
# Chapter 11: The Sun

Chapter 11 Reading Assignment due now

Nearby/Brightest Stars HW
&
Chapter 12 Reading Assignment
due Thursday, October 3rd

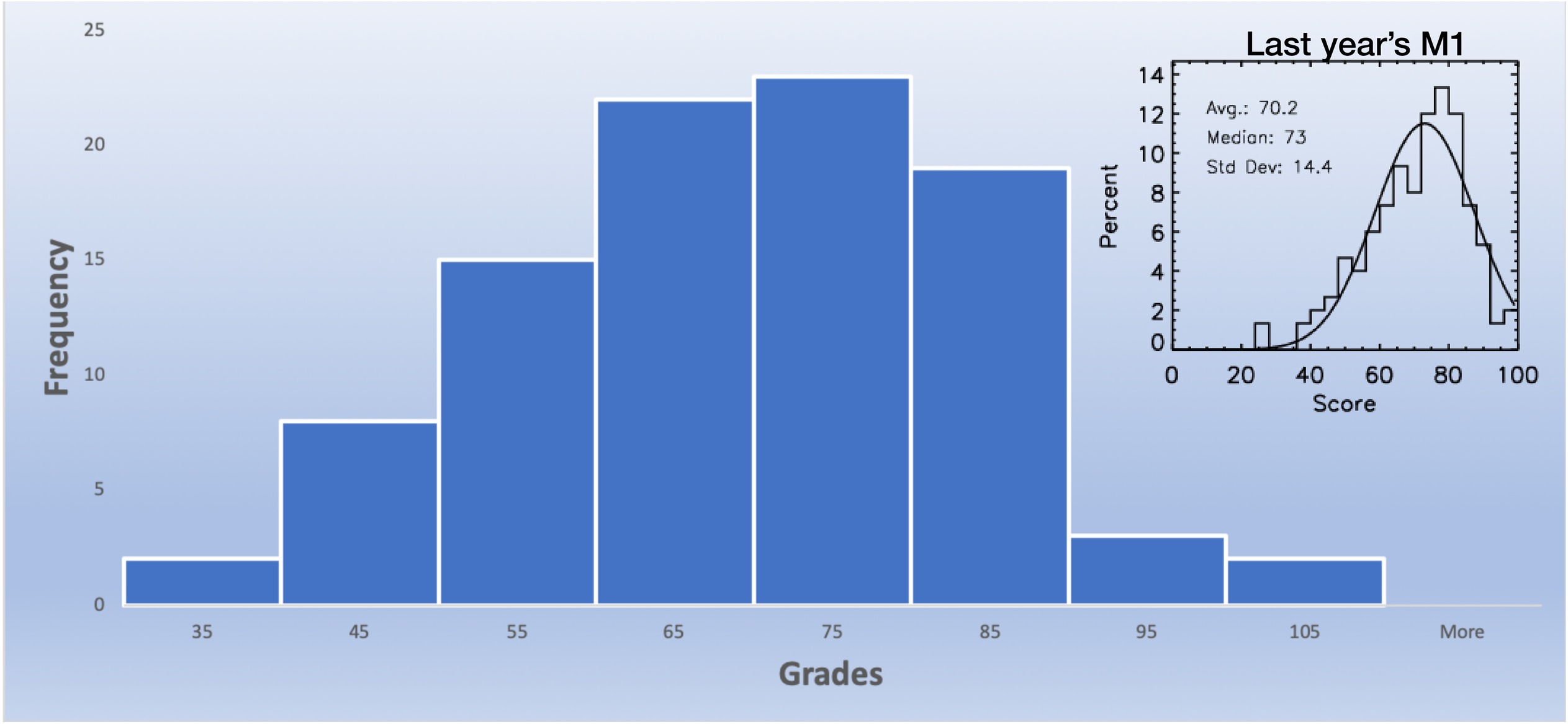
Are your grades in Canvas correct???

South Physics Observatory
Public Nights, every
Wednesday: EC opportunity

Planetarium EC opportunity
"Night Visions" Program

(see the syllabus for how to
earn the Extra Credit)

# Midterm 1 results



_____ When we determine the angular resolution of an interferometric array of radio telescopes using the formula $\theta = \lambda/D$, the variable $D$ stands for the:

A. number of telescopes.

B. focal length of the telescopes.

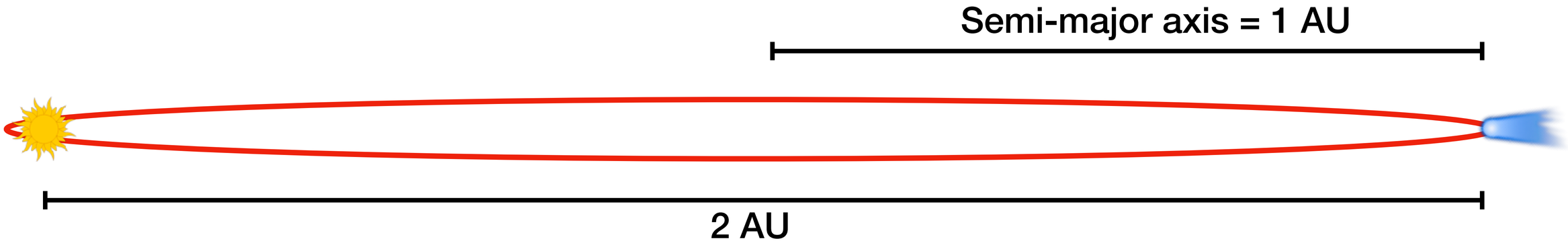
**C. separation between the telescopes.**

D. diameter of the telescopes.

# Kepler's Law Short Answer Question

28. An asteroid is discovered to have an extremely elliptical orbit, such that its major axis is much much larger than its minor axis. It is found that its farthest distance from the Sun is 2 AU. How long does it take to complete one orbit?

**Solution:** Because the orbit is highly elliptical, the foci are close to the outer edges of the ellipse, with the Sun at one of the foci. This means that the asteroid passes very near the Sun on closest approach, so its farthest distance of 2 AU corresponds to the entire length of the major axis, yielding a semi-major axis $a = 1$ AU. Plugging this into Kepler's third law, $P(\text{in years})^2 = a(\text{in AU})^3$, we find the asteroid's period $P = \sqrt{1^3} = \sqrt{1} = 1$ year.

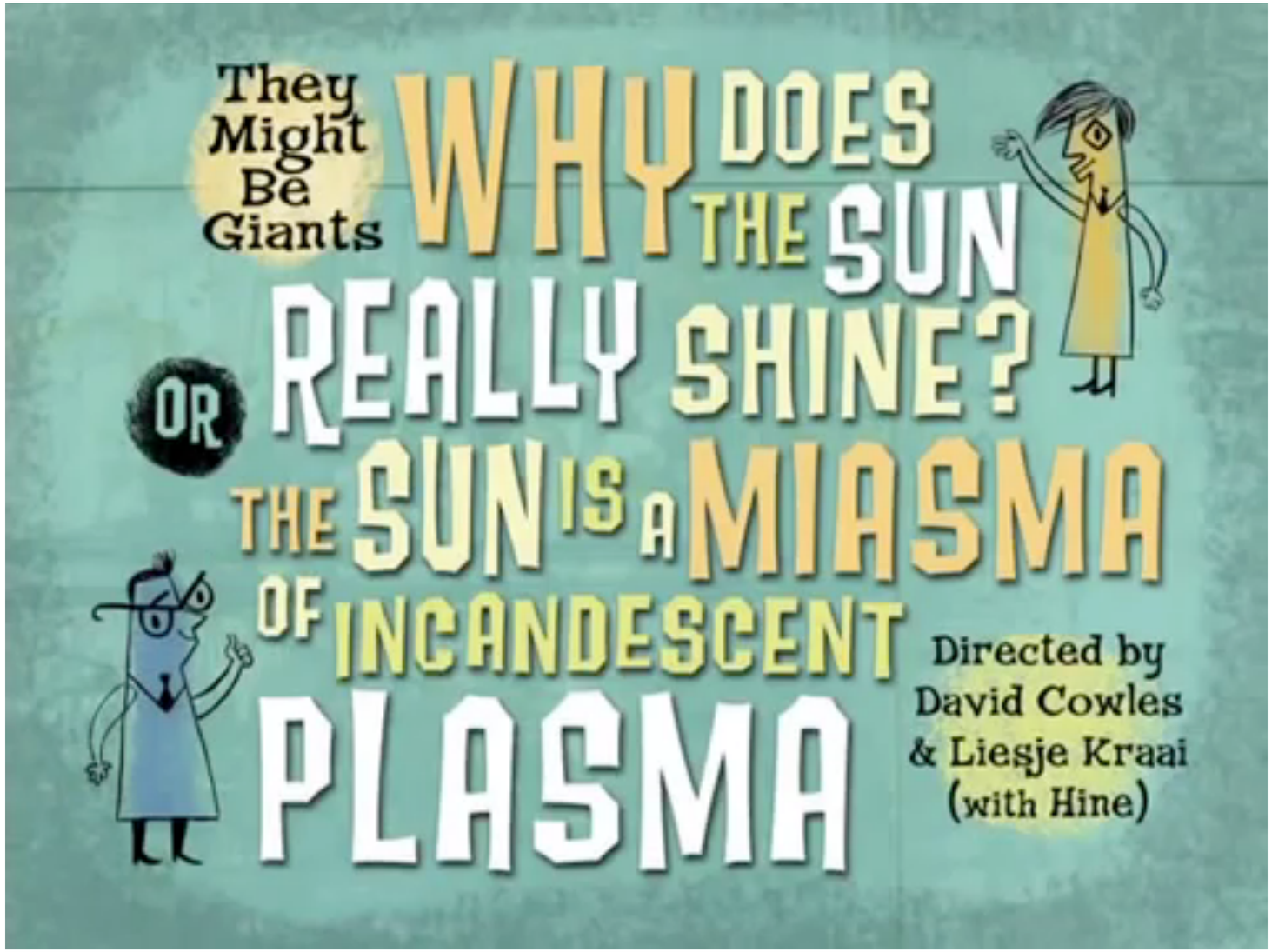


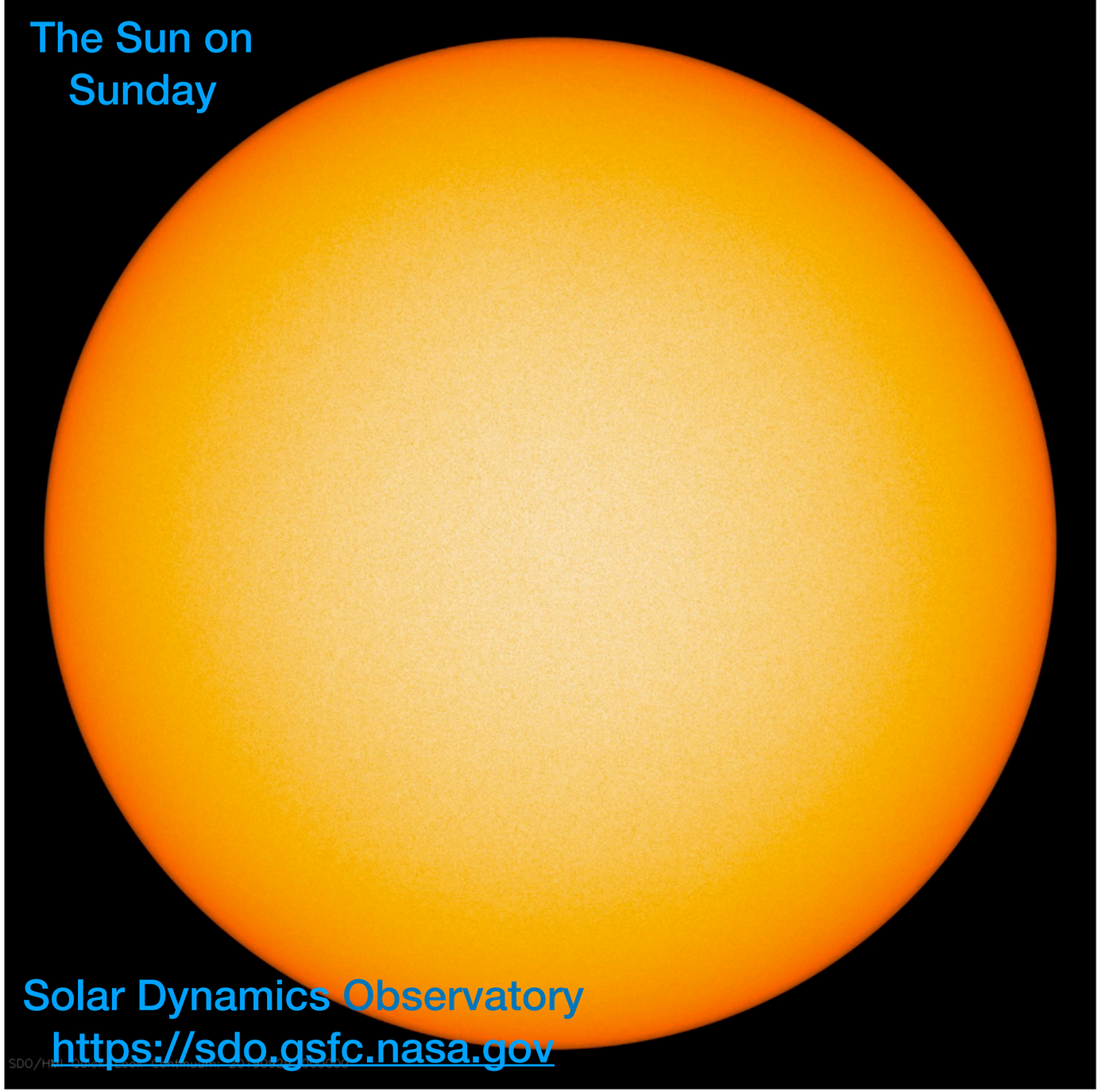
# Why does the Sun shine?

