A VLBA survey of opacity-driven positional shifts in AGN jets

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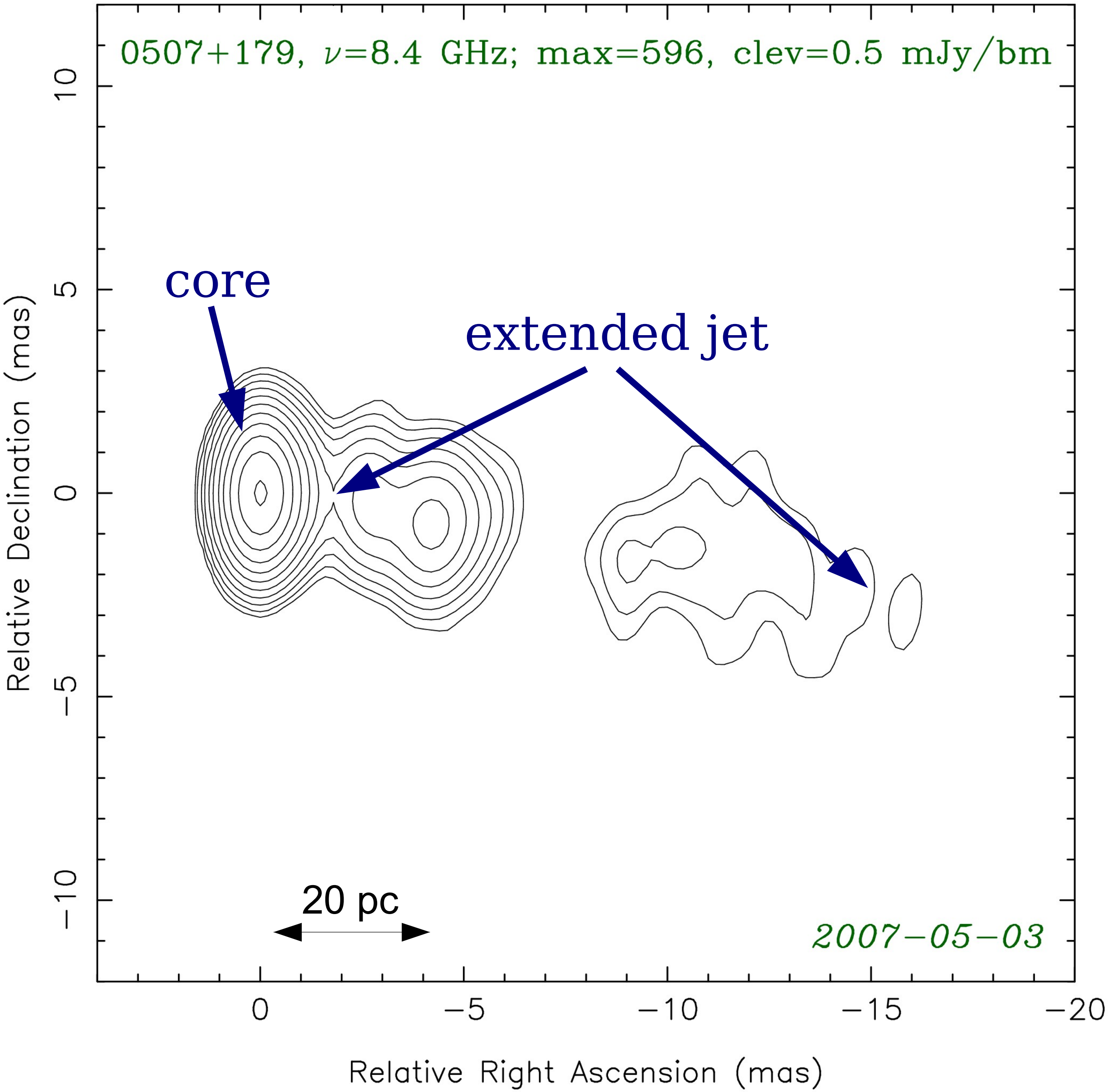
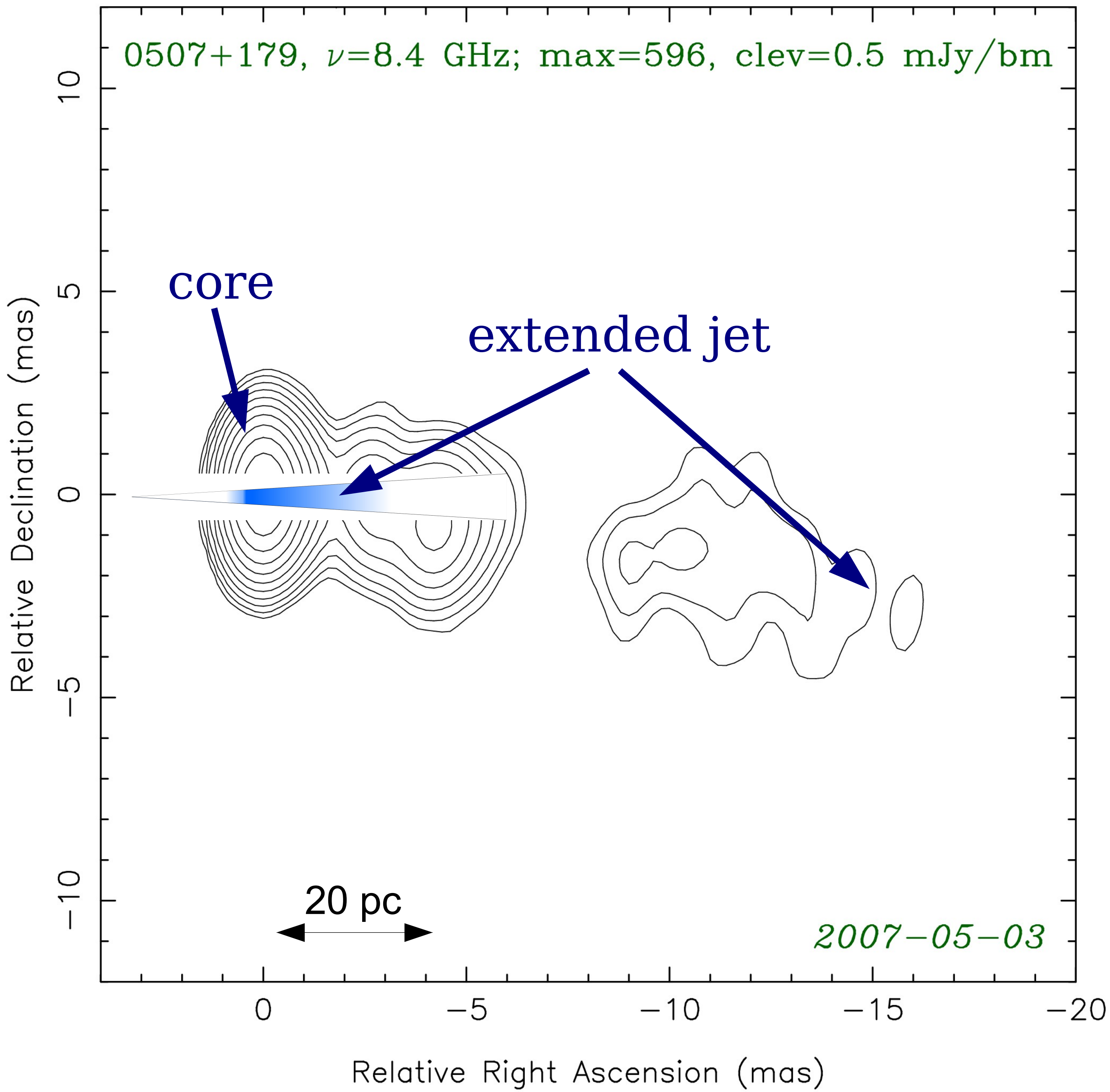
Outline

- Parsec-scale radio core and the core-shift effect
- VLBA observations & measurement technique
- Results, interpretation
- Summary

