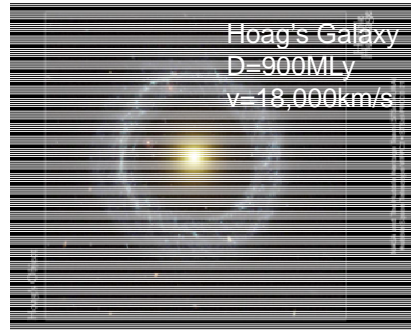


Hubble's Law—31 Oct

- Outline
 - Intro: What are galaxies?
 - Hubble's Law describes how galaxies move and how the universe expands.
 - Questions on Big Bang
- Objectives: To answer and give evidence for these questions.
 - Was there a Big Bang?
 - Are we at the center of the Big Bang?
 - Why are galaxies moving?
 - How long ago did the Big Bang occur?



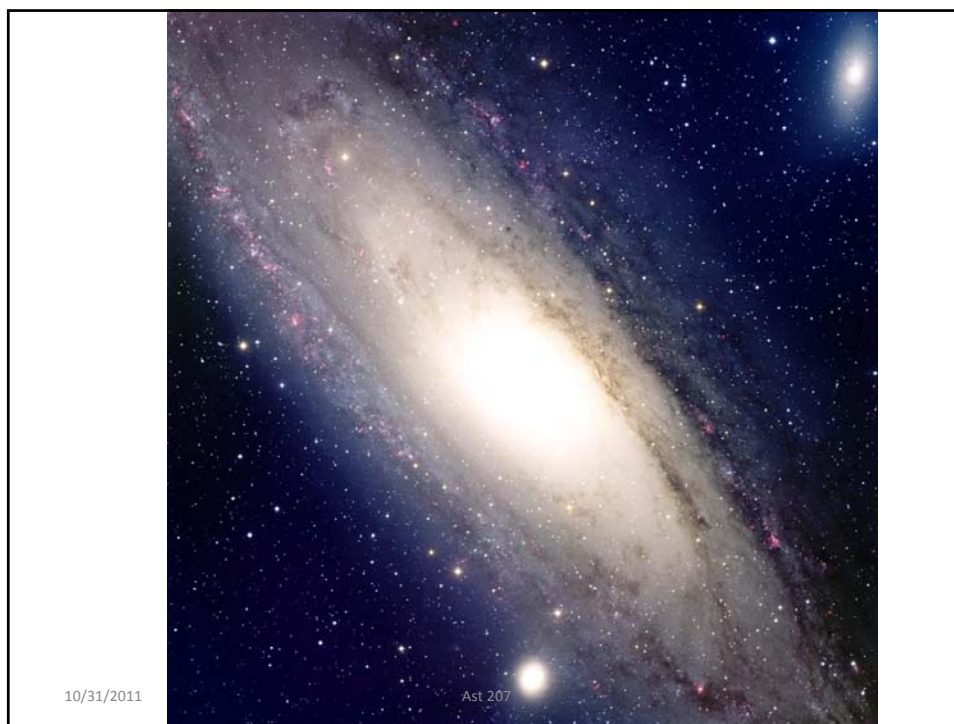
