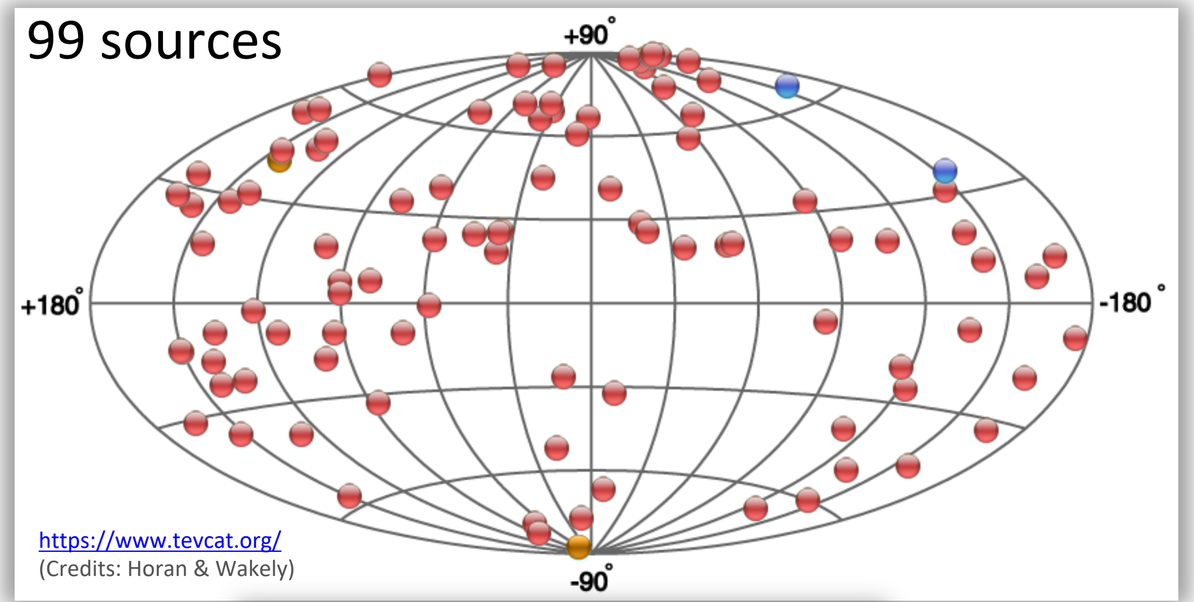
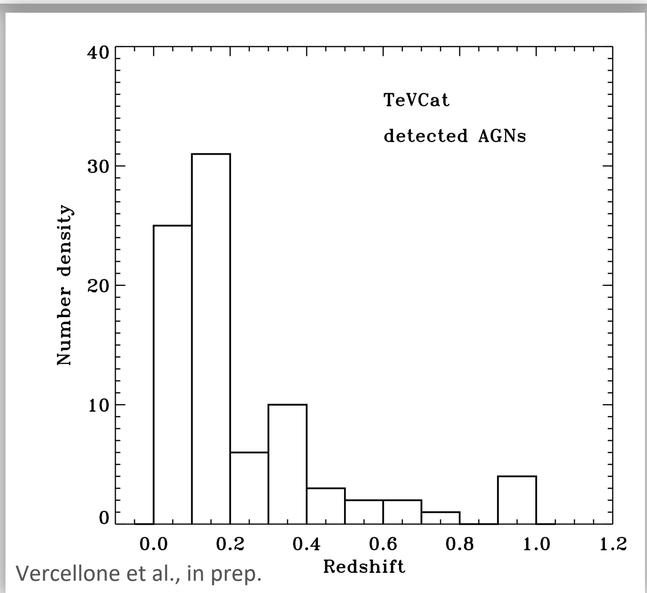
ASTRI Mini-Array preliminary results on extra-galactic sources

Stefano Vercellone – INAF Osservatorio Astronomico di Brera
for the ASTRI Project

From 9 to 40: the SST Telescopes and Gamma-Ray Science with ASTRI and CTAO

The current VHE sky – the IACT view





Object type	Quantity
HBL	59
FSRQ	12
IBL	10
FR-I	5
Blazar	4
Starbursts	2
LBL	2
AGN	2
BL Lacs (unc)	2
LLAGN	1

The current VHE sky – the LHAASO view

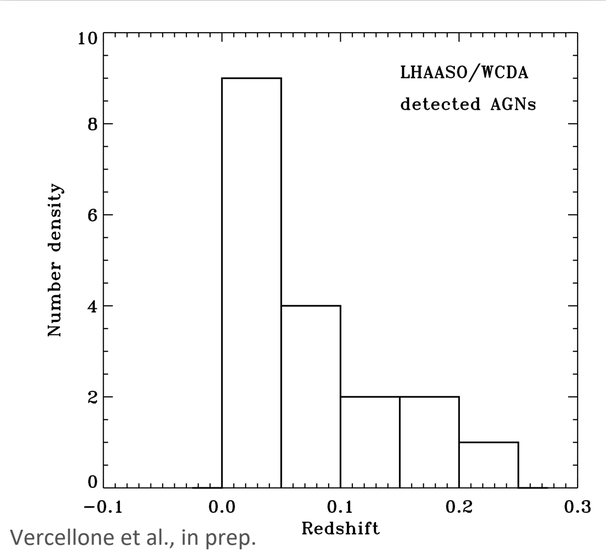
AGNs collected in 1180 days

➢ Total 18 including 10 variables

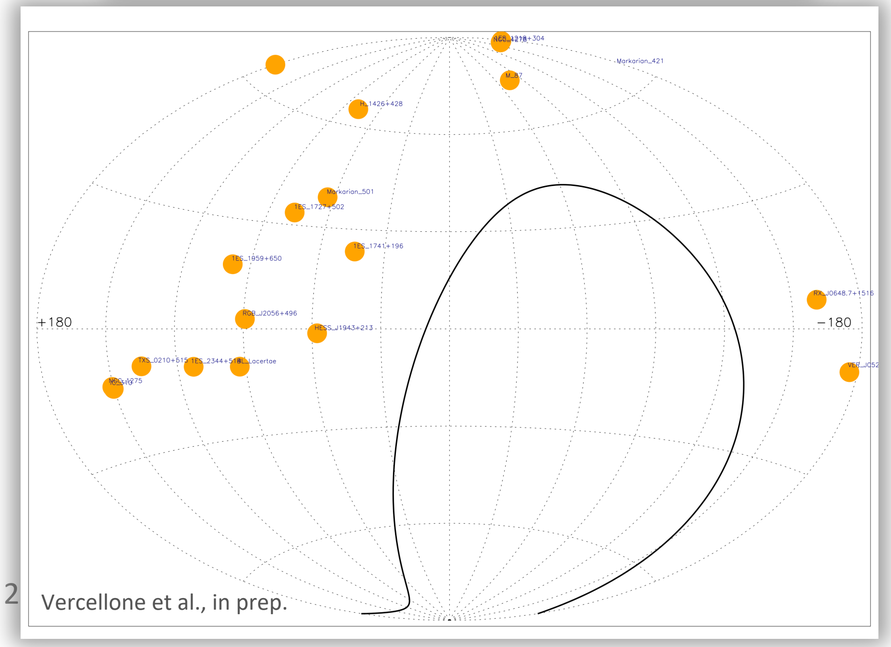
ID	Name	Type	RA	DEC	Sig	Dist [deg.]	Z	Variability	Time scale
1	NGC 4278	LLAGN	185.05	185.05	8.71	0.03	0.0038	√	Months
2	M 87	FRI	187.75	12.45	8.38	0.07	0.0044	√	Days
3	IC 310	Unknown type	49.05	41.25	-/22σ	<0.1	0.0189	√	Days
4	NGC 1275	FRI	49.95	41.45	-/8σ	<0.1	0.0175	√	Days
5	Markarian 421	HBL	166.05	38.15	221.38	0.05	0.031	√	Days to months
6	Markarian 501	HBL	253.45	39.75	92.54	0.02	0.034	√	Days to months
7	1ES 1727+502	HBL	262.05	50.15	12.08	0.07	0.055	√	Days
8	1ES 1959+650	HBL	299.95	65.15	11.33	0.02	0.048	√	Days
9	HESS J1943+213	HBL	295.95	21.35	10.34	0.06	~0.2		
10	1ES 2344+514	HBL	356.75	51.75	9.33	0.04	0.044	√	Days to weeks
11	1ES 1218+304	HBL	185.25	30.05	8.54	<0.1	0.182		
12	RX J0648.7+1516	HBL	101.75	15.15	7.34	<0.1	0.179		
13	H 1426+428	HBL	217.05	42.55	6.86	<0.1	0.129		
14	RGB J2056+496	Blazar	314.25	49.65	6.71	0.05	?		
15	1ES 1741+196	HBL	266.05	19.55	5.97	0.05	0.084		
16	TXS 0210+515	HBL	33.55	51.75	5.60	0.01	0.049		
17	BL Lacertae	IBL	330.75	42.15	7.79	<0.1	0.069	√	Days
18	VER J0521+211	IBL	80.45	21.05	5.28	<0.1	?		

5/13/2025 Cao Z., et al., 2025, CTAO Meeting 6

Object type	Quantity
HBL	11
IBL	2
FR-I	2
Uncert.	1
Blazar	1
LLAGN	1



Vercellone et al., in prep.



Vercellone et al., in prep.

ASTRI-1 and Blazars

Commissioning results (June – October 2025)

Mrk 421 MWL campaign (January – February 2026)

Prospects (January 2027 – …)

Planning well ahead

Swift proposal 2024 – 2025

Flares in bright TeV blazars with *Swift* and the ASTRI Mini-Array

S. Vercellone, P. Romano, G. Bonnoli, G. Pareschi, F. Tavecchio (INAF/OAB)
J. Becerra González (IAC), A. Giuliani (INAF/IASFMI), M. Capalbi, S. Lombardi (INAF/OAR)

Table 1: Observing parameters for each requested source.

Source[a] (ranked by relevance)	z	*Swift*/XRT Trigger criteria[b] [cts/s (0.3-10 keV)]	ASTRI Mini-Array Trigger criteria[b,c]	*Swift*/XRT Expec. cts/obs [Counts]	*Swift*/XRT Obs. mode	Visibility period[d] (*Swift* & ASTRI)
Mrk 501	0.033	7	C-1 OR C-2	2.1×10^4	AUTO[f]	Apr. 2025–Sep. 2025
Mrk 421	0.030	50	C-1 OR C-2	5.0×10^4 [e]	AUTO[f]	Dec. 2024–May 2025
1ES 1959+650	0.047	10	C-1 OR C-2	3.0×10^4	AUTO[f]	Nov. 2024 Apr. 2025–Nov. 2025
BL Lacertae	0.067	0.5	C-1 OR C-2	1.5×10^3	AUTO[f]	Nov. 2024–Dec. 2024 June 2025–Nov. 2025

The *Swift* Team allowed us to change the proposed trigger conditions and observe **Mrk 501 for the granted 25 ks**

