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High Energy Messengers: Gamma-rays and muons for citizen research

Antonio Iuliano
(INFN Sezione di Napoli)
on behalf of the INFN-OCRA Collaboration

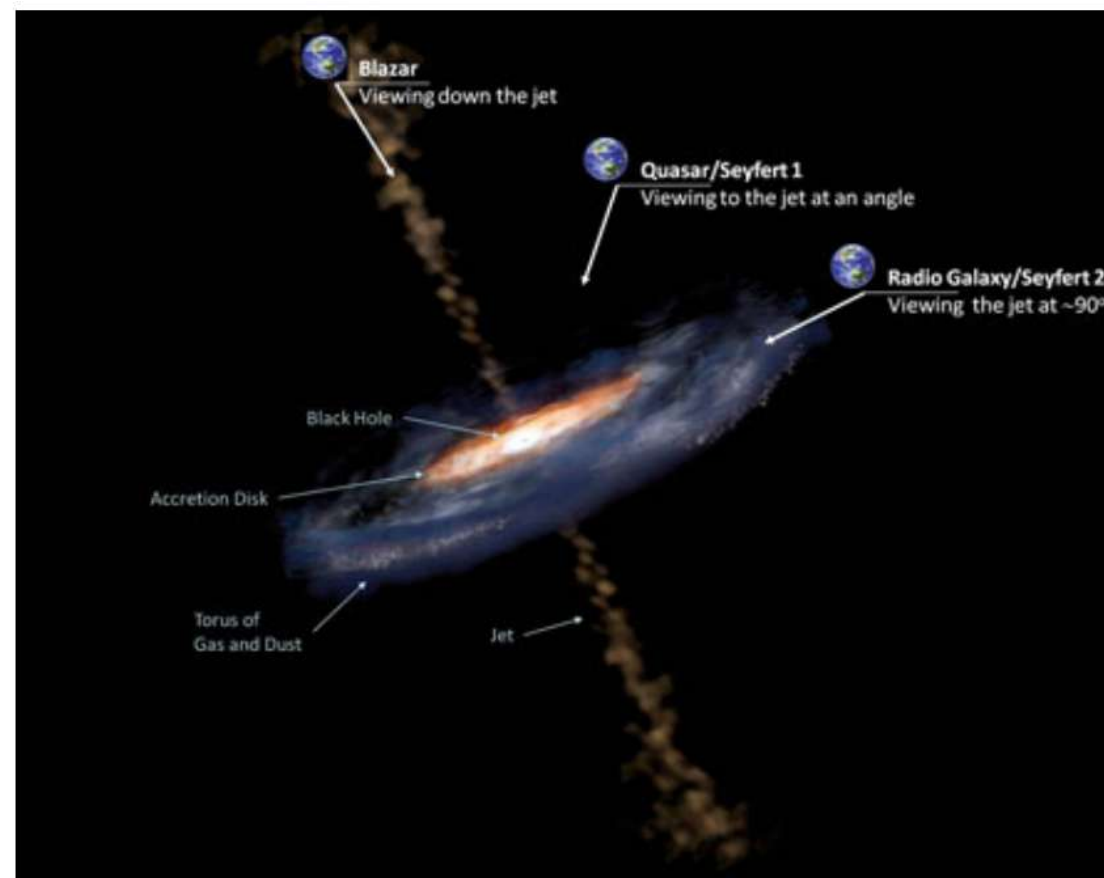


10 June 2025

ACME Multimessenger Citizen Science:
Training Event for Amateur Astronomers

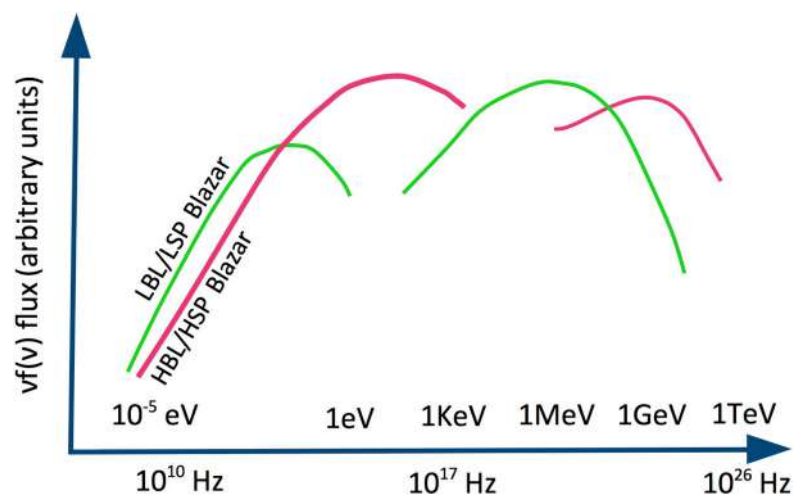
Introduction

- Blazars: Active Galactic Nuclei (AGN), with the jet direction closely aligned to the line of sight of the observer
- Emission over a wide range of wavelengths, from radio-waves to gamma-rays
- Important targets for multiwavelength observations, and theoretical modeling of their spectrum distributions

