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Review

Long-Term Optical Monitoring of Blazars

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Abstract: Systematic monitoring of specific targets in the optical regime was historically applied on a very narrow sample of known variable stars. The discovery of blazars in the 20th century brought to the foreground the need for new global sky surveys, covering the entire sky and fainter sources. Full-sky surveys are conducted more easily from space observatories, while radio telescopes perform follow up observations from the ground. Blazars are detected in a wide range of energies, while they exhibit strong variability in various wavelengths from γ-rays and X-rays to the optical and radio domain. This results in a detailed classification, according to their emission properties in each region. The rapid variability in optical domain makes blazars interesting targets for optical sky surveys, offering a new opportunity to study their variability in the time domain. Digital sky surveys in optical and near-IR found a fertile ground with the aid of sensitive sensors. Only a few dedicated programs are focusing on blazar variability, a trend which evolved rapidly in the last decade. Modern techniques, in combination with dedicated sky survey programs lead towards a new era of long-term monitoring of blazars, aiming towards the search or variability on various time scales. In this work, an overview of blazar optical surveys and monitoring projects is given, addressing the major points of each one, and highlighting the constraints that the long-term study of blazars will bring through future international campaigns.

Keywords: blazar variability; monitoring; Active Galactic Nuclei; Multi-Wavelength

1. Introduction

Blazars are active galactic nuclei (AGN) with irregular and strong emissions in radio and TeV energies (Ulrich et al. [1]), in which the jet is closely aligned along the observer's line of sight. The term blazars include all BL Lac-type objects, as well as Flat-Spectrum Radio Quasars (FSRQ), a classification which depends on their emission characteristics. They consist of a rare class of the wider range of AGNs (only 5%), while they exhibit rapid variability in all observed energies, including Doppler boosting emission from the relativistic jet. Blazars (both BL Lac-type and FSRQ objects) are among the most variable extragalactic objects detected in optical and radio surveys. X-ray and γ-ray astronomy also pointed out that the high energy flux of these energetic sources vary significantly in time, making Blazars ideal targets for long-term monitoring from both ground-based and orbital telescopes, in the entire electromagnetic spectrum.

It is difficult to detect and characterize a blazar from its optical variability. Usually such objects are detected and classified by their radio and high energy spectrum, or by the corresponding spectral energy distribution (SED). Space telescopes monitor the sky in high energies, resulting in a long list of potential targets of this kind. For example, The Fermi Gamma-ray Space Telescope (Fermi GST) conducts a full sky survey in γ-rays, utilizing the Large Area Telescope (LAT, Atwood et al. [2]) instrument. This provided the deepest so far survey in the 100 MeV–100 GeV regime, resulting in the LAT source catalog (2FGL, Nolan et al. [3]) with 1873 sources.

Only a small fraction of these targets are bright enough in the optical bands, limiting the optical monitoring campaigns to a small number of targets. Moreover, large telescopes do not dedicate sufficient time on long-term monitoring projects, further reducing the available sources to the bright ones. Digital sky surveys in optical and near-IR found a fertile ground with the aid of sensitive sensors in recent decades. Sloan Digital Sky Survey (SDSS) (York et al. [4]), Two Micron All-Sky Survey (2MASS) (Skrutskie et al. [5]), All-Sky Automated Survey (ASAS) (Pojmanski [6]), Optical Gravitational Lensing Experiment (OGLE) (Udalski et al. [7]), Super Wide Angle Search for Planets (SWASP) (Pollaco et al. [8]), are some of the main sources of long-term monitoring photometric surveys nowadays. Future optical sky surveys will play an important role in this domain. New projects such as Pan-STARRS (Kaiser et al. [9]), the Catalina Real-Time Transient Survey (Drake et al. [10]), the Palomar Transient Factory (PTF, Rau et al. [11]), and the Large Synoptic Survey Telescope (LSST, Ivezić et al. [12]) will spread new light to the long-term optical monitoring of faint blazars.

Only a few dedicated programs are focusing on blazar variability, a trend which evolved rapidly in the past decade. A small number of individual bright blazars have been studied up to date (Webb et al. [13]; Carini et al. [14]) without any solid conclusion of statistic correlation between the observed behavior. Non-homogeneity of the data, as well as sparse data sampling are the most common problems in long-term blazar observations. Presently, modern techniques, in combination with dedicated sky survey programs lead towards a new era of blazar monitoring and variability studies on various time scales.

