ASTR 1040: Stars & Galaxies

Stefan's Quintet

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Lecture 24   Thur 15 Nov 2018
zeus.colorado.edu/astr1040-toomre

Our Schedule

- Mid-Term Exam 3 in class on Thur Nov 28, after Fall Break (FB)
- Review Sheet #3 available for MT Exam
- Re-read *21.3 Quasars and active galactic nuclei* with care
- Overview read Chap 22 Birth of Universe
- New HW #12 passed out, HW #11 due
- *Observatory Night #9* tonight, *Night #10* on Monday Nov 26, just after FB (signups)

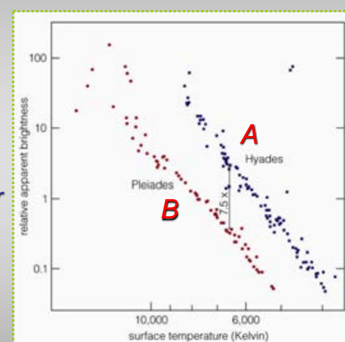
Mapping the universe: need distances to galaxies!

- *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*



Distances up to ~200,000 light years

Main Sequence Fitting often compared to nearby Hyades Cluster (M45)

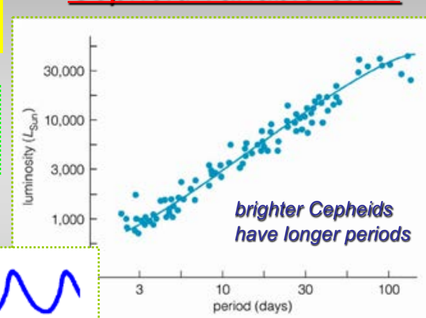
Only 151 ly away

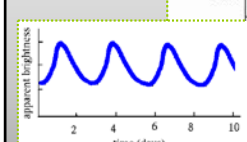
Close enough to get distance estimate through parallax

Cepheid variable stars

DISTANCE ESTIMATE 2

Period - Luminosity relation

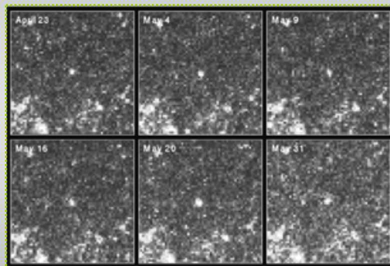




DISTANCE ESTIMATE 2

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



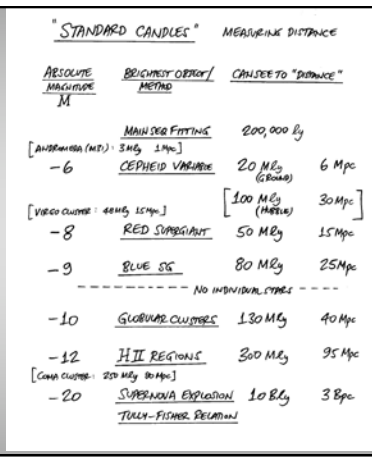
Cepheid variable in M100 (HST)

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')

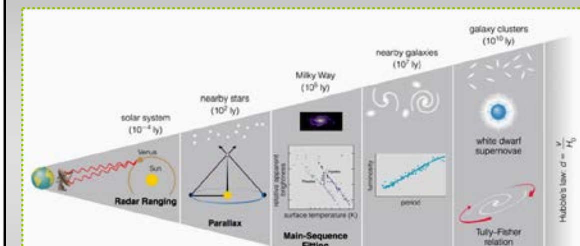
"Distance ladder"

Overlapping "standard candles"


"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
		[100 MLy (HUBBLE)	30 Mpc]
[VIRGO CLUSTER: 48 MLy 15 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	H II REGIONS	300 MLy	95 Mpc
[COMA CLUSTER: 250 MLy 80 Mpc]			
−20	SUPERNOVA EXPLOSION	10 BLy	3 Bpc
	TULLY-FISHER RELATION		

Distance ladder to measure universe



Different standard candles are useful for different distances

Overlap is important!

