The ASTRI Mini Array gamma-ray experiment

G. Pareschi (INAF / Osservatorio Astronomico di Brera)

for the ASTRI collaboration

Sexten, 3 July 2025

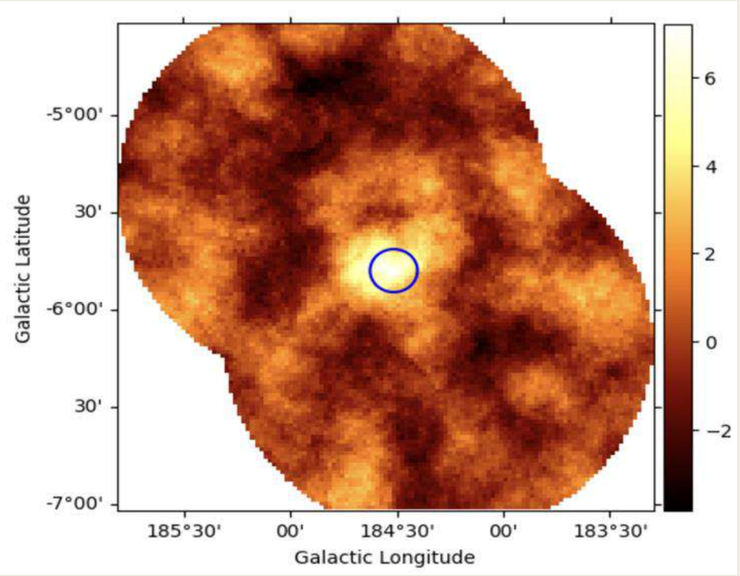
The ASTRI Mini-Array

- The ASTRI MA is an array of 9 Cherenkov telescopes of the 4 meters class under construction at the **Observatorio del Teide** in Tenerife (Spain)
- More than 150 researchers belonging to **INAF** institutes (IASF-MI, IASF-PA, OAS, OACT, OAB, OAPD, OAR) Italian Universities (Uni-PG, Uni-PD, Uni-CT, Uni-GE, PoliMi), **INFN**, **Fundacion Galileo Galilei**, **IAC** (Spain), **University of Sao Paulo** (Brazil), **North-West University** (South Africa), **Université & Observatoire de Genève** (CH).
- End to end approach, from design/implementation of all HW/SW components to dissemination of final scientific products
- Unprecedented performance and wide FoV for observations at **multi-TeV energy scale**
- **Core Science Program** in the first 4 years
- **Important synergies** with other Northern ground-based gamma-ray facilities (LHAASO, HAWC, MAGIC, VERITAS, CTAO-N)

ASTRI HORN

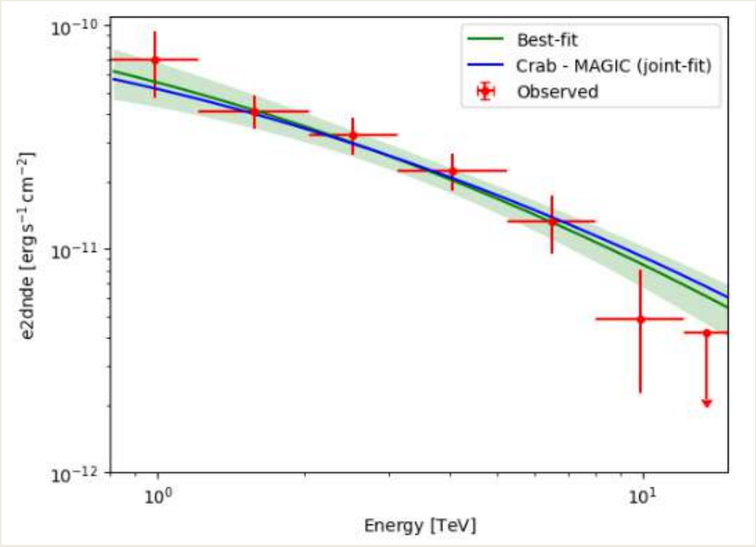
ASTRI (Astrofisica con Specchi a Tecnologia Replicante Italiana) was born as “Progetto Bandiera” funded by MIUR with the initial aim to design and realize an innovative end-to-end prototype of the 4 meters class telescopes in the framework of the CTA observatory

ASTRI-Horn. at OACT in Serra La Nave, Etna



Crab Observations in 2022-2023

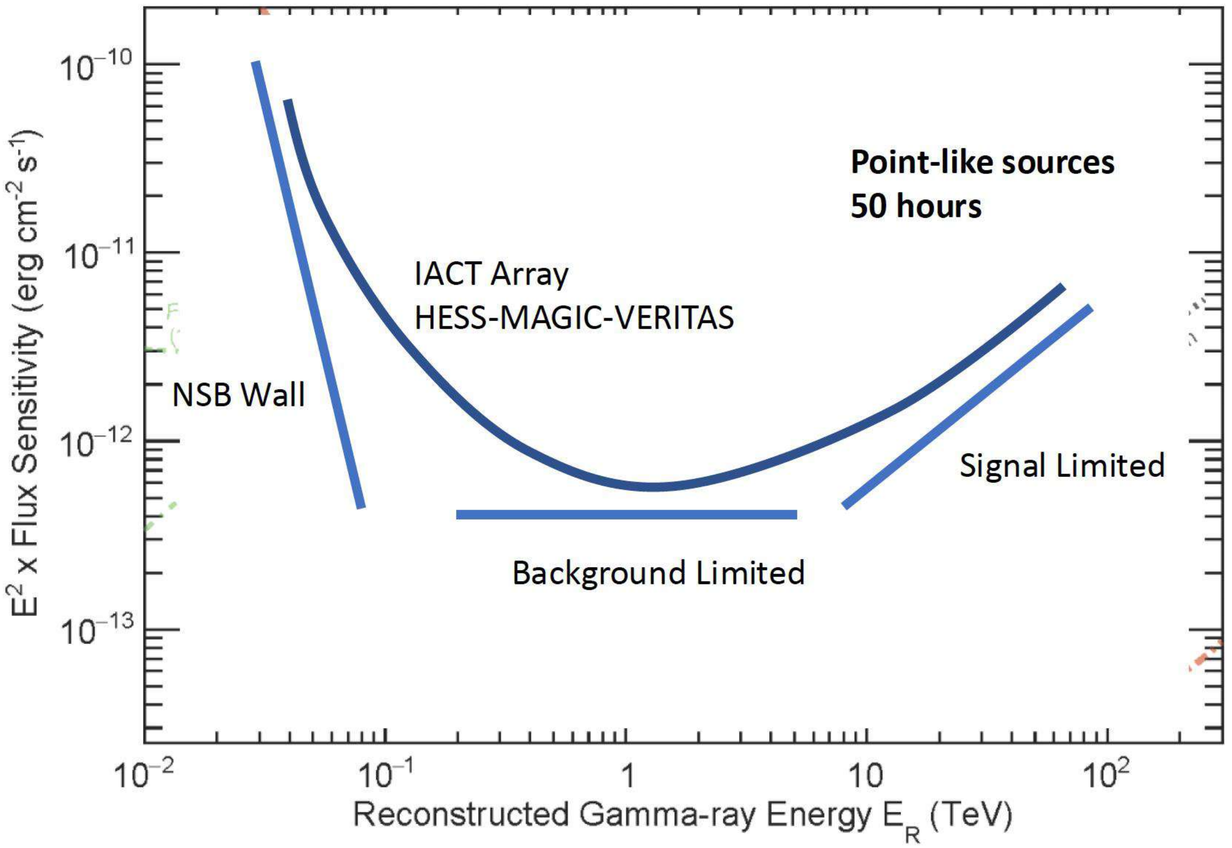
- Detection at ~7.2σ in ~22.6 hr
- 0.05° location accuracy
- Spectrum in 0.8-10 TeV energy range well modeled by a log-parabola



Leto et al., in preparation

Why ASTRI?

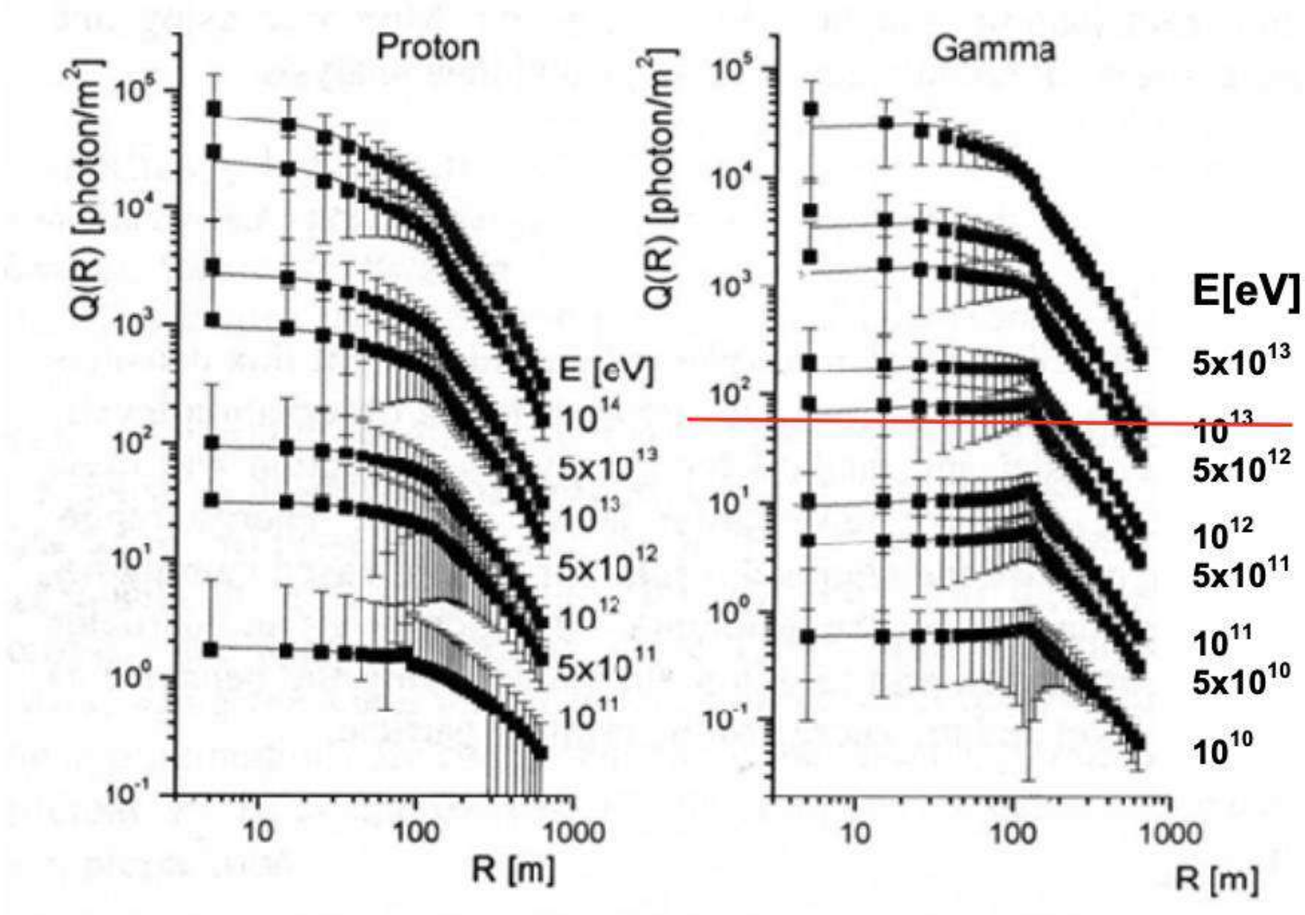
Sensitivity?



