ASTR 150

- **Homework 5** due next Monday
- Night Observing continuing

- Last time: The death of the Sun
- Today: White Dwarf

Music: I Don't Believe in the Sun – The Magnetic Fields

Night Observing

Night Observing probably last week

- if you do it, need to go one night
- allow about 1 hour

When: M,T,W: 8-10pm

3 observing stations:

- Large telescope in observatory dome
- 2 outdoor telescopes
- Night sky constellation tour

Subscribe to Night Observing Status Blog

http://illinois.edu/blog/view/413

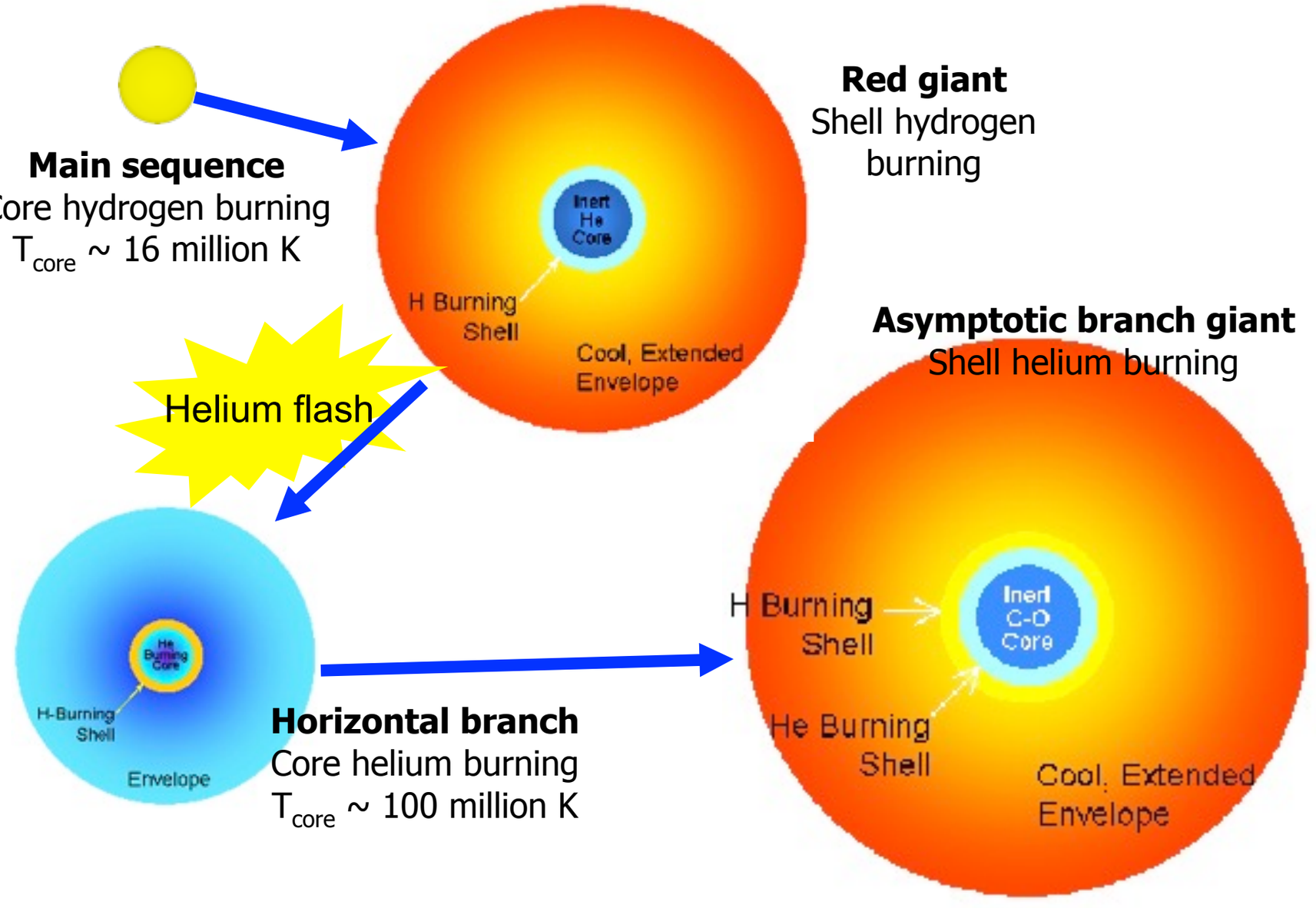
Get weather cancellation updates

Assignment details on class website

Read rubric before you go!

- Complete report due on or before Oct. 25

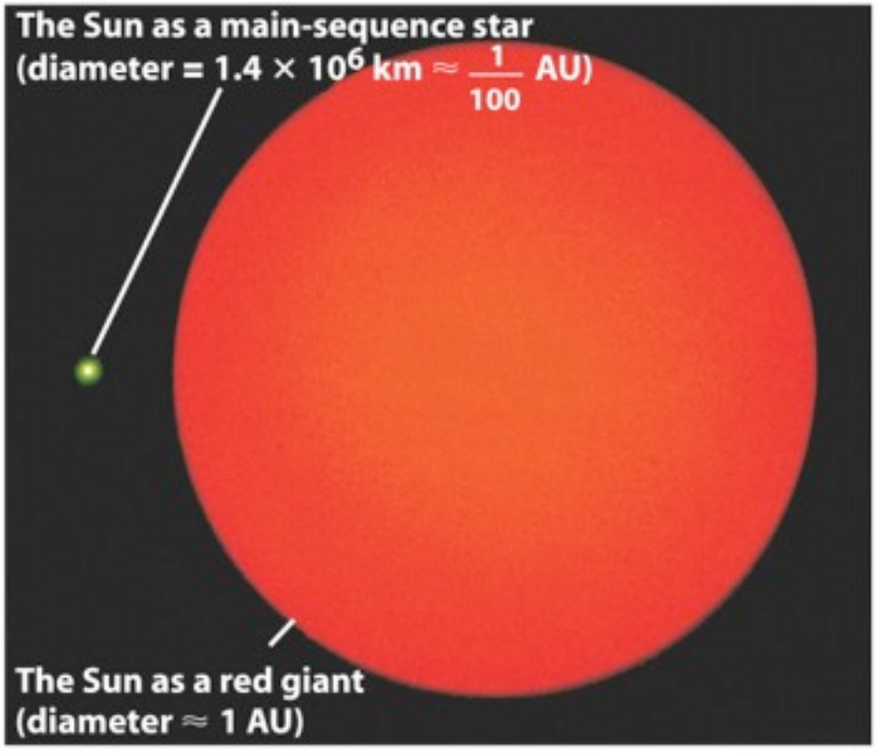
Life of a Low Mass Star



Main sequence: H into He in the core
Red Giant: No fusion in He core surrounded by a shell of H into He
Horizontal Branch: He into C & O in the core surrounded by a shell of H into He
Asymptotic Branch: No fusion in the C & O core surrounded by a shell of He into C & O surrounded by a shell of H into He

Red Giant On Mitigation

- Habitable zone moves out to huge distances
- We would have to move the Earth out to Pluto or further!
- Probably not possible.
  - Interactions with Jupiter may eject us from Solar System
- Other phases, Sun no longer in equilibrium, will oscillate in size and brightness.
- Good news: we got billions of years to figure it out!