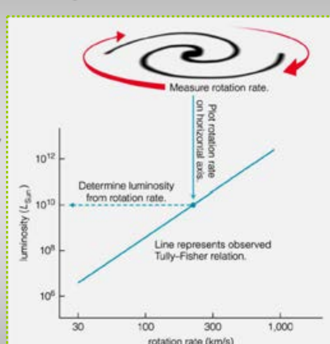
Tully-Fisher Relation

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

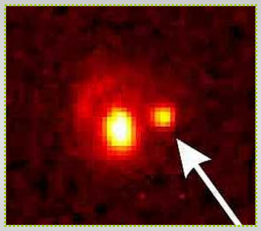


DISTANCE ESTIMATE 4

Even brighter: White dwarf supernovae

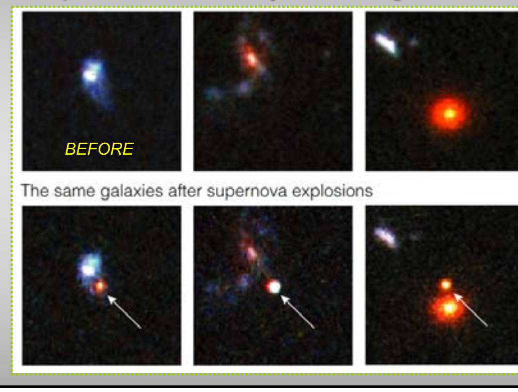
- "Standard explosion" = fusion of 1.4 solar masses of material
- Nearly the same amount of energy released

Bright enough to be seen halfway across observable universe



Useful for mapping the universe to the largest distances

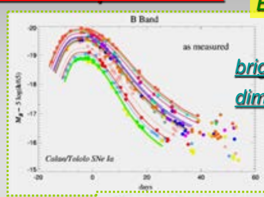
Supernovae in very distant galaxies



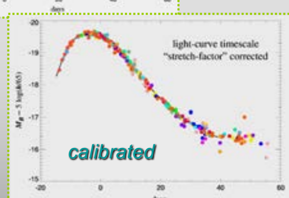
White dwarf supernovae

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!



Measuring big distances to galaxies

"STANDARD CANDLES" -- important ones in `distance ladder '

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

Brightness ~ Luminosity / (Distance)^2

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

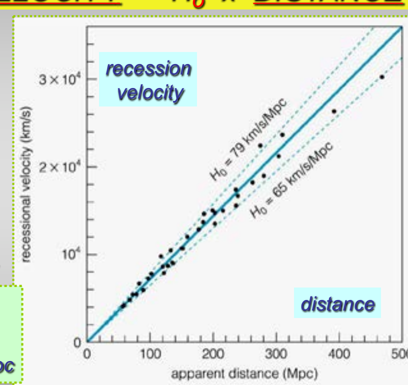
D = 700 km/sec / 70 km/sec/Mpc = 10 Mpc = 32 million light years

REVIEW

VELOCITY = H_o x DISTANCE

"HUBBLE CONSTANT"

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



Cosmological (Big) Redshifts
(from expansion of universe)

Alternative definition of redshift :

Z = redshift
= change in wavelength/ "normal" wavelength

1 + Z =
observed wavelength / "normal" wavelength

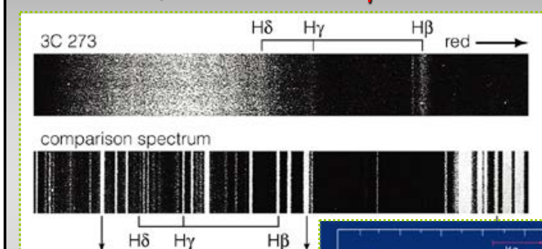
redshifts always have Z > 0
(redder light has larger wavelengths)

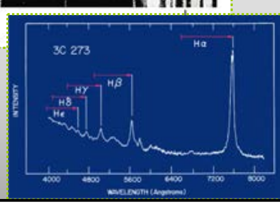
Quasars

New topic: VERY bright sources

- Quasi-stellar Radio Source (QSOs)
- Nuclei so bright that the rest of the galaxy is not easily seen
- First discovered as radio sources - then found to have high redshifts ! (far, far away?)