2. Optical Sky Surveys and Monitoring Programs

Sky surveys usually cover a fraction of the sky and span for a short duration in time. Wide field cameras scan the entire sky from both hemispheres, offering a good knowledge of the brightness distribution of the bright blazars. Only a limited number of survey programs with large aperture telescopes can go deeper in magnitude. Therefore, the available telescopes focus on the brighter sources, or in narrow sky strips. Instruments that focus on a small number of bright targets, can perform long-term monitoring for several years. They offer information on short-term and long-term variability but they are missing the faint sources. Finally, there are telescopes that observe the entire sky (visible from a given location) for a long time, but the data sampling (frequency of observation) is very sparse, usually of the order of once every week or every month. This results in a serious limitation in variability recording and intra-day or short-term variability detection. All short-term variability is wiped out in the Fourier spectrum.

Below, a list of optical sky surveys and monitoring programs is given, along with the main characteristics and expected goals.

- **BATC Survey**: a spectrophotometric survey on selected areas of the northern sky down to 21 mag limit, in combination of Beijing-Arizona-Taiwan-Connecticut telescopes. Aims for quasars of known properties, bright nearby galaxies and randomly selected objects (Burstein et al. [15]).
- **Sloan Digital Sky Survey—SDSS**: imaging and spectroscopy with a 2.5 m telescope. Aims to cover more than 10^6 galaxies and 10^5 quasars at north galactic cap (York et al. [4]).
- **Sedentary Survey**: combination of monitoring surveys in X-rays, optical and radio signals, aiming for high energy blazars, covering the equatorial zone (Giommi et al. [16]).
- **Lincoln Near-Earth Asteroid Research (LINEAR) survey**: based on the near-Earth asteroid survey program, which was first presented in Stokes et al. [17]. The extracted data set contains more than 5 billion photometric measurements, mostly of stellar objects. It overlaps with SDSS catalog and goes down to 17 mag in r-band (Sesar et al. [18]).
- **Robotic Optical Transient Search Experiment—ROTSE-I**: designed to search for bright (10 mag $< V <$ 15.5 mag) astrophysical transients, associated with GRBs. Covered 2000 deg^2 twice. (Akerlof et al. [19]).
- **Northern Sky Variability Survey (NSVS)**: temporal sky monitoring in optical bands, covering the bright sources (8 mag $< V <$ 15.5 mag), based on ROTSE-I catalog (Wozniak et al. [20]).

- **All-Sky Automated Survey—ASAS**: entire southern sky and part of northern down to 14 mag. Monitoring about 14 million stars and transient objects (Pojmanski [6]).
- **Lowell Observatory Near-Earth-Object Search—LONEOS I**: a clear aperture (no photometric filter) survey of 1430 deg^2 of the northern sky down to 18.5 mag (Miceli et al. [21]).
- **Palomar Transient Factory—PTF**: wide area coverage in two optical bands down to 20 mag, aiming at systematic exploration of the optical transient sky (Rau et al. [11]).
- **Pan-STARRS (1 & 2)**: wide field optical and near-IR imaging. Aims to discover NEO and stellar transients in the galactic plane and bulge and perform a time domain survey in specific targets with 1.8 m telescope (Kaiser et al. [9]).
- **Catalina Sky Survey—CSS**: large sky coverage (26,000 deg^2) down to 15 mag, aiming to detect real time transient phenomena with Catalina Real-Time Transient Survey (Drake et al. [10]).
- **Blazar Optical Sky Survey—BOSS Project**: optical monitoring program, initiated on April 2013 at the University of Athens (http://users.uoa.gr/~kgaze/boss_project.html). It aims at monitoring the optical multi-band variability on active Blazars, in parallel with other multi-wavelength observations obtained from space and ground-based observatories. More than 20 bright targets are observed in a long-term on a daily basis, in order to cover the frequency range from IDV to STV and LDV (Figure 1).
- **Two-degree Field Galaxy Redshift Survey—2dFGRS**: spectroscopic survey of 140,000 galaxies with a 4 m telescope in southern hemisphere, covering a small area in narrow sky strips (Peterson et al. [22]).
- **Two-Micron All Sky Survey—2MASS**: near-IR survey in both hemispheres with 1.3 m telescopes. Performs photometric and astrometric measurements down to 15 mag (Skrutskie et al. [5]).
- **Super Wide Angle Search for Planets—SWASP**: photometric survey of bright objects (10 mag < V < 13.5 mag), aiming for exoplanet transits. Created a catalog of 400,000 stars with long-term photometric measurements (Christian et al. [23], Pollaco et al. [8]).
- **Optical Gravitational Lensing Experiment—OGLE**: long-term large scale photometric sky survey on stellar variability, aiming to detect microlensing phenomena. Utilizes 1 m and 1.3 m telescopes, covering 2000 deg^2 down to 18.5 mag (22 mag in the future) (Udalski et al. [7]).
- **Kilo-Degree Survey—KIDS**: optical imaging survey of 1500 deg^2 in the southern hemisphere, utilizing a VLT survey telescope (VST) with a wide field camera and four filter photometry. Overlaps with SDSS catalog and covers several extragalactic sources (de Jong et al. [24]).
- **CFHT optical survey**: photometry and multi-slit spectroscopy, performed for a short duration (a few days) with the Canada-France-Hawaii Telescope, aiming on galactic redshifts, faint galaxies and clusters (Adami et al. [25])
- **UKIRT Infrared Deep Sky Survey—UKIDSS**: near-IR photometric survey, conducted for 7 years at 1800 deg^2 on north galactic plane, aiming for high proper motion sources (Smith et al. [26]).
- **La Silla/QUEST survey**: optical photometry with 1 m telescope down to 21.5 mag (Walker et al. [27]).
- **Robotic Polarimeter—RoboPol**: specialized photopolarimeter designed specifically for the 1.3 m telescope at the Skinakas Observatory, Crete. Aims to monitor the optical linear polarization of >100 gamma-ray bright blazars, which will allow testing models of the jet structure, composition, magnetic fields, and emission mechanism (Pavlidou et al. [28]) (Figure 2).
- **Polar-Areas Stellar-Imaging in Polarization High-Accuracy Experiment—PASIPHAE**: aims to map the polarization of millions of stars at areas of the sky away from the Galactic plane, in both the Northern and the Southern hemispheres. The goal is to clear the path towards the detection of the imprint of inflation on primordial light. The experiment will take place at the Skinakas Observatory, Crete, and the South African Astronomical Observatory in Sutherland, South Africa (Tassis et al. [29]).