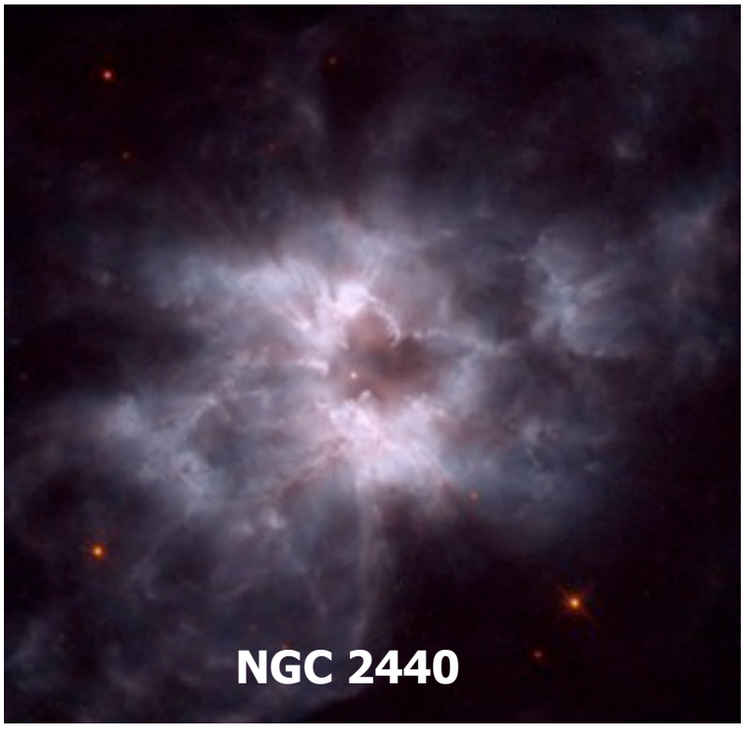


The Sun today and as a red giant

Then, at the next stage there is nothing we can do.

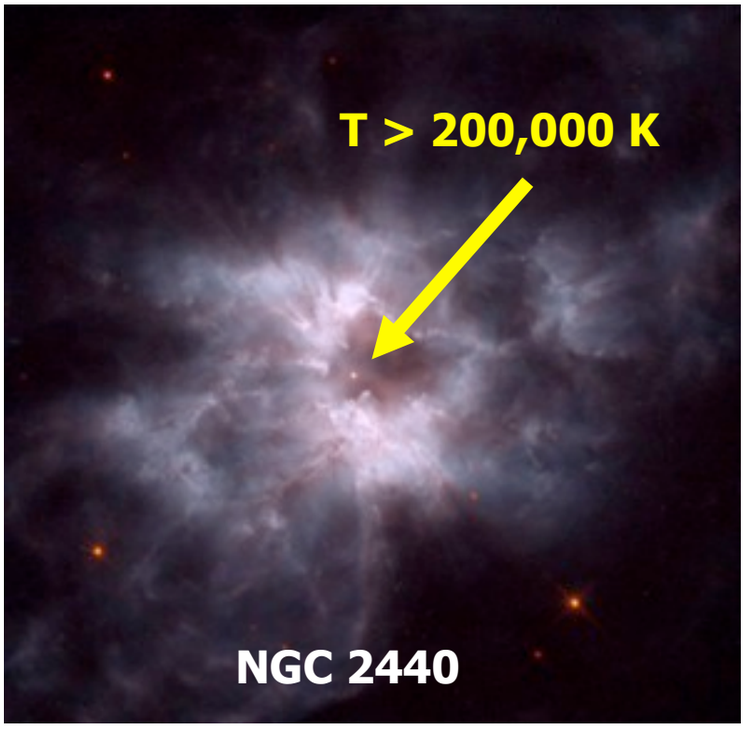
End Game

- At these last stages, the Sun will likely oscillate in size and temperature.
- The two burning shells are unstable and their oscillations lead to a "Superwind"
- Outer layers of the red giant star are cast off
  - Up to 80% (at least 50%) of the star's original mass
  - carries away all but the innermost material of the star
  - including all of the new elements created there: helium, carbon

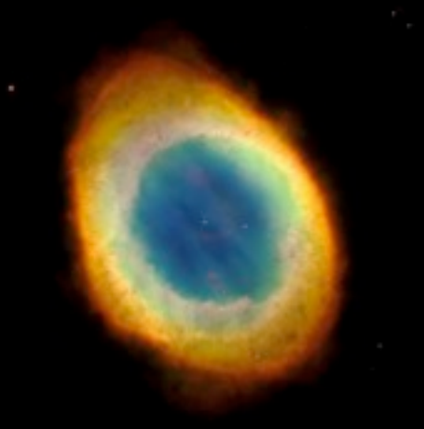


End Game

- The core remains, made of carbon/oxygen "ash" from helium fusion
  - The core is very hot, above 200,000 K
  - laid bare, and seen as "white hot"
- Ultraviolet radiation from the core ionizes the cast off outer layers
  - Becomes a planetary nebula
  - Unfortunate name (nothing to do with planets), but some of the most beautiful objects in the sky.

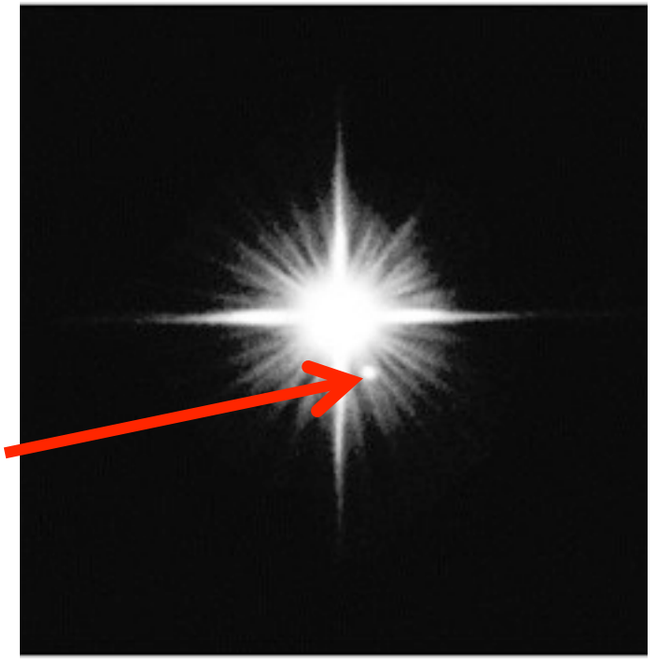


Planetary Nebulae



What About the Core?

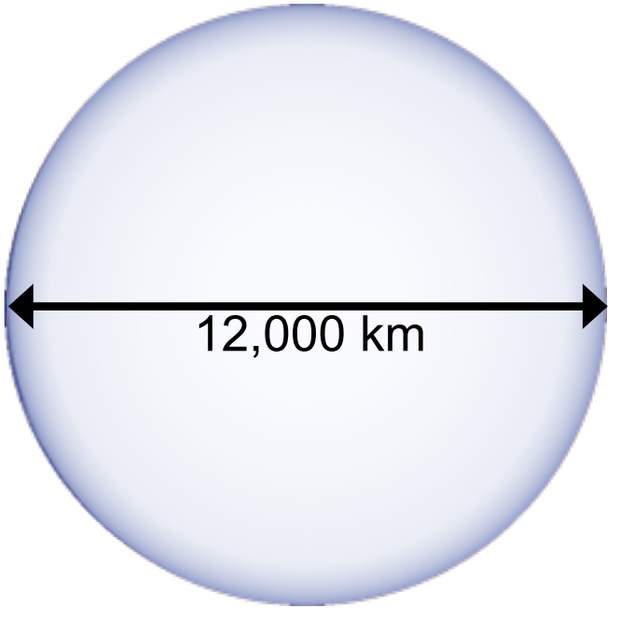
- Final fate - White dwarf
  - "cinder" of burnt out core of sunlike star
  - Slowly cools off over billions of years
  - Just a hot body
  - No fusion
  - Not really a star in some ways



Sirius B

What About the Sun's Core?

