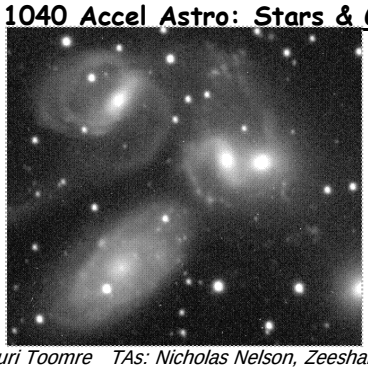
ASTR 1040 Accel Astro: Stars & Galaxies



Stefan's Quintet

Prof. Juri Toomre TAs: Nicholas Nelson, Zeeshan Parkar

Lecture 25 Tues 13 Apr 2010

zeus.colorado.edu/astr1040-toomre

On Galaxy Evolution Lane

- Challenge of *measuring distances in universe*
- Most striking: *many galaxies experience collisions* thus becoming *"interacting galaxies"*
- Begin to discuss *active galaxies* and *quasars*
- Re-read *21.3 Quasars and active galactic nuclei* in detail
- New *Homework # 11* passed out today
- *Third Mid-Term Exam on Mon* Apr 19 *Evening review* by Nick on Thur 7-9 pm

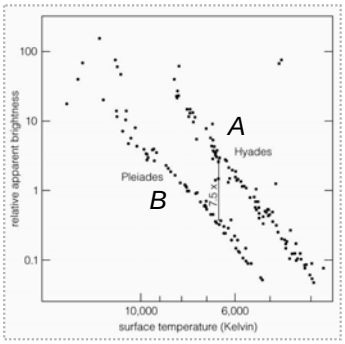
Mapping the universe: need distances to galaxies!

- *Identify (and calibrate) properties of galaxies that could serve as "STANDARD CANDLES" -- beyond direct measure by trigonometric parallax*
- *1. Make some measure of an object which identifies its luminosity (like period in Cepheid)*
- *2. Use this luminosity and measure apparent brightness to infer distance to it*

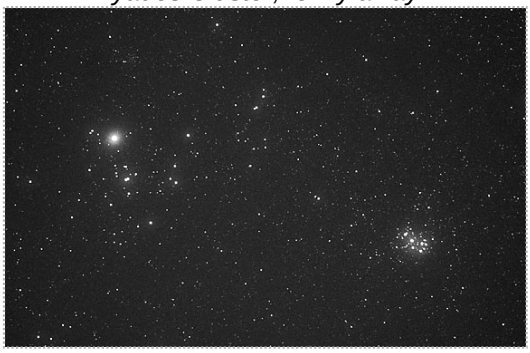
Main-Sequence Fitting

DISTANCE ESTIMATE 1

- *Start with cluster A (upper) whose distance known via parallax*
- *Compare with other cluster B (lower)*
- *Get distance to B from brightness difference*



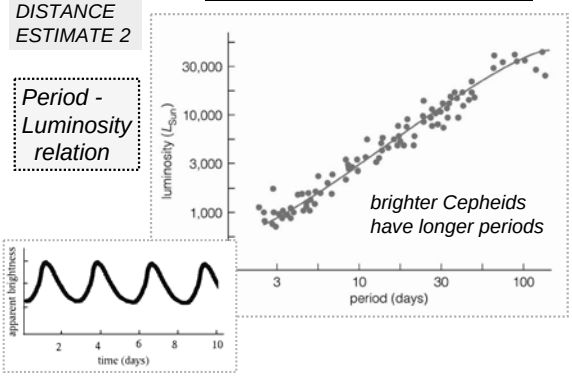
M-S Fitting "pinned to" nearby M45, Hyades Cluster,151 ly away



