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Blazar Spectral Energy Distributions with Firmamento web tool

**Antonio Iuliano
(INFN Sezione di Napoli)**

28 May 2025

2nd VHEGAM Meeting, Bari



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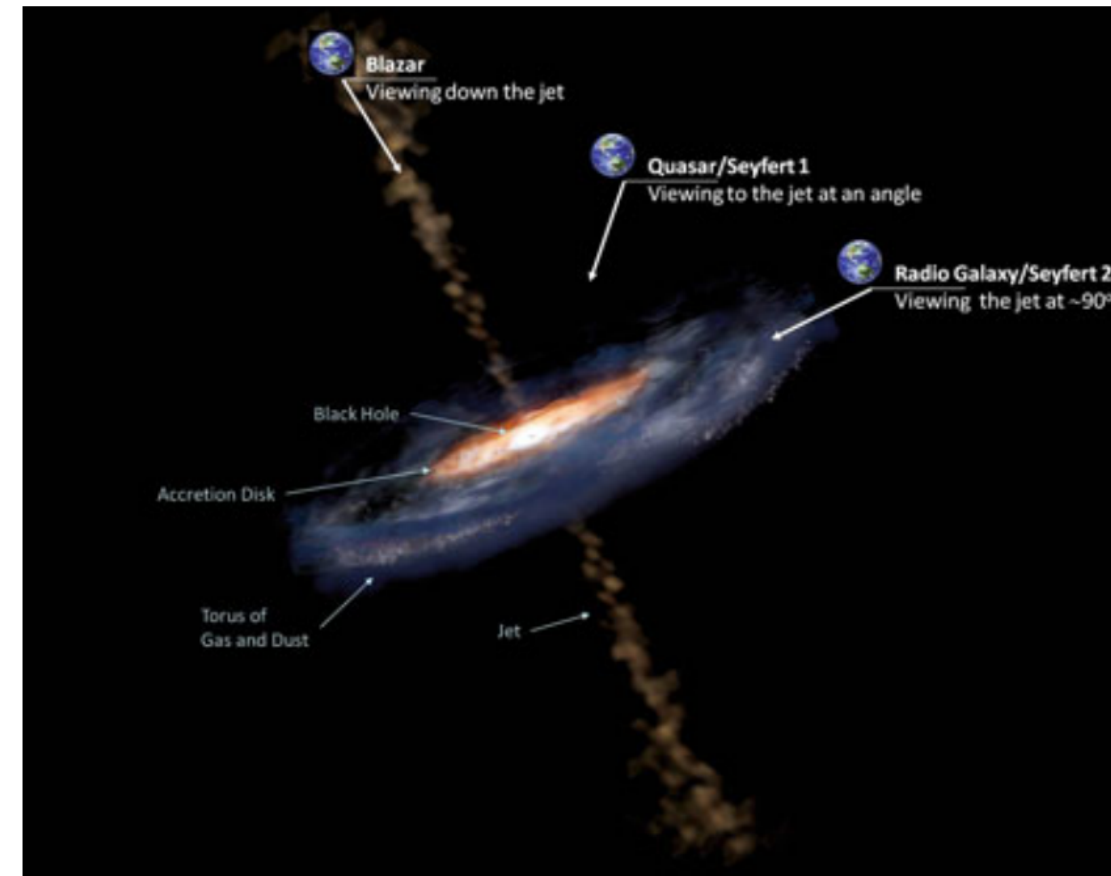


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Introduction

- 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





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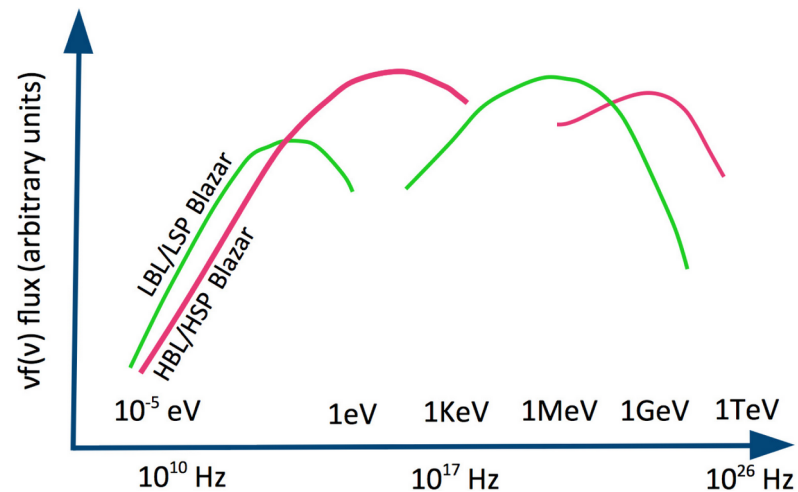


