
The Cosmos
Planets & Life
PHYS 214
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Please start all class related emails with "214:"

Interesting links & events

- Interesting website:
  - http://www.astrobio.net
- Lots of articles on Astrobiology

- Next observatory open house:

  Feb 10, 7:30-9:30
  - (Observatory is on top of Ellis Hall)
  - I'm giving a short talk on early Universe
  - BUT! You can look through the observatory's 16 inch reflecting telescope

What variables do we know so far?

- In the equation for the number of civilizations in the observable Universe:

$$N = GRp_b n_E p_l p_i L$$

100 billion

- Over the next two days we'll constrain the value of R – the rate of formation of stars

Today's Lecture

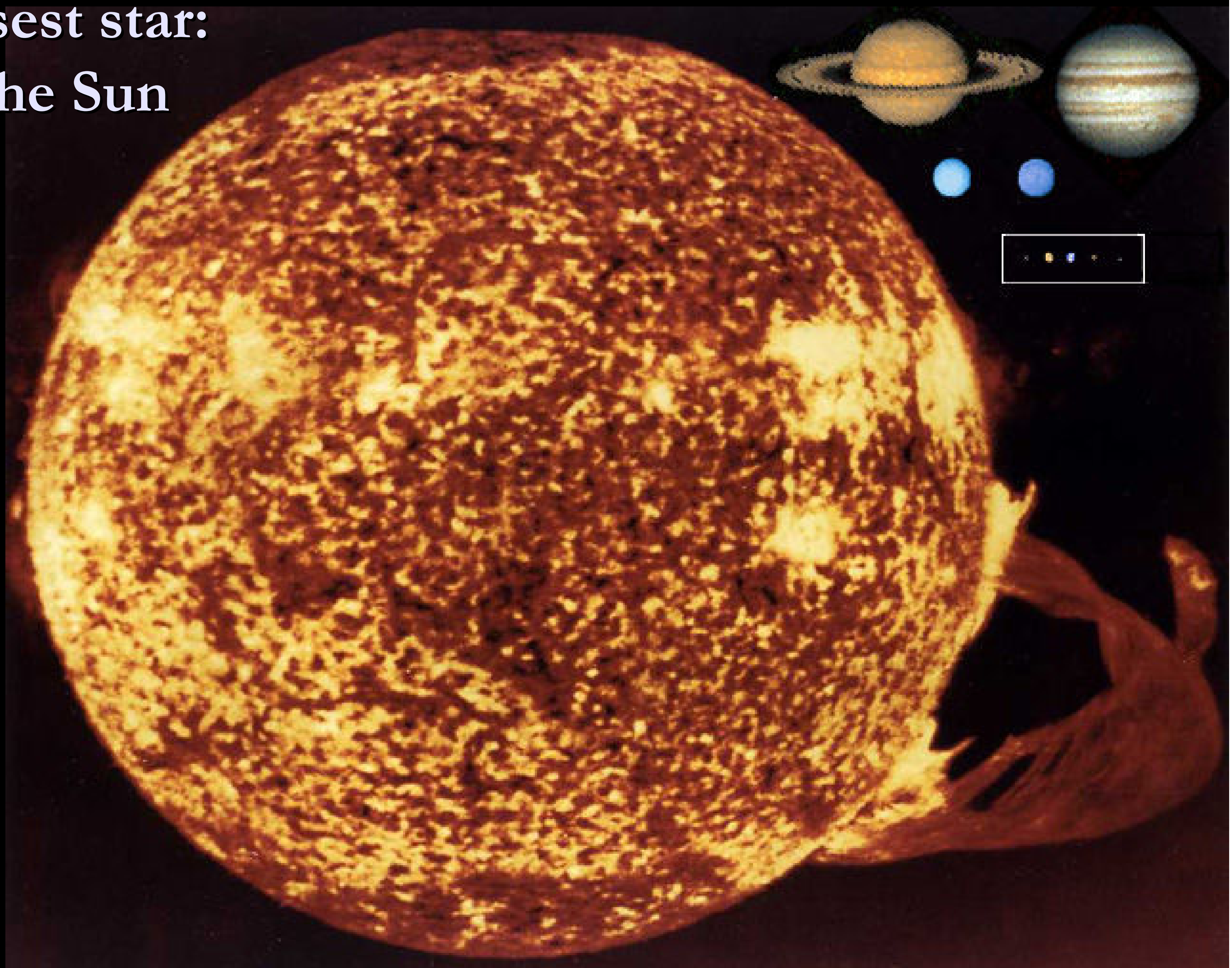
- Properties & classification of stars
  - See blue section in book, p.236
  - Nearest star – the Sun
  - Stellar sizes
  - Stellar classification & temperatures
  - Stellar structure
  - Powering stars: nuclear fusion

- Suggestions for additional reading (not compulsory!)
- Prof. Richard Pogge's Astronomy 162 notes:
  - http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit2/structure.html

Properties of Stars

- **Stars are important in the search for life because:**
  - ***planets*** form along with stars
  - stars provide ***energy*** for life on planets
  - all of the ***heavy elements*** are created in stars
  - stars are best places to look in the ***SETI***
- Thus we need to know more about stars: how they are ***formed***, what keeps them ***going***, how they ***die***
  - Some stars die in a *supernova* explosion and end up as “black holes”
- Which stars are ***most suitable*** for evolving intelligent life?
  - Determined by stellar ***luminosities*** and ***lifetimes***

Closest star:
The Sun



McMath-Pierce Solar Telescope

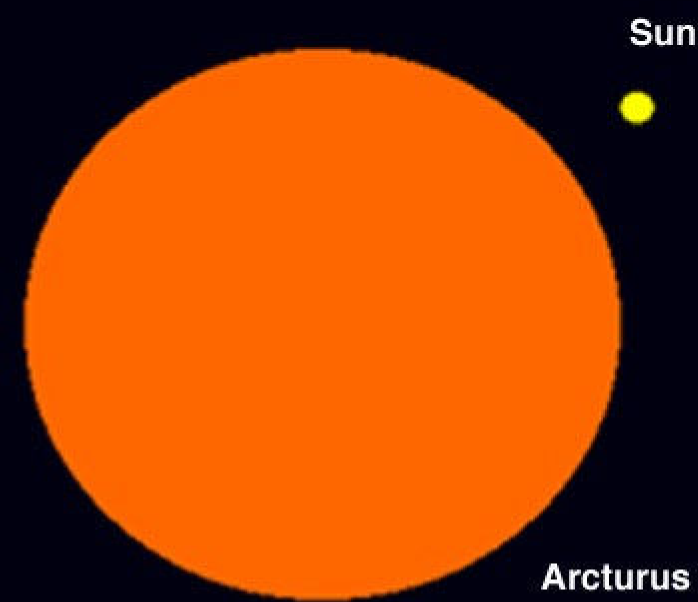
- Unusual design since the light is projected down the structure to observing room(s)

WARNING!

