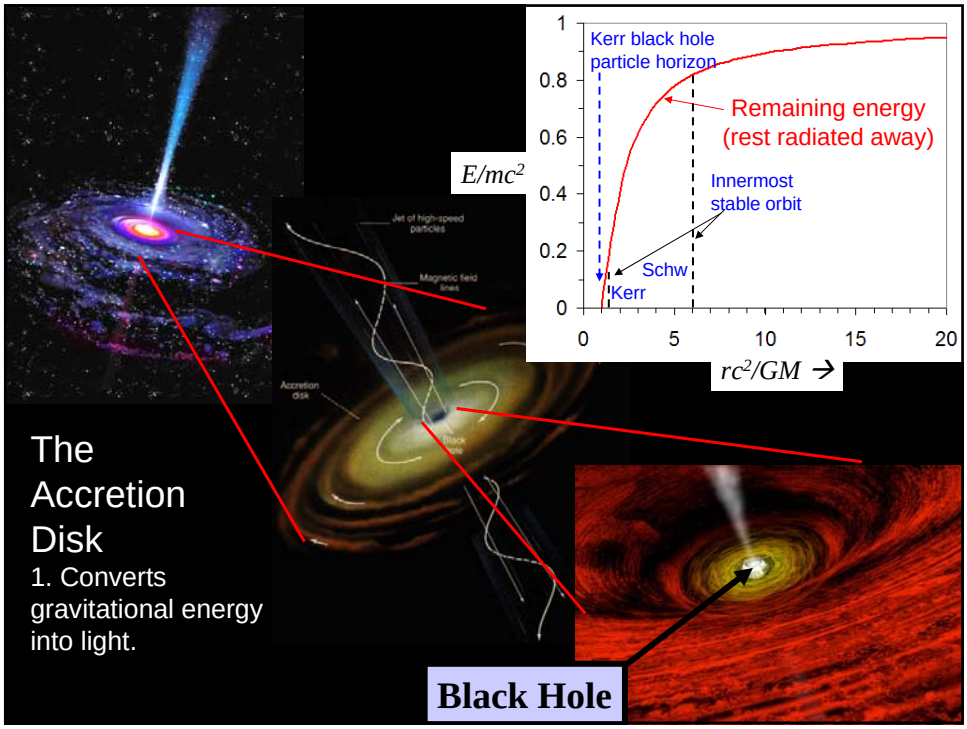
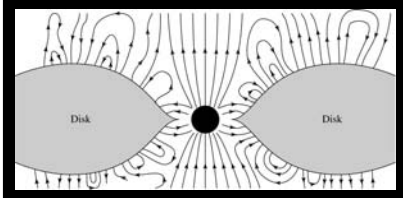


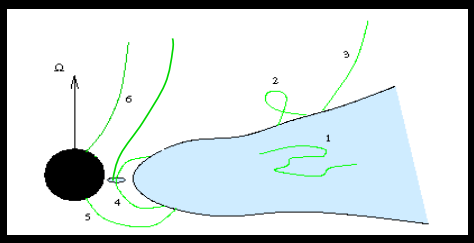
The Accretion Disk

1. Converts gravitational energy into light.

2. The Special Case of Kerr (Rotating) Black Holes: Direct Magnetic Coupling by the Blandford-Znajek Effect



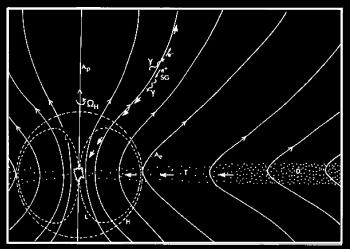
[CO Fig 28.24]



- Accreting plasma presses magnetic field onto Kerr hole
- Magnetic field lines temporarily thread Kerr hole
- Field extracts rotational energy and angular momentum from hole

$$L_{BZ} \sim 10^{46}\, erg\, s^{-1}\, m_9\, \dot{m}\, j^2$$

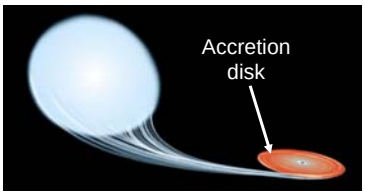
$$\gamma_{BZ} = ?????$$



Blandford & Znajek (1977)