Typical VLBI image of a quasar

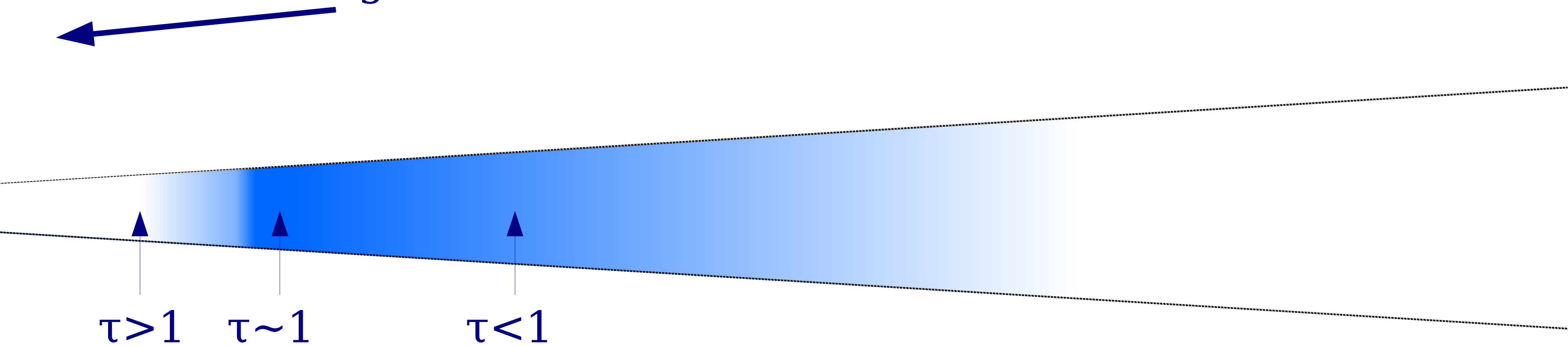


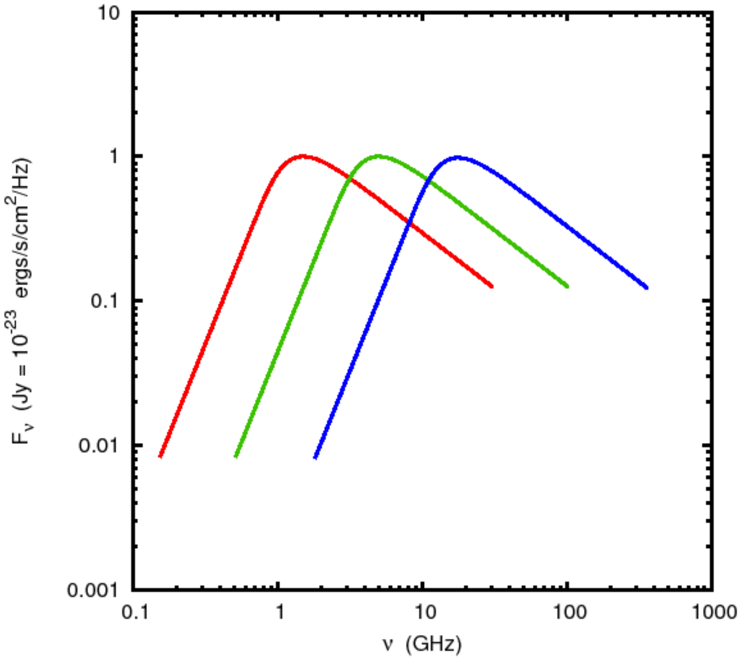
Core is the τ=1 region in the jet



Core is the τ=1 region in the jet

Central engine is there

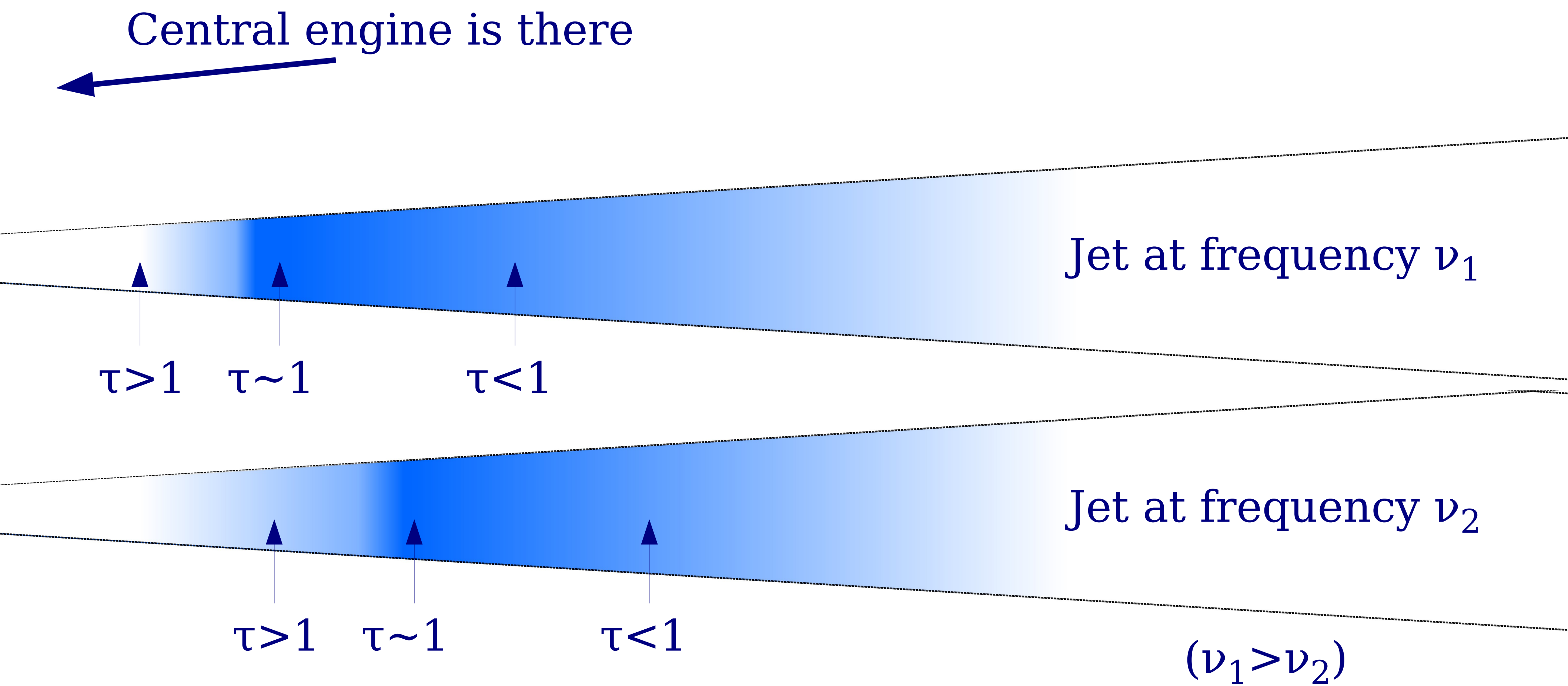




- Optical depth (τ) at a given observing frequency (ν) varies with distance from the central engine.

- Most of the emission comes from τ~1 region (photosphere).

The core shift effect



Position of the $\tau=1$ surface depends on ν - this is known as the core shift effect.

So... Why bother?

Astrophysics:

- Physical interpretation of the core (photosphere or shock?)
- Structure and parameters of sub-parsec scale jet

(more details in the talk by Andrei Lobanov)

Astrometry:

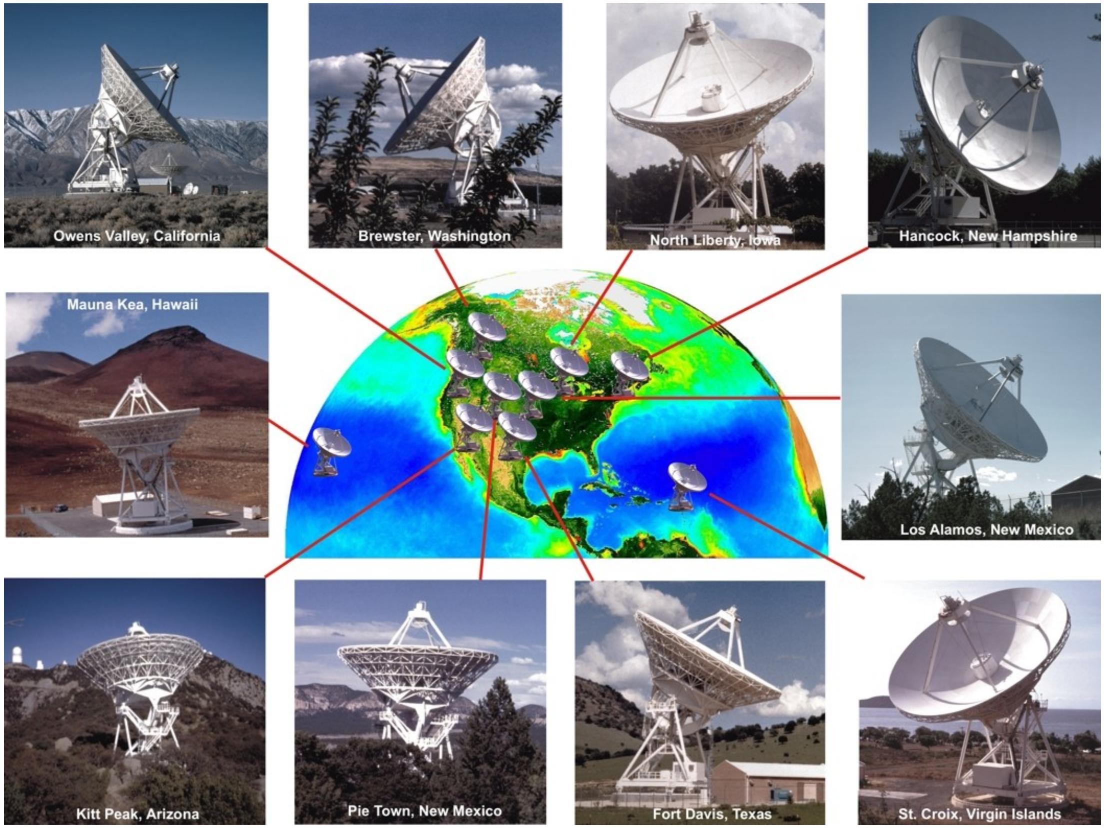
- Radio/optical (ICRF2/Gaia) reference frame alignment
- Spacecraft navigation with VLBI
- Interpreatation of radio astrometric data

(more details in the talk by Richard Porcas)

VLBA observations

• We observed 20 sources previously measured to have significant core shifts between 2 and 8 GHz.
• Simultaneous observations at 9 frequencies (1.4-15.4 GHz).

