A model-driven search for extreme BL Lacs among LAT BCU

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Abstract

The emission of very-high-energy photons (VHE, E>100 GeV) in active galactic nuclei (AGN) is closely connected with the production of ultra-relativistic particles. Among AGN, the subclass of extreme BL Lacertae are of particular interest because they challenge state-of-art models on how these cosmic particle accelerators operate. By cross-matching two gamma-ray catalogs (this is, 4FGL-DR2 and 2BIGB), we identified 23 high-synchrotron-peaked (HSP) blazar candidates with photometric or spectroscopic redshifts, good multi-wavelength coverage, that are possibly detectable by VHE instruments. We performed a new analysis of Fermi Large Area Telescope data including the effects of attenuation from the extragalactic background light and complemented these results by collecting multiwavelength data from optical, radio and X-ray archival observations. Their broadband spectral energy distributions were interpreted in terms of synchrotron-self-Compton models with external-Compton components and compared with the properties of prototypical extreme HSP blazars. Finally, we test their detectability with imaging atmospheric Cherenkov telescopes (IACTs) and propose a new method for selecting these extreme targets for these ground-based telescopes.

Main Objectives

Blazars, radio-loud AGNs whose jet is closely aligned to us, can be classified according to the synchrotron peak frequency [1]:

1) low-synchrotron-peaked (LSP, $\nu^S_{\rm peak} < 10^{14}$ Hz)
2) intermediate-synchrotron-peaked (ISP, $\nu^S_{\rm peak} \in [10^{14}, 10^{15}]$ Hz)
3) high-synchrotron-peaked (HSP, $\nu^S_{\rm peak} \in [10^{15}, 10^{17}]$ Hz)
4) extreme high-synchrotron-peaked (EHSP, $\nu^S_{\rm peak} > 10^{17}$ Hz)

The extragalactic VHE sky is dominated by HSP and EHSP BL Lacs. ISP/LSP BL Lacs and FSRQs are more common in the HE ($E > 100\,\mathrm{MeV}$) band. Here we suggest a method to efficiently extract EHSP blazars from *Fermi*-LAT unclassified sources based on catalog matching plus modeling of SEDs.

Materials and Methods

Source selection: Done by crossing the 4LAC-DR2 [2] and 2BIGB [3] catalogs to look for good blazar candidates of unknown type (BCU) based on photometric properties.

4FGL Name	RAJ2000	DEJ2000	z	TS	FOM	Index	VarIndex	FracVar
J0132.7−0804	23.183	-8.074	0.148	88	0.8	1.9	5.54	
J0212.2−0219	33.066	-2.319	0.250	61	0.8	2.2	16.70	0.47 ± 0.29
J0350.4−5144	57.613	-51.743	∼0.32	98	0.8	1.8	11.62	0.32 ± 0.36
J0515.5−0125	78.891	-1.419	∼0.25	55	0.8	2.1	13.04	0.32 ± 0.31
J0526.7−1519	81.692	-15.321	∼0.21	218	1.6	2.0	8.21	
J0529.1+0935	82.297	9.597	∼0.30	86	1.3	2.1	12.81	0.23 ± 0.26
J0557.3−0615	89.344	-6.265	∼0.29	53	1.6	2.0	7.08	
J0606.5−4730	91.642	-47.504	0.030	137	1.0	2.0	17.90	0.39 ± 0.20
J0647.0−5138	101.773	-51.638	∼0.22	81	2.5	1.8	17.03	0.32 ± 0.40
J0733.4+5152	113.362	51.880	0.065	162	2.5	1.8	12.43	0.26 ± 0.30
J0847.0−2336	131.757	-23.614	0.059	921	0.8	2.0	14.72	0.14 ± 0.09
J0953.4−7659	148.367	-76.993	∼0.25	104	0.8	2.0	5.88	
J0958.1−6753	149.534	-67.894	∼0.21	29	1.0	2.2	12.73	0.46 ± 0.51
J1132.2−4736	173.056	-47.613	∼0.21	129	1.0	2.0	11.47	0.26 ± 0.22
J1447.0−2657	221.765	-26.962	∼0.32	46	2.0	2.0	6.81	
J1714.0−2029	258.522	-20.486	∼0.09	110	2.0	1.6	24.95	0.59 ± 0.28
J1824.5+4311	276.126	43.196	0.487	99	0.8	1.8	8.17	
J1934.3−2419	293.582	-24.326	∼0.23	63	1.6	1.8	11.21	
J1944.4−4523	296.101	-45.393	∼0.21	164	1.0	1.7	14.32	0.22 ± 0.32
J2001.9−5737	300.491	-57.631	∼0.26	123	0.8	2.1	2.94	
J2142.4+3659	325.602	36.986	∼0.24	110	1.3	2.0	13.35	0.25 ± 0.29
J2246.7−5207	341.682	-52.126	0.194	95	2.5	1.7	19.10	0.57 ± 0.30
J2251.7−3208	342.944	-32.140	0.246	52	2.0	1.8	11.20	0.28 ± 0.49