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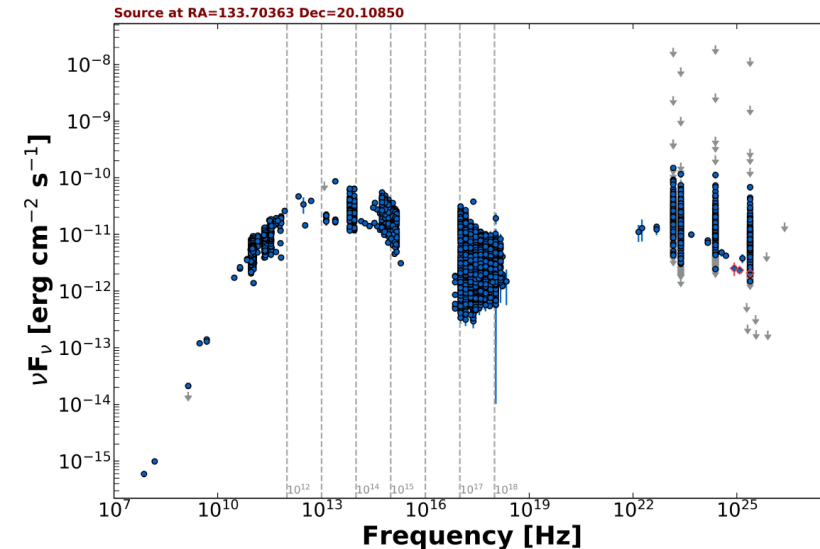


Spectrum Energy Distribution (SED)

- 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



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Search for blazars and retrieve data with VOU-Blazars

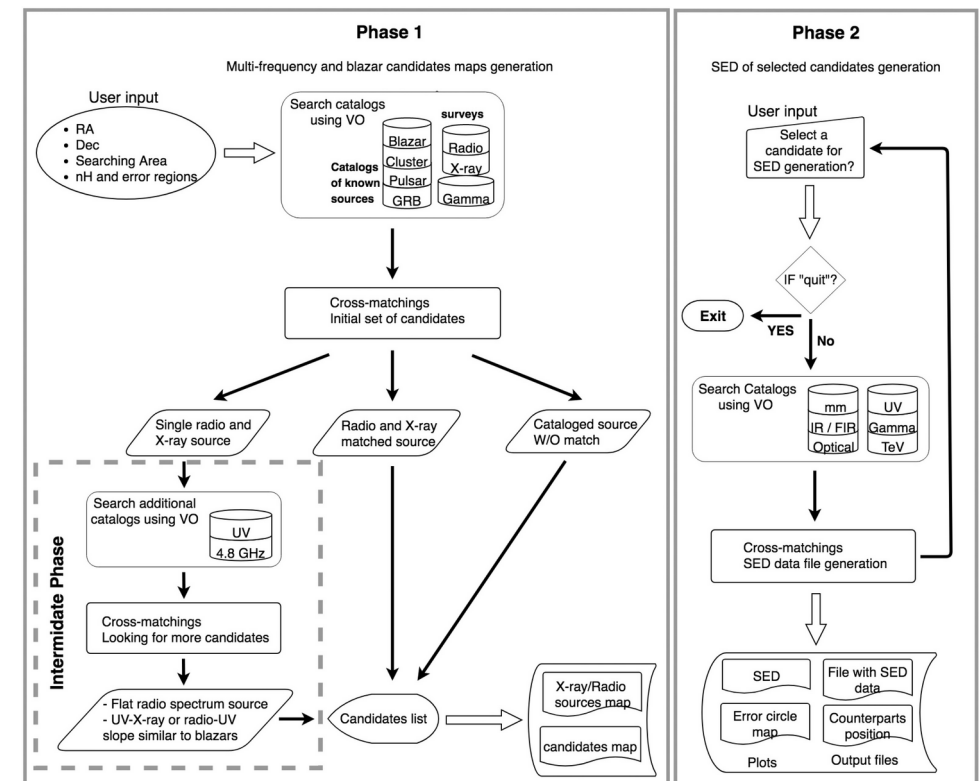
Developed in the framework of Open Universe, based
on Virtual Observatory (VO) protocols

