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Observational constraints on the blazar jet wobbling timescales

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Introduction

Blazars are a subclass of radio-loud active galactic nuclei (AGNs), where the jet is aligned close to the line of sight. Emission of blazars is dominated by the jet in a wide range of wavelenghts from radio to very high energy gamma-rays. Blazars are also characterized by a rapid variability, the origin of which is not yet clear. Changes of the viewing angle of the emitting region in a twisted or wobbling jet has been proposed as one of the mechanisms that could explain the variability of blazars [1].

Detailed simulations of a tilted disc-jet systems show disc-jet wobbling by several degrees in amplitude on relatively short timescales of about 10^3-10^4 t_g [2]. Such variations of the jet viewing-angle could boost jet emission in and out of the line-of-sight, resulting in observations of high-energy flares on a timescale of the wobbling [2].

The goal is to constrain a typical intervals between the flares for selected bright blazars and compare them with the expected wobbling timescales dependent on the supermassive black hole (SMBH) mass.

Detection of flares

We selected 4 bright blazars from the Fermi 4LAC catalog [3], with well covered *Swift*-XRT light curves and reliably determined mass: Mrk 421, Mrk 501, 1ES 1959+650 and 3C 273. To detect individual flares, we first iteratively applied second order Savitzky-Golay filter [4] in order to subtract the long term variations in the light curves. The flare candidates (shown in Fig. 1) were then identified in the detrended data using 95% percentile cut on the count rate distribution.

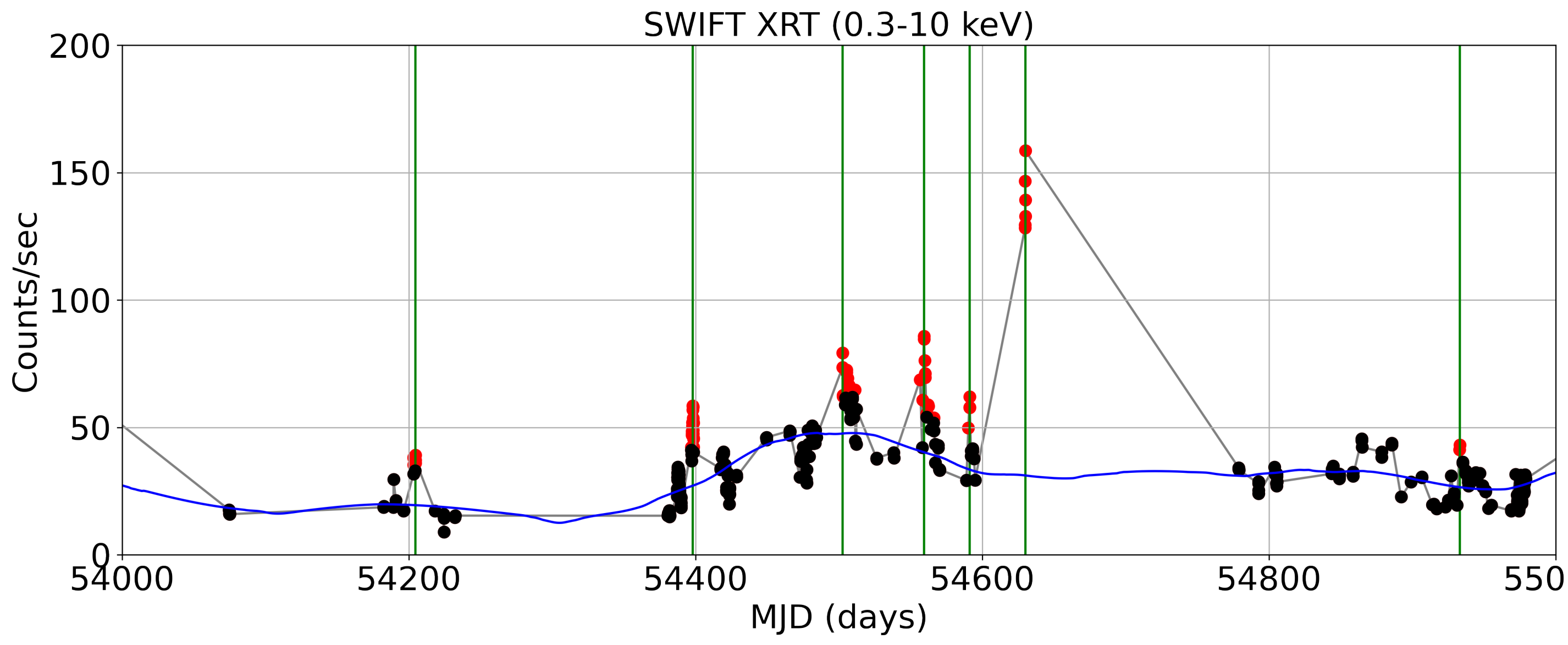

Figure 1: Flares (marked by green lines) detected in a part of the *Swift*-XRT light curve of Mrk 421. The blue line shows the long term variability, and the red points are the suspected flares detected by our algorithm.

