

Estimating Magnetic Field Strengths in 25 AGN Jets Using Core-Shift Measurements

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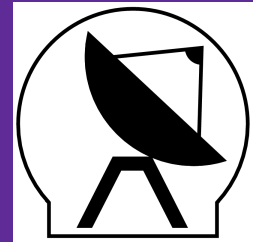
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Aim of our project:

Study magnetic jet acceleration in AGN jets

- AGN jets are likely accelerated through conversion of magnetic energy to particle kinetic energy
- The specifics of the acceleration mechanism and the nature of the jet magnetic field are still uncertain
- Magnetic field strength measurements from near the acceleration-collimation-zone may help constrain magnetic acceleration models



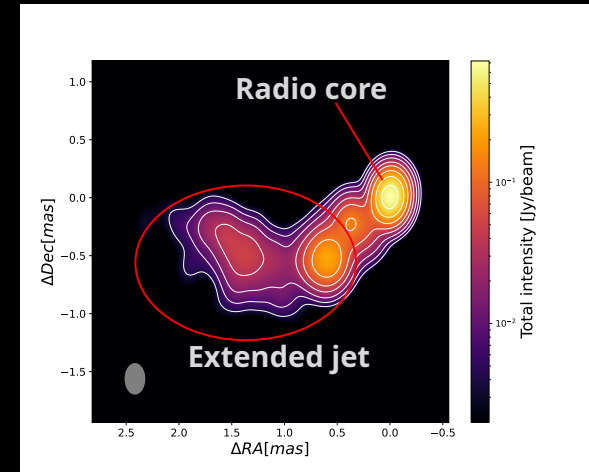
Image credit: Juan Carlos Algaba

Using multifrequency VLBI to study jet magnetic fields

- Very-long-baseline interferometry (VLBI) allows for high angular resolution
 - > spatially resolve the jet structure
 - Extended jet
 - Radio core (transition point from optically thick to optically thin regime)
- Multiple frequencies give information about the synchrotron self-absorption (SSA) emission
 - > get information about the magnetic field



Image credit: Paul Boven
<https://www.jive.eu/about-evn>



The core-shift effect

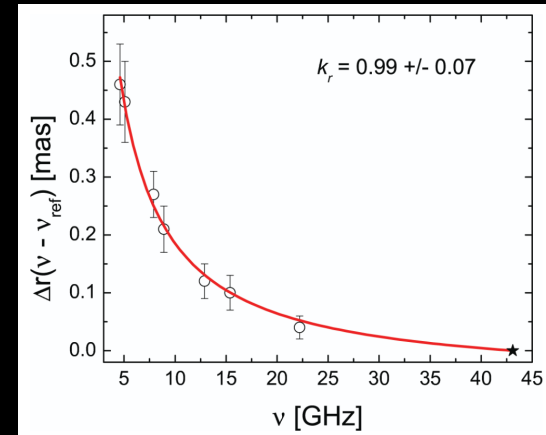
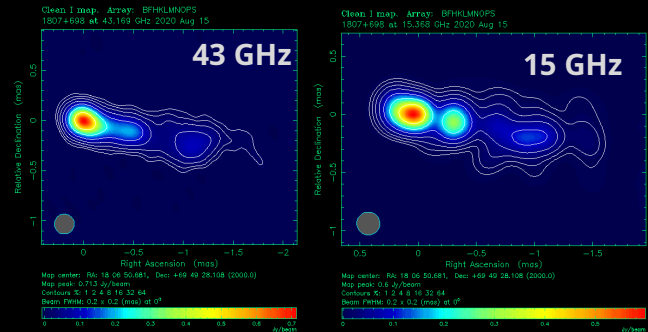
- **Position of the radio core changes** with observation frequency due to the opacity effect (Blandford & Königl, 1976; Königl, 1981):

$$r_{\text{core},\nu} \propto \nu^{-1/k_r}$$

- Common assumption: **energy equipartition, conical shape** -> $k_r=1$
- Can be used to **estimate magnetic field strength at 1 pc** from jet base (e.g. Lobanov, 1998; Chamani et al. 2023):

$$B_{1\text{pc}}^{\text{eq}} \approx 0.025 \left[\frac{\sigma_{\text{rel}} \Omega_{rv}^{3k_r} (1+z)^3}{\delta^2 \theta_j \sin^{3k_r-1} \theta} \right]^{\frac{1}{4}} \text{ [G]},$$