NRAO's Very Long Baseline Array (VLBA)

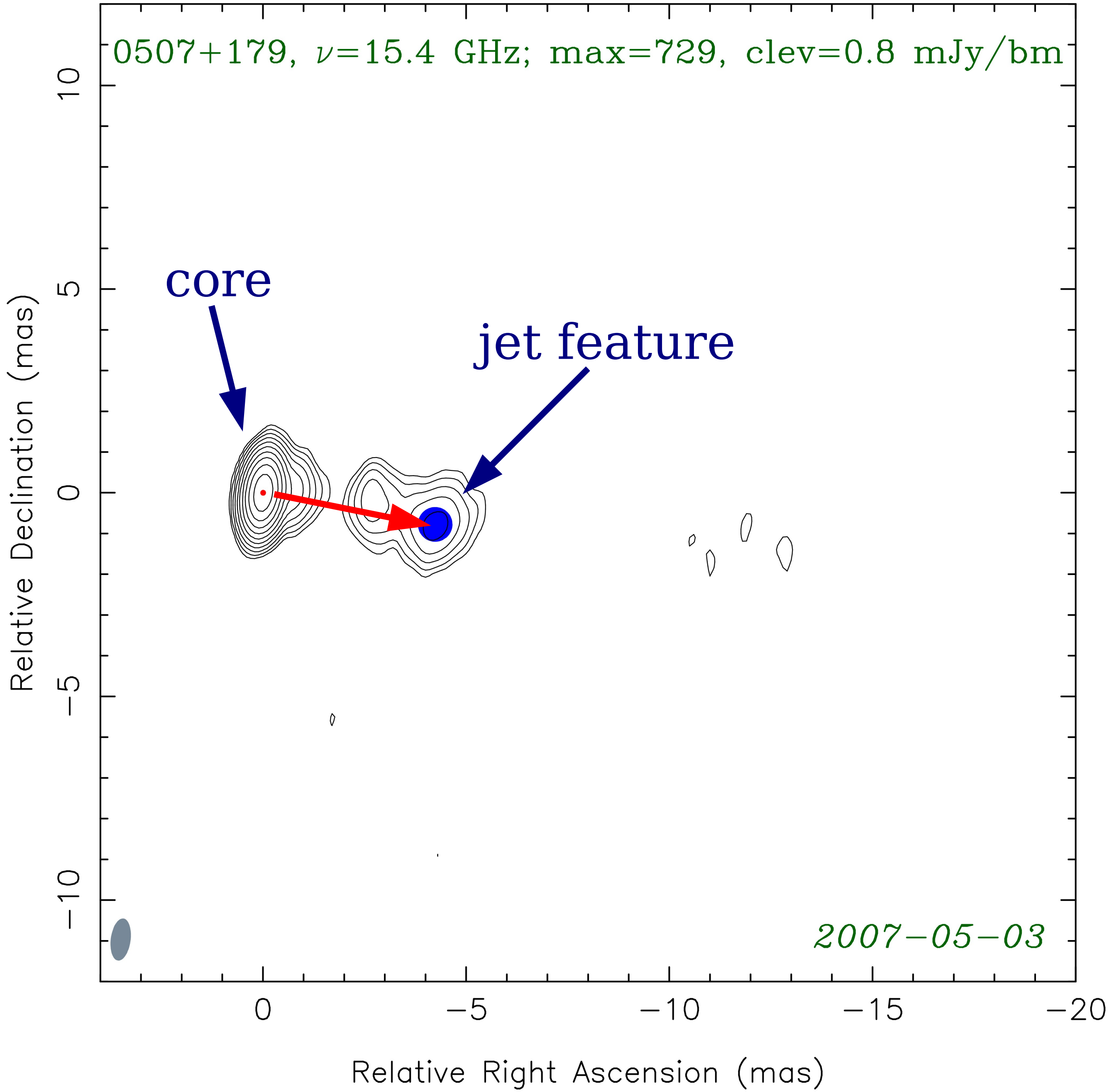


Observed radio sources

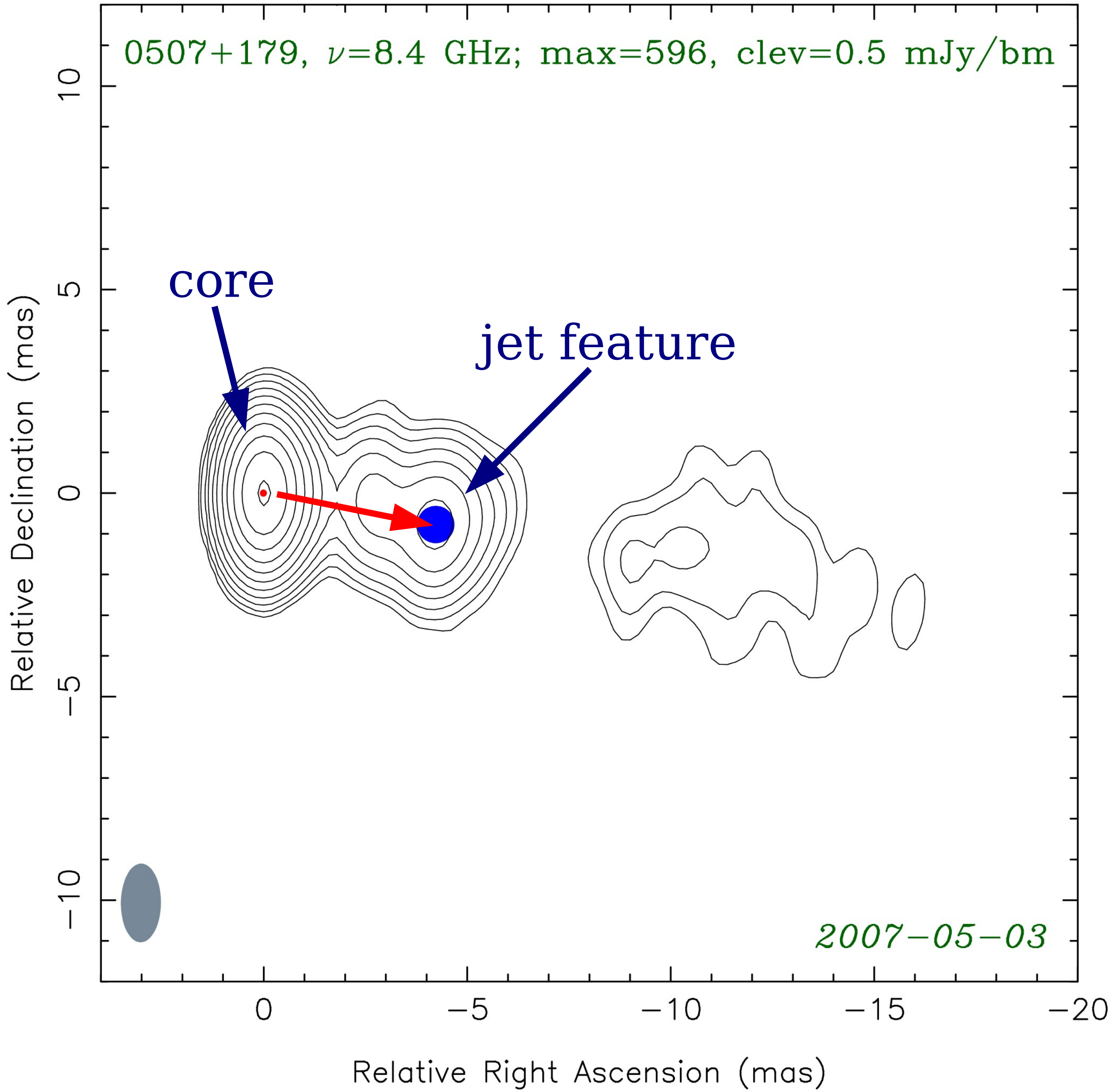
Name	Alias	R.A. (J2000)	Dec. (J2000)	z	Optical class	VLBA epoch
0148+274		01:51:27.146174	+27:44:41.79363	1.26	QSO	2007-03-01
0342+147		03:45:06.416545	+14:53:49.55818	1.556	QSO	2007-06-01
0425+048	OF 42	04:27:47.570531	+04:57:08.32555	0.517[a]	AGN	2007-04-30
0507+179		05:10:02.369133	+18:00:41.58160	0.416	AGN	2007-05-03
0610+260	3C 154	06:13:50.139161	+26:04:36.71971	0.580	QSO	2007-03-01
0839+187		08:42:05.094175	+18:35:40.99050	1.272	QSO	2007-06-01
0952+179		09:54:56.823616	+17:43:31.22204	1.478	QSO	2007-04-30
1004+141		10:07:41.498089	+13:56:29.60070	2.707	QSO	2007-05-03
1011+250		10:13:53.428771	+24:49:16.44062	1.636	QSO	2007-03-01
1049+215		10:51:48.789077	+21:19:52.31374	1.300	QSO	2007-06-01
1219+285	W Comae	12:21:31.690524	+28:13:58.50011	0.161[b]	BL Lac	2007-04-30
1406−076		14:08:56.481198	−07:52:26.66661	1.493	QSO	2007-05-03
1458+718	3C 309.1	14:59:07.583927	+71:40:19.86646	0.904	QSO	2007-03-01
1642+690		16:42:07.848505	+68:56:39.75639	0.751	QSO	2007-04-30
1655+077		16:58:09.011464	+07:41:27.54034	0.621	QSO	2007-06-01
1803+784		18:00:45.683905	+78:28:04.01839	0.680	QSO	2007-05-03
1830+285		18:32:50.185622	+28:33:35.95514	0.594	QSO	2007-03-01
1845+797	3C 390.3	18:42:08.989895	+79:46:17.12825	0.056	AGN	2007-06-01
2201+315		22:03:14.975788	+31:45:38.26990	0.298	QSO	2007-04-30
2320+506		23:22:25.982173	+50:57:51.96364	1.279	QSO	2007-05-03

[a] Spectroscopic redshift obtained by Afanas'ev et al. (2003, ARep, 47, 458).
[b] Photometric redshift, see Finke et al. (2008, A&A, 477, 513).

