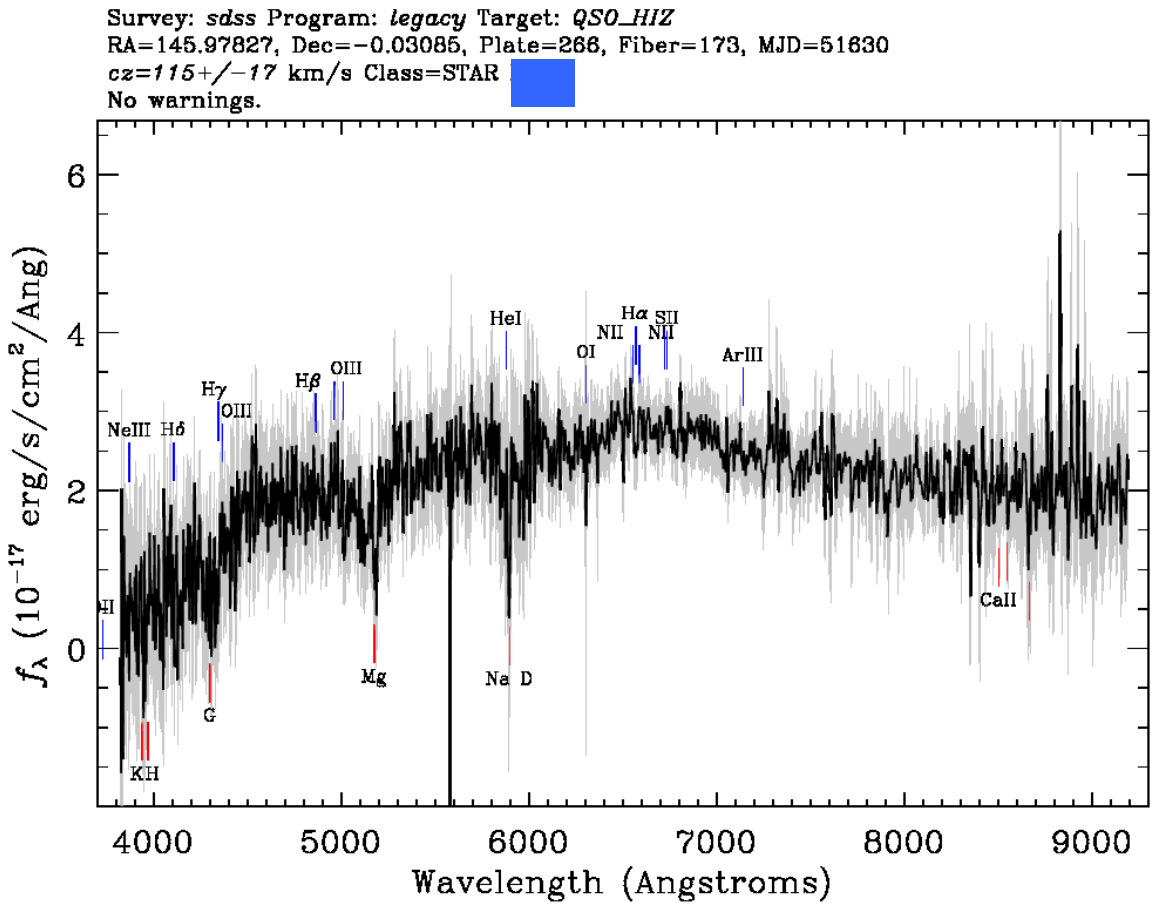
Opening spectrum to classify



- **Please pick up your papers**

- **Next TIMESTEP meeting (Wednesday; PAS 218)**
  - ***Resume Building and Interview Preparation***

- **Exam #1 (Wednesday)**
  - **now posted:**
    - **practice problems and study guide**
  - **open book, notes, calculator**
  - **handwritten crib sheet**

Exam #1
directions

1. There are too many questions to complete in the available time.
   - Do as many problems as possible in any order you wish.

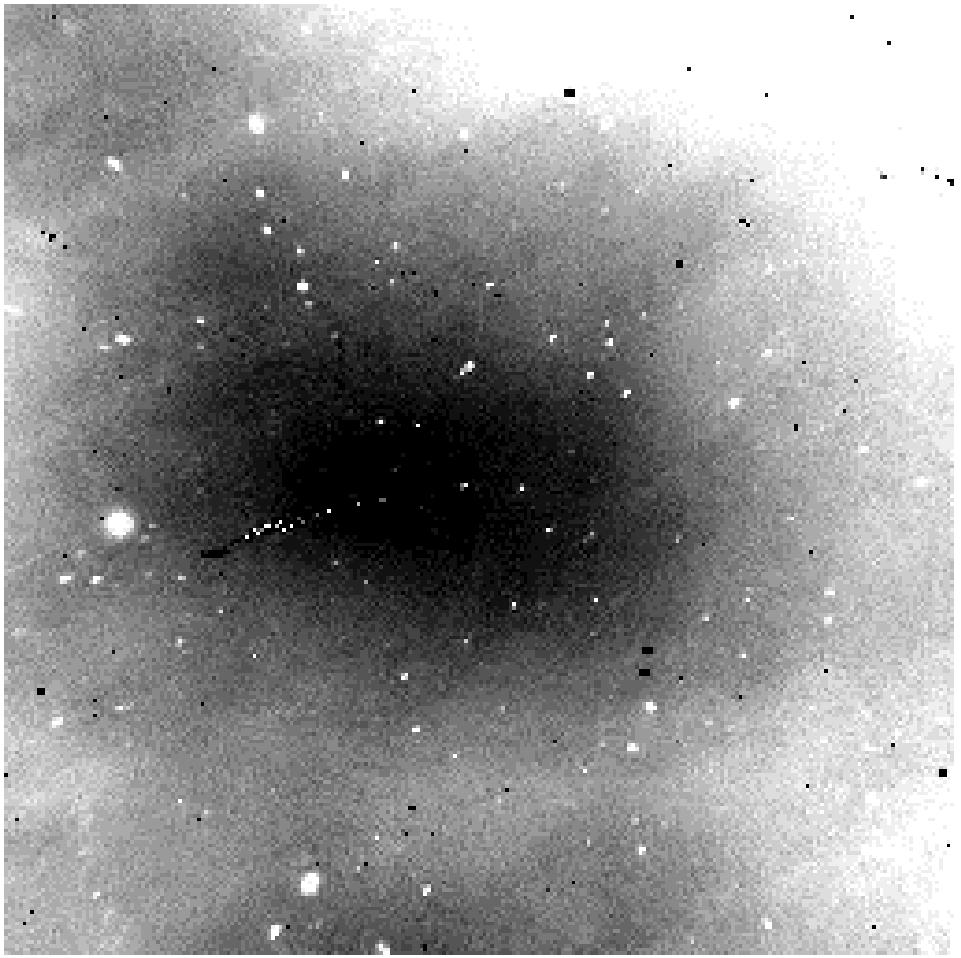
2. Present your work in a logically, legibly, and understandably.
   - You may need to recopy some portions, so plan ahead!

3. Show all logical steps of your work.

4. Explanatory responses must use sentences and good grammar.

5. You may bring:
   - one handwritten crib sheet, open book, notes, calculators

Atmospheric Airglow



Homework #17
check your assumptions and understanding

A common answer explaining the low density (0.11 g/cm^3) of exoplanet Kepler-7b:

"… because the planet is most likely a gas giant."

Calculate the density of Jupiter:

