Frequency-dependent core shifts and parameter estimation in blazars

Aditi Agarwal, Alok C. Gupta, et al.

Aryabhatta Research Institute of Observational Sciences (ARIES), Manora Peak, Nainital – 263002, INDIA

Abstract

We studied the core shift effect in blazars using the 4.8–36.8 GHz radio light curves (LCs) of three decades using telescopes at UMRAO, CrAO, & MRO. From a piecewise Gaussian fit to each flare, time lags between the observation frequencies ν and spectral indices (α) based on peak amplitudes (A) were determined. Also the index k_r was found to be ~ 1, indicating equipartition between the magnetic field energy density and the particle energy density. A mean magnetic field strength at 1 pc, at the core, the core position offset were inferred consistent with previous. Based on the core radius r as a function of ν, we inferred that the synchrotron opacity model may not be valid for all cases. Fourier periodogram analysis yields power-law slopes and bend timescales. Both positive/negative α, implies that the flares originate from multiple shocks in a small region.

Blazar (A class of AGN)

- ✓Subclass of radio-loud AGN
- ✓**BL Lacs** (Featureless optical spectra) & **FSRQs** (prominent optical emission lines)
- ✓ Flux Variability (in complete EM) on diverse timescales
- ✓ Variable Polarization radio to optical bands
- ✓ Non-thermal radiation (predominantly)
- ✓ Jet axis angle **< 10°**

Motivations behind this study

- Demonstration of the computational efficiency and statistical basis of the piecewise Gaussian fit.
- Find evidence for the core shift dependence on observation .
- Time lags: acceleration/deceleration processes, source geometry.
- Check consistency with the previously reported results.
- Using core-shift to study jet diagnostics in the region close to the resolving limit of VLBI observations.
- Derived parameters: magnetic field strength and size of emitting core, based on theoretical models proposed in earlier literature.

