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INFN

Blazar Spectral Energy Distributions with Firmamento web tool

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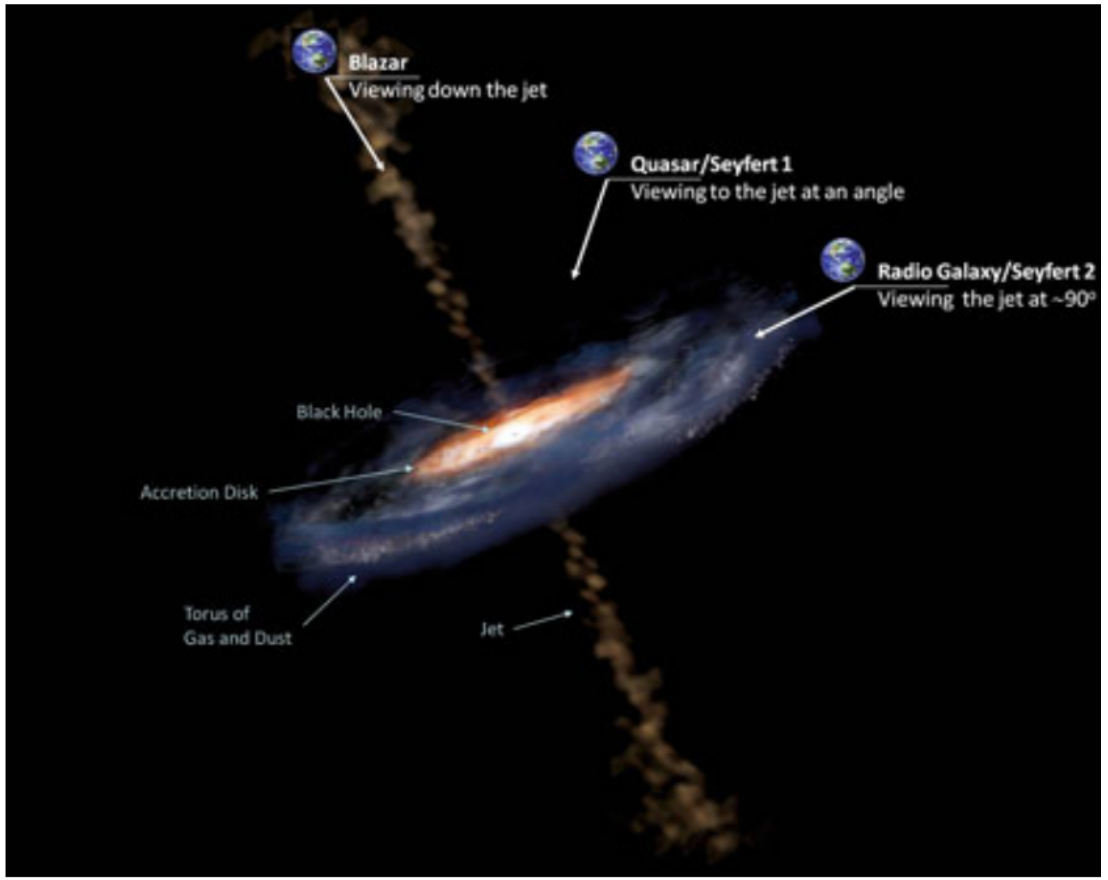
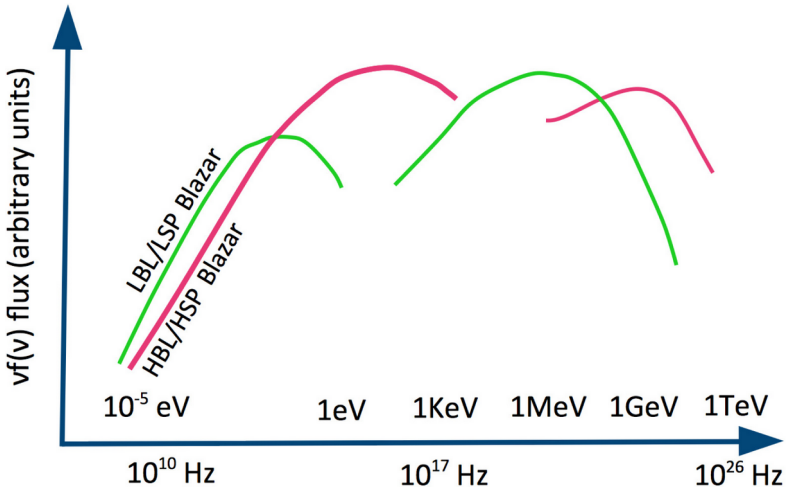
Introduction

- 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

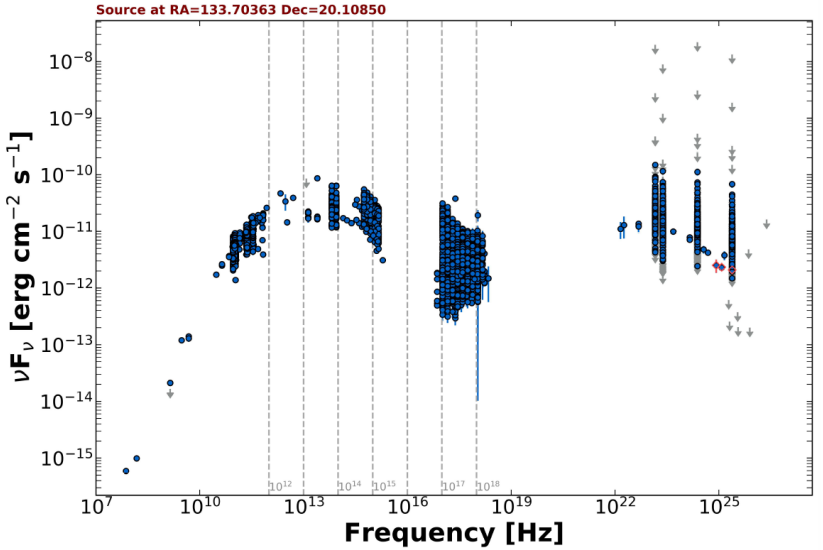


Spectrum Energy Distribution (SED)

