Variability of the core shift effect in AGN jets

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Significant frequency-dependent core-shift variability during AGN core flares is detected on sub-parsec scales. The shift as well as magnetic field strength in the jet apex region peak prior to the peak of observed core flux density.

Introduction

The observed position of the core in radio jets of active galactic nuclei changes with the observing frequency because of synchrotron self-absorption and external absorption. Measuring this shift allows to reconstruct geometry of the jet base, probe physical conditions close to the core and determine the core position itself more accurately.

Observations

For this study we use observations conducted for astrometry VLBA projects at epochs ranging from 1994 to 2012; typical number of epochs for each source we studied is about 40. Two sources are shown as examples below: Figure 1 shows a typical source with a long jet structure providing stable results of cross-correlation, and Figure 2 shows a source which has regions with very different spectral index, which makes cross-correlation unstable; such sources are not common, this is one of the most extreme examples.

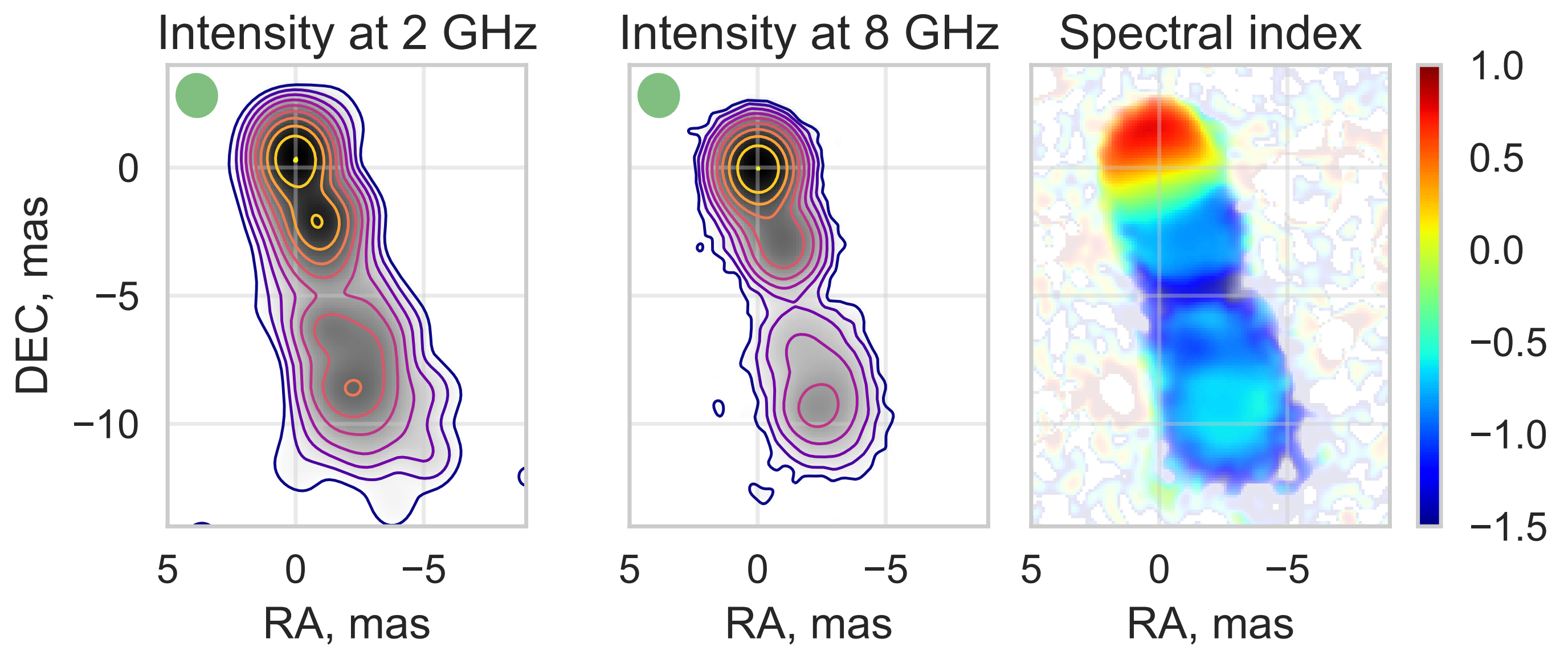

Figure 1: Maps of an object with a long jet (J1642+6856 at 1999-12-20): intensities at 2 GHz and 8 GHz convolved with the same beam and pixel size, spectral index.