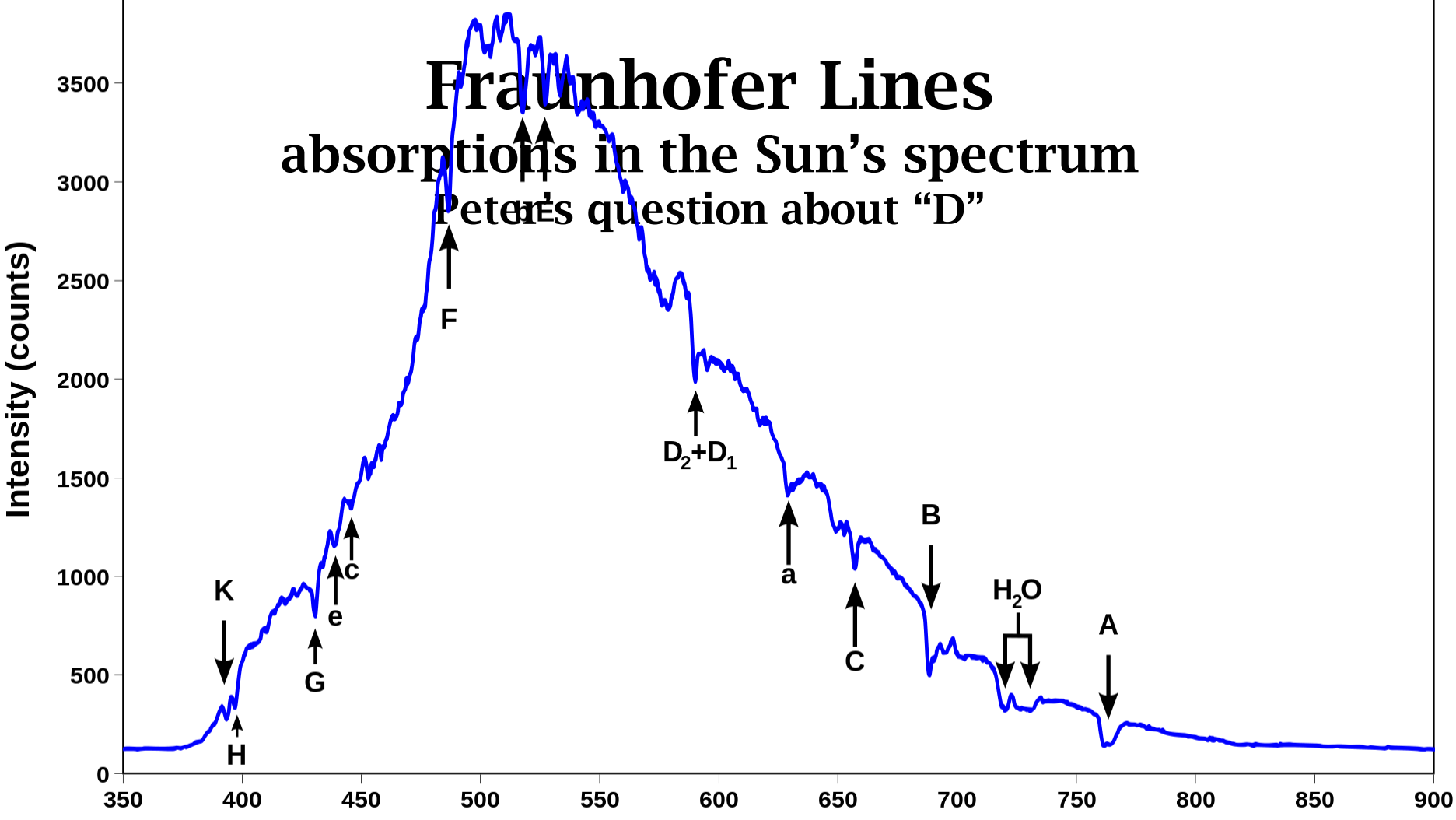
M_{Sun} = 2 x 10^{30} kg

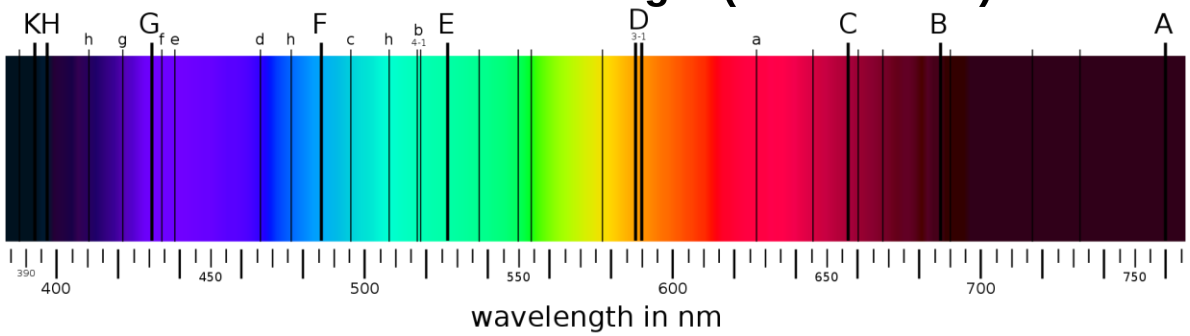
R_{Sun} = 7 x 10^{8} m

Fraunhofer Lines

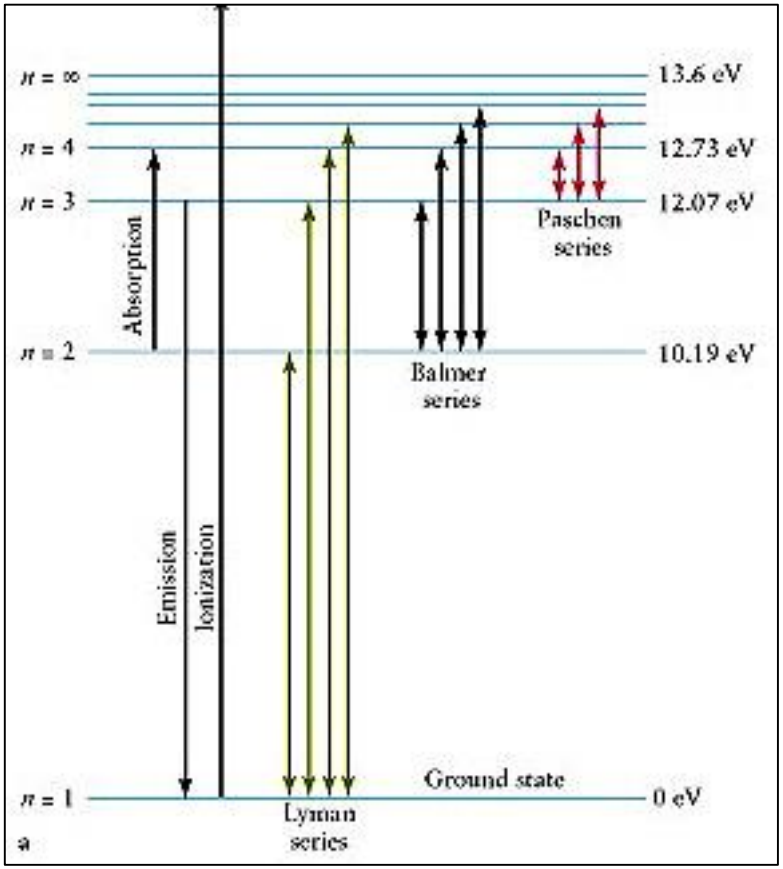
absorptions in the Sun's spectrum

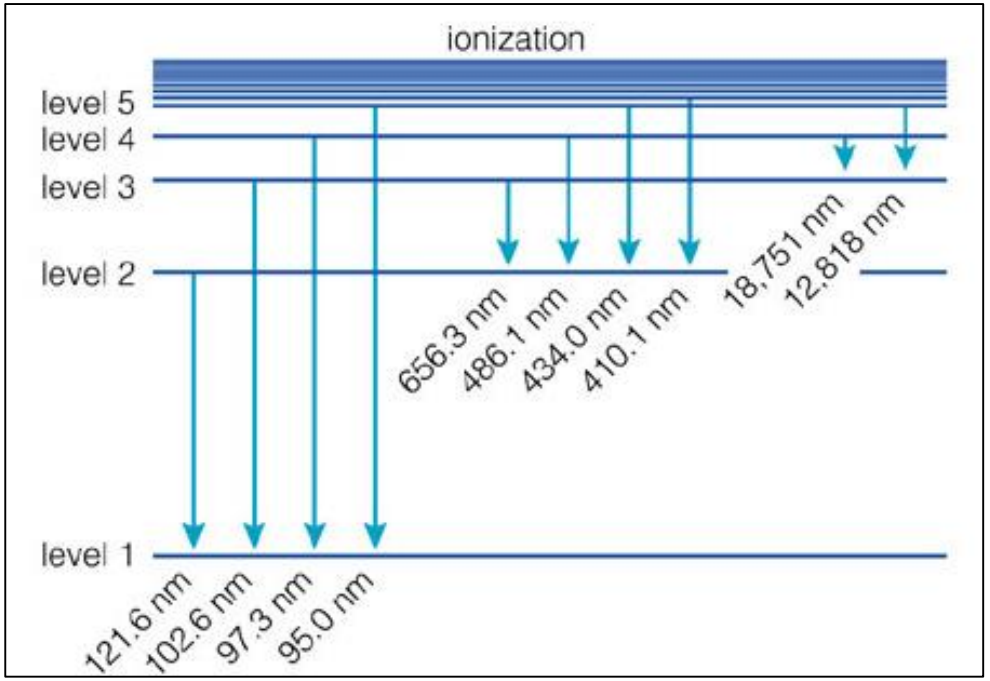
Peter's question about "D"





The Hydrogen Atom
Lyman, Balmer, Paschen, … series





"Lyman limit" = 91.2 nm (912 Å; 13.6 ev)

