Week 7

The Sun as a star

Begin thinking about stars

Wednesday, Nov. 2

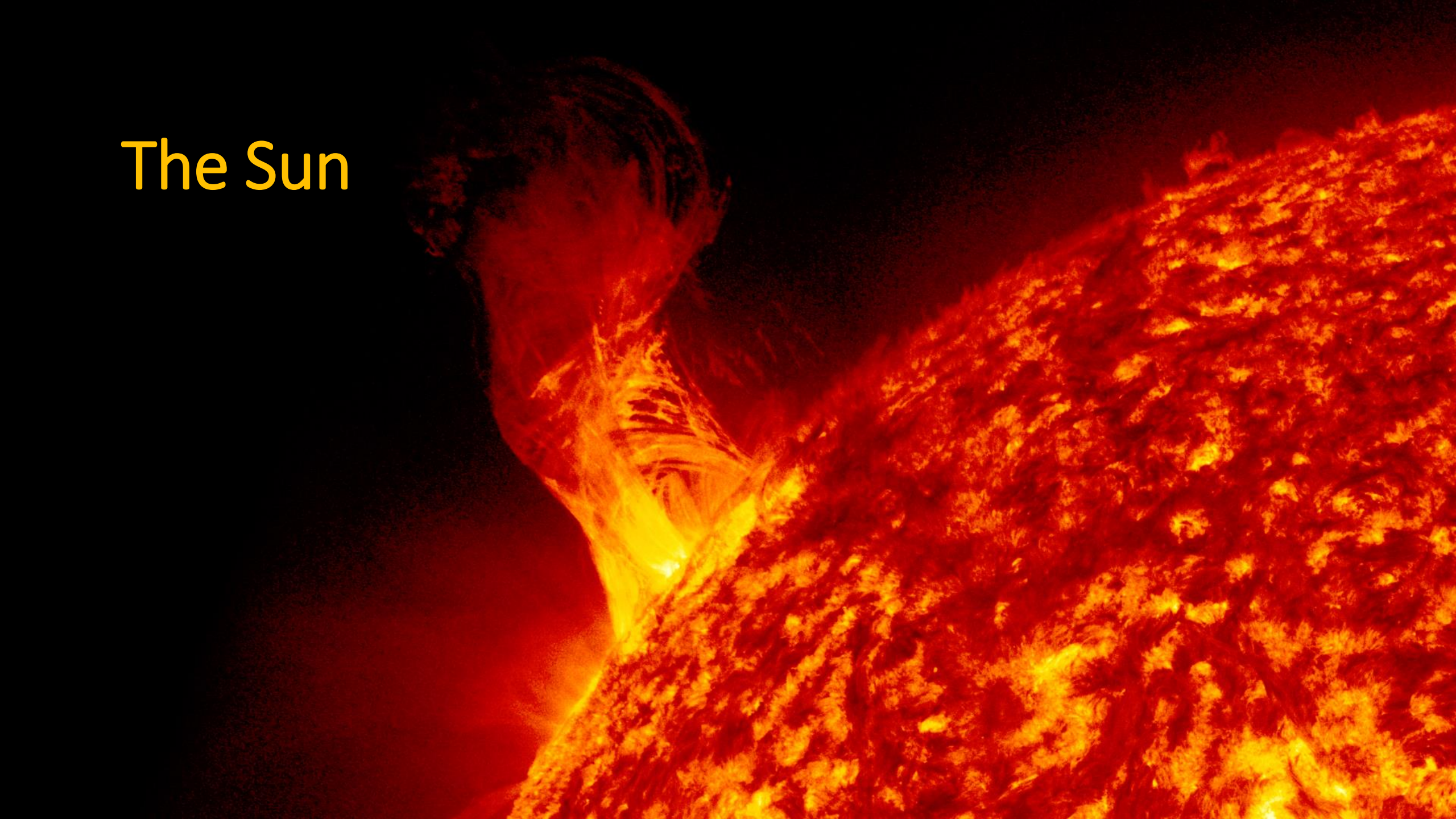
Today….

- Our Sun

  <u>Learning objectives: Explain</u>

  - Why we study the Sun
  - How we know things about the Sun
  - What makes the Sun different from other bodies in our solar system
  - The inner workings of the Sun

The Sun

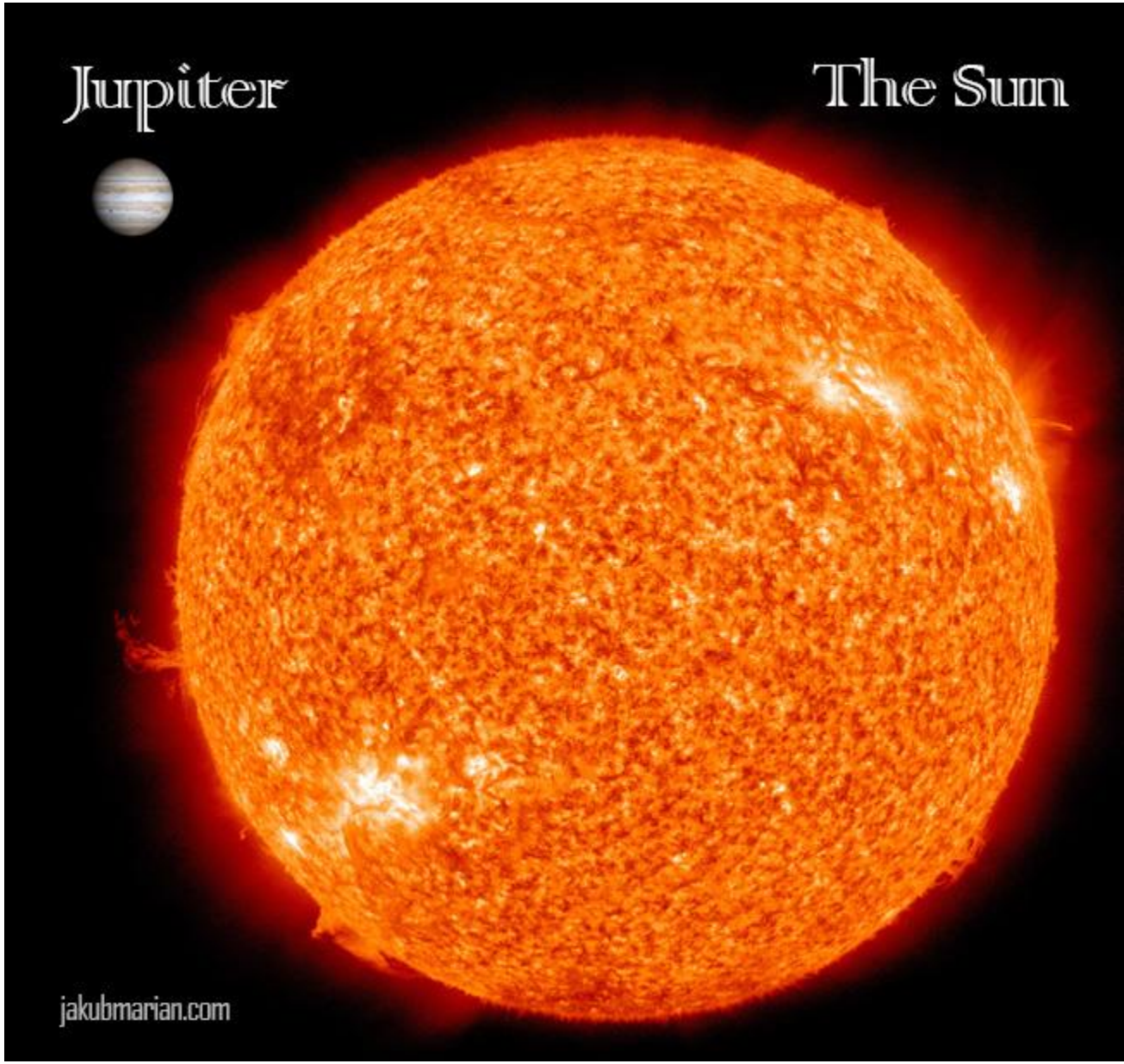


Why study the Sun?

- It’s there
- It makes up most of the mass of the solar system
- It provides the energy to support life on Earth
- It is made of matter that behaves in ways unlike what we find on Earth
- It is a window into understanding other stars

What is different about the Sun compared to other solar system objects?

- Generates energy
- **<u>Size</u>**. Much more massive than Jupiter or other planets

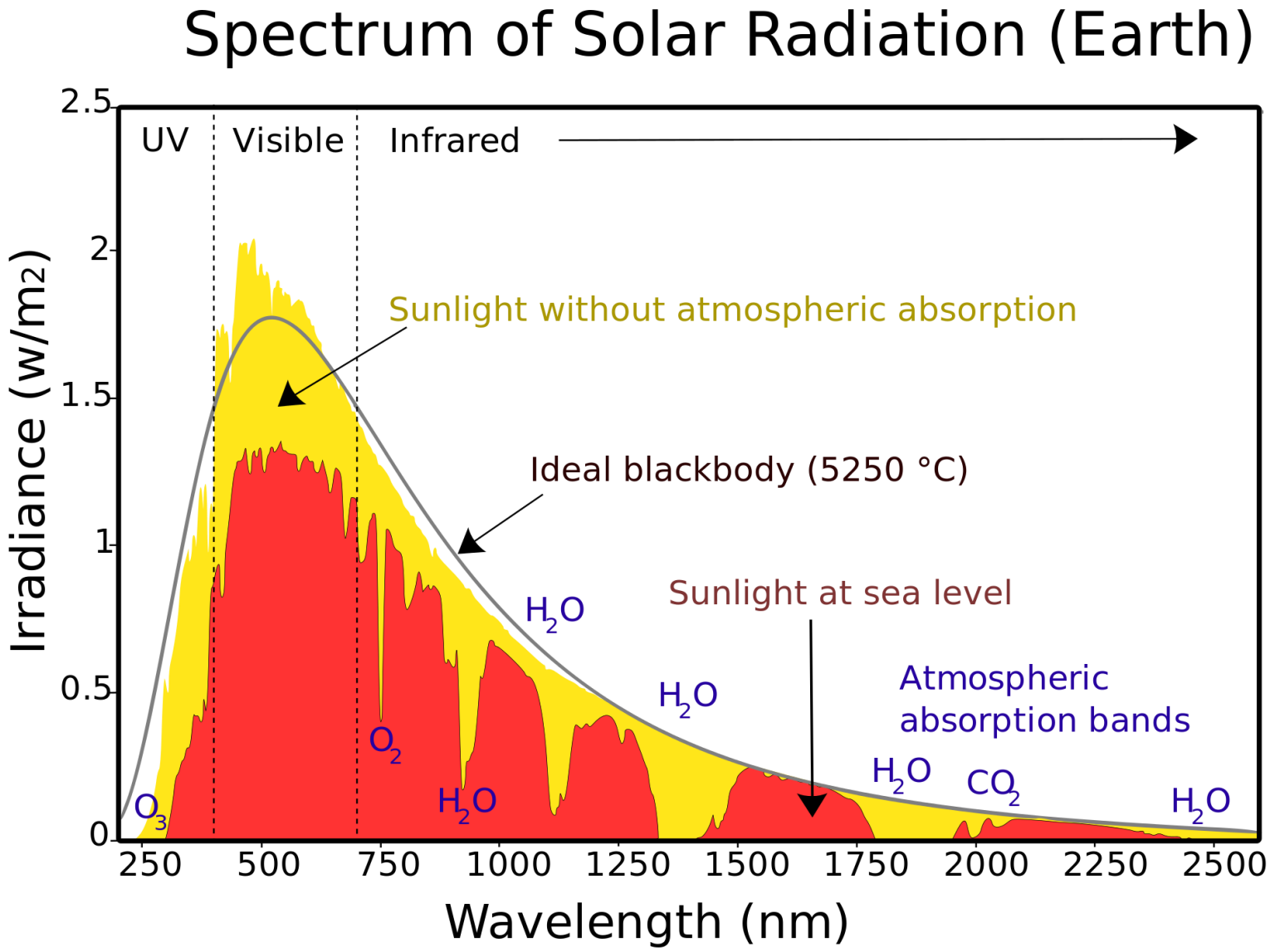


Fundamental Questions

What is the temperature of the Sun?

