Blazar Optical Sky Survey –BOSS Project

(2013-2018)

The quasi-periodic variability of BL Lac

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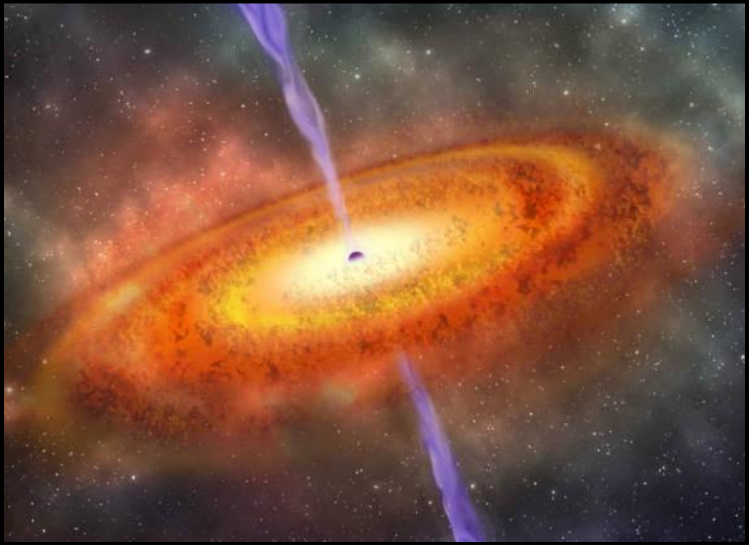


The prototype blazar, in brief ….

- ✓ 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, being at z = 0.0688(2)
- ✓ BL Lac is distinguished by rapid and high-amplitude brightness variations in the wider range of the electromagnetic spectrum.

- ✓ Brightness variations are observed in both long and short time scales (Villata et al. 2002)
- ✓ No clear correlation between high energy and optical variability was ever found
- ✓ On contrary, optical and radio variability are correlated on WEBT data (Villata et al. 2009)

Blazar Optical Sky Survey (BOSS) project

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 at the University of Athens Observatory, UOAO in 2013.

In the frame of BOSS Project, ground-based optical photometric observations are performed, in parallel with orbital (SWIFT/XRT, FERMI/LAT) X-ray observatories.

BOSS Project Target List

Target	Other Names	RA (J2000)	DEC (J2000)	Rmag	Type
Mrk1018	PGC 8029	02:06:16	-00:17:29	10.3 mag	Seyfert 1 Galaxy
1ES 0236+610	LS I +61 303	02:40:32	+61:13:42	10.2 mag	HMXB (V615 Cas)
1H 0323+342	PGC 2045127	03:24:41	+34:10:46	13.1 mag	Blazar
PKS 0716+714	GSC 0368:0899	07:21:54	+71:19:21	14.3 mag	Blazar
OJ287	GSC 1400:0230	08:54:49	+20:06:30	14.1 mag	Blazar
Mrk110	PGC 26709	09:25:13	+52:17:11	15.2 mag	Seyfert 1 Galaxy
Mrk421	PGC 33452	11:04:27	+38:12:31	8.3 mag	Blazar
Mrk180	PGC 35899	11:36:26	+70:09:28	14.5 mag	Blazar
3C273	PGC 41121	12:29:07	+02:03:09	14.1 mag	Blazar
3C279	PGC 2817645	12:56:11	-05:47:22	15.9 mag	Quasar
PKS 1510-089	PGC 2828331	15:12:51	+09:06:00	16.5 mag	Quasar
PKS 1553+113	GSC 0947:1098	15:55:43	+11:11:24	14.6 mag	Blazar
Mrk501	PGC 59214	16:53:52	+39:45:36	13.3 mag	Blazar
1ES 1959+650	PGC 2674942	20:00:00	+65:08:55	11.2 mag	Blazar
BL Lac	1ES 2200+42.0	22:02:43	+42:16:40	14.7 mag	Blazar (prototype)
CTA 102	PGC 2819036	22:32:36	+11:43:51	16.7 mag	Quasar (4C 11.69)
3C 454.3	PGC 2819327	22:53:58	+16:08:54	15.2 mag	Quasar
1ES 2344+514	QSO B2344+514	23:47:05	+51:42:18	15.5 mag	Blazar

Blazar Optical Sky Survey (BOSS) project

The targets are continuously observed on a daily basis, with the aim to achieve dense temporal coverage in optical wavelengths.

