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 8:00 am.
  – 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/m². 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.

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

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

The creation of elements - nucleosynthesis

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

Helium Burning

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.

Stars are Different: A sample of stars

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*

<table>
<thead>
<tr>
<th>Mass</th>
<th>Lifetime (By)</th>
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<tbody>
<tr>
<td>0.3 M_{\odot}</td>
<td>1000</td>
</tr>
<tr>
<td>1.0 M_{\odot}</td>
<td>10</td>
</tr>
<tr>
<td>3.0 M_{\odot}</td>
<td>0.35</td>
</tr>
<tr>
<td>10 M_{\odot}</td>
<td>0.025</td>
</tr>
<tr>
<td>60 M_{\odot}</td>
<td>0.002</td>
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</table>

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 Hertzsprung Russell diagram
Stellar Parallax

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

Distances to 300 ly can be measured this way

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.

Knowledge or Certainty: Ascent of Man

The Ascent of Man: A Personal View by J.Bronowski Episode 11 - "Knowledge or Certainty"

Heisenberg’s Uncertainty Principle

\[ \Delta x \Delta p \geq \frac{h}{4\pi} \]

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