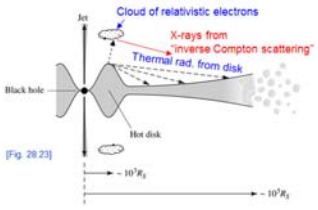
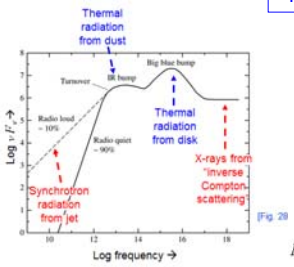
QSOs

- Study guide now on web.
- Evaluation: https://sirsonline.msu.edu
- Final: Tuesday, Dec 13 at 12:45PM

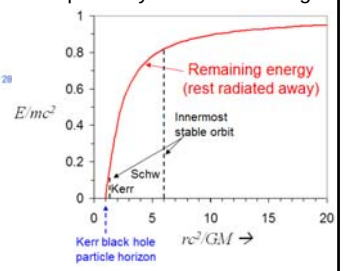
Continuum Radiation





Energy Source

probably = material falling in



Energetics

- Accretion rate & luminosity.
  - mass falls into black hole: $L_{disk} = \eta \frac{dM}{dt} c^2 = \eta \dot{M} c^2$

$\eta \approx 0.1$

$\dot{M} \approx 1-10\ M_\odot\ yr^{-1}$

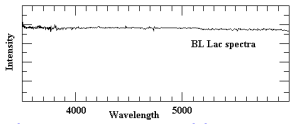
- Eddington limit.
  - Radiation pressure = gravity: $\frac{L_{Edd}}{4\pi r^2} m\sigma = \frac{GmM_{BH}}{4\pi r^2}$ (absorption cross-section)

$$L_{Edd} = \frac{GM_{BH}}{\sigma}$$

Luminous QSOs: $L \sim L_{Edd}$

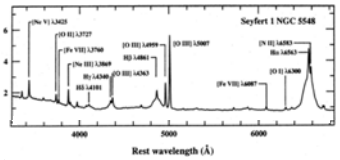
Seyferts, Radio Galaxies: $L << L_{Edd}$

Viewing Angle Effects



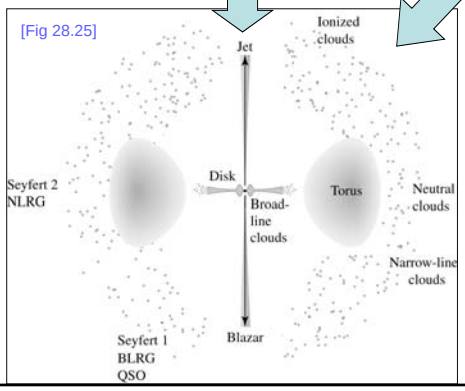
Blazar or "BL Lac" object:

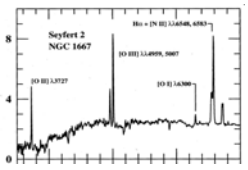
- Special-relativistic "beaming"
  - ➔Continuum made vastly brighter .
- So only continuum is seen,



Type 1:

Broad + narrow emission lines
+ non-thermal continuum

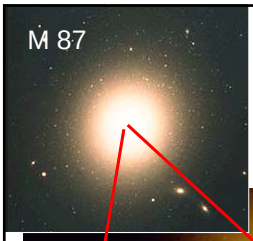


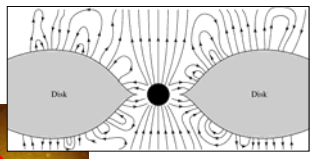


Type 2:

Just narrow emission lines

Radio Jets



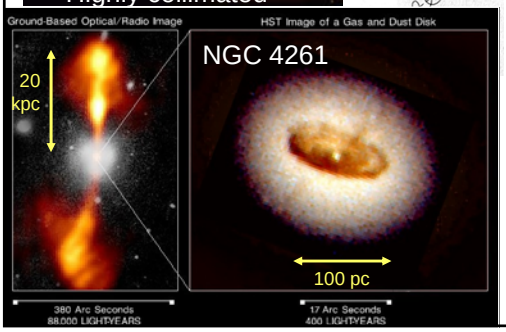


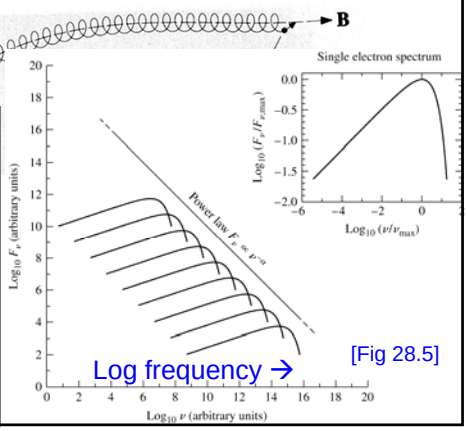
Acceleration thru Nozzle:

- Radiation pressure
  + thickened disk?
- A magnetic toothpaste tube?
- Or extracting energy from Black Hole?

Radiation is synchrotron emission:

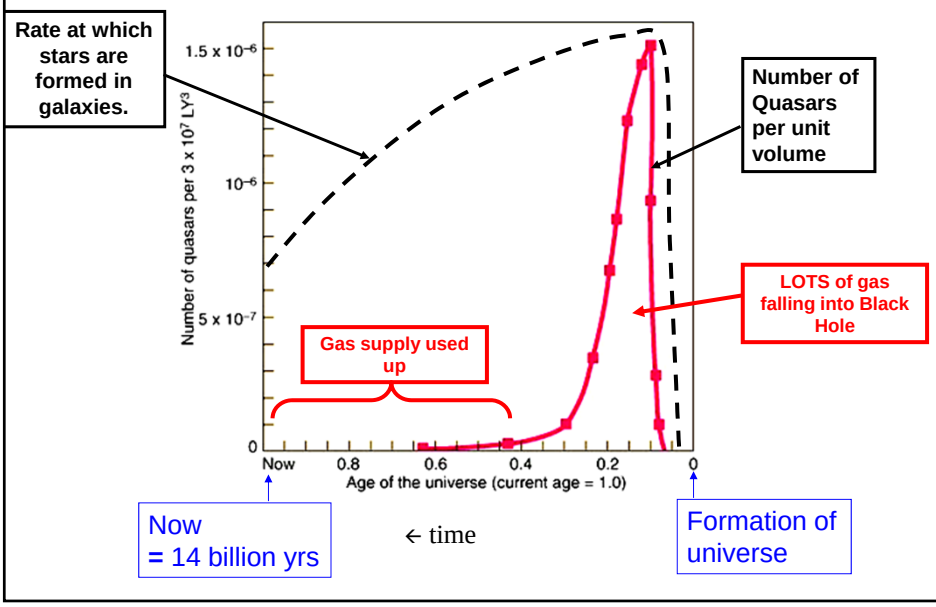
+ inverse Compton





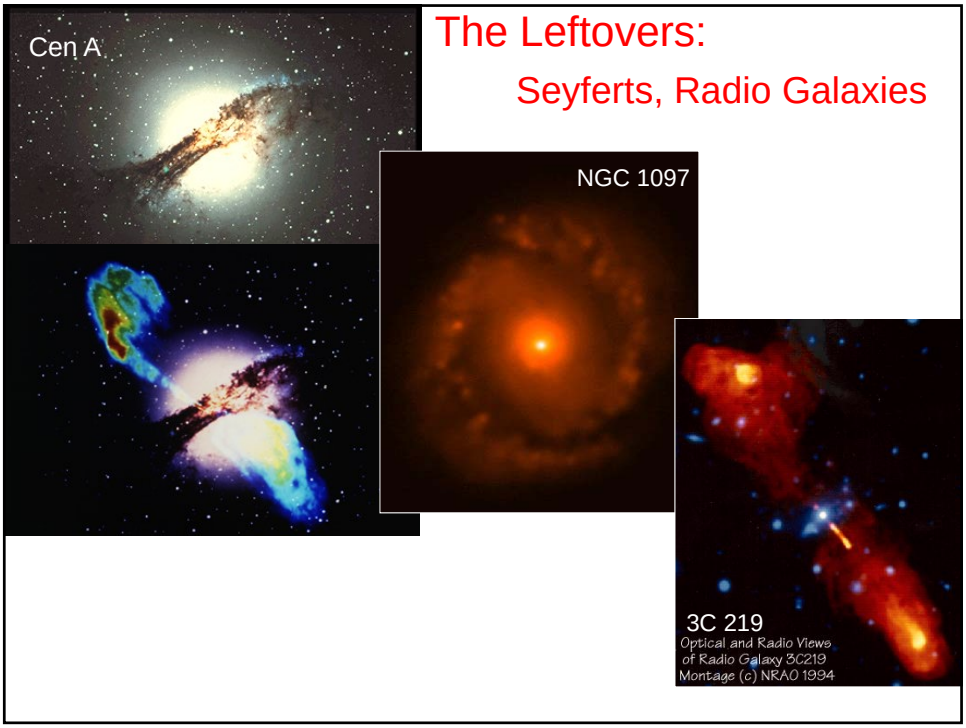
[Fig 28.5]