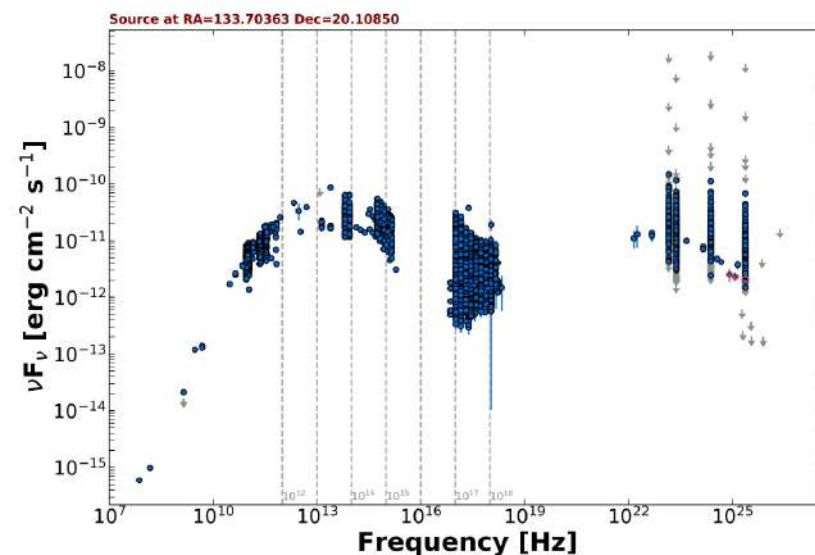


Spectrum Energy Distribution (SED)

- Common representation of the source flux at different frequencies
- Presence of two peaks: synchrotron emission and Inverse Compton (IC)
- First peak used for blazar classification, Low or High Synchrotron peaked



Typical Blazar SEDs
from VOU-Blazars paper (Chang+19)



Example SED for a source

Search for blazars and retrieve data with VOU-Blazars

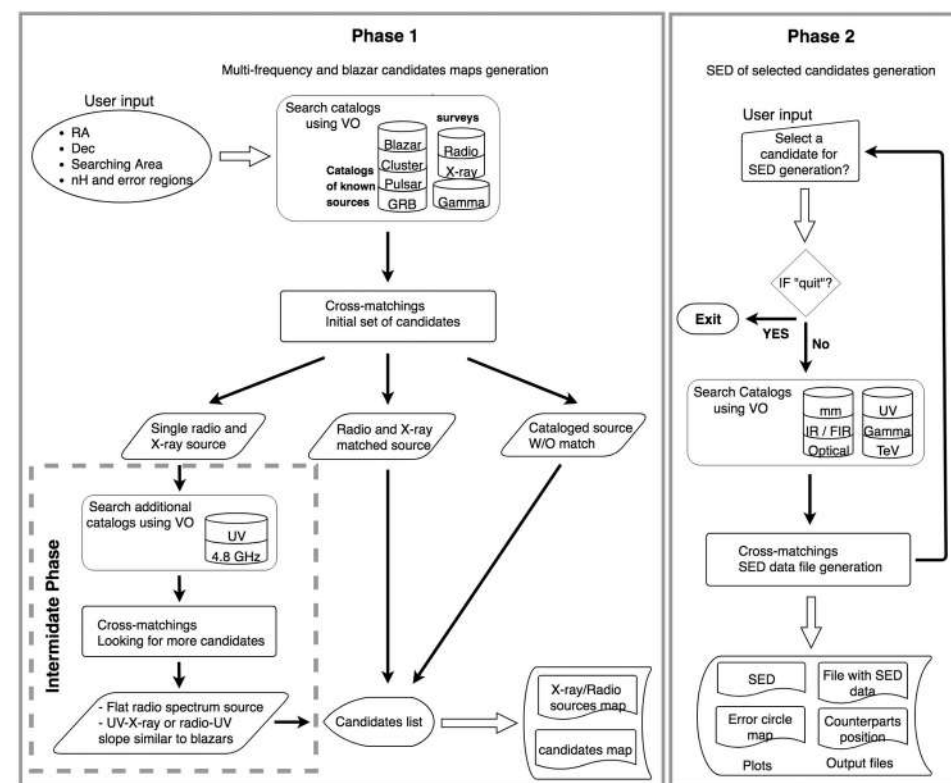
Developed in the framework of Open Universe, based on Virtual Observatory (VO) protocols