Moreover, we issued **ToOs on BL Lac**

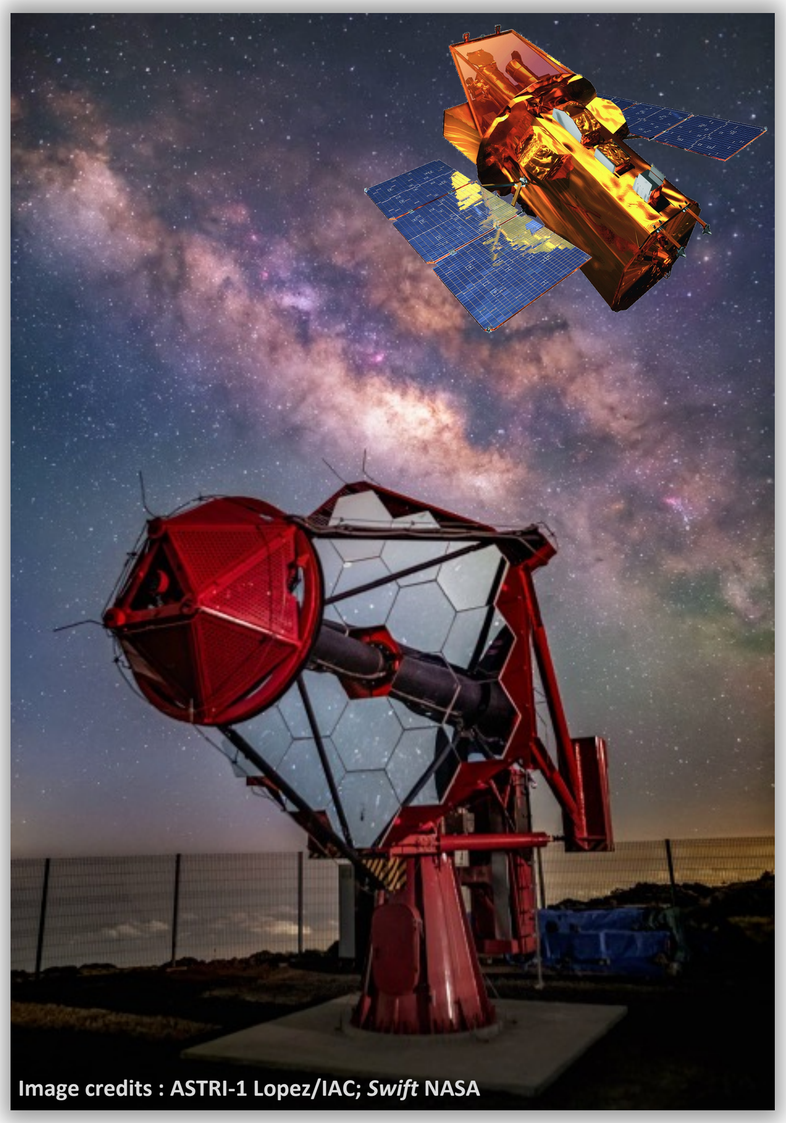
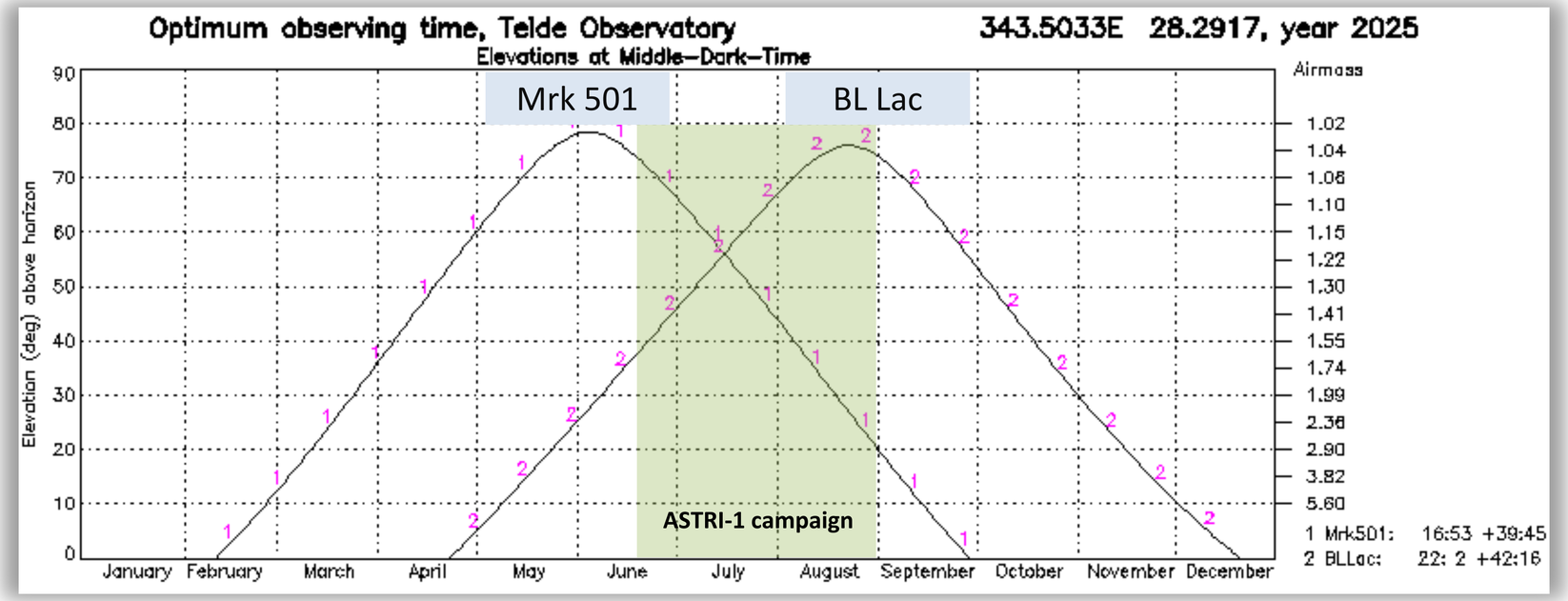


Image credits : ASTRI-1 Lopez/IAC; *Swift* NASA

ASTRI-1 Campaign on Mrk 501 & BL Lac



Blazar commissioning
June 22 – August 31 2025

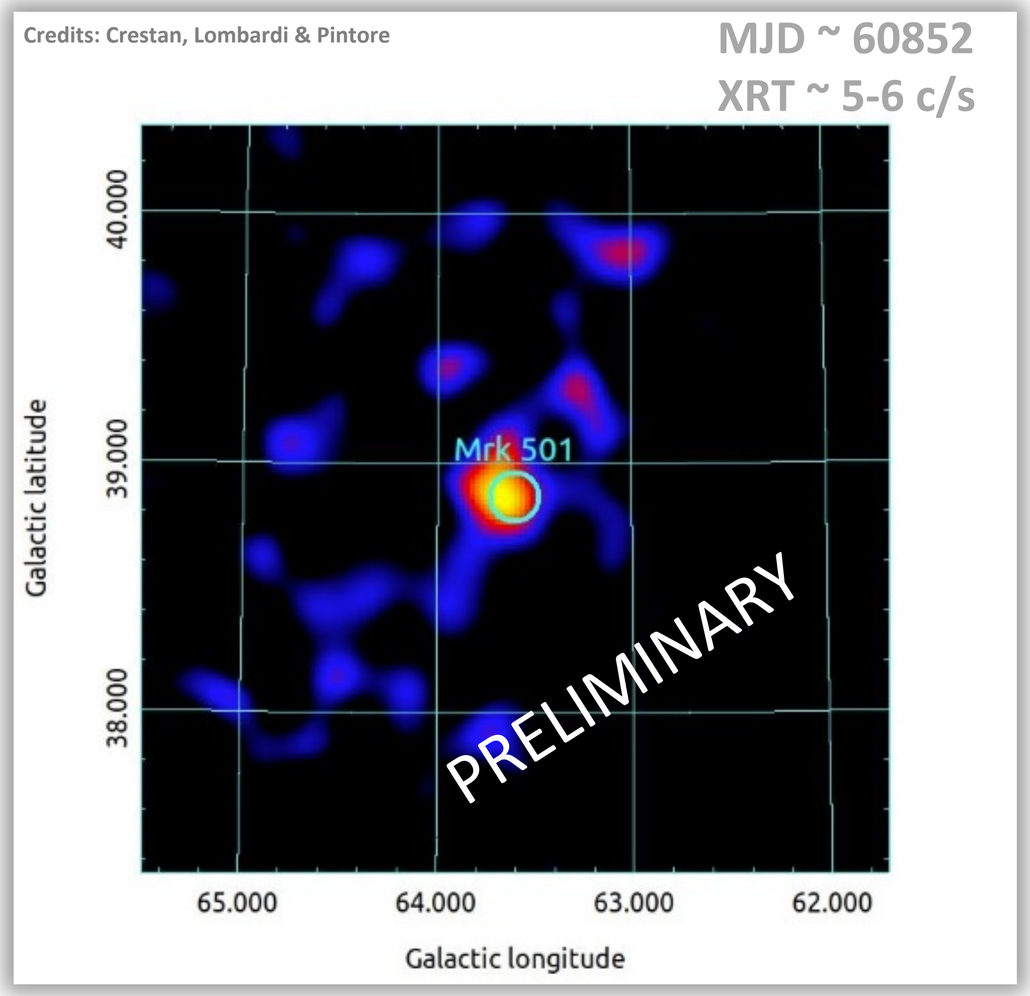
ASTRI-1 (before cut selection)
- 30hr on Mrk 501
- 64hr on BL Lac

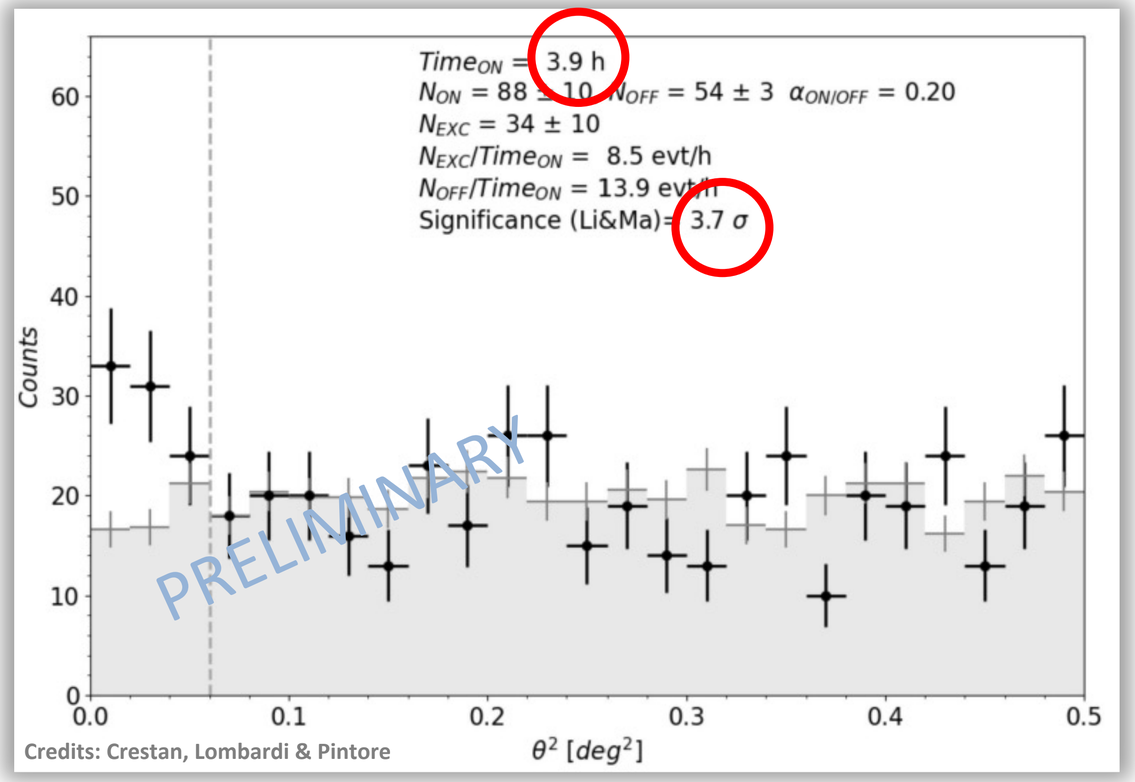
Swift
- 20ks on Mrk 501
- 10ks on BL Lac

Preliminary *Swift* analysis shows that we observed these sources are in a intermediate (Mrk 501) and quiescent (BL Lac) states

