Hubble’s Law—28 Oct

- Intro: What are galaxies?
- Hubble’s Law
- Universe is expanding
- Universe started with a Big Bang
- Age of the universe

Exam 2

- Top 1/10: 25/30
- Top quartile: 22
- Median: 19
- Bottom quartile: 15
- If you got less than 10, figure out what you need to change.
Galaxies

- Galaxies are made of billions of stars, gas, dust, and dark matter.
- Our galaxy is the Milky Way.
- Nearest big galaxy is our big sister Andromeda, which is 700kpc, 3Mly from us. Sun is 8kpc from center of the Milky Way.
Sombrero Galaxy • M104

M51

Whirlpool Galaxy • M51
• V M Slipher, Lowell Observatory, pioneered the measurement of the Doppler velocities of galaxies.
  • Some spectra took several nights.
• Hubble measured / estimated distances of galaxies.
  • Not measurements by parallax. Indirect. Very complicated.
• Hubble 1929, Proc. Nat. Acad. Sci. 15, 168
• Summarize Hubble’s plot. What is the main finding? (3min)

First Hubble Diagram

Edwin Hubble 1889-1953

V = H D

H is called Hubble’s constant
Hoag’s Galaxy

NGC4881, central galaxy in Coma Cluster
Milky Way Galaxy

Hubble’s Law

- Velocity $V$ is proportional to distance $D$
  - $V = H \times D$
- Demo: Let Coma & Hoag’s Galaxy move according to Hubble’s Law.
  - Move forward in time. Note relative spacing.
  - Move backward in time. Note relative spacing.
  - Move backward so that Coma and MW are coincident.

1. If Coma moves one meter, how much should Hoag move?
   a. 1 m
   b. 3 m
   c. 1/3 m
   d. 9 m
   e. 1/9 m

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<tr>
<th></th>
<th>Speed</th>
<th>Dist</th>
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<tbody>
<tr>
<td>Milky Way</td>
<td>0 km/s</td>
<td>0 Mpc</td>
</tr>
<tr>
<td>Coma</td>
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<td>100Mpc</td>
</tr>
<tr>
<td>Hoag’s Object</td>
<td>18,000 km/s</td>
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Hubble’s Law

- Velocity V is proportional to distance D
  - \( V = H \times D \)

2. Hoag is 3 times as far as Coma. Is this still true in the future? Was this true in the past?
   a. YY
   b. YN
   c. NY
   d. NN

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Hubble’s Law

- \( V = H \times D \)

2. Hoag is 3 times as far as Coma. Is this still true in the future? Was this true in the past? YY.

- H’s Law => Universe began in a Big Bang
  - Universe was very dense
  - What became Milky Way was very close to what became Coma & Hoag’s Galaxy.

- Current physics can explain universe \(10^{10}\)s after Big Bang, when proto-Coma was 1 mm from proto-us.
Hubble’s Law

- \( V = H \times D \)

3. If we are in Coma, would H’s Law apply? (All guesses are OK.)
   a. Y
   b. N

- Do the demo.

3. If we are in Coma, would H’s Law apply?
   a. Y
   b. N

- Key observation: Hubble’s Law applies everywhere.

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What does value of H imply?

- \( V = H \times D \)

4. What is the value of Hubble’s constant? Express your answer in km/s/Mpc

- \( H = \frac{V}{D} \)
  - \( = \frac{30000\text{km/s}}{470\text{Mpc}} \)
  - \( = 64\text{km/s/Mpc} \)

- Change Mpc to km
  - \( H = \frac{64\text{km/s}}{(3 \times 10^{19}\text{km})} \)
  - \( = \frac{1}{15\text{Byr}} \)
What does value of H imply?

- Write H’s law in more familiar form
  \[ D = V \times \left( \frac{1}{H} \right) \]
  \( 1/H \) is the time for an object moving at speed V to move distance D.
- \( 1/H = \frac{D}{V} \)
  \( = \frac{(470 \text{Mpc})}{30000 \text{km/s}} \)
  \( = 15 \text{Byr} \)

5. Some matter that was very near us soon after the Big Bang was moving at 30,000km/s. How far has it moved in 1.5 Byr? In 15 Byr?

Value of H implies age of universe

- Write H’s law in more familiar form
  \[ D = V \times \left( \frac{1}{H} \right) \]
- \( 1/H = \frac{D}{V} \)
  \( = \frac{(470 \text{Mpc})}{30000 \text{km/s}} \)
  \( = 15 \text{Byr} \)
- Some matter that was very near us soon after the Big Bang was moving at 30,000km/s.
- The age of the universe is 15 Byr.
  - In 1.5 Byr, that matter moved 47 Mpc from our primordial location.
  - In 15 Byr, that matter has moved 470 Mpc and become part of a galaxy. We became MSU students and part of the solar system.
- Be aware: We assumed matter does not speed up or slow down.
Summarizing questions

• Why does Hubble’s Law imply a Big Bang?
• Do aliens on another galaxy also observe galaxies to move according to H’s Law?
• If the motion of matter slows down, is the age of the universe longer or shorter than 1/H?