


**ASTR 1040: Stars & Galaxies**




Stefan's Quintet

Prof. Juri Toomre TAs: Peri Johnson, Ryan Horton  
Lecture 24 Thur 12 Apr 2018  
[zeus.colorado.edu/astr1040-toomre](http://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

The Science of Stephen Hawking  
with Dr. Andrew Hamilton



Hamilton on Hawking tonight

April 12<sup>th</sup> 7pm  
FREE for CU Boulder Students  
FISKE PLANETARIUM  
[colorado.edu/fiske](http://colorado.edu/fiske) | 303.492.5002

**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)<sup>2</sup>**

REMINDER

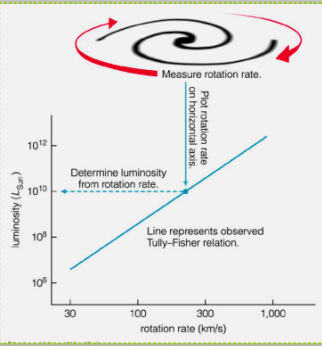
**DISTANCE ESTIMATE 3**

- 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

**Tully-Fisher Relation**



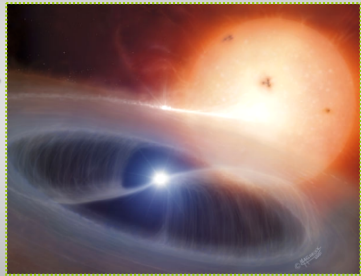
The graph shows a log-log plot of luminosity (L<sub>21cm</sub>) on the y-axis (ranging from 10<sup>8</sup> to 10<sup>12</sup>) versus rotation rate (km/s) on the x-axis (ranging from 30 to 1,000). A solid blue line represents the observed Tully-Fisher relation. A dashed line indicates the process: 'Measure rotation rate' (from a diagram of a spiral galaxy with rotation arrows) leads to 'Determine luminosity from rotation rate', which then leads to 'Put rotation rate into Tully-Fisher relation'.

REMINDER

**DISTANCE ESTIMATE 4**

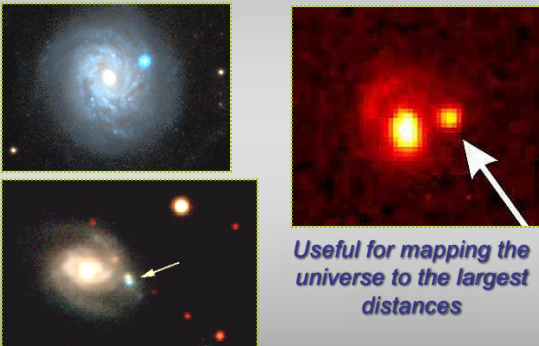
**Even brighter: White dwarf supernovae**

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



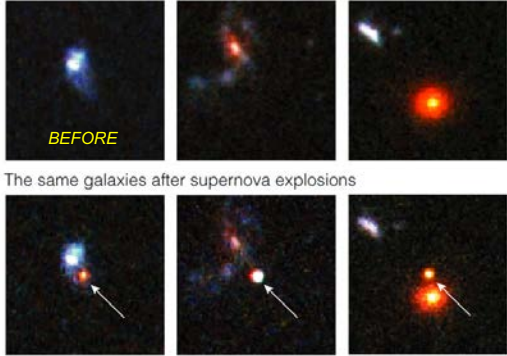
The image shows a bright, expanding shell of gas and dust from a white dwarf supernova, with a glowing core in the center.

**Bright enough to be seen halfway across observable universe**



**Useful for mapping the universe to the largest distances**

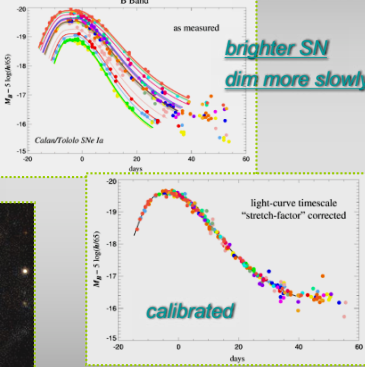
**Supernovae in very distant galaxies**



The same galaxies after supernova explosions

**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!*

*light-curve timescale "stretch-factor" corrected*

*calibrated*




DISTANCE ESTIMATE 5 Use Hubble's Law itself to estimate vast distances D

- Measure velocity, then:  $D = v / H_0$
- Example: using  $H_0 = 70 \text{ km/sec/Mpc}$ , and finding that  $v = 700 \text{ km/sec}$