- NEVER EVER look at the Sun through binoculars or a telescope
- With the exception of specialist filters, almost all solar telescopes project their light on to a viewing surface

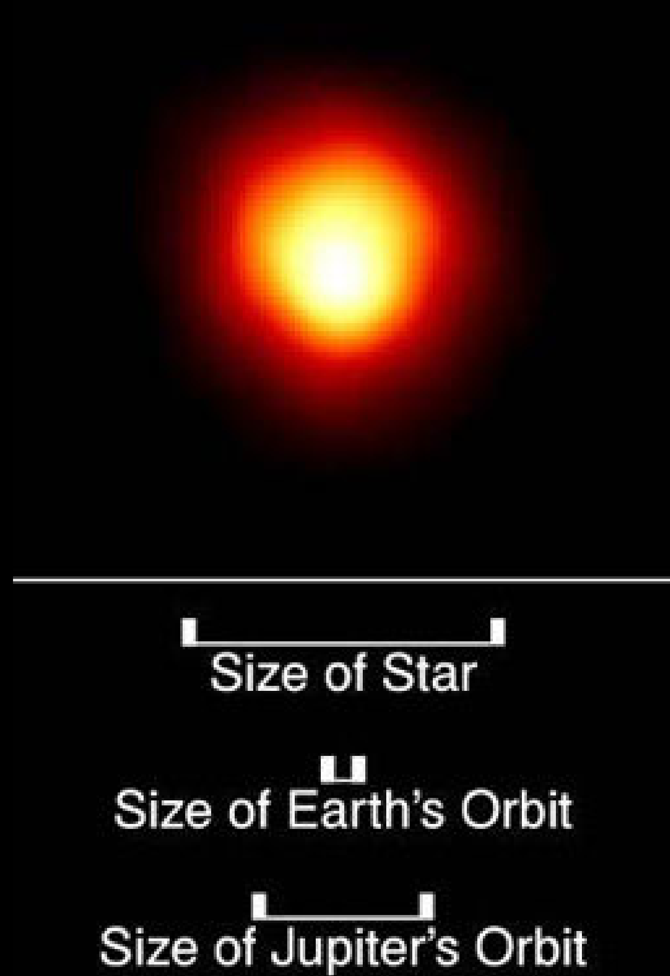
Stellar sizes

- Much like planets stars come in a wide variety of sizes
- At the lowest end of the stellar size scale are dwarf stars
  - Most of the stars in the Milky Way are actually dwarf stars
- At the highest end of the size scale are supergiants like Betelgeuse



Arcturus, a red giant, is only about 1.5 times more massive than the Sun, yet its diameter is over 16 times that of the Sun.

Comparison of Betelgeuse to the orbit of the Earth



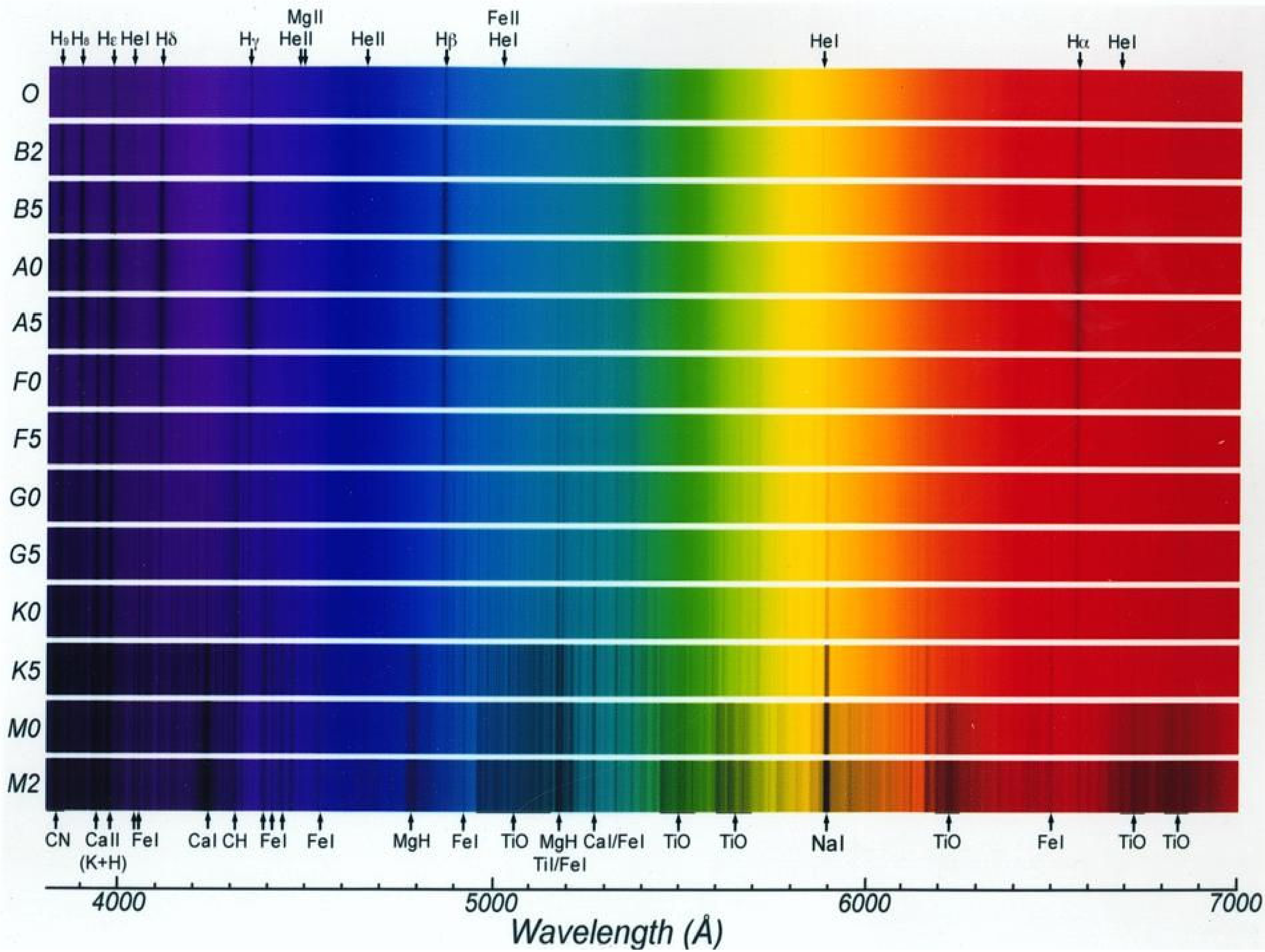
- Betelgeuse is an example of a *supergiant* star
  - The mass of Betelgeuse is only about 15 times the mass of the Sun though
- Even at a distance of 130 pc the disk is barely resolvable and has angular diameter of 0.054”
  - $D=\theta d$ implies a diameter of about 7.2 AU!
  - i.e. radius is 3.6 times Earth’s orbit
  - Sun’s radius is around 0.00045 AU for comparison