- Calculate from blackbody curve

λ_{max} T = 2898 micron K



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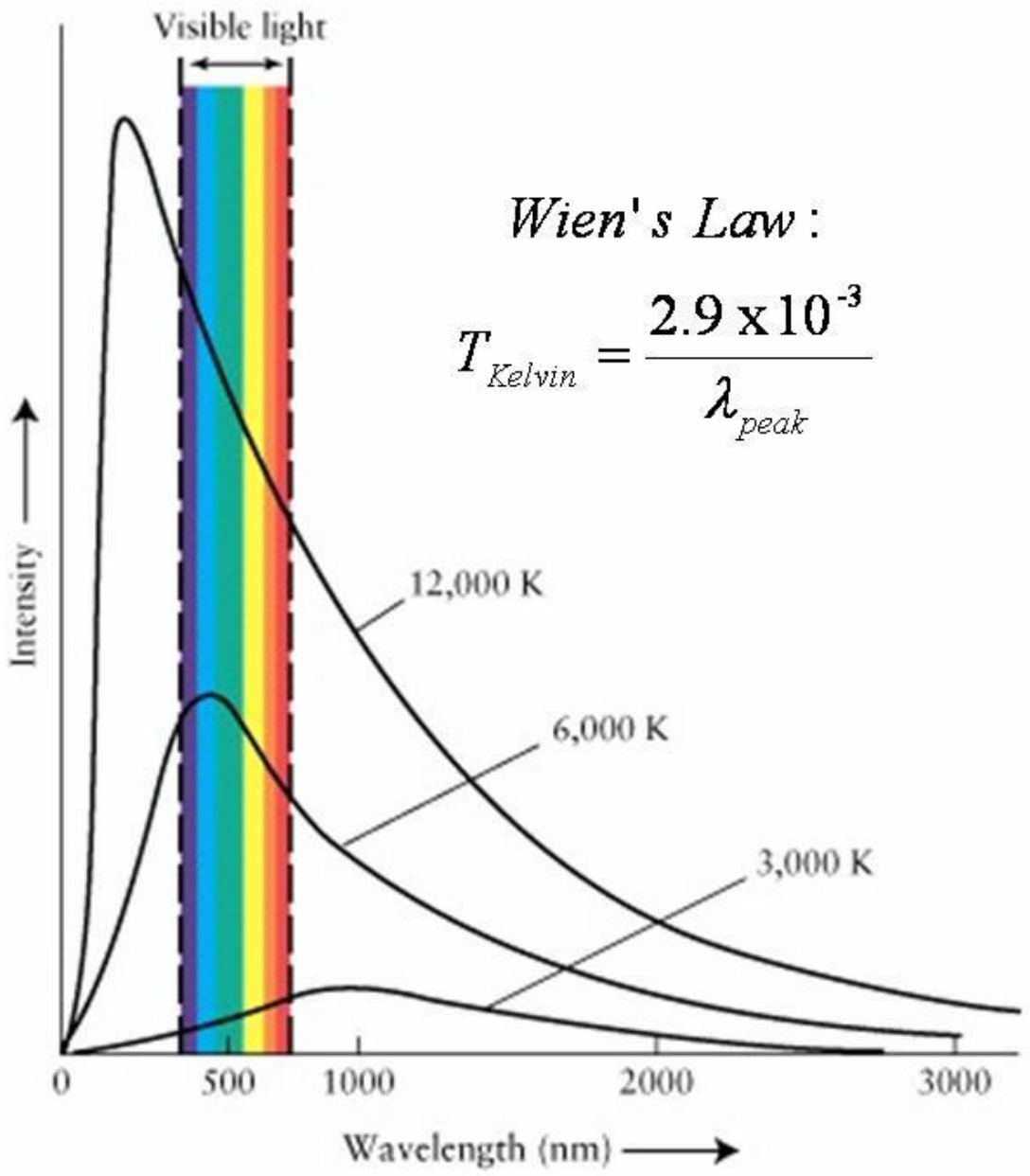
λ_{max} T = 2898 micron K

T = 2898 micron K/ λ_{max}



$$Wien's\ Law: \quad T_{Kelvin} = \frac{2.9 \times 10^{-3}}{\lambda_{peak}}$$

Fundamental Questions

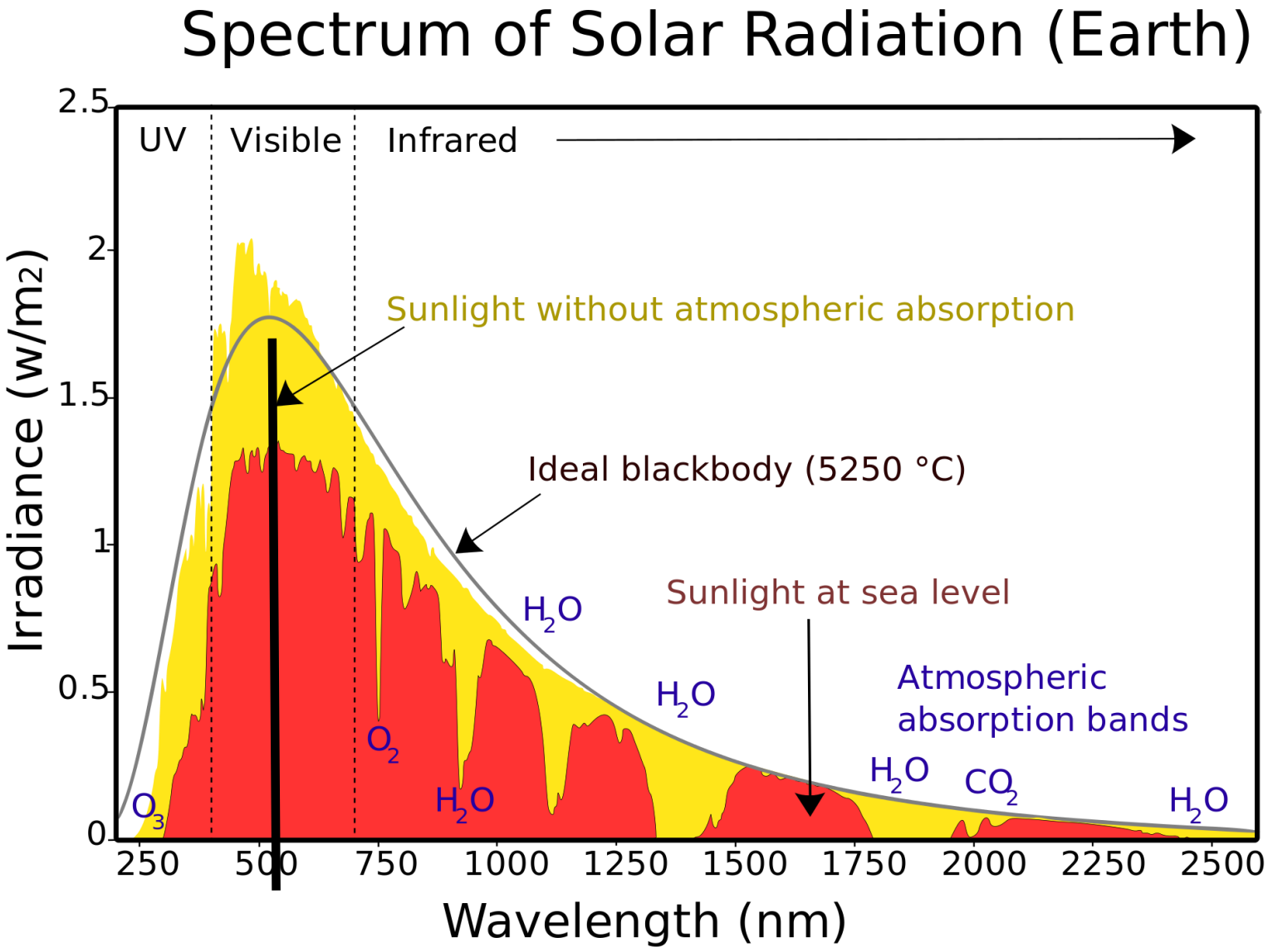
What is the temperature of the Sun?