"Balmer limit" = 354 nm

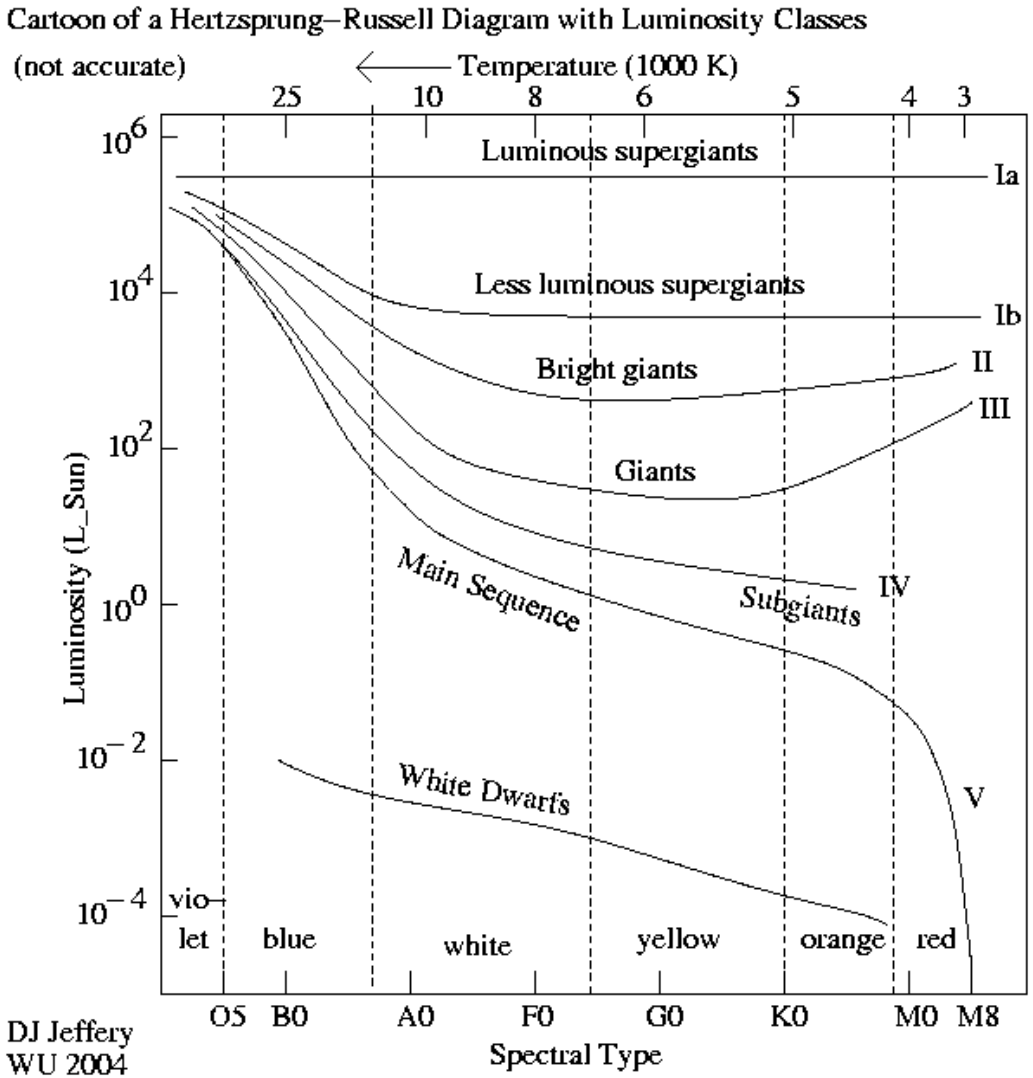
Lyman-alpha (Lα): 121.6 nm (1216 Å)

Balmer-alpha (Hα): 656 nm

Luminosity Classes

plot these stars on the H-R Diagram

$$L = 4\pi R^2 \sigma T^4$$

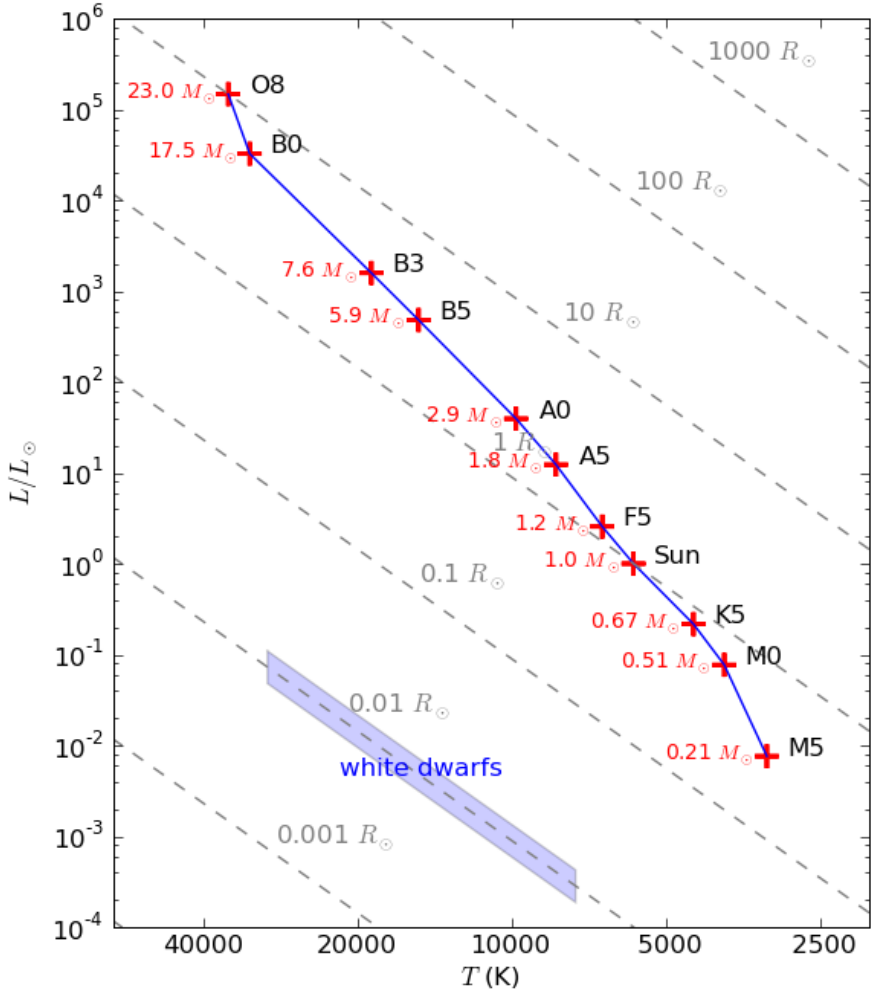


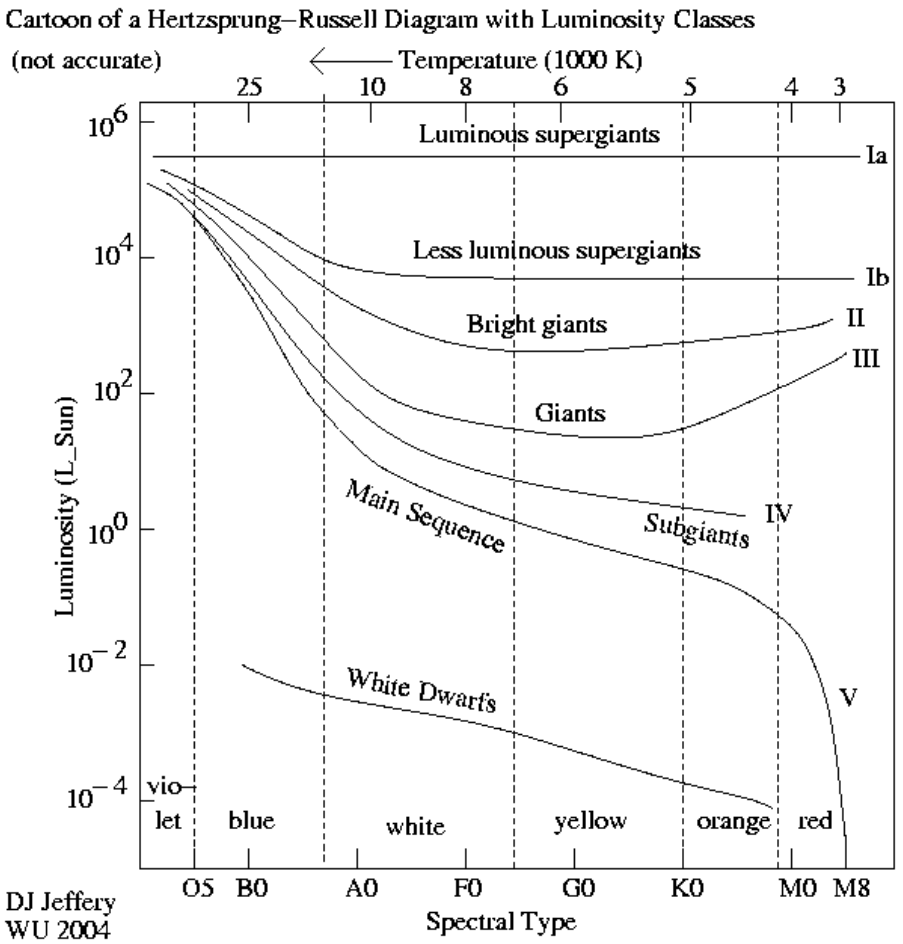
Sun:	**G2 V**
Betelgeuse:	**M2 Ia**
Achernar:	**B6 V**
Aldebaran:	**K5 III**
Vega:	**A0 V**
Spica:	**B1 V**

