3C 84: a Possibly Precessing Jet in 43 GHz Observations

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SFB 876 Providing Information by Resource-Constrained Data Analysis

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Introduction

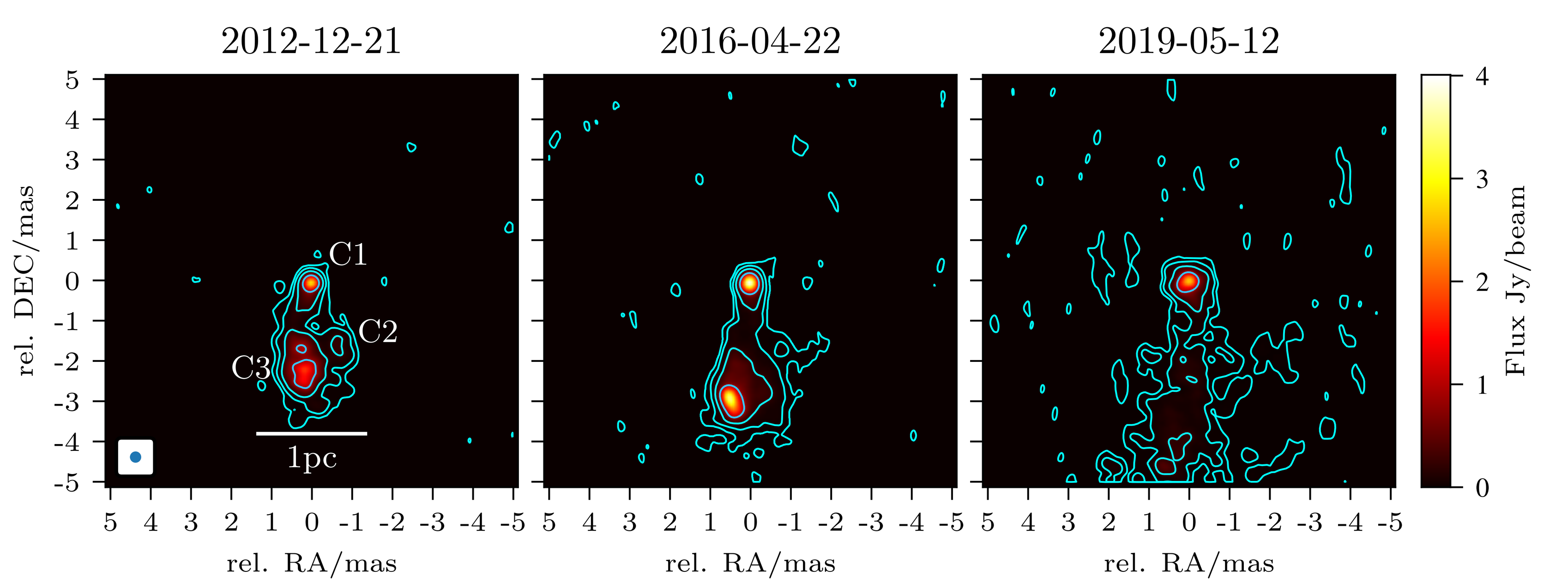

Figure 1: Three epochs of 3C 84 BU-BLAZAR observations. A change in the position angle η (measured to the DEC-axis) of the jet emerging the C1 component is visible.

3C 84, the radio counterpart of the central galaxy of the Perseus cluster NGC 1275, is a well observed active galactic nucleus (AGN). Despite all efforts, inconsistent values for its inclination angle, the angle between the jet axis and the line of sight, were reported in previous publications. Very Long Baseline Interferometry (VLBI) experiments calculated this angle to be 30–55° [1], 11° [2] and $(64 \pm 16)°$ [3]. Krichbaum et al. found a strongly bent jet, whose inclination angle changes from $\lesssim 2.7°$ on a milli-arcsecond scale up to 39.4–58.2° on an arcsecond scale [4]. In the gamma-ray regime, *Fermi*-LAT reported an inclination of 25° [5] while MAGIC found an angle $\lesssim 12°$ [6]. Our paper [7] aims to resolve this ambiguity, studying the possibility of a precessing jet inside the AGN using the 43 GHz data obtained by the VLBA-BU Blazar Monitoring Program. Signs for such a precession were previously reported, for example in the X-ray regime [8].

Precession Model

As the available observations are intrinsically 2D and only offer access to the position angle η, a conversion to the 3D reality is needed to gain information about the inclination angle ϕ. To establish this connection, Caproni & Abraham [9] employed a set of rotations to derive the changes in η due to a jet precessing with an angular frequency ω. Even though a constantly changing ϕ results in an equally changing doppler-factor, including these relativistics would result in an overly complicated model with respect to the limited amount of data available. We have, in consequence, chosen to treat the jet as non-relativistic.