LTV Light Curves

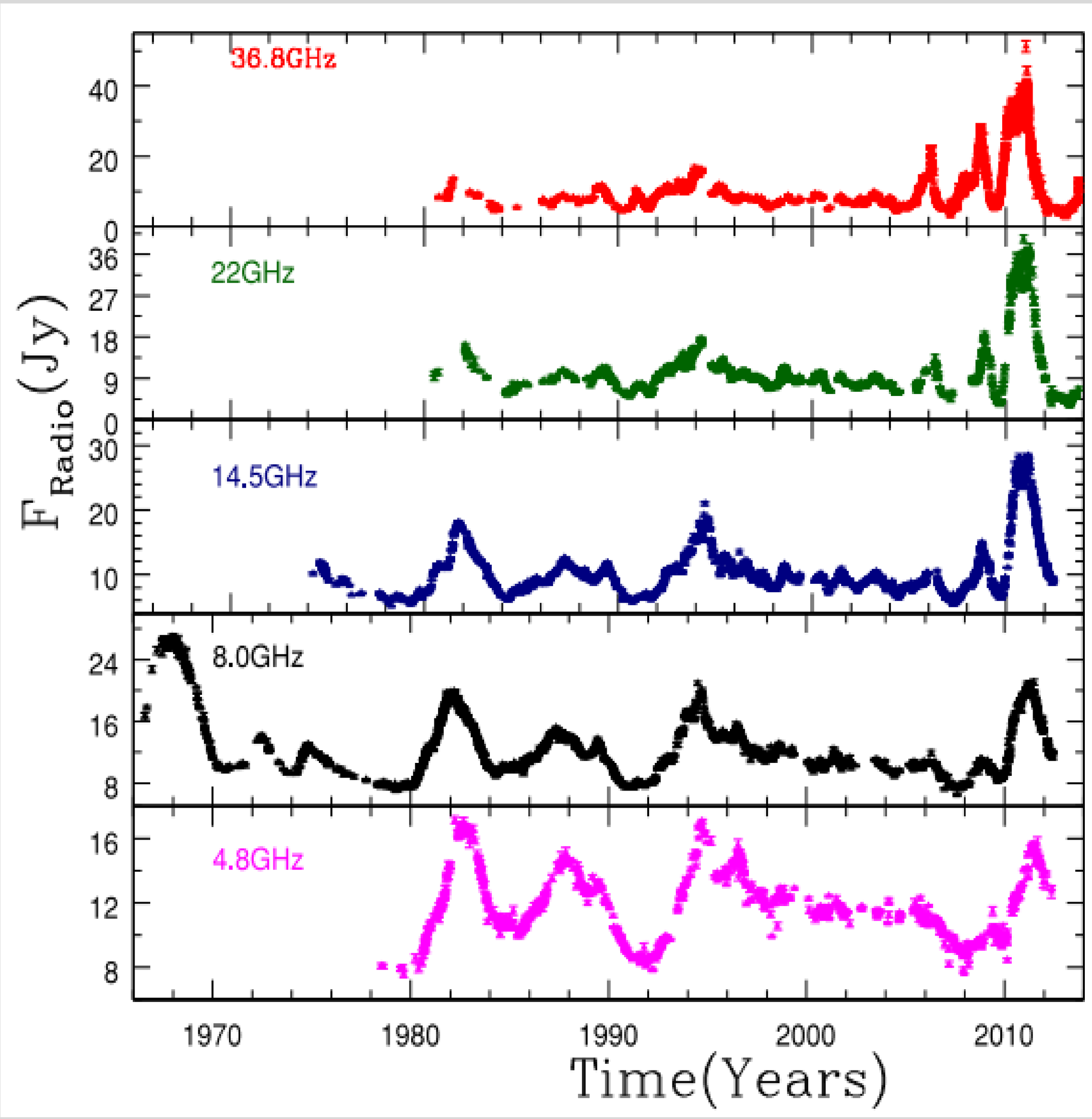


Figure1: Long-term variability light curves of 3C 454.3 in the 4.8 – 36.8 GHz frequency range.

Analysis method

- Pre-processing: determine the positions of the maxima and minima which represent the boundaries of the flaring portions.
- Gaussian function used to represent the shape of each flare: $y = Ae^{[-(t-\overline{m})^2/(2\sigma^2)]}$
- Trial values for A, sigma, and mu generated based on a region around the amplitudes of the maxima.
- For each combination {A,mu,sigma}, the simulated light curve section is compared with that in the original light curve using the chi-squared fit procedure.
- Combination which gives the best fit is the one with minimum chi squared value.
- Full best fitted LC is then generated piecewise from the best fit parameter combination for each section.
- The Gaussians are now evaluated with these best fit parameters for all times.
- LCs split into two segments: one from the start of observations - 2007.0 and other from 2007.0 - end of the observations.
- LC slitting done to check for consistency of results between both segments, determine evolution in the fit parameters and due to the nature of flaring in the LC, i.e. the flares before 2007.0 are of lower amplitude compared to the post 2007.0 flares.

