A systematic study of the multi-wavelength properties of extreme γ-ray blazars

More details here!

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1 Introduction

Blazars are the most extreme active galactic nuclei, with their relativistic jets pointing towards us. Among them, **extremely high synchrotron peaked (EHSP) blazars** are the most energetic ones, being able to accelerate electrons up to energies where the corresponding synchrotron emission peak is found in the X-ray band or beyond ($\nu_{sync} > 10^{17}$ Hz). The number of known sources of this class is still limited to a few dozen, yet they are critical to understand the acceleration processes in jets and the emission mechanisms. In this work, we search for EHSPs within a selection of more than 600 blazars and blazar candidates, by studying their broadband spectral energy distribution (SED). After modeling their SEDs, we identify new EHSPs and analyze their physical properties, and possible evolution in the context of the more general population of blazars.

2 Blazar sample selection

The base catalog that we use is the **2BIGB catalog** (Arsioli et al., 2022), a database of 1160 γ-ray emitting blazars with infrared (IR) properties similar to those of high synchrotron peaked (HSP) blazars. We require each source to:

- have flux measurements in all bands
- have a redshift estimate (even if photometric)
- to be outside the galactic plane ($|b| > 10^{\circ}$)

➡ **657 sources** (269/388 variable/non-variable in gamma rays), all of them observed with NASA's *Fermi Gamma-ray Space Telescope*. A skymap with the location of the resulting sources is shown in **Fig.1**.

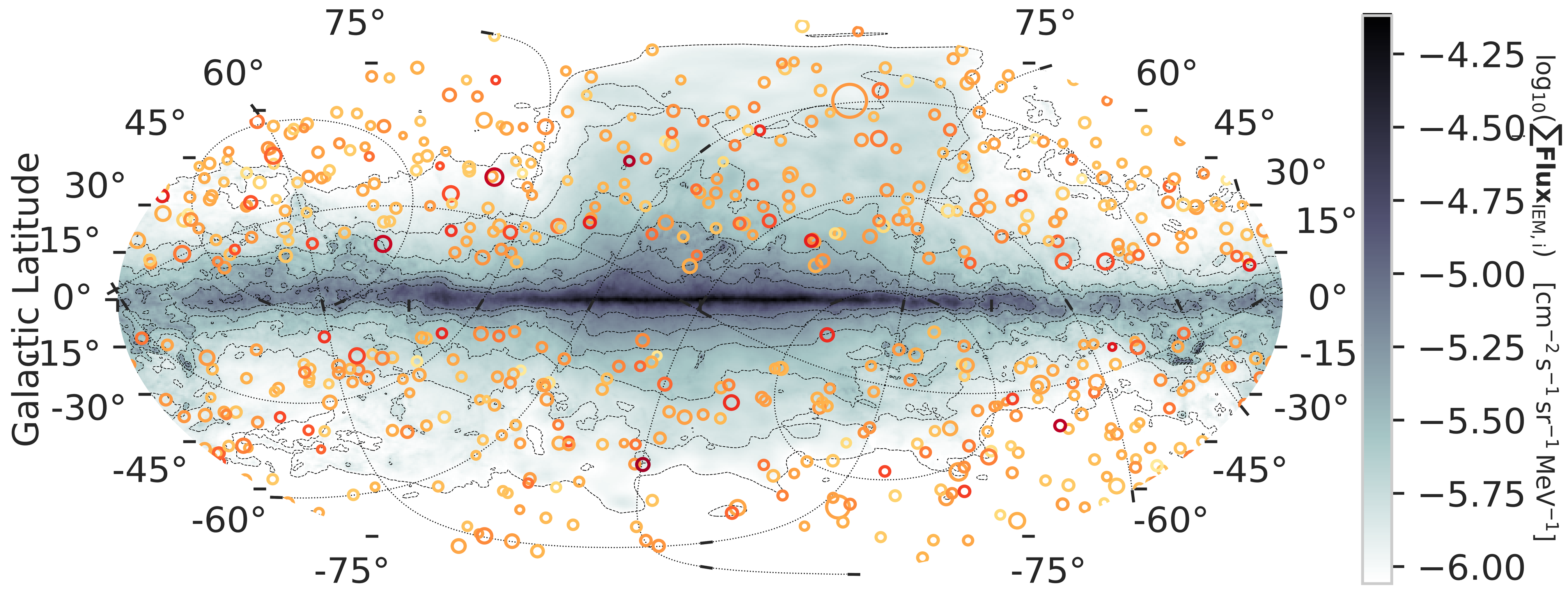

Figure 1: Location of the selected sources (galactic coordinates). Each circle represents a source, with a color that corresponds to their flux (in log-scale, with red tones for brighter sources). The size of the circle is proportional to $1/\sqrt{z}$. For reference, the diffuse γ-ray emission from the Galaxy is shown in blue tones.

