AST 101
Introduction to Astronomy: 
Stars & Galaxies

Midterm #1 Next Tuesday, Sept. 29 – It will cover the first 8 lectures

Last three classes

• The Sun
  – Energy by Fusion
  – Solar Structure
  – Solar Activity

Next: Measuring the Stars

1. Measuring distances
2. Measuring stellar luminosities
3. Measuring temperatures
4. Measuring masses

Often only seeing a point of light

• Stars are so small compared to their distance to us that we almost never have the resolution to see their sizes and details directly—“point sources”
• We deduce everything by measuring the amount of light (brightness) at different wavelengths (color, spectra)

Angular size of Alpha Centauri = .004 arcsec
• Stars take millions or even billions of years to go through their life stages— we rarely see a single star change.

• Observing many different stars lets us figure out the sequence of a single star's life.

One of the Most Basic Problems in Astronomy

Star of given APPARENT BRIGHTNESS could be either
A. very luminous star far away
B. low luminosity star closer by

DISTANCE to the star matters!

Inverse Square Law of Brightness

Apparent Brightness = \( \frac{L_0}{4\pi(distance)^2} \)

Clicker Question

If you quadruple (x4) your distance to a light and look again, how much dimmer does it appear?

A. one-half as bright as originally
B. one-fourth as bright
C. one-eighth as bright
D. one-sixteenth as bright
E. unchanged, since really same light
Clicker Question

If you quadruple (x4) your distance to a light and look again, how much dimmer does it appear?

A. one-half as bright as originally
B. one-fourth as bright
C. one-eighth as bright
D. one-sixteenth as bright
E. unchanged, since really same light

Stellar Luminosity

• **What we measure:**
  APPARENT BRIGHTNESS
  = how bright it appears to us here on Earth

• **What we want to know:**
  (absolute) LUMINOSITY
  = how much energy is emitted (Joules/sec or watts)

• **Need to know**
  DISTANCE to the star

How Do We Measure the Distances to Astronomical Objects?

• We’ll keep asking this question again and again over the semester

• Several techniques, each valid for different objects at different distances

• Technique #1: **Parallax**

Determining Distance Using Parallax

• Measure the apparent movement of stars over a year
  Movement is caused by Earth’s movement around the Sun
Self-demo of parallax

- Your nose is the Sun
- Your left eye is the Earth in January
- Your right eye is the Earth in June
- Your thumb (placed six inches from your face) is a nearby star

- Watch the apparent motion of your thumb against a distant reference point as you take measurements in January and June
  - Repeat experiment with a further star (thumb at arm’s length)

Which “move” more -- closer or farther objects?

Parallax formula

- New Distance Unit invented for just this method of distance measurement!!
  - Parsec = (parallax+arcsecond)
    - An object at a distance of one parsec has a parallax of 1 arcsecond

- Distance (parsecs) = 1/p (arcsec)
  - 1 parsec = 1 pc = 3.26 light years

(Remember 1 arcsecond = 1/3600 degree!)

Parallactic angle (p) = 1/2 of the change in angular position over 6 months

- Larger for closer objects
- Smaller for farther objects

Parallax

What is parallax?

A. The total amount of power that a star emits into space.
B. A measurement of the separation of two stars in a visual binary.
C. A classification of a star based on its temperature.
D. The shift of a star’s apparent position due to the motion of the Earth.
E. A statement that is seemingly contradictory or opposed to common sense and yet is perhaps true
Clicker Question

What is parallax?

A. The total amount of power that a star emits into space.
B. A measurement of the separation of two stars in a visual binary.
C. A classification of a star based on its temperature.
D. The shift of a star’s apparent position due to the motion of the Earth.
E. A statement that is seemingly contradictory or opposed to common sense and yet is perhaps true.

Clicker Question

The biggest ground-based telescopes with adaptive optics can measure stars’ positions to accuracies of about 0.1 arcseconds. How far away can they map the positions of stars via parallax?

A. 1 pc
B. 10 pc
C. 100 pc
D. 1000 pc

Clicker Question

Parallax

- B. maximum distance is set by the accuracy with which you can measure positions in the sky (space does better than ground)

Distance (pc) = 1 / 0.1 arcsec = 10 pc = 32.6 ly

Brad and Angelina are two stars that have the same apparent brightness. Brad has a larger parallax angle than Angelina. Which star is more luminous?

A. Brad
B. Angelina
C. Not enough information to know
• Brad has a larger **PARALLAX ANGLE**. Thus, he is closer to us.

• If they both have the same **APPARENT BRIGHTNESS**, but Brad is closer…

• **B. Angelina** must be more luminous.