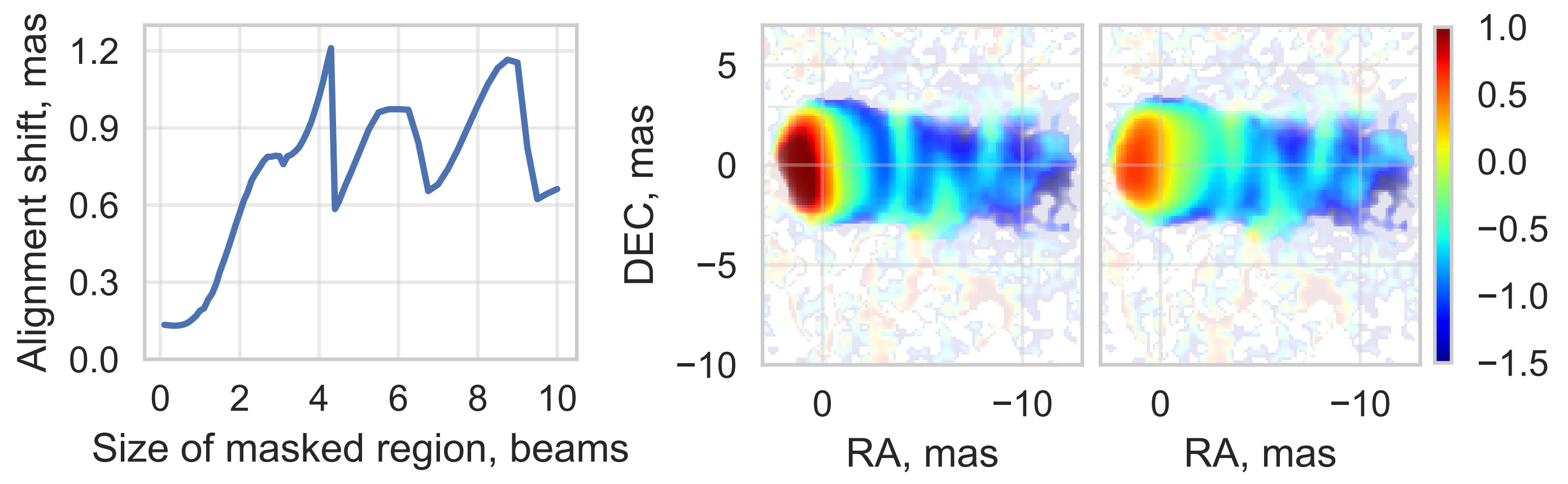

Figure 2: An object with large spectral index variations in jet (J1800+7828 at 2001-03-12), left to right: plot of estimated alignment shift between maps depending on mask size, spectral index maps for two different alignments.

Methods

Determining core shift requires aligning maps made at different frequencies and locating the core positions on them:

- *Aligning maps at different frequencies* is performed using 2D masked normalized cross-correlation. We mask the core region on the 8 GHz map and find the best-fit shift.
- *Core position* is estimated with fitting a gaussian component to calibrated visibilities in the UV plane. As we are interested in the core component only, CLEAN model components outside of the core region are subtracted from visibilities prior to fitting gaussians.

Having computed the core shift vector, we can derive other physical parameters, most importantly — the magnetic field at the core region of the jet, at 1 pc from the jet vertex — $B_1 \sim \Delta r^{3/4}$ (Pushkarev et al. 2012).