The Hertzsprung-Russell Diagram

spectral type (temp) and luminosity class (radius)

masses





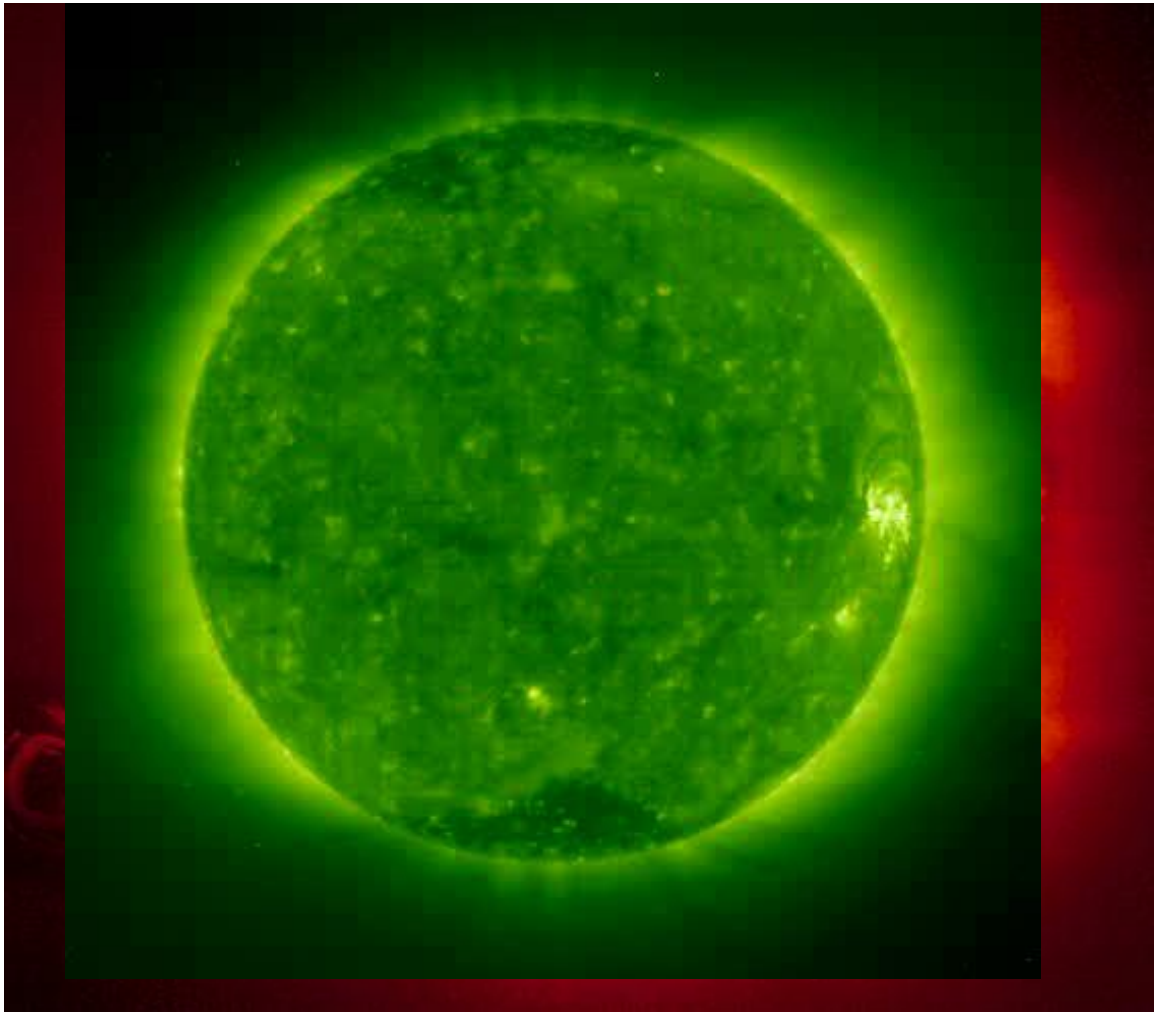

Star: Betelgeuse
Spectral Type: M2 I
Parallax: 0.00763"
Distance: 131 pc
Apparent Magnitude: 0.41
Luminosity: 38,000 L☼
Star: Procyon
Spectral Type: F5 IV-V
Parallax: 0.28593"
Distance: 3.50 pc
Apparent Magnitude: 0.37
Luminosity: 7.4 L☼
Star: Sirius
Spectral Type: A1 V
Parallax: 0.37922"
Distance: 2.64 pc
Apparent Magnitude: -1.46
Luminosity: 26 L☼
Star: Rigel
Spectral Type: B8 I
Parallax: 0.00422"
Distance: 237 pc
Apparent Magnitude: 0.14
Luminosity: 70,000 L☼

The Sun: *"A Mass of Incandescent Gas"*

How is it powered: Shrinking, chemical burning, …?

"The Sun is the only astronomical object that critically matters to humankind."

Dr. Jack Harvey (NSO)



Check out: http://www.spaceweather.com/

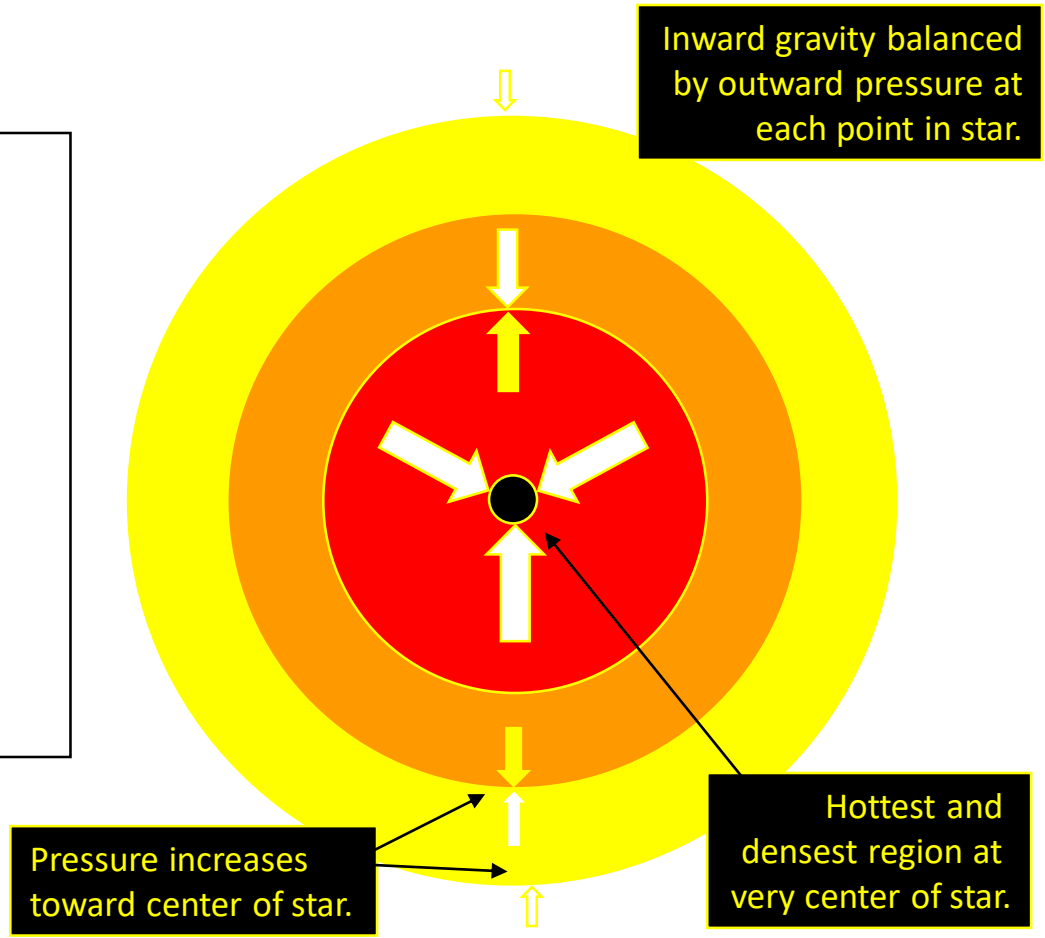
Energy Source: "Core Fusion"

inward gravity & outward pressure balance everywhere

How much energy AT ALL WAVELENGTHS comes out of the Sun's surface per second?

