The ASTRI Mini-Array follow-up of transient events in the TeV band

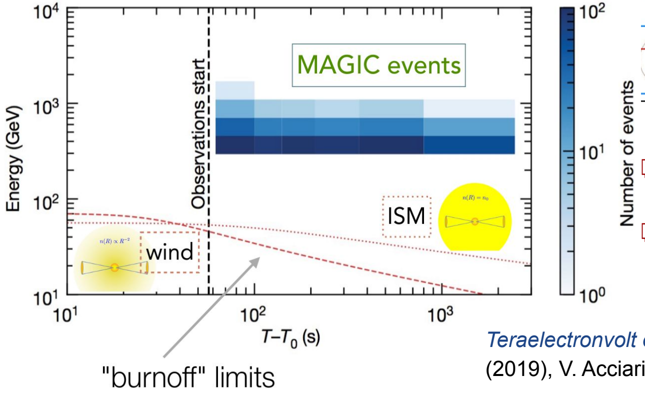
Alessandro Carosi - INAF Osservatorio Astronomico di Roma

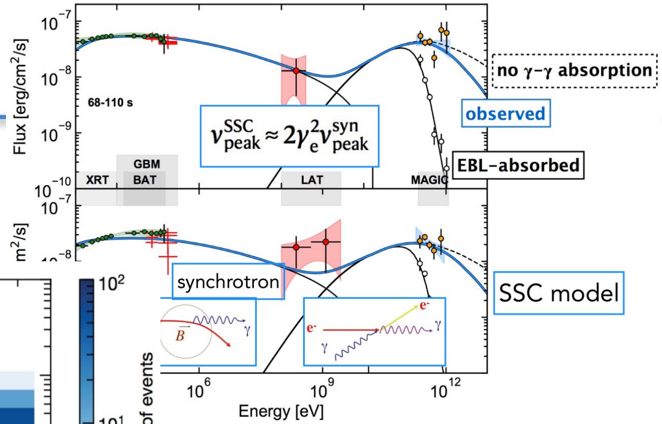
and A.Stamerra, L.Nava, G. Ghirlanda, L.A. Antonelli, A. D'Ai', F. G. Saturni, F. Lucarelli, S. Lombardi, F. Pintore, S. Scuderi, G. Tosti, A. Bulgarelli, S. Vercellone, A. Giuliani, G. Pareschi for the ASTRI Project

GRB at VHE: a long-awaited result

After ~20 years quest by current IACTs, GRBs were confirmed as a new class of TeV emitters

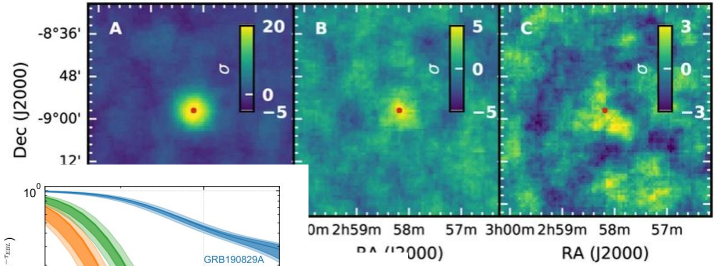
GRB 190114C

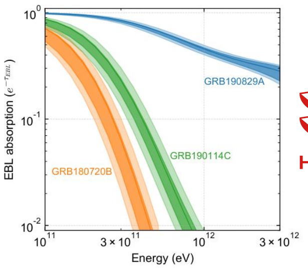




- Synchrotron burnoff limit largely exceeded
- First clear evidence of a second emission component (SSC - blazar-like)

Teraelectronvolt emission from the gamma-ray burst GRB 190114C (2019), V. Acciari et al. (MAGIC Collaboration) Nature, 575, 45





GRB 190829A

Revealing X-ray and gamma ray temporal and spectral similarities in the GRB 190829A afterglow, H. Abdalla et al. (H.E.S.S. Coll.), Science, 372, 6546

- 1st GRB unambiguous detection at TeV energies
- 1st GRB observed over 20 orders of magnitude in energy
- 1st GRB with unambiguous detection of a new energetic emission component distinct from synchrotron
- 1st single broad-band modeling of a GRB including both components
- Brightest TeV source ever detected (>~ 100 crab)

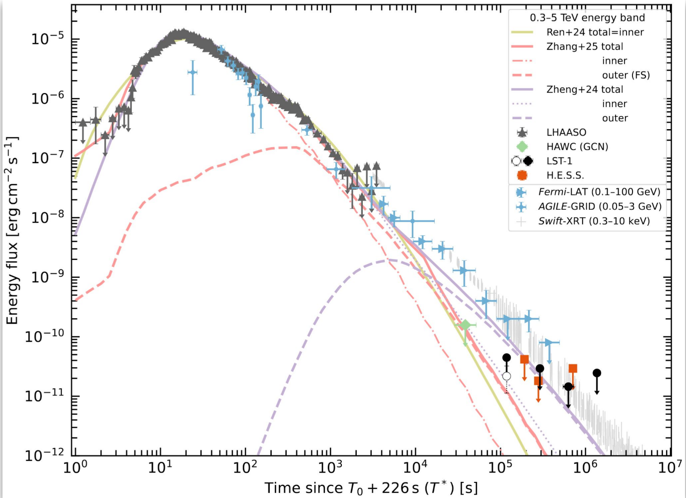
GRB at VHE: a long-awaited result

ASTRI Mini-Array

Name	T_{90} [s]	Redshift	E_{iso} [erg]	IACT	α_{obs}	E_{max}
180720B	48.9	0.653	6×10^{53}	H.E.S.S.	3.7 ± 1.0	440 GeV
190114C	362	0.4245	3×10^{53}	MAGIC	5.43 ± 0.22	1 TeV
190829A	58.2	0.0785	2×10^{50}	H.E.S.S.	2.59 ± 0.08	3.3 TeV
201216C	48	1.1	5×10^{53}	MAGIC	-	-
201015A	9.8	0.423	10^{50}	MAGIC	-	-

+ GRB 221009A LHAASO >~10 TeV

Abe et al. (LST-1 Collaboration), 2025, *ApJL* 988 L42

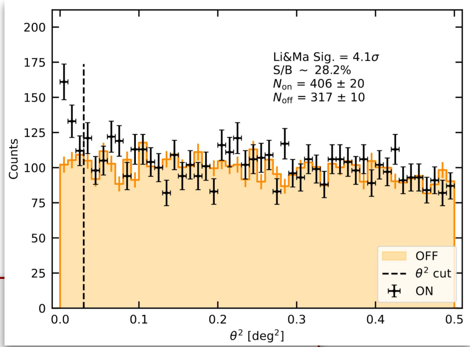


Super-powerful GRB

E_{iso} ~ 2×10^{54} erg

z = 0.151

detected up to **~multi TeV** with LHAASO but not with IACT



LST observation:

- 2022/10/10 ~21:34 UTC $T_0 + 1.1 \times 10^5$ sec (~31 h, red. HV)
- First two observing nights under strong moonlight
  + Several days under dark/low moonlight afterwards