Most Quasars Lived and Died Long Ago



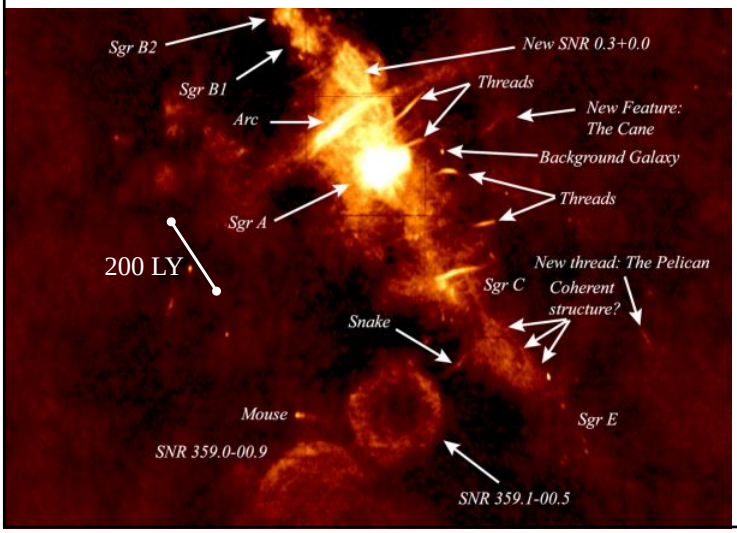
The Leftovers:

Seyferts, Radio Galaxies



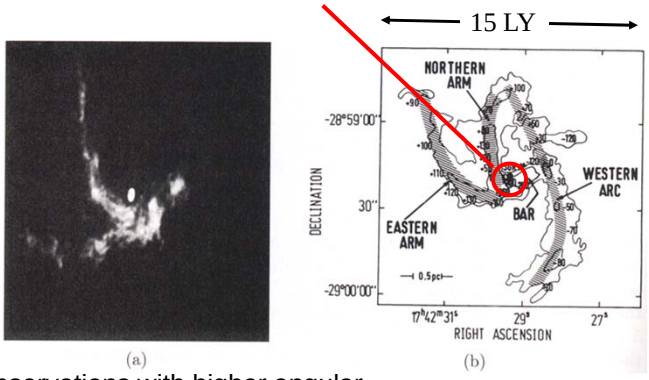
The Center of our own Galaxy [CO 24.4]

Visible light



Radio

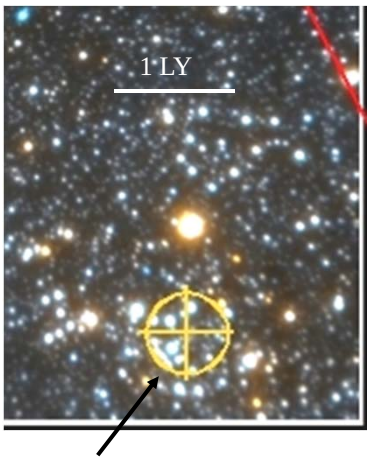
Sagittarius A*



Radio observations with higher angular resolution.

Small oval is the point source Sagittarius A*
= center of galaxy

Infra-red Images of the Galactic Center

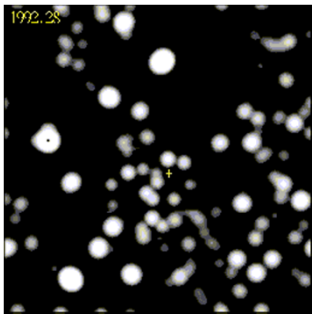


Galactic Center (Sagittarius A*)

Using "adaptive optics" technique on Gemini 8m telescope.

