Exploring Blazar “PKS 1440-389”: Insights into Gamma-Ray Emissions and Astrophysical Phenomena

Andrea Cappella, Elisa Di Cerbo, Leonardo Massaro

Istituto d’Istruzione Superiore Telesi@, Telese Terme (BN), Italy

dicerbo.e.studente@iistelese.it

This article discusses the study of the blazar “J1443.9-3908” (“PKS 1440-389”) through hands-on activities and advanced data analysis, conducted by high school students in collaboration with INFN and OCRA. The research involved collecting data from TeVCat and Firmamento, analyzing the blazar's energy flux and light curve, highlighting the peaks of synchrotron and inverse compton, together with the variations of the emissions in time. The study highlights the integration of experimental methods and computational tools in high-energy astrophysics education.

1. Introduction

Cosmic rays represent astroparticle physics’ object of study, the field of the subject with the aim of elaborating a model of the universe through the particles coming from space, the so-called messengers. It is pivotal to analyze them because, originating from high-energy sources (galactic ones such as supernovae, pulsars and quasars and extra-galactic ones as clusters and starbursts), they suffer from modifications in their path due to the interactions with other cosmic particles and electromagnetic fields, giving essential information about the climate, the Earth’s magnetic field and the Sun [1].

The below mentioned activities have been performed by high school students thanks to the collaboration with INFN (Istituto Nazionale di Fisica Nucleare) and OCRA (Outreach Cosmic Rays Activities). The rays which OCRA is particularly concerned about are generated by blazars, a specific type of AGN (Active Galactic Nuclei), powered by supermassive black holes. They produce relativistic jets of high-energy particles which emit on all frequencies, pointing directly toward Earth: these jets emit gamma rays, making blazars the brightest known extragalactic sources in the gamma-ray sky. The objective of the research is to study blazars: each group of students has been assigned a source in order to analyze the already existing papers, collect information about the morphology and the position of the blazar and compare the charts obtained with data offered by the websites TeVCat and Firmamento.

The blazar studied in this paper is named “J1443.9-3908”. An 8ks exposure with the Swift observatory of “PKS 1440-389” (blazar’s common identification) was obtained on April 29 in 2012 [2], following the H.E.S.S. (from the name of the Austrian physician Victor Hess, who received the Nobel in 1946 for having discovered a radiation external to the Earth) detection of very high energy gamma-ray emission in the direction of this BL Lac object [3]. In June 2015, this source was selected as the target for H.E.S.S. based on its high-energy gamma-ray properties measured by Fermi-LAT [4]. The extrapolation of this bright, hard-spectrum gamma-ray blazar into the VHE regime made a detection on a relatively short time scale very likely, despite its uncertain redshift: this parameter, which offers information about the distance of the source and the direction of its movement, is not known relatively to the analyzed blazar.

1.1 Start of operations

The activity began with a treasure hunt, “Hunting for gamma rays”, in which students were divided into groups and challenged to find OCRA’s stands all around Città della Scienza, in Naples. At the stand, they were taught information about the construction and classification of some telescopes, together with their location and components, knowledge that will have been object of some following questions by the experts: after the right answer, students were given a paper letter, to complete a final word that will have led them to victory. The winning team was offered an experience with augmented reality viewers, to experiment the view of astronomers in space and try to pick objects with their pliers.

Then, on the occasion of the International Day of Cosmic Rays [5], the students were invited to the Department of Physics at Monte Sant’Angelo, in Naples, where they learnt how to use CRC (Cosmic Ray Cube), counting the number of rays arrived to the device, in relation to the inclination of the same; the key observations were:

- the quantity of rays is maximum with an inclination of 90° among the chosen face of the cube and the direction of the jet of particles, because the path is the shortest one;
- the quantity decreases when inclining the telescope, because the path to be taken by the rays is longer, and a smaller number of them can resist the impact with the atmosphere.

