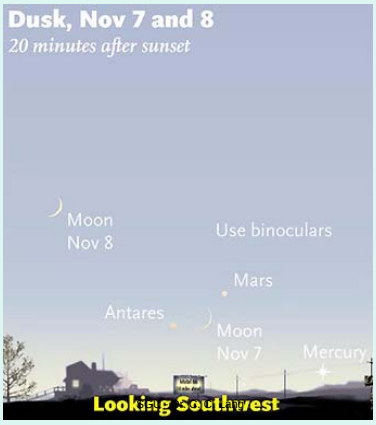
Stars, Galaxies & the Universe Announcements

- **Reading Quiz #11** – Wednesday
  - Mix of questions from today's lecture & reading for Wed. on active galaxies
- **HW#10 in ICON** – due Friday (11/12) by 5 pm
  - available on Wednesday morning
- **Exam #3 next Wednesday**
  - study materials available by end of week!
- **Final Exam will be cumulative; Thursday 16 Dec @7:30 am in VAN LR1 (where our class usually meets)**

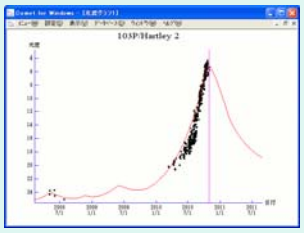
Sky & Telescope's Week at a Glance

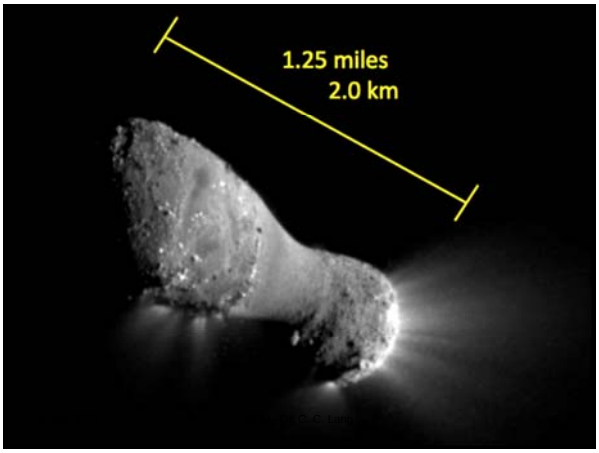
iPhone App – available now at the App store for 99c.

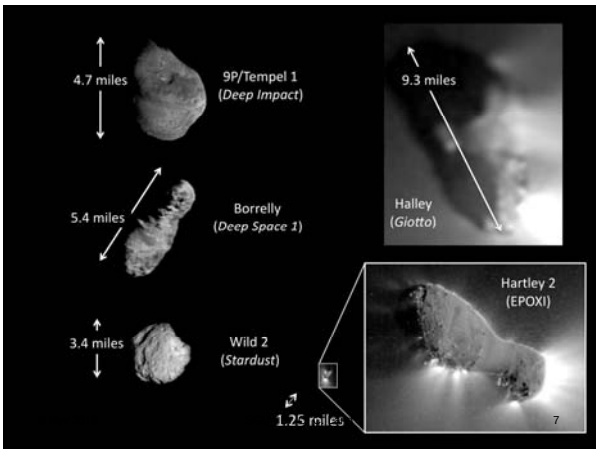


Comet Hartley 2 –

Faintly visible for next few days just before dawn!







Stars, Galaxies & the Universe Lecture Outline

Galaxies

(1) Short review of types

(2) Galaxy collisions

(3) Dark Matter in other galaxies – part I

Distances and Expansion in the Universe

(1) The distance ladder

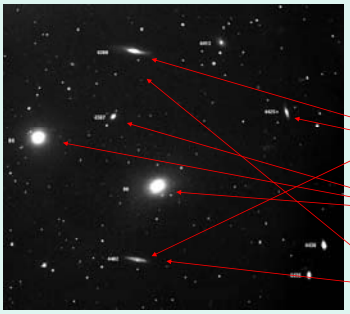
(2) Hubble & his law for expansion in the universe



1. Size	5-50 kpc	1-200 kpc	1-10 kpc
2. Mass	10^9-10^{12} M_o	10^5-10^{13} M_o	10^6-10^{11} M_o
3. Luminosity	10^8-10^{11} L_o	10^6-10^{12} L_o	10^6-10^9 L_o
4. Rotation	yes	no, motions of stars	chaotic motions
5. Gas/star content	gas, dust in disk	little gas, dust	much gas, dust
6. forming stars?	yes!	no	YES!