3.9×10^{26} Watts
400 trillion trillion watts

~1400 watts per square meter reaches Earth

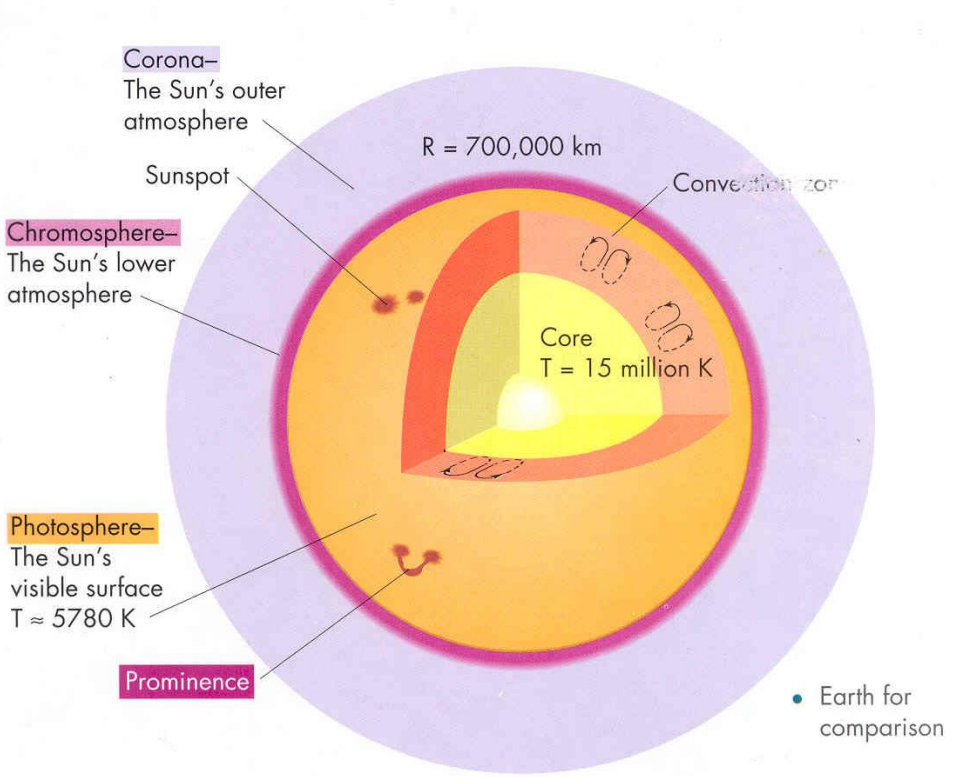


The Sun's Core

Sun's core has half its mass in 1/4th its size.

16×10^6 degrees K
200×10^9 x Earth's atmospheric pressure

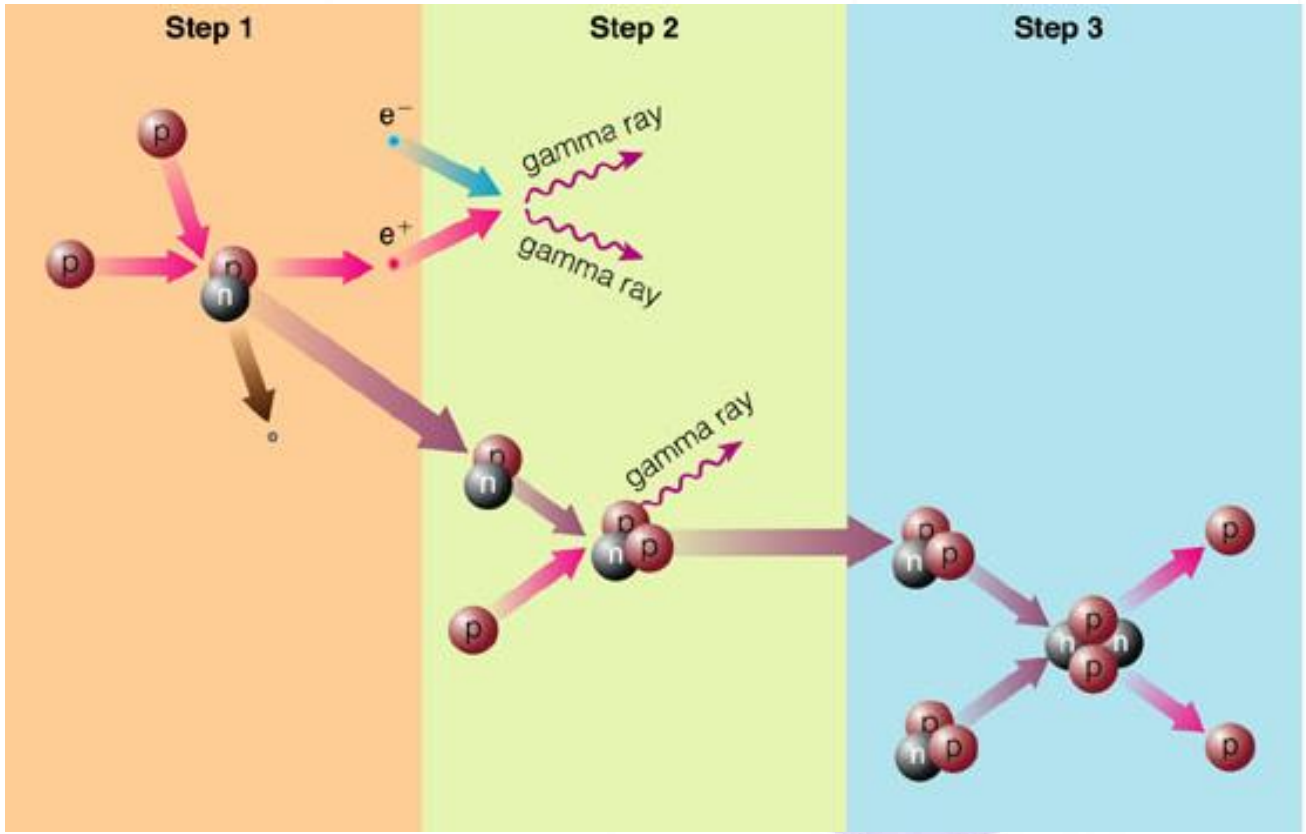
density ~160 gm/cm^3
(BUT still a gas!)

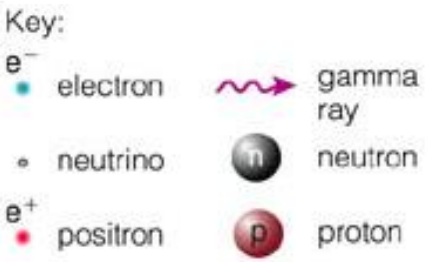


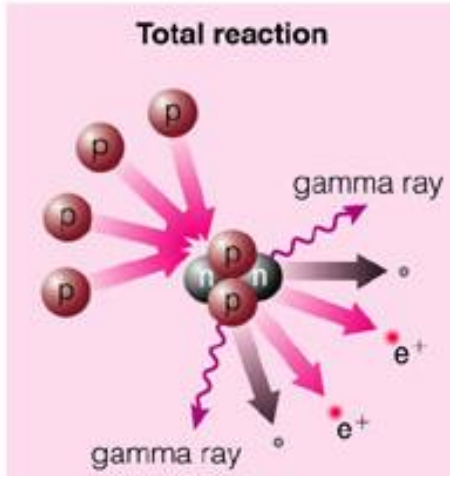
The "proton-proton chain"

26.2 MeV of energy in each reaction

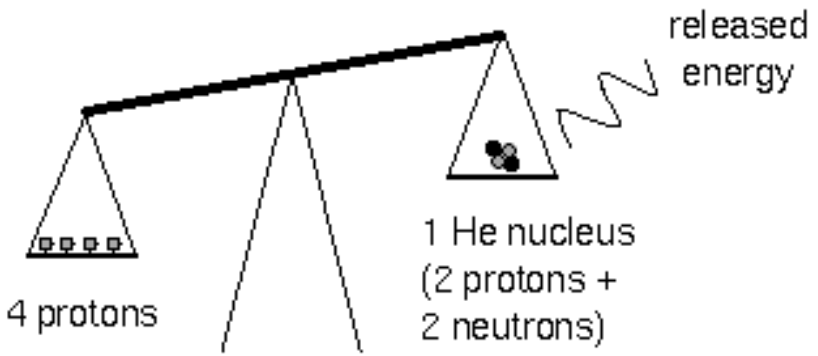
1 MeV = 1.6 x 10^{-13} Joules







Luminosity



Some mass is converted into energy ($E=mc^2$)

For every 1000 gm of hydrogen used only 993 gm of helium are produced.

The rest becomes energy.
low efficiency – thankfully!

Sun converts 700 x 10^6 tons of hydrogen per second of which 5 million tons become energy.

Start Homework #21 (Monday)

Most of the Sun's energy comes from the fusion of hydrogen in the Sun's core via the "p-p chain" of nuclear reactions ("proton-proton chain").

One cycle of the p-p chain of reactions converts mass into about 26.2 MeV of net energy (1 eV = 1.602×10^{-12} erg = 1.602×10^{-19} J).

