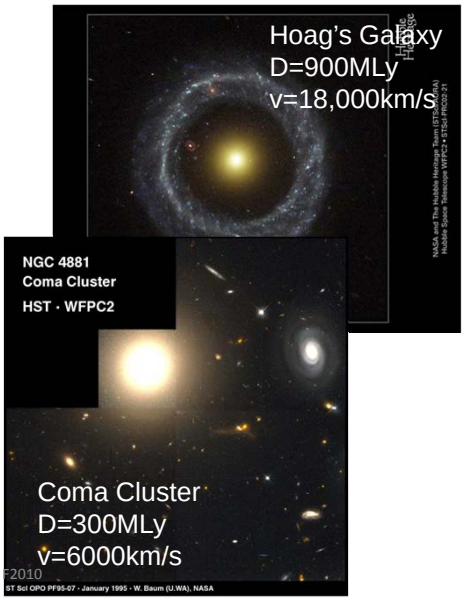
Hubble's Law—29 Oct

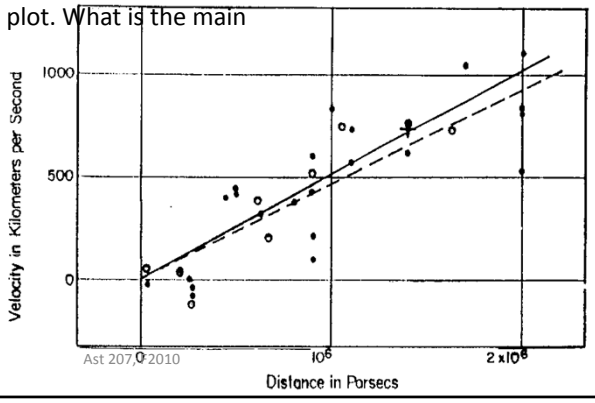
- Hwk6, Q2. 1mo=.08yr.
- Hubble's Law describes how galaxies move and how the universe expands.
- Objectives: To answer and give evidence for these questions.
  - Was there a Big Bang?
  - Galaxies move away from us in all directions. Are we at the center of the Big Bang?
  - Why are galaxies moving?
  - How long ago did the big bang occur?



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?



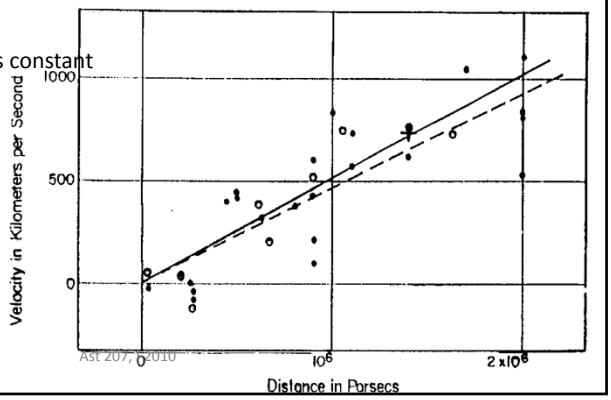
How do galaxies move?

- They move according to Hubble's Law.
- Answer these questions by analyzing the motion.
  - Was there a Big Bang?
  - Galaxies move away from us in all directions. Are we at the center of the Big Bang?
  - Why are galaxies moving?
  - How long ago did the big bang occur?
- Analyze the motion of 3 galaxies.

