Identifying TeV source candidates among Fermi-LAT unclassified blazars using Artificial Neural Network.

Presentation FERMI _HBL presentation.pdf

HBL_answers_agncoordinators.docx

HBL_A&A_v2.pdf

Referee report_AA.docx

Internal reviewer comments on the April, 2019, ApJ version

Changes made April, 2019, due to suggestions from Vaidehi:

Updated wording as suggested

Dropped TSvar, because that variability analysis was not used in the paper.

Combined and consolidated tables.

ApJ Referee Report

Reviewer's Comments:
The identification of the gamma-ray sources that can be detected at TeV energies with the current and future slate of Imaging Atmospheric Cherenkov Telescopes (IACTs) is an important task. The development of efficient methods to select such TeV targets from the catalog of sources observed by the Fermi LAT instrument is a fundamental task to maximize the scientific output of both the Fermi and IACTs telescopes and, as a consequence, improve our understanding of the extremely energetic emission from blazars.

The manuscript "Identifying TeV Source Candidates among Fermi-LAT Unclassified Sources" presents a method to select potential TeV targets observable by IACTS based on the variability and spectral properties of gamma-ray sources observed by Fermi LAT instrument. A set of candidate high-synchrotron-peaked (HSPs), the spectral class of blazars most likely to emit at TeV energies, is selected based on their reported variability by applying an already tested machine learning technique. Among these candidates, sources which can be detected by IACTs under reasonable assumption on the duration of the exposures are further identified by comparing their spectral energy distributions extrapolated to TeV energies with the sensitivity curves for current and future IACTs.
The extrapolation of the SEDs of such sources are based on fitted spectral models of the candidate HSPs sources from Fermi LAT data collected until April 2017, at the TeV energy

The paper represents a valuable contribution to the literature in this field and deserves publication once the questions and comments below will be addressed. The manuscript is well written and clear. I would like to see the revised manuscript.

Comments

- The authors should explain why they decided to perform the extrapolation of the SED for high-confidence HSPs sources only, i.e. with L_HSP>=0.89. Based on the estimated purity of their classification based on the validation of their machine learning method reported at the end of Section 2, a lower L_HSPs>0.8 threshold will still produce a 75% efficiency that would probably yield a quite large number of HSPs detectable by IACTs under the same assumptions used for the high-confidences ones. Is this study a proof-of-concept that will be extended to the other (slightly less likely) HSPs candidates selected with the Chiaro et al. 2016 method in a future work? Or there are more fundamental reasons why the other sources in Table 1 and 2 were not investigated that I am missing?

- Section 2: the description of the method used to select HSPs sources from 3FGL is terse. The manuscript, as it stands, is not self-consistent and does not provide the minimal set of information that are needed to assess the viability of the machine learning method used to select HSPs based on their gamma-ray flaring activity. I suggest that the authors add to this section a summary of the basics about the method described in Chiaro+2016.

- As the authors mention in the introduction, other methods have been proposed to select candidate TeV blazars that do not use gamma-ray information, at least directly. It would be interesting to know if their list of high and low-confidence HSPs candidates can be spatially associated to candidates HSPs from the catalogs produced by Chang et al. 2017 (2WHSP) and D'Abrusco et al. 2019 (2019ApJS..242....4D).

- In order to model the EBL attenuation, a redshift for the gamma-ray source needs to be provideds. The authors should specify how they sampled the 0 to 0.5 interval used to obtain the two extreme behaviors, or did they just use the z=0 and z=0.5 values to determine the boundaries of the blue shaded areas between the two fitted SEDs?

- Figure 1: since the focus of the papers is on sources located in scarcely populated bins for large L_HSP, I would suggest to use a logarithmic y scale.

- Line 136: "did we find" -> "we found"

- Reply
- Like

- Aug 20, 2019

Response to the ApJ Review:

We extend our thanks to the referee for a careful reading and helpful suggestions. Responses to the recommendations are given below. Changes in the text appear in bold font.