Cepheid variable stars

DISTANCE ESTIMATE 2

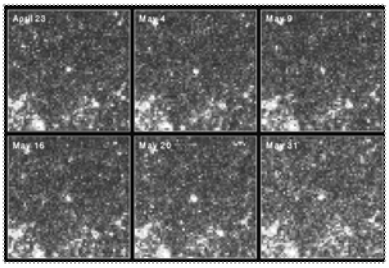
Period - Luminosity relation



DISTANCE ESTIMATE 2

Cepheids variables as standard candles

1. Measure period of variability
2. From period-luminosity relation, infer the luminosity
3. Compare with apparent brightness and thus determine distance



Cepheid variable in M100 (HST)

Number of Fuzzier Distance Estimators

- *A. Apparent brightness of (resolved) red and blue supergiants*
- *B. Size and brightness of H II regions (emission nebulae) or starbirth regions*
- *C. Intercompare distances so deduced for specific galaxies (overlapping rungs in `distance ladder')*

Clicker: halo stars C.

- *Massive O-type stars are not found in the galactic halo because they are:*

A. too massive to be kicked into the halo from the disk

B. so massive that they settle into the thinner disk

C. too short-lived to have persisted from halo formation until today

D. too far away for us to see them

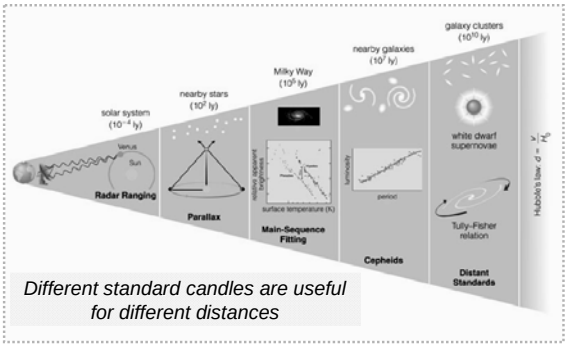
Why no O-stars?

- *C. Too short lived to be in the halo*

Halo stars were born billions of years ago; the most massive stars don't live nearly that long

Will have disappeared by now (after having "enriched" the proto-galaxy gas with heavy elements)

Distance ladder to measure universe



Different standard candles are useful for different distances

Measuring big distances to galaxies

"STANDARD CANDLES" -- important ones in `distance ladder', or `chain'

- *1. Main-sequence fitting*
- *2. Cepheid variables*
- *3. Tully-Fisher relation*
- *4. White dwarf supernovae*

Brightness ~ Luminosity / (Distance)^2

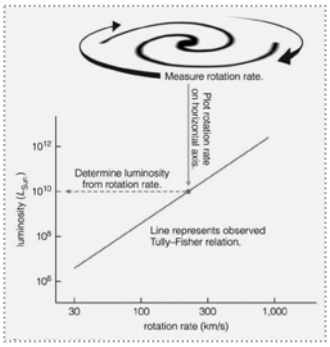
Tully-Fisher Relation

DISTANCE ESTIMATE 3

- *Fast rotation speeds in spiral galaxies*
- *→ more mass in galaxy*
- *→ higher luminosity*

Measure rotation speeds to infer luminosity

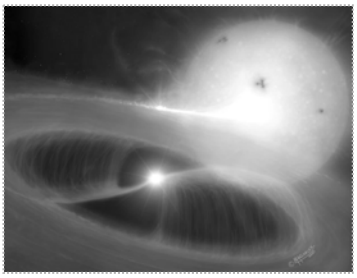
Need bright "edge-on" spirals, estimate tilt



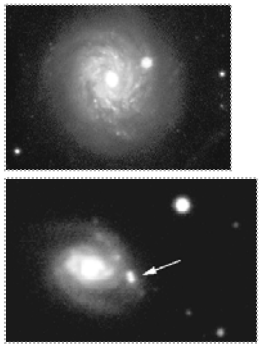
Even brighter: White dwarf supernovae

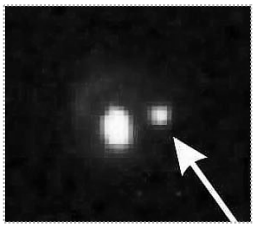
DISTANCE ESTIMATE 4

- *"Standard explosion" = fusion of 1.4 solar masses of material*
- *Nearly the same amount of energy released*