Spectral classes of stars

- By end of 1800s, 1000s of stellar spectra were available, thanks to **Henry Draper** – huge undertaking!
- Edward Pickering, **Annie Jump Cannon** and other women classified these stars from spectral lines. Their classes – A, B, C, D, etc, were mostly based on **temperature** and **hydrogen lines**
- **Henry Draper Catalog** (1918-1924) had spectral data for > 225,000 stars.

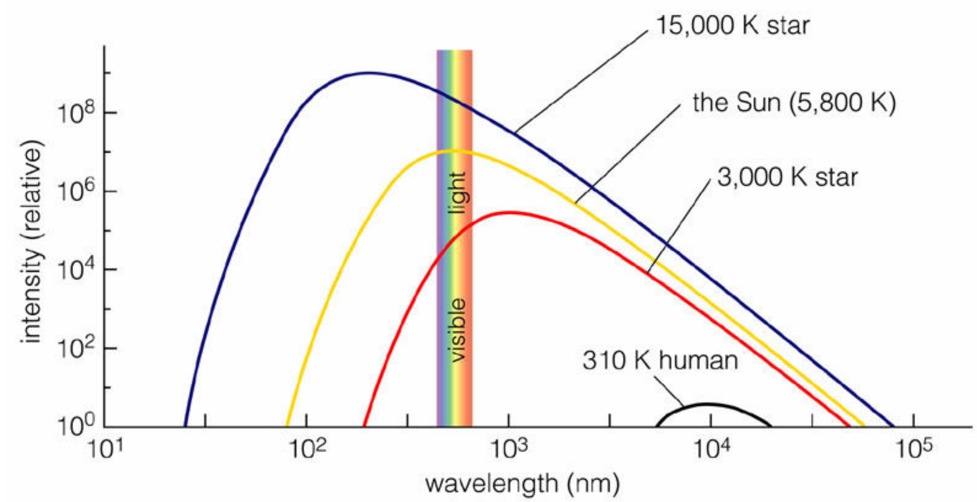
Physics of Stellar Classification

- The ***spectral patterns*** classified by Cannon weren't understood until 1920s or so. They are mostly due to Hydrogen, but other elements also present.
- ***Temperature*** is most important: determines what lines are present (e.g. ions, and how many electrons are in different ***energy levels***) and their ***strengths*** (e.g. amount of absorption)
- Now stellar spectral classes are ***ordered by temperature***, and the order is: O, B, A, F, G, K, M (RNS, L,T). Lots of mnemonics ...
- Each class further **subdivided** into 10: e.g. the Sun is G2. A G5 star is hotter than a G2 star and so on


Hε HeI Hδ
Hγ
MgII
HeII
HeII
Hβ
FeII
HeI
HeI
Hα
HeI
O
B2
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M2
CN
CaII
(K+H)
FeI
CaI
CH
FeI
FeI
MgH
FeI
TiO
MgH
TiI/FeI
CaI/FeI
TiO
TiO
NaI
TiO
FeI
TiO
TiO
4000
5000
6000
7000
Wavelength (Å)