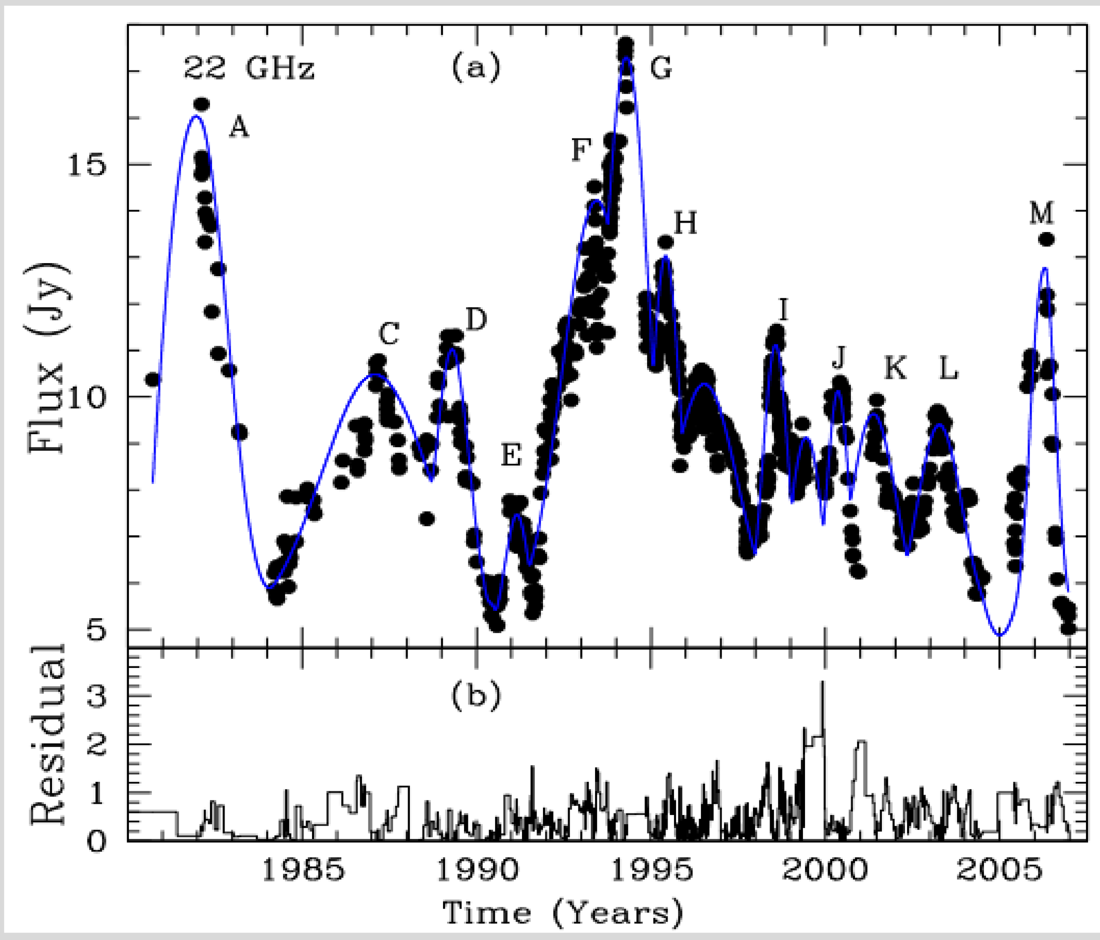


Figure 2: Segment 1 of the 22.0 light-curve flares fit with a piecewise Gaussian function. The residual in the lower panel.

Theoretical Models

1. Core-position offset:

$$\Omega_{r\nu} = 4.85 \times 10^{-9} \frac{\Delta r_{\rm mas} D_L}{(1+z)^2} \left(\frac{\nu_1^{1/k_r} \nu_2^{1/k_r}}{\nu_2^{1/k_r} - \nu_1^{1/k_r}} \right)$$

(Lobanov, A. P. 1998; O'Sullivan S. P., Gabuzda D. C., 2009)

2. VLBI core distance from the jet base at frequency:

$$r_{\rm core}(\nu) = \frac{\Omega_{r\nu}}{\sin\theta} \nu^{-1/k_r}$$

3. Magnetic field strength at 1 pc from jet base:

$$B_1 \cong 0.025 \left(\frac{\Omega_{r\nu}^3 (1+z)^2}{\delta^2 \varphi \sin^2\theta} \right)^{1/4}$$

4. Magnetic field strength near core:

$$B_{\rm core}(\nu) = B_1 r_{\rm core}^{-1}$$

5. Index k_r:

$$k_r = \frac{(3-2\alpha)m + 2n - 2}{5 - 2\alpha}$$

For equipartition: m = 1, n = 2.