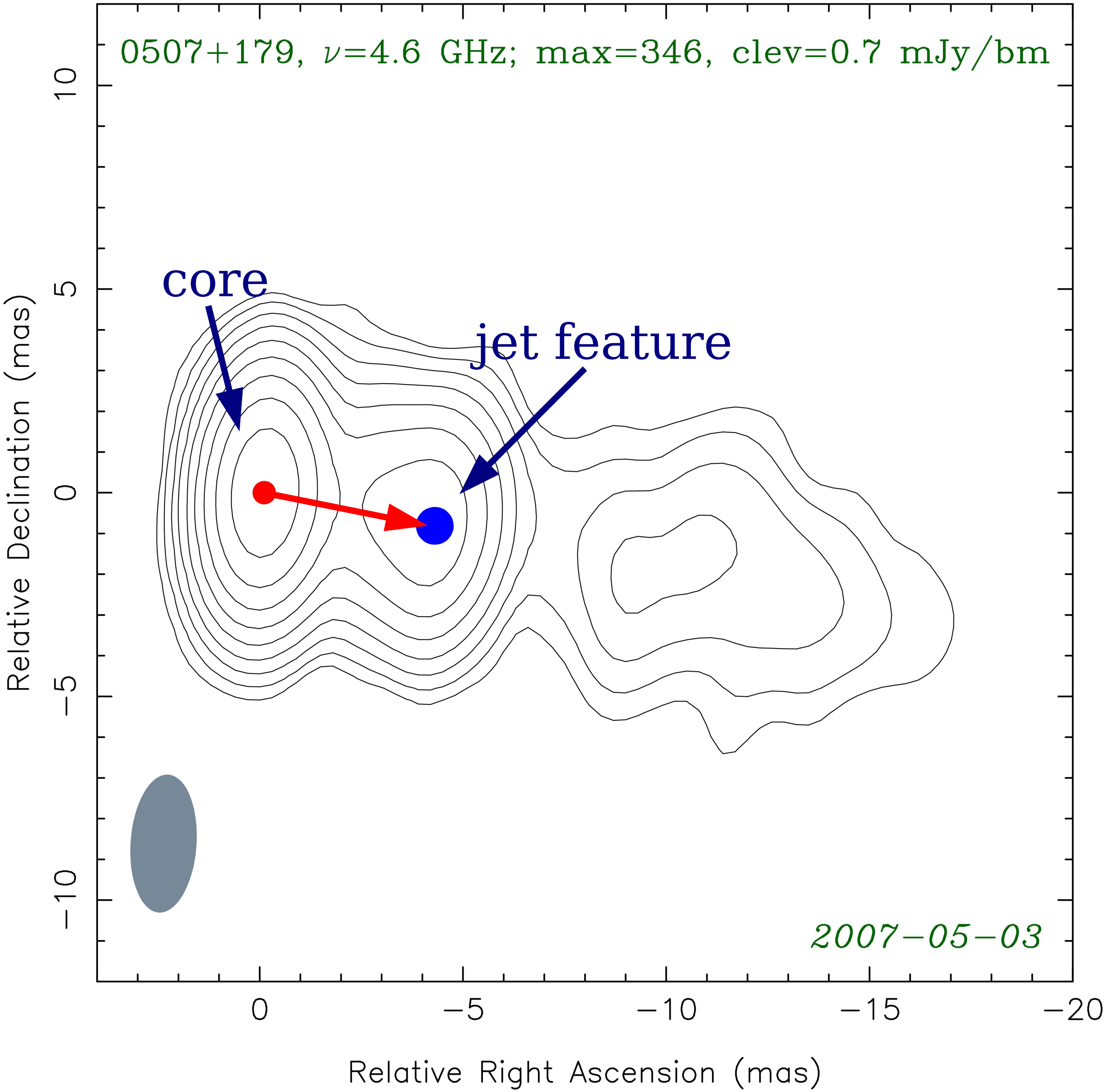
Core position measurement



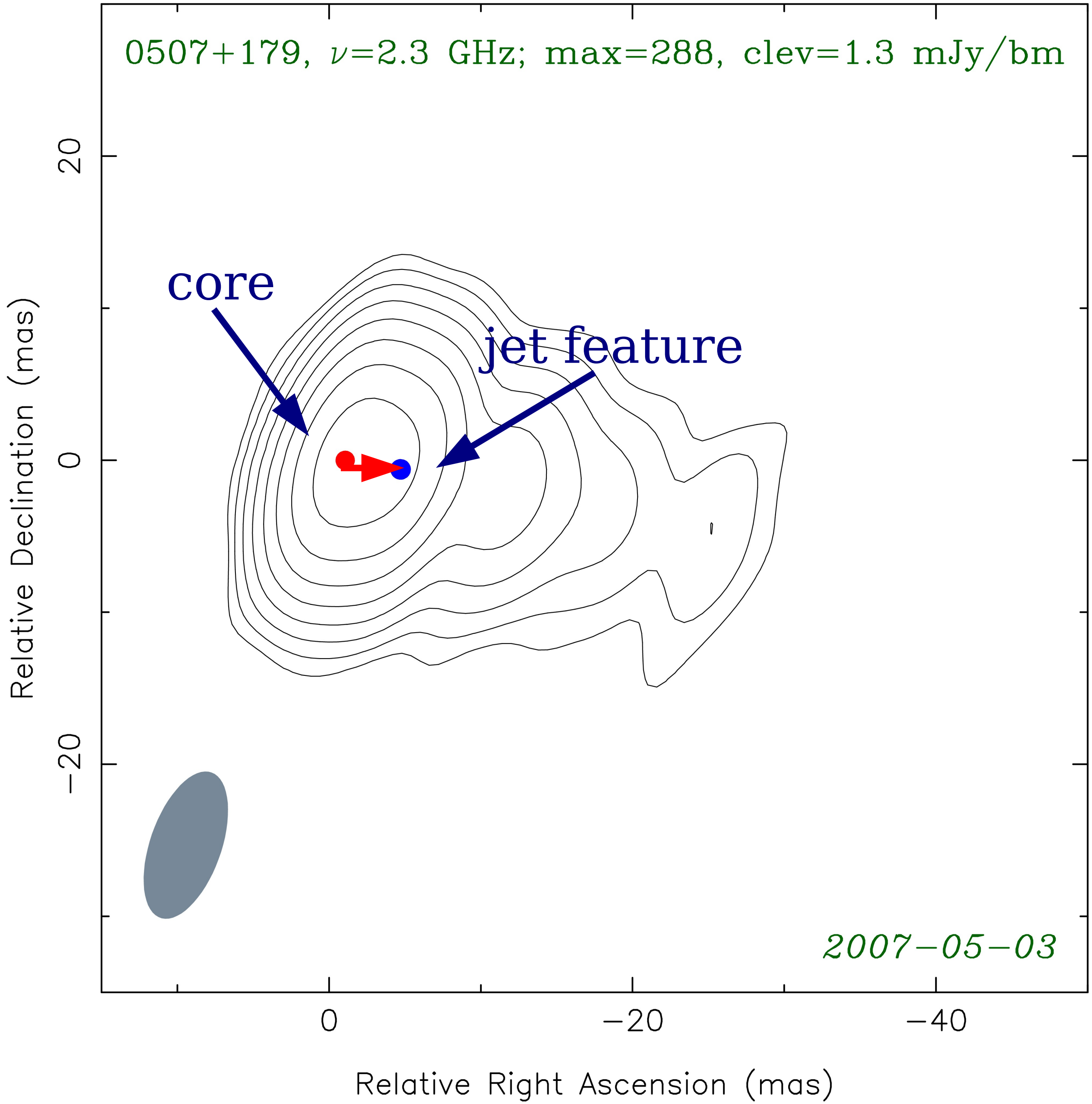
Core position measurement



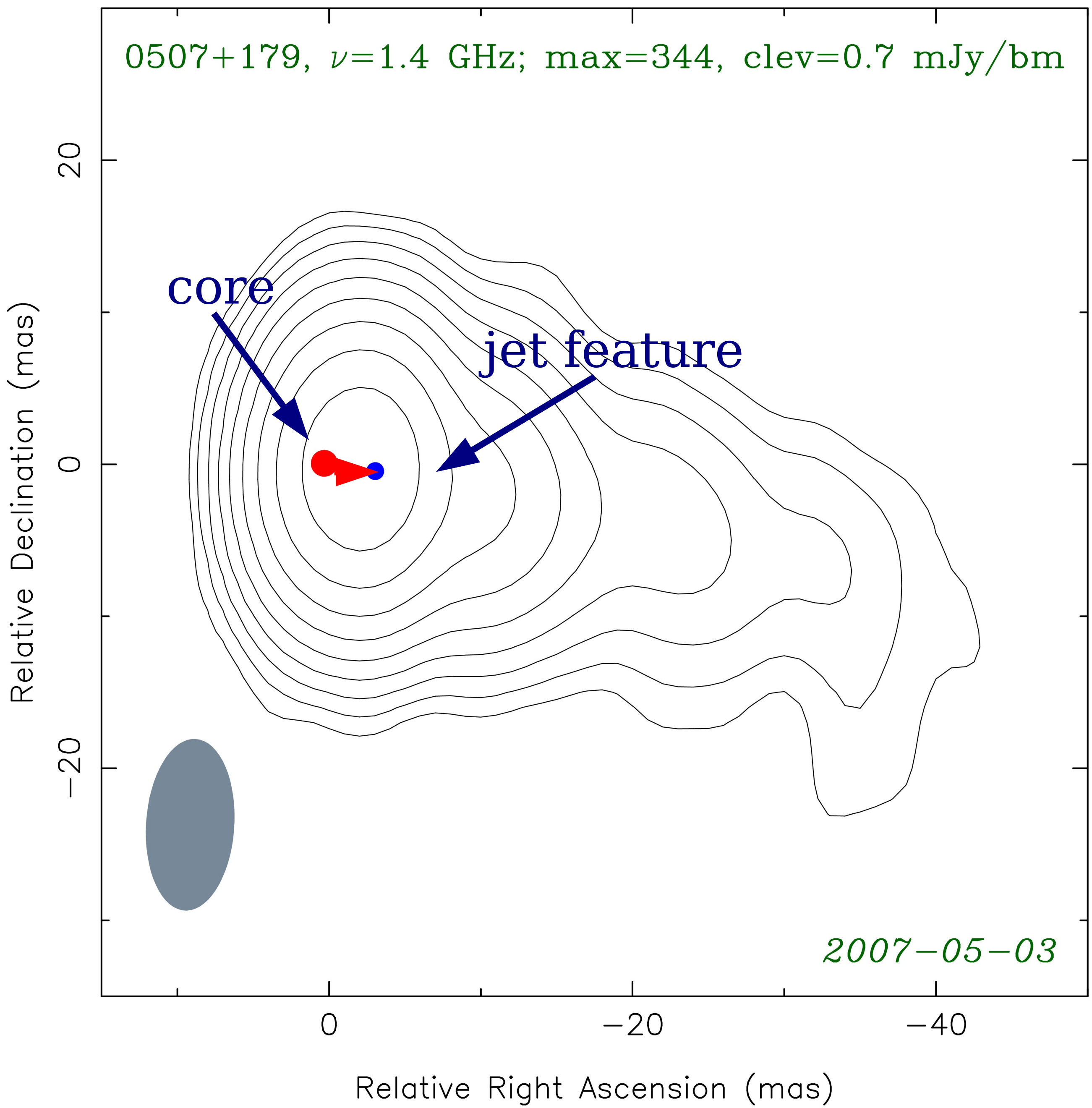
Core position measurement



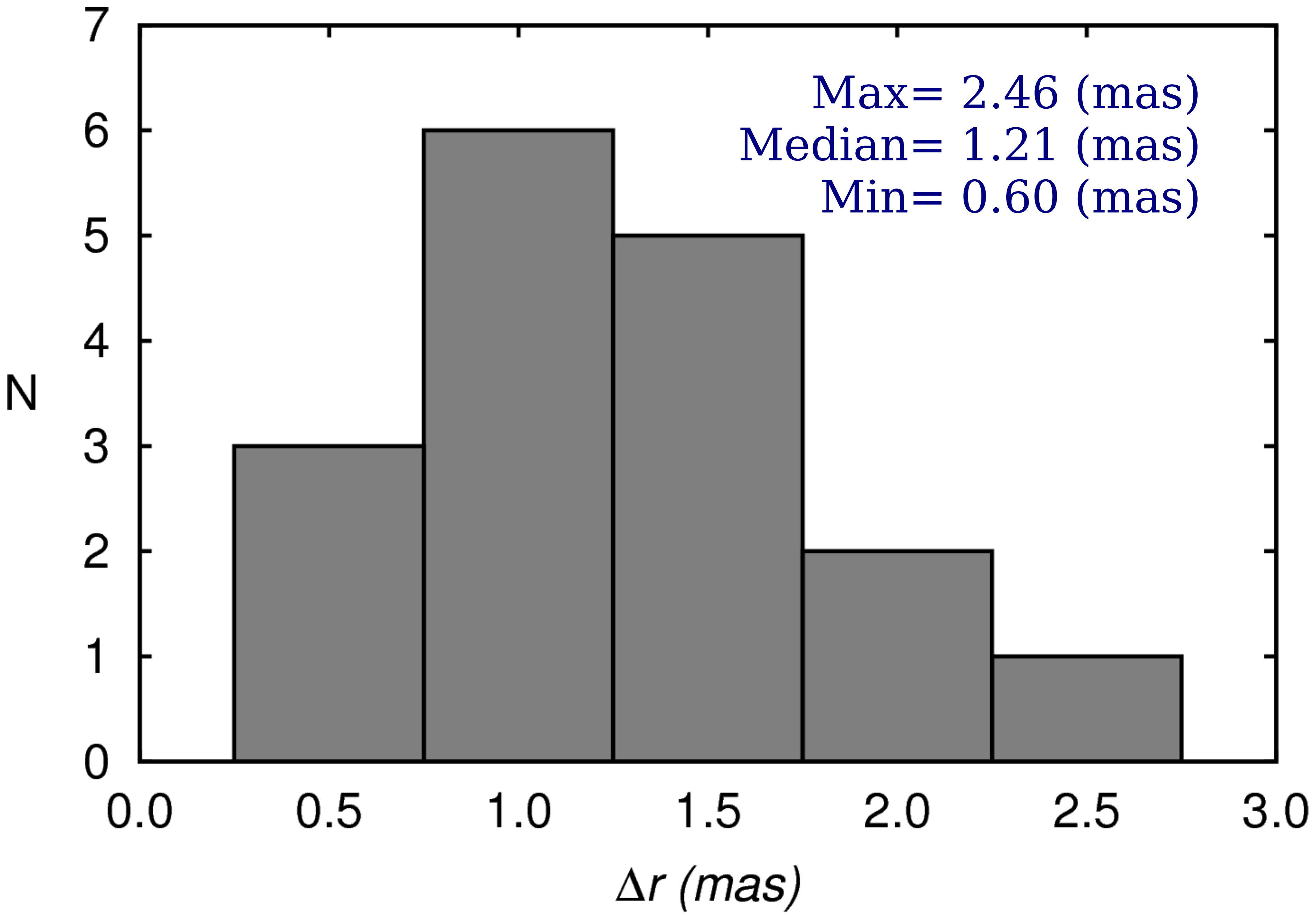
Core position measurement