Credits: Jim Hinton

Why ASTRI?

Cherenkov radiation fluxes vs lateral size of the pool @1500 m altitude



A. Mishev et al., Proc. 29th ICRC, 6, 1 (2005)

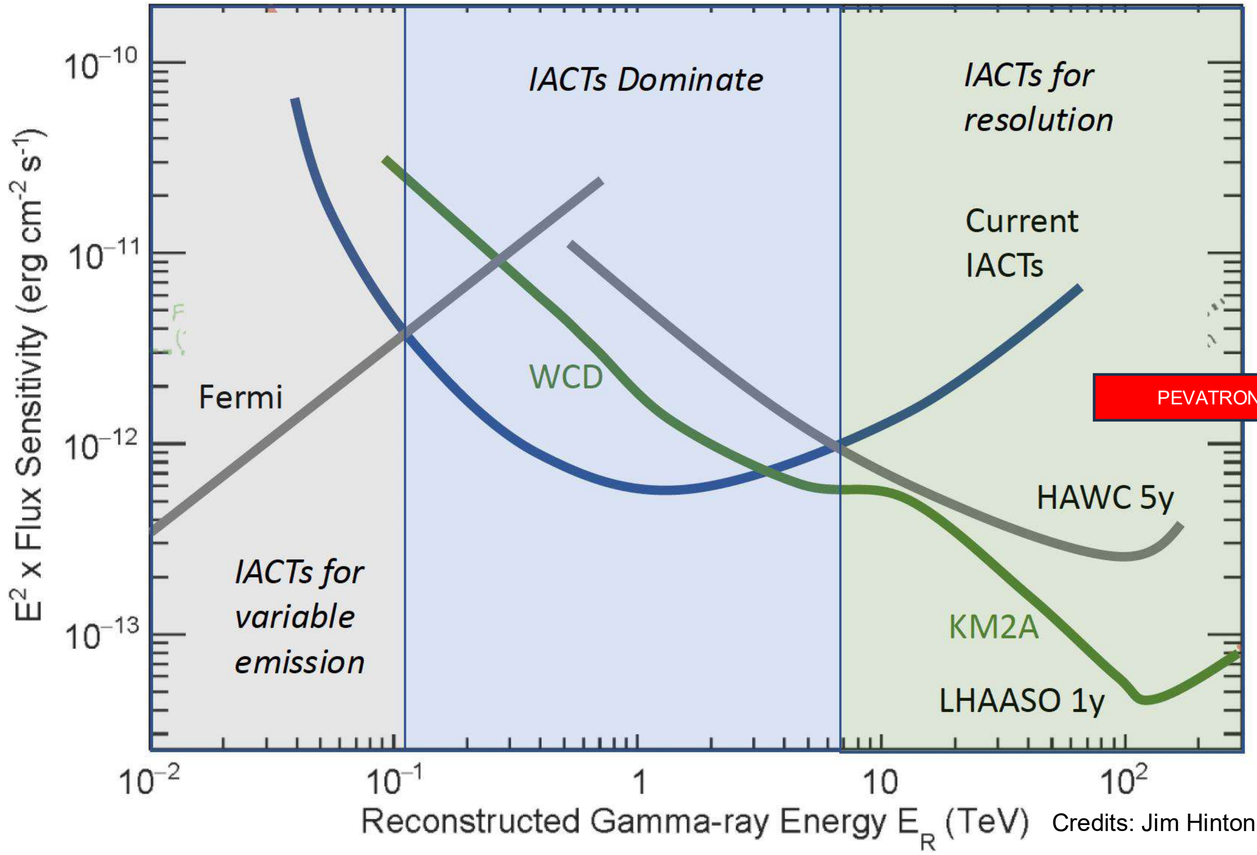
A. Mishev et al., Proc. 29th ICRC, 6, 1 (2005).

Why ASTRI?

ASTRI Mini-Array

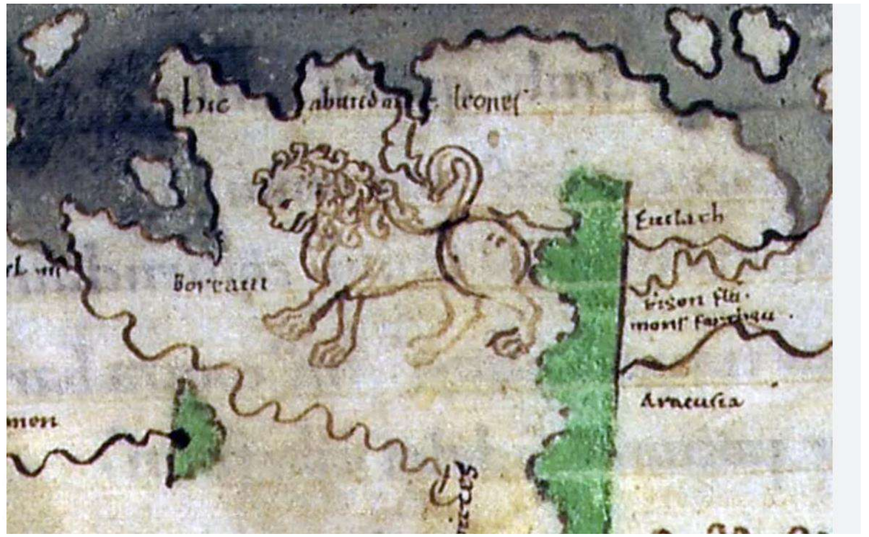
Sensitivity?

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK



Credits: Jim Hinton

PEVATRONS



HIC SUNT LEONES!

➔ **arrays of many small-diameter, wide field-of-view air-Cherenkov telescopes placed at large reciprocal distances**

First suggestion

ASTRI Mini-Array

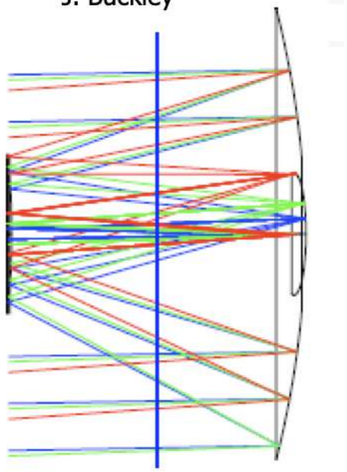
CTA

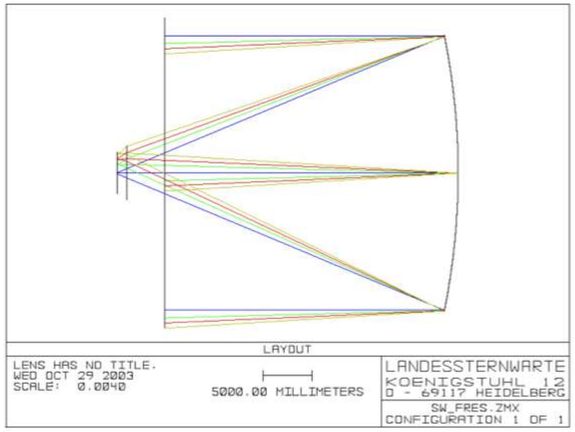
Camera field of view: Optics

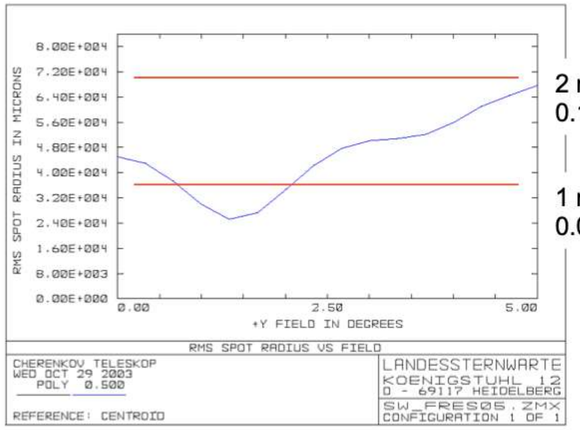
An advanced facility for ground-based high-energy gamma ray astronomy

- Optics for wide fov
  - very large f/d
    - mechanically non-trivial
  - Dual-mirror optics with (large) secondary
    - cost, alignment, large effective focal length?
  - Frensnel corrector plate in front of camera
    - cost, transmission

J. Buckley







2 mrad
0.12°

1 mrad
0.06°

1° CTA meeting, Berlin 2006, W. Hofman and J. Hinton

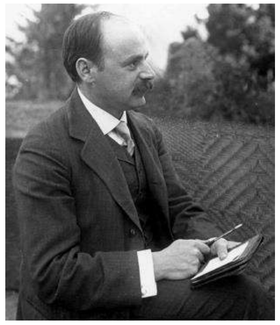
The Schwarzschild Aplanatic Telescope

Vladimir Vassiliev, UCLA

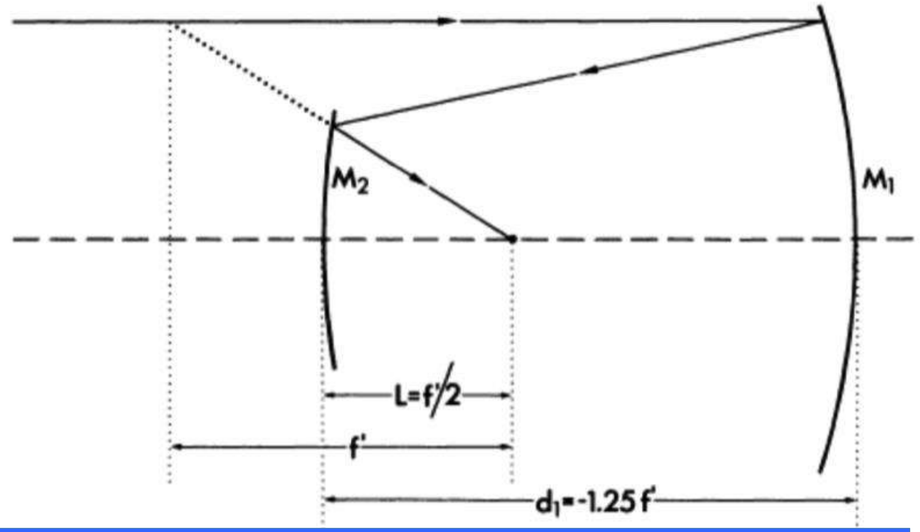
1905: Karl Schwarzschild solved the Seidel ‘s equations for **spherical** aberration and **coma** finding a relation between parameters capable to make a telescope **aplanatic**. *(Couder 1926 ➔ also correction of* ***astigmatism*** *with curved focal plane)*

“For any geometry, 2 aspheric mirrors allow the correction of SI and SII to give an aplanatic telescope”

