## ASTR 1040: Stars & Galaxies

Stefan's Quintet

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Lecture 24 Thur 12 Apr 2018
zeus.colorado.edu/astr1040-toomre

## Our Schedule

- Next class (Tues Apr17) *meets in Fiske Planetarium*
- *Mid-Term Exam 3* in class next Thur Apr 19
- *Review Sheet #3* still available, with review next Wed Apr 18 here, 5pm-7pm (Ryan)
- 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


Hamilton on Hawking tonight

## 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)$^2$*

REMINDER

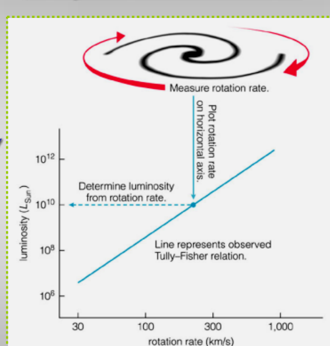
## Tully-Fisher Relation

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*

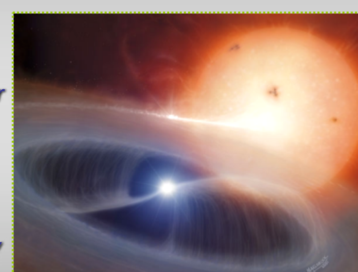



REMINDER

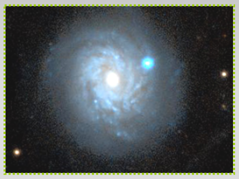
## Even brighter: White dwarf supernovae

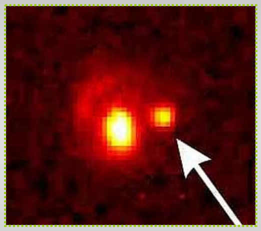
DISTANCE ESTIMATE 4

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



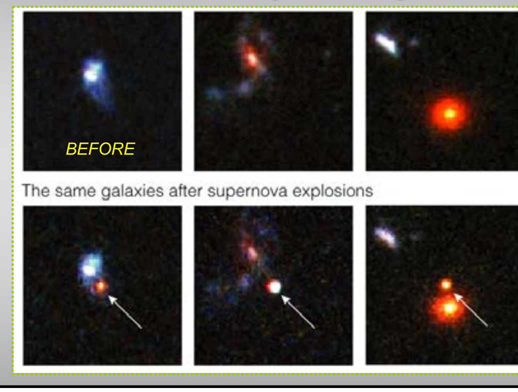
## Bright enough to be seen halfway across observable universe





*Useful for mapping the universe to the largest distances*

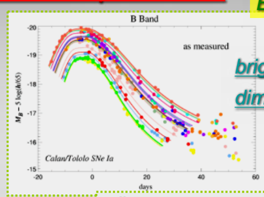
## Supernovae in very distant galaxies



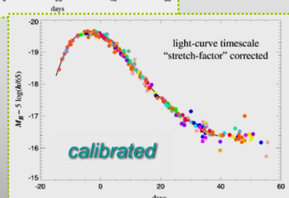

## White dwarf supernovae

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*

## Use *Hubble's Law* itself to estimate vast distances D

DISTANCE ESTIMATE 5

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

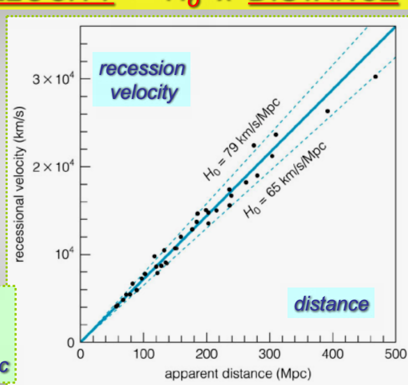
*D = 700 km/sec / 70 km/sec/Mpc = 10 Mpc*
*= 32 million light years*

