On Today’s Radar

- Edwin Hubble used Cepheid Variable stars to show Andromeda is a galaxy of its own – major discovery!
- Today we look at the challenge of measuring big distances to figure out how far away things are in universe – leads to Hubble’s law of expansion
- Re-read 20.4 Measuring Cosmic Ages carefully
- Overview read Chap 21 Galaxy Evolution for Tues lecture, plus 21.5 Quasars in detail
- Observatory Night # 6 next Tues 18 Apr
- We have shifted content of Planetarium #3 into lecture format – so come here next Tues

Measuring galactic distances

REMINDER

Edwin Hubble made breakthrough using Cepheid variables to measure distance

Found Andromeda far outside Milky Way

Huge step forward in thinking about universe

Cepheid stars in H-R diagram

- “Instability strip” – region in H-R diagram with large, bright stars
- Outer regions of star are unstable and tend to pulsate
- Star expands and contracts, getting brighter and fainter

Clicker -- reading on galaxies

- How might you classify this galaxy?
  - A. Sa
  - B. SBb
  - C. E
  - D. SO

Cepheid variable stars as distance indicators: “standard candle”

Vital discovery by Henrietta Leavitt (1912)
Cepheid variable stars

Period - Luminosity relation

brighter Cepheids have longer periods

Andromeda found to be far outside Milky Way – another “island universe”: galaxy!

- Edwin Hubble in 1924 identified Cepheids in Andromeda (M33) → showed they were far outside of Milky Way!
- Now known distance: 2.3 million ly
- His first big discovery (more to come) …

Hubble using new 100" Hooker telescope at Mt. Wilson (above LA)

100" Hooker telescope at Mt Wilson

Begins new era in 1924!

Hubble: next showed universe appeared to be expanding!

- Vesto Slipher (1912) reported that most galaxies showed Doppler redshifts
- Edwin Hubble, using new 100" telescope, started busily measuring galaxy redshifts
- Hubble (1929) announced that redshifts of galaxies appear to increase with distance from us
- This was startling: suggests an EXPANDING UNIVERSE!

Hubble and recession of galaxies: measured many redshifts

Further away, greater redshift!

Hubble guessed their distances by size and brightness – underestimated by factor 10!
“Hubble’s Law”

\[ \text{Hubble Velocity-Distance Law} \]

\[ V = H \cdot d \]

\( H = \text{Hubble Constant} \)

\( \text{(For an Expanding Universe)} \)

Scatter here from random velocities of nearby galaxies, unreliable distance estimates

Best current values for expansion

\[ H_0 = 71 \pm 4 \text{ km/s/Mpc} \]

“HUBBLE CONSTANT”

Hubble (1929) plot extended only to 2 Mpc. \( H_0 \) was \( \sim 500 \) !

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)

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
**VELOCITY** = \( H_0 \times \text{DISTANCE} \)

**HUBBLE CONSTANT**

\[ H_0 = 71 \pm 4 \quad \text{km/sec/Mpc} \]

**HUBBLE LAW** implies:

Universe expands like raisin bread!

**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

**Cepheid variable stars**

1. Measure period of variability
2. From period-luminosity relation, infer the luminosity
3. Compare with apparent brightness and thus determine distance

**Cepheids variables as standard candles**

- **DISTANCE ESTIMATE 1**
- **DISTANCE ESTIMATE 2**
- **DISTANCE ESTIMATE 2**

**M-S Fitting “pinned to” nearby Hyades Cluster, 151 ly away**
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")