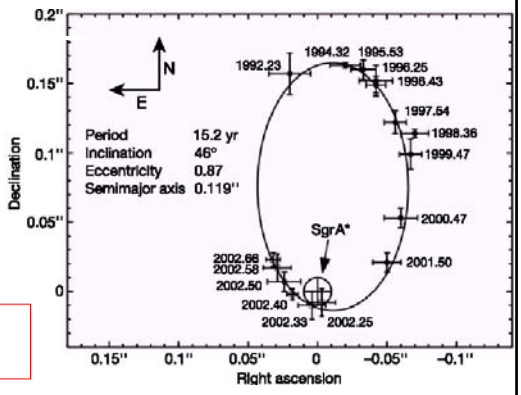
300,000 x more stars per unit volume than in vicinity of Sun

The Black Hole at the the Galactic Center



Infrared observations over 6 years.

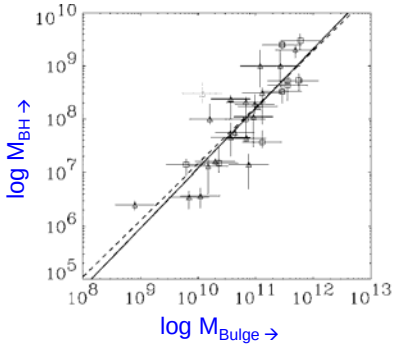
Velocities of stars in very center
➔ 4 million $M_{\odot}$ black hole
at position of Sagittarius A*



Data follow complete orbits to within 60AU from black hole.

The Role of AGN in Galaxy Formation

- All massive galaxies contain massive black holes.
- $M_{\text{Black Hole}} \propto M_{\text{Bulge}}$
  - ➔ cause & effect
- AGN feedback
  - Mass accretion rate is governed by
    - radiation pressure (Eddington limit)
    - and/or energy in jets/winds.
  - Limits size of galaxy.
  - Also operates on scale of galaxy cluster.



From stellar velocity dispersion + virial theorem.

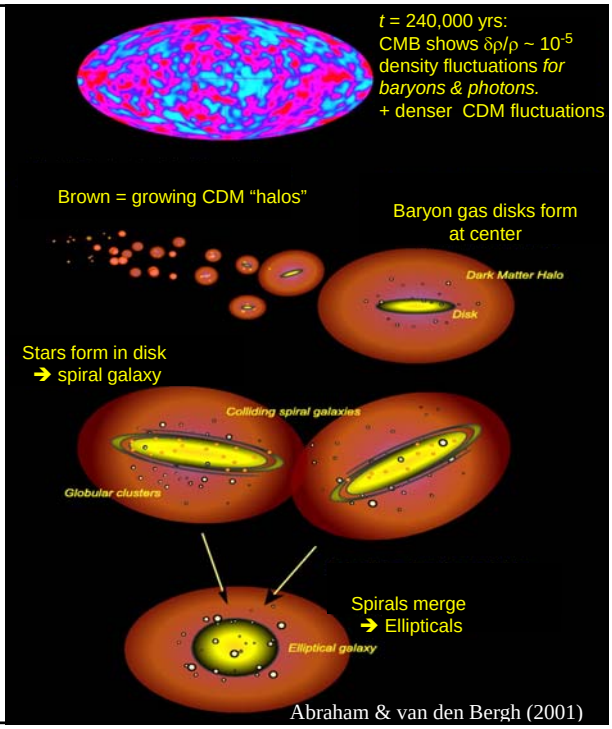
$$M \propto \frac{v^2 R}{G}$$

Basic idea behind galaxy formation - objects start small and grow by merging

Do galaxies form this way?

Does star formation occur before, during or after mass assembly?

When and how do Hubble Types form?