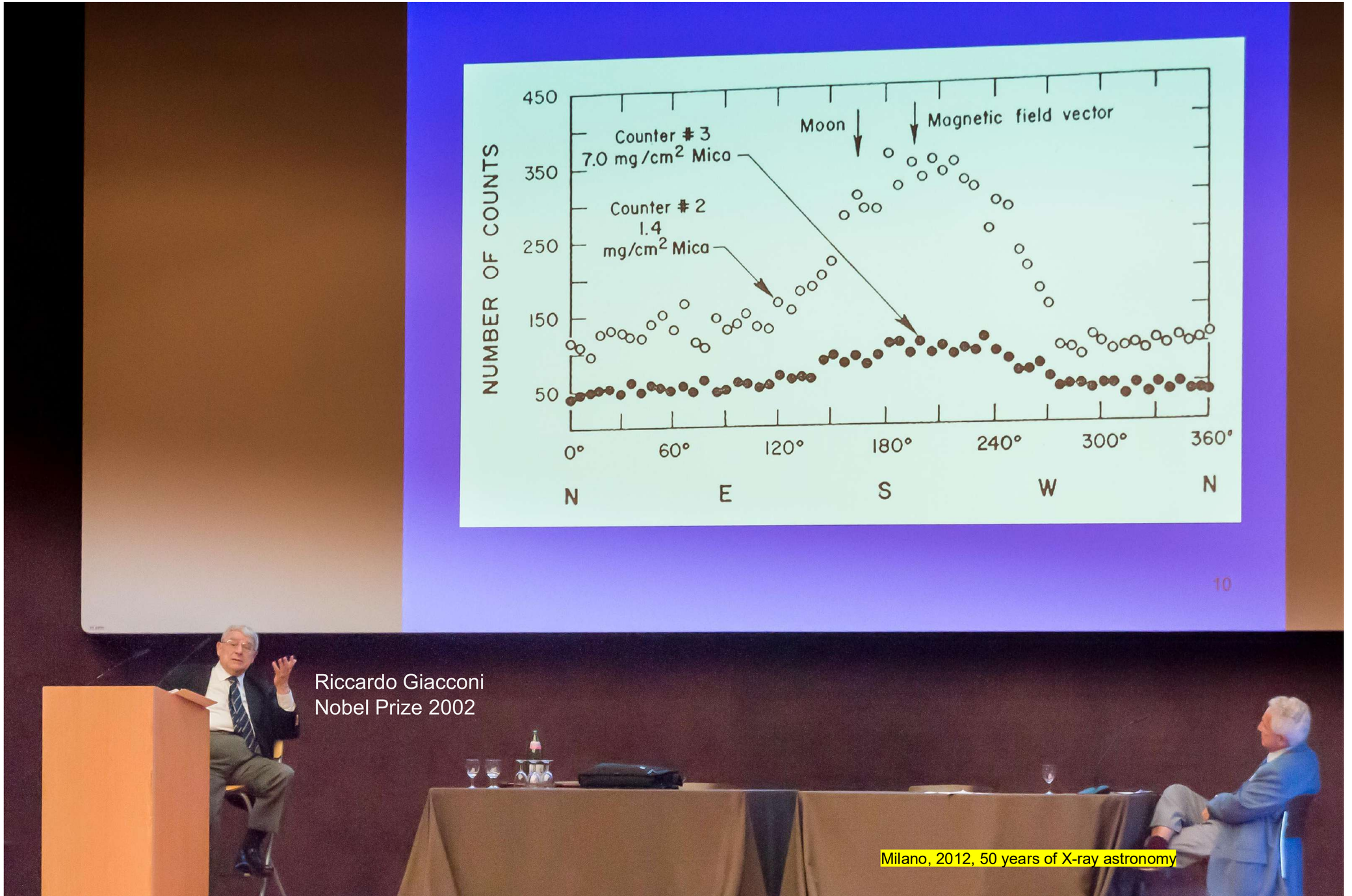
Schwarzschild telescope



KS: f/3.0
b_{S1}= -13.5 (Hyperbola)
b_{S2}= 1.963 (Spheroid)
FoV:2.8 deg
RMS_{edge}~12’’



Technology challenge: Aspherical Optics manufacturing + large secondary mirror


NUMBER OF COUNTS
450
350
250
150
50
Counter # 3
7.0 mg/cm2 Mica
Counter # 2
1.4
mg/cm2 Mica
Moon
Magnetic field vector
0°
60°
120°
180°
240°
300°
360°
N
E
S
W
N
10
Riccardo Giacconi
Nobel Prize 2002
Milano, 2012, 50 years of X-ray astronomy

From X-ray grazing telescopes to SC Cherenkov telescopes

Mini-Array

Specific requirement

First empirical focalization

Analytical solution

RT Polynomial optimization

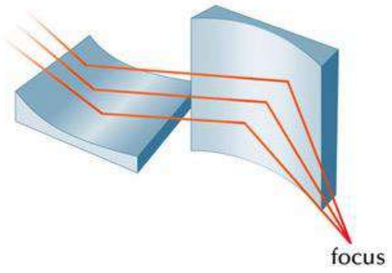
High Energy

Grazing Incidence

Few fast pulses

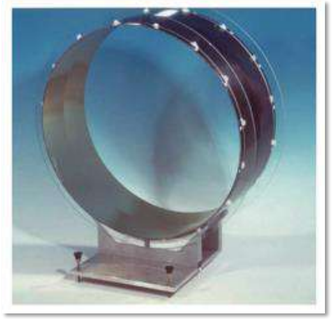
Large Area

Kirkpatrick - Baez

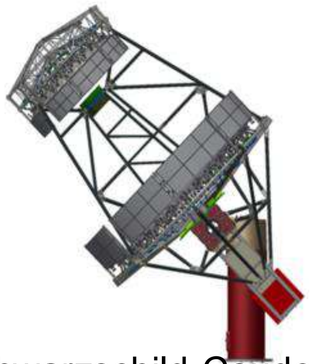


Wolter &
Wolter-Schwarzschild

WFXT



Davies- Cotton



Schwarzschild-Couder

ASTRI/CTA-SST

X-ray and Cherenkov Aplanatic Polynomyal Telescopes

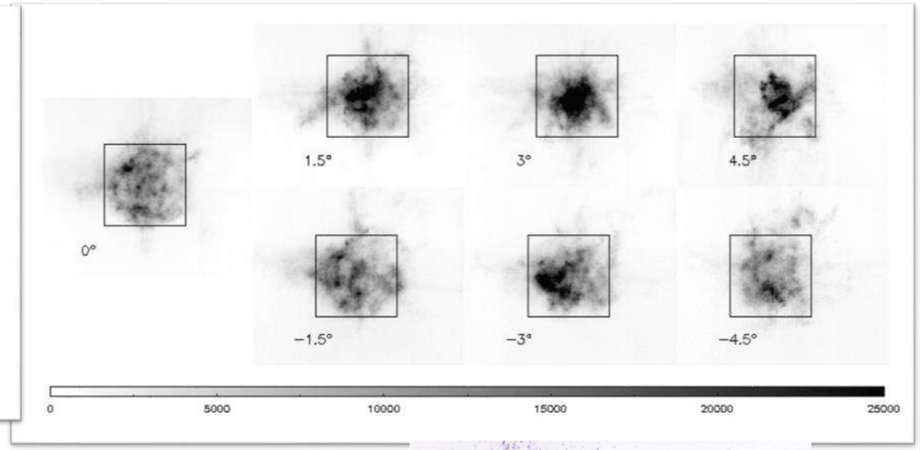
ASTRI Mini-Array

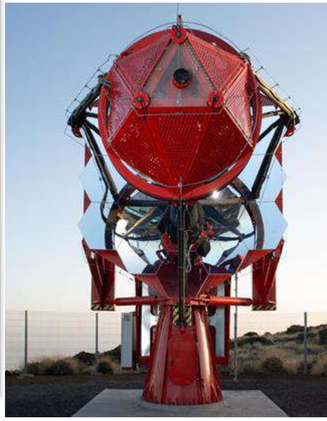
A&A 608, A86 (2017)
DOI: 10.1051/0004-6361/201731602
© ESO 2017

Astronomy & Astrophysics

First optical validation of a Schwarzschild Couder telescope: the ASTRI SST-2M Cherenkov telescope

E. Giro[1,2], R. Canestrari[2], G. Sironi[2], E. Antolini[3], P. Conconi[2], C. E. Fermino[4], C. Gargano[5], G. Rodeghiero[1,6], F. Russo[7], S. Scuderi[8], G. Tosti[3], V. Vassiliev[9], and G. Pareschi[2]





Paper

Paper

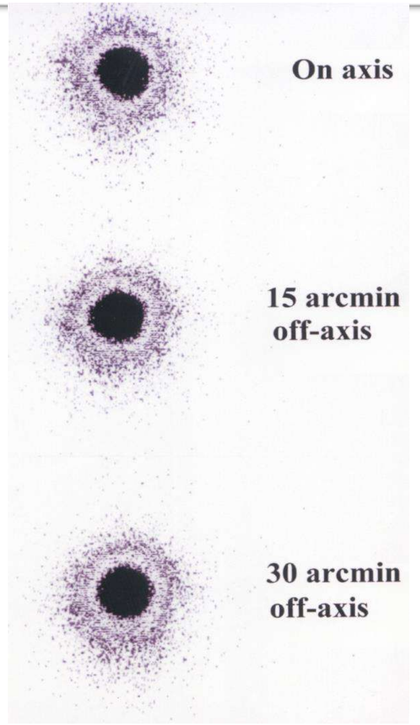
29 September 1999

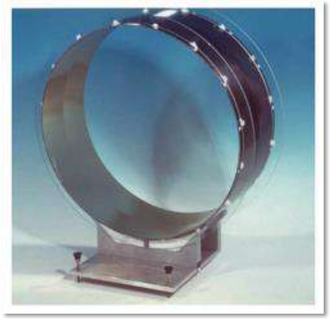
X-ray optics for the WFXT telescope

Oberto Citterio, *Sergio Campana*, *Paolo Conconi*, *Mauro Ghigo*, *Francesco Mazzoleni*, *Heinrich W. Braeuninger*, *Wolfgang Burkert*, *Andreas Oppitz*

Author Affiliations +

Proceedings Volume 3766, X-Ray Optics, Instruments, and Missions II; (1999)
https://doi.org/10.1117/12.363636
Event: SPIE's International Symposium on Optical Science, Engineering, and Instrumentation, 1999, Denver, CO, United States





SAME OPTICAL DESIGNER (Paolo Conconi, INAF Brera)

