**Announcements**

- HW#4: posted Thursday; due Monday (9/20)
- Reading Quiz on Ch. 16.5 – Monday (9/20)
- Exam #1 (Next Wednesday 9/22)
  - In class (50 minutes) – *first 20 minutes: review*
  - 25 multiple-choice questions (each 4 pts)
  - Bring pencil; no calculators
  - No talking during exam: strict policy about cheating
  - Review Sheet and Practice Exam – see course website:

**Lecture #7 Outline**

- A few more comments on parallax
- Properties of Stars: Temperature & Chemical Composition (Ch 16.5 pp 383-388)
  - Blackbody Radiation & Wien’s Law (notes)
  - Spectral Lines
  - Luminosity class, Chemical Abundances, Doppler Effect on spectra (MONDAY)

**Parallax: Space Observatories**

- *Hipparcos (mission 1989-1993)*
  - 118,218 parallax distances determined
- *GAIA (launch 2012; 2012-2017)*
  - chart a three-dimensional map of our Galaxy
  - kinematic census of about one billion stars in our Galaxy and throughout the Local Group (1%).
Basics of Electromagnetic Radiation (or “Light”)

- What we can learn from observing EM radiation from an astronomical object
  - Energy – Photoelectric effect
  - Temperature – blackbody radiation, Wien’s Law
  - Chemical composition – atomic structure, spectral lines
  - Line-of-sight motion – Doppler shift of spectral lines

Astronomical objects as blackbodies

- Blackbodies are good absorbers and radiators
  - Astronomers look at the INTENSITY of EM radiation as a function of WAVELENGTH or frequency

1. A BB emits something at EVERY wavelength
2. The *temperature* of the object determines how much radiation the blackbody will emit

HOTTER objects emit MORE intensity at all wavelengths than cooler ones
HOTTER objects have their peak intensity at SHORTER wavelengths than cooler ones. “Bluer”

Astronomers use Kelvin or Celsius Temperatures

<table>
<thead>
<tr>
<th>Kelvin scale</th>
<th>Celsius scale</th>
<th>Fahrenheit scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 K is no atomic motion</td>
<td>273° C</td>
<td>–459.6° F</td>
</tr>
<tr>
<td>0 K on Celsius scale</td>
<td>273° C</td>
<td>599.4° F</td>
</tr>
<tr>
<td>0 K on Fahrenheit scale</td>
<td>546° F</td>
<td>Absolute zero</td>
</tr>
</tbody>
</table>

Wien’s Law for blackbodies:

Relationship between the TEMPERATURE of an object the intensity of its radiation the wavelength of peak intensity

$$\lambda_{\text{peak}} = \frac{0.0029 \text{ m K}}{T}$$

HOTTER objects have peak radiation at shorter wavelengths

COOLER objects have peak radiation at longer wavelengths
The Sun is also a blackbody with $T=5800$ K and the wavelength of peak intensity is at 500 nm.

The “spectrum” of a star in the visible part of the EM spectrum.

A plot of INTENSITY vs. WAVELENGTH.
Features of stellar spectra:

Blackbody objects (wavelength of peak intensity)
Have additional features – “spectral lines”

A detailed look at the spectrum of the Sun

Things to note in solar spectrum:
- Brightest intensity at green/yellow wavelengths
- Presence of many dark lines and features

Spectra for a variety of stars

- Some stars have fewer dark lines in their spectra than the Sun
- Others have more dark lines than the Sun
- The dark lines are also at different positions than the Sun’s
Both of these plots show wavelength vs. intensity.

Experiments on Spectra of the early 1900’s

Burned different elements over a bunsen burner

⇒ glow different colors!!

Scientists discovered that the bright lines also correspond to the dark lines.
Different spectra can be explained by thinking about HOW you view the EM radiation – either directly or through a hotter or cooler gas examples:
- Earth’s atmosphere
- Sun’s layers
- Planet’s atmosphere

The energy levels of the Hydrogen atom:
Places where the electron is located
Fixed levels by quantum mechanics
Energy levels depend on atomic make-up
In order to go UP a level, electron must absorb energy.

In order to go DOWN a level, electron releases energy.

- **ENERGY** takes the form of EM radiation, or "photons".
- Photons have wavelength which corresponds to energy change.

Spectral lines originate from electrons moving in atoms.