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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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`

```
----- source nr. 1 -----
IPCSLEW/NVSS ra dec 02 32 46.6, 20 16 21.5 radio flux d. 3.600 flux-ratio 150192. arx 0.371 possible radio-detected AGN Dist. 2.821 arcmin
Match nr. 1 ra dec: 38.19425, 20.27264
4XMM-DR13/NVSS ra dec 02 32 48.5, 20 17 16.2 radio flux d. 82.400 X-ray/radio flux-ratio 4125. arx 0.561 Log(nu_p) 17.6+/-1 possible HBL Dist. 1.814 arcmin
XMMLEW2/NVSS ra dec 02 32 48.5, 20 17 16.2 radio flux d. 82.400 X-ray/radio flux-ratio 4440. arx 0.557 Log(nu_p) 17.7+/-1 possible HBL Dist. 1.814 arcmin
RASS/NVSS ra dec 02 32 48.5, 20 17 16.2 radio flux d. 82.400 X-ray/radio flux-ratio 4915. arx 0.552 Log(nu_p) 17.8+/-1 possible HBL Dist. 1.814 arcmin
2SXPS/NVSS ra dec 02 32 48.5, 20 17 16.2 radio flux d. 82.400 X-ray/radio flux-ratio 5913. arx 0.542 Log(nu_p) 18.0+/-1 possible HBL Dist. 1.814 arcmin
IPCSLEW/NVSS ra dec 02 32 48.5, 20 17 16.2 radio flux d. 82.400 X-ray/radio flux-ratio 6562. arx 0.537 Log(nu_p) 18.1+/-1 possible HBL Dist. 1.814 arcmin
BMM/NVSS ra dec 02 32 48.5, 20 17 16.2 radio flux d. 82.400 X-ray/radio flux-ratio 3502. arx 0.570 Log(nu_p) 17.4+/-1 possible HBL Dist. 1.814 arcmin
Match nr. 2 ra dec: 38.20192, 20.28783
3HSPJ023248.6+201717
5BZG J0232+2017
4XMM-DR13/VLASSQL ra dec 02 32 48.6, 20 17 17.6 radio flux d. 46.989 X-ray/radio flux-ratio 3376. arx 0.572 Log(nu_p) 17.4+/-1 possible HBL Dist. 1.779 arcmin
XMMLEW2/VLASSQL ra dec 02 32 48.6, 20 17 17.6 radio flux d. 46.989 X-ray/radio flux-ratio 3634. arx 0.568 Log(nu_p) 17.4+/-1 possible HBL Dist. 1.779 arcmin
RASS/VLASSQL ra dec 02 32 48.6, 20 17 17.6 radio flux d. 46.989 X-ray/radio flux-ratio 4022. arx 0.562 Log(nu_p) 17.6+/-1 possible HBL Dist. 1.779 arcmin
2SXPS/VLASSQL ra dec 02 32 48.6, 20 17 17.6 radio flux d. 46.989 X-ray/radio flux-ratio 4839. arx 0.553 Log(nu_p) 17.7+/-1 possible HBL Dist. 1.779 arcmin
IPCSLEW/VLASSQL ra dec 02 32 48.6, 20 17 17.6 radio flux d. 46.989 X-ray/radio flux-ratio 5370. arx 0.547 Log(nu_p) 17.9+/-1 possible HBL Dist. 1.779 arcmin
BMM/VLASSQL ra dec 02 32 48.6, 20 17 17.6 radio flux d. 46.989 X-ray/radio flux-ratio 2865. arx 0.580 Log(nu_p) 17.2+/-1 possible HBL Dist. 1.779 arcmin
Repeated radio counterpart, 2.702 arcsec away from match nr. 2

XMMLEW2/VLASSQL ra dec 02 32 48.9, 20 17 23.1 radio flux d. 0.933 flux-ratio 183011. arx 0.361 possible radio-detected AGN Dist. 1.672 arcmin
RASS/VLASSQL ra dec 02 32 48.9, 20 17 23.1 radio flux d. 0.933 flux-ratio 202581. arx 0.356 possible radio-detected AGN Dist. 1.672 arcmin
IPCSLEW/VLASSQL ra dec 02 32 48.9, 20 17 23.1 radio flux d. 0.933 flux-ratio 270442. arx 0.340 possible radio-detected AGN Dist. 1.672 arcmin
!!!Warning, check X-ray counterpart!
Repeated radio counterpart, 9.044 arcsec away from match nr. 2

Gamma-ray sources
2BIBJ023248.6+201717 38.20250000000001 20.288139999999999
3FHL J0232.8+2017 38.223599999999998 20.298400000000001
4FGL J0232.8+2018 38.213900000000002 20.315899999999999
4FGL-DR4 J0232.8+2018 38.213900000000002 20.315899999999999
4LAC-DR3/1ES 0229+200 38.202559999999998 20.288190000000000
12Y-MST J0232+2017 38.207000000000001 20.289999999999999
```

Please enter the source number and zoom in area (in arcsec) interred: (Type 'q' to quit) (Type 'candlist' to show all candidates)



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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

STEP 2 - Download the desired packages:

Selecting an individual mission package will automatically select a set of recommended general-use tools.

☐ All

☐ Mission-Specific Tools

☐ [ASCA](#) ☐ [CALET](#) ☐ [Einstein](#) ☐ [EXOSAT](#) ☐ [CGRO](#) ☐ [HEAO-1](#) ☐ [Hitomi](#) ☐ [INTEGRAL](#) ☐ [IXPE](#) ☐ [MAXI](#)

☐ [NICER](#) ☐ [NuSTAR](#) ☐ [OSO-8](#) ☐ [ROSAT](#) ☐ [Suzaku](#) ☐ [Swift](#) ☐ [Vela](#) ☐ [XRISM](#) ☐ [XTE](#)

☐ General-Use FTOOLS

☒ [Attitude](#) ☐ [Caltools](#) ☐ [Futils](#) ☐ [Fimage](#) ☒ [HEASARC](#) ☐ [HEASim](#) ☒ [HEASptools](#)

☒ [HEATools](#) ☒ [HEAGen](#) ☐ [FV](#) ☐ [Time](#)

☐ [XANADU](#)

☐ [Ximage](#) ☐ [Xronos](#) ☐ [Xspec.*](#)

☐ [XSTAR](#)



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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`





