BL Lacertae objects - Blazars

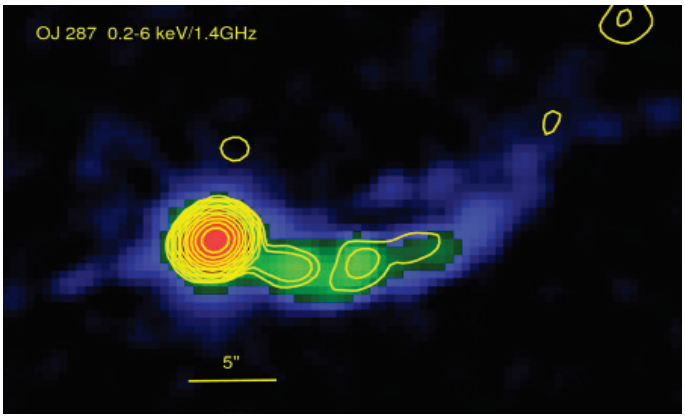
BL Lacertae objects demonstrate the most violent behavior known among active galactic nuclei (AGN). These objects are mostly notable for being strongly and rapidly variable at all wavelengths, displaying substantial variations in brightness over a short period of time. Their properties also include high optical polarization and the lack of optical emission lines. They are named after the prototype object BL Lacertae, located in the constellation Lacerta (the Lizard), which was initially believed to be a variable star in our galaxy.

Being discovered as a high-amplitude variable star (Hoffmeister, 1929), BL Lacertae was originally thought to be an irregular variable star in the Milky Way galaxy, and thus was given a variable star designation. In 1968, John Schmitt at the David Dunlap Observatory matched BL Lacertae with a bright variable radio source VRO 42.22.01 (MacLeod & Andrew, 1968). A faint trace of a host galaxy was also found. In 1974, Oke and Gunn measured the redshift of BL Lacertae as z = 0.07, corresponding to a recession velocity of 21,000 km/s with respect to the Milky Way (Kinman, 1975).

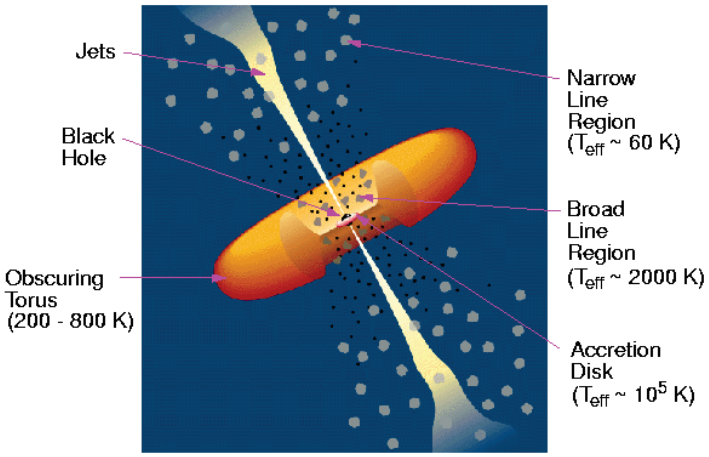
BL Lacertae objects, abbreviated BL Lac, are a rare type of Active Galactic Nuclei(AGN), the extremely energetic nuclei of active galaxies. Roughly 40 BL Lac objects are known. Perhaps the most obvious property of BL Lac objects is that they are quasi-stellar, but very distant active galactic nuclei in fact. The light from BL Lacertae is dominated by non-thermal emissions. There are different types of BL Lacs, depending on the wavelength they are brightest at (radio or X-ray domain). In many cases they have been identified with radio sources. BL Lacs are observationally distinguished primarily by the absence of strong emission lines (Stein et al. 1976) and mainly known as the largest population of emitters in gamma-ray band. Thus, their redshifts can only be determined from features in the spectra of their host galaxies.

An active galactic nucleus (AGN) is a compact region at the centre of a galaxy which has a much higher than normal luminosity. A galaxy hosting an AGN is called an active galaxy. The radiation from AGNs is believed to be a result of accretion onto the supermassive object at the centre of the host galaxy. AGNs are both compact and extremely luminous. AGN terminology is often confusing, but it is reasonable to divide those objects into two classes, depending on their radio activity.