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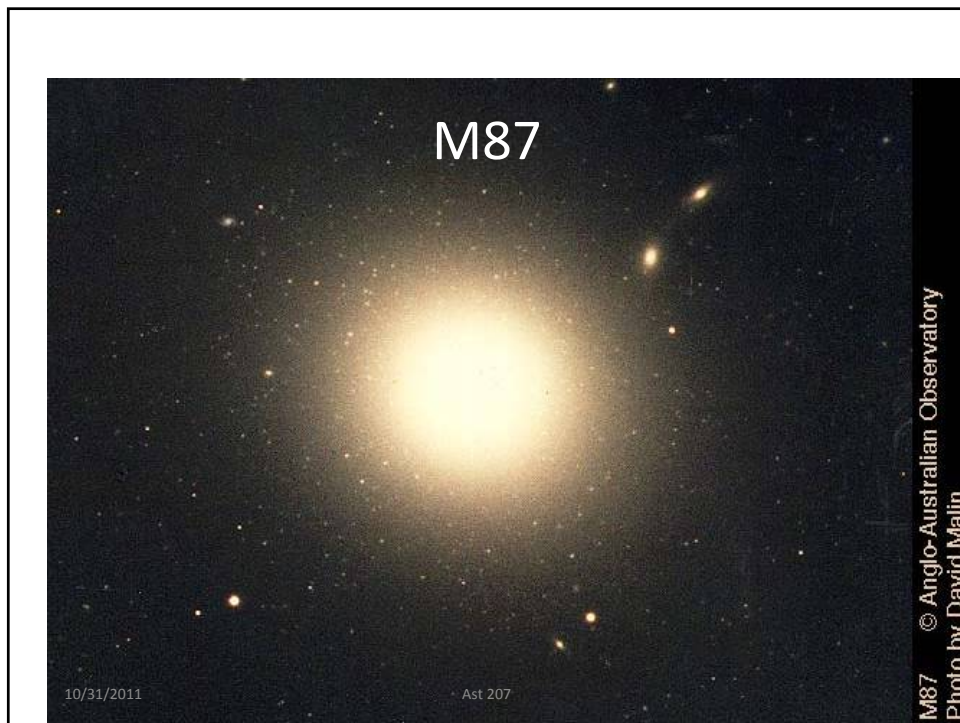
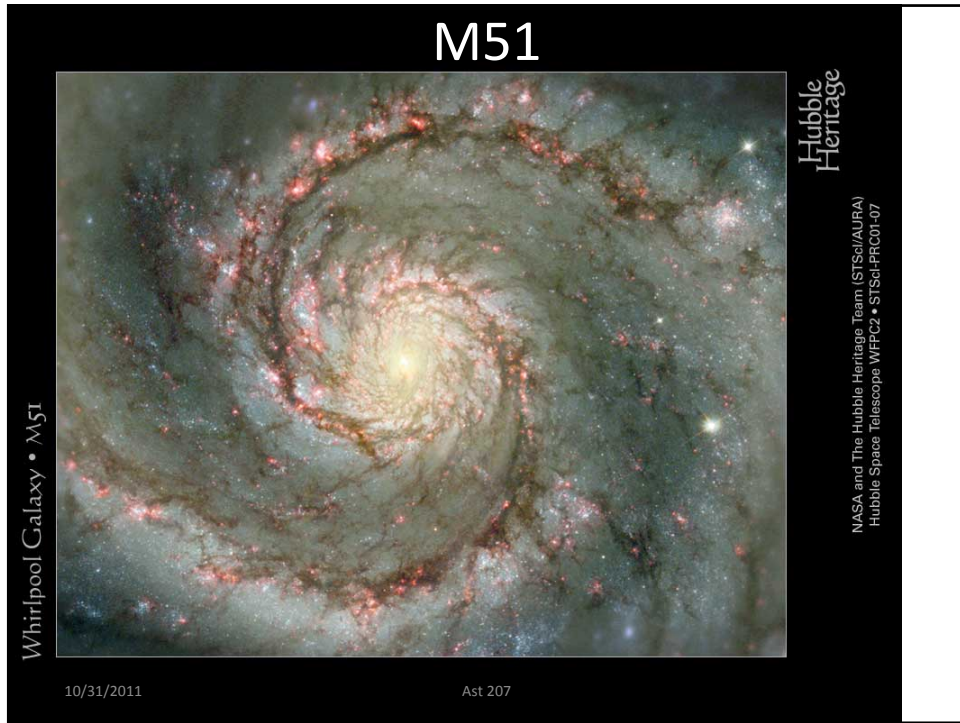
Realm of the nebulae (galaxies)

- 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 from us. Sun is 8kpc from center of the Milky Way.

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1. Which is bigger, galaxy or star cluster? Galaxy or solar system?
 - A. Galaxy. Solar system.
 - B. Star cluster. Solar system
 - C. Star cluster. Galaxy.
 - D. Galaxy. Galaxy.