Check your knowledge --

The Virgo Cluster of galaxies



which galaxies:

- have more young stars?

spiral galaxies

- are redder?

elliptical galaxies

- have large rotations?

spiral galaxies

What happens with two galaxies collide?

HST picture of the "antennae" galaxies

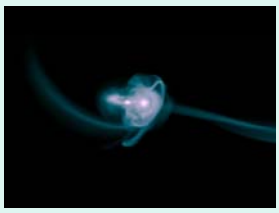
→ we can observe galaxies in process of colliding

→ slow process, orbits of stars are disrupted

→ repeated collisions become MERGERS of two galaxies

Galaxy collisions cause galaxies to be "tidally disrupted"

- effects due to gravitational pull between the two galaxies

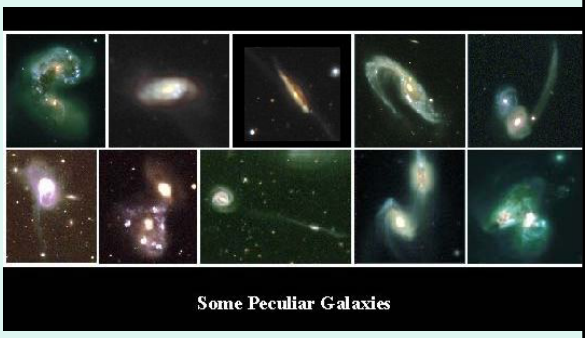


simulation of a galaxy "encounter"

Andromeda (M31) and the MW

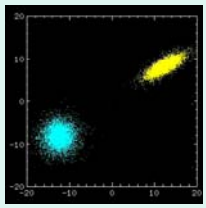
also, the MW and the Magellanic clouds will collide within a few billion years

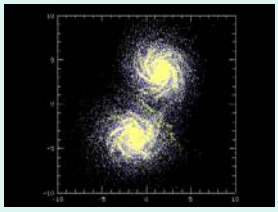
Galaxy collisions result in peculiar galaxies

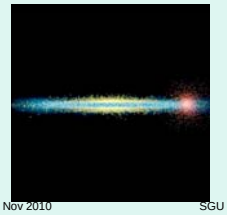


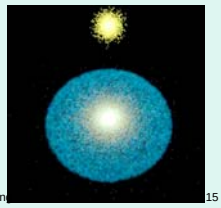
When Spirals Collide

Model of Galaxy Interaction

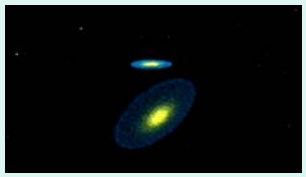




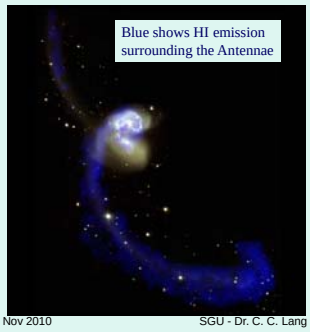




"The Mice"
Interacting galaxies

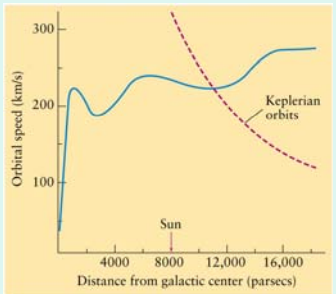


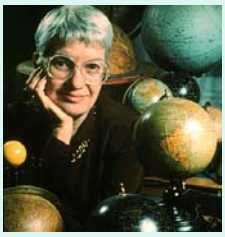
Streamers of atomic hydrogen (HI) are often leftover after a collision



HI cloud set to collide with the Milky Way

What do the rotation curves for other spiral galaxies look like?





