Multifrequency Catalogue of BLAZARS

Volume I (0h – 6h)

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Foreword

Blazars are the only type of extragalactic sources whose emission covers the entire electromagnetic spectrum, from radio waves to the TeV range. Other objects with comparable spectral emission are pulsars and Supernova Remnants in our Galaxy. The discovery of Blazars, as frequently happens in science, was unexpected. Since the beginning of the past century some of these objects were classified as peculiar variable stars and only after the association with radio sources their extragalactic nature was established.

From a general viewpoint a Blazar can be defined as an *Active Galactic Nucleus whose emission is dominated by non-thermal radiation, amplified by relativistic effects.* Many surveys have been carried out to identify new Blazars and their number is continuously increasing. Nevertheless, only a relative small number of Blazars have been studied intensively. There are still many unsolved problems about the origin of the Blazar phenomenon, the physical processes occurring in the nuclear region, and about the cosmological evolution of these sources. Furthermore, because of their very wide spectral emission, Blazars are expected to play an important role in the generation of the extragalactic background and of its fluctuations in many energy bands.

Present and near-future space and ground-based observatories are bound to provide large amounts of fresh multi-frequency data on many Blazars, a wealth of information that can be fully exploited only if properly handled within well organized databases. The first step in this direction is to build an updated and carefully checked list of all known Blazars and this is the main motivation behind this *Blazar Catalogue*. Our catalogue is not just a simple list of sources, as we report fluxes in different energy bands and detailed Spectral Energy Distribution for a selection of well-studied Blazars. In this first volume we concentrate on Blazars with Right Ascension between 0h:00 to 6h:00. Three more volumes will follow in the near future with the aim of completing the entire sky by the end of 2006. Blazars will almost certainly be important observational targets for the next generation of space missions like AGILE, GLAST, and will be detected in large numbers by PLANCK.

This catalogue should therefore be considered also as a contribution to the activities carried out in preparation for these upcoming space observatories. We stress that it would have been impossible for us to prepare this catalogue without the availability of many on-line astronomical databases. In particular, we acknowledge the indispensable service provided by the NASA Extragalactic Database (NED) and by the Centre de Données Astronomiques (CDS) of Strasbourg.

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A NEW BLAZAR CATALOGUE

1. The name BLAZAR

Blazars are a relatively rare class of AGNs characterised by an electromagnetic emission over the entire spectrum, from radio frequencies to the most energetic gamma rays. Angel and Stockman (1980) reported that the word BLAZAR, a combination of BL Lac object and quasar, was proposed for the first time by Edward A. Spiegel in a talk given at the banquet of the famous first BL Lac Conference in Pittsburg (1978). At that epoch these sources were mainly characterised by a violent optical flaring, a compact, flat-spectrum radio source and, occasionally by a high linear polarisation. Their emission in the X and γ-ray bands was practically unknown.

The name found a great fortune: it was soon adopted by astronomers and became 'official' with the review paper by Angel and Stockman (1980). These authors gave also one of the first list of Blazars containing 57 sources.

2. The discovery of Blazars: a brief historic outline

Before radio astronomical observations only few BL Lac objects were known. They were universally considered irregular variable stars with a peculiar spectra and nobody was aware of their extragalactic nature. The photographic magnitude of BL Lac was observed to vary between 13.0 and 16.0 by van Schewick (1941) and large and fast brightness changes were also reported for W Com, AP Lib and BW Tau.

Later, in the sixties, radio astronomers were involved in many survey programs aimed to discovery and identify radio sources. In 1965 MacLeod et al. (1965) published in *The Astronomical Journal* the first list of sources detected in a radio survey at 610 MHz performed with 400-ft radio telescope of the Vermillion River Observatory (VRO). The radio source VRO 42.22.01, having a flux density of 4.0 Jy, was furtherly studied by MacLeod and Andrew (1968) who found that its radio spectrum was different form usual and its centimetric emission was linearly polarised. VRO 42.22.01 was identified by Schmitt (1968) with the "star" BL Lac from a positional agreement, however images revealed a bright core inside a nebulous object. Subsequent optical observations (DuPuy et al. 1969, Oke et al. 1969, Visvanathan 1969, Bertaud et al. 1969) indicated a high variability as fast as 0.7 mag in 74 minutes, a high linear polarisation of about 10% and an unusual spectral distribution. Visvanathan (1969) suggested that BL Lac could be a synchrotron source because its spectrum was in a good agreement with the computations by Matthews and Sandage (1963), but the absence of spectral lines made it quite different form recently discovered quasars and its nature remained obscure. Racine (1970) confirmed the fast changes of the BL Lac brightness with a rate of about

