A catalog of new Blazar candidates with Open Universe by High School students

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Abstract. Blazars are active galactic nuclei whose ultra-relativistic jets are co-aligned with the observer direction. They emit throughout the whole e.m. spectrum, from radio waves to VHE gamma rays. Not all blazars are discovered. In this work, we propose a catalog of new highly probable candidates based on the association of HE gamma ray emission and radio, X-ray an optical signatures. The relevance of this work is also that it was performed by four high school students from the Liceo Ugo Morin in Venice, Italy using the open-source platform Open Universe in collaboration with the University of Padova. The framework of the activity is the Italian MIUR PCTO programme. The success of this citizen-science experience and results are hereafter reported and discussed.

Keywords: Citizen Science, Gamma-ray Astronomy, Open Universe, Blazar

1. Introduction

1.1. The Italian PCTO program

The Italian Ministry for education, University and Resarch (MIUR, Ministero Istruzione Università e Ricerca) fosters a program called "Percorsi per le Competenze Trasversali e per l'Orientamento" (PCTO) [1], which stands for "Paths for cross disciplinary skills and orientation". The program aims at making students acquire skills outside the standard educational program. This may happen outside the school walls. Every student of any school must do a minimum of 90 hours of PCTO experience in order to graduate. The

University of Padova has PCTO agreements with several high schools in Italy including the Liceo Scientifico Statale Ugo Morin (LSSUM) in Venice [2]. Within this agreement, a specific program was started with 4 high school students of the 4th year, whose first phase lasted from September 2021 to March 2022, for a total of about 40 h of work for each student, partly at the University premises partly at home.

1.2. The Open Universe project and the `Firmamento` portal

"Open Universe" [3] is an initiative under the auspices of COPUOS (Committee on the Peaceful Uses of Outer Space) with the objective of stimulating a dramatic increase in the availability and usability of space science data, extending the potential of scientific discovery to new participants in all parts of the world and empowering global educational services. Open Universe is now defined in detail under the leadership of the United Nations Office Of Outer Space Affairs (UNOOSA). It is officially funded by Brasil and sees collaboration in many participating Countries. The main software infrastructure was a wide-scope Open Universe portal [4], currently not further developed, and a new modern site, specific for blazar science, called `Firmamento` [5] under development at the Center for Astro, Particle and Planetary Physics of the New York University of Abu Dhabi in the United Arab Emirates. `Firmamento` is also smartphones friendly[6]. In turns, `Firmamento` builds on the experience obtained with the tool `VOU-Blazar` [7] in the previous portal [4].

1.3. Blazars candidates in the Unidentified `Fermi`-LAT 4FGL DR3 catalog

For this work the students started with `Fermi`-LAT data [8]. LAT is a satellite born instrument sensitive to gamma rays in the range $0.1 - 300$ GeV operating since 2008. In its last 4FGL catalog (DR3) [9] there are 6658 sources out of which several hundreds are blazars. These are ultrarelativistc jets of particles and radiation with extremely high fluences, formed at super massive black holes when strongly accreting. Blazars are strong emitters at all wavelengths, from radio to very high energies [10]. Out of all unassociated sources in this catalogue, a selection was done based on spectral hardness and distance from the galactic plane. The students were given a list of 198 unidentified LAT sources as input, selected by spectral hardness and location. Their goal was to find counterparts at other wavelengths and eventually propose an identification.

2. The search for a blazar counterparts

The first step was to verify whether these sources had counterparts in any other wavelength. This check was performed with the Open Universe portal [4]. The first tool used was `VOU-Blazars` (now in `Firmamento`). The instrument takes as input the coordinates of the region and of the uncertainty area that needs to be analyzed and checks for potential associations in more than 70 different catalogs within this area. The association is based on internal criteria (at the moment not tunable by the user)

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that weights the existence of counterparts at other wavelengths and rank them according to relative weights. For example, if both an X- and radio counterparts are found at close distance, the significance of the proposed association is ranked high. The results are show in Figure 1.