- **Polarimetric Monitoring of Blazars from San Pedro Martir**, as well as optical variability studies, conducted in San Pedro Martir Observatory in (Mexico) (Benítez et al. [30]) (Figure 3).
- **Radial Velocity (RAVE) Experiment**: radial velocity experiment, in optical and near-IR regime. Acquired 500,000 spectra of bright objects (9 mag $< V <$ 12 mag), resulting in a large spectroscopic data base (Kordopatis et al. [31], Kunder et al. [32]).
- **Tuorla blazar monitoring program**: a long-term photometric program, dedicated on blazar variability. Performs monitoring of 24 bright blazars with a 1 m telescope in R band, supporting the VHE γ-ray observations of the MAGIC telescope (Takalo et al. [33]).

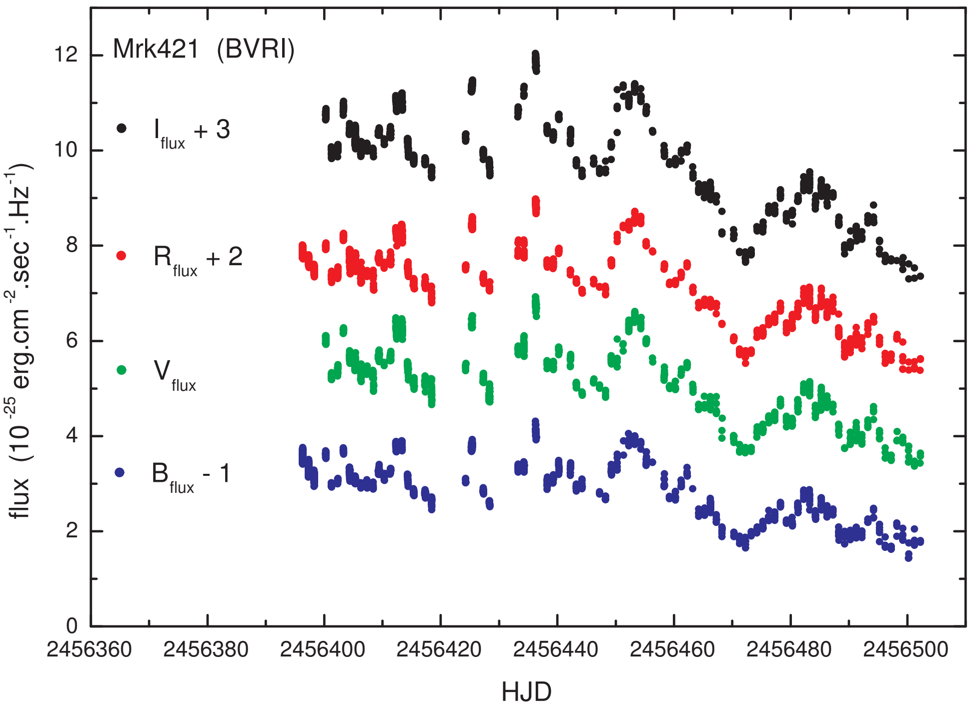

Figure 1. Sample of multi-band light curve in optical wavelengths of the active blazar Mrk421, obtained from the long-term monitoring program "BOSS Project", which is conducted at the University of Athens Observatory (UOAO). Copyrights: BOSS Project.

