# Astronomy 122

<u>This Class (Lecture 10):</u>

Fusion for you and me

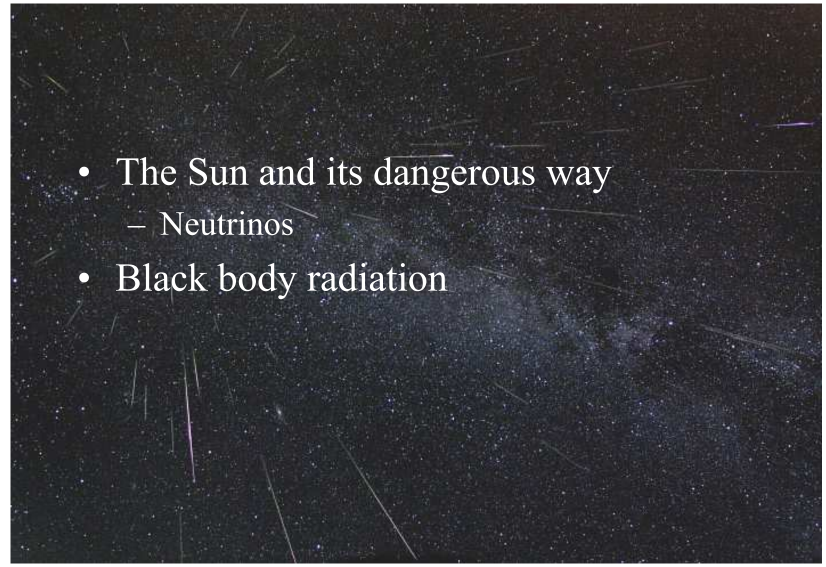
<u>Next Class:</u>

From Dust to Star

Music: *Invisible Sun* – The Police



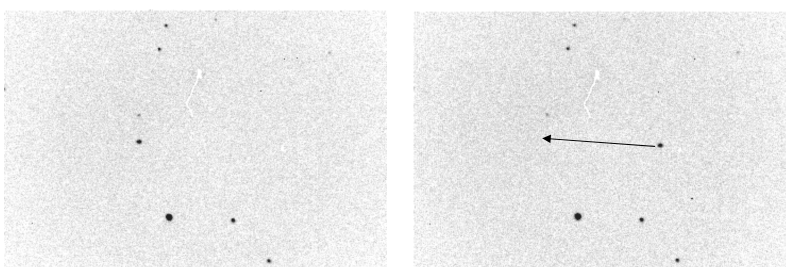
# Outline



- The Sun and its dangerous way
  - Neutrinos
- Black body radiation



# Parallax



- In 6 months, the star seems to move compared to the other stars.
- If star moves 1 arcsecond in 6 months, then its parallax is p= ½ arcsecond.
- Then, its distance away is d = 1/p = 2 parsecs



# Question

For the last question, what really happened?

a) The star moved
b) We moved
c) The background stars moved
d) The Moon moved
e) Nothing moved

# *They Might Be Giants*
# *Why Does The Sun Shine*

Why Does the Sun Shine?

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

The Sun is hot, the sun is not
A place where we could live
But here on Earth there'd be no life
Without the light it gives

We need its light
We need its heat
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

The Sun is hot

The Sun is so hot that everything on it is a gas: Aluminum, Copper, Iron, and many others

The Sun is large... If the sun were hollow, a million Earth's would fit inside
And yet, it is only a middle-sized star

The Sun is far away... About 93,000,000 miles away
And that's why it looks so small

But even when it's out of sight
The Sun shines night and day
We need its heat, we need its light
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

Scientists have found that the Sun is a huge atom smashing machine
The heat and light of the sun are caused by nuclear reactions between Hydrogen, Nitrogen, Carbon, and Helium

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where Hydrogen is built into Helium
At a temperature of millions of degrees



# *Interesting Question*

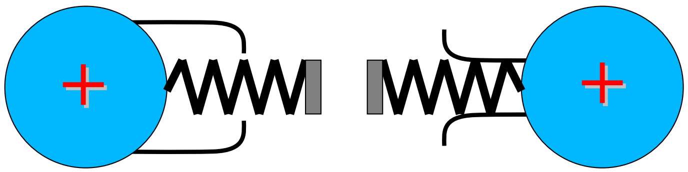
A star is in hydrostatic equilibrium. What does that mean?

a) Pressure from fusion is pushing back against the force from planetary orbits.
b) The star's radius does not change much.
c) Pressure from fusion is winning the war against gravity.
d) Gravity is perfectly balanced with electromagnetism.
e) None of the above.



