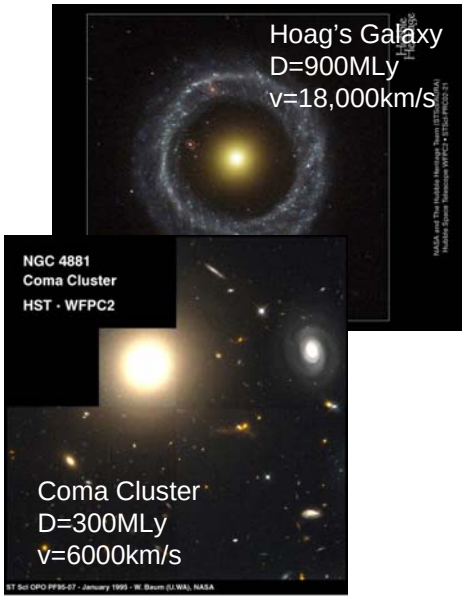
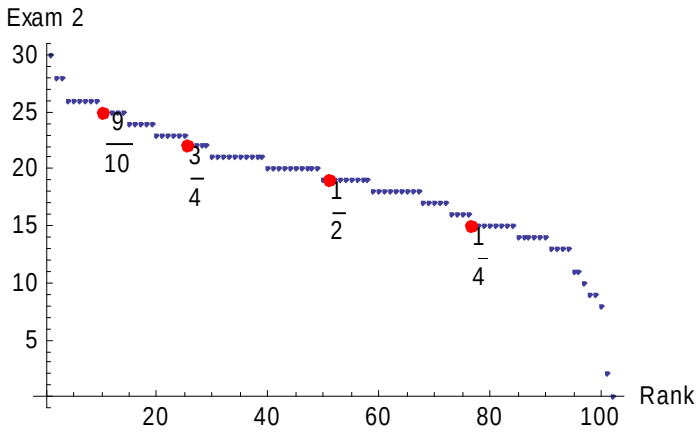
Hubble's Law—28 Oct