- Calculate from blackbody curve

T = 2898 μm K/ λ_{max}

T = 2898 μm K/0.52 μm

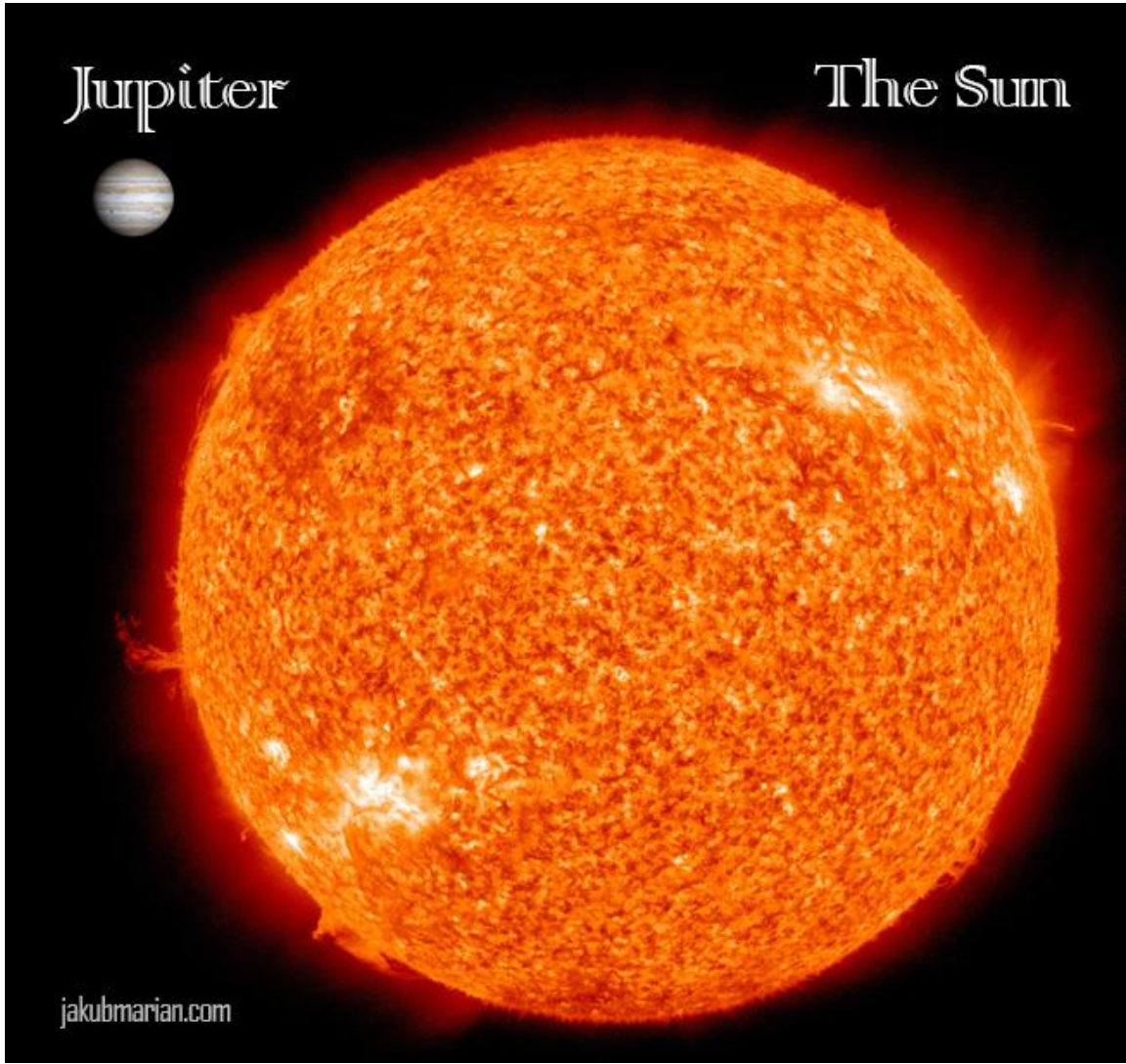
T = 5573 K



520 nm = 0.52 μm

T_{sun} = 5500 K vs. $T_{jupiter}$ = 130 K

- What does this tell us?

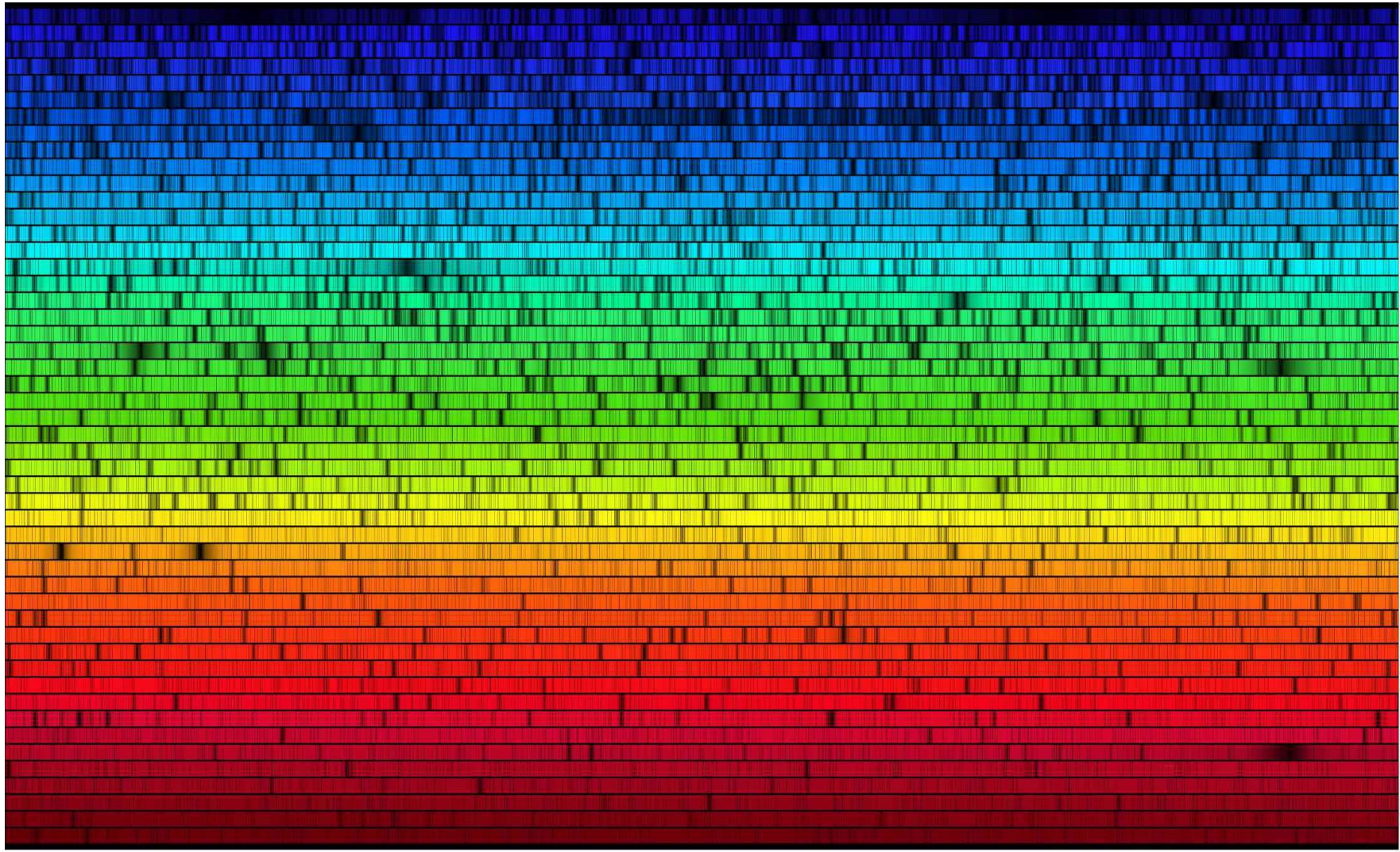


Fundamental Questions

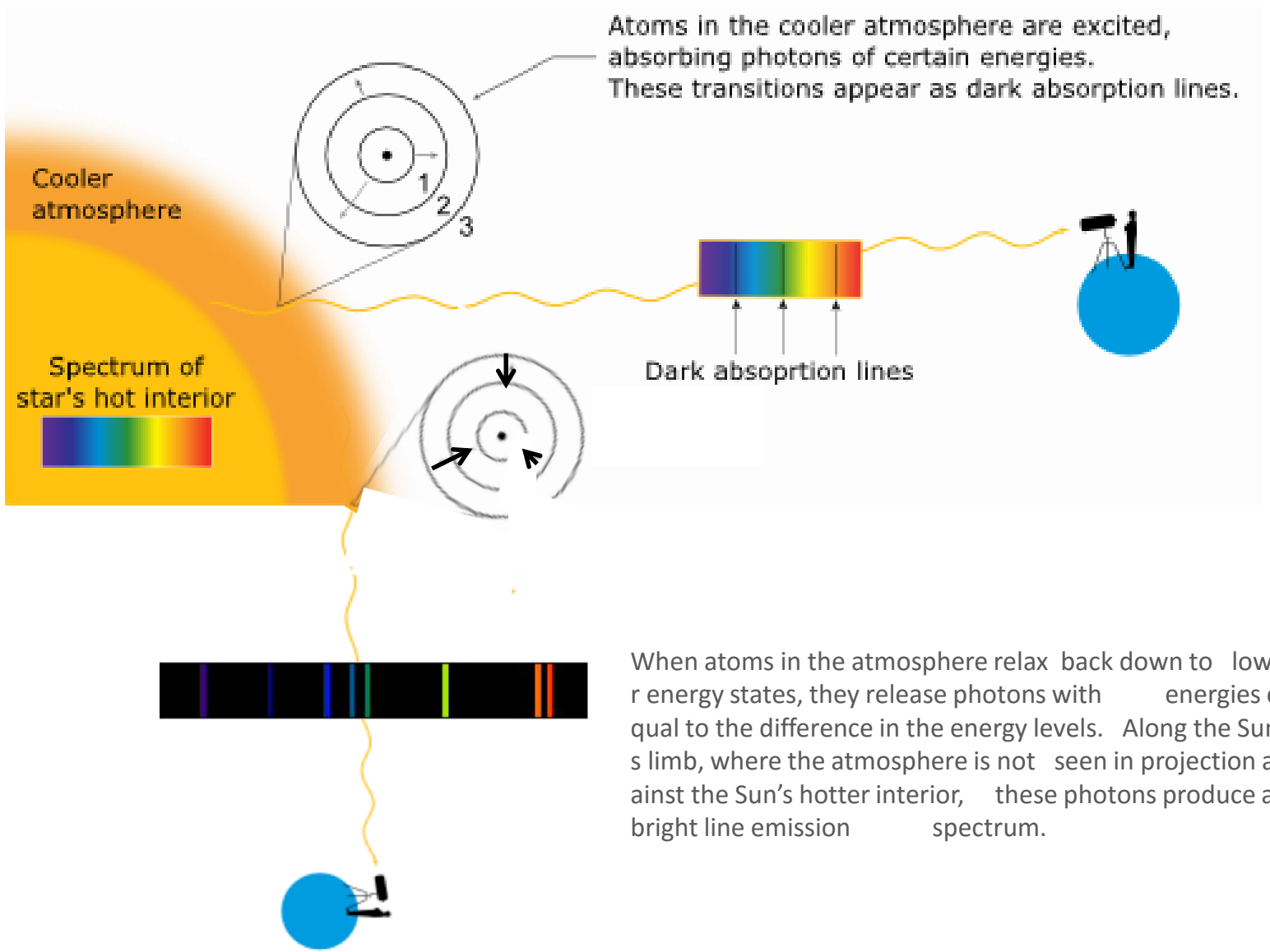
What is the Sun made of?