In parallel, simultaneous observations in high and low energy bands are cross-correlated with the BOSS database.

After the first 5 years of operation, BOSS Project brought precious results, while the advantage of small, robotic telescopes is highly acknowledged.

Blazar Optical Sky Survey (BOSS) project

Highlights…

- ✓ Detection of flux variability in various time-scales
- ✓ Quasi-periodic variability in the range of minutes to weeks
- ✓ Correlation between optical and radio or high energies during MW campaigns

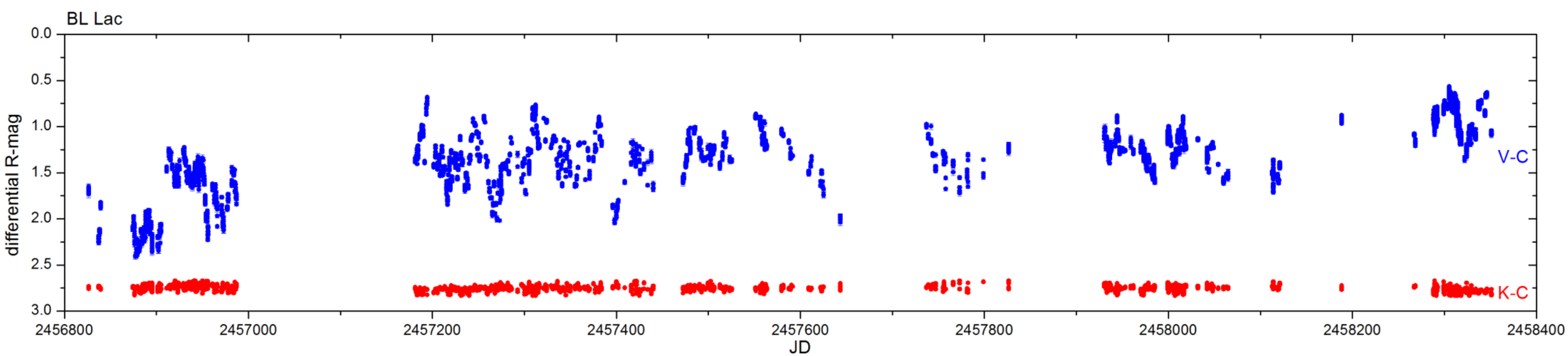
Photometric monitoring of BL Lac

- ✓ The prototype blazar BL Lac is monitored, during the period of 2014-2018.

- ✓ The project aims towards the detection of variability in various timescales, i.e.
    - the intra-day variability (IDV), ranging between a few minutes up to one day
    - the short-term variability (STV), ranging between a few days to a few months
    - the long-term variability (LTV), covering periods longer than a few months or years