## Why Nuclear Fusion Doesn't Occur in Your Coffee

- Fusion requires:
  - High enough temperature (> 5 million K)
  - High enough density
  - Enough time

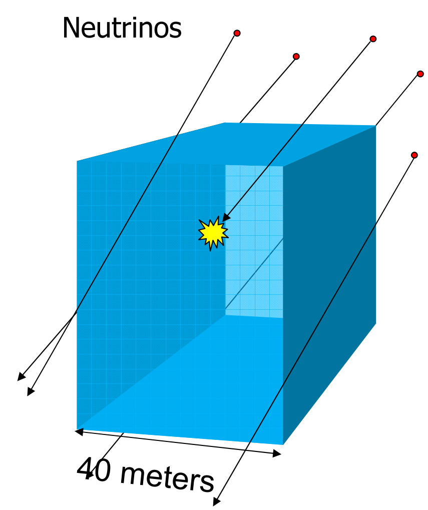


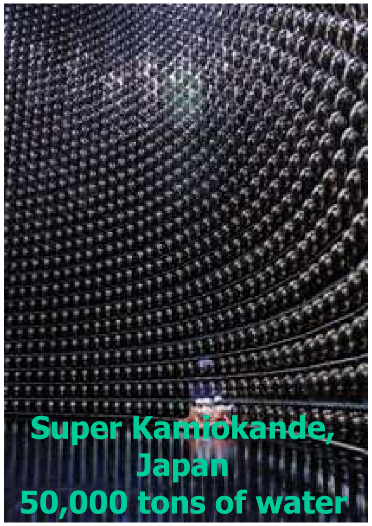
# *Sneaky Little Neutrinos*

- If we could detect them, we would prove that the Sun is a thermonuclear reactor.
- Matter is almost transparent to neutrinos
- On average, it would take a block of lead over a quarter of a light-year long to stop one
- Roughly 1 billion pass through every square centimeter of you every second!



# *Detecting Neutrinos*

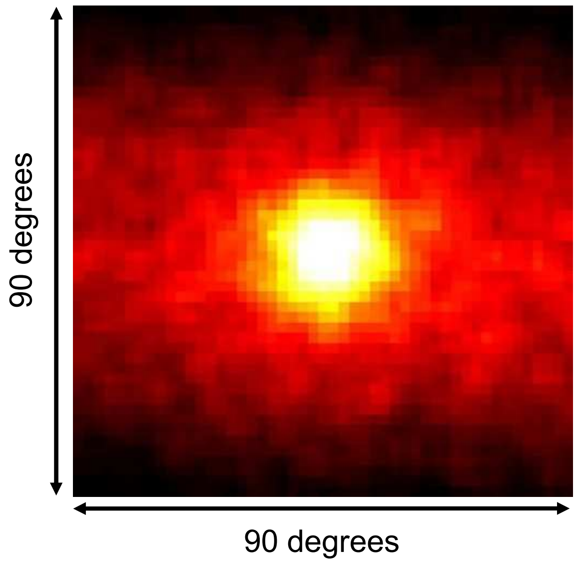





# *The Sun in Neutrinos*

- **Confirmation** that nuclear fusion is happening in the Sun's core
- 500 days of data
- As they can only be produced by nuclear processes, our energy source concept must be fundamental






# *Cosmic Gall*

**NEUTRINOS, they are very small.**
**They have no charge and have no mass**
**And do not interact at all.**
**The earth is just a silly ball**
**To them, through which they simply pass,**
**Like dustmaids down a drafty hall**
**Or photons through a sheet of glass.**
**They snub the most exquisite gas,**
**Ignore the most substantial wall,**
**Cold shoulder steel and sounding brass,**
**Insult the stallion in his stall,**
**And scorning barriers of class,**
**Infiltrate you and me! Like tall**
**and painless guillotines, they fall**
**Down through our heads into the grass.**
**At night, they enter at Nepal**
**and pierce the lover and his lass**
**From underneath the bed-you call**
**It wonderful; I call it crass.**

very little
hardly

Telephone Poles and Other Poems, John Updike, Knopf, 1960

# Think-Pair-Share

If we could sustain fusion in the lab we could meet humankind's energy needs forever! Why is it so difficult to achieve this, when stars do it every day?



# Question

If we could sustain fusion in the lab we could meet humankind's energy needs forever! Why is it so difficult to achieve this, when stars do it every day?

a) Need a lot of hydrogen
b) Need high temperature and pressure to overcome the natural repulsion of protons
c) Need exotic mass particles, neutrinos, to glue the protons together.
d) Need a really hot cup of really good tea.



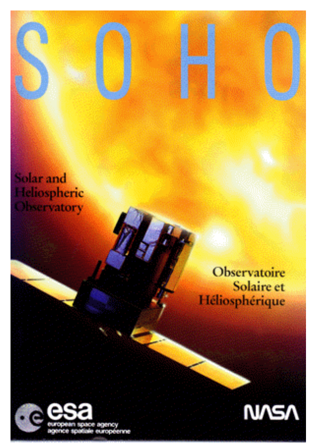
# How much Gas do we have left?

- Total energy available is easily calculated by mass of hydrogen in Sun and energy released by each hydrogen conversion.
- We only have about 5 billion years left!