Preliminary

Redshifts: Extracted from the 4LAC-DR2 and complemented using [4] and 2BIGB's photometric redshifts.

***Fermi*-LAT's γ-ray data analysis:** We matched 4LAC-DR2's exposure and took into account the interaction between γ-rays and Extragalactic Background Light (EBL).

Search for MW counterparts: Based on SSDC's SED builder: `https://tools.ssdc.asi.it/SED/`. We looked for archival data from radio to X-rays to complement our γ-ray spectra. The resulting SED is then modeled using the `jetset` [5].

Detectability in the VHE band: We generated and analysed simulated VHE γ-ray samples using CTA's Prod3b response functions ($5\,\mathrm{h}$ exposure, similar to the performance of current IACTs in $50\,\mathrm{h}$, Fig. 1).

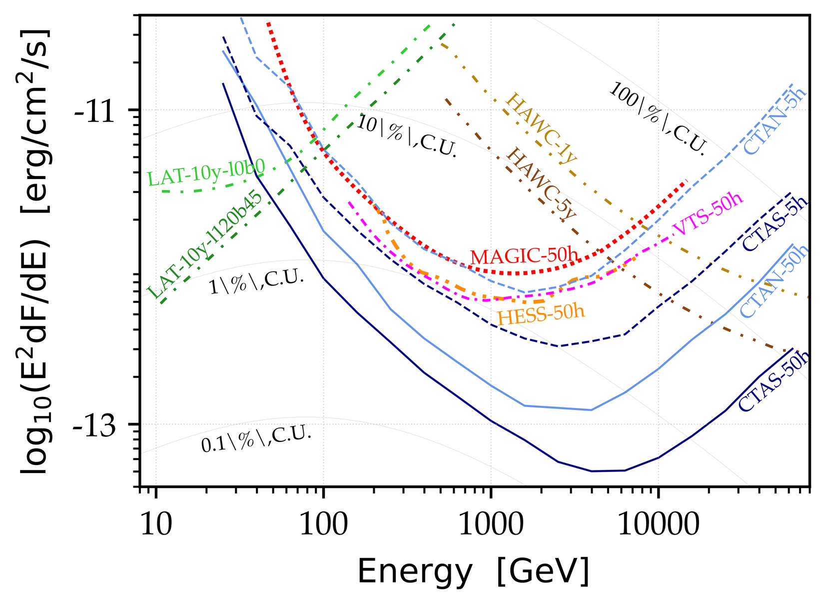


Figure 1: Sensitivities of various γ-ray instruments in operation and planned.