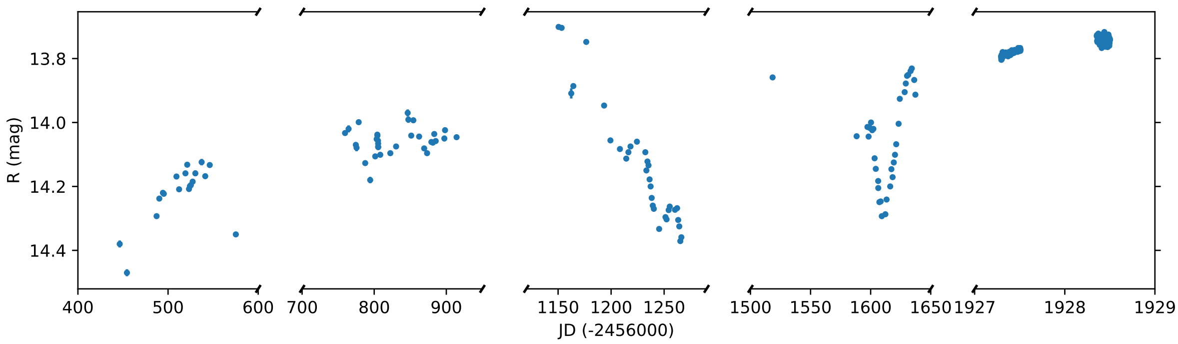

Figure 2. Sample light curve of the active blazar PG 1553-113 from the long-term monitoring program "RoboPol", which is conducted at Skinakas Observatory. (Copyrights: RoboPol Program. Reproduced with permission).