- 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

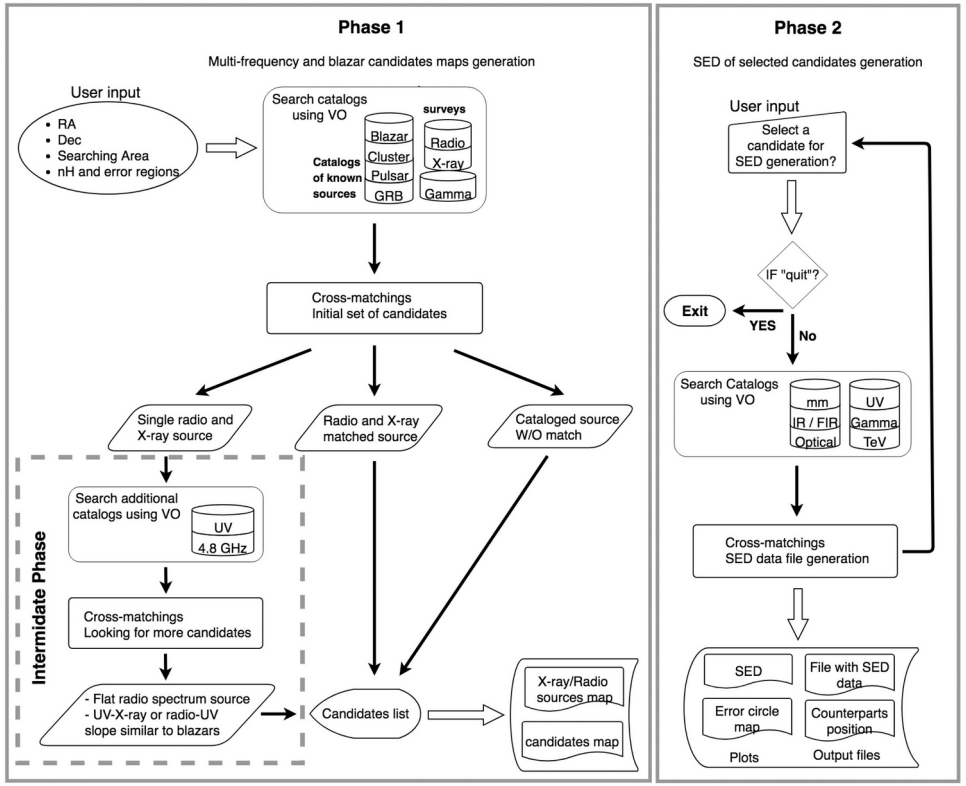
Developed in the framework of Open Universe, based on Virtual Observatory (VO) protocols

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

Using VOU-Blazars locally in your computer

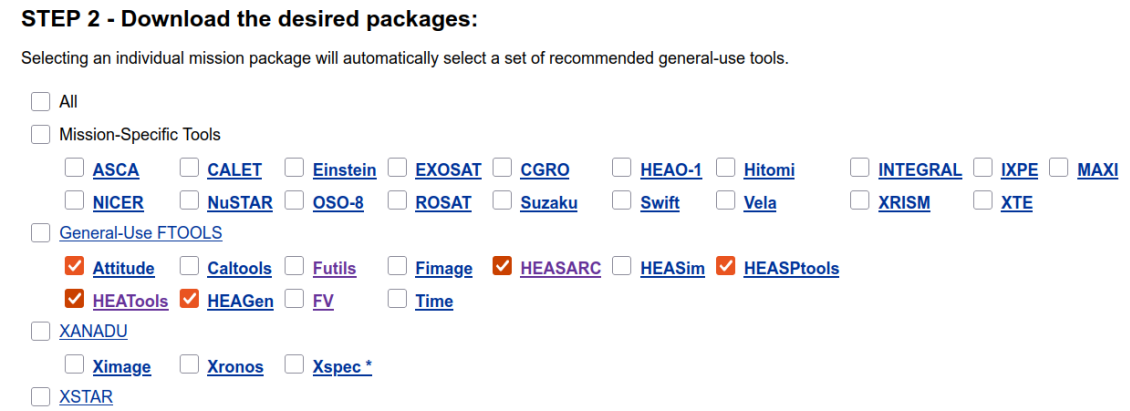
- Open-source, with source code in GitHub repository:
  https://github.com/ecylchang/VOU_Blazars
- List of catalogs provided as links to conesearch services
- Code in Fortran with a Python main script interface
- Example:
  - ./bin/vou-blazars-hybrid.sh --ra 38.2139 --dec 20.3159 --FOV 5.0

VOU-Blazars local installation - requirements

- **Not required for today hands-on** (we will directly use the web tool)
- Listing here for your (and mine) future convenience if you would like to try it yourself

Global libraries:

- PGPlot5 for Fortran compilation (sudo apt-get install pgplot5 on Ubuntu)
- Anaconda/Miniconda to setup your environment
- Heasoft (optional) for automatic nH computation (https://heasarc.gsfc.nasa.gov/lheasoft/download.html)
  - Select “HEASARC” as desired package, the webpage will check all other required packages automatically



Instructions for VOU-Blazars installation

Set up Conda environment:

- conda create -n eada_tutorial python=3.10 pip ipython requests
- conda activate eada_tutorial

Eada package for conesearch according to Virtual Observatory services

- git clone https://github.com/antonioiuliano2/eada.git (my fork of https://github.com/chbrandt/eada)
- cd eada
- python setup.py install
- cd ..