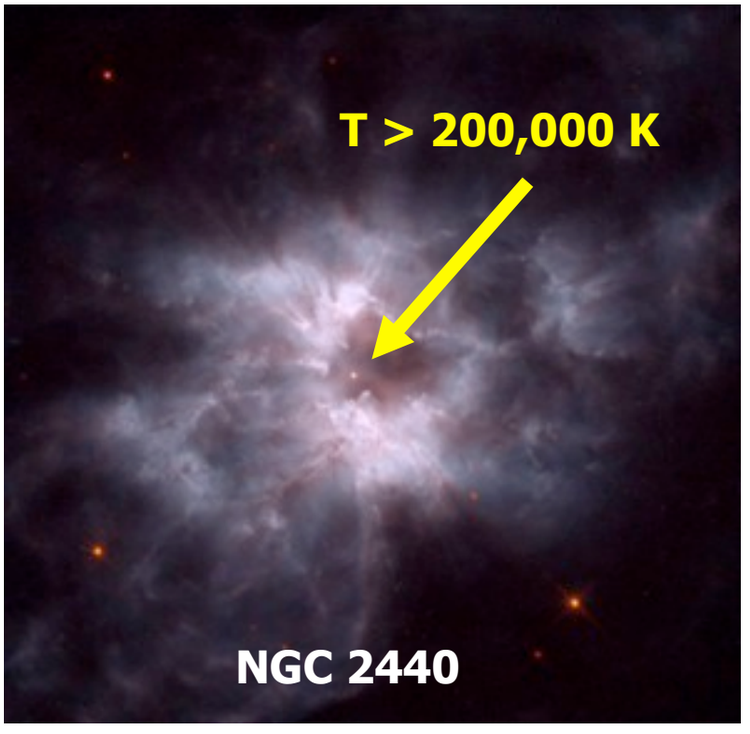
- Nuclear fusion has stopped, and gravity begins to win the battle
- Core contracts to the size of the Earth
  - But its about 60% the Sun's mass!
  - Material in the core is compressed to a density of 1,000 kg/cm^3
  - 10^6 times denser than you!
  - Very hot, surface temperature >100,000 K



but will usually weigh around 0.6 Solar masses

What Happens to Earth?

- We have detected planets around white dwarfs, but they have presumable had a hard time.
- If you were to visit the wasteland of Earth, the Sun would only be a very bright point of light.
- Not sufficient for life.



Electron Degeneracy

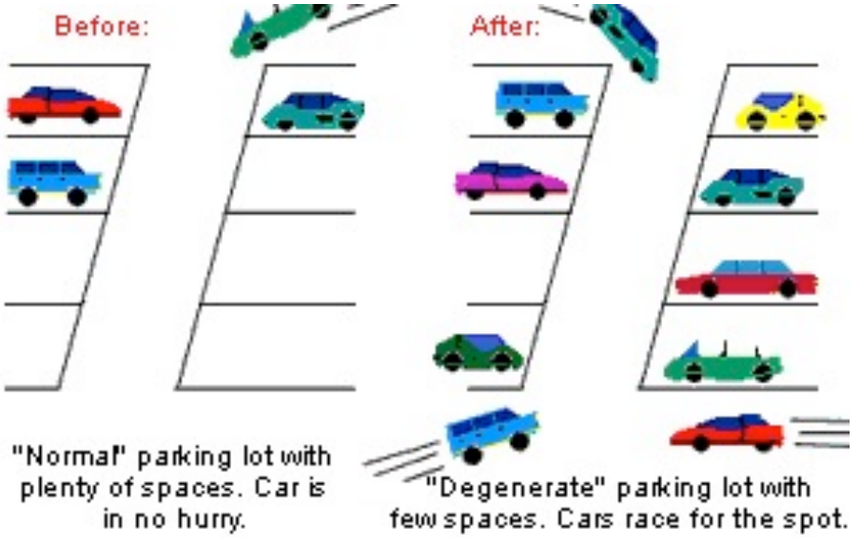
- The electrons get so squashed together that they get pushed into degenerate states
  - packed into ultradense quantum solid
  - This creates pressure to counteract gravity (Pauli exclusion)
  - Stops contraction

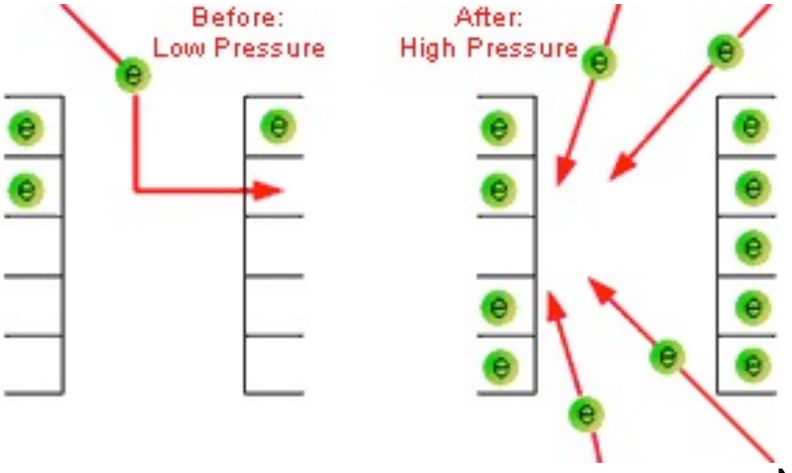
Matter in the core of a normal star

Electron-degenerate matter
1 ton per cubic cm

Degeneracy Pressure

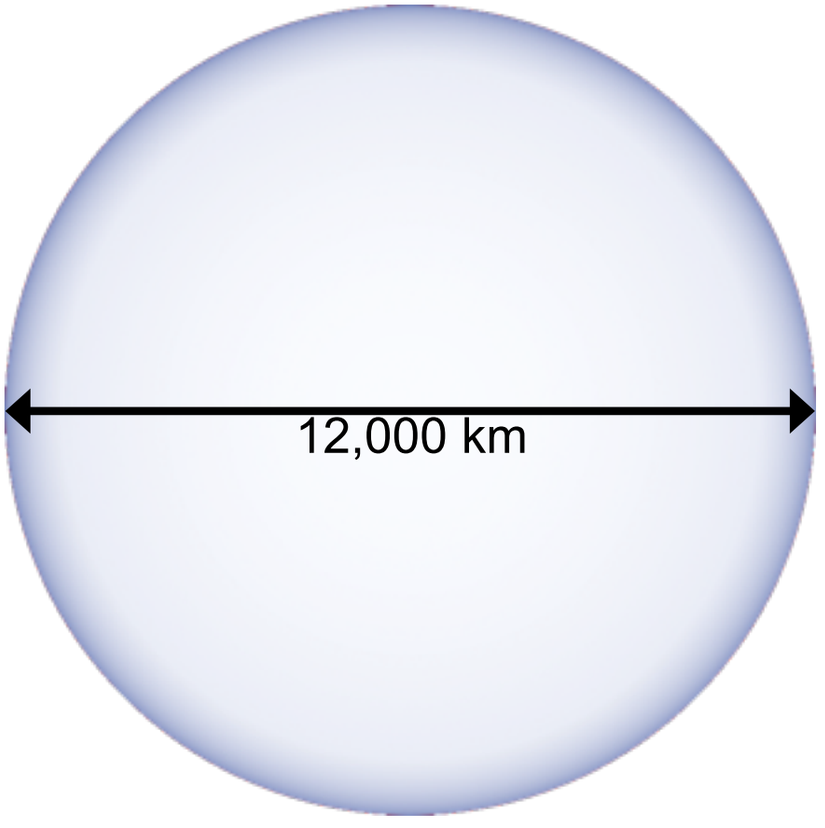
- Electrons are forced into higher energy levels than normal – all of the lower levels are taken
- Effect manifests itself as pressure





NASA

Relative Size of White Dwarf



White dwarf– but will usually weigh about 0.6 Solar masses

IClicker Question

Why doesn't a white dwarf collapse into a black hole?

a) Electron degeneracy pressure
b) Heat pressure
c) Fusion pressure
d) Proton degeneracy pressure
e) For the same reason that the Earth doesn't collapse into a black hole.