(From Meier & Nakamura
http://www.atnf.csiro.au/education/workshops/jaunceyfest/Talks/19.DavidMeier/Meier_DJ65.ppt)

Accretion Disks



- Well-studied phenomena in local binary star systems
  - "cataclysmic variables"
- Angular momentum ➔ material cannot fall directly onto central mass.
- Binary stars ➔ "thin" accretion disks
  - Material works its way in toward center due to viscosity
- For QSO: Material eventually falls into Black Hole
  - From innermost stable orbit

Disk material loses energy by black body radiation

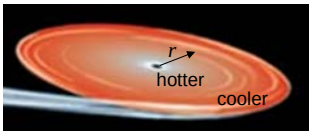
$$L(r) \propto T(r)^4 \times (2\pi r\, dr)$$

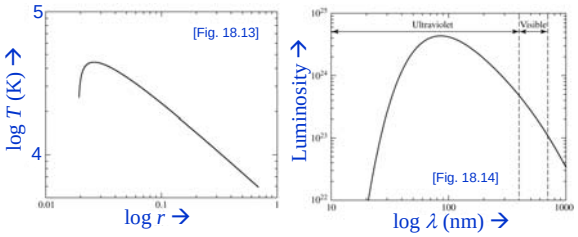
$$\Downarrow$$

$$T(r) \propto r^{-3/4}$$

[CO pgs. 661-665]

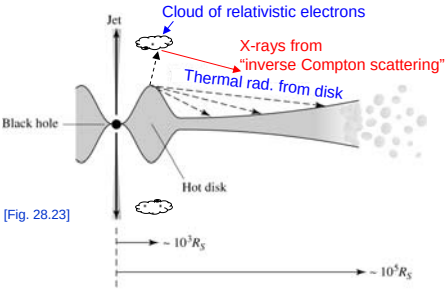
➔ total radiation = sum of black bodies.



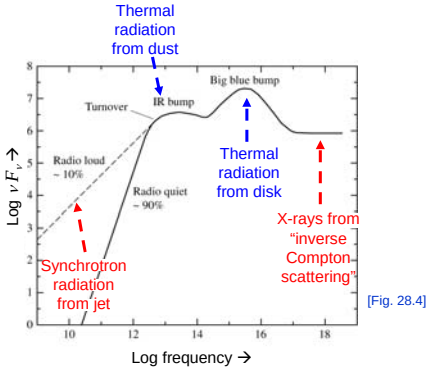


Binary star results, but QSOs are similar.

Continuum Source



[Fig. 28.23]



[Fig. 28.4]

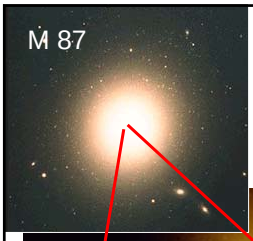
Energetics

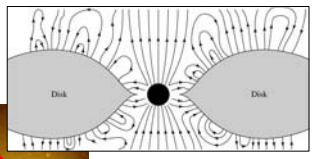
- Accretion rate & luminosity.
  - mass falls into black hole: $L_{disk} = \eta \frac{dM}{dt} c^2 = \eta \dot{M} c^2$ $\quad \eta \approx 0.1$, $\dot{M} \approx 1\text{–}10\ M_\odot\ \mathrm{yr}^{-1}$
- Eddington limit.
  - Radiation pressure = gravity: $\frac{L_{Edd}}{4\pi r^2} m\sigma = \frac{GmM_{BH}}{4\pi r^2}$ (σ: absorption cross-section)