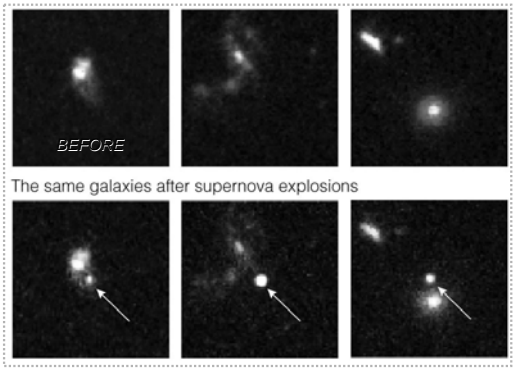
Bright enough to be seen halfway across observable universe





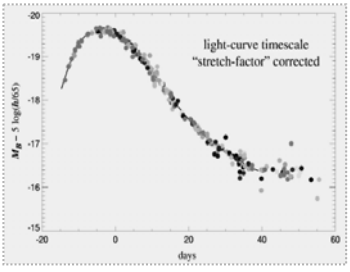
Useful for mapping the universe to the largest distances

Supernovae in very distant galaxies



Practical difficulty: White dwarf SN

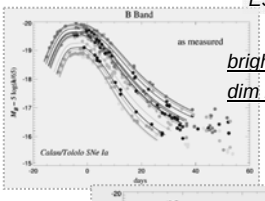
- *Need to catch them within a day or two of the explosion*
- *About 1 per galaxy per century*
- *Need to monitor thousands of galaxies to catch a few per year → galaxy clusters are useful*



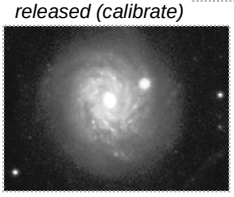
White dwarf supernovae

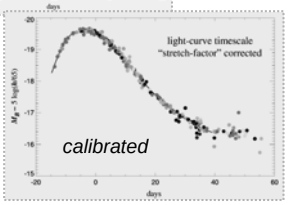
DISTANCE ESTIMATE 4

- *Carbon fusion explosion: mass transfer in binary takes white dwarf `over the edge'*
- *Roughly same amount of energy released (calibrate)*



brighter SN
⋮
dim more slowly!





calibrated

"Distance ladder"

Overlapping "standard candles"

DEMO

"STANDARD CANDLES" MEASURING DISTANCE

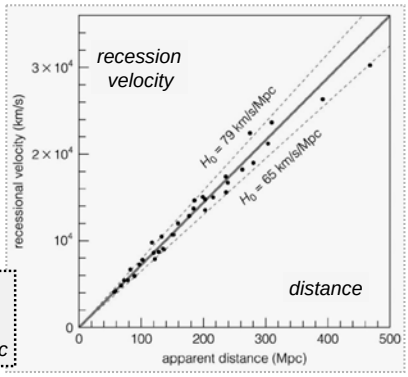
ABSOLUTE MAGNITUDE M	BRIGHTEST OBJECT/ METHOD	CAN SEE TO "DISTANCE"	
	MAIN SEQ FITTING	200,000 ly	
[ANDROMEDA (M31): 3 Mly 1 Mpc]			
−6	CEPHEID VARIABLE	20 Mly (GROUND)	6 Mpc
[VIRGO CLUSTER: 48 Mly 15 Mpc]		[100 Mly (HUBBLE)]	[30 Mpc]
−8	RED SUPERGIANT	50 Mly	15 Mpc
−9	BLUE SG	80 Mly	25 Mpc
	---------- NO INDIVIDUAL STARS ----		
−10	GLOBULAR CLUSTERS	130 Mly	40 Mpc
−12	HII REGIONS	300 Mly	95 Mpc
[COMA CLUSTER: 250 Mly 80 Mpc]			
−20	SUPERNOVA EXPLOSION	10 Bly	3 Bpc
	TULLY-FISHER RELATION		