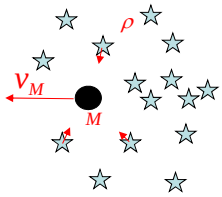


Merger Processes

- **Dynamical Friction** - A slow accretion process.
  - Massive body moving through uniform distribution of stars
    - Pulls stars in behind it.
    - Creates high-density wake.
    - Gravitational pull from wake slows down massive body.
    - If massive body is in orbit in a galaxy, it will gradually spiral into the center.
    - Force on body of mass M is $f_d \simeq C\frac{G^2M^2\rho}{v_M^2}$ ⇨ $t_c = \frac{2\pi v_M r_i^2}{CGM}$

$$r_{max} = \sqrt{\frac{t_{max} CGM}{2\pi v_M}}$$

[CO eqn. 26.3]



r_i = initial distance from center of galaxy.

t_c = time to spiral into center due to dynamical friction.

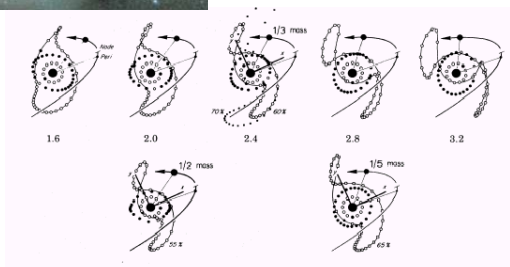
r_{max} = max radius for capture within age of universe.

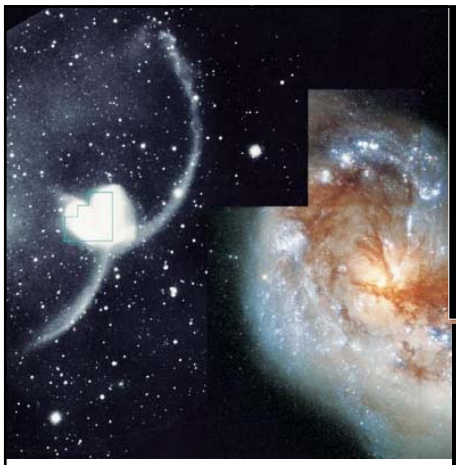
(= 4 kpc for M31 and t = 13 Gyr)

The Antennae Galaxies

NGC 4038
NGC 4039

- **Galaxy collisions** – "impacts".
  - Numerical simulations
  - Toomre & Toomre, 1972, ApJ 178, 623.
    - Tidal tails, etc.

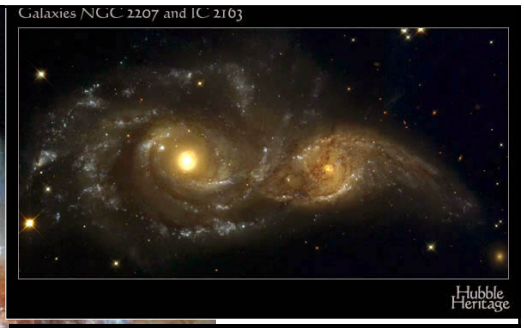




Do collisions between Spirals make Ellipticals?

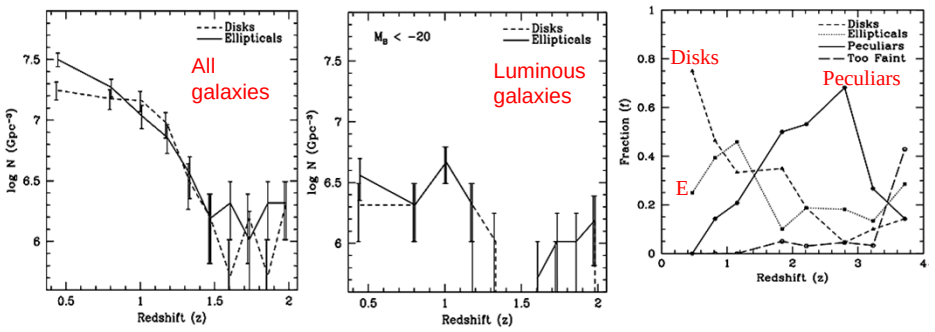
The Milky Way Meets Andromeda

2.5 million ly away
Approaching at 500,000 km/hr
➔ Collision in 3 billion yrs
Movie lasts 1.3 billion yrs.



Did peculiar galaxies merge to form today's massive E and S galaxies?

Co-moving density of Hubble Types vs. Redshift



Co-moving density drops from z ~ 1 to 1.5, even when considering only bright galaxies

Slide by Chris Conselice