Properties of the selected BCU sample

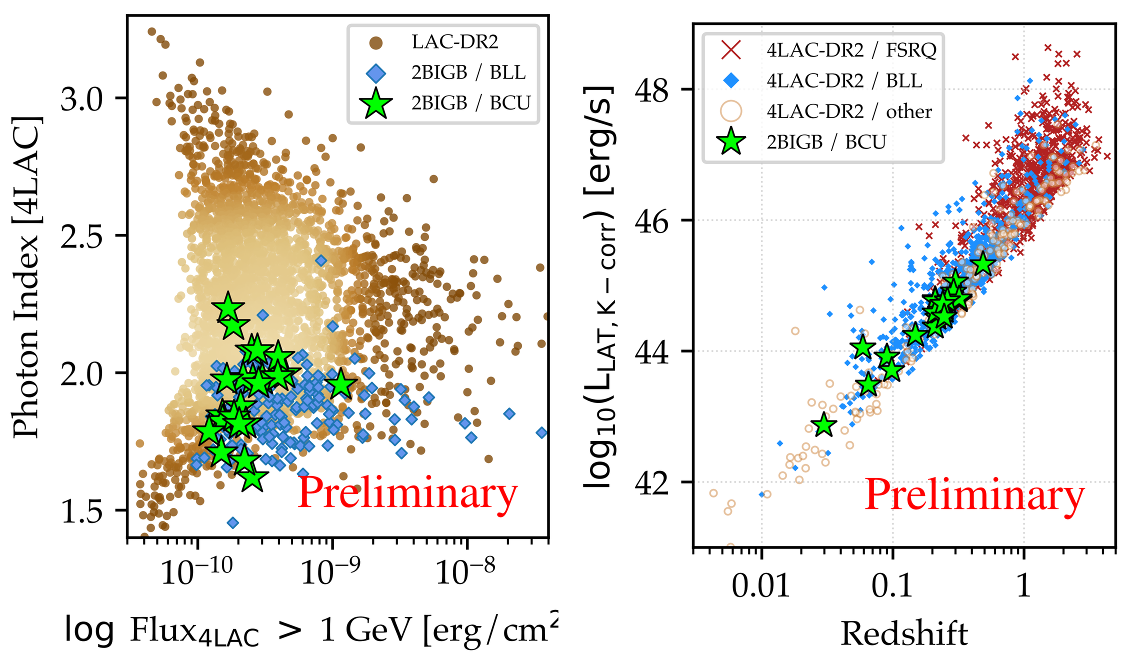


Figure 2: Left: Spectral index vs Flux in the Fermi-LAT band for: LAC-DR2 sources (density color coded brown tones), 2BIGB BL Lacs (blue) and our targets (green stars); **right:** K-corrected γ-ray luminosity vs redshift for FSRQs (red crosses), BL Lacs (blue diamonds) and other extragalactic objects (open orange circles).

BL Lacs have statistically harder γ-ray spectra and are less luminous than FSRQs. We created diagnostic plots (Fig. 2) to put our sources in the context of blazars detected by *Fermi-LAT*. The result is that our targets tend to have intermediate redshifts ($0.05 \lesssim z \lesssim 0.30$), hard spectra as BL Lacs but low fluxes and luminosities ($L_\gamma \lesssim 10^{45}\,\mathrm{erg/s}$).

Broadband SED modeling

Non-thermal low-energy component: One-zone leptonic scenario with emission originating in a spherical plasma region of radius R embedded in the blazar jet. Its distance to the nucleus is R_H and its magnetic field strength B. Electrons in the plasma are assumed to have a broken power-law spectrum with indices p_1 between Lorentz factors $\gamma_{\rm min}$ and $\gamma_{\rm br}$ and high-energy index p_2 between $\gamma_{\rm br}$ and $\gamma_{\rm max}$.