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Core shift and magnetic field distributions

In most cases estimated core shift vectors align well with the jet direction computed based on the jet component closest to the core (Figure 3), and even when not aligned, they doesn't seem to have a systematic error in direction. We consider core shift to be in the direction from the 8 GHz core to 2 GHz core, so this means that the core at lower frequencies is located further along the jet, as expected.

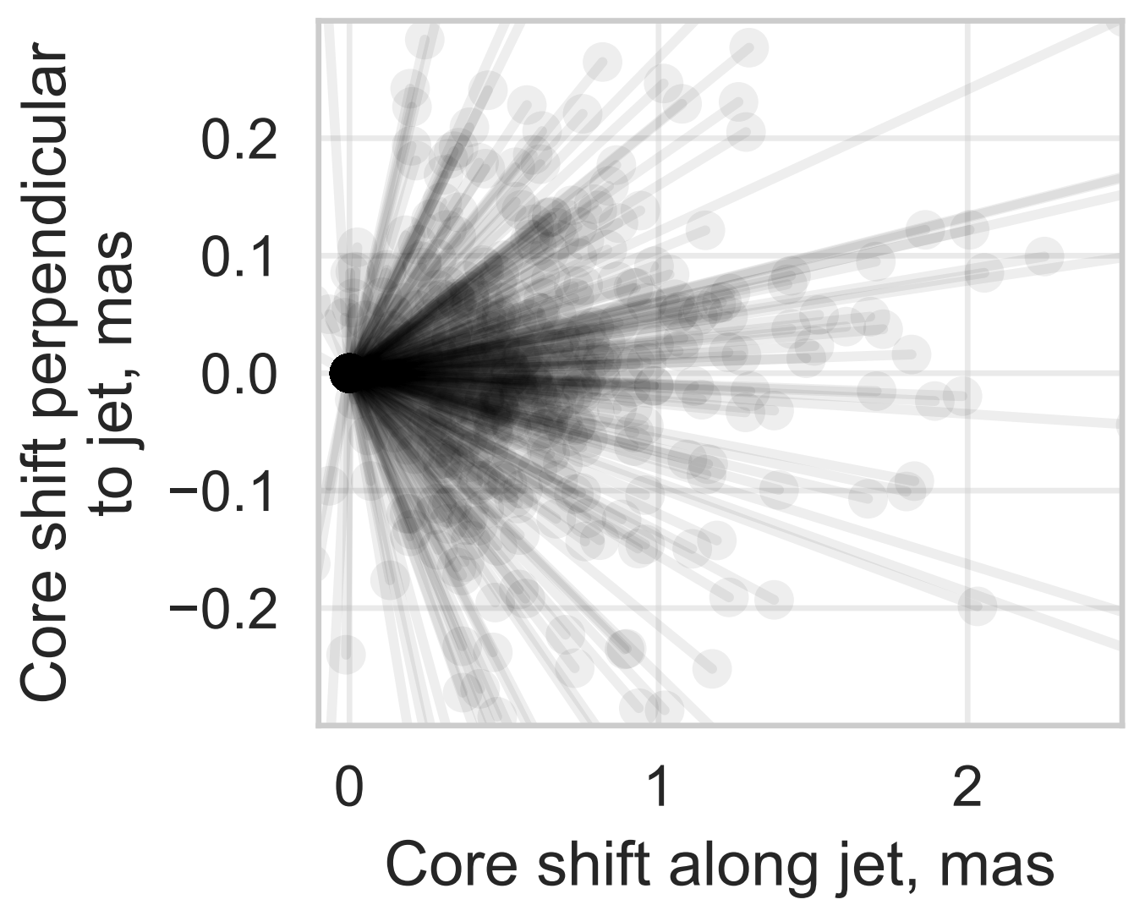


Figure 3: Core shift alignment with the jet direction.

For all computations below we use the projection of the core shift to the jet direction, as the perpendicular component is likely dominated by noise.
Typical values and distributions of estimated core shift magnitude and magnetic field B_1 are shown at Figure 4 for different sources and their classes.