Two main phases:

1. Identify blazar candidates within searched area;
2. Build Spectral Energy Distribution (SED) data for a given candidate;

If source is already known, phase 1 can be skipped

Astronomy and Computing, 2020, 30, 100350





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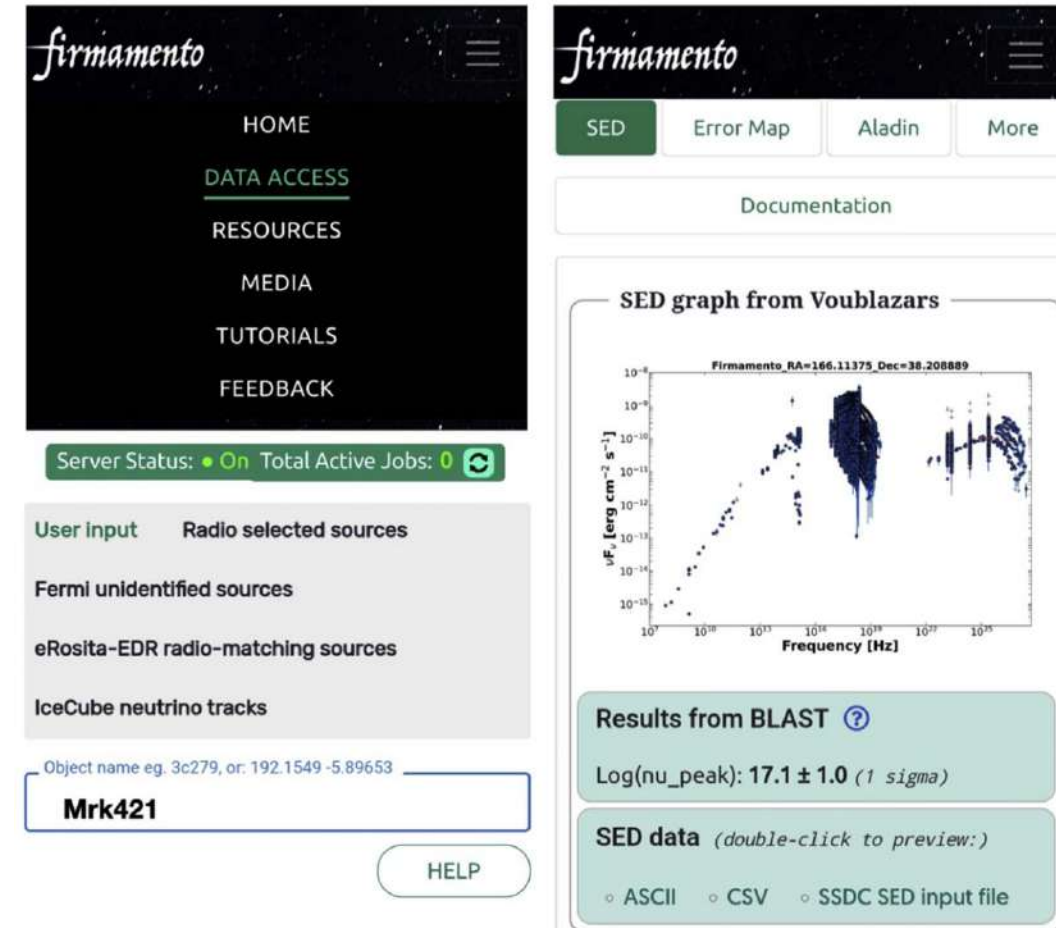
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The Firmamento Platform

- Web tool with an user-friendly interface suited to both PC and mobile phones
- Available freely on:
<https://firmamento.hosting.nyu.edu>
- Accesses data from catalog at all wavelengths, in order to obtain SED distribution
- Resulting file can be used as input for fitting and extrapolation to TeV emission

Tripathi et al. 2024, AJ 167 116



Usage of the Firmamento Platform - source selection

- Can be provided either as a CSV input file, or selected from available catalogs
- Again, if FOV is not provided it will skip the search phase
- Once a source is processed, is saved in the Firmamento server and can be freely immediately retrieved by anyone

☐ TevCat Blazars
 ☐ LHAASO
 ☒ Fermi 4FGL-DR4
 ☐ Fermi 1FLT
 ☐ Fermi 1FLE
 ☐ IceCube Tracks
 ☐ AGILE 2AGL

Go to row number.

