Study of the variability of Blazars γ-ray emission

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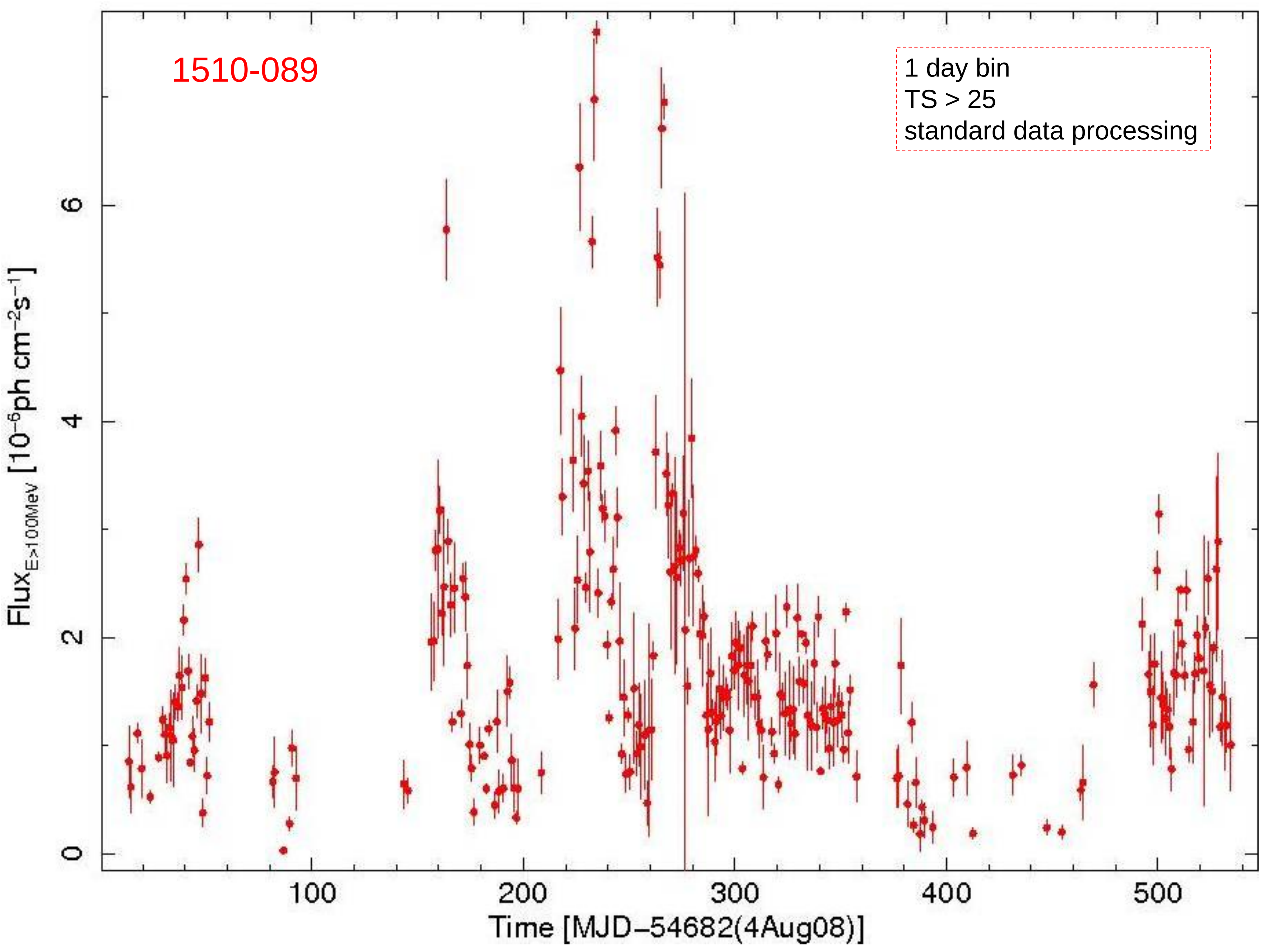
The γ-ray emission of blazar jets shows a pronounced variability and this feature provides limits to the size and to the motion of the emitting region.
We study the γ-ray variability of blazars using data from the first two years of activity of the Large Area Telescope on the Fermi Gamma-Ray Space Telescope.
From the daily light-curves of the blazars characterized by a remarkable activity, we firstly determine the **minimum variability time-scale**, giving an upper limit for the **size of the emitting region** of the sources, assumed to be spheroidal blobs in relativistic motion. These regions must be smaller than ~10^{-3} parsec.
Another interesting time-scale is the **duration of the outbursts**. We conclude that they cannot correspond to radiation produced by a single blob moving relativistically along the jet, but they are either the signature of emission from a standing shock extracting energy from a modulated jet, or the superposition of a number of flares occurring on a shorter time-scale.
We also derive lower limits on the **bulk Lorentz factor** needed to make the emitting region transparent for gamma-rays interacting through photon-photon collisions.