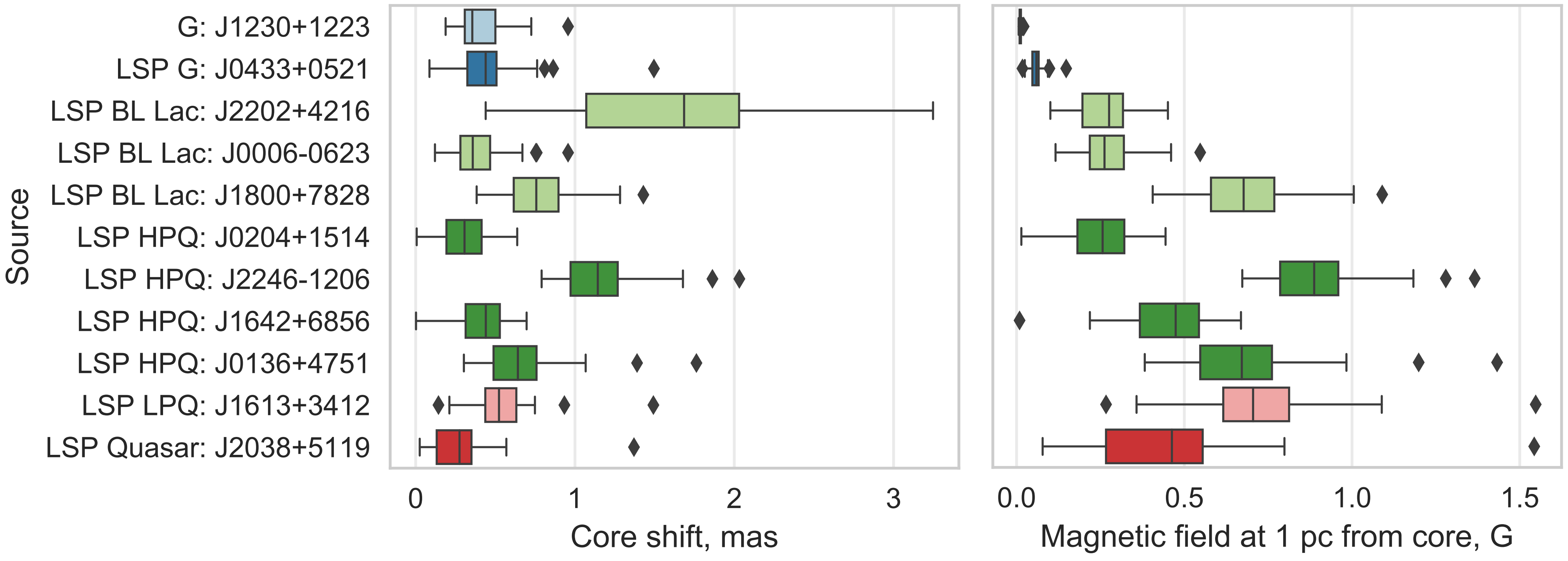