https://www.youtube.com/watch?v=3JdWISF195Y

# A Small Correction…

https://www.youtube.com/watch?v=sLkGSV9WDMA






# Sun Facts

- Diameter: 1.4 million km (~100x Earth's)
- Mass: $2 \times 10^{30}$ kg (300,000x Earth's)
- Total Luminosity: $4 \times 10^{26}$ Watts
- Energy Reaching Earth: 1400 Watts/meter$^2$
- Surface Temperature: 5800 K

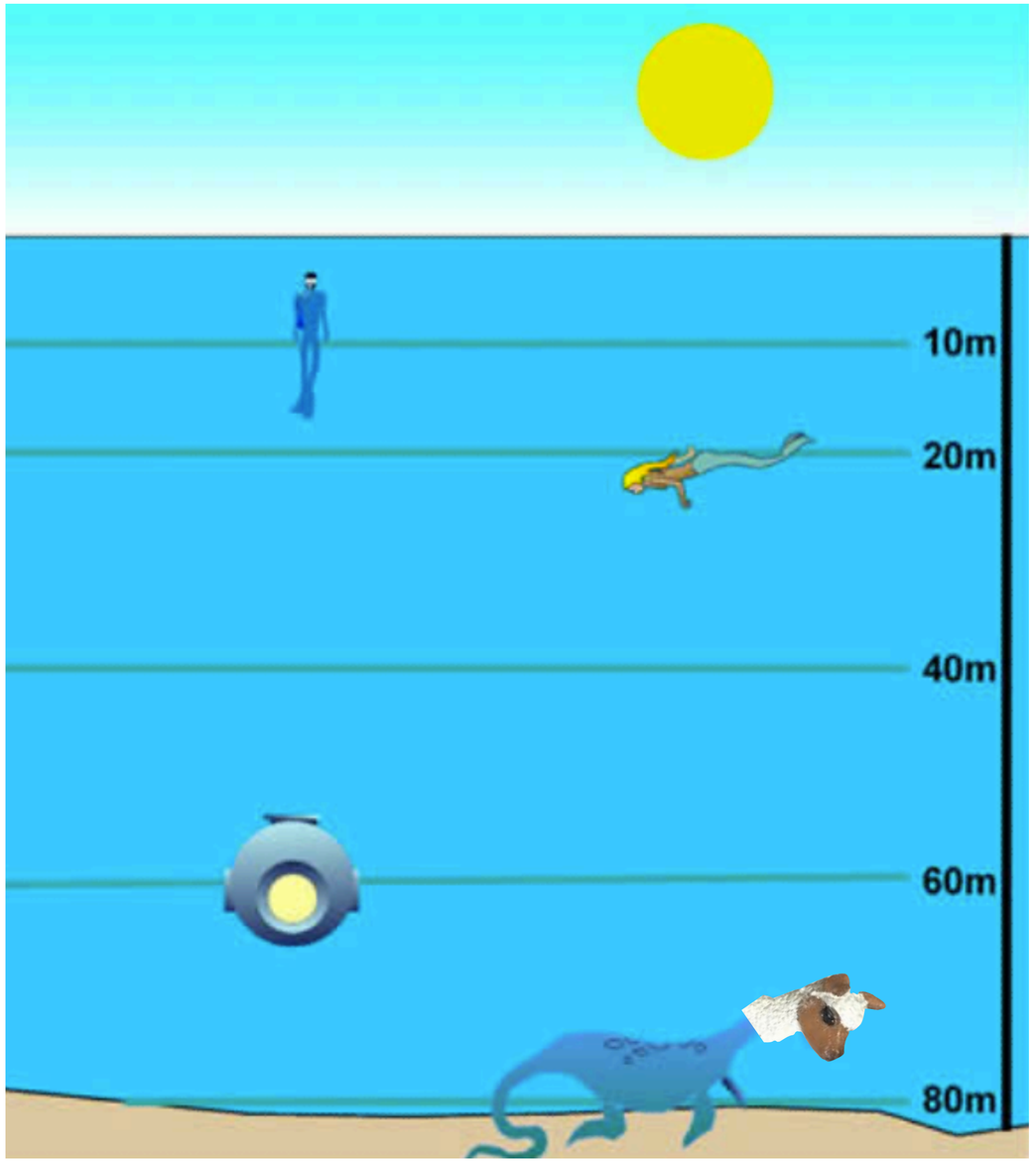
# The greatest pressure is experienced by the…