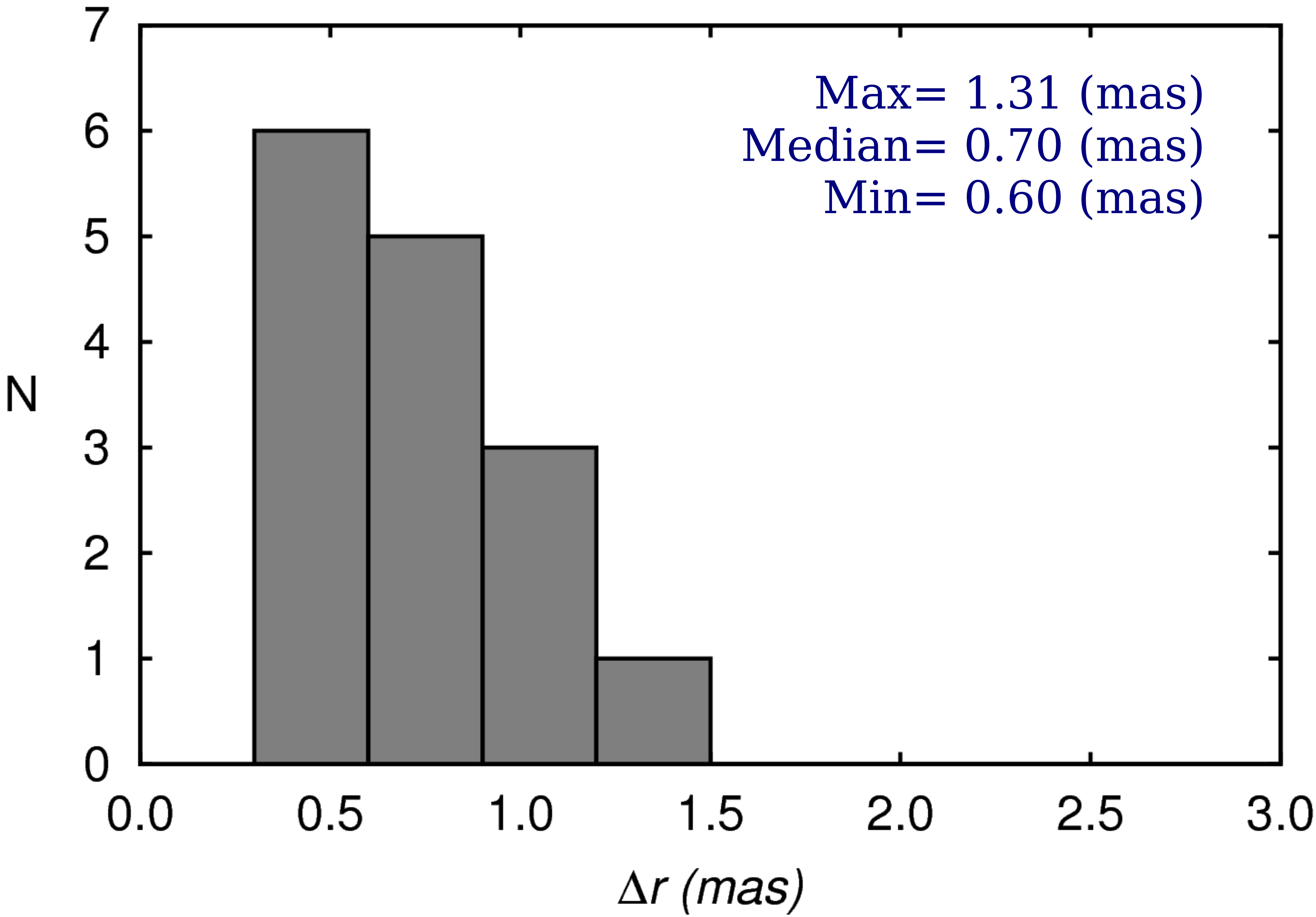
Core position measurement



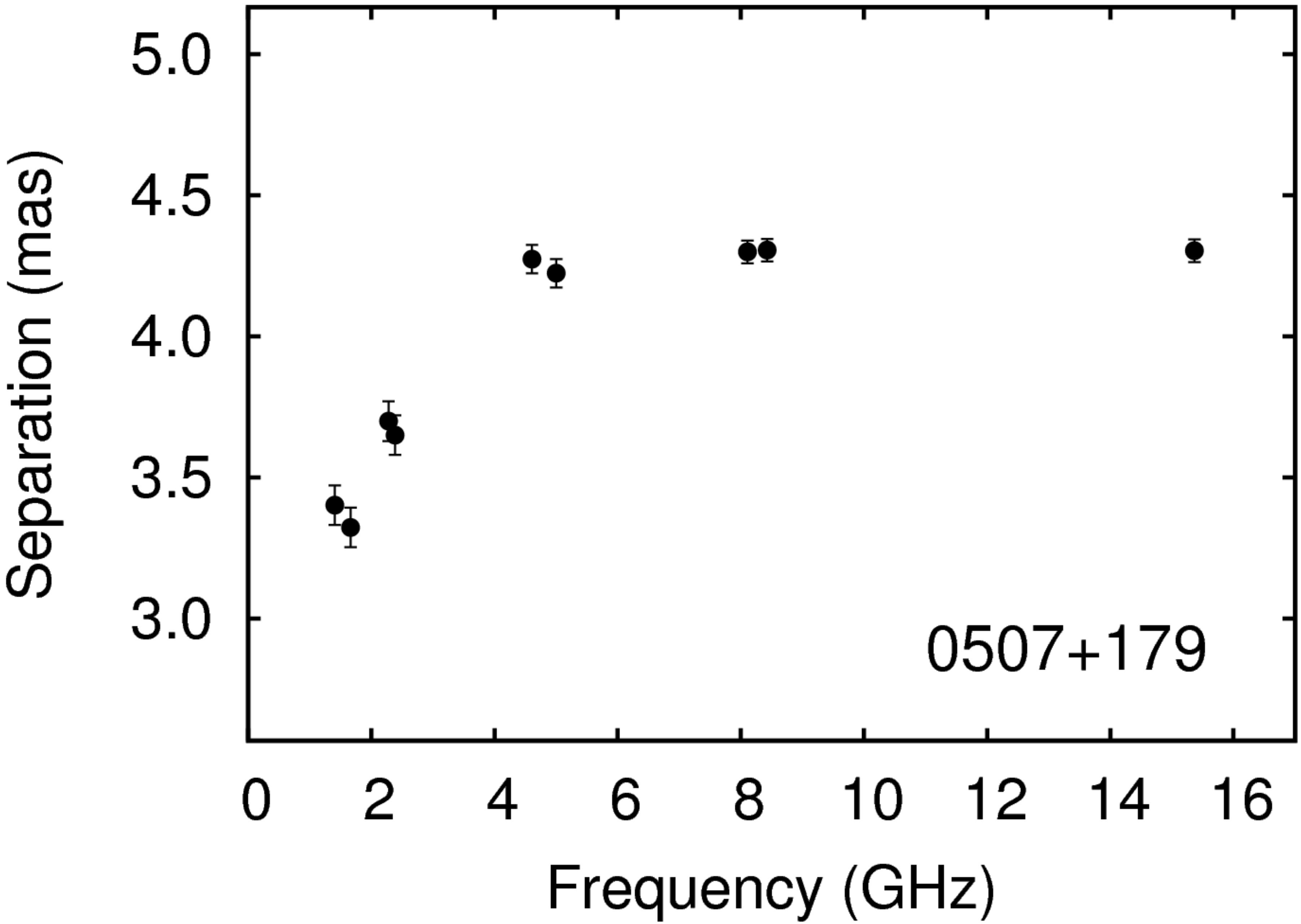
Core position difference: 15.4 – 1.4 GHz



Core position difference: 8.4 – 2.3 GHz



Core position as a function of ν



Model prediction