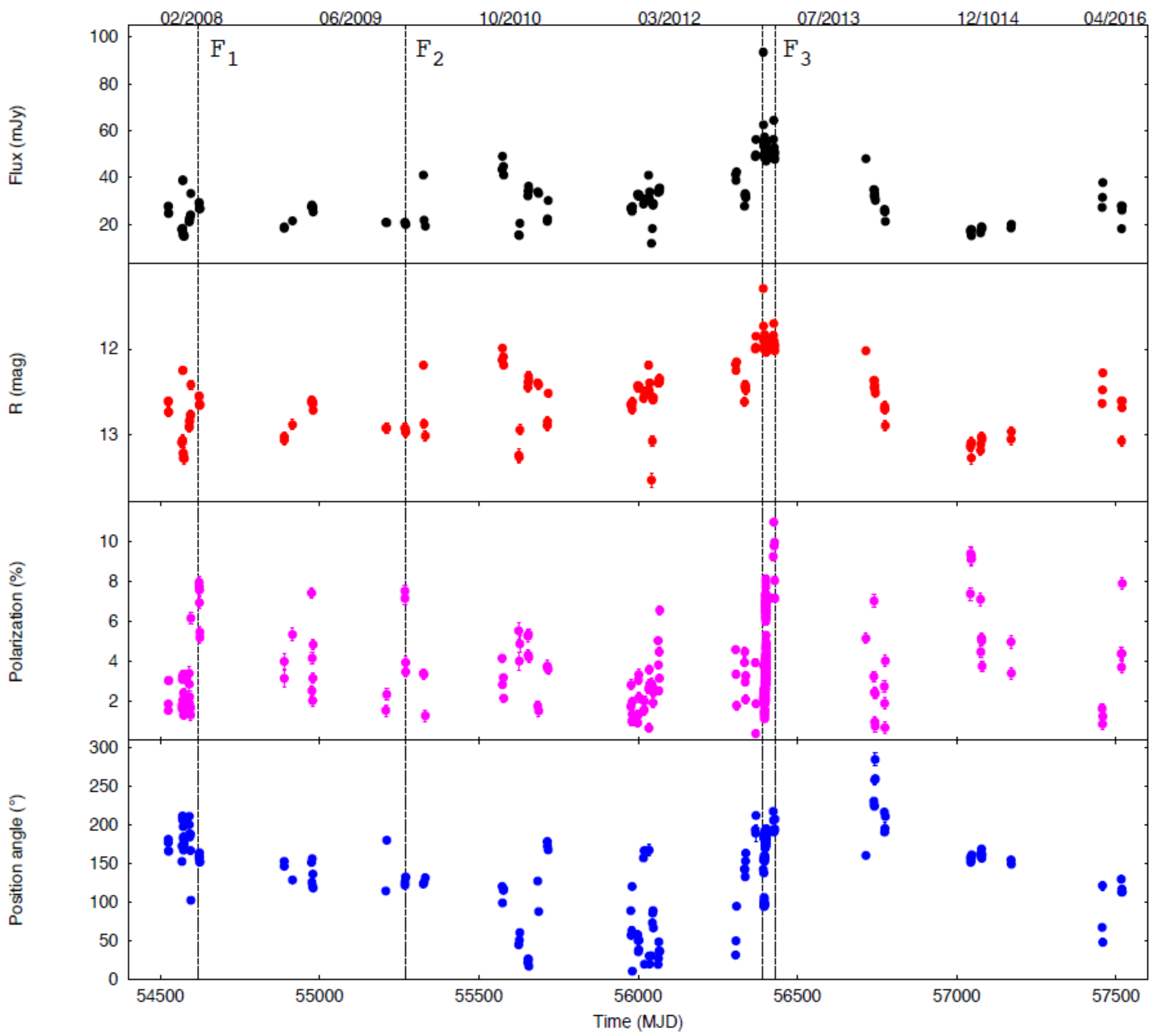

Figure 3. Opto-polarimetric light curve of Mrk 421 from 2008 to 2016, obtained from San Pedro Matrir Observatory. From top to bottom: The optical flux, the R-band mag, the polarization degree and the position angle variations are presented. Dashed vertical lines mark three observed flares (Fraija et al. [34]. Reproduced with permission).

Some of the most important telescope networks globally include:

- **The Whole Earth Telescope (WET)**: (Nather et al. [35]) is an international cooperative network structured to provide precision time-series photometric observations on multiple targets during campaigns lasting 2–8 weeks. Continuous observations with these time bases are required to fully capitalize on the tools of asteroseismology. Because of their numbers and availability, small telescopes (apertures less than 2 m) play vital roles in the WET network.
- **The Whole Earth Blazar Telescope (WEBT)**: international consortium, utilizing several telescopes in optical, near-IR and radio regime, dedicated to observe blazars in a long-term monitoring mode (Villata et al. [36]).
- **SkyNet robotic telescope network**: global network of fully automated, or robotic telescopes serving over the Internet. The top scientific priority for Skynet Telescopes is to observe γ-ray bursts (GRBs) (Reichart [37]).
- **MASTER** (Lipunov et al. [38]) and **MASTER II** (Kornilov et al. [39]): Robotic optical telescopes global network, designed to study the prompt (simultaneous with gamma radiation) optical emission of γ-ray bursts and to perform the sky survey to detect unknown objects and transient phenomena.

- **Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes (PROMPT)**: scanning the night sky in a regular basis with six 0.41 m telescopes with a fast response to GRB alerts and transient phenomena (Reichart et al. [40]).
- **BCK**: network of optical telescopes: consists of three research grade robotic telescopes of 0.6 m–1.3 m telescopes. The network is designed to observe variable stars, blazars and transient events (McGrunder et al. [41]).
- **The Automatic Telescope Network (ATN)**: Automated monitoring program, performing simultaneous optical monitoring of blazars during the FERMI-LAT γ-ray NASA mission (Mattox et al. [42]).
- **LCO network**: utilizes 21 telescopes around the world in order to contribute in time domain astronomy (Brown et al. [43].)

3. Large Scale Surveys in Various Domains

Our knowledge of blazars and their emission is based on a limited number of bright sources, which are initially detected in high energies. There is an even smaller number of individual targets observed systematically in optical bands (i.e., and just a handful of sources monitored in the frame of a multi-wavelength survey. The need for deep blazar surveys was pointed out in a review paper by Padovani [44], where he addressed the constraints and limitations that a deep survey will exhibit in high energy domain.

What we are actually looking for in large surveys is a uniform sample and as many data as possible. Ideally, we need to cover the entire sky, in all bands, in both deep and shallow flux rates and for a long duration, preferably exceeding the span of several years. In addition to the above, hourly and daily sampling is essential when short-term flux modulation is studied.

3.1. The Time Domain

Blazar variability timescales are often divided into three categories: the intra-day variability (IDV) which ranges between a few minutes up to one day (Wagner and Witzel [45]), 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 (Gupta et al. [46]).

It is very common for a blazar to exhibit irregular IDV, usually smaller than an order of magnitude. This is why such an effect is also referred to as "microvariability". An example of this kind of variability was reported in the past by Raiteri et al. [47] on the prototype blazar BL Lac. Such an IDV behavior was also reported by Nesci et al. [48]; Speziali Natali [49]; Papadakis et al. [50]; Howard et al. [51], Zhang et al. [52] and Bachev et al. [53]. Smooth flux variation of the order of 0.03–0.06 mag/hour is observed on the same target systematically during July 2018 by the BOSS Project. In all the above cases, the Fourier analysis reveal quasi-periodic behavior of about 45–50 min (Figure 4).

