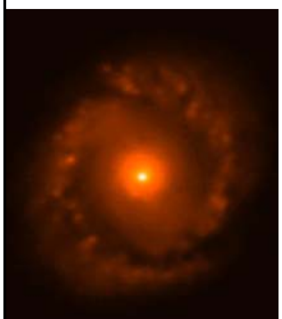
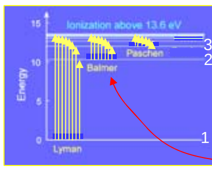
Quasars and Active Galactic Nuclei

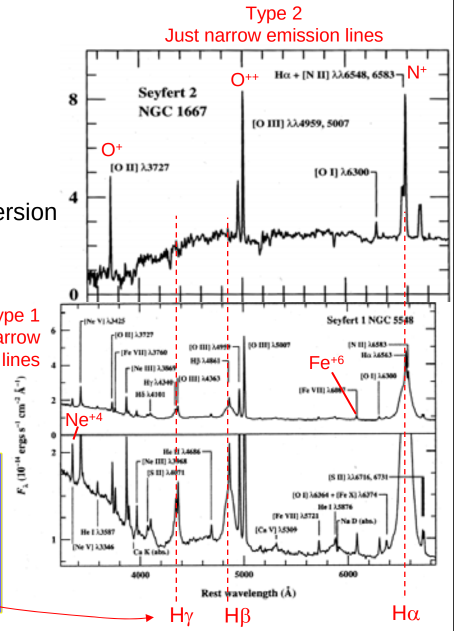
Seyfert Galaxies
- Carl Seyfert, 1940's
- Spirals
- Very bright unresolved nucleus
- Strong emission lines
  - High ionization states
  - Broad lines = large internal velocity dispersion
    - 10,000 km/s



NGC 1097
Gemini J-band image
+ diffraction ring??

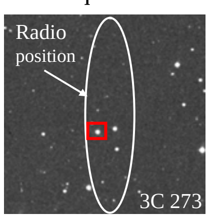


H energy levels



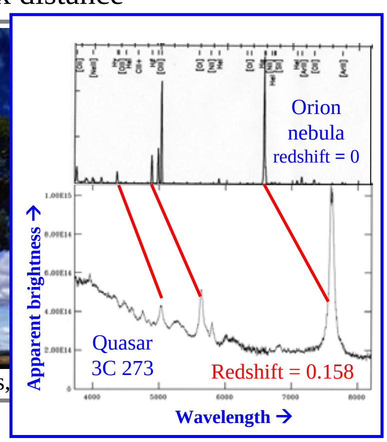
Quasars

- **Luminosity** = (apparent brightness) x distance^2
- **Apparent brightness:**
  - Discovered quasars from their ra



  - But… *which object???*

Parkes,



- **Distance:** Now measure optical spectrum
  - *Doppler shift* of wavelength of light

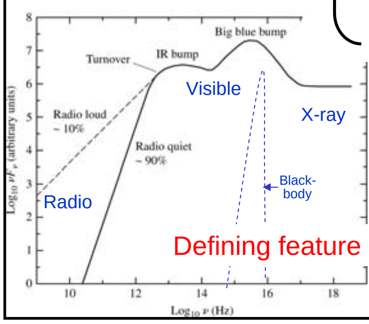
    ➔ velocity of recession (redshift) due to expansion of Universe.