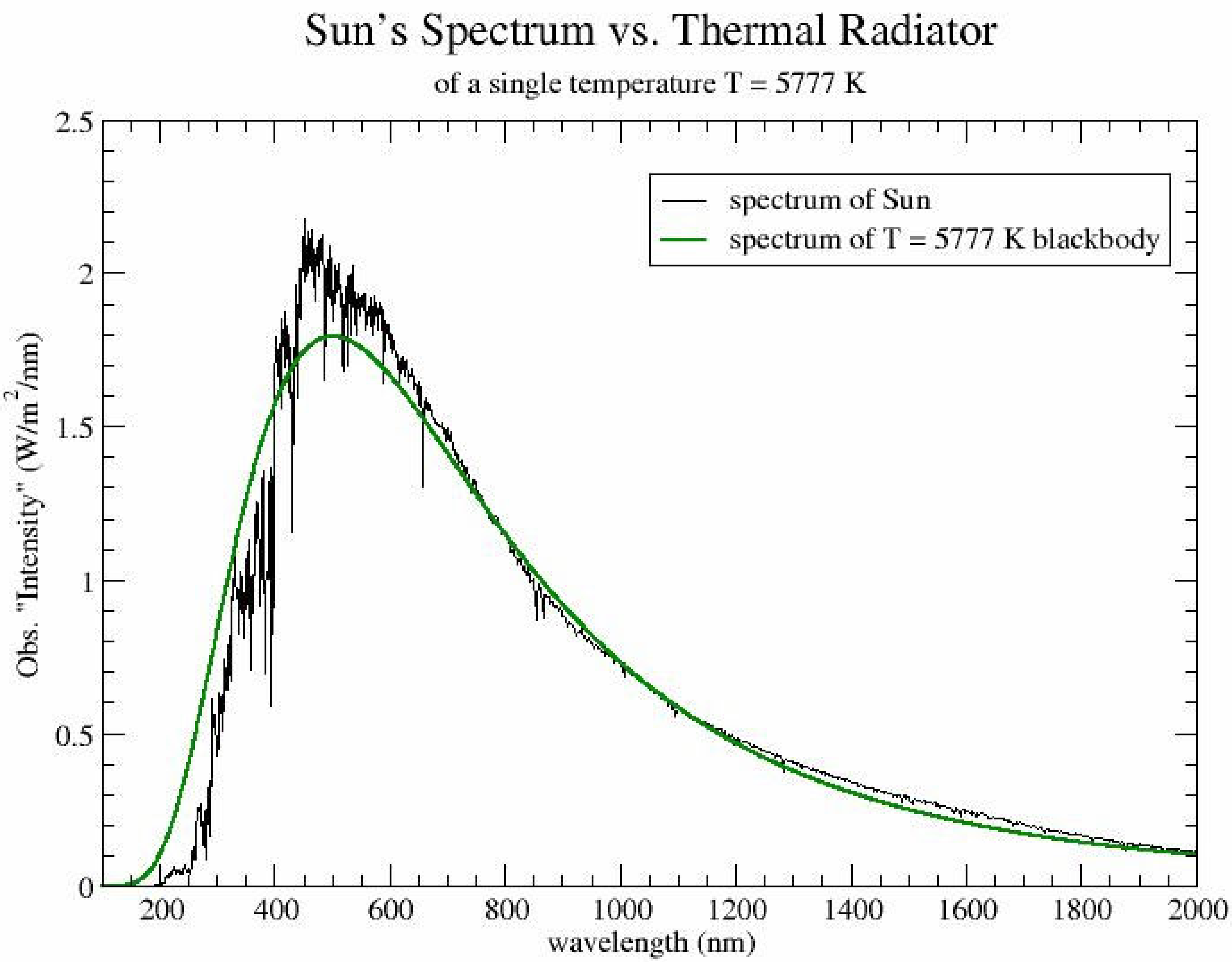
Measuring stellar temperatures

- We use the black body spectrum to evaluate the temperature of a star
- We can look at the luminosity at various wavelengths to find the wavelength at which peak luminosity occurs, λ_{max}
- Wien's Law $\lambda_{max} T = 3 \times 10^6$
  - when λ_{max} is in nm and T is in K, is then used to evaluate the temperature

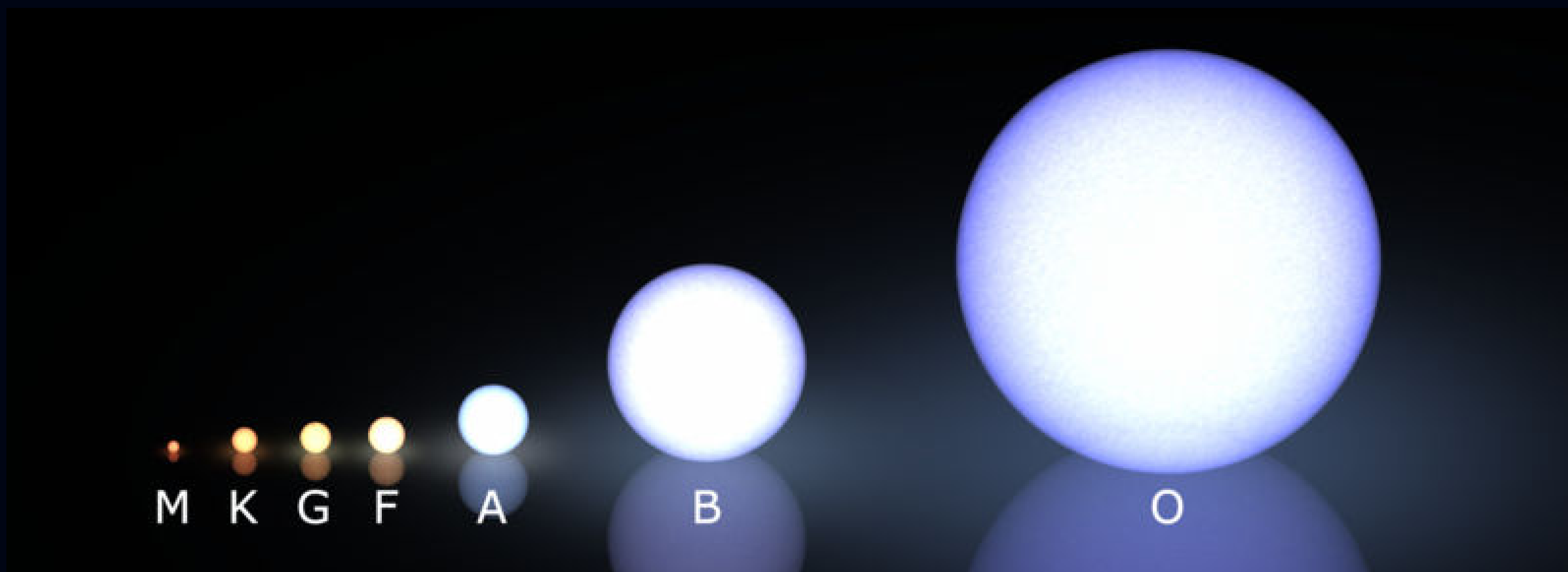


As the peak emission wavelength gets shorter with increasing temperature cooler stars appear redder while hotter stars appear bluer.

However, stellar classification is more important than temperature – tells about both temperature and composition


Sun's Spectrum vs. Thermal Radiator
of a single temperature T = 5777 K
spectrum of Sun
spectrum of T = 5777 K blackbody
Obs. "Intensity" (W/m^2/nm)
wavelength (nm)
0
0.5
1
1.5
2
2.5
200
400
600
800
1000
1200
1400
1600
1800
2000

