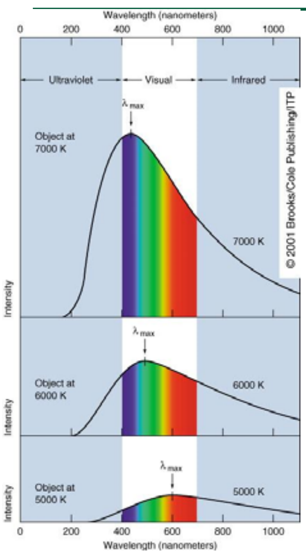
Today

- Announcements:
  - The average on Exam 2 was 32.7/40; outstanding
  - Exam #2 extra credit is due tomorrow March 19 at 8:00 am.
  - HW#8 will be due 26 March at 8:00am.
  - Submissions for the Spring Break Story Contest are due March 19. All voting will be anonymous.
- The life of the stars
- The Uncertainty Principle Revisited

Our Sun

- A huge, hot ball of mostly hydrogen and helium (3% other stuff)
- Power output (luminosity) 3.26E+26 W
- It is 93 million miles from Earth. Intensity at the Earth is about 1000 W/m^2. That is like 10 100 W light bulbs every square meter
- The Sun is a complicated object

Blackbody Radiation



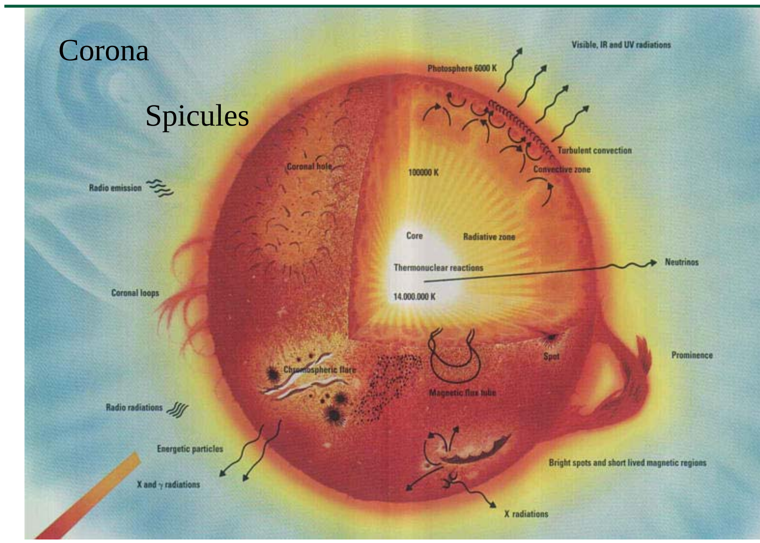
All objects emit a spectrum of photons. A perfect black body has the spectrum shown at the left.

The emission spectrum depends on temperature. The amount depends on size.

$$L = \sigma A T^4 \; ; \sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$

$$E_{mean} = 2.705 \cdot kT ; k = 8.617 \times 10^{-5} \frac{eV}{K}$$

Our Sun is a complex object



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A Stars Energy Source – nuclear fusion

The sun generates its energy by a set of fusion reactions called the pp or proton-proton chain:

- proton+proton = 2-Hydrogen + neutrino + anti-electron
- then 2-hydrogen+1-hydrogen = 3-helium+gamma-ray
- then 3-Helium+3-Helium = 4-helium + 2 protons.

Fusion does not happen everywhere. Conditions required for fusion (two things):

- High temperature: the central temperature of the sun is 15 million Kelvin. This is necessary to overcome the repulsion between the positively charged protons.
- High density: the probability of collisions must be high.

Note: the Sun is balanced just right. It does not burn too fast or two slowly for us to have a potentially comfortable existence.

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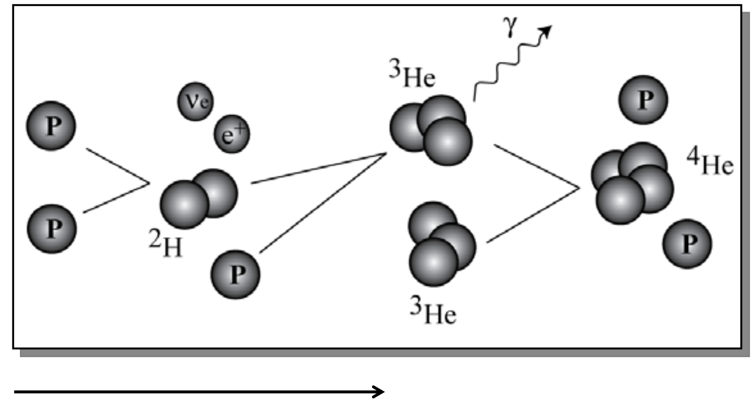
The pp-chain in the Sun