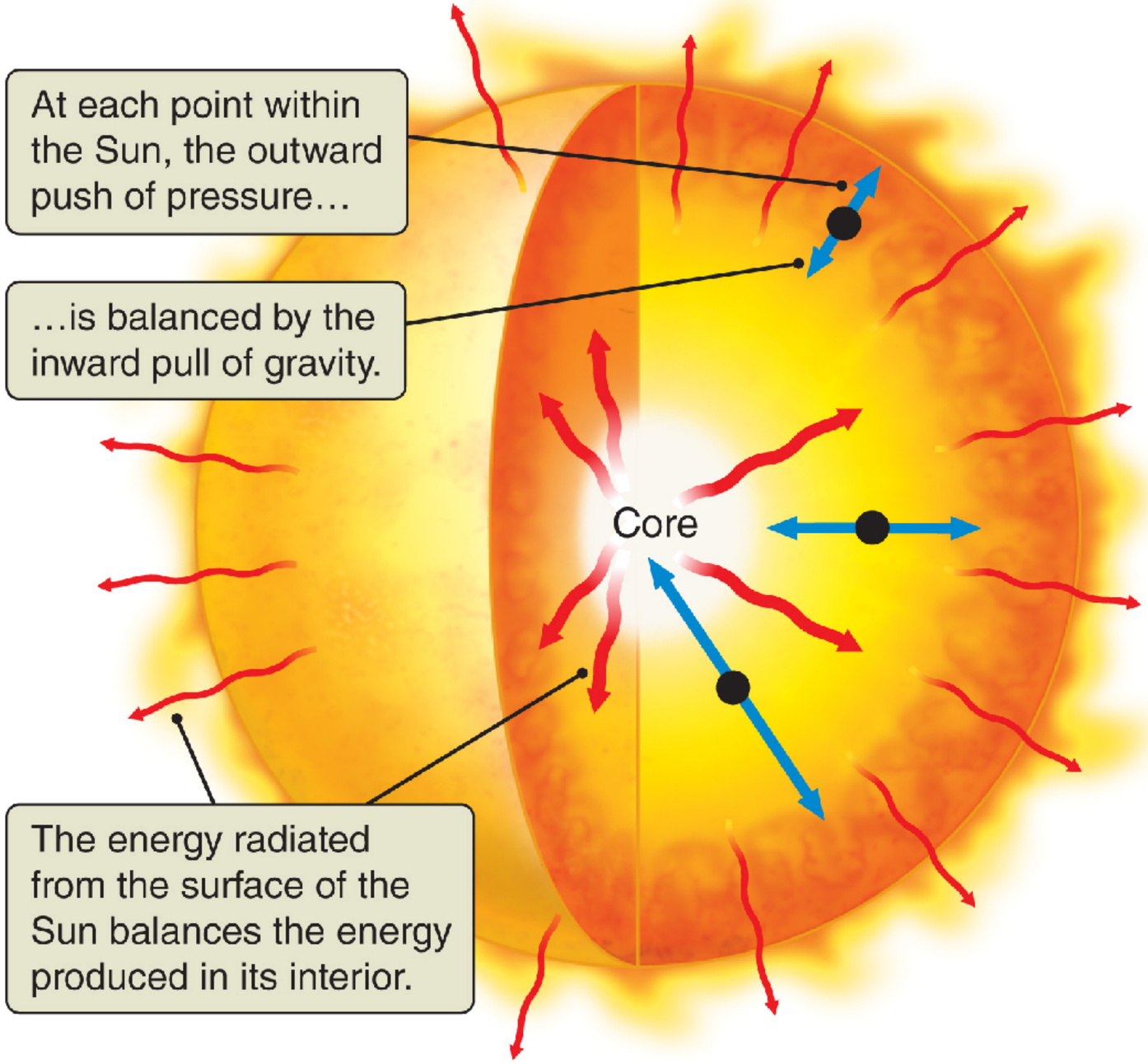
A) Diver

B) Mermaid

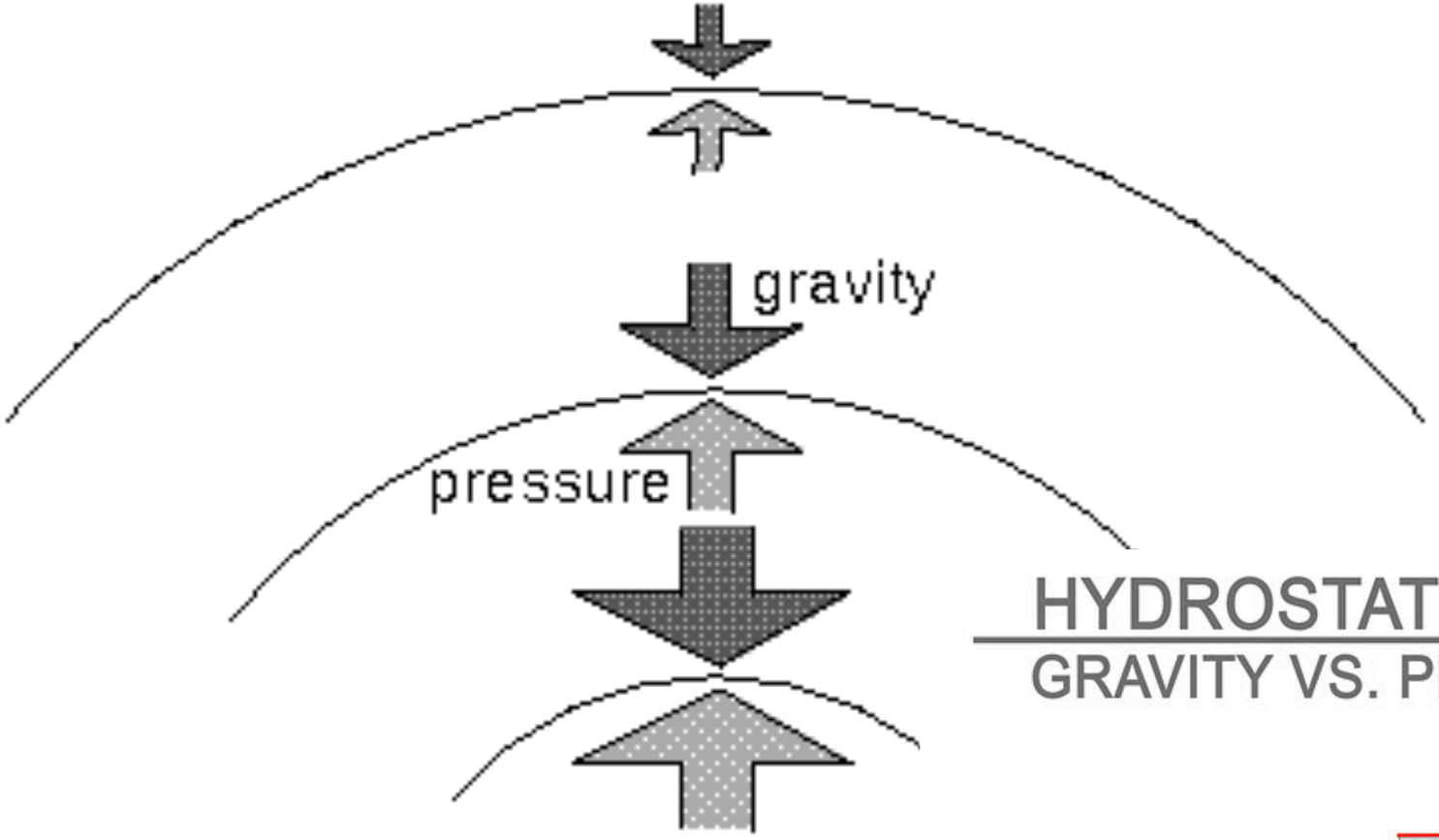
C) Bathysphere

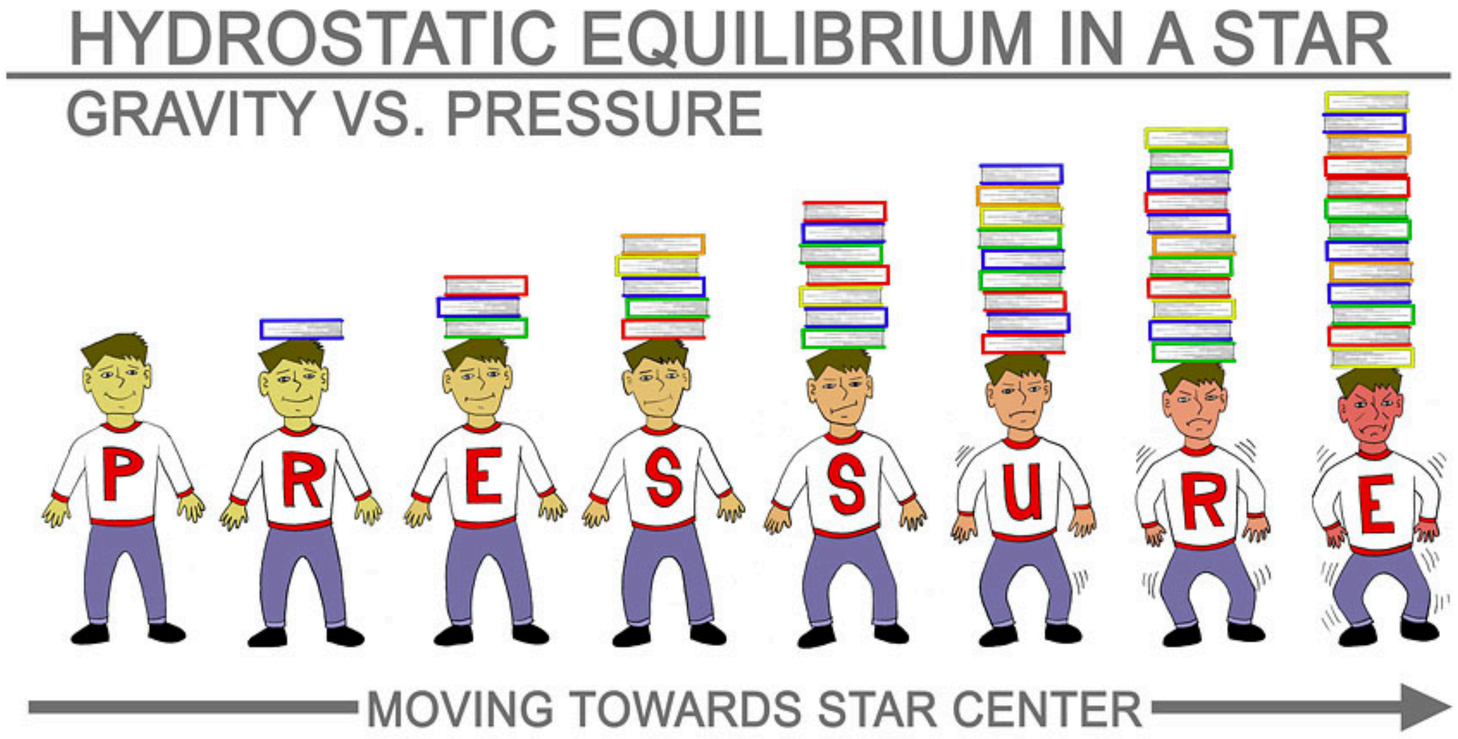
D) Loch Ness Llama






# Hydrostatic Equilibrium


gravity
pressure


HYDROSTATIC EQUILIBRIUM IN A STAR
GRAVITY VS. PRESSURE
P
R
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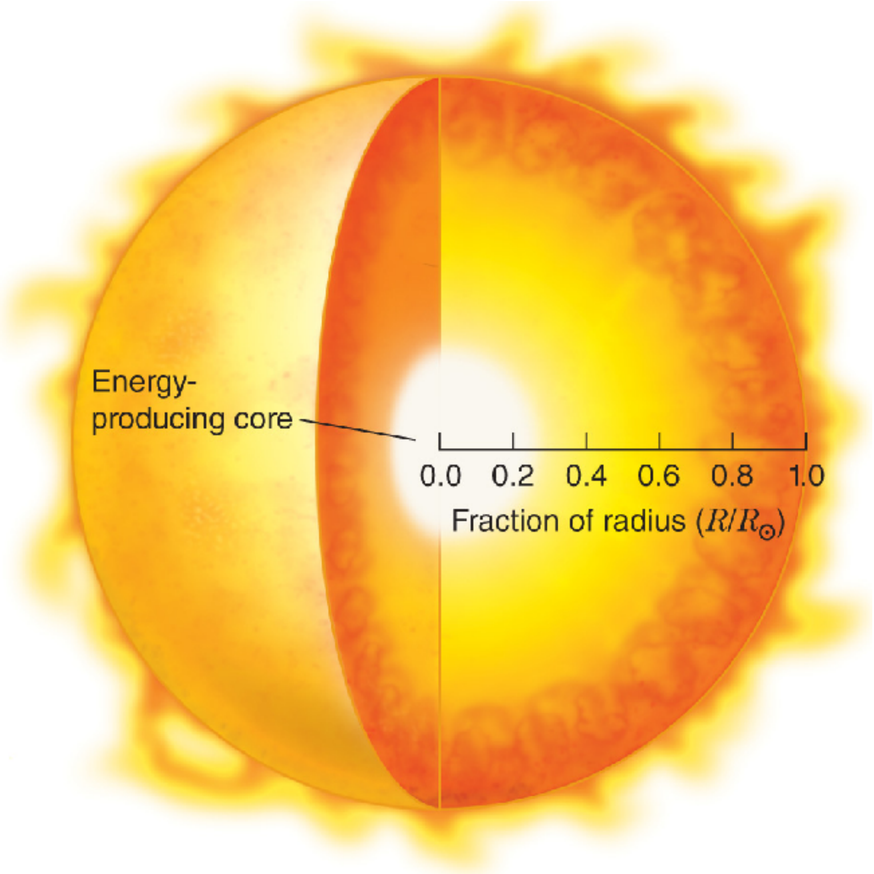
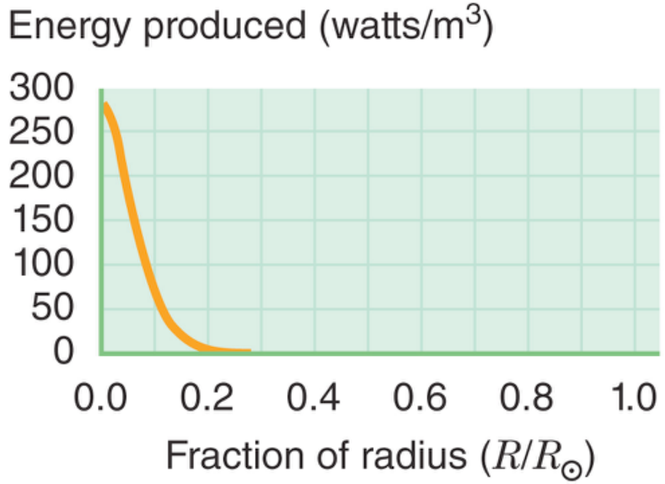
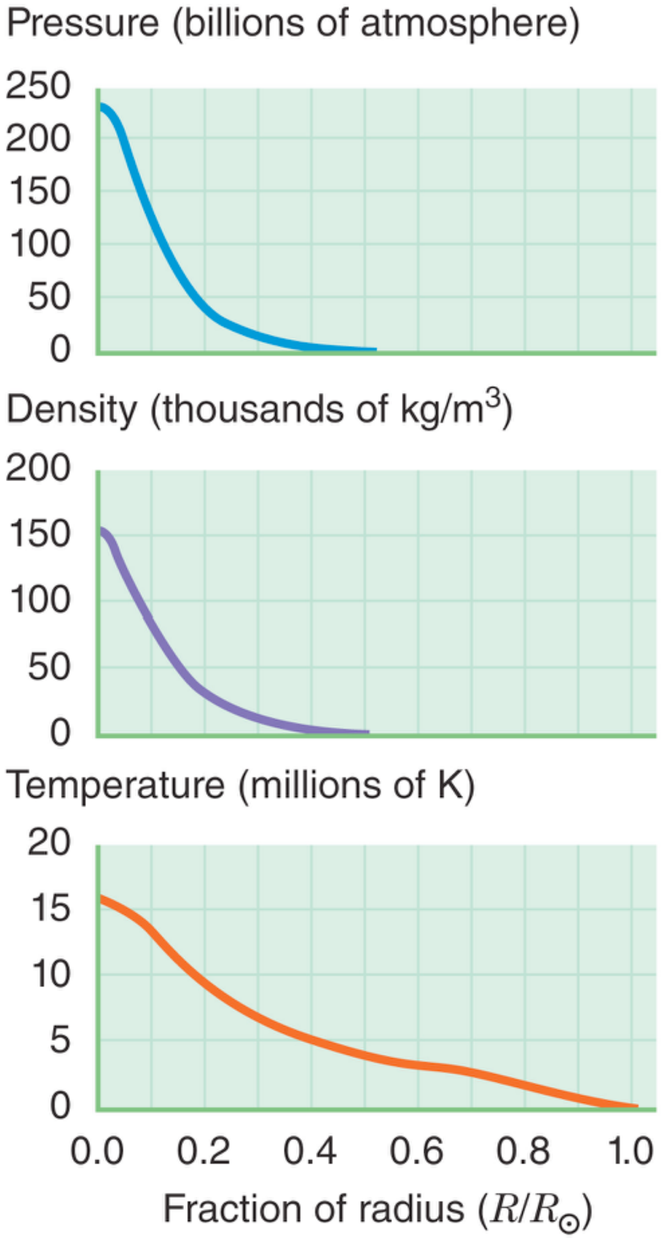
MOVING TOWARDS STAR CENTER

# Pressure, Temperature, Density, Energy Produced all change with radius



# The Sun's Luminosity Comes From:

A) Chemical Burning (loss of electron energy)

B) Nuclear Fusion

C) Gravitational Collapse

# Kelvin-Helmholtz Timescale

How long can you drive on I-15?

- have 10 gallons of gas
- car gets 40 mpg

$$t_{KH} = \frac{\text{amount of fuel}}{\text{rate of consumption}}$$

$$\approx \frac{GM^2/R}{L}$$

$$\approx 30 \text{ Myr}$$

# Rutherford contradicts Lord Kelvin on the Age of the Earth (KH timescale of Earth matched the Sun's)

I came into the room, which was half dark, and presently spotted Lord Kelvin in the audience and realized that I was in for trouble with the last part of my speech dealing with the age of the Earth, where my views conflicted with his. To my relief, Kelvin fell asleep, but as I came to the important point, I saw the old bird sit up, open an eye and cock a baleful glance at me!

Then a sudden inspiration came and I said, "Lord Kelvin has limited the age of the Earth, provided no new source [of energy] was discovered. That prophetic utterance refers to what we are now considering tonight: radium!" Behold! the old boy beamed upon me.