Not all quasars exhibit STV, but some show variability on the order of 0.01 mag on 1 day timescales (Gopal-Krishna et al. [54]; Stalin et al. [55,56]; Gupta & Joshi [57]; Mushotzky et al. [58]). The cause of quasar variability on such short timescales is an unresolved problem, although the presence of strong intraday variability is correlated with radio-loudness. Previous studies of blazar microvariability have often focused on the most variable blazars, and have reported night-to-night variations as high as 1.0 mag (e.g., Carini et al. [59]; Ghosh et al. [60]). Photometric monitoring by BOSS Project reveals a flux modulation of a similar IDV and STV scale for active blazars like Mrk421 and BL Lac.

LTV is something well known for all observed blazars. There is a limited amount of available data in order to talk about QPOs and anything related to periodicity. However, the observed flux is highly variable and in most cases irregular. The available data are usually not sufficient enough to talk about short-time scale QPOs. Long-term flux modulation can also combine observations from orbital and ground-based telescopes. Such studies aim towards the search of time lags between the observed flares in different wavelengths, which are associated with physical emission mechanisms, such as electron cooling or inverse Compton radiation.

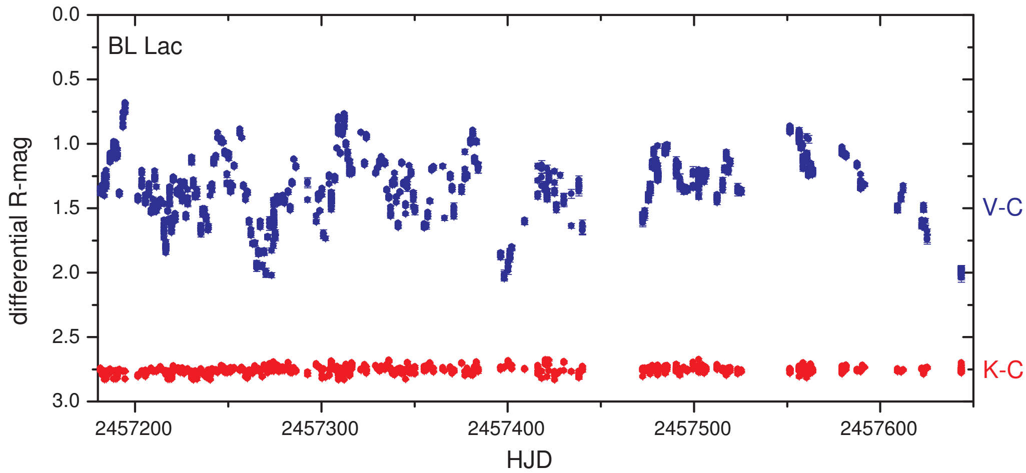

Figure 4. Sample light curve of the prototype blazar BL Lac from the long-term monitoring program "BOSS Project", which is conducted at the University of Athens Observatory (UOAO). Copyrights: BOSS Project.

3.2. The Covered Area Domain

Sloan Digital Sky Survey (SDSS) covers a sky area of about 10,000 deg^2 of imaging and about 6000 deg^2 of spectroscopy down to 22.5 mag in optical band. However, only a small fraction of this area is covered for a long-term time-domain astronomy (~290 deg^2), which is not sufficient for blazar studies. The same applies for 2MASS catalog. LINEAR survey (Sesar et al. [18]), on the other hand, covers the same area of the 10,000 deg^2 by SDSS down to 17 mag for several epochs, which is essential for a long-term variability studies. Palomar-Quest Survey covers an area of 15,000 deg^2 (Bauer et al. [61]), which was used for short-term blazar variability study in the past decade (Bauer et al. [62]).

Some of the upcoming imaging and spectroscopic surveys include: LSST (20,000 deg^2), Pan-STARRS (30,000 deg^2), CFHT legacy (400 deg^2), QUEST (15,000 deg^2), UKIDSS (4000 deg^2), and the Dark Energy Survey (5000 deg^2).

Future extragalactic surveys aim towards the study of baryon oscillations and galaxy properties, such as those being discussed for Subaru (WMOS, WFMOS), HET (VIRUS), and San Pedro Martir telescopes. All the above sky surveys will contribute significantly in the full-sky and long-term monitoring of blazars, while they will obtain valuable data for the future variability studies on blazars.

