Blazar Optical Sky Survey - BOSS project (2013-2017)
The long-term blazar variability monitoring

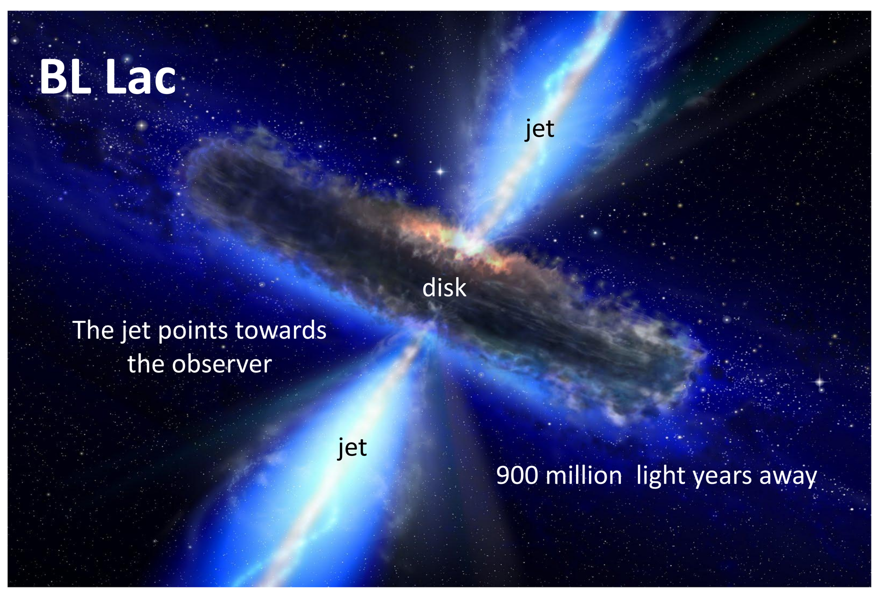
K. Gazeas

Department of Astrophysics, Astronomy and Mechanics, National and Kapodistrian University of Athens, GR 157 84 Zografos, Athens, Greece

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* immediately met international attention, attracting the interest of several collaborators worldwide. It 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*. Several targets of interest are monitored in the frame of *BOSS Project*, such as highly variable blazars and *AGNs*. The targets are continuously observed on a daily basis, with the aim to achieve dense temporal coverage in optical wavelengths. Furthermore, simultaneous observations in high and low energy bands are cross-correlated with *BOSS* database and crucial information are gathered, in order to understand the mechanisms that are taking place in these objects. In this work, some of the major achievements after the first 4 years of operation of the *BOSS Project* are given, while the advantage of small, robotic and remotely controlled telescopes is highlighted.

Introduction

Blazar Optical Sky Survey (*BOSS Project*) is an observational survey of active blazars in optical wavelengths. It was initiated at the University of Athens Observatory (UOAO) in March 2013 under the coordination of Dr. Kosmas Gazeas. In the frame of BOSS Project, ground-based optical photometric observations are performed, in parallel with orbital X-ray observatories and ground-based radio telescopes. The project is running as an international observing campaign, in collaboration with various institutes worldwide, including University of Athens (Greece), Purdue University (USA), Max Planck Institut-MPIfA (Germany), Jagiellonian University of Krakow (Poland), University of Turku (Finland), and Würzburg University (Germany). An example of two of the mostly observed blazars, the prototype BL Lac and the super-massive binary black hole OJ 287, is given in the plots below, highlighting the advantage of small, robotic telescopes and the need for long term commitment in scientific research (Gazeas 2016).