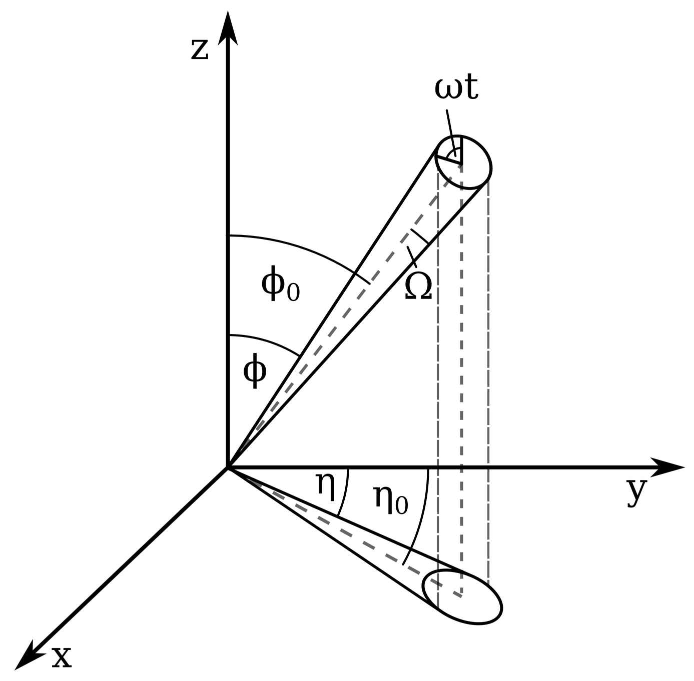

Figure 2: Precession model in 3D as discussed in [9]. The observer looks along the z-axis onto the 3D motion.

Position Angle Extraction and Model Fitting

We automated the extraction of the position angle η from the provided images by applying a primary component analysis on the segmented C1 component after restoring all images to a common circular beam. This approach resulted in good estimation even for noisy images, although a clearly identifiable jet base is needed for this to work. To fit the parameters of the complex precession model we used a two-step Bayesian inference process, starting with uniform priors and refining the results using Gaussian priors derived from the first step posteriors in the second run. Using Bayesian inference allows us to estimate systematic uncertainties.