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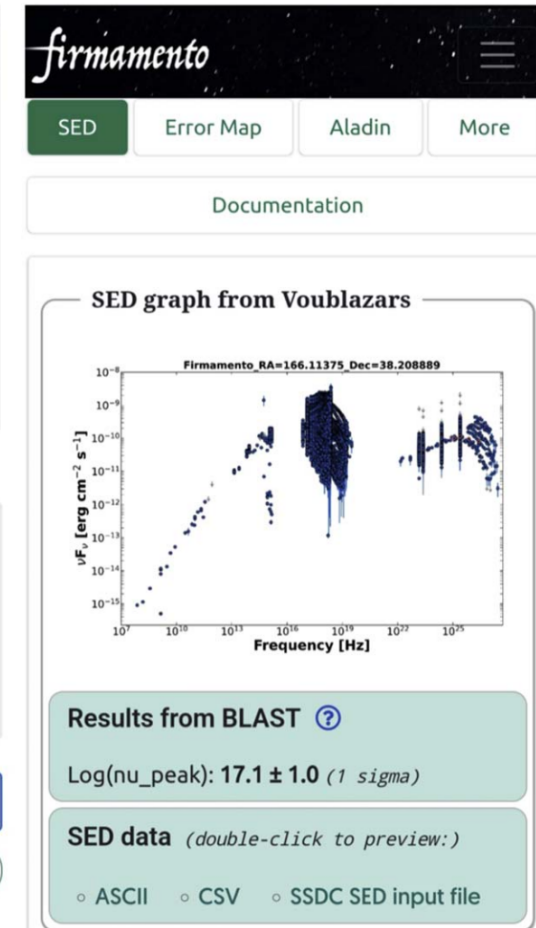
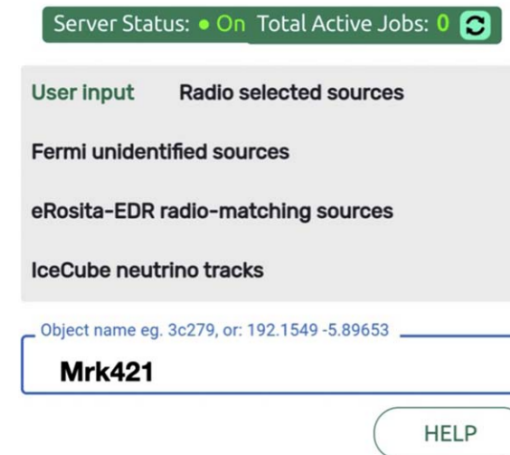
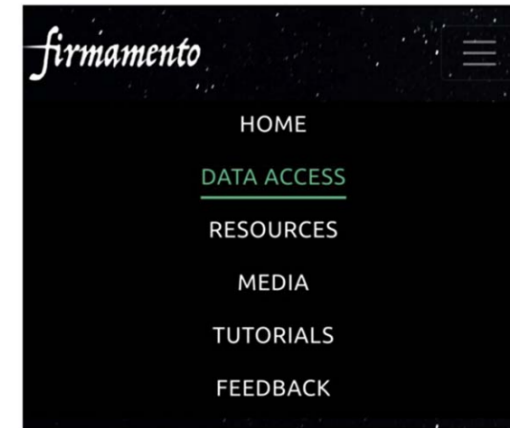
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The Firmamento Platform

- 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





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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

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

Go to row number.

#	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



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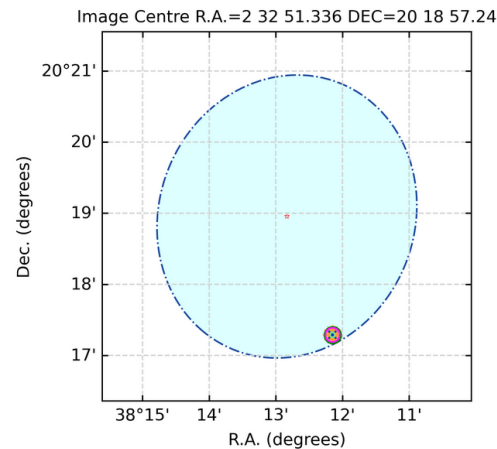