1510-089 daily light curve. The variability time-scale is defined as the shortest doubling or halving time among the significant flux variations present in the daily light curve.

Minimum variability time-scale analysis

$$R < c\Delta t_{var}\frac{\delta}{1+z}$$

transparency condition: $$\delta \geq \left[(1+z)^{2\alpha}\frac{\sigma_T d_L^2}{5hc^2}\frac{F(\nu_0)}{\Delta t_{var}}\right]^{\frac{1}{4+2\alpha}}$$

$$\delta = \frac{1}{\Gamma(1-\beta\cos\vartheta)} \approx \Gamma > 5$$

$$R < 10^{-3}\left(\frac{\delta}{5}\right)\mathrm{pc}$$

$$\Delta t_{var} \leq 0.5\,\mathrm{day}$$

The **minimum variability time-scale** observed in daily light curves gives a limit on the size of the blazar emitting region, assumed to be a spherical blob in relativistic motion.
The constraint on the **Doppler factor** is derived from the necessity for the emitting region to avoid pair production, (Dondi, Ghisellini 1994).

Parameters used

Source	z	d_L [cm]	F_X [μJy]	α
0235+164	0.940	1.88 x10^{28}	0.34	0.44
3C 273	0.158	2.33 x10^{27}	67.77	0.56
3C 279	0.536	9.51 x10^{27}	0.98	0.76
1510-089	0.360	5.93 x10^{27}	0.44	0.40
3C 454.3	0.859	1.69 x10^{28}	2.97	0.70

data from Ghisellini et al. 2010

Results with ν_0=1 GeV

Source	Rise			Decay		
	Δt_{min} [days]	δ_{min}	R_{max} [pc]	Δt_{min} [days]	δ_{min}	R_{max} [pc]
0235+164	0.24	5.54	5.81 x 10^{-4}	0.25	5.46	6.14 x 10^{-4}
3C 273	0.27	5.89	1.19 x 10^{-3}	0.27	5.88	1.20 x 10^{-3}
3C 279	0.30	4.50	7.60 x 10^{-4}	0.16	5.03	4.60 x 10^{-4}
1510-089	0.30	3.25	6.27 x 10^{-4}	0.185	3.61	4.24 x 10^{-4}
3C 454.3	0.48	6.65	1.48 x 10^{-3}	0.34	7.11	1.11 x 10^{-3}