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

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

Radio Jets



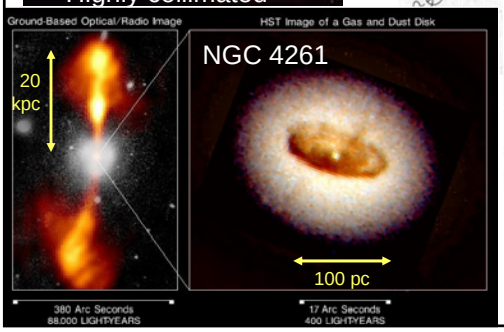


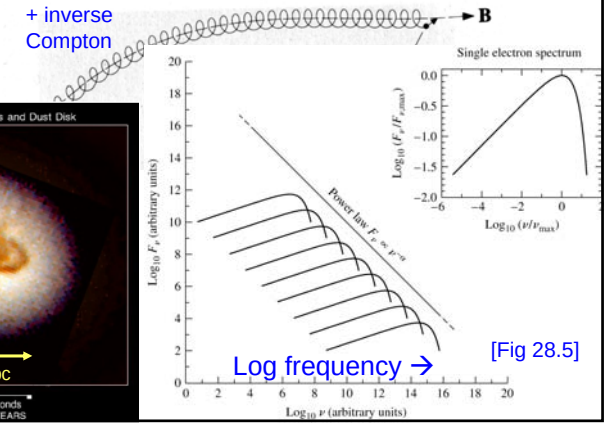
Acceleration thru Nozzle:

- Radiation pressure
  + thickened disk?
- A magnetic toothpaste tube?

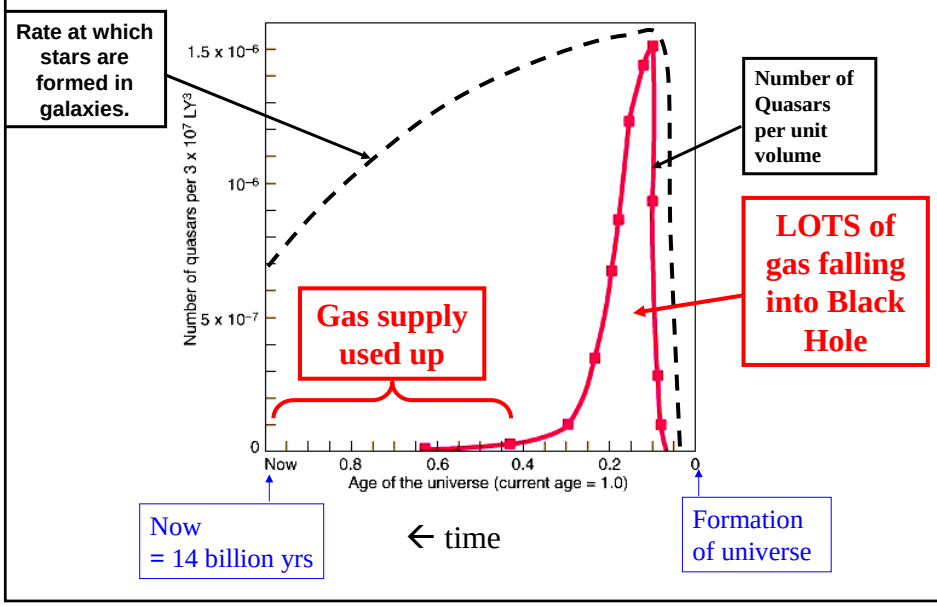
Radiation is synchrotron emission:

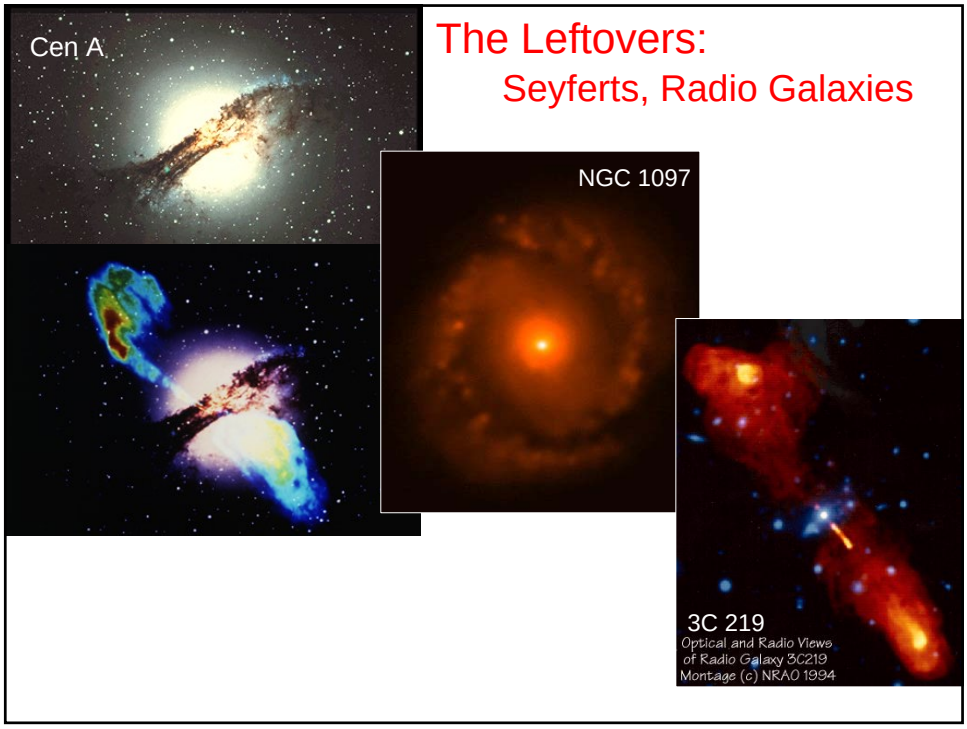
+ inverse Compton

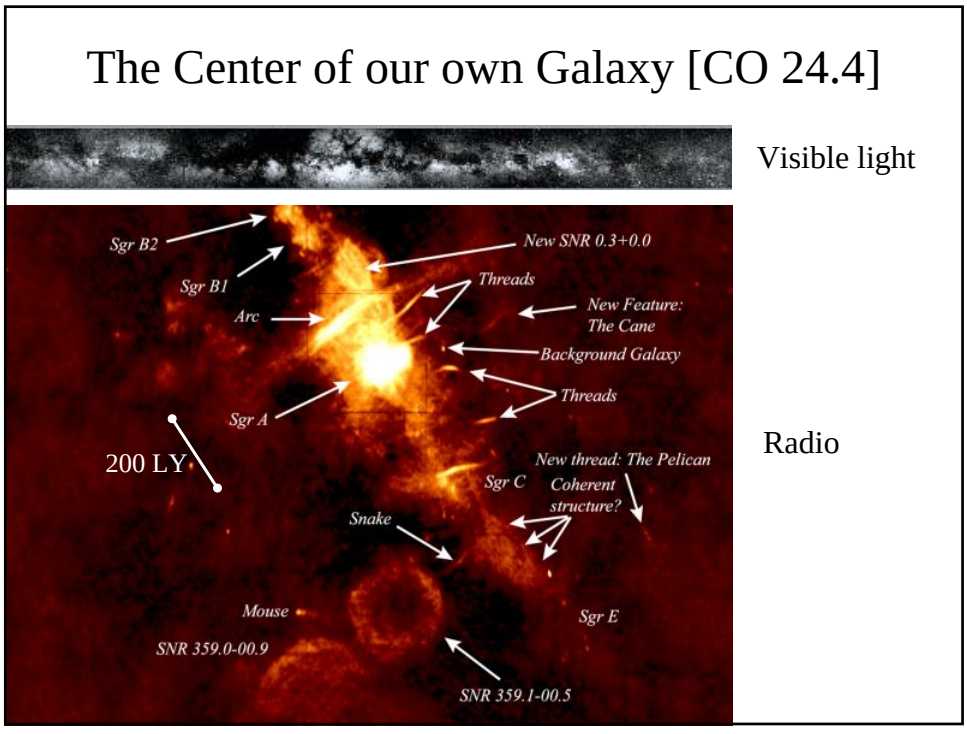




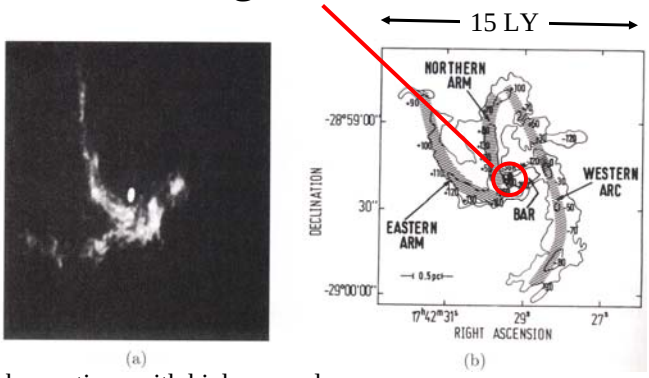
Most Quasars Lived and Died Long Ago




Cen A
The Leftovers:
Seyferts, Radio Galaxies
NGC 1097
3C 219
Optical and Radio Views
of Radio Galaxy 3C219
Montage (c) NRAO 1994


The Center of our own Galaxy [CO 24.4]
Visible light
Radio
Sgr B2
Sgr B1
Arc
Sgr A
200 LY
New SNR 0.3+0.0
Threads
New Feature:
The Cane
Background Galaxy
Threads
New thread: The Pelican
Sgr C
Coherent
structure?
Snake
Mouse
SNR 359.0-00.9
Sgr E
SNR 359.1-00.5

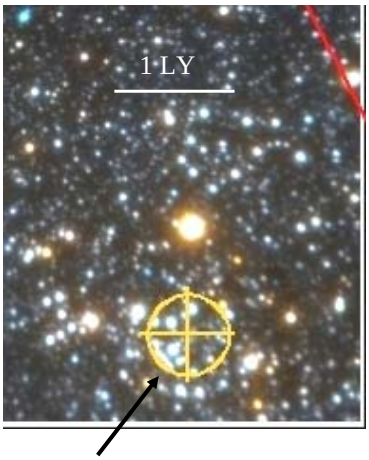
Sagittarius A*



Radio observations with higher angular resolution.

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

Infra-red Images of the Galactic Center

