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A multi-frequency view of blazars

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Abstract. This paper presents a number of recent results on blazar observations in several energy bands across the electromagnetic spectrum. It is showed that non-thermal extragalactic sources, like blazars and radio galaxies, will be discovered in large numbers by the next generation of microwave and high-energy (hard X-ray and gamma-ray) observatories. The implications for Simbol-X are addressed through specific simulations that make use of the latest expected performances of both Simbol-X detectors.

Key words. galaxies: active – galaxies: blazar: BL Lacertae – Surveys:

1. Introduction

Blazars are a small minority among extragalactic sources, however their unique property of being strong non-thermal emitters across the entire electromagnetic spectrum makes them stand out very strongly in some non-traditional astronomical energy bands that are about to be deeply explored by a new generation of space observatories such as Planck, GLAST, Simbol-X, and by Cherenkov and millimeter telescopes on the ground. This will probably lead to the discovery of new blazars in large numbers triggering a significant increase of research interest on these sources and on non-thermal emitters in general. In the optical and X-ray bands, where the radiation that we receive from the sky is mostly due to either thermal processes taking place in stars and galaxies or through accretion onto the central black holes of AGNs, blazars are a very small minority. In other parts of the electromagnetic spectrum, where thermal emission is unimportant, they dominate the extragalactic sky. Following the technological evolution and the availability of astronomical resources, most blazars have so far been discovered as counterparts of flat spectrum radio sources or as X-ray sources. In this paper I consider recent results on blazar research, emphasizing present or expected results in those energy bands where non-thermal emitters, like blazars and radio galaxies, are bound to play a crucial role. Simbol-X will operate at the time when the number of known blazars will be much larger than today and blazar research will almost certainly be one of hottest topics in astrophysics. With its large sensitivity in the soft and for the first time, hard X-ray energy band Simbol-X has the potential to make a large step forward in the understanding of the physical mechanisms and the cosmological implications of these puzzling sources.

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2. Blazars and the AGN paradigm

It is widely accepted that AGN are powered by accretion onto a super-massive black holes (e.g. Urry & Padovani (1995), Urry

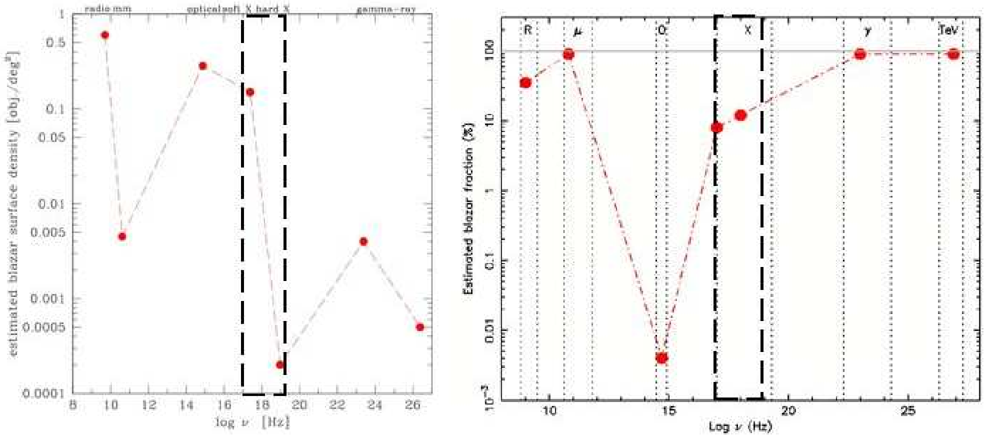

Fig. 1. Left. The largest surface density of blazars so far measured by surveys carried out in different parts of the electromagnetic spectrum. The dashed box delimits the Simbol-X energy band where the density is currently lowest due to the lack of sensitive instruments. Right. Same as on the left for the expected fraction of blazars in the extragalactic sky. The fraction of blazars is lowest at optical frequencies where they are diluted by a large number of stars and galaxies, whereas is maximum in the millimeter band and at gamma-ray energies where only strong-non-thermal sources radiate efficiently.

