The blazar OJ 287 jet from parsec to kiloparsec scales

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Purpose

Search for evidence of the central engine precession in OJ 287 through the bend of kiloparsec-scale jet and correspondence with precession on parsec-scales.

Why is it important?

In many studies over more than 20 years, the 12-year optical flares of the OJ 287 blazar are interpreted by the jet helical shape resulting from the central engine precession. A precession with such a short period can only occur in a binary supermassive black hole system.

Butuzova & Pushkarev [1] have suggested that the true precession of the central engine manifests itself in the modulation of peak fluxes during 12-year flares. Then the precession period in the source reference frame is approximately 1200 years (which corresponds to the period in the observer's reference frame of 92 years). This period may arise as a result of the Lenze-Thirring effect in the system of a single supermassive black hole and its accretion disk.

If the last case is correct, then the periodicity of the light curves on time scales from several to a dozen years is formed due to the jet helical shape, which it acquired due to the development (magneto)hydrodynamic instabilities. Therefore, the assumption of binary black hole systems in the centers of active galaxies is unwarranted.

Kiloparsec-scale jet of blazar OJ 287

In the VLA observations at a frequency of 1.4 GHz (**Fig. 1**), a kiloparsec-scale jet for OJ 287 is detected, which morphologically corresponds to the FR I radio source, has a length of more than 25″ and exhibits a

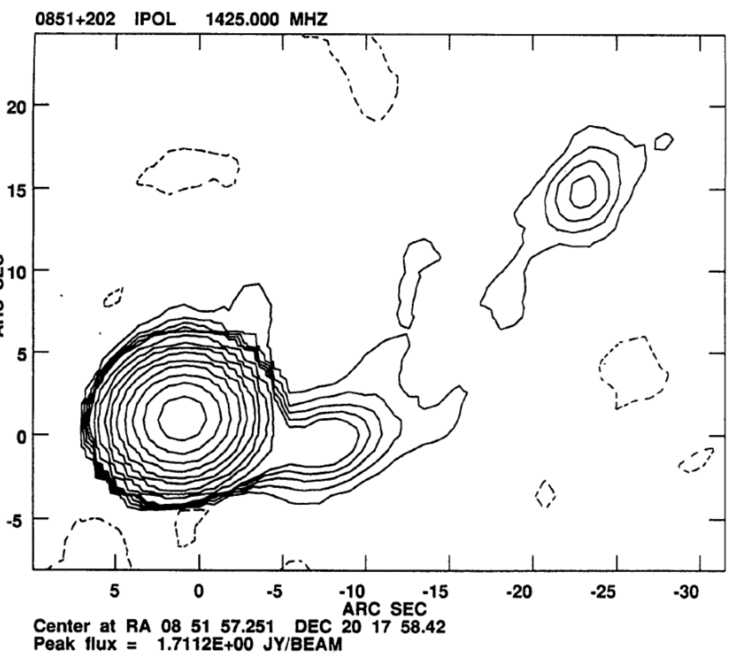

Fig. 1. The 1.4 GHz VLA map of OJ 287 reproduced from [2].

In the optical and infrared ranges, the kpc-scale jet is undetected [3, 4]. In the X-ray range, the jet extends up to a distance of ≈20″ from the core. At the distance of 8″, corresponding to the end of the relatively bright and near to the core radio knots, the X-ray jet bends by ≈55° [3]. After the bend X-ray intensity has almost constant low level (**Fig. 2**).