Index k_r calculation

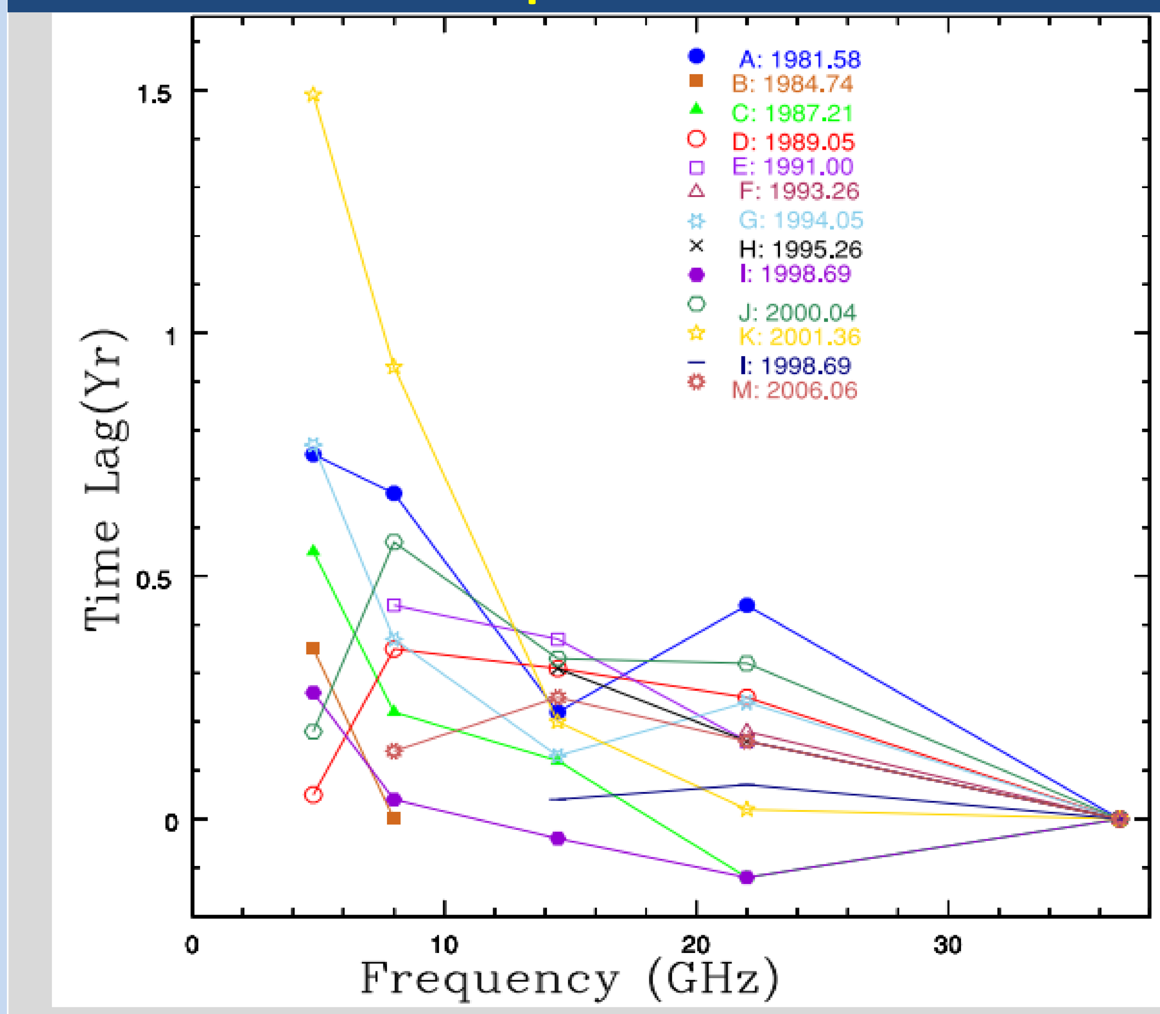


Figure 3: Time lags Δt as a function of ν for segment 1 light curves.