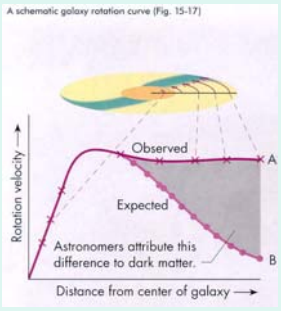
Dr. Vera Rubin
Carnegie Observatories

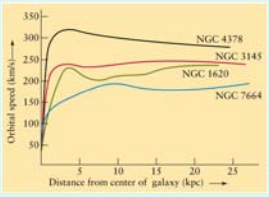
Dr. Rubin set to find out how stars, gas orbited in other galaxies

• understand how galaxies (spiral, elliptical, irregular) differ

• she studied the rotation curves for HUNDREDS of other galaxies

Rotation curves for nearby spiral galaxies:





all galaxies have up to 90% "Missing Mass"!!

Why do we need to calculate distances in astronomy?

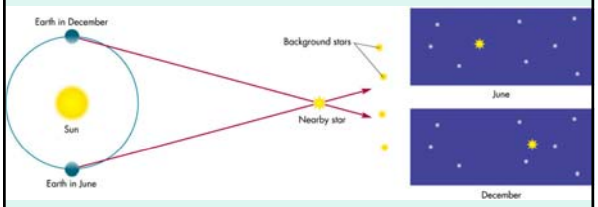
• to convert a measure of "brightness" or flux into something physically meaningful
- LUMINOSITY (e.g. 10 solar luminosities)

• to convert a measure of "angular size" into something physically meaningful
- physical size (e.g. cluster of galaxies is ~10 Mly across
- physical size (e.g. the moon is 3500 km across)

• to study how galaxies "age" by studying distant galaxies

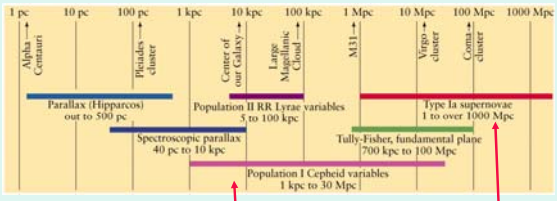
• to study the structure of the early universe!

1. PARALLAX: distances to nearby stars



• technique only used for *stars* within 500 pc
• parallax is an angular measure – 0.01-0.1"
• the smaller parallax angle, more distant star

Beyond parallax, a variety of ways to find distances



Cepheids

Type I SN

2. Use "Standard Candles" –
→ objects we know LUMINOSITY well for in our own Galaxy
→ detect them in other galaxies, make assumption they have L

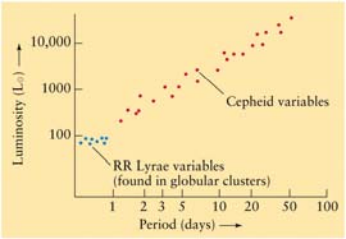
• LUMINOUS – so that you can see them in distant galaxies

• Understand their LUMINOSITY well

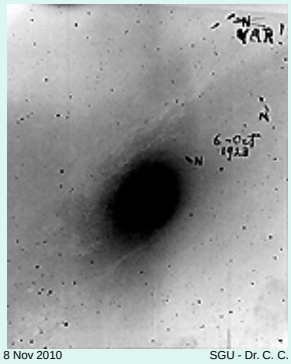
• Easily identifiable – Light Curves

• Relatively common phenomena – novae, Cepheids

Standard Candle Example #1: CEPHEIDS



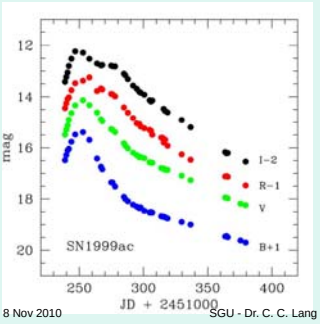
- observer measures PERIOD → LUM
  FLUX
- then derives **distance**
- bright: L~2x10^4 L_o
- can identify Cepheid variables out to 30 Mpc (100 million ly) away!



Edwin Hubble's discovery of a Cepheid in Andromeda Galaxy in 1923 (Mt. Wilson Observatory)

this picture shows the photographic plate identifying a Cepheid as "VAR!"

Standard Candle Example #2: TYPE 1 SN



- observer measures FLUX → LUM
  by assuming a characteristic luminosity for SN Type 1
- SN are bright: L~3x10^9 L_o
- can identify Type 1 SN out to 1000 Mpc (3 billion ly) away!