Answer A

Chandrasekhar limit

- Maximum mass of a white dwarf.
  - 1.4 solar masses!
- No white dwarf observed is over this.
- If mass is higher, the white dwarf can not support itself with electron degeneracy, and it collapses more!
- Gravity is a harsh mistress!
  - More of this latter.
- But Sun already has less mass
  - and will have less still as white dwarf
  - so the Sun's white dwarf corpse will be stable, able to support its own gravity
  - and will simply cool off forever

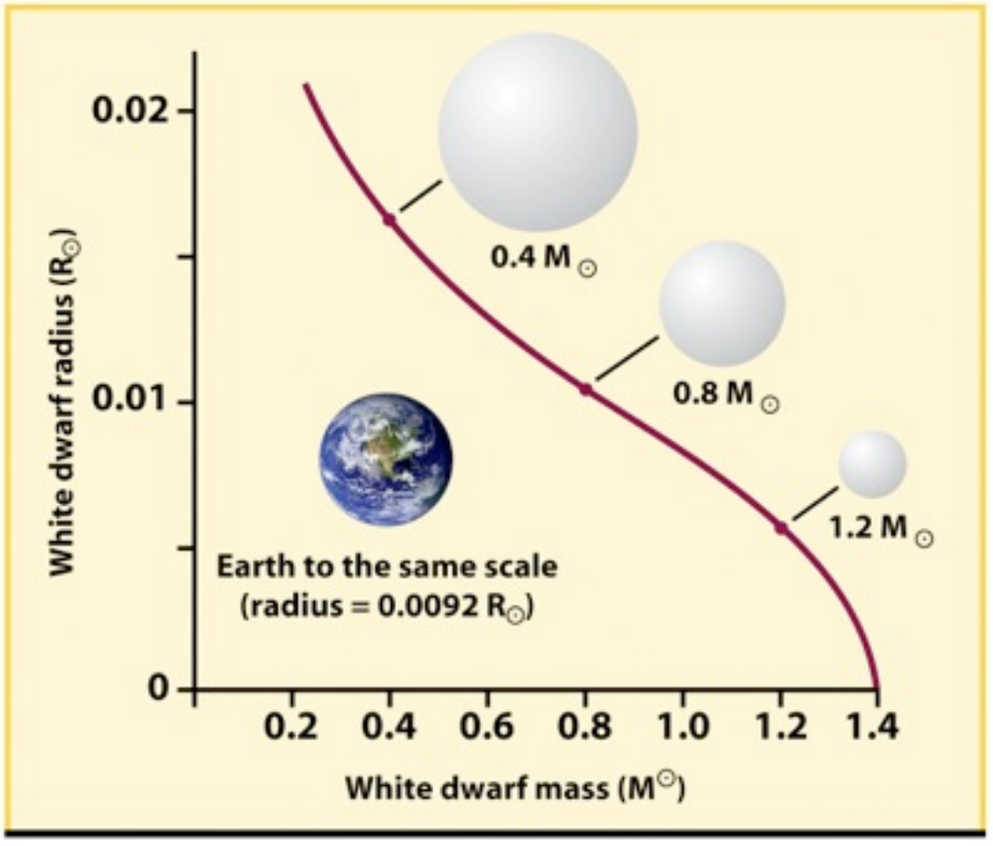
Subrahmanyan Chandrasekhar 1910-1995

White Dwarfs are Weird

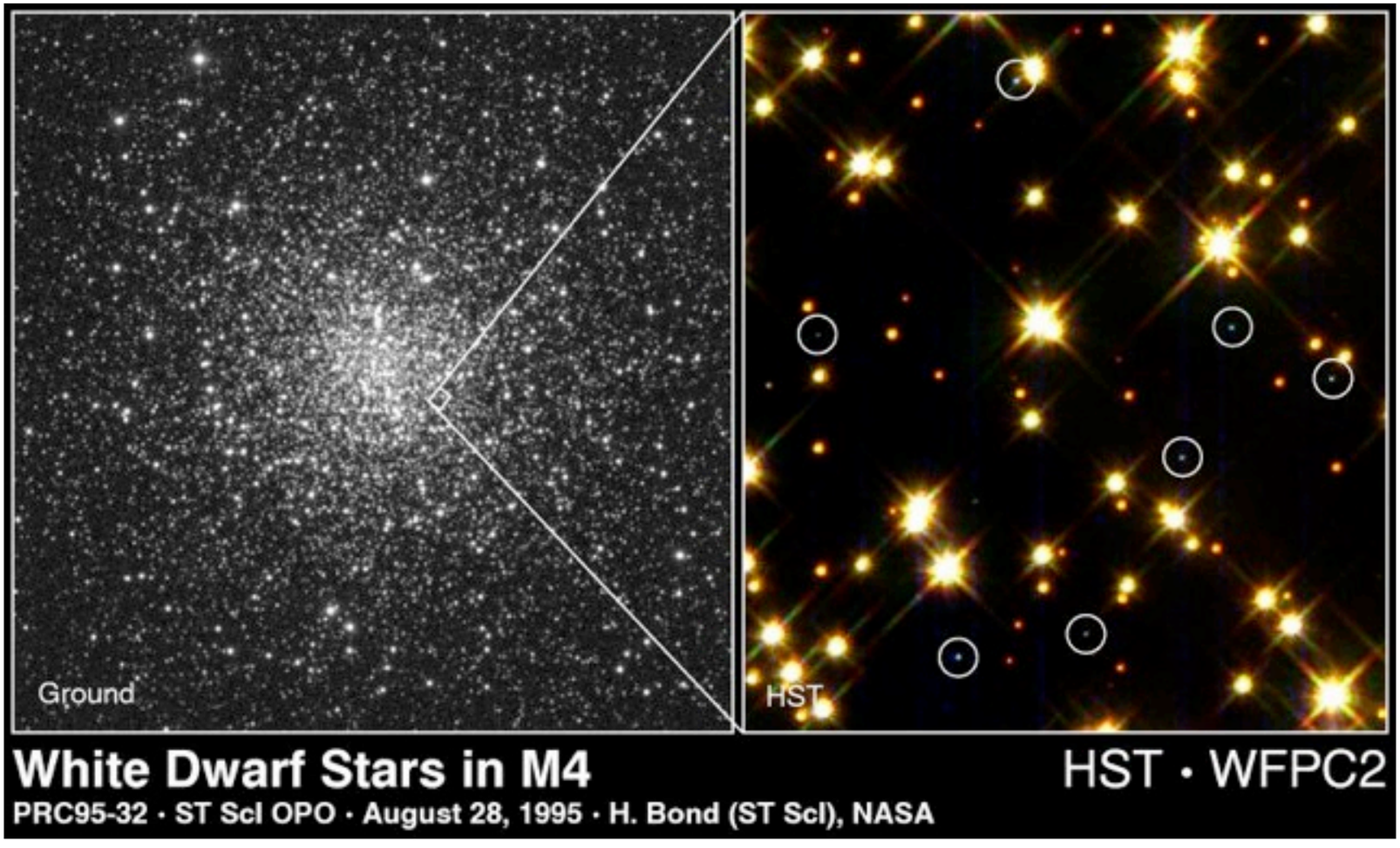
The more massive, the smaller!

Their radius decreases with mass!

Why? More mass=more gravity, star compressed more



White Dwarves!



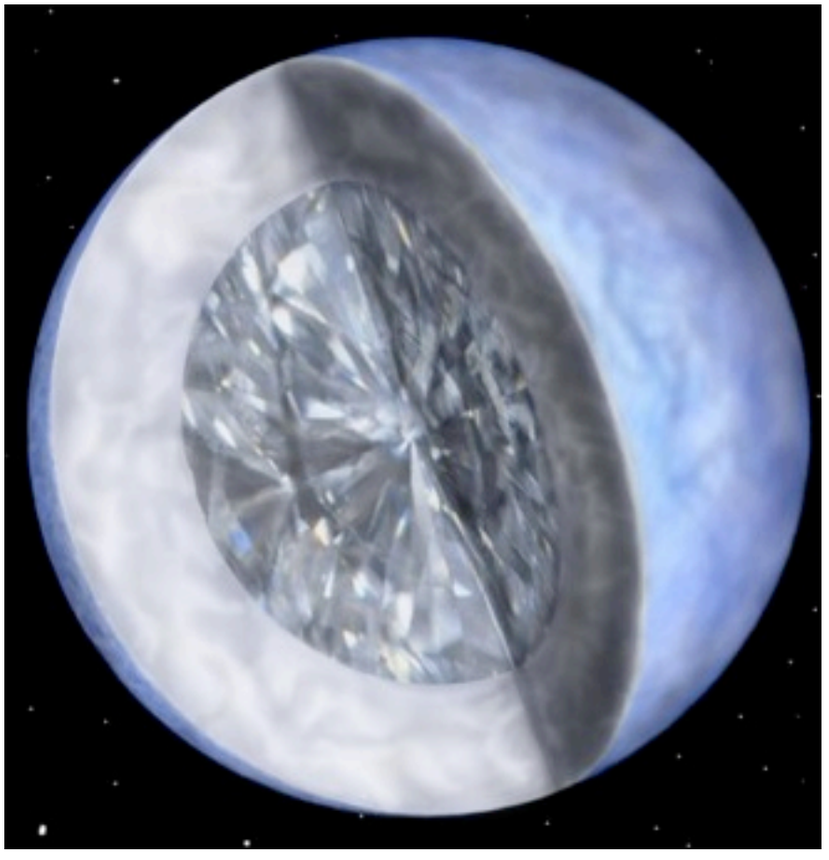
What If?