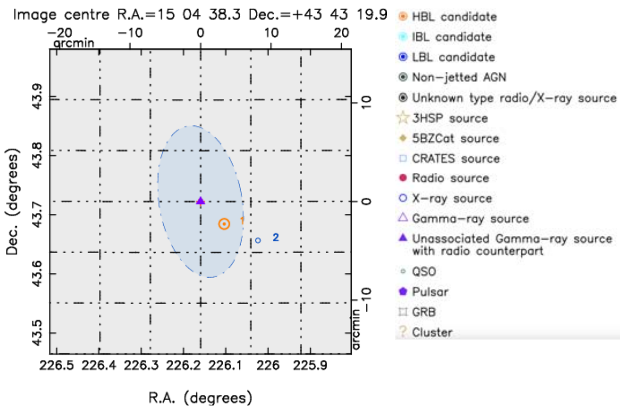

Figure 1. Candidate associations search. The tool find for candidates within the error ellipse of the *Fermi*-LAT candidate (purple triangle) and finds associations that are classified with color-code and size-code markers according to the multi-wavelenghts relations.

In a second step, the students verified each single candidate association one by one. This was done by inserting the candidate coordinates in a second tool called `SSDS Sky survey` (now in `Firmamento`), also from the Open Universe portal [4]. This tool returns a skymap in the optical spectrum around the direction of the candidate, as shown in Figure 2 (left). In a third step, the students used the tool called `VOU-SED` (now in `Firmamento`), that generates the Spectral Energy Distribution (SED), as shown in Figure 2 (right) and a table data file, e.g.:

`1 matched source 0.11633 25.46800 99`

Frequency Hz	nufnu erg/cm2/s	nufnu unc. upper	nufnu unc. lower	start MJD	end MJD	Catalog	Reference
1.400E+09	1.372E-16	1.498E-16	1.246E-16	55000.	55000.	NVSS	Condon et al. 1998, AJ, 115, 1693
2.418E+17	1.185E-12	1.780E-12	5.893E-13	55000.	55000.	XMMSL	Saxton et al. 2008, A&A, 480, 611
2.660E+17	9.824E-13	1.473E-12	4.916E-13	55000.	55000.	XMMSL	Saxton et al. 2008, A&A, 480, 611
1.692E+18	0.000E+00	0.000E+00	0.000E+00	55000.	55000.	XMMSL	Saxton et al. 2008, A&A, 480, 611
4.455E+14	2.257E-13	0.000E+00	0.000E+00	55000.	55000.	GAIA	The Gaia Coll. 2016, A&A, 595, A2
8.328E+14	0.000E+00	0.000E+00	0.000E+00	55000.	55000.	HST	Lasker et al. 2008, AJ, 136, 735
6.813E+14	1.881E-13	2.434E-13	1.453E-13	55000.	55000.	HST	Lasker et al. 2008, AJ, 136, 735
5.451E+14	0.000E+00	0.000E+00	0.000E+00	55000.	55000.	HST	Lasker et al. 2008, AJ, 136, 735
4.684E+14	0.000E+00	0.000E+00	0.000E+00	55000.	55000.	HST	Lasker et al. 2008, AJ, 136, 735
3.795E+14	0.000E+00	0.000E+00	0.000E+00	55000.	55000.	HST	Lasker et al. 2008, AJ, 136, 735
6.233E+14	2.748E-13	2.791E-13	2.706E-13	55000.	55000.	PANSTARRS	Chambers et al. 2016 1612.05560
...							

The students ultimately applied a program called `blast` (Blazar Synchrotron Tool) [11], based on a machine learning algorithm, to estimate the position of the synchrotron peak of a blazar given their SED as a txt file (now automatically computed in `Firmamento`, see Figure 2). This position is important to classify blazars into sub-categories (e.g. Low-Energy peaked, High-Energy peaked etc.)