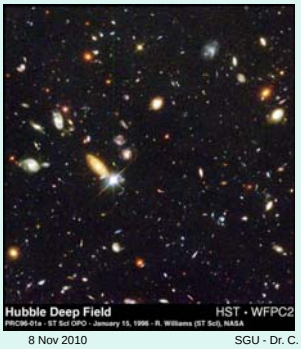
3. Even more ways to find distance...

- objects for which we have brightnesses or sizes from studies in nearby galaxies
- use them to find distances to even further galaxies

EXAMPLES: -> size of the largest HII region
-> average brightness of glob. clusters

beyond that...brightest cluster in a galaxy cluster

Distances beyond 1000 Mpc (~10^{24} km)...



- difficult to resolve individual objects
- can still measure Doppler shifts of spectral lines
- can measure velocity of entire galaxy –

RECESSIONAL VELOCITY

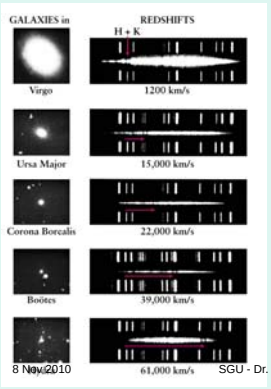
Distances to the most distant galaxies...

Edwin Hubble (1889-1953)

Mt. Wilson Observatory

100" Hooker telescope - 1917
most powerful of time
met Harlow Shapley – DEBATE!

Measuring the Doppler Shift in Galaxies

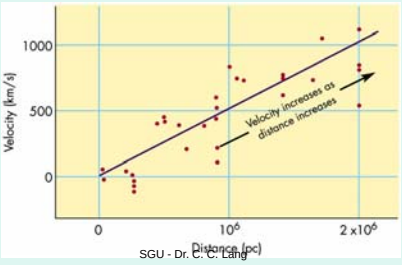


- look for H + K lines of singly ionized Calcium in the galaxy
- identify lines of H + K Ca
- lines occur at wavelengths **much longer than they are supposed to be - *redshifted***
- calculate the speed of motion AWAY using the Doppler shift

→ *recessional velocity*

Hubble measured the recessional speeds of galaxies for galaxies with known distances

→found that galaxies with bigger velocities are more distant Hubble's Law: v = H d



Hubble's Law
$v = H_o d$

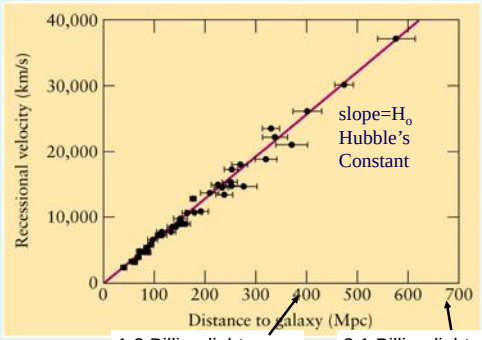
v = recessional velocity measured by redshifted lines in km/s

Ho = Hubble's constant in units of km/s/Mpc
average value of 70 km/s/Mpc
→ means: for every Mpc a galaxy is distant, it should appear to be moving away from the observer at 70 km/s

d = distance of galaxy in Mpc

implications:
→more distant galaxies moving away faster
→"Hubble Flow" in the universe

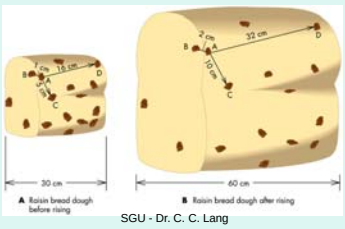
Current data for distant galaxies: Hubble's Law



1.2 Billion light years

2.1 Billion light years

- **Overall, Hubble's Law tells you that the further away the galaxy, the faster the galaxy is receeding – universe is expanding!**
- **Although universe is expanding, it looks the same from ANY galaxy – we are not at the center!**
- **The galaxies themselves are not getting bigger, expanding, but the SPACE between them is expanding**



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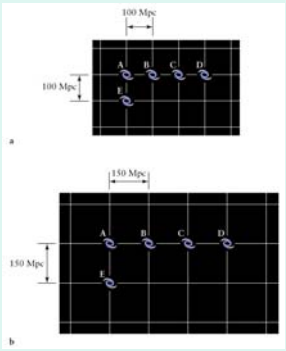

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