Usage of the Firmamento Platform - error region map

- 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

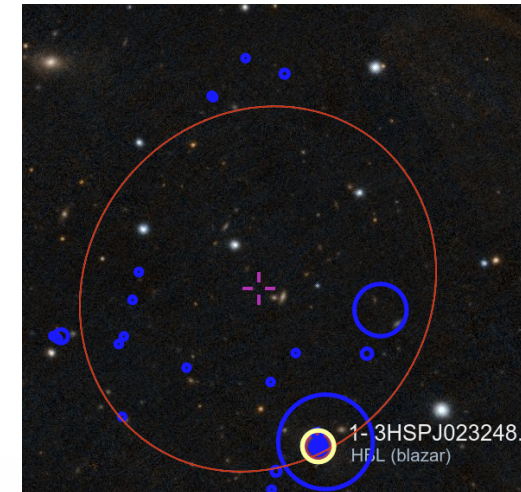
Candidates Image from voublazar



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



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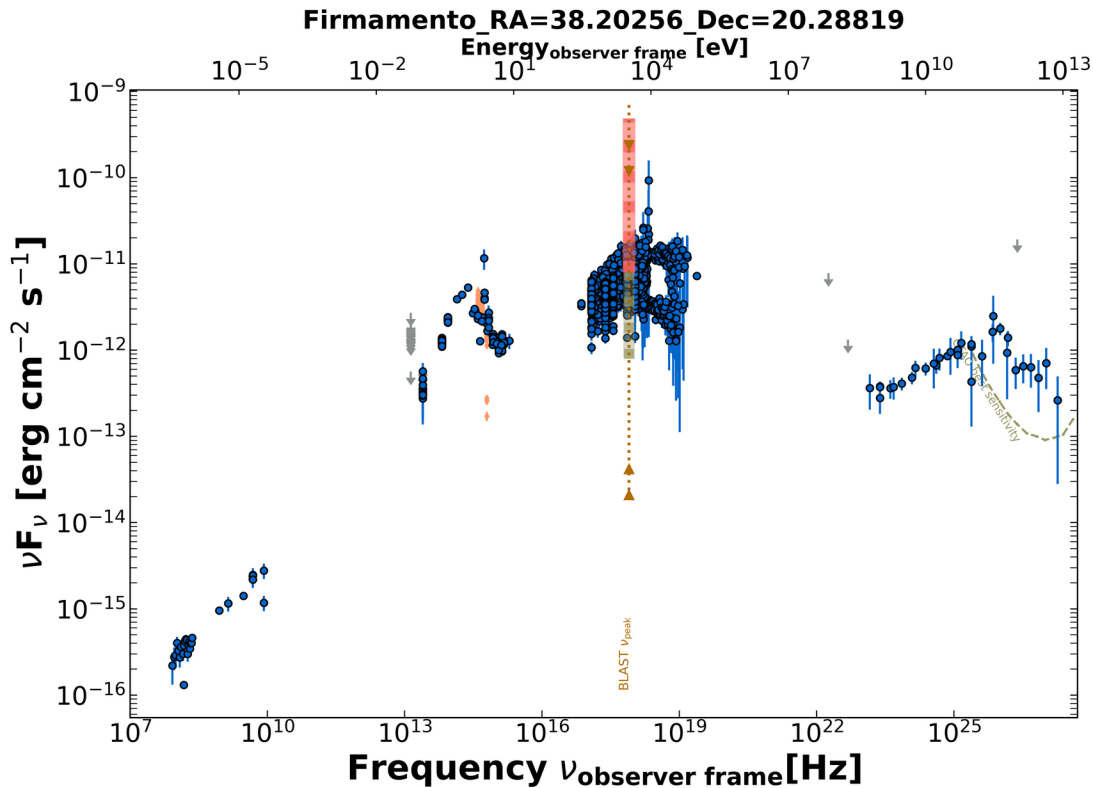


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Usage of the Firmamento Platform - SED production

- 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(ν_{peak}): 17.9 ± 0.5 (1 sigma)

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



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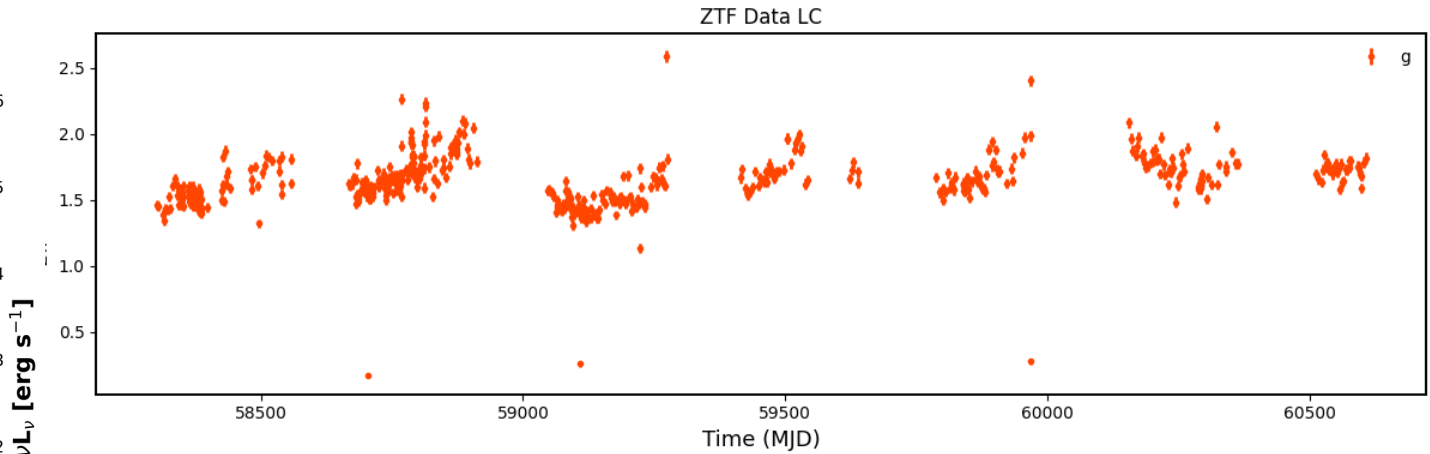
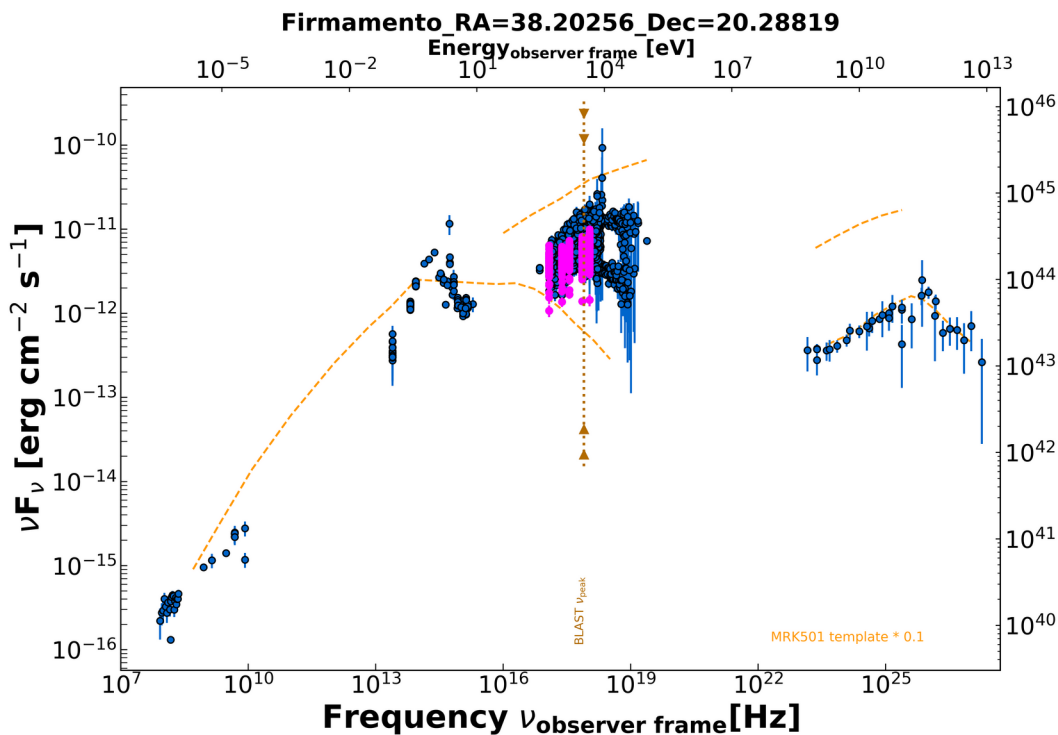