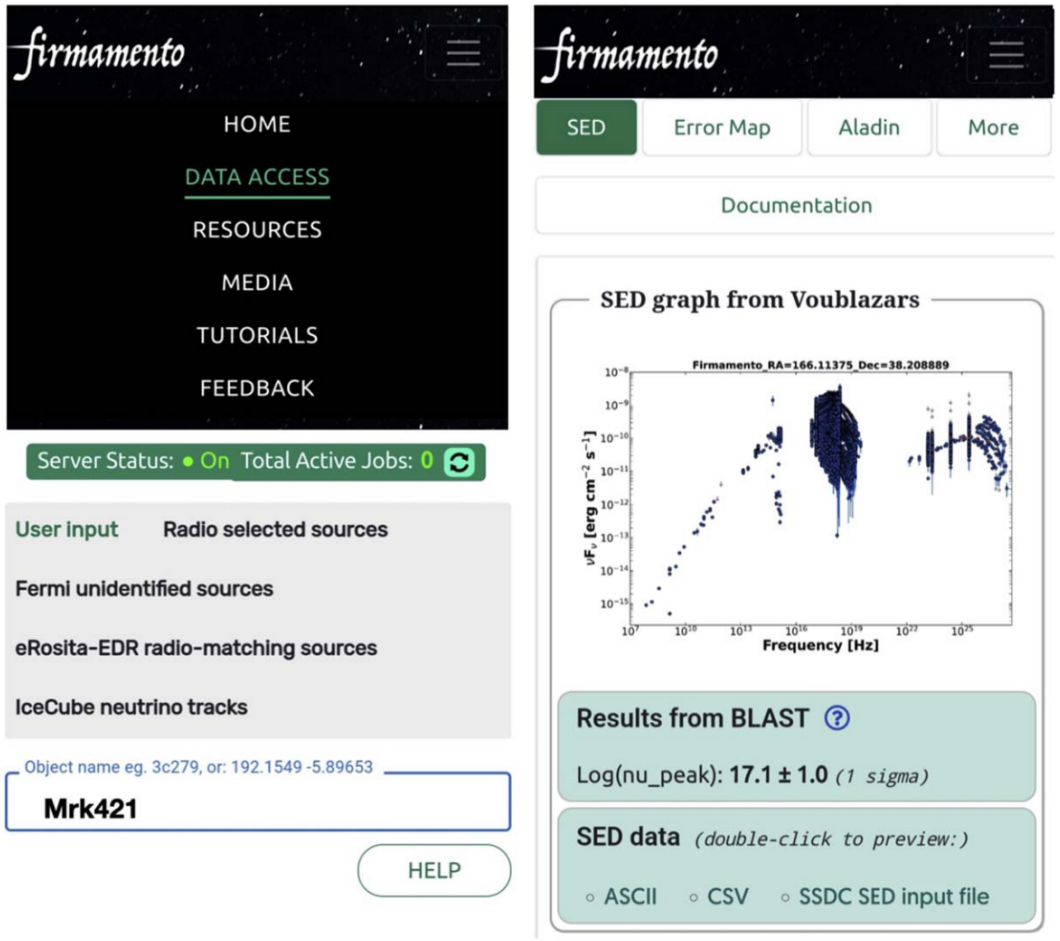
VOU-Blazars setup:

- git clone https://github.com/ecylchang/VOU_Blazars
- cd VOU_Blazars/bin/fort
- Export PGPLOT_DIR='YOUR_PGPLOT_LIBRARY_DIRECTORY' (in ubuntu: /usr/lib/pgplot5)
- ./compile.sh

The Firmamento Platform

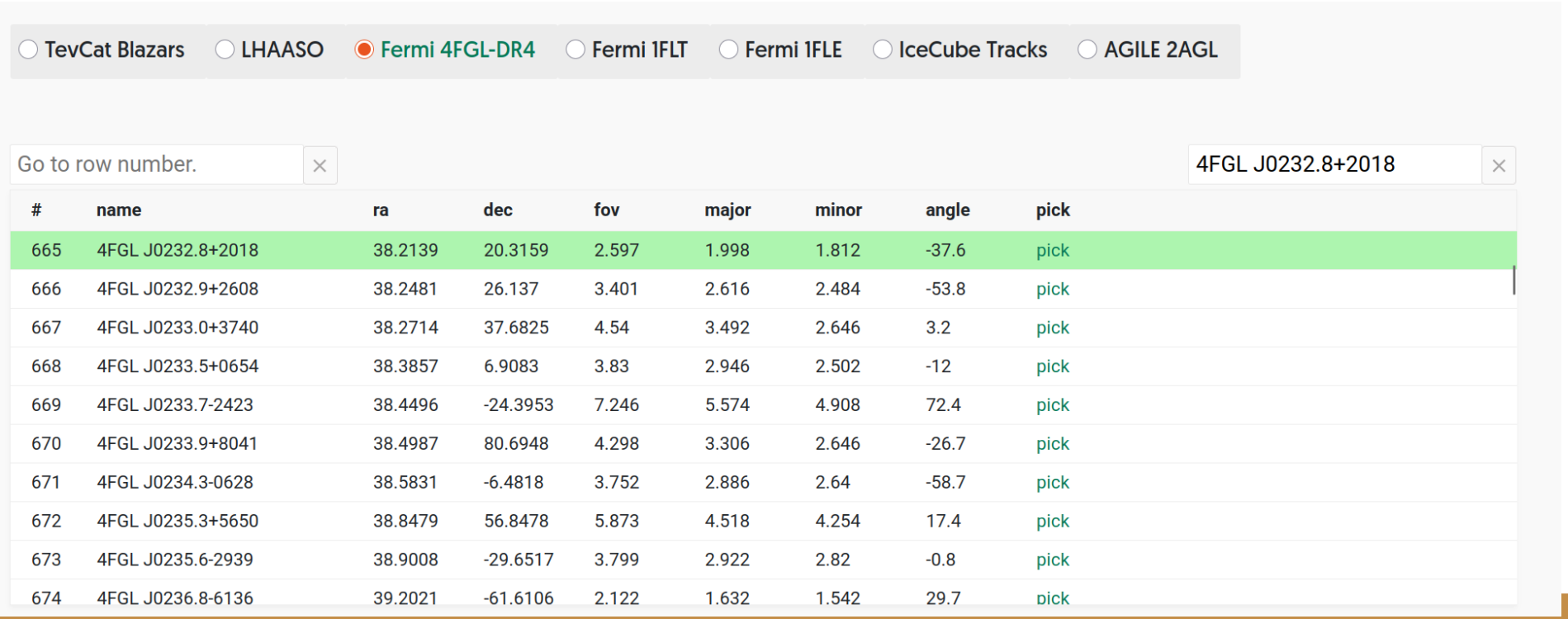
- Web tool with an user-friendly interface suited to both PC and mobile phones
- Available freely on:
  https://firmamento.hosting.nyu.edu
- Accesses data from catalog at all wavelengths, in order to obtain SED distribution
- Resulting file can be used as input for fitting and extrapolation to TeV emission

Tripathi et al. 2024, AJ 167 116



Usage of the Firmamento Platform – source selection

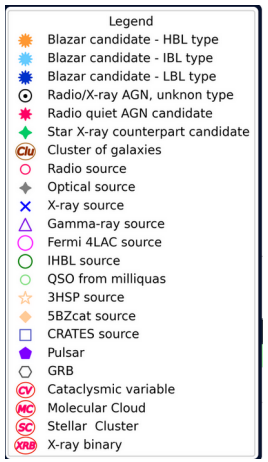
- Can be provided either as a CSV input file, or selected from available catalogs
- Again, if FOV is not provided it will skip the search phase