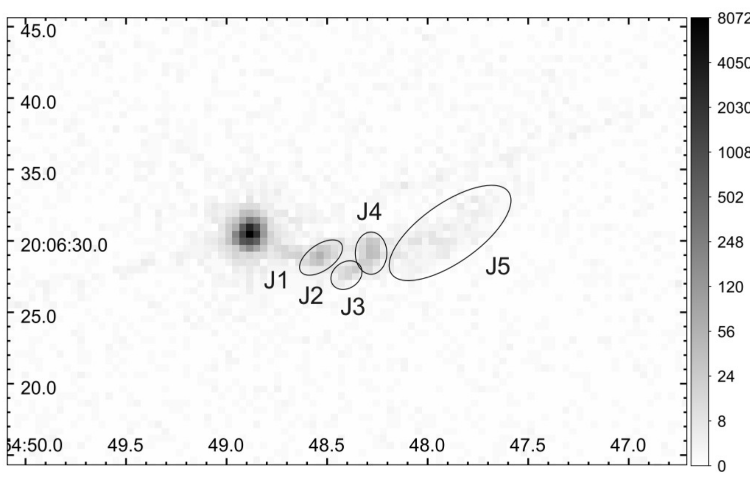

Fig. 2. The OJ 287 X-ray jet map in the range of 0.2-6 keV. The grays-scale is given in the instrumental units of the photon count rate. J1-J5 are jet knots.

There are two possible X-ray emission mechanisms. First of them is ***inverse Compton scattering of cosmic microwave background*** (IC/CMB) under ultra-relativistic kpc-scale jet pointed towards to the observer [5]. The second mechanism is the inverse ***Compton scattering of central source*** photons (IC/CS). Under the radiation of the central source, we mean the pc-scale jet radiation relativistically amplified in the reference frame of the kpc-scale jet [6].

These X-ray mechanisms give different jet speeds $\beta_{\rm kpc}$ and directions to the observer $\theta_{\rm kpc}$ (**Table 1**).

Assuming that the distance ΔR between the farthest knot in the radio band and the knot J1 is the half-wavelength of the precession-curved jet in the projection on the plane of the sky, we calculate a precession period in the observer's reference frame:

$$T_{\rm kpc} = \frac{2\Delta R}{\beta_{\rm kpc}\, c \sin\theta_{\rm kpc}}. \qquad (1)$$

Obtained $T_{\rm kpc}$ values are significantly higher than the periods on parsec-scale. But these values originate at a different distance from the central engine and jet components at parsec- and kiloparsec-scales have different speeds and viewing angles.

Table 1. Obtained jet parameters.

Parameter	IC/CMB	IC/CS
$\delta_{\rm kpc}$	8 [3]	1.02
$\theta_{\rm kpc}$, °	3.8 [3]	≈38
$\beta_{\rm kpc}$	0.97	0.025
$\xi_{\rm kpc}$, °	3 [3]	18
$T_{\rm kpc}$, yrs	$8.1\cdot10^6$	$4.5\cdot10^7$

To coincide them, we find an expression for the period through the azimuth angle change at some distance d from the precession cone apex (**Fig. 3**):

$$\Delta\varphi \approx \frac{\upsilon\Delta t \tan\rho}{(d+\upsilon\Delta t)\cos\xi}, \qquad (2)$$

where ρ is the swirl angle of the jet matter. Taking into account that $d>>\upsilon\Delta t$ and $T=n\Delta t$, we find the period ratio of the quantities corresponding to the pc- and kpc-scales

$$\frac{T_{\rm pc}}{T_{\rm kpc}} = \frac{d_{\rm pc}\cos\xi_{\rm pc}\,\beta_{\rm kpc}}{d_{\rm kpc}\cos\xi_{\rm kpc}\,\beta_{\rm pc}}. \qquad (3)$$

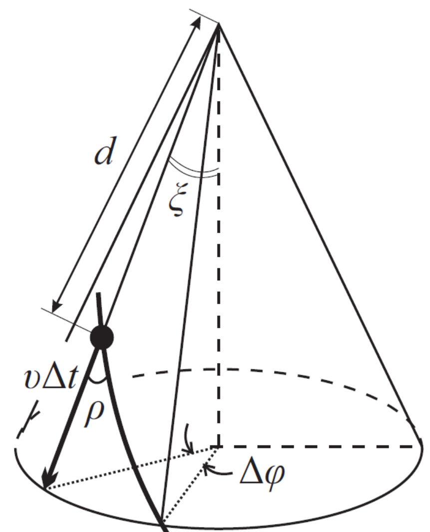

Fig. 3. Scheme illustrating the change in the azimuth angle at a fixed distance from the cone apex when the jet components move along the precession cone generatrix. It is shown one jet component (the filled circle) and a jet part near it (the thick line). Geometrical and kinematic parameters, using for estimation of $\Delta\varphi$, are denoted.