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Usage of the Firmamento Platform - SED templates

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





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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.ssdsc.asi.it/SED/>



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Input file options

- A customized source list can be provided with an input csv file
- After importing, they will 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,
```



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Input file options

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

Example_input_Firmamento

Go to row number. Search by name.

#	name	ra	dec	fov	major	minor	angle	comment	pick
1	4FGL J0001.2+4741	0.3126	47.6859	7.18	3.59	3.23	-45.9	this is a comment	pick
2	4FGL J0001.2+0747	0.3151	-7.7971	3.59	1.79	1.71	64.1		pick
3	4FGL J0001.4-0010	0.3717	-0.1699	7.1	3.55	3.53	-52.74	comments can also be blank lines	pick
4	4FGL J0001.5+2113	0.3815	21.2183	5.06	2.53	2.33	-60.52	this is a comment	pick
5	4FGL J0001.6+3503	0.4098	35.0573	12.24	6.12	4.88	-49.1	this is a comment	pick

Or, get a random source from the list: [Get](#) Download: [\[csv file\]](#)

[Force Run](#)

[Results](#) [Logs](#) [Error Region Map](#)

3. Source name: 4FGL J0001.4-0010

Candidates Image from voublazar

Image Centre R.A.=0 01 29.208 DEC=-0 10 11.64

Last run date:
2024-06-12

[Candidate legend >>](#) [Aladin error region legend >>](#)

VOU-Blazars - SED error circles map for *Firmamento* Based on "Aladin Lite" developed at CDS, Strasbourg Observatory

J2000



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Services accessible in Firmamento

- A VOU-Blazars instance with a remote database
 - It will immediately retrieve a source if already processed, otherwise it will be 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



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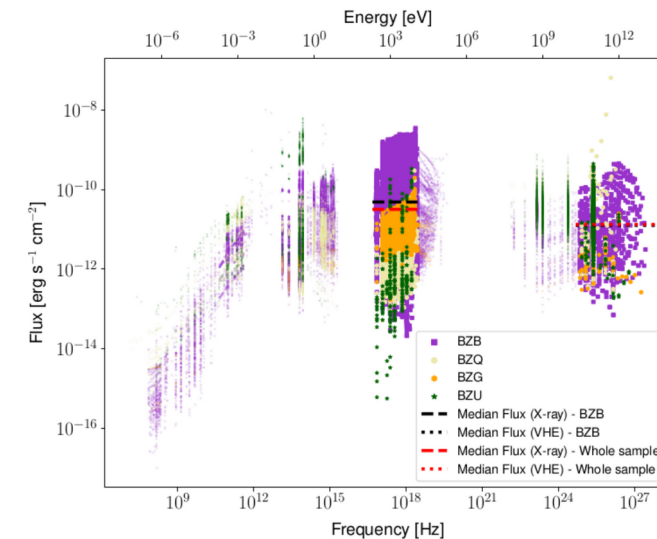
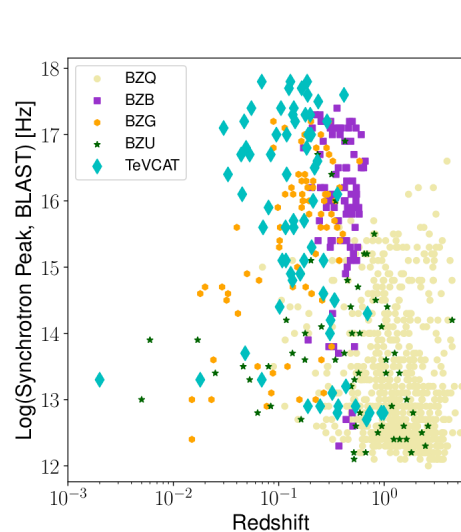


Firmamento application to our research

5BZCAT sources detected
in catalogs of X-ray sources

Catalog	X-ray Instrument	Area Covered deg ²	Sources	With <i>Fermi</i> -LAT	Without <i>Fermi</i> -LAT
4XMM-DR13	<i>XMM-Newton</i>	1328	313	181 (58 %)	132 (42 %)
2CSC	<i>Chandra</i>	560	218	131 (60 %)	87 (40 %)
2SXPS	<i>Swift-XRT</i>	3790	1666	1191 (71 %)	475 (29 %)
eRASS1	eROSITA	20627	1379	726 (52 %)	653 (48 %)
NuBlazar	<i>NuSTAR</i>	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)



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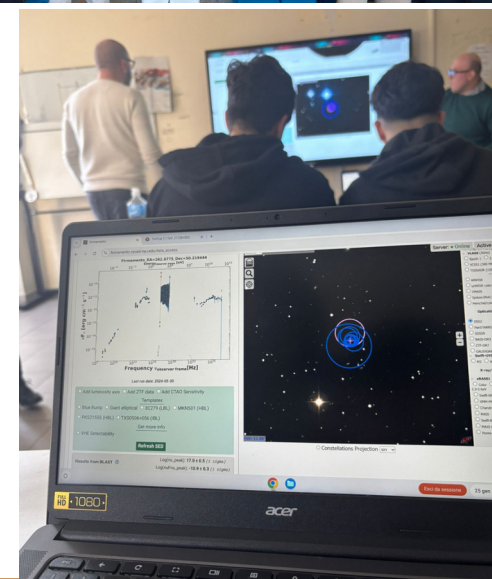


