Evolution of AGN jets from multi-epoch core-shift studies

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Core shift in AGN jets

Due to synchrotron self-absorption (e.g. Blandford & Konigl, 1979)
apparent jet origin (core) location $r_c$ depends on $\nu$

Radio core at different frequencies
($v_5 > v_4 > v_3 > v_2 > v_1$)

Central black hole and accretion flow

Jet Obscuring Torus Narrow Line Region
Black Hole Broad Line Region Accretion Disk

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Why study core-shift variability

AGN physics

- What is the nature of radio flares and how they propagate?
- Independent estimates of jet parameters close to its origin.

Astrometry

- Is AGN position jitter expected?
- Can group delay measurements be affected? Not when $r_c \sim 1/\nu$.
- Effect on VLBI/Gaia alignment?
  Talk by Petrov+ today.
Observational data

- Simultaneous 2 and 8 GHz VLBA+, 1994-2016
- 40 AGNs with jets & observed at > 10 epochs

Blue — all 4143 AGNs
Red — 40 studied here

Redshifts
up to $z = 2.37$,
median $z = 0.74$
Core-shift measurement

1. Acquire two-frequency calibrated images:

   **2 GHz**

   ![2 GHz Image]

   **8 GHz**

   ![8 GHz Image]

2. Align them: no absolute position.

3. Estimate core position on each image.

We developed an automated method.
Median magnitudes of 8-2 GHz core shift

40 quasars, 1691 individual observations

Median 0.55 mas

Median 3.2 pc
Median magnitudes of 8-2 GHz core shift

40 quasars, 1691 individual observations

Median 0.55 mas
⇒ \( r_c(8 \text{ GHz}) = 0.2 \text{ mas} \)

Median 3.2 pc
⇒ \( r_c(8 \text{ GHz}) = 1 \text{ pc} \)

assuming \( r_c(\nu) \sim 1/\nu \)
Detected 8-2 GHz core-shift variability

Median max – min difference 0.35 mas, maximum around 0.8 mas

Significant variability for 33 of 40 AGNs!
Assume: flux & position change due to the same parameter variations.

Find that $r_c \sim S_c^{0.3}$  \Rightarrow  $N_c \sim S_c^{1.5}$ and $B_c \sim S_c^{-0.33}$
Flare propagation

Flare reaches core at $\nu_2$

Flare reaches core at $\nu_1$ while still affecting $\nu_2$

Flare leaves the $\nu_2$ core region

Flare leaves both core regions
Implications

Core position varies by $\sim 0.5$ mas $\Rightarrow$ flare region extent is at least this long

Flares at $\nu_1$ and $\nu_2$ happen with a delay $\Rightarrow$ cores $r_c(\nu_1)$ and $r_c(\nu_2)$ move separately $\Rightarrow$ any fixed dependency like $r_c \sim 1/\nu$ cannot hold.

- Apparent core is not only shifted from the jet base, but the shift varies in time;
- Need to take variability of $\Delta r_c$ into account when inferring physical parameters.
Apparent velocity: comparison with MOJAVE

MOJAVE measurements from Lister+13, 16.

Core velocity: lower bound on the jet flow speed.
Summary

- We measured 8-2 GHz core shift for the largest sample of AGN observations; typical values are $\sim 0.5$ mas;
- Variability detected for the majority of AGNs: up to 0.8 mas, typically $\sim 0.3$ mas;
- Cores at different frequencies move separately from each other: no fixed frequency dependence.
- Flare regions are extended along the jet, $\geq 2$ pc.
- Independent method to probe flow speed: apparent core velocity as a lower bound.