- The authors should explain why they decided to perform the extrapolation of the SED for high-confidence HSPs sources only, i.e. with L_HSP>=0.89. Based on the estimated purity of their classification based on the validation of their machine learning method reported at the end of Section 2, a lower L_HSPs>0.8 threshold will still produce a 75% efficiency that would probably yield a quite large number of HSPs detectable by IACTs under the same assumptions used for the high-confidences ones. Is this study a proof-of-concept that will be extended to the other (slightly less likely) HSPs candidates selected with the Chiaro et al. 2016 method in a future work? Or there are more fundamental reasons why the other sources in Table 1 and 2 were not investigated that I am missing?

Authors: This new method of identifying HSP blazars was untested. We know that the 4FGL catalog will have many more sources to investigate if this method is useful; therefore we concentrated our spectral analysis on the Very High Confidence sample. We added text to that effect at the beginning of section 4, line 120.

- Section 2: the description of the method used to select HSPs sources from 3FGL is terse. The manuscript, as it stands, is not self-consistent and does not provide the minimal set of information that are needed to assess the viability of the machine learning method used to select HSPs based on their gamma-ray flaring activity. I suggest that the authors add to this section a summary of the basics about the method described in Chiaro+2016.

Authors: We have reorganized the description of the machine learning method and added information about the basic idea of the method (line 80) and the way the neural network works (line 88).

- As the authors mention in the introduction, other methods have been proposed to select candidate TeV blazars that do not use gamma-ray information, at least directly. It would be interesting to know if their list of high and low-confidence HSPs candidates can be spatially associated to candidates HSPs from the catalogs produced by Chang et al. 2017 (2WHSP) and D'Abrusco et al. 2019 (2019ApJS..242....4D).

Authors: We added a paragraph comparing our results to the 2WHSP catalog at the end of section 3, line 112. We did not try to compare our results with the D'Abrusco catalog, because their work attempts to identify the general BL Lac population, and not specifically HSPs.

- In order to model the EBL attenuation, a redshift for the gamma-ray source needs to be provideds. The authors should specify how they sampled the 0 to 0.5 interval used to obtain the two extreme behaviors, or did they just use the z=0 and z=0.5 values to determine the boundaries of the blue shaded areas between the two fitted SEDs?

Authors: We did the calculation for z=0 and z=0.5, without attempting to do a sampling. These two values encompass most of the known HSP redshifts, providing limits. We added this information to the text at line 165.

- Figure 1: since the focus of the papers is on sources located in scarcely populated bins for large L_HSP, I would suggest to use a logarithmic y scale.

Authors: We changed to logarithmic scaling for Figure 1.

- Line 136: "did we find" -> "we found"

We prefer to keep the original wording. We feel it reads more smoothly, and it is grammatically correct.

G.Chiaro, M.Meyer, M. Di Mauro, D.Salvetti, G. La Mura, D.J. Thompson

Blazars and in particular the subclass of high synchrotron peaked objects are the main targets for the present generation of Imaging Atmospheric Cherenkov Telescopes (IACTs)and will remain of great importance for very high-energy gamma-ray science in light of the future Cherenkov Telescope Array (CTA).

The observation time of high energy sources by IACTs is limited by their small field of view, by the presence of many competing source populations to observe and science cases to study. Therefore, it is important to select the most promising targets in order to save observation time and consequently to increase the number of detections.

The aim of this study is to search for unclassified blazars , using Artificial Neural Network (ANN) algorithm that can realistically observed with IACTs or CTA in 50 or 5 hours.

The 3FGL catalogue contains two classes of source with uncertain classification that offer opportunities to identify HBLs and subsequently TeV candidates according with the TeV catalog census : (i) the 573 BCU and (ii) 1010 UCSs. Recently in https://arxiv.org/abs/1602.00385 the authors applied a number of machine-learning techniques to classify 3FGL UCSs as pulsars or AGN. The authors found 334 pulsars, 559 sources of AGN type and 117 remained uncertain.