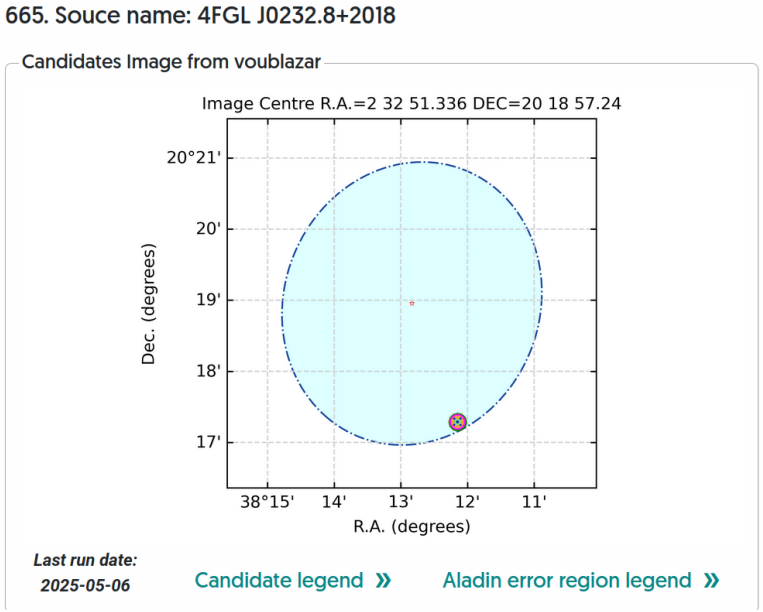


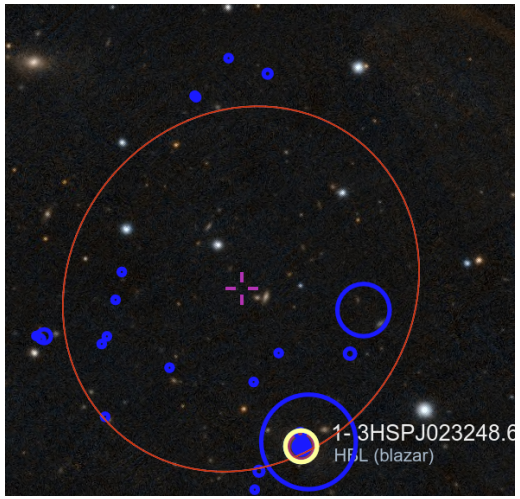
#	name	ra	dec	fov	major	minor	angle	pick
665	4FGL J0232.8+2018	38.2139	20.3159	2.597	1.998	1.812	-37.6	pick
666	4FGL J0232.9+2608	38.2481	26.137	3.401	2.616	2.484	-53.8	pick
667	4FGL J0233.0+3740	38.2714	37.6825	4.54	3.492	2.646	3.2	pick
668	4FGL J0233.5+0654	38.3857	6.9083	3.83	2.946	2.502	-12	pick
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

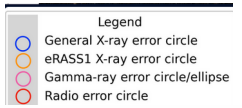
Usage of the Firmamento Platform – error region map

- 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)







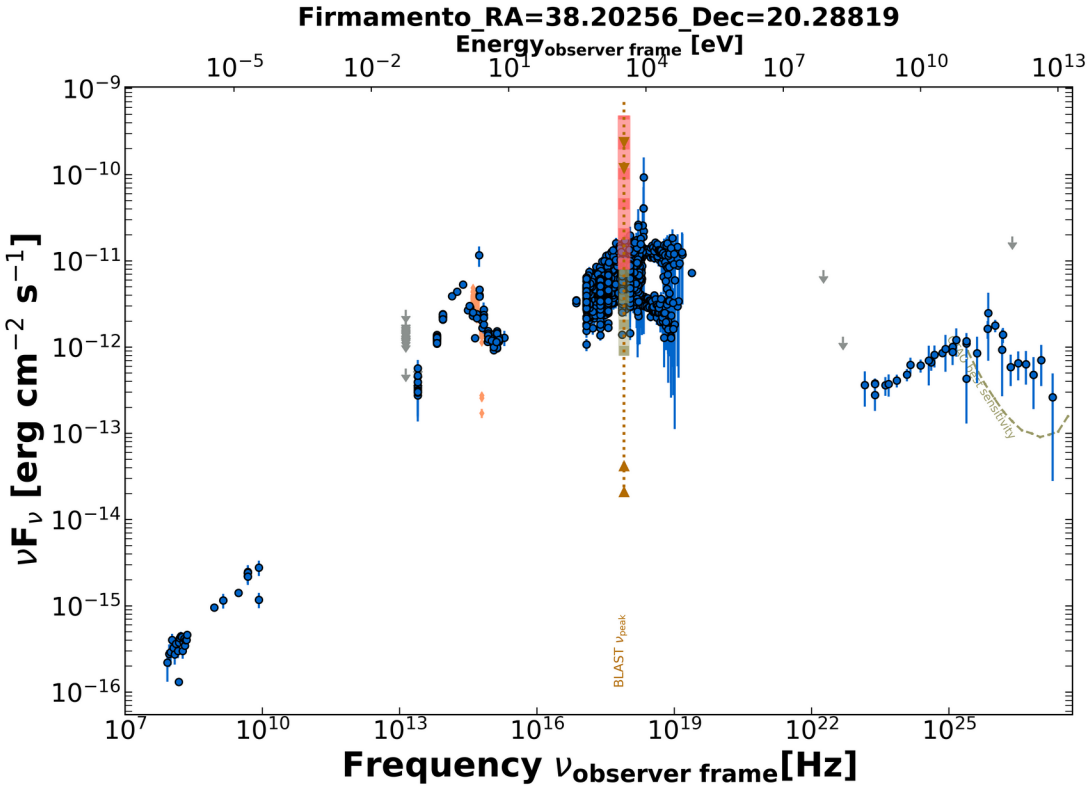


List of candidates found. Please pick one.