REVIEW

VELOCITY = H_o x DISTANCE

"HUBBLE CONSTANT"

H_o = 71 +/- 4 km / sec / Mpc



DISTANCE ESTIMATE 5

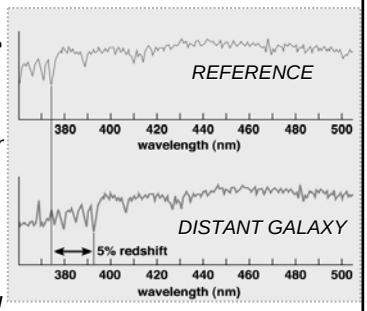
Use Hubble's Law itself to estimate vast distances D

- Measure velocity, then: $D = v / H_o$
- Example: using H_o = 70 km/sec/Mpc, and finding that v = 700 km/sec

D = 700 km/sec / 70 km/sec/Mpc = 10 Mpc
= 32 million light years

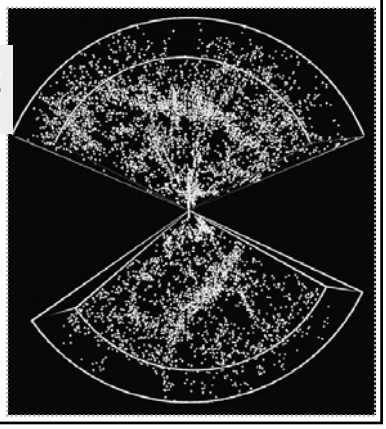
Use Hubble's Law for "distances"

- Measuring distances to remote galaxies is difficult, but measuring Doppler shifts (velocities) is easier from spectra
- Use Hubble's Law to estimate biggest distances (really LOOKBACK TIME)!

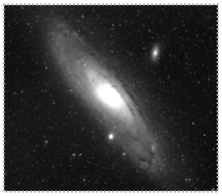


Knowing distances reveals large-scale galaxy clustering

Find clusters + super-clusters : sheets and voids like `bubble bath'

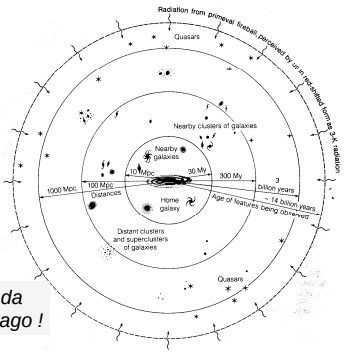


Telescopes are "lookback" time machines



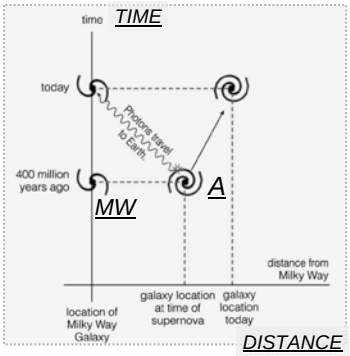
Today, we see Andromeda as she was 2.5 M years ago !

AS WE LOOK OUTWARD, WE LOOK AT OBJECTS AT A MUCH EARLIER AGE ....



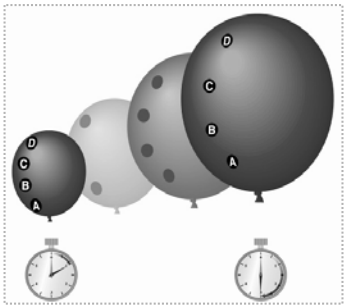
Lookback time (in expanding universe)

- *Say it takes 400 million years for light to get from galaxy A to us in Milky Way*
- *Yet during travel in spacetime, both A and MW have changed positions by expansion*
- *Thus "distance" is a fuzzy concept – LOOKBACK TIME is better*



Balloon analogy for expanding universe

- *On an expanding balloon, no galaxy is at the "center" of expansion; no edge*
- *Expansion happens into a higher dimension (2-D surface into a 3-D space)*
- *Is our 3-D space expanding through a 4th dimension?*