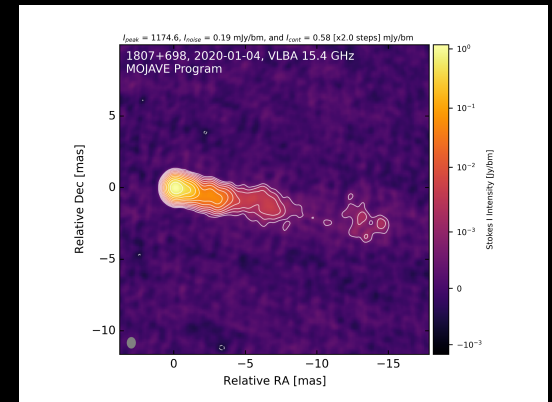
$$\Omega_{rv} = 4.85 \times 10^{-9} \frac{\Delta r_{\text{mas}} D_L}{(1+z)^2} \frac{v_1^{1/k_r} v_2^{1/k_r}}{v_2^{1/k_r} - v_1^{1/k_r}} \text{ [pc GHz}^{1/k_r}\text{]},$$



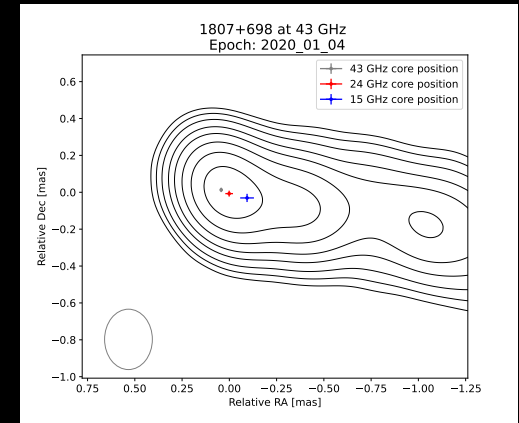
O'Sullivan & Gabuzda (2009)