ASTRI-1 data analysis is ongoing

ASTRI-1 preliminary results – Mrk 501

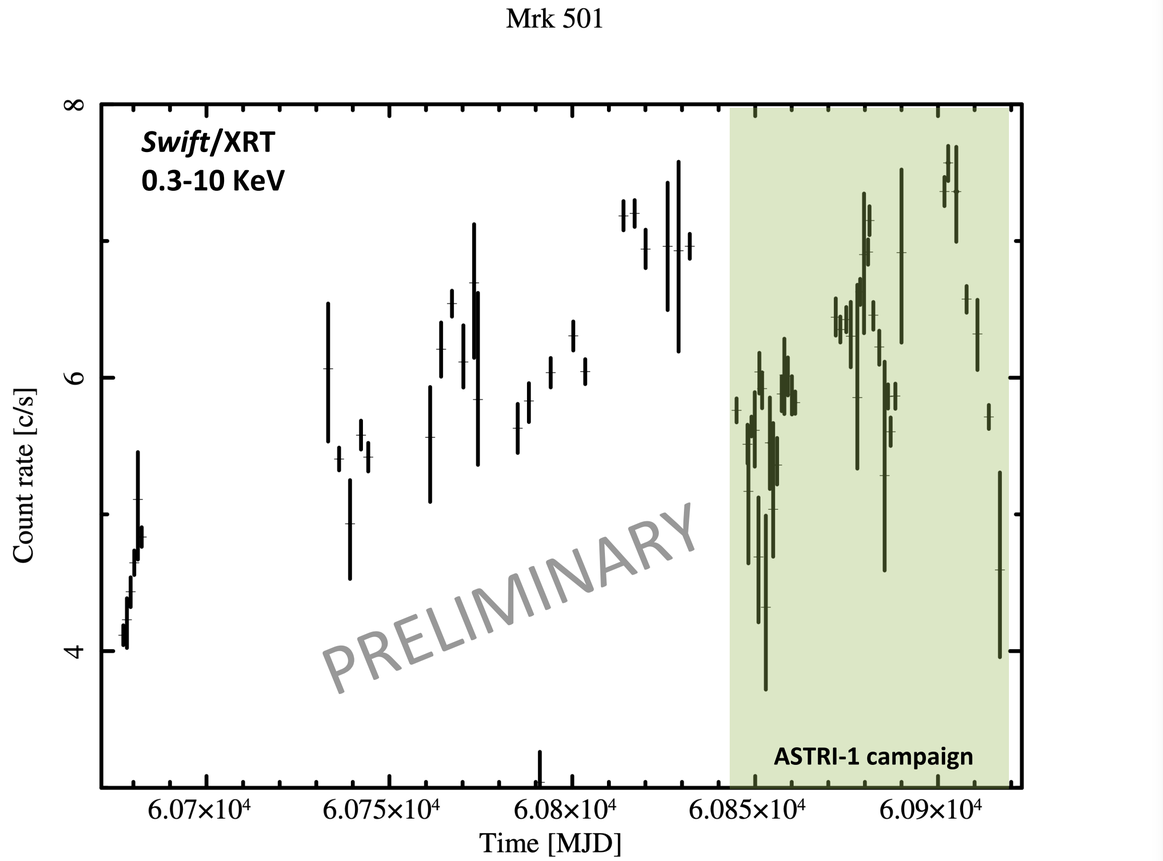




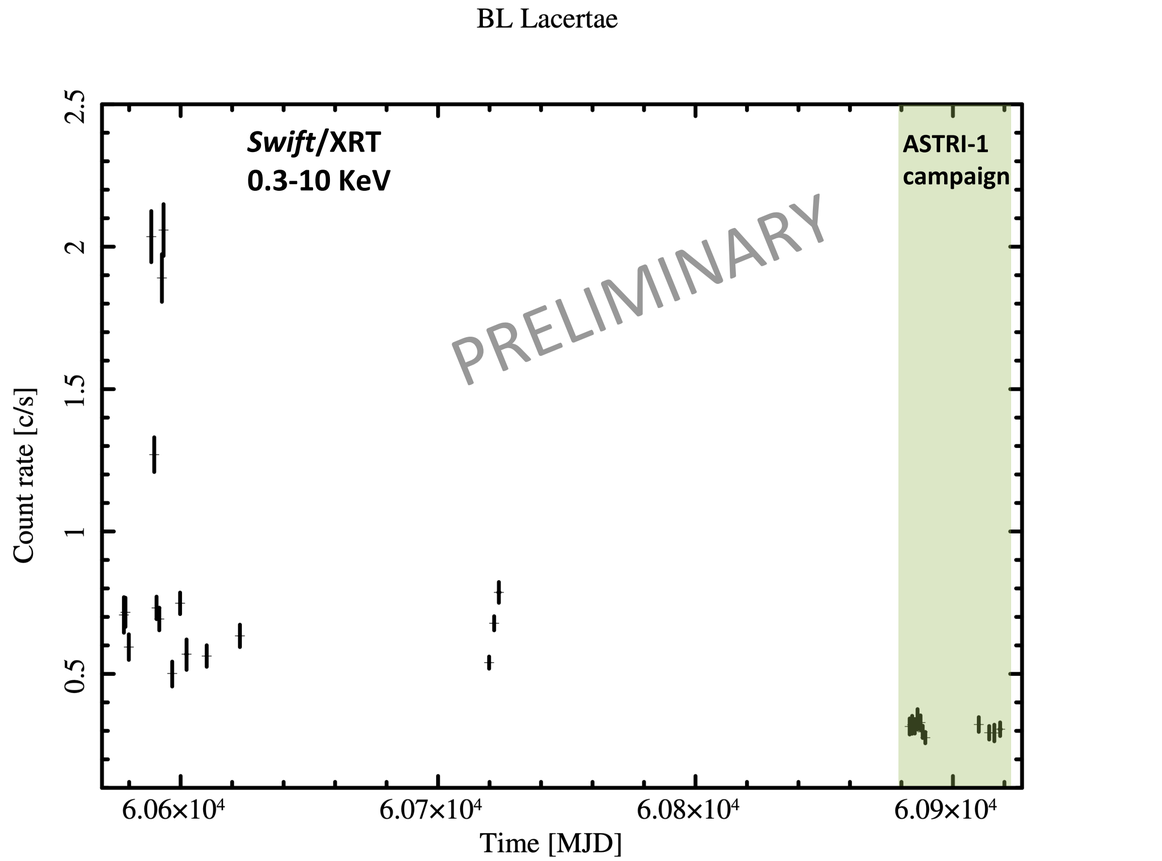
Weak detection of Mrk 501 (~ 0.5 Crab) 26-06-2025

First source detected after the Crab

Mrk 501 & BL Lac with *Swift*

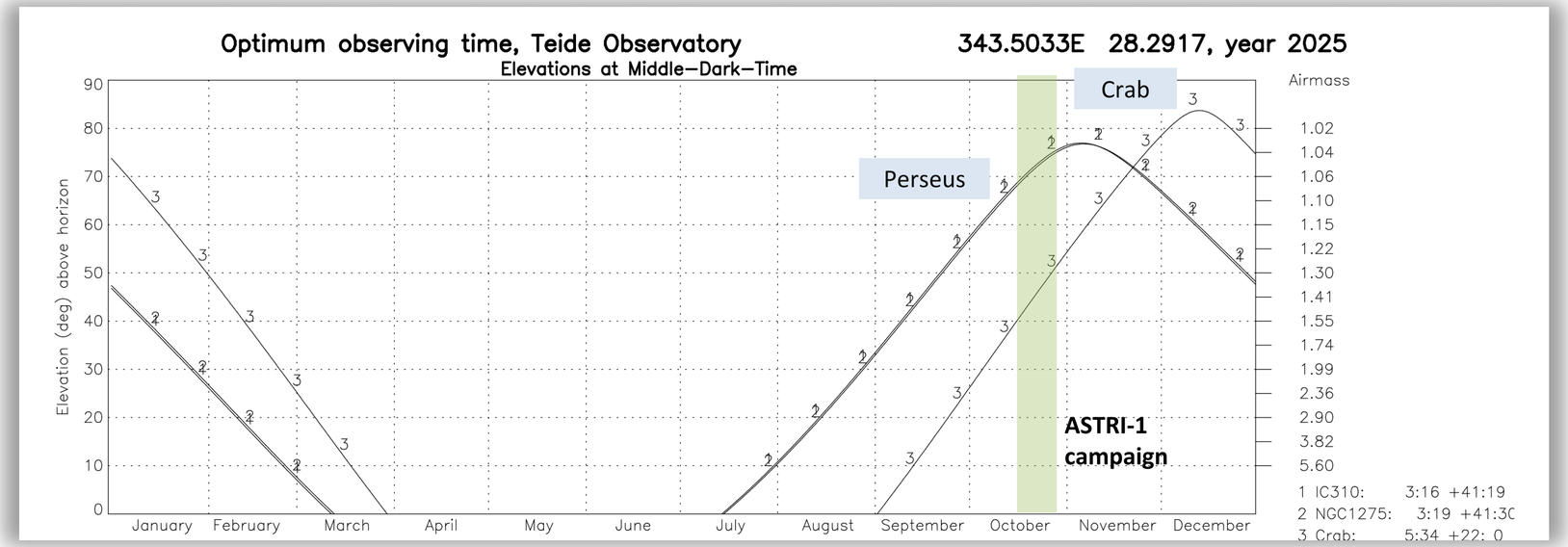


Romano, Vercellone et al., in preparation



Romano, Vercellone et al., in preparation

ASTRI-1 campaign on Perseus



Blazar commissioning
October 16 – 26 2025

ASTRI-1 (before cut selection)

- 12hr on Crab
- 10hr on Perseus

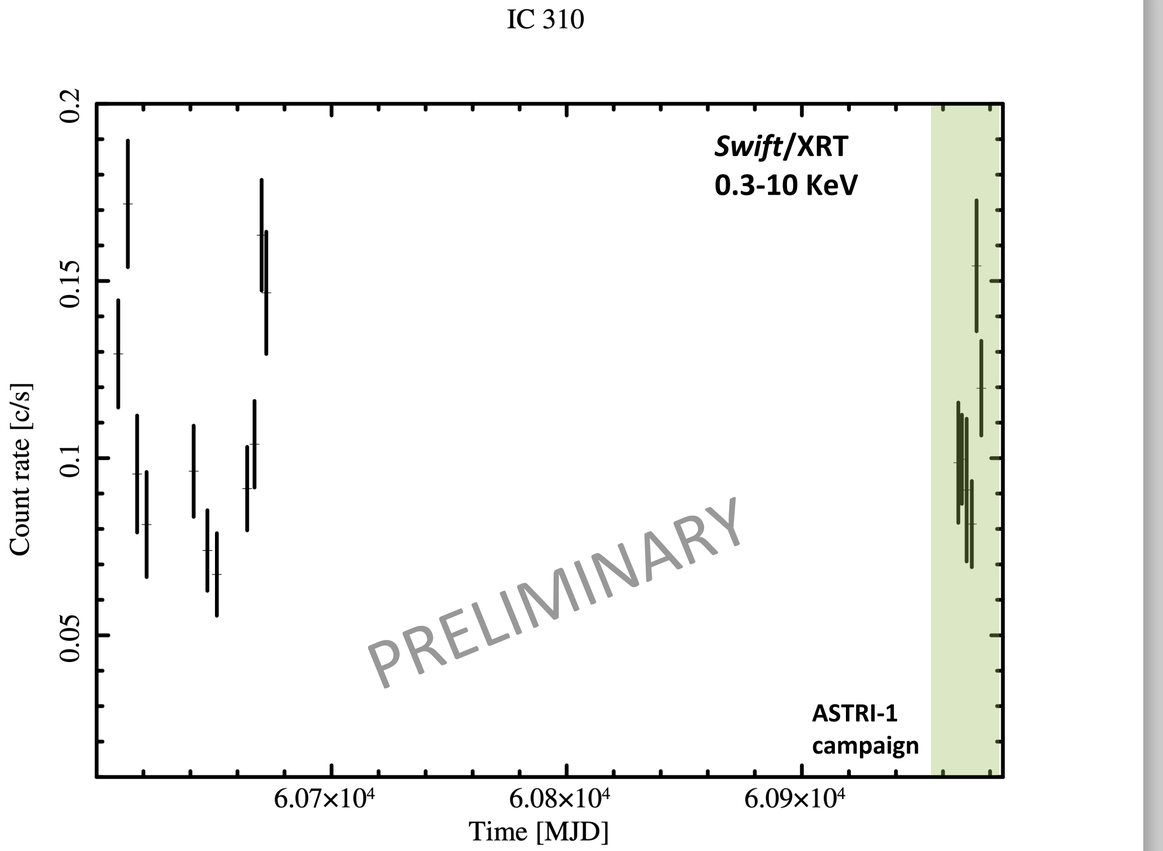
Swift

- 4.2ks on NGC 1275
- 4.7ks on IC 310

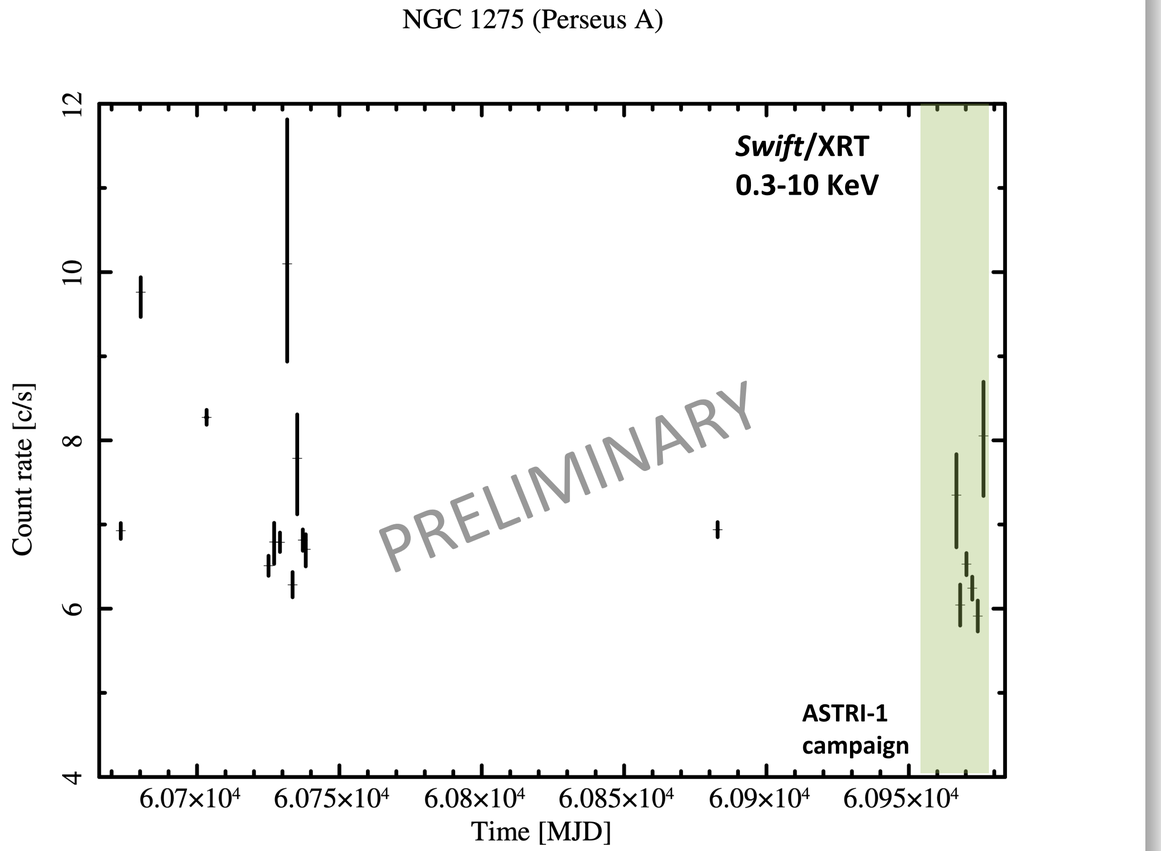
Preliminary *Swift* analysis shows that we observed these sources in a low/intermediate state

ASTRI-1 data analysis is ongoing

IC 310 & NGC 1275 (Perseus) – *Swift*



Romano, Vercellone et al., in preparation



Romano, Vercellone et al., in preparation

2026 Commissioning observations

New Year’s fireworks

ASTRI – LHAASO collaboration

Collaboration between ASTRI Mini-Array and LHAASO-WCDA

(Stefano Vercellone & Min Zha)

Starting from mid of May 2025, we established a preliminary agreement with LHAASO-WCDA to receive email alerts from their real-time AGN monitoring program.