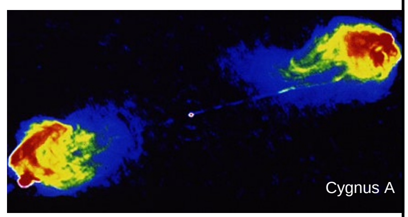
    ➔ huge distance ➔ **huge luminosity!**

Classification

Active Galactic Nuclei (AGN)

- Quasar = Quasi Stellar Radio Source
- QSO = Quasi Stellar Object
  - radio-quiet
  - 1000's of times more numerous than Quasars
- Blazars (or BL Lac objects)
  - bright continuum source, but no emission lines
- Seyfert Galaxies
  - Types 1 and 2
- Radio galaxies
- etc



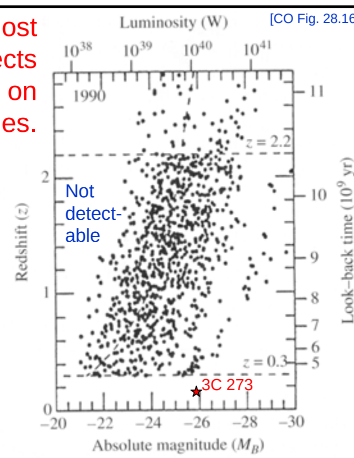


Defining feature = non-thermal continuum

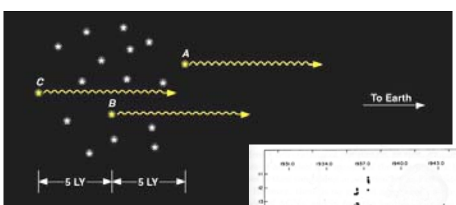
- Strong in Quasars, QSOs
- Weaker in Seyferts, radio galaxies

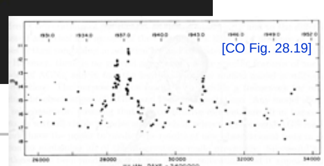
Measured Properties

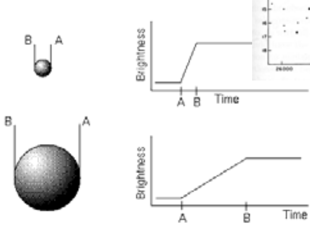
QSOs are most luminous objects in universe on 10^7 yr timescales.



Rapid brightness changes (weeks, days. hours).



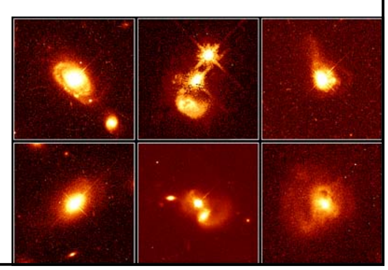




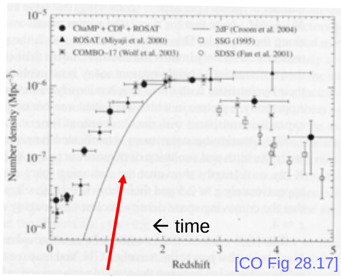
➔ Size = light-weeks, light-days, light-hours.

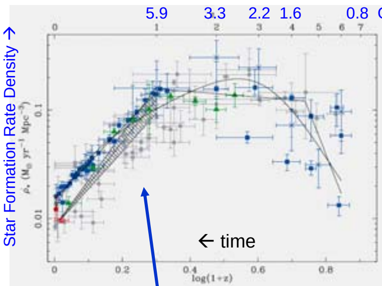
In centers of galaxies

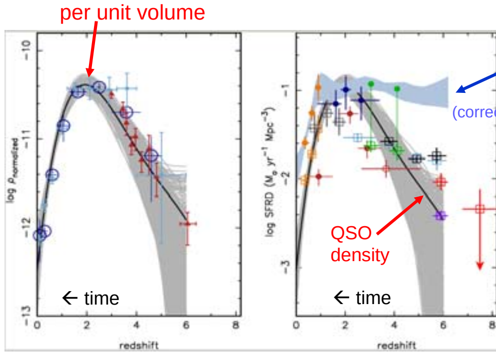
HST images



Most Quasars Lived and Died Long Ago





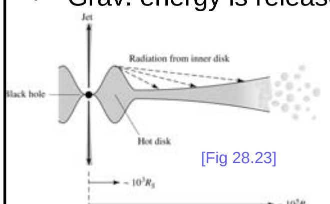


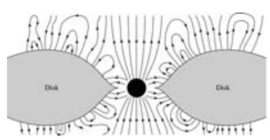
Observations show:

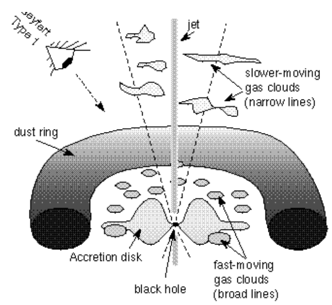
- huge luminosity
- from a tiny volume
- at centers of galaxies
- happened early in history of galaxies

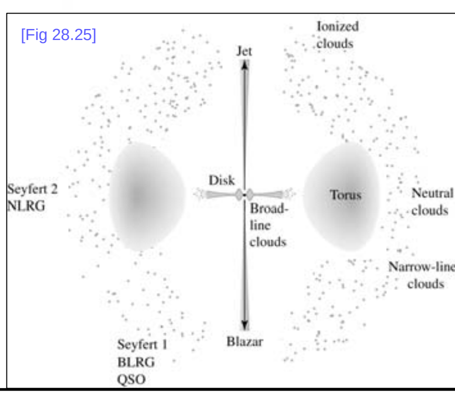
What are they?

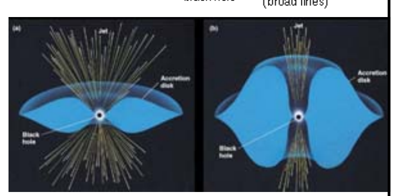
- Gas, stars fall into 10^6-10^8 M_{sun} black hole.
- Grav. energy is released





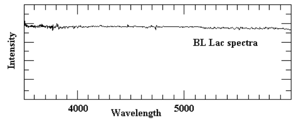






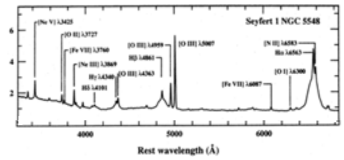
- Black hole
- Accretion disk
- Broad emission-line region
- Obscuring torus
- Narrow emission-line region

Viewing Angle Effects



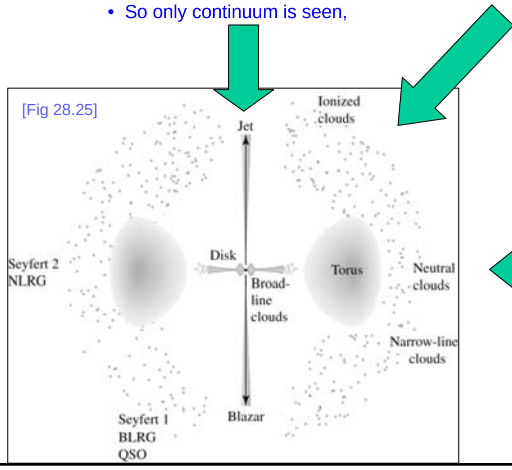
Blazar or “BL Lac” object:

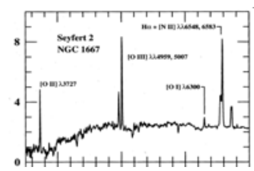
- Special-relativistic beaming
  ➔Continuum made vastly brighter .
- So only continuum is seen,



Type 1:

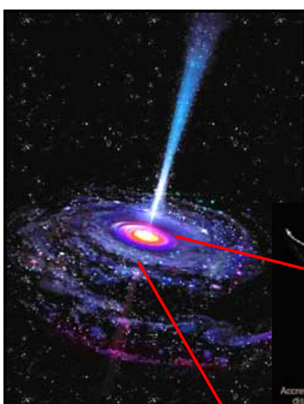
Broad + narrow emission lines
+ non-thermal continuum