REVIEW

## VELOCITY = $H_o$ x DISTANCE

*"HUBBLE CONSTANT"*

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




## Quasars

- *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?)*

## Cosmological (Big) Redshifts
(from expansion of universe)

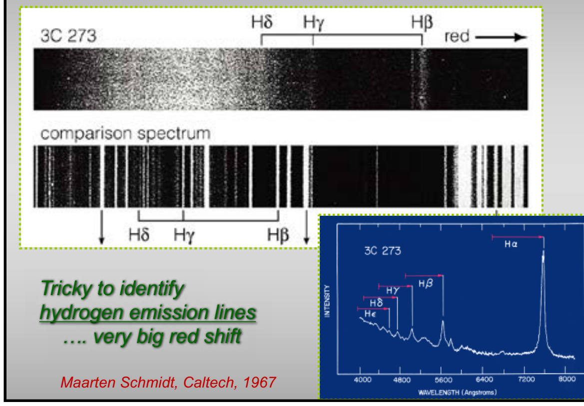
Alternative definition of redshift :

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

1 + Z =
observed wavelength / "normal" wavelength

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

## Quasar 3C 273 spectrum

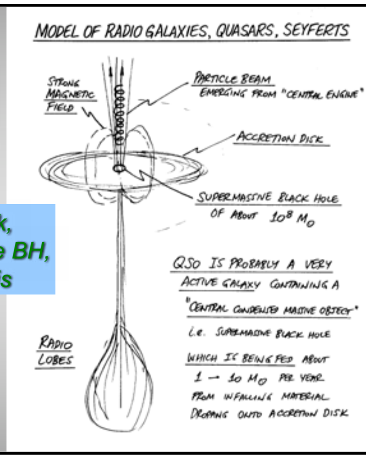



Tricky to identify hydrogen emission lines
…. very big red shift

Maarten Schmidt, Caltech, 1967

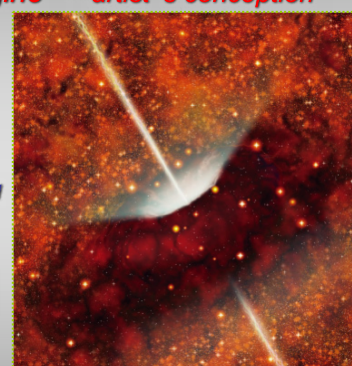
## Model for "active galaxies"

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

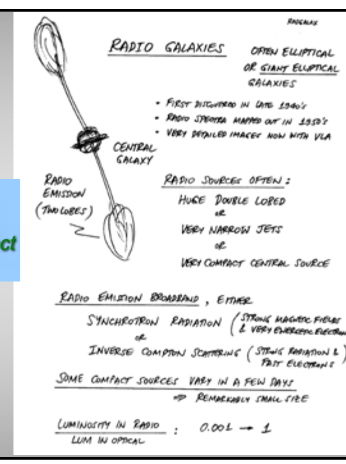


## Flying toward supermassive black hole

## Radio galaxies

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

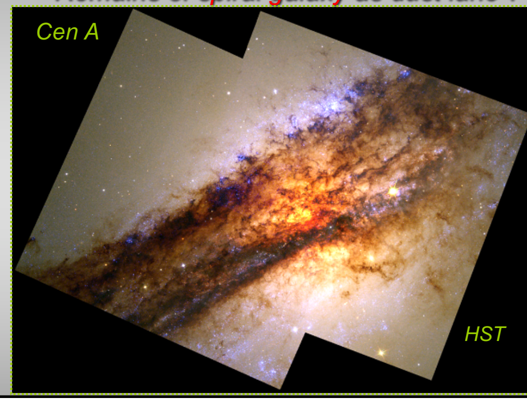
Synchrotron radiation



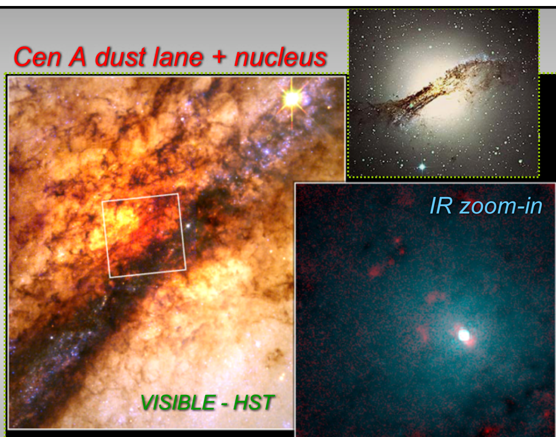
**Prototypical "radio galaxy"**

*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:

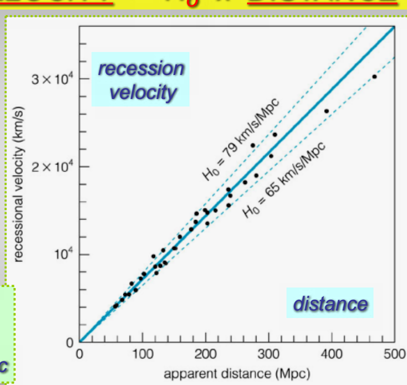
A. The further away we look in the universe, the faster things are moving
B. The further away we look in the universe, the slower things are moving
C. Everything in the universe is moving away from us at the same speed
D. Everything in the universe is staying still, we're just the ones moving
E. We must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

REVIEW

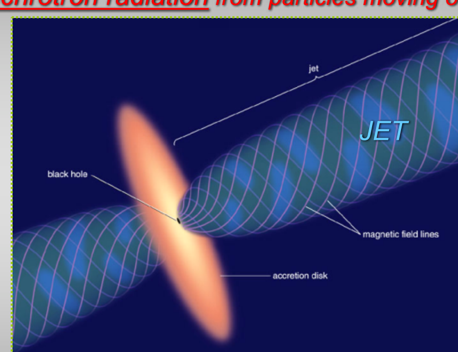
**VELOCITY = $H_o$ x DISTANCE**

"HUBBLE CONSTANT"

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




**Synchrotron radiation from particles moving outward**




Spinning accretion disk drags along magnetic fields

REVISIT

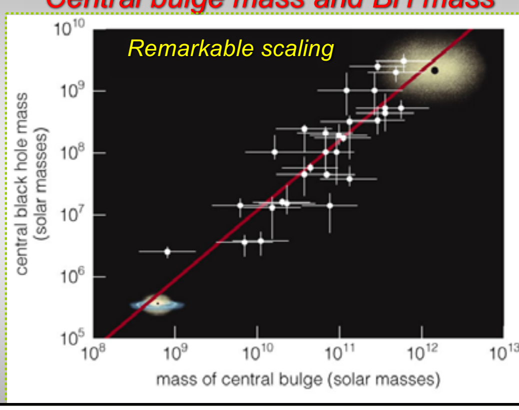
**Prototypical "radio galaxy"**

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

## 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)

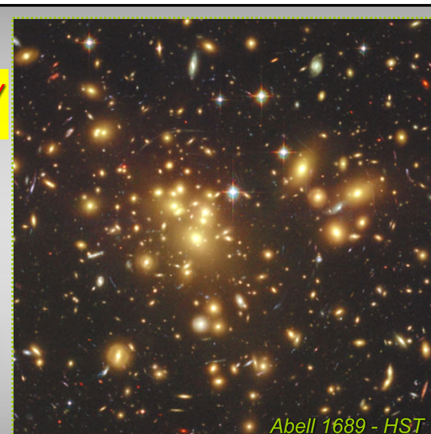
## Central bulge mass and BH mass



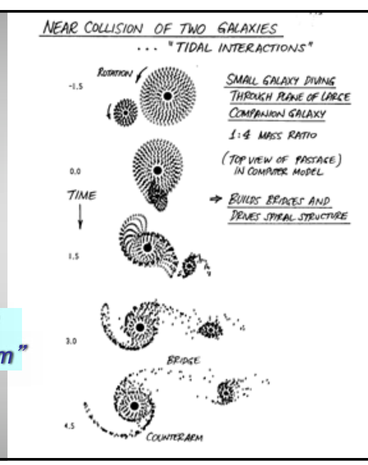

**Rich galaxy cluster**

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

also curious arcs of light?




**Collision of small galaxy with big one**



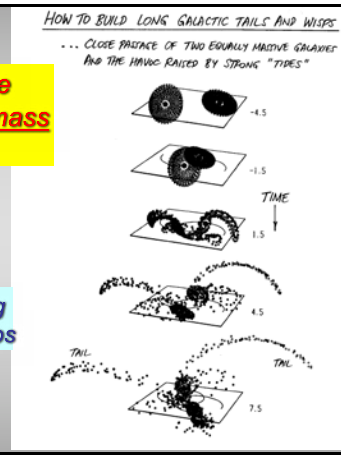

Builds "bridge" and "counterarm"