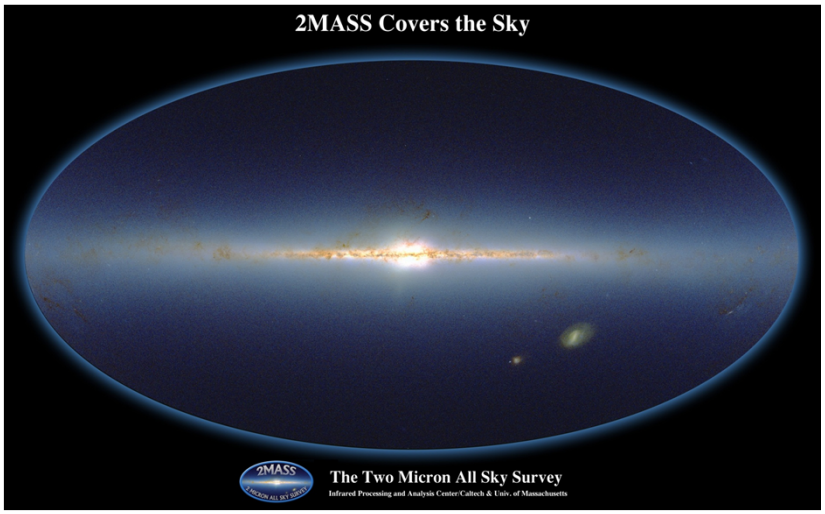
First Hubble Diagram

Edwin Hubble 1889-1953

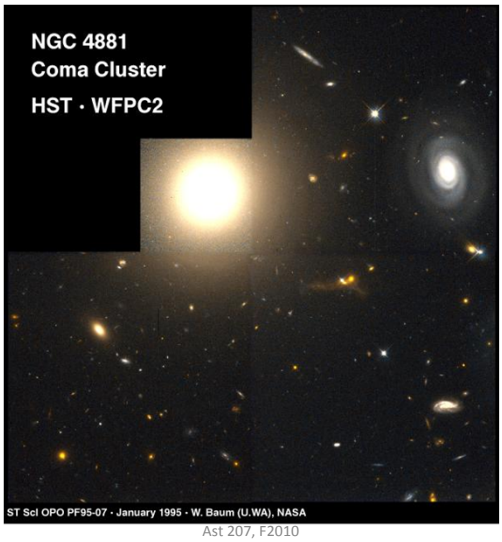
- Hubble 1929, Proc. Nat. Acad. Sci. 15, 168
- Summarize Hubble's plot. What is the main finding?
- The speed of a galaxy is proportional to its distance. Almost every galaxy is moving away from us.
  - V = H D
  - H is called Hubble's constant



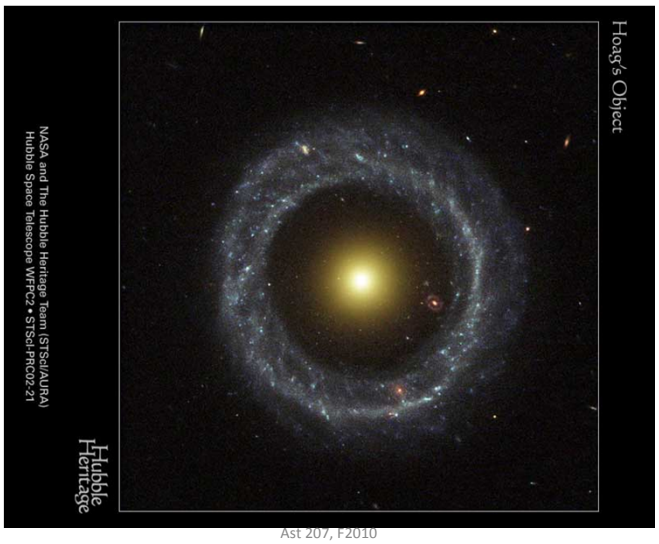
Milky Way Galaxy



NGC4881, central galaxy in Coma Cluster



Hoag's Galaxy

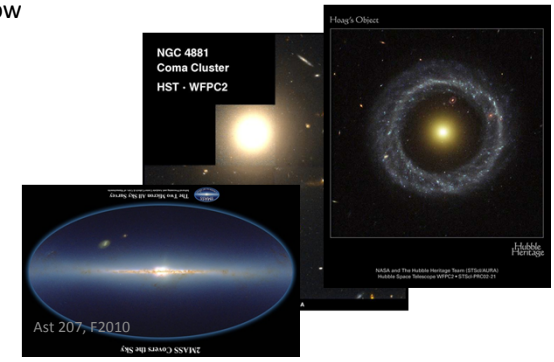


Motion according to Hubble's Law

- Hubble's Law: Velocity V is proportional to distance D
  $V = H\ D$
- 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.