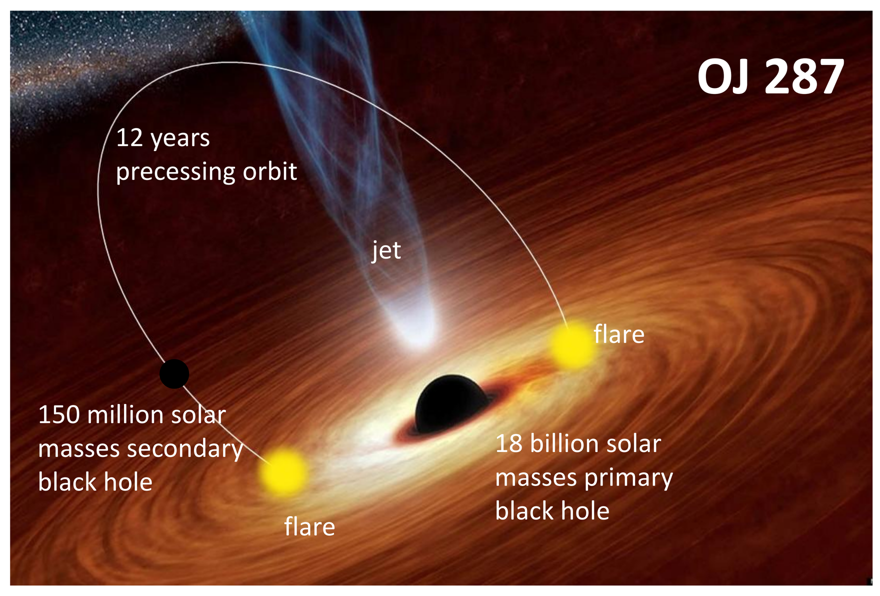


BL Lac

BL Lac is a highly variable AGN, discovered by Hoffmeister (1929) and initially classified as a typical variable star. BL Lac was identified by Schmitt (1968) at the David Dunlap Observatory as a bright, variable radio source, while Oke and Gunn (1974) measured a redshift of z = 0.07, corresponding to a recession velocity of 21,000 km/s with respect to the Milky Way, which implies that the object lies at a distance of 900 million light years. BL Lac became the prototype of the class of AGNs known as "Blazars" and it is distinguished by rapid and high-amplitude brightness variations. This behavior is caused due to relativistic beaming from a jet of plasma, ejected from the vicinity of a super-massive black hole.

BOSS Project Target List

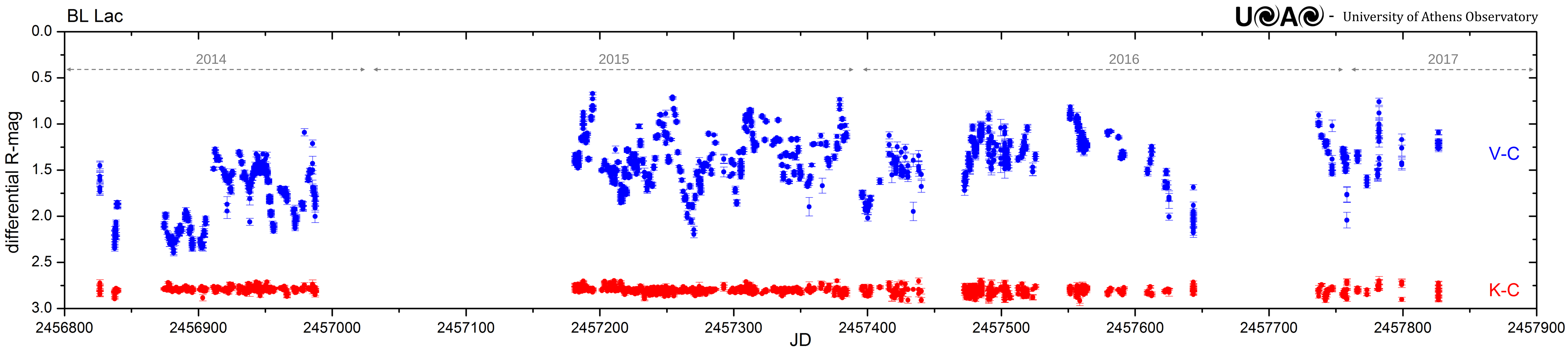
Target	Other Name	RA (J2000)	DEC (J2000)	Rmag	Type
Mrk1018	PGC 8029	02:06:16	-00:17:29	10.3 mag	Seyfert 1 Galaxy
1ES 0236+610	LS I +61 303	02:40:32	+61:13:42	10.2 mag	HMXB (V615 Cas)
1H 0323+342	PGC 2045127	03:24:41	+34:10:46	13.1 mag	Blazar
PKS 0716+714	GSC 0368:0899	07:21:54	+71:19:21	14.3 mag	Blazar
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