2. Research methods

The procedure started searching information about the assigned blazar: after having analyzed the already collected works in literature describing the history and the importance of the source for the astroparticle physics’s research, thanks to the bibliography offered by the software TeVCat 2.0 [6], the students continued using the latter to pick the notions regarding position, distance, morphology and flux of the blazar. The position is identified through the parameters of latitude and longitude; the distance through the redshift, a value with which deducting the direction of the source’s movement: since a removal causes a shift to red frequencies and an approach to blue ones, from the number identifying this value scientists deduct the distance of the blazar in the passing years and centuries. Moreover, the website states whether the source is extended or not, and contains information about the variability and the energy of its flux in relation to the Crab Nebula (a supernova remnant visible in the constellation of Taurus, first observed in 1054 and discovered in 1731: it is now more than six light years wide and used to calibrate telescopes).

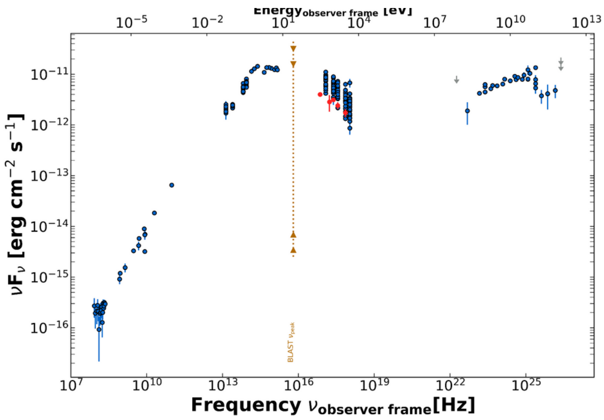
Then, the researchers showed students another software, Firmamento [7], with the aim of interactively exploring and analyzing data: providing a comprehensive catalogue of cosmic ray events detected by various instruments, it also includes information about their properties and origins. In order to obtain the mentioned information, in the section “High-energy catalogs” choose “Fermi 4FGL-DR4” and write the name of the source, in the studied case “J1443.9-3908”; then, download SED (Spectral Energy Distribution) Data. The data are necessary for the generation of a chart about the frequency in relation to the energy of the emissions: in particular, it highlights the synchrotron peak and the inverse compton one; the first is about the synchrotron radiation, an electromagnetic radiation emitted by charged particles circulating in a magnetic field, while the second about a scattering effect in which ultra energetic electrons collide with lower frequency photons[8].

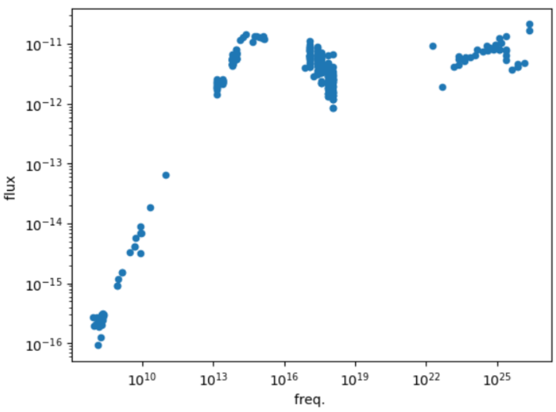
Having obtained the data relating to the spectral energy distribution, the students saved it in a CSV file (Comma-Separated Values), specifically used to import or export data tables maintaining the tabular form to proceed to the next phase of the analysis. It employs Google Colab, a hosted Jupyter Notebook that makes it possible to harness the full power of popular Python libraries to analyze and visualize data. For the described project, it is used to organize a chart of the energy and the frequency of the blazar, similar to that provided by Firmamento: after having apprehended the functioning of the system, students have imported the saved .csv file and ordered the programme to read the information contained in it, thus leading to the generation of a three-entry graph (frequency, flux and scatter).

This preliminary analysis facilitates the classification of the blazar; however, a thorough understanding necessitates an examination not only of the particle flux across various frequencies but also of its temporal variations [9]. Blazars are inherently dynamic and exhibit significant variability, often linked to extreme astrophysical phenomena and observable through their light curves.