3 Multi-wavelength variability

We use the ***fractional variability***, F_{var}, to study blazar variability in different bands and different times. The histogram of F_{var} in the different bands is shown in **Fig.2**. Our sample of sources has similar distributions of F_{var} for γ rays and X-rays, larger than the ones in optical and ultraviolet (UV), which suggests a significantly stronger variability at higher energies, perhaps due to thermal components (low variability) significantly polluting the optical/UV data.

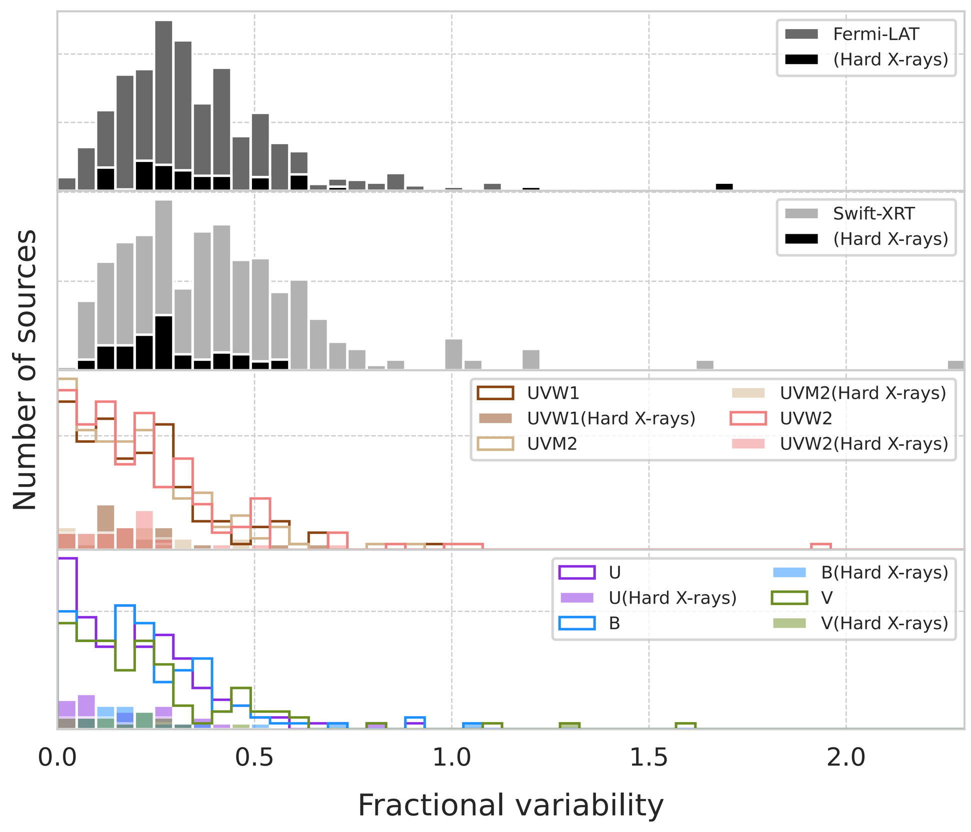

Figure 2: Fractional variability in different bands, for both the full sample with fractional variability measurements in all bands, and the subsample of sources with hard X-ray spectra (index $\Gamma_X < 2$).

4 Broadband SED modeling

As for other blazars, the broadband SED of EHSPs has a double-peaked structure, with the lower energy region usually attributed to synchrotron emission from relativistic electrons, and a higher energy component whose origin is disputed. For the modeling of the SEDs, we use a simple **one emission zone synchrotron-self-Compton (SSC) model**, in which the higher energy peak is attributed to inverse Compton scattering of the electron population with the photons produced in the synchrotron process. We add other components that may exist from IR to X-rays, mainly due to the host galaxy or other elements such as the accretion disk. Out of the first 134 modeled sources, 60 are classified according to the model as EHSPs ($\nu_{sync} > 10^{17}$ Hz) and 74 can be classified as less energetic blazars ($\nu_{sync} < 10^{17}$ Hz). An example of an EHSP candidate is shown in **Fig. 3**, where the synchrotron component seems to extend into the hard X-rays, favouring extreme maximum Lorentz factors of the emitting electrons ($\gamma_{max} \gtrsim 10^8$) over more typical values of $\sim 10^6$.