Results with ν_0=10 GeV

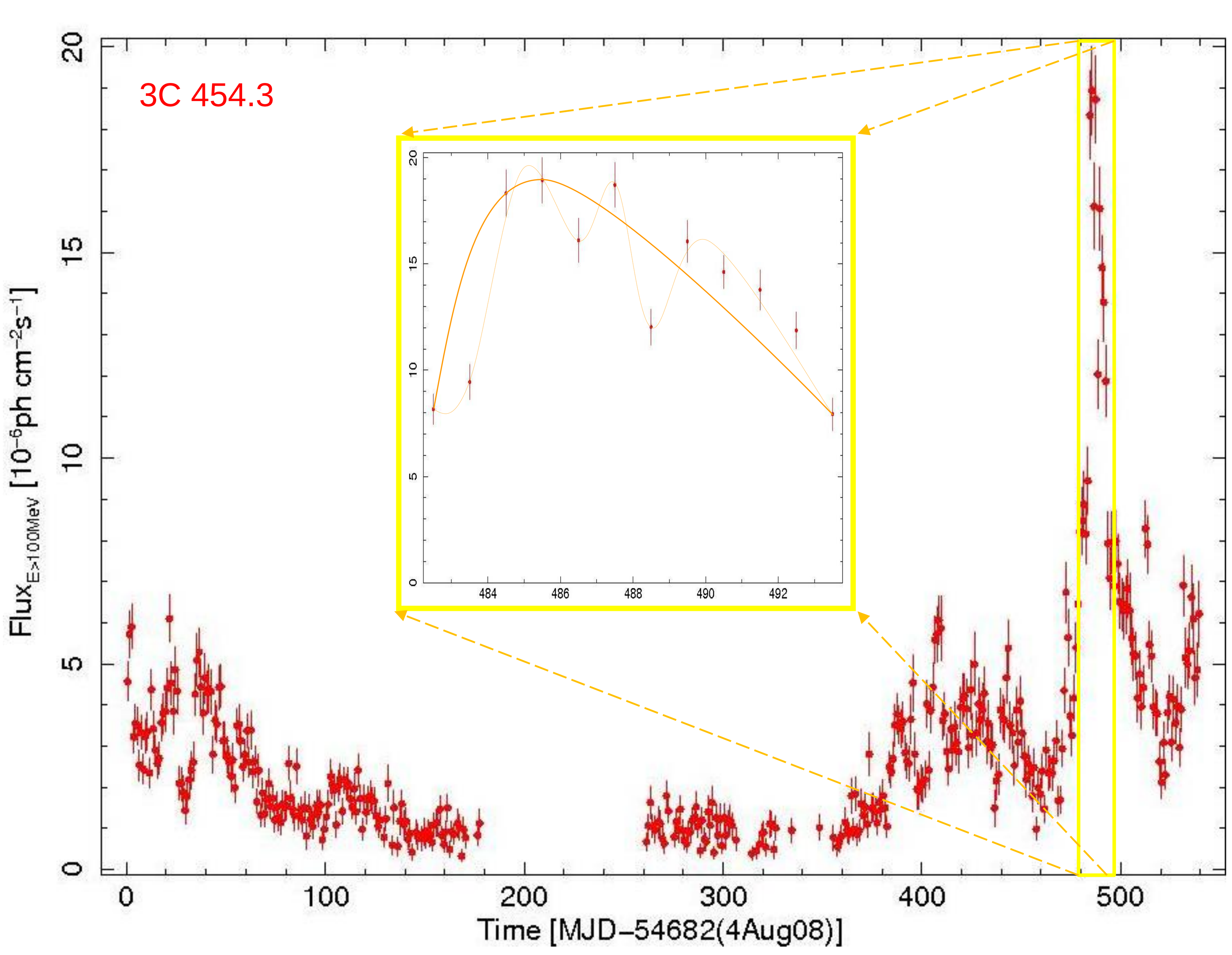
Source	Rise			Decay		
	Δt_{min} [days]	δ_{min}	R_{max} [pc]	Δt_{min} [days]	δ_{min}	R_{max} [pc]
0235+164	0.24	6.82	7.15 x 10^{-4}	0.25	6.73	7.55 x 10^{-4}
3C 273	0.27	7.58	1.53 x 10^{-3}	0.27	7.56	1.54 x 10^{-3}
3C 279	0.30	6.18	1.04 x 10^{-3}	0.16	6.91	6.32 x 10^{-4}
1510-089	0.30	3.94	7.59 x 10^{-4}	0.185	4.37	5.14 x 10^{-4}
3C 454.3	0.48	8.97	2.00 x 10^{-3}	0.34	9.58	1.49 x 10^{-3}

Outburst identification

A well defined outburst is a substantial variation in flux, lasting few days with a coherent trend in rise and decay.
A good example of this kind of variability can be observed during the **exceptional activity of 3C 454.3** in December 2009 (for more details see Bonnoli et al. 2010). The outburst (more clear in the central panel) lasts 11 days and starts from a phase in which the source is already increasing its activity.

In the case of **3C 279**, the most coherent case of activity is a couple of long-time variations in the first half of the light curve.