4FGL J0232.8+2018

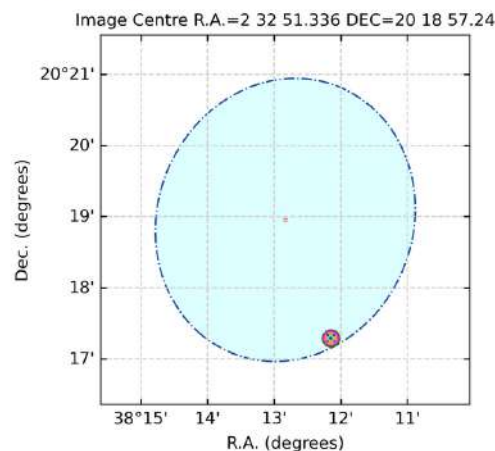
#	name	ra	dec	fov	major	minor	angle	pick
665	4FGL J0232.8+2018	38.2139	20.3159	2.597	1.998	1.812	-37.6	pick
666	4FGL J0232.9+2608	38.2481	26.137	3.401	2.616	2.484	-53.8	pick
667	4FGL J0233.0+3740	38.2714	37.6825	4.54	3.492	2.646	3.2	pick
668	4FGL J0233.5+0654	38.3857	6.9083	3.83	2.946	2.502	-12	pick
669	4FGL J0233.7-2423	38.4496	-24.3953	7.246	5.574	4.908	72.4	pick
670	4FGL J0233.9+8041	38.4987	80.6948	4.298	3.306	2.646	-26.7	pick
671	4FGL J0234.3-0628	38.5831	-6.4818	3.752	2.886	2.64	-58.7	pick
672	4FGL J0235.3+5650	38.8479	56.8478	5.873	4.518	4.254	17.4	pick
673	4FGL J0235.6-2939	38.9008	-29.6517	3.799	2.922	2.82	-0.8	pick
674	4FGL J0236.8-6136	39.2021	-61.6106	2.122	1.632	1.542	29.7	pick

Usage of the Firmamento Platform - error region map

- It employs VOU-Blazars for error map and SED production
- Interfaced with Aladin for visualization
- Peak frequency provided with a **BLAST** fit (Glauch et al. 2022)

665. Source name: 4FGL J0232.8+2018

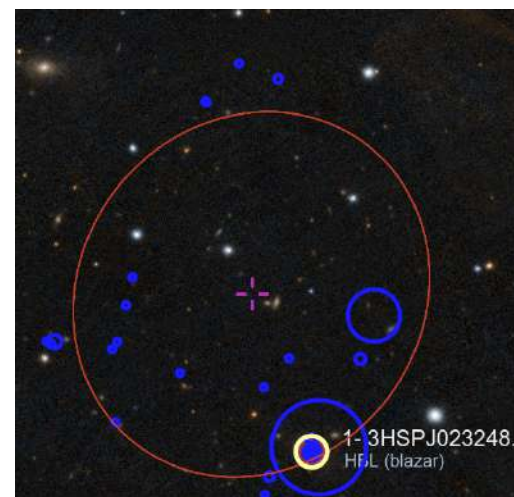
Candidates Image from voublazar



Last run date:
2025-05-06

[Candidate legend >>](#)

[Aladin error region legend >>](#)



Legend

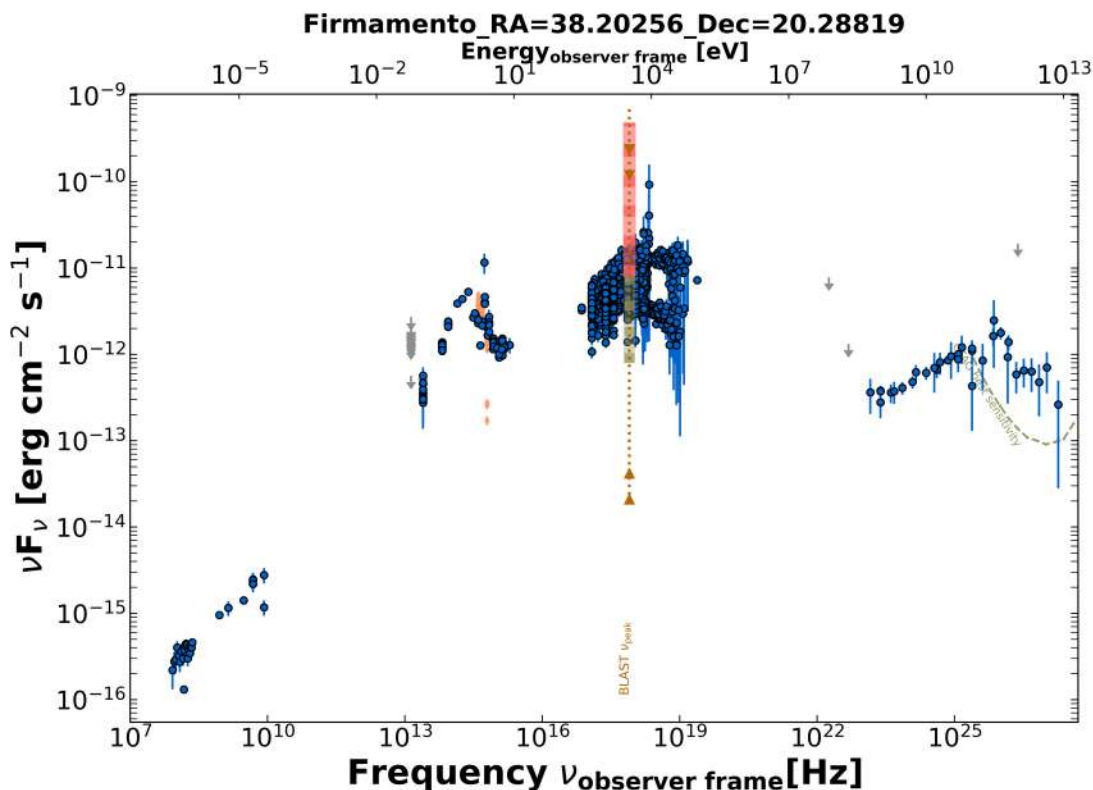
- General X-ray error circle
- eRASS1 X-ray error circle
- Gamma-ray error circle/ellipse
- Radio error circle