- Rutherford's recollection of his talk in 1904 announcing the Earth to be at least 700 million years old

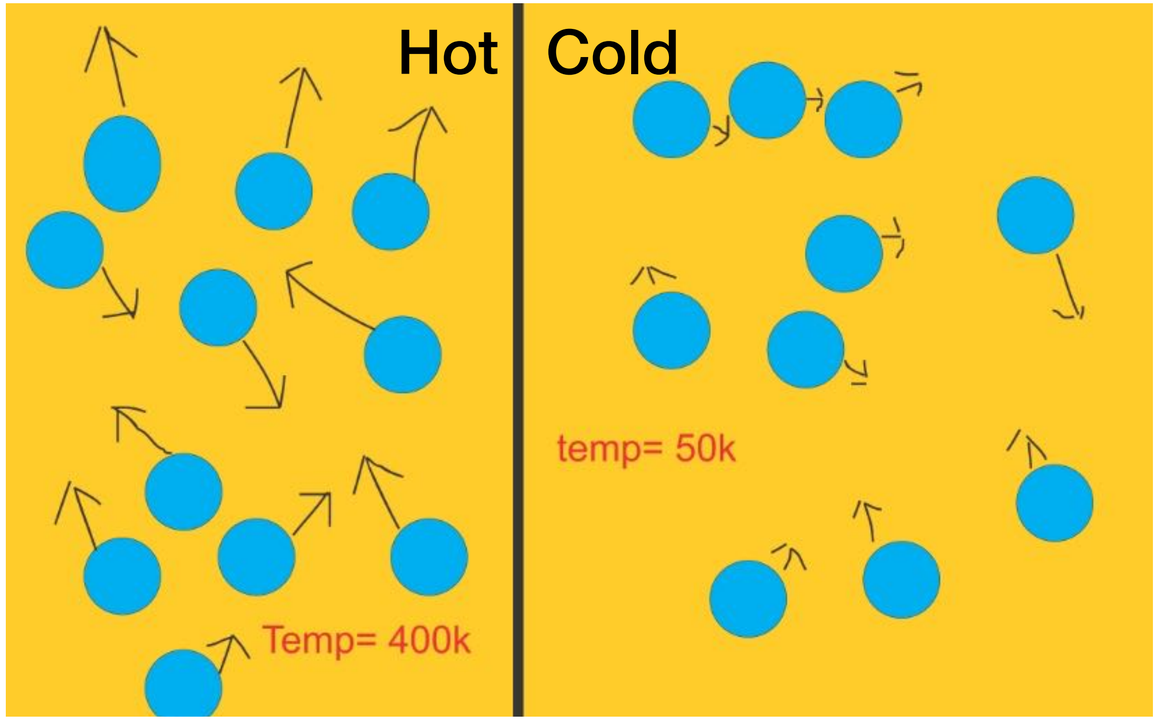
# Fusion happens at the center of the Sun because:

A) High Temperature

B) High Density

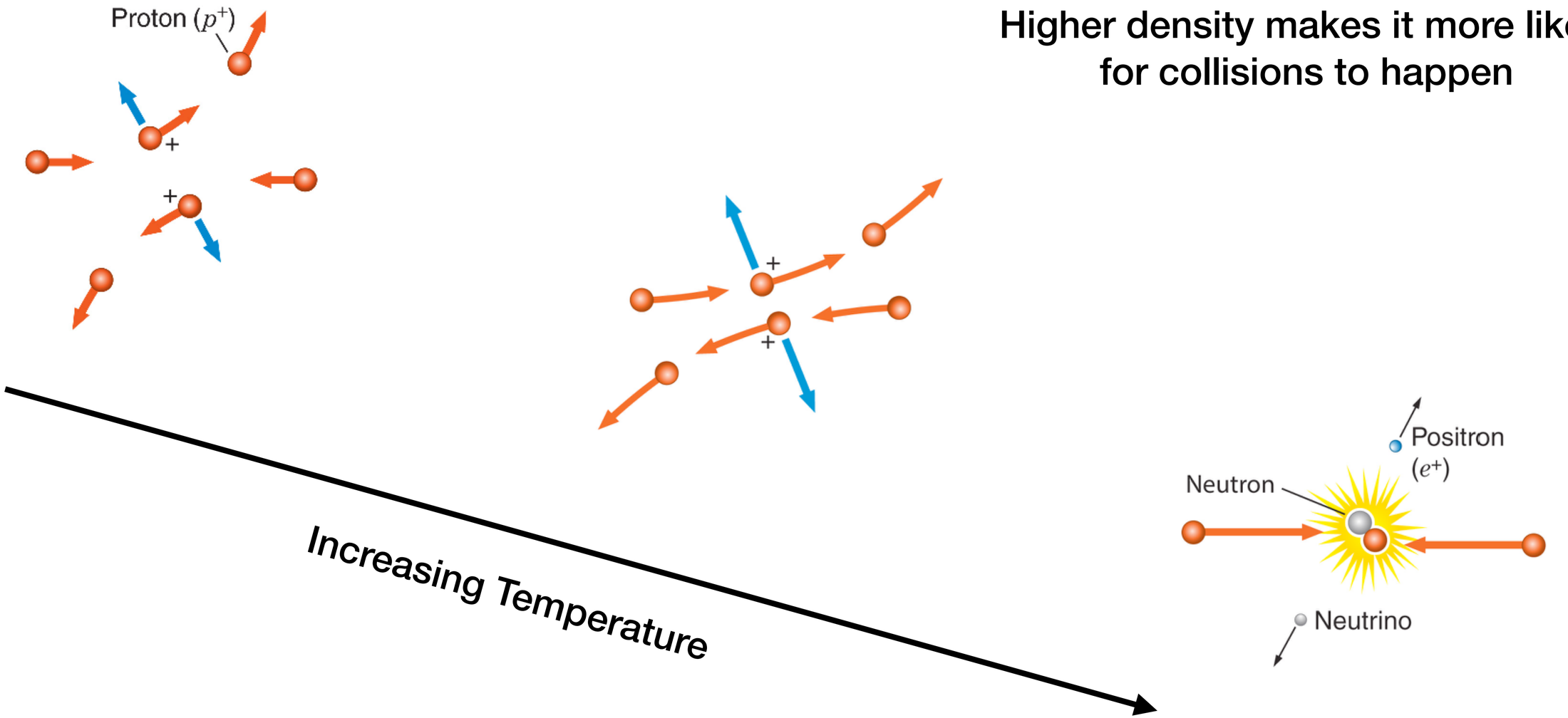
C) High Density & Temperature

# Higher Temperature —> Faster Movement



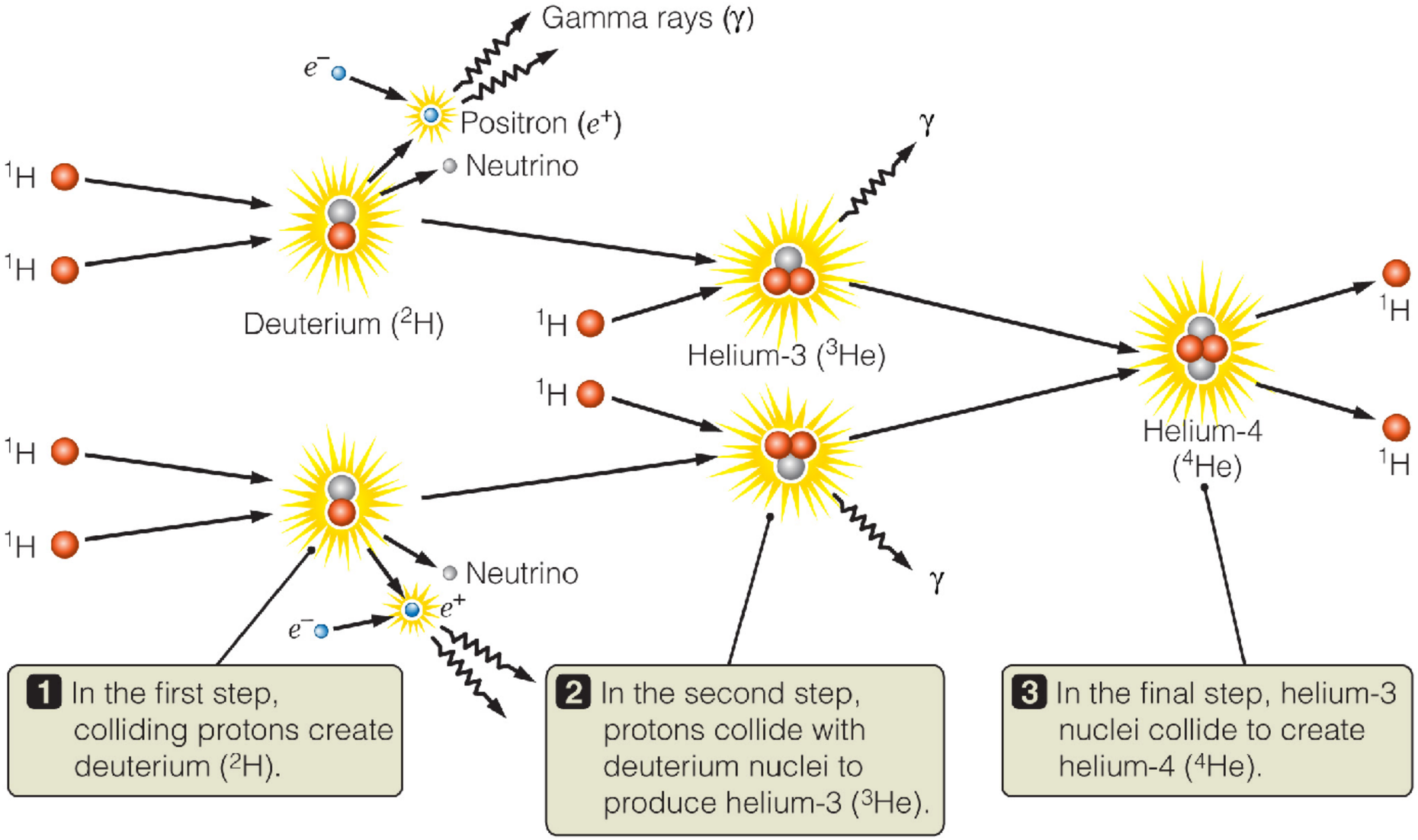

# High Density —> More likely to run into things

# Higher temperature makes collisions possible

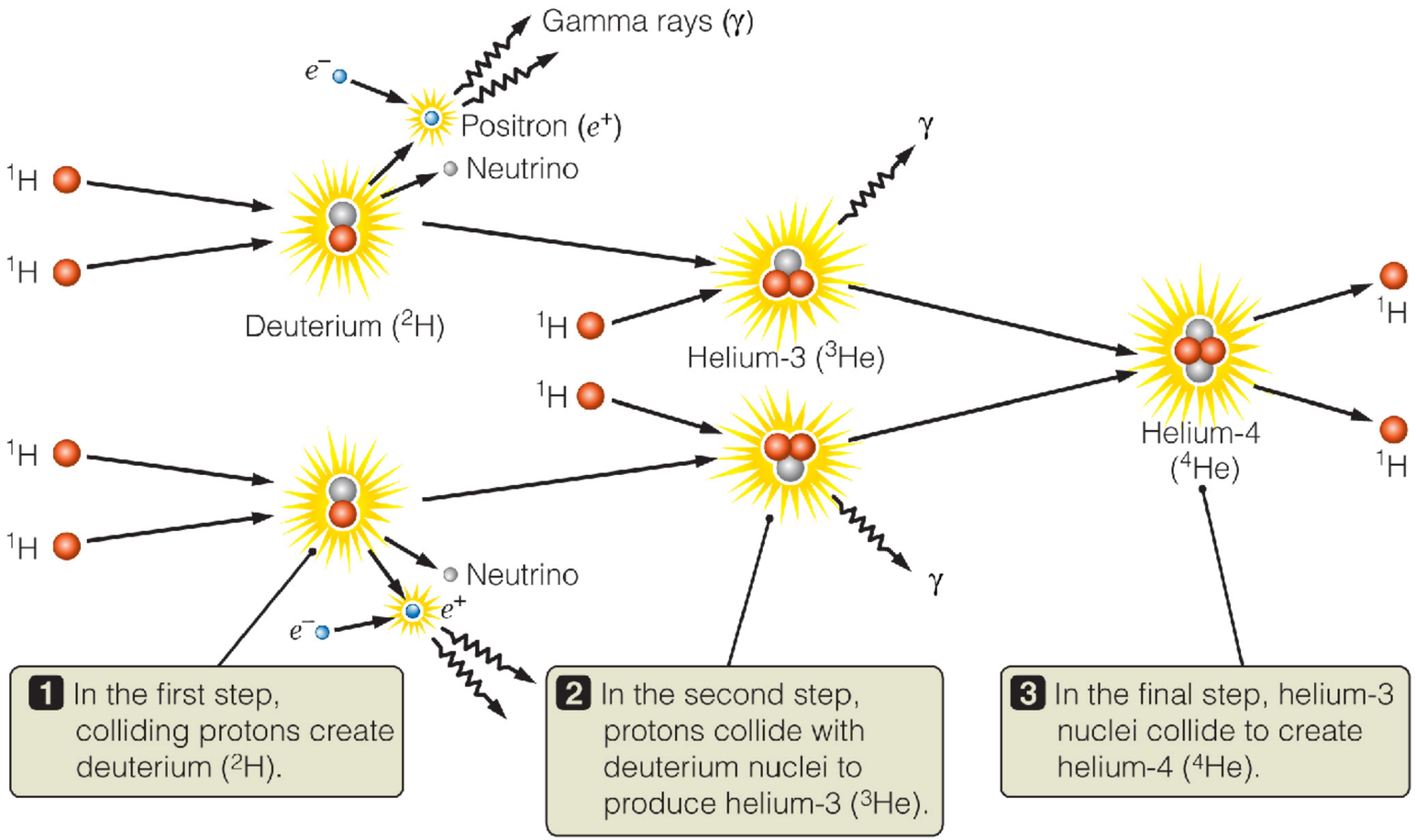



Higher density makes it more likely for collisions to happen

# Hydrogen burning via the p-p chain



# Energy is conserved (and $E=mc^2$), so…




A) then 4 Hydrogen atoms must weigh more than one Helium atom

B) then 4 Hydrogen atoms must weigh less than one Helium atom

# Can estimate the lifetime of the Sun with ease!

$$t_{\text{Sun}} = \frac{\text{amount of fuel}}{\text{rate of consumption}}$$

$$\approx \frac{M_{\text{Sun}} \text{ x } 10\% \text{ x } 0.7\% \text{ x } c^2}{L_{\text{Sun}}}$$