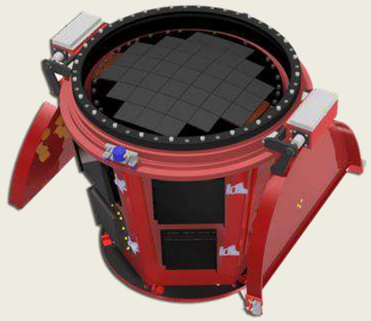
ASTRI Telescopes

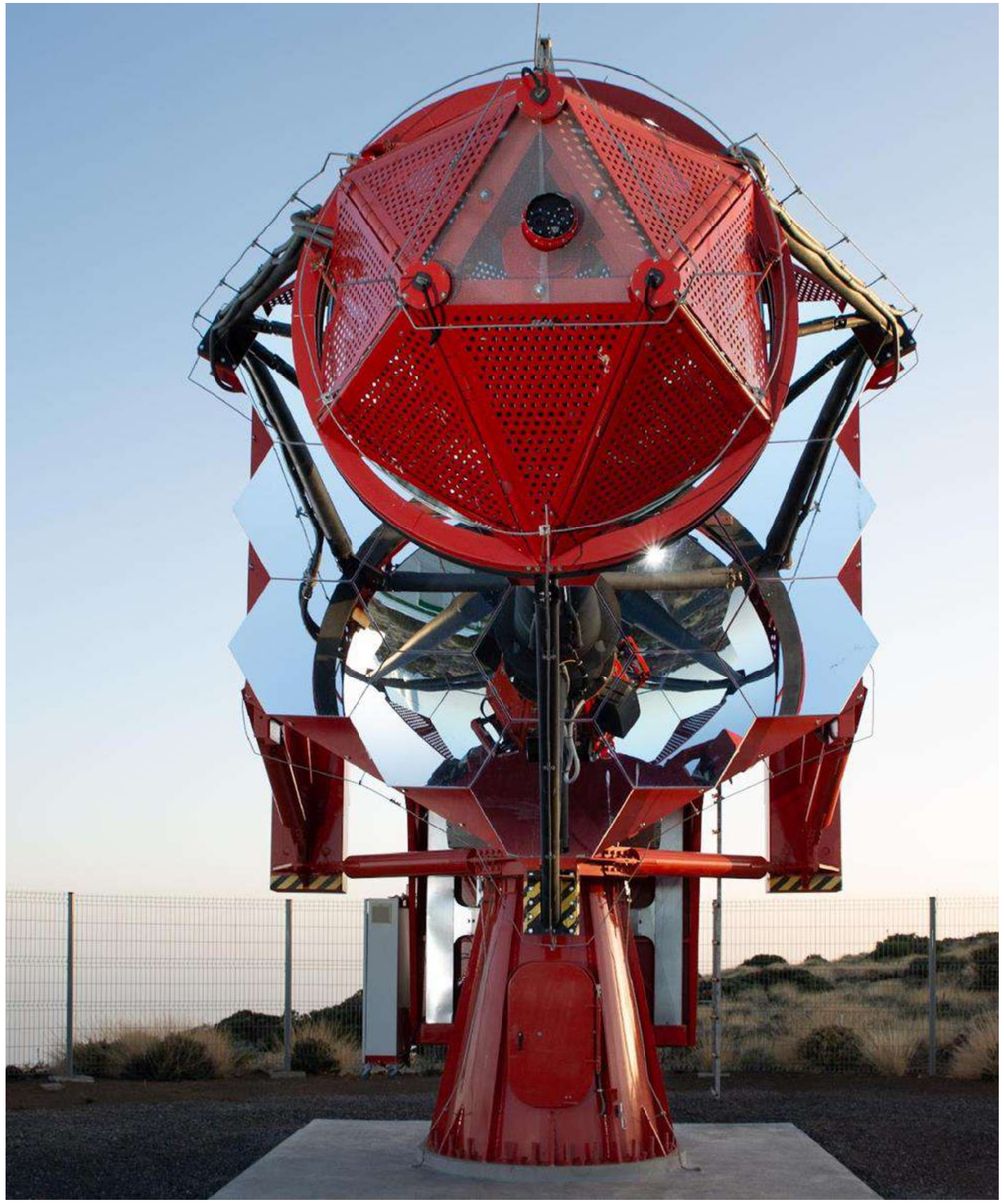
The current ASTRI telescopes are an evolution of the ASTRI-Horn prototype telescope

The electromechanical structure was optimized in terms of mass, functionality and maintainability (mass has been reduced by 30%).

Dual-mirror optical layout (Schwarzschild-Couder)
- Wide FOV (~10)
- Optimal PSF across the entire FoV

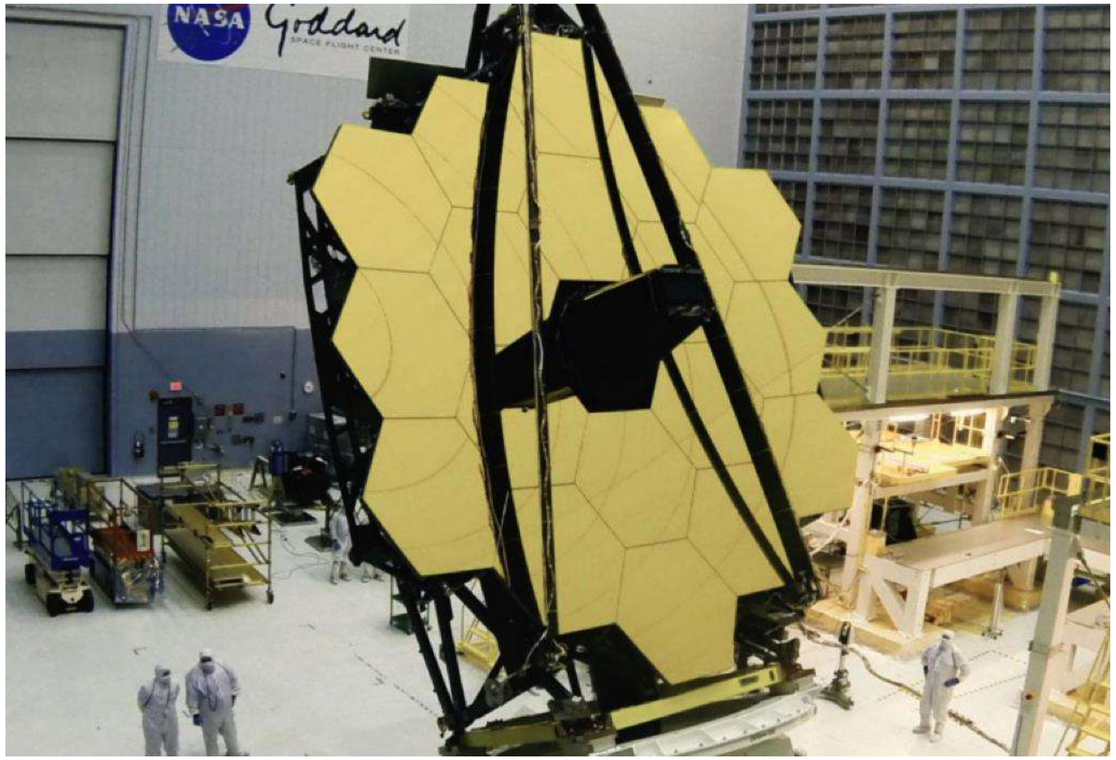
ASTRI Silicon photomultipliers camera
- 37 (8x8) matrices are arranged to adapt to the curved focal plane of the telescope.
- Small pixel-size (0.19°)
- Work also with moonlight





Segmented reflecting surface

Mini-Array



Credits: NASA

JWST, reflecting surface cost: ➔ **a few MEuro/m²**

ASTRI, reflecting surface cost: ➔ **A few KEuro/m²**

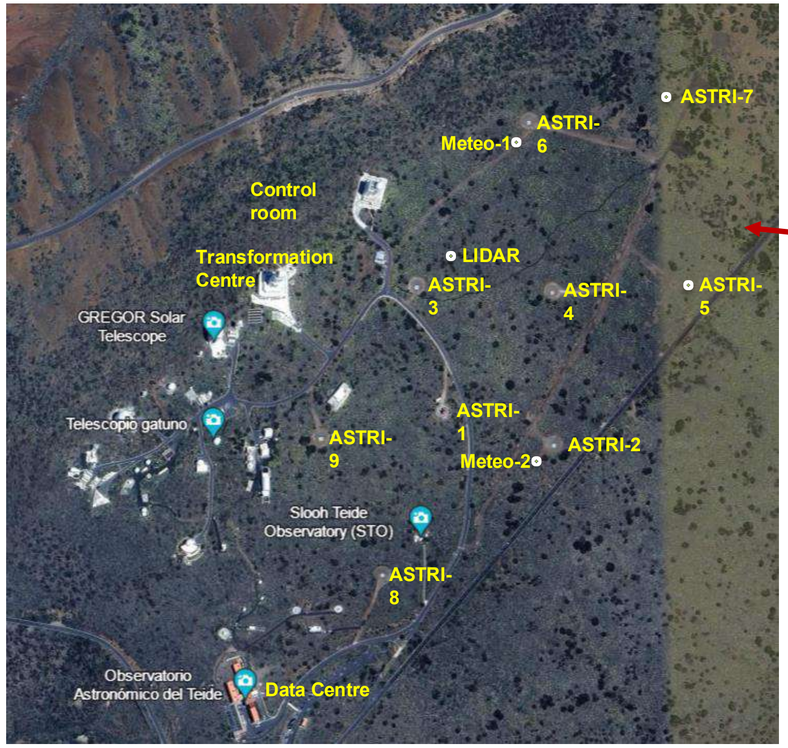
The ASTRI Mini-Array in a nutshell

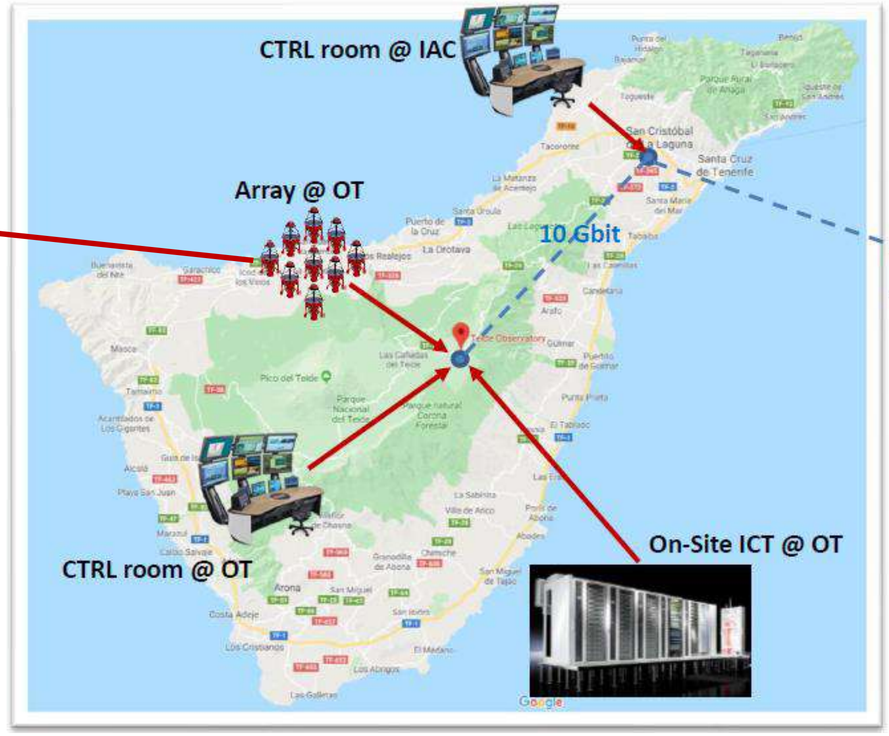
The ASTRI Mini-Array in Tenerife

- Telescope Array & auxiliaries (Observatorio del Teide - OT)
- Local Control Room @THEMIS building (OT)
- On site Data Centre @IAC Residencia (OT)
- Array operation center @IACTEC in La Laguna