3.3. The Luminosity Domain

Telescope aperture sets a limit on detector's efficiency and therefore only bright blazars are monitored properly. Faint sources are often dominated by large photometric errors, making them useless for accurate time-domain analysis. On the other hand, bright sources are frequently saturated in automated sky surveys and therefore special treatment has to be applied.

Dedicated observing programs with small telescopes or even wide angle lenses usually cover the bright regime of blazars. It is a trend of the current decade for small telescopes or even optical arrays with telephoto lenses to act as survey programs and scan the entire sky for transient events.

Fainter targets are observed with medium size telescopes, which dedicate some (limited) observing time on this field. For example, 140 bright blazars from LINEAR catalog 14 mag < m < 17 mag are used for variability science (Ruan et al. [63]), more than 100 blazars are observed with RoboPol program and about 20 blazars are monitored in a daily basis with BOSS Project. All these collected data are used to find reliable associations among Candidate Gamma-Ray Blazar Survey (CGRaBS) (Healey et al. [64]), Fermi 2FGL and 3FGL catalogs (Nolan et al. [3], Ackermann et al. [65]) and perform cross-correlation analysis among all available energy regimes (Figure 5, left panel).

3.4. The Location Domain

There is a large chance that some sources are classified in more than one catalogs, with several types of AGN (blazar, FSRQ or quasar), due to their complicated properties. Also several blazars are associated with bright or faint counterparts at the same time, as a result of their rapid and high variability. Low resolution astrometry can often mistake a high energy source with a stellar object in the field.

Astrometric location of blazars is essential in creating a target list for future automated surveys, where the optical counterparts of X-ray and γ-ray sources will be based on their celestial coordinates. In order to create such target lists, it is common to cross-correlate catalogs in high energies with optical counterpart and search for BL Lac objects and FSRQs among the highly energetic sources. Faint source catalogs created with large aperture telescopes play a significant role in this study, since they offer accurate flux determination, as well as high angular resolution (Figure 5, right panel).

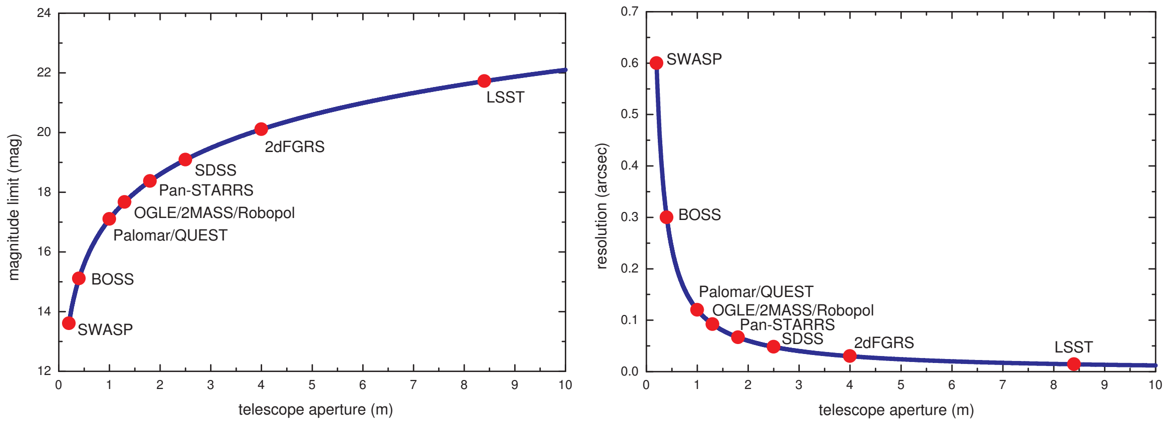

Figure 5. Summary histograms, showing the limiting magnitude (**left**) and angular resolution (**right**), for a sample of monitoring programs and surveys that utilize narrow and wide telescope apertures. Please note that the magnitude limit is calculated for visual observations (i.e., exposure is not accounted in calculation) and angular resolution is diffraction limited, without taking into account local seeing conditions or detector limitations.

4. Discussion—The Future of Long-Term Surveys on Blazars

There are only a few blazars (around 100) that can be monitored by a moderate size telescope with a typical CCD camera. On the other hand, there are several instruments available for surveys, even networks of small telescopes that monitor the sky every night. It is impossible for a single telescope to collect the desired information at once, covering the entire sky, for a long time. Telescope networking is a new trend in the last decade, which acts as a full-time dedicated and multi-aperture instrument. Such a network is well described with the Whole Earth Telescope (Nather et al. [35]).