---

**Best parallax measurer:**
**Hipparcos satellite (1989-1993)**

• Space measurements not affected by atmosphere

• Measurement made many times until accurate to 0.001 arcsec (≈ 3000 light years)

• 100,000 stars mapped
• (2.5 million to slightly lesser accuracy)

---

**Magnitudes: Crazy Units**
• Dates back to the original Hipparchus (the person! 190-120 B.C.)
  – Brightest stars were of first magnitude
  – Dimmest stars were of sixth magnitude
  – Everything else sorted in between.

Apparent magnitude = 1 are the brightest stars in the sky
Mag = 6 is faintest naked eye can see.

**NOTE THE BACKWARDS SCALE!**
Bigger number is fainter!

---

**Magnitudes: The modern version**
• Later calculated more precisely and found our eye sees on a semi-logarithmic scale.
  – Linear difference of 2.5 in magnitude is a factor of 10 in apparent brightness
    • Mag 1 is 100 times brighter than mag 6 (diff=5=2**2.5)

Sirius (brightest star in the night sky) = -1.5
Sun = -26.7
Mag 30 = faintest ever detected (with Hubble)

**NOTE THE BACKWARDS SCALE!**
Bigger number is fainter!
Clicker Question

Tom is a magnitude 5 star and Katie is a magnitude 12.5 star. Who is brighter and by how much?

A. Tom is 7.5 times brighter than Katie.
B. Katie is 7.5 times brighter than Tom.
C. Tom is 100 times brighter than Katie.
D. Tom is 1000 times brighter than Katie.
E. Katie is 1000 times brighter than Tom.

Clicker Question

Tom is a magnitude 5 star and Katie is a magnitude 12.5 star. Who is brighter and by how much?

A. Tom is 7.5 times brighter than Katie.
B. Katie is 7.5 times brighter than Tom.
C. Tom is 100 times brighter than Katie.
D. Tom is 1000 times brighter than Katie.
E. Katie is 1000 times brighter than Tom.

So far:

- Measure **Distance**:
  - parallax…good to nearby stars but not beyond

- Measure **Luminosity**:
  - measure apparent brightness and distance, infer luminosity

Next:

**Measure Surface Temperature**

Two ways to measure temperature

1) Thermal spectrum (i.e. Wien’s Law, recall…)
   Hotter = bluer; cooler = redder
2.) Spectral lines even better!

- Different atoms and molecules can be characterized as “tough” or “fragile”.

- The more complex an atom or molecule (more electrons, more atoms), the more fragile it is.
  - Fragile types are more easily ionized or knocked apart by collisions in high temperature regions.

→ If there are signs of fragile atoms and molecules, the temperature must be low.

Clicker Question

Which star is hotter?

A. This star near the top (less “fragile” atoms)
B. This star near the bottom (more “fragile” atoms)
C. We don’t have enough information.
**A bit of history: Classifying Stars**

*World War I, Harvard College observatory*

Women were hired by the observatory director as “computers” to help with a new survey of the Milky Way.

Most had studied astronomy, but were not allowed to work as scientists.

---

**Devising the strange temperature code**

- **Original classification of spectra (1890) was:**
  - \( A \) = strongest hydrogen feature
  - \( B \) = less strong hydrogen … \( C, D \), etc.

- Annie Jump Cannon realized that, visually, a different sequence made more sense (~1910)!

\( \rightarrow O B A F G K M !! \)

---

- Important: the different spectral lines seen are NOT primarily because stars are made of different elements.

- Most stars are made mostly of **hydrogen**.

- The variety in spectra is due to temperature and the survival of electrons attached to atoms and molecules at the star’s surface.

---

**OBAFGKM**

- **Spectral (color) classification**
  - \( O \) = hottest, bluest
  - \( G \) = middle type, yellow (Sun)
  - \( M \) = coolest, reddest

---

Cecelia Payne-Gaposchkin figured this out.

---

Globular Cluster NGC 6397

- [Image of Globular Cluster NGC 6397]
How to remember the sequence?

Oh Be A Fine Girl/Guy, Kiss Me

(historical mnemonic)

Spectral Classification: O B A F G K M

- **Hottest stars**: O B
  - mostly helium, little hydrogen
- **Hot stars**: A F
  - helium, hydrogen
- **Cooler stars**: G
  - hydrogen, heavier atoms
- **Coolest stars**: M
  - molecules, (complex absorption bands)

**Astronomer’s Toolbox:**

So far:

- **Measure Distance**:
  - parallax...good to nearby stars but not beyond
- **Measure Luminosity**:
  - measure apparent brightness and distance, infer luminosity
- **Measure Temperature**:
  - Wien's law, or, better yet, take spectra and use spectral classification

Next class:

**Measure Mass**