#	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 templates and CTAO Sensitivity



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

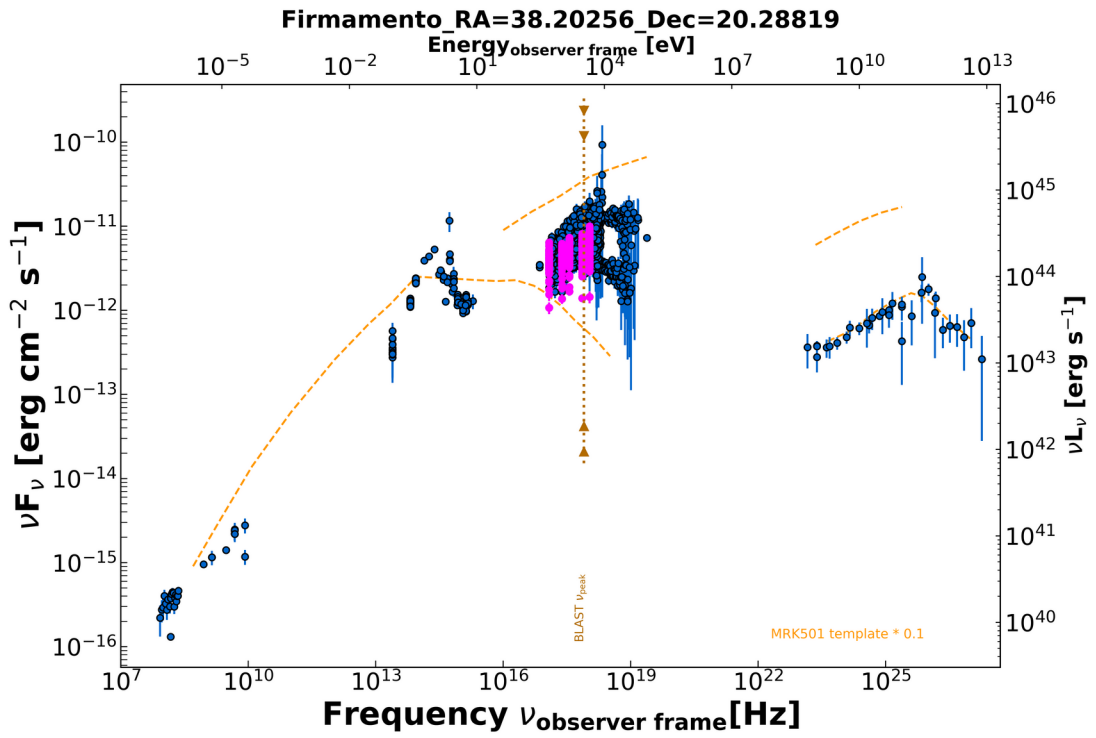
Results from BLAST

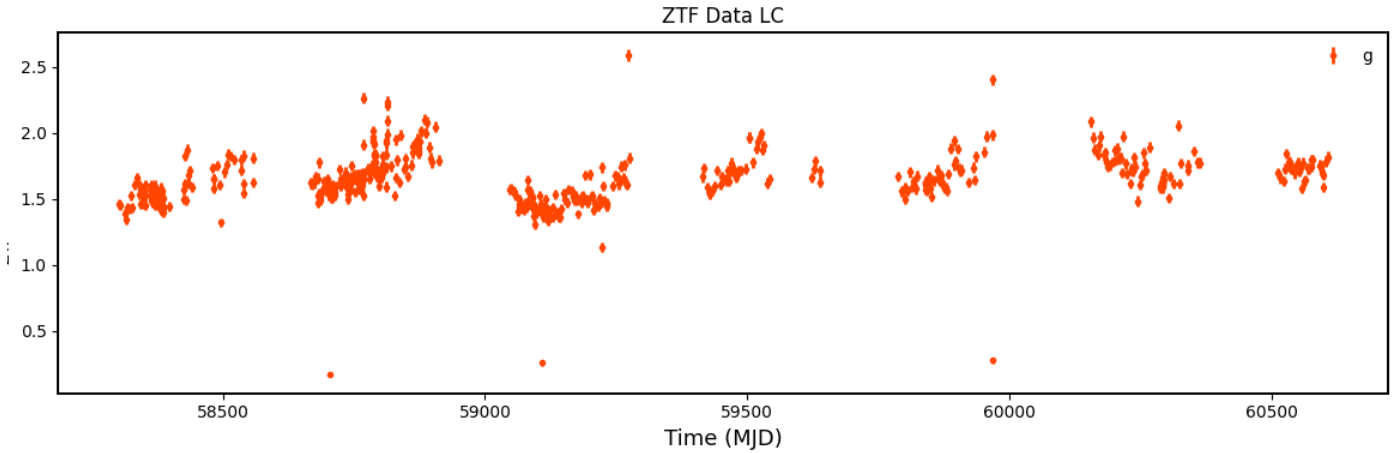
Log(nu_peak): **17.9 ± 0.5** *(1 sigma)*

Log(nuFnu_peak): **-11.3 ± 0.3** *(1 sigma)*

Usage of the Firmamento Platform – SED templates

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





Export SED data

- After retrieving the SED, it can be exported into three output file formats:
  - ASCII text file with all the detailed information;
  - CSV text file for easy import in Python;
  - Input text file for the ASI Space Science Data Center Platform (SSDC)
- To import a SED into SSDC, you first need to create an account there
- Access the User Data page and upload the text file downloaded from Firmamento
- Afterwards, they will be available in the SSDC as “user data”
- Less user-friendly platform with respect to Firmamento, but with a customizable GUI

https://tools.ssdc.asi.it/SED/

Input file options

- A customized source list can be provided with an input csv file
- After importing, they will be appear with the same format as the available catalogs

Example files

Type 1 (containing Fov)