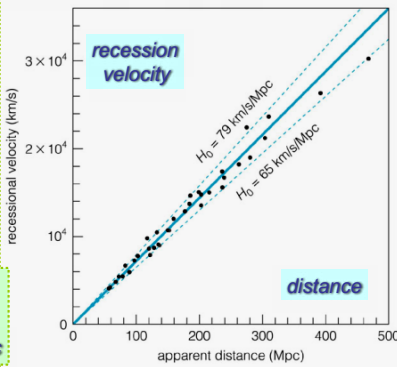
$D = 700 \text{ km/sec} / 70 \text{ km/sec/Mpc} = 10 \text{ Mpc}$   
 $= 32 \text{ million light years}$

REVIEW VELOCITY =  $H_0 \times$  DISTANCE



**"HUBBLE CONSTANT"**

$H_0 = 71 \pm 4 \text{ km/sec/Mpc}$



recession velocity (km/s)

apparent distance (Mpc)

*recession velocity*

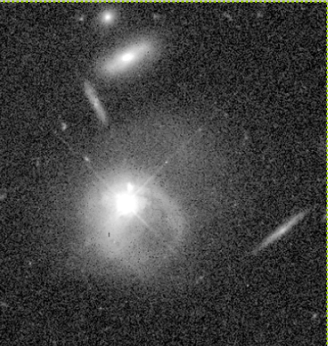
*distance*

$H_0 = 79 \text{ km/sec/Mpc}$

$H_0 = 65 \text{ km/sec/Mpc}$

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?)**



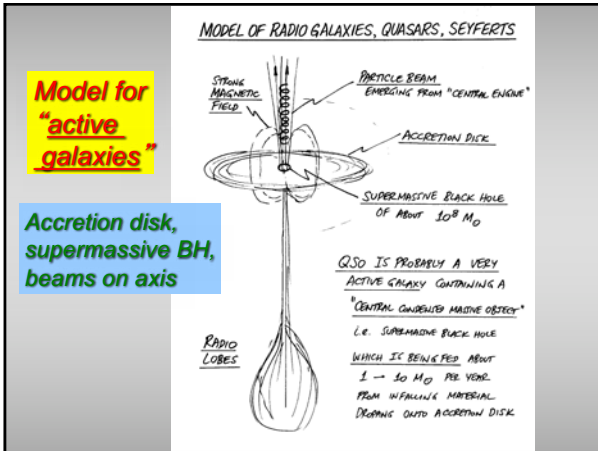
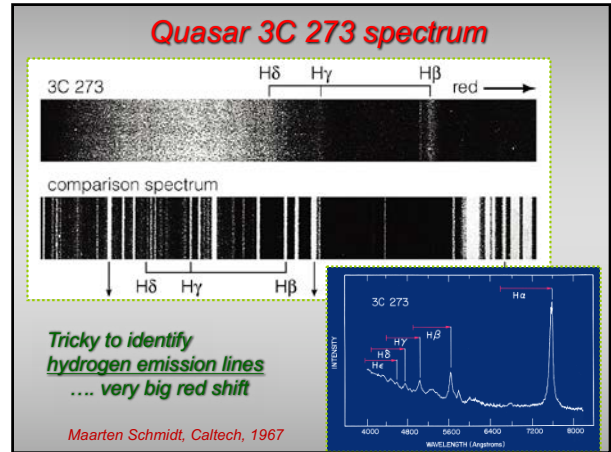
**Cosmological (Big) Redshifts**  
(from expansion of universe)

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)



**"Central Engine" -- artist's conception**

- Accretion disk around supermassive 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



**Radio galaxies**

CENTRAL ELLIPTICAL galaxy, huge lobes of emission, compact central source

**Synchrotron radiation**

RADIO GALAXIES OPEN ELLIPTICAL OR SLIGHT ELLIPTICAL GALAXIES

- FIRST DISCOVERED IN 1940S
- RADIO SPECTRA HADDED UP IN 1950'S
- VERY DETAIL IMAGES NOW WITH VLA

CENTRAL GALAXY

RADIO EMISSION (THE LOBES)

RADIO SOURCES OFTEN 2 HUGE DOUBLE LOBED OR VERY NARROW JETS OR VERY COMPACT CENTRAL SOURCE


RADIO EMISSION BROADBAND, EITHER SYNCHROTRON RADIATION (STRONG MAGNETIC FIELD & VERY FAST MOVING ELECTRONS) OR INVERSE COMPTON SCATTERING (STEADY RADIATION & FAST ELECTRONS)

