The jet parameters implied by the measured extreme brightness temperatures in BL Lac and 3C273

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Overview

1. Magnetic field, particle number density, and magnetization through measurements of core shift effect — equipartition model
2. Magnetic field, particle number density, and magnetization through measurements of brightness temperature and core shift effect — non-equipartition model
3. Magnetic field, particle number density, and magnetization through measurements of brightness temperature and core shift effect — non-equipartition and non-uniform model
4. Conclusions

Jets physical parameters

The activity of galactic nuclei (jets) is due to:

- magnetic field (frozen-in the disk or genereted in the disk, and brought in the vicinity of BH by accretion)
- BH rotation
- plasma filling jets

It is important to have estimates for the jets physical parameters to understand the physical processes governing the observed emission. The possible choice of a mechanism responsible for the particles acceleration impacts the radiation in all energies.

One of the instruments — the VLBI jet cores in radio (high resolution, 'simple' emission model).

Core shift measurements method (Lobanov, 1998)

Core shift method provides jet parameters through the emission in radio core.

Core shift measurement

$$(\nu_m)^{4+p} \propto B^{2+p} n^2$$

Blandford–Königl scalings

$$n \propto r^{-2}, \quad B \propto r^{-1}$$

Equipartition assumption

$$\Sigma = 1, \quad \Sigma \propto \frac{B^2}{n}$$

Emission model: synchrotron self-absorbed spherical source (Gould, 1979). The magnetic field and particle number density have amplitudes depending on the distance by the Blandford–Königl scalings (Blandford & Königl, 1979). Needs to assume energy equipartition between magnetic field and radiating plasma.

Core shift measurements method

Core shift measurement

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Blandford–Königl scalings

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Equipartition assumption

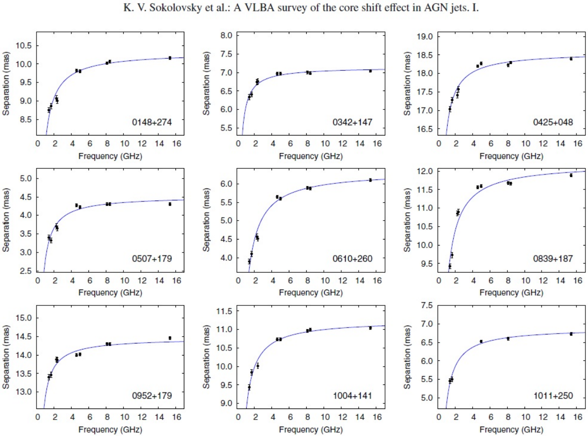
$$\Sigma = 1, \quad \Sigma \propto \frac{B^2}{n}$$

Typical values:

- $B_1 \sim 1\,\mathrm{G}$
- $n_1 \sim 10^3\,\mathrm{cm}^{-3}$

(Lobanov 1998, Hirotani 2005, O& Gabuzda 2009, Nokhrina et al. 2015)

Multi frequency core shift measurements



K. V. Sokolovsky et al.: A VLBA survey of the core shift effect in AGN jets. I.

Figure: From Sokolovsky et al. (2011)

Blandford–Königl scalings provide the observed core position $r_{\rm obs} \propto \nu_{\rm obs}^{-1}$.

Why, probably, not equipartition?

- Readhead (1994): the equipartition brightness temperature

$$T_{br,eq} \sim 10^{11.5}\,\mathrm{K}$$

- However: recent observations of radio cores by Gomez et al. (2016), Kovalev et al. (2016), Lisakov et al. (2017) provide

$$T_{br} > 10^{12}\,\mathrm{K}$$

Non equipartition

Instead of equipartition assumption let us use the additional measurement: the brightness temperature measurement.

Core shift measurement

$$(\nu_m)^{4+p} \propto B^{2+p} n^2$$

Blandford–Königl scalings

$$n \propto r^{-2}, \quad B \propto r^{-1}$$

Brightness temperature measurement

$$B \propto T^{-2}$$

The measurement of brightness temperature is enough to obtain the magnetic field amplitude in the observed core. The position of this core is unknown without additional assumptions (Zdziarski et al. 2015, Nokhrina 2017).

Non equipartition

Instead of equipartition assumption let us use the additional measurement: the brightness temperature measurement.

Core shift measurement

$$(\nu_m)^{4+p} \propto B^{2+p} n^2$$

Blandford–Königl scalings

$$n \propto r^{-2}, \quad B \propto r^{-1}$$

Brightness temperature measurement

$$B \propto T^{-2}$$

- magnetic field B
- core position along a jet $r_{\rm rad}$
- particle number density n
- magnetization Σ

Non equipartition parameters

BL Lac (Gomez et al. 2016):
$\nu_{obs} = 15\,\mathrm{GHz}$
$T_{br} = 7.9 \times 10^{12}\,\mathrm{K}$

$r_{\mathrm{rad}} = 0.48\,\mathrm{pc}$
$B = 3.3 \times 10^{-2}\,\mathrm{G}$
$n = 3.4 \times 10^{7}\,\mathrm{cm}^{-3}$
$\Sigma = 1.3 \times 10^{-5}$
(Equipartition $B = 0.56\,\mathrm{G}$,
$n = 1.2 \times 10^{5}\ cm^{-3}$)

$B_1 = 1.6 \times 10^{-2}\,\mathrm{G}$
$n_1 = 7.8 \times 10^{6}\,\mathrm{cm}^{-3}$