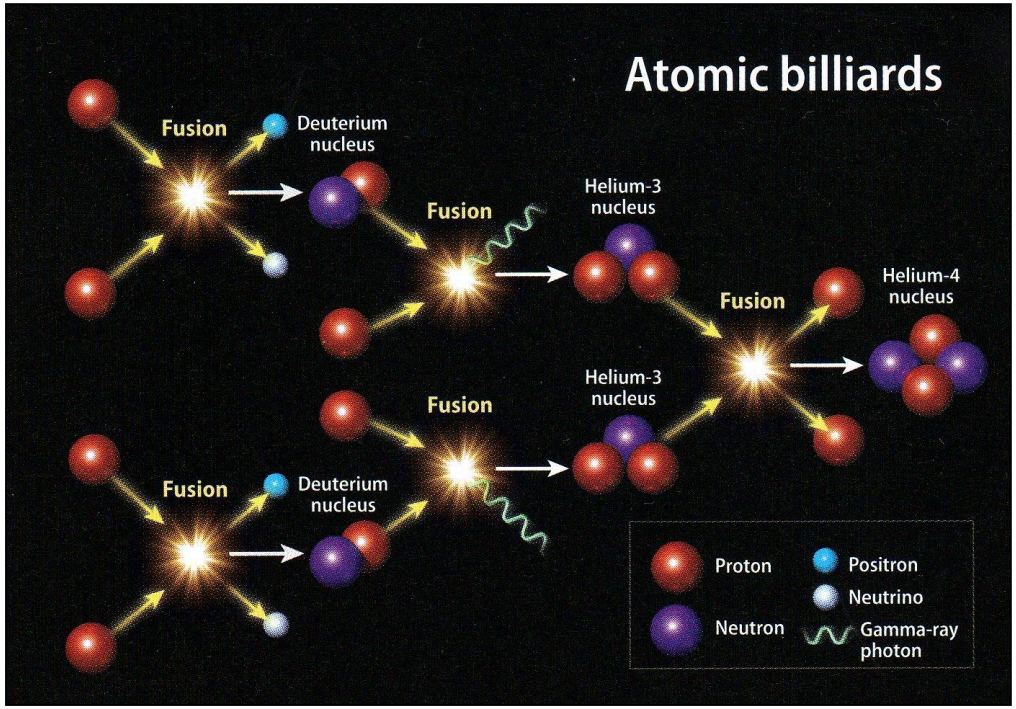
a. Estimate how many times per second the p-p chain cycle is being completed in the Sun.

b. The mass of the Eiffel Tower in Paris is about 7300 tons or 6.6×10^{9} g. How many Eiffel Towers worth of mass are converted into energy every second in the Sun?

Nuclear "Fusion" in the Sun's Core
0.7% efficient

The Sun's interior is a gas = "plasma"
Mostly ionized hydrogen (electrons & protons)

Temperature:	**16 x 10^6 degrees K**
Pressure:	**200 x 10^9 times Earth's atmosphere**
Density:	**160 gm/cm^3**



Each particle collides ~100 million times per second. Still only a small percentage of protons fuse very often.

In the Sun the average time for the first step:

[p + p -> d] = 1 Gyr

The other steps are:

[d + p -> 3He] = 1 sec

[3He +3He -> 4He + p + p] = 1 Myr

All Four Forces Work Inside the Sun

Gravitational force

pulls Sun's mass together causing pressure & heat

Electromagnetic force

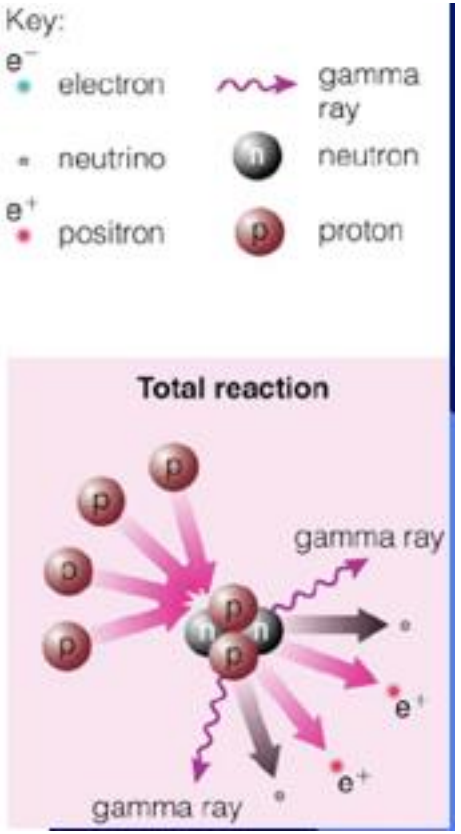
Protons repel each other.
High temp. & pressure force protons together.
Protons "tunnel" through their electrical barrier.

Strong nuclear force

holds protons within atomic nucleus

Weak nuclear force

Proton decays into neutron and energy.



Sun Produces ~10^{38} Neutrinos Per Second

"plankton of the Universe"

Neutrinos are weird subatomic particles:

little (or no) mass

they travel close to the speed of light

no electric charge

They interact VERY WEAKLY with matter and can usually pass through the entire Earth with ease.

On rare occasions, a neutrino can "hit" a neutron and convert it to a proton.

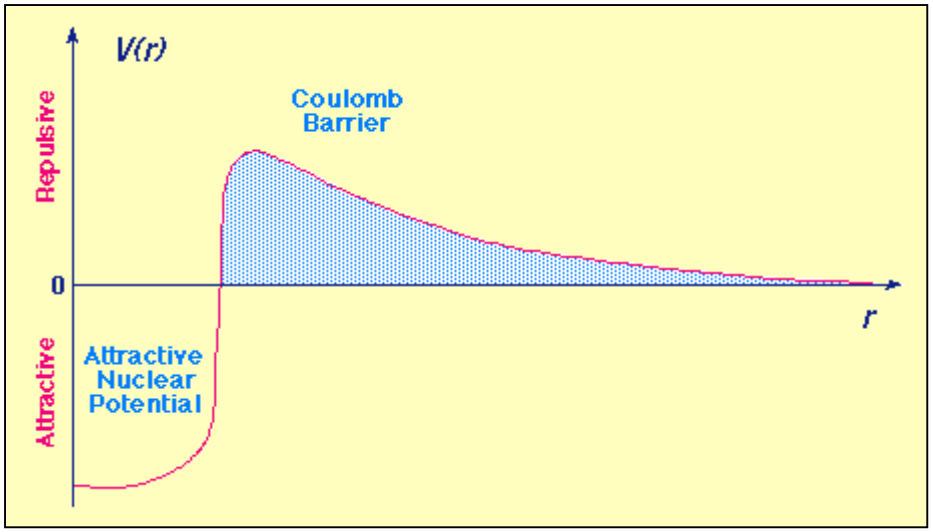
10^{15} Neutrinos Pass Through Your Body Every Second

Ray Davis's Homestake Gold Mine in South Dakota
(Nobel prize in physics 2002)

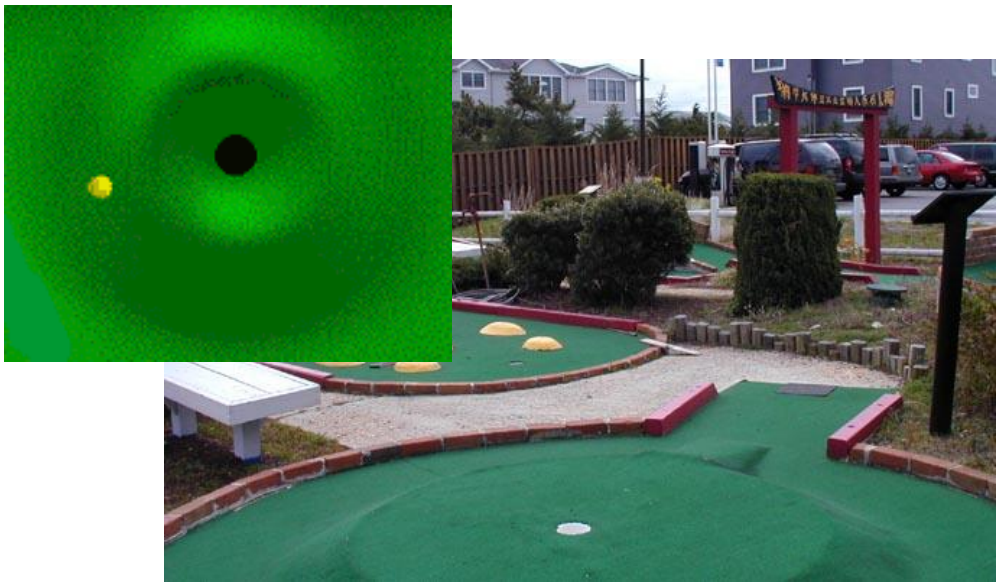
A neutrino detector 1.5 km underground since mid-1960's
100,000 gallons of cleaning fluid are used to detect occasional neutrinos.