The resulting 573 BCU and 559 AGN type sources represent the first targets for this search and we apply an optimized version of the ANN described in https://arxiv.org/abs/1709.05727 in order to compute the likelihood distribution of HBL and non-HBL sources

We perform an analysis of Fermi-LAT data in order to find the gamma-ray SED of our HBL candidates and confirm the nature of them.
We analyze 104 months of Pass 8 data, from 2008 August 4 to 2017 April 4, selecting gamma-ray events in the energy range E=[0.1,1000] GeV, passing standard data quality selection criteria.

We also compare the extrapolated fluxes of the candidates against the sensitivity of present IACTs and the future CTA. We use the Fermi-LAT spectral shape of the sources obtained in the range between 0.1 and 300 GeV using the best-fit model parameters from the LAT 4-year 3FGL Catalogue and particularly we referred to the following relation derived from the spectral model that fits the data.

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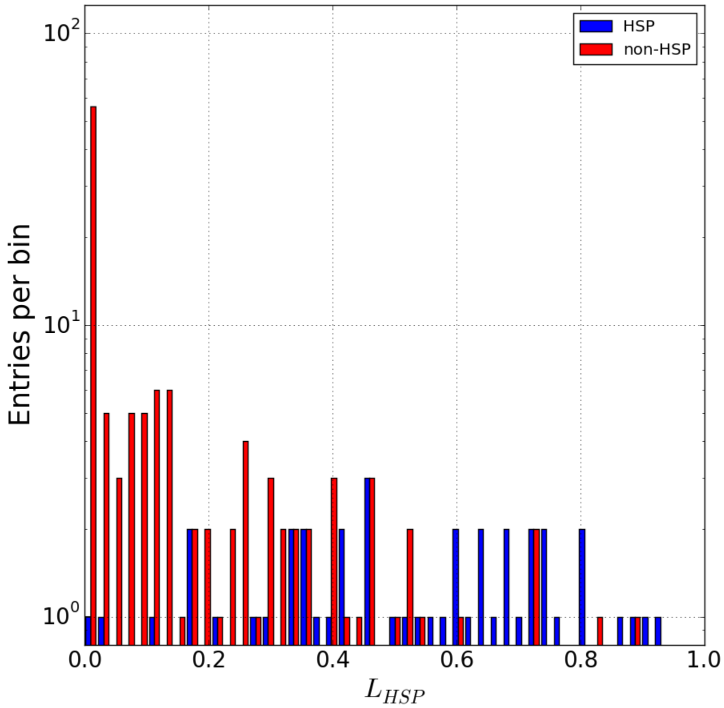
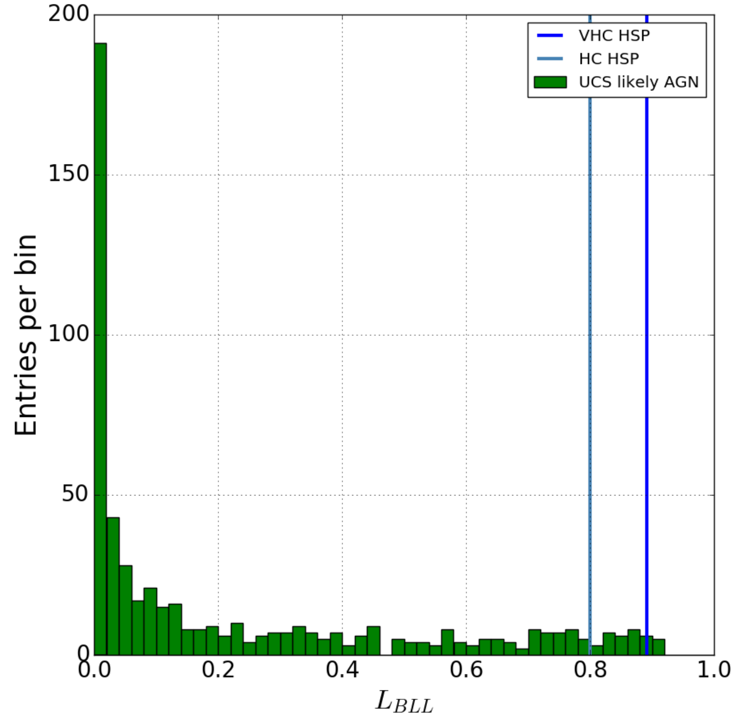
DATA

