Hubble's Law—8 Apr

- Your grades were emailed this morning.
  - 65 email errors: If you did not receive your grade, send me an email.
- In the message
  - Scores on homework, clicker questions, & tests
  - Excused dates
  - Cuts
  - Total grade
- Class average is 73%, 2.8.
- Final (35%) may change your grade substantially.

About Hubble's Law

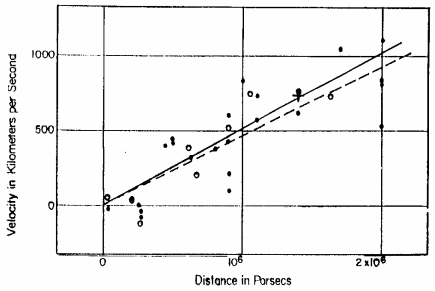
- Simplicio's questions
  - Expansion of the universe is difficult because we are part of the universe
- How Hubble discovered Hubble's Law

Edwin Hubble 1889-1953

Dialogue Concerning Two Chief World Systems
Sagredo, Simplicio, and Salviati

Hubble's Law

- Slipher measured velocities; Hubble measured distances
- Hubble's Law: v = H D
  - Hubble 1929, Proc. Nat. Acad. Sci. 15, 168



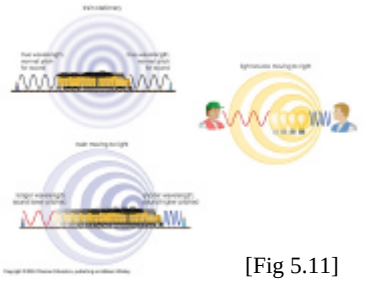
Measuring Radial Velocity: The Doppler effect

- If wave's source is moving,
  - stationary observer measures different frequency
  - = different wavelength.
- True for water waves, sound waves, and light waves.
  - Shift in wavelength is

    $\Delta\lambda = \lambda_{observed} - \lambda_{rest}$
  - For v = velocity of emitter,

    $\frac{?}{?} = \frac{v}{c}$

    c = velocity of light
  - This *Doppler shift* only measures velocity along line of sight.



[Fig 5.11]

Measuring Radial Velocity: The Doppler effect

- Vesto Slipher in Flagstaff
  - Observed spectra of nearby galaxies
  - Some observations took several nights

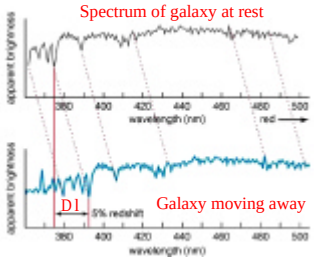
Vesto Slipher

- Shift in wavelength is
  $\Delta\lambda = \lambda_{observed} - \lambda_{rest}$
- For v = velocity of emitter,
  c = velocity of wave

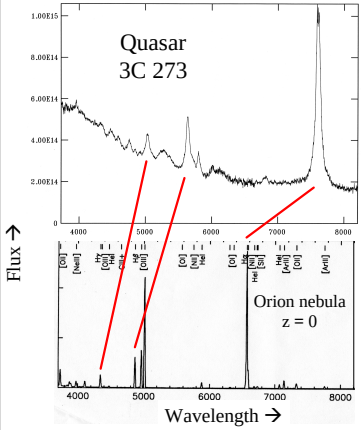
$$\frac{??}{?} = \frac{v}{c}$$

- This *Doppler shift* only measures velocity along line of sight.

[Fig. 15.14]



Large redshifts

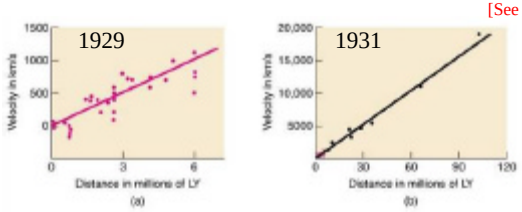


- Measure Doppler shift from emission or absorption lines:

Redshift z = Dl/l = v/c

Hubble's Law (1929)

[See Fig 15.15]

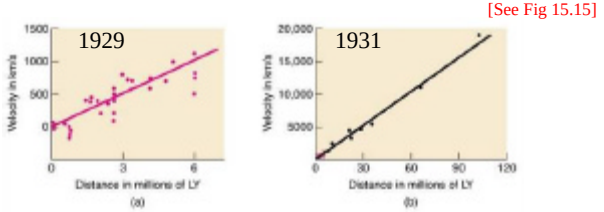


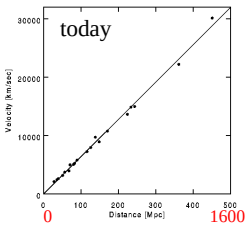
- Measure radial velocity v from Doppler shift.
- Hubble's Law:
  $v = H_o\, d$
- Proportionality constant H_o is called "Hubble constant"

1. What did Hubble find for Hubble's constant in 1929?
   a. 6 million Ly
   b. 1000 km/s
   c. 160 km/s/Myr
   d. .006 km/s/MLyr

Hubble's Law (1929)

[See Fig 15.15]





- Measure radial velocity v from Doppler shift.
- Hubble's Law:
  $v = H_o\, d$
- Proportionality constant H_o is called "Hubble constant"
- Note huge change in measured value of H_o between 1931 and today
  - Constant refinement of distance scale

Simplicio

- Simplicio: Coma is 300MLy from us, and it is moving away from us at 6000km/s. Galaxy NGC 2323, which is 600MLy away, moves at 12,000km/s.

2. What is the basis of Simplicio's reasoning?
   a. Simplicio is guessing
   b. Big objects move fast
   c. Simplicio recalls how fast NGC2323 is moving
   d. Hubble's Law
3. Is Simplicio's thinking correct?
   a. Yes
   b. No

Simplicio

- Simplicio: (a) Coma is 300MLy from us, and (b) it is moving away from us because of the Big Bang. (c) The sun is 1 AU from us, and (d) it is moving away from us (e) because it is part of the universe.

4. Is Simplicio's thinking correct?
   a. Yes
   b. No

Simplicio

- Simplicio: (a) Coma is 300MLy from us, and (b) it is moving away from us because of the Big Bang. (c) The sun is 1 AU from us, and (d) it is moving away from us because it is part of the universe.

5. What part of Simplicio's reasoning is incorrect?

Simplicio

- Simplicio: You tell me the universe is expanding, and some things do move away but other things do not. How does a thing know what to do?

6. Sagredo explains: The fundamental reason is
   a. Galaxies move away; other things do not.
   b. Big objects move away; little objects do not.
   c. If the force holding the object is big enough, it does not move away.
   d. Nearby objects do not move away; distant objects do.

Simplicio

- Simplicio: The Andromeda galaxy is coming toward us, not moving away. That must be a mistake.

7. Sagredo explains: The reason is
   a. Part of the Big Bang went the wrong way.
   b. Andromeda is a little galaxy.
   c. Over time, the gravitational force between Andromeda & the Milky Way has slowed and reversed the expansion.
   d. Andromeda is nearby.