AGN physics from multi-epoch core-shift measurements

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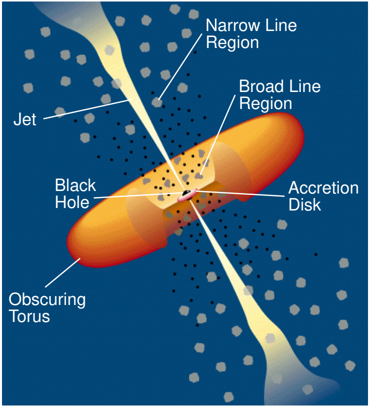
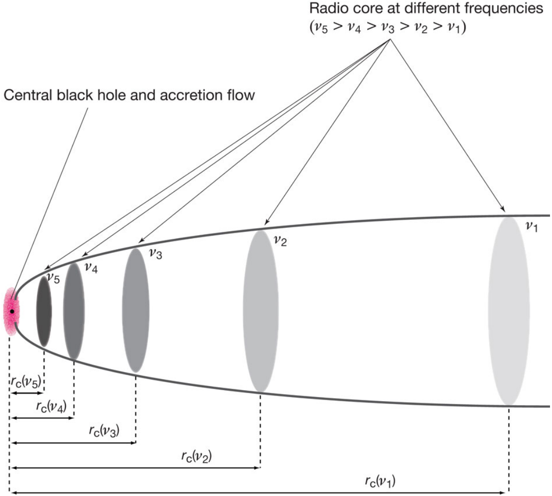
Half a Century of Blazars and Beyond

Core shift in AGN jets

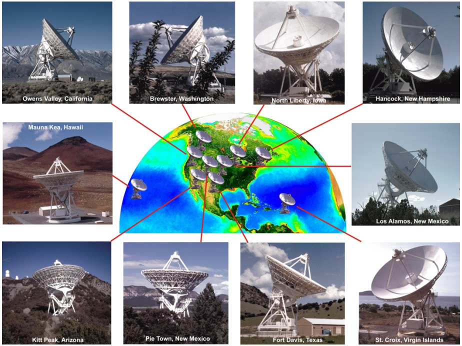
Due to synchrotron self-absorption
(e.g. Blandford & Konigl,1979)
apparent jet origin (*core*) location r_c depends on ν





Observational data

- Simultaneous 2 and 8 GHz VLBA+ observations during 1994-2016 years
- About 1000 of 4000 quasars have noticeable extended jet
- 40 of them observed at $>$ 10 epochs



Observational data

- Simultaneous 2 and 8 GHz VLBA+ observations during 1994-2016 years
- About 1000 of 4000 quasars have noticeable extended jet
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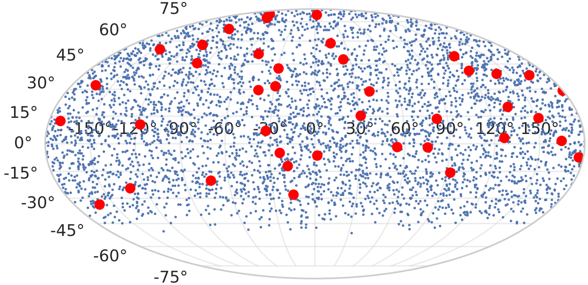
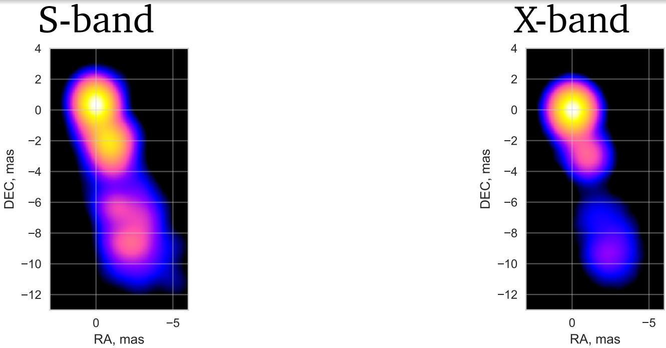
Blue — all 4143 AGNs
Red — 40 studied here