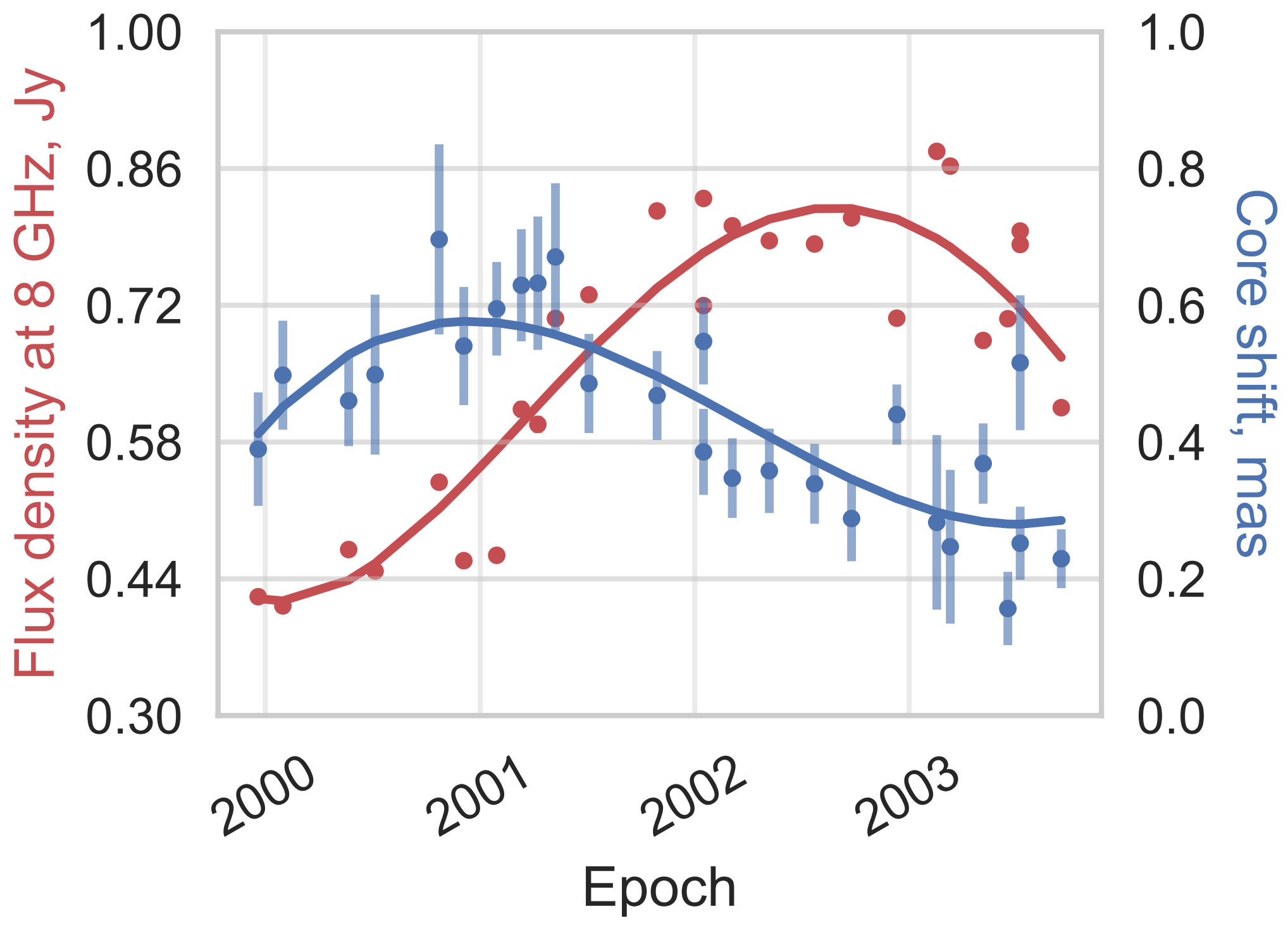