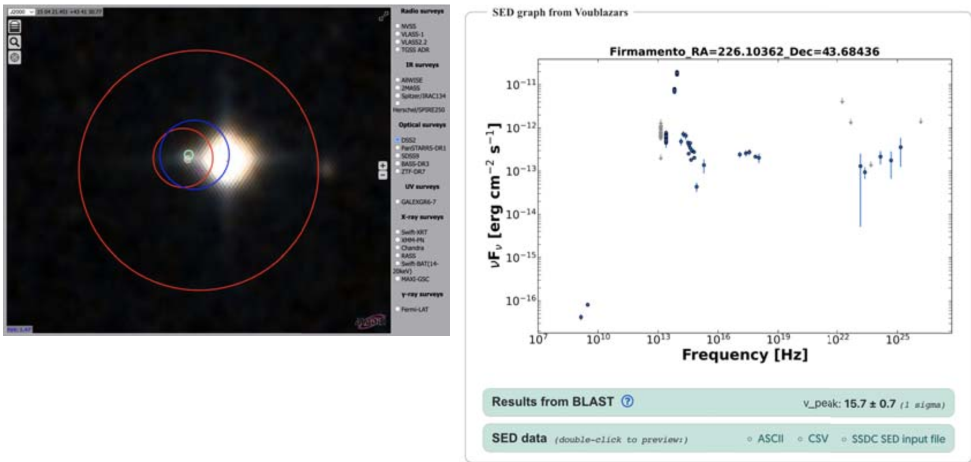

Figure 2. (left) Error circles of the radio (red) and X-ray (blue) catalogue sources around the selected association; (right) The spectral energy distribution of a candidate associated blazar plus the estimated synchrotron peak estimated with `blast` and the link to download data in table format.

3. The catalog of new blazar candidates

We have collected our results in Table 1. The table reports the `Fermi`-LAT 4FGL name and position on the left hand side and on the right hand side some basic information of the best candidate: the catalog ID name, its position, the redshift when available, and the position and uncertainty of the synchrotron peak computed by the `blast` code [11]. The catalog acronym LSSUM stands for Liceo Scientifico Statale Ugo Morin.

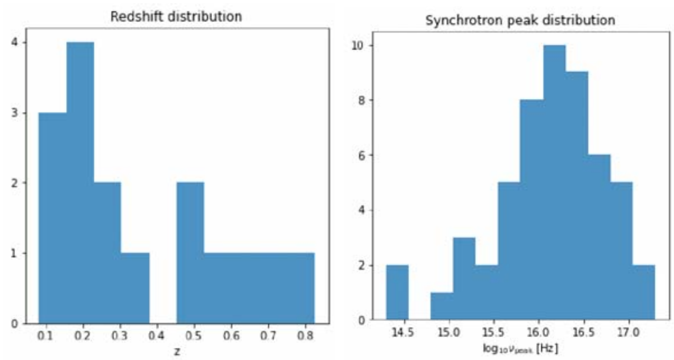

Figure 3. (left) Redshift distribution and (right) Synchrotron Peak Distribution of the LSSUM targets of Table 1.

In Figure 3 we show the redshift and synchrotron peak distribution of the associations. Both makes sense: the redshift distribution peaks at low distances and the synchrotron peak distribution is somewhat symmetrically peaked around 10^{16} Hz, in accord with our cuts in spectral hardness of starting *Fermi*-LAT candidate set.