List of candidates found. Please pick one.

#	name	ra	dec	possible SED type	redshift	pick
1	3HSPJ023248.6+201717	38.20256	20.28819	HBL (blazar)	0.139	pick

Usage of the Firmamento Platform - SED production

- Peak frequency provided with a **BLAST** fit (Glauch et al. 2022)
- Recently added various options to compare SED with various templates and study detectability



☐ Add luminosity axis ☐ Add ZTF data ☐ Add CTAO Sensitivity

Templates

☐ Blue Bump ☐ Giant elliptical ☐ 3C279 (LBL) ☐ MKN501 (HBL)
☐ PKS2155S (HBL) ☐ TXS0506+056 (IBL)

Get more info

☐ VHE Detectability

Refresh SED

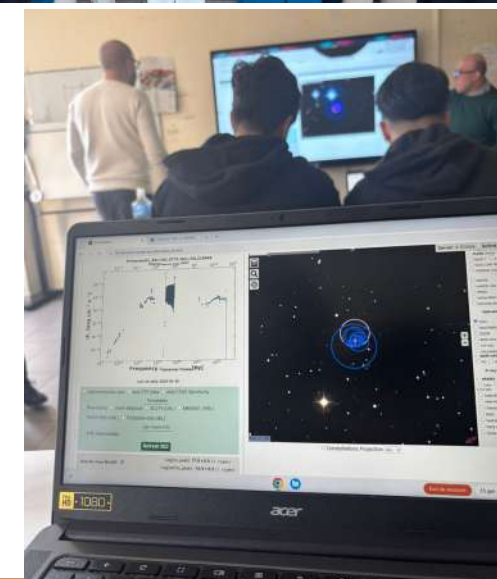
Results from BLAST ?

Log(ν_{peak}): 17.9 ± 0.5 (1 sigma)

Log($\nu F_{\nu_{\text{peak}}}$): -11.3 ± 0.3 (1 sigma)

Firmamento application to outreach

- Catalog of blazars realized with Firmamento by high school students:
<https://iopscience.iop.org/article/10.1088/1742-6596/2429/1/012045/pdf>
- Course for high school teachers held at INFN Padova, encouraging the development of new pathways for introducing gamma ray astronomy observations in their curricula
- This year in Naples, multiple PCTO classes involved in activities with both Firmamento and Cosmic Rays Cube detectors
- Using Google Colab and Jupyter notebooks online for teaching the students how to inspect and plot data