If Sun was replaced with a white Dwarf: still about 400 times brighter than current Full moon

Image is impossible for many reasons... but nice comparison. Although the Sun is hotter it is still less bright because it is MUCH smaller than the original Sun. The brightness depends on both size and temperature.

Stellar Diamonds!?!

- The interior of the white dwarf crystallizes due to the extreme pressures
- Made mostly of carbon (some oxygen)
- Crystallized carbon = a diamond
  - With a blue-green tint from the oxygen
  - 10 billion trillion trillion carats!



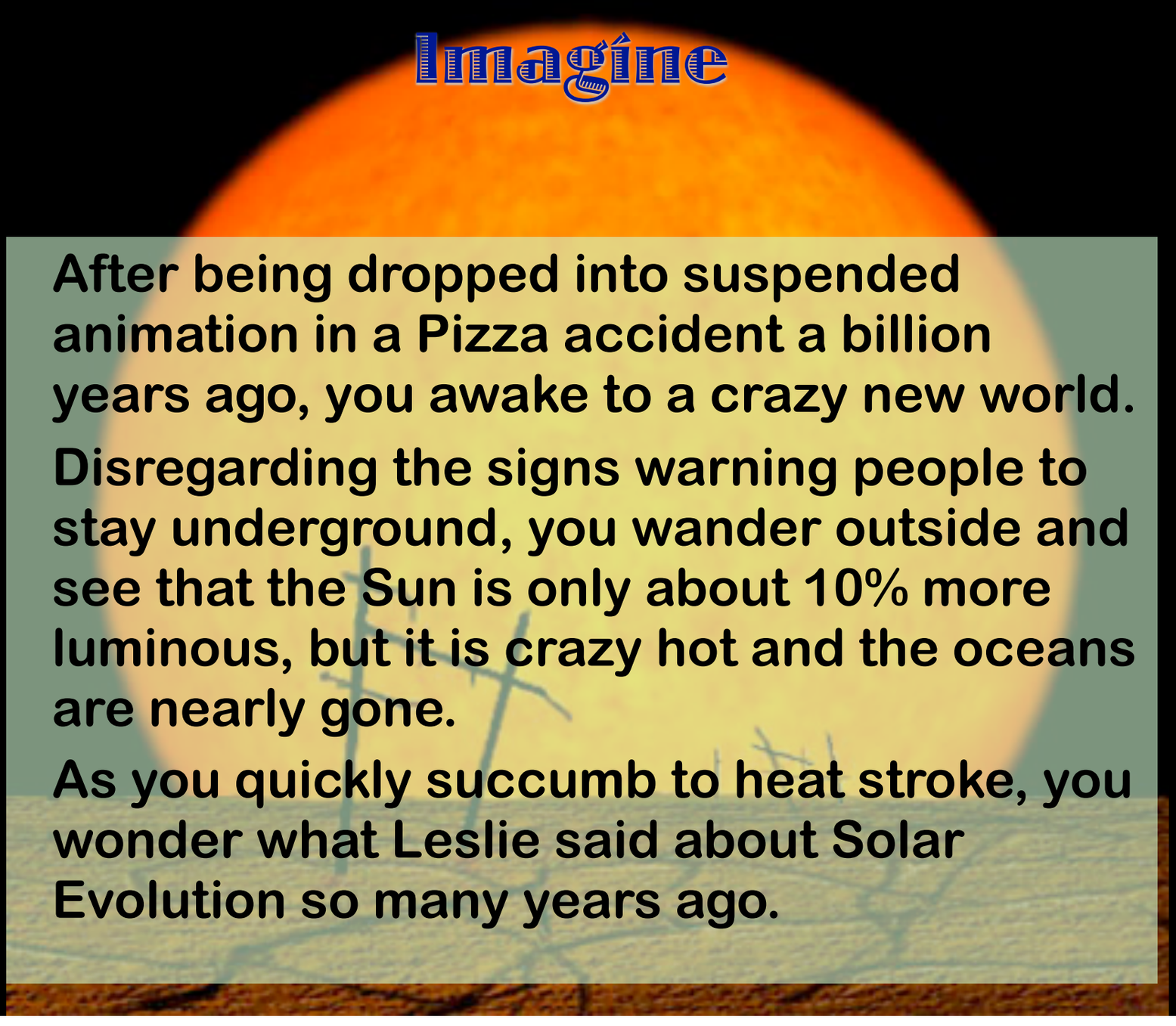
Question

This is the way the Sun ends. This is the way the Sun ends, not with a bang but a

a) whimper; it just cools down over time.
b) supernova blasting heavy elements into space.
c) blackhole.
d) planetary nebula and a white dwarf that cools with time.
e) a helium flash.

Answer D, sorry TS Eliot fans.

Imagine



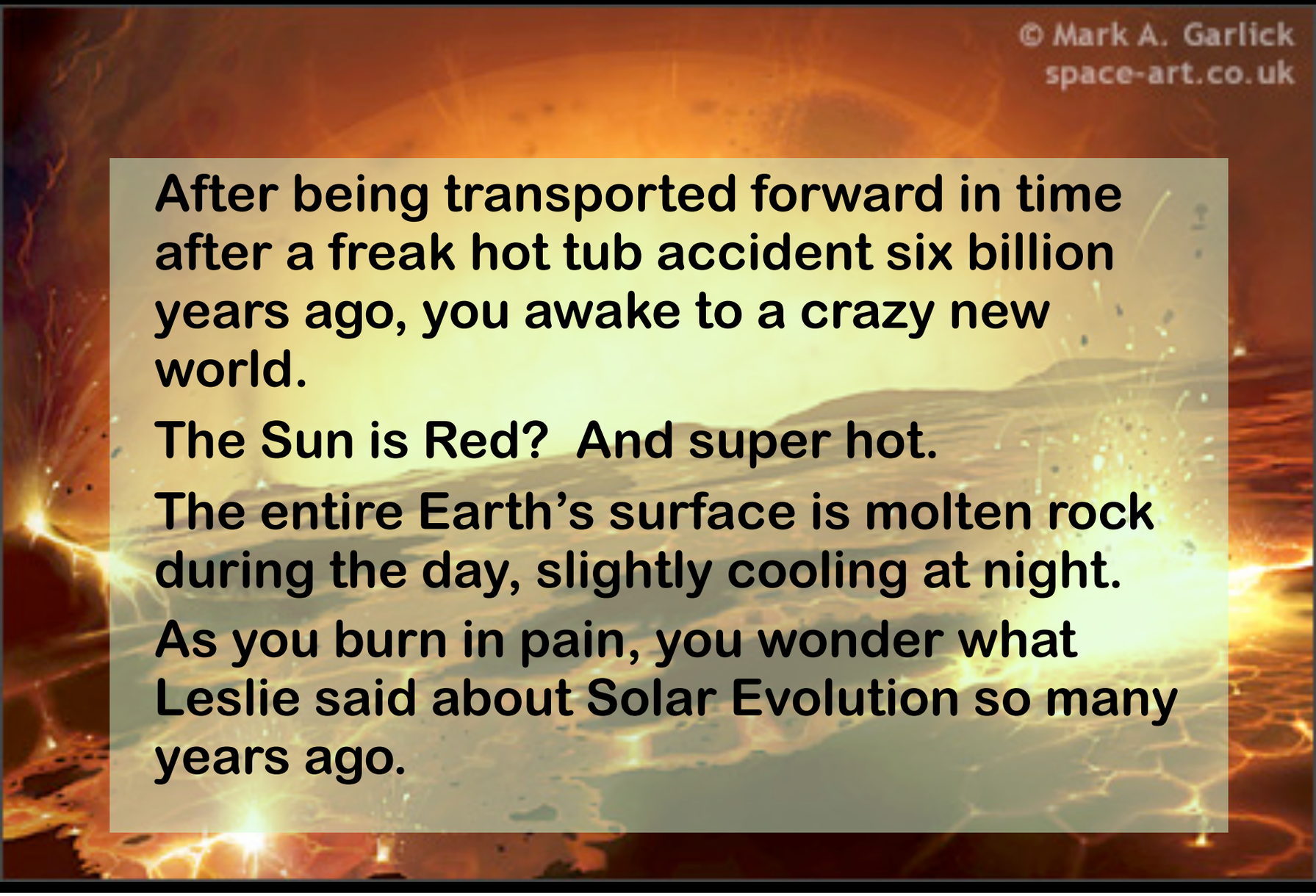
After being dropped into suspended animation in a Pizza accident a billion years ago, you awake to a crazy new world.