The ASTRI Mini-Array in Italy

- Data Centre in Rome
- Remote Array operation centers

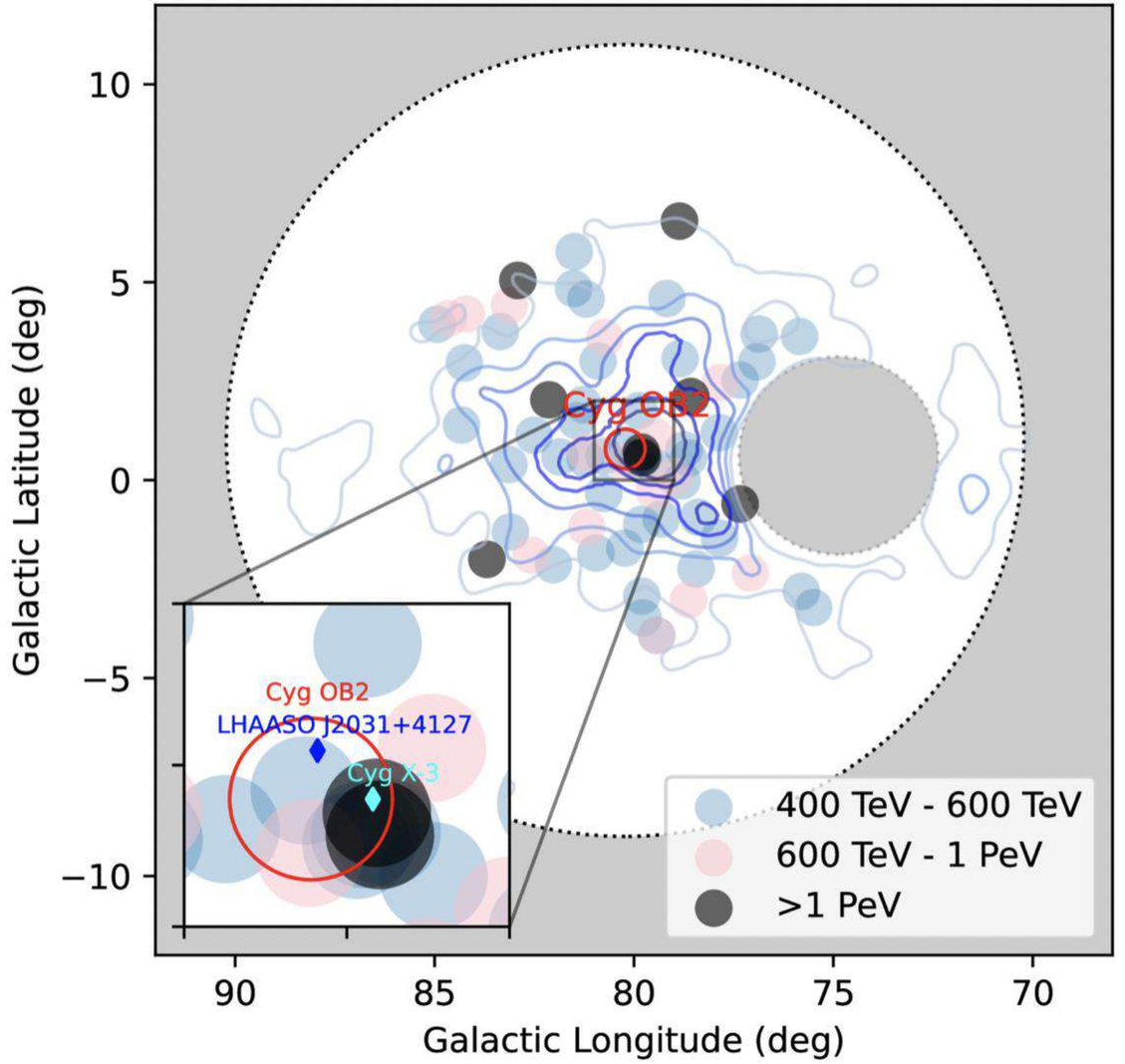




10 Gbit

Cygnus OB2 region after LHAASO

A Messy situation…

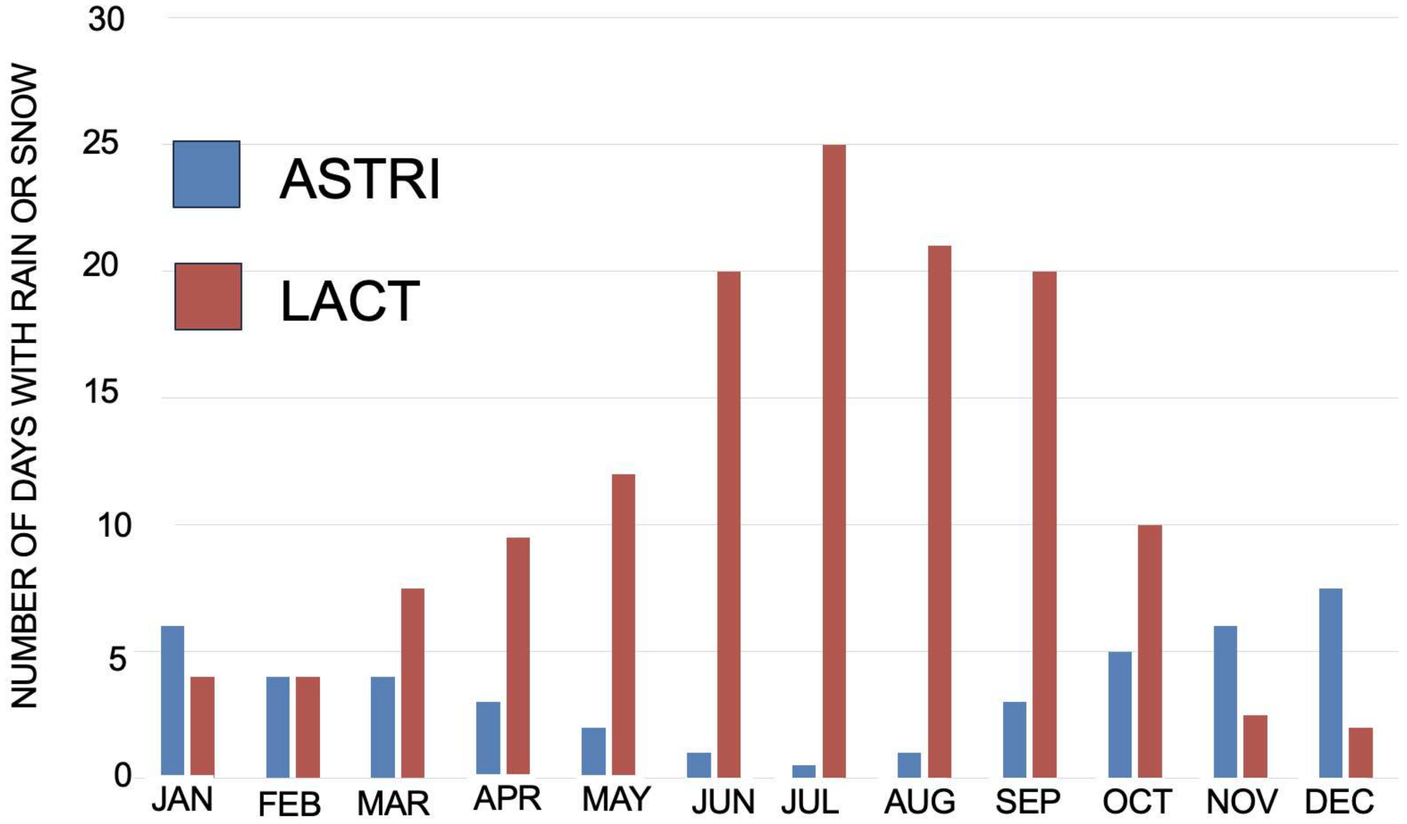


DAYS OF PRECIPITATIONS

SOURCES:

https://www.sichuantravelguide.com/

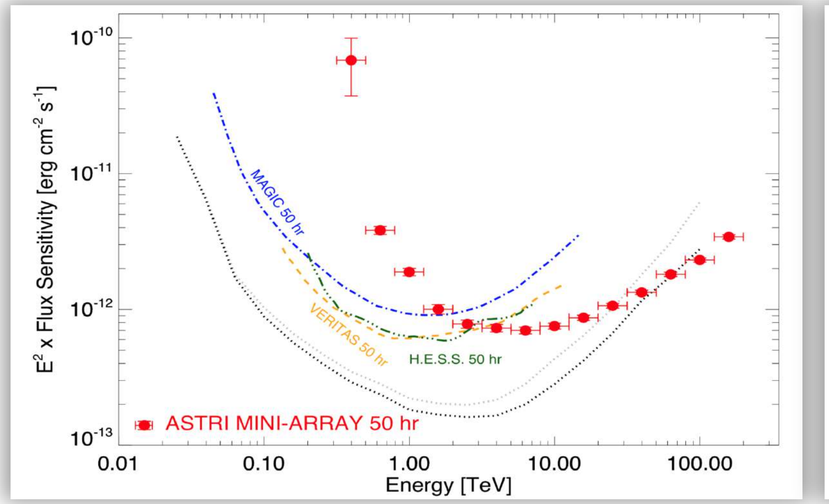
http://www.izana.org/index.php?option=com_content&view=article&id=23&Itemid=23&lang=en

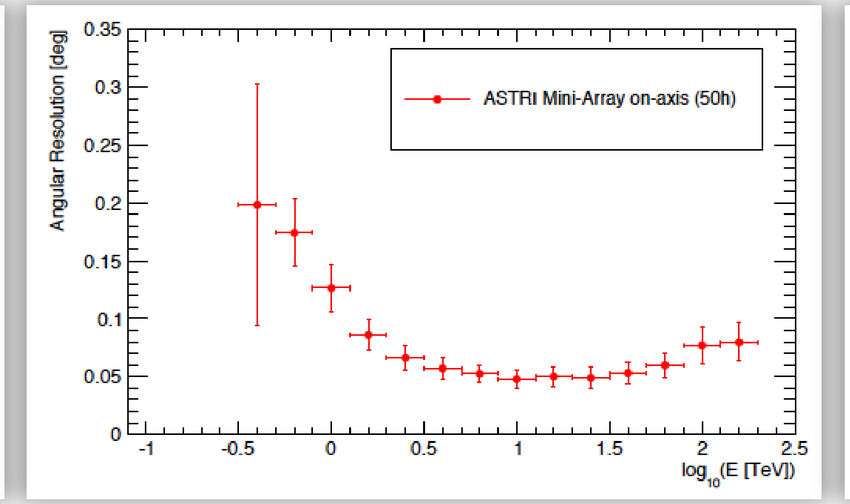


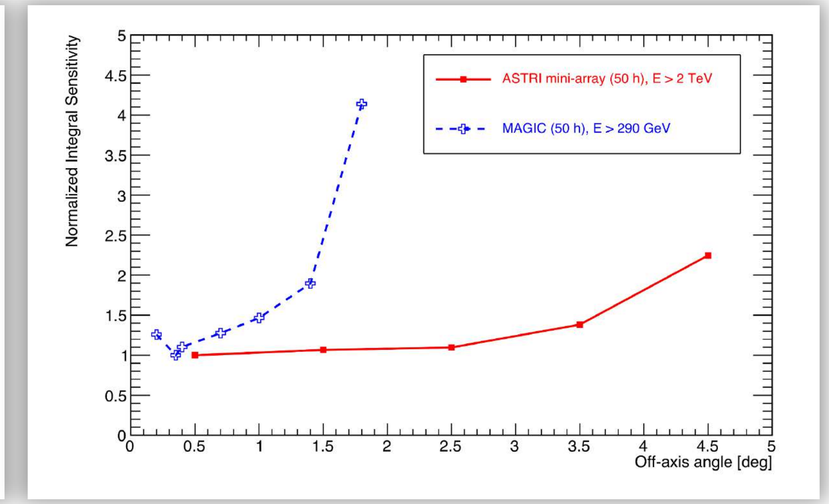
Mini but not small...