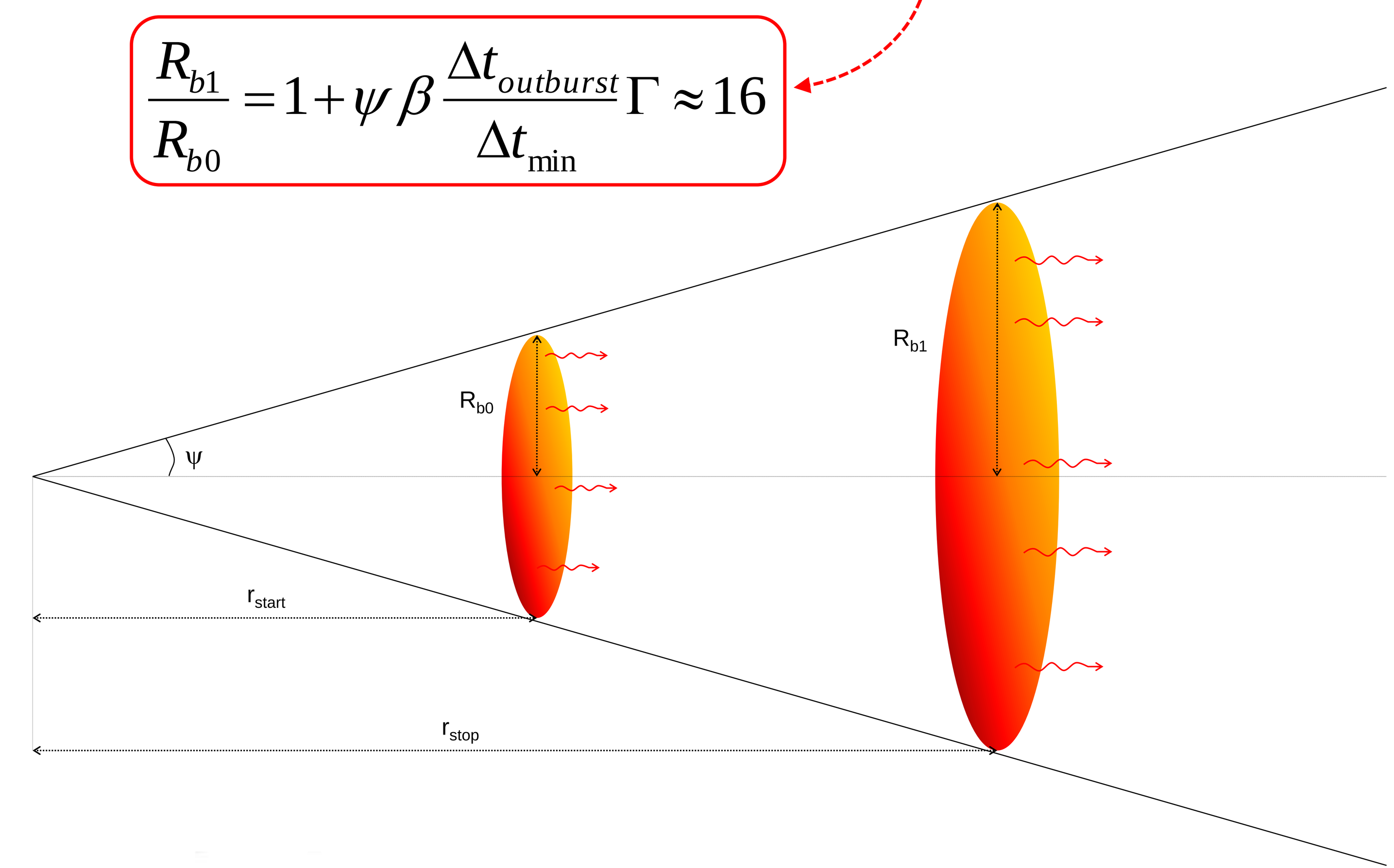
3C 273 presents instead a peculiar profile in its outbursts (more detailed in 3C 273 central panel). Every outburst seems to be composed of at least two initial spikes, followed by a more gradual decay. Every spike lasts 3 or 4 days.