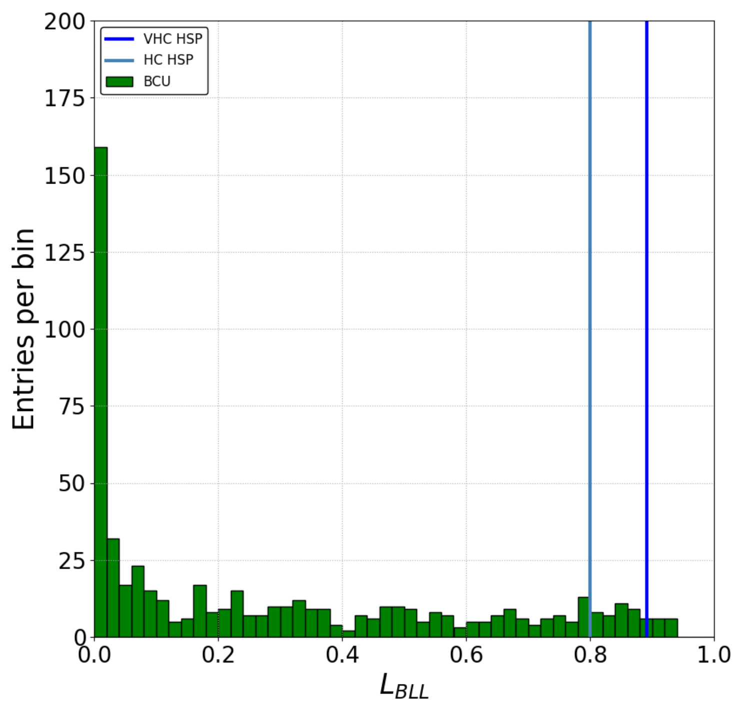
Blazar subclasses HBL and non-HBL distribution against gamma-ray flux



Likelihood distribution of HBL and non-HBL sources in 3FGL blazars by our applied ANN algorithm.

This result could show that the applied algorithm is not able to clearly identify HBLs but the likelihood distribution can still be acceptable for the aim of this study





Distribution of the ANN likelihood to be HBL candidates of 3FGL BCUs. (right) and UCS_bcu (left). Vertical blue and steel blue lines indicate the applied classification thresholds to identify sources as High Confidence candidates.

Full list of BCU HBL candidates. In Cols. 9, 10, 11 the observabilty at the IACT sites. On the top of the list the candidates with the highest Likelihood (L> 0.89) .

