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 ultrarelativistic 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)
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 shown 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.](image)

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.:

| Frequency (Hz) | Source | mJy | mJy | mJy | mJy | 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 |
| 2.618E+17     | 1.180E-12 | 1.789E-12 | 5.893E-13 | 55000. | 55000. | XMMSS       | Saxton et al. 2008, A&A, 480, 611 |
| 2.660E+17     | 9.624E-13 | 1.473E-12 | 4.916E-13 | 55000. | 55000. | XMMSS       | Saxton et al. 2008, A&A, 480, 611 |
| 1.692E+18     | 0.000E+00 | 0.000E+00 | 0.000E+00 | 55000. | 55000. | GAIA        | The Gaia Coll. 2016, A&A, 595, 2A |
| 4.558E+14     | 2.257E-13 | 0.000E+00 | 0.000E+00 | 55000. | 55000. | HST         | Lasker et al. 2008, AJ, 136, 735 |
| 6.918E+14     | 1.818E-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 1612.0560 |

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 subcategories (e.g. Low-Energy peaked, High-Energy peaked etc.)
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.

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.
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 SDSS17 or NED targets.
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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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