Largest Imaging Atmospheric Cherenkov Telescopes facility until CTAO will start to operate

ASTRI Mini-Array expected performance







Sensitivity: better than current IACTs (E ≳ 3 TeV):

Extended spectrum and cut-off constraints

Energy/Angular resolution: ~ 10% / ~ 0.05° (E > a few TeV)

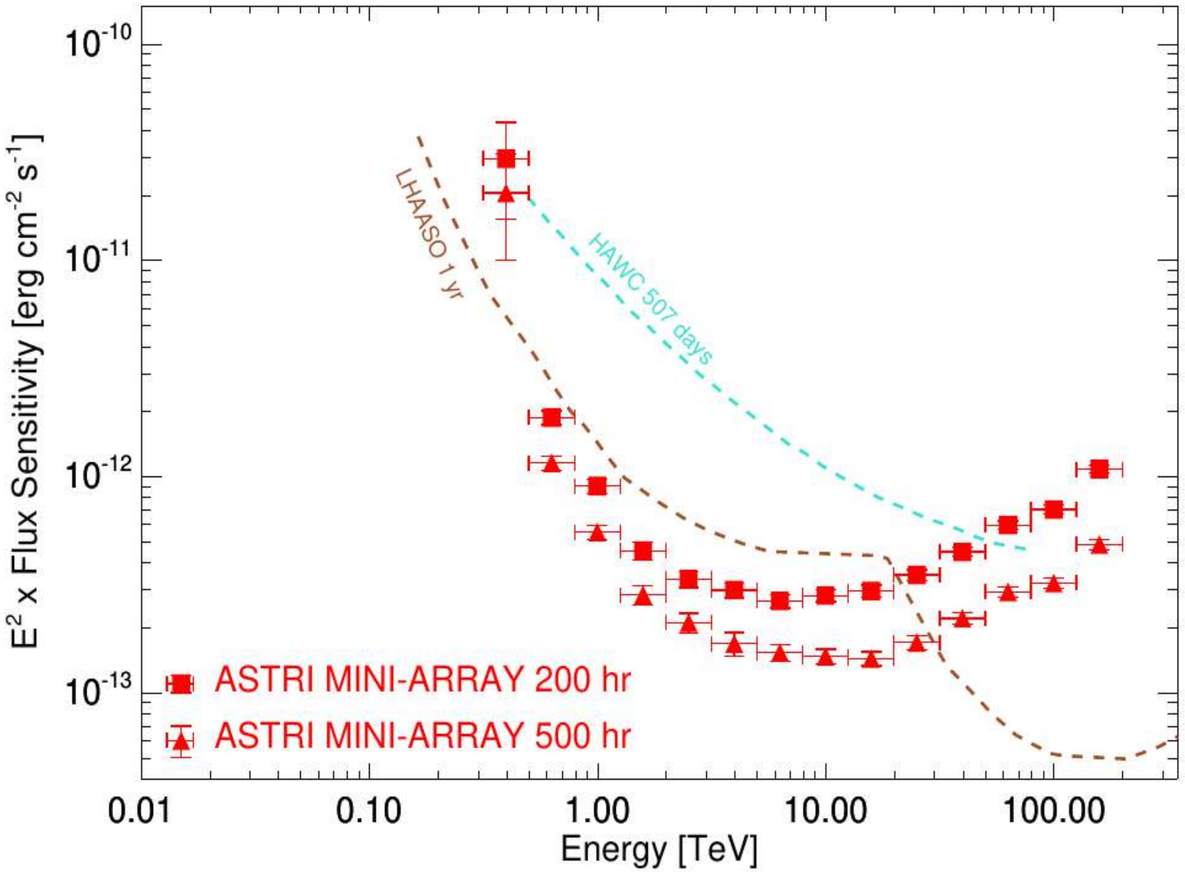
Characterize extended sources morphology

Wide FoV (≥ 10°), with almost homogeneous off-axis acceptance

Multi-target fields and extended sources

Enhanced chance for serendipity discoveries

ASTRI Performance - Flux sensitivity with integration with hundreds of hours on the same source

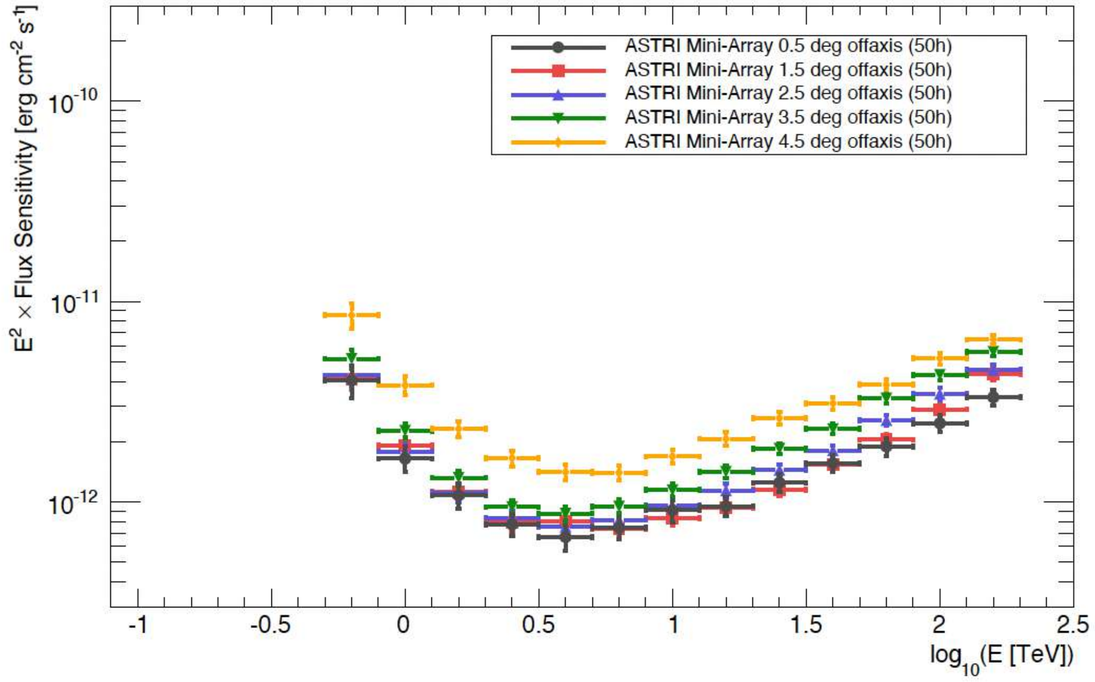


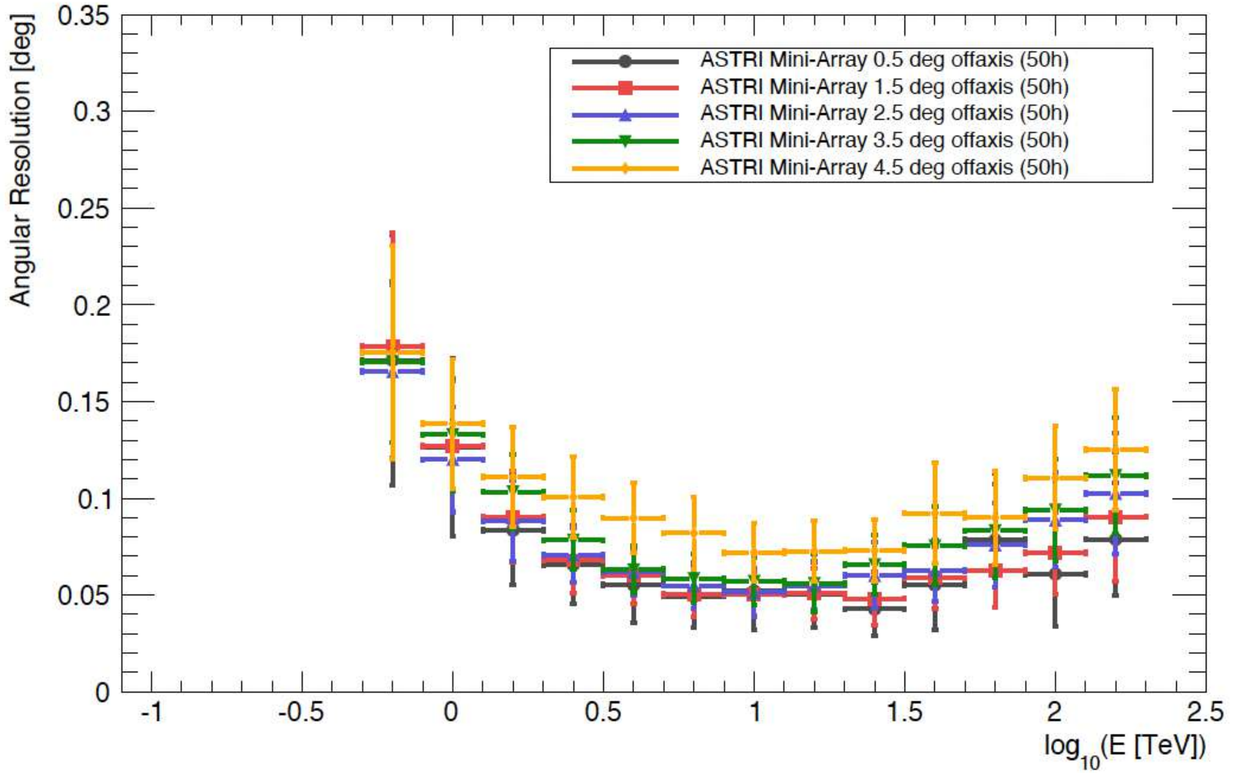
Expected performance

Sensitivity: better than that of current IACTs (E > a few TeV)

- Extend the spectra of already detected sources and/or measure cut-offs .
- Much better angular resolution

Off – Axis Behavior





The ASTRI Mini-Array – Synop

PRELIMINARY

	ASTRI Mini-Array	MAGIC	VERITAS	H.E.S.S.	HAWC	LHAASO
Location	28° 18′ 04″ N 16° 30′ 38″ W	28° 45′ 22″ N 17° 53′ 30″ W	31° 40′ 30″ N 110° 57′ 7.8″ W	23° 16′ 18″ S 16° 30′ 00″ E	18° 59′ 41″ N 97° 18′ 27″ W	29° 21′ 31″ N 100° 08′ 15″ E
Altitude [m]	2,390	2,396	1,268	1,800	4,100	4,410
FoV	~ 10°	~ 3.5°	~ 3.5°	~ 5°	2 sr	2 sr
Angular Res.	0.05° (30 TeV)	0.07° (1 TeV)	0.07° (1 TeV)	0.06° (1 TeV)	0.15°[(a)] (10 TeV)	(0.24–0.32)°[(b)] (100 TeV)
Energy Res.	12% (10 TeV)	16% (1 TeV)	17% (1 TeV)	15% (1 TeV)	30% (10 TeV)	(13–36)% (100 TeV)[(b)]
Energy Range	(0.3-200) TeV	(0.05-20) TeV	(0.08-30) TeV	(0.02-30) TeV[(c)]	(0.1-100) TeV	(0.1-1,000) TeV

Observing Strategy

ASTRI will study gamma-ray sources at E >> 1 TeV

LOW FLUX!