Perceived colours



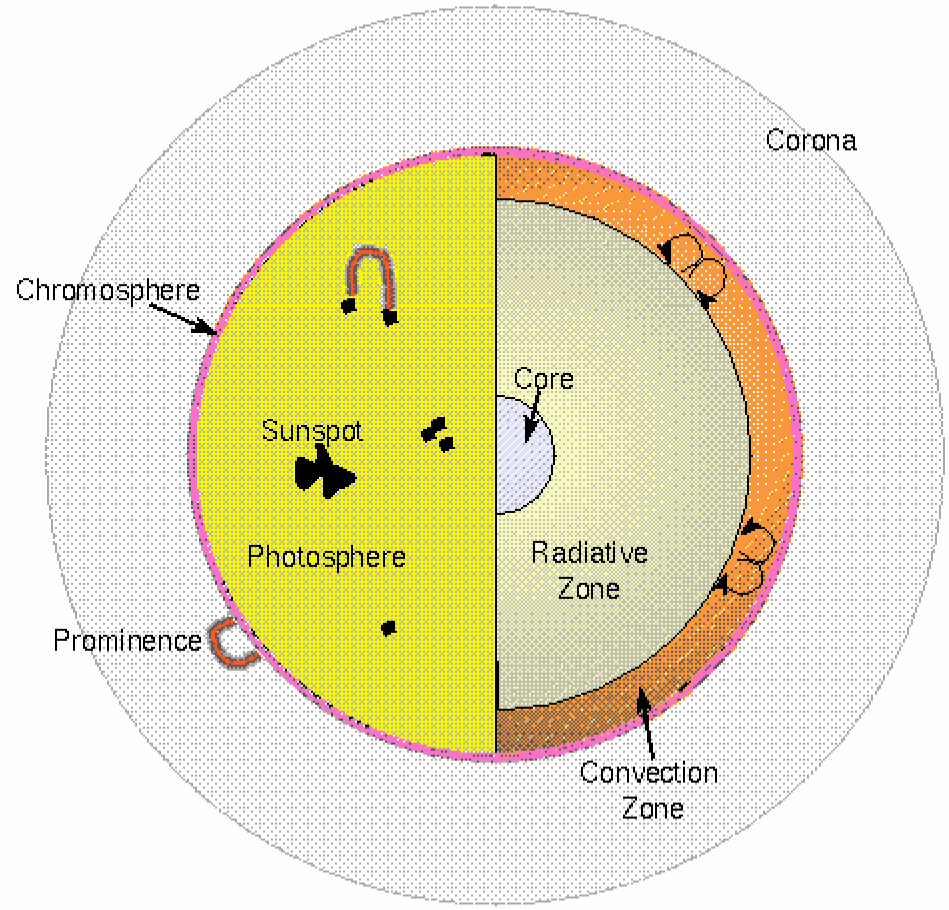
Classes & "average" properties

Class	Temperature	Star colour	Mass (times that of Sun)	Radius (times that of Sun)	Luminosity (times that of Sun)
O	30,000-60,000 K	Blue	60	15	1,400,000
B	10,000 – 30,000 K	Blue-white	18	7	20,000
A	7,500 – 10,000 K	White	3.1	2.1	80
F	6,000 – 7,500 K	Yellow-white	1.7	1.3	6
G	5,000 – 6,000 K	Yellow	1.1	1.1	1.2
K	3,500 – 5,000 K	Orange	0.8	0.9	0.4
M	2,000 – 3,500 K	Red	0.3	0.4	0.04

Colours are exaggerated, note that sizes, luminosity and radius also vary (more next lecture)

Stellar Properties: Preliminaries

- Before we discuss stellar properties in more detail, it is worth looking at the fundamental phenomena behind stars
- Much like the Big Bang, all the four forces have a role to play in stellar physics
  - Some are significantly more important than others though
- Let’s begin by looking at the overall structure of a star



Energy is generated in the **core** where the temperature reaches 16 million K and the density is 160 g/cm^3 and then transported outward by radiation. In the **convection zone** rising and falling gas is used to tranfer the energy to the **photosphere** (''surface'' of the Sun). **Sunspots** are cooler, dimmer regions with strong magnetic fields. Some sunspots have **prominences** forming over them. The **chromosphere** is a thin pink layer above the photosphere that is hotter than the photosphere. The temperature increases outward into the **corona**, the very hot (1–2 million K) but tenuous atmosphere of the sun. Fast moving ions in the corona escape the Sun to form the **solar wind.**

Transfer of energy from the solar core

- ***Conduction:*** *direct transfer of heat (kinetic energy)* by atomic collisions. Heat is passed along from atom to atom.
  - *e.g.* heat conduction along a metal bar
- ***Convection:*** heat is transferred by **bulk movement** of material
  - *e.g.* hot air rising, water boiling on a stove, *etc.*
- ***Radiation:*** heat is transmitted via radiation. Does not require a medium in which to travel
  - e.g. Sun heats up Earth via radiation (feel infra-red)
- **In the Sun**: in the **center** heat moves mostly by **radiation**, but near the **surface** by **convection**