Figure 4: Core shift and magnetic field distributions.

Variability of derived parameters

The studied observations include sources with apparent flares, which gives us the opportunity to examine what changes happen in core shift and magnetic field during these epochs. One of such examples is at Figure 5, which shows that magnetic field increases first, and brightness follows. Figure 6 shows another source, which was probably at the beginning of the flare already when the observations started, so its core shift was already declining.



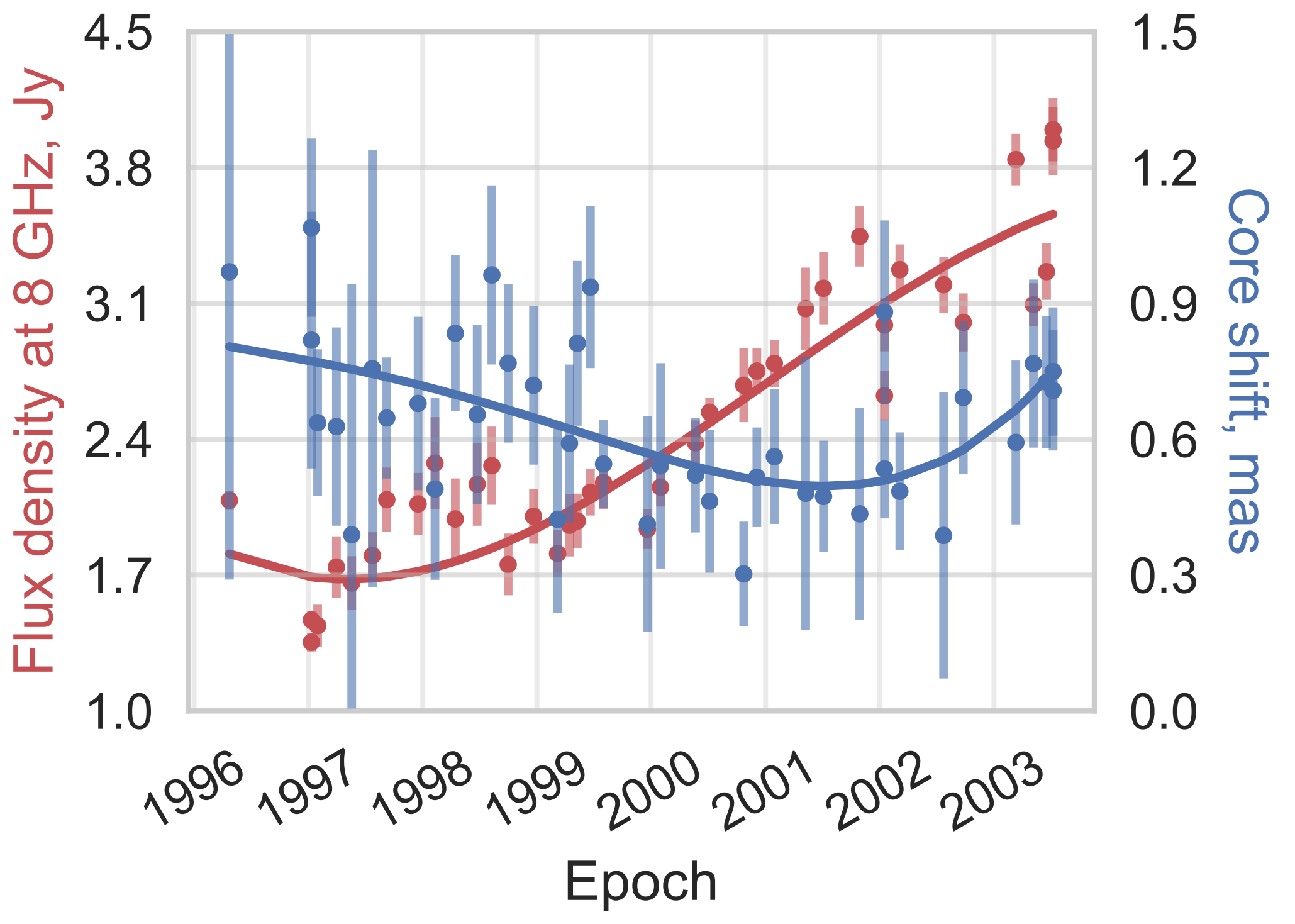
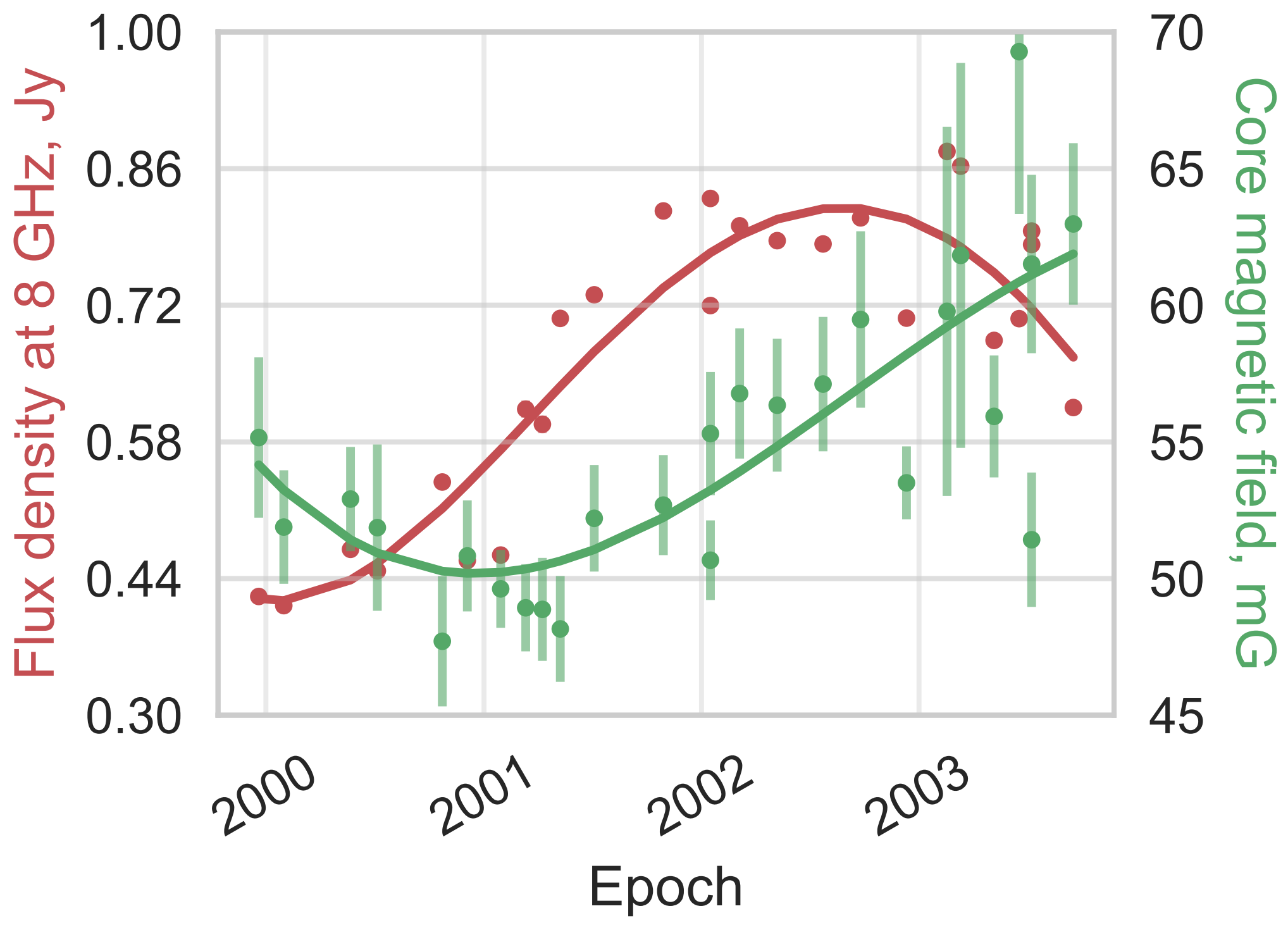