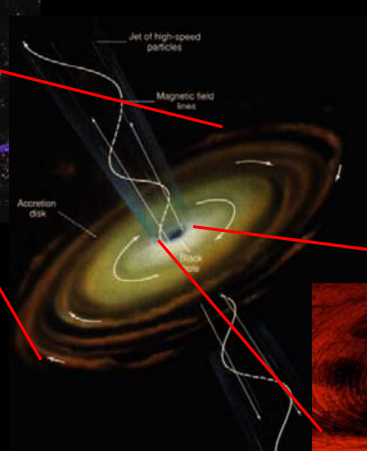




Type 2:

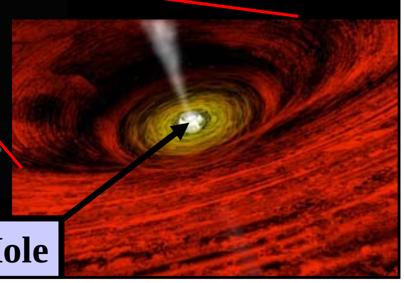
Just narrow emission lines





The Source of the Luminosity:

- Matter falls onto accretion disk.



Spinning Black Holes

Notation:
No G, no c

Kerr metric (1963)

$d\phi d\tau$ cross term → "frame dragging"

$$ds^2 = -\left(1 - \frac{2Mr}{\rho^2}\right) dt^2 - \frac{4M\,ar\,\sin^2\theta}{\rho^2}\, d\phi dt + \frac{\rho^2}{\Delta}\, dr^2 + \rho^2 d\theta^2 + \left(r^2 + a^2 + \frac{2M\,ra^2 \sin^2\theta}{\rho^2}\right) \sin^2\theta\, d\phi^2$$

where $a \equiv J/M, \quad \rho^2 \equiv r^2 + a^2\cos^2\theta, \quad \Delta \equiv r^2 - 2Mr + a^2$

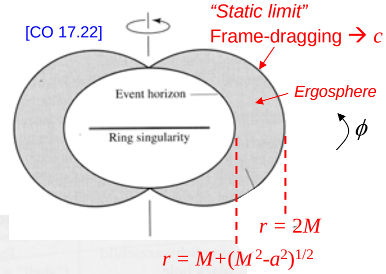
J = Angular Momentum

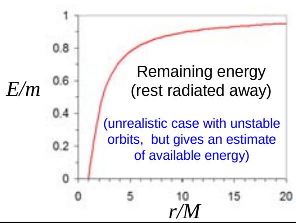
Maximal spin: $J_{max} = M^2$ (or = GM^2/c^2 in CO units)

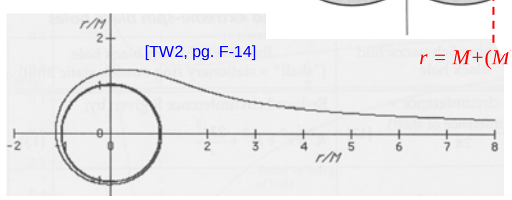
- Usually ~ the case.
- Then Event Horizon in equatorial plane is at $r=M$

Infalling particle with no angular momentum:

[CO 17.22]

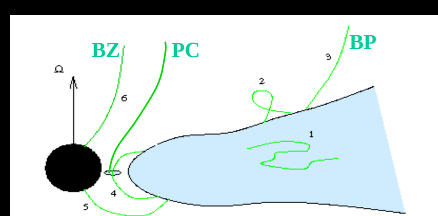






Both plots for equatorial plane only

The Special Case of Kerr (Rotating) Black Holes: Direct Magnetic Coupling by the BZ Effect

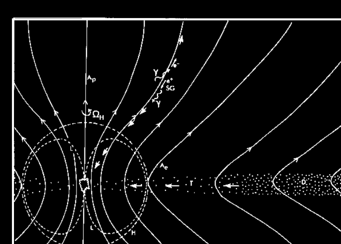


Blandford (2001; 2003)