Photosphere

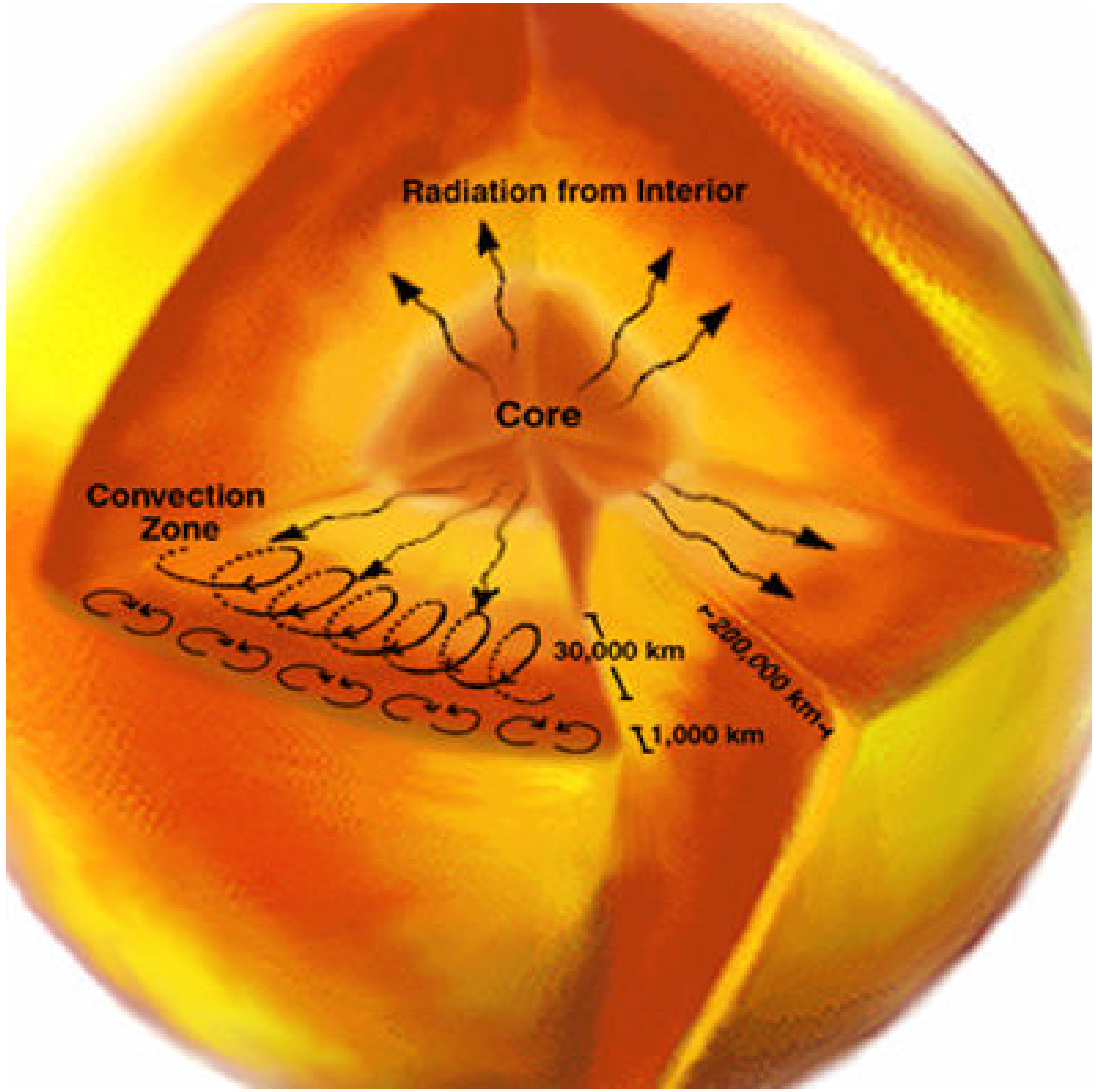
Photosphere temperature around 5800 K

Chromosphere

Hotter than the photosphere
(around 7500 K)