Fermi-LAT ID	RA	Dec	LSSUM ID	RA	Dec	z	$\log_{10}\nu_{\rm peak}$
4FGL J0000.7+2530	0.188	25.515	LSSUM J000027.9+252805	0.11633	25.4680	0.49	16.6 ±0.5
4FGL J0026.1−0732	6.540	-7.543	LSSUM J002611.6−073115	6.54842	-7.52097	-	16.9 ±0.4
4FGL J0045.8−1324	11.472	-13.403	LSSUM J004602.8−132422	11.51154	-13.4060	-	15.6 ±0.6
4FGL J0055.7+4507	13.940	45.124	LSSUM J005542.7+450701	13.92792	45.11706	-	15.8 ±0.5
4FGL J0152.9−1109	28.237	-11.162	LSSUM J015313.2−110627	28.30487	-11.10753	-	16.4 ±0.4
4FGL J0159.8−2234	29.951	-22.576	LSSUM J015946.9−223246	29.94541	-22.54637	-	16.1 ±0.5
4FGL J0231.0+3505	37.775	35.100	LSSUM J023112.2+350444	37.80078	35.07916	-	17.2 ±0.5
4FGL J0249.2+1652	42.303	16.882	LSSUM J024902.8+165259	42.26183	16.88331	-	16.3 ±0.4
4FGL J0251.1−1830	42.784	-18.509	LSSUM J025111.5−183112	42.79800	-18.52019	-	15.7 ±0.5
4FGL J0357.7−6808	59.440	-68.134	LSSUM J035732.10−680932	59.38733	-68.15911	0.0886	16.1 ±0.4
4FGL J0420.6−4802	65.173	-48.048	LSSUM J042038.7−475703	65.16121	-47.95103	-	16.3 ±0.6
4FGL J0438.0−7329	69.524	-73.485	LSSUM J043837.1−732921	69.65446	-73.48933	0.0948	15.5 ±0.3
4FGL J0539.2−6333	85.055	6.917	LSSUM J053855.9−633239	84.73275	-63.54431	-	14.1 ±1.0
4FGL J0625.5+7029	96.392	70.497	LSSUM J062534.7+702943	96.39471	70.49533	-	16.3 ±0.7
4FGL J0641.4+3349	100.356	33.820	LSSUM J064142.0+334928	100.42501	33.82450	-	14.3 ±0.6
4FGL J0751.2−0029	117.812	-0.488	LSSUM J011119.2−002748	17.830002	-0.463578	-	15.7 ±0.4
4FGL J0800.9+0733	120.226	7.551	LSSUM J080056.5+073235	120.23562	7.54308	-	15.5 ±0.4
4FGL J0815.5+6554	123.880	65.900	LSSUM J081539.8+655004	123.91592	65.83461	-	16.1 ±0.3
4FGL J0838.5+4013	129.629	40.224	LSSUM J083903.1+401545	129.76283	40.26272	0.194	15.7 ±0.4
4FGL J0903.5+4057	135.899	40.962	LSSUM J090314.7+405559	135.81129	40.93325	0.188	16.2 ±0.5
4FGL J0914.5+6845	138.647	68.751	LSSUM J091429.7+684508	138.62379	68.75242	-	15.9 ±0.5
4FGL J0944.6+5729	146.090	-9.192	LSSUM J94432.3+573536	146.13471	57.59336	0.72	16.1 ±0.4
4FGL J1047.2+6740	161.820	67.674	LSSUM J104705.9+673758	161.77458	67.63278	-	16.4 ±0.6
4FGL J1118.1+5857	169.542	58.965	LSSUM J111709.8+585921	169.29063	58.98917	0.0814	15.8 ±0.6
4FGL J1146.0−0638	176.502	-6.638	LSSUM J114600.8−063854	176.50354	-6.64858	-	16.1 ±0.4
4FGL J1155.2−1111	178.820	-11.189	LSSUM J115514.9−111122	178.81192	-11.18958	-	16.6 ±0.5
4FGL J1158.8−1430	179.709	-14.501	LSSUM J115912.6−143154	179.80263	-14.53189	-	17.0 ±0.5
4FGL J1403.7+2429	210.936	24.495	LSSUM J140350.3+243304	210.95954	24.55133	0.343	16.2 ±0.4
4FGL J1409.8+7921	212.464	79.351	LSSUM J141046.4+792412	212.69314	79.40343	-	14.3 ±0.6
4FGL J1441.4−1934	220.350	-19.578	LSSUM J144127.1−193552	220.36650	-19.59789	-	15.7 ±0.5
4FGL J1452.0−4148	223.017	-41.804	LSSUM J145224.6−414948	223.10243	-41.82995	-	15.2 ±0.6
4FGL J1504.6+4343	226.159	43.722	LSSUM J150425.1+434106	226.10468	43.68521	-	15.7 ±0.7
4FGL J1519.7+6727	229.943	67.458	LSSUM J152000.4+672613	230.00179	67.43703	-	15.0 ±0.4
4FGL J1544.9+3218	236.239	32.304	LSSUM J154433.2+322148	236.13829	32.36350	featureless	15.2 ±0.5