According to Lobanov (1998 A&A, 330, 79), if

• **synchrotron self-absorption** (SSA) is the dominating opacity mechanism,

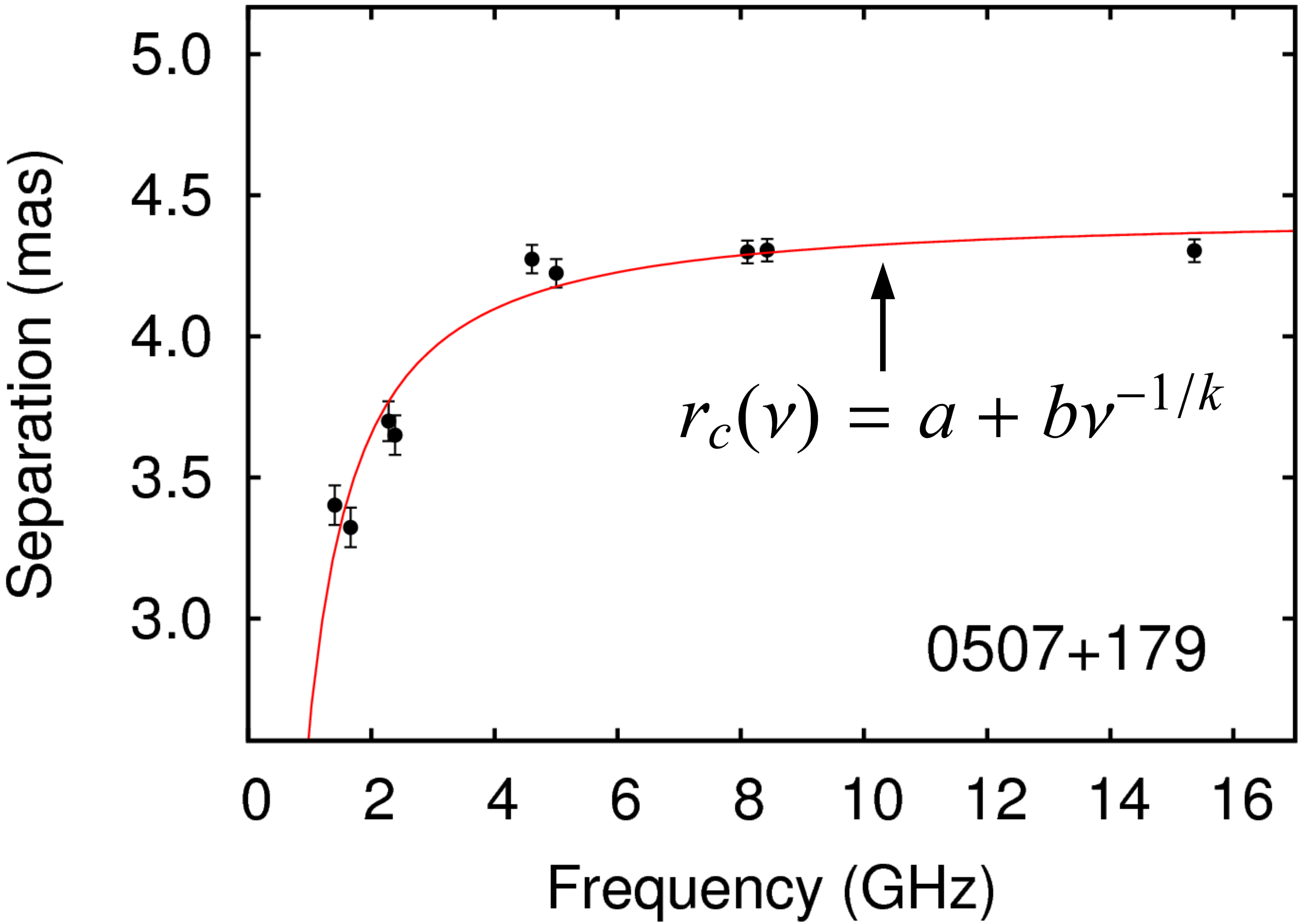
• the jet has a **conical shape** and

• there is an **equipartition** between the particle and magnetic field energy densities,