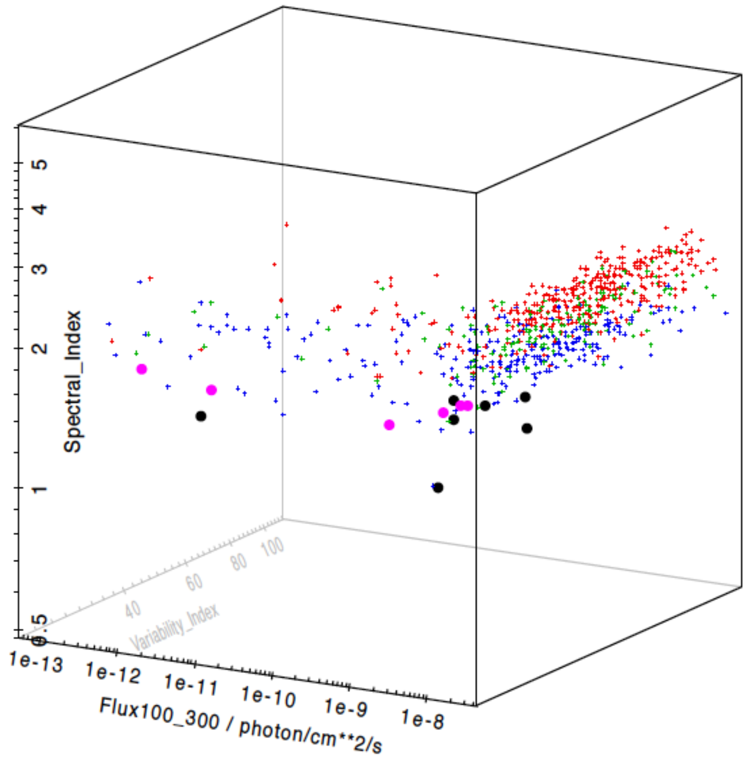
3FGL name	Association	TS	Sp.Index	TS_var	L_hbl	RAJ2000	DecJ2000	HESS	VERITAS	MAGIC
3FGL J0047.9+5447	1RXS J004754.5+544758	56.73	1.57	11.7	0.92	12.0160498	4.80784405		X	X
X 3FGL J1155.4-3417	NVSS J115520-341718	147.32	147.32	16.24	0.92	178.8740215	-34.32645279	X		
3FGL J1434.6+6640	1RXS J143442.0+664031	73.9	1.58	16.78	0.92	218.7228694	66.67084133		X	X
3FGL J0921.0-2258	NVSS J092057-225721	62.51	62.51	10.5	0.91	140.2437951	-22.94845947	X	X	X
3FGL J0648.1+1606	1RXS J064814.1+160708	40.1	1.81	13.91	0.90	102.0277929	16.08911409	X	X	X
3FGL J1711.6+8846	1RXS J171643.8+884414	44.3	1.83	12.4	0.90	258.6700448	88.75072331		X	X
3FGL J1714.1-2029	1RXS J171405.2-202747	73.8	1.44	18.16	0.90	258.5155102	-20.47598092	X	X	X
3FGL J1910.8+2855	1RXS J191053.2+285622	102.25	1.61	15.16	0.90	287.7132899	28.9403263	X	X	X
3FGL J0153.4+7114	TXS 0149+710	80.86	1.81	19.72	0.89	28.42864335	71.25516089	X	X	
3FGL J0506.9-5435	1ES 0505-546	455.43	1.49	29.82	0.89	76.75704931	-54.59583993	X	X	
3FGL J1944.1-4523	1RXS J194422.6-452326	100.69	1.63	11.11	0.89	296.1113217	45.38296215	X		
3FGL J0742.4-8133c	SUMSS J074220-813139	32.29	2.03	11.8	0.92	115.4463652	-81.53829083			
3FGL J0040.3+4049	B3 0037+405	75.94	1.93	12.02	0.9	10.08708372	40.83205536			
3FGL J0043.7-1117	1RXS J004349.3-111612	69.4	1.91	12.51	0.88	10.93797337	-11.31276512			
3FGL J1824.4+4310	1RXS J182418.7+430954	80.91	1.82	19.74	0.88	276.1228226	43.17807155			
3FGL J0528.3+1815	1RXS J052829.6+181657	35.69	1.67	14.66	0.87	82.11289303	18.27306451			
3FGL J0646.4-5452	PMN J0646-5451	190.34	1.46	17.37	0.87	101.6181351	-54.91863251			
3FGL J1959.8-4725	SUMSS J195945-472519	923.79	1.51	94.31	0.87	299.9397253	-47.42901042			
3FGL J2108.6-8619	1RXS J210959.5-861853	91.04	1.65	10.72	0.87	316.9856579	-86.30865936			
3FGL J0039.0-2218	PMN J0039-2220	89.34	1.66	11.61	0.86	9.766909807	-22.31500028			
3FGL J0305.2-1607	PKS 0302-16	147.6	1.6	22.94	0.86	46.29075836	-16.14465396			
3FGL J1040.8+1342	1RXS J104057.7+134216	69.15	1.7	11.06	0.86	160.2594773	13.71799931			
3FGL J2312.9-6923	SUMSS J231347-692332	35.32	1.72	16.13	0.86	348.4026935	-69.39020448			