In order to cover a lot of the sky, we need dedicated wide-field and large aperture telescopes. This can be done with either large format cameras or with special optical design telescopes. A significant contribution of small robotic and automated telescopes and their networks will open a new era in the long-term optical monitoring of blazars (Gazeas [66]).

It was more than 20 years ago, when researchers began considering the potential of a global telescope network. Presently, we have SkyNet robotic telescope network, MASTER (Lipunov et al. [38]), or the Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes (PROMPT), scanning the night sky in a daily basis. Past, present and future space telescopes, such as GAIA, Kepler, TESS, JWST, can also contribute to blazar study, although they are not characterized as blazar survey programs.

The importance of blazar monitoring programs is essential. Some of the major results extracted though the dedicated blazar surveys include the connection between optical polarization plane rotations and γ-ray flares in blazars (Blinov et al. [67]). Rapid intraday variability (IDV) was observed in BL

Lac during the 2000–2001 campaign of WEBT program (Raiteri et al. [68]). They observed a ~1 mag brightening in a couple of weeks and several variations up to a few tenths of mag on hour time scales. BOSS Project contributes in the time domain study of blazars (Gazeas et al. [69]). Preliminary findings include the 17–22 day QPOs found in Mrk421 and BL Lac during the 2013–2018 photometric observing campaign, which are connected with the accretion disk rotational period. Multi-wavelength studies between BOSS Project and γ-ray, X-ray and radio surveys reveal significant time lags between high and low energy flares, which can be explained through electron cooling process.

All that is needed to perform a dedicated monitoring program is a good target list of well determined sources. Optical and near-IR astronomy opened a new window in the time domain astronomy very recently. The advantage of global telescope networks is an asset and they guarantee high quality homogeneous data bases, from which future studies can mine information on blazar variability, even for large scale galaxy structure and cosmological studies that are based on data uniformity and global sky coverage.

Multi-wavelength studies are bringing researchers from different domains together. A combination of several electromagnetic bands is extremely important to understand the physics behind the observed variations in light and spectra. From the opposite point of view, the newly designed survey programs use the physics of blazars in order to design the future telescope setups and establish the observing strategy.

Multi-messenger astronomy and coordinated observations with all available detectors, offer a unique opportunity to study the physics of blazars through its networks (i.e., Astrophysical Multimessenger Observatory Network—AMON, Smith et al. [70]). The overwhelmingly large amount of collected data brings eventually the future astronomers towards the era of big data analysis in blazar study.

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Abbreviations

The following abbreviations are used in this manuscript:

2dFGRS	Two-degree Field Galaxy Redshift Survey
2FGL-3FGL	Fermi Gamma-Ray LAT
2MASS	2-Micron All Sky Survey
AGN	Active Galactic Nuclei
AMON	Astrophysical Multi-messenger Observatory Network
AMON	Astrophysical Multi-messenger Observatory Network
ASAS	All-Sky Automated Survey
ATN	Automatic Telescope Network
BATC Survey	Beijing-Arizona-Taiwan-Connecticut Survey
BCK Network	Bell-Crimean-Kitt Peak Network
BOSS	Blazar Optical Sky Survey
CCD	Charge-Coupled Device
CFHT	Canada-France-Hawaii Telescope
CSS	Catalina Sky Survey
FFT	Fast Fourier Transform
FSRQ	Flat-Spectrum Radio Quasar
IDV	Intra-Day Variability
KIDS	Kilo-Degree Survey

LAT	Large Area Telescope
LCO	Las Cumbres Observatory
LINEAR	Lincoln Near-Earth Asteroid Research
LONEOS	Lowell Observatory Near-Earth-Object Search
LSST	Large Synoptic Survey Telescope
LTV	Long-Term Variability
MASTER	Mobile Astronomical System of TElescope Robots
NSVS	Northern Sky Variability Survey
OGLE	Optical Gravitational Lensing Experiment
Pan-STARRS	Panoramic Survey Telescope and Rapid Response System
PASIPHAE	Polar-Areas Stellar-Imaging in Polarization High-Accuracy Experiment
PROMPT	Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes
PROMPT	Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes
PTF	Palomar Transient Factory
QUEST	Quasar Equatorial Survey Team
RAVE	Radial Velocity
RoboPol	Robotic Polarimeter
ROTSE	Robotic Optical Transient Search Experiment
SAAO	South Africa Astronomical Observatory
SDSS	Sloan Digital Sky Survey
SED	Spectral Energy Distribution
STV	Short-Term Variability
SWASP	Super Wide Angle Search for Planets
UKIDSS	UKIRT Infrared Deep Sky Survey
UKIRT	United Kingdom Infra-Red Telescope
WEBT	Whole Earth Blazar Telescope
WET	The Whole Earth Telescope

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