Quasar 3C 273 spectrum



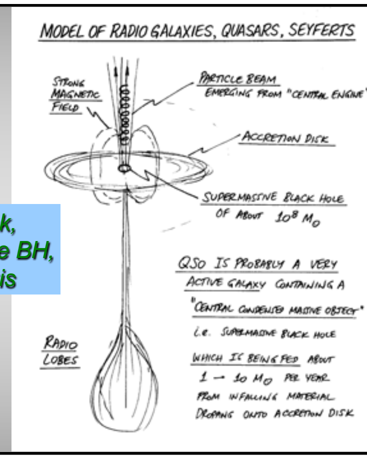


Tricky to identify hydrogen emission lines
…. very big red shift

Maarten Schmidt, Caltech, 1967

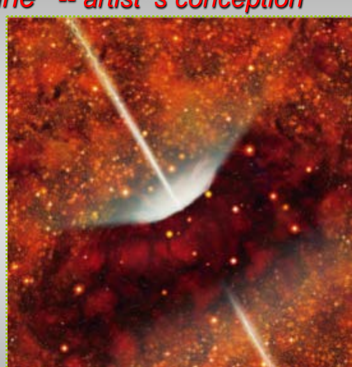
Model for "active galaxies"

Accretion disk, supermassive BH, beams on axis

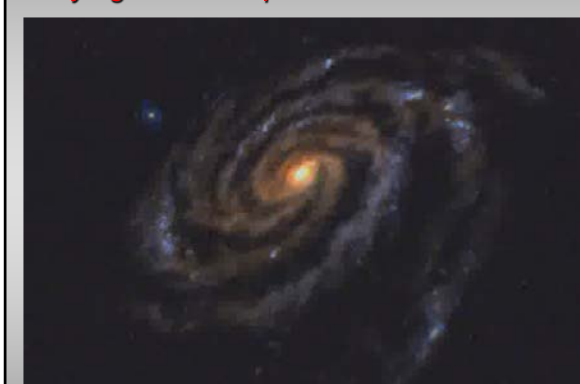


"Central Engine" -- artist's conception

- Accretion disk around super-massive black hole
- Disk itself may or may not be obscured by dust
- If bright nucleus is visible, looks like a quasar, if not, then a radio galaxy



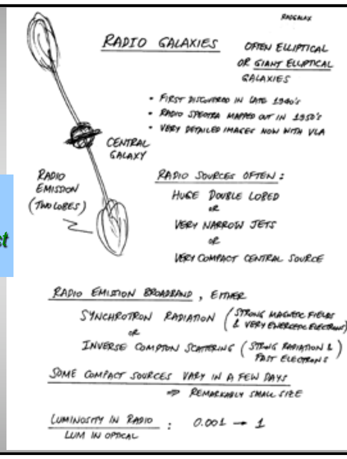
Flying toward supermassive black hole



Radio galaxies

Central elliptical galaxy, huge lobes of emission, compact central source

Synchrotron radiation


RADIO GALAXIES
OFTEN ELLIPTICAL OR GIANT ELLIPTICAL GALAXIES

- FIRST DISCOVERED IN LATE 1940's
- RADIO SPECTRA MAPPED OUT IN 1950's
- VERY DETAILED IMAGES NOW WITH VLA

RADIO SOURCES OFTEN:
HUGE DOUBLE LOBED
or
VERY NARROW JETS
or
VERY COMPACT CENTRAL SOURCE

RADIO EMISSION BROADBAND, EITHER
SYNCHROTRON RADIATION (STRONG MAGNETIC FIELDS & VERY ENERGETIC ELECTRONS)
or
INVERSE COMPTON SCATTERING (STRONG RADIATION & FAST ELECTRONS)

SOME COMPACT SOURCES VARY IN A FEW DAYS
⇒ REMARKABLY SMALL SIZE

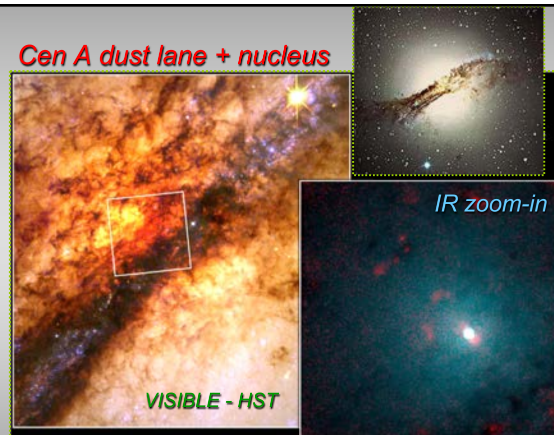
LUMINOSITY IN RADIO / LUM IN OPTICAL : 0.001 → 1

Prototypical "radio galaxy"

Giant elliptical galaxy NGC 5128 with dust lane (from spiral galaxy?)
+
Centaurus A (Cen A) radio source (color lobes)

Remains of spiral galaxy as dust lane ?