GRB at VHE: a long-awaited result

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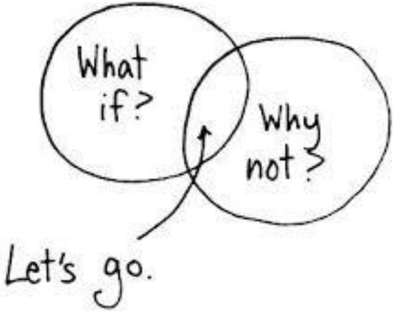
T_0+10h
T<~15 min
up to T_0+3days

\+ GRB 221009A LHAASO >~10 TeV

Fast reaction & low threshold are important but maybe not as important as we thought *for "simple" detection*

Although the physics they give access to is dramatically different (prompt-to-early-afterglow phase, time resolved spectra, high redshift…)

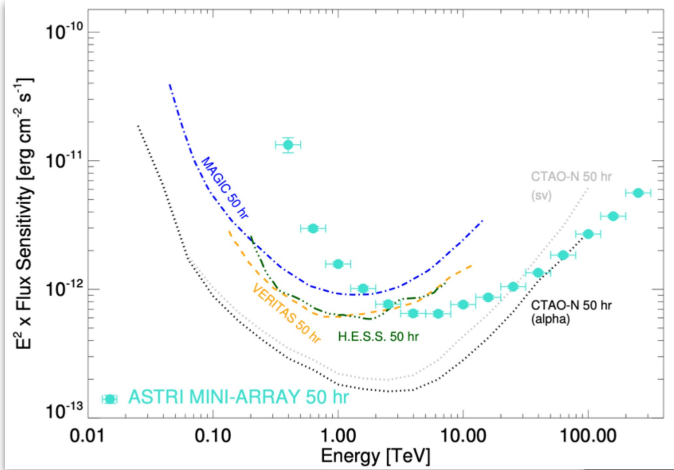
>~ TeV observations are possible also for GRBs. Opportunities for >Tev optimized instruments such as the ASTRI Mini-Array

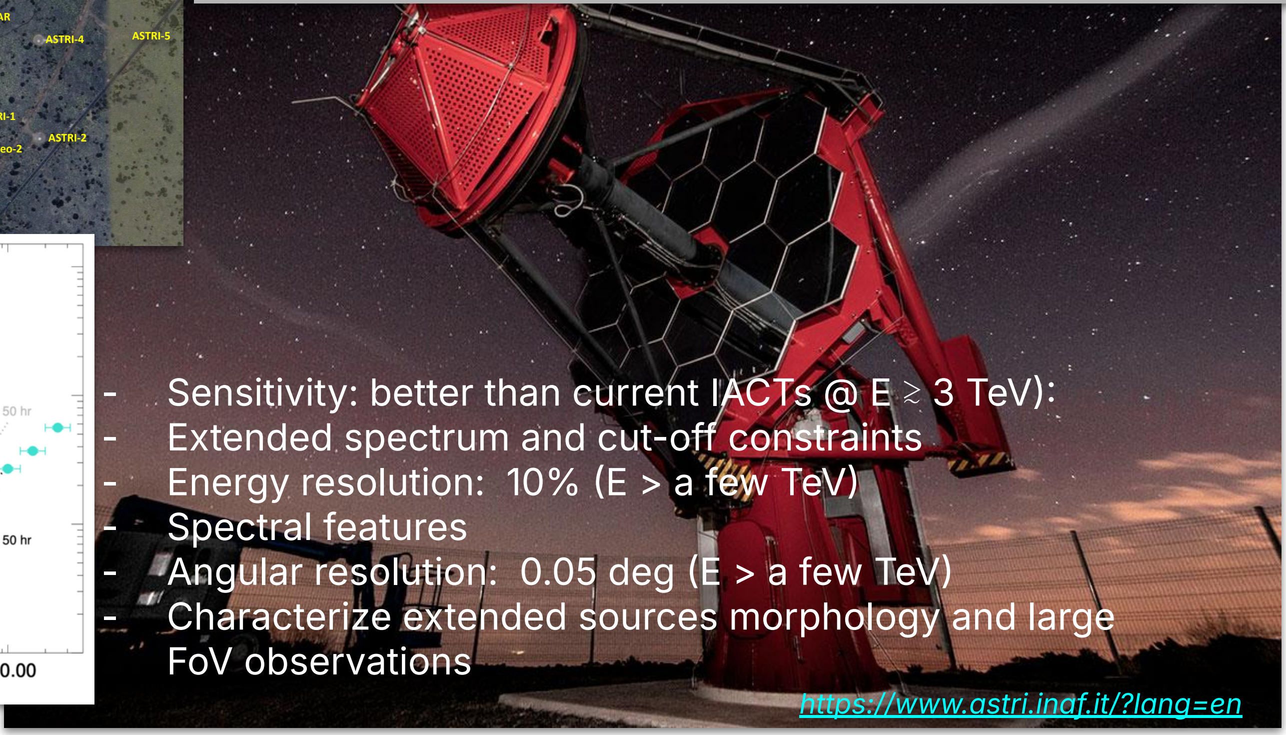


The ASTRI Mini-Array

The **ASTRI Mini-Array** (PI G. Pareschi) is an experiment based on 9 Cherenkov, dual-mirror, 4-meter class telescopes installed at the Observatorio del Teide in Tenerife

Telescopes are an evolution of the ASTRI-Horn prototype, optimized for observations from 1 to ~100 TeV (precursors for the SST CTAO array)



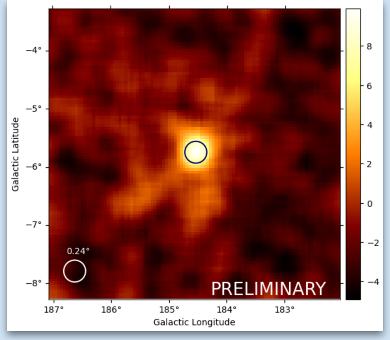


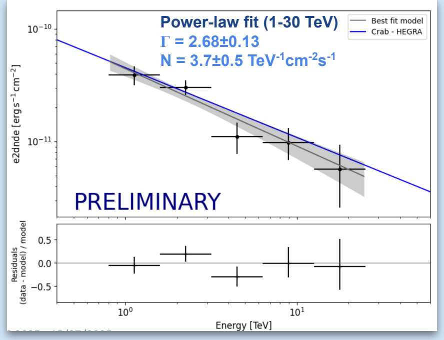
- Sensitivity: better than current IACTs @ E $\gtrsim$ 3 TeV):
- Extended spectrum and cut-off constraints
- Energy resolution: 10% (E > a few TeV)
- Spectral features
- Angular resolution: 0.05 deg (E > a few TeV)
- Characterize extended sources morphology and large FoV observations