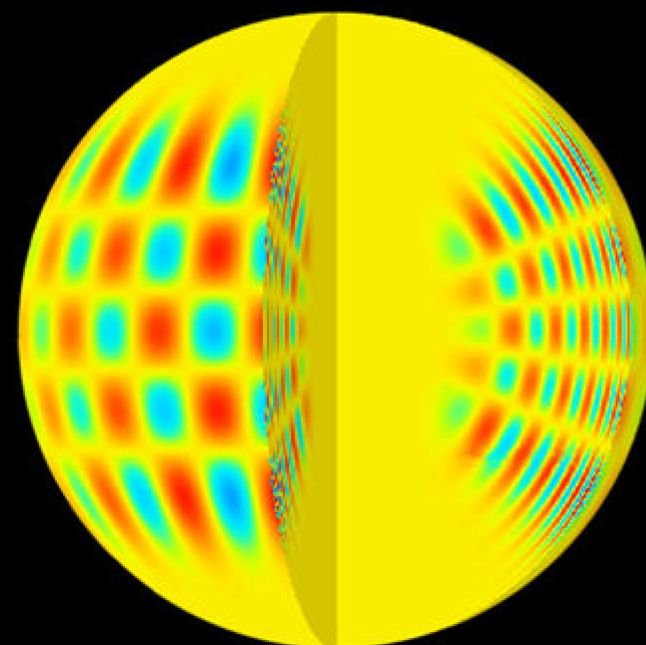
Corona

Hotter than the chromosphere – temperature is over million K

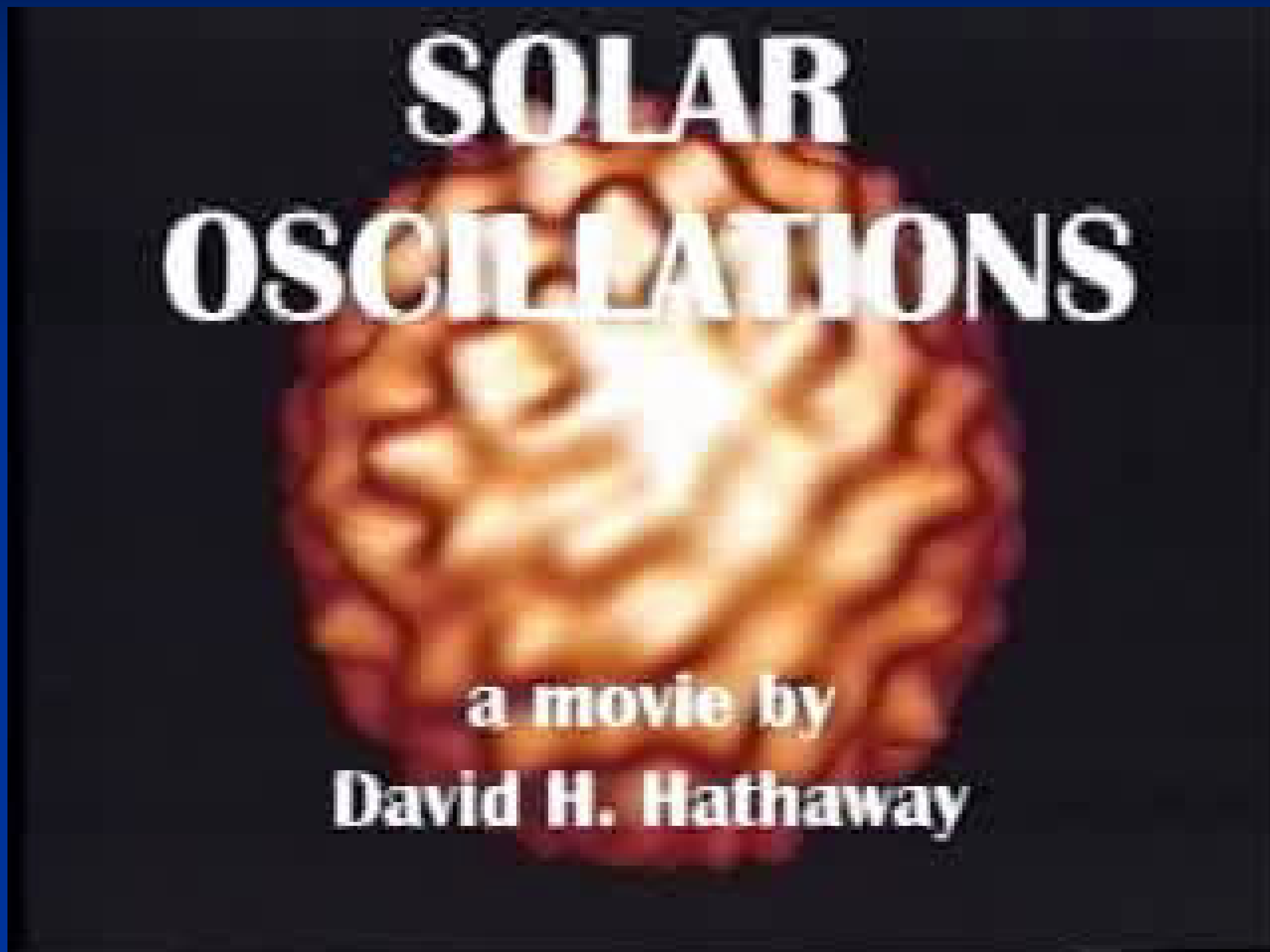

Radiation from Interior
Core
Convection
Zone
30,000 km
~200,000 km
1,000 km

Helioseismology

- Just like seismic disturbances on the Earth the Sun exhibits responses to pressure waves
  - "Music of the spheres"
- We can probe the inner parts of the Sun using data about these oscillations

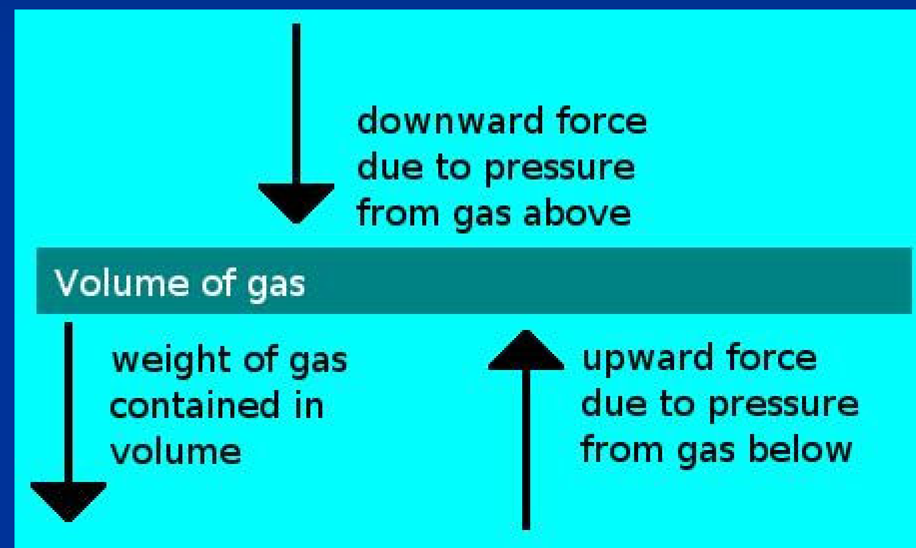


Pattern of oscillations in the Sun – we can measure these oscillations by following the velocity of the surface of the Sun


SOLAR
OSCILLATIONS
a movie by
David H. Hathaway

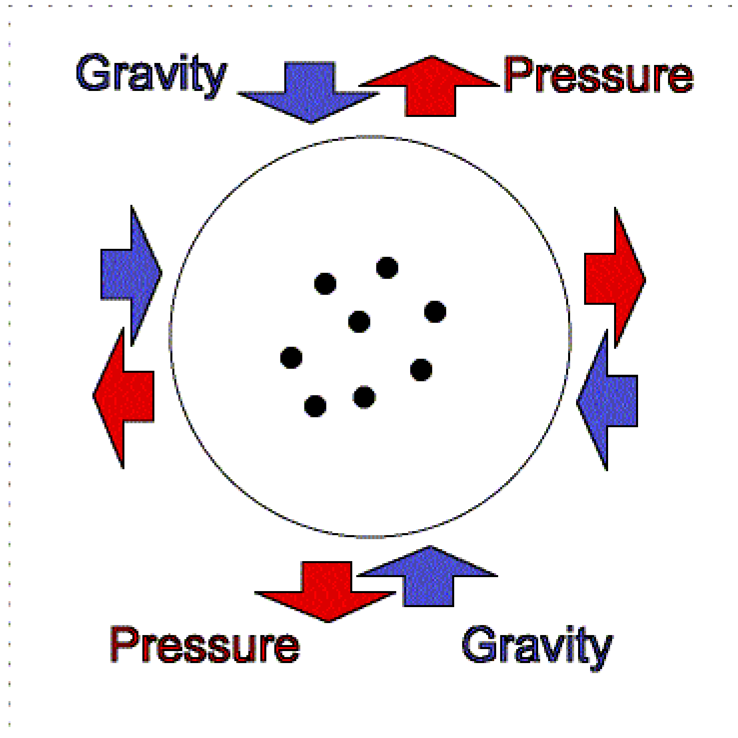
Stellar structure: Balance between pressure and gravitational collapse

- The Sun is in a stable equilibrium
  - Size changing very slowly
  - Temperature also changing very slowly
- The superheated gas in the Sun (a plasma) exhibits a very high pressure
- This pressure is balanced by the mutual gravitational attraction by all the gas within the Sun
- These two competing effects determine the overall structure & size of the Sun



Hydrostatic Equilibrium

- Stars **adjust to balance these two forces,** and remain in equilibrium
- ***Self-regulating process***
  - if gravity increases, gas compresses making it hotter and denser and it re-expands
  - if pressure increases, gas becomes less dense and cooler, pressure decreases, and gravity compresses star again.