Detected 1 flare(s).

Mrk 421 **2025 Dec. 8th**

Continue Flaring	Name	Position(R.A,Dec,J2000)	Sig_max(in sigma)	Duration	MJD	Flux(Crab Units > 1 TeV)
✗	Markarian421	166.20,38.16	5.87	0.5	61016.97 - 61017.14	1.4

We activated our **MWL monitoring with *Swift***
Since January 2026 we started **dedicated ASTRI-1 observations**

ASTRI-1 preliminary results – Mrk 421

ASTRI-1 detection of enhanced very high-energy gamma-ray emission from Mrk 421 at TeV energies

ATel #17602; *S. Crestan (INAF/IASF Milano), C. Quartiroli (INAF/IASF Milano), A. Sunny (INAF/IAPS Roma), S. Lombardi (INAF/OAR Roma), F. Lucarelli (INAF/OAR Roma), F. Pintore (INAF/IASF Palermo), for the ASTRI Project*

*on **15 Jan 2026; 17:41 UT***

Credential Certification: Fabio Pintore (fabio.pintore@inaf.it)

Subjects: Gamma Ray, TeV, VHE, AGN, Blazar

Referred to by ATel #: 17622

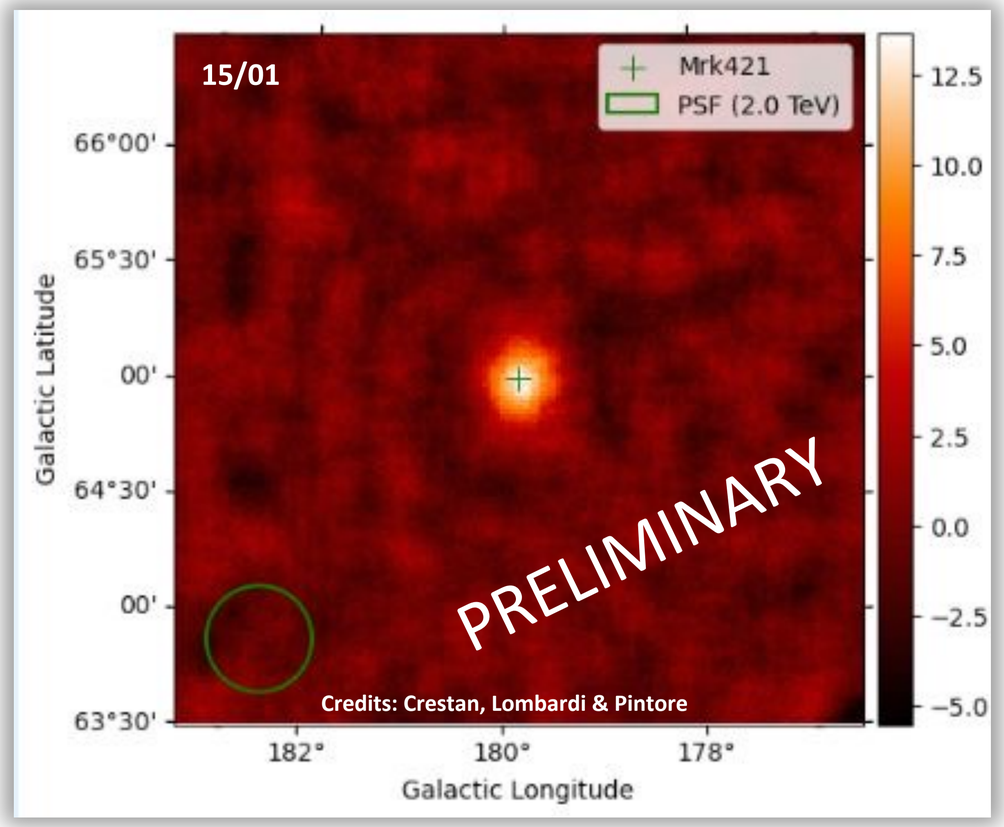
Tweet

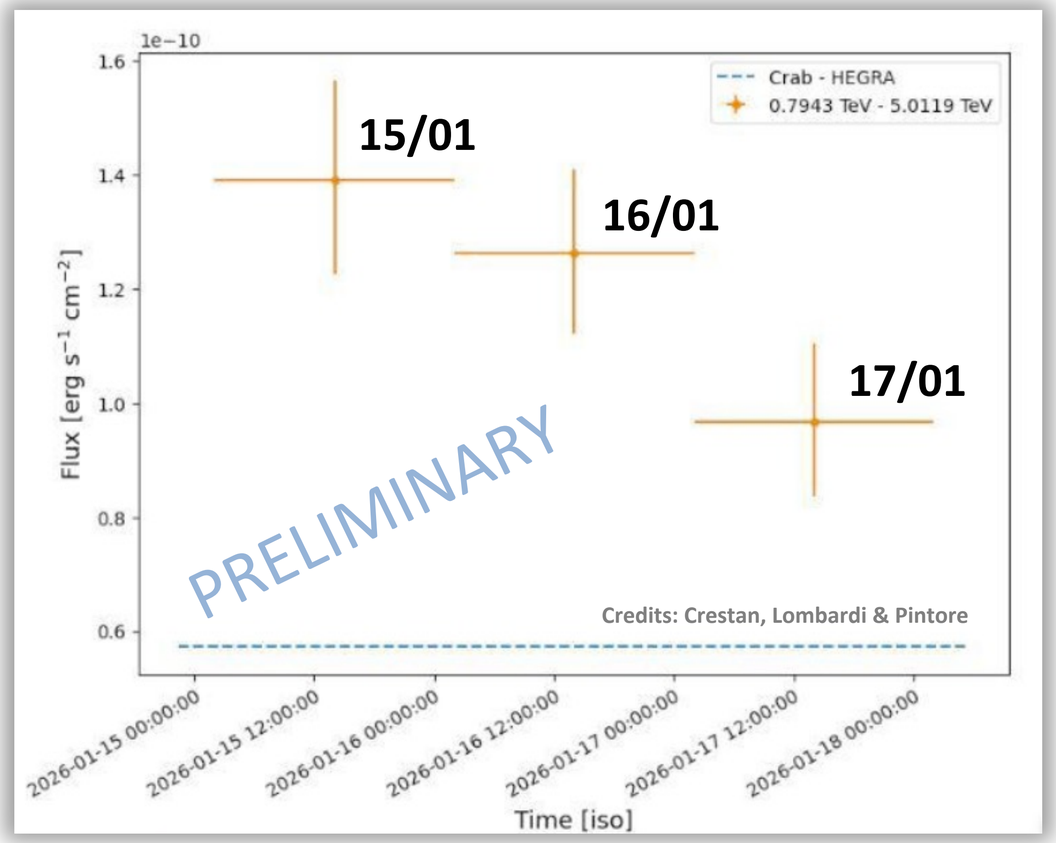
ATel issued in about 12 hours!

The ASTRI-1 telescope has observed an increase in the very high-energy gamma-ray flux from the blazar Mrk 421 (z = 0.031). Observations were performed between 2026/01/15 - 2:00 UTC (MJD 61055.08) and 04:40 UTC (MJD 61055.20) for a total effective observation time of approximately 2.5 hr. A preliminary analysis of the collected data reveals a significant detection of 11 sigma. The detected gamma-ray flux between 0.8 and 5 TeV is estimated to be 2.3 +/- 0.3 (stat) Crab Units.

ASTRI-1 preliminary results – Mrk 421

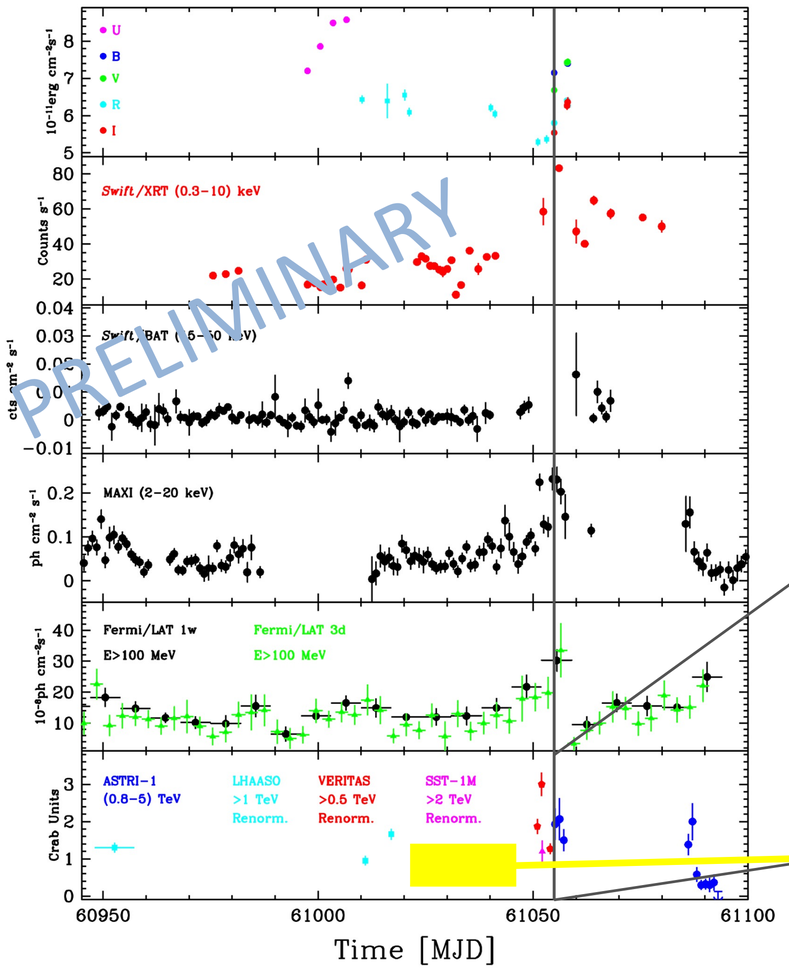
Semi-automatic quick-look data analysis





Mrk 421 multi-wavelength campaign

ATel



Vercellone et al., to be submitted

Astronomy & Astrophysics manuscript no. output
July 3, 2026

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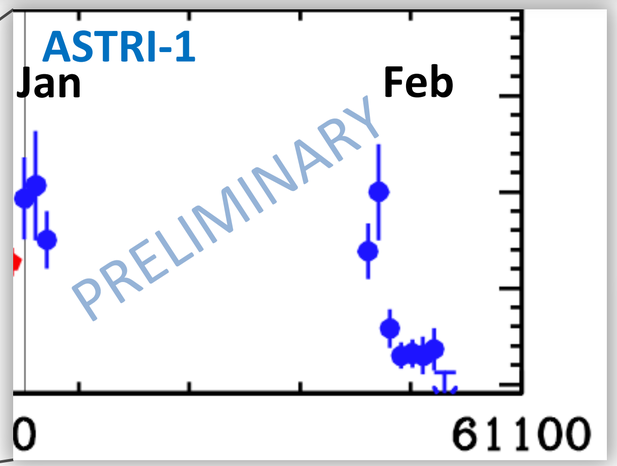
ASTRI Mini-Array and multi-wavelength observations of Mrk 421 during the January 2026 flare