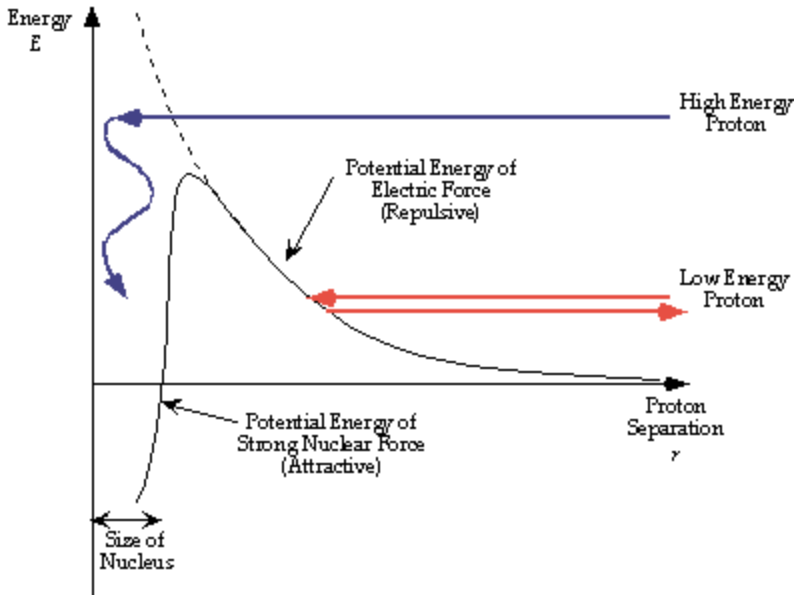
Neutrinos can convert atoms of chlorine into argon.

The Uncertainty Principle at Work



A typical proton in the Sun's core simply bounces off another. Occasionally one "tunnels" through the electrical barrier and fuses.

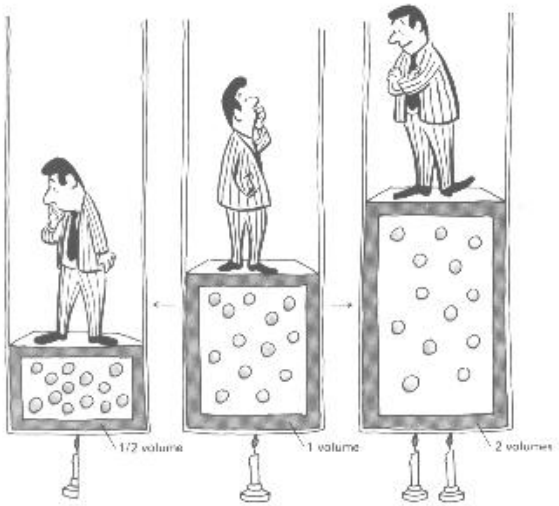


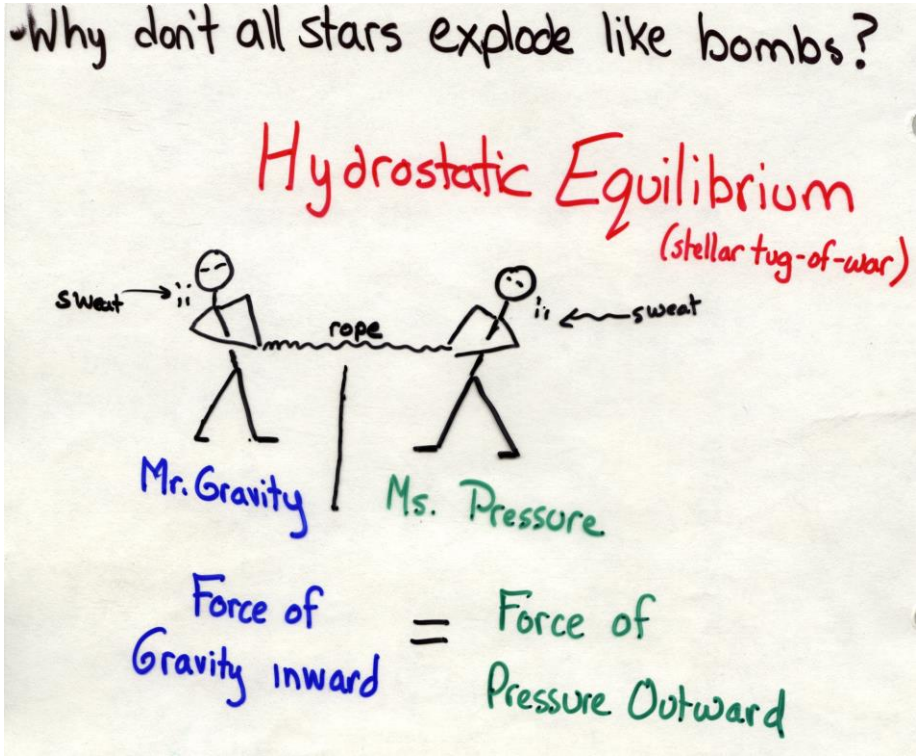


Gravity & Pressure: A "Give and Take"

in balance as long as the star generates nuclear pressure

self-regulating (i.e., not a bomb!)



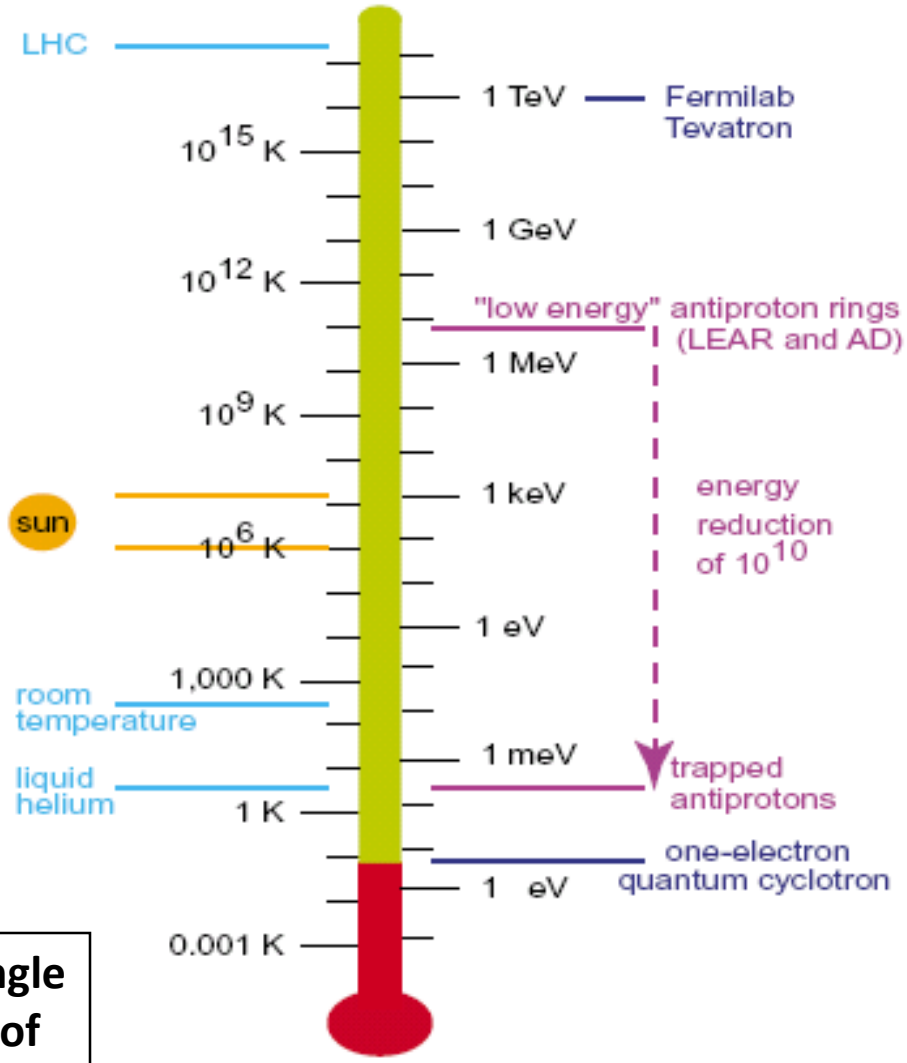


If Core Temperature Increases

nuclear pressure increases
star expands
decreases temperature
a new balance is achieved

The Universe has a large temperature range.

From empty space to the centers of stars.



1 Kev of energy means a single proton travels an average of 10^6 mph in the Sun's center.

How Could this Sculpture Relate to Stars?

"Beyond Borders"

near Harvill Building

Our Sun generates energy by fusing protons into helium nuclei at an efficiency of 0.7%. As a result, 700×10^6 tons of protons are converted into energy every second.

How much hydrogen was required originally to make the 700 million tons?

