Today: Chapter 11 -- Stars

Optional: Sec. 11:12-13 & Guided Discovery

Office Hours: Monday 11-2, TH 520

Midterm Exam Oct. 22
Covers Ch. 1-4, 10, 11
Review Sheet will be handed out
First Extra Credit due

See website for: HW Solns. & Next HW
physics.sfsu.edu/~chris/astro115
Voting Question

What happens every 11 years on the Sun?

A.) The energy production increases
B.) There is an eclipse
C.) The number of sunspots increases
D.) The light output decreases significantly
Voting Question

The source of energy in the Sun is

A.) The chemical burning of Hydrogen
B.) The nuclear fusion of Hydrogen into Helium
C.) Nuclear fission of Helium into Hydrogen
D.) Nuclear fission of Uranium
Field of background stars:  Parallax test
Parallax

- We obtain a different perspective on a star by observing it at different times of the year.

- The star is compared to distant background stars.

- In 6 months, Earth moves 2 AU.

- If a star is very far away (1000 light years or more) then parallax won’t work.
Parallax Measures Distance

The larger the star’s distance, $d$, the smaller its parallax $p$.

So distance and parallax are inversely related.

$d = \frac{1}{p}$
Measuring Angles & Distances

- Most stars have a small parallax angle, $p$.
- .... much smaller than 1 degree.
- So parallax angles are measured in units of arc seconds.

- $1/60$ of one degree = 1 arc minute.

- $1/60$ of one arc minute = 1 arc second.

- **Distances** to stars are measured in either: light years, or **parsecs**.

- 1 parsec = 3.2 light years  
  (parsec = PARallax of one arcSEC)
If a star has a parallax 1 arcsecond, then its distance is 1 parsec.

Suppose a star has a parallax 0.1 arc seconds

**Question:** what is its distance in parsecs?

**Answer:**

\[ d = \frac{1}{p} \]

\[ d = \frac{1}{0.1} \]

\[ d = 10 \text{ parsecs} = 32 \text{ light years.} \]

(note: “p” = parallax angle, not parsecs)
Parallax \((p)\) is the **angle** a star appears to move by when Earth orbits the Sun. (\(p\) measured in ‘arc seconds’)

It tells us the distance \((d)\) to the star: (\(d\) measured in ‘parsecs’)

\[
p = \frac{1}{d}
\]
Discussion Question

Three stars have different parallaxes:

- Proxima’s parallax is: 0.8 arc sec
- Sirius’ parallax is: 0.4 arc sec
- Polaris’ parallax is: 0.008 arc sec

Q1: Which Star is closest, which is farthest?
Q2: Can you tell which star is brightest?
How Powerful Are the Stars?

- “Power” is energy output per second.
- **Power** is measured in Joules per second, or Watts
  - eg. a 100 Watt light bulb uses 100 Joules of energy per sec.

- We measure the power, or brightness, of stars in 2 ways: **luminosity** and **magnitude**.

The Luminosity (L) of a star is just its wattage. The Sun’s luminosity is:

\[ L_{\text{Sun}} = 380,000,000,000,000,000,000,000,000,000 = 3.8 \times 10^{26} \text{ Watts!} \]

=380 Yottawatts!

Other stars can be measured against the Sun.
Instead of Watts, we’ll use the **Sun’s Luminosity** \((L_{\text{Sun}} = L_\odot)\) to measure other stars.

### Luminosities of Different Stars

- **Our Sun:** \(L = 1.0 \, L_{\text{sun}}\)
- **Sirius:** \(L = 25 \, L_{\text{sun}}\)
- **Polaris (North star):** \(L = 1,300 \, L_{\text{sun}}\)
- **Proxima:** \(L = 0.002 \, L_{\text{sun}}\)
The Most Luminous Star

- Eta Carinae is the most luminous star known.
- \( L = 4 \text{ Million } L_{\text{sun}} \) !!!!
- In \(~5\) seconds, it emits as much light as the Sun in \(~1\) year!
Another way to measure the brightness of a star is its “Magnitude”

Ancient people put stars into 5 classes, from

“First Magnitude” (brightest) to “Fifth Magnitude” (dimmest)

This system is still in use today
Magnitudes of stars in Orion
Magnitudes

- *Lower* magnitudes = *brighter* stars

- So a 1st magnitude star is *brighter* than a 2nd mag. star

- We use the symbol: $m$ to mean magnitude.

- Originally there were only magnitudes 1-5

- However a very *bright* object can even have a negative magnitude.
Magnitude Examples

• The planet Venus’ magnitude is $m = -4.0$

• A very *faint* object can have a magnitude above 5.

• E.g.: A distant galaxy has a magnitude: $m = 20$.

• Q: What object in the sky has the *lowest* magnitude?
Magnitude

- Sun (-26.7)
- Full moon (-12.6)
- Venus (at brightest) (-4.4)
- Sirius (brightest star) (-1.44)
- Naked eye limit (+6.0)
- Binocular limit (+10.0)
- Pluto (+15.1)
- Hubble Space Telescope and large Earth-based telescopes (+30.0)
Some stars are a million times brighter than others. But, their magnitude difference is just 15.