3FGL J0515.5-0123	NVSS J051536-012427	45.65	1.79	11.76	0.85	78.87455087	-1.419462214			
3FGL J0620.4+2644	RX J0620.6+2644	92.02	1.53	15.1	0.85	95.17349572	26.74390304			
3FGL J0640.0-1252	TXS 0637-128	174.15	1.52	14.44	0.85	100.0137646	-12.90013415			
3FGL J0733.5+5153	NVSS J073326+515355	104.32	1.68	11.18	0.85	113.3491751	51.86215575			
3FGL J1141.2+6805	1RXS J114118.3+680433	140.09	1.68	23.32	0.85	175.3295357	68.0822362			
3FGL J1203.5-3925	PMN J1203-3926	103.2	1.69	18.55	0.85	180.8463393	-39.42493679			
3FGL J1939.6-4925	SUMSS J193946-492539	64.55	1.84	15.92	0.85	294.9560989	-49.46611442			
3FGL J2316.8-5209	SUMSS J231701-521003	37.3	1.78	15.19	0.85	349.2774178	-52.18819115			
3FGL J0132.5-0802	PKS 0130-083	71.92	1.87	12.42	0.84	23.18651181	-8.065356912			
3FGL J0342.6-3006	PKS 0340-302	43.17	1.96	13.37	0.84	55.71024104	-30.11480314			
3FGL J1446.8-1831	NVSS J144644-182922	27.9	1.7	8.69	0.84	221.7533056	-18.51448366			
3FGL J1855.1-6008	PMN J1854-6009	21.39	1.83	6.74	0.84	283.672544	-60.1250475			
3FGL J0043.5-0444	1RXS J004333.7-044257	75.94	1.91	11.93	0.83	10.8838869	-4.721385702			
3FGL J0746.9+8511	NVSS J074715+851208	118.95	1.67	18.34	0.83	117.2491059	85.21791595			
3FGL J0650.5+2055	1RXS J065033.9+205603	206.21	1.72	20.06	0.82	102.6389899	20.92952844			
3FGL J1319.6+7759	NVSS J131921+775823	182.64	1.95	25.12	0.82	199.9478129	78.00731101			
3FGL J1908.8-0130	NVSS J190836-012642	306.43	2.1	35.5	0.82	287.2015241	-1.527053471			
3FGL J2347.9+5436	NVSS J234753+543627	163.04	1.78	21.76	0.82	356.9713227	54.58170077			
3FGL J0204.2+2420	B2 0201+24	27.62	1.7	12.29	0.81	31.09102234	24.27132207			
3FGL J0439.6-3159	1RXS J043931.4-320045	119.86	1.74	24.96	0.81	69.85155048	-32.03484089			
3FGL J1547.1-2801	1RXS J154711.8-280222	96.77	1.77	16.75	0.81	236.8077415	-28.04443418			
3FGL J1612.4-3100	NVSS J161219-305937	494.96	1.86	116.18	0.81	243.1006458	-30.99149787			
3FGL J0030.2-1646	1RXS J003019.6-164723	168.7	1.66	30.18	0.8	7.586848013	-16.82218924			
3FGL J1158.9+0818	RX J1158.8+0819	51.45	1.81	11.81	0.8	179.7088941	8.311328097			
3FGL J1841.2+2910	MG3 J184126+2910	195.91	1.79	22.89	0.8	280.3558247	29.15522239			