Cen A dust lane + nucleus

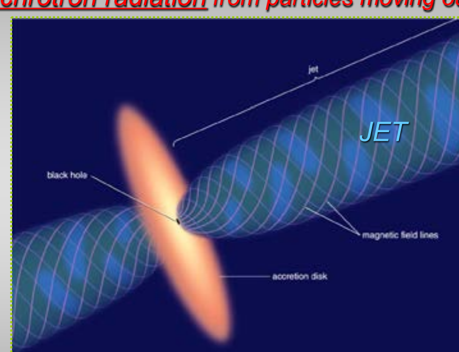


Clicker Question

Hubble's Law shows that:

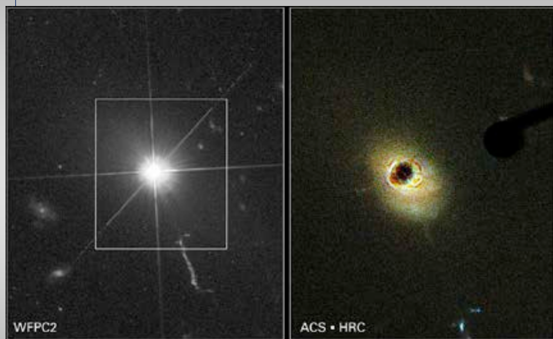
A. The further away we look in the universe, the faster things are moving
B. The further away we look in the universe, the slower things are moving
C. Everything in the universe is moving away from us at the same speed
D. Everything in the universe is staying still, we're just the ones moving
E. We must be the center of the Universe

Synchrotron radiation from particles moving outward



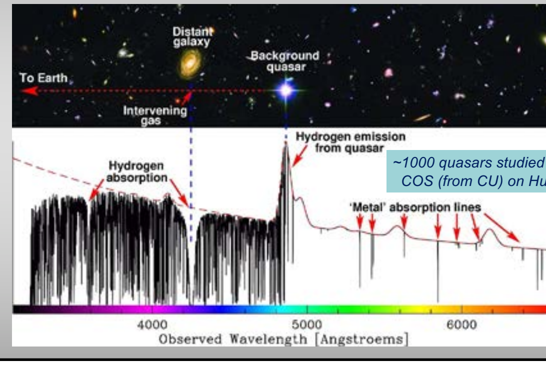
Spinning accretion disk drags along magnetic fields

Revisit Quasar 3C273



With advanced HST instruments, can see extended surrounding galaxy

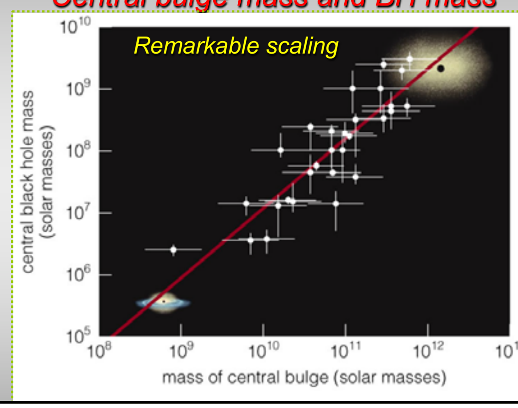
Viewing distant quasar: "Lyman alpha forest" of absorption from intervening gas



Do ALL big galaxies have supermassive black holes?

- As of 2018: probably YES !
- Part of normal galaxy formation ?
- More quasars seen in the distant (early) universe than now
- Black holes gradually grow, but can run out of available fuel and become relatively invisible (like in our Milky Way)