Redshifts
up to $z = 2.37$,
median $z = 0.74$



Core shift measurement

1. Acquire two-frequency calibrated images
2. Align corresponding images (i.e. find $\mathrm{r}_{1\to 2}$)
3. Estimate core position on each image — $\mathrm{r}_1, \mathrm{r}_2$
4. Core shift is $r_c(\nu_1) - r_c(\nu_2) = \mathrm{r}_1 - \mathrm{r}_2 - \mathrm{r}_{1\to 2}$



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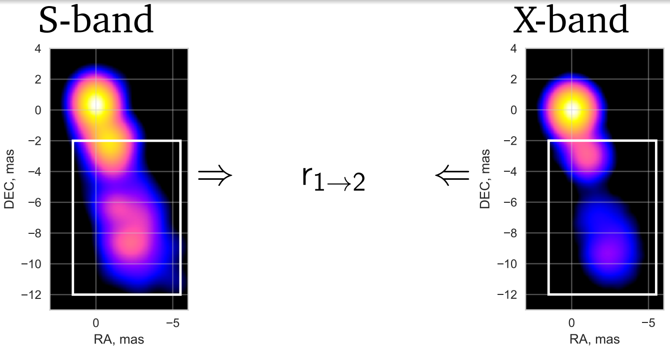

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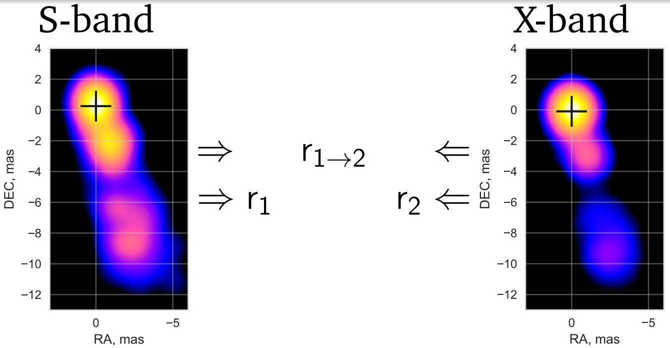

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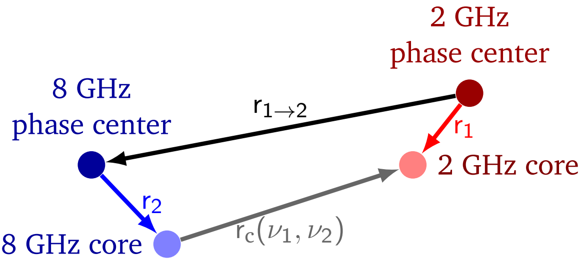

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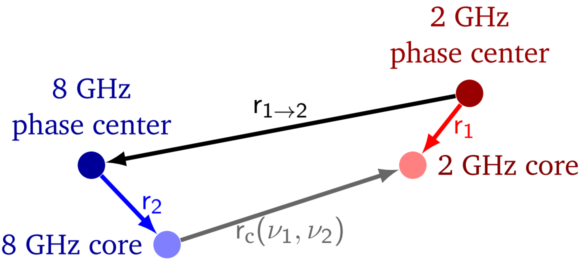
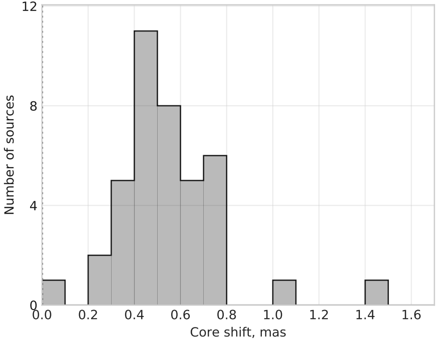
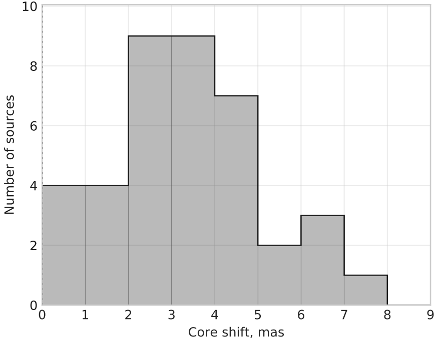
We developed an automated method.