Full list of BCU HBL candidates. In Cols. 8, 9, 10 the observabilty at the IACT sites. On the top of the list the candidates with the highest Likelihood (L> 0.89)

3FGL name	TS	Sp.Index	TS_var	L_hbl	RAJ2000	DecJ2000	HESS	VERITAS	MAGIC
3FGL J2142.6-2029	36.07	1.68	8.19	0.914	325.6572	-20.4955	X	X	X
3FGL J2321.6-1619	34.14	1.73	45.13	0.911	350.3966	-16.3171	X	X	X
3FGL J2145.5+1007	52.53	1.70	19.90	0.906	326.3815	10.1296	X	X	X
$3FGL J2300.0+4053	174.53	1.64	6.97	0.904	345.0583	40.8750	X	X	X
3FGL J2224.4+0351	29.5	1.93	9.55	0.89	336.1020	3.8590			
3FGL J1525.8-0834	59.52	1.92	23.26	0.89	231.4700	-8.5790			
3FGL J1619.1+7538	107.12	1.86	14.91	0.88	244.9610	75.6730			
3FGL J0251.1-1829	104.26	1.58	10.20	0.88	42.7970	-18.4860			
3FGL J0020.9+0323	60.66	2.09	22.50	0.88	5.2310	3.3950			
3FGL J0813.5-0356	57.02	1.71	13.15	0.88	123.3870	-3.9390			
3FGL J1234.7-0437	51.54	2.00	29.76	0.87	188.6970	-4.6220			
3FGL J1922.2+2313	80.83	2.22	22.63	0.87	290.5650	23.2260			
3FGL J2043.6+0001	48.48	2.01	24.43	0.87	310.9010	0.0290			
3FGL J0312.7-2222	177.14	1.84	18.27	0.87	48.1760	-22.3710			
3FGL J1513.3-3719	54.74	1.91	18.06	0.87	228.3290	-37.3190			
3FGL J0524.5-6937	94.15	2.05	18.37	0.86	81.1280	-69.6290			
3FGL J1225.4-3448	22.27	1.74	7.01	0.86	186.3560	-34.8070			
3FGL J1222.7+7952	43.83	2.12	14.79	0.86	185.9965	79.8921			
3FGL J2309.0+5428	77.06	1.75	17.68	0.85	347.2520	54.4760			
3FGL J2015.3-1431	17.42	1.81	14.63	0.85	303.8543	-14.5344			
3FGL J2053.9+2922	359.63	1.76	43.97	0.85	313.4760	29.3740			
3FGL J0234.2-0629	90.7	2.00	20.73	0.84	38.5640	-6.1050			
3FGL J1545.0-6641	150.1	1.59	11.85	0.84	236.2650	-66.6997			
3FGL J0731.8-3010	37.07	1.96	12.91	0.84	112.9740	-30.1770			
3FGL J0952.8+0711	50.96	1.91	14.12	0.84	148.2170	7.1990			
3FGL J0527.3+6647	51.89	1.90	14.78	0.83	81.9000	66.7767			
3FGL J1528.1-2904	26.28	1.80	11.72	0.83	232.0360	-29.0680			
3FGL J0049.0+4224	36.95	1.80	16.58	0.82	12.2530	42.4130			
3FGL J1057.6-4051	40.23	1.71	15.54	0.82	164.4090	-40.8620			
3FGL J0928.3-5255	98.75	2.09	26.68	0.8	142.0300	-52.8680			

The 3D plot shows the distribution of HBL candidates against the 3FGL blazar subclasses HBL [blue], IBL [green] , LBL [red].