Disregarding the signs warning people to stay underground, you wander outside and see that the Sun is only about 10% more luminous, but it is crazy hot and the oceans are nearly gone.

As you quickly succumb to heat stroke, you wonder what Leslie said about Solar Evolution so many years ago.

Or…..

Imagine



After being transported forward in time after a freak hot tub accident six billion years ago, you awake to a crazy new world.

The Sun is Red? And super hot.

The entire Earth's surface is molten rock during the day, slightly cooling at night.

As you burn in pain, you wonder what Leslie said about Solar Evolution so many years ago.

I Know You're Thinking

Sure, Solar Evolution is deadly, but the dangers are so far in the future.

Is there anyway that the Sun can kill us today?

Yes!

Top 10 Ways Astronomy Can Kill you or your Descendents

1. **Impacts!**

   Splat.. Boom… Watch out for space rocks!

2. **Solar Evolution.**

   Hydrogen burning to Red Giant to White Dwarf.

3. **Solar Storms: Coronal Mass Ejections**

   The Sun gets angry..

Imagine

It's winter. It's cold.

The Sun is unusually active, and you hear NASA is worried about something called Space Weather.

A huge batch of new sunspots on the Sun's equator are seen..

A huge coronal mass ejection from the Sun comes screaming toward the Earth.

Imagine

All of our satellites are knocked out.

Airplanes are left without communication

Electrical transmission lines overload and melt, causing wildfires.

Half the planet is without power.

Thousands die the first night…

Then, more sunspots…

And you can't remember what Leslie mentioned about CMEs….

Top 10 Ways Astronomy Can Kill you or your Descendents

2. Coronal Mass Ejections, CMEs !

The Sun is a star!

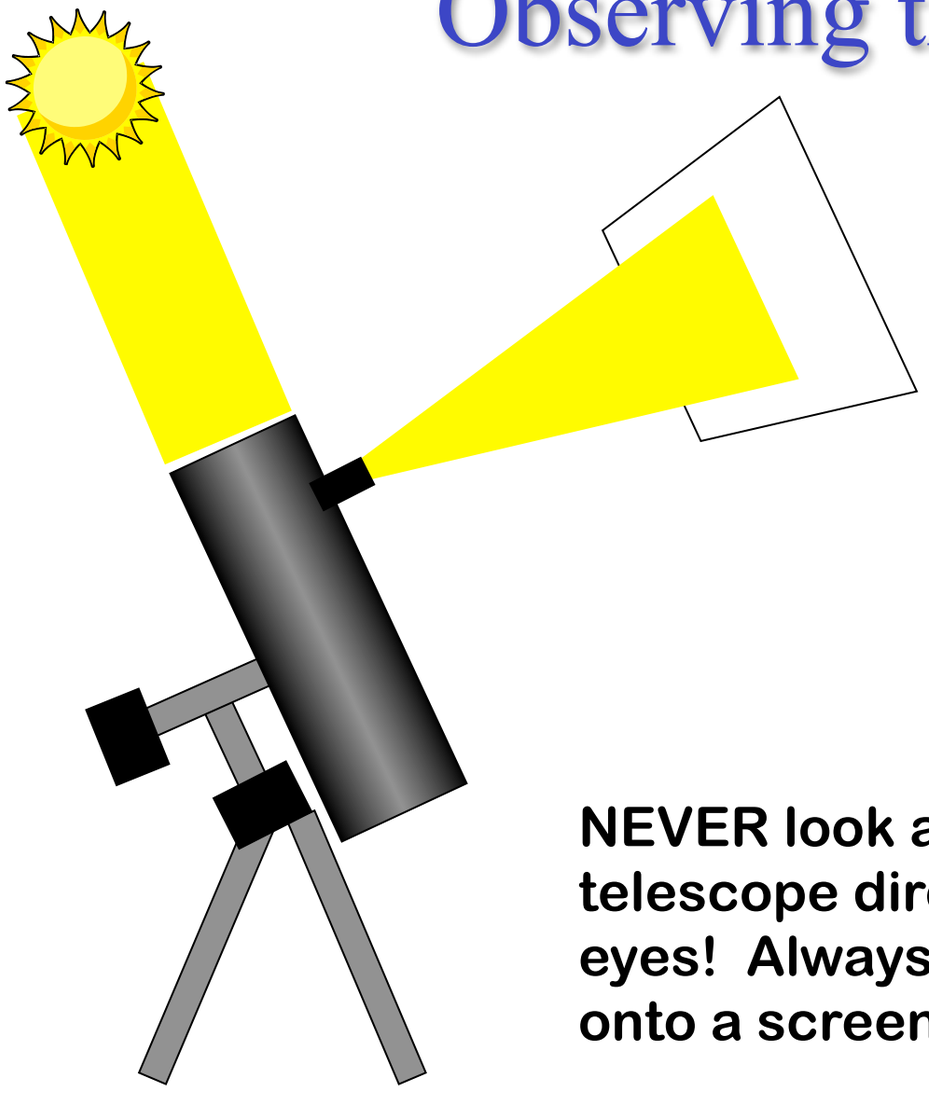
The Sun seems the same every day, but it isn't. It changes.

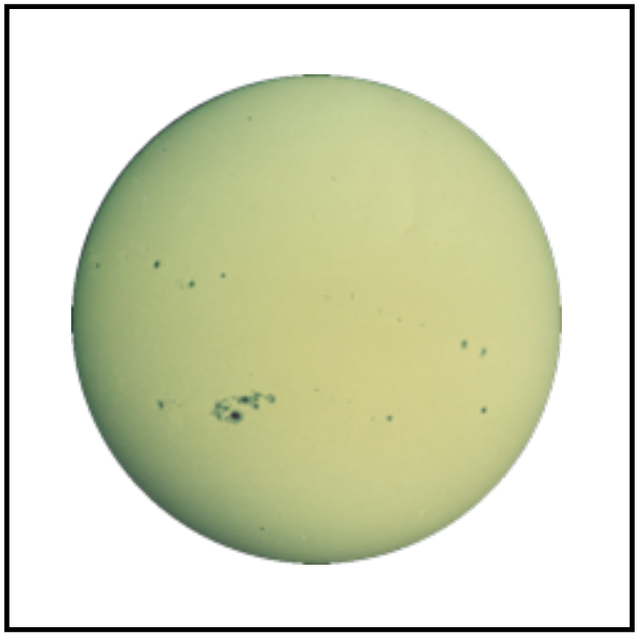
The Sun is a huge vast mighty furiously seething cauldron of mass and energy!

The Sun can get mean!

I mean rock impacts may never happen, and Solar Evolution is so far away, but CMEs can kill today.

