Blazar Optical Sky Survey - BOSS project (2013-2018)
The quasi-periodic variability of BL Lac

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Abstract. Blazar Optical Sky Survey (*BOSS Project*) is a dedicated observational survey with the aim of monitoring known blazars in optical wavelengths. The project was initiated in March 2013 at the University of Athens Observatory (*UOAO*), performing ground-based optical photometric observations in parallel with orbital (*SWIFT/XRT, FERMI/LAT*) X-ray observatories. *BOSS Project* is currently running as an international collaboration of the National and Kapodistrian University of Athens, utilizing the robotic and remotely controlled telescope at the *UOAO*. The prototype blazar BL Lac is monitored in the frame of the *BOSS Project*, during the period of 2014-2018. BL Lac is continuously observed on a daily basis, in order to achieve dense temporal coverage in optical wavelengths and study the short time-scale flux variability. Several long-runs have been conducted, with the target monitored for several hours during the night, aiming towards the IDV detection and characterization. In this presentation, the preliminary results of the frequency analysis are given, summarizing the achievements after the 5-year long operation of the BOSS Project, while the advantage of small, robotic and remotely controlled telescopes is highlighted.

Introduction

BL Lac is a highly variable AGN, discovered by Hoffmeister (1929) and initially classified as a typical variable star. It was later identified by Schmitt (1968) as a variable radio source, while Miller & Hawley (1977) measured a redshift of z = 0.0688±0.0002. BL Lac became the prototype of the class of AGNs known as *Blazars* and it is distinguished by rapid and high-amplitude brightness variations in the wider range of the electromagnetic spectrum. These variations are observed in both long and short time scales (Villata et al. 2002), while no clear correlation between high energy and optical variability was ever found. On contrary, optical and radio variability was found to be correlated on WEBT data (Villata et al. 2009).

Optical observations of BL Lac

BL Lac is continuously monitored since 2014, utilizing the robotic and remotely controlled telescope at the University of Athens Observatory (UOAO) in Greece (Gazeas 2016). Up to date, 5 years of continuous monitoring on BL Lac resulted in a total of 470 clear nights, and more than 7500 individual measurements with a single instrument. The project aims towards the detection of blazar variability in various timescales, i.e. the intra-day variability (IDV) which ranges between a few minutes up to one day (Wagner & Witzel 1995), the short-term variability (STV) which ranges between a few days to a few months and the long-term variability (LTV), which covers all variations longer than a few months, up to several years.

Short and long-scale flux variations

The observed flux in the optical R-band (Fig. 1) presents strong variability of 0.5 mag within a few days, while in some cases even 1 mag flux variation is detected. Similar variability was also reported in the past by Raiteri et al. 2009. Smooth flux variation of the order of 0.03-0.06 mag/hour are observed systematically during July 2018, where BL Lac was observed for 12 consecutive nights, of 10 hours each. Such an IDV behavior was also reported by Nesci et al. 1998; Speziali & Natali 1998; Papadakis et al. 2003; Howard et al. 2004, Zhang et al. 2004 and Bachev et al. 2012. In all the above cases, the standard deviation of comparison star used in this study is of the order of 0.01 mag, adding confidence to the observed variability.

