# The ICRANet Brazilian Science Data Center (BSDC) and Multi-frequency selection and studies of blazars

# 1 Topics

- Definition and set up of the technical infrastructure for the ICRANet Science Data Center in Pescara and Rio de Janeiro
- Development of a VO interface to the MAGIC published results repository and integration within the ASDC/BSDC tools.
- Implementation of VO + Web interfaces to catalogs of astronomical sources published as part of ICRANet research.
- Installation, adaptation and testing of software suitable for the generation of Fermi adaptive bin $\gamma$-ray light curves and construction of a database of blazar $\gamma$-ray light curves to be interfaced to ASDC/BSDC and Open Universe systems.
- Implementation, adaptation and testing of software for cross-correlation analysis of time series and light curves.
- Selection of large samples of high energy peaked(HSP)/high energy $\gamma$-ray emitting blazars (1WHSP and 2WHSP sample)
- Detection of $\gamma$-ray emission in HSP blazars (150 new Fermi of $\gamma$-ray detection of 2WHSP blazars: the 1BIGB sample)
- Search for possible spatial correlation between HSP blazars and astrophysical neutrinos
- Modelling of the variable SED of blazars using large multi-frequency/multi-temporal data sets
- Generation of high level multi-frequency data products of blazars (e.g. Fermi adaptive bin light curves, Swift spectra and X-ray light curves, optical polarization)

# 2 Participants

## 2.1 ICRANet participants

- Paolo Giommi
- Ulisses Barres de Almeida
- Narek Sahakyan
- Benno Bodmann

## 2.2 Ongoing collaborations

- Paolo Padovani (ESO)
- Elisa Resconi (TUM)
- MAGIC Collaboration
- ASDC

## 2.3 Past collaborations

- ASI-ASDC
- CESUP

## 2.4 Students/Postdocs

- Yu-Ling Chang
- Bruno Sversut Arsioli
- Bernardo Machado Fraga
- Carlos Enrique Brandt

# 3 Brief description

The activity includes two main components:

- the construction and consolidation of an ICRANet distributed science data center based in Pescara, Rio de Janeiro (this component is named BSDC, Brazilian Science Data Center), Yerevan, and other sites; discussions are ongoing for a possible expansion of these activities within the BRICS network. Concerning database expansion, the complete incorporation of VHE MAGIC dataset for AGNs within the BSDC/ASDC framework, is undergoing, with future expansion to other VHE collaborations being sough.

- a scientific part, based on the data coming from the ICRANet data center, dedicated to the identification of samples of high energy emitting blazars (e.g. 1/2 WHSP) and to the theoretical interpretation of the radio to $\gamma$-ray emission of selected bright blazars. The latter includes, for the first time, a detailed look and consideration of multi-band light curve cross-correlations within the SED analysis.

## 3.1 Implementation of the ICRANet Brazilian Science Data Center (BSDC)

Following the preparatory work carried out in the past year, the establishment of the ICRANet - Brazilian Science Data Center (BSDC) on the premises of ICRANet-Rio is ready to start the implementation phase. The BSDC will host a mirror copy of the ASDC (ASI Science Data Center) public data, catalogs and of all the data reduction and analysis software that is publicly available. Specific software for archive data access at BSDC will be developed as part of this project. It will also host public data from several projects in which the Brazilian community, and in particular the Brazilian centres participating in the BSDC, are involved. Three major steps are foreseen: 1) start up phase (concluded in 2016), 2) BSDC archive and team building (January to June 2017), 3) establishment of a fully functional BSDC and related science teams at CBPF/Rio (by the end of 2017).

When fully operation, but he end of next year, in its first phase of scientific operations, the BSDC will focus on very high energy data and polarised radiation. In parallel, the novel Yerevan component of the collaboration will focus in the production of Fermi high level data products, such as adaptive-binning $\gamma$-ray light curves of selected bright blazars. The BSDC is built in collaboration with the ASI Science Data Center (ASDC) and contributes to the development of the recently approved United Nations initiative named Open Universe.

## 3.2 High energy emitting blazars

### 3.2.1 The VHE blazar sample, 2WHSP

Blazars are a class of radio-loud active galactic nuclei (AGN) hosting a jet oriented at a small angle with respect to the line of sight (Blandford and Rees, 1978; Antonucci, 1993; Urry and Padovani, 1995). The emission of these objects is non-thermal over most or the entire electromagnetic spectrum, from radio frequencies to hard $\gamma$-rays. HSP blazars play a crucial role in very high energy (VHE) astronomy. Observations have shown that HSPs are bright and variable sources of high energy $\gamma$-ray photons (TeVCat)[1] and that they are likely the dominant component of the extragalactic VHE background (Padovani et al., 1993; Giommi et al., 2006; Di Mauro et al., 2014; Giommi and Padovani, 2015; Ajello et al., 2015). In fact, most of the extragalactic objects detected so far above a few GeV are HSPs (Giommi et al., 2009; Padovani and Giommi, 2015; Arsioli et al., 2015; Ackermann et al., 2016, see also TeVCat). However, only a few hundred HSP blazars are above the sensitivity limits of currently available $\gamma$-ray surveys. Significantly enlarging the number of high energy blazars is important to better understand their role within the AGN phenomenon, and should shed light on the cosmological evolution of blazars, which is still a matter of debate.