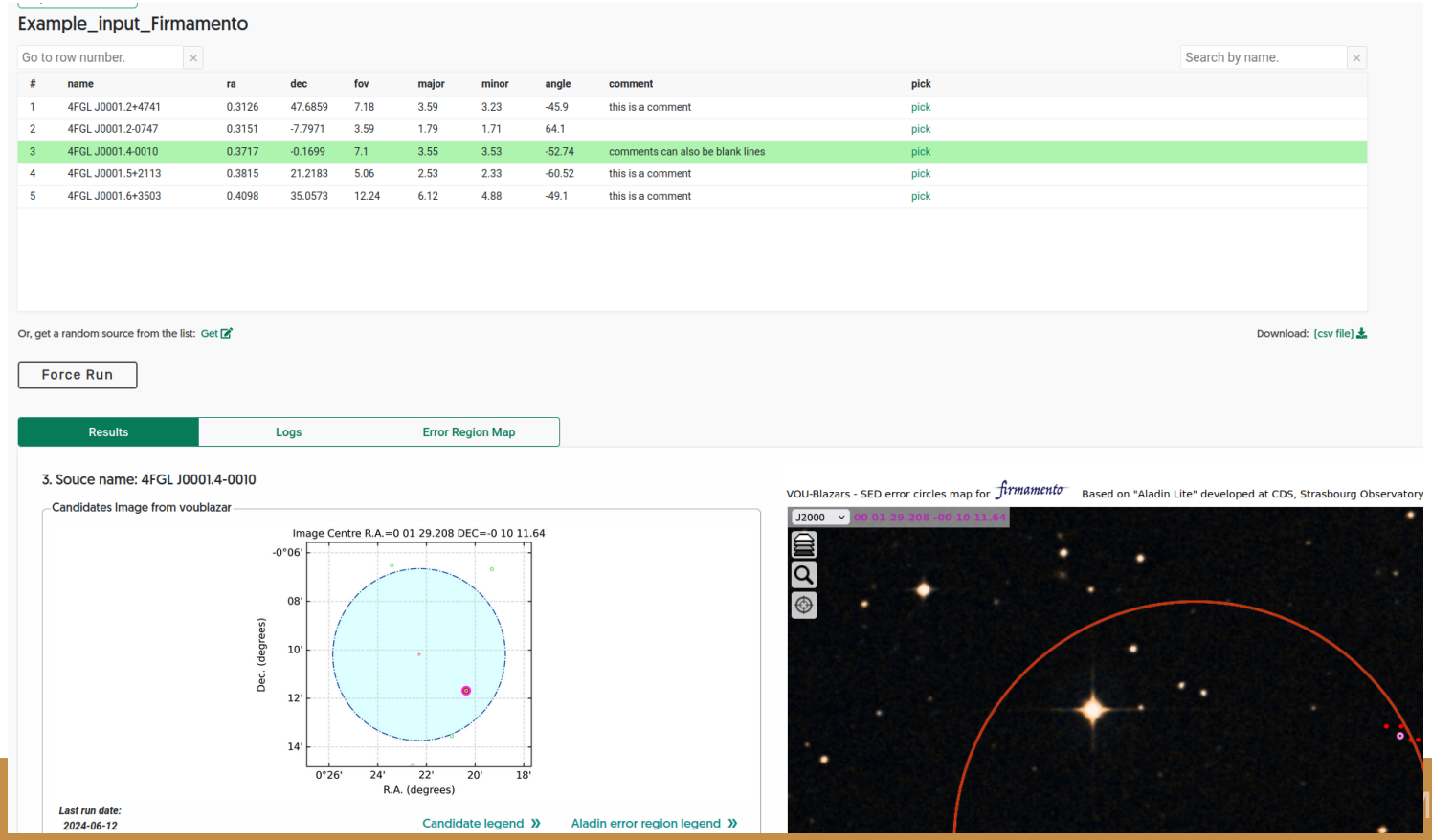
```
Name,ra,dec,fov,major,minor,angle,comment
4FGL J0001.2+4741 , 0.31260, 47.68590, 7.18, 3.59, 3.23, -45.90, this is a comment
4FGL J0001.2-0747 , 0.31510, -7.79710, 3.59, 1.79, 1.71, 64.10,
4FGL J0001.4-0010 , 0.37170, -0.16990, 7.10, 3.55, 3.53, -52.74, comments can also be blank lines
4FGL J0001.5+2113 , 0.38150, 21.21830, 5.06, 2.53, 2.33, -60.52 , this is a comment
4FGL J0001.6+3503 , 0.40980, 35.05730, 12.24, 6.12, 4.88, -49.10, this is a comment
```

Type 2 (not containing Fov)

```
name,ra,dec,comment
3c279 , 194.046527, -5.78931, this is a test comment
3c273 , 187.277916, 2.05239, second comment
PKS0528+134 ,82.735070, 13.53199,
```

Input file options

- A customized source list can be provided with an input csv file
- After importing, they will be appear with the same format as the available catalogs



Services accessible in Firmamento

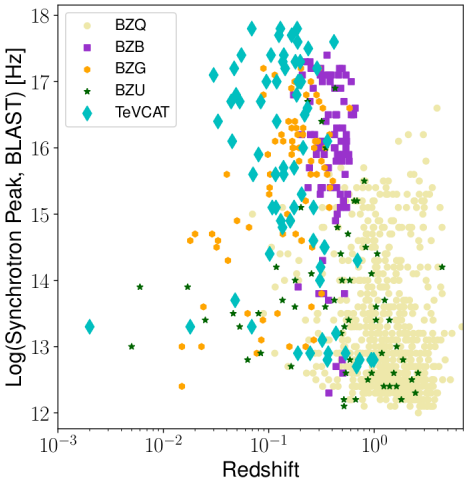
- A VOU-Blazars instance with a remote database
  - It will immediately retrieve a source if already processed, otherwise it will computed
  - Force Run option to request update (will be queued if too many processes in parallel)
- Blast and w-peak tools for Synchrotron Peak computation
- Aladin for region and error maps visualization
- AI assistant for automated support about general issues and questions
- Resources pages with documentation and links to other platforms/initiatives

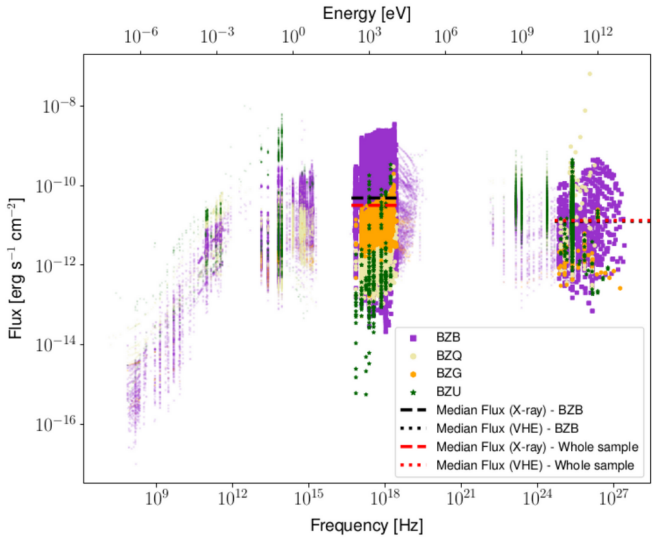
Firmamento application to our research

5BZCAT sources detected in catalogs of X-ray sources

Catalog	X-ray Instrument	Area Covered deg^2	Sources	With *Fermi*-LAT	Without *Fermi*-LAT
4XMM-DR13	XMM-*Newton*	1328	313	181 (58 %)	132 (42 %)
2CSC	*Chandra*	560	218	131 (60 %)	87 (40 %)
2SXPS	*Swift-XRT*	3790	1666	1191 (71 %)	475 (29 %)
eRASS1	eROSITA	20627	1379	726 (52 %)	653 (48 %)
NuBlazar	*NuSTAR*	6	114	88 (77 %)	26 (23 %)
4XMM-DR13 or 2CSC			464	271 (58 %)	193 (42 %)
2SXPS, no 4XMM or 2CSC			1347	968 (72 %)	379 (28 %)
eRASS1 only			624	189 (30 %)	435 (70 %)
Overall			2435	1428 (59 %)	1007 (41 %)
Of which in TeVCAT			77	77 (100 %)	0 (0 %)