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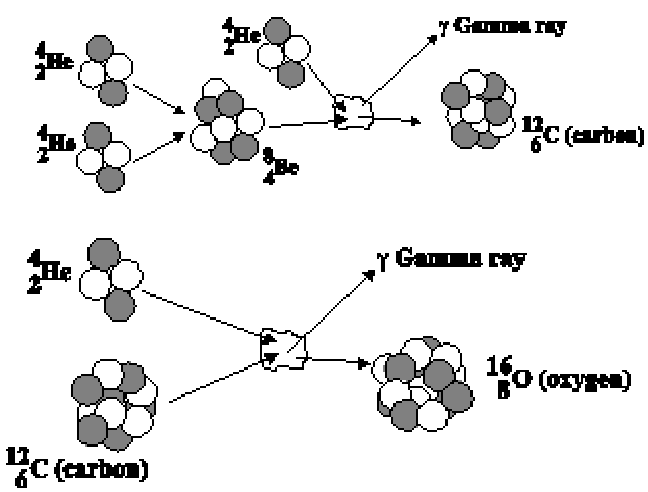
The creation of elements - nucleosynthesis



The rate of this reaction is just right to have the Universe work like it does.

Helium Burning

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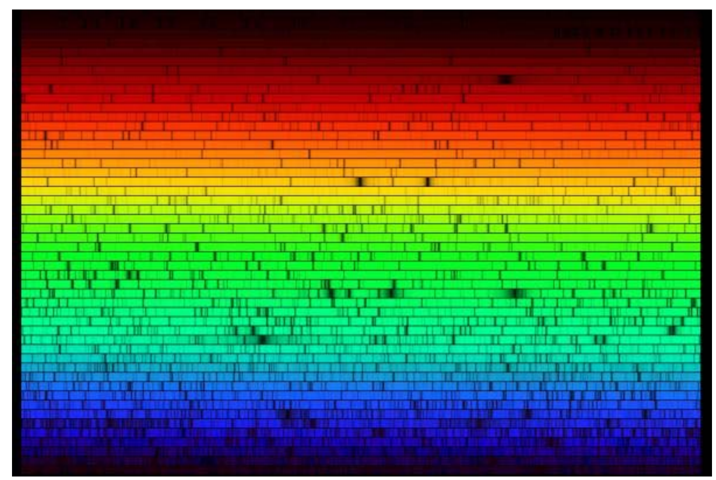
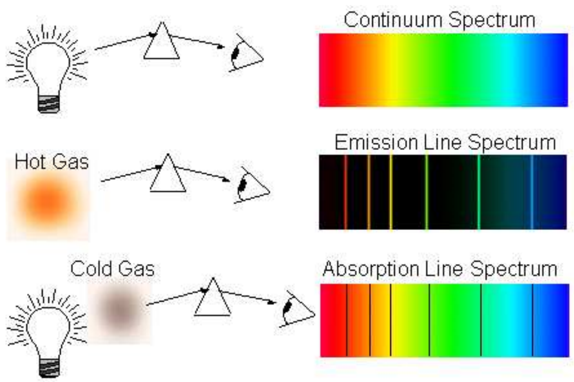
The spectrum from our Sun



Spectra come in 3 kinds



Examples

Heated rod or candle

Atoms in a gas excited by high temperature or high energy photons

Spectrum from the Sun

The pattern of lines tells what elements are present.

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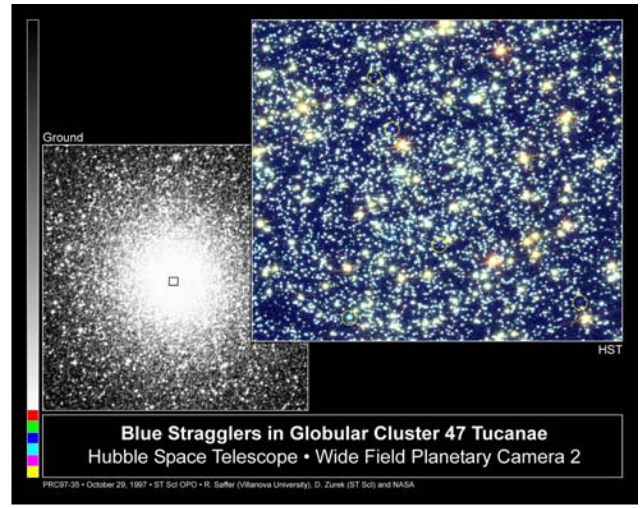
Stars are Different: A sample of stars