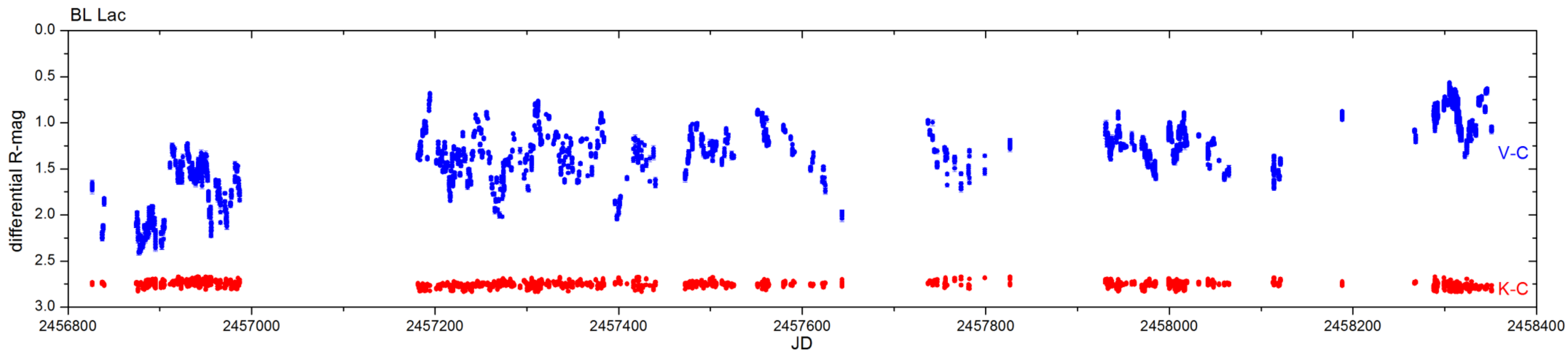
Photometric monitoring of BL Lac

- ✓ Continuous monitoring of BL Lac for within 1500 nights between 2014-2018 in optical R-band.
- ✓ More than 7000 useful individual observations
- ✓ 2 minute cadence during the data aquisition
- ✓ In all 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 (0.5-1.0 mag).



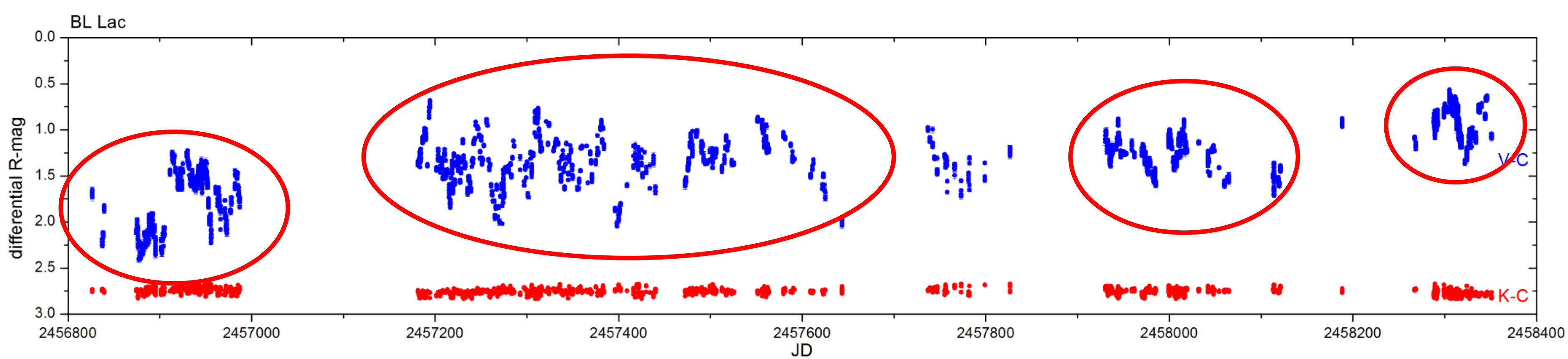
Short and long time-scale flux variation

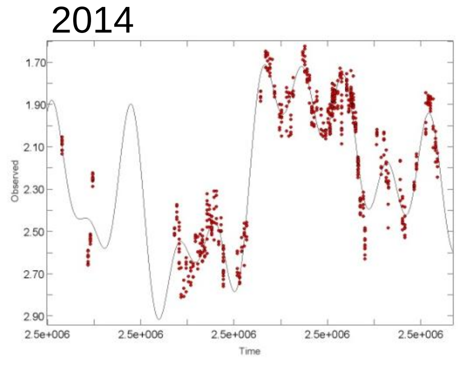
- ✓ The observed brightness in the optical R-band presents strong variability of 0.5 mag within a few days
- ✓ In some cases even 1 mag variation is detected (also reported in the past by Raiteri et al. 2009)
- ✓ Smooth variations of the order of 0.03-0.06 mag/hour are observed systematically during July 2018