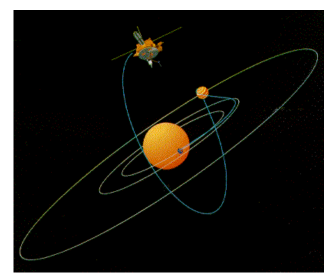

http://skeptically.org/sitebuildercontent/sitebuilderpictures/.pond/suv-econ-gas-pump.jpg.w300h294.jpg



# Spacecraft Observing the Sun




SOHO

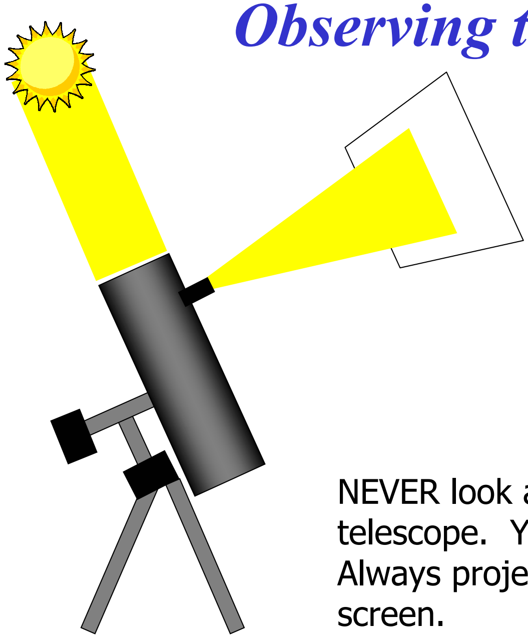


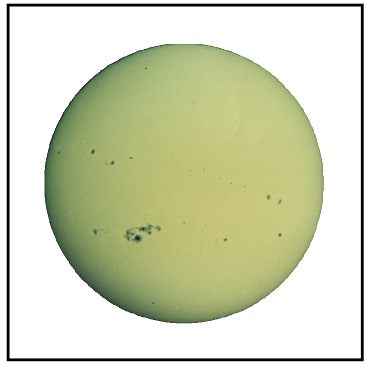
Ulysses

TRACE

RHESSI

# Observing the Sun

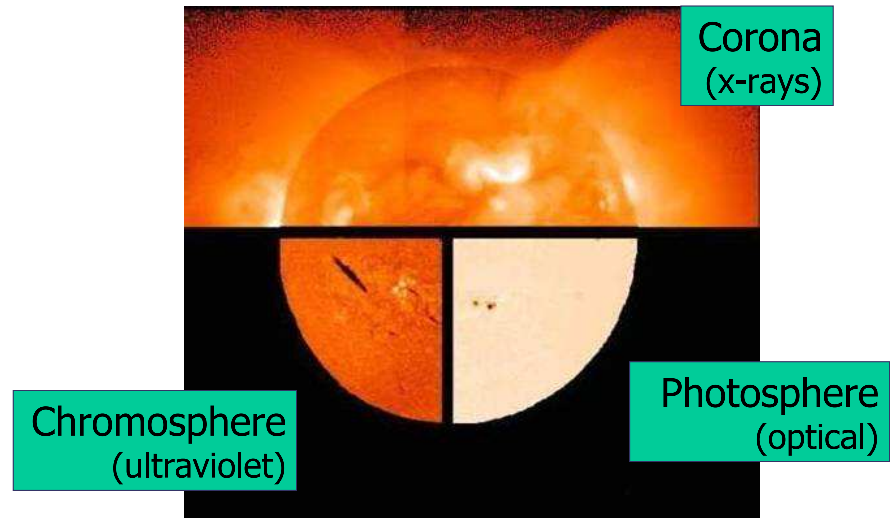




NEVER look at the Sun through a telescope. You will damage your eyes! Always project the Sun's image onto a screen.