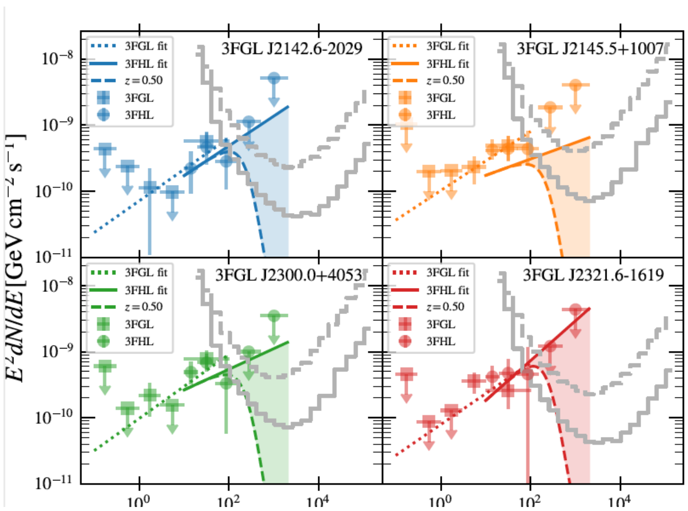
All the candidates lie in the clean HBL area validating the ANN results that classified the target as HBL sources.



TeV candidates

We compare the extrapolated fluxes of the candidates against the sensitivity of present IACTs and the future CTA. We used the Fermi-LAT spectral shape of the sources obtained in the range between 0.1 and 300 GeV using the best-fit model parameters from the LAT 4-year 3FGL Catalogue and particularly we referred to the spectral model that fits the data.

We compare the extrapolated fluxes with the CTA sensitivity for 50 hours (5hours) of observations as a solid (dashed) grey line.
Above a declination of 0 degrees we use the sensitivity of the northern array and the southern array otherwise.
The CTA sensitivity for 5 hours of observations is similar to that of currently operating IACTs for 50 hours of observations except a higher threshold energy of ~ 80 GeV.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3FHL fit
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3FGL
3FHL
3FGL J2142.6-2029
3FGL J2145.5+1007
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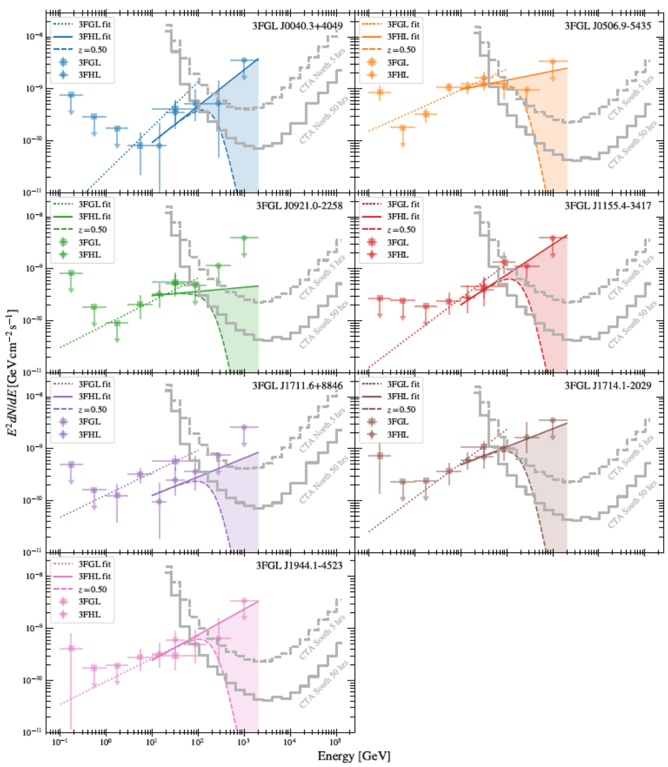
$E^2 dN/dE\,[\mathrm{GeV\,cm^{-2}\,s^{-1}}]$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3FGL J1714.1-2029
3FGL J1944.1-4523
CTA North 5 hrs
CTA North 50 hrs
CTA South 5 hrs
CTA South 50 hrs
$E^2 dN/dE\,[\mathrm{GeV\,cm^{-2}\,s^{-1}}]$
Energy [GeV]