Time intervals between flares

The distributions of time intervals between the flares in the observer's frame Δt are shown in Figure 2. In order to constrain a possible range of the jet wobbling timescale, we assumed that Δt can be approximated by Weibull distribution, with suitable property of Δt being always greater than 0. For each distribution, we also performed Kolmogorov-Smirnov test to verify that the zero hypothesis (both distributions are the same) cannot be rejected. P-values of the KS-test was > 0.85 for all four sources. We also assumed that the secondary peaks in the Δt distribution are due to missing flares that were too weak to be detected by our algorithm, or fell in the periods not covered by the *Swift*-XRT observations in-between the flares detected. If that is the case, the longer time intervals would split in half and contribute to the first peak.

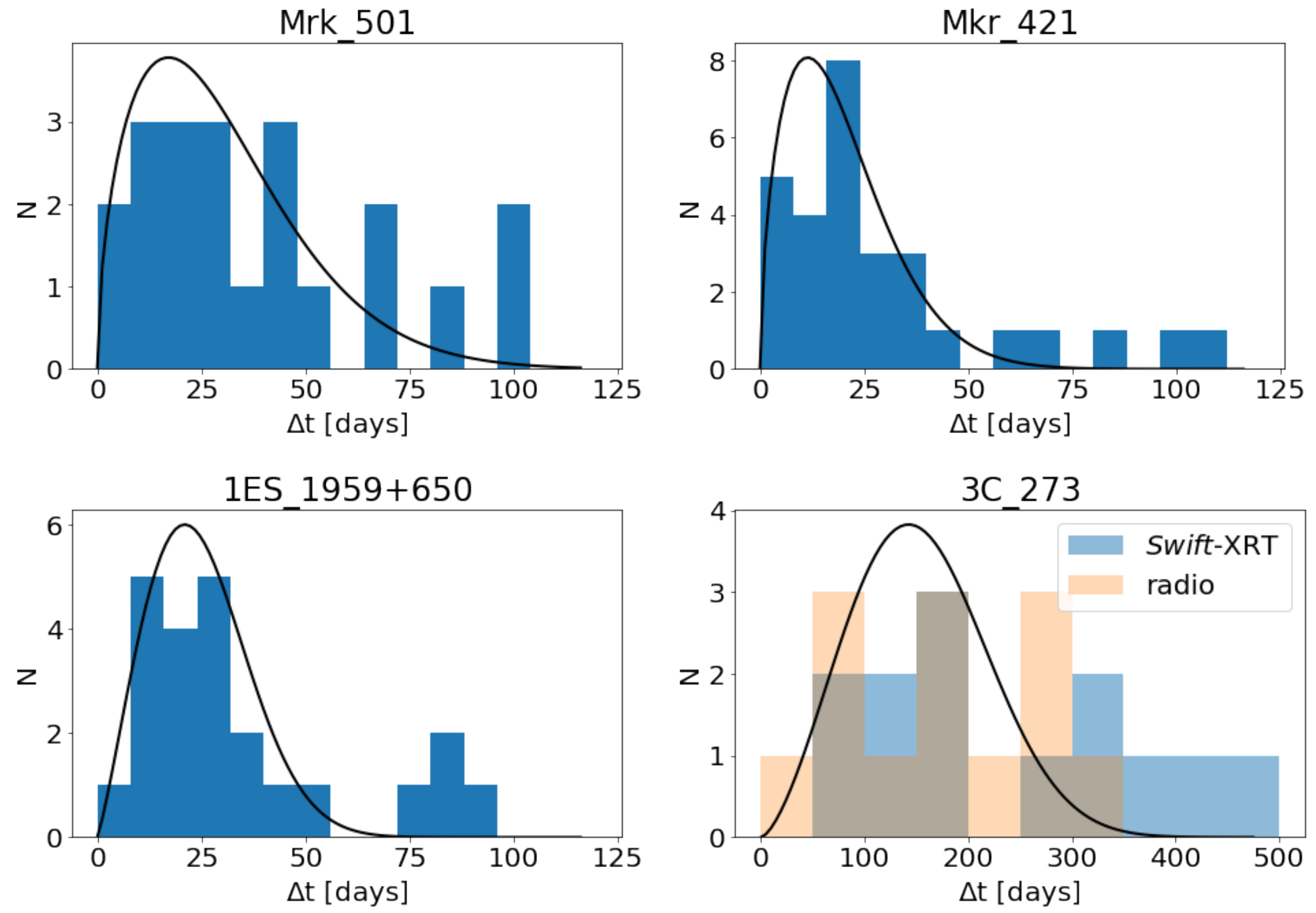

Figure 2: Distributions of Δt, where the first peaks are approximated by the Weibull distribution (black lines). For 3C 273, the only FSRQ in our sample, Δt between X-ray flares is compared with radio observations of superluminal knots ejection times, observed by VLBA at 43 GHz [5-7].

References

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Comparison of timescales

The time intervals between flares in the units of t_g transformed in the source frame can be expressed as

$$\frac{\Delta\tau}{t_g} = k\frac{\delta\Delta t}{(1+z)M_{\mathrm{SMBH}}},\ k = 8.7\times10^9\ M_\odot \mathrm{day}^{-1}, \tag{1}$$

where δ is the Doppler beaming and z is the redshift. While z for the bright blazars in our sample are determined with high precision, uncertainties of the other parameters cannot be neglected.