https://www.astri.inaf.it/?lang=en

The ASTRI Mini-Array

ASTRI-1 preliminary results



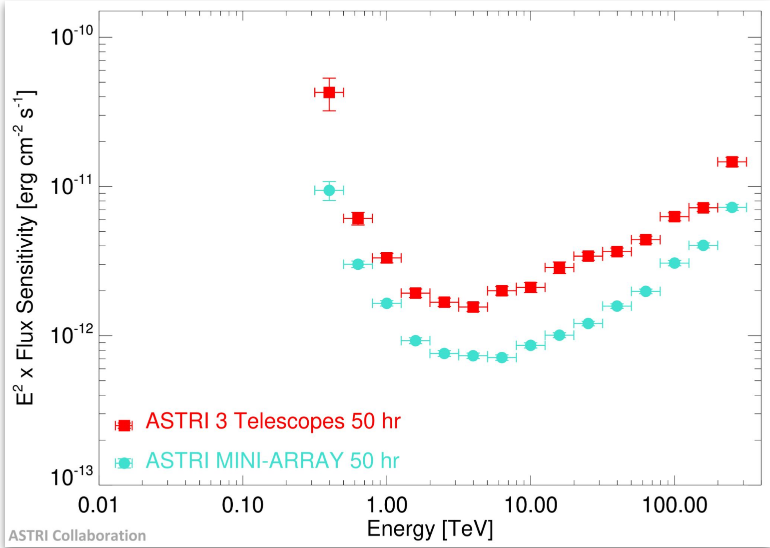


Crestan & Lombardi, ICRC2025

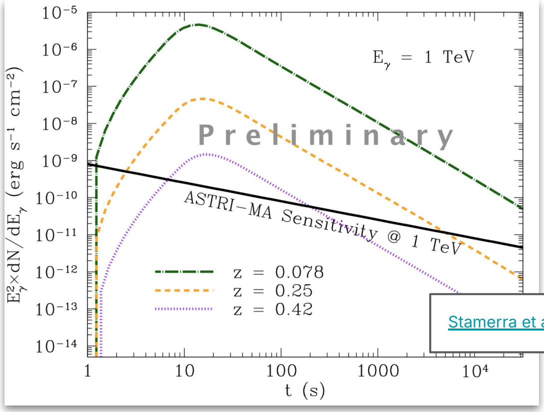
Crab Nebula data:
(Nov. 2024 – Feb. 2025)

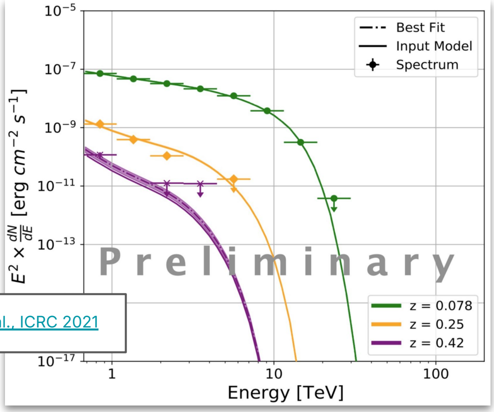
- subsample of ~9 hr of good quality data
- up to ~20 TeV (in 9 hr)
- excellent off-axis & moon performance

- **ASTRI-1**, **ASTRI 2** & **ASTRI-3** already equipped with cameras
- 5 out of 9 telescopes fully assembled by the end of the summer
- Other telescopes ready in Spring 2027

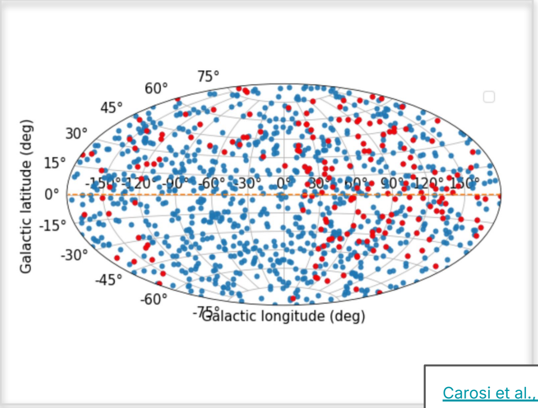


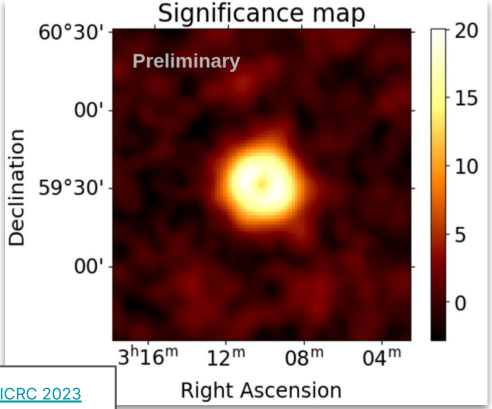
TeV Transients with ASTRI Mini-Array





Stamerra et al., ICRC 2021





Carosi et al., ICRC 2023

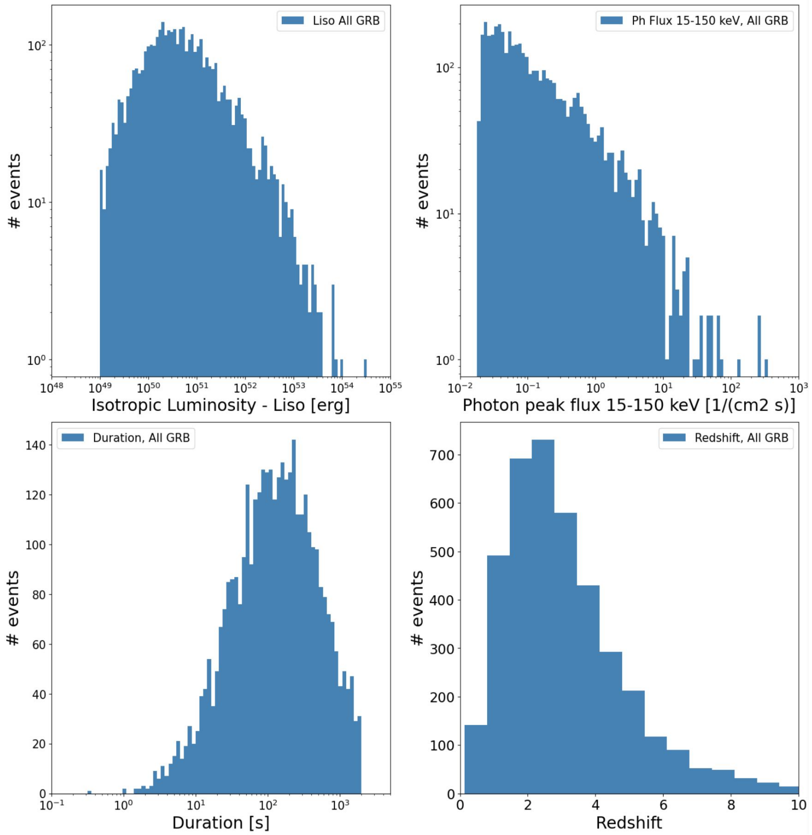
Preliminary studies about GRB detection perspective were presented starting from single case study (GRB 190114C, ICRC 2021) and sub-population study (ICRC 2023)