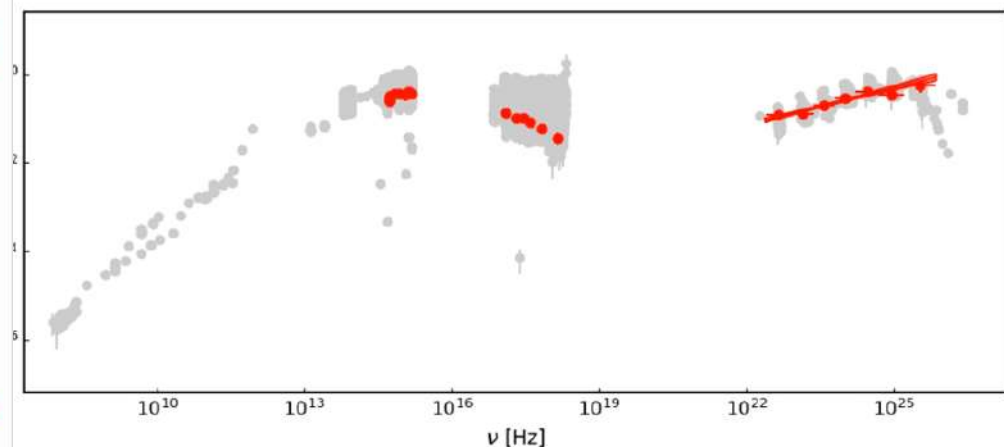
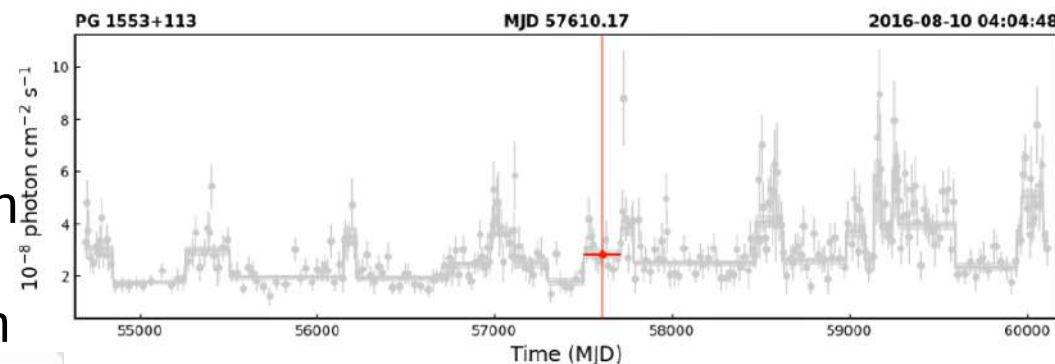


The Markarian Multiwavelength data center

- A web platform for comprehensive blazar research
<https://mmdc.am/>
- From the same group of Firmamento, allows to perform analysis of the retrieved blazar SED
- Simple and effective visualization of blazar variability with an animated Light Curve
- Data fit to model parameters by Machine Learning algorithm

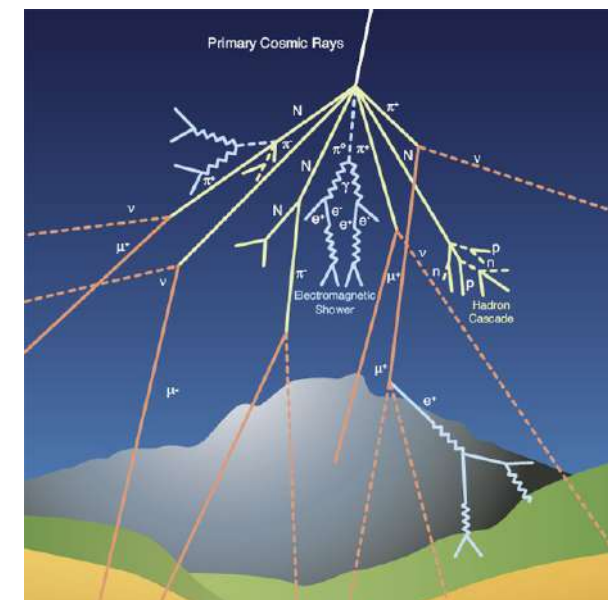


SED SED/LC ANIMATION ALADIN RELATED ARTICLES



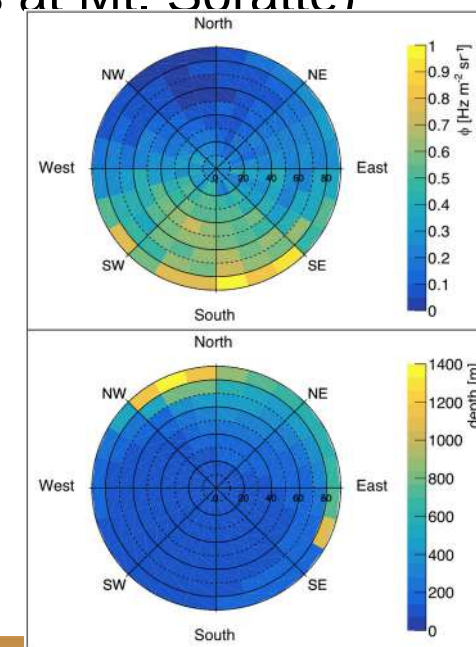
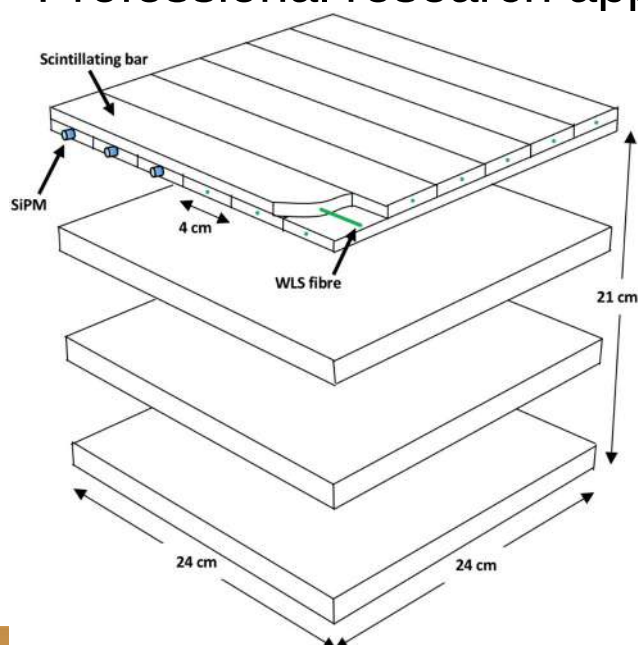
Cosmic Rays and citizen research