We carefully evaluated possible ranges of δ and M_{SMBH}, determined by various methods, collected from different studies and observations. In Figure 3, there are distributions of $\Delta\tau/t_g$ for individual sources, obtained by Monte Carlo sampling of the Eq. 1 within the observed ranges of δ and M_{SMBH} and compared with the expected jet wobbling timescales.

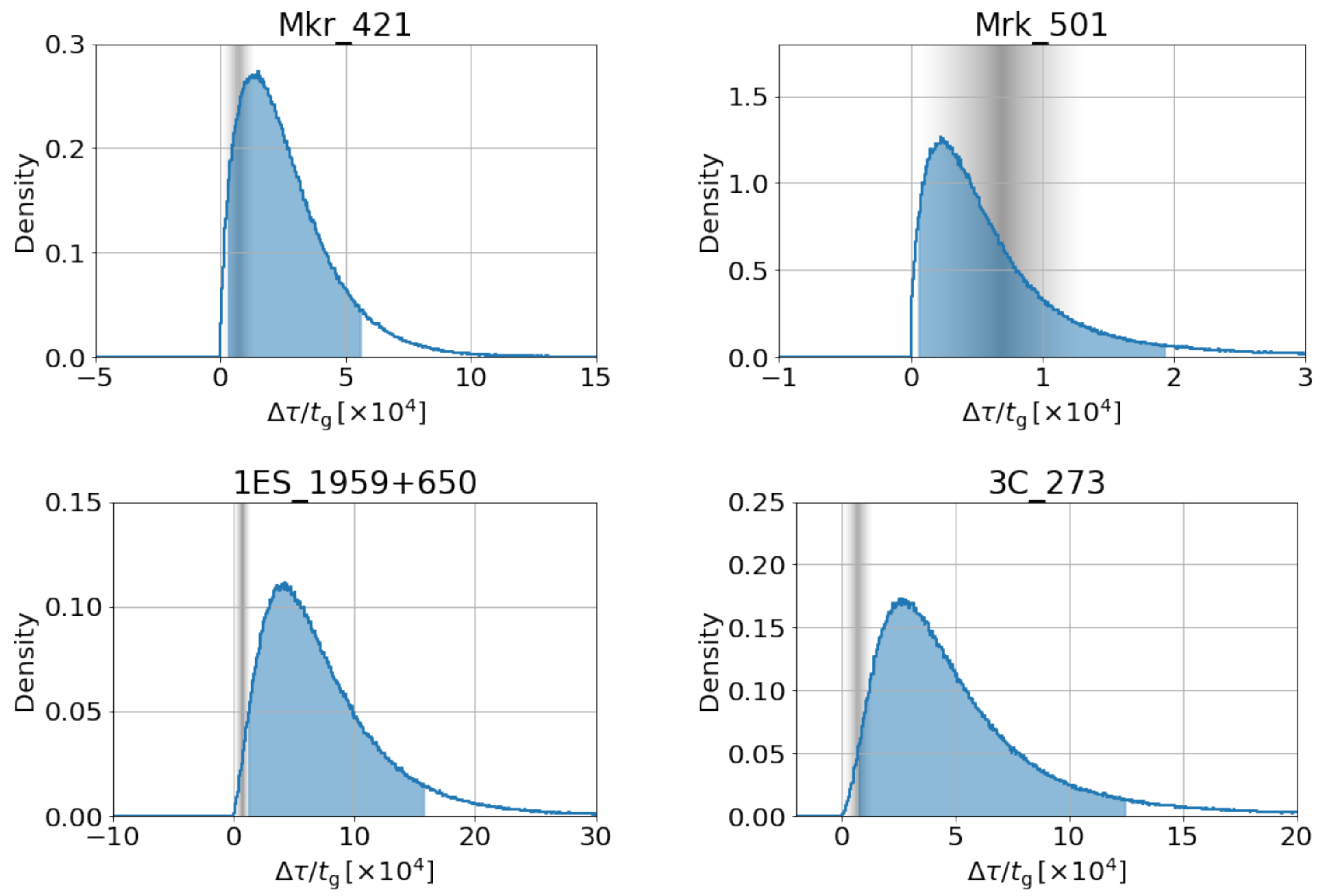

Figure 3: Distribution (blue line) of estimated $\Delta\tau/t_g$ for individual sources. Filled regions represent 95% confidence intervals. The fuzzy grey regions show the expected range of jet wobbling timescale according to [2].

Conclusions

Observational constrains on $\Delta\tau/t_g$ are rather weak, mostly due to the uncertainties of δ. The jet wobbling timescale falls in the 95% confidence interval of $\Delta\tau/t_g$ for Mrk 421, Mrk 501 and 3C 273. For 1ES 1959+650, the timescale of blazar flares constrained by observations tends to be higher. A detailed analysis of a power spectrum of the tilt angle variations simulated on a longer interval would be necessary for exact determination of the jet wobbling timescale.

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