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Stars

- The mass of a star determines most properties of a star: lifetime, color, size, luminosity
- Massive stars are very bright and hot, but they don't last very long.
- Stars are a balance between gravity and pressure from the internal heat – *hydrostatic equilibrium*

Mass	Lifetime By
$0.3\ M_{sun}$	1000
$1.0\ M_{sun}$	10
$3.0\ M_{sun}$	0.35
$10\ M_{sun}$	0.025
$60\ M_{sun}$	0.002

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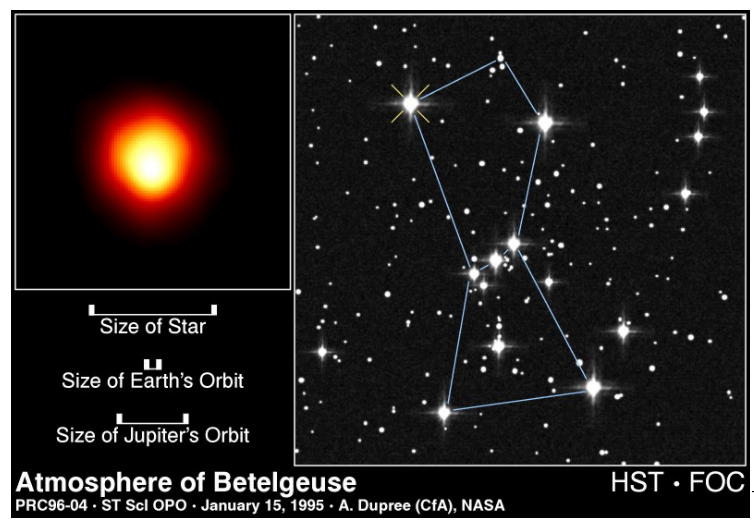
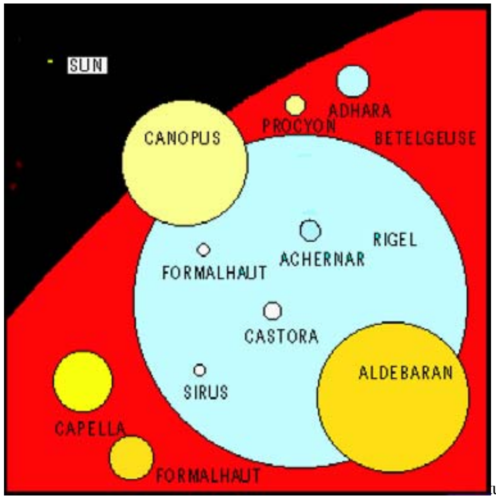
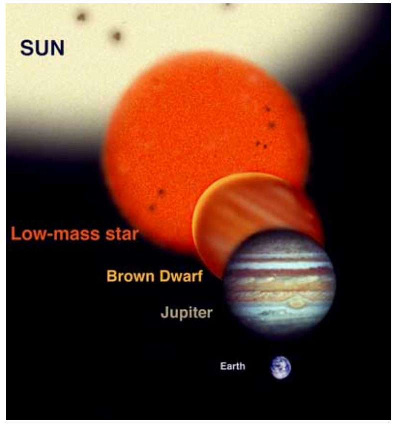
An example of a red supergiant