OJ 287

OJ 287 is a binary supermassive black hole, located at a distance of 3.5 billion light years. It has been observed for at least 120 years (Sillanpää et al. 1988). The primary black hole has a mass of 18 billion $M_{\odot}$, while the smaller one weights "only" 100 million $M_{\odot}$, and orbits the larger one with a 12-year orbital period. Physical and geometrical properties of OJ 287 are well studied by Valtonen et al. (2006, 2008, 2010), who estimated the mass of the central black hole, using the principles of General Relativity. Recently, (Valtonen et al. 2016) calculated the spin of the primary black hole as 0.313±0.01. The companion's orbit is decaying via gravitational radiation and the system is expected to merge within approximately 10,000 years.

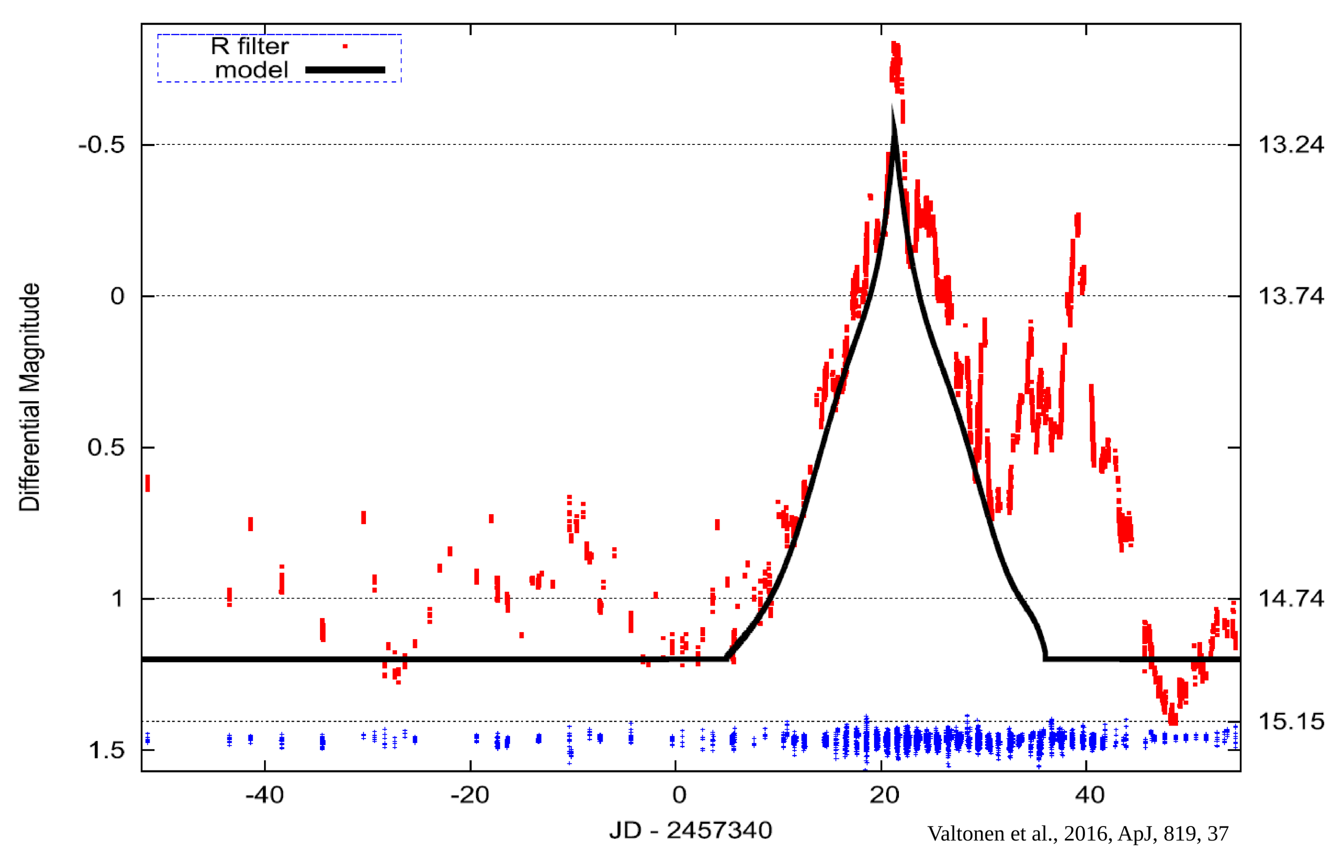
UOAO - University of Athens Observatory



BOSS Project preliminary results on the photometric variability of BL Lac data, spreading from 2014 to 2017. 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.

The observational strategy

The primary science goal of *BOSS Project* is to monitor the optical flux of several γ-ray and X-ray luminous blazars, which will allow to test models of the jet structure, kinematics chemical composition, magnetic field, and emission and light variability mechanism. Observations are obtained almost in a daily basis, monitoring intra-day variability (IDV) of blazars, or resulting in a very dense annual coverage. *BOSS Project* utilizes the robotic and remotely controlled telescope at the *UOAO*, which is equipped with a CCD camera and photometric filters in all optical bands. In the frame of *BOSS Project*, each target can be monitored several times within an observing night, while several targets can be followed within a single night. The high percentage of clear sky (over 75% of useful nights within a year) allows the continuous monitoring of all program targets. *BOSS Project* can contribute to the field of High Energy Astrophysics, where there is poor coverage on low energy bands (optical) and follow-up observations, there is a need for cross-correlation studies, where multi-wavelength studies