3C273 (Kovalev et al. 2016):
$\nu_{obs} = 4.8\,\mathrm{GHz}$
$T_{br} = 13 \times 10^{12}\,\mathrm{K}$

$r_{\mathrm{rad}} = 2.84\,\mathrm{pc}$
$B = 8.1 \times 10^{-3}\,\mathrm{G}$
$n = 1.4 \times 10^{7}\,\mathrm{cm}^{-3}$
$\Sigma = 2.9 \times 10^{-6}$
(Equipartition $B = 3\,\mathrm{G}$,
$n = 26\ cm^{-3}$)

$B_1 = 2.3 \times 10^{-2}\,\mathrm{G}$
$n_1 = 1.1 \times 10^{8}\,\mathrm{cm}^{-3}$

Time evolution of the parameters for 3C 273 (Lisakov et al. 2017)

epoch	$T_{\rm br}$ (10^{12} K)	implied $B_{\rm core}$ (G)
2009 Aug 28	1.1	5.000
2009 Oct 25	4.7	0.270
2009 Dec 05	6.1	0.157
2010 Jan 26	5.3	0.210

Table: The first two columns are adopted from Lisakov et al. 2017 @ 43 GHz. The third column — result for B.

Non equipartition parameters

We have for the sources wih high brightness temperature of radio cores:

- Low magnetic field
- Low magnetization (far departure from the equiaprtition)
- There is an evolution of T_{br} with time

It may point to the mechanism of plasma accelerating to the relativistic energies $dn \propto \gamma^{-p} d\gamma$. Reconnection?

Jet transversal structure

The results above are based on uniform across a jet model. The MHD models together with the observations of M87 (Mertens et al. 2016) point to high stratification.

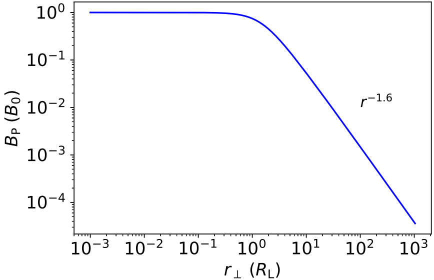


Figure: Poloidal magnetic field.

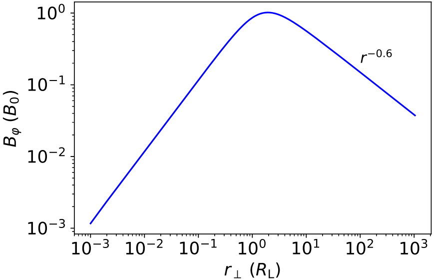


Figure: Toroidal magnetic field.

Jet transversal structure

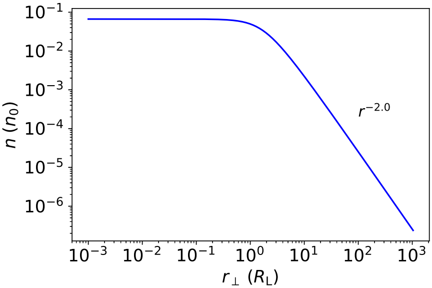


Figure: Particle number density.

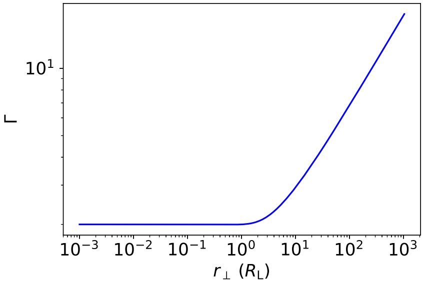


Figure: Bulk Lorentz factor.

Amplitude magnetic field

We calculate the observed flux for such a jet structure, and connect brightness temperature with the magnteic field mplitude B_0.

$$B_{\rm uni} = 7.4 \times 10^{-4} \frac{\Gamma\delta}{(1+z)} \left(\frac{\nu_{\rm obs}}{\rm GHz}\right) \left(\frac{T_{\rm b,obs}}{10^{12}~{\rm K}}\right)^{-2}$$

$$B_0 = 6.4 \times 10^{-4} \frac{R_j}{R_{\rm L}} \frac{\Gamma\delta}{(1+z)} \left(\frac{\nu_{\rm obs}}{\rm GHz}\right) \left(\frac{T_{\rm b,obs}}{10^{12}~{\rm K}}\right)^{-2}$$

There is an unknown factor $R_j/R_{\rm L}$, which is (from MHD models) must be greater than 100.
For BL Lac $B_0 = 3$ G, for 3C273 $B_0 = 0.7$ G.
The magnetization is still low as (Readhead, 1994) $\Sigma \propto (T_{\rm br}/T_{\rm eq})^{-17/2}$.

Conclusions

- High brightness temperatures are in conflict with the conventional method of using the core shift measurements to estimate B and n. But we have a method of estimating B and n for the sources with brightness temperature far from the equipartition.
- Direct estimate of B by the brightness temperature measurement implies low uniform amplitudes of magnetic field B in radio core, although the non-uniform model provides greater values. In both cases the magnetic field about two orders lower than the equiaprtition magnetic field, and the radio core have a low magnetization. Is it needed for extreme blazars?
- Far departures from equipartition may point to the acceleartion process, leading to extremely effective particles acceleration along with a drop in magnetic field amplitude, hence the high brightness temperature. Reconnection?

Thank you for your attention!