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
  - $V = H \times D$
- 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?
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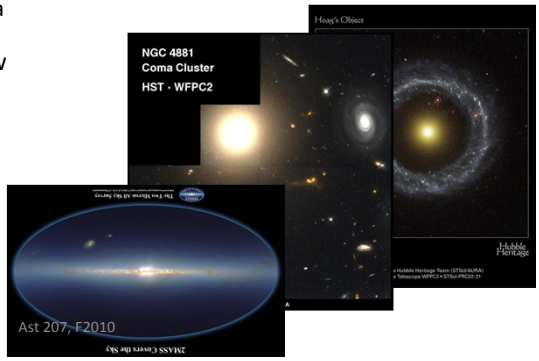

Hubble's Law

- Hubble's Law
  $V = H\ D$
- What form is the expansion?

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
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Self similar expansion

- Hubble's Law
  $V = H\ D$
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
- Motion according to Hubble's Law is self-similar. Relative distances are preserved. A special type of expansion.
- Is the "expansion" of cars leaving a football game self similar? Consider Joe, Laura, & Nancy. Joe parked near S Stadium. Laura parked at lot on Farm La. Nancy parked on Grand River.

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

- Now Later

Evidence of Big Bang

- Hubble's Law
  $V = H\ D$
- Move backward so that Coma and MW are coincident.
- Where is Hoag's object?
- All three galaxies were close at the same time.
  - Since these three are not unique, we have shown this is true for every galaxy.
  - Everything was very close at the same instant.
- H's Law $\Rightarrow$ Universe began in a Big Bang
  – Universe was very dense
  – What became Milky Way was very close to what became Coma & Hoag's Galaxy & everything else.

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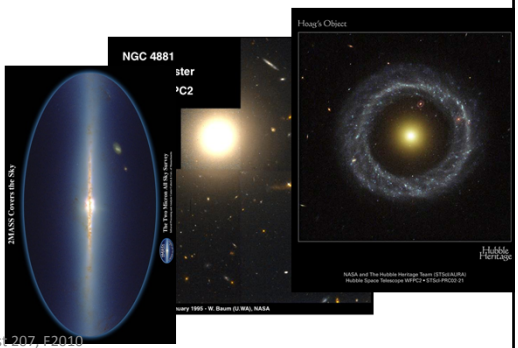
Coma	6,000 km/s	100Mpc
Hoag's Object	18,000 km/s	300Mpc



Is Hubble's Law's valid for Coma?

3. If we are astronomers on some planet in Coma, would H's Law apply? (All guesses are OK.)
   a. Y
   b. N
- Do the demo.

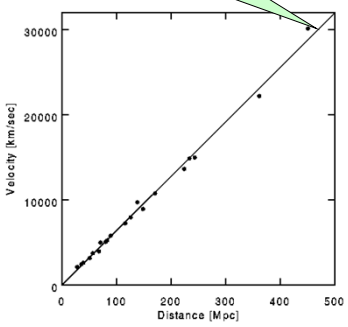
3. If we are in Coma, would H's Law apply?
   a. Y
   b. N
- Hubble's Law applies everywhere.

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

Value of H implies age of universe

- Write H's law in more familiar form
  $D = V\ (1/H)$
  which is the same idea as ___.
- 1/H = D/V
  = (470Mpc) / 30000km/s (1pc=3e13km)
  = 15Byr (1yr=3e7s)

Galaxy that moves at 30000km/s is 470Mpc from us



Hubble Diagram 2003

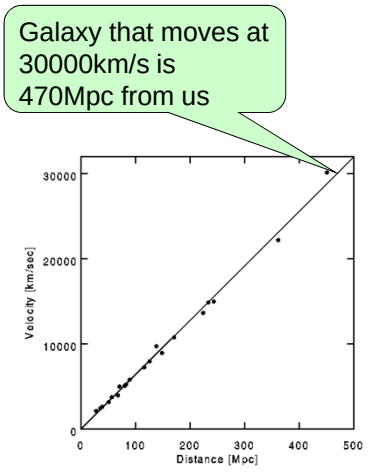
Why do galaxies move?

- Write H's law in more familiar form

  $D = V\ (1/H)$

  which is the same idea as

  distance = speed × time.
- 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: V is the current velocity. We assumed matter does not speed up or slow down.



Hubble Diagram 2003