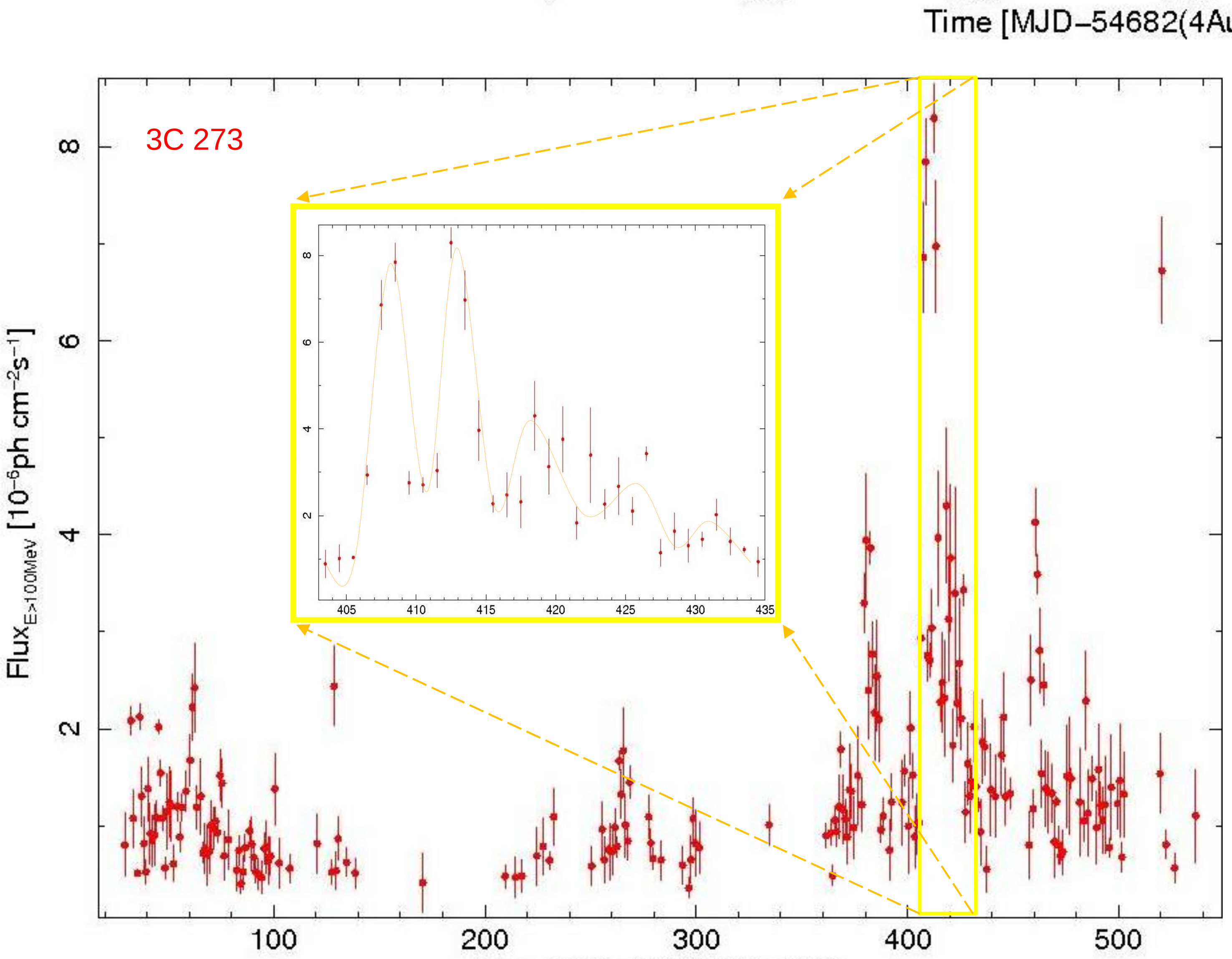


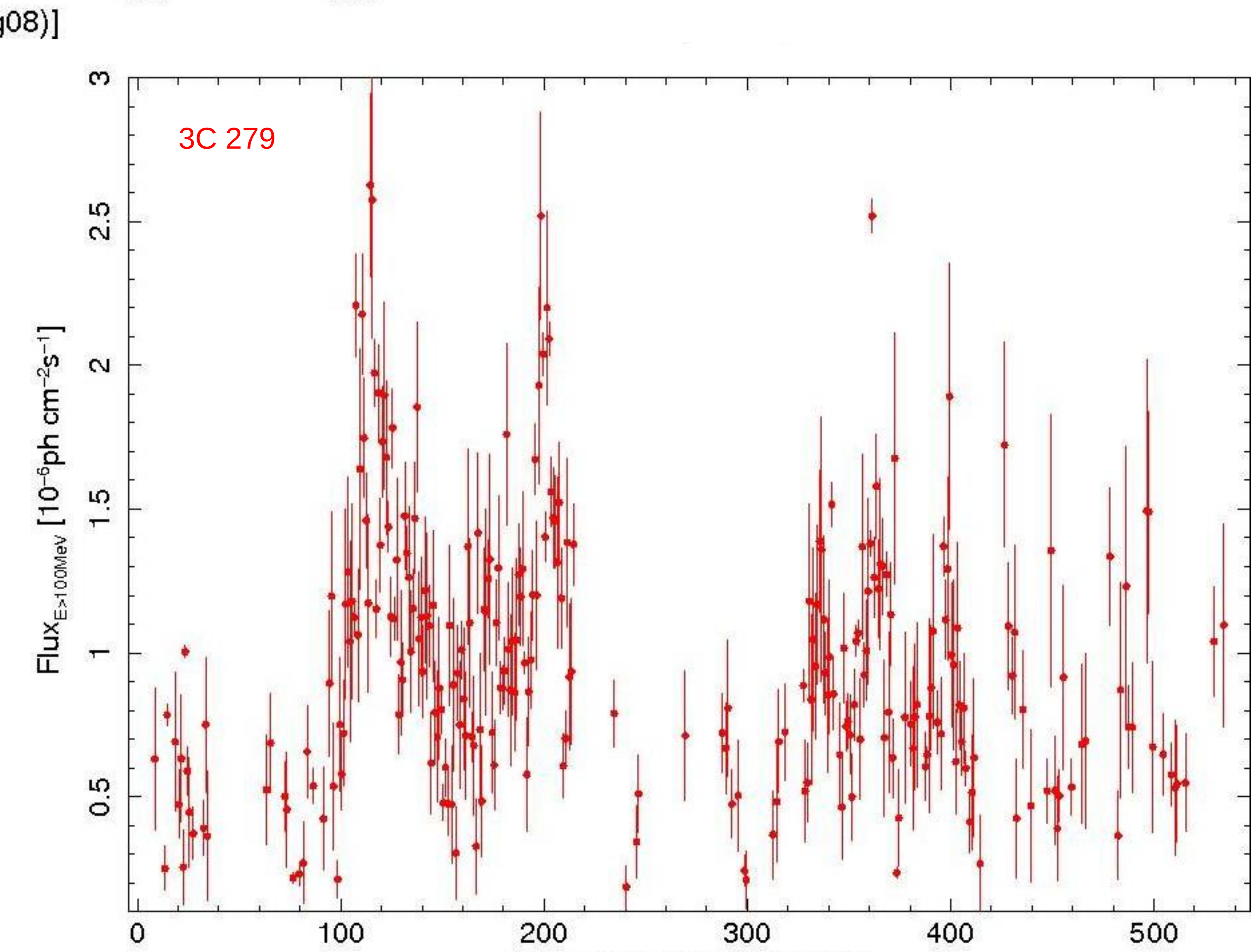
Outbursts time-scale analysis

If these outbursts are caused by the same **moving blob**, the distance it covers is $r \approx \Delta t\,\Gamma^2 c$, i.e. very long. The blob should **expand considerably** and change quite dramatically its emission properties, contrary to what we observe.

$$\frac{R_{b1}}{R_{b0}} = 1 + \psi\beta\frac{\Delta t_{outburst}}{\Delta t_{min}}\Gamma \approx 16$$







Analysing the outbursts time-scale, we conclude that this kind of variation **can't be justified by a single blob** in relativistic motion.
We can interpret them either with a modulated emission from a **standing shock**, or a superposition of a number of flares occurring on shorter time-scales.