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

Type 1: Broad + narrow emission lines
Type 2: Just narrow emission lines

Quasars
- Apparent brightness: Discovered quasars from their radio emission.
- But… which object???

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 $10^6$-$10^8 \, M_{\odot}$ 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.

Black Hole
Spinning Black Holes

Kerr metric (1963)

\[ ds^2 = -\left(1 - \frac{2Mr}{\rho^2}\right)dt^2 - \frac{4M^2a^2 \sin^2 \theta}{\rho^2} d\phi dt + \frac{\rho^2}{\Delta} dr^2 + \rho^2 d\theta^2 + \left(\frac{\rho^2}{\rho^2} + \frac{2Ma^2 \sin^2 \theta}{\rho^2}\right) \sin^2 \theta d\phi^2 \]

where \( \Delta = \rho^2 - 2Mr + a^2 \)

\[ J = \frac{M \Delta}{\rho^2} \]

Maximal spin: \( J_{\text{max}} = \frac{M^2}{2} \) (or \( \approx \frac{GM^2}{c^2} \) in CO units)

• Usually – the case.
• Then Event Horizon in equatorial plane is at \( r = M \)

Infalling particle with no angular momentum:

\[ J = \frac{\text{Angular Momentum}}{\text{Radius}} \Delta \frac{\text{Cross Term}}{\text{d} \tau} \rightarrow \text{"frame dragging"} \]

"Static limit" Frame-dragging \( c \)

\[ r = M + \left(M^2 - a^2\right)^{1/2} \]

Ergosphere

\[ \frac{r}{M} = \frac{2}{r} \]

Remaining energy (rest radiated away)

(Realistic case with unstable orbits, but gives an estimate of available energy)

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

\[ L_{\text{BZ}} \approx 10^{36} \text{ erg s}^{-1} \frac{m_0 \dot{m} j^2}{\gamma_{\text{BZ}}} \]

(From Meier & Nakamura

Blandford & Znajek (1977)
Accretion Disks

- Well-studied phenomena in local binary star systems
  - "cataclysmic variables"
- Angular momentum \( \Rightarrow \) material cannot fall directly onto central mass.
- Binary stars \( \Rightarrow \) "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

\[
L(r) \approx T(r)^4 \times (2\pi dr)
\]

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

\( \Rightarrow \) total radiation = sum of black bodies.

Iron K\(\alpha\) profiles

- X-ray emission line.
- From inner electron shell.

Actual data

Changing inclination

Rotating vs. non-rotating
Continuum Source

Cloud of relativistic electrons

X-rays from "inverse Compton scattering"

Thermal radiation from disk

X-rays from "inverse Compton scattering"

Thermal radiation from disk

Synchrotron radiation from jet

Energetics

- Accretion rate & luminosity.
  - mass falls into black hole: 
    \[ L_{\text{disk}} = \eta \frac{dM}{dt} c^2 = \eta \dot{M} c^2 \]
    \[ \eta = 0.1 \]
    \[ \dot{M} = 1 - 10 \, M_\odot \, \text{yr}^{-1} \]

- Eddington limit.
  - Radiation pressure = gravity:
    \[ \frac{L_{\text{Ed}}}{4\pi r^2} m c^2 = \frac{GmM_{\text{BH}}}{4\pi r^2} \]
    Luminous QSOs: 
    \[ L = L_{\text{Ed}} \]
    Seyferts, Radio Galaxies: 
    \[ L << L_{\text{Ed}} \]