Figure 5: Flux density and core shift during a flare in J1642+6856 (LSP HPQ).

Figure 6: Flux density and core shift at the beginning of a flare for J0136+4751 (LSP HPQ).

Such behavior makes sense from the physical perspective as core shift is related to magnetic field close to the jet vertex, and flares are probably moving along the jet. For comparison, figures 7 and 8 show magnetic field at the apparent jet core: as we can see, peaks are reached at different epochs.



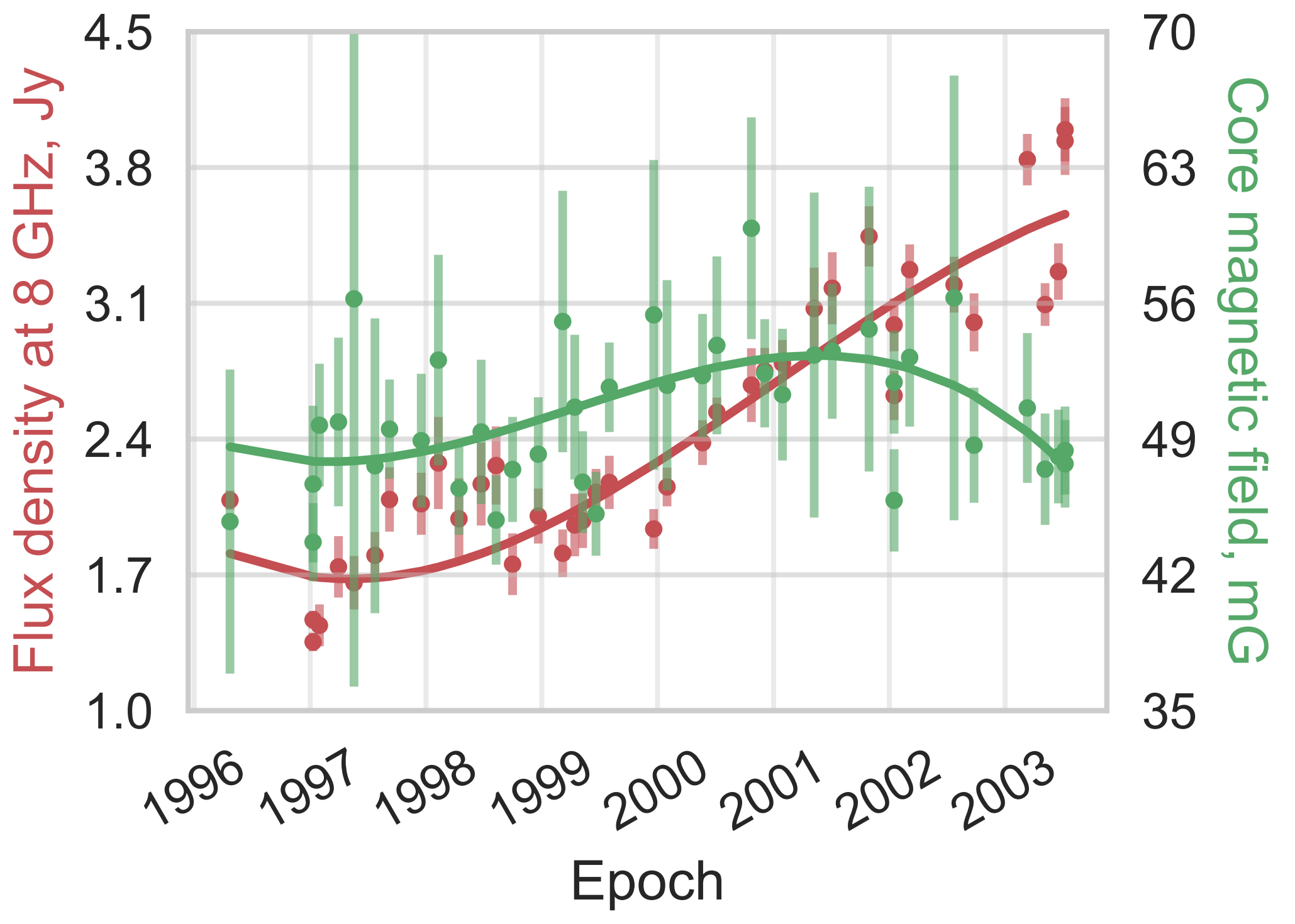


Figure 7: Flux density and magnetic field during a flare in J1642+6856 (LSP HPQ).

Figure 8: Flux density and magnetic field at the beginning of a flare J0136+4751 (LSP HPQ).

Note: solid lines represent polynomial fit and are shown for guidance only.

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