Arsioli et al. (2015) (Paper I) built a HSP catalog, 1WHSP, based on WISE color-color diagram with the sources inside the (*S*edentary WISE color region)SWCD region, extended from WISE blazar strip (Massaro et al., 2011; D'Abrusco et al., 2012; Massaro et al., 2012) to include all the sources from the Sedentary survey blazars (Giommi et al., 1999, 2005; Piranomonte et al., 2007). They cross-matched the AllWISE sources (Cutri et al., 2013) in SWCD with different radio and X-ray catalogs using TOPCAT[2], applied spectrum slope criteria, and selected the source with Synchrotron peak $\nu_{peak} > 10^{15}$ Hz (Padovani and Giommi, 1995; Abdo et al., 2010) and Galactic latitude $b >$

[1]http://tevcat.uchicago.edu
[2]http://www.star.bris.ac.uk/ mbt/topcat/

$|20°|$. Note that there are three slope criteria in Paper I, which are radio to IR slope, IR to X-ray slope, and the AllWISE W1 to W3 slope; the criteria are obtained from normalized and rescaled the SEDs of three well-known HSP blazars.

Recently, Chang et al. (2016) (Paper II) assembled a most complete and largest HSP catalog, 2WHSP, an extension of 1WHSP catalog to $b > |20°|$. Similar as Paper I, building the 2WHSP catalog starts from cross-matching three radio catalogs (NVSS, FIRST, and SUMSS: Condon et al., 1998; White et al., 1997; Manch et al., 2003) with AllWISE IR catalog and then with various X-ray catalogs (RASS BSC and FSC, 1SWXRT and deep XRT GRB, 3XMM, XMM slew, Einstein IPC, IPC slew, WGACAT, Chandra, and BMW: Voges et al., 1999, 2000; D'Elia et al., 2013; Puccetti et al., 2011; Rosen et al., 2016; Saxton et al., 2008; Harris et al., 1993; Elvis et al., 1992; White et al., 2000; Evans et al., 2010; Panzera et al., 2003). However, 2WHSP is not subjected to WISE color-color diagram and the AllWISE W1-W3 slope criterion when selecting the sources. Therefore, the 2WHSP sample will not miss some good HSPs that IR and optical radiation are dominated by host galaxies. We used ASDC SED tool[3] to examine and fit the Synchrotron component with a third degree polynomial to get the Synchrotron peak position ($\nu_{peak}$) and Synchrotron peak flux ($\nu_{peak} f_{\nu_{peak}}$) for each WHSP pre-selection candidate.

The 2WHSP catalog totally includes 1 691 sources with 540 known HSPs, 288 new HSPs, and 814 HSP candidates. The name "WHSP" stands for WISE high Synchrotron peaked blazars since except for one source, 2WHSP J135340.2−663958.0, all the other sources in 2WHSP have WISE counterparts. For each 2WHSP source, we adopted as best coordinates those taken from the WISE catalog. The average $\nu_{peak}$ for our catalog is $\langle \log \nu_{peak} \rangle = 16.22 \pm 0.02$ Hz and the average redshift is $\langle z \rangle = 0.331 \pm 0.008$. We have shown that the SWCD region needs to be extended to include HSPs in which the host galaxy is dominant. The 2WHSP radio logN-logS shows that the number of HSP blazars over the whole sky is $> 2,000$ and that HBL make up $\sim 10\%$ of all BL Lacs.

### 3.2.2 The 1BIGB catalog

The 2WHSP sources has been used as seeds of HE and VHE searches to discover new VHE detections or to find the counterparts of VHE catalogs. So far, 439 of 2WHSP sources have counterparts within the error circles from the 3FGL catalog; there is still a large number of 2WHSP HSPs which does not have $\gamma$-ray detections yet. Therefore, Arsioli and Chang (2016) analyzed bright 2WHSP sources using archival Fermi-LAT data integrated over 7.2 years observations, Pass 8 data release. By using the position of 2WHSP

[3]http://tools.asdc.asi.it/SED

sources as seeds for the likelihood analysis, we found 150 previously unreported $\gamma$-ray detections.

The 150 new $\gamma$-ray sources are named with the acronym 1BIGB (first version of the Brazil ICRANet Gamma-ray Blazar catalog). Clearly, the subsample of 2WHSP blazars that have not yet been detected by Fermi-LAT is a key representative population of faint $\gamma$-ray emitters, and we show how the new detections down to TS $> 10$ level can probe the faint-end of the flux-distribution.

The new detections also unveil a fraction of the $\gamma$-ray sky. Our current work enabled us to associate a relevant fraction of the IGRB to a population of faint $\gamma$-ray emitters that had been previously unresolved. Moreover, we show the increasing relevance of faint-HSPs for the IGRB composition with respect to energy, specially for E $> 10$ GeV, reaching 6-8% in the $100 - 200$ GeV band.