Clicker – Cepheids and distance

- *Two Cepheid stars, Fred and Barney, have the same apparent brightness. Fred has a period of 5 days, and Barney of 10 days. Which is closer ?*

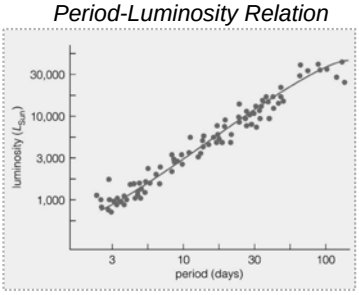
A.

- *A.* Fred
- *B.* Barney

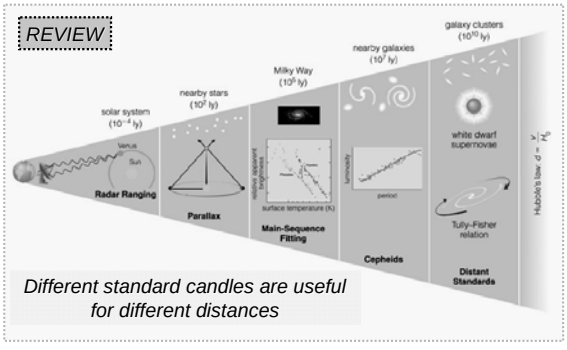
Why A. Fred ?

- *Fred has a shorter period and so must be less luminous*
- *Less luminous but the same apparent brightness means that Fred is closer to us*

Period-Luminosity Relation



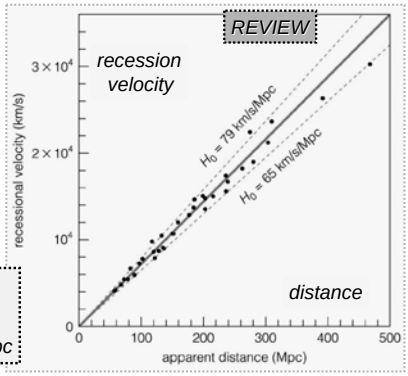
Distance ladder to measure universe



VELOCITY = H_o x DISTANCE

"HUBBLE CONSTANT"

H_o = *71 +/- 4 km / sec / Mpc*



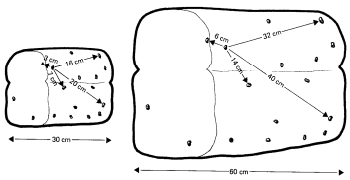
UNIVERSE EXPANDS ON THE LARGE SCALE

LIKE EXPANDING RAISIN BREAD !

REVIEW

Hubble's Law implies:

Universe expands like raisin bread !



THIS COULD EXPLAIN HUBBLE'S VELOCITY-DISTANCE LAW

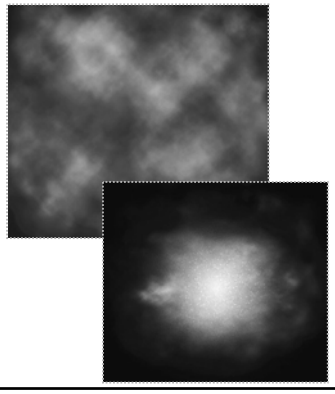
.... CLUSTERS OF GALAXIES APPEAR TO BE MOVING AWAY FROM ALL OTHERS !

(TRUE ON AVERAGE)

True for very large scales between galaxies – but not for stars, planets, us!