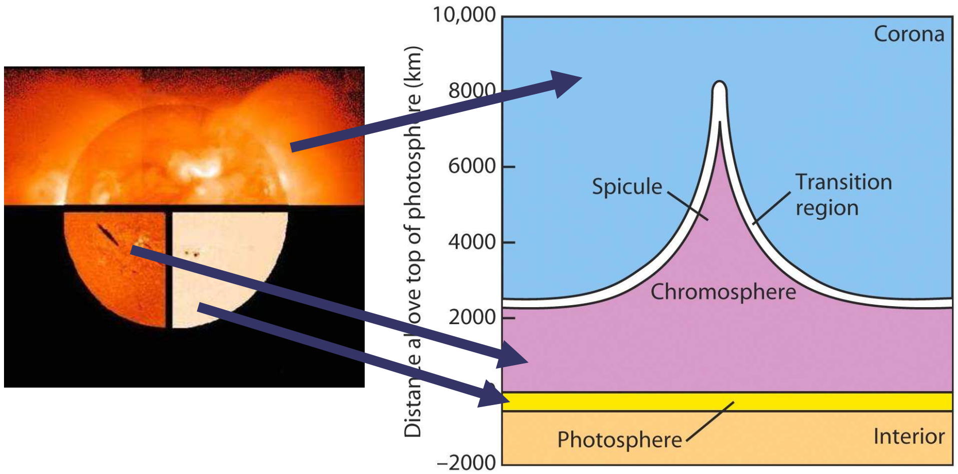


# The Outer Layers of the Sun






# Structure of the Outer Layers



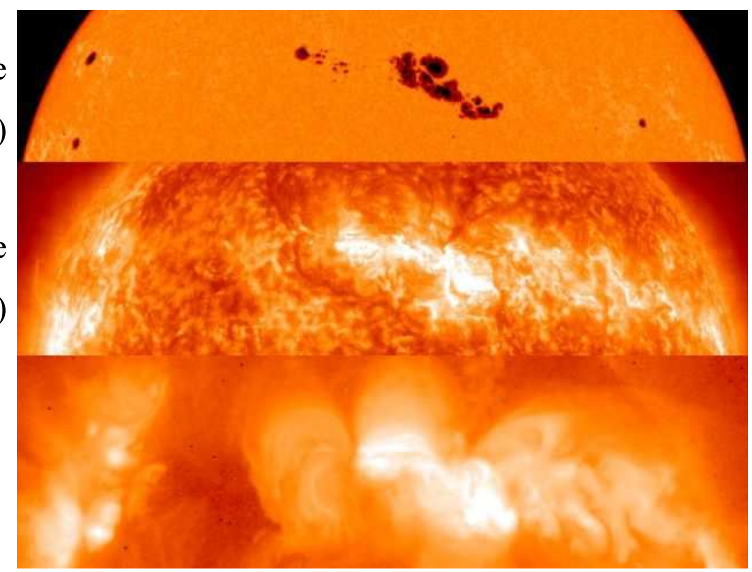



# The Various Layers

Photosphere (optical)

Chromosphere (ultraviolet)

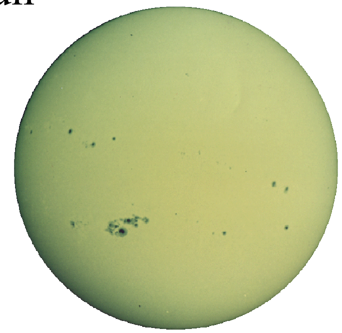
Corona (x-rays)



http://antwrp.gsfc.nasa.gov/apod/ap010419.html

# The Photosphere

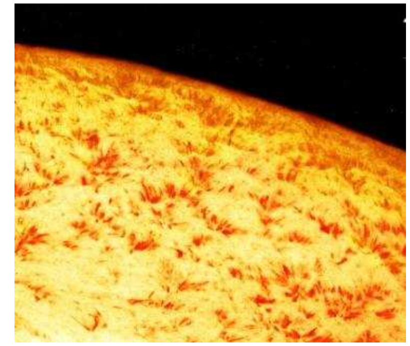
- Apparent "surface" of the Sun
  - Ionized atoms make the gas highly opaque
- Most of the Sun's light we see comes from the photosphere
- Temperature, about 5800 K
  - Hotter as you go deeper into the Sun





# The Chromosphere

- Very sparse layer of gas above the photosphere
- Hot – Over 10,000 K
- Produces very little radiation – too sparse
- Only seen during eclipse or with special instruments
- Helium was first discovered in the chromosphere





# The Corona

- Sun's outer atmosphere
- Visible only by blocking light from photosphere
- Heated by magnetic activity
- Temperatures about 2 million K
- Hot enough to produce X-rays!

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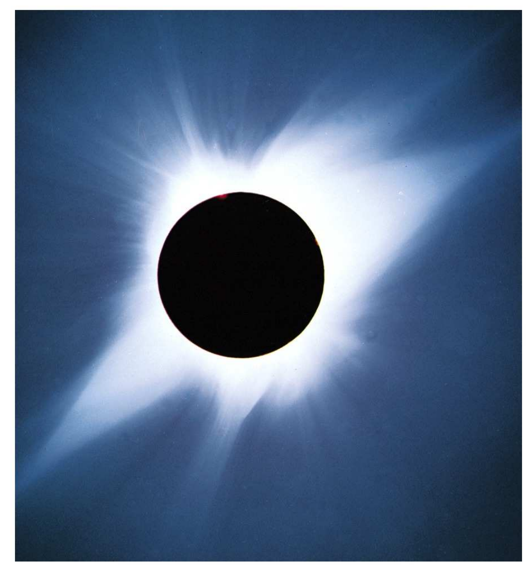
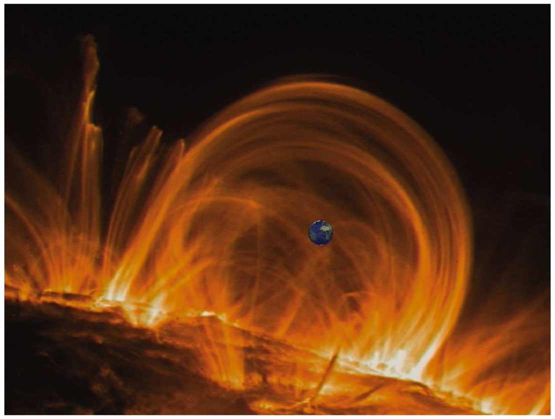


