Stars, Galaxies & the Universe

Announcements
- HW#3 – due Tuesday (Tomorrow) at 3 pm
- Lab Observing Trip – Tues (9/28) & Thurs (9/30)
- First Exam – next Wed. (9/22) in class
  - will post review sheet, practice exam on website
Measuring stars:
Luminosity, size, distance,
Temperature, age, composition

What properties might we want to know about stars?
• luminosity
• distance
• radius
• temperature
• velocity through space
• companion or alone?

Properties of Stars: Star Names
• refer to Greek, Latin, Arabic names of constellations
• pair a Greek letter with name representing the brightness (alpha, beta, gamma, delta...)
• “catalog” names from various space missions (e.g. IRAS 06429-1639)
• stars often have multiple names
Astronomers do not use “name a star” services!

Stellar Properties: Distance

<table>
<thead>
<tr>
<th>Star</th>
<th>Distance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigel</td>
<td>773 ly</td>
<td>B8, 700,000x more LUMINOUS than Sun, 0.2x as bright as Sirius</td>
</tr>
<tr>
<td>Betelgeuse</td>
<td>427 ly</td>
<td>Very red, &quot;red giant&quot;, 135,000x L(_{\text{Sun}}), cooler than Sun, radius past ~5 AU</td>
</tr>
</tbody>
</table>

Distance: 1 AU 4.35 ly 4.22 ly
Properties of Stars: Distances

**DISTANCE is the fundamental piece of information to know about an astronomical object!**

**WHY?**

- to convert angular size into physical size
- in order to know the intrinsic energy output (or “Luminosity”) of a star, you need its distance
- “flux” is what we measure, need to convert that into Luminosity

**Parallax**

- as Earth orbits the Sun, stars appear to change positions against “fixed” background stars
- due to our motion around the Sun
- eye sees about 1’ in resolution, so not apparent to naked-eye observers (early Greek astronomers)
Parallax

- All parallaxes are less than 1 arcsecond
- Larger parallaxes for closer stars
- Smaller parallaxes for distant stars

The nearest star has a distance of 4.2 light years, which is 1.3 pc. Its parallax angle is 0.77” — small!

Parallax

- Very tiny parallax angles difficult to measure from Earth due to smearing of the atmosphere

- **HIPPARCOS** satellite able to measure parallaxes for 118,000 stars, this group only represents the very closest stars!

- However, most stars in our Galaxy are too distant to see any noticeable parallax and for distant galaxies, can’t use parallax!
Measuring stars:

- Brightness, parallax

What we’d like to know:

- Luminosity, size, distance,
- Temperature, age, composition

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• the brightness we observe from a star or a galaxy is known as “flux”

• “flux” depends on the objects’ distance
  - the more distant the object, the less bright
  - the closer the object, the more bright

• The object’s intrinsic energy does not change!

→ if the Sun were at the distance of a nearby star (~10 pc) it would barely be visible with the naked eye!!
The Inverse-Square Law for brightness

\[ \text{flux} = \frac{L}{4\pi d^2} \]

Distance-Luminosity relation:
Which star appears brighter to the observer and by how much?

Star 2

Star 1

\[ L \]

\[ 2d \]

(a) Star 1 by 2 times
(b) Star 2 by 2 times
(c) Star 1 by 4 times
(d) Star 2 by 4 times

Trickier: Distance-Luminosity relation:
Which star appears brighter to the observer?

Star 2

Star 1

\[ 2L \]

\[ 2d \]

(a) Star 1
(b) Star 2
(c) Not enough info.
Brightness of stars

- The brightness of a star is a measure of its flux.
- Ptolemy (150 A.D.) grouped stars into 6 'magnitude' groups according to how bright they looked to his eye. Human eyes have a logarithmic response to light.
  - Range of eye is magnitude 1 (brightest) to 6 (limit!)
  - Change in magnitude of 1 means 2.5 brighter/dimmer
- Herschel (1800s) first measured the brightness of stars quantitatively and matched his measurements onto Ptolemy's magnitude groups and assigned a number for the magnitude of each star.
  - Range of eye is magnitude 1 (brightest) to 6 (limit!)
  - Change in magnitude of 1 means 2.5 brighter/dimmer

Note that brighter stars have lower numbers, and dimmer stars have higher numbers!

- Sun (+26.7)
- Full moon (+12.6)
- Venus (at brightest) (+4.4)
- Sirius (brightest star) (+1.4)
- Naked eye limit (+6.0)
- Binocular limit (+10.0)
- Pluto (+15.1)
- Large telescope (visual limit) (+21.0)
- Limit of +19 small telescope like Rigel, robotic telescope in AZ

Pleiades Cluster

- Hubble Space Telescope and large Earth-based telescopes (photographic limits) (+30.0)
Flux and Apparent Magnitude

Consider two stars, 1 and 2, with apparent magnitudes \( m_1 \) and \( m_2 \) and fluxes \( F_1 \) and \( F_2 \). The relation between apparent magnitude and flux is:

\[
\frac{F_1}{F_2} = 10^{(m_1 - m_2)/2.5}
\]

For \( m_2 - m_1 = 5 \), \( \frac{F_1}{F_2} = 100 \).

Absolute magnitude

- To talk about the properties of star, independent of how far they happen to be from Earth, we use "absolute magnitude".
- Absolute magnitude is the magnitude that a star would have viewed from a distance of 10 parsecs.
- Absolute magnitude is directly related to the luminosity of the star.

<table>
<thead>
<tr>
<th>Star</th>
<th>Apparent magnitude (parsecs)</th>
<th>Absolute magnitude (relative to Sun)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>-26.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Proxima Centauri</td>
<td>(1.01)</td>
<td>3.30</td>
</tr>
<tr>
<td>Proxima Centauri</td>
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How do Spica and Sirius compare:

(a) as observed from Earth [apparent magnitude]

(b) Intrinsically [luminosity]?
Stars come in a wide variety of temperatures and sizes

- Stellar temperatures: ~2500 K – 75,000 K!

- Small stars will have low luminosities unless they are very hot.

- Stars with low surface temperatures must be very large in order to have large luminosities.

Stars come in a wide variety of sizes

Stefan-Boltzmann law relates POWER to temperature

- very strongly related to temperature

POWER per area $\propto T^4$

Star’s LUMINOSITY = POWER per area * surface area

Star’s LUMINOSITY can be related to its temperature and size.

$LUMINOSITY = \frac{4\pi R^2 \sigma T^4}{\text{power per area * surface area}}$

$LUMINOSITY$ is measured in joules per square meter of a surface per second and $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

or in cgs: $\sigma = 5.67 \times 10^{-5} \text{ erg cm}^{-2} \text{ sec K}^{-4}$
Luminosity - Radius –Temperature Law

\[ R = 2 \, R_{\text{sun}} \quad \quad \quad R = R_{\text{sun}} \]

\[ T = \frac{1}{2} \, T_{\text{sun}} \quad \quad \quad T = T_{\text{sun}} \]

**Which star is more luminous?**

*Emits the most energy every second*

(a) Star 1  
(b) Star 2