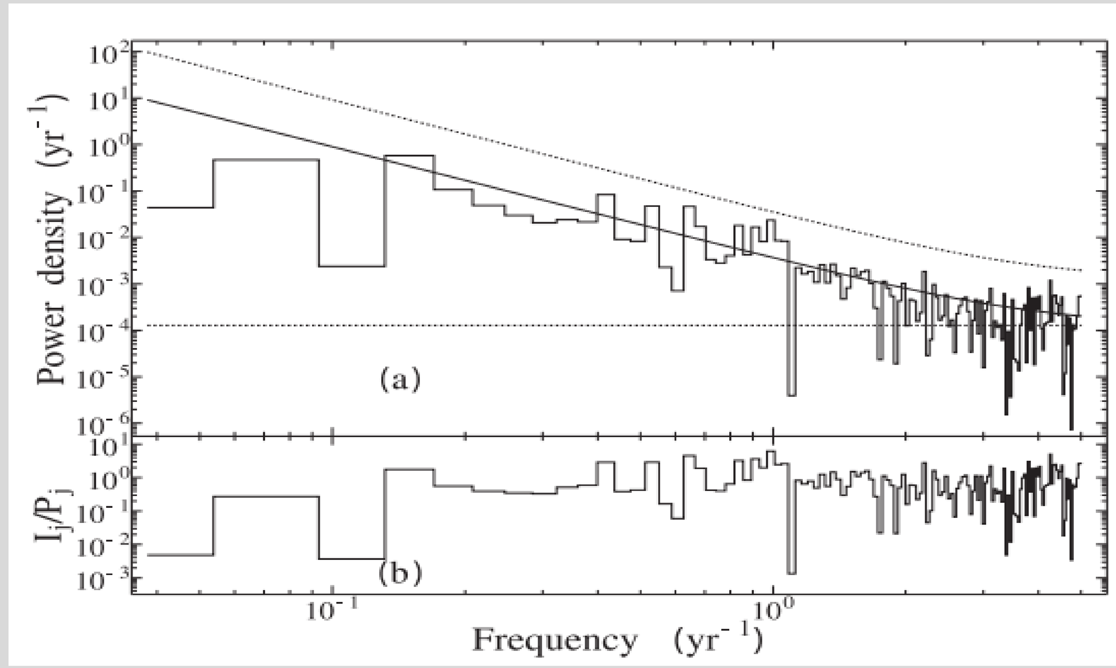
- ❑ Using weighted non-linear least squares method, we fitted time lags derived from the Gaussian fits Vs frequency with a function: $\Delta t = a\nu^{-1/k_r} + b$
- ❑ Median of each parameter and the associated median deviation are: $b = -0.28 \pm 0.19$ yr

$$a = 5.51 \pm 1.03 \text{ yr (GHz)}^{-1/k_r}$$

$$k_r = 0.97 \pm 0.24.$$

Fourier periodogram analysis

- ✓ **Linearly interpolated and sampled LCs at intervals of 0.1 d.**
- ✓ **This evenly sampled LC used to determine PSD shape and any statistically significant QPOs.**



Results

- ➢ Inferred Δt are in agreement with frequency dependence of synchrotron emission from core.
- ➢ Spectral indices varied from −0.24 to 1.52 for both segments. The flaring activity can thus be attributed to multiple propagating shocks.
- ➢ B_1 = 0.48 ± 0.21 G & B_{core} = 46 ± 16 mG considering both segments; consistent within error bars of B_1 = 0.493 G (Chai et al. 2012), B_{core} = 0.04 ± 0.02 G (Kutkin et al. 2014).
- ➢ Weighted mean $\Omega_{r\nu}$ = 6.4 ± 2.8 pc $GHz^{1/kr}$ averaged over all frequency pairs.
- ➢ Based on the trend of r_{core} as a function of ν, we infer that synchrotron opacity model may not be valid for all cases.
- ➢ Power-law slopes: −1.6 to −3.5 for power and bending power-law PSD. From the analysis: LCs are consistent with multiple shock excitation events. Bending power-law model inferred to be better PSD fit with −3.5 slope, consistent bend time-scales ranging between 0.51 - 0.66 yr.

References

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Contact: aditi@aries.res.in