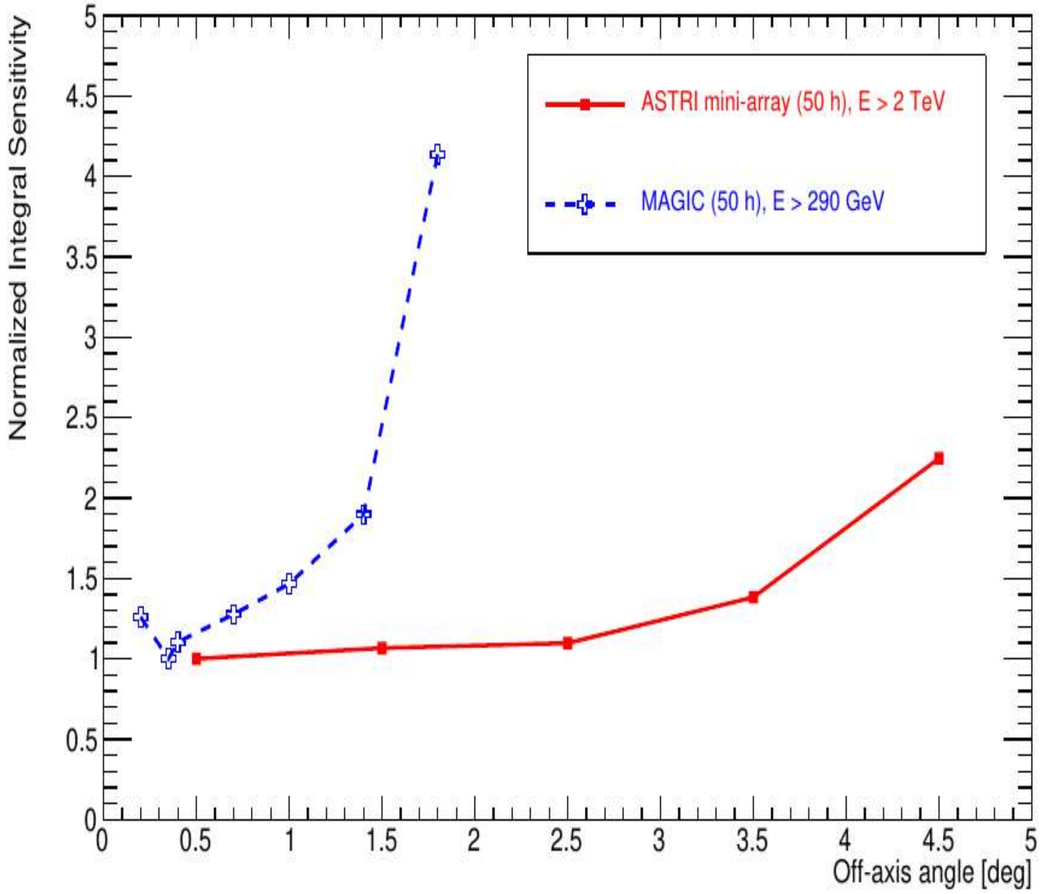
➔ **Need for deep exposures**

Strategy:

Focus on a few sky fields with long integration time

But with features acing-up our sleeve :

- Large FoV
  - → Several sources in the FOV
- Observations with moonlight
  - → Increases avail. time ~50-80%
- Large Z.A.
  - → Increase Aeff @ high energies



ASTRI Science

Example of possible soures

Pillar 1: The origin of CRs

- **PeVatrons**
- **CRs Propagation**
- **Pulsar Wind Nebulae**

Pillar 2 : Cosmology and Fundamental Physics

Name	Type	Req. Exposure (Hrs)
Tycho Snr	SNR	400
Gal. Center	Diffuse	260
VER J1907	[illegible]	500
G106.3+2.7	[illegible]	200
γ-Cygni	[illegible]	500
W28	[illegible]	500
M82	[illegible]	400
Crab	[illegible]	300
Geminga	[illegible]	500
IC 310	Radio gal	10-500
M87	Radio gal	10-500
Mkn 501	Blazar	5-500
1ES 0229+200	Blazar	200-250

Large exposure time is required

ASTRI Mini-Array - Schedule

Summer 2021

Site foundation

ASTRI Mini-Array - Schedule

Summer 2021

Site foundation

Autumn 2022

ASTRI 1 construction and calibration

Autumn 2024

ASTRI Mini-Array - Schedule

Summer 2021

Site foundation

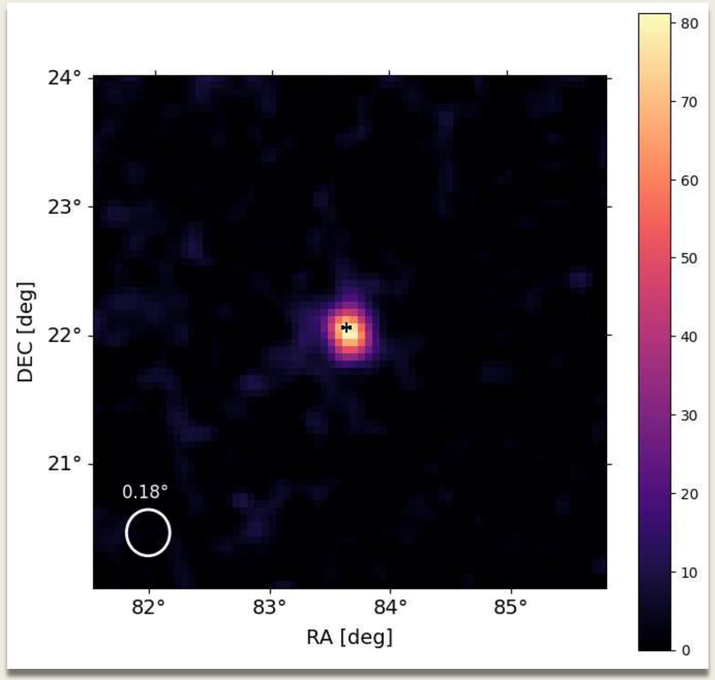
Autumn 2022

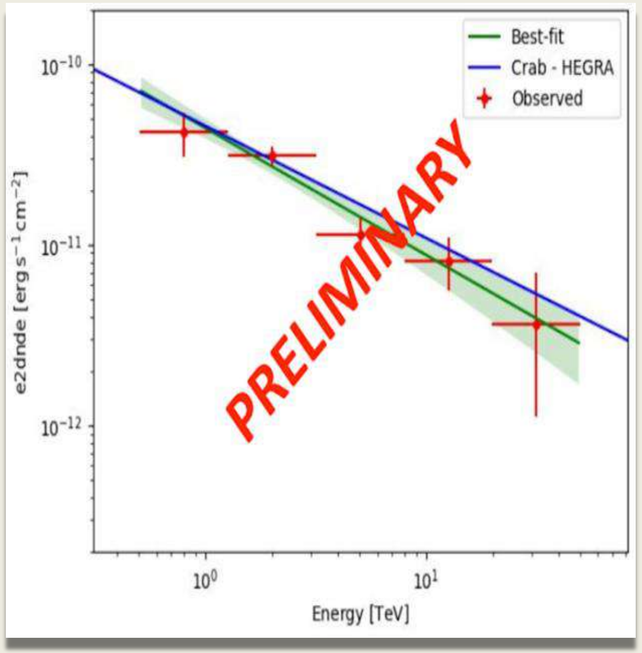
ASTRI 1 construction and calibration

"Mono" observations

Autumn 2024

Crab Campaign, winter 2024-2025





Crestan et al., ICRC 2025, in preparation

ASTRI Mini-Array - Schedule

June 2022

Site foundation

Autumn 2022

ASTRI 1 construction and calibration

"Mono" observations

Autumn 2024

ASTRI 2, 3, 4 construction and calibration

Autumn 2025

S. Scuderi, PO meeting

ASTRI Mini-Array - Schedule

June 2022

Site foundation

Autumn 2022

ASTRI 1 construction and calibration

"Mono" observations

Autumn 2024

ASTRI 2, 3, 4 construction and calibration

Stereoscopic observations

Autumn 2025

Full array

Autumn 2026

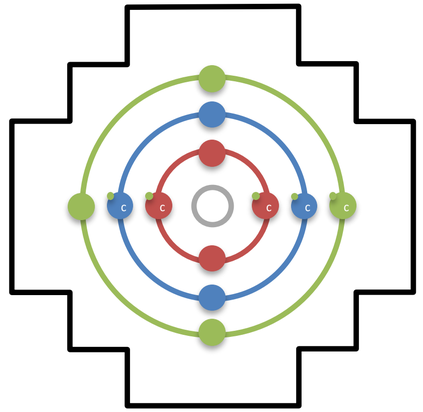
http://10.10.20.91:5000/

S. Scuderi, PO meeting

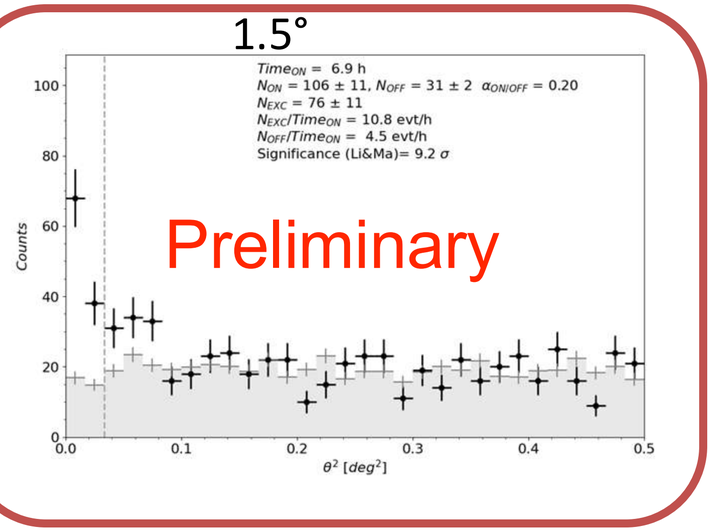
ASTRI-1 detection at increasing offsets

We got very nice detection at increasing offset position

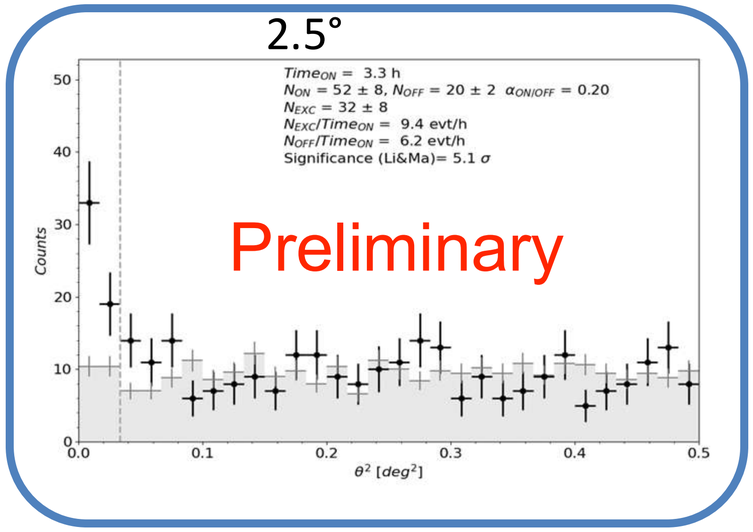
-> This is the indication that the camera's acceptance is quite flat up to an offset angle of 3.5°