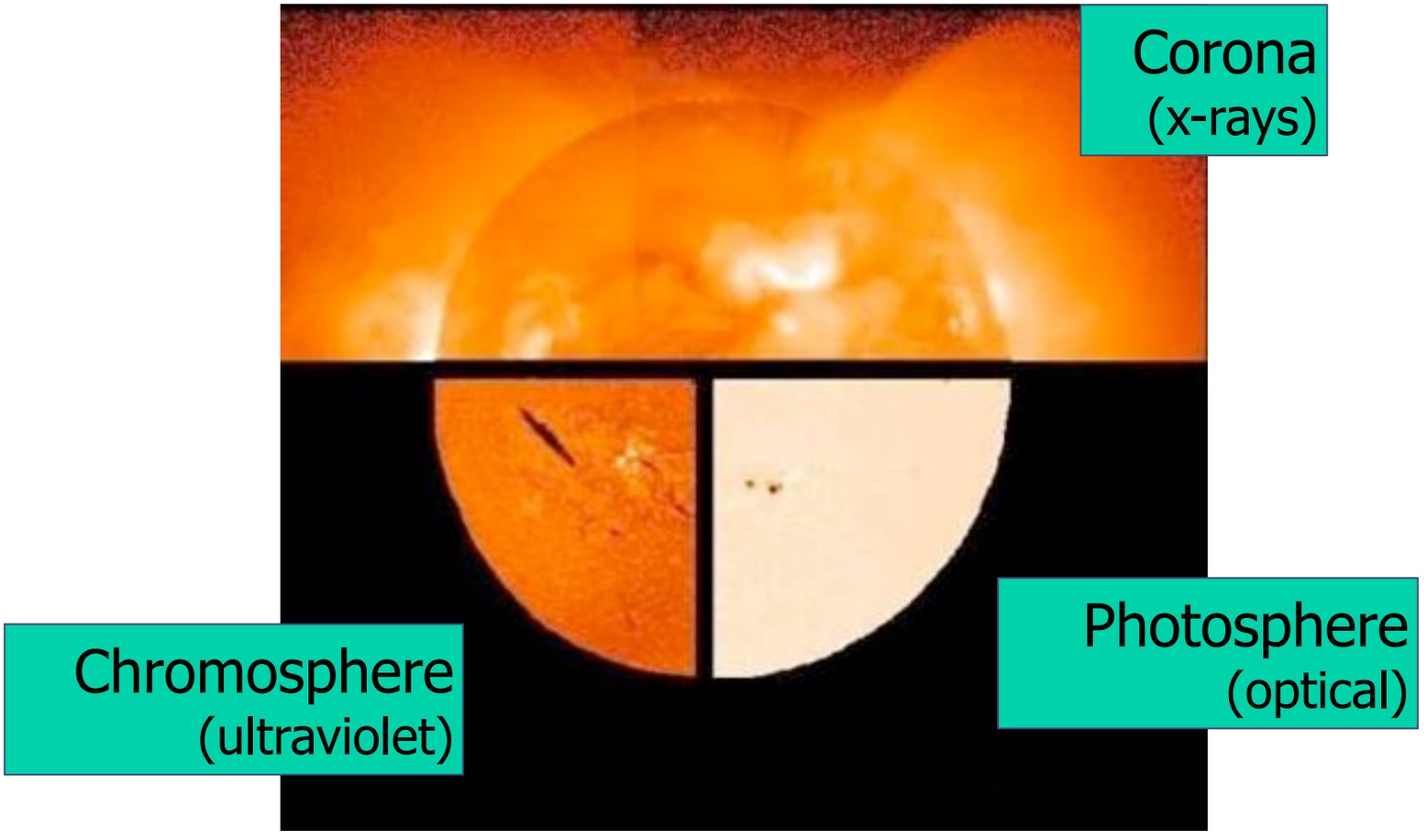
Observing the Sun





NEVER look at the Sun through a telescope directly. You will damage your eyes! Always project the Sun's image onto a screen.

The Outer Layers of the Sun



1. Photosphere – "surface", About 500 km thick, Average temp: 5,800 K
2. Chromosphere – lower atmosphere, Roughly 1,000x fainter than the photosphere, Temps: 4,500 – 500,000 K
3. Corona – outer atmosphere, Temps up to 2,000,000 K!, But very faint

You can think of the chromosphere as being an irregular layer with a depth on average less than Earth's diameter. The density is about 100 million times less than that of the air you breathe.

The corona is so dim that it is not visible in Earth's daytime sky – only seen during an eclipse. It extends out at least 10% of the Earth-Sun distance. The density of the corona about one-trillionth that of the air you breathe.

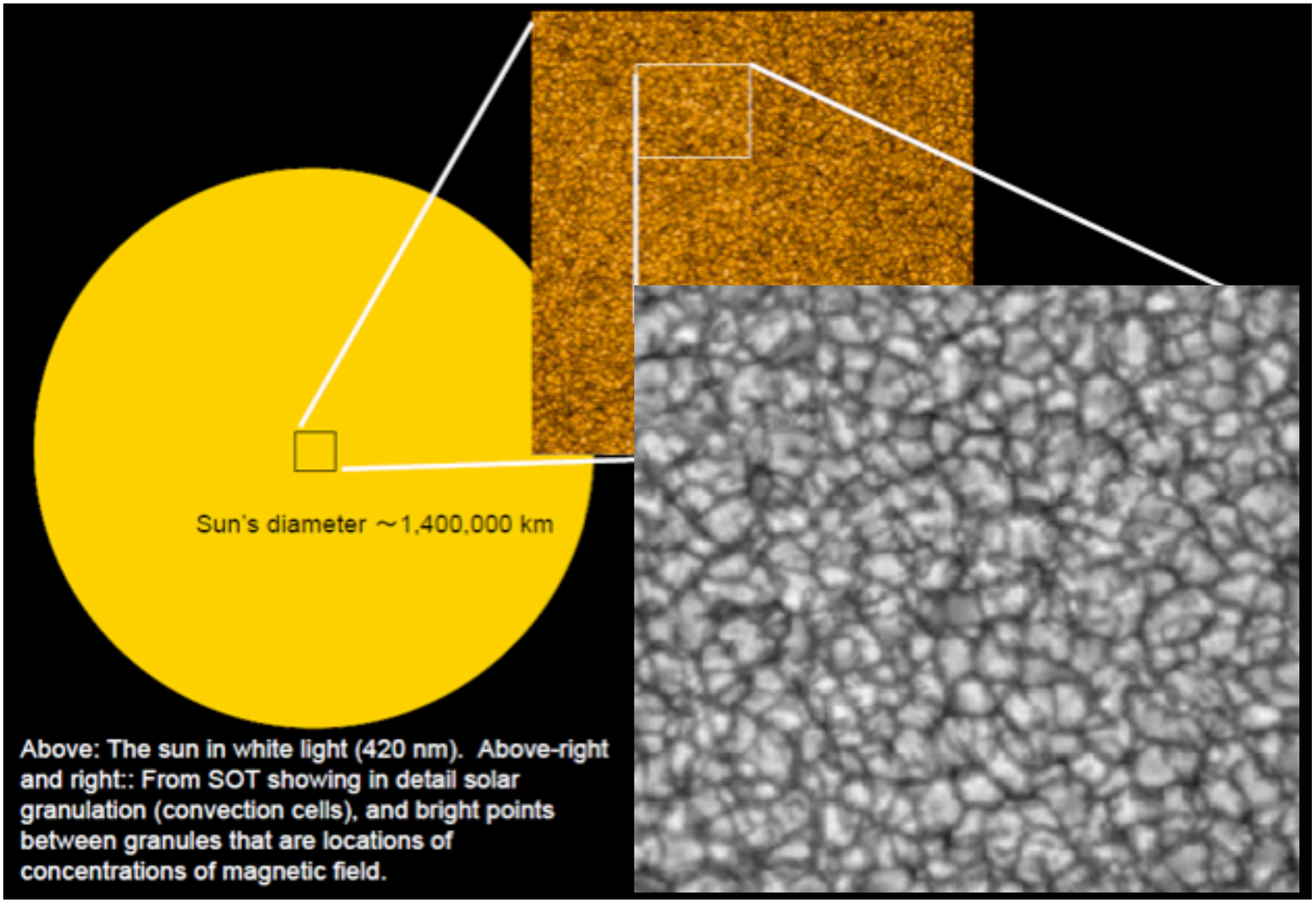
IClicker Question

Which of the following is not a layer of the Sun?