Although not specifically designed for follow-up of fast transient,

The ASTRI Mini-Array

- might detect emission from GRB 190114C and GRB 190114C-like events up z~0.4
- potentially able to confirm afterglow emission in the multi-TeV band, as long as z<~0.4-0.5 and follow-up starts within the first tens of seconds up to few minutes from the GRB onset
- can measure the spectral cut-off, either originated by the EBL absorption or intrinsic, if greater than 1 TeV

TeV Transients with ASTRI Mini-Array



To better understand ASTRI Mini-Array capabilities, we have expanded these study to a more complete GRB population (10^5 simulated events)

Afterglow emission simulated in the framework of synchrotron and SSC processes

Jet

- initial kinetic energy E_k
- initial bulk Lorentz factor Γ_0
- redshift z

External medium

- number density n_0

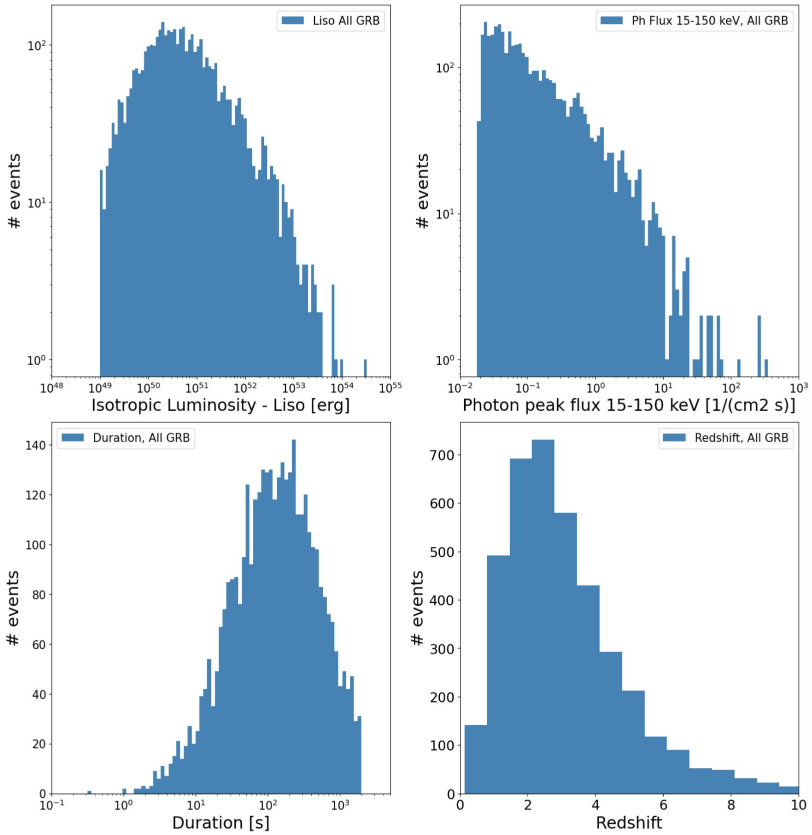
Acceleration process

- fraction of energy in electrons ε_e
- fraction of energy in magnetic field ε_B
- energy index of the electron spectrum p

Ghirlanda et al. 2015, MNRAS, 448, 2514

Ghirlanda & Salvaterra, 2022, ApJ, 932, 10

TeV Transients with ASTRI Mini-Array



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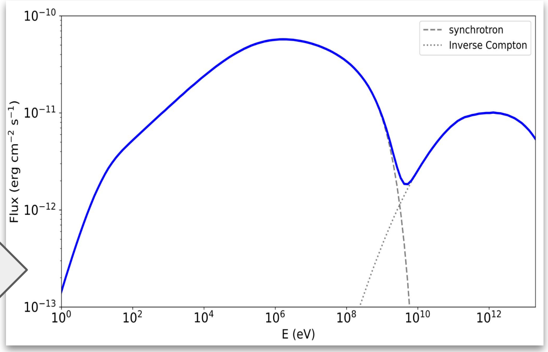


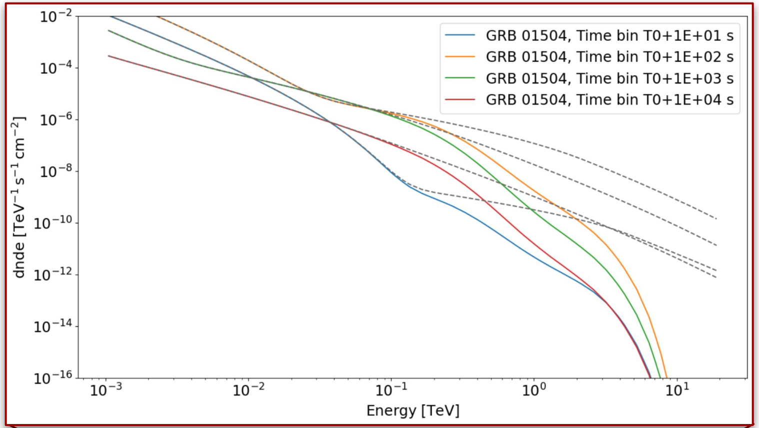
Ghirlanda et al. 2015, MNRAS, 448, 2514

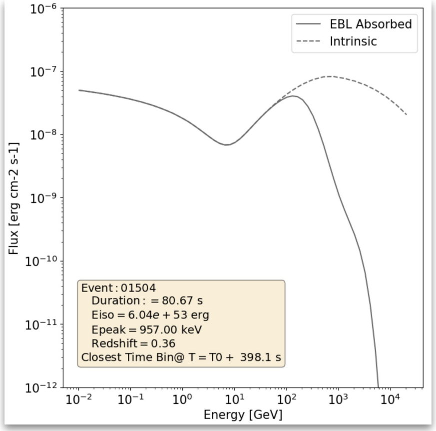
Ghirlanda & Salvaterra, 2022, ApJ, 932, 10

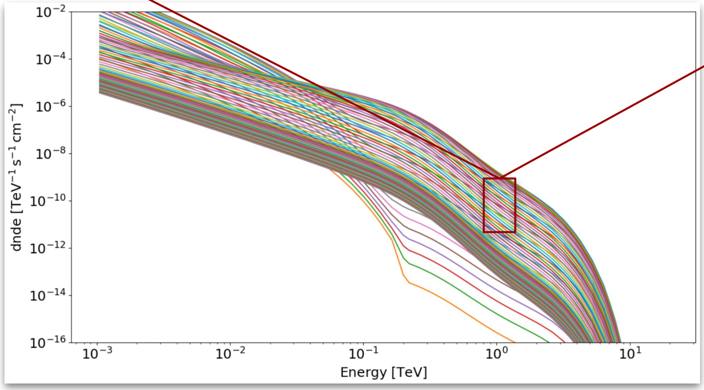
Simulations of ASTRI Mini-Array follow-up