- The study of cosmic rays has been at the origin of Modern Particle Physics
- Charged particles (mostly protons) interacting with the Earth atmosphere leading to shower of particles
- Penetrating and long lived muons reaching the ground level detectors
- Great recent interest for citizen research contribution, due to muons:
 - Continuously reaching us everywhere
 - Relatively easy to detect (research project involving even mobile phones), <https://www2.wipac.wisc.edu/deco/project>
 - Physics interest in the variability of the cosmic ray flux



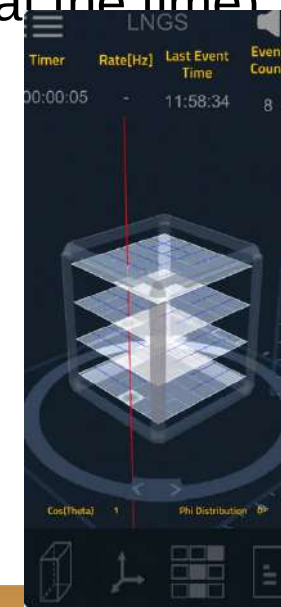
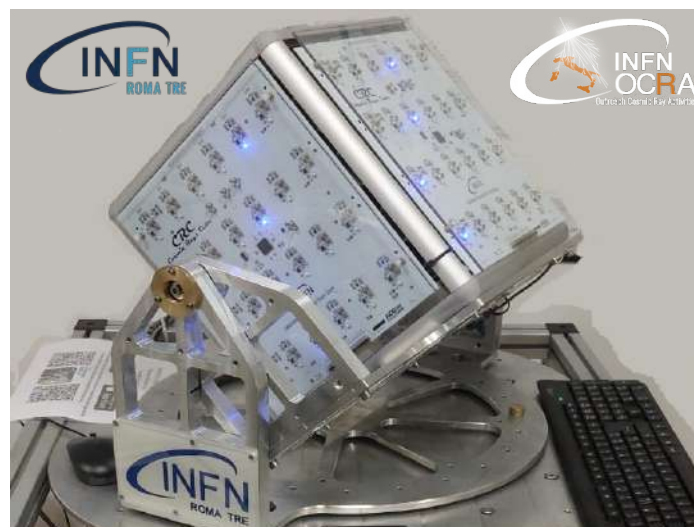
The Cosmic Rays Cube Network

- Compact and portable muon telescope designed by INFN – LNGS (Laboratori Nazionali del Gran Sasso)
- Based on layers of plastic scintillators, highlight muon trajectory in both coordinate with optical LED
- Suited for public events, both high school education and outreach for the general public
- Design of a user-friendly interface for detector assembly and customization of its trigger options
- Professional research applications such as muon radiography (measurements at Mt. Soratte)



The Cosmic Rays Live Application

- Cosmic Rays Cube in real time data available to everyone online
- More than 20 detectors registered in the network
- Mobile phone applications to select the location of the detectors, inspect tracks and download tables
- Available to both Android and iOS devices, as well as Linux and Windows clients
- New update currently in test phase: remote rotation of CRC detectors mounted to electronic supports, to let the user choose its zenith angle freely (only allowing one control for each telescope at the time)