S. Vercellone[1]⋆, F. Pintore[2], S. Lombardi[3], S. Crestan[4], A. Giuliani[4], P. Romano[1], F. Tavecchio[1], F. Casaburo[3,5,6], C. Bartolini[7,8,9], S. Ciprini[6,10], G. La Mura[11], J. Becerra González[12,13], M. Capalbi[3], G. Bonnoli[1], G. Pareschi[1], C. Quartiroli[4,14], A. Sunny[15,16], F. Lucarelli[3], V. F. Ramazani[17], F. Wierda[17,18], A. Marchini[19], G. Verna[19], S. Leonini[20], M. Conti[20], P. Rosi[20], L. M. Tinjaca Ramirez[20], A. Nastasi[21], S. Masiero[21], A. Squilloni[21], and ***Many Many Many Others...***

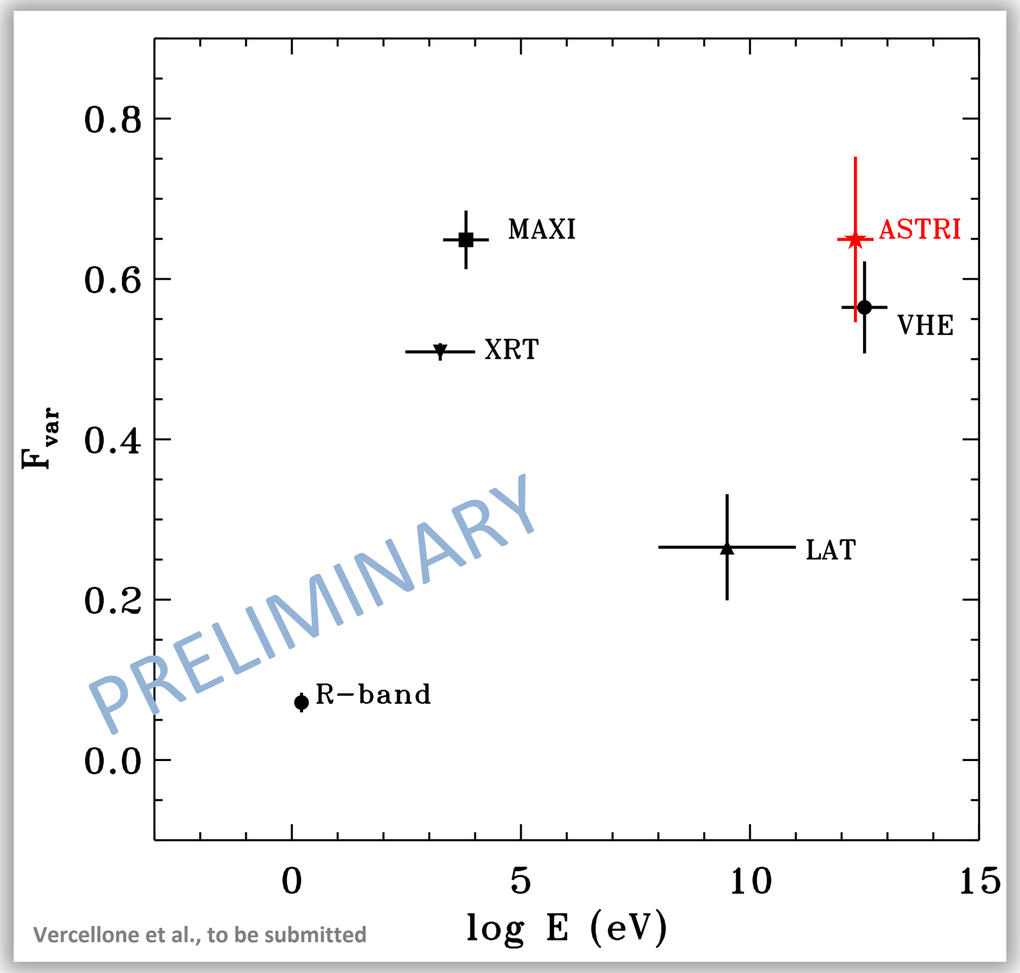


Mrk 421 multi-wavelength campaign

Variability studies

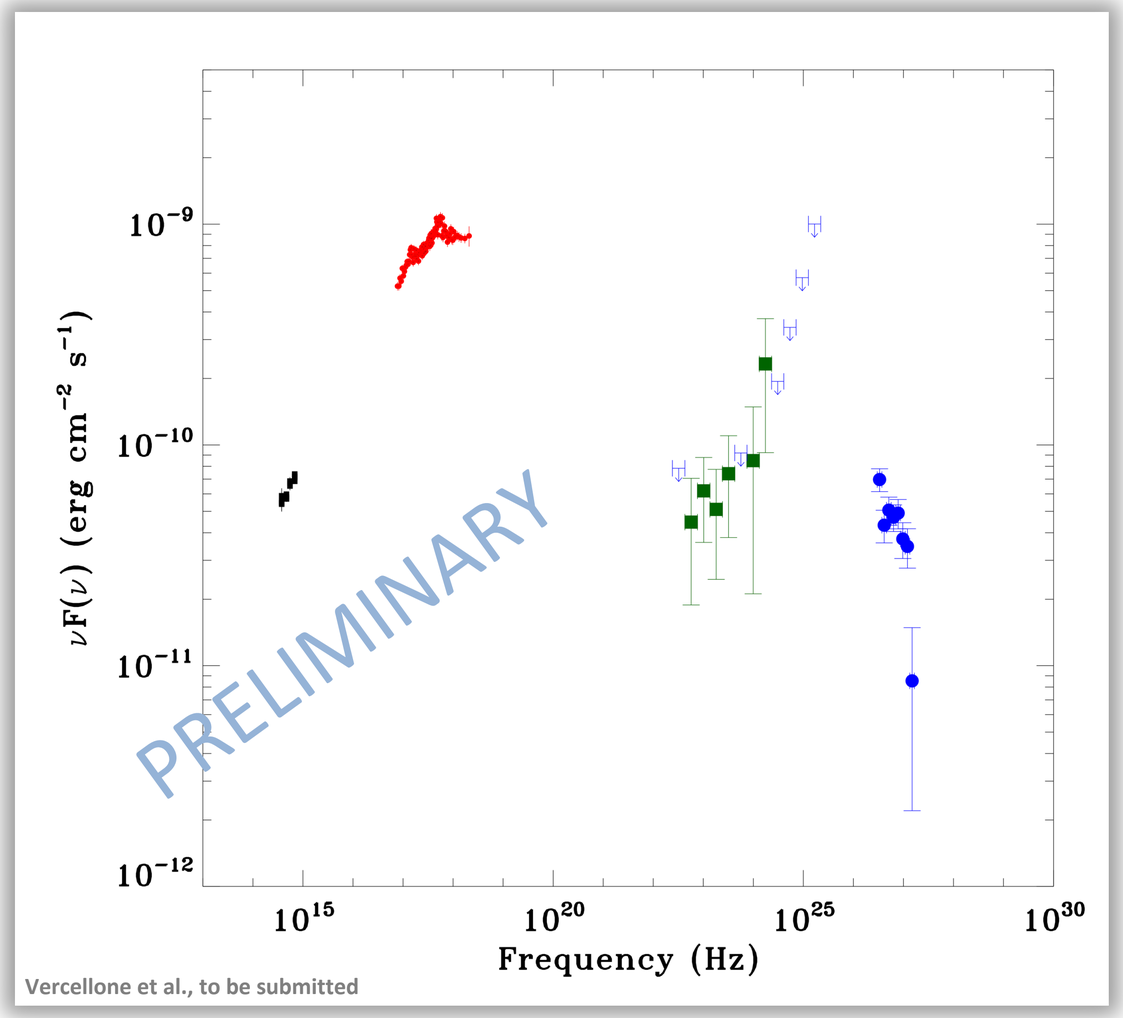
D/R	R	D
	Swift/XRT (bin = snapshot)	
τ_d	1.12	0.69
$\sigma(\tau_d)$	6.35	102.44
$CR(t_1)$	16.39 ± 2.30	30.77 ± 0.19
$CR(t_2)$	31.02 ± 0.20	11.01 ± 0.62
t_1	61010.1416	61031.0217
t_2	61011.1762	61032.0400
	MAXI/GSC (bin = 1 d)	
τ_d	0.62	0.76
$\sigma(\tau_d)$	8.86	3.10
$CR(t_1)$	0.073 ± 0.017	0.062 ± 0.012
$CR(t_2)$	0.23 ± 0.019	0.025 ± 0.012
t_1	61050.5	60966.5
t_2	61051.5	60967.5
	Fermi/LAT (bin = 3 d)	
τ_d	-	0.91
$\sigma(\tau_d)$	-	3.42
$CR(t_1)$	-	$(33.5 \pm 8.8) \times 10^{-8}$
$CR(t_2)$	-	$(3.4 \pm 2.2) \times 10^{-8}$
t_1	-	61056.5328
t_2	-	61059.5328

PRELIMINARY



Vercellone et al., to be submitted

Mrk 421 multi-wavelength campaign



Vercellone et al., to be submitted

Optical: MJD 61055

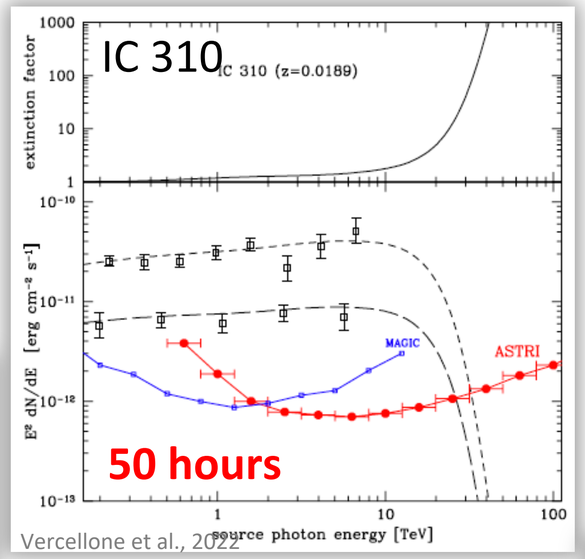
XRT: MJD 61055 (LP)
α = 1.77
β = 0.24

LAT: MJD 61055 – 61057 (PL)
Γ = 1.75

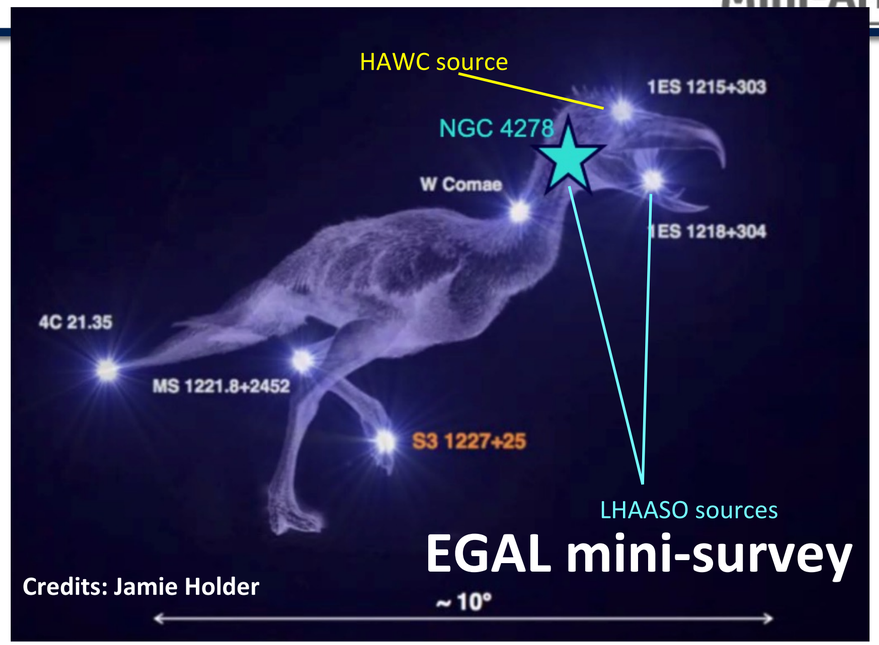
ASTRI-1: MJD 61055 – 61057 (PL)
ASTRI-1 spectral index in agreement with the LHAASO one in a similar energy range (Zha & Cao, priv. comm.)