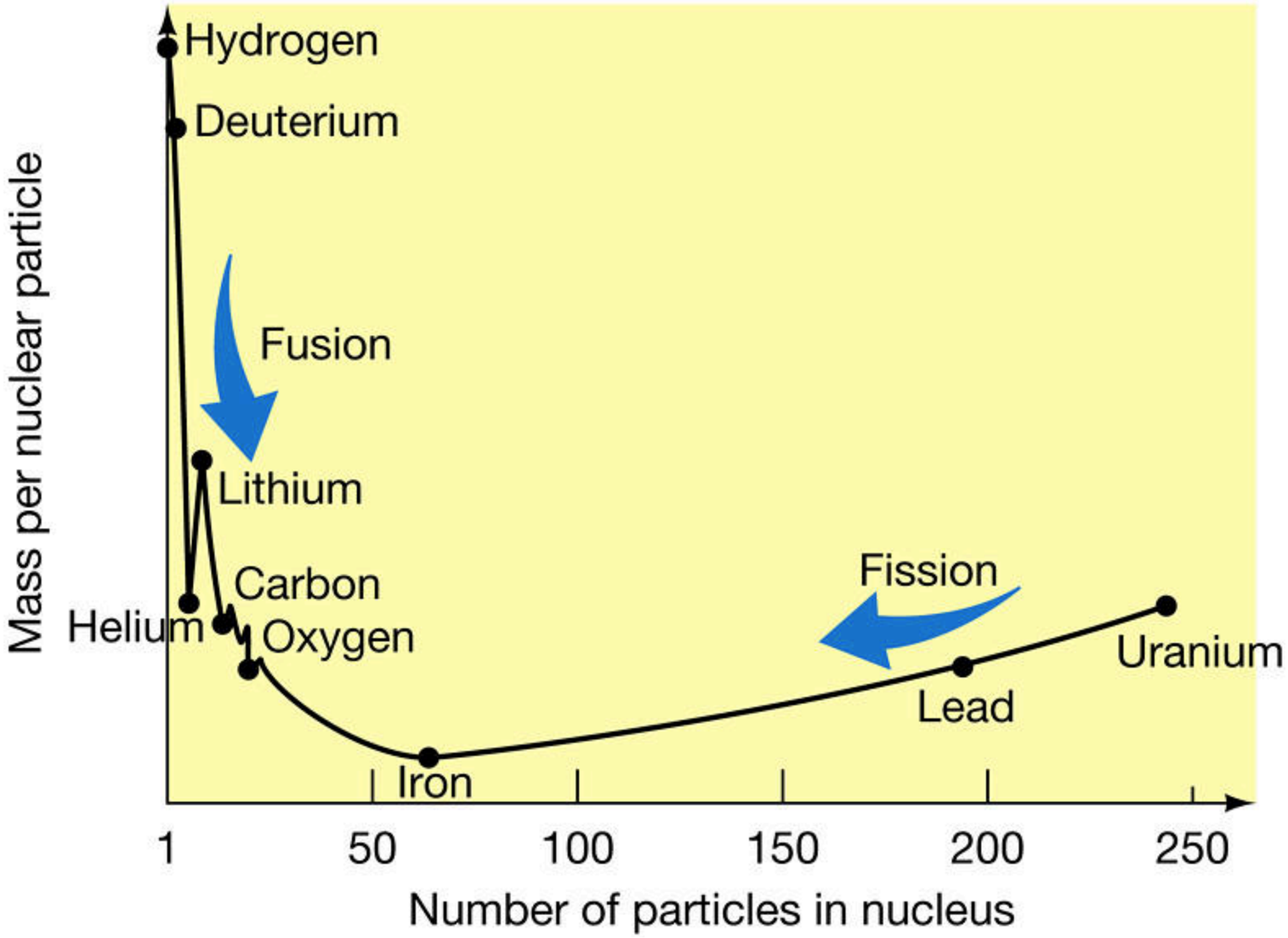
$$\approx \frac{2\text{x}10^{30} \text{ kg x } 0.0007 \text{ x } (3\text{x}10^{8} \text{ m/s})^2}{3.8\text{x}10^{26} \text{ J/s x } (3.1\text{x}10^{7} \text{ s/yr})}$$

~ 10 x $10^9$ years = 10 billion years!

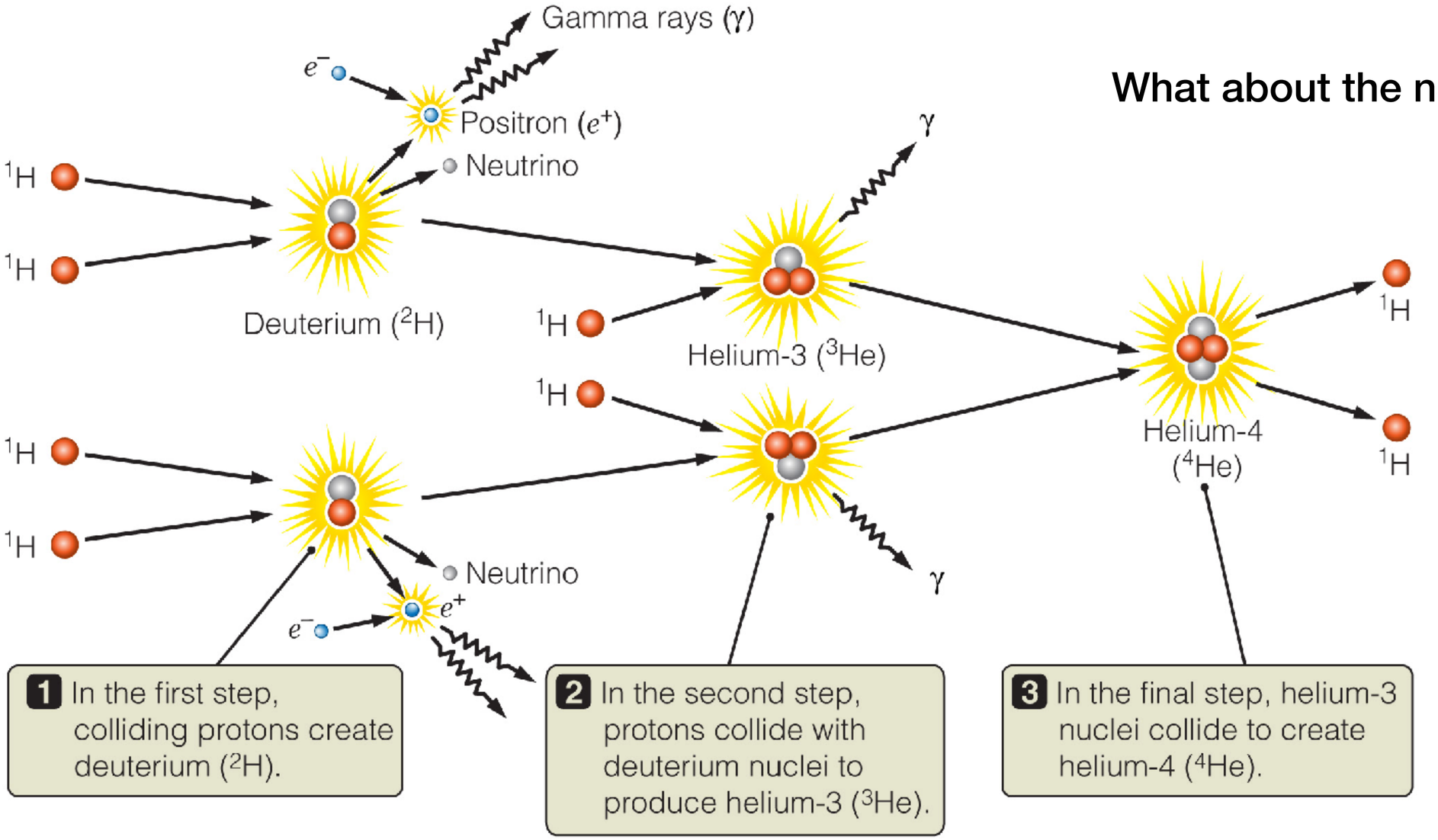
$M_H = 1.6726\text{x}10^{-27}$ kg
$4M_H = 6.6904\text{x}10^{-27}$ kg
$M_{He} = 6.6447\text{x}10^{-27}$ kg

$(4\ M_H - M_{He}) / 4M_H \sim 0.7\%$

# Energy from Mass



# Hydrogen burning via the p-p chain




**What about the neutrinos?**

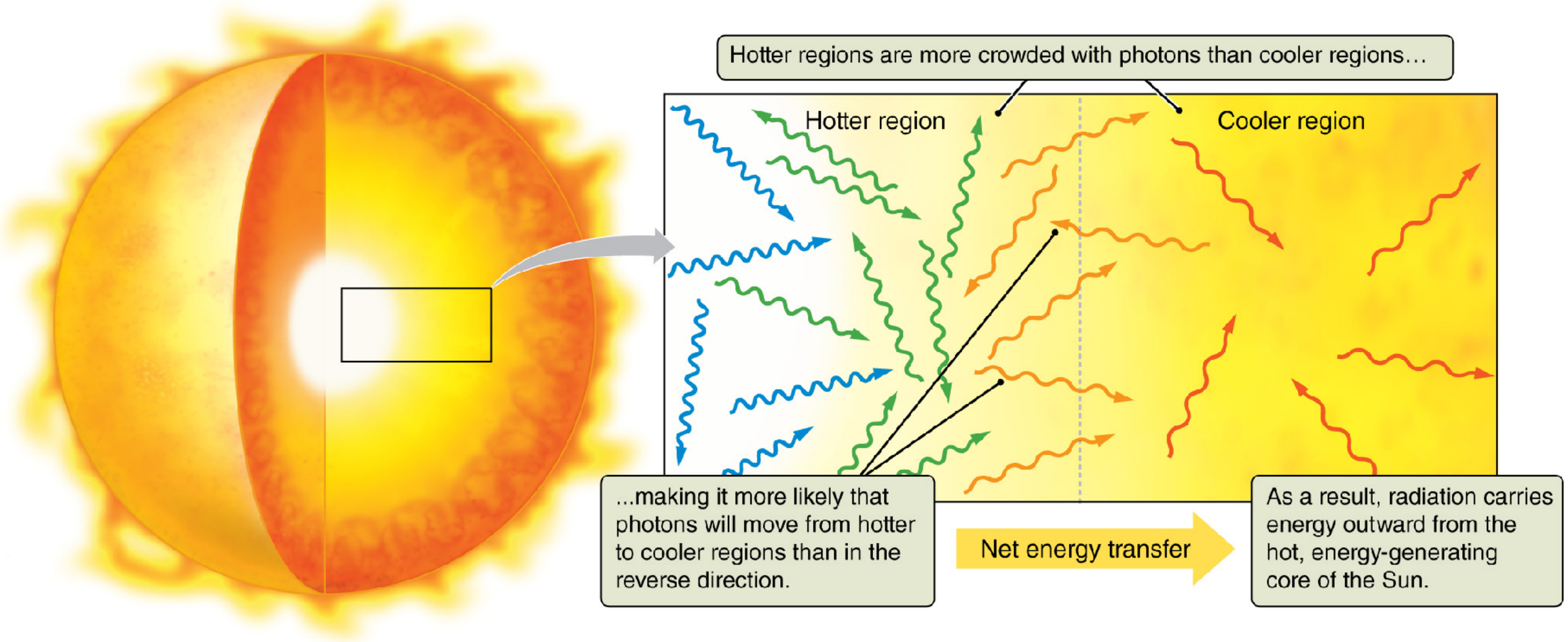
# Solar Neutrino Problem

Homestake mine in South Dakota (credit: Brookhaven National Lab)