- Hot solid, liquid, dense gas: no lines, continuous spectrum.
- Hot object through cooler gas: cooler gas ABSORBS the hotter photons (electrons go up in their energy levels).
- Cloud of thin gas: bright lines formed from atoms in gas colliding (excitation), electrons move down energy levels: EMISSION.
Identifying the spectral lines in the Sun’s spectrum

There are many dark absorption lines – what does this mean??

The Sun’s cooler gaseous outer layers are absorbing the photons arising from the hotter inside!

Mainly hydrogen absorption lines, but over 60 different elements identified in small quantities

O\textsubscript{2} at 759.4 to 726.1 nm (A)
O\textsubscript{2} at 686.7 to 688.4 nm (B)
O\textsubscript{2} at 627.6 to 628.7 nm (a)

H at 656.3 nm – Hydrogen alpha line H\textalpha{} (C)

→ electron moves between n=3 and n=2

H at 486.1, 434.0 and 410.2 nm (F, f, h)
Ca at 422.7, 396.8, 393.4 nm (g, H, K)
Fe at 466.8, 438.4 nm (d, e)

Identifying chemical composition of the Sun’s spectrum

<table>
<thead>
<tr>
<th>Element</th>
<th>Number %</th>
<th>Mass %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>92.0</td>
<td>73.4</td>
</tr>
<tr>
<td>Helium</td>
<td>7.8</td>
<td>25.0</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.02</td>
<td>0.20</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.008</td>
<td>0.09</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.06</td>
<td>0.8</td>
</tr>
<tr>
<td>Neon</td>
<td>0.01</td>
<td>0.16</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.003</td>
<td>0.06</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.004</td>
<td>0.09</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.002</td>
<td>0.05</td>
</tr>
<tr>
<td>Iron</td>
<td>0.003</td>
<td>0.14</td>
</tr>
</tbody>
</table>
Spectra for a variety of stars

- Some stars have fewer dark lines in their spectra than the Sun and others have more dark lines than the Sun.
- The dark lines are also at different positions than the Sun's.

Using spectra to identify chemical compositions

- Procyon (F5)
- Arcturus (K1)
What determines “signatures” of different kinds of stars?

Major research effort at Harvard in the 1920’s

Need to inspect many, many different stellar spectra
look for categories, patterns among them

The Harvard College Observatory: female “computers”
 under direction of Professor Henry N. Russell

Figuring out the various
types of stars

Annie Jump Cannon
(1863-1941)
1918-1924: she classified
225,000 stellar spectra!

Cecelia Payne-Gaposchkin
(1900-1979)
PhD 1925 Harvard
(first Astronomy PhD)
Figured out that different
spectra were due to TEMP.
The categories of stars: O B A F G K M

Differences are due to the TEMPERATURE of star

TEMPERATURE can determine:
• where the electrons are located (which energy levels)
• which elements have absorption, emission lines
  -- an O-star has a temperature of ~50,000 K
  -- an A-star has a temp of ~10,000 K, enough for hydrogen to be ionized (spectral lines in the UV)
  -- a G-star (like our Sun) has a temperature of ~6,000 K

• Different stars have different spectral “signatures”
• All stars fall into several categories: O-B-A-F-G-K-M
<table>
<thead>
<tr>
<th>Class</th>
<th>Color</th>
<th>Prominent Spectral Lines</th>
<th>Surface Temp. (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Blue</td>
<td>Ionized helium, hydrogen</td>
<td>&gt; 25,000 K</td>
</tr>
<tr>
<td>B</td>
<td>Blue-white</td>
<td>Neutral helium, hydrogen</td>
<td>11,000 – 25,000 K</td>
</tr>
<tr>
<td>A</td>
<td>White</td>
<td>Hydrogen, ionized sodium and calcium</td>
<td>7,500 – 11,000 K</td>
</tr>
<tr>
<td>F</td>
<td>White</td>
<td>Hydrogen, ionized and neutral sodium and calcium</td>
<td>6,000 – 7,600 K</td>
</tr>
<tr>
<td>G</td>
<td>Yellow</td>
<td>Neutral sodium and calcium, ionized calcium, iron, magnesium</td>
<td>5,000 – 6,000 K</td>
</tr>
<tr>
<td>K</td>
<td>Orange</td>
<td>Neutral calcium, iron, magnesium</td>
<td>3,500 – 5,000 K</td>
</tr>
<tr>
<td>M</td>
<td>Red</td>
<td>Neutral iron, magnesium, and neutral titanium oxide</td>
<td>&lt; 3,500 K</td>
</tr>
</tbody>
</table>