Perspectives for EGAL science

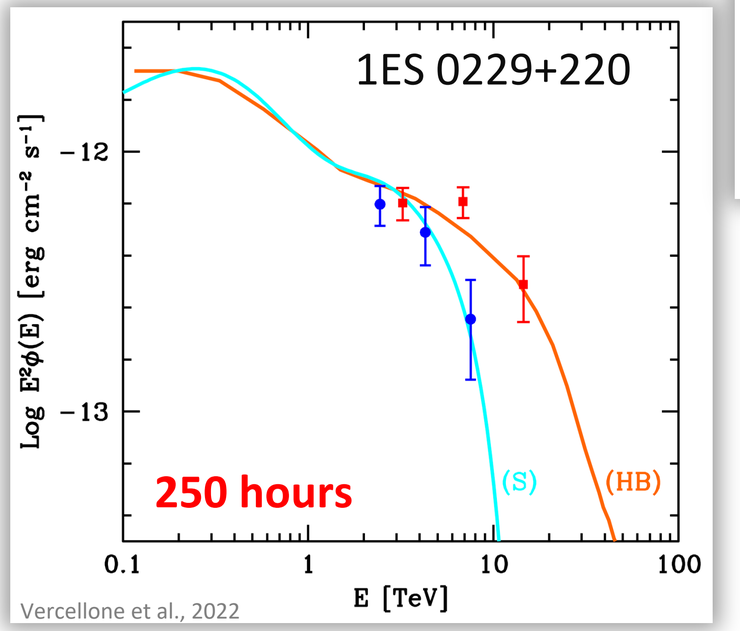
EBL in IR



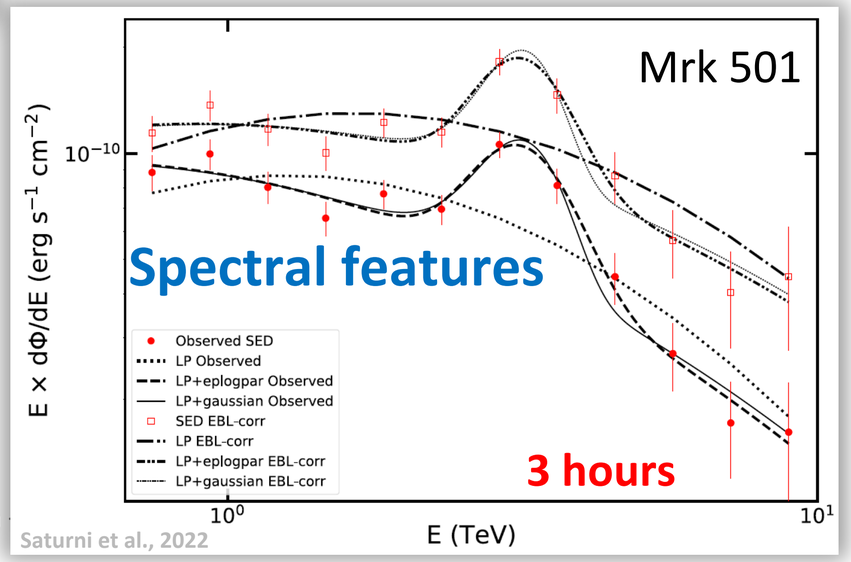
Vercellone et al., 2022



Hadron beams



Vercellone et al., 2022

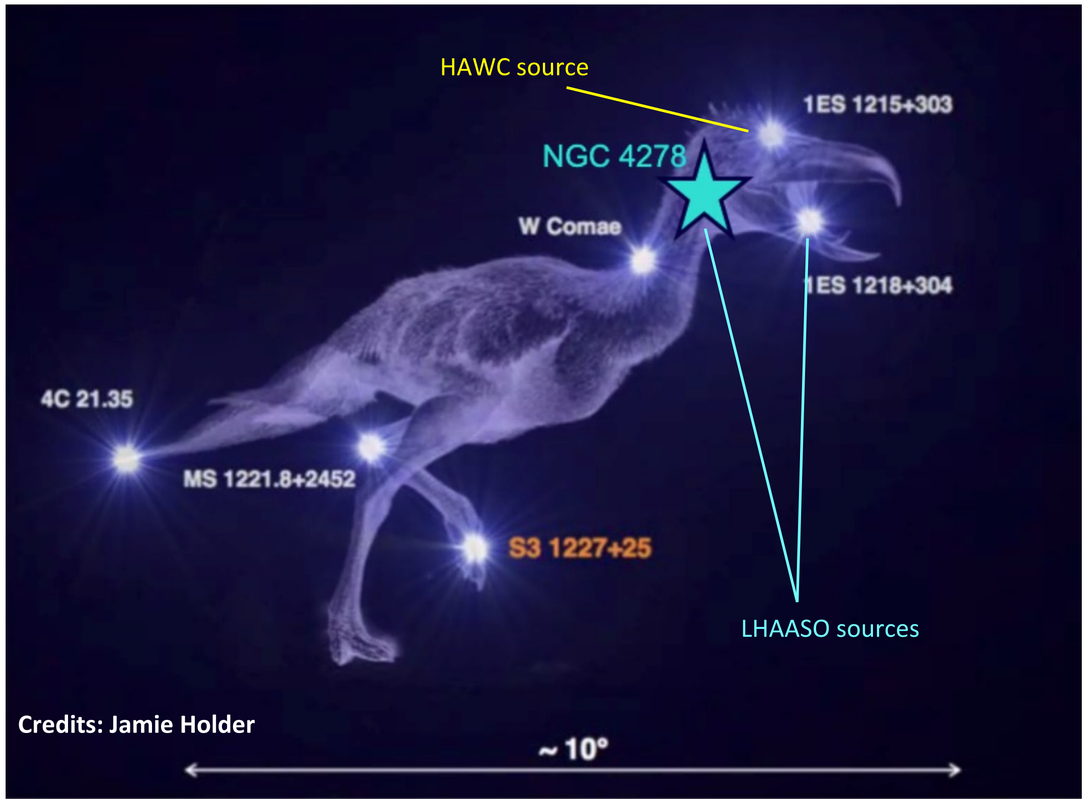


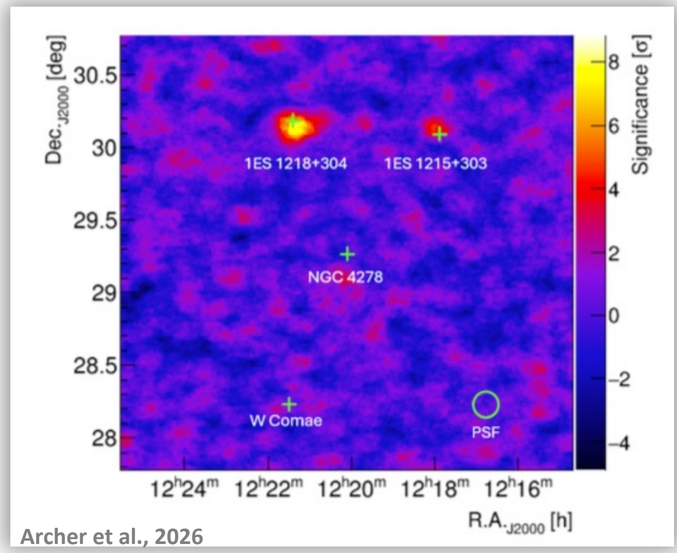
Saturni et al., 2022

ASTRI Mini-Array large FoV

TeraBird Constellation

All sources can be observed in the same period, namely between the **end of January and the end of May**





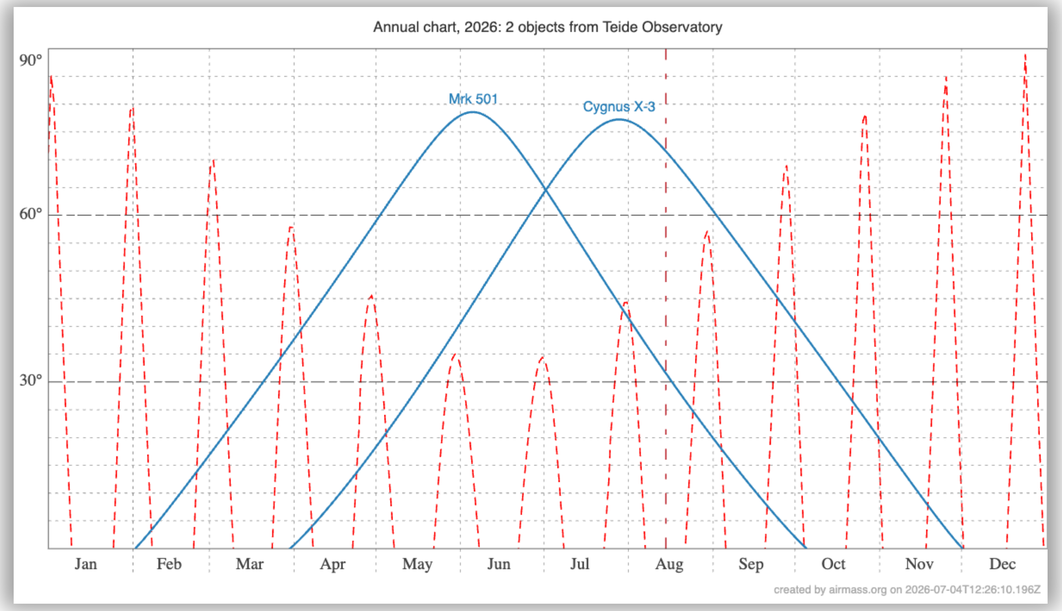
6.93hr (2021 March 7 and 2022 April 28)

23.8 minutes during the LHAASO flare

VERITAS almost simultaneous observazions of the «head» of the TeraBird Constellation during the LHAASO detection of NGC 4278.

Excellent prospects for ASTRI

In the meanwhile,…



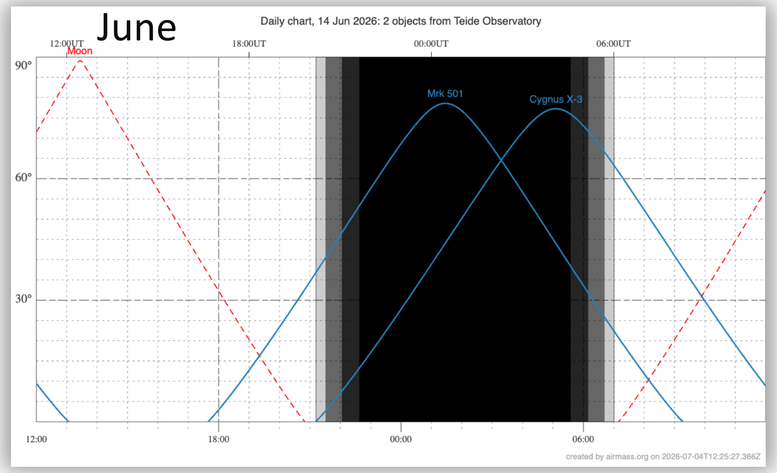
Multi-purpose campaign on Mrk 501 as a secondary target w.r.t. the Cygnus Region

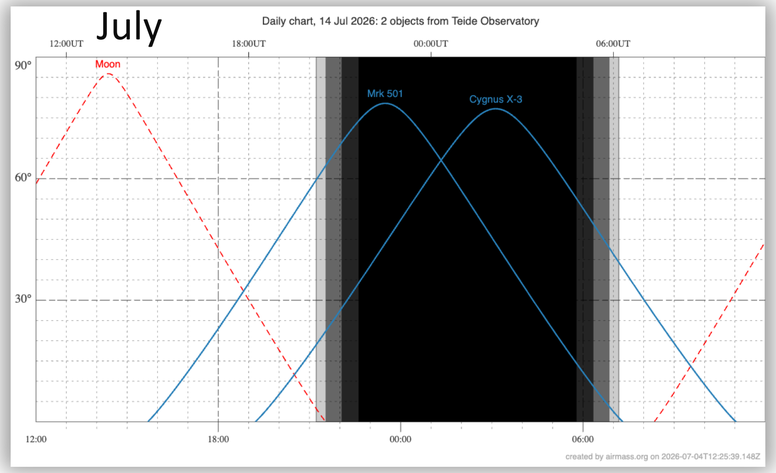
Inter-calibration

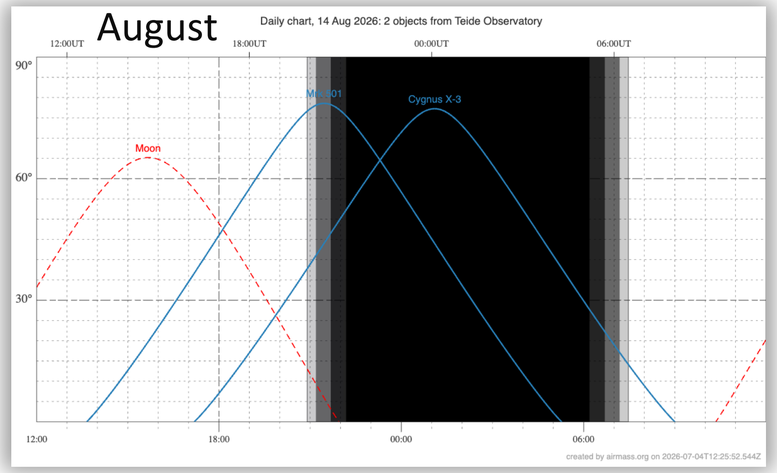
- MAGIC (Paneque, Arbet-Engels et al.)