0.03 mag in 2 minutes and again noticed the similarities with the N-type galaxies and Seyfert nuclei. Pigg and Cohen (1971) studied the 21 cm absorption spectrum of BL Lac and concluded that its distance *is certainly more than 200 parsecs ... the absorption spectrum is consistent with this object being extragalactic.*

In the same year Bond (1971) identified the optically variable object AP Lib, discovered by Ashbrook (1942) at the Harvard College Observatory, with the radio source PKS 1514-24 which was before associated with a 16-mag elliptical galaxy by Bolton, Clarke and Ekers (1965), and classified by Westerlund and Wall (1969) as an N-type galaxy. Searle and Bolton (1968) reported that its optical spectrum did not show emission lines.

The number of sources belonging to the class of BL Lac objects continued to increase and in 1976, when Stein, O'Dell & Strittmatter (1976) wrote a first review paper, it was 32, with only four sources in the southern hemisphere. After two years the first conference on BL Lac objects was held in Pittsburg and on that occasion Blandford and Rees (1978) presented their model of a relativistic beamed source seen at a small angle to enhance the Doppler boosting. Other major conferences on BL Lac objects (excluding, of course, several other workshops) were at the distance of 10 years in Como (Italy, 1988) and Turku (Finland, 1998).

The discovery that some radio-loud quasars show characteristics similar to BL Lac objects, with the exception of the occurrence of broad spectral lines, was important for a complete definition of the blazar properties. Moore and Stockman (1981) gave an important contribution when performed a polarisation survey in which discovered 17 high polarisation quasar (HPQ) and discussed their relation with BL Lacs. Before they work only four radio quasar were known to show high variable optical linear polarisation. Some years later Impey and Tapia (1988) extended the polarisation surveys and discovered 31 new Blazars. The division of the class of Blazars into the two main subgroups of BL Lacs and Flat Spectrum Radio Quasars was then firmly established.

3. Blazar surveys and catalogues

Starting from the late 1980's several sizable Blazar samples were produced as a result of a number of systematic searches in large radio or X-ray surveys. These highly organized efforts were initially carried out following a standard approach involving the optical identification of all sources above the survey's flux limit. However, when the necessity to assemble deeper and larger samples pushed the need for optical telescope time to hardly manageable amounts, multi-frequency (usually radio, optical and X-ray) pre-selection techniques were developed in order to significantly reduce the number of candidates requiring optical spectroscopy.

Table **I** gives a list of all the major surveys of both types that led to the discovery of most of the Blazars known today and included in this catalogue.

After the first list of 32 BL Lac objects given by Stein, O'Dell and Strittmatter (1976), Angel and Stockman (1980) increased the number to 57. A further catalogue of BL Lac objects was prepared by Hewitt and Burbidge (1987), containing 87 sources, but it did not include all the sources listed by Angel and Stockman (1980). At that epoch the total number of Blazar was 103. Since 1984 Veron-Cetty and Veron published a general catalogue of Active Galactic Nuclei including, starting from the 2nd edition (Veron-Cetty and Veron 1985), a table of BL Lac objects, whose number is continuously increasing from the

TABLE I
Major Blazar surveys

Survey name	Blazar type	Survey type	Number of objects	Reference
2Jansky	BL Lacs+FSRQs	radio flux limited $f_{2.7GHz} > 2$ Jy, $\alpha_r \leq 0.4$	60	[1,2,3]
1Jansky	BL Lacs	radio flux limited $f_{5GHz} > 1$ Jy, $\alpha_r \leq 0.5$	34	[4]
1Jy NVSS-RASS	BL Lacs+FSRQs	radio, opt, X-ray selection radio fl. limited, $f_{1.4GHz} > 1$ Jy	157	[5]
1Jy WMAP	BL Lacs+FSRQs	microwave flux limited $f_{61GHz} \gtrsim$ 1Jy	180	[6,7]
Parkes 0.25 Jy	BL Lacs+FSRQs	radio flux limited $f_{2.7GHz} > 0.25$ Jy	371	[8]
EMSS	BL Lacs	X-ray flux limited $f_X \gtrsim 2 \times 10^{-13}$ $erg\ cm^{-2}\ s^{-1}$	41	[9,10]
IPC slew survey	BL Lacs	X-ray flux limited $f_X \gtrsim 2 \times 10^{-12}$ $erg\ cm^{-2}\ s^{-1}$	51	[11]
DXRBS	BL Lacs+FSRQs	radio+opt+X-ray selection radio fl. limited, $f_{5GHz} > 50$ mJy	227	[12,13]
REX	BL Lacs	radio+opt+X-ray selection	∼100	[14,15]
RGB	BL Lacs	radio+opt+X-ray selection	127	[16]
Sedentary	extreme BL Lacs	radio+opt+X-ray selection radio fl. limited, $f_{1.4GHz} > 3.5$ mJy	150 150	[17,18]
CLASS	BL Lacs+FSRQs	radio+opt $f_{5GHz} > 30$ mJy, $\alpha_r \leq 0.5$	147	[19,20,21]
Gamma-ray Blazars	BL Lacs+FSRQs	radio+X-ray selection	241	[22]
2dF BL Lac Survey	BL Lacs	Optical selection	56 candidates	[23]
SDSS BL Lac Survey	BL Lacs	Optical selection	347	[24]

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original 73 to 876 of the 11th edition (Veron-Cetty and Veron 2003). Although very useful the VCV catalogue is not a Blazar catalogue because many sources are listed in the BL Lac table and others among the quasars and for this reason the Blazar nature of the sources is not directly apparent.

A sample oriented catalogue was compiled by Padovani & Giommi (1995) including all BL Lacertae objects that were known at that time. After ten years that list has

become largely incomplete and needs updating.

4. Possible 'anomalous' BL Lac objects

The number of published lists of candidate BL Lac sources is continuously increasing. Some of them contain sources showing a stellar appearance with featureless optical spectra and many of them have been observed in only one or two occasions. It is not still clear if all these sources are really BL Lacs and therefore we applied more severe selection criteria.

The first sample of 'optically selected' BL Lac candidates, containing 56 sources, has been defined by Londish et al. (2002), named 2dF BL Lac Survey, as a by product of the much wider 2QZ sample of QSOs (Croom et al. 2001). The majority of these sources (47) has not been detected in the radio at the sensitivity limit of the NVSS limit (about 2.5 mJy), and only five are included in the RASS. In a subsequent revision of the sample (Londish 2003) some sources were rejected because of their stellar nature. Nesci et al. (2005) have searched for optical variability of a subsample of the 2BL sources and found that only few of them have significant brightness changes, including all the radio loud ones. It is our opinion that a good filtering of stellar sources has not been obtained. These sources, however, can be found in the BL Lac table of VCV catalogue (11th edition), although with a question mark because of their not confirmed nature.

Another sample of 236 'probable' optically selected BL Lac objects (plus 111 'possible' sources) based on the SDSS spectra has been more recently given by Collinge et al. (2005). We examined these sources and found that only seven are compatible with our criteria and they were included in the candidate table.

To reduce the possibility of including in the present catalogue non blazar sources, we adopted a conservative criterion and included in the table of candidate BL Lac objects only 2BL and SDSS sources having a well established radio emission. According to our point of view a blazar must be characterised by the presence in the SED of a significant non-thermal emission component, covering a broad frequency interval and associated with the nuclear activity. The detection of a featureless optical spectrum and the absence of proper motion cannot be considered to now an efficient and safe way to select BL Lac objects.

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