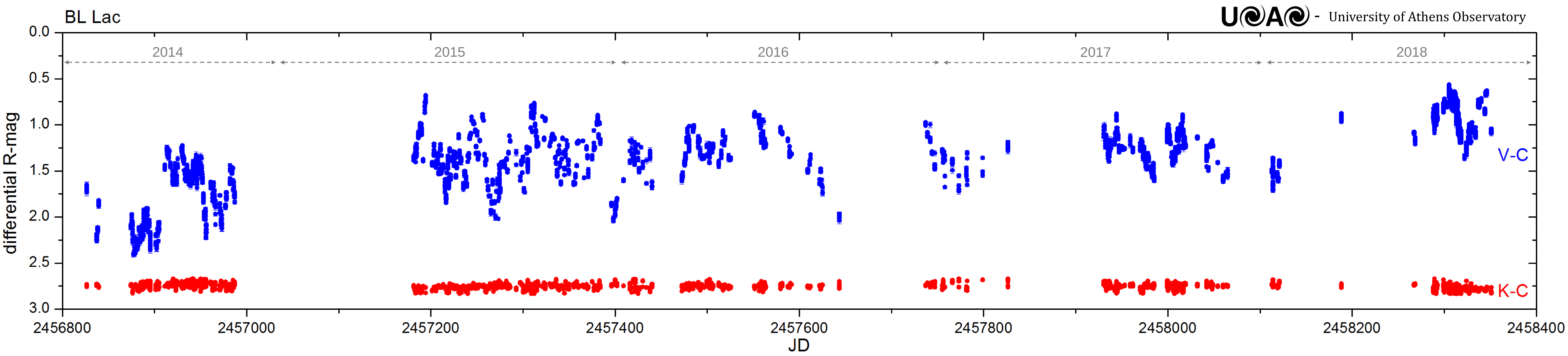

Figure 1. BOSS Project results on the photometric variability of BL Lac data, spreading from 2014 to 2018. The variability of BL Lac (V) is displayed with respect to the nearby standard star GSC 3206:1047 (C), while the stability of the standard star is monitored with respect to the check star GSC 3206:0907 (K). BL Lac is a highly variable optical source, the prototype of the entire class of active AGNs, known as blazars.

Preliminary results from the FFT analysis - STV

The entire photometric dataset is split in four distinct observing seasons (2014, 2015-2016, 2017 and 2018), when observations were collected continuously, without significant time gaps. Preliminary analysis of the collected data utilize an FFT method on each observing season. Table 1 lists the detected periodic signals for the major peaks on the periodograms, while Fig. 2 shows the corresponding signals applied on the photometric data. Symmetric ascending and descending rates may occur in conservative dynamical systems (microlensing, orbital motion etc), while asymmetric rates may direct towards explosive events (electron cooling etc). A possible cause of flux variability could be the evolution of the energy density distribution of the relativistic particles, which leads to a variable synchrotron emission (Bachev et al 2012).

Table 1. *The most significant periodic signals, detected as STV.*

ID	2014	2015-2016	2017	2018	2014-2018
	Period (d)	Period (d)	Period (d)	Period (d)	Period (d)
P_1	18.14(±0.33)	17.02(±0.19)	13.58(±0.33)	10.90(±0.21)	17.22(±0.03)
P_2	27.71(±1.25)	27.47(±0.49)	25.73(±0.69)	28.30(±0.53)	34.07(±0.09)
P_3	30.90(±0.85)	33.57(±0.57)	83.42(±4.18)	51.09(±1.44)	123.47(±1.21)
P_4	67.85(±4.20)	60.43(±1.54)			

Table 2. *The most significant periodic signals, detected as IDV.*

ID	2457984	245999	2458000	2458008	2458292
	Period (h)	Period (h)	Period (h)	Period (h)	Period (h)
P_1	11.05(±5.36)	9.62(±3.12)	7.85(±2.92)	5.11(±2.71)	8.33(±1.25)
P_2	4.00(±1.67)	2.33(±0.66)	4.19(±0.93)	0.78(±0.19)	1.87(±0.43)
P_3	0.78(±0.07)	1.09(±0.13)	1.81(±0.35)	0.54(±0.11)	3.58(±0.96)
P_4		0.90(±0.10)			0.76(±0.13)

Preliminary results from the FFT analysis – IDV

BL Lac was observed continuously for several hours in selected nights. Such observations show a clear IDV (Fig. 3) while FFT analysis reveal quasi-periodic behavior of about 45-50 min (Table 2). These signals are over imposed to a wider variability trend of a larger time scale, which is unique for each observing run. Bachev et al. 2012 report that there is not a single periodic signal dominating their observing sample. However, micro-oscillations can be detected after subtracting the leading polynomial trend. According to their study, such periodical signals reach the value of ~1 h. The present study confirms the above findings. Micro-oscillations with a period of an hour or so may have significant implications for our understanding of how matter accelerates along the jet.