SEDs of TeVCat sources, divided by class





Marchesi S., Iuliano A. et al.
A&A 693 A142 (2025)

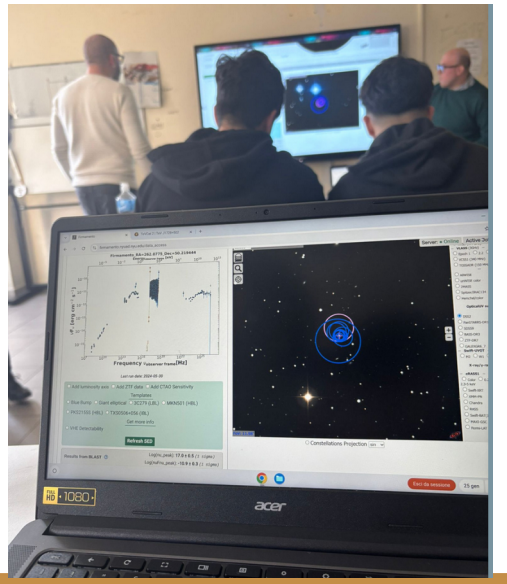
Firmamento application to outreach

- 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

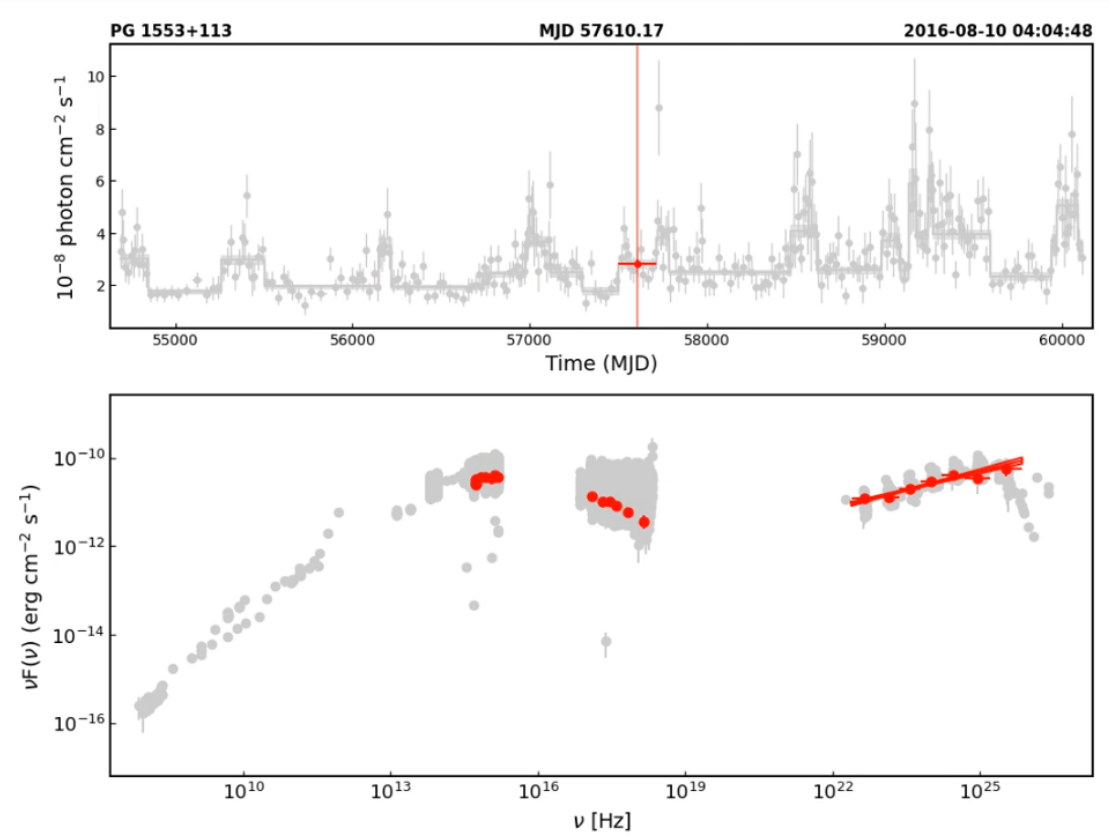
- This year in Naples, multiple PCTO classes involved in activities with both Firmamento and Cosmic Rays Cube detectors

- Using Google Colab and Jupyter notebooks online for teaching the students how to inspect and plot data



The Markarian Multiwavelength data center

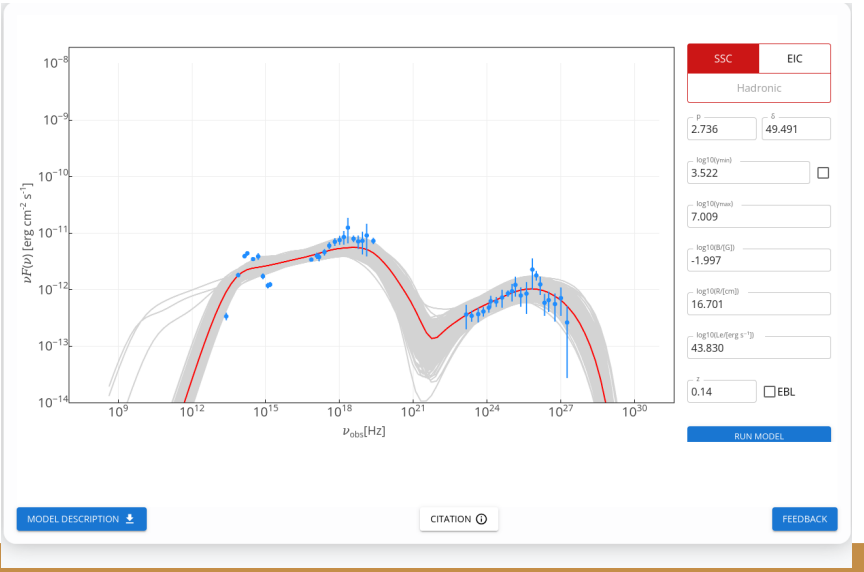
- A web platform for comprehensive blazar research https://mmdc.am/
- From the same group of Firmamento, also uses VOU-Blazar to build SE
- However, larger emphasis on the analysis, allows to plot light curve
- Simple and effective visualization of blazar variability



