AGN (Continued): Radio properties of AGN

I) Basic features of radio morphology
II) Observed phenomena
  • Superluminal motion
III) Unification schemes
Radio features

Lobes

Hotspot
Core
Jet
Speed of Jets

What is the speed of radio jets in AGN? Since this is non-thermal plasma where no spectral lines are seen, the Doppler-shift cannot be used to derive a jet velocity for the nucleus!
Radio Telescopes: VLA, VLBI

- The Very Large Array has angular resolution

\[ R = \frac{\lambda}{D} = \frac{6 \text{cm}}{10 \text{km}} = 1'' \]

- At \( z=0.5 \) this is \( \sim 2 \text{ kpc} \)
- For the Very Long Baseline Interferometry, \( R \sim 1 \text{m.a.s.} \)
- At \( z=0.5 \) this is \( \sim 2 \text{ pc} \)
The power of resolution

Energy is transported by jets from the cores to the outer regions.
Superluminal Motion

• VLBI observations of the inner jet of 3C273 shows ejected blobs moving at $v \sim 3-4c$

• This is called superluminal motion

How is this possible??
Explain apparent superluminal motion as an optical illusion caused by the finite speed of light. Consider a knot in the jet moving almost directly towards us at high speed:

Source at position B emits a blob of gas with velocity $v$, at an angle $\theta$ to the line of sight to an observer at position A. A time $\delta t$ later, the blob has moved to position C.
Observer sees blob reach position C at time $t_2$:

$$t_2 = \delta t + \frac{D}{c}$$

Time difference is:

$$\Delta t = t_2 - t_1 = \delta t + \frac{D}{c} - \frac{D + v\delta t \cos \theta}{c}$$

$$= \delta t \left(1 - \beta \cos \theta\right)$$

…where we have defined $\beta = v / c$

Observer infers a transverse velocity:

$$\beta_T = \frac{v_T}{c} = \frac{1}{c} \times \frac{D \Delta \phi}{\Delta t} = \frac{v \sin \theta}{c \left(1 - \beta \cos \theta\right)} = \frac{\beta \sin \theta}{1 - \beta \cos \theta}$$

For $\beta$ close to 1, and $\theta$ small, can clearly get an apparent transverse velocity $v_T > c$ (i.e. $\beta_T > 1$). e.g. $\beta = 0.99$, $\theta = 10$ degrees gives $\beta_T = 6.9$
Apparent transverse velocity as a function of angle $\theta$ for different values of the true velocity: $\beta = 0.5, 0.9, 0.95, 0.99$

If real $v > 0.9$ c, apparent superluminal motion will be seen in majority of sources (assuming random orientations)
True velocity must exceed a critical value for superluminal motion to be observed (irrespective of orientation).

First find angle at which $\beta_T$ is maximized:

$$\frac{\partial \beta_T}{\partial \theta} = \frac{\beta \cos\theta}{1 - \beta \cos\theta} - \frac{\beta^2 \sin^2\theta}{(1 - \beta \cos\theta)^2} = 0$$

Solving this equation for $\theta = \theta_{\text{max}}$ gives: $\theta_{\text{max}} = \cos^{-1} \beta$

Substituting this back into the expression for $\beta_T$ find:

$$\beta_T^{\text{max}} = \frac{\beta}{\sqrt{1 - \beta^2}}$$

Set left hand side equal to one and solve for $\beta$:

$$1 - \beta_{\text{min}}^2 = \beta_{\text{min}}^2$$

$$\beta_{\text{min}} = \frac{\sqrt{2}}{2} = 0.707...$$
Physics of AGN
The Emission-Line Regions (BLR, NRL)

Reprocessed Radiation

An AGN produces a lot of ionizing radiation, most likely from the accretion disk.

This emission is intercepted by gas and dust in the host galaxy. Correspondingly an AGN spectrum shows reprocessed radiation from this gas and dust. The respective features are:

• Broad-Line Region (BLR)
• Narrow-Line Region (NLR)
• IR-bump from a molecular (dusty) “torus”
Luminous AGN are classified as:

- Seyfert galaxies (Type I and II)
- Quasars, QSOs
- BL Lacs
- Radio galaxies (in `Broad line’ and `Narrow line’ variants)
- LINERs

All powered by accretion onto supermassive black holes. But why so many classes - are these all physically distinct objects?
AGN: Basic Ingredients

An AGN consists of the following basic ingredients:
• Black Hole (power source)
• Accretion Disk (UV/x-rays)
• Jet (radio)
• -Core (compact, flat-spectrum, radio-to-gamma emission)
• -Jet
• -Lobes & Hotspots (extended, steep spectrum)

• Broad-Line Region (BLR)
• Narrow-Line Region (NLR)
• molecular (dusty) “torus" (feeding and obscuration)
• host galaxy (feeding)
Seyferts 1 and 2: Unification Scheme

In the broad-line region (BLR)

- The Keplerian orbital speeds of the clouds around the central massive body will be large => lines are Doppler broadened.
- Density is high => no forbidden lines are emitted

In the narrow-line region (NLR)

- The Keplerian orbital speeds of the clouds will be much smaller => lines are narrow
- Density is low => forbidden lines are emitted
Seyferts 1 and 2: Unification Scheme

So, if the above Seyfert were viewed from direction (1), you would see:

• Broad permitted lines
• Narrow Forbidden Lines
• Bright continuum from the central engine
• i.e. a Seyfert 1

If, on the other hand, it were viewed from direction (2), you would see:

• No broad permitted lines (obscured by dust torus)
• Narrow Forbidden Lines
• No bright continuum from the obscured central engine
• except in the infrared and X-ray region, which gets through the dust
• i.e. a Seyfert 2
Seyferts 1 and 2: Unification Scheme: Evidence for Torus
Support for this picture: in some Seyfert 2 galaxies the polarized emission shows broad lines!

Consistent with the unified model, since scattering produces polarization. Conclude:

- At least some Seyfert 2 galaxies are intrinsically similar to Seyfert 1’s
- If this applies to all Seyferts, statistics mean that the torus must block about 3/4 of the sky as seen from the nucleus
Reasonably secure to also fit quasars and blazars into this unified scheme:

- Obscured
  - Seyfert 2
  - Type 2 quasar
- Unobscured
  - Seyfert 1
  - Type 1 quasar
- Viewed directly down the jet
  - Blazars
  - Accretion rate

Type 2 quasars aren’t seen in the optical, but highly obscured luminous AGN are needed to make up the X-ray background.

Giant elliptical galaxies have higher mass black holes, so reasonable to expect quasars to favor these galaxies.
The big picture

It is not possible to unify all sources into one picture by just changing one parameter. At least the following factors have to be considered:

- Inclination
- Power
- Time (Age)
- Radio-Loudness (binary?)
- Black Hole mass (disk structure?)
- Host galaxy (jet/ISM interaction)