Revealing the jet properties in the bulk of the BL Lac population

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Despite being the most abundant population of gamma-ray sources detected by Fermi, a severe bias in the selection at other wavelengths still limits our knowledge of BL Lac objects. We define a new unbiased sample of BL Lacs, and present results from new VLBA and gamma-ray observations of all its members.

Abstract

Thanks to its sensitivity and broad energy range extending up to several GeV, Fermi has dramatically improved our knowledge of the gamma-ray properties of BL Lacs. The LAT has in fact discovered and characterized about 300 BL Lacs after 1 year, and they are now the most abundant population of extragalactic gamma-ray emitters. By contrast, little progress has been made in our understanding of the properties of BL Lacs in the radio. Most BL Lacs are just too weak in radio to reach the flux density threshold for inclusion in the ongoing main VLBI monitoring projects. A large fraction of BL Lacs in the 1FGL have not been observed with VLBI. We present here dual frequency (8 and 15 GHz) VLBA observations for a complete sample of 42 low redshift BL Lacs, in which high-energy peaked sources (HSPs) are well represented. 29 (68%) of the sources in the sample had never been observed at milliarcsecond resolution. The majority of the sources (over 80%) are detected, some at a flux level of a few mJy. We discuss the morphology, brightness temperature, and spectral index of the detected sources. We also discuss the gamma-ray properties of the sources detected in the 2FGL catalog, and provide a combined look of the VLBA and Fermi properties. Finally, we highlight a few peculiar cases, including some possible misclassifications.

Background

In the EGRET era (1991-1999), most high galactic latitude sources remained unidentified. Moreover, among the identified ones, BL Lacs were a minority, and High-Frequency Peaked BL Lacs a negligible fraction!

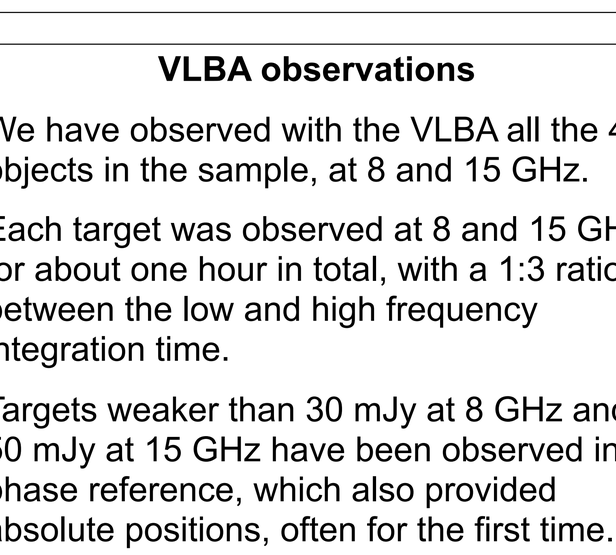
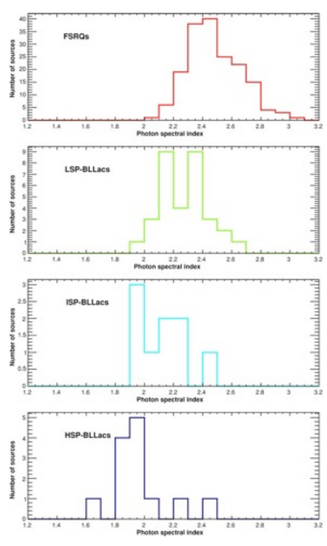


Fig. 1; source type distribution in the 3rd EGRET catalog (Hartman et al. 1999, ApJS 123, 79)

However, VHE observatories detect preferably BL Lacs, and of the HSP type!

With Fermi, BL Lacs are as abundant as FSRQ (eg in the 1LAC, Abdo et al. 2010, ApJ 715, 429), and their spectral properties appear quite well separated - as shown in the 1LAC paper (see Fig. below, from Abdo et al. 2010, ApJ 715, 429):



In radio, BL Lac jets are less extreme than those of FSRQs, but also much less studied! Hence, the need to define a sample without large flux density limits, which severely biases the existing programs against BL Lacs. One such attempt was performed by Giroletti et al. (2004, ApJ 613, 752) but a more rigorous approach was needed.

Sample selection

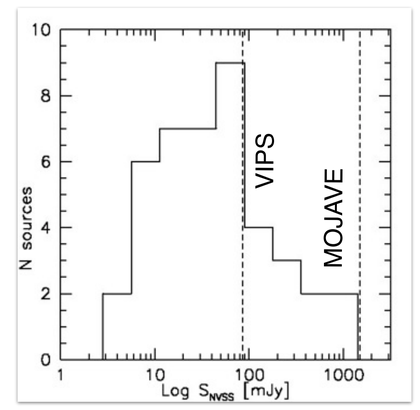
We have extracted a BL Lac sample from the ASDC Catalog of known blazars (http://www.asdc.asi.it/bzcat, Massaro et al. 2009), with the only criterion of $z<0.2$.

At $z<0.2$, we have good linear resolution (1 pc=0.5 mas at z=0.1) and access to the least powerful sources, such as HBLs.

The starting selection is independent of the presence of γ-ray emission. The only additional request is that the location be within the SDSS coverage. In total, the number of sources in the sample is 42.

Multiband photometry of the sample is being carried out with Fermi-LAT, SWIFT, Chandra, XMM-Newton, INTEGRAL, and at the Vallinfreda Astronomical Station.

Right: Flux density distribution for our sample, with flux density limits for VIPS and MOJAVE shown by dashed lines. The bulk of the BL Lac population is virtually unexplored.



VLBA observations

We have observed with the VLBA all the 42 objects in the sample, at 8 and 15 GHz.

