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The kinematics of S5 1803+784

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We present the results of a multi-frequency analysis of the structural variability in the parsec-scale jet of the blazar S5 1803+784. More than 90 epochs of observations at 6 frequencies from 1.6 GHz up to 22 GHz have been combined and analyzed. We discuss an alternative jet model for the source. In contrast to previously discussed motion scenarios for S5 1803+784, we find that the jet structure within 12 mas of the core can most easily and plausibly be described by seven "oscillating" jet features. We find that the parameters of jet features, such as core separation, position angle and flux density, change in a periodic way with a timescale of about 4 years. We also find evidence for a correlation between these parameters and the total flux density variations. We suggest a scenario incorporating a periodic form of motion (e.g. rotation, precession), with a non-negligible geometrical contribution to explain the observational results.

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1. Introduction

The BL Lac object S5 1803+784 is a compact flat-spectrum radio source with z = 0.68 [25] and shows a misalignment between kpc- and pc-scales[4]. It has been observed for more than 30 years at different frequencies and with different resolutions (e.g. [5, 6, 23, 27, 9, 16, 2]). These observations enable us to investigate the long-term evolution of its flux and structure. The brightest jet component in S5 1803+784 used to be one of the most prominent candidates for a "stationary" component. However, as shown in [3], the so-called stationary component "moves" or "oscillates".

2. Observations

We analyzed archival VLBI observations at six frequencies ν =1.6, 2.3, 5, 8, 15 and 22 GHz (1.6 and 2.3 GHz: see [19, 10] for details of these observations; 5 GHz: [10] and L.I. Gurvits (priv. comm.); 8.4 GHz: [20, 21, 22]; 15 GHz: [20, 12, 13] and the 2-cm survey webpage; and observations we carried out at 1.6 GHz). We analyzed archival data, re-imaged all the epochs and parameterized the flux density distribution at parsec scales using Gaussian functions fitted to the interferometric visibilities. The fitting was made using *DIFMAP* package [24]. We used circular Gaussian components in order to avoid extended elliptical components and to facilitate the component identification. In order to compare our results with results described in the literature, we included the model-fitting parameters collected from different papers [8, 18, 17, 26, 3]. In Fig. 3 (bottom right), a list of all the observational epochs analyzed for this work is presented. The total number of analyzed epochs is 94.

3. Results

3.1 Oscillating components.

We have carried out a new identification for the jet features of S5 1803+784, using the whole database. In Fig. 1 we show the model-fitting results at 5 GHz (bottom left panel), 8 GHz (top right for the geodetic data from 1986 – 1994; bottom right for data from the literature) and 15 GHz (top left). It is clearly seen that in addition to a "stationary" component **Ca** 1.4 mas from the core, there are several other components that also appear stationary, both interior to **Ca** (**C0** at $\sim$ 0.3 mas, **C1** at $\sim$ 0.8 mas) and exterior to **Ca** (**C2** at $\sim$ 2 mas, **C4** at $\sim$ 3–4 mas, **C8** at $\sim$ 6–8 mas, and **C12** at $\sim$ 10–12 mas).

The jet components remain at similar core separations from 1986 until 2006, while their position angles change with time (Britzen et al., in prep.). We find only one component, B3, moving outwards during twenty years of observations, which is shown in the upper left in Fig. 1. It follows that the jet of S5 1803+784 consists of a number of "*oscillating*" components, which do not move outwards, but remain at an average value of the core separation.

3.2 Quasi-periodicity.

The mean jet ridge line of S5 1803+784 changes gradually with time in a periodic way. Fig. 2 shows the temporal evolution of jet component positions at 15 GHz for the period 1994 – 2005. Each dot represents the position of one jet component in rectangular coordinates X and Y. The lines connect all the components for one particular epoch of observation. From an almost straight line in 1994.67, the shape of the jet evolves into a sinusoidal contour with a maximum positive Y at X $\sim$ 1 mas and a maximum negative Y at X $\sim$ 2 mas. The amplitude of the sinusoid reaches its maximal values in the Y coordinate in 1998.84, decreases again, forming an almost straight line in 2003.10. One period is completed after $\sim$ 8.5 years and the jet shape begins to evolve into a sinusoid again. However, the position of the straight lines in 1994.67 and 2003.10 are different and the difference in the Y coordinate is 0.1 mas.