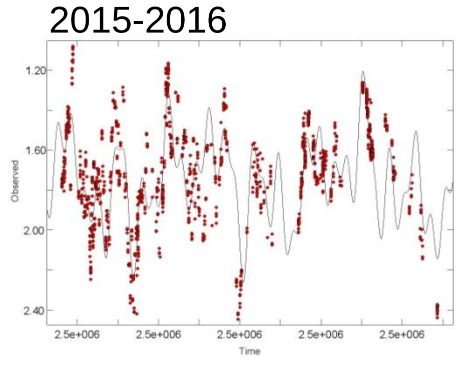


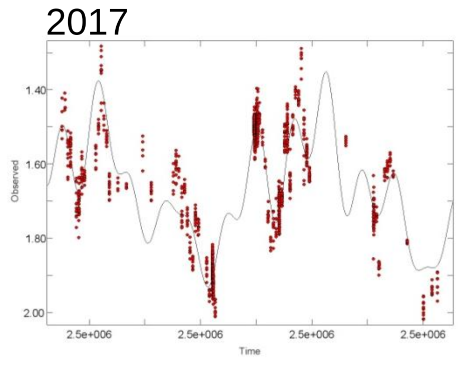
Preliminary results from the FFT analysis - STV

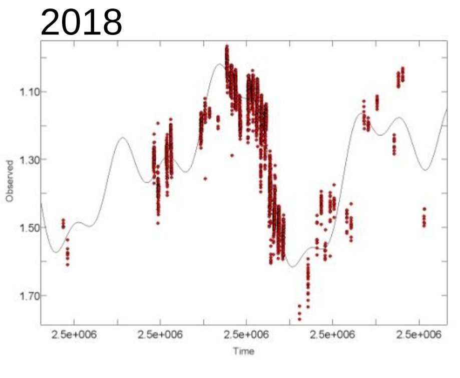
- ✓ The photometric dataset is split in four distinct observing seasons (2014, 2015-2016, 2017, 2018).
- ✓ Preliminary analysis of the collected data utilize an FFT method on each observing season.
- ✓ Symmetric ascending and descending rates may occur in conservative dynamical systems (microlensing, orbital motion etc).
- ✓ Asymmetric rates may direct towards explosive events (electron cooling etc).