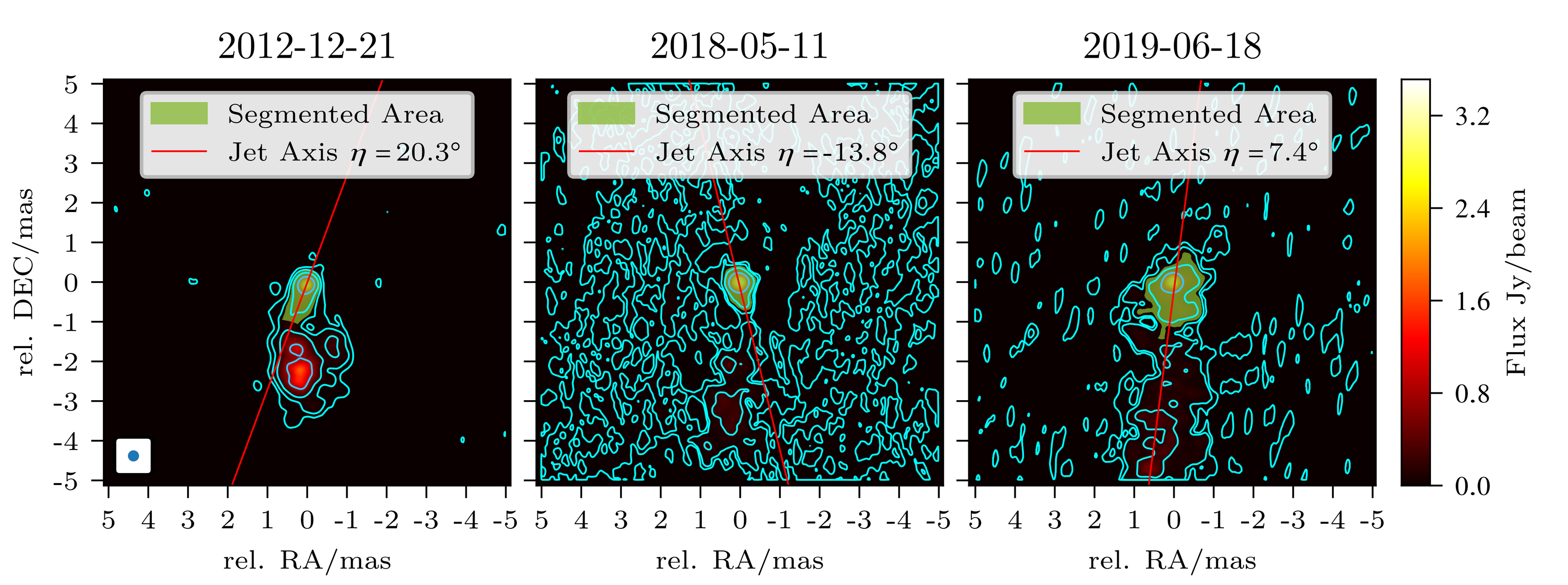

Figure 3: Illustration of the extraction process. *Left:* Good quality epoch. *Mid:* Noisy epoch. *Right:* Epoch with indistinct jet base.

Precession Results

Using the described model, we derive a precession with a frequency ω of $(12.5 \pm 1.8)\,°\,\mathrm{yr}^{-1}$ which corresponds to a period of $\approx 28.8\,\mathrm{yr}$ and a precession cone half opening angle Ω of $(22.7 \pm 4.0)°$. The resulting model follows the data and can explain the position angle of the C2 and C3 component (derived from [10]) that were used as a cross-check.

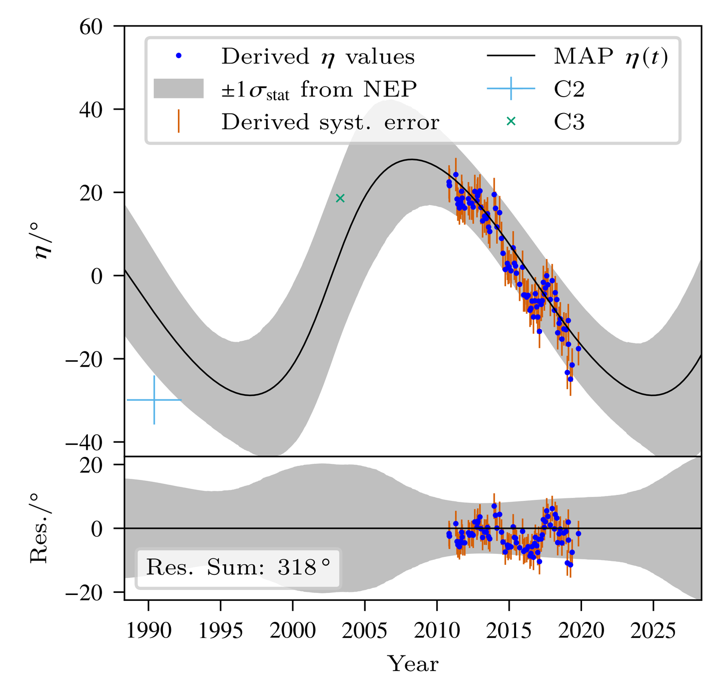

Figure 4: Extracted data and fitted model (MAP) with statistical error computed by numerical error propagation (NEP) for η.

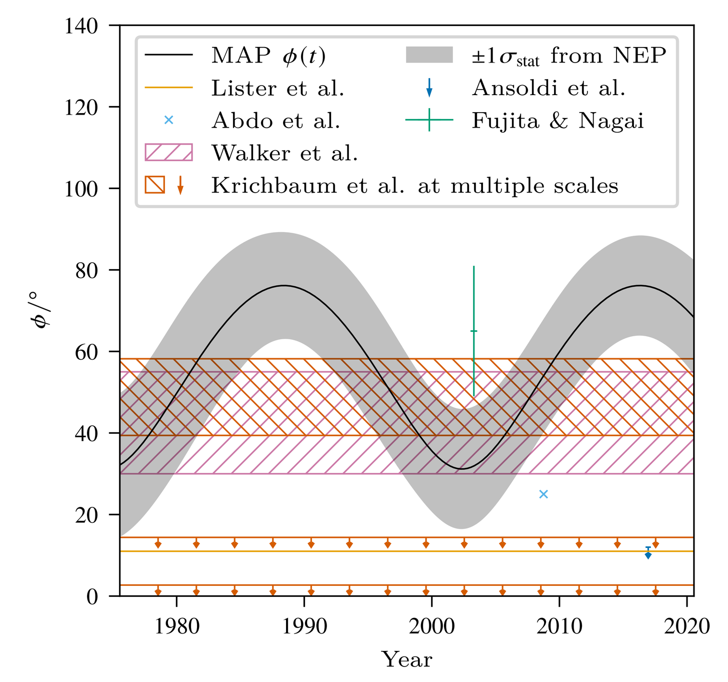

Figure 5: Inclination angle ϕ computed from the η-model fit with error estimation and previously published values.