In order to check for possible quasi-periodic changes in the shape of the jet, we applied a discrete autocorrelation function (DACF, [7]) and the Jurkevich method [11] to the variations of the jet components' parameters with time for the all available data from 1981 until 2005, including the core separation, the position angle and the flux, from the inner-most component **C0** to the outer-most **C12**. For the inner jet components **C0**, **C1**, **Ca** and **C2**, we find that at 8 and 15 GHz a quasi-periodicity of about 4 years exists in the variation of the core separation, the position angle and the flux. The DACF peaks at 0.8–0.9 and the f function which indicates the trustworthiness of the identified periods[15] ($f > 0.5$ indicates very strong periodicity) ranges from 0.51 to 1.80. The 8.5-year cycle mentioned above has been found for the time period 1994 – 2005, whereas this

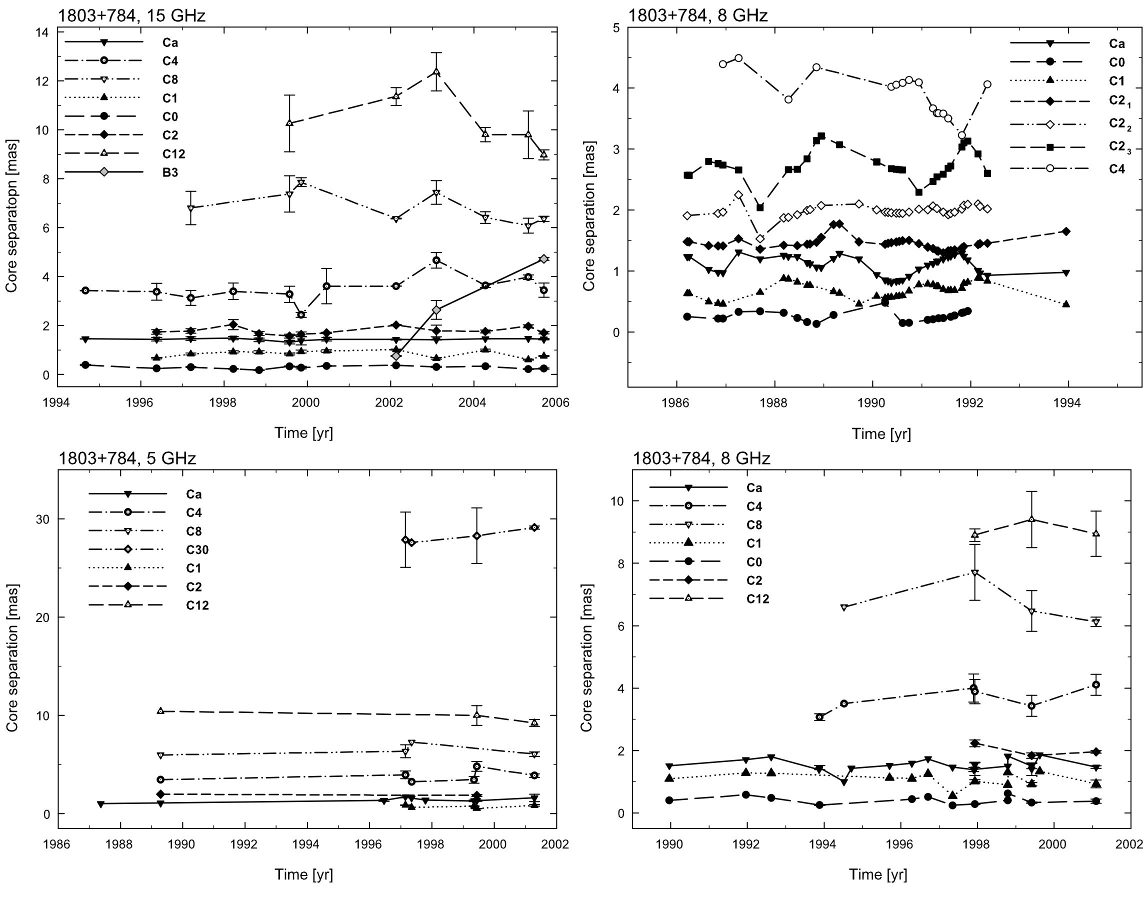

Figure 1: The core separation as a function of time for the jet components detected at 15 GHz (upper left), 8 GHz (upper right for the period of time 1986 – 1994; bottom right for 1990 – 2002) and 5 GHz (bottom left). Individual components are denoted by different symbols and different lines.