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



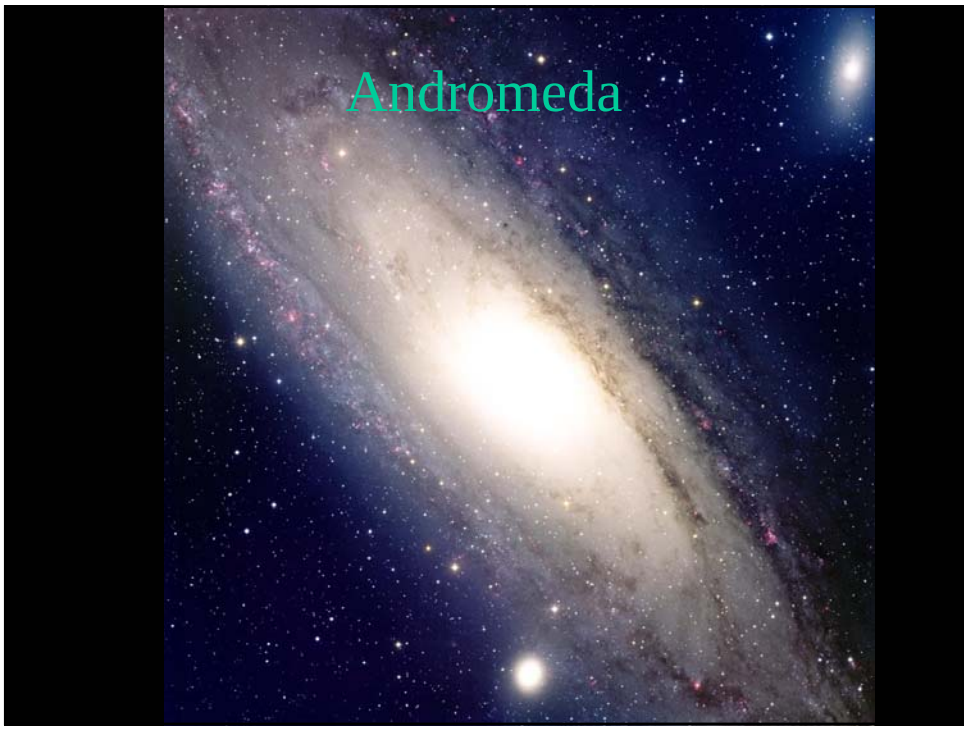
Exam 2



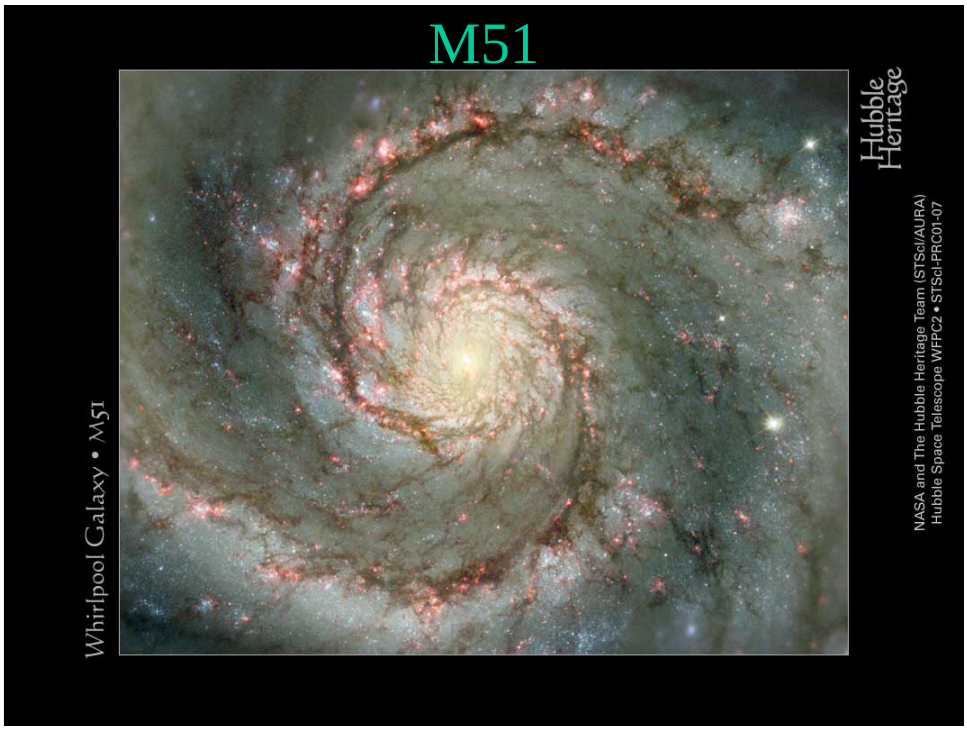
- Top 1/10 25/30
- Top quartile 22
- Median 19
- Bottom quartile 15
- If you got less than 10, figure out what you need to change.