- Spectra

Absorption of continuous spectrum by elements

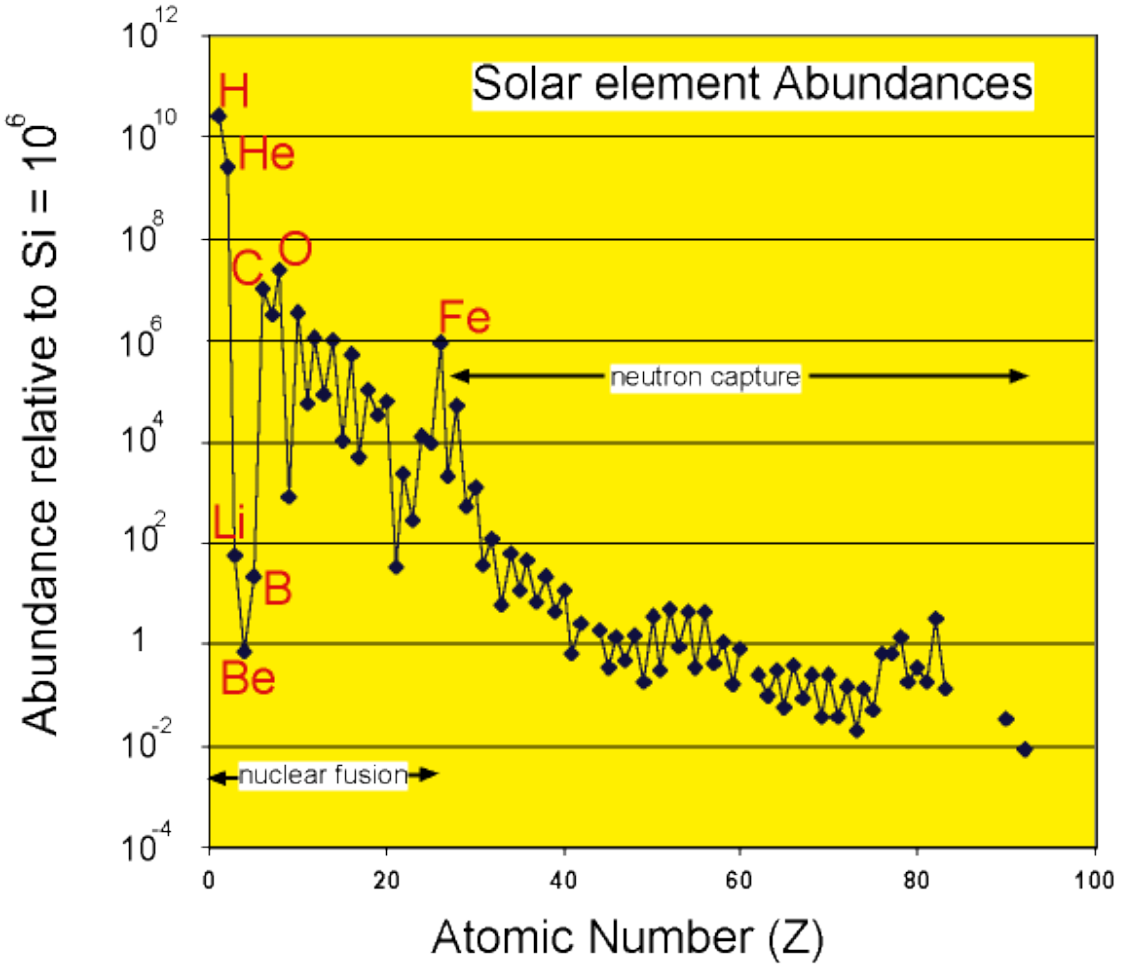


The presence of Hydrogen *emission* along the solar limb is also consist ent with this picture: these are the photons released when excited elec trons drop back down to lower energy levels.

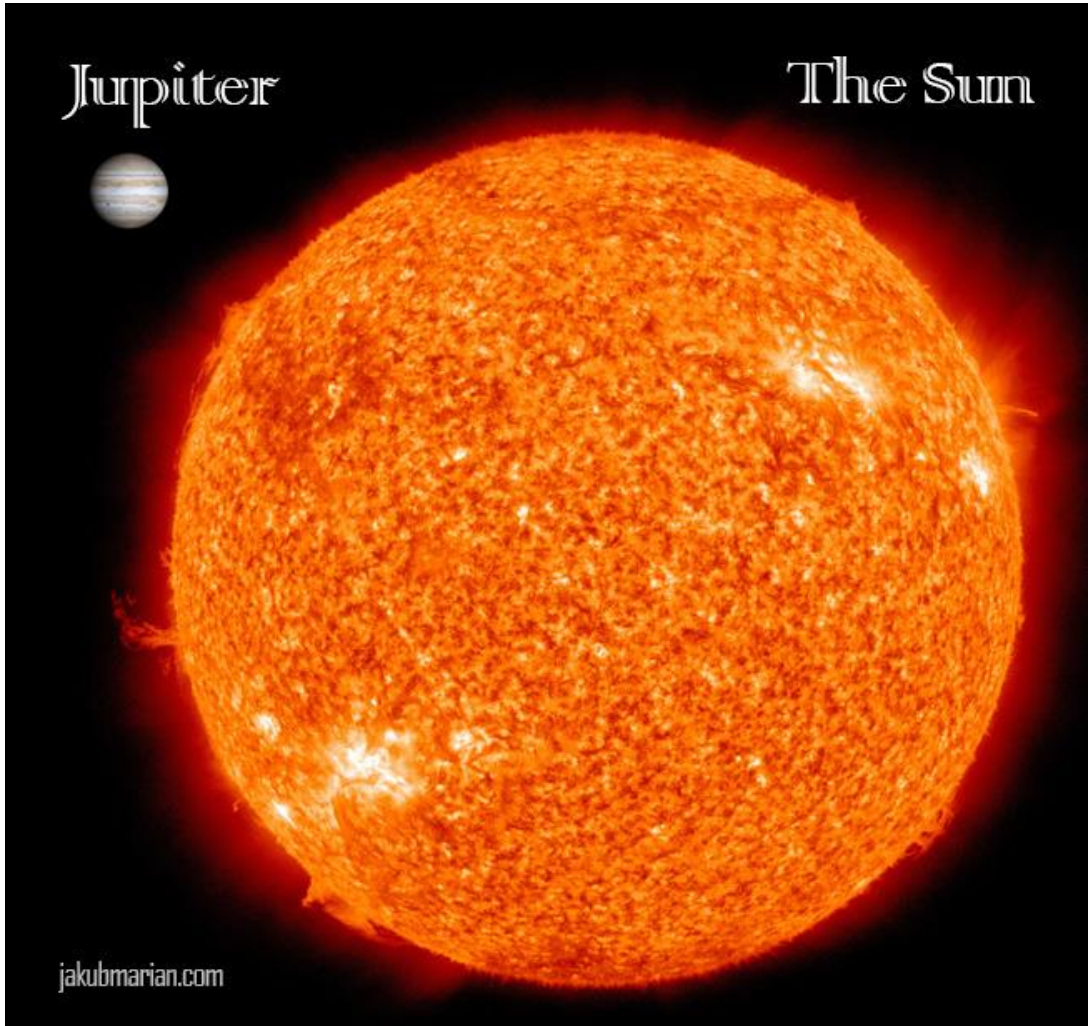


When atoms in the atmosphere relax back down to lowe r energy states, they release photons with energies e qual to the difference in the energy levels. Along the Sun' s limb, where the atmosphere is not seen in projection ag ainst the Sun's hotter interior, these photons produce a bright line emission spectrum.

We find that the Sun is composed mainly of Hydrogen (+ some helium)



Jupiter also composed mainly of Hydrogen (+ some helium)



What best explains the similar compositions of the Sun and Jupiter?

A. They formed from the same source material.

B. They have followed similar evolution since they formed.

C. Jupiter spun off from the Sun and is a remnant piece of the Sun.

D. It is mostly chance that they would have the same composition.

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The Sun and Jupiter are made of the same stuff but they are radically different in temperature and size.

What is the best explanation of this?

A. The Sun is so large because it is so hot.

B. The Sun is so hot because it is so large.

C. The Sun must contain material in its interior that is very different from Jupiter.

D. There is no relationship between size and temperature.

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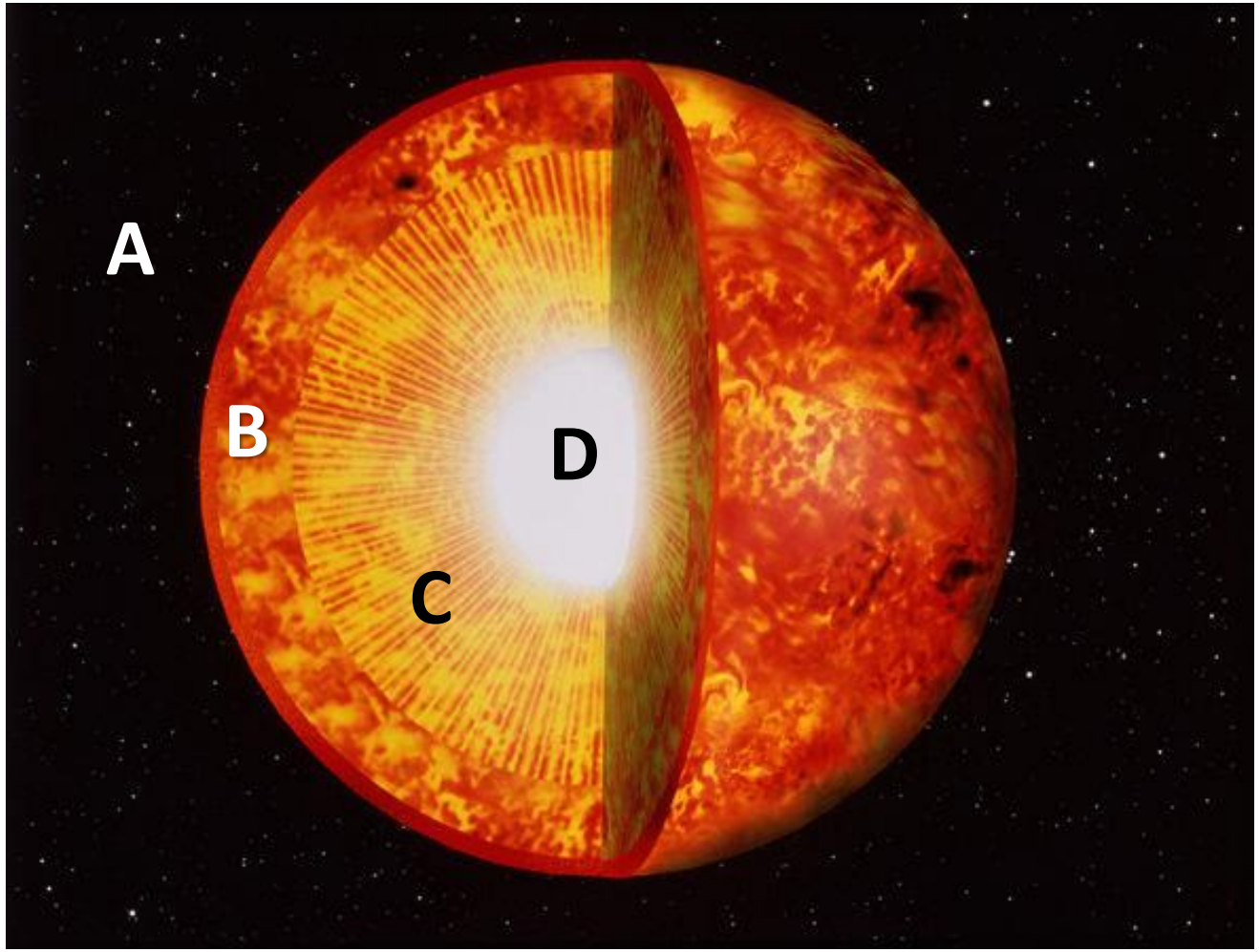
Why does size matter?