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First Hubble Diagram



Edwin Hubble 1889-1953 in 1924
http://www.sciencephoto.com/images/download_lo_res.html?id=724080109

- V M Slipher, Lowell Observatory, pioneered the measurement of the Doppler velocities of galaxies.
- Hubble measured / estimated distances of galaxies.
- 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.

$$v = HD$$

- H is called Hubble's constant

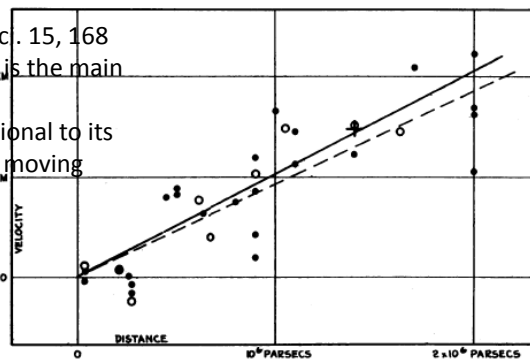


FIGURE 1

Ast 20 Hubble 1929, Proc. Nat. Acad. Sci. 15, 168

How do galaxies move?

- They move according to Hubble's Law.
- We will answer these questions by analyzing the motion of 3 galaxies.
 - Was there a Big Bang?
 - Are we at the center of the Big Bang?
 - Why are galaxies moving?
 - How long ago did the big bang occur?

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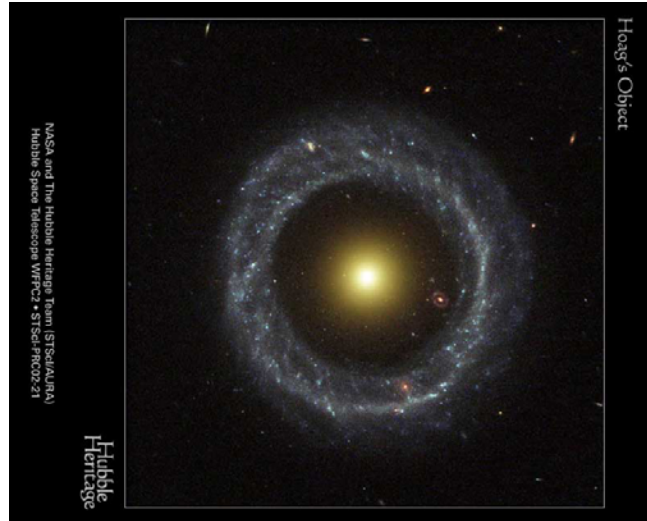
NGC4881, central galaxy in Coma Cluster



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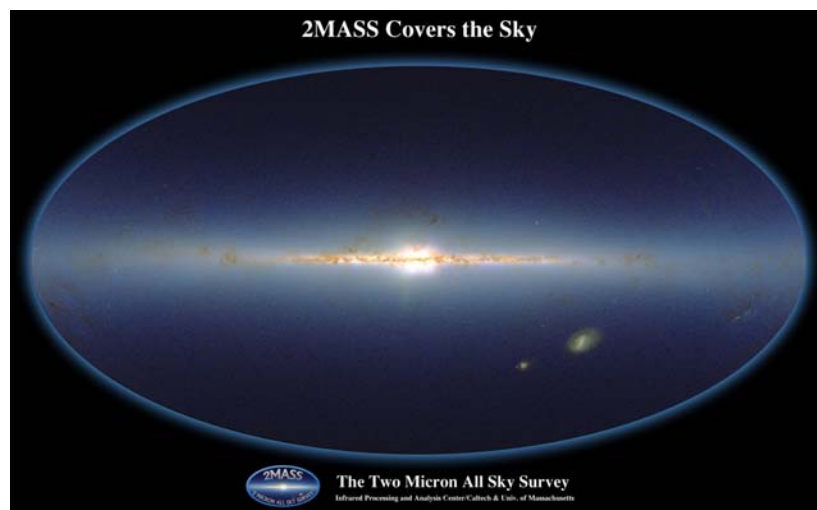
Hoag's Galaxy