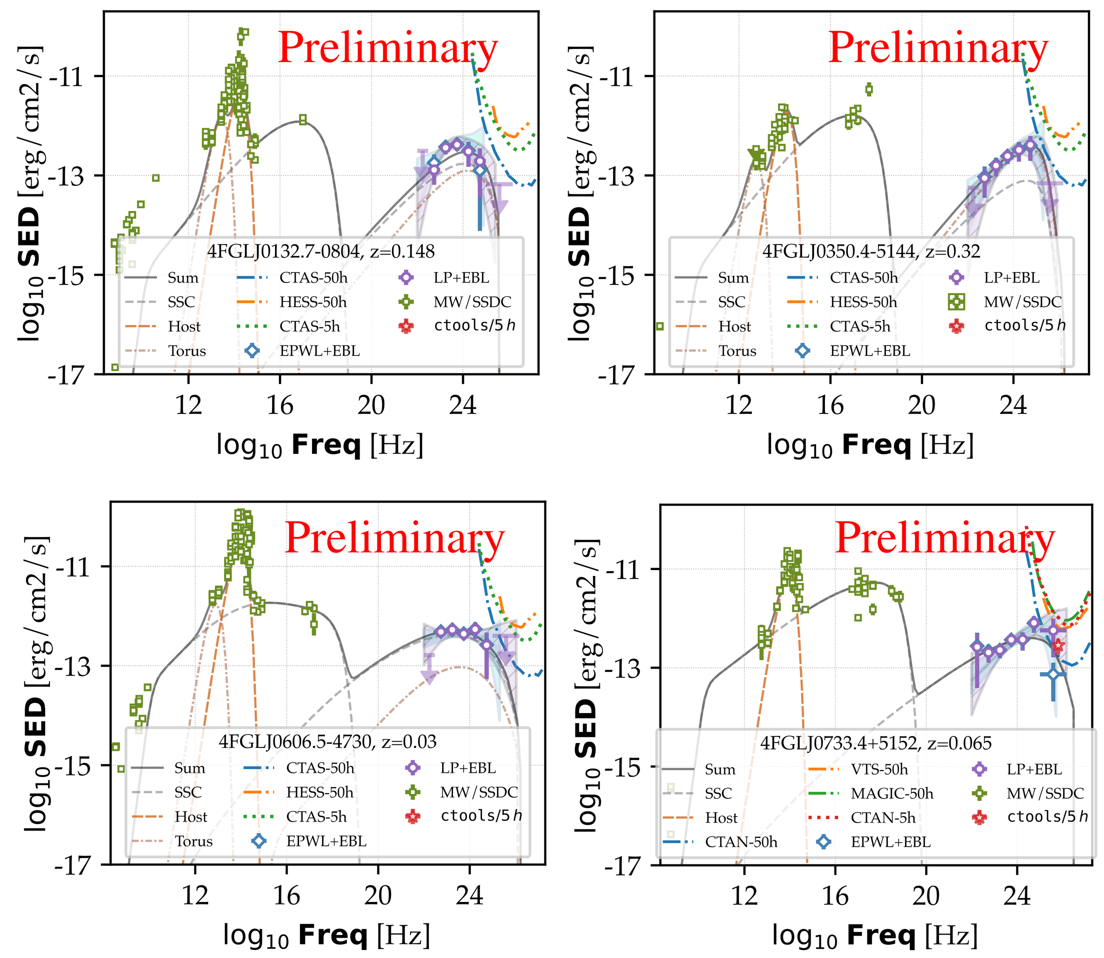
High energy emission: Due to inverse Compton scattering from the same population of electrons on both synchrotron radiation and, if present, the infrared radiation from a dusty torus.

Thermal radiation: A clear excess in the optical band is visible for all the sources, and assumed to be host emission from a giant elliptical galaxy. We model it as a black body with effective temperature $\mathrm{T_{eff,Host}}$ and luminosity $\mathrm{L_{Host}}$. For sources with a dusty torus, we assume a characteristic size R_{DT}, opacity τ_{DT} and effective temperature T_{DT}.

Spectral fitting: Done using `jetset`. Some parameters are fixed to typical values: $\gamma_{min} = 1$, $\Gamma = 20$, $R = 1 \times 10^{16}\,\mathrm{cm}$, $R_H = 2 \times 10^{18}\,\mathrm{cm}$.

Modeling results

The resulting SEDs for 8 of the 23 sources are shown in Fig. 3.