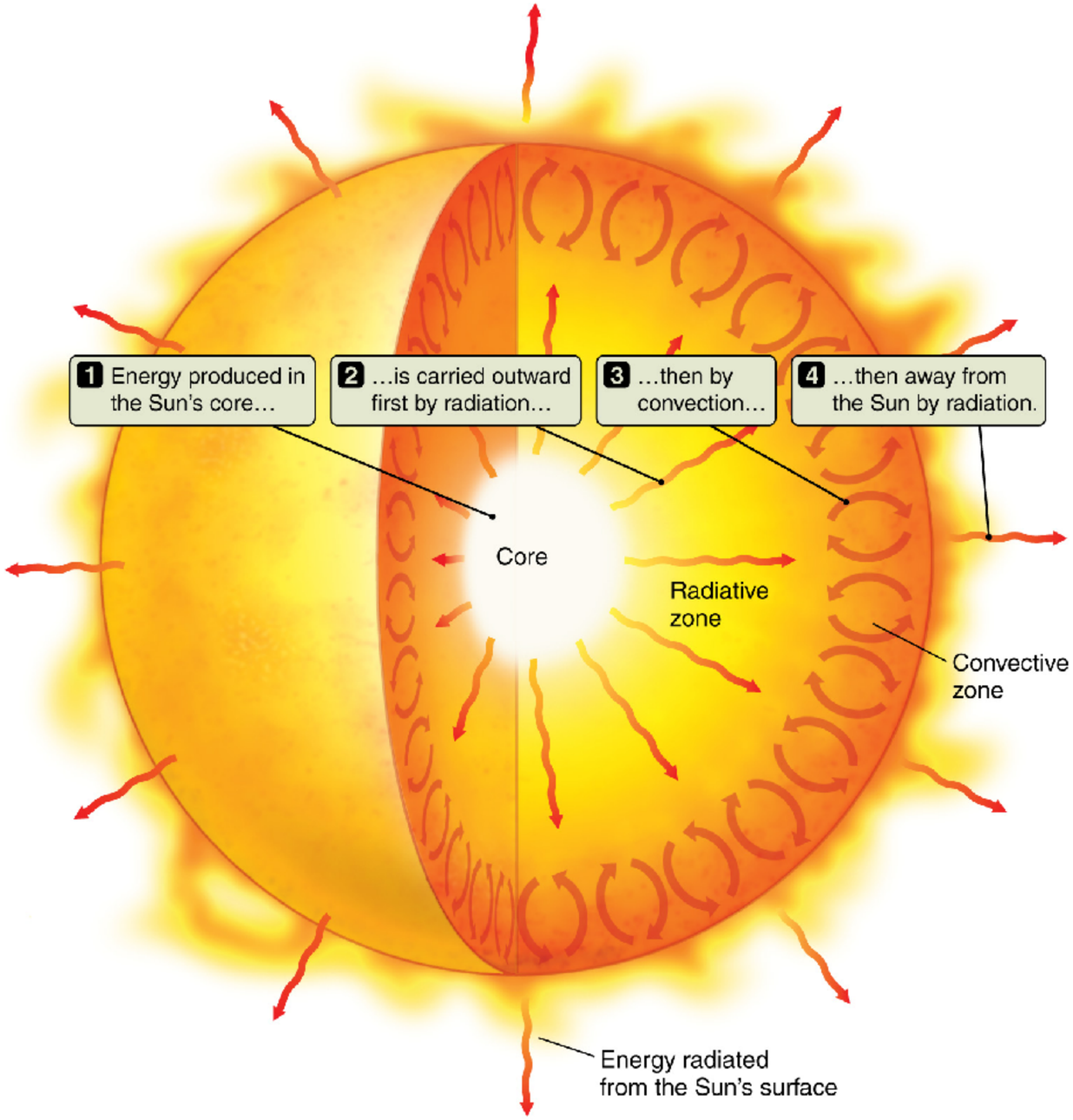
Neutrinos

- Interact with matter very rarely
- Travel (almost) at the speed of light
- ~100 trillion pass through your body every second
- Sun produces only electron neutrinos
- Only 1/3 of the predicted number were detected
- If they have mass, however, they should oscillate between their 3 “flavors” - 2/3 became muon or tau neutrinos on the way here!

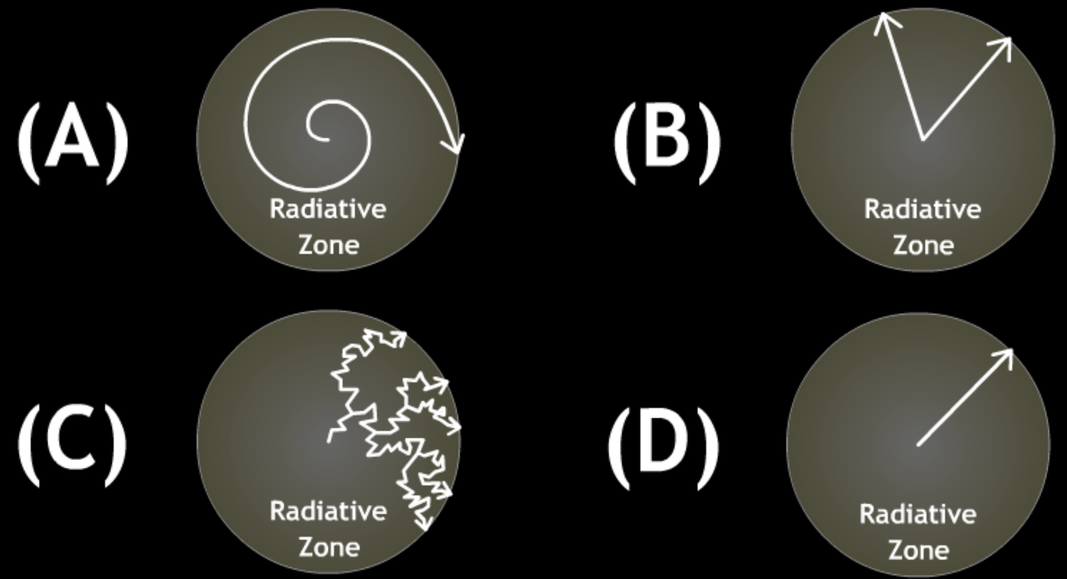
# Photons are created in the core and move outward to the surface



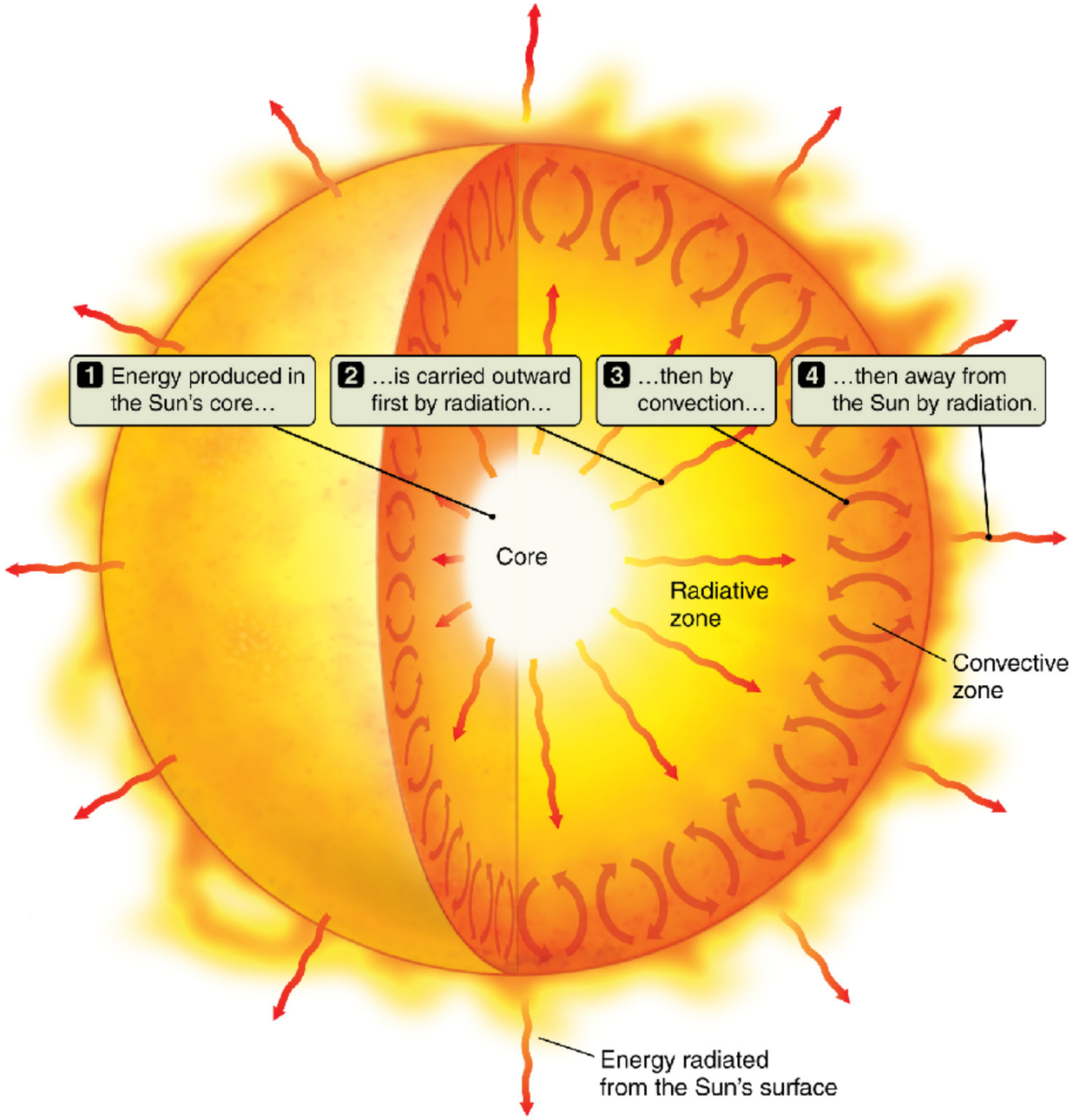
# How light escapes the Sun

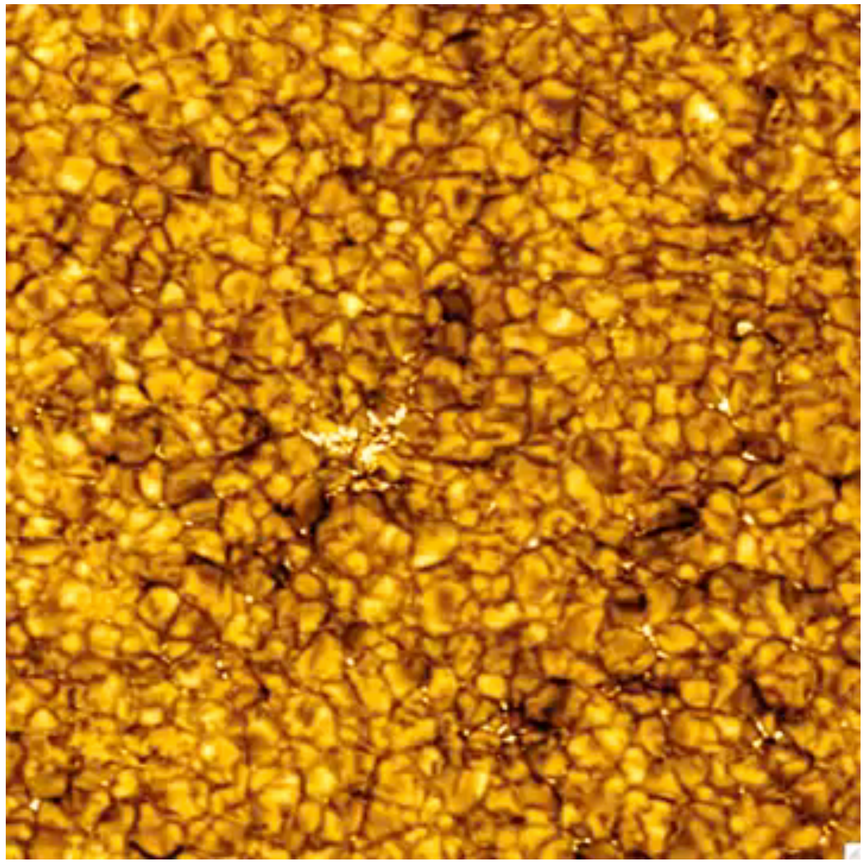



A high-energy photon is produced by a nuclear reaction at the center of the Sun. Which diagram best represents how that photon's energy escapes from the Sun's radiative zone?