4FGL J1554.2+2008	238.553	20.148	LSSUM J155424.1+201125	238.60050	20.19039	0.222	16.9 ±0.8
4FGL J1626.5+6257	246.644	62.959	LSSUM J162646.0+630048	246.69188	63.01350	0.24 (Phot.)	16.8 ±0.5
4FGL J1628.2+4642	247.063	46.715	LSSUM J162755+464249	246.98105	46.71342	0.2135	15.8 ±0.4
4FGL J1658.5+4315	254.646	43.254	LSSUM J165831.5+431615	254.63126	43.27085	0.63 (Phot)	16.0 ±0.5
4FGL J1706.4+6428	256.606	64.475	LSSUM J170623.3+642725	256.59688	64.45706	0.27 (Phot)	15.9 ±0.7
4FGL J1727.1+5955	261.776	59.926	LSSUM J172640.4+595549	261.66833	59.93036	featureless	16.1 ±0.4
4FGL J1923.0−4746	290.752	-47.769	LSSUM J192304.4−474501	290.76829	-47.75053	-	16.7 ±0.5
4FGL J1928.5+5339	292.139	53.653	LSSUM J192833.6+533902	292.14005	53.65058	-	17.3 ±0.4
4FGL J2012.1−5234	303.039	-52.570	LSSUM J201213.7−523251	303.05712	-52.54753	-	16.2 ±0.4
4FGL J2020.7−4536	305.198	-45.614	LSSUM J202022.9−452924	305.09543	-45.49008	-	16.6 ±0.5
4FGL J2022.3+0413	305.598	4.222	LSSUM J202225.1+041235	305.60469	4.209826	-	16.7 ±0.6
4FGL J2028.8−0010	307.215	-0.171	LSSUM J202850.4−000840	307.20998	-0.14451	-	16.3 ±0.5
4FGL J2030.3−5038	307.590	-50.634	LSSUM J203024.0−503413	307.60017	-50.57028	-	16.6 ±0.4
4FGL J2038.7−3655	309.686	-36.925	LSSUM J203839.10−365426	309.66664	-36.90732	-	16.1 ±0.6
4FGL J2142.5−2029	325.642	-20.497	LSSUM J214239.8−202819	325.66575	-20.47197	-	16.4 ±0.4
4FGL J2144.8−1600	326.216	-16.010	LSSUM J214439.1−155931	326.16300	-15.99200	-	16.4 ±0.6
4FGL J2207.1+2222	331.791	22.374	LSSUM J220704.1+222231	331.76713	22.37542	0.557	15.8 ±0.5
4FGL J2217.0−6727	334.255	-67.453	LSSUM J221659.5−672800	334.24813	-67.46672	-	16.4±0.5
4FGL J2237.2−6726	339.304	-67.437	LSSUM J223709.4−672618	339.28917	-67.43861	-	15.9±0.4
4FGL J2237.8+2430	339.458	24.511	LSSUM J223738.2+243256	339.40900	24.54910	0.50	15.9±0.4

Table 1. The preliminary LSSUM (Liceo Scientifico Statale Ugo Morin) catalog of blazar candidates. In the redshift column, "phot" means the redshift is taken from SDSS17 or NED and not from the galaxy spectra, while "featureless" is in case there are no optical lines.

4. Outlooks and Conclusions

Although we regard our associations as highly reliable, Table 1 is only preliminary and incomplete. We plan to re-evaluate the targets by relaxing our criteria on the number of

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Fermi-LAT unassociated sample. After that, our aim is to try and validate as much as possible our candidates. In some cases, we need additional data. We are discussing the possibility to carry out proposal of observation in optical (for redshift estimation) and in X-ray and gamma-ray to validate the inverse Compton peak. We hope our achievements will end in a journal publication.

We close with the students' thoughts:

> *"This PCTO experience has been a fundamental opportunity to grow as persons, it gave us the possibility to see the research environment in close contact and to understand what working at a University really means. Thanks to this occasion we now know that we'd like to have a career as researchers someday."*

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