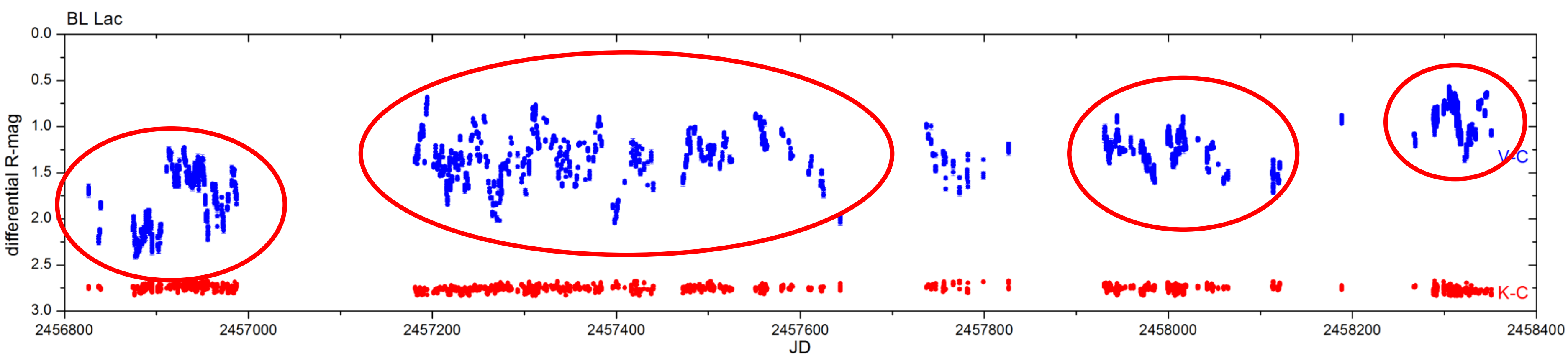


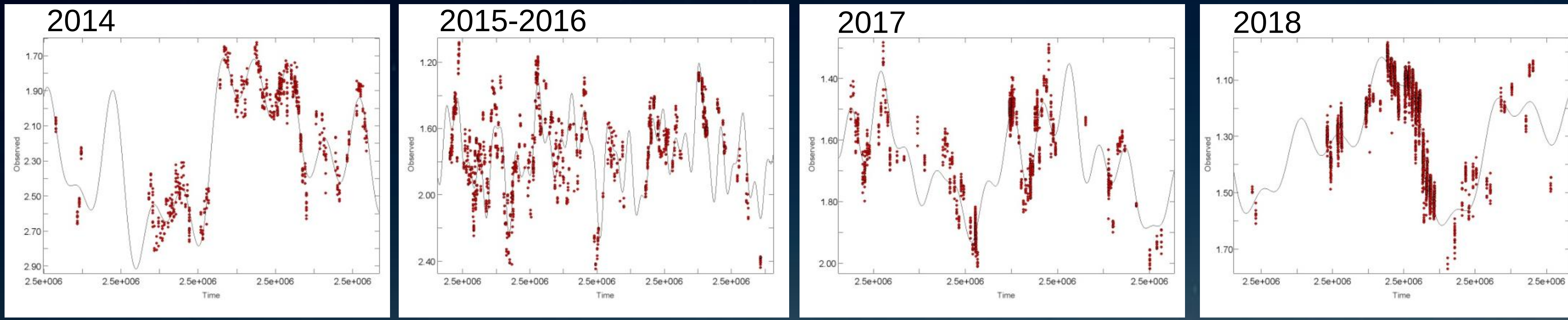






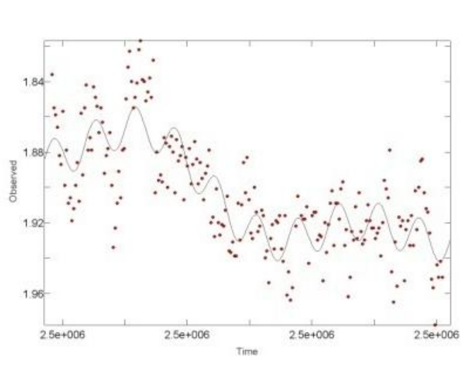
Different observing seasons present unique flux variability. However, they all exhibit a quasi-periodic behavior of the order of 27-28 days, among other (weaker or stronger) signals.