than

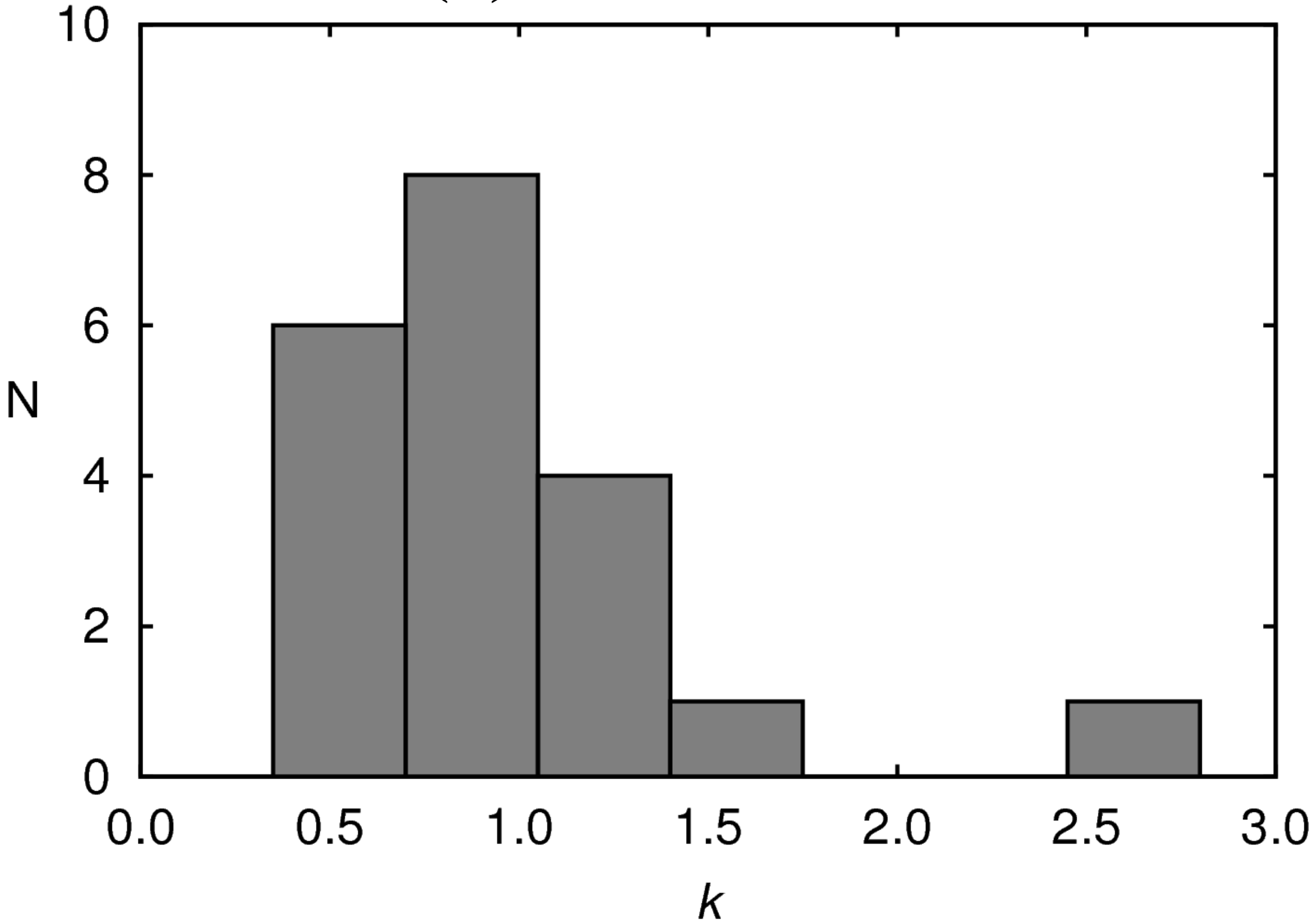
$$r_c(\nu) = a + b\nu^{-1/k} \quad \text{where } k=1$$

Core position as a function of ν



Best-fit values of k

$$r_c(\nu) = a + b\nu^{-1/k}$$



Mean k=0.98 +/-0.11, consistent with k=1.

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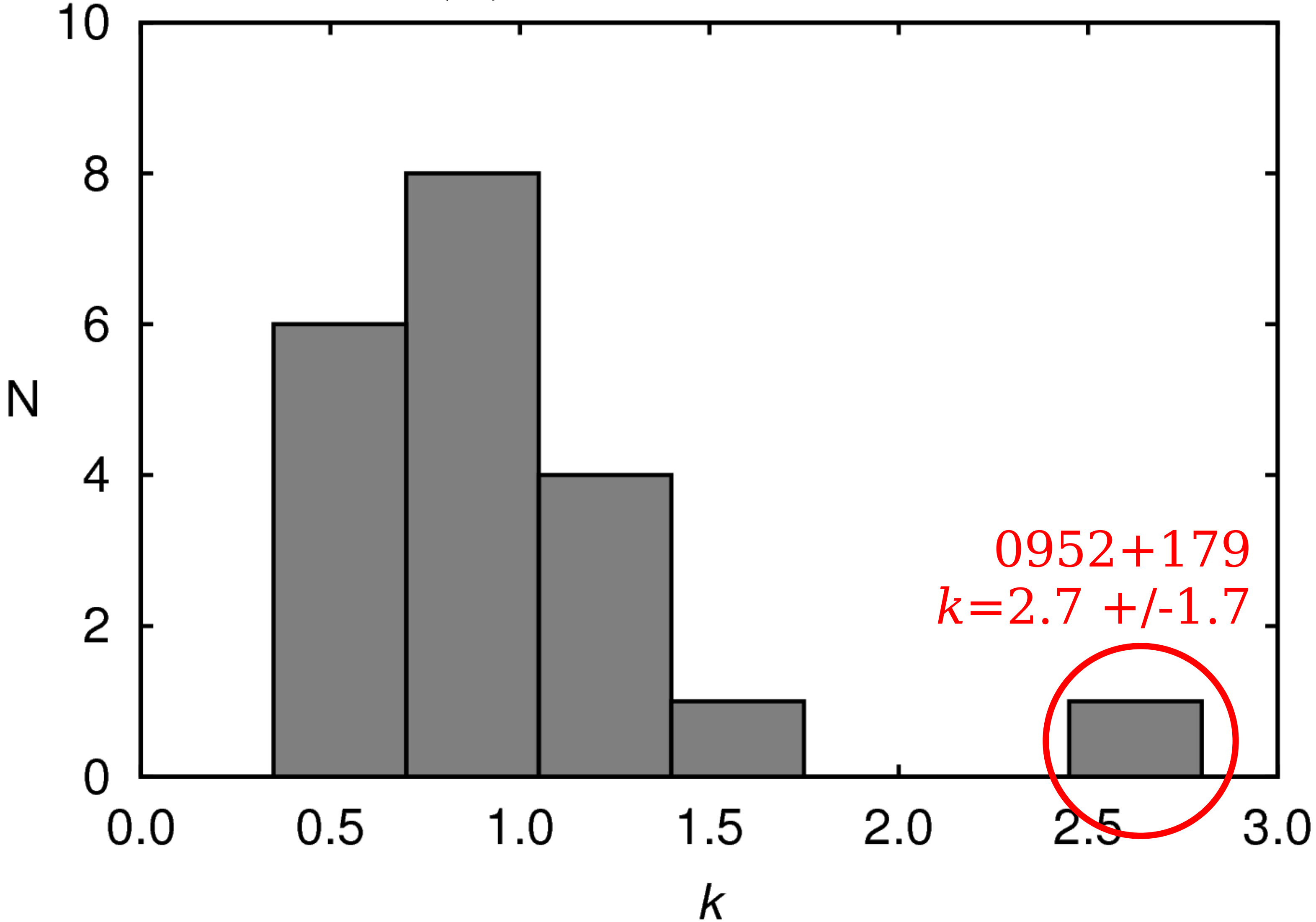