<table>
<thead>
<tr>
<th>Magnitude Difference</th>
<th>Intensity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>6.3</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>250</td>
</tr>
<tr>
<td>7</td>
<td>630</td>
</tr>
<tr>
<td>8</td>
<td>1600</td>
</tr>
<tr>
<td>9</td>
<td>4000</td>
</tr>
<tr>
<td>10</td>
<td>10,000</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>15</td>
<td>1,000,000</td>
</tr>
<tr>
<td>20</td>
<td>100,000,000</td>
</tr>
<tr>
<td>25</td>
<td>10,000,000,000</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Calculating Magnitude Differences

- Each magnitude is a factor of 2.5
- So a difference of 3 magnitudes = $2.5 \times 2.5 \times 2.5 = 15.6$ times brighter!
- 5 magnitudes difference corresponds to a star which is 100 times brighter.

Example:

- Star A’s magnitude is 1.0, Star B’s magnitude is 6.0
- The difference in magnitudes is $6.0 - 1.0 = 5$ Mags.
- So, Star B is 100 times fainter than Star A.
Inverse Square Law

As the light from a star goes into space, it fills a larger and larger sphere.
If "r" is the radius of the sphere, then the area of a sphere is given by: \( A = 4 \pi r^2 \)

The intensity of light decreases with the square of our distance from the star:

Brightness of a star \( \sim \frac{1}{r^2} \)
Distance & Brightness

- If we view the same star from **double** the distance, it will *appear* **four times** fainter.
- Its **apparent magnitude** will be higher.
- So, *nearby* stars can trick us into thinking they are truly bright.
- To compare stars fairly, we need to place them all at the same distance...

- We need a way to measure the **intrinsic** (true) brightness of stars.
- The **Absolute Magnitude** *does not depend* on how far away it is.
- It is a measure of the star’s true energy output, not just its brightness as viewed from Earth.
**Absolute & Apparent Magnitude**

**Apparent** magnitude (m): the magnitude we see from Earth.

**Absolute** magnitude (M): the Intrinsic Magnitude (regardless of distance)

Absolute Mag. is defined as the magnitude that a star would have if we viewed it at a distance of 10 parsecs.

The Sun’s Apparent magnitude is: $m = -27$ !

The Sun’s Absolute magnitude is: $M = 4.8$

If the Sun were moved to a distance of 10 parsecs away, it would just barely be visible (Apparent Magnitude 4.8)
Example:

<table>
<thead>
<tr>
<th></th>
<th>Betelgeuse</th>
<th>Rigel</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>0.45</td>
<td>0.15</td>
</tr>
<tr>
<td>M</td>
<td>-5.5</td>
<td>-6.8</td>
</tr>
<tr>
<td>d</td>
<td>152 pc</td>
<td>244 pc</td>
</tr>
</tbody>
</table>

Betelgeuse

m = 0.45 mag

Rigel

m = 0.15 mag
Different Types of Star
(How many are there?)

- To understand the diversity of stars, we first classify them.
- We can use the star’s *spectrum* to do this.
- This was first done in the early 1900’s at Harvard Univ. by Annie Jump Cannon

- She was assigned the job of classifying stellar spectra into types (A,B,C ....)
- In her life she classified over 200,000 spectra!!!
Different Types of Star

- Cannon found that most stars fell in to 7 different categories

- A star’s spectral lines depend on what its temperature is.

- Cannon re-organized the spectral types to form a temperature sequence:

  O, B, A, F, G, K, M
These absorption lines are used to distinguish the different spectral types
How Do We Classify Stars?

- O type stars are the hottest
- M type stars are the coolest.

“Ooh, Be A Fine Guy/Girl Kiss Me.”
Student Submissions....

- Oh Boy, An F Grade Kills Me!
- Octavius became Augustus, fighting gallantly, killing many.
- Only Boys Accepting Feminism Get Kissed Meaningfully.
- Oops! Bacon Appetizers for generally Kosher man.
- On Break After Finals: Good, Key Moment

OBAFGKM shows spectral types in order of decreasing temperature
Spectral Sub-Types

OBAFGKM

- A star’s **spectral type** can be specified more precisely using a **subtype** ranging from 0 to 9.

- Example: spectral type **A** is divided into **A0, A1, A2 .... A9**

- **A0** is the hottest, and **A9** is the coldest.

- **F0** is cooler than **A9**.

- If you know a star’s spectral type, then you know its temperature.

- The Sun is a type **G2** star, corresponding to a temperature of 5800 K.
Stars: What do We Know?

- Temperature (T) & Spectral Type
- Distance

- Brightness
  - Luminosity \((L_{\text{star}})\) - energy output of a star
  - Apparent Magnitude (m) - how bright a star appears
  - Absolute Magnitude (M) - how bright a star really is
So many stars...so little time
Organizing the Family of Stars

- To understand the huge diversity of stars, we organize them according to their:
  - Temperature (T)
  - Luminosity ($L_{\text{star}}/L_{\text{Sun}}$)

- How are these properties related?
- To find out, each star is plotted as a point on a graph
  - The x-coord. is Temperature (T)
  - The y-coord. is Luminosity ($L_{\text{star}}$)