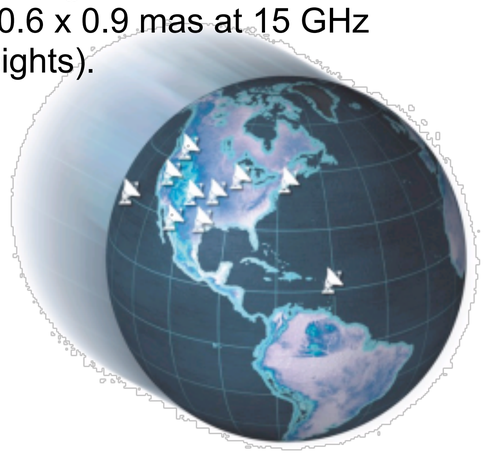
Each target was observed at 8 and 15 GHz for about one hour in total, with a 1:3 ratio between the low and high frequency integration time.

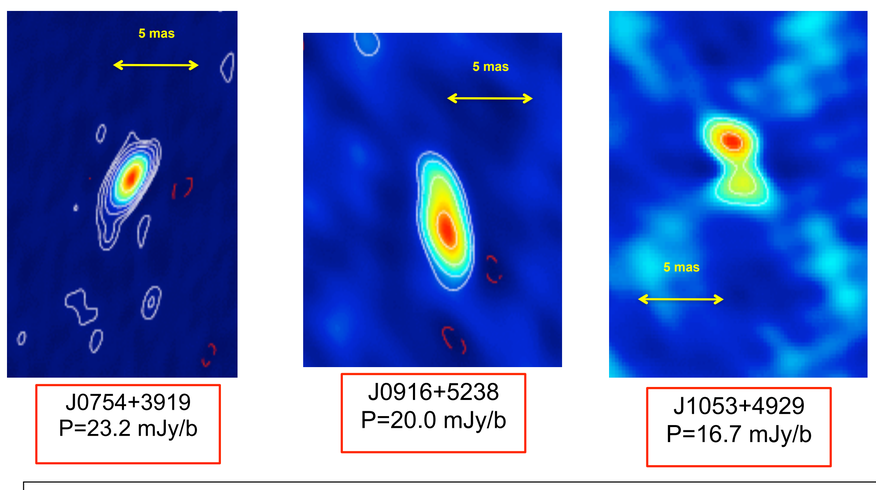
Targets weaker than 30 mJy at 8 GHz and 50 mJy at 15 GHz have been observed in phase reference, which also provided absolute positions, often for the first time.

Observations used 256 Mbps with 9 VLBA telescopes (no SC) – in some cases 8 because of weather conditions.

Good data quality: rms noise ~0.2 mJy beam^{-1} (close to theoretical limit)

Typical restoring beam: ~1.2 x 1.8 mas at 8 GHz and ~0.6 x 0.9 mas at 15 GHz (natural weights).

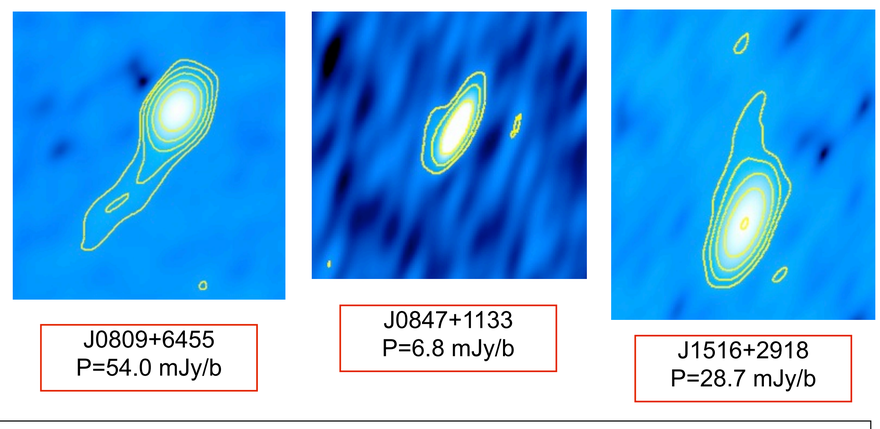




J0754+3919
P=23.2 mJy/b

J0916+5238
P=20.0 mJy/b

J1053+4929
P=16.7 mJy/b



J0809+6455
P=54.0 mJy/b

J0847+1133
P=6.8 mJy/b

J1516+2918
P=28.7 mJy/b

Results

Most sources are detected with good significance, either at the fringe fitting stage or directly in the image plane after phase calibration. Only a couple of sources do not seem to be detected; in another couple of cases the visibility data suggest there might be a detection, not yet revealed in the image plane.

The total radio flux densities range from as little as a few mJy to almost 1 Jy, with the bulk of the population below ~30 mJy. Such comparatively low flux densities do not allow self calibration with short solution intervals, so it is difficult to constrain the final flux density of the targets.

The total flux uncertainty affects also the estimate of the spectral index, which in general appears to be moderately steep. This result is consistent with the presence of a fair amount of extended emission, which we clearly detect in a few sources.The detection of jet features even in weak targets (see Figures) is certainly remarkable and somewhat surprising.

The detection rate in γ-rays in the 1FGL is about 58% for the radio brightest half of the sample, while it goes down to 38% when all the sources are considered. The photon indices are typical of BL Lacs, i.e. quite hard, and even as hard as $\Gamma=1.3$ for the TeV source J1428+4240. No source has a photon index in excess of $\Gamma=2$.

All the γ-ray detected sources are revealed as compact radio sources .This makes somewhat more interesting the fact that the VLBA non detections occur for sources that are not detected by Fermi either. While waiting for additional data, it may be important to reconsider the classification of these elusive sources.