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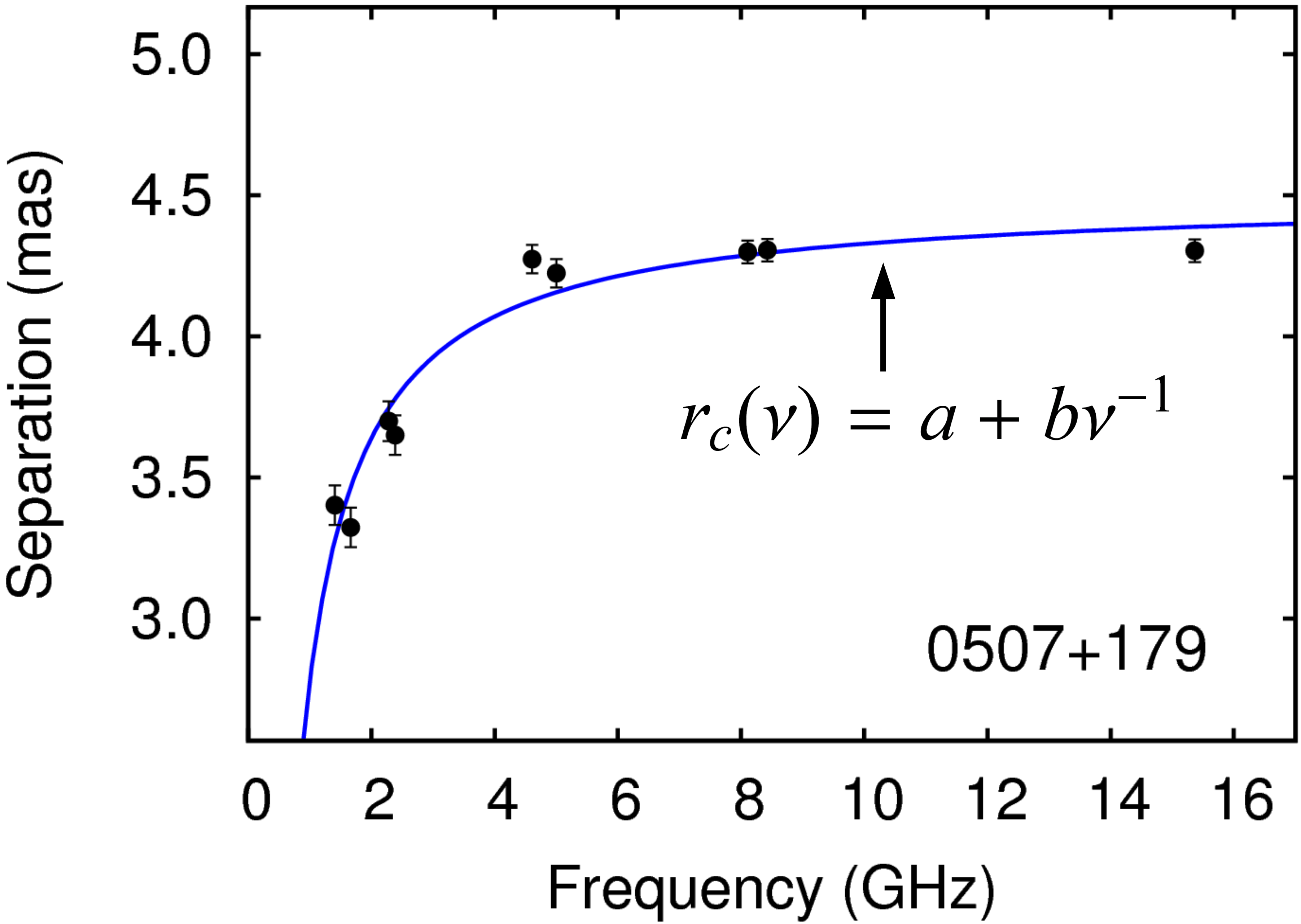
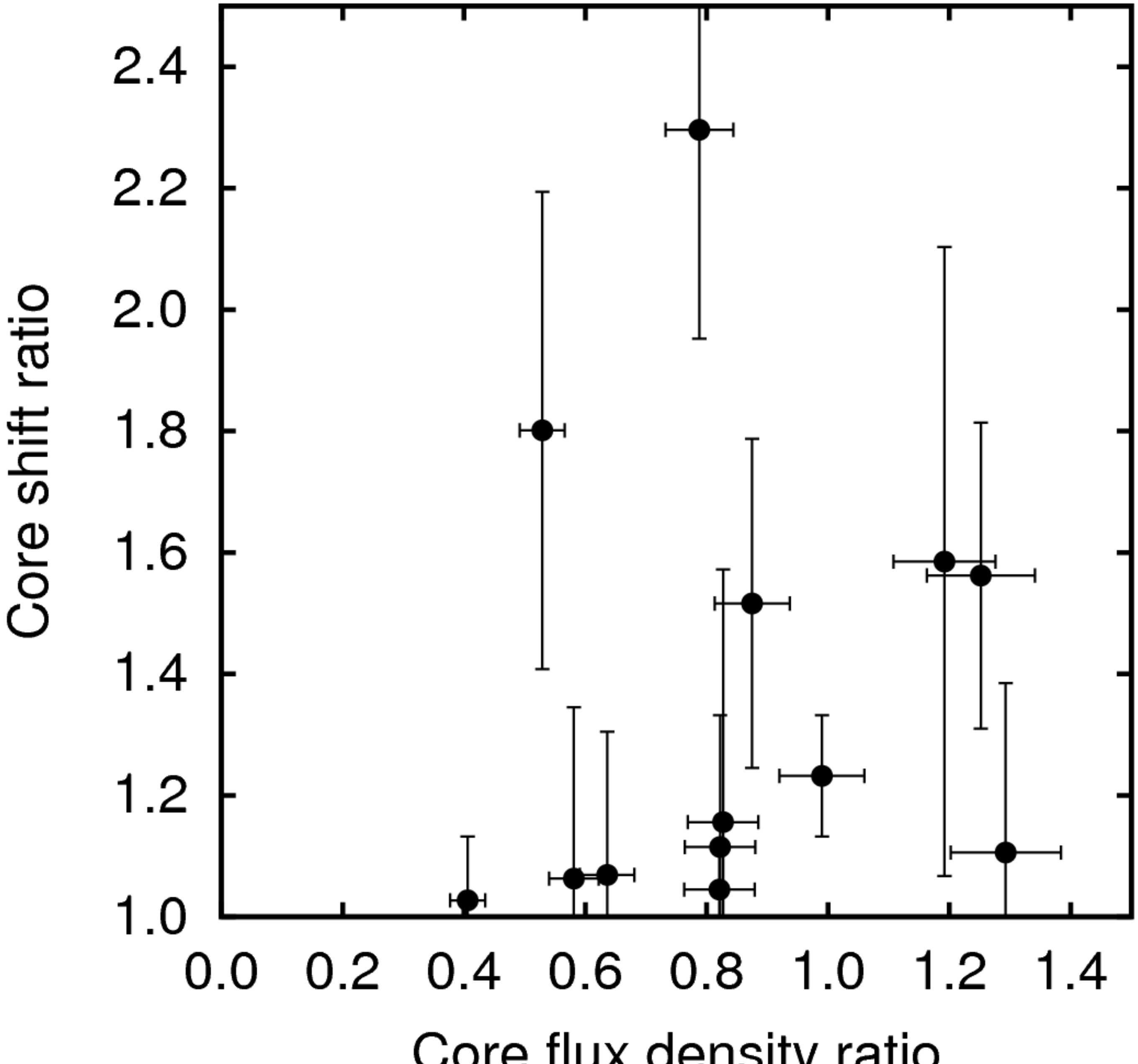
Core position as a function of ν



Core shift variability?



2/8 GHz data at two epochs:

2002 (Kovalev 2008)

and

2007 (this work)

Summary

- We observed 20 extragalactic radio sources showing large frequency-dependent core shifts at nine frequencies (1.4-15.4 GHz) with VLBA.

- Core position was measured at each frequency with respect to an optically thin jet component.

- Typical core shift values: 1.2 mas (1.4 - 15.4 GHz)
  0.7 mas (2.3 - 8.4 GHz)

- Observations are consistent with $r_c(\nu) \propto \nu^{-1}$
  => Interpretation of the core as a **conical jet** in **equipartition** exhibiting **synchrotron self-absorption** (SSA).

ArXiv:1103.6032

A VLBA survey of the core shift effect in AGN jets

I. Evidence of dominating synchrotron opacity

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ABSTRACT

Context. The effect of a frequency dependent shift of the VLBI core position (known as the "core shift") was predicted more than three decades ago and has since been observed in a few sources, but often within a narrow frequency range. This effect has important astrophysical and astrometric applications.
Aims. To achieve a broader understanding of the core shift effect and the physics behind it, we conducted a dedicated survey with NRAO's Very Long Baseline Array (VLBA).
Methods. We used the VLBA to image 20 pre-selected sources simultaneously at nine frequencies in the 1.4–15.4 GHz range. The core position at each frequency was measured by referencing it to a bright, optically thin feature in the jet.
Results. A significant core shift has been successfully measured in each of the twenty sources observed. The median value of the core shift is found to be 1.21 mas if measured between 1.4 and 15.4 GHz, and 0.24 mas between 5.0 and 15.4 GHz. The core position, r_c, as a function of frequency, ν, is found to be consistent with an $r_c \propto \nu^{-1}$ law. This behavior is predicted by the Blandford & Königl model of a purely synchrotron self-absorbed conical jet in equipartition. No systematic deviation from unity of the power law index in the $r_c(\nu)$ relation has been convincingly detected.
Conclusions. We conclude that neither free-free absorption nor gradients in pressure and/or density in the jet itself and in the ambient medium surrounding the jet play a significant role in the sources observed within the 1.4–15.4 GHz frequency range. These results support the interpretation of the parsec-scale core as a continuous Blandford-Königl type jet with smooth gradients of physical properties along it.