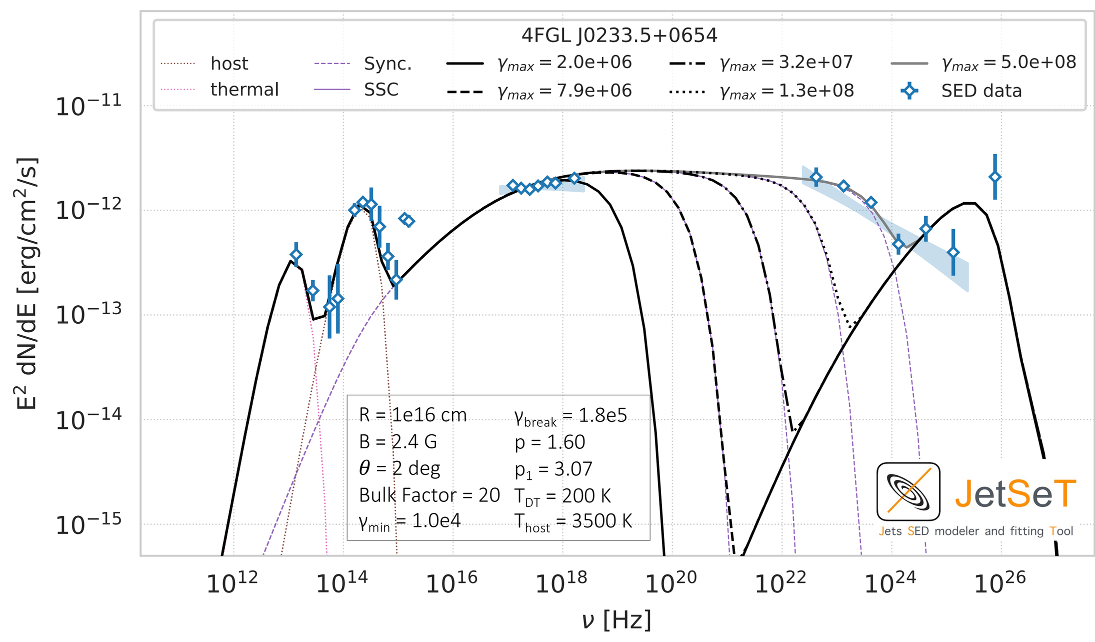

Figure 3: SED modeling of 4FGL J0233.5+0654 using a SSC scenario plus a dusty torus and the host galaxy radiation field.

5 Energy budget

As EHSP blazars are supposedly well-developed jets, **equipartition** is expected to happen, since as the jet develops the magnetic energy density is converted into kinetic energy of the accelerated particles until equipartition is reached. **Fig. 4** shows the energy budget of the first 134 modeled sources, showing with red triangles those for which we have obtained an expected detection significance $\geq 5\ \sigma$ as observed by the future Cherenkov Telescope Array (CTA). Some recent studies (Tavecchio & Ghisellini, 2016) have suggested that weak magnetization seems to be required only for sources with significant very-high-energy (VHE, E > 100 Gev) gamma-ray emission, while non-VHE emitters are in rough equipartition. In contrast, as in the study performed by Nievas Rosillo et al., 2022, most sources of our sample are clustering around the line $U_B = U_e$, independently of their probability to be detected at VHE.