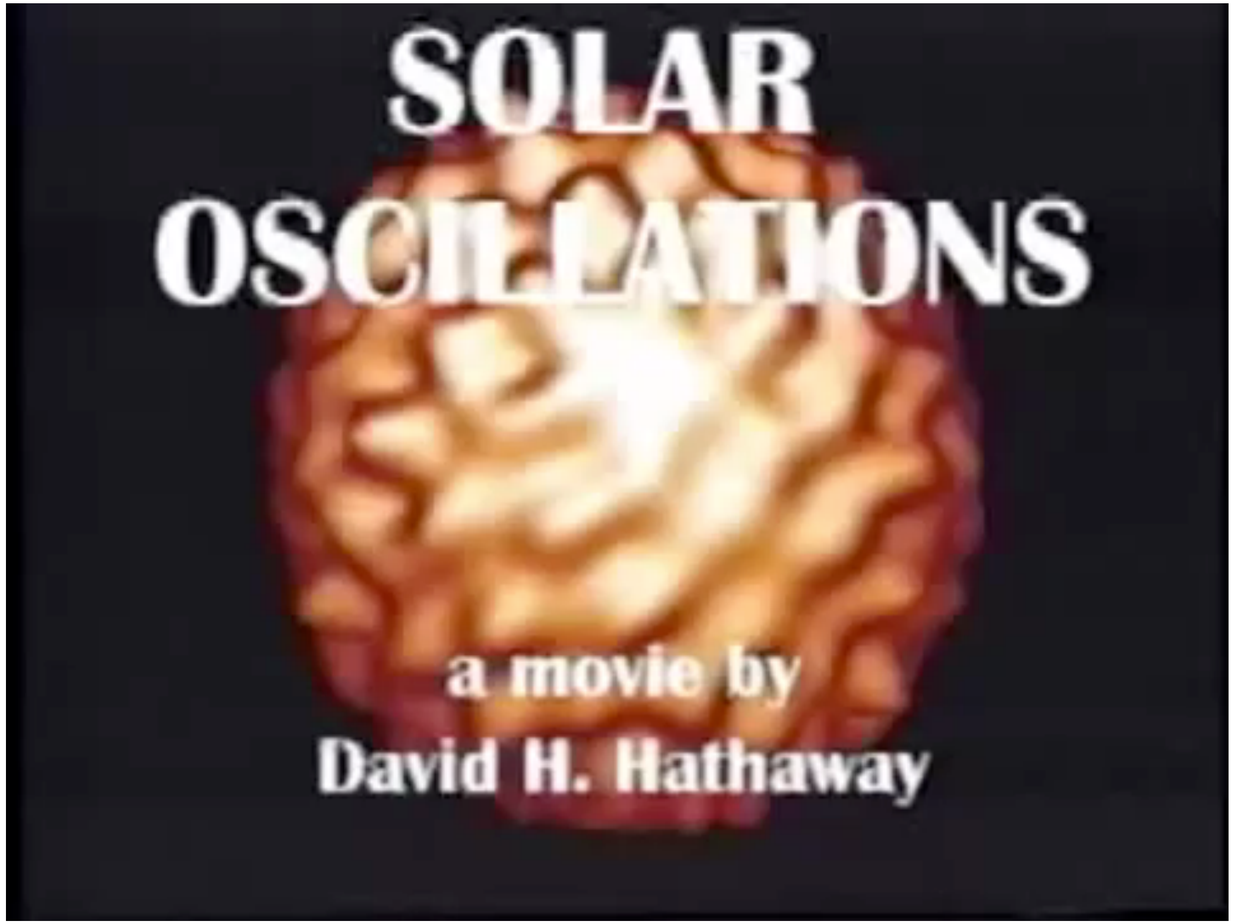
# How light escapes the Sun

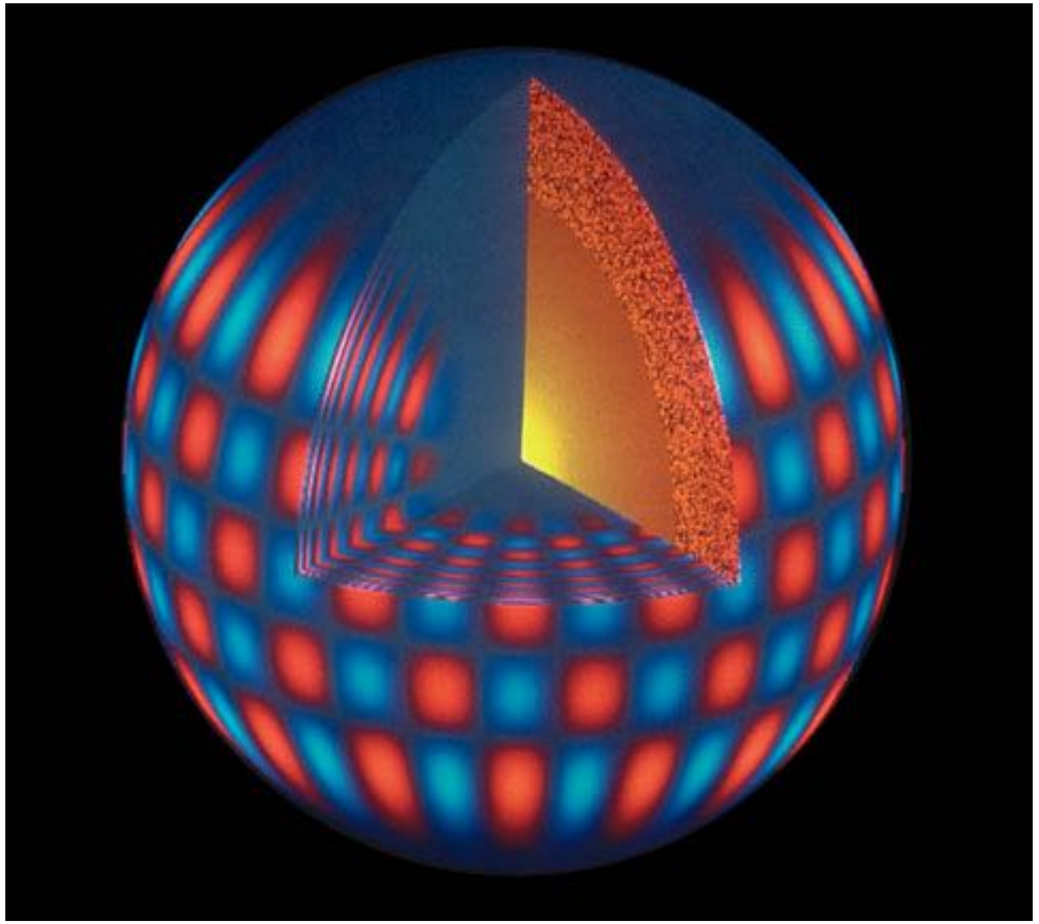


https://www.youtube.com/watch?v=W_Scoj4HqCQ

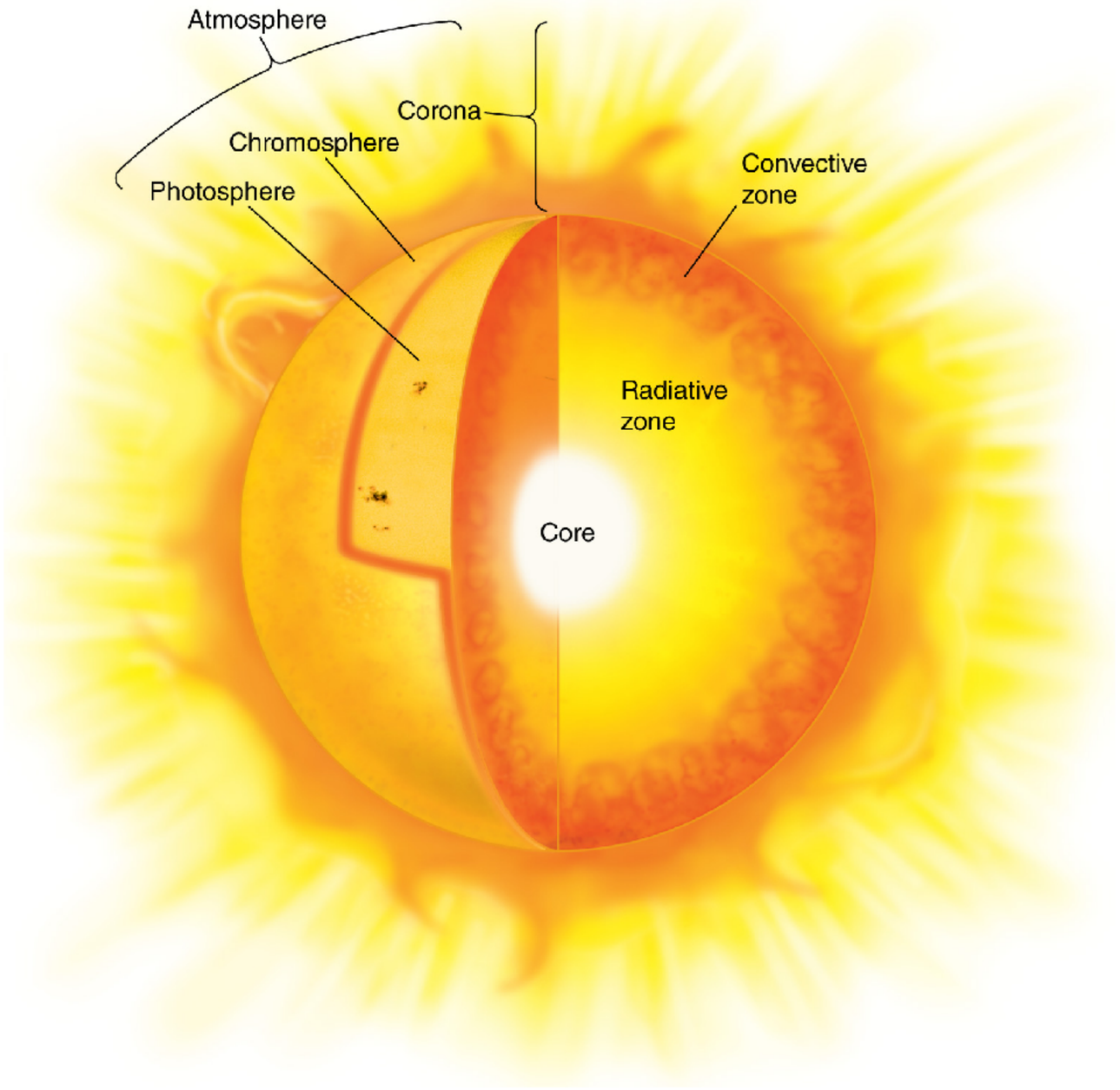
# We learn about the Sun's interior from "sunquakes": helioseismology