Core shift magnitudes

40 quasars
1691 individual observations
Magnitude of 8→2 GHz shift:





Median 0.55 mas

Median 3.2 pc

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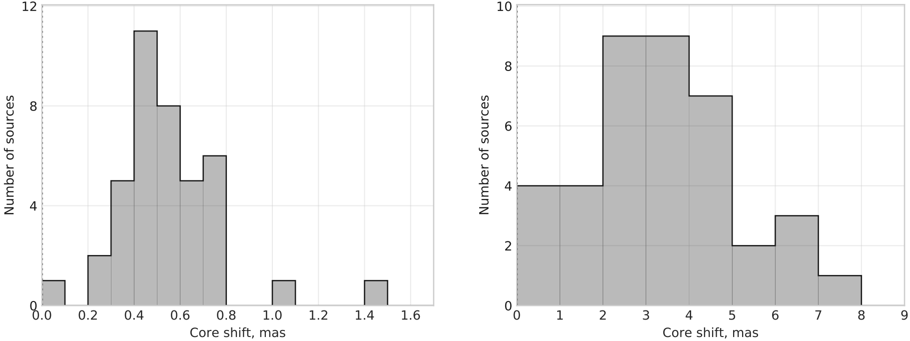


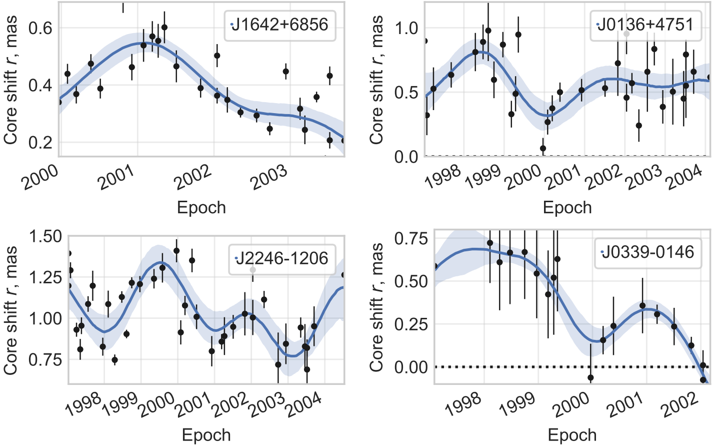
Median 0.55 mas
$\Rightarrow r_c(8\ \text{GHz}) = 0.2$ mas

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

assuming $r_c(\nu) \sim 1/\nu$

Detected 8-2 GHz core-shift variability

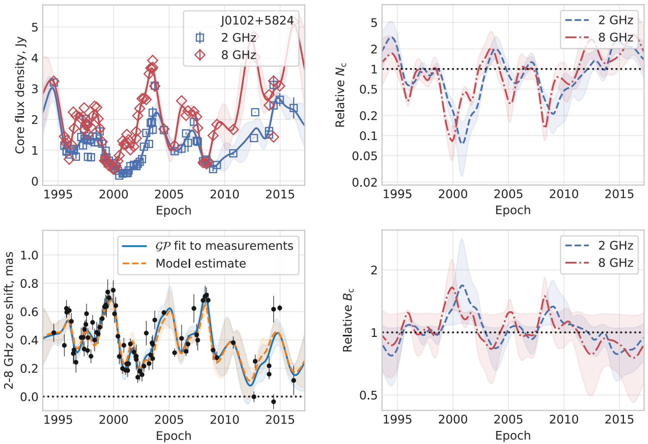
Characteristic examples:



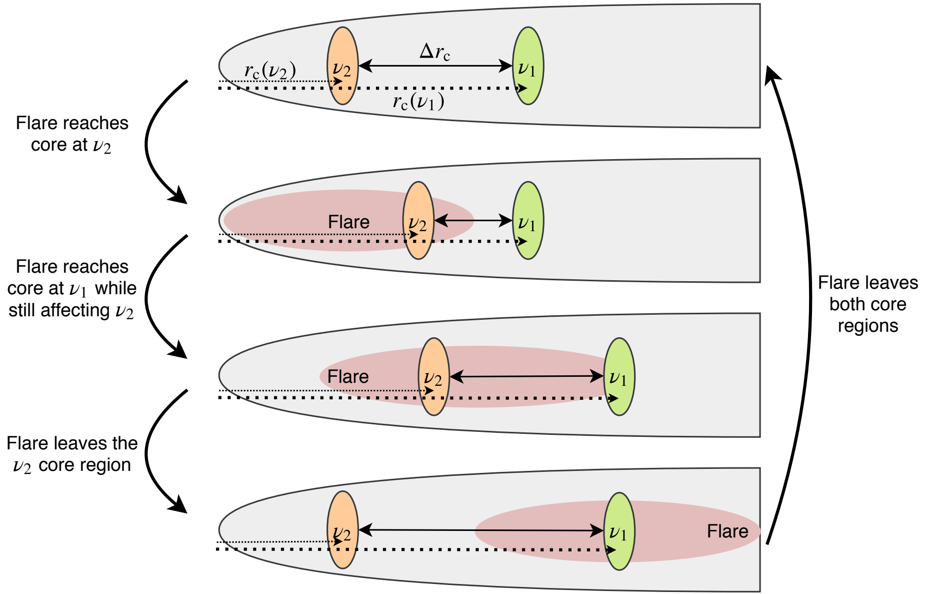
Median max – min difference 0.35 mas, maximum around 0.8 mas
Significant variability for 33 of 40 AGNs

Jet parameters evolution

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



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

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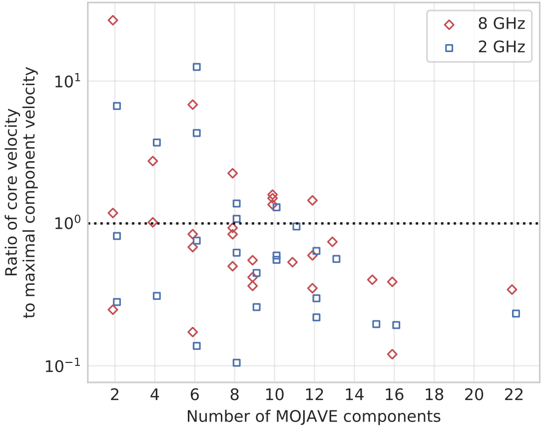
- Apparent core is not only shifted from the jet base, but the shift varies in time;
- Need to take variability of Δr_c into account when inferring physical parameters.

Apparent core velocity

Comparison with 15 GHz kinematic measurements:



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 ~ 0.5 mas;
- Variability detected for the majority of AGNs: up to 0.8 mas, typically ~ 0.3 mas;
- Cores at different frequencies move separately from each other: no fixed frequency dependence.
- Flare regions are extended along the jet, ≥ 2 pc.
- Independent method to probe flow speed: apparent core velocity as a lower bound.

Individual core movements

Assuming changes in S_c and r_c caused by jet parameters changing, we get $r_c(\nu) \sim S_c(\nu)^p$.

$\Delta r_c =$	Measured value
a	
$+ b_1 S_c(\nu_1)^p$	Core movement at ν_1
$- b_2 S_c(\nu_2)^p$	Core movement at ν_2
$+ c \cdot r_{\mathrm{beam}}$	Bias due to finite beam

All terms are significant.

No time shift between $S_c(\nu)$ and $r_c(\nu)$ variations.

$p \approx 0.3$