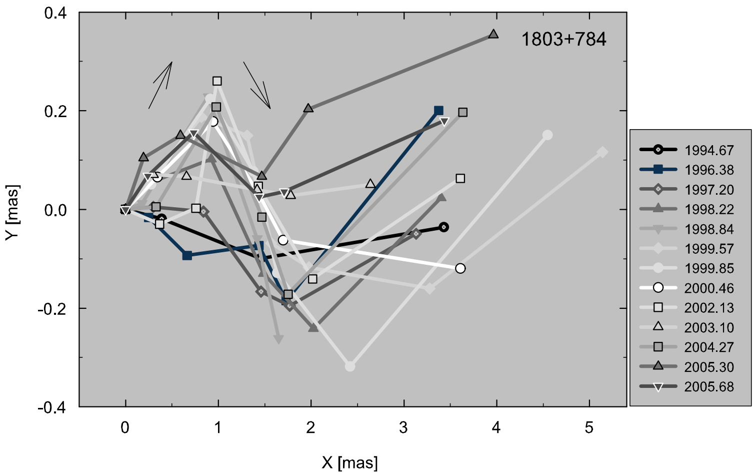

Figure 2: The changes in the mean jet ridge line as a function of time at 15 GHz. Each dot represents the position of one jet component in rectangular coordinates X and Y. The lines connect all the components for one particular epoch of observation. The shape of the jet changes from epoch to epoch from an almost straight line to a sinusoidal form and then back to the straight line again and thus possibly describes an oscillating motion with a period of 8.5 years. The arrows indicate the direction of changes.

4-year period has been found for the whole period 1981 – 2005. The 8.5-year cycle is twice the period found by the time series analysis. Possible explanation of this could be that the peak in 1999, in the middle of a 8.5-year cycle, had an unusual low amplitude compared to other peaks. The periodicity of 2 and 3.9 years was found before in total radio flux density light curves [14] by means of a cross-wavelet transform and the second period is similar to the four-year period found here.

3.3 Correlations.

We determined the cross-correlation functions [7] to search for possible correlations between the variability of various jet parameters and the total flux density. We calculated the cross-correlation functions for the pairs of parameters within one of the components **C0**, **C1**, **Ca**, **C2** and **C4**, such as the core separation, the flux density, the position angle changes and the total flux density variability (UMRAO data, [1]) at different frequencies. For a few jet components such a correlation is clearly visible. As an example, we show in Fig. 3 (left) the variation of core separation, position angle and flux density for the component **C1** at 8 GHz in the period 1984 – 1996. We found that for all the inner components **C0**, **C1**, **Ca**, **C2** and **C4** at 8 and 15 GHz there is a correlation between different parameters of components (peak values of discrete correlation function vary from 0.60 to 0.99 for different parameters). At other frequencies, for which the data are much more sparse and inhomogeneous, the correlation could not be detected.

Moreover, a correlation exists not only between parameters of the jet components, but also between the variation of the jet parameters and the total flux density changes (see Fig. 3, top right). For the inner components **C0**, **C1**, **Ca** and **C2**, the core separation and position angle changes correlate with the total flux density light curves at 8 and 15 GHz with correlation coefficients ranging from 0.3 to 0.8 and almost zero time delay. We did not find any correlation for component **C4**. A special case is component **Ca**, which shows a correlation between changes in the core separation and the total flux density but an anti-correlation between changes in the position angle and the total flux density behaviour that applies both to 8 and 15 GHz.