We use $d_{\rm pc}$=4 pc, $\xi_{\rm pc}$=1° to plot the ratio of parsec- to kiloparsec-scale periods (**Fig. 4**).

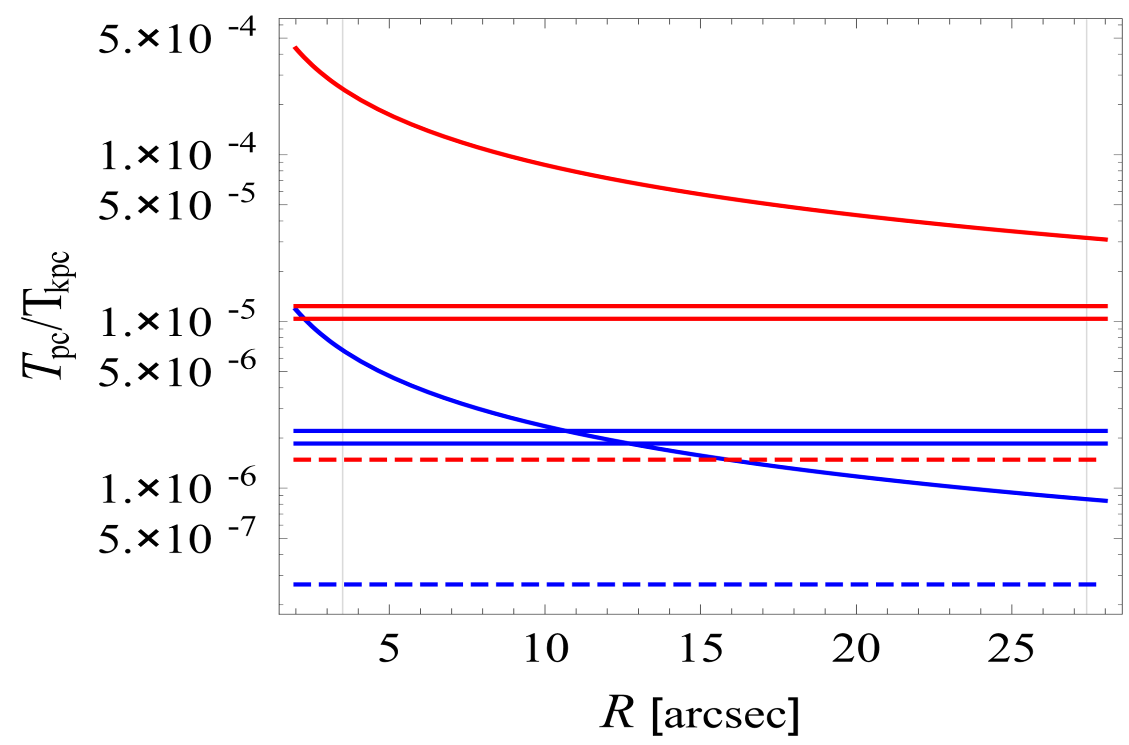

Fig. 4. The ratio of defined at pc- and kpc-scales precession periods. Blue color corresponds to values, which obtained under IC/CS, gray color — to values for IC/CMB. The curved lines show expression (3) as a function of the angular distance from the core. The straight lines mark the corresponding ratios of the periods 92±8 (solid) and 12 years (dashed) to the values $T_{\rm kpc}$.

The accordance of the periods found based on pc- and kpc-scale data is present only for the period obtained within the framework of IC/CS. Under this, the period of the kpc-scale jet helix agrees well only with the precession period of 92 years (in the observer's reference frame), expected under the assumption of a single supermassive BH at the center of OJ 287.

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