Motivated by this first assessment, we plan to perform a complete $\gamma$-ray analysis of the 2WHSP sample, down to the lowest fluxes, and probably extend the search to other blazar families with potential to improve the $\gamma$-ray description of lower-significance $\gamma$-ray blazars, also helping to constrain the origins of the extragalactic diffuse -ray background.

### 3.2.3 Correlation between HSPs and neutrinos

Padovani et al. (2016) cross-matched the 2WHSP with IceCube neutrino events. Their result suggests that,among the blazar family, HSPs blazars are the most possible counterparts for neutrino. They further reported five neutrino events which have HSPs counterparts. Resconi et al. (2016) have presented evidence of a direct connection between 2FHL HBLs, very high energy neutrinos, and ultra high energy cosmic rays (UHECRs) when cross-matching 2FHL HBL subsample with UHECRs from the Pierre Auger Observatory and the Telescope Array. In a nutshell, HSPs catalogs are important and timely for HE and VHE astronomy.

### 3.2.4 Temporal study of the spectral energy distribution of blazars

Many of the studies on blazars are focused on their spectral energy distribution (SED). These provide a photographic view of the source state, which in turn gives an overview of the emission energy balance. Despite we can get some limits on models, the approach not able to satisfactorily explain the dynamics of the physical emission processes, because they evolve in time in a complex way, as can be seen by the emission's variability and multi-band correlations. In particular, there is evidence for the existence of delays between emissions at different frequencies, a feature enot accounted for in traditional SSC models of the SED. To try and get around these problems, other models have been proposed, such as those with contribution from radiation fields external to the jets for the inverse-Compton emission, or models where an emission zone is not homogeneous and multiple emitting blobs are considered to build up simultaneously the SED. However promising, these studies remain incipient and require further analysis. Key to the success of more in-depth studies is the availability of a large amount of multi-band data, for a detailed and combined view of the spectral properties and temporal evolution of the sources.

Usually, when dealing with the temporal evolution of blazar emission, the most commonly used method is to consider strictly simultaneous observations in multi-wavelength campaigns, and try to impose limits on different models. However, as previously mentioned, the emission at different frequencies may be correlated. Correlations between different bands are useful for determining the emission mechanism and constrain emitting region. In addition, if a correlation is discovered between two frequencies, it can be used to predict the emission of sources not yet detected. Some studies have found correlations in flare emission between, for example, radio and gamma rays and between optical and gamma rays. These multi-band correlations, if real, imply a delay in the variation of the emission at different frequencies. It is then clear, in these cases, that strictly simultaneous observations are not exploiting the same state of a source, since the lags are not taken into account. In order to analyze the time evolution of the emission, it is necessary to first analyse the multi-band correlations and to determine the lags between them, and then to collect the data of simultaneous observations, that is, separated by a period of time similar to the lag. This allows for a more rigorous study of emission models and the imposition of limits on their parameters. Although there are codes to calculate correlations and lags, a tool that would automate the whole process, from data selection and lag calculation to the construction of simultaneous SEDs, would be of immense value to the scientific community and could be integrated to the ASDC, making it available in a fast, easy and effective way for everyone. This is one of the technical goals and legacies of this work.

At first we intend to use a specific source, Mkn421, as a prototype for our study. We plan to publish a paper about the analysis of the temporal evolution of this source and its modelling by the end of the first year of research. At the same time, we have a preliminary version of the lags calculation tool and light curve construction already ready to be tested for a greater number of sources and deployment in ASDC.

With this study, we hope to be able to shed some light on the cause of variable emission in blazars. The lags estimation will allow us to determine how the emission at different frequencies are related and which physical mechanisms may be responsible for such a relationship. The construction of simultaneous SEDs will serve to discriminate between the different emission models already proposed, as well as to find out whether or not there is periodicity in a range of time scales. Today we have a large amount of data at hand, making it possible to create large catalogs of blazars (such as BZCAT and 1WHSP), making statistical studies more rigorous and precise. In order to work with a large number of sources it is necessary that the selection of simultaneous data be, to a great extent, automated. ASDC, being a great integrated platform for data analysis and visualisation, is a perfect option to implement this procedure, making the determination of correlations, lags and the subsequent construction of simultaneous SEDs easier, faster and more accessible to the community at large. The beginning of the implementation of the Brazilian Science Data Center (BSDC) in CBPF, an integrated data platform analogous to ASDC, focusing on collecting data from missions to which Brazil is a partner, will be another opportunity for the implementation of the automated analysis of the time evolution of blazars.

# 4 Publications

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- Chang, Y.L.; Arsioli, B.; Giommi, P.; Padovani, P. 2WHSP: A multi-frequency selected catalog of VHE gamma-ray blazars and blazar candidates 2016, A&A, in press
- Arsioli, B.; Chang, Y.L. Searching for $\gamma$-ray signature in WHSP blazars: Fermi-LAT detection of 150 excess signal in the 0.3-500 GeV band (1BIGB sample) 2016, A&A, in press
- Padovani P., Resconi E., Giommi P., Arsioli B., Chang Y.L.
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