*Below: **BL Lac object OJ287**, at a redshift of 0.306 (distance of 5.15 billion light-years), so that 1" corresponds to 15,000 light-years False color: X-ray image from the Chandra X-ray Observatory - **http://cxc.harvard.edu/**; contours: 1.4 GHz radio image from the Very Large Array - **http://www.nrao.edu/vla***



AGN Unification
(Diagram from Urry & Padovani 1995)



A schematic diagram of the current paradigm for radio-loud AGNs (Urry & Padovani, 1995)

New members to the AGN family was added in the late 1970s, with the identification of a few outstanding objects from variable star catalogs as highly variable nuclei of distant galaxies.

By 1968, the first two objects were identified: BW Tauri (3C 120) and BL Lacertae. In 1965 Arp and Burbidge found that the object called 3C 120, a radio source detected at Cambridge in 1959, is a Seyfert galaxy - another kind of active galaxies. Later, in 1971, AP Librae and W Comae Berenices (ON 231, which changes by 6 magnitudes - the largest known amplitude for blazars) were identified as remote BL Lacertae objects.

Blazars appear to be, in fact, very similar to Seyfert galaxies, except that blazars tend to be elliptical galaxies and Seyferts tend to be spiral galaxies. Seyfert galaxies belong to radio-quiet AGN class, while Blazars show strong radio and X-ray emission.

An interesting fact: it took 59 years until the extragalactic nature of the "variable star" X Com, discovered in 1914 by Wolf, was proven (Steinicke, 2000). By 1976, there were 30 known objects (Stein, 1976).

Yale Fermi/SMARTS *(Small and Moderate Aperture Research Telescope System) project's monitoring programs of Optical/IR Observations of LAT Monitored Blazars include a wide list of targets. The SMARTS Consortium operates four small telescopes (1.5-m, 1.3-m, 1.0-m and 0.9-m) on Cerro Tololo Inter-American Observatory (Chile) for that purpose. Membership in SMARTS is open to individuals or institutions, including international partners. Web: www.astro.yale.edu/smarts*

The list of targets is available at: ***http://www.astro.yale.edu/smarts/glast/targets.html***

Fermi Gamma-ray Space Telescope *was launched from the Kennedy Space Center on June 11, 2008. The Fermi spacecraft supports two gamma-ray instruments: the Large Area Telescope (LAT) and the Gamma-ray Burst Monitor (GBM).*

Image Credit: NASA

The ***Fermi-LAT*** is a wide-field gamma-ray telescope, while the GBM is an all-sky monitor for transient events detection, such as occultations and gamma-ray bursts. Fermi-LAT can be used for detection of gamma-ray activity of BL Lacertae objects. The Fermi science data (along with the software to analyze it) is available at the Fermi Science Support Center portal at http://fermi.gsfc.nasa.gov/ssc/data

The term "blazar" was coined in 1978 by astronomer Edward Spiegel. At the end of the seventies the use of modern detectors (CCD) allowed observers to probe with better accuracy the nature of the nebulosity. First images of the BL Lac object PKS 0548-322 taken by M. Disney in 1974 found it to be composed by a giant elliptical galaxy with a bright nucleus, with their jets pointed straight at us. We now believe that the source of the energetic emissions from blazars, or BL Lacertae Objects (as they are often called), is a super-massive object at the center of the galaxy.

Unlike most stars, BL Lac objects are very strong sources of radio and infrared emission. This emission, which is called synchrotron emission, arises from electrons traveling near the speed of light in spiral paths in strong magnetic fields. Synchrotron emission is generally polarized. When light or other electromagnetic radiation is polarized, the directions of the oscillations are the same. The amount of polarization and the brightness of BL Lac objects is highly variable. This variability is usually very rapid and irregular: they can change significantly in 24 hours or less. The rapid variability tells us that the energy source is small. It is considered that in the BL Lacs the relativistic jet is closely aligned to the line of sight (less than 20 degrees) and relativistic effects play an important role in the observed properties of the BL Lacs (Blandford & Rees 1978).

Blazar - broader term including *BL Lacertae* objects and those quasars, which share their characteristics of unusually weak spectral features, along with strong and rapid variability, so-called Optically Violent Variables (OVVs). Blazars are some of the most energetic objects in the Universe. At the other hand, they are all so called quasi-stellar objects (QSO), with large red shifts.