MWL

- GASP-WEBT (Raiteri et al.)
- Radio (Giroletti, Marchili et al.)







Strategic VHE/UHE synergies

- Both **MAGIC** and **CTAO-N** will be of paramount importance for their capability not only to investigate the local Universe, but also to reach **redshifts well beyond one** (hopefully!)

- Both **MAGIC** and **CTAO-N** will allow us to extend the ASTRI Mini-Array spectral performance in the **sub-TeV regime**, with almost no breaks **from a few tens of GeV up to hundreds of TeV**

- Excellent **synergies with LHAASO/WCDA** for the **VHE alert of blazar** in a similar energy

Summary

- The Commissioning phase demonstrated the **excellent ASTRI performance on AGNs when in flare**, even in a single telescope configuration
- **Excellent analysis chain performance**: about 12 hours from data acquisition to ATel dissemination
- Extra-galactic jetted sources can yield important results on **different time-scales**, from a few months down to a few hours

Questions & Comments

Thank you


Photo credits : Lopez/IAC

stefano.vercellone@inaf.it

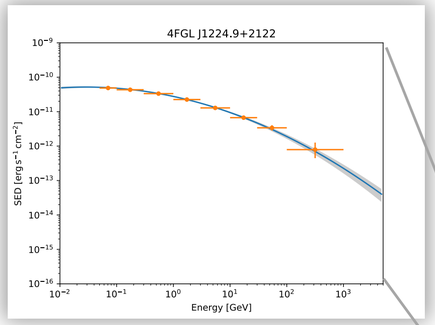
«There are more things in heaven and earth, Horatio,
Than are dreamt of in your philosophy.» [W. Shakespeare]