Machine Learning Tool for SED Modeling

- Fitting SEDs with a Machine Learning tool, employing Convolutional Neural Networks, in the same platform (*D. Bégué et al* 2024 ApJ **963** 71)
- Employing the synchrotron-self Compton (SSC) model to perform a fit with seven free parameters, provided the SED and the redshift
- Fit results may be unreliable according to upper limits and other physics requirements
- See next talk by Lea Heckman for more details about modeling

1ES 0229+200 fit with MMDC



Conclusions

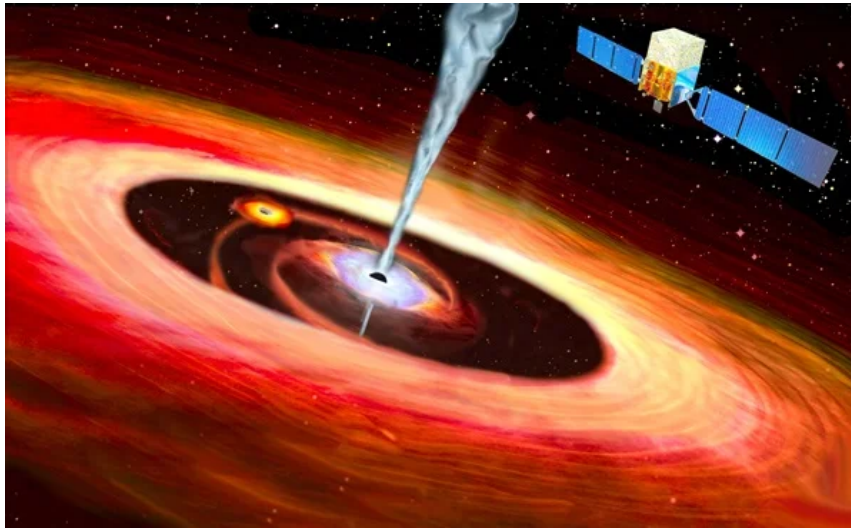
- VOU-Blazars and Firmamento provide an user-friendly interface, suited to both outreach and research, to look for blazar candidates and retrieve their SED.
- Hands-on session with Firmamento for a given source/catalog

Next steps:

- Model spectral distributions of interesting sources

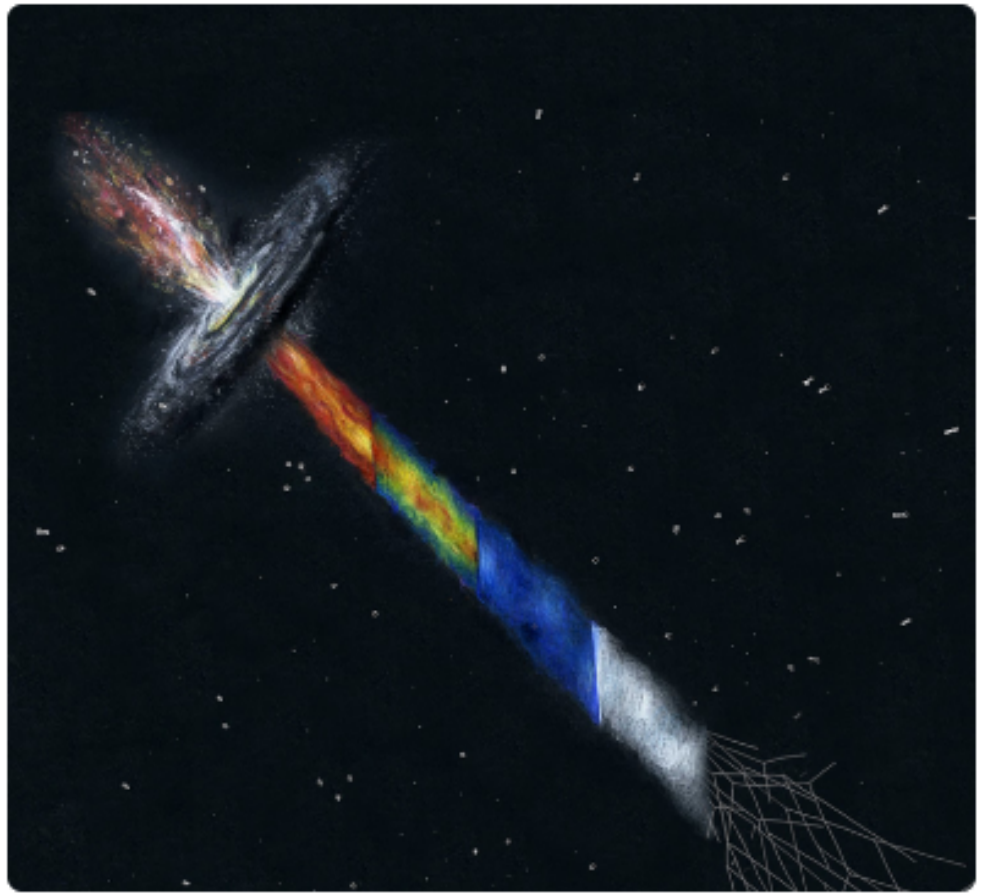
Hands-on session

- Connect to the Firmamento platform:
  - https://firmamento.hosting.nyu.edu
- Select a source from the already available catalogs
  - I will use **PG_1553+113** from TevCat Blazars
    You can choose anyone else you would like
  - Please avoid manual input or force run if not necessary
    (the server may not support too many simultaneous requests)
- Retrieve the SED and compare it with the Firmamento templates
- Try to plot light curve in the MMDC portal, and cross-check the data with the SSDC platform



A visualization of NASA's Fermi satellite observing the blazar as it emits gamma rays. Stefano Ciprini

Thank you for your attention



Troubleshooting local VOU-Blazars

- Complain about missing files/catalogs:
  - That is normal, these are optional catalogs external to VOU-Blazars.
  - They are not needed for default SED production, if you need it you can download them yourself
  - Same for CTAO sensitivity files

- Complain about not enough memory for light curve production:
  - In file 'plot_lc.f', around line 86: Error allocating 48000000000 bytes
  - Edit input file bin/fort/array_size.f to reduce binning enough for your system memory

Iuliano et al. (in prep.)