Galaxies

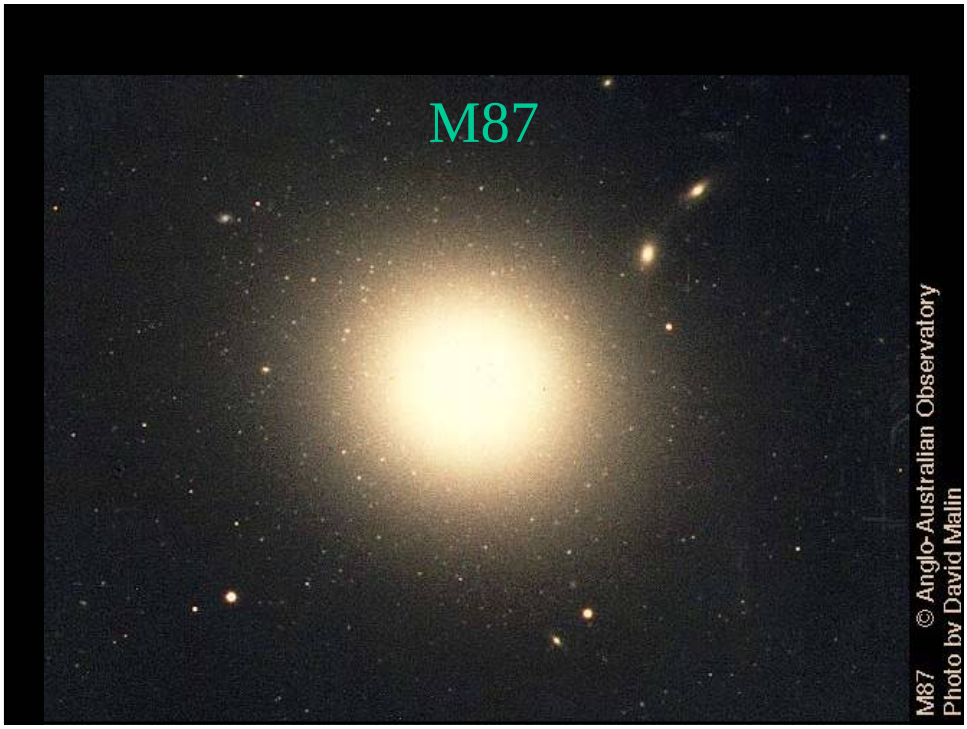
- Galaxies are made of billions of stars, gas, dust, and dark matter.
- Our galaxy is the Milky Way.
- Nearest big galaxy is our big sister Andromeda, which is 700kpc, 3Mly from us. Sun is 8kpc from center of the Milky Way.



Sombrero



M51

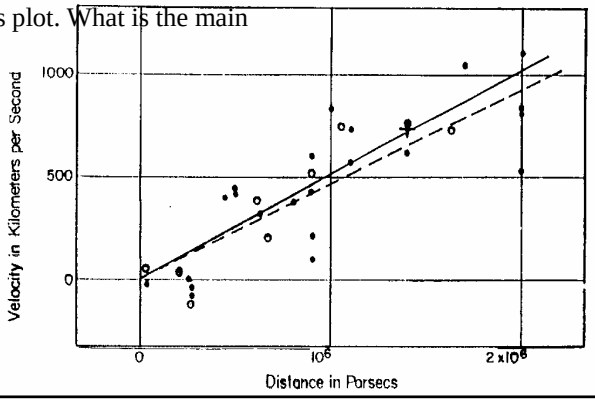

M87
M87 © Anglo-Australian Observatory
Photo by David Malin


Galaxy cluster A2218

First Hubble Diagram

Edwin Hubble 1889-1953

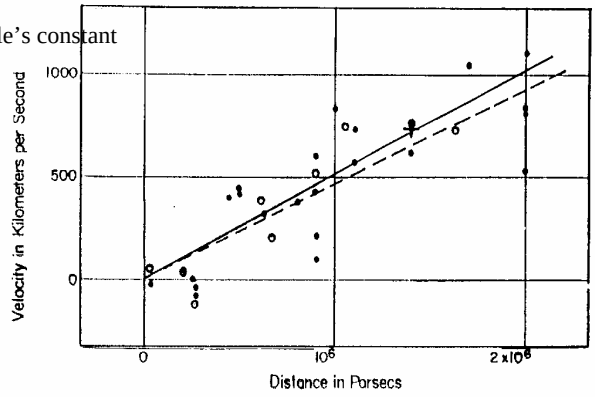
- V M Slipher, Lowell Observatory, pioneered the measurement of the Doppler velocities of galaxies.
  - Some spectra took several nights.
- Hubble measured / estimated distances of galaxies.
  - Not measurements by parallax. Indirect. Very complicated.
- Hubble 1929, Proc. Nat. Acad. Sci. 15, 168
- Summarize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