- Where is the highest density?

  A, B, C, D?



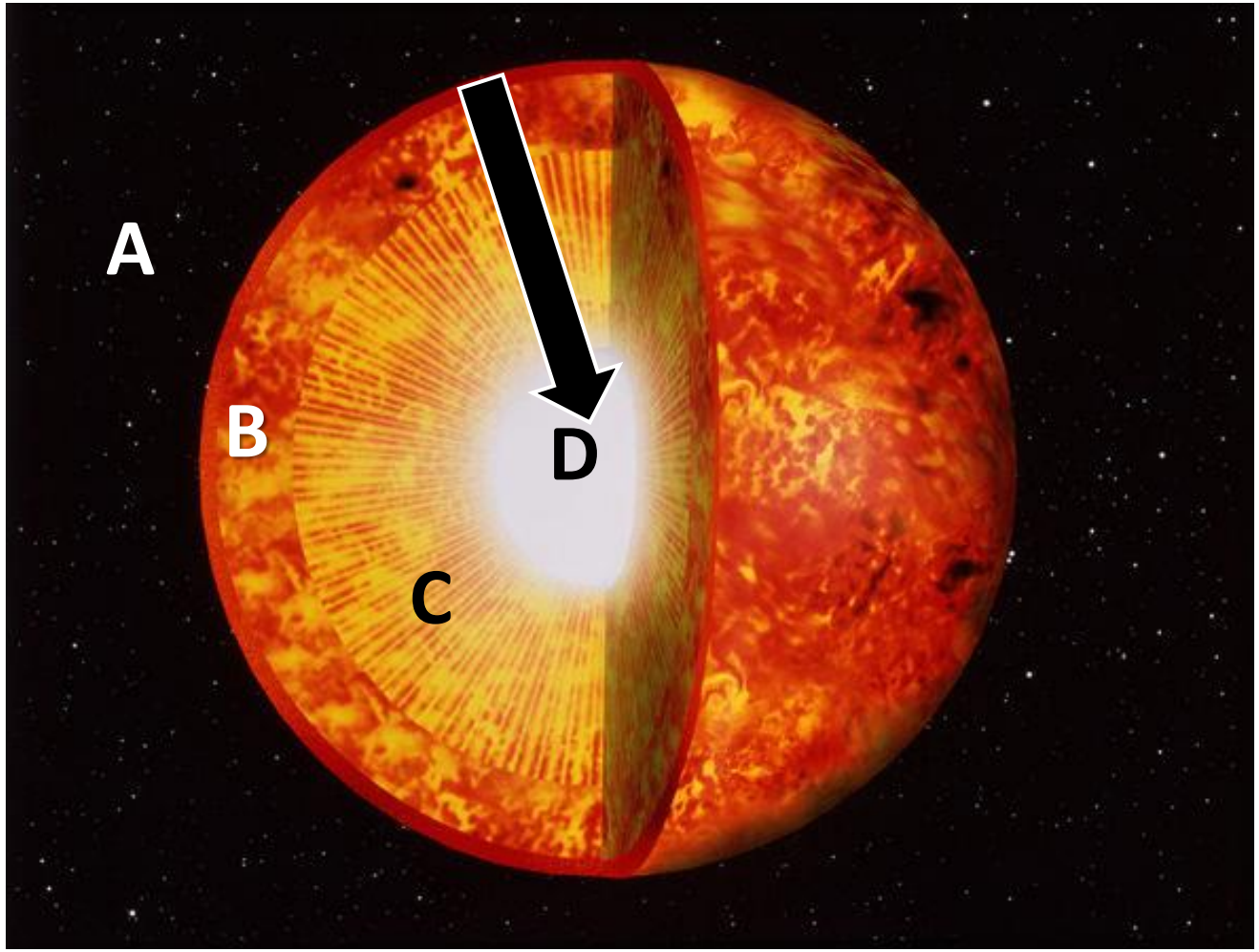
Why does size matter?

- Where is the highest density?

  A, B, C, **D**?

Gravity is pulling all the material above toward the center of the Sun

- Bigger size means more matter.
- More matter means stronger gravitational pull.
- More gravity means higher density and pressure.

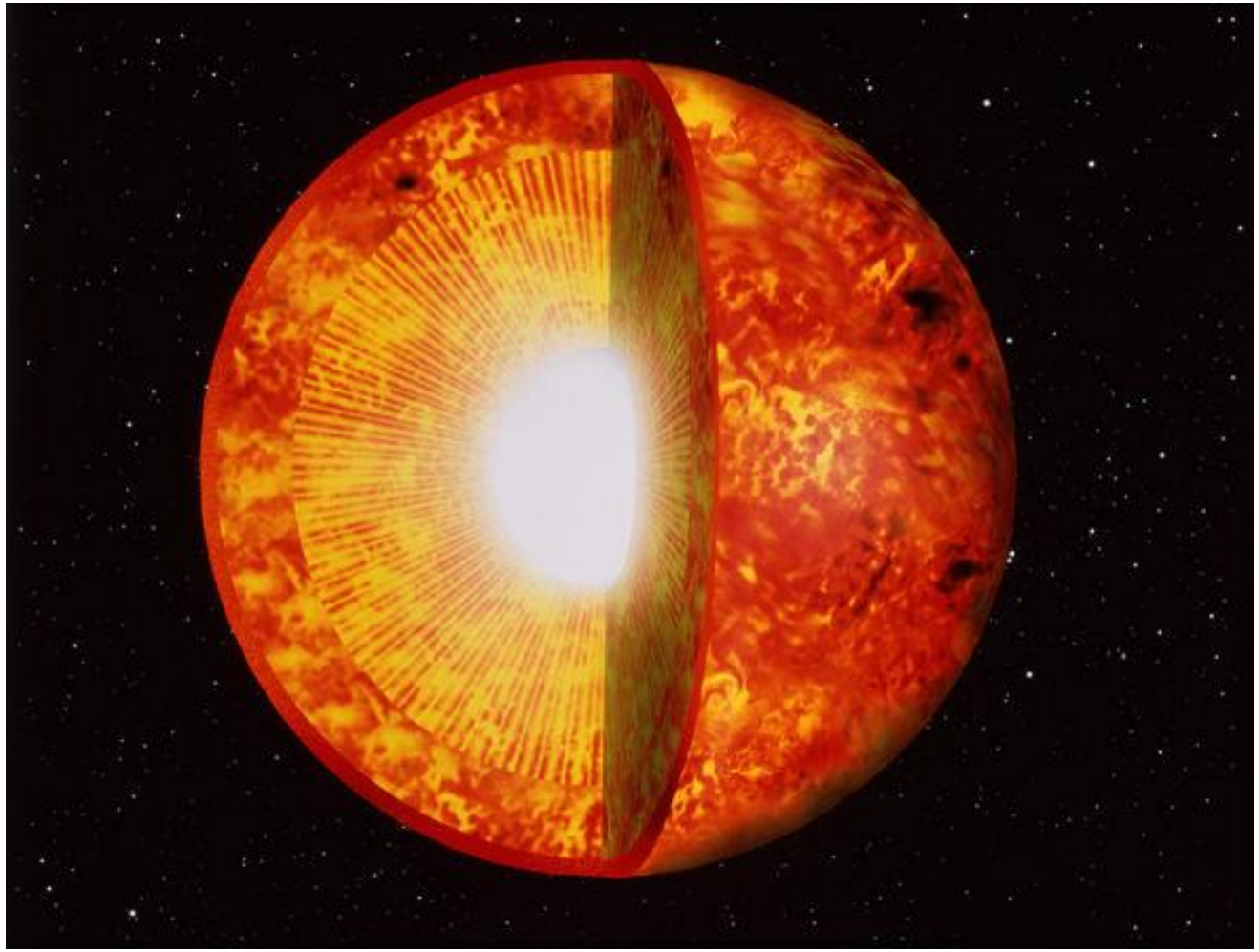


Inside the Sun

- Huge pressure (>200 billion atmospheres)
- Pressure causes immense density (150,000 kg/m^3)
- Temperature is **hot** from heat of formation

All this leads to…..

Thermonuclear Fusion!

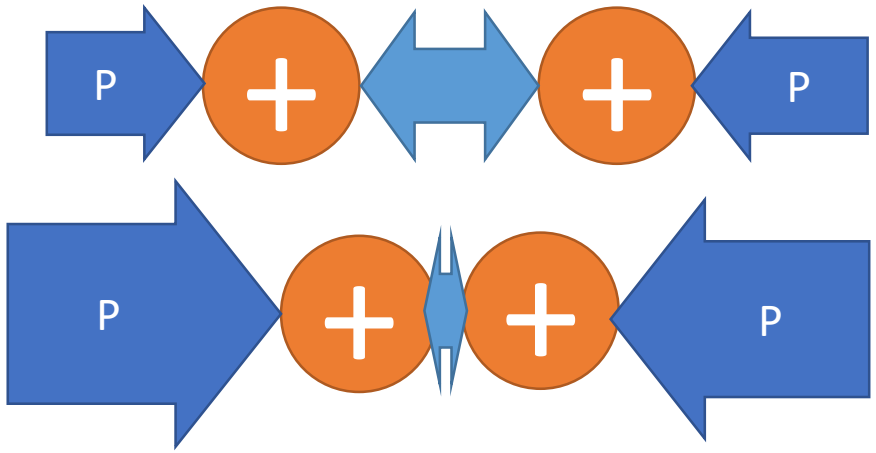


Nuclear Fusion

- Atomic nuclei combine to form new, heavier elements

- Atomic nuclei usually do not contact each other because of large electrostatic repulsive force

- But under huge pressure inside the Sun's core…



…density gets high enough that nuclei over come electrostatic repulsion and join via the strong nuclear force.

Wednesday, Nov. 2

Today….