Our core-shift measurements

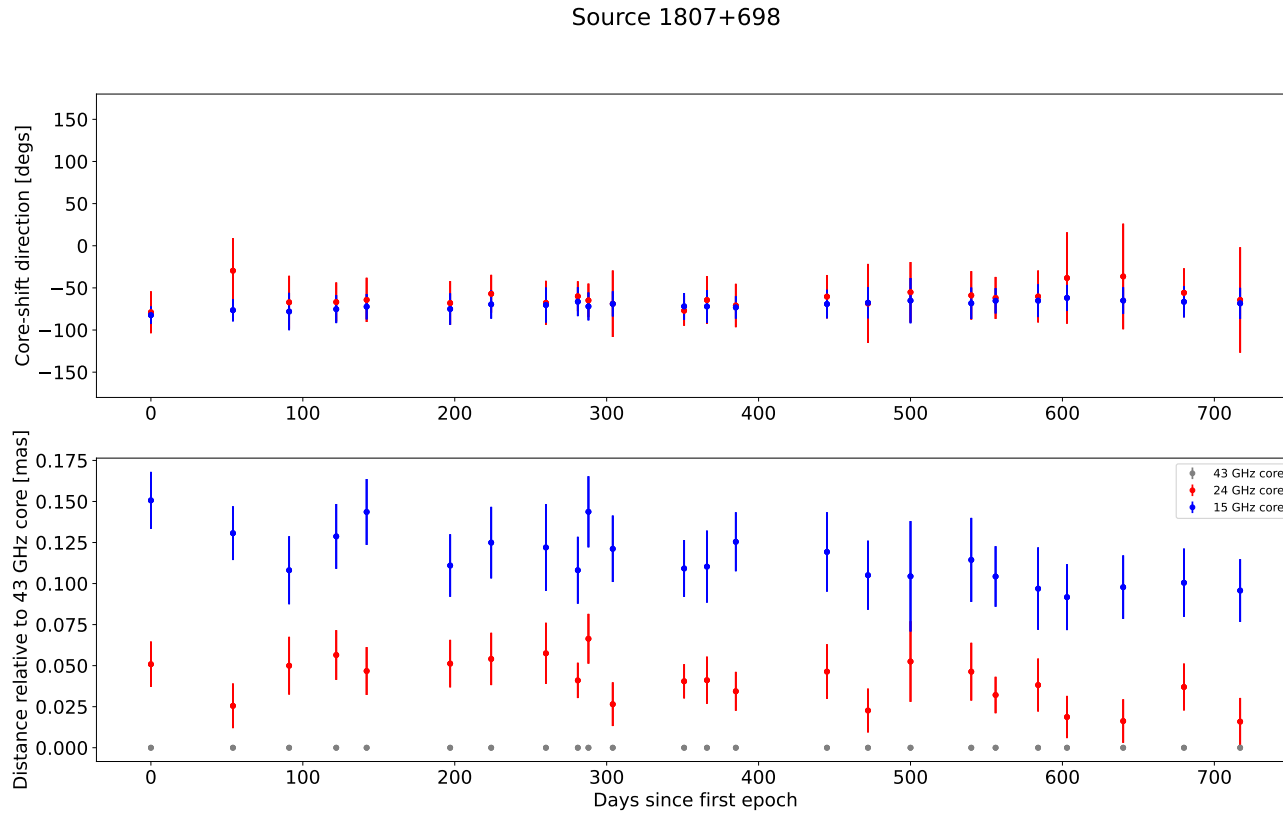
- Data comes from the **MOJAVE** multifrequency VLBI experiment (Lister et al. 2018)
 - Conducted using the Very Long Baseline Array (VLBA)
 - Monthly observations of 25 sources in a 2 year period
 - Quasi-simultaneous observations at 15, 24 and 43 GHz
- Previous studies have had either...
 - limited in number of sources or epochs
 - observations at lower frequencies (≤ 15 GHz)



Credits: MOJAVE program (Lister et al. 2018)



Example of core-shift results



Magnetic field estimates

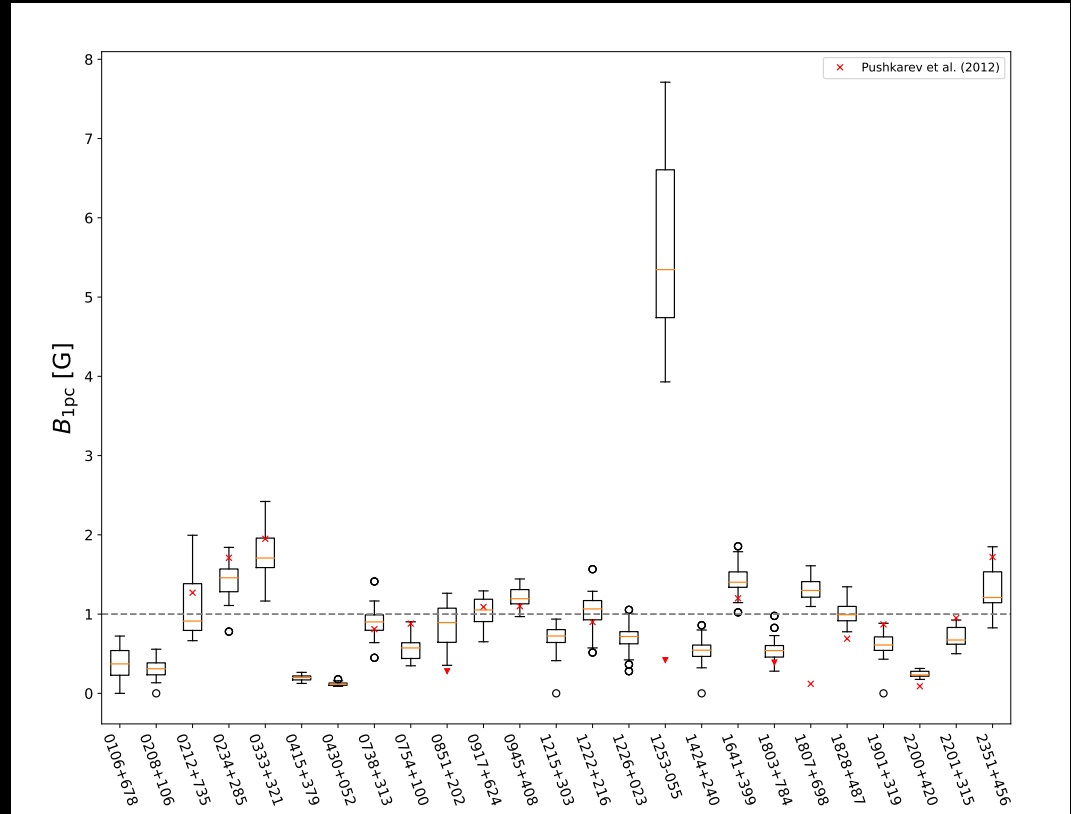
Magnetic field strength at 1 pc calculated for each source using our core-shift measurements

