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BLAZAR OPTICAL VARIABILITY: 20 YEARS OF OBSERVATIONS AT BELOGRADCHIK OBSERVATORY

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Abstract. Blazars are a type of active galactic nuclei with very unusual and interesting properties, one of which is their rapid variability. We show some examples of blazar variability, present a plausible explanation and review the contribution of Belogradchik observatory in blazar studies.

1. INTRODUCTION

The term "blazar" has been introduced about 40 years ago and indicates a special type of active galactic nucleus (AGN), whose emission is first dominated by non-thermal processes in a relativistic jet and secondly – this jet happens to be pointed within a small angle to the line of sight. Thus, due to the relativistic effects, the motion of the jet components often appears "superluminal", as observed from the Earth.

Unlike the other types of AGN, the blazar spectral energy distribution (SED) often covers up to 17-18 orders in magnitude in frequency – from radio to VHE gamma rays. The SED consists typically of two peaks – a synchrotron one (IR/optical regions), due probably to synchrotron emission from relativistic particles and an Inverse Compton (IC) one (X/gamma range), for which the most plausible explanation is inverse Compton scattering of the synchrotron or external photons off the same relativistic electrons. Another option for the high energy peak is the proton-synchrotron instead of the IC process, which however requires a much stronger magnetic field in the jet (10-100G vs. about 0.1G). In addition, some opticl/UV contribution from an accretion disk is also detected in some objects (flat-spectrum radio quasars, FSRQ). Except for the emitted electromagnetic radiation, the blazars were very recently suspected to be also neutrino sources, when a 290TeV neutrino signal was detected from a position, coincident with a blazar (TXS 0506+056), IceCube collaboration (2018a, b).

Blazars are long known to be highly and rapidly variable throughout their entire SED. Such variability is especially well documented in the optical region. The most extreme cases show variations of up to 6 magnitudes on long-term scales and up to 0.3 – 0.7 magnitudes for several hours. Some object show variations of up to 0.2 magnitudes for an hour, which is extreme variability even for a stellar-mass object.

This paper reviews the Belogradchik observatory contribution to the blazar optical variability studies.

2. EXAMPLES OF EXTREME BLAZAR VARIABILITY AND ITS POSSIBLE EXPLANATIONS

In the next figure (Fig. 1) we show examples of long-term optical variability of 2 objects – CTA 102, a FSRQ and BL Lac – the architype of the BL Lac type objects. Most of the data is obtained with Belogradchik 60cm telescope. It has

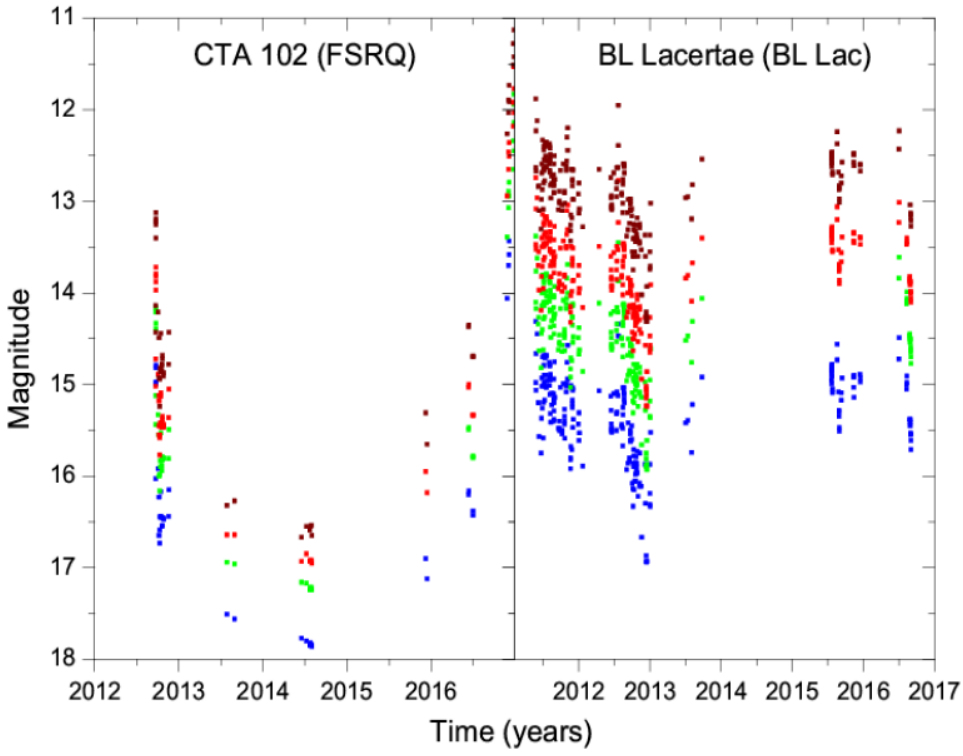

Figure 1: Long-term optical variability of CTA 102 (left) and BL Laceratae (rights). BVRI light curves are shown in blue, green, red and brown, respectively. Most of the data is from Belogradchik 60cm telescope.

already been noticed (Bachev, 2018) that the long-term variations may be characteristically different for the two blazar subclasses: The FSRQ show strong but relatively rare outbursts, while BL Lacs show intermittent but limited in amplitude variations.