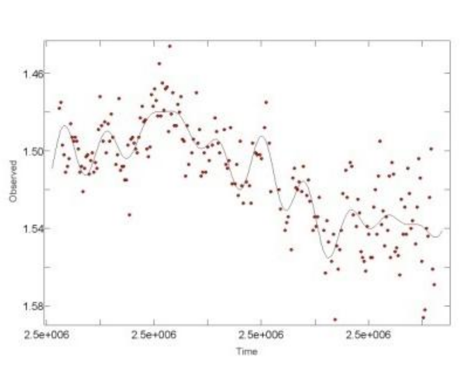


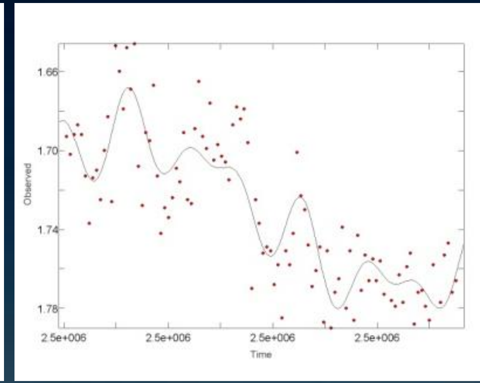


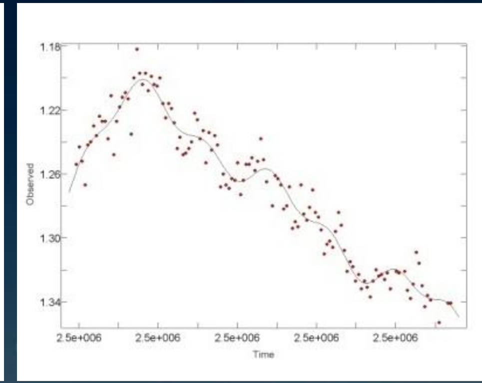
Different observing seasons present unique flux variability. However, they all exhibit a quasi-periodic behavior of the order of 27-28 days, among other (weaker or stronger) signals.

ID	2014	2015-2016	2017	2018
	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)
P_2	27.71(±1.25)	27.47(±0.49)	25.73(±0.69)	28.30(±0.53)
P_3	30.90(±0.85)	33.57(±0.57)	83.42(±4.18)	51.09(±1.44)
P_4	67.85(±4.20)	60.43(±1.54)		







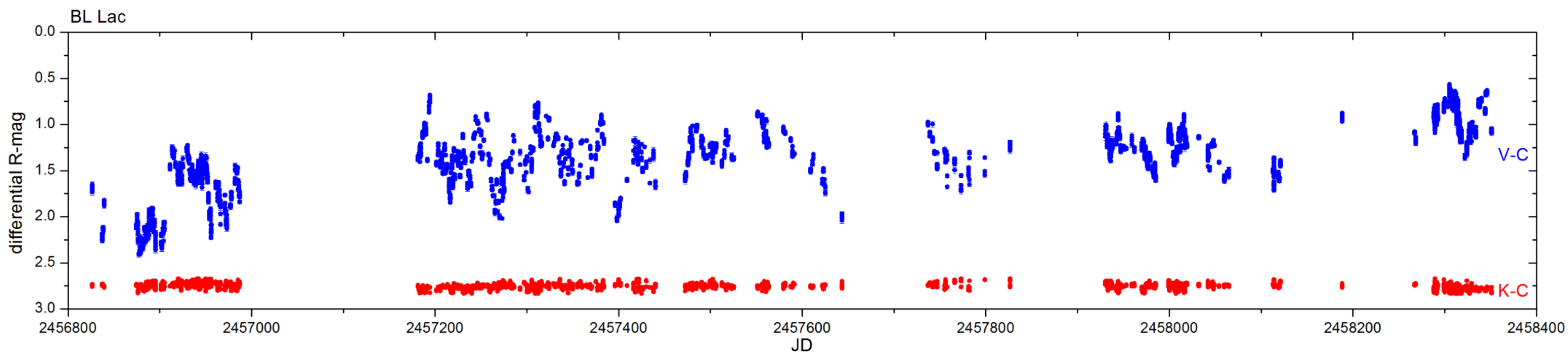


Selected individual night present rapid IDV within a few minutes. Periodic signals reveal a quasi-periodic behavior of 45-50 min.

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

BOSS Project and BL Lac

- ✓ 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.