Learning objectives

- Describe how fusion reactions work
- Explain the major fusion reactions occurring in the Sun
- Describe and explain the structure of the Sun
- Describe how the Sun affects the Earth

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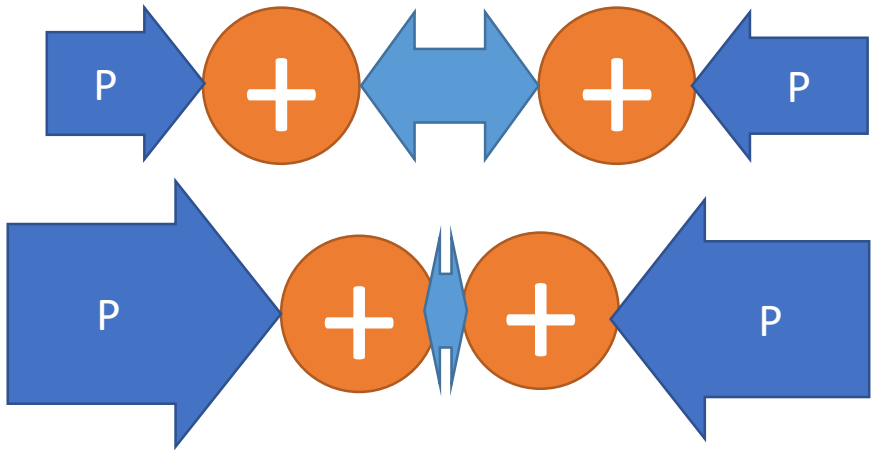

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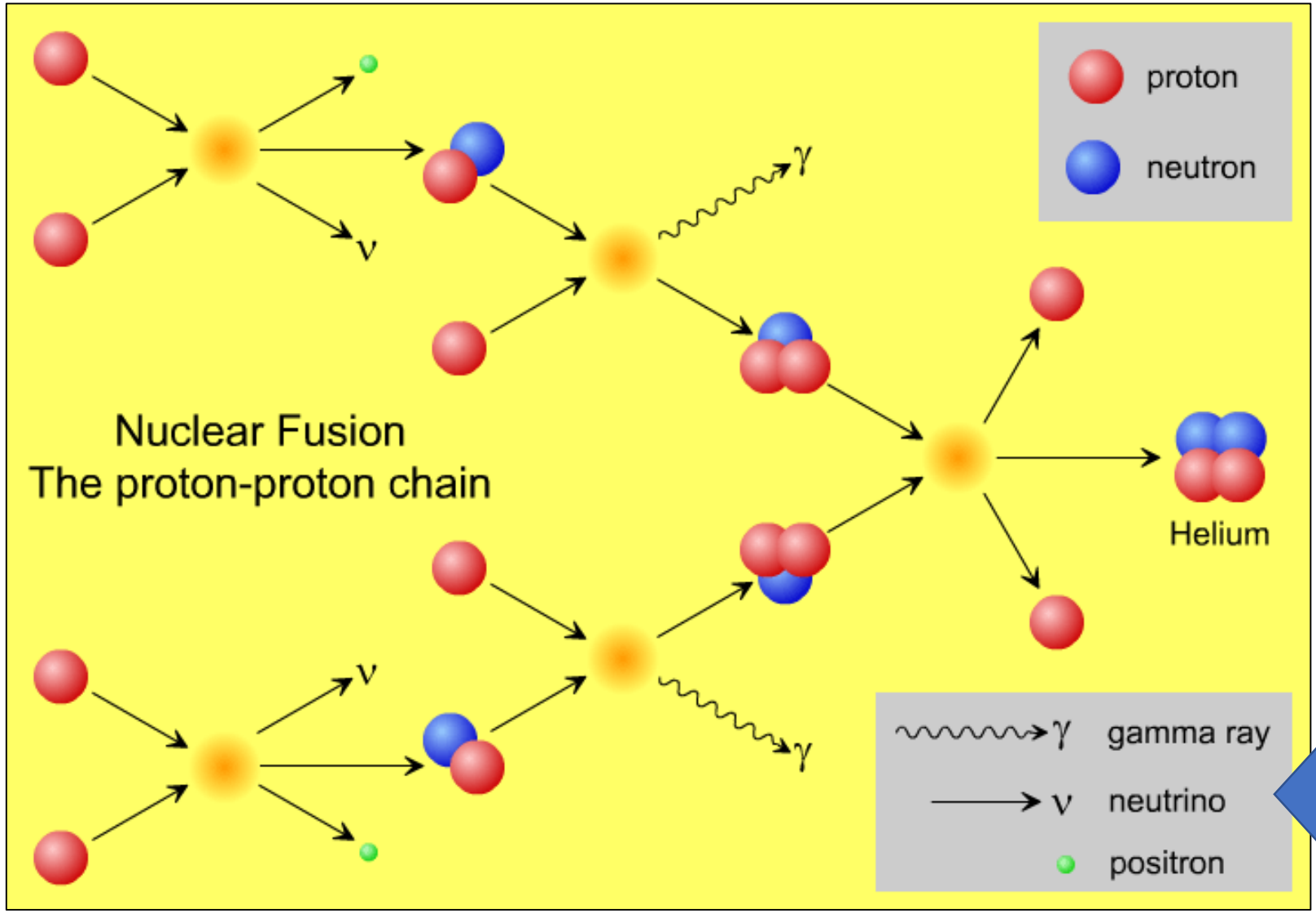
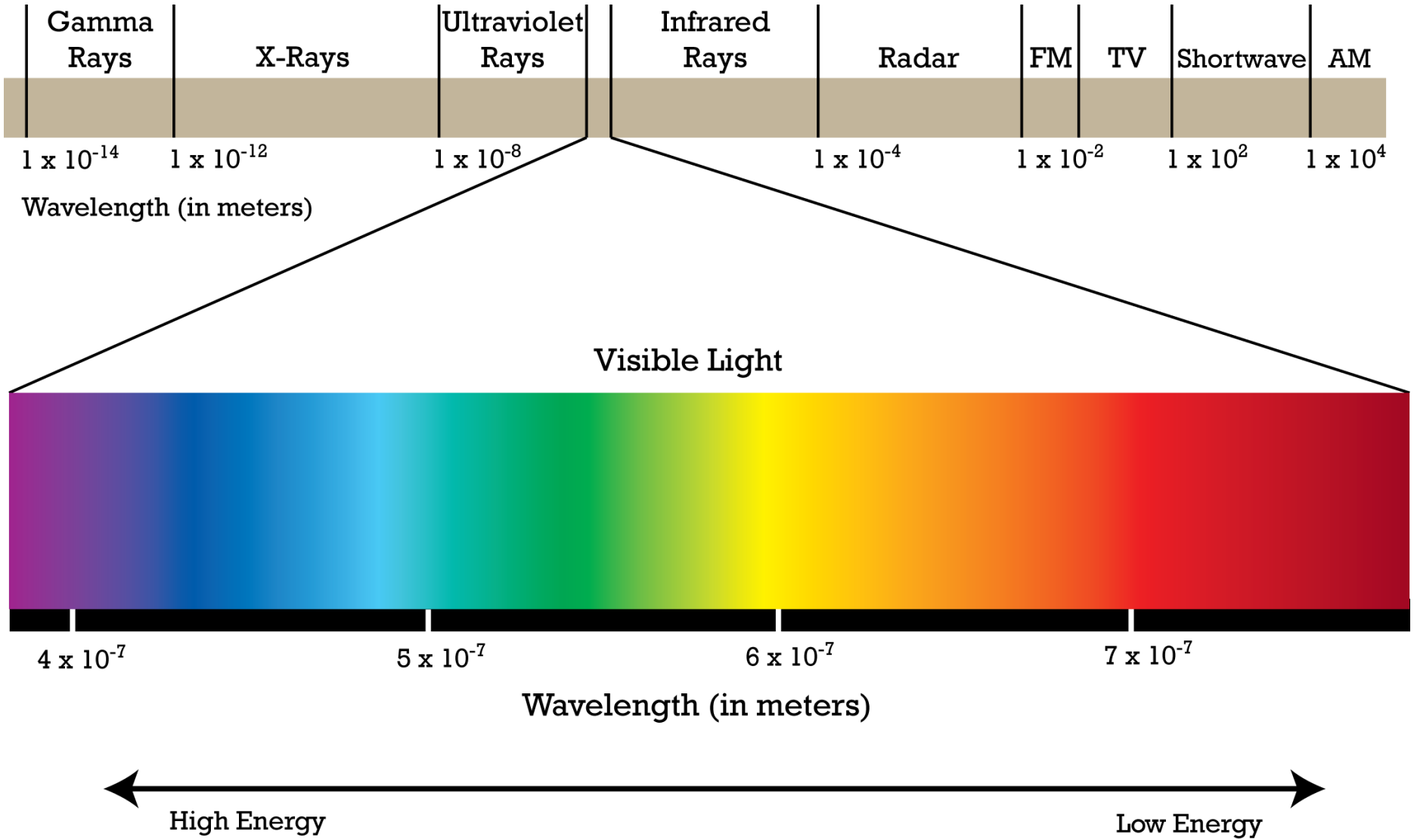
The proton-proton chain



Neutrinos and positrons are subatomic particles from H nucleus breaking down

What are these things and where do they come from?

Gamma rays = electromagnetic radiation



Gamma rays come from….

- 4 hydrogen atoms = 6.693×10^{-27} kg
- 1 helium atom = 6.645×10^{-27} kg

- Wait! There's 0.048×10^{-27} kg left over

  (That's a 0.7% difference)

What happens to that difference?