SOME COMPACT SOURCES VARY IN A FEW DAYS  $\Rightarrow$  REMARKABLY SMALL SIZE

LUMINOSITY IN RADIO : 0.001  $\rightarrow$  1  
LUM IN OPTICAL

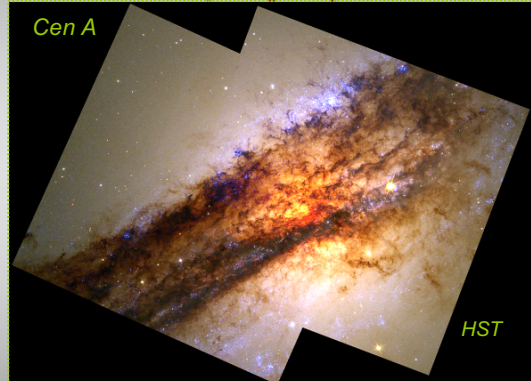
**Prototypical "radio galaxy"**

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



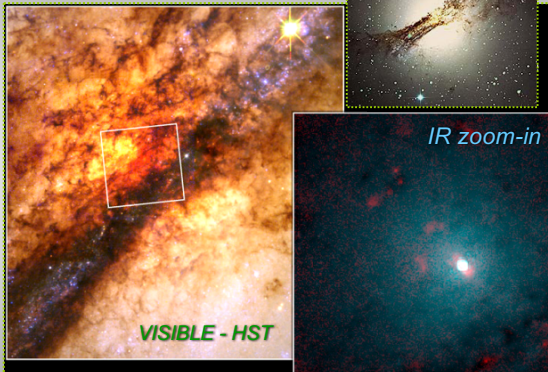
**Remains of spiral galaxy as dust lane ?**

Cen A



HST

**Cen A dust lane + nucleus**



IR zoom-in

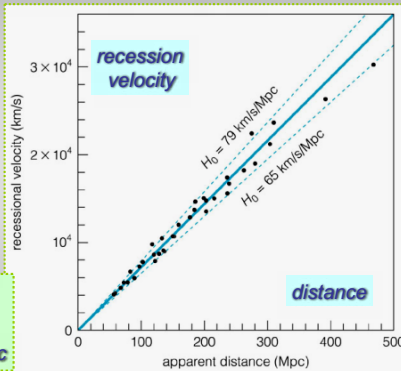
VISIBLE - HST

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 =  $H_0 \times$  DISTANCE**



recession velocity (km/s)

distance

$H_0 = 79 \text{ km/s/Mpc}$

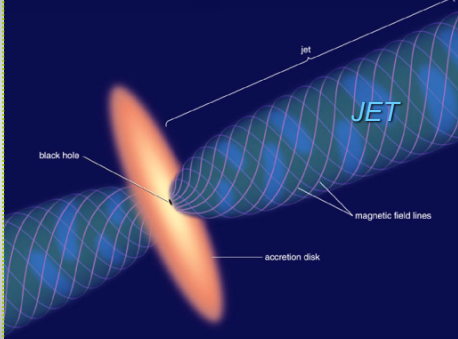
$H_0 = 65 \text{ km/s/Mpc}$

apparent distance (Mpc)

**"HUBBLE CONSTANT"**

$H_0 = 71 \pm 4 \text{ km/sec/Mpc}$

**Synchrotron radiation from particles moving outward**



black hole

accretion disk

jet

JET


magnetic field lines

**Spinning accretion disk drags along magnetic fields**

**REVISIT**

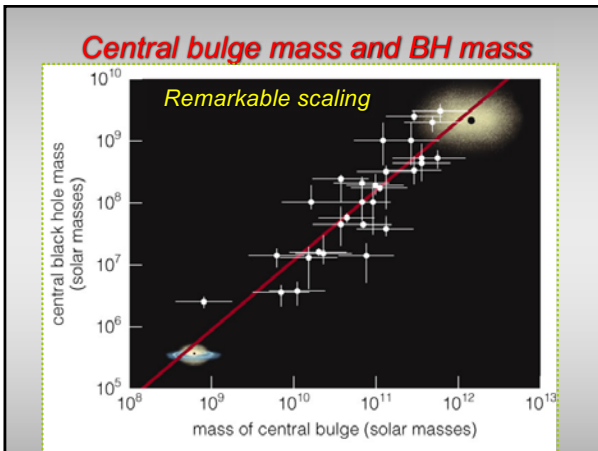
**Prototypical "radio galaxy"**

*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)



**Rich galaxy cluster**

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

also curious arcs of light?