ASTRI MA GRB Sim Pipeline

Synthetic GRB Population







- 10^5 events with random T_0 assigned for each event
- the afterglow emission is modeled according to a leptonic synchrotron and synchrotron self-Compton model (SSC) in the **1 GeV - 20 TeV** band, in time bins from **1 s** to **>~10^5 s**
- EBL absorption modeled following Franceschini model ([A&A 603, A34 (2017)])

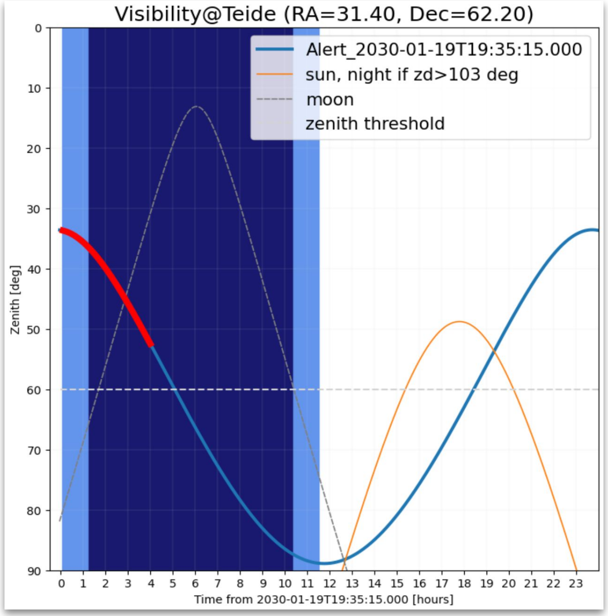
Simulations of ASTRI Mini-Array follow-up

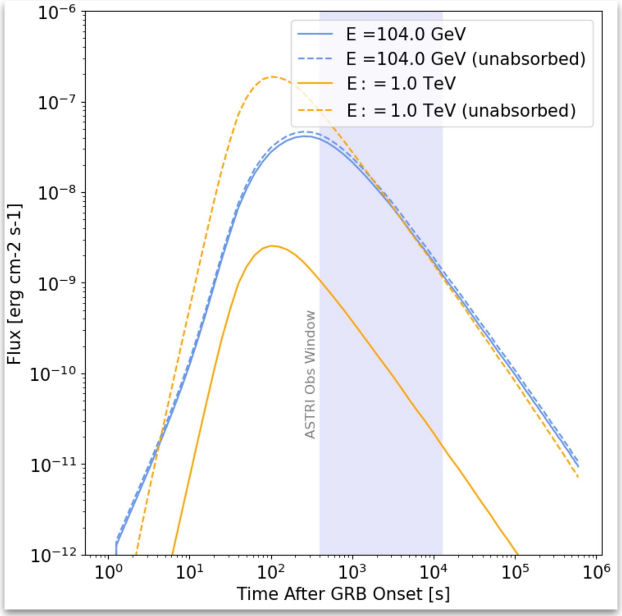
ASTRI Mini-Array GRB Sim Pipeline

Synthetic GRB Population

Mini-Array Follow up strategy

- Visibility for each GRB evaluated according to basic strategy:
  - **Zd GRB max = 60 deg**
  - **Zd Sun min = 103 deg**
  - **Angular Distance from the moon > 30 deg**
  - **Max Observing Time: 4h**





Alessandro Carosi, INAF-OAR, Sesto 2026

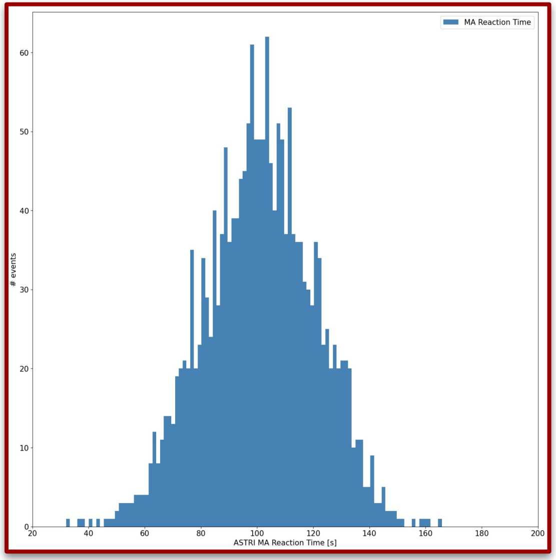
Simulations of ASTRI Mini-Array follow-up

Mini-Array

ASTRI MA GRB Sim Pipeline

Synthetic GRB Population

Mini-Array Follow up strategy

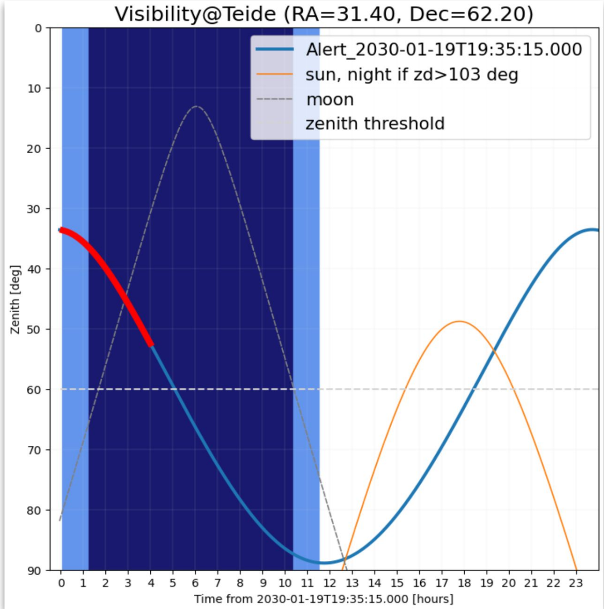


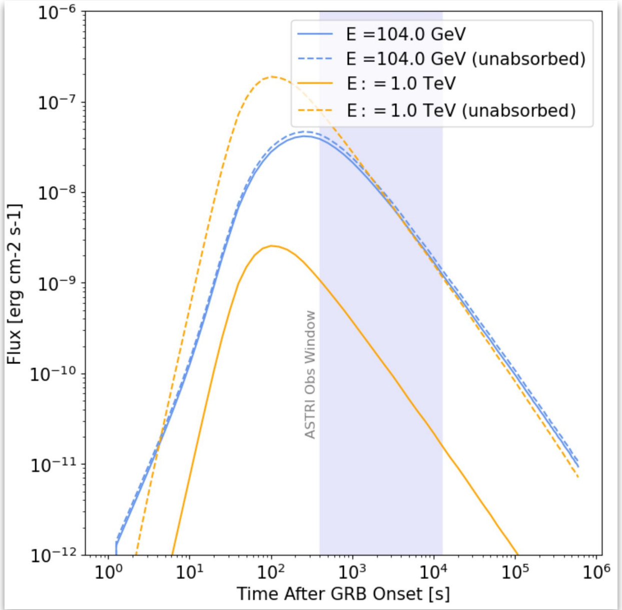
❑ Visibility for each GRB evaluated according to basic strategy:

- **Zd GRB max = 60 deg**
- **Zd Sun min = 103 deg**
- **Angular Distance from the moon > 30 deg**
- **Max Observing Time: 4h**