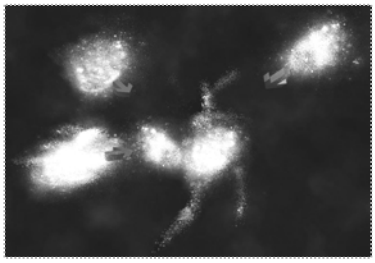
Making of a spiral galaxy

- *Start with a fairly uniform cloud of hydrogen*
- *Gravitational collapse forms protogalactic clouds*
- *First stars are born in this spheroid (such stars are billions of years old → "fossil record")*



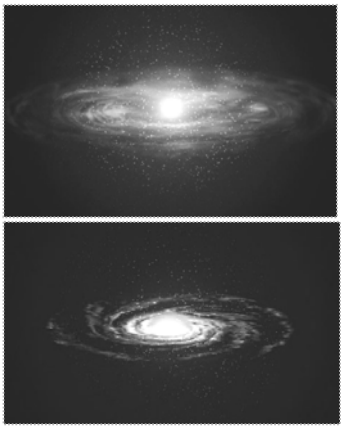
Small variant in spiral making …

- *Several smaller protogalactic clouds may have merged to form a single large galaxy*
- *May explain slight variations in stellar ages in the MW*



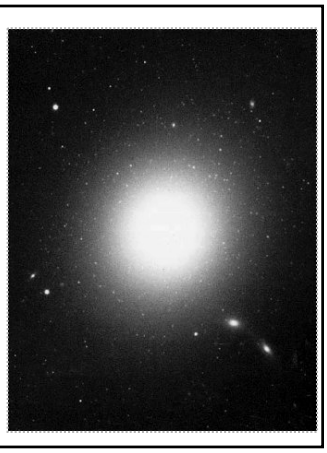
Forming a disk with spiral

- *As more material collapses, angular momentum spins it into a disk*
- *Stars now formed in dense spiral arms – disk stars are younger!*



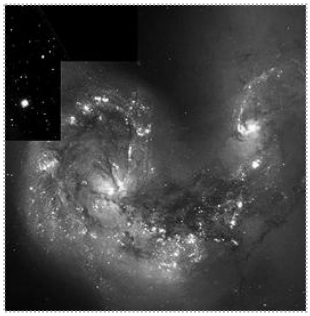
Making ellipticals

- *Higher density: much faster star formation uses up all the gas*
- *Nothing left to make a disk*
- *Now we see sphere of old stars*



Or now a different story….

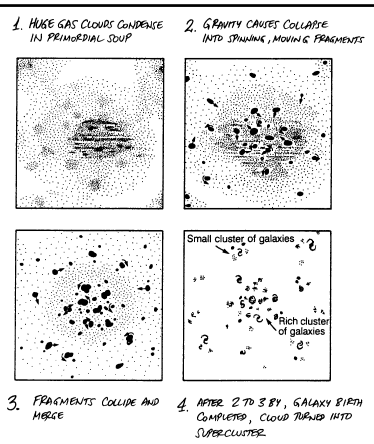
- *Spiral galaxy collisions destroy disks, leave behind elliptical*
- *Burst of star formation uses up all the gas*
- *Leftovers: train wreck*
- *Ellipticals more common in dense galaxy clusters*



NGC 4038/39 Antennae

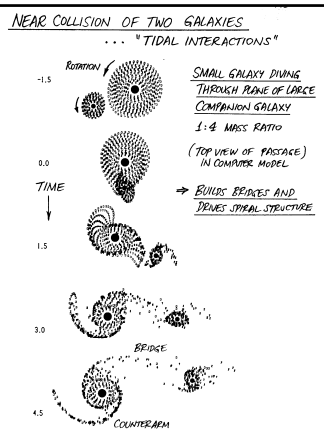
Birth of galaxies in clusters

Few galaxies (none ?) BORN alone

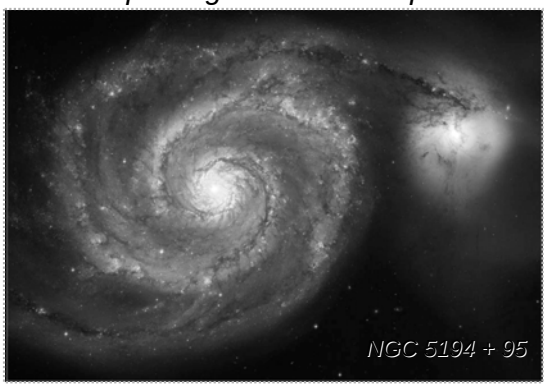


Collision of small galaxy with big one

Builds "bridge" and "counterarm"