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Milky Way Galaxy



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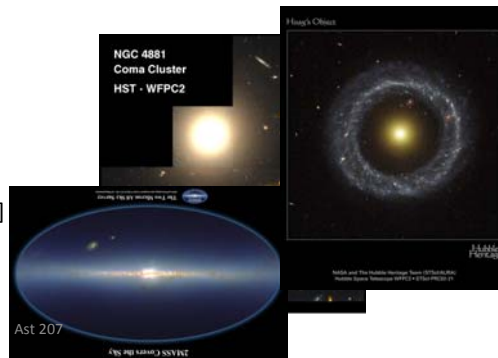
Motion according to Hubble's Law

- Hubble's Law: Velocity v is proportional to distance D
 $v = HD$
- Demo: Let Coma & Hoag's Galaxy move according to Hubble's Law.
 - Move forward in time. Note relative spacing.

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

- If Coma moves one meter, how much should Hoag move?
 - 1 m
 - 3 m
 - 1/3 m
 - 9 m
 - 1/9 m

[Translate Hubble's Law to the demo. Later you will have to translate the demo to the Universe.]



What form is the expansion?

- Hubble's Law

$$v = HD$$

- Hoag is 3 times as far as Coma. Is this still true in the future? Was this true in the past?
 - YY
 - YN
 - NY
 - NN

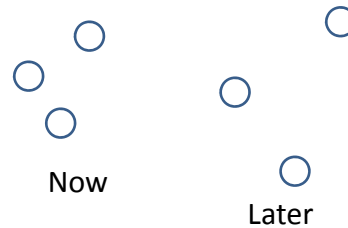
[Discover a property of H's Law.]

Self similar expansion

- Hubble's Law

$$v = HD$$

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
- Two method: Visual & mathematical.
 - The amount that the distance changes is proportional to the distance.
 - Motion according to Hubble's Law is self-similar. Relative distances are preserved with this special type of expansion.



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Evidence that Big Bang occurred

- Hubble's Law

$$v = HD$$

- Demo: Let Coma & Hoag's Galaxy move according to Hubble's Law.
 - Move backward in time.
 - Move backward so that Coma and MW are coincident.
- Where is Hoag's object? What is this event called?
- 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.
- Hubble's Law \Rightarrow Universe began in a Big Bang

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

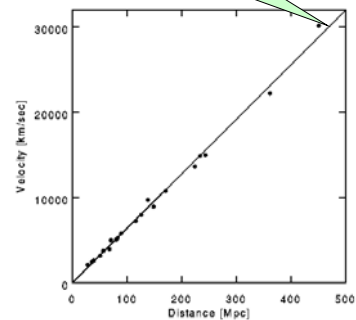
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Value of Hubble's constant implies age of universe

- Write H's law in more familiar form

$$D = V (1/H)$$
 This is the same idea as ____.
- $1/H = D/V$
 $= (470\text{Mpc}) / 30000\text{km/s}$ ($1\text{pc}=3\text{e}13\text{km}$)
 $= 15\text{Byr}$ ($1\text{yr}=3\text{e}7\text{s}$)

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



Hubble Diagram 2003

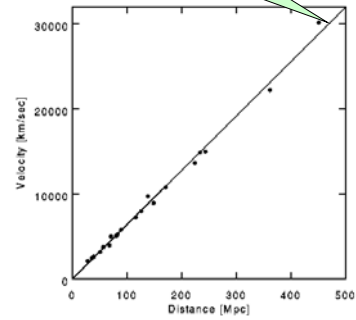
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Value of H implies age of universe

- Write H's law in more familiar form

$$D = V (1/H)$$
 This is the same idea as
 distance = speed × time.
 time=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 15 Byr, that matter has moved 470 Mpc to its present distance (and become part of a galaxy). (Our atoms became part of the solar system and later MSU students.)
- Be aware: V is the current velocity. We assumed matter does not speed up or slow down.

Galaxy that moves at 30,000km/s is 470Mpc from us



Hubble Diagram 2003

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