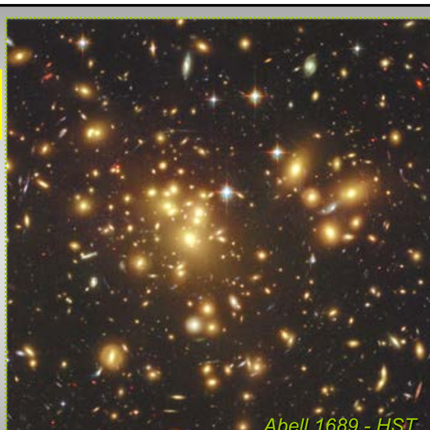
Central bulge mass and BH mass



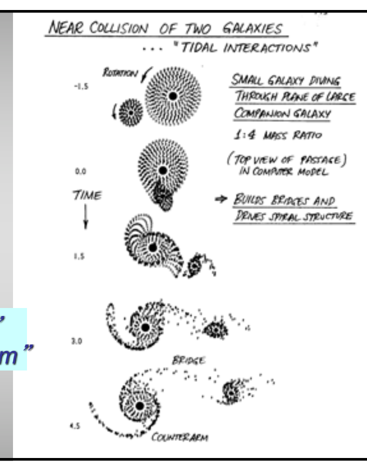
Rich galaxy cluster

Galaxies are not lonely -- many "interactions" most likely!

also curious arcs of light?



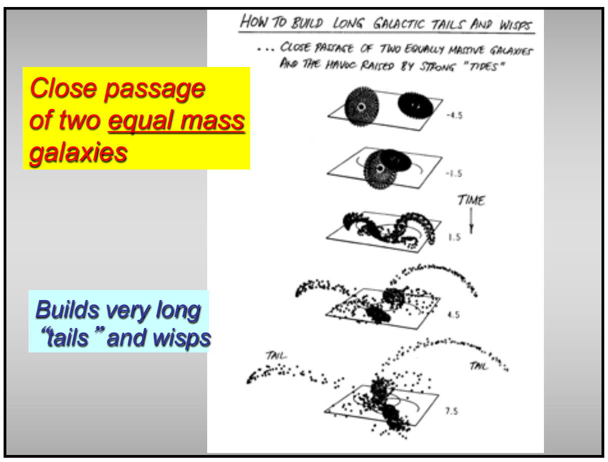
Collision of small galaxy with big one



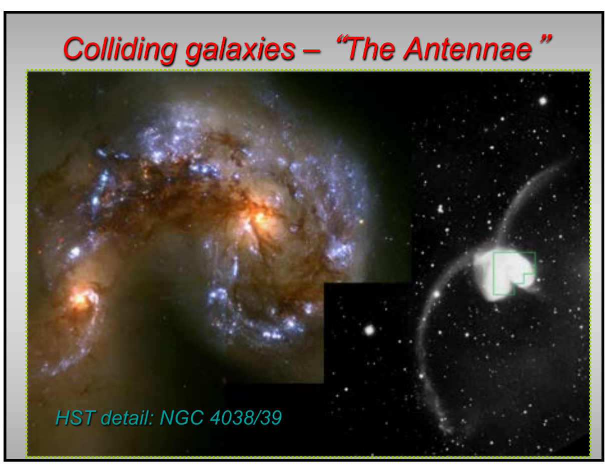
Builds "bridge" and "counterarm"