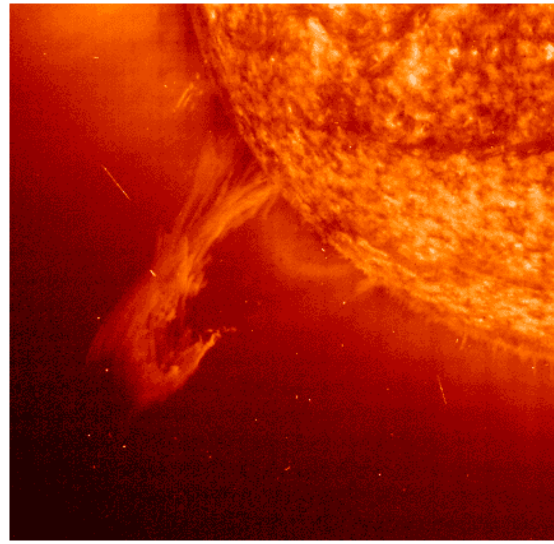
# Prominences

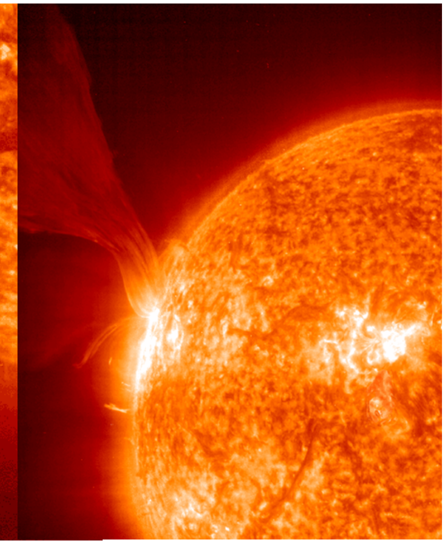
- Ropes of gas trapped in magnetic loops
- Almost always associated with sunspots
- Gas can reach temperatures of 50,000 K!