Assumed equipartition and conical shape ($k_r=1$)

Results appear to be as expected

Magnetic field strength ~ 1 G at 1 pc (Lobanov 1998; Pushkarev et al. 2012)

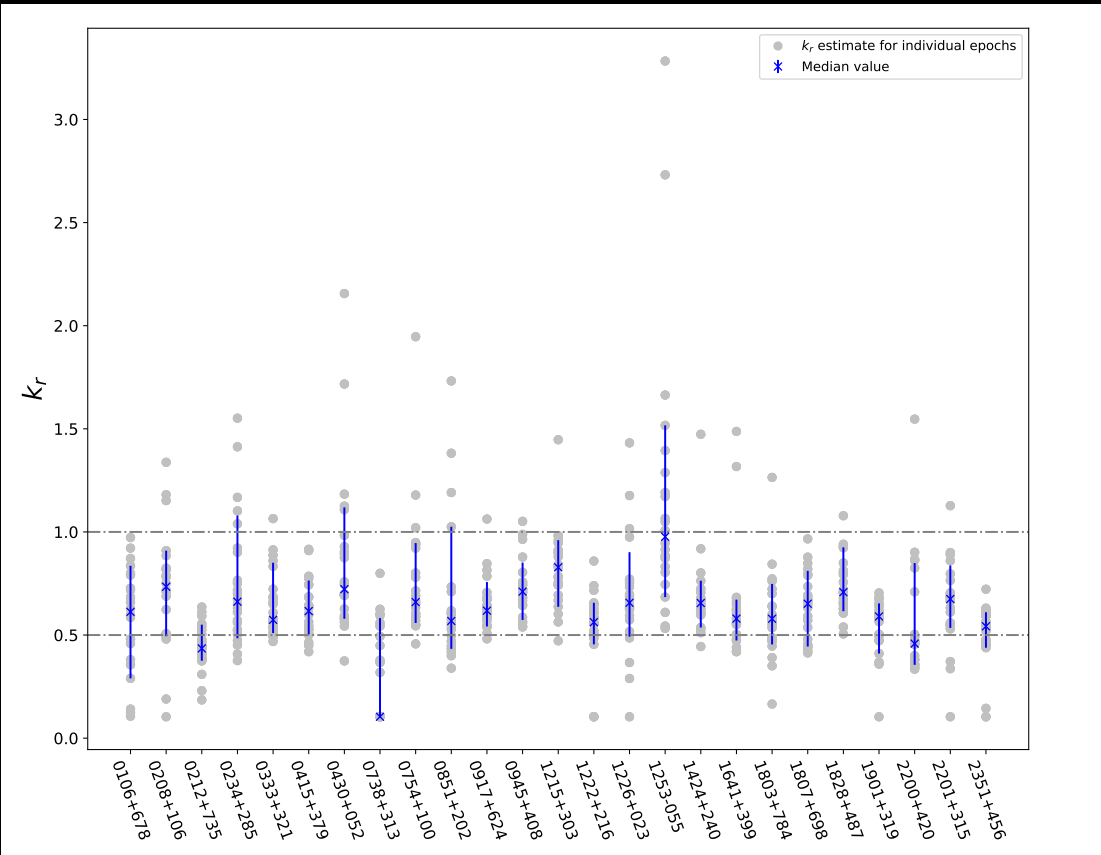
Similar results to Pushkarev et al. (2012)