Abell 1689 - HST

**Collision of small galaxy with big one**

Builds "bridge" and "counterarm"

NEAR COLLISION OF TWO GALAXIES  
... "TIDAL INTERACTIONS"

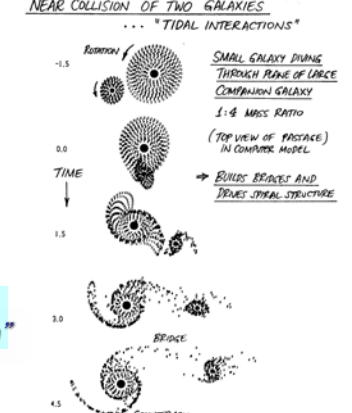
ROBUST

SMALL GALAXY DIVING THROUGH PLANE OF LARGE COMPANION GALAXY  
1:4 MASS RATIO  
(TOP VIEW OF PASTAGE) IN COMPUTER MODEL

TIME

BRIDGE

COUNTERARM

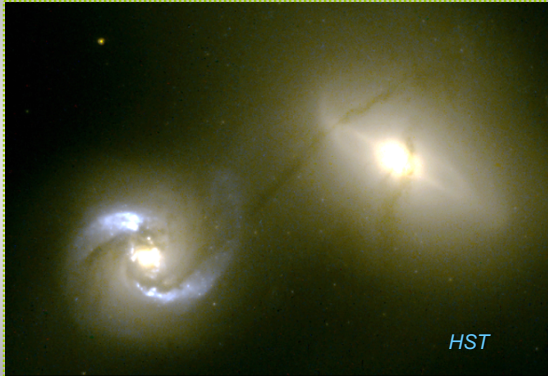


**Close passage: M51 + companion**



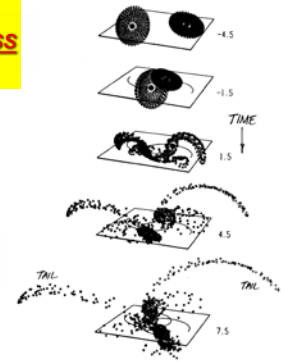
NGC 5194 + 95

**Tidal streams between galaxies**



**Close passage of two equal mass galaxies**

HOW TO BUILD LONG GALACTIC TAILS AND WISPS  
... CLOSE PASSAGE OF TWO EQUALLY MASSIVE GALAXIES  
AND THE HAVING RAISED BY STRONG "TIDES"

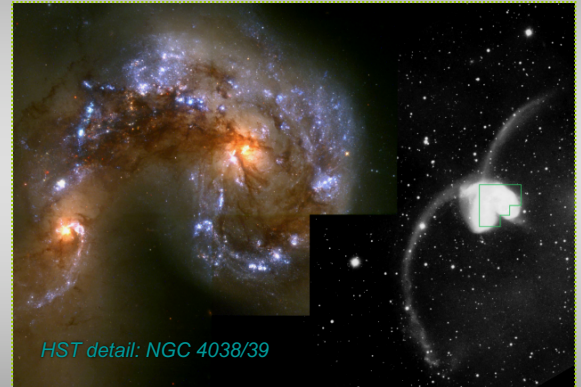


**Builds very long "tails" and wisps**

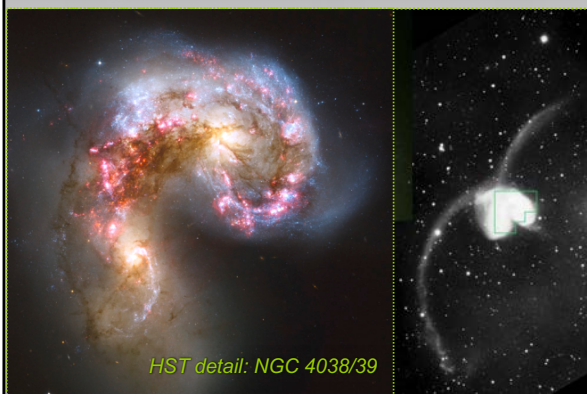
**Two galaxies form "The Antennae"**



**Colliding galaxies – "The Antennae"**



**Vigorous star birth – "The Antennae"**



**Interacting:  
NGC 2207  
+ IC 2163**