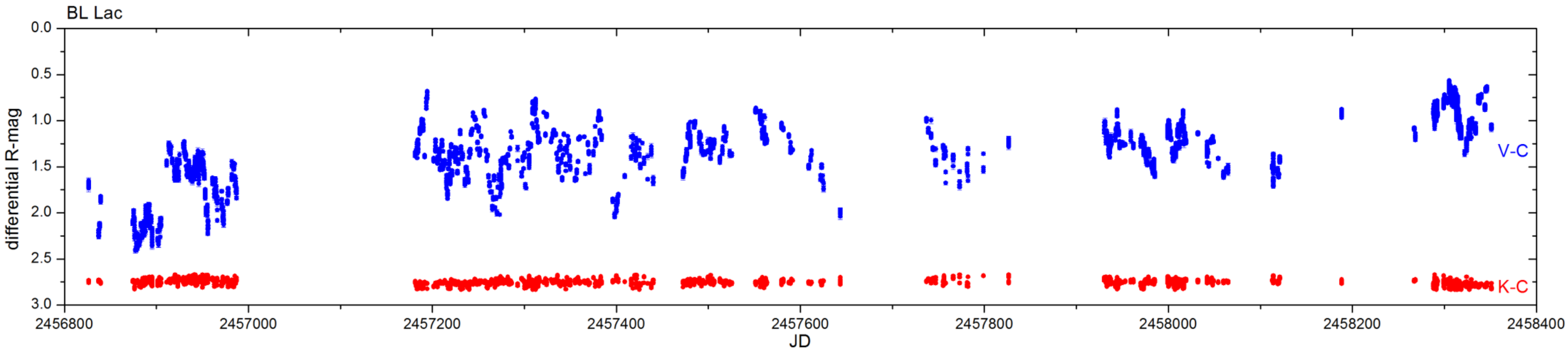


BOSS Project and BL Lac

- ✓ Micro-oscillations with a period of ~1 hour may have significant implications for our understanding of how matter accelerates along the jet.

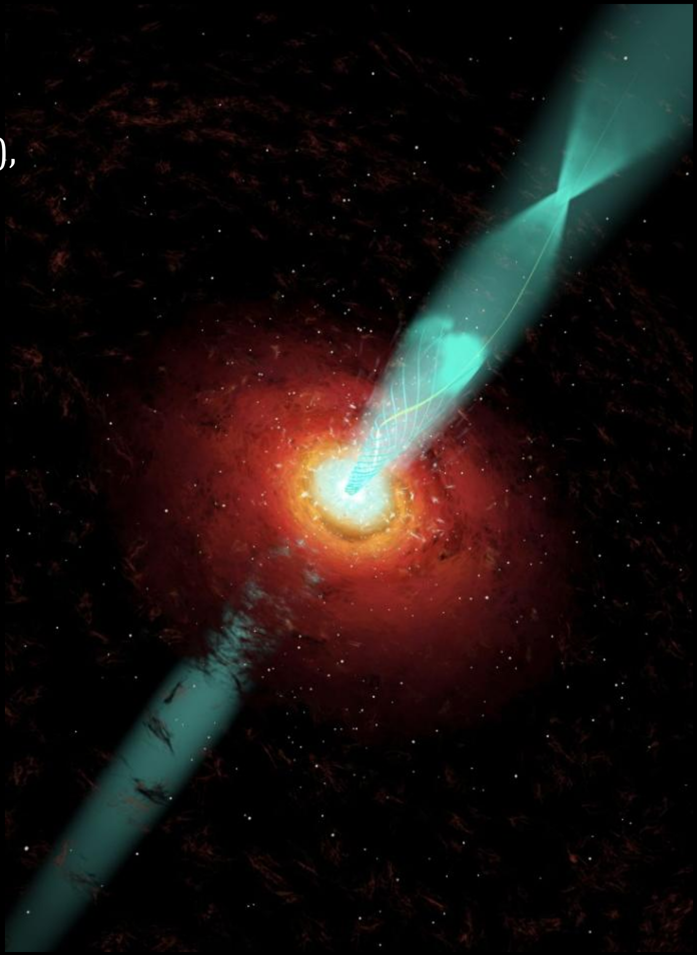
- ✓ The present study suggests that:

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



BOSS Project
Future steps

BL Lac



- ✓ Apply sophisticated statistical analysis tools (i.e. Bayesian analysis), in order to unveil the hidden periodicities
- ✓ Put constraints on the kinetics and morphology of accretion disk and plasma jet, electron density and magnetic field
- ✓ Examine the electron cooling scenario by the flux decay rate and light curve asymmetries
- ✓ Cross – correlate optical data with high and low-energy spectrum (γ-ray, X-ray, radio)