Assuming equipartition and conical shape ($k_r=1$) might not be appropriate in our frequencies

When fitting the core-shift profile to data, k_r values are generally < 1

-> Conical approximation and energy equipartition can't both hold



Summary and conclusions

Measuring the core-shift effect can be used to estimate jet magnetic field strength

Making the same general assumptions of equipartition and conical shape used in most core-shift studies gives expected values

Fitting the core-shift profile to the data shows that the assumption might not be accurate for jet region probed by 15, 24 and 43 GHz

References

- Blandford & Königl 1979, ApJ 232, 34-48
Chamani et al. 2023, A&A 672, A130
Croke & Gabuzda 2008, MNRAS, 386, 619–626
Homan et al. 2021, ApJ 923:67
Kovalev et al. 2025, ApJ 991:33
Königl 1981, Apj 243 700-709
Lister et al. 2018, ApJS 234:12
Lobanov 1998, A&A, 330, 79–89
O’Sullivan & Gabuzda 2009, MNRAS, 400, 26-42
Pushkarev et al. 2012, A&A 545, A113
Pushkarev et al. 2017, MNRAS, 468, 4992–5003

Backup slides

Measuring core-shift

Core-shift measured by frequency pair (15-24 GHz, 24-43 GHz, 15-43 GHz)

Measurements needed for calculating core shift between two frequencies:

$$\Delta r_{\text{core}, \nu_1 \nu_2} = r_{\text{core}, \nu_1} - (r_{\text{core}, \nu_2} + IS_{\nu_1 \nu_2})$$

Core position relative to image center

Offset between the image centers of the two observations

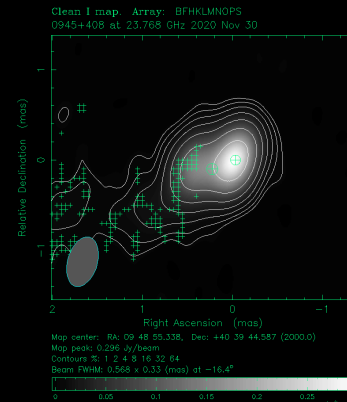
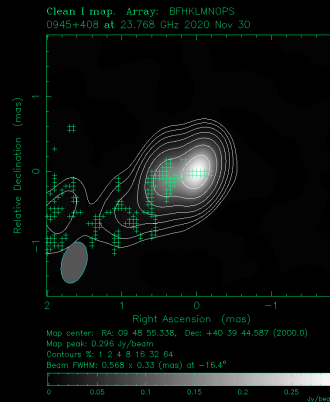


Image offset **not** taken into account

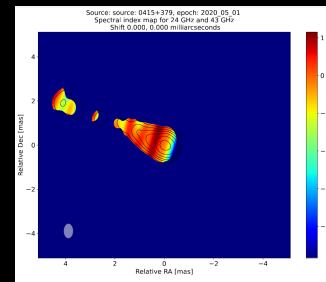
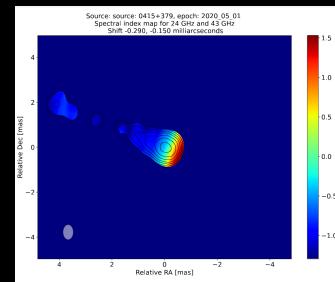


Image offset **taken** into account



Caveat with k_r estimation

With 3 observing frequencies, there are no degrees of freedom in the fit

$$\Delta r_{\text{core},43\text{GHz}} = A \left(\nu^{-1/k_r} - 43^{-1/k_r} \right)$$

Example: core shift fit for 0430+052