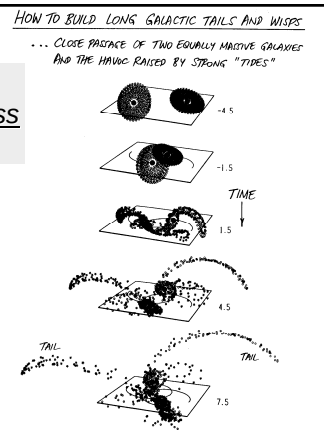


Close passage: M51 + companion

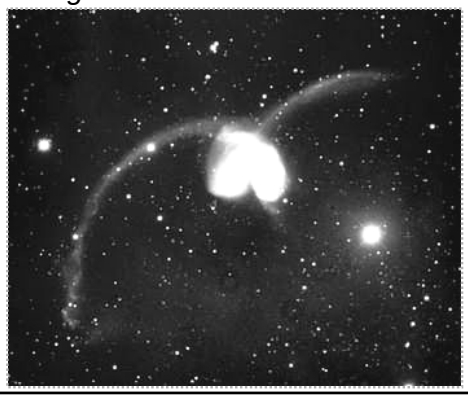


Close passage of two <u>equal mass</u> galaxies

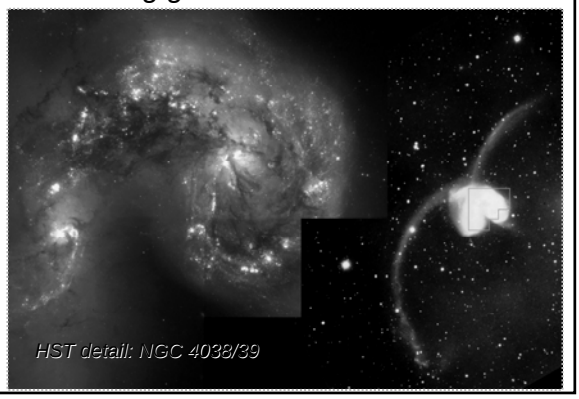
Builds very long "tails" and wisps



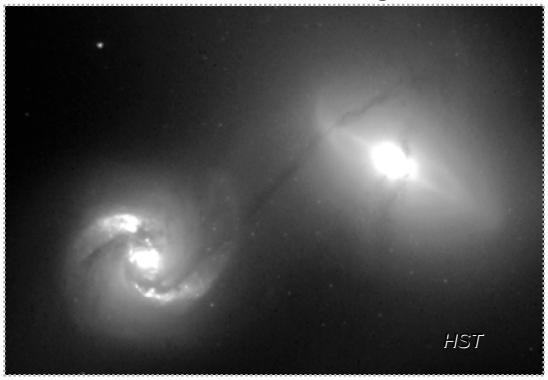
Two galaxies form "The Antennae"



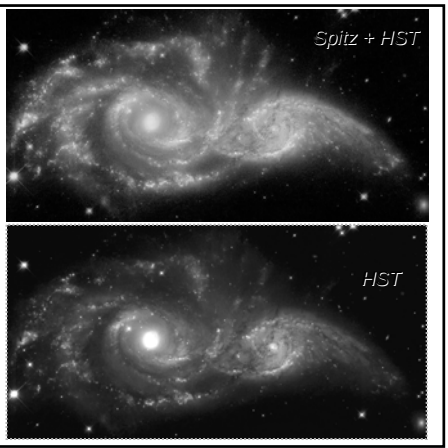
Colliding galaxies – "The Antennae"