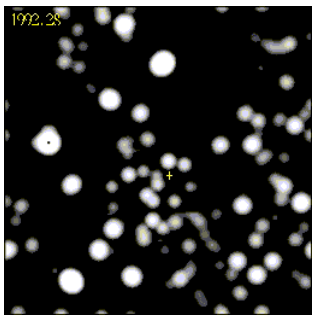


Galactic Center (Sagittarius A*)

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

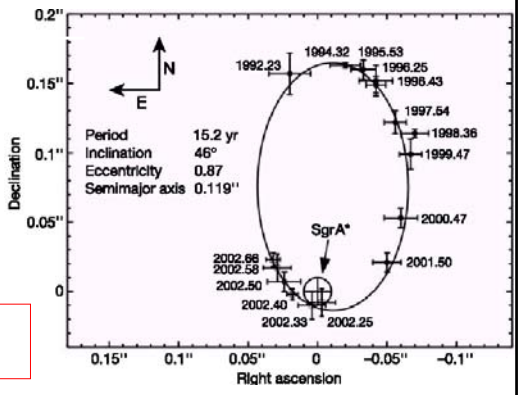
300,000 x more stars per unit volume than in vicinity of Sun

The Black Hole at the the Galactic Center



Infrared observations over 6 years.

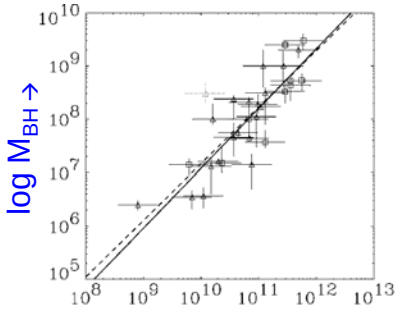
Velocities of stars in very center
➔ 4 million $M_\odot$ black hole
at position of Sagittarius A*



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

The Role of AGN in Galaxy Formation

- All massive galaxies contain massive black holes.
- $M_{Black\ Hole} \propto M_{Bulge}$
  - ➔ 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.

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