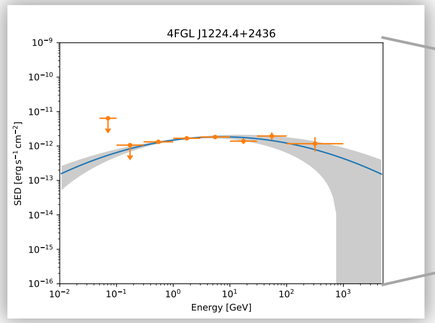
Extra slides

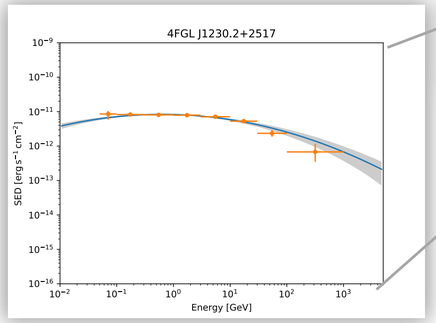
Mini-Array

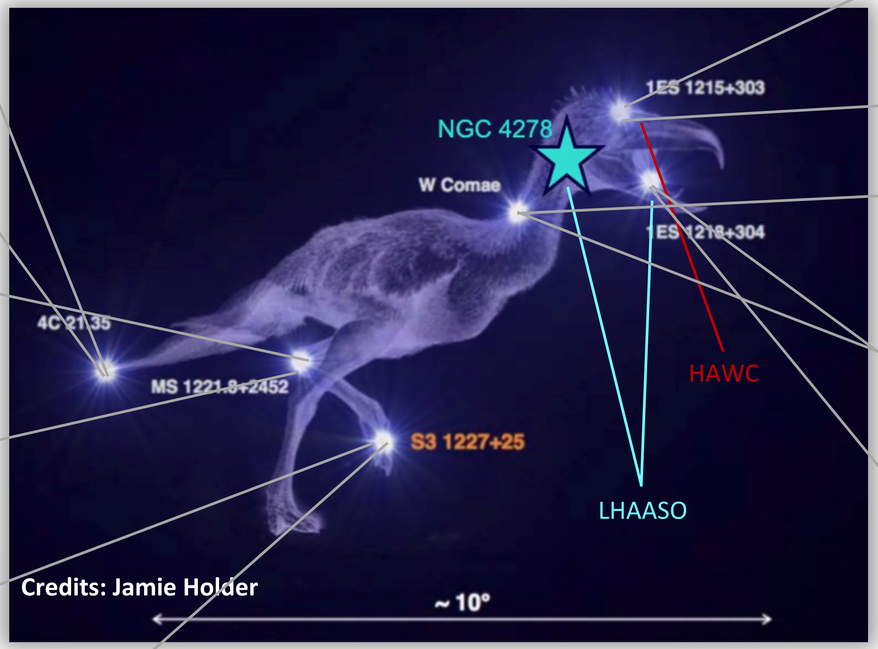
EXTRA SLIDES

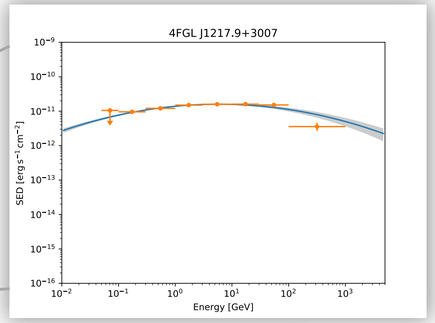
Large FoV and UHE jetted sources

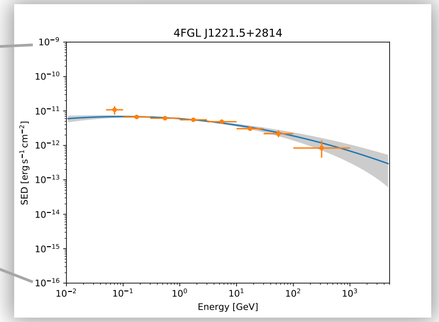


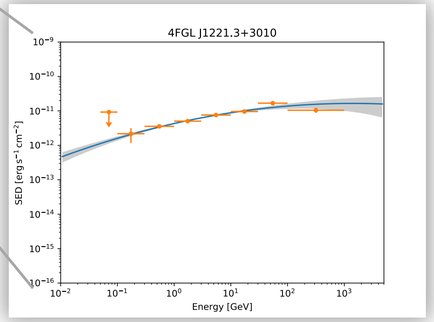






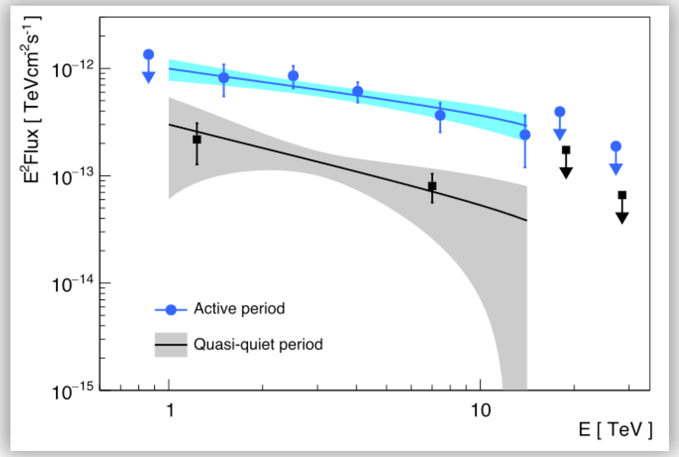




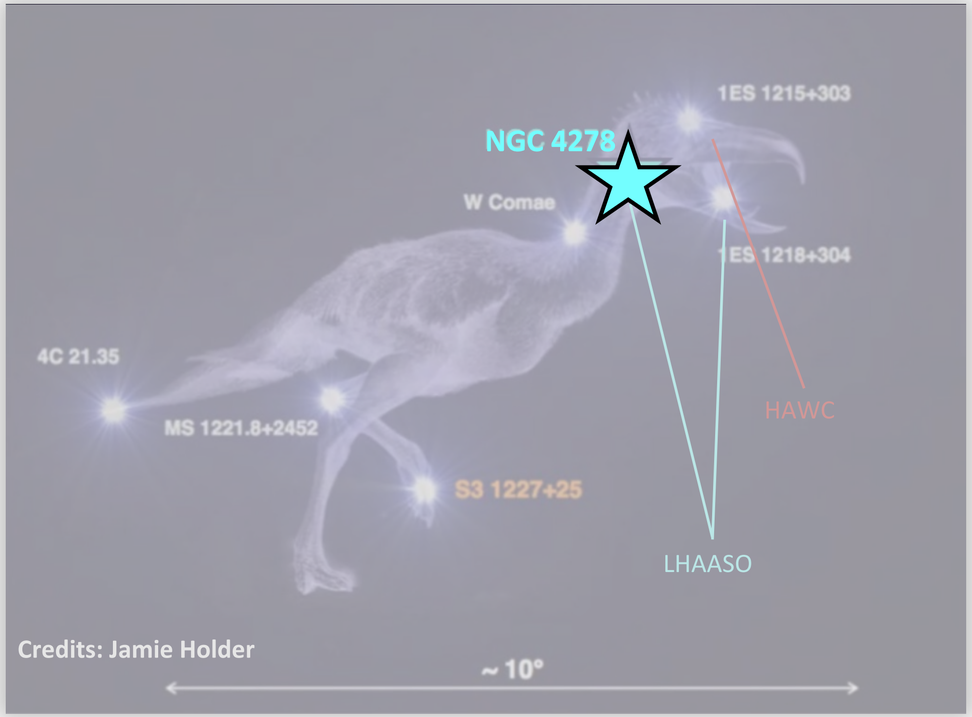


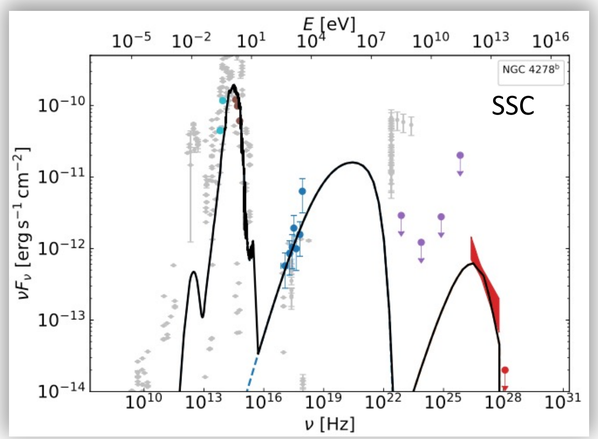
Fermi/LAT 4FGL spectra

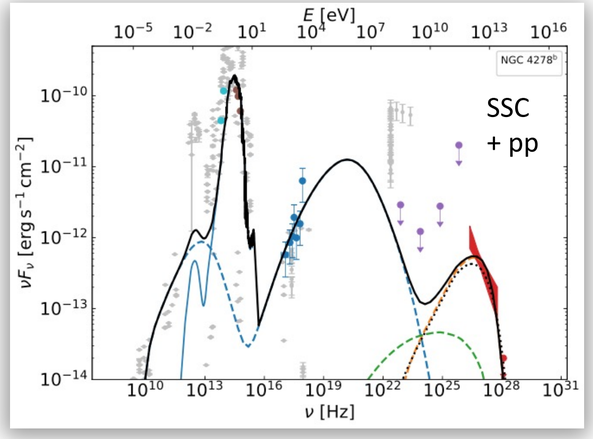
Large FoV and UHE jetted sources



Cao et al., 2024, ApJL, 971, L45

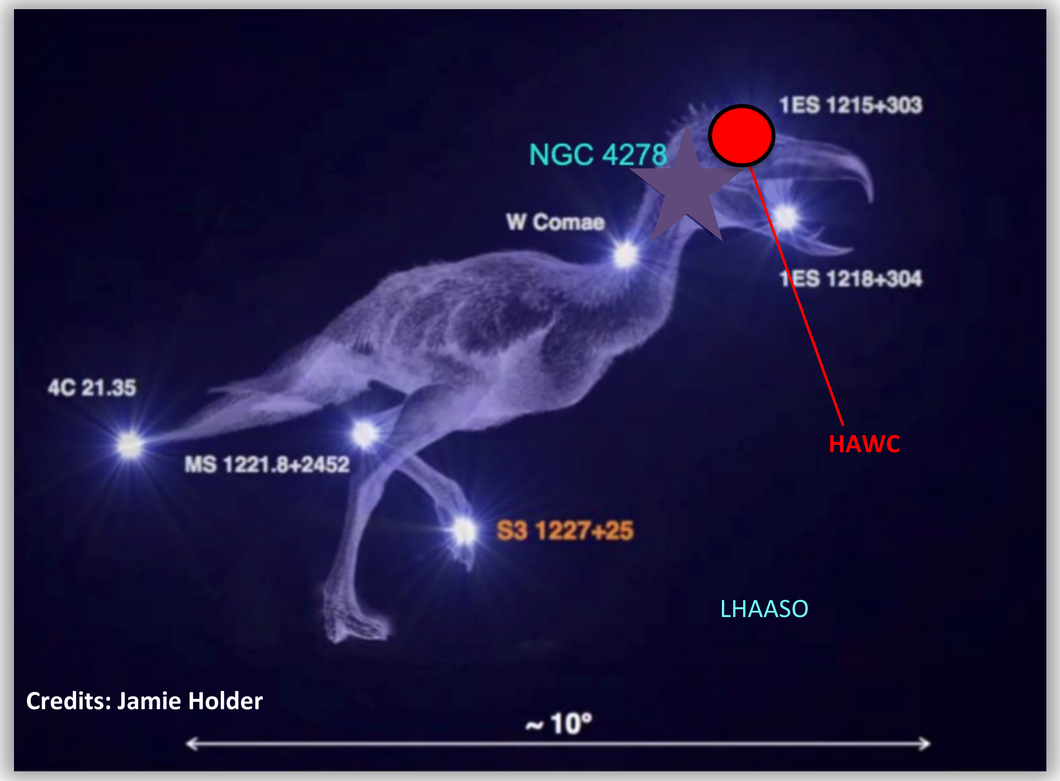


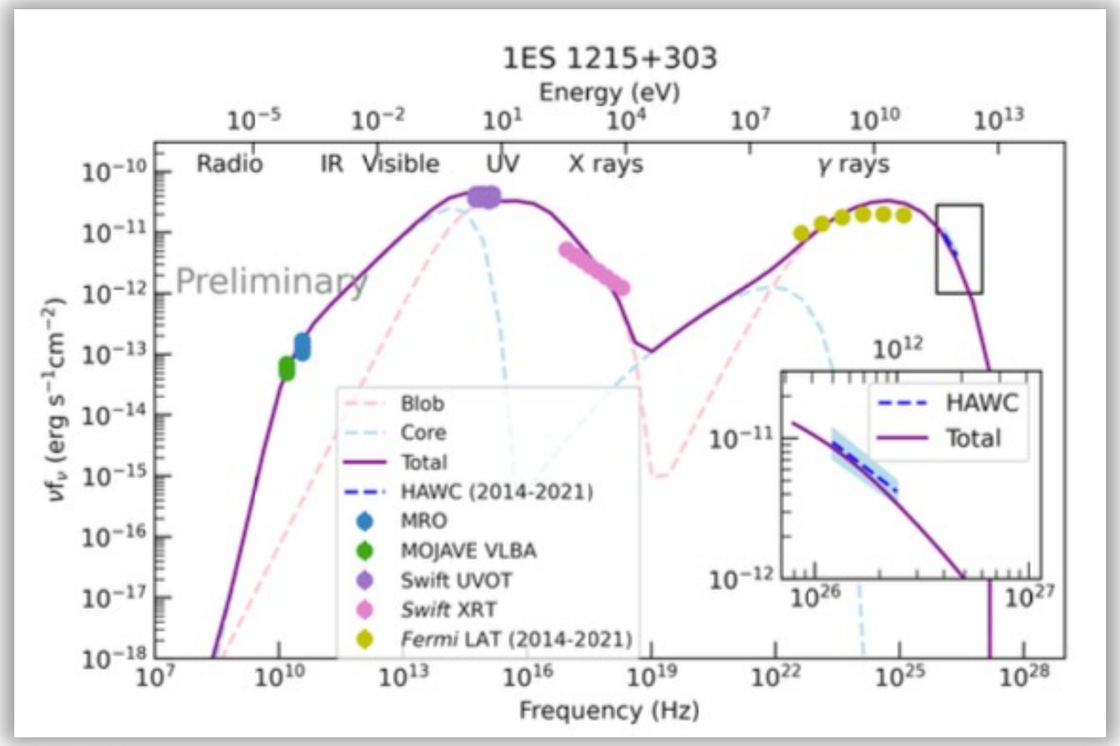




Wang et al., 2024, ApJS, 271, 10

Large FoV and UHE jetted sources





Ureña-Mena, 2023, arXiv:2310.02468v1

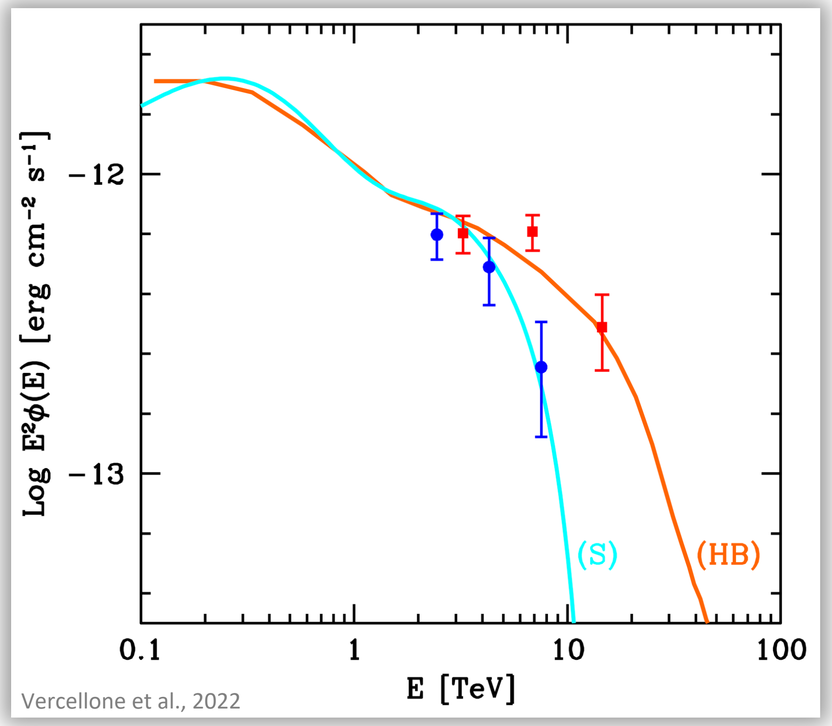
Fundamental physics – hadron beams

Relativitic jets from extreme BL Lacs could be one of the **UHECR acceleration sites**

Jets in extreme BL Lac objects could produce hadron beam (collimated beams of high-energy protons/nuclei)

While travelling towards the Earth

- UHECR lose energy through photo-meson and pair production
- these trigger the development of electromagnetic cascades producing γ and ν
- Because of the reduced distance, **γ experience a less severe EBL absorption**
- The **observed gamma-ray spectrum extends at energies much higher (E > 10TeV)** than those allowed by the conventional EBL propagation



Vercellone et al., 2022

Simulated VHE spectrum of 1ES 0229+220 for the **standard** (light blue, 200 hr) and **hadron beam** (red, 250 hr) scenarios

The ASTRI Mini- Array would be able to obtain a **significative detection up to 20 TeV with a deep observation ~250 hr**

EBL studies in the IR regime

From the **mid-IR to the far-IR**, where the IR background intensity is maximal, **EBL direct measurements are prevented** by the overwhelming dominance of local emission from both the Galaxy and our Solar system

wavelength of the target EBL photon — energy of the γ-ray

$$\lambda_{max} \sim 1.24 \times E_{TeV}\ [\mu m]$$

Measurements in the **(10-30)TeV energy band probe the EBL in the ~(10-30)μm regime**, otherwise unaccessible

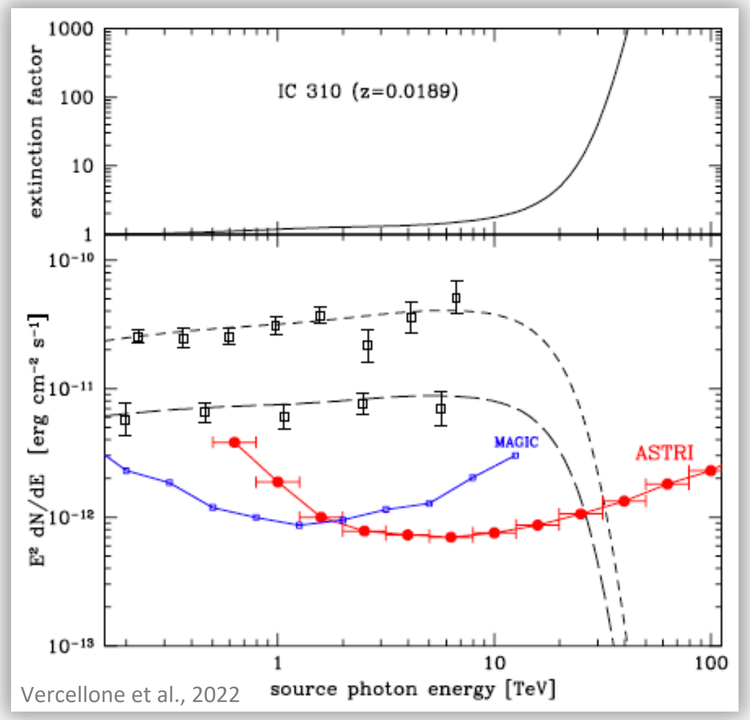
Best candidates to constrain the EBL up to $\lambda \sim 100\mu$m:

low-redshift radio galaxies

M 87, **IC 310**, Centaurus A

local star-bursting and active galaxies

M 82, NGC 253, NGC 1068



Vercellone et al., 2022

Upper panel: extinction factor for photon-photon interaction on EBL at the IC 310 source distance.

Bottom panel: MAGIC (blue dots) and ASTRI Mini-Array (red dots) **50 hours, 5σ differential sensitivity**

Spectral features in Mrk 501

Rationale

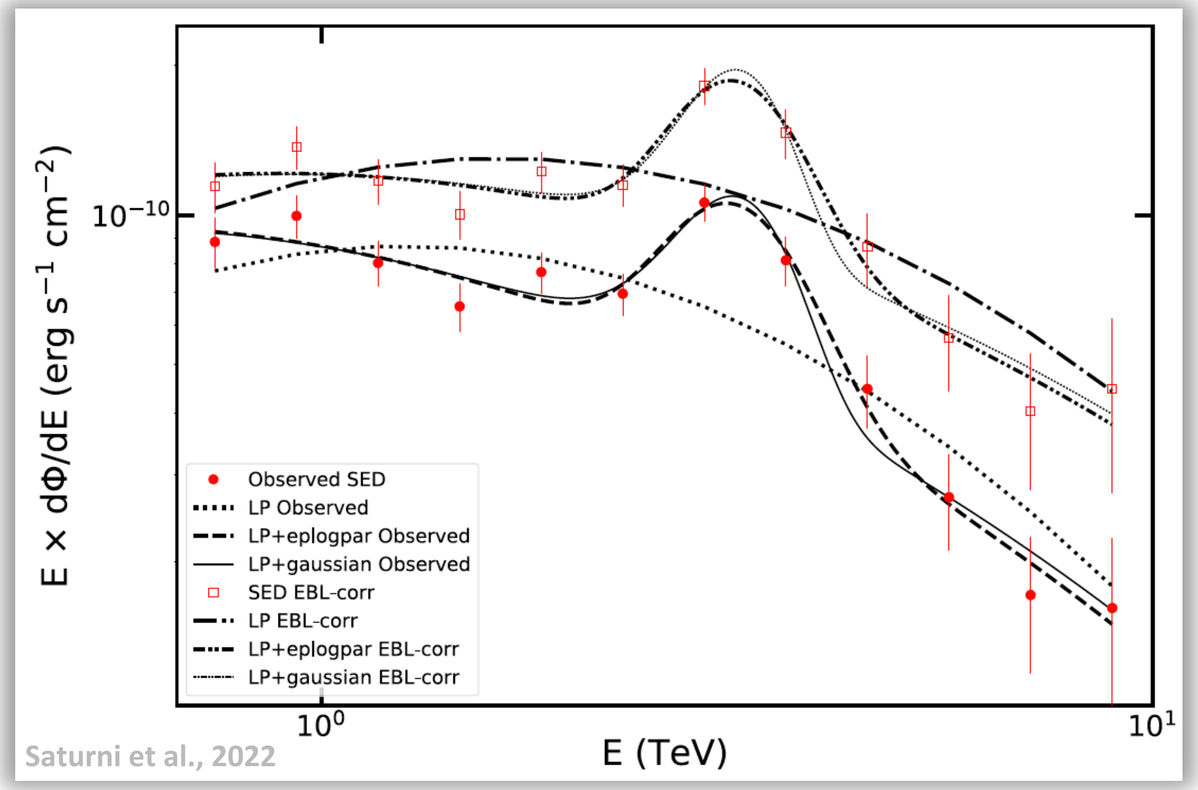
- A narrow spectral feature centered around 3 TeV was detected at ~4σ in coincidence with the day with the highest *Swift*/XRT X-ray flux (>0.3keV) (MAGIC Collaboration, 2020).

Method

- We investigated the percentage of number of detections of the spectral feature with respect to a broad LP above 5σ confidence level for 200 realizations.

Results

- In order to have at least a ~50% probability of detection of the feature, 1.5h of observation time would be required, increasing up **to ~80% probability for 2h of exposure.**



The VHE status at the Canary Island in 2027