Active Galactic Nuclei and Quasars

A little history….

1960  Discovery of radio “stars.” Weird optical spectra, emission lines at unusual wavelengths. Quasi-Stellar Radio Source, Quasar or QSO.

1963  Maarten Schmidt suggests that the strange lines = H emission with enormous redshifts.

   QSOs receding at nearly the speed of light!

   Hubble Law —> QSOs are at the edge of the universe.

1970s  Stockton and others find QSO “fuzz,” i.e. the underlying galaxy.

QSO Properties:  1. Large redshift, few are close.

2. Small angular size, “quasi-stellar.”

3. Irregular variability over many timescales.

4. Broad power-law continuum spectrum. 10% have radio emission.
More QSO properties....

• Large redshift + observed brightness → QSOs are extremely luminous, $10^{12-14} L_{\text{sun}}$!

• Small intrinsic size: brightness changes over weeks → “central engine” size < few light weeks $\approx 0.03$ pc $\approx$ few x 1000 a.u.

  Like a solar system, but brighter than a galaxy!

Some are sources of huge radio jets.

![Diagram of QSO](image-url)
**QSO Emission Lines**

Two components: broad and narrow.

**Broad line region**: gas clouds moving at high speeds near QSO center.

**Narrow line region**: $\Delta v \leq 200$ km/s, clouds orbiting in accretion disk farther away from the center.

Many narrow absorption lines often observed too.

- Redshift always less than the QSO.
- Intervening “clouds” (galaxy halo gas, protogalaxies?)
- Provide very important info on young galaxies and the *intergalactic medium*. 
Relatives of Quasars

Galaxies with strong nonthermal energy sources.

Seyfert galaxies: spirals with bright star-like cores.

- $L \approx 10^{11} L_{\text{sun}}$, rapid variations.
- Broad lines, but only 5000 km/s.
- A few % of all spirals (more in interacting systems).

QSO

Seyfert 1

Seyfert 2
BL Lac objects

- Bright, stellar appearance, in elliptical galaxies.
- Variable, sometimes sources of high energy gamma rays.
- Featureless spectra, faint “fuzz” at high redshift.

Radio galaxies

- Ellipticals with intense radio emission.
- Jets + double lobed sources.
- Enormous scale.
Accretion Disk Structure

So small, hard to observe directly.
QSO Min. M - Max. L Relation

QSOs are incredibly bright — radiation pressure is huge.

\[ P_{rad} = \frac{\text{momen. flux}}{\text{area}} = \frac{L}{4\pi r^2 c}. \]

The corresponding force on an electron is,

\[ F_{rad} = \sigma_e P_{rad} = \sigma_e \frac{L}{4\pi r^2 c}. \]

Where \( \sigma_e \) is the “Thomson” cross section of the electron. Gravity must hold the QSO “fuel” together against this force. So \(|F_{rad}| \leq |F_{grav}|\).

In the limiting cases,

\[ L = \frac{4\pi G c m_p}{\sigma_e} M \approx 1.3 \times 10^{31} \left( \frac{M}{M_{\text{sun}}} \right) W, \]

where \( M \) is the mass of the “central engine.” This is called the Eddington luminosity (or mass).
Do Supermassive Black Holes Power QSOs & other AGN?

• A large \((10^6-9 \, M_{\text{sun}})\) black hole at the center can do it, if it “eats” \(10 \, M_{\text{sun}}/\text{yr}\).

• Matter falling into a black hole dissipates much of the infall energy, and gets heated to millions of K.

• The BH emission comes mostly from a very small area and varies (a lumpy flow).

  Observed variation: 1 month \(\longrightarrow\) 1 week.

  So, \(R \leq c \tau_{\text{var}} \approx 3 \times 10^{11} \, \text{km} \approx 2000 \, \text{a.u.}\)

• Radio interferometry observations also imply very small sizes.
How does material get into the hole?

• Energy is beamed perpendicular to the disk.
• Black hole rotation and magnetic field can also help focus the beam.
• Because of the tiny scales involved it is hard to test this picture against observation!

Many questions remain…

• Why were QSOs more active in the past?
• Does activity continue only occasionally? What is the duty cycle? Or does it continue at very low levels?
• Has the Milky Way’s central black hole ever been active?
What kind of galaxies host AGN?

Radio galaxies tend to be early-types, ellipticals. Many QSOs live in merging systems.