Quick starts to Cosmic Rays Live

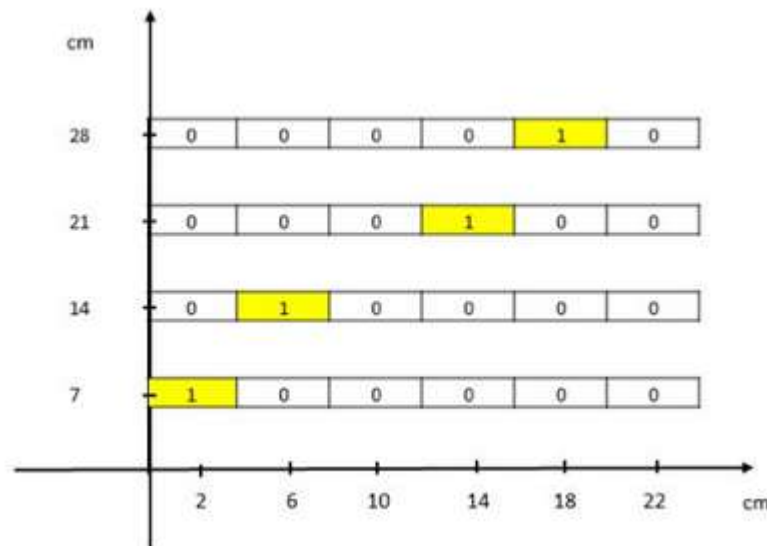
- Download the app on your mobile phone
- Go to Live Event and choose the site of your preference (LNGS is usually online continuously)
- Inspect the data tracks with the different panels at the bottom
- Go to SHARE/SAVE DATA option to retrieve the output file



Data format and analysis

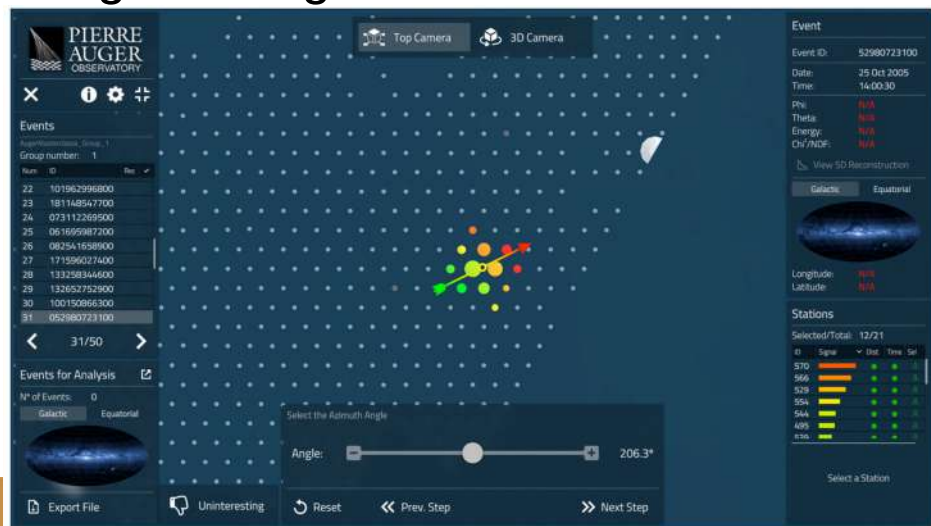
- Each event provides, in hexadecimal, the information of the triggered bars in the two planes
- Example of data conversion and visualization available in this Google Colab notebook:
<https://colab.research.google.com/drive/14vI10tnXFD4i2vImmAEE029m1vDxYe3hV?usp=sharing>
- Contribute to it yourself by collecting and comparing data at different times and in different conditions

```
15:59 04-22-2020 15:33-37.txt
1249 03010901 02030101
1250 01010202 20202020
1254 02020201 02041020
1255 01020204 04020101
1256 0102040C 01010204
1257 02020408 01040820
1258 01010204 01010101
1259 08102020 20202020
1260 01010301 20201010
1261 01010101 02020404
1262 02020202 10101020
1263 10102020 10101020
1264 0E253D34 053B3D3B
1265 01010102 20202020
1266 01010101 20202020
1267 10101020 04040201
1268 05030202 20301030
1269 20180403 01030303
1270 10102020 20202020
1271 01040830 10080402
1272 01010204 01020408
1273 02020202 01010204
1274 02041828 20301010
1275 20080401 08080808
1276 10101010 20202020
1277 03141203 22011210
```



Conclusions

- The INFN OCRA (Outreach Cosmic Rays Activities) has developed programs regarding both gamma-rays and charged cosmic rays
- Even if initially designed for outreach/education, they can be employed by a wider community both in professional research and citizen research application
- Due to time constraints, not all activities could be covered. Please feel free to have a look at:
 - The AUGER Masterclass software experience for cosmic rays extreme high energy data analysis;
 - The Toledo telescope, similar to the CRC with a larger number of planes in Naples subway (currently being also registered in the CRC network)





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Thank you for your attention