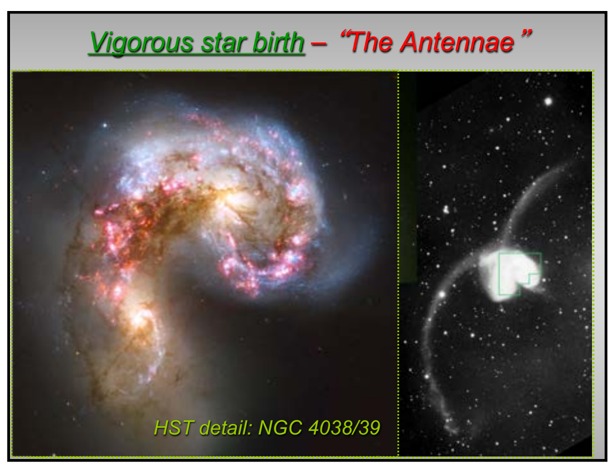

Close passage: M51 + companion
NGC 5194 + 95

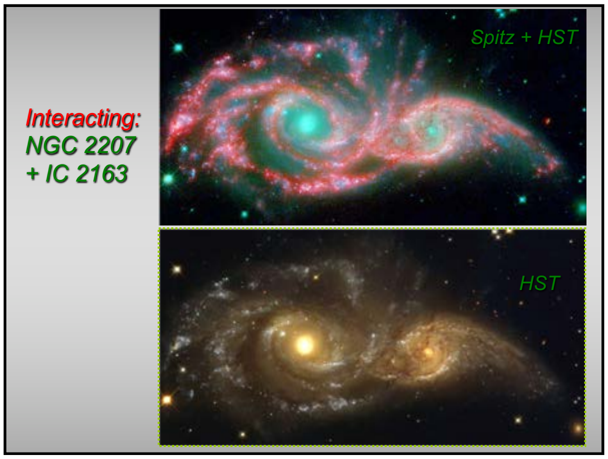

Tidal streams between galaxies
HST

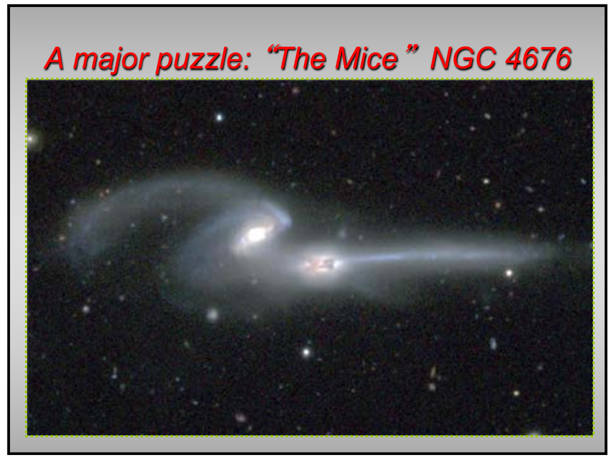

Close passage
of two equal mass
galaxies
HOW TO BUILD LONG GALACTIC TAILS AND WISPS
... CLOSE PASSAGE OF TWO EQUALLY MASSIVE GALAXIES
AND THE HAVOC RAISED BY STRONG "TIDES"
-4.5
-1.5
TIME
1.5
4.5
TAIL
TAIL
7.5
Builds very long
"tails" and wisps

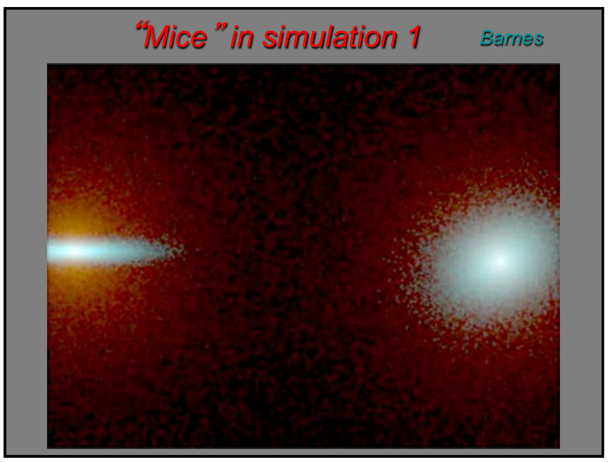

Two galaxies form "The Antennae"

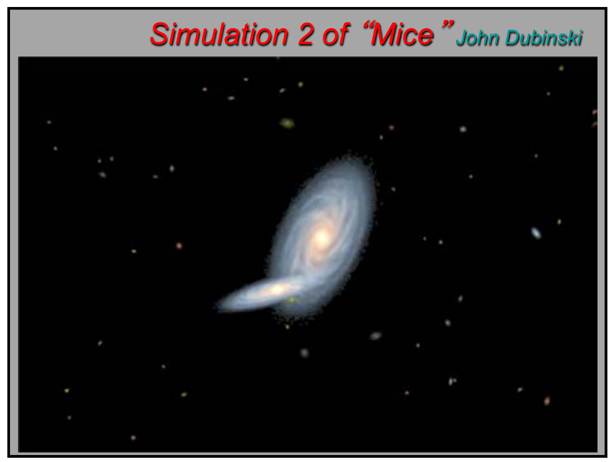

Colliding galaxies – "The Antennae"
HST detail: NGC 4038/39


Vigorous star birth – "The Antennae"
HST detail: NGC 4038/39


Interacting:
NGC 2207
+ IC 2163
Spitz + HST
HST


A major puzzle: "The Mice" NGC 4676


"Mice" in simulation 1
Barnes


Simulation 2 of "Mice"
John Dubinski


Stefan's Quintet in HST detail