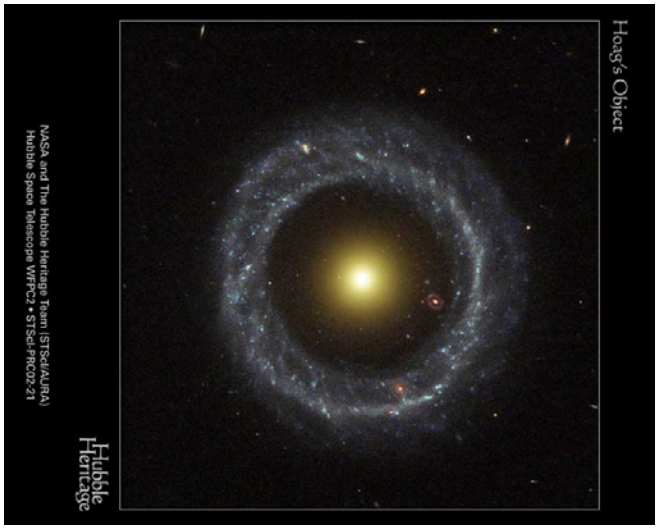
First Hubble Diagram

Edwin Hubble 1889-1953

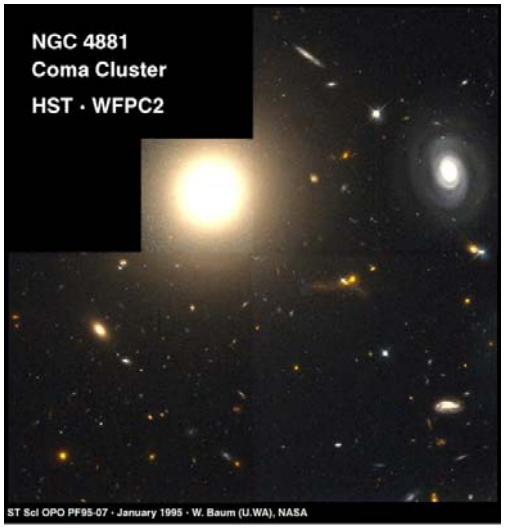
- Hubble 1929, Proc. Nat. Acad. Sci. 15, 168
- Summarize Hubble's plot. What is the main finding?
- The speed of a galaxy is proportional to its distance. Almost every galaxy is moving away from us.
  - V = H D
  - H is called Hubble's constant



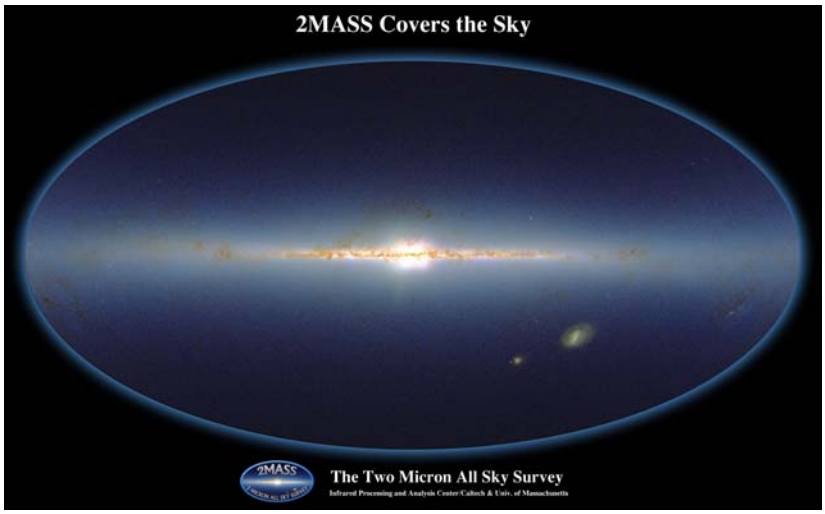
Hoag's Galaxy



NGC4881, central galaxy in Coma Cluster



Milky Way Galaxy

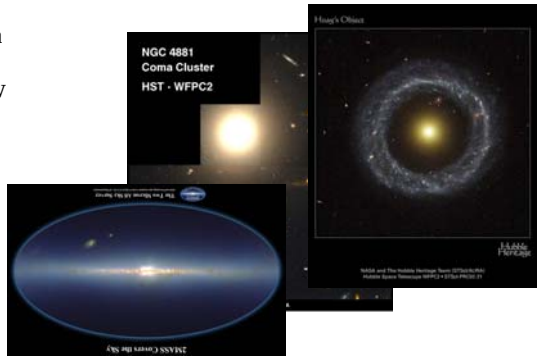


Hubble's Law

- 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

	Speed	Dist
Milky Way	0 km/s	0 Mpc
Coma	6,000 km/s	100Mpc
Hoag's Object	18,000 km/s	300Mpc



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

	Speed	Dist
Milky Way	0 km/s	0 Mpc
Coma	6,000 km/s	100Mpc
Hoag's Object	18,000 km/s	300Mpc

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.