+

ASTRI Mini-Array Reaction Time
(gauss distributed around 100 s +/- 20 s)





Alessandro Carosi, INAF-OAR, Sesto 2026

Simulations of ASTRI Mini-Array follow-up

Mini-Array

ASTRI MA GRB Sim Pipeline

Synthetic GRB Population

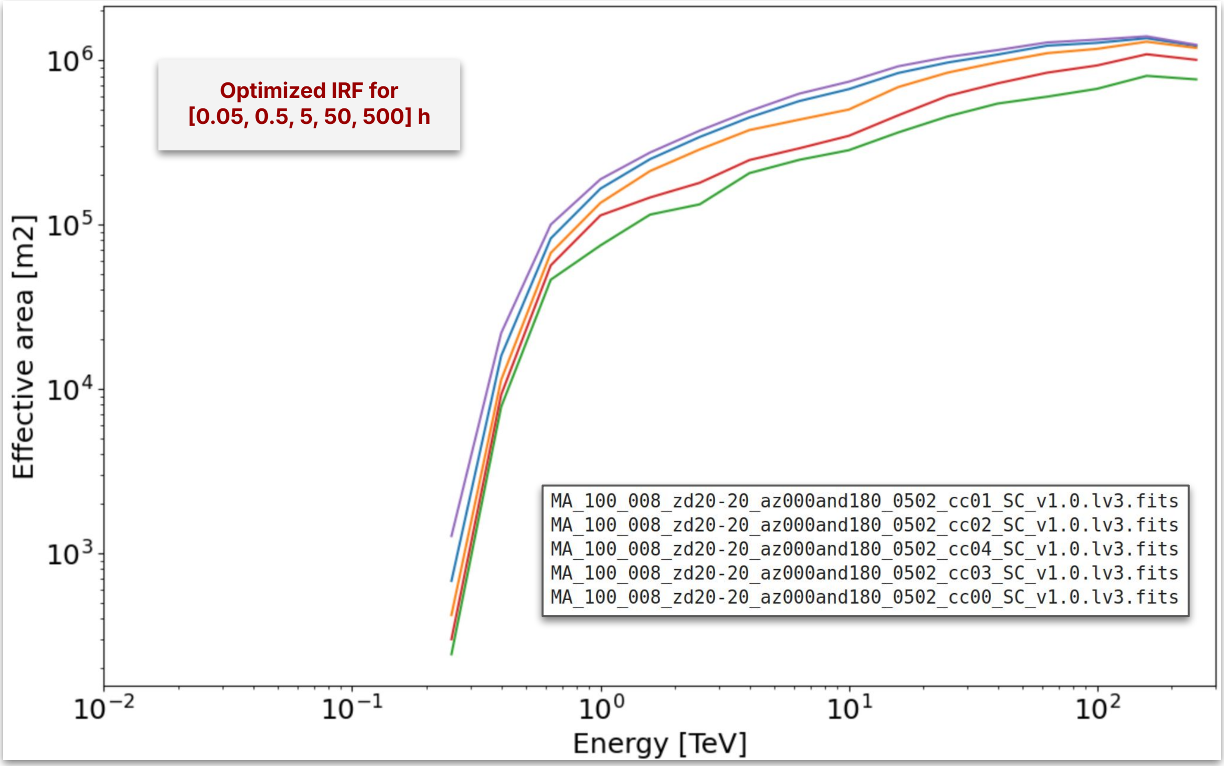
↓

Mini-Array Follow up strategy

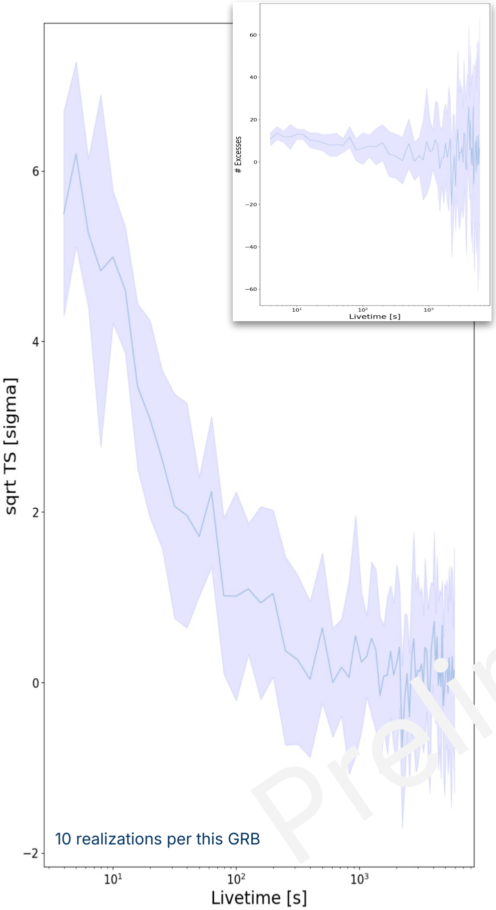
↓

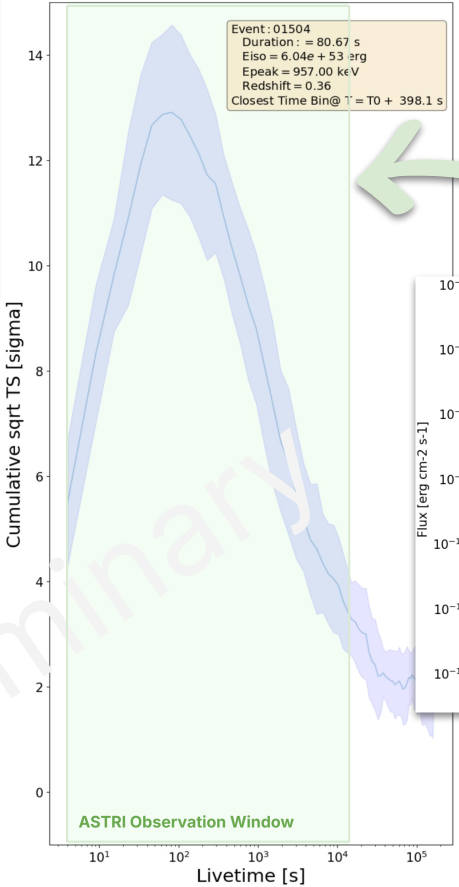
IRFs + Gammapy for simulations

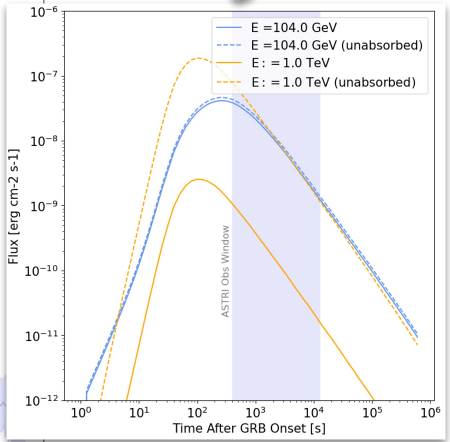
- IRF selected based on the exposure (not optimized for short time scale signal + only 1 zenith available)
- 10^5 events parallelized on the Rome HPC