The advantage of small, robotic and remotely controlled telescopes

- ✓ Telescope networking among automatic surveys around the world
- ✓ Semi-automatic of fully-automatic surveys appear every year, covering the entire sky in various wavelengths

BOSS Project
Additional information

BOSS Project Link:

http://users.uoa.gr/~kgaze/boss_project.html

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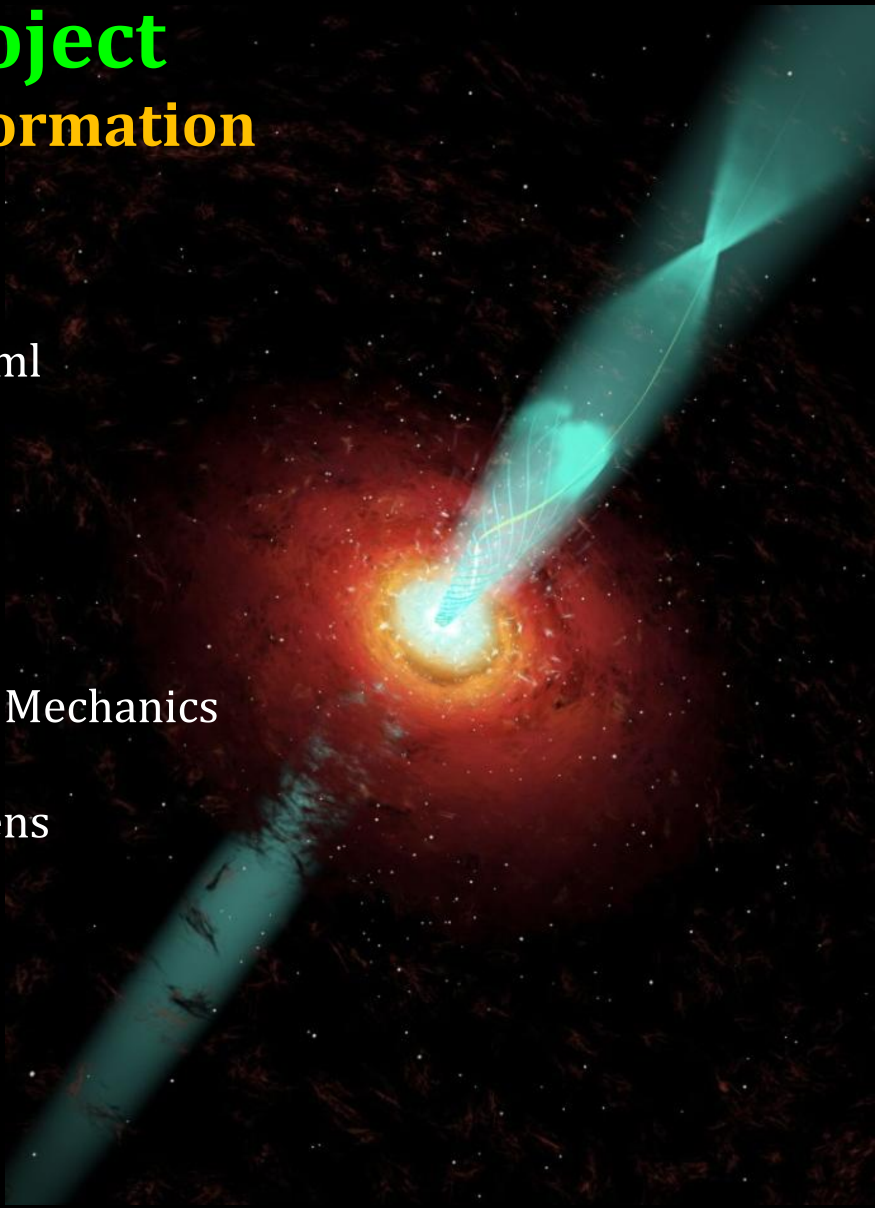

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