Testing an Additional Nutation

The pure precession model used above can easily be extended to account for an additional nutation [11]. We find a frequency of $(16.8 \pm 1.1)\,°\,\mathrm{yr}^{-1}$ (period of $\approx 21.4\,\mathrm{yr}$), a half opening angle of $(19.3 \pm 1.7)°$, a nutation cone half opening angle of $(2.9 \pm 0.7)°$ and a nutation frequency of $(106.3 \pm 5.4)\,°\,\mathrm{yr}^{-1}$ (period of $\approx 3.4\,\mathrm{yr}$). However, the computed inclination angle does even exceed 90° - something which is not indicated by observations. Consequently, we expect these results to be overfitted and suggest revisiting this when more data is available.

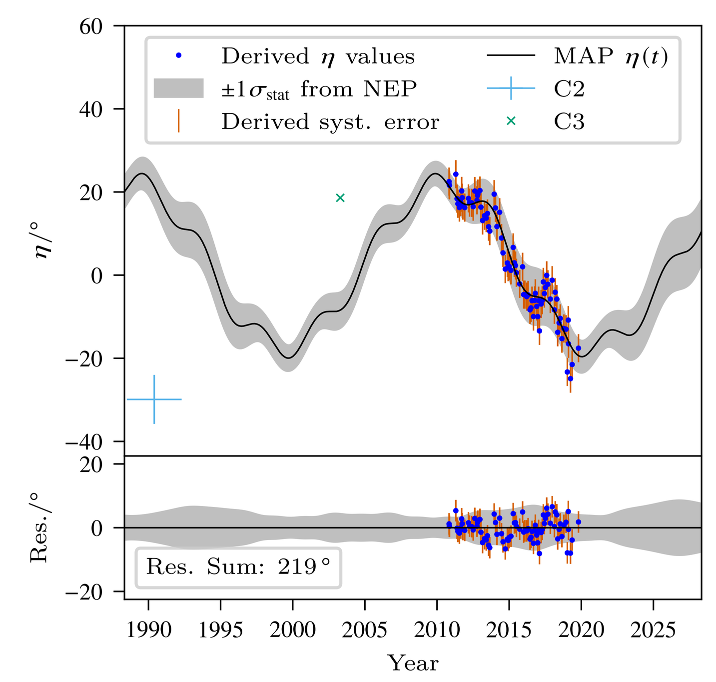

Figure 6: Extracted data and fitted nutation model.

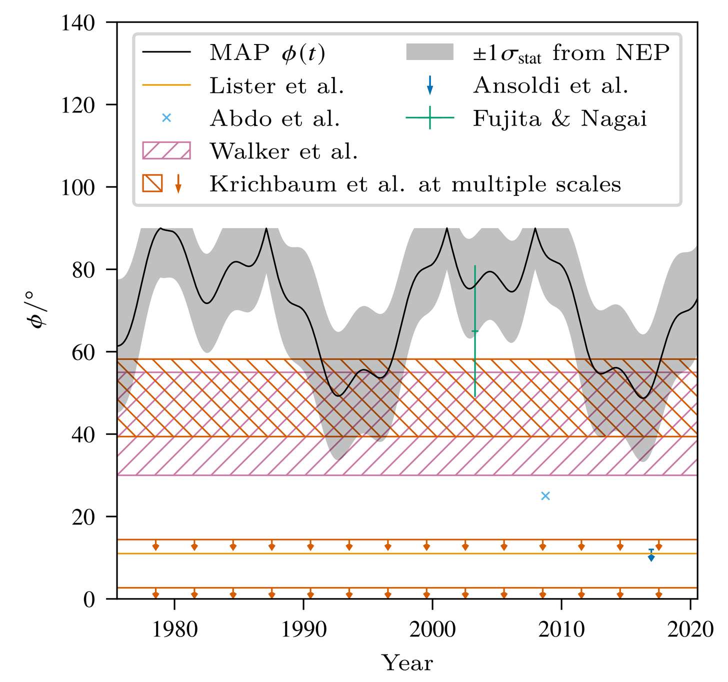

Figure 7: Corresponding inclination angle ϕ.

Conclusions

We find a strong indication for a precessing jet as we can see a clear change in the jet's position angle over time. The fitted precession on time-scales between 25 and 30 yr is, compared to existing publications, extremely short. If the evidence for a precessing jet would tighten, this would be a strong sign for a binary black hole system inside 3C 84's center. We strongly suggest revisiting this analysis when more observations of the ongoing program are available.

References

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