- Extra mass is converted to energy!

$$\mathbf{E = mc^2}$$

E = energy, m=mass, c=speed of light

(Einstein's Law of special relativity)

Energy from making a single He atom

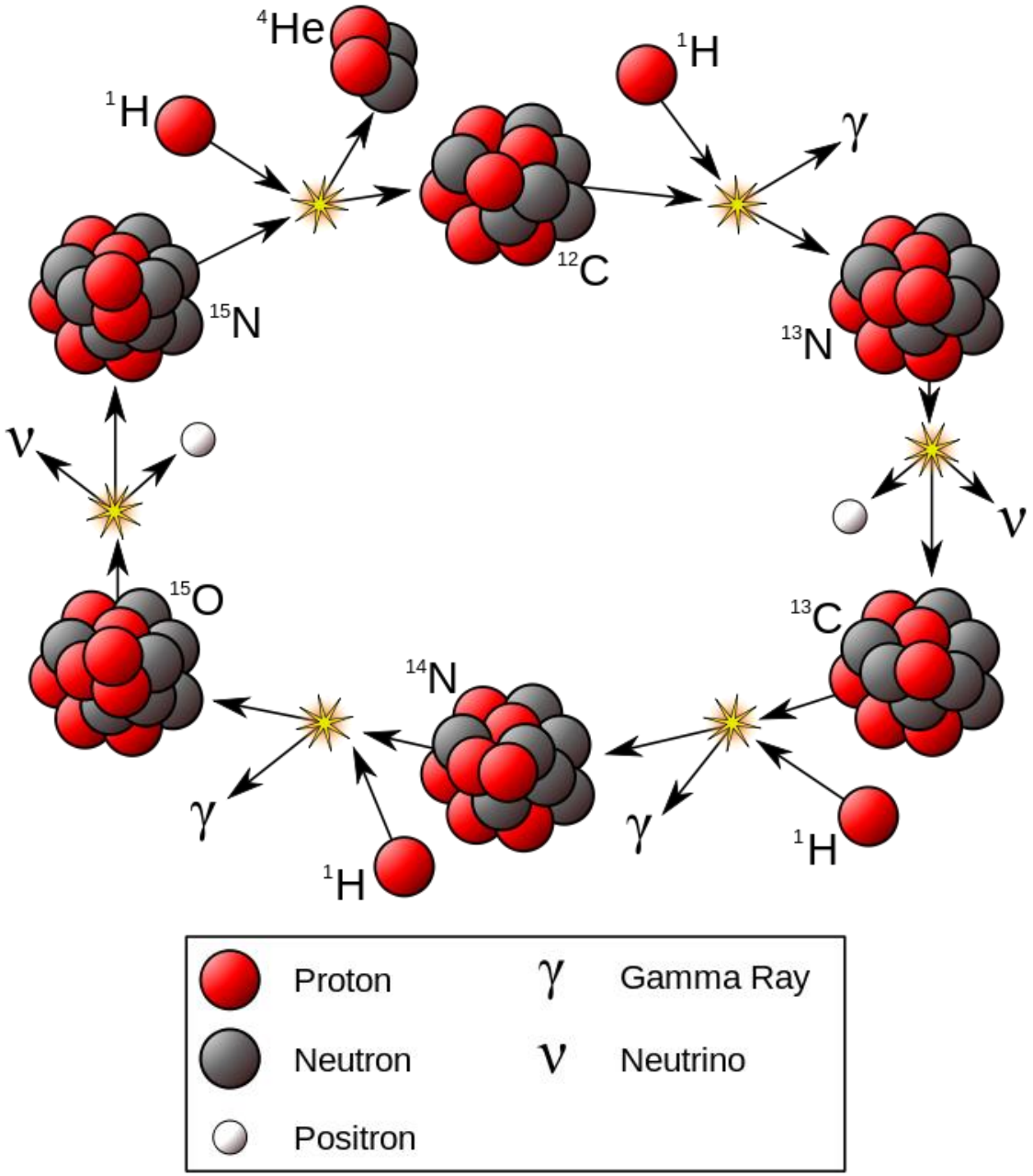
- $E = mc^2$
- $E = (0.048 \times 10^{-27}\ kg) * (3.0 \times 10^{8}\ m/s)^2$
- $E = 4.1 \times 10^{-12}\ kg\ m^2/s^2 = 4.1 \times 10^{-12}$ Joules

But there's lots of H atoms in the Sun!

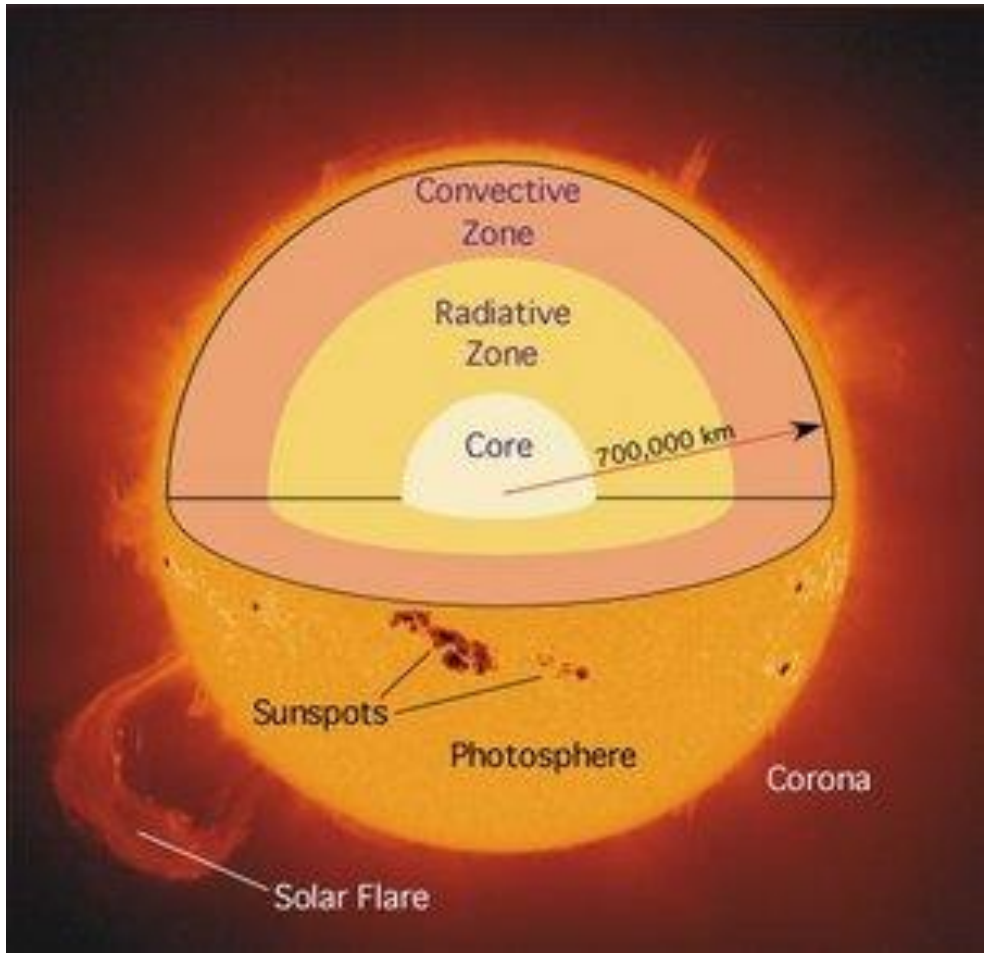
- 1 g of H → 6×10^{11} Joules
- That's about 100 barrels of oil!

CNO chain

- Other set of nuclear fusion reactions
- Important in other stars
- We'll revisit this later



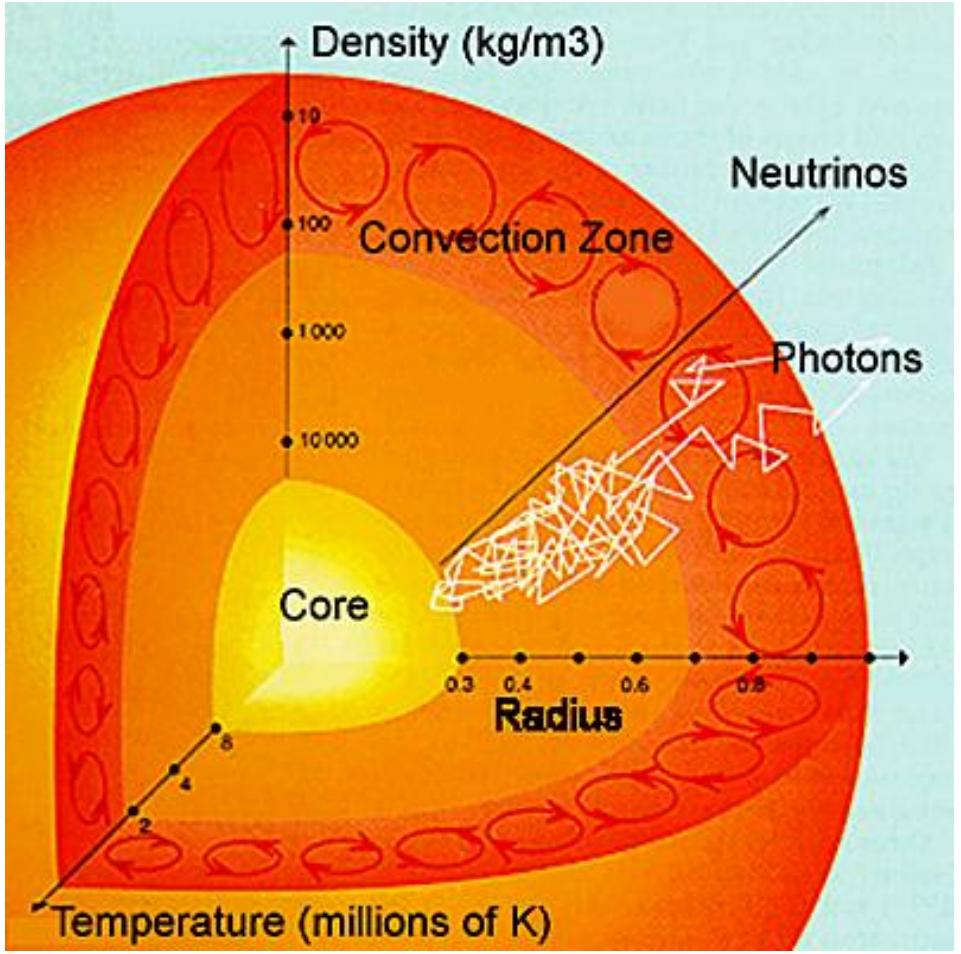
Sun’s interior structure



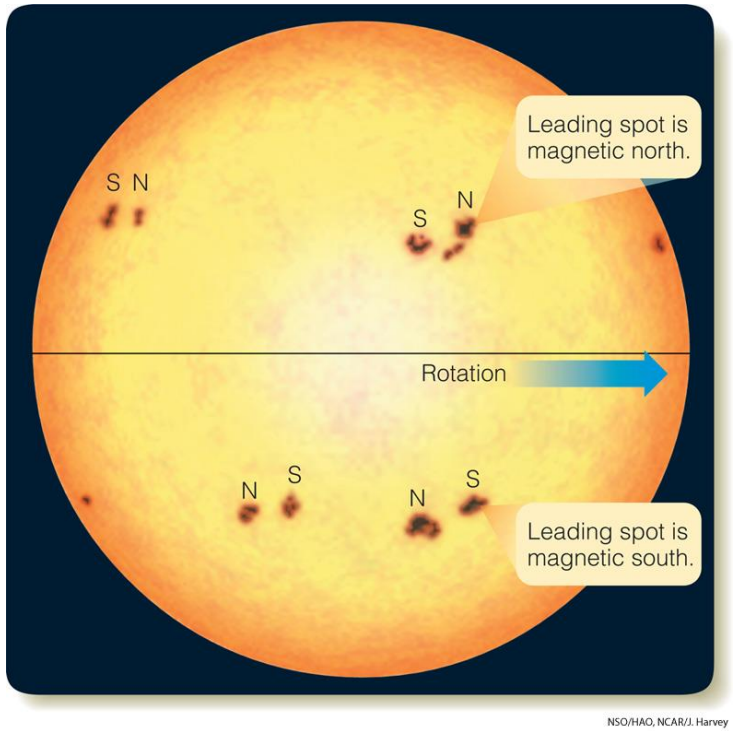
- Energy produced in the core
- Other zones defined by how energy escapes the Sun to space
  - Radiative zone (energy is radiated)
  - Convective zone (energy transfer by convection)