4. Discussion

We find that the jet can be described as a set of seven "*oscillating*" features, which do not move outwards, but stay near an average value of core separation. The jet component parameters, such as core separation, position angle and flux density change in a periodic way with a period of ~4 years for the inner jet components at 8 and 15 GHz. A similar 3.9-year period is found in the total flux density light curves by Kelly et al. (2003) [14]. Moreover, changes of the core separation, position angle and flux are correlated with each other and the total flux density variability. Based on the results presented here, we conclude that a scenario incorporating a periodic form of motion (e.g. rotation, precession), with a non-negligible geometrical contribution, can possibly describe the behaviour of the jet components. A detailed analysis of the kinematics of S5 1803+784 will be presented in a forthcoming paper (Britzen et al., in preparation).

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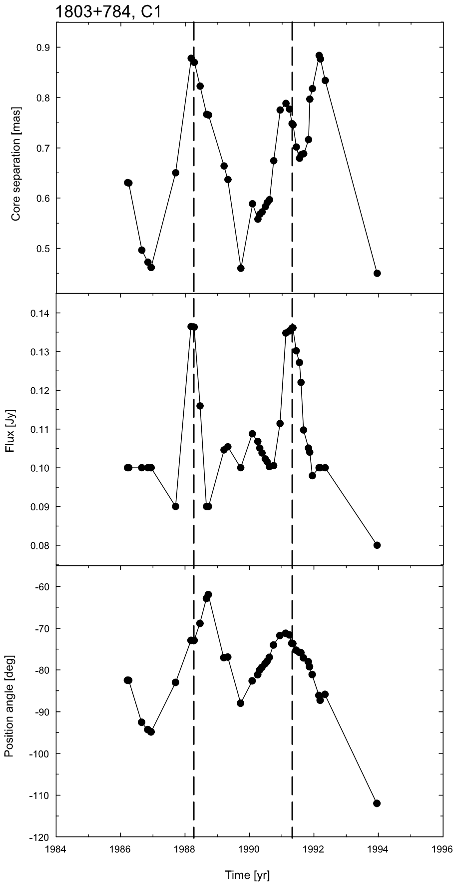

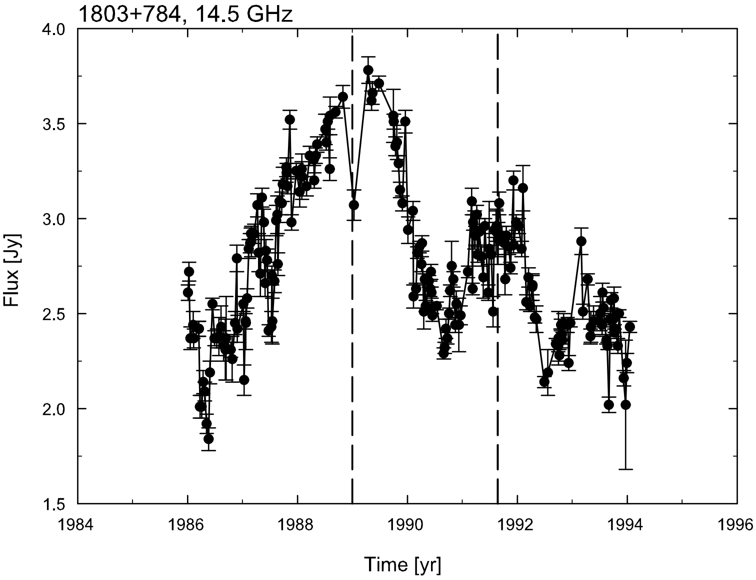

ν [GHz]	N_{epochs}	Interval of observations
1.6	7	1981.8 – 2001.9
2.3	2	1994.5 – 1996.4
5.0	8	1987.4 – 2001.3
8.0	61	1986.2 – 2001.1
15.0	14	1994.7 – 2005.7
22.0	2	1995.6 – 1997.3

Figure 3: Left: The core separation, flux density and position angle of a component **C1** as a function of time at 8 GHz during the period 1984–1996. It is clearly seen that these three component parameters are correlated. Dashed lines indicate the position of the peaks. **Top Right**: Total flux density light curve for 14.5 GHz (Aller et al. 1985). **Bottom Right**: The list of observational epochs of S5 1803+784, where ν is the frequency of the observations in GHz, N_{epochs} is the number of epochs, and *Interval of observations* is the time span covered by the observations.

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