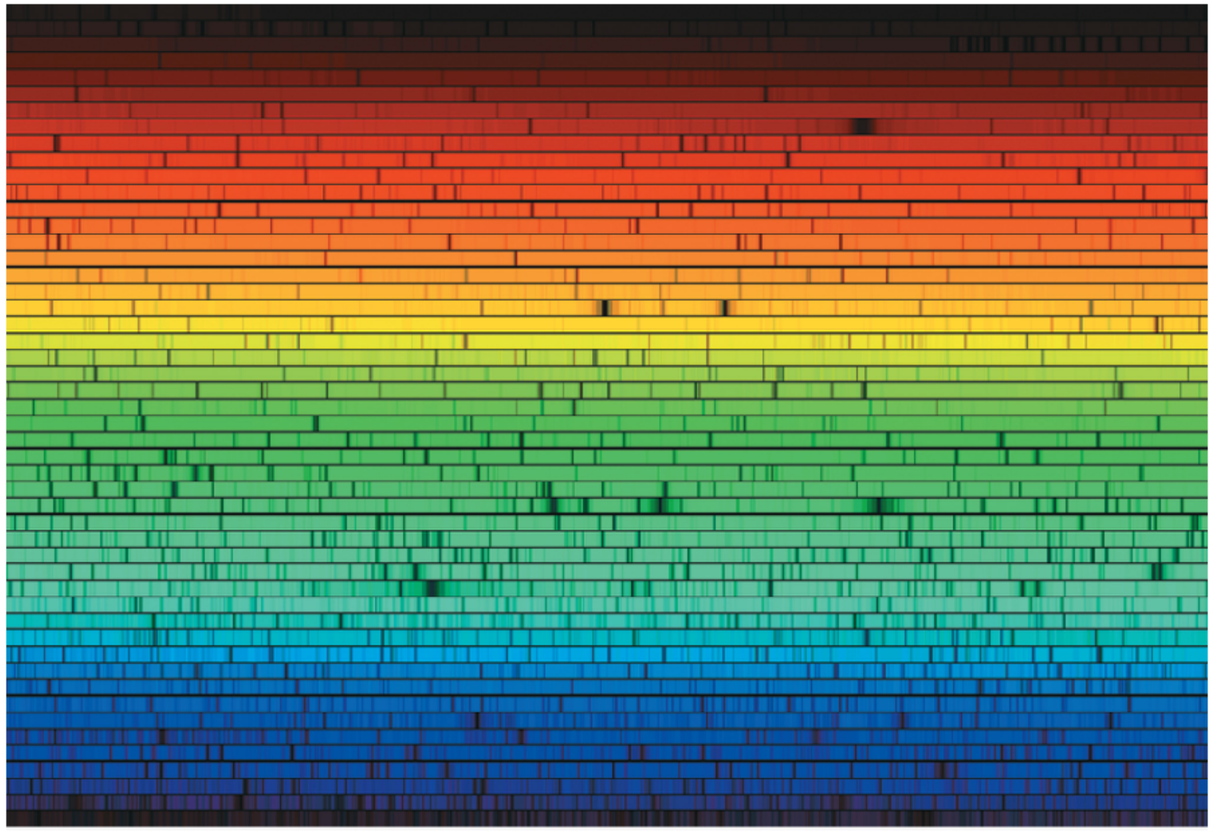



http://www.youtube.com/watch?v=YxUsr4vp3yM

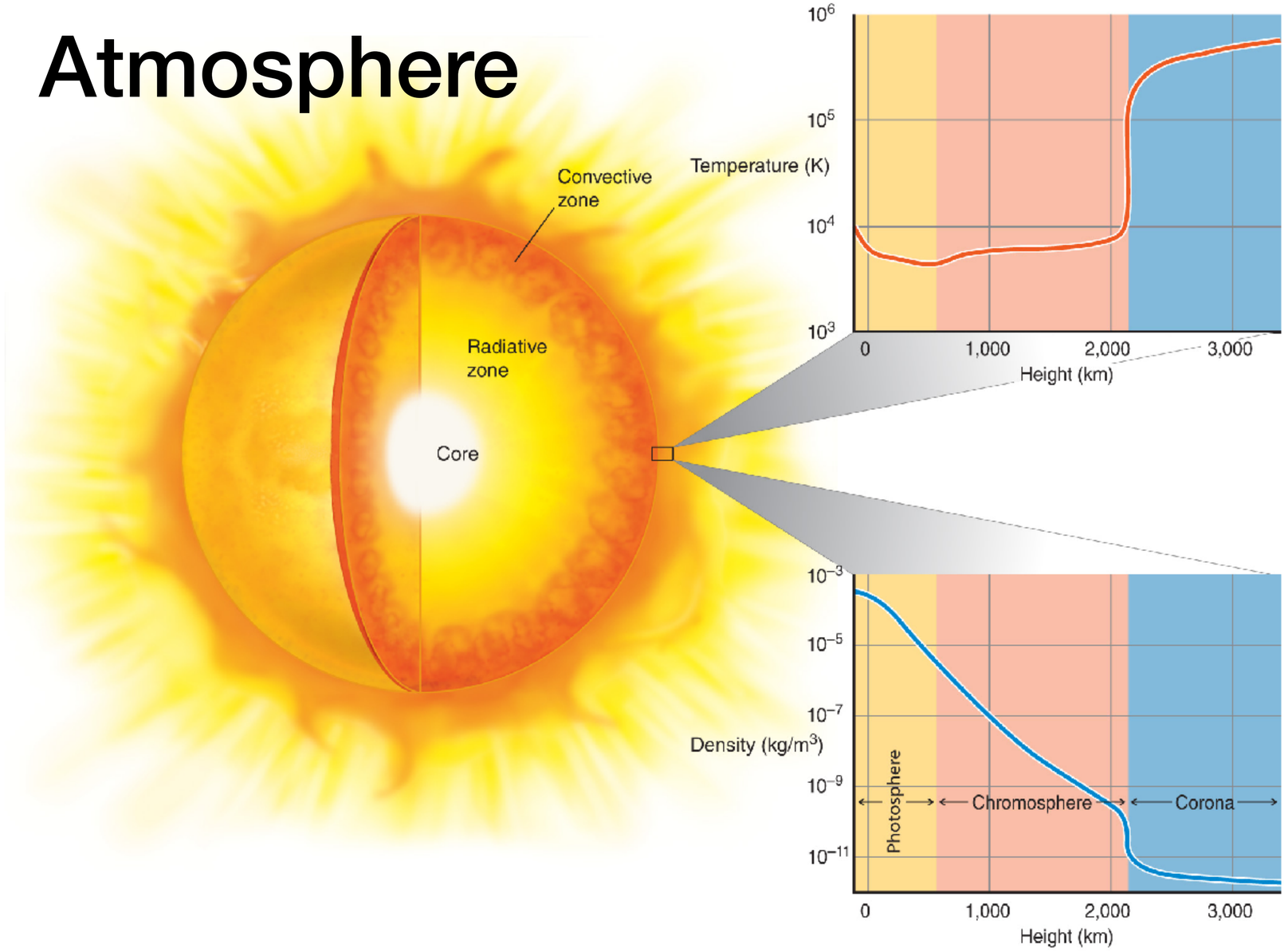
# Zones of the Sun




## High Resolution Solar Spectrum

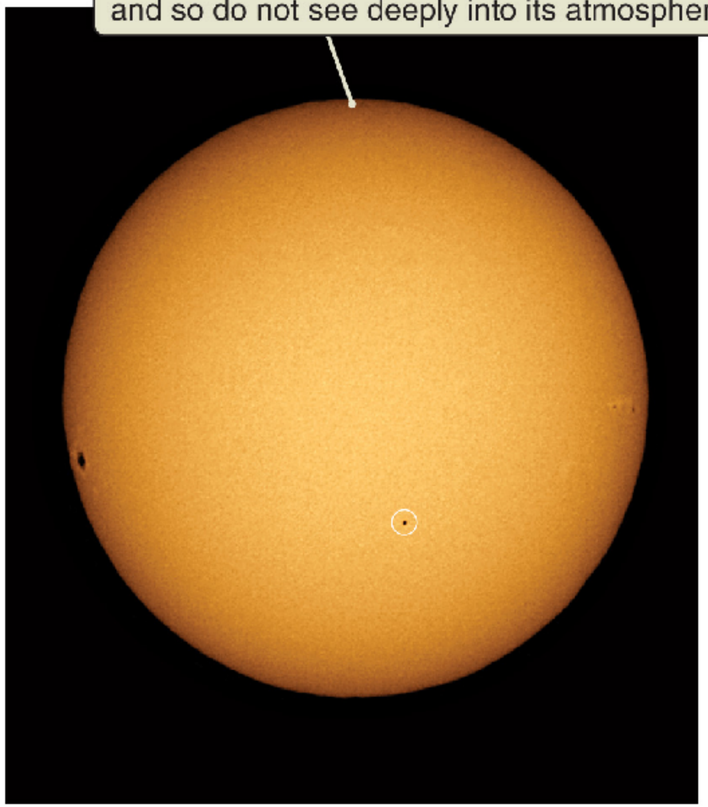


# Sun's Atmosphere

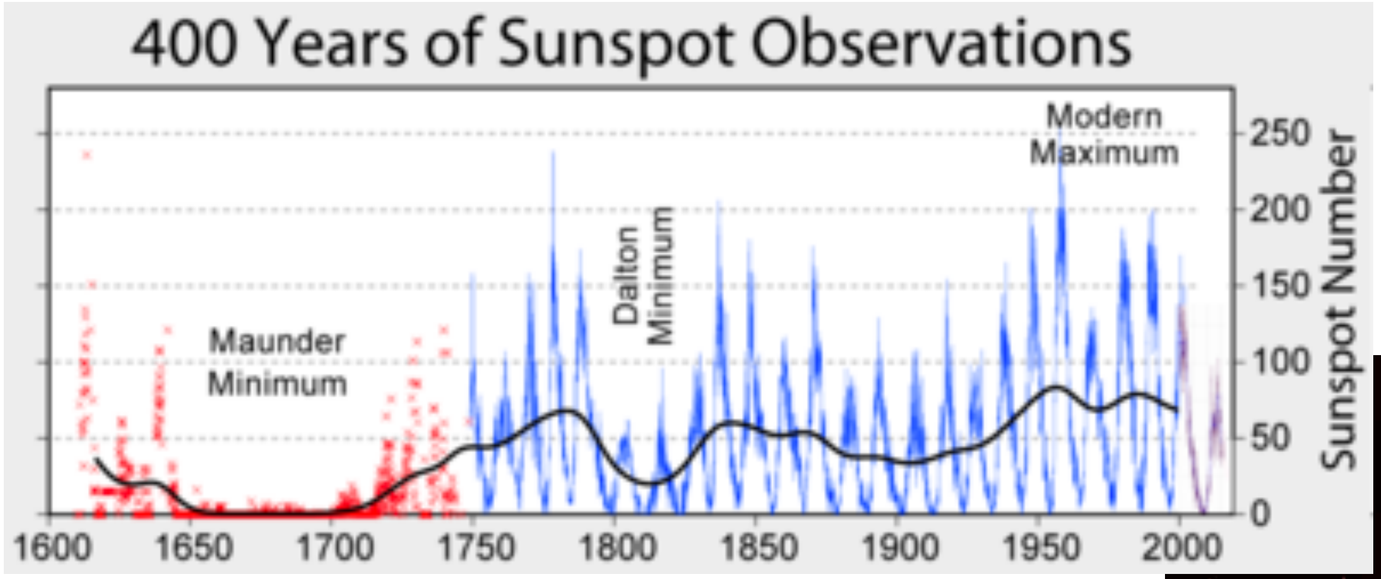


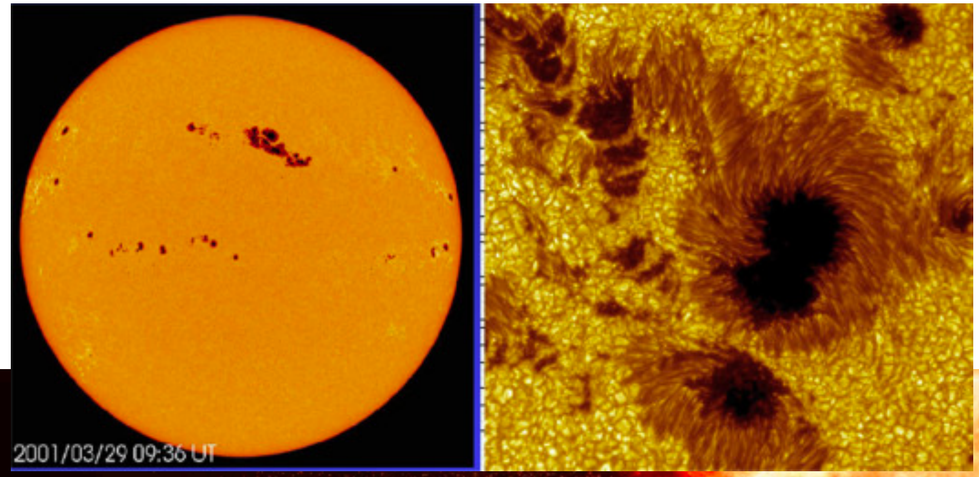

## Limb Darkening

The Sun is "limb darkened." It is dimmer near its edge because near its edge we see the Sun at a steep angle and so do not see deeply into its atmosphere.

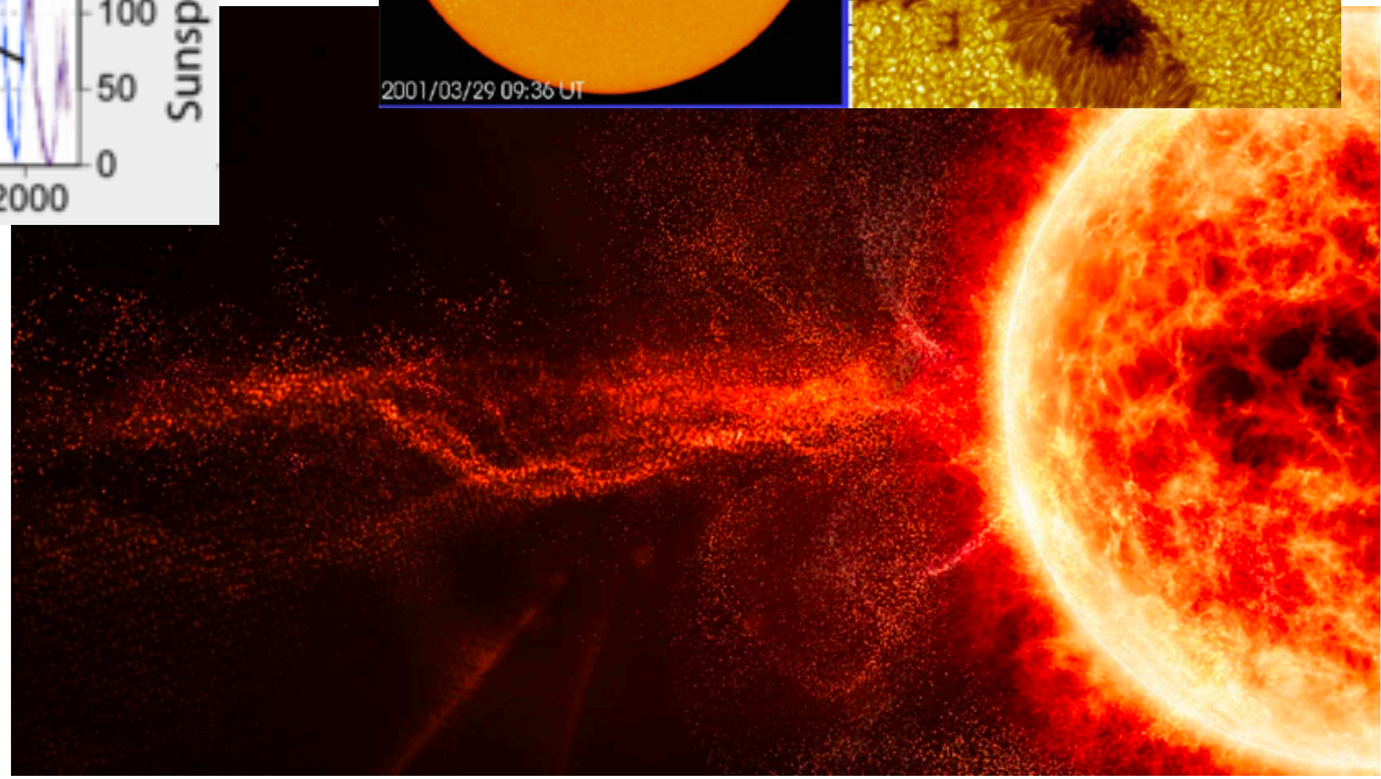


# Sunspots & the Magnetic Sun




11 year cycle caused by magnetic fields inside the Sun



<u>Coronal Mass Ejections</u>: energetic particles escape in the solar wind when magnetic loops “reconnect”