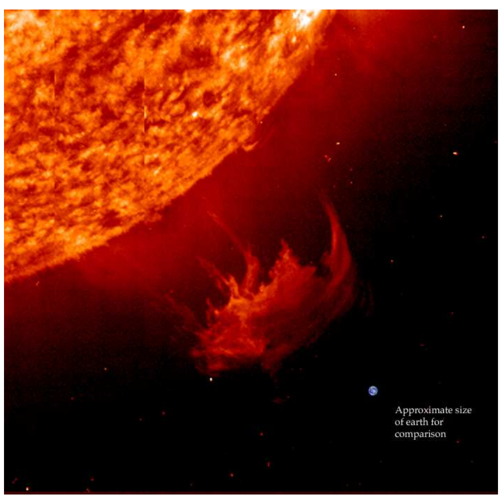
# And more…

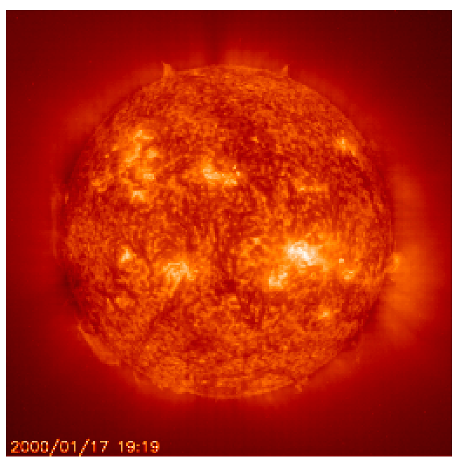






# And more!

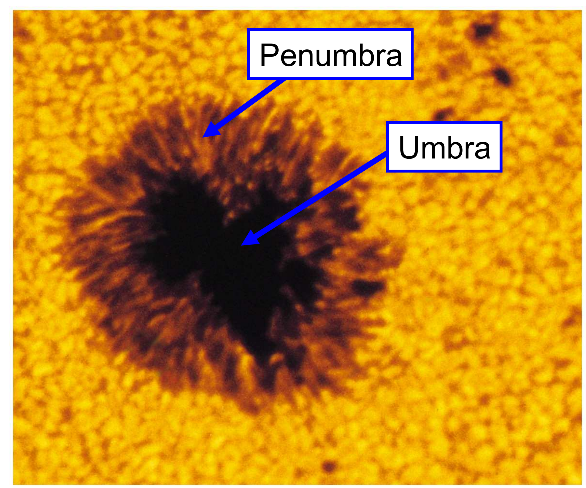




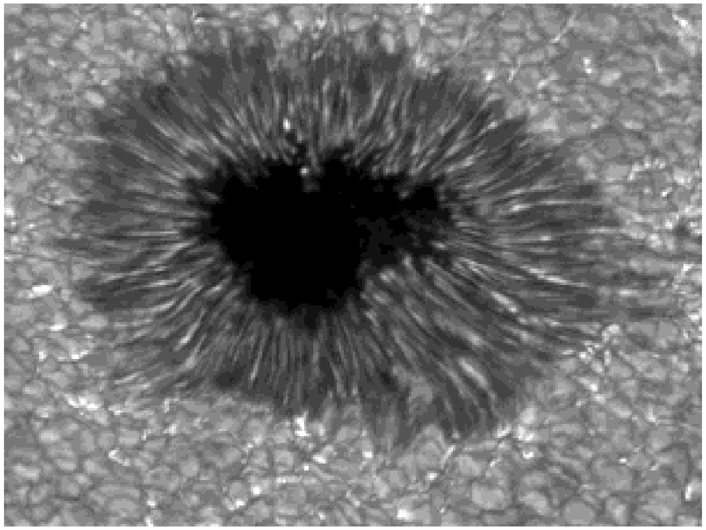

# Why are Sunspots Dark?

- Magnetic field “loops” popping through photosphere
- Cooler than surroundings (4000 K) – but still hot!
- Sizes ~ 1,500 – 50,000 km



# *Sunspots*

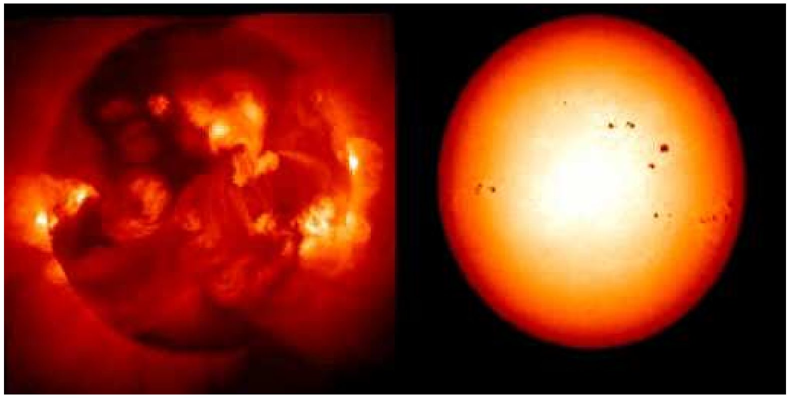
- Can be used to find the rotation rate of Sun.
- Usually last for around 2 months.



http://antwrp.gsfc.nasa.gov/apod/ap000223.html



# *Optical and X-Ray Sunspots*

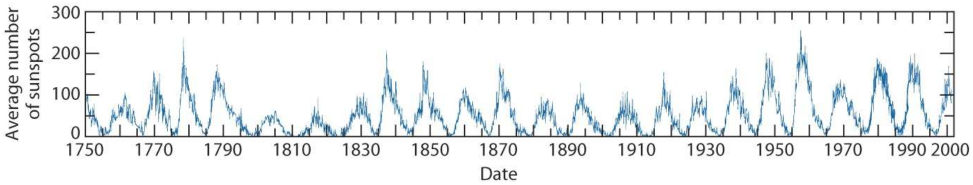


http://eeyore.astro.uiuc.edu/~lwl/classes/astro100/fall03/Lectures/xrayvsvis.mov



# Sunspot Cycles

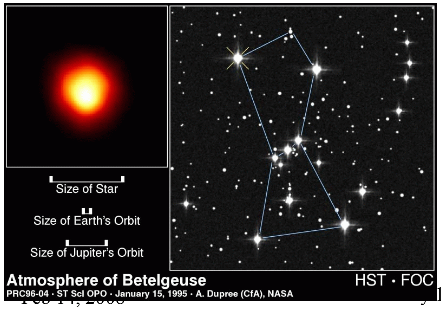
- Start near 30°N/S, migrate toward equator
- More numerous every 11 years (**solar maximum**)

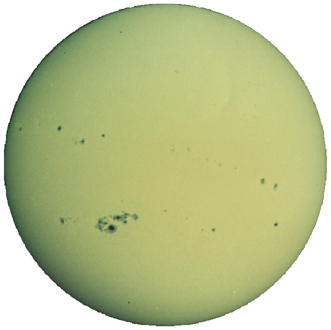





# *Stars as Suns*

- The Sun is a nuclear reactor, but I'm saying much more than that: Sun is a typical star
- So all stars are run by thermonuclear fusion
- Night sky, Universe lit up ultimately by dense nuclear furnaces scattered everywhere
- How do we know Sun is typical?

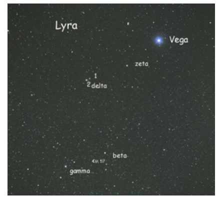


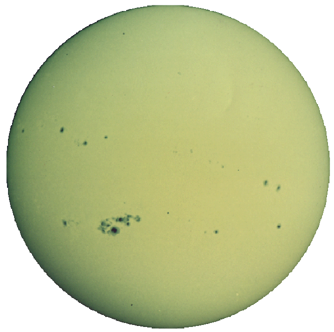



# *Why is the Sun Yellow-ish?*

- If you look at the stars, you may notice that the stars have different colors.
- Blue, red, yellow.. etc..
- Why?