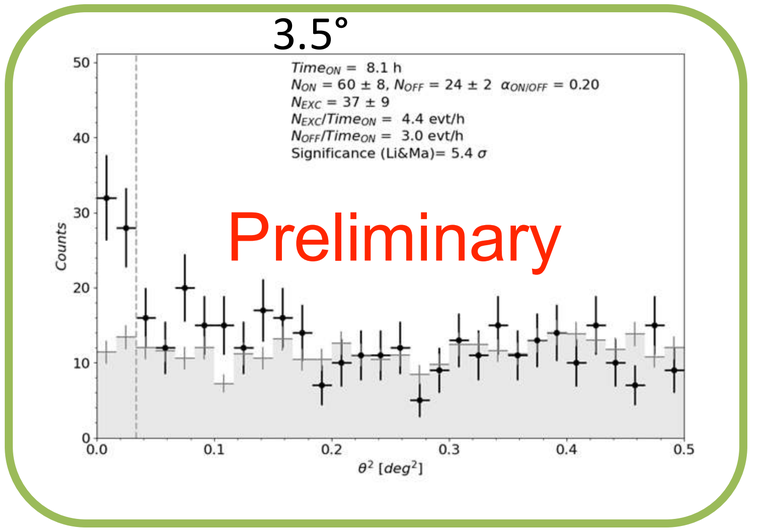
Offset 1.5°



Offset 2.5°

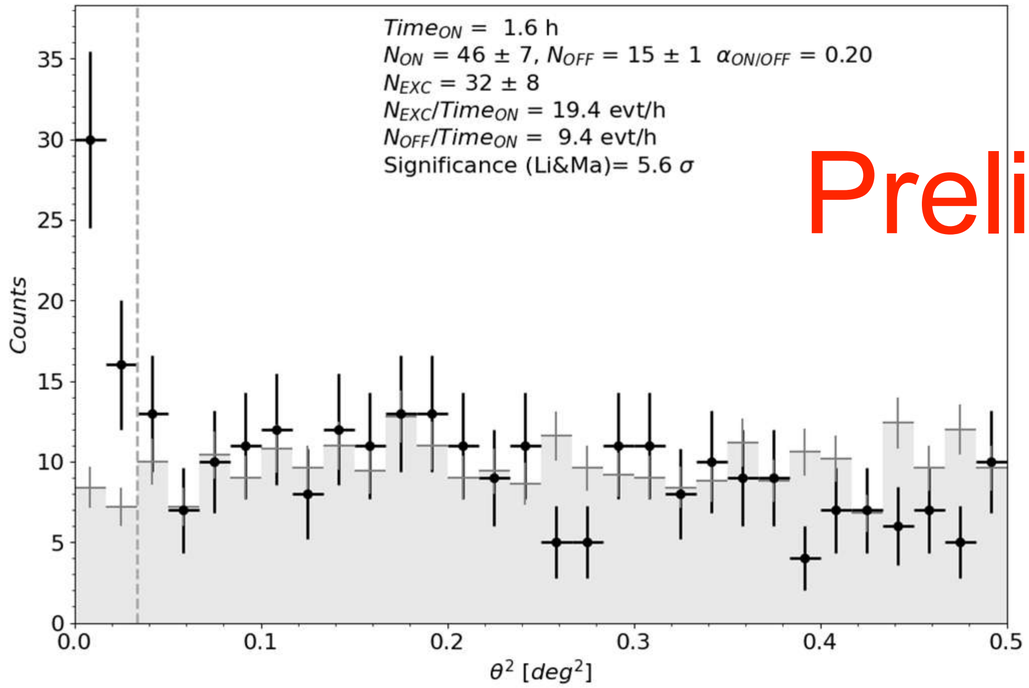


Offset 3.5°

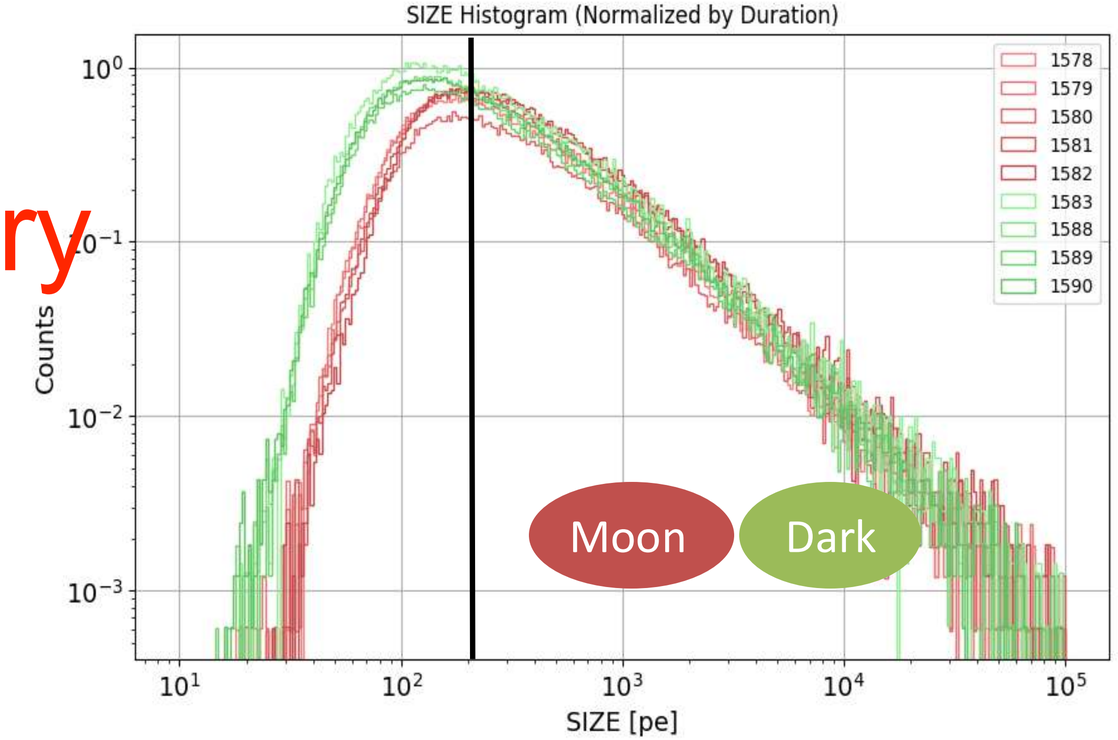


Crestan et al., ICRC 2025, in preparation

ASTRI-1 detection with the Moon



Preliminary



Crab runs taken during the first night:

- 4 in moonlight condition
- Offset angle: 0.5°

Analysis :

- Baseline analysis configuration
- Not-yet fine-tuned Monte Carlo simulation
- Applied cuts: Size>150 , Leakage=0, Numisland=1, ZD<30°, Gammaness>0.85, Th2<0.034 deg^2

Observing Strategy

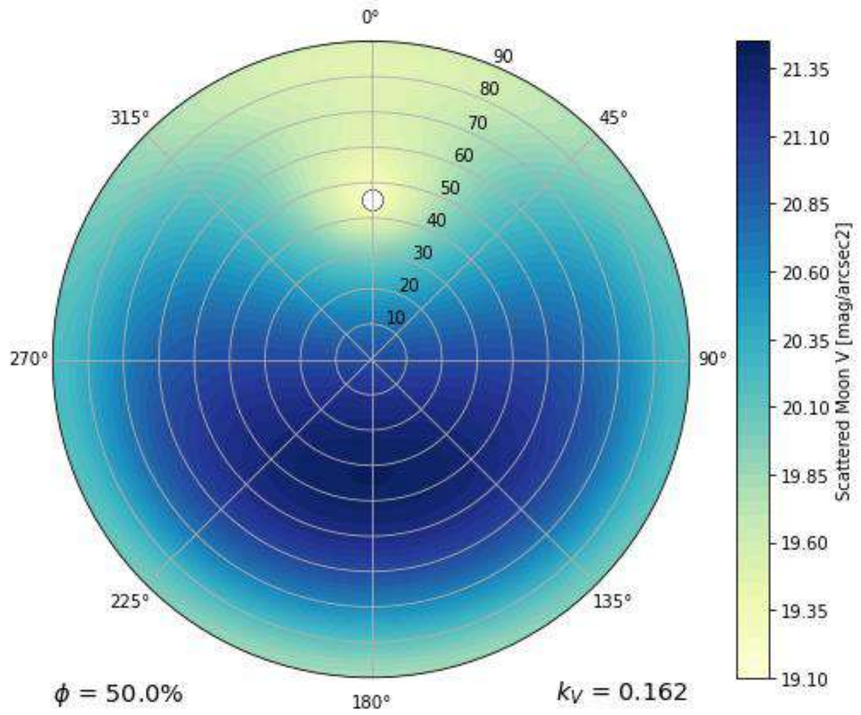
ASTRI needs deep exposures

Strategy :

Focus on few sky fields in order to obtain long exposures

3 aces up the sleeve :

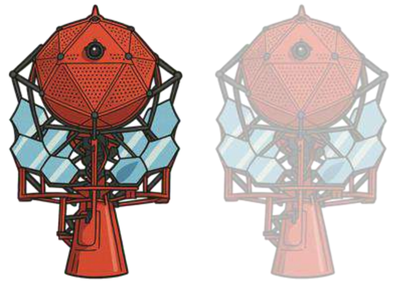
- Large FoV
  → Several sources in the FOV
- Observations with moonlight
  → Increases avail. time ~50-80%
- Large Z.A.
  → Increase Aeff @ high energies

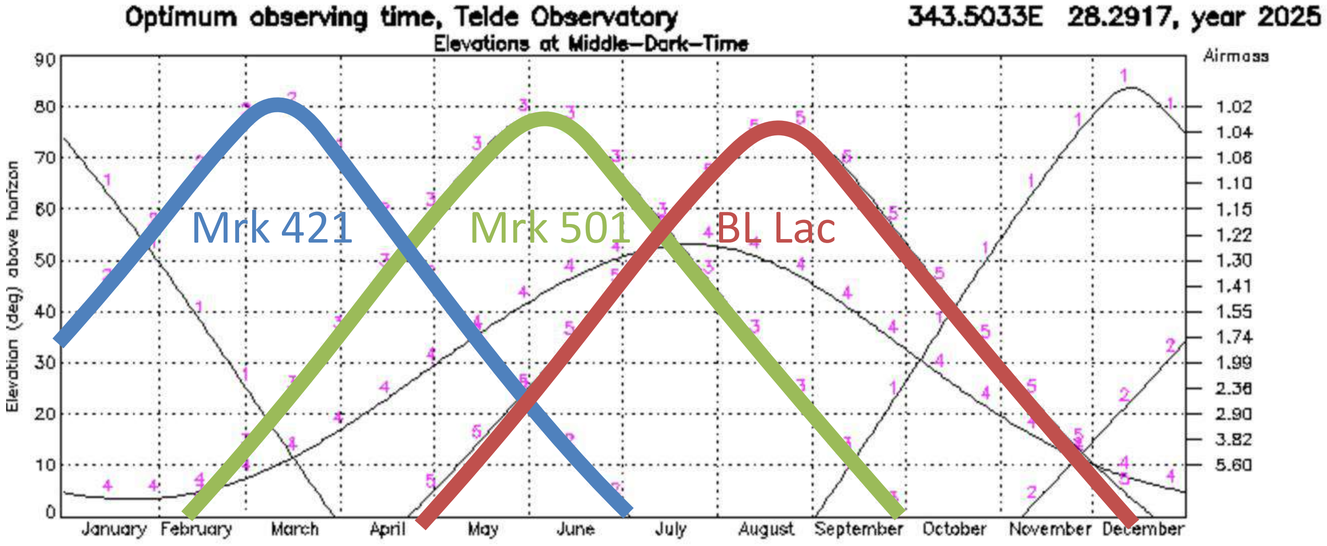


Setting 15 NSB as limit → AAOT ~ 2000 h

ASTRI Very