Tidal streams between galaxies



Interacting:
NGC 2207
+ IC 2163

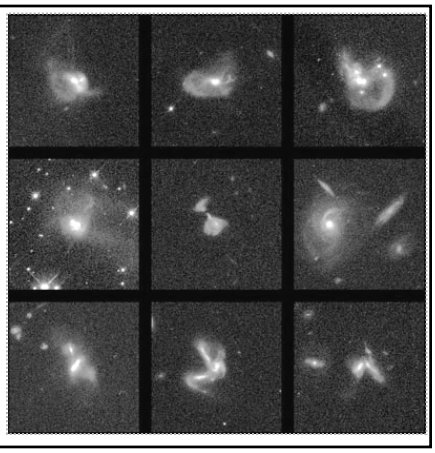


Interacting system NGC 6745

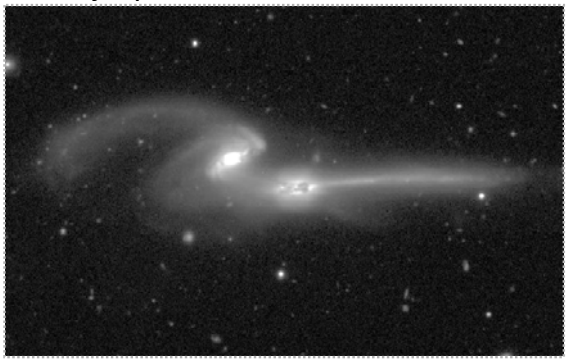
Ring galaxy AM 0644-741

Many interacting galaxy systems

Very distant (big lookback time) with HST

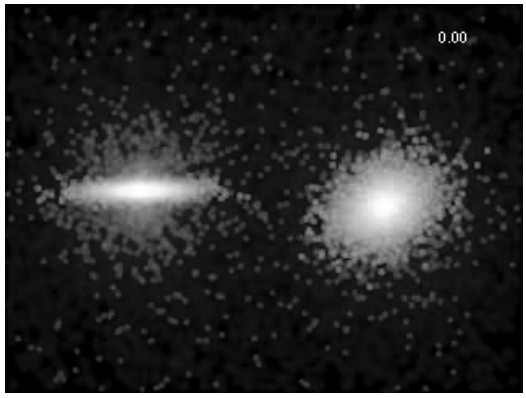


A major puzzle: "The Mice" NGC 4676

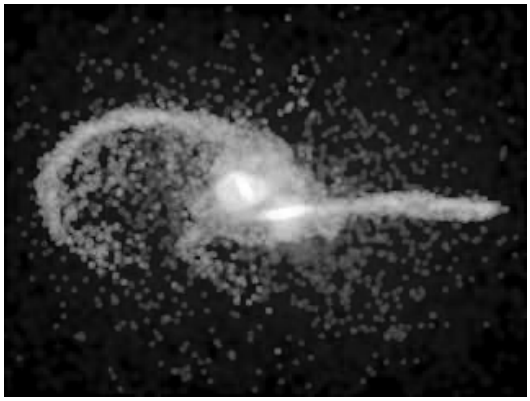


"Mice" with HST Advanced Camera for Surveys

"Mice" in simulation 1 *Josh Barnes*



Rotate the "Mice"

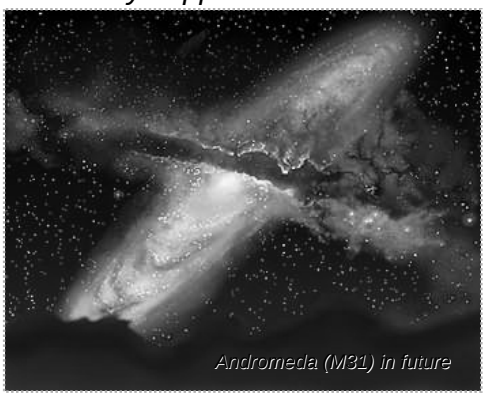


"Mice" in finer simulation 1 *Barnes*

Latest simulation 2 of "Mice" *John Dubinski*

Stefan's Quintet in HST detail

It may happen to us in future!



M31 and Milky Way in future collision *Dubinski*