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Firmamento application to outreach

- 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





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The Markarian Multiwavelength data center

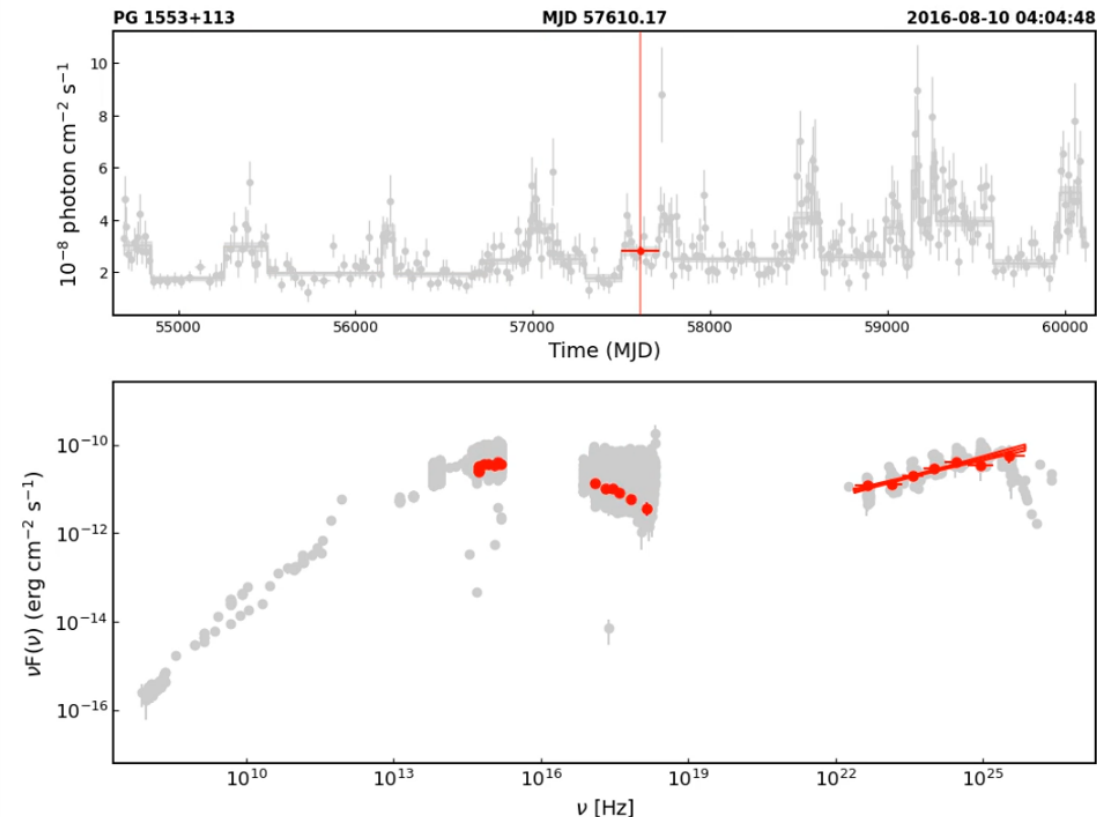
SED

SED/LC ANIMATION

ALADIN

RELATED ARTICLES

- 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





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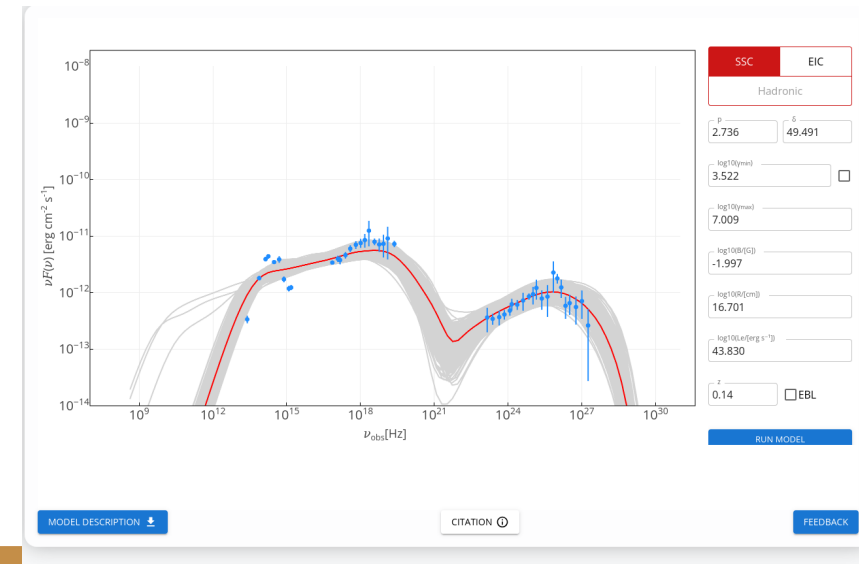
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Machine Learning Tool for SED Modeling

- 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





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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



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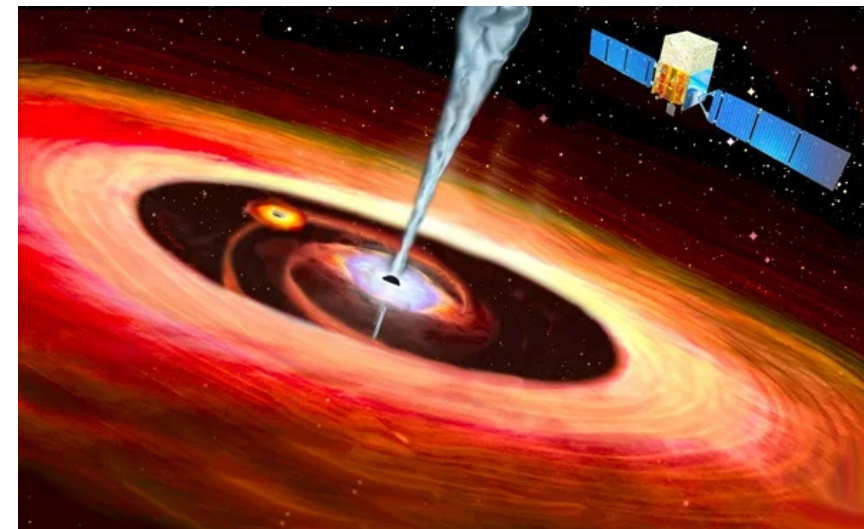


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Hands-on session

- 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



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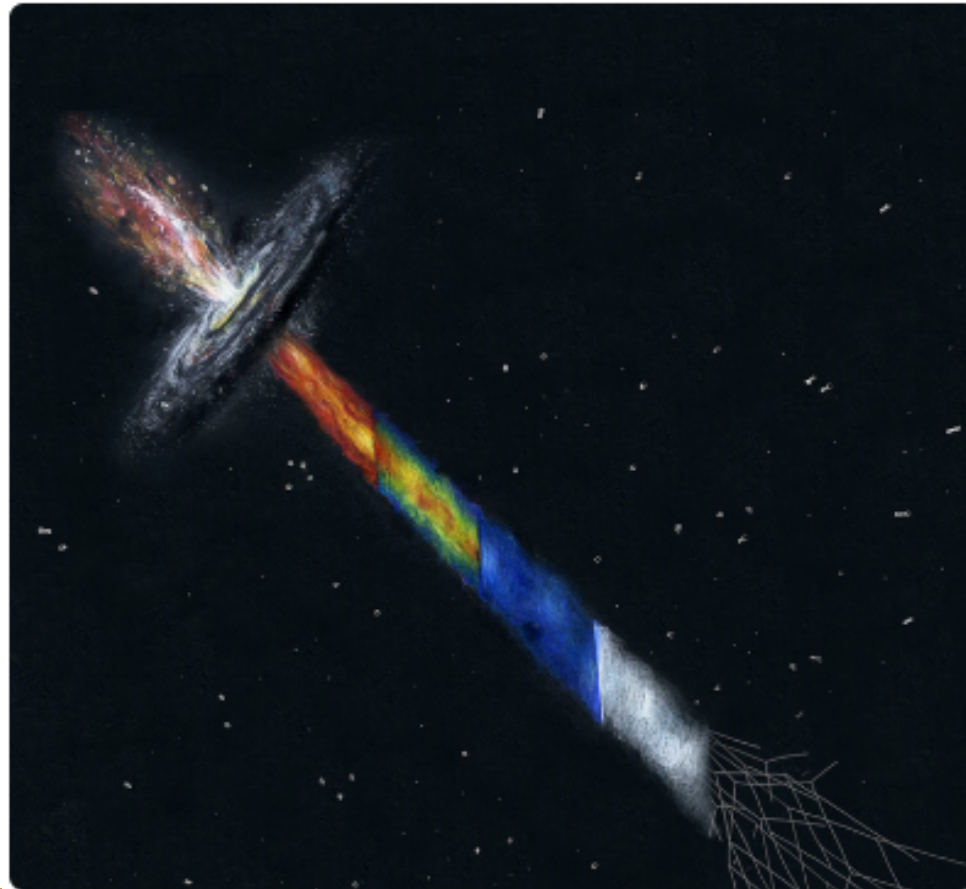
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Thank you for your attention





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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.)