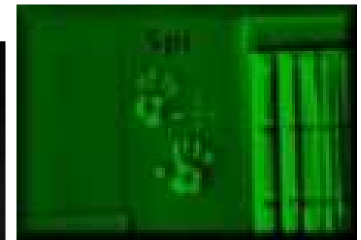






# *Glowing Bodies*

- Everything we know is in fact giving off light– as long as it has a temperature (T > 0 K), it is glowing.
- The higher the temperature the shorter the wavelength it glows in– compare the person on the right (in the near infrared) and a light bulb (in the visible).

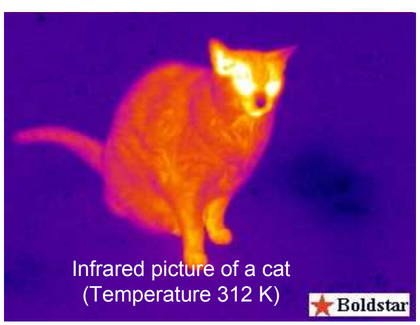




http://www.x20.org/thermal/thermal_weapon_sight_TIWS320.htm

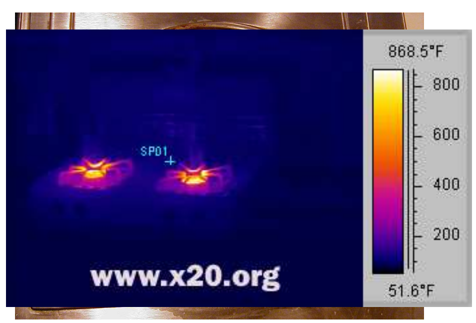


# Blackbody Radiation

- Light that objects emit because of their temperature is called **blackbody radiation**
- Blackbody radiation is composed of a continuous spectrum of wavelengths
- The **hotter** an object gets, the **more intense** and **shorter wavelength** (blue-er) its blackbody radiation becomes



Infrared picture of a cat
(Temperature 312 K)



Visible-light picture of a stove element
(Temperature ~ 400 K)

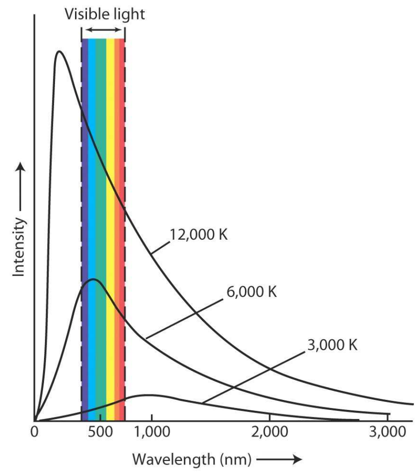


# *Define Blackbody*

- A body that re-emits radiation according to its temperature
- Therefore, “blackbody radiation" = thermal radiation
- Usually, most familiar objects are well approximated as blackbody radiators
- A clear exception is a laser pointer.
  - Why?
- The spectrum of this ideal, only depends on its temperature!

# The Spectrum of Blackbody Radiation

- Brightness is > 0 for all λ
- For higher temperature the maximum occurs at shorter wavelengths.
- For lower temperatures the maximum occurs at longer wavelengths.






# The Spectrum of Blackbody Radiation

- Brightness is > 0 for all λ
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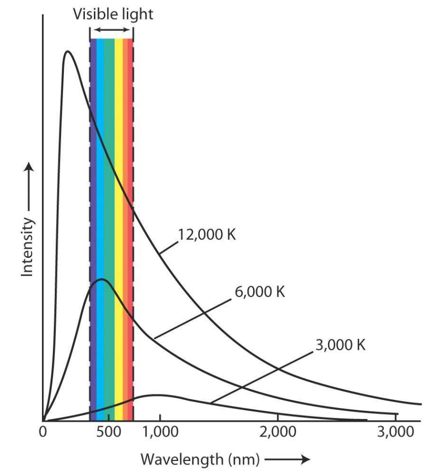
- For lower temperatures the maximum occurs at longer wavelengths.

Wien's Law

$$\lambda_{max} = \frac{0.0029}{T}$$

(T is in Kelvin & $\lambda$ in meters)






# The Spectrum of Blackbody Radiation

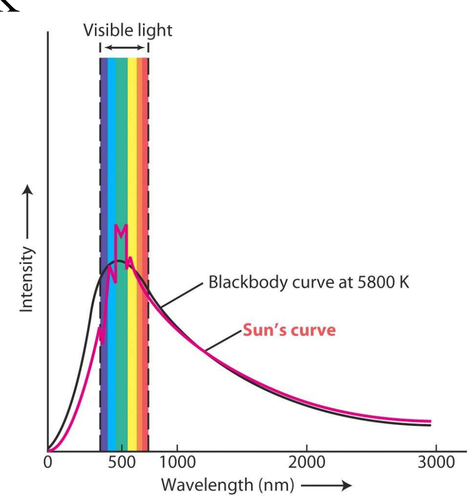
Sun's maximum is at ≅ 500 nm

$$\text{So, T} \approx \frac{0.0029\ \text{m}}{500 \times 10^{-9}\ \text{m}} K = 5800\ \text{K}$$

The Sun’s spectrum looks almost like a 5800 K blackbody.

This is a very powerful tool! We can find the temperature by the light shape (spectrum).