$E=mc^2$: The solar power source

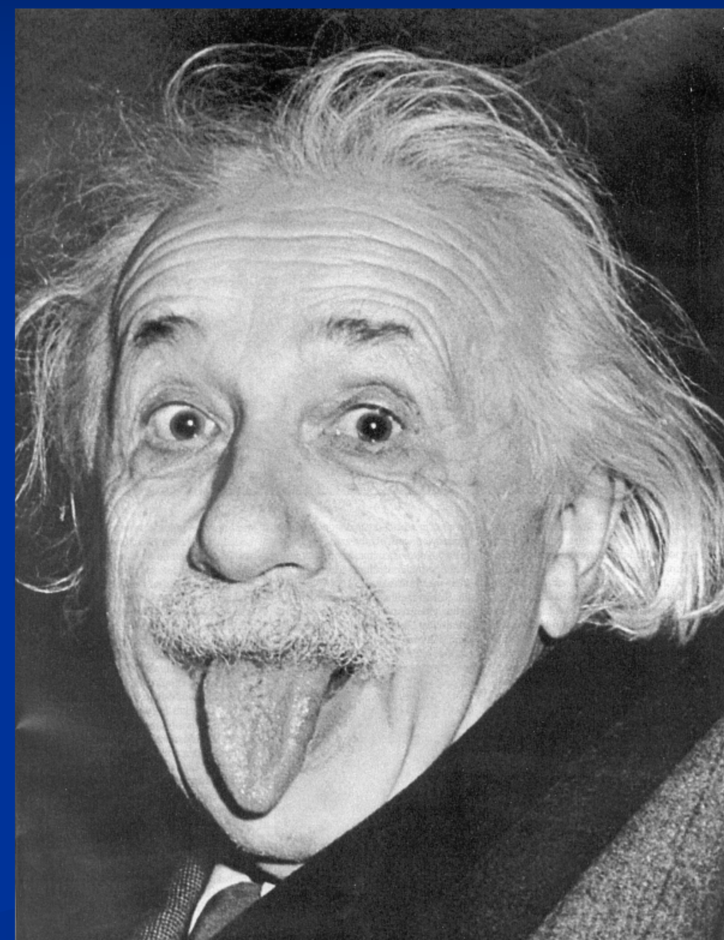
- Given that the Sun has lived for ~5 billion years already, chemical, gravitational energy, etc, cannot power the Sun.

  $$E = mc^2$$

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

- **Energy** and **mass** are closely linked: mass can be **converted into energy** and vice-versa.

  Conversion of mass into energy is what powers the Sun.

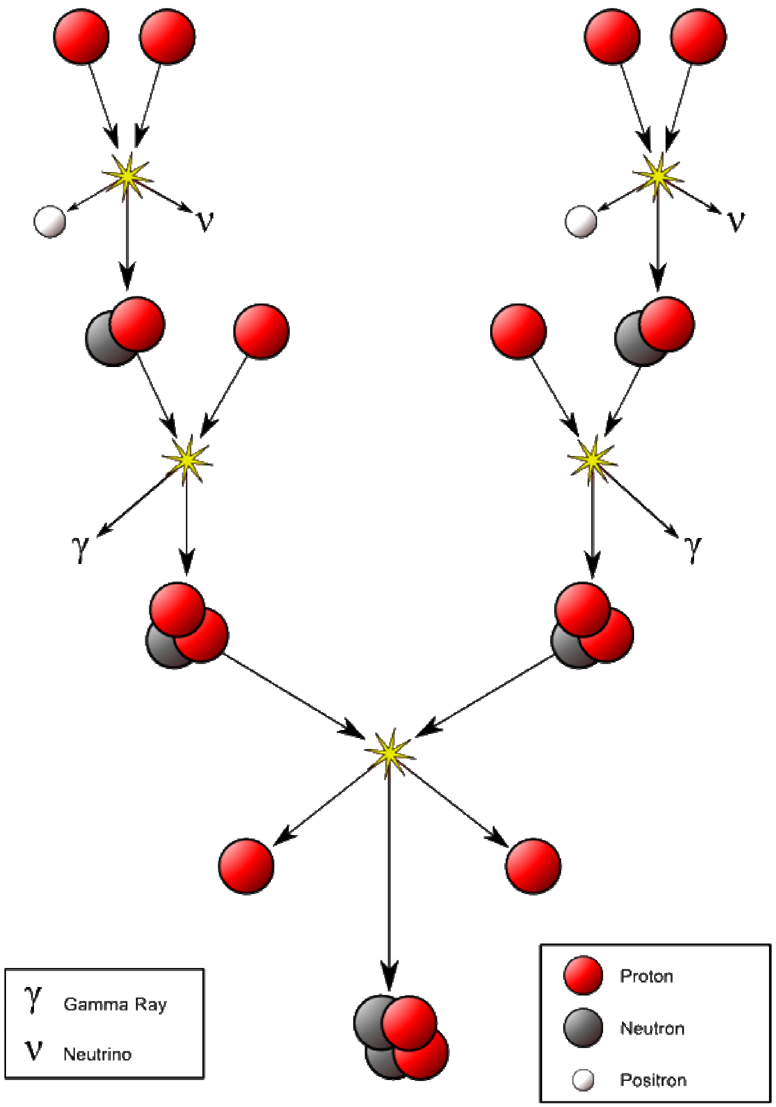


See http://www.pbs.org/wgbh/nova/einstein/experts.html

Nuclear Fusion

Animations from Nick Strobel's Astronomy Notes (www.astronomynotes.com)

The p-p chain



- This series of nuclear reactions powers stars for the most of their lifetimes
- $p + p \rightarrow {}^2H + e^+ + \nu_e$
  (ν_e = neutrino)
  (e^+= positron)
- ${}^2H + p \rightarrow {}^3He + \gamma$ (this reaction happens twice)
  (γ = Gamma ray radiation)
- ${}^3He + {}^3He \rightarrow {}^4He + 2p$

Net Result: $4p \rightarrow {}^4He + 2e^+ + 2\nu_e$ + energy release

Mass conversion rate

- So net result is conversion of 4 protons into Helium nucleus. The mass of the Helium nucleus is ***less*** than the mass of the 4 protons, and this mass is converted into energy, which powers the Sun (and other stars)
- Turns out that 0.7% of the mass of the original protons is converted to energy (so efficiency ~1%).
- To generate its observed luminosity, the Sun must ***convert 600 billion kg of hydrogen to helium per second!*** Compare with the Sun's mass= 2×10^{30} kg ... ***Sun's lifetime is ~10 billion years!***

Summary of lecture 8

- Stars come in a multitude of sizes from dwarfs to supergiants
  - They can have radii hundreds of times larger than the Sun
- Stellar classification is achieved through examining the spectral absorption lines
  - Main classes O,B,A,F,G,K,M
  - The Sun is a G2 class star
- The structure of the Sun can be roughly divided into the core, radiation and convection zones
- Stellar structure is maintained by a balance between pressure and gravity – hydrostatic equilibrium
- The p-p chain is main nuclear reaction that powers stellar fusion
  - 4 protons are converted in a single nucleus of He, with the release of energy

Next lecture

- Evolution & lifetimes of stars