Currently, the most extensive list of the BL Lacertae objects is presented in the *Roma-BZCAT catalogue* of 2700 radio/optical blazar-like sources, by Massaro et al. (2009). This catalog is based on multifrequency surveys and detailed checkout of the literature, and contains 1180 BL Lacertae objects and candidates. But only a relatively small number of objects have been observed intensively at many wavelengths simultaneously. The spectral coverage of many of them is poor, both in time and in frequency. Generally, BL Lacs have been discovered in either radio or X-ray band. That forms the base of their classification as radio-selected (RBL) and X-ray-selected (XBL) BL Lacs. There are three BL Lac subclasses: HBL, IBL and LBL. The difference between them is the peak frequency of the synchrotron component of their spectral energy distribution (SED). HBLs have high-energy peaks, LBLs - low-energy peaks, IBLs - intermediate (Nieppola et al., 2006).

Being equipped with modern CCD cameras, amateurs are also able to monitor apparent changes in brightness of AGNs (including blazars, of course) and alert professional astronomers about their unusual activity. There are several catalogs out there for targets selection.

Below several useful catalogs for blazar-like targets selection are listed:

Optically selected BL Lac objects from SDSS-DR7 (Plotkin et al., 2010)
http://cdsarc.u-strasbg.fr/viz-bin/Cat?cat=J/AJ/139/390

A Sample-oriented Catalogue of BL Lacertae Objects (Padovani & Giommi, 1995). A catalogue of 233 BL Lacertae objects compiled through an extensive bibliographic search updated to mid-1995 is presented.
http://www.eso.org/~ppadovan/catalogue.html (many listed as candidates)
http://ned.ipac.caltech.edu/level5/Padovani/Padovani_contents.html

BL Lacertae objects beyond redshift 1.3 - UV-to-NIR photometry for Fermi/LAT blazars (Rau et al., 2013)
http://cdsarc.u-strasbg.fr/viz-bin/Cat?J/A+A/538/A26

BL Lac candidates for TeV observations (Massaro et al., 2013)
http://cdsarc.u-strasbg.fr/viz-bin/Cat?J/ApJS/207/16

A spectroscopic Library of BL Lac objects (Sbarufatti et al., 2005)
http://archive.oapd.inaf.it/zbllac/index.html

The Second Catalog of Active Galactic Nuclei detected by the Fermi Large Area Telescope, comprising 395 BL Lacertae objects (Ackermann et al., 2011) - http://cdsarc.u-strasbg.fr/viz-bin/Cat?J/ApJ/743/171

NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory
http://ned.ipac.caltech.edu/

Useful monitoring projects conducting photometric measurements of quasars:

MOJAVE (Monitoring Of Jets in Active galactic nuclei with VLBA Experiments) is a long-term program to monitor radio brightness and polarization variations in jets associated with active galaxies visible in the northern sky. At their website there is a list which contains all blazars known to be regularly monitored:
http://www.physics.purdue.edu/MOJAVE/blazarlist.htm

HQM - Hamburg Quasar Monitoring

The Hamburg Quasar Monitoring Programm (HQM) has been performed between 1988 and 1995. Later follow-up observations in 1996, 1998, 2000 and 2001 as well as some earlier data between 1984 and 1986 from previous projects enlarged the overall sample time for some of our targets up to 15 years. The HQM sample contains lightcurves for roughly 500 quasars, in total about 35.000 individual datapoints, although the main target list is much shorter - around 300 targets.

http://www.friedensblitz.de/hqm/hqm-home.html

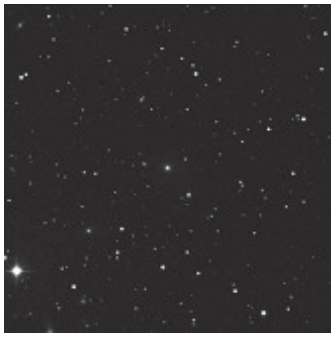
FQM - Frankfurt Quasar Monitoring

The Frankfurt Quasar Monitoring Project is a privately run observing program by Stefan Karge (Frankfurt, Germany), focusing on photometric measurements of quasars, BL Lac objects and selected AGNs. Since the beginning of this observing program in 1998, some 5800 observations have been recorded for about 400 quasi-stellar objects. A selection of particularly interesting objects is presented there: objects data, detailed finding charts, *including comparison stars*(!), light curve data and notes.

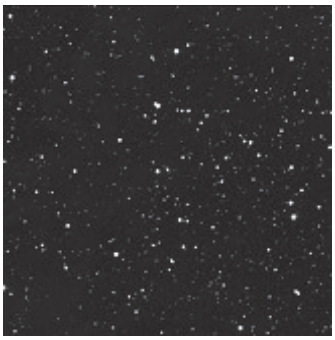
http://quasar.square7.ch/fqm/fqm-home.html

Hamburg-Quasar-Monitoring (1988 — 1998 data)
http://www.hs.uni-hamburg.de/DE/Ins/Per/Refsdal/jschramm/hqm98/hqm-titel.html

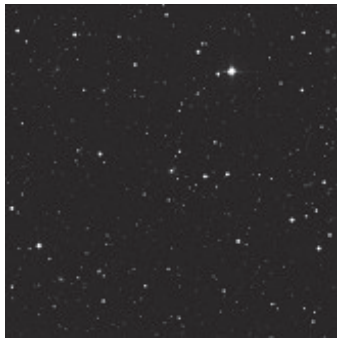
Mrk 501



3C 371



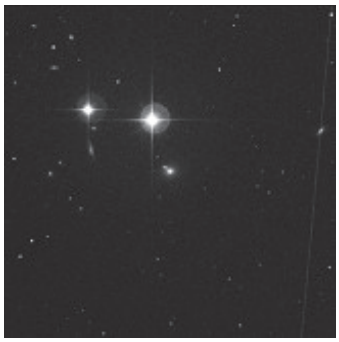
BL Lacertae



1ES 1959+650

OQ 530

S5 0716+71



Mrk 421

OJ 287

BL Lacertae objects considered for monitoring using moderate apertures

Object Designation		Const.	RA (J2000)	DEC (J2000)	z	Mpc	Mag. Range
3C 66A	PKS 0219+428	And	02 22 39.6	+43 02 08	0.444	1647	12.81-16.56
PKS 0422+00	TXS 0422+004	Tau	04 24 46.8	+00 36 07	0.310	– –	13.65-17.0
S5 0716+71	EGRET J0720+71	Cam	07 21 53.3	+71 20 36	0.310	1154	12.40 - 15.3 V
OJ 287	PKS 0851+202	Cnc	08 54 48.8	+20 06 30	0.306	1178	12.0 - 17.5
Mrk 421	OM+303	UMa	11 04 27.2	+38 12 32	0.031	126	11.6 - 16.5
W Com	LINEAR 3472523	Com	12 21 31.7	+28 13 58	0.102	414	11.5 - 17.5 B
AU CVn	B2 1308+32	CVn	13 10 28.7	+32 20 44	0.997	3221	14.2 - 20 B
OQ 530	PG 1418+546	Boo	14 19 46.6	+54 23 14	0.152	617	10.8 - 16.5
AP Lib	PKS 1514-24	Lib	15 17 41.8	- 24 22 20	0.048	243	14 - 16.7 B
Mrk 501	OS+387	Her	16 53 52.2	+39 45 37	0.033	137	13.2 - 14.0 V
3C 371	UGC 11130	Dra	18 06 50.7	+69 49 28	0.050	233	13.5 - 15.4
1ES 1959+650	TXS 1959+650	Dra	19 59 59.9	+65 08 55	0.047	250	12.8 - 16
PKS 2155-30	TXS 2155-304	PsA	21 58 52.0	-30 13 32	0.116	462	12.0 - 14.1
BL Lac	PKS 2200+420	Lac	22 02 43.3	+42 16 39	0.069	274	12.4 - 17.2 B
3C 454.3	PKS 2251+158	Peg	22 53 57.7	+16 08 53	0.859	2871	12.3 - 17.2

Suspected BL Lacs: *NSV 21875, NSV 477, NSV 16877* (very faint)

The article would be incomplete without mentioning of the next two useful resources:

- Extragalactic Objects Discovered As Variable Stars (Wolfgang Steinicke, 2000)
  http://www.klima-luft.de/steinicke/AGN/vargal/vargal2000.htm
- Bruce Gary's list of blazars compiled from AAVSO data, which will be useful for amateur observers.
  http://brucegary.net/blazar

References for further reading:

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