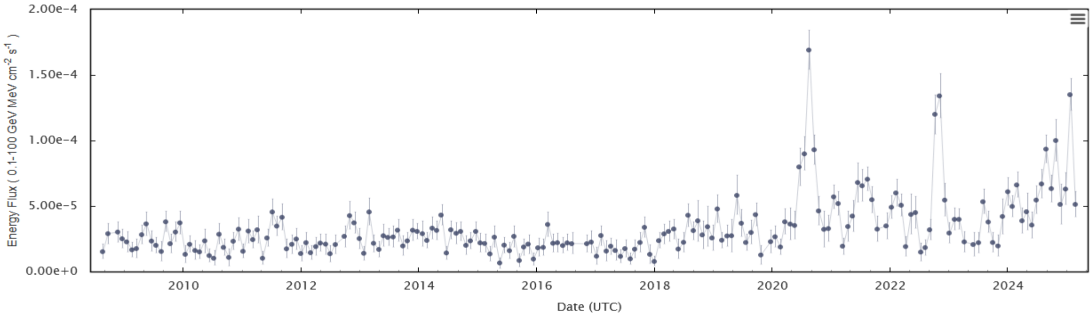
3. Results

The studied blazar “J1443.9-3908” has 325.6528 degrees of longitude and 18.7153 of latitude; an uncertain redshift, estimated at about 0.1385 ± 0.0005; it is neither extended nor variable, and its emissions’ flux is 5400 in relation to the ones from Crab Nebula. This obtained redshift value means the wavelength of light from the object is 13.85% longer than it would be if the object were not moving away from us: since it is relatively low, it means the source is moving slowly in getting away from the place of observations.





These are the charts obtained, respectively, from Firmamento and Colab, of the analyzed blazar. They are perfectly superimposable, respecting both the synchrotron peak and the inverse compton one, thus demonstrating the reliability of the collected data and the analysis made by students. The blazar object of study has the peak of the synchrotron, in relation to the powers of 10, in the order of 10 for energy [eV], 10^{-11} for flux [erg cm^-2 s^-1] and 10^{16} for frequency [Hz], while the inverse compton one is observable in the orders of 10^{11} for energy [eV], 10^{-11} for flux [erg cm^-2 s^-1] and 10^{25} for frequency [Hz].



Data to analyze temporal variations are offered by the website Fermi Light Curve Repository: by inputting the object's name in the "keywords" field and selecting the appropriate observation period in the "source ID" section, the relevant data can be retrieved. Using Colab, it is possible to subsequently generate visualizations of the light curve, employing a method analogous to that used in Spectral Energy Distribution (SED) analysis. This approach allows for a detailed exploration of the physical properties and temporal evolution of blazars, thereby enhancing a deeper understanding of their nature and emission mechanisms. The light curve of the analyzed source (representing energy flux variations in time), observed in the time period 2010-2024, features three important peaks in the matter of energy flux, respectively in the years 2020-2022, 2022-2024 and 2024-2025, representing significant variations in the speed of the jet's expansion. These changes also give information about the blazar's behavior, the jet's structure, the energy distribution and the activity of the super massive central black hole.

4. Conclusion and final remarks

The experimental approach described in this article highlights the importance of integrating various detection methods, computational tools, and data analysis techniques in the study of high-energy astrophysical objects like the blazar "PKS 1440-389". Through the use of muon detection with the Cosmic Rays Cube, modeling with TeVCat, Firmamento and Fermi Light Curve Repository, and custom analysis with Colab, students and researchers can gain a comprehensive understanding of the mechanisms at play in these energetic phenomena. The experience of working with these tools not only deepens knowledge about the specific behavior of "PKS 1440-389", but also enhances the overall understanding of astrophysical research and the techniques used in modern astronomy. This study serves as a valuable learning experience, demonstrating the intersection of theory and practice in the field of high-energy astrophysics.

References

[1] https://web.infn.it/OCRA/, https://web.infn.it/OCRA/cosa-sono-i-raggi-cosmici/
[2] https://ui.adsabs.harvard.edu/abs/2012ATel.4098....1H/abstract
[3] https://ui.adsabs.harvard.edu/abs/2020MNRAS.494.5590A/abstract
[4] https://ui.adsabs.harvard.edu/abs/2015ICRC...34..862P/abstract
[5] https://agenda.infn.it/event/44324/
[6] https://tevcat2.tevcat.org/
[7] https://firmamento.nyuad.nyu.edu/data_access
[8] https://www.roma1.infn.it/exp/ams/LezioniAP/2010/AP_lez8_2010.pdf
[9] https://fermi.gsfc.nasa.gov/ssc/data/access/lat/LightCurveRepository/