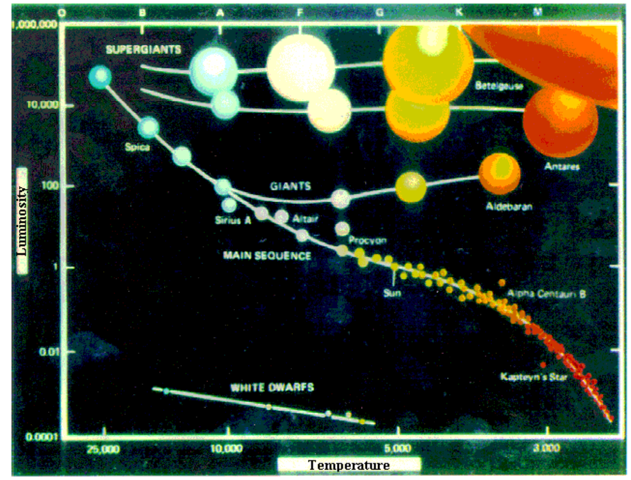
Relative Sizes of Stars





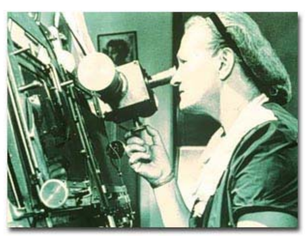
Blue – hot Red - cooler

Hertzsprung-Russell Diagram

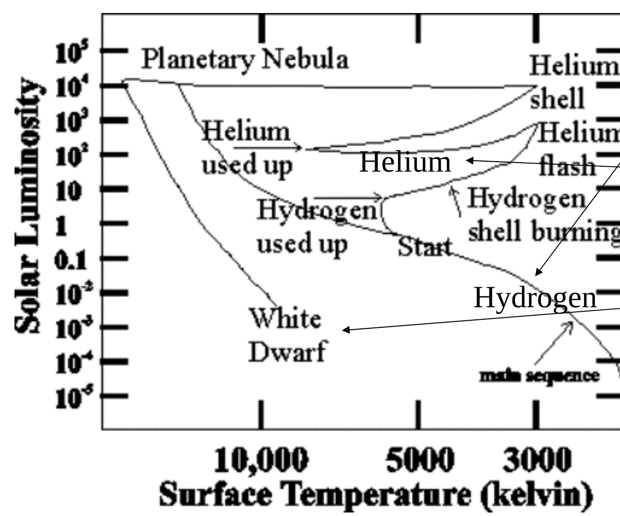


Cecilia Payne-Gaposchki Story

- Studied astronomy at Oxford
- Came to Harvard for graduate study because the only career for women in England in astronomy was teaching
- Was the first person to realize that the stars are mostly made of hydrogen and helium
- Here thesis is widely regarded as the best ever in astronomy.



Evolutionary Path of our Sun



Long parts:

Hydrogen 10 By

Helium 1 By

White Dwarf many BY

Planetary Nebula

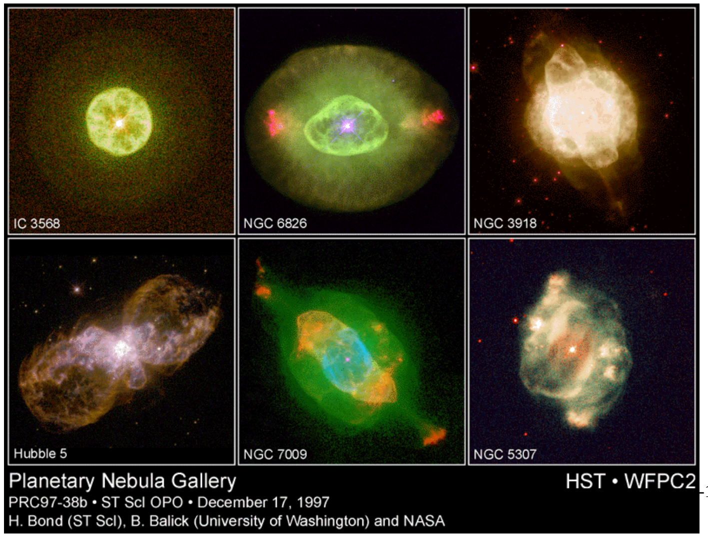
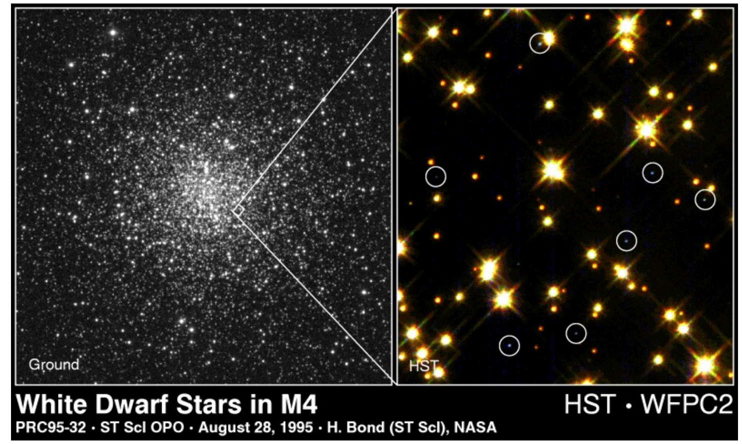
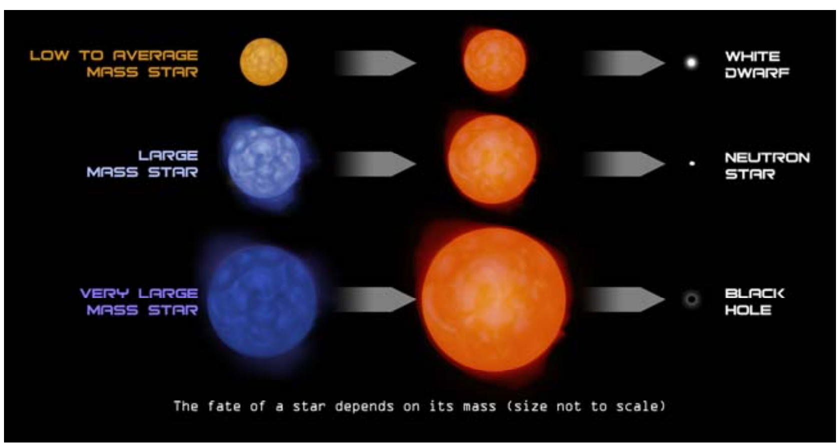