Color ⇔ Temperature!






# Think

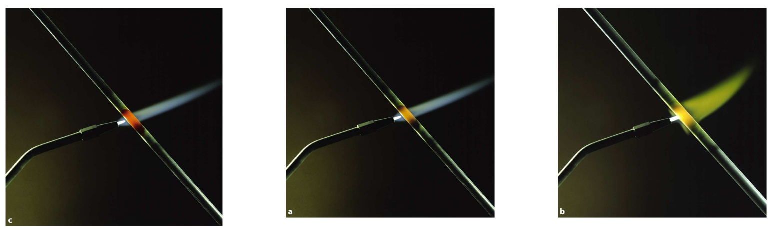
Which star is hotter?

a) Vega (blue)
b) Capella (yellow)
c) Antares (red)

- Note: It doesn’t matter how far away the star is!

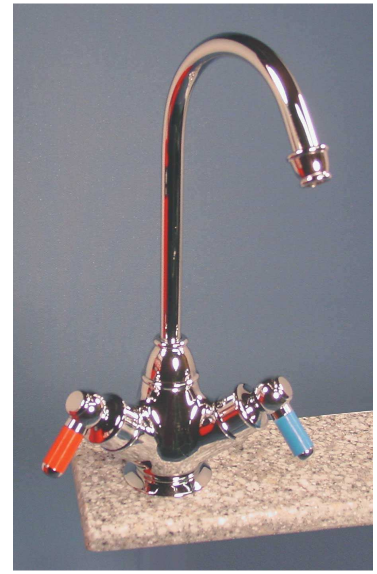
# Red Hot?

- Actually Red hot is not too hot.
- Blue hot is hot.
- White hot is even hotter.



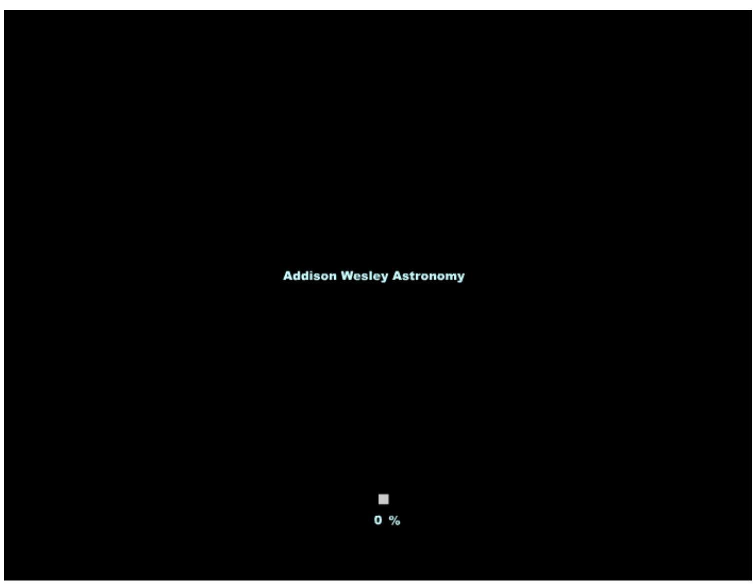


# Common Error?





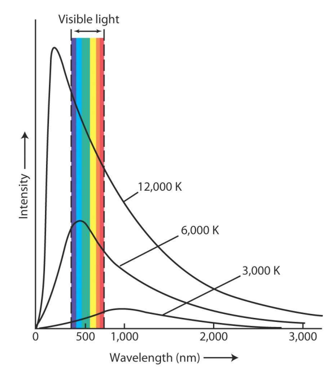
# Wien's Law






# Blackbody Flux-ed

- Flux is the energy flow, or how rapidly energy flows out of the blackbody.
- The total flux from a blackbody is found by adding up the intensity in the spectrum.
- Do you think it depends on temperature?




a) Yes

b) No

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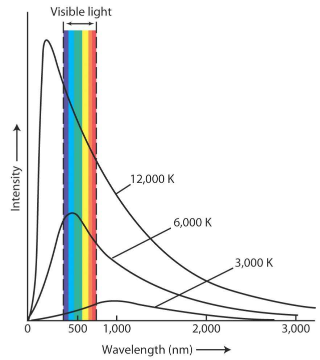
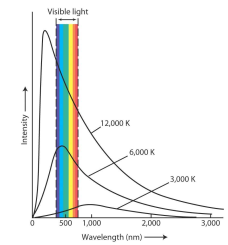



- Strongly dependent on temperature.
  - $F = \sigma T^4$ energy per per unit area per unit time



# Blackbody Flux-ed




- Strongly dependent on temperature.
  - $F = \sigma T^4$ energy per per unit area per unit time

$$\sigma = 5.67 \times 10^{-8} \frac{\mathrm{W}}{\mathrm{m}^2 K^4} \quad \text{Stefan - Boltzmann}$$



# Stephan-Boltzmann Law

If the Sun, suddenly became twice as hot, it would be

a) 1/4 times dimmer
b) 1/16 times dimmer
c) 2 times as bright
d) 4 times brighter
e) 16 times brighter