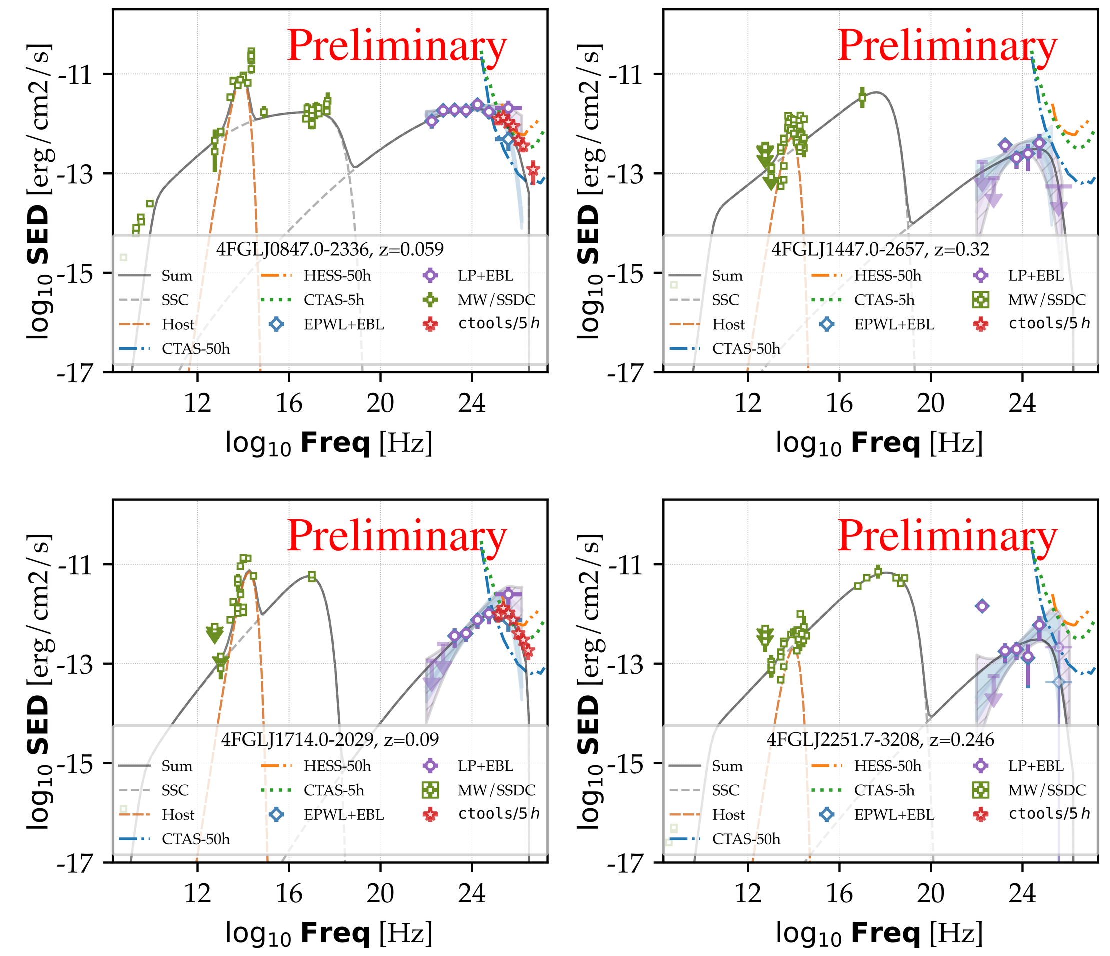


Figure 3: SEDs for 8 of the 23 sources considered in this work. Green open square markers represent archival data, purple and blue open circles show the Fermi-LAT analysis results (using a LogParabola and PowerLaw with exponential absorption shapes respectively, both absorbed by EBL) and red stars show the simulated $5\,h$ exposure observations with CTA, as a proxy for observations with existing IACTs in $50\,h$. Finally, the different curves show the different components of the resulting model.

Conclusions

- Out of 23 candidates, 16 classified as EHSPs and 7 as HSPs.
- One zone leptonic models are enough to fit all spectra. Expected host emission common in EHSPs, but unexpected hints of torus-like excess in IR for some.
- 3 sources exhibit extreme synchrotron peak frequencies, $\nu_{SP} \gtrsim 10^{18}\,\mathrm{Hz}$: J0733.4+5152, J1447.0-2657, J2251.7-3208. Only the first and the last have enough X-ray data constraining the peak position, while for J1447.0-2657 it was constrained mainly from the Fermi-LAT spectrum (therefore a lower limit).
- Only J0847.0-2336 and J1714.0-2029 are promising VHE candidates. They are both EHSPs, none with extreme synchrotron peaks, $\log_{10}\nu_{SP} \sim 17.2$. Both have very low magnetization ($B \sim 10^{-4}\,\mathrm{G}$), strong host emission and no IR torus.

References

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