## Close passage: M51 + companion

## Tidal streams between galaxies

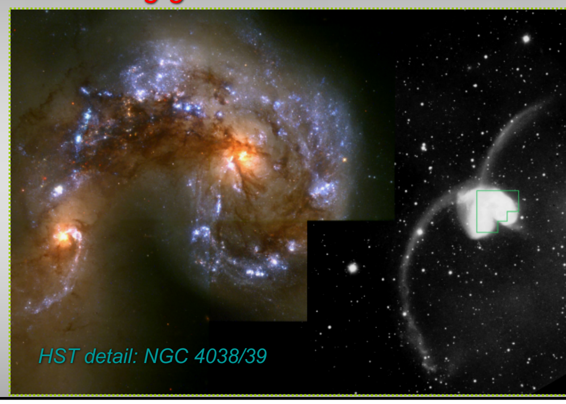

**Close passage of two equal mass galaxies**

**Builds very long "tails" and wisps**

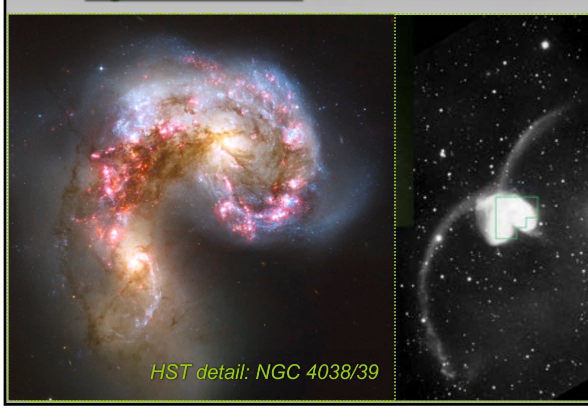



## Two galaxies form "The Antennae"

## Colliding galaxies – "The Antennae"




## Vigorous star birth – "The Antennae"

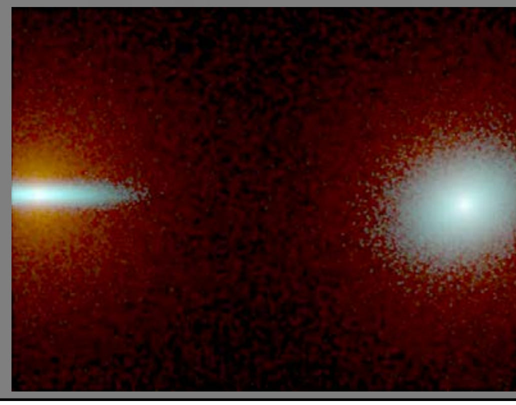



**Interacting: NGC 2207 + IC 2163**


## A major puzzle: "The Mice" NGC 4676

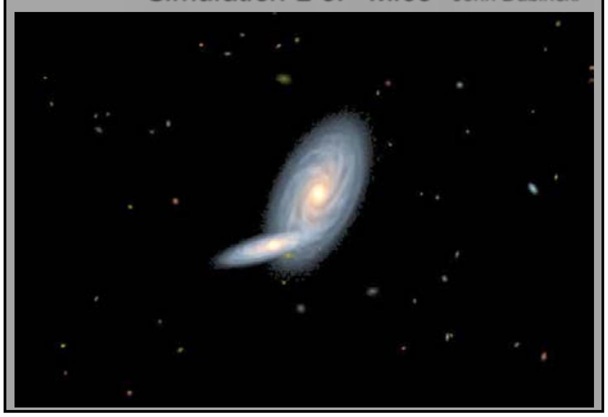
## "Mice" in simulation 1

Barnes

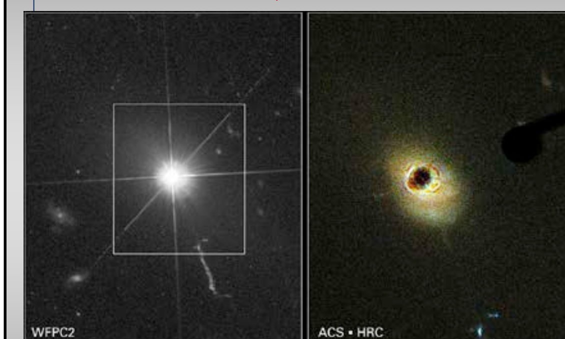


## Simulation 2 of "Mice"

John Dubinski



## Revisit Quasar 3C273




*With advanced HST instruments, can see extended surrounding galaxy*

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