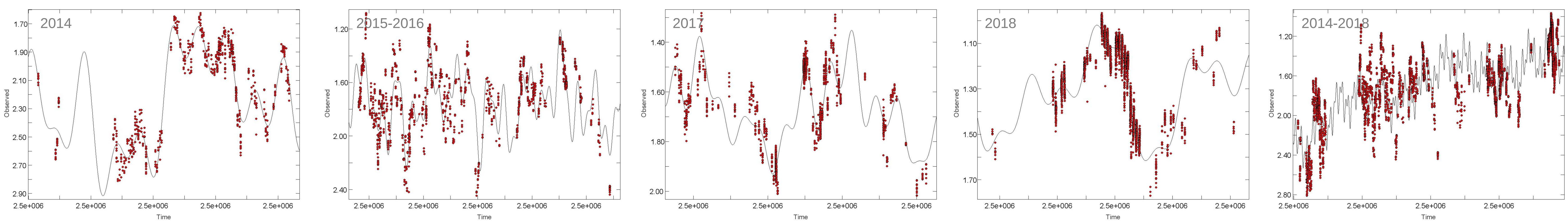

Figure 2. Different observing seasons present unique flux variability. However, they all exhibit a quasi-periodic behavior of the order of 27-28 days, among other (weaker or stronger) signals.

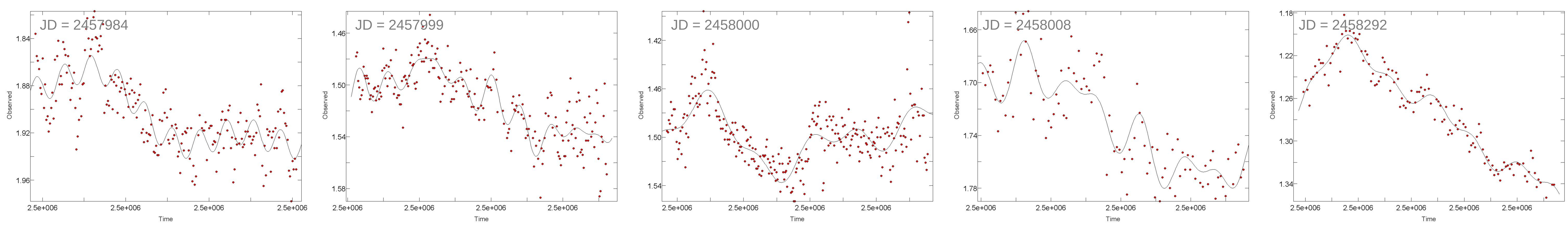

Figure 3. Selected individual night present rapid IDV within a few minutes. Periodic signals reveal a quasi-periodic behavior of 45-50 min.

Conclusions

The well-sampled optical light curves clearly show high flux variability during the 5-year observing campaign. Preliminary results show that BL Lac exhibits both IDV and STV in a wide range of frequencies, as a result of short-scale flare events. The variability shows a quasi-periodic behavior, which seems to be constant in every annual observing run. Such a behavior is caused due to relativistic beaming from a jet of plasma, ejected from the vicinity of an accretion disk.

The present study suggests that:

1) IDV is observed inlong observing runs, with timescales of ~1 h.
2) STV is observed, while FFT analysis suggests a period of ~27 days.
3) the overall flux is getting higher with time (LTV) during 2014-2018.

Further analysis of the quasi-periodic variability on BL Lac will put constraints on the jet structure and kinematics within the disk, while it will help in constructing a more solid model on the magnetic field and emission mechanism in blazars, which host a super-massive black hole.

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