https://www.youtube.com/watch?v=TWjtYSRIOUI>

# Solar Neutrinos

Fusion:



Specific type of neutrino, known as “electron neutrino.”  
Recall,  $9.58 \times 10^{37}$  are made every second.



**Solar neutrino problem:**

We can predict how many neutrinos per second we should receive.  
However, we only observe 1/3 of them.