Today’s Topics

• How we measure big distances -- and what an expanding universe means
• Planetarium #3 this Wed 6 April – Dick McCray presents “SUPERNOVAE” – go there directly
• Observatory Night # 7 this Wed 8:30pm+ signup
• Overview read Chap 21 Galaxy Evolution for Friday lecture, plus 21.5 Quasars in detail
• Homework Set 8 on Cosmic Distances and Hubble Law due today
• New Homework Set 9 PLANET FINDER still available: team format, all Web / Java based
• HELP LABS this Tues, Wed, Thurs 4-6m, plus Thurs 7-9pm – get started now, if not already

Clicker: halo stars

• Massive O-type stars are not found in the galactic halo because they are:
  A. too massive to be kicked into the halo from the disk
  B. so massive that they settle into the thinner disk
  C. too short-lived to have persisted from halo formation until today
  D. too far away for us to see them

Why no O-stars?

• C. Too short lived to be in the halo

Halo stars were born billions of years ago; the most massive stars don’t live nearly that long

Will have disappeared by now (after having “enriched” the proto-galaxy gas with heavy elements)

VELOCITY = H₀ × DISTANCE

Hubble’s Law implies:

Universe expands like raisin bread!

True for very large scales between galaxies – but not for stars, planets, us!

"HUBBLE CONSTANT"

H₀ = 71 +/- 4

km / sec / Mpc
Mapping the universe: need distances to galaxies!

- Identify (and calibrate) properties of galaxies that could serve as "STANDARD CANDLES" -- beyond direct measure by trigonometric parallax.

1. Make some measure of an object which identifies its luminosity (like period in Cepheid).
2. Use this luminosity and measure apparent brightness to infer distance to it.

Main-Sequence Fitting

- Start with cluster A (upper) whose distance known via parallax.
- Compare with other cluster B (lower).
- Get distance to B from brightness difference.

M-S Fitting "pinned to" nearby Hyades Cluster, 151 ly away.

Cepheid variable stars

- Two Cepheid stars, Fred and Barney, have the same apparent brightness. Fred has a period of 5 days, and Barney of 10 days. Which is closer?

A. Fred
B. Barney

Clicker – Cepheids and distance

- Two Cepheid stars, Fred and Barney, have the same apparent brightness. Fred has a period of 5 days, and Barney of 10 days. Which is closer?

A. Fred
B. Barney
Why A. Fred?

- Fred has a shorter period and so must be less luminous.
- Less luminous but the same apparent brightness means that Fred is closer to us.

Number of Fuzzier Distance Estimators

- A. Apparent brightness of (resolved) red and blue supergiants.
- B. Size and brightness of H II regions (emission nebulae) or starbirth regions.
- C. Intercompare distances so deduced for specific galaxies (overlapping rungs in distance ladder).

Tully-Fisher Relation

- Fast rotation speeds in spiral galaxies.
- More mass in galaxy.
- Higher luminosity.

Measure rotation speeds to infer luminosity.

Need bright “edge-on” spirals, estimate tilt.

Even brighter: White dwarf supernovae

- “Standard explosion” = fusion of 1.4 solar masses of material.
- Nearly the same amount of energy released.

Practical difficulty: White dwarf SN

- Need to catch them within a day or two of the explosion.
- About 1 per galaxy per century.
- Need to monitor thousands of galaxies to catch a few per year; galaxy clusters are useful.

DISTANCE ESTIMATE 3

DISTANCE ESTIMATE 4

Bright enough to be seen halfway across observable universe.

Useful for mapping the universe to the largest distances.

Practical difficulty: White dwarf SN
**White dwarf supernovae**

- Carbon fusion explosion; mass transfer in binary takes white dwarf 'over the edge'
- Roughly same amount of energy released (calibrate)

**Distance ladder**

- Brighter SN dim more slowly!

**Overlapping “standard candles”**

- Roughly same amount of energy released (calibrate)

**Distance ladder to measure universe**

- Different standard candles are useful for different distances

**Balloon analogy for expanding universe**

- On an expanding balloon, no galaxy is at the "center" of expansion; no edge
- Expansion happens into a higher dimension (2-D surface into a 3-D space)
- Is our 3-D space expanding through a 4th dimension?

**Measuring big distances to galaxies**

- "STANDARD CANDLES" -- important ones in ‘distance ladder’, or ‘chain’
  - 1. Main-sequence fitting
  - 2. Cepheid variables
  - 3. Tully-Fisher relation
  - 4. White dwarf supernovae

**Use Hubble’s Law itself to estimate vast distances D**

- Measure velocity, then: $D = v / H_0$
- Example: using $H_0 = 70$ km/sec/Mpc, and finding that $v = 700$ km/sec

$$D = \frac{700 \text{ km/sec}}{70 \text{ km/sec/Mpc}} = 10 \text{ Mpc}$$

= 32 million light years
Use Hubble’s Law for “distances”

- Measuring distances to remote galaxies is difficult, but measuring Doppler shifts (velocities) is easier from spectra.
- Use Hubble’s Law to estimate biggest distances (really LOOKBACK TIME)!

Knowing distances reveals large-scale galaxy clustering

Find clusters + super-clusters: sheets and voids like ‘bubble bath’

Lookback time (in expanding universe)

- Say it takes 400 million years for light to get from galaxy A to us in Milky Way.
- Yet during travel in spacetime, both A and MW have changed positions by expansion.
- Thus “distance” is a fuzzy concept – LOOKBACK TIME is better.

Telescopes are “lookback” time machines

Today, we see Andromeda as she was 3 M years ago!

Next class: Wed 6 April
Go directly to Fiske Planetarium
Dick McCray: SUPERNOVAE
Also -- Observatory Night # 7 on Wed