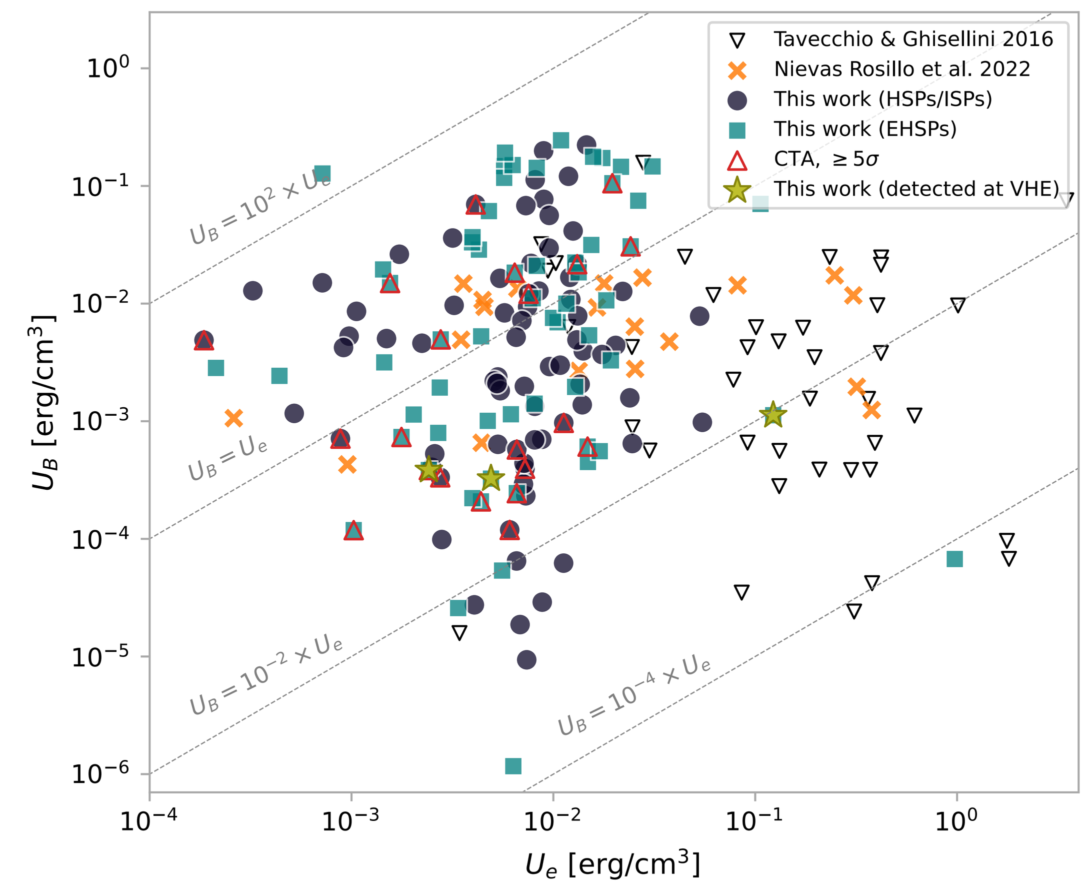

Figure 4: Magnetic energy density as a function of the kinetic energy density of the electrons derived from our sample (distinguishing between EHSPs and less energetic blazars), compared with the one obtained in Nievas Rosillo et al., 2022 and Tavecchio & Ghisellini, 2016. The sources of our sample that could potentially be detected by CTA are shown as red triangles.

6 CONCLUSIONS

Considering a large sample of 657 EHSP-candidate sources, we have performed one of the first systematic studies of the **multi-wavelength properties of HSP and EHSP blazars**, including not only spectral information but also their time-resolved emission.

- Study of the **variability** of the full sample through the ***fractional variability*** method: the variability is stronger in X-rays and γ rays than in optical and UV, a possible indicator of thermal features (less variable) existing in the optical and UV spectra of the sources.
- **Multi-wavelength SED modeling** of the first 134 non-variable sources of the sample (roughly half are EHSPs and the rest are high or intermediate synchrotron peaked blazars): no indication of significantly different magnetization of the jets of both populations, both samples are in rough **equipartition** (as observed previously by Nievas Rosillo et al., 2022).

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References

1. Arsioli B., Chang Y. L., Musiimenta B., 2020, VizieR Online Data Catalog, p. J/MNRAS/493/2438
2. Nievas Rosillo M. et al., 2022, MNRAS, 512, 137
3. Tavecchio F., Ghisellini G., 2016, MNRAS, 456,2374

Other ongoing projects during the PhD:

lstosa

- Maintenance and development of the **onsite analysis** software of the IACTs MAGIC and LST-1 (**MAGIC OSA, lstosa**)
- Determination of redshifts of blazars using a new method based solely on the extragalactic background light attenuation and *Fermi*-LAT data → see **Domínguez A., Láinez M. et al., 2023 (arXiv:2307.10083),** oral contribution and proceeding to the ICRC'23 Conference (https://pos.sissa.it/444/558/pdf)