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

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

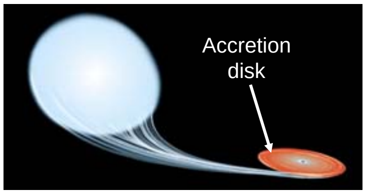
$$\gamma_{BZ} = ?????$$



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

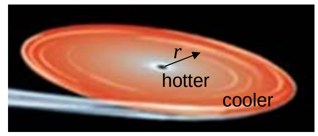
$$L(r) \propto T(r)^4 \times (2\pi r\, dr)$$

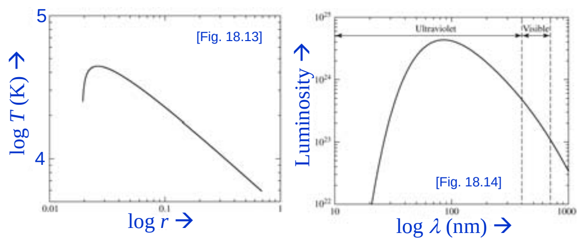
$$\Downarrow$$

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

[CO pgs. 661-665]

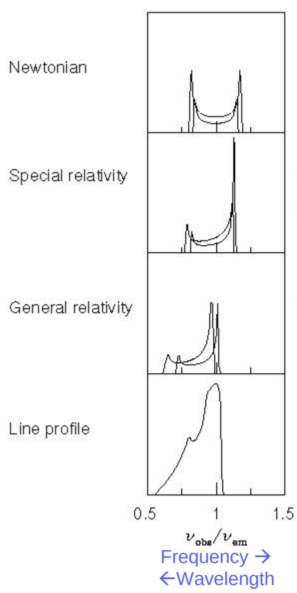
➔ total radiation = sum of black bodies.



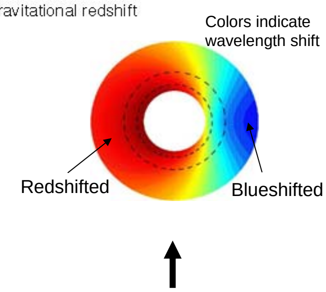


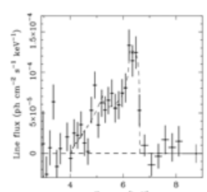
Binary star results, but QSOs are similar.

Iron Kα profiles

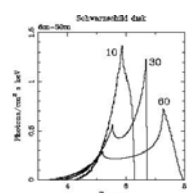


X-ray emission line.
From inner electron shell.

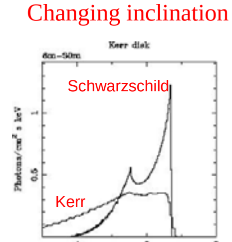




Actual data



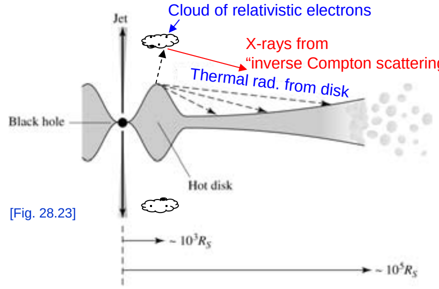
Changing inclination



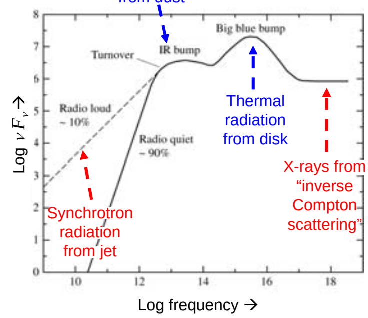
Rotating vs. non-rotating

Fabian et. Al., 2000, PASP, 112, 1145

Continuum Source



[Fig. 28.23]



[Fig. 28.4]

Energetics

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

$\eta \approx 0.1$

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

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

absorption cross-section

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

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