A. one billion
B. 700 million
C. one hundred billion
D. one million

Work together!

$0.007 \text{ (amount)} = (700 \times 10^6)$

$\text{amount} = (700 \times 10^6) / (7 \times 10^{-3})$

How Do We Know About Stellar Evolution?

Observations

HR diagrams of clusters

supernovae

spectra: Heavy elements

Computer Models

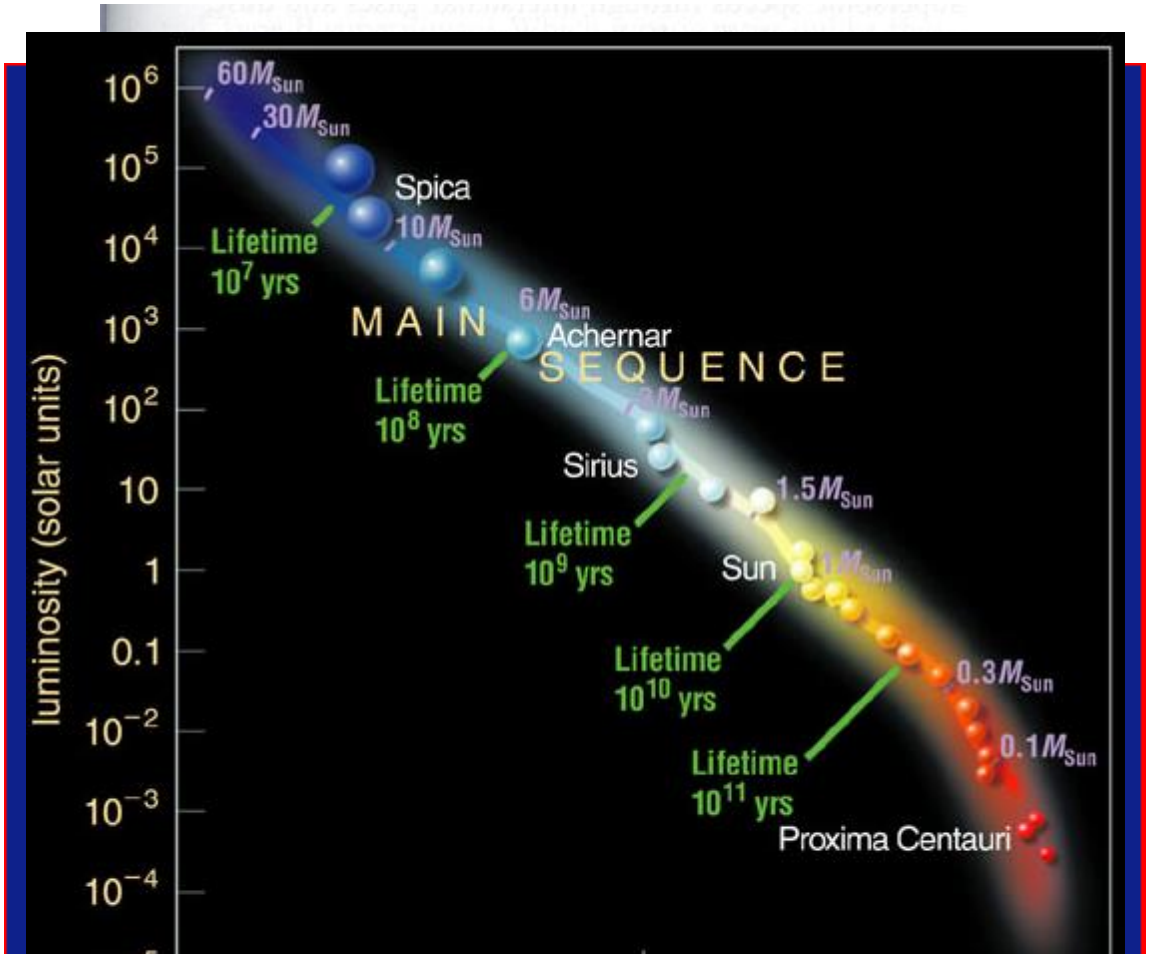
Only 4 equations needed to build a star

$$\frac{dP}{dr} = -\frac{GM_r\rho}{r^2}$$

$$\frac{dM_r}{dr} = 4\pi r^2\rho$$

$$\frac{dL}{dr} = 4\pi r^2\rho\left(\varepsilon_r - T\frac{dS}{dt}\right)$$

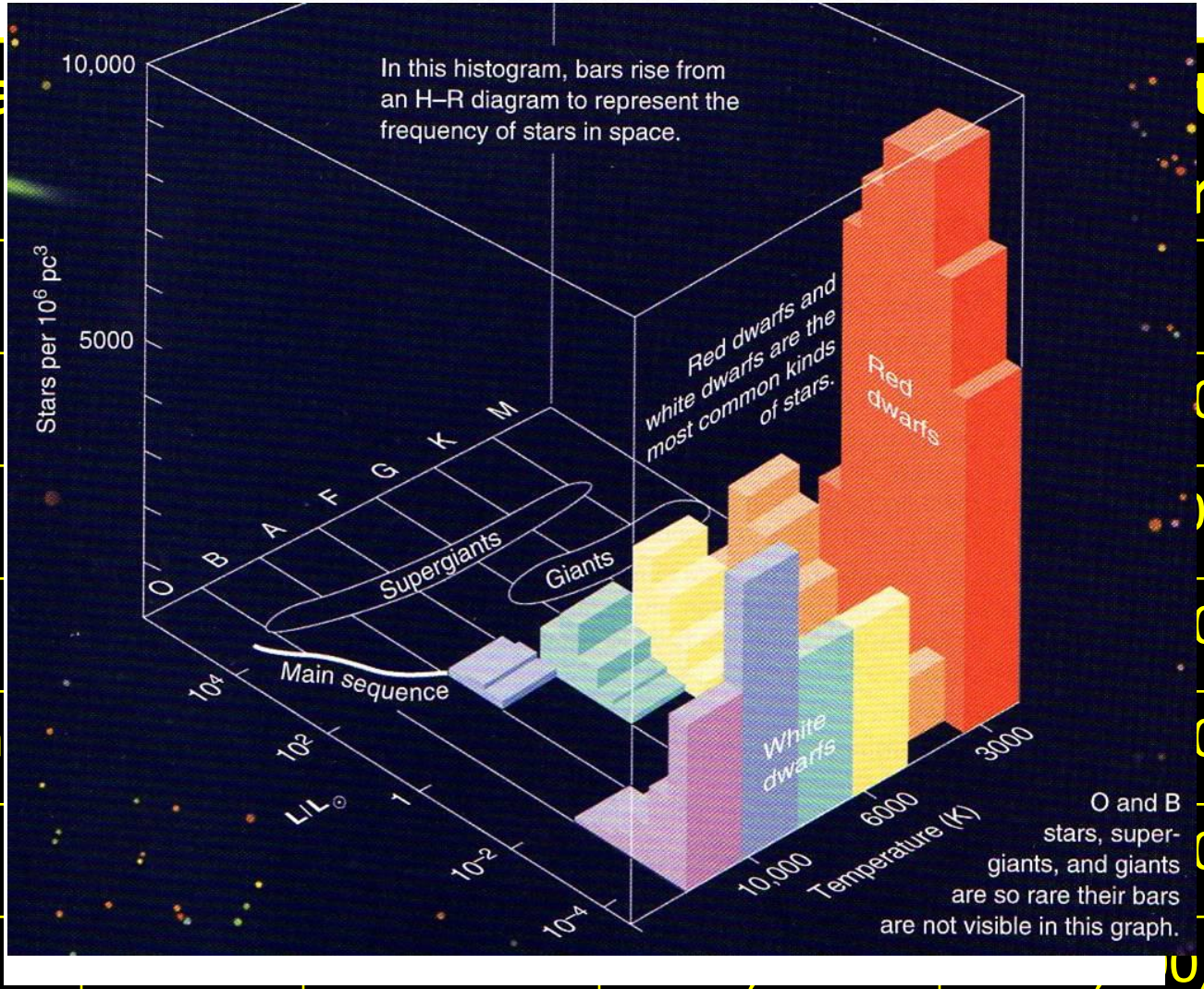
$$\frac{dT}{dr} = \frac{-3kL\rho}{16\pi acr^2T^3}$$



The "turn-off" point indicates an age of 10-13.5 ± 2 Gyrs for the oldest globular clusters in our galaxy.

Mass to Luminosity Ratio

Spectra Type					tive rence
O5					
B					00
A					000
F					000
G2 (Sun					000
K					000
M					0,000



Mass is ALL!

Mass causes gravity. Gravity causes …

(lower/higher)
its core temperature and pressure

(more/less)
fusion energy is released

(lower/higher)
its "surface temperature" -> bluer

(higher/lower)
its luminosity

(slower/faster)
it exhausts its fuel

(longer/shorter)
its lifetime

(more/less)
violent its death.