On the other hand FSRQs tend to be more variable on intra-night time scales, sometimes reaching changes of about 0.5 – 0.7 mag for several hours. The next example (Fig. 2) shows such rapid variability during an outburst of the blazar CTA 102.

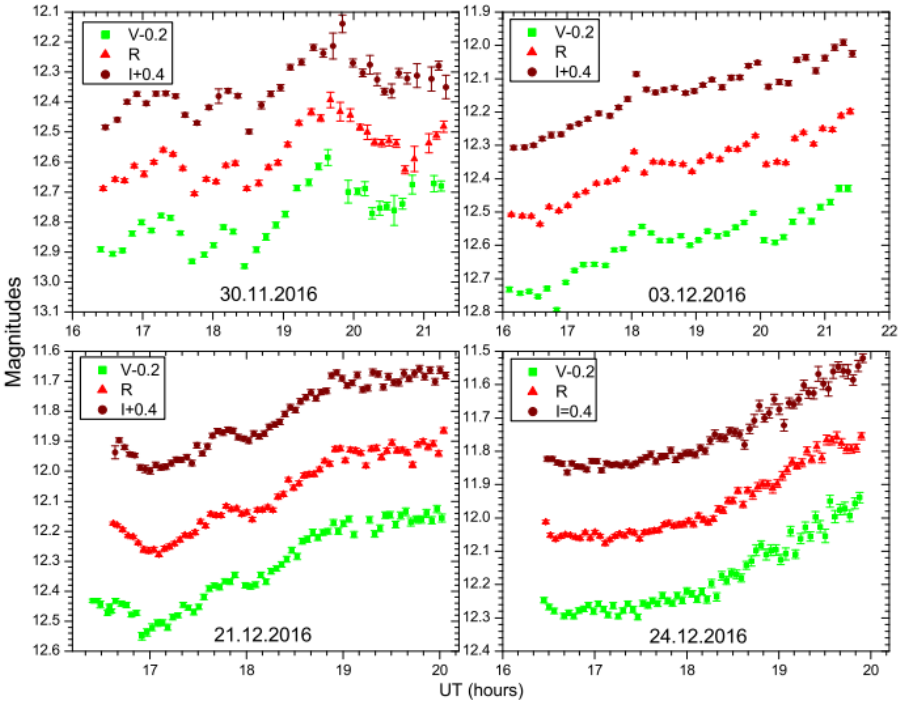

Figure 2: Rapid intra-night variability in 3 colors of CTA 102 during the 2016/2017 outburst (Bachev et al., 2017). Data are obtained from Belogradchik observatory.

The question is how to explain such large-amplitude (on long-term scales) and rapid (on intra-night scales) variations in blazars. There are two possibilities – one related to the evolution of the electron energy density distribution and the other one – related to the change of the Doppler factor in a curved (helical) jet. The first option predicts however some time asymmetry of the light curves as well as some time delays between light curves of different colors. None of these has been positively confirmed throughout the years (Bachev et al., 2017). Therefore, it is likely that a changing Doppler factor (D) plays the most important role in driving blazar variability (Raiteri et al., 2017).

Indeed, knowing that:

$$D = \frac{1}{\Gamma(1-\beta cos\theta)} \quad \text{and} \quad F_{obs} \propto D^{3+\alpha}$$

where $\alpha \approx 1, \Gamma \sim 15$ - 20, is the Lorentz factor, and θ is the jet direction with respect to the line of sight, one sees that a small change in θ can lead to a huge change in the observed flux (F_{obs}). Such light curves will be time-symmetric and no time lags between optical bands should be expected, as observed.

3. BELOGRADCHIK OBSERVATORY AND BLAZAR STUDIES

Belogradchik observatory is situated in the vicinity of the town of Belogradchik, north-west Bulgaria, at 620m above the sea level. The main instrument is a 60cm Cassegrain telescope. The cameras in use are SBIG ST-8 (1997-2009) and FLI PL-9000 (2010-now), both equipped with standard BVRI filters. About 150 clear nights per year are available, of which about 75 are during the non-moon period.

Blazar observations have been performed with this telescope since 1998. Since about 2009 blazar variability studies became the main objective of the Observatory as for them the most of the observing time was dedicated. Throughout the years we have performed over 1000 single BVRI estimates for more than 50 blazars. In addition several object ware monitored on intra-night time scales for a total of more than 500 hours. The most of the observations have been parts of wider international programs for blazar monitoring, such as WEBT, GASP, MAGIC or have been collaborations with groups from India, Poland, Russia, etc. There are more than 40 high-ranking journal (ApJ, A&A, MNRAS, Nature) publications since 2007 on blazar variability, whose data are partially or entirely obtained from Belogradchik.

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