Sun's interior structure

- Temperature in core is ~15 million K
- T at base of convection zone is ~100,000 K
- T at the surface (photosphere) is ~5600 K



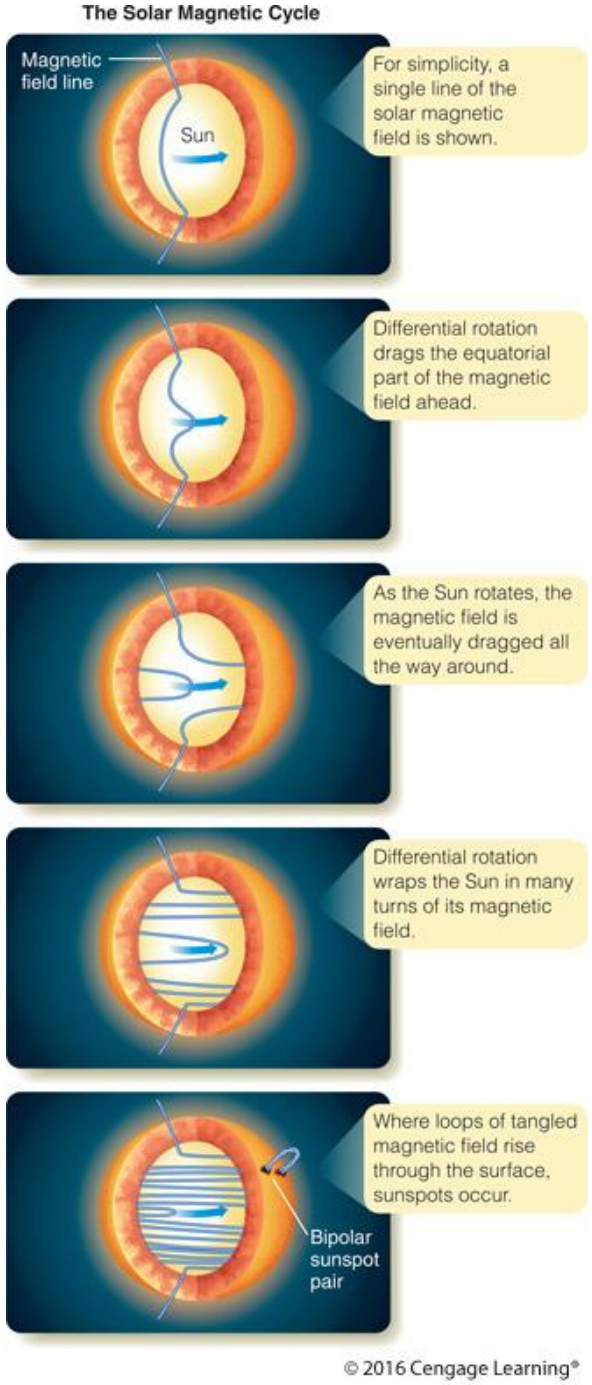
Magnetic field of Sun



NSO/HAO, NCAR/J. Harvey

- Mag field seen in sun spots and solar flares
- Mag field changes over time due to differences in rotation speed of different areas of the Sun

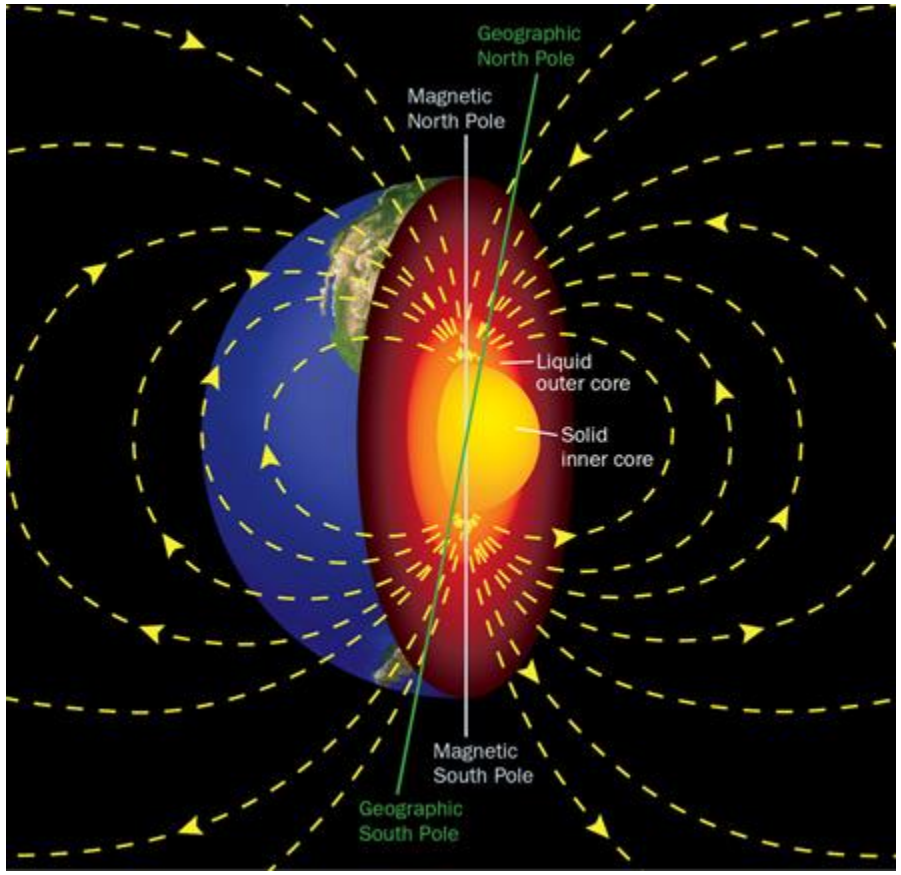
https://youtu.be/2g1epPppIOM



Solar wind

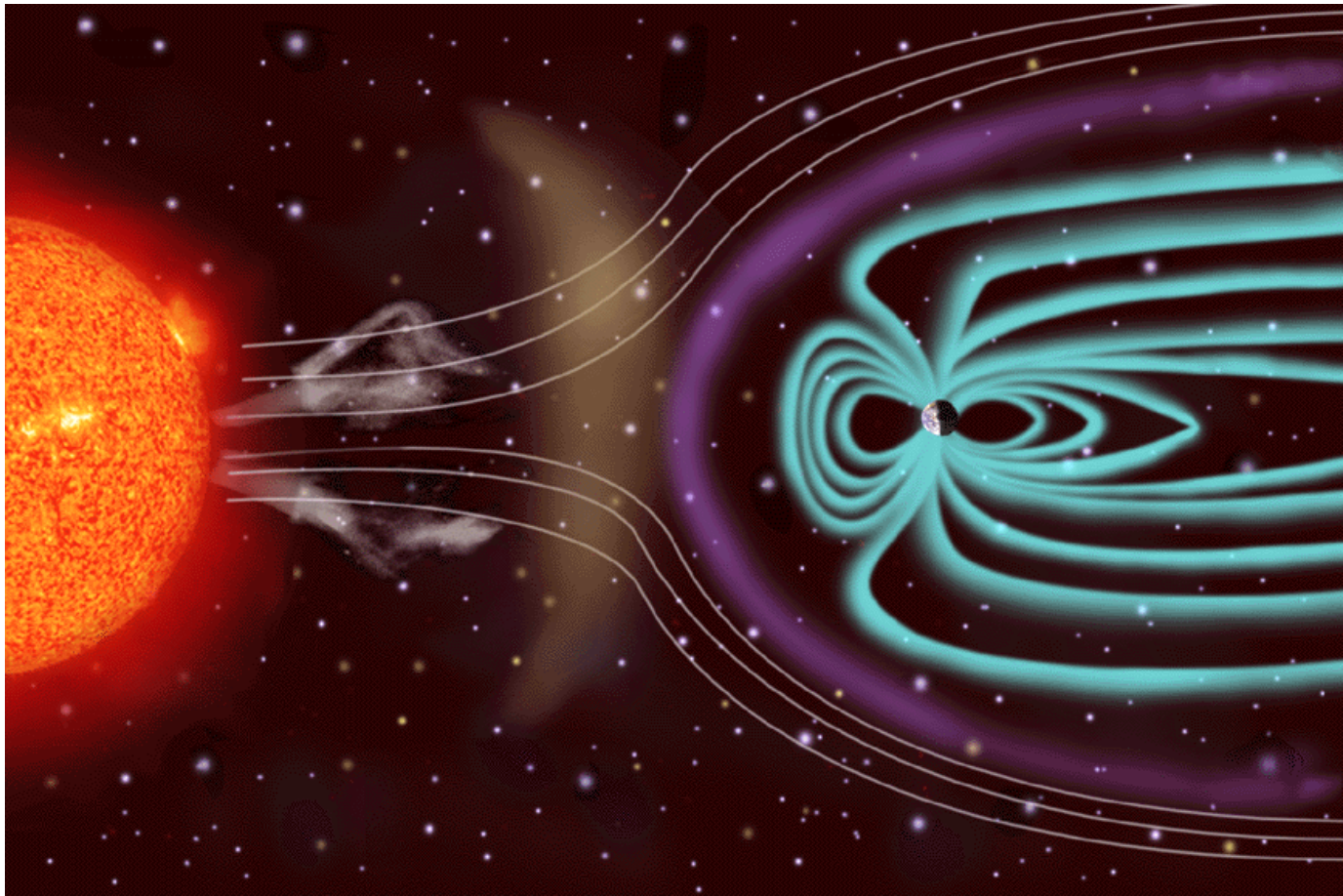
- Ionized gases (mostly H and He) that are stripped of their electorns
- Ejected from parts of the Sun's corona
- Travels throughout the solar system, moving away from the Sun at up to 200 km/second
- Maybe protects us from extrasolar radiation, interacting with stuff from interstellar space

Earth protected by its magnetic field



- Earth’s liquid outer core produces a magnetic field

- Earth’s magnetic field deflects charged particles from the Sun
- Protects surface from solar wind



What observations can you make?

- Different sizes
- Different colors
- Different brightness
- Random clusters

Why are stars different?

or

What causes these differences?

Next Time…

Activity 2: Astronomical Measurements: Examples from Astronomical Research

- New groups
- Group requests or seating preferences?
  - ➢Let me know ASAP
- Look for group listing & seating assignment on Canvas prior to next class