Image of White Dwarfs



Stellar Evolution



How do we determine distances?

- Radar – nearby things like the Sun
- Parallax – 1 arcsec motion 1 pc = 3.24 ly
- Spectroscopic parallax – use location on the Hertzsrpung Russell diagram

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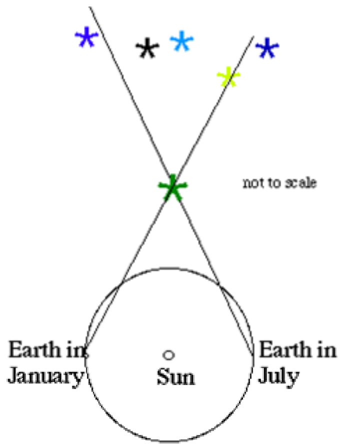
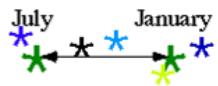
Stellar Parallax



As seen on the sky in



Star distances are measured in units of the distance from the Sun to the Earth, the Astronomical Unit. The nearer the star, the larger is the angle (called the parallax) between the January and the July observations.

1 arcsec corresponds to a distance of 1 parsec (pc) = 3.24 ly

Distances to 300 ly can be measured this way

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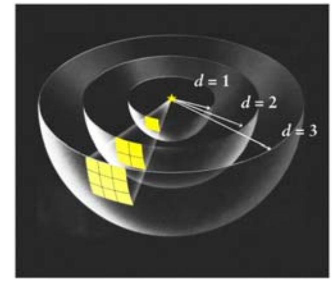
Why is there always r^2? I hate r^2.

Inverse square law

$$\text{intensity} = \frac{L[\text{Watts}]}{4\pi d^2}$$



If we know L the luminosity (measured in watts), and measure the intensity, we can determine d, the distance to the source

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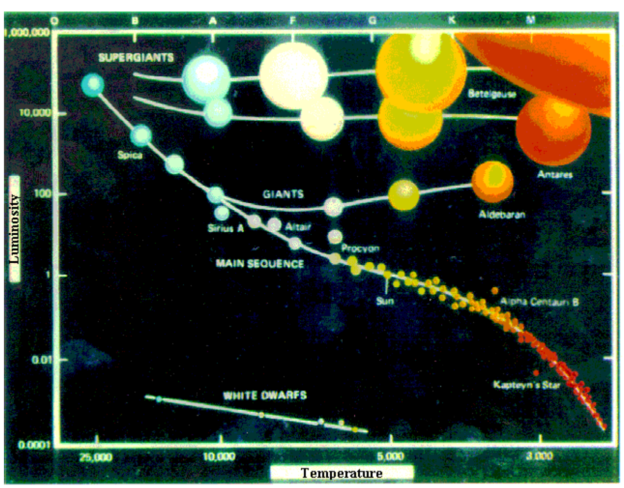
Hertzsprung-Russell Diagram



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Knowledge or Certainty: Ascent of Man

The **Ascent of Man**: A Personal View by J.Bronowski

Episode 11 - "Knowledge or Certainty"

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

It is not possible to know the position and velocity of a particle with absolute precision.

Heisenberg's Uncertainty Principle