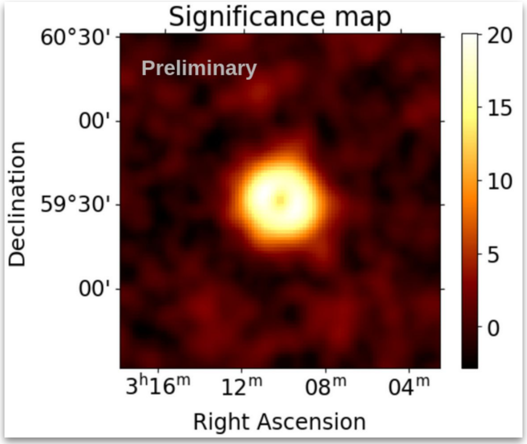


Detection Perspective





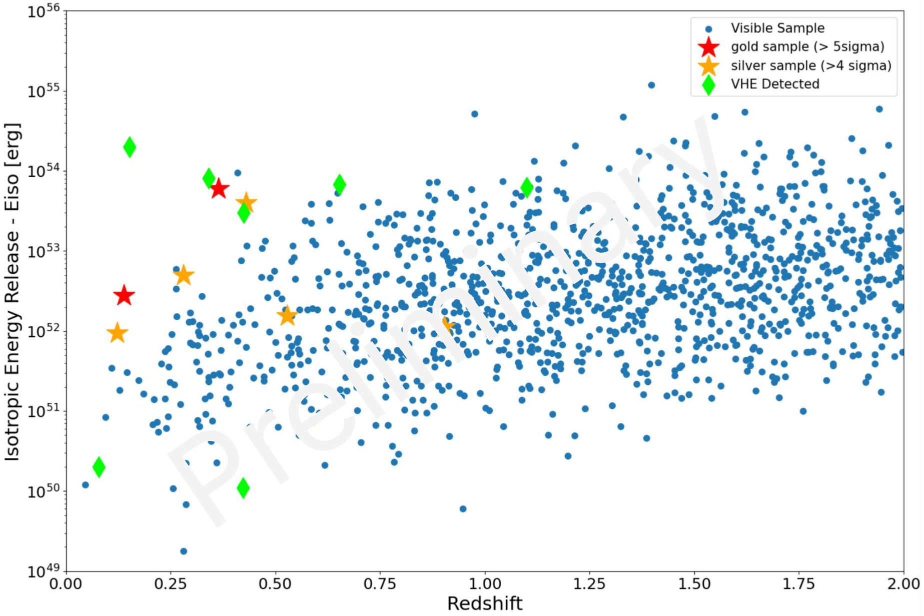


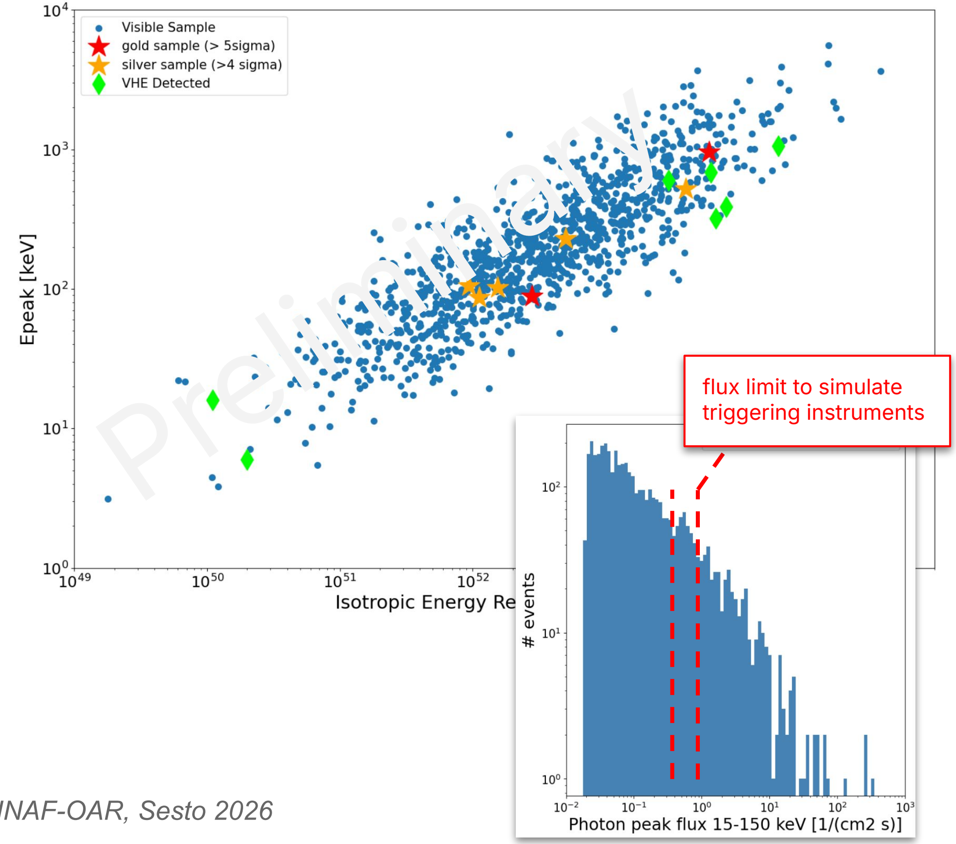


EV. 01504

E_{iso} ~ 6×10^{53} erg
Redshift 0.36
Observable ~300 s after T_0

Detection Perspective





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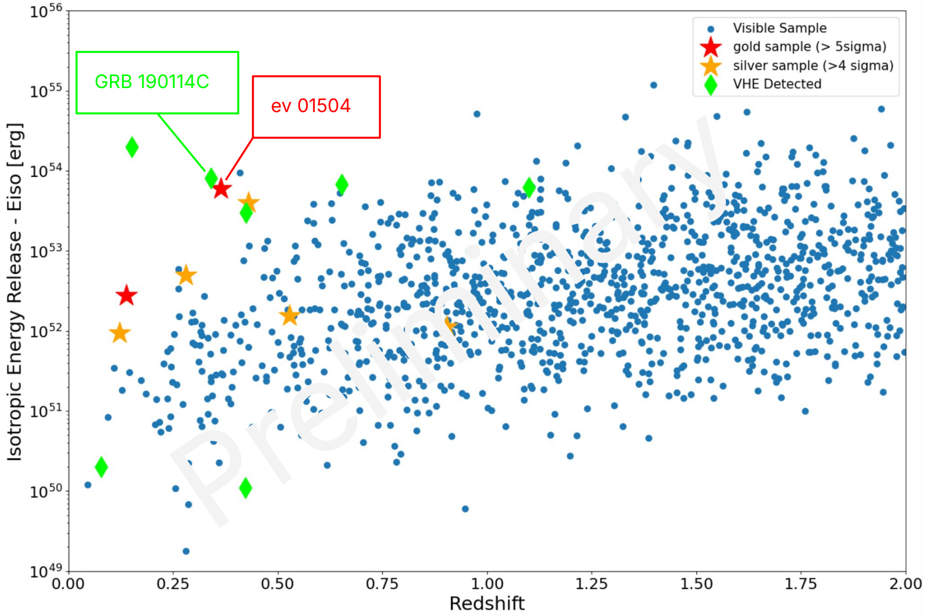
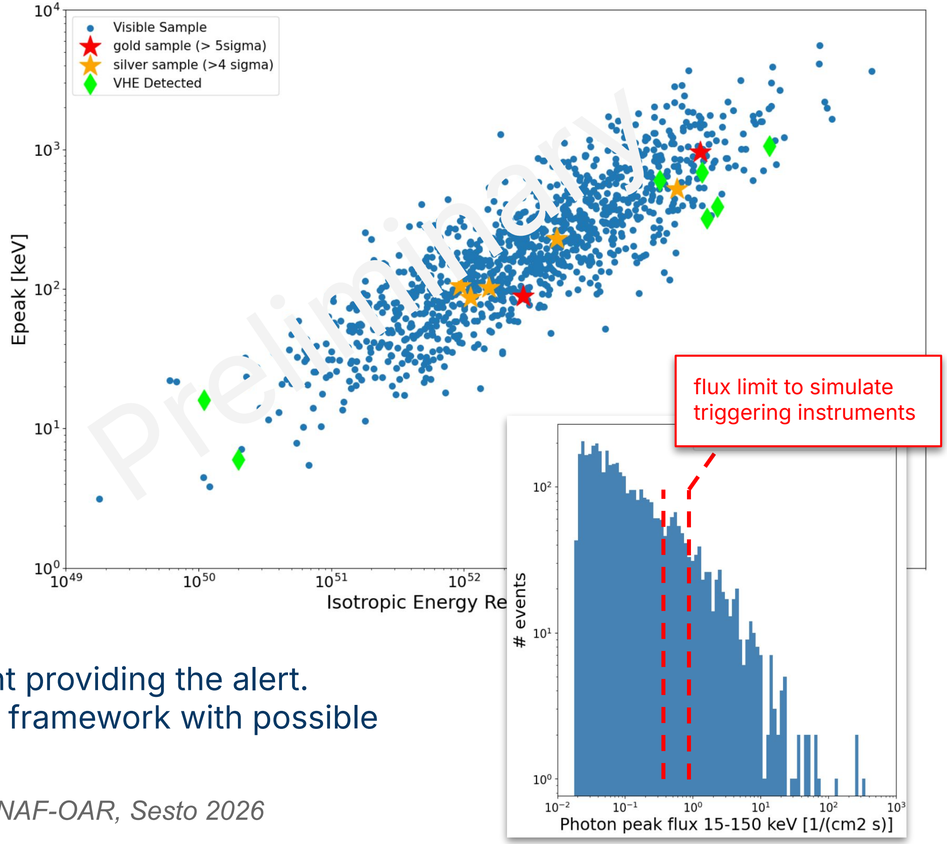
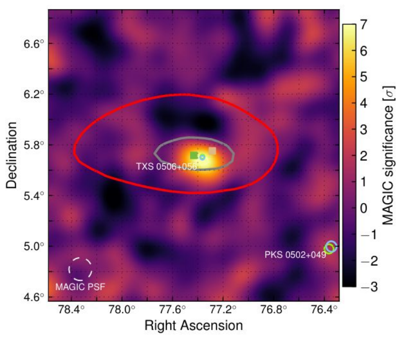




The total detection rate depends on the specific instrument providing the alert.
Work is ongoing to establish the expected rate based on a framework with possible multiple alert chains (Swift, GBM, SVOM…)

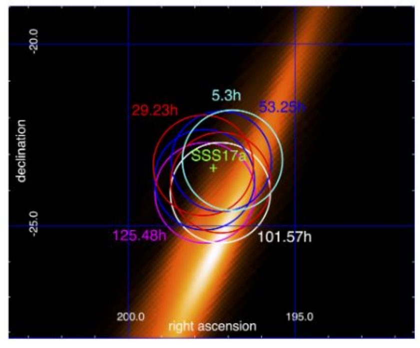
Not Only GRBs...

- Neutrino/VHE connections (TXS 0506+056 and IceCube alert follow-up)

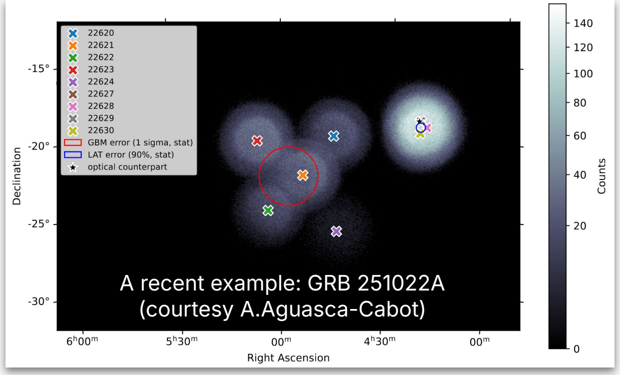


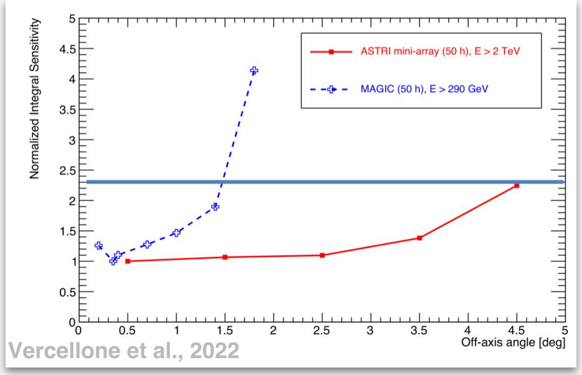
IceCube/MAGIC....
(2018, Science, 361, 6398)
+
New opportunities with seyfert/neutrino connection

- GW-astrophysics with IACT



H.E.S.S. GW 170817
(2017, ApJL, 850, L22)
+
MAGIC & LST1 work on GW follow-up (GCN #38443)





The excellent off-axis performance of the ASTRI MA would stand a significant advance for follow-up of alerts with large uncertainty in the localization (GW, GBM Alerts, IC follow up)

Conclusions

- The ASTRI Mini-Array will perform follow-up observations of transients, providing insights into the physics of events such as GRBs, that have been proved to be powerful TeV emitters.
- ASTRI Mini-Array will be able to achieve detection above the 5 sigma level for nearby events and as long as observations were carried out within few tens of minutes from the GRB onset, a time interval well within the ASTRI repointing capability.
- A firm evaluation of the expected detection rate is ongoing.
- The ~10° FoV of the ASTRI telescopes will allow us to cover with single pointing alerts with large uncertainty in the localization, such as for GW and/or neutrino, making the best out of the synergies with other facilities also in a multi-messenger framework.