a) Stratosphere
b) Corona
c) Chromosphere
d) Photosphere
e) Core

Answer A, which is layer of the Earth's atmosphere

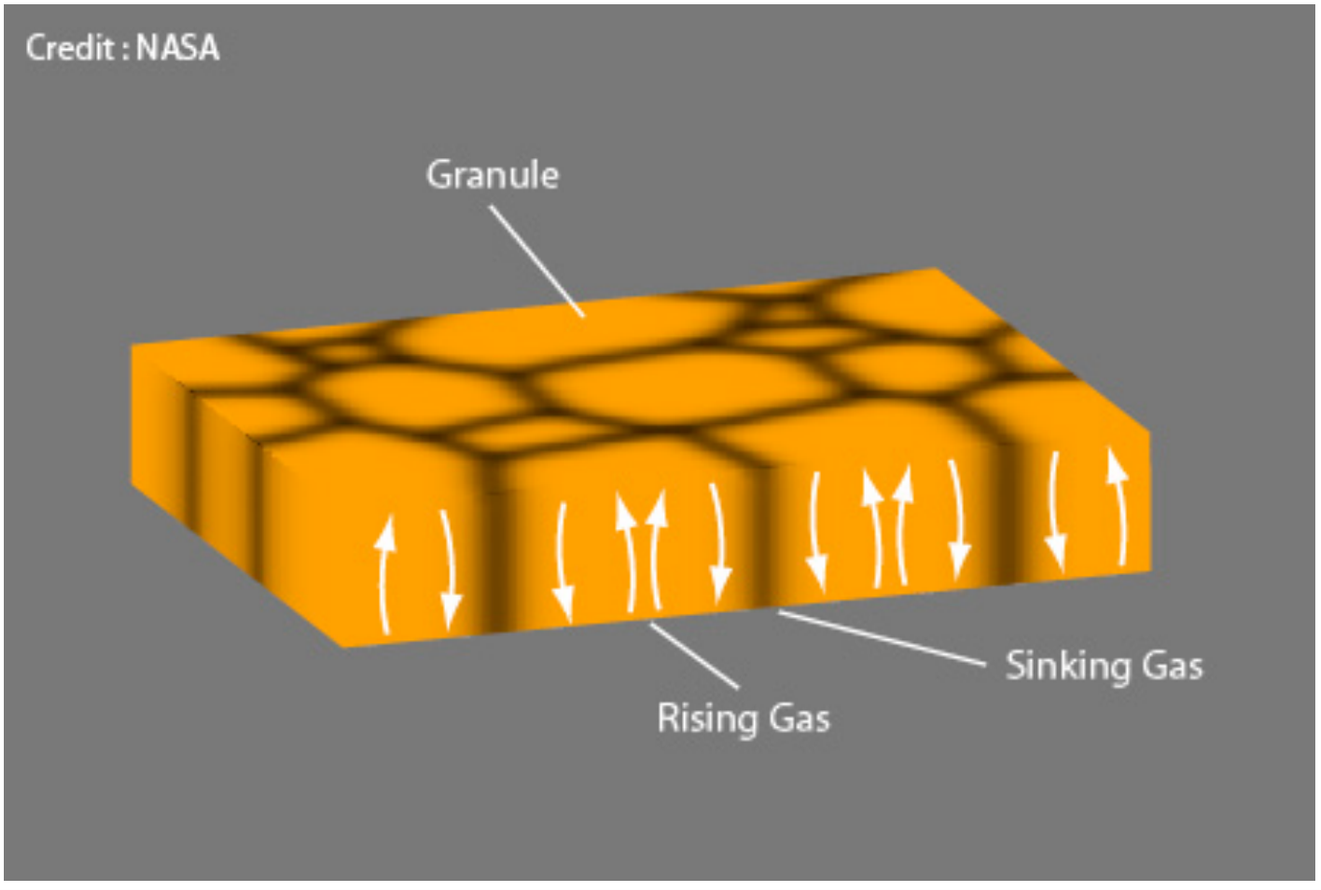
Sun's photosphere shows *granules*



NASA

The photosphere has a mottled appearance. This is because it is made up of dark-edged regions called granules. Each granule is about 1000 km across - approximately the size of Texas, lasting about 10-20 minutes.

Granules result from *convection*



In convection, energy is moved by hot material rising and cool material falling

Energy is flowing outward from the Sun's interior. Convection brings heat energy to the Sun's surface. Motion of the rising/falling gas in the photosphere causes granulation

Thought Question

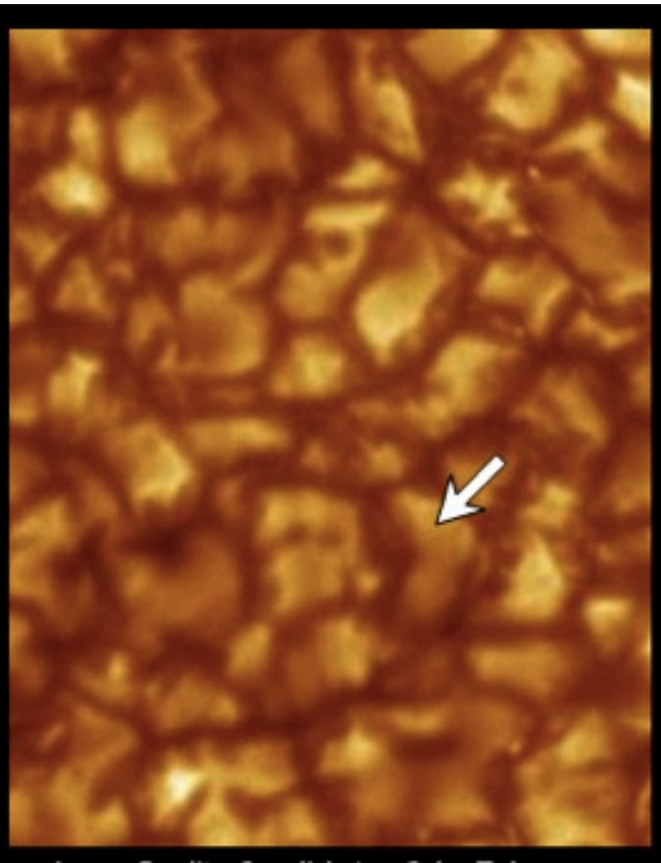


Image Credit: Swedish 1-m Solar Telescope

At left is a close-up picture of the Sun, showing the granulation of the surface. The location indicated by the arrow is **brighter** because...

(A) hotter material is rising

(B) hotter material is sinking

(C) cooler material is rising

(D) cooler material is sinking

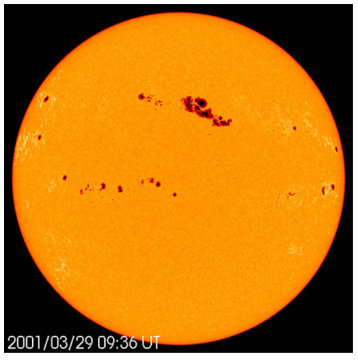
Show Answer

Hint: Think thermal radiation - which emits <u>more</u> light, a hotter object or a cooler object?

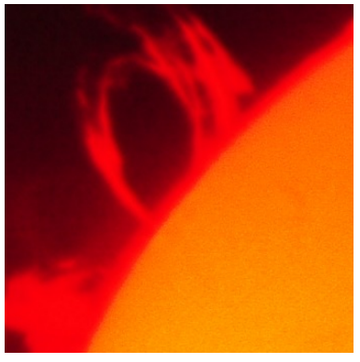
Answer A

The Active Sun

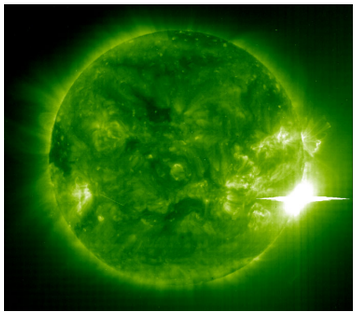
- Periodic disruptions in the Sun's atmosphere
  - **Sunspots**
  - **Prominences**
  - **Solar Flares**
  - **Coronal Mass Ejections**
- Connected to each other and the Sun's magnetic field!



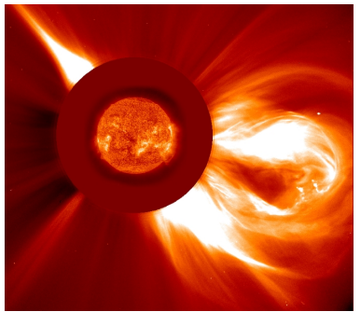
Sunspots



A solar prominence



A solar flare



A coronal mass ejection