	Speed	Dist
Milky Way	0 km/s	0 Mpc
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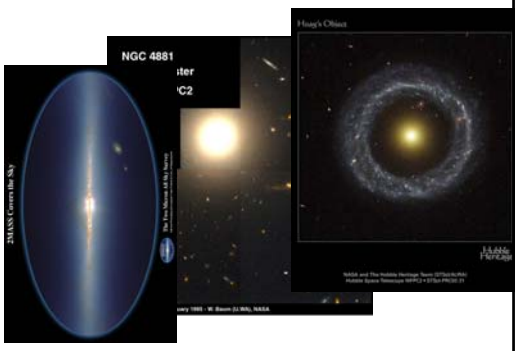


Hubble's Law

- $V = H \times D$

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.

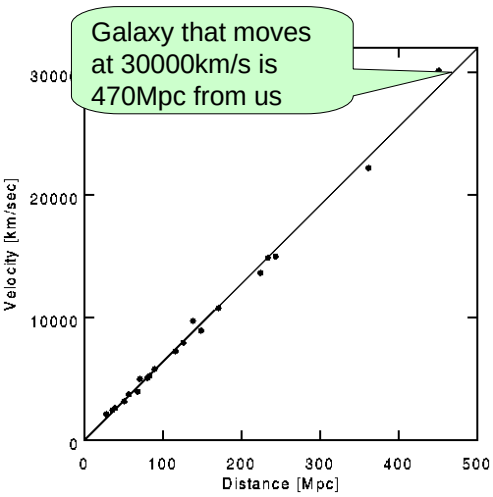
	Speed	Dist
Milky Way	0 km/s	0 Mpc
Coma	6,000 km/s	100Mpc
Hoag's Object	18,000 km/s	300Mpc

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=V/D
  = 30000km/s/(470Mpc)
  = 64km/s/Mpc
- Change Mpc to km
  $H = 64\text{km/s}/(3\times10^{19}\text{km})$
  = 1/(15Byr)



Hubble Diagram 2003

What does value of H imply?

- Write H's law in more familiar form

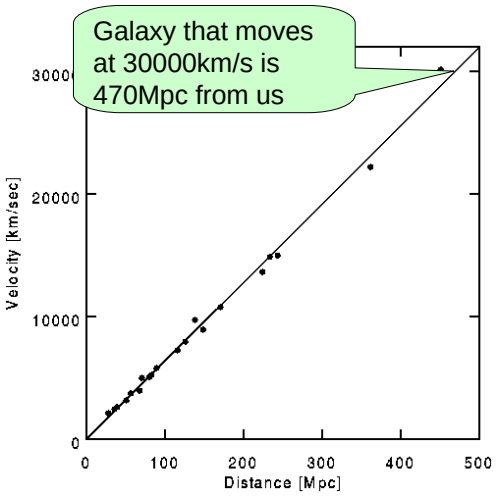
  D = V × (1/H)

  1/H is the time for an object moving at speed V to move distance D.
- 1/H = D/V

  = (470Mpc) / 30000km/s

  = 15Byr

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?



Hubble Diagram 2003

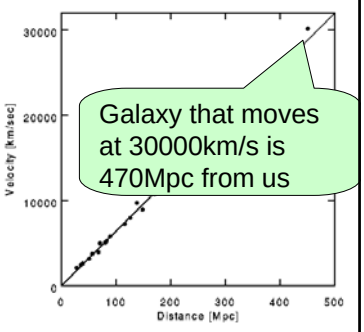
Value of H implies age of universe

- Write H's law in more familiar form

  D = V × (1/H)
- 1/H = D/V

  = (470Mpc) / 30000km/s

  = 15Byr
- 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.



Hubble Diagram 2003

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?