are essential for modeling purposes, or where rapid flux variability is "missed" in non-frequent monitoring campaigns. The carefully designed observing scheme maximizes the telescope's efficiency, resulting in a large database of optical measurements taken with a single instrument, while creating a homogenous, dense, and uniform database of a large number of blazars.



The University of Athens Observatory contributes significantly to the long-term optical monitoring of OJ 287. A sample of the most recent R-band data is displayed, covering the range between October-December 2015, when a bright flaring event occurred.

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Long-term database

The blazar Mrk421 was the first target to be observed in *BOSS Project*. It was later extended in several other targets, which are continuously monitored in a daily basis, with the aim to achieve a similar highly dense coverage in optical wavelengths. In parallel, other wavelengths are cross-correlated with our database, either with archival data or after requested to be observed (i.e. through proposals for orbital observatories). Recently (December 2016), *BOSS Project* was extended further in a few more targets (see table above), which show energetic and flaring behavior. Entering the fifth year of operation, *BOSS Project* brought precious results, while the advantage of small, robotic telescopes is highly acknowledged. Among them, the multi-wavelength monitoring of the highly active blazar Mrk421 (Gazeas et al. 2013) and the monitoring of the ultra-luminous flaring event of OJ 287 in December 2015 (Valtonen et al. 2016, Bhatta et al., 2016 and Zola et al. 2016) gives a good and representative list of the advantages, brought through a dedicated observational program. A similar example is the discovery of the OJ 287 binary black hole system, which is a result of an extensive monitoring program of quasars, carried out both in radio (*Metsähovi Radio Observatory, Helsinki*) and in the optical (*Tuorla Observatory, Turku*), which started in 1980. Therefore OJ 287 is a perfect example of the need for long term commitment in scientific research.