(2003),Vellieux (2003)) which causes the formation of a disk of falling material and in some cases a highly collimated jet that is ejected at relativistic speeds. This paradigm can be used to divide AGN into two broad categories defined by their intrinsic emission mechanism Giommi et al. (2007).

- **AGN that are energetically dominated by radiation of thermal origin** produced by matter that is strongly heated in the inner parts of a disk of matter falling onto the super-massive black hole and illuminates the circumnuclear matter that is responsible for the broad line emission. These objects can be called Accretion Dominated AGN or AD-AGN.
- **AGN whose power is dominated by Non-Thermal radiation** (or NTED-AGN) where most of the emission is generated through non-thermal processes like the synchrotron and the inverse Compton mechanisms by particles accelerated in a jet of material that moves at relativistic speeds away from the central black hole. The jet itself if formed converting part of the accretion energy in a way that is presently not well understood.

Within this general definition the class of blazars corresponds to the small subset of NT-AGN that are viewed at a small angle w.r.t. the jet axis (for this reason their emission is strongly amplified by relativistic effects Blandford & Rees (1978), Urry & Padovani (1995)), whereas Radio Galaxies are those NT-AGN that are viewed at a large angle w.r.t. the jet axis. Here we do not distinguish between line-less objects, or BL Lacs, and broad-line Flat-Spectrum Radio Quasars, or FSRQs.

3. Blazars demography through different energy windows

Figure 1 (left) plots the density of presently known blazars (objects/sq degree) in the energy bands where blazars surveys have been carried out so far (e.g. radio, microwave, optical, X-ray and gamma-ray band). As of today the deepest blazars surveys (corresponding to a density of $\approx$ 0.5 sources/sqdeg) have been performed in the radio band followed by the optical and the soft-Xray band. The Simbol-X band, marked by vertical dashed lines, is where blazar are least known with a measured density of only a few sources in 10,000 square degrees. This is despite the recent results from

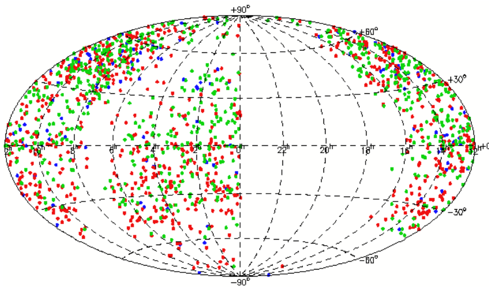

Fig. 2. The distribution of blazars in the ROMA-BZCat are plotted in an Aitoff projection of the sky in equatorial coordinates.

INTEGRAL and the Swift BAT coded-mask instruments. The right part of Fig. 1 shows the expected fraction of blazars in the sky in the same energy bands. In the microwave and gamma-ray parts of the spectrum the expected blazar fraction is very large and close to 100%, whereas the minimum is in the optical band where most of the objects are expeced to be stars, galaxies and Accretion Dominated AGN. In the hard X-rays (most relevant for Simbol-X) the fraction of blazar rapidly grows from about 10% to reach verly large fractions in the MeV, GeV and TeV bands.

4. The catalog of known blazars

At present approximately 2000 blazars have been reported in the literature. However, the amount and the quality of the information that is available for these sources is highly heterogeneous and is scattered over a large number of publications, sometimes it is even contradictory. In order to build a uniform and reliable list of blazars Massaro and collaborators (see the ROMA-BZCat, these proceedings) started a project based on an extensive review of the literature and of public archival data with the goal of assembling a single catalog that is as much as possible complete and homogeneous. At the time of this Simbol-X meeting the catalog is still under construction and it covers the part of sky defined by 0h $<$ R.A. $<$ 17h. The complete sky is expected to be covered by the end of 2007. Fig. 2 shows a Aitoff projection of the sky in equatorial coordinates of all the entries in the catalog. The on-line version of the catalog can be found at this URL http://www.asdc.asi.it/bzcat. The scientific goals of the *ROMA-BZCat* are: *i*) to have the most complete and verified list of published Blazars; *ii*) to search for counterparts of high energy extragalactic sources; *iii*) to have a population from which it will be possible to extract samples satisfying statistical criteria to investigate Blazar properties and evolution; *iv*) to have a large database of SEDs for different types of Blazars to study radiation mechanisms and relativistic beaming effects.

5. Two new blazars surveys

In this section I briefly describe two new surveys based on data collected for reasons unrelated to blazar research but that are nevertheless contributing many new blazars detected in regions of the parameters space that have never been probed before: the microwave survey of foreground sources in WMAP 3-year data and the Swift survey of serendipitous X-ray/radio sources discovered in deep observations of Gamma Ray Bursts (GRBs).

5.1. Foreground blazars in WMAP CMB anisotropy maps

The microwave band is one of the best energy window where blazars can be discovered. However, this band has not been available for large sky surveys until recently when experiments designed to measure faint fluctuations of the Cosmic Microwave Background (CMB) also detected several blazars as bright foreground sources. The best dataset available so far is the WMAP 3-year data.

The catalog of foreground point sources detected in the WMAP 3-year CMB anisotropy maps include 324 bright point-like objects Hinshaw et al. (2007) detected in at least one of the 5 WMAP microwave channels. Giommi et al. (2007) have carefully checked all sources in this catalog and have shown that 98% of them are either blazars or radio galaxies Giommi et al. (2007). The same authors have defined a subsample of 183 sources that is complete above the flux level of 1 Jy at 41

GHz and is almost 100% identified. This sample has been used to calculate the LogN-LogS, the luminosity function and cosmological evolution which have been found to be similar to that measured at radio (5GHz) frequencies (see Giommi et al. (2007) for details).

5.2. Serendipitous blazars in Swift GRB deep X-ray fields

The Swift satellite has so far discovered and observed with its X-Ray telescopes over 250 GRBs. Each burst is usually observed several times to monitor the fading of its X-ray light curve over a period ranging from several days to some months depending on source intensity and persistency. In an effort to search for serendipitous blazars in very deep X-ray images we have stacked all XRT data of each GRB observed with Swift building a survey of the X-ray sky that is unbiased (since GRBs explode at random positions and blazars are unrelated to GRBs) and quite sensitive, with the deepest exposures reaching limiting fluxes below 10^{-15} erg cm^{-2}s^{-1} in the 0.5-2.0 keV band. So far we have analyzed 235 fields, 160 of which are at high Galactic Latitude ($|b|$ > 20). We have run a standard slide-cell detect on each stacked image detecting over 7,000 sources (Puccetti et al. in preparation). A cross-correlation of this sample of faint X-ray sources with a set of radio catalogs (NVSS, SUMSS, FIRST) led to the definition of a sample of 219 sources with broad-band radio, optical , X-ray) characteristics typical of blazars. In order to optically identify these blazar candidates we have first considered objects located in parts of the sky covered by the Sloan Digital Sky Survey (SDSS Data release 6). We have found 81 X-ray sources matching at least one SDSS optical object. In 21 cases we could also retrieve an optical spectrum that turned out to be always typical of blazars or of radio galaxies. The redshift ranges from 0.04 to 3.76 (Turriziani et al. in preparation). When completed this survey will produce a well defined and unbiased sample including a few hundred blazars and radio galaxies useful to measure the radio LogN-LogS and Luminosity function of blazars down to unprecedentedly low fluxes

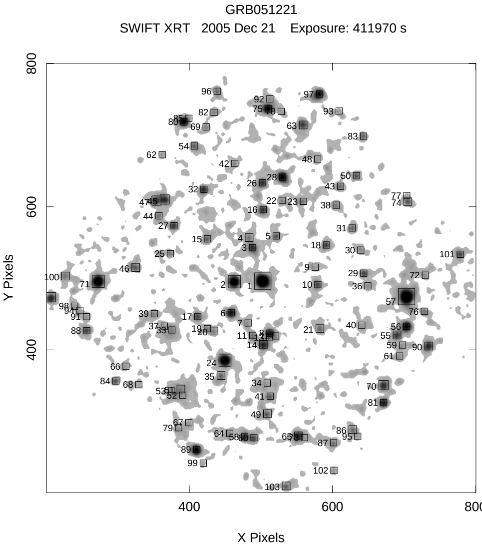

Fig. 3. An example of deep XRT field centered on a Gamma Ray Burst. Note the large number of serendipitous sources. However, only about one source per field is expected to be a blazar with radio flux larger than 10 mJy at 5GHz.

and luminosities and to build for the first time a volume limited (z $\lesssim$ 0.5) X-ray survey of blazars with Lx > 5×10^{42}erg s^{-1} .

6. High power HBLs: the case of BZB J1456+5048

There is no room in this paper to present a representative set of Spectral Energy Distributions (SED) observed in blazars. Here I consider only the case of the blazar BZB J1456+5048 that is an object where the synchrotron emission reaches the X-ray band (objects of this type are known as HBLs). that is particularly interesting because of its relatively large redshift (z=0.479) and, consequently, its very large X-ray luminosity ($L_x = 5 \times 10^{46}$ erg s^{-1}). Fig.3 shows the SED of this source built using archival measurements (from NVSS, SDSS, USNO and ROSAT) and with Swift UVOT and XRT data taken in April 2007 (Giommi et al. in preparation). As in several other cases the high energy part of the synchrotron component (UVOT and XRT points) can be well represented by a log-parabolic model that may result

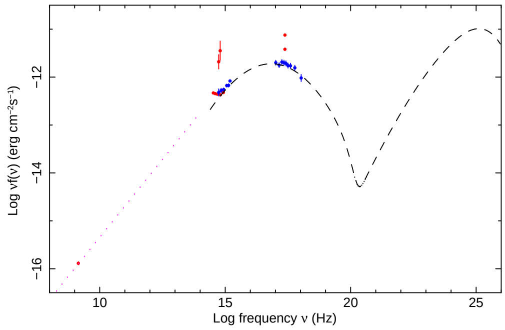

Fig. 4. The SED of the HBL Blazar BZB J1456+5048 (z=0.479) built with archival data and with Swift (UVOT and XRT) data taken in April 2007.

from inefficiencies in the statistical acceleration of the emitting particles (solid line, see e.g. Massaro et al. (2006)). The ROSAT and optical archival data clearly show that this source is highly variable and that in the past it was much brighter than during the Swift and SDSS observations (the SDSS data are consistent with the UVOT measurements). The redshift of this source has been derived from some of the spectral features of the host galaxy that is just visible above the non-thermal continuum in the red part of SDSS spectrum. Clearly, if this source happened to be in a bright state during the SDSS observation its optical light would have been completely featureless and no measurement of its redshift would have been possible. It could well be that many well known featureless BL Lac objects are in fact very high X-ray luminosity, and therefore high z, blazars.

7. Blazars and the Cosmic X-ray background

By integrating the LogN-LogS measured at radio frequencies and combining the result with the observed distribution of X-ray to radio flux ratios Giommi et al. (2006) and Giommi & Colafrancesco (2006) estimated that the contribution of blazars to the soft (1keV) cosmic X-ray background is about 10% consistently with estimates based on more direct measurements obtained using XMM data (Galbiati et al. (2004)). The number of sources detected at energies in the hard X-ray band is growing but still quite low, so building reliable distributions of flux ratios between radio and hard X-ray fluxes is not currently possible. Thus, to estimate the blazar contribution to high energy Cosmic Backgrounds ($E > 10$ keV) Giommi et al. (2006) and Giommi & Colafrancesco (2006) extrapolated the blazar integrated flux at radio/microwave frequencies to the hard X-ray and soft γ-ray band using a set of Synchrotron Self Compton spectral energy distributions that are consistent with the data typically observed in blazars. Giommi et al. (2006) concluded that blazars of the LBL type must be the most important constituents of the high energy extragalactic background with a contribution that ranges from a substantial fraction of the background in the Simbol-X band to possibly almost 100% at soft γ-ray energies (see Giommi et al. (2006) for details). Given this significant contribution to the cosmic flux in the Simbol-X band and considering that the high energy spectrum of LBL blazars is due to a flat inverse Compton component these sources may be responsible for some of the hard (> 10 keV) flux usually attributed to highly obscured radio quiet AGN in background synthesis models (see Giommi et al. (2006) and Giommi & Colafrancesco (2006) for details).

8. Blazars and Simbol-X

In this section we present some simulations of Simbol-X observation of different blazar types based on the most recent estimates of Symbol-X sensitivity and response matrices. In Fig. 5 we show a simulation of a 10,000 seconds Simbol-X observations of the well known LBL blazar 3C279 with a spectral shape and flux level similar to those observed by Chandra and Swift during the observing campaign of January 2006 ($\approx$ 0.5 mCrab, Collmar et al. (2007)) and with the same spectral shape but at a flux level 100 times fainter (5 μCrab, 100,000 seconds observation). While the photon statistics at low energy is comparable to that of Chandra above 10 keV the Simbol-X data are still with very good statistics. At the 5 μCrab flux level the source is

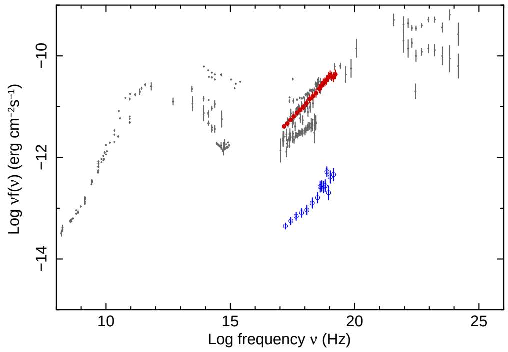

Fig. 5. The SED of the LBL Blazar 3C 279 built with multi-frequency archival data (light gray symbols) is shown together with Simbol-X simulations of the same source a a flux level similar to that observed in early 2006 by Chandra and Swift (filled red circles) and at a flux level 100 times lower (open blue circles).

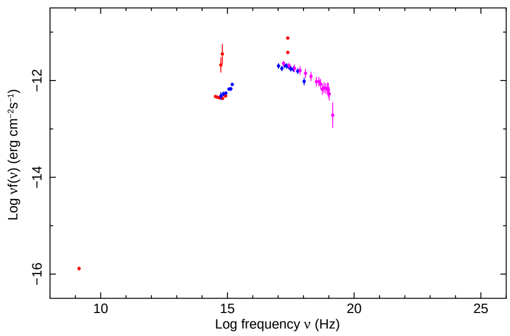

Fig. 6. The SED of the HBL Blazar BZB J1456+5048 together with the data from a 100 ks Simbol-X simulation (filled red circles) showing how the spectral curvature of the synchrotron emission from this object can be measured up to the highest energies reached by Simbol-X.

still detected with sufficient statistics to measure the spectrum well into the hard-Xray band. Fig. 6 plots the SED of the high-power ($L_{x(0.5-2.5keV)} > 10^{46}$erg cm^{-2}s^{-1}) HBL blazar BZB J1456+5048 which shows clear evidence of spectral curvature close to the peak of the its Synchrotron spectral component as measured by a recent Swift observation. A simulation of a 100 ks Simbol-X observation of this object (filled red circles) clearly shows that spectral curvature in HBL BL Lacs of this flux level (Fx $\approx$ 0.2 mCrab) can be measured well up to the highest energy channels posing strong constraints to the physical parameters in sources at the edge of the blazars parameter space where large luminosity objects accelerate particles to the extremely large energies.

9. Conclusions

Simbol-X will greatly improve the statistics of blazars in an energy band (up to $\approx$ 100 keV) that is extremely important for non-thermal sources and that is presently very poorly explored. Detailed simulation demonstrate that Simbol-X will also be an excellent instrument for constraining models of non-thermal emission from accelerated particles in radio galaxies and blazars jets. Simbol-X observations combined to studies of the population of Blazars in different wavebands will tightly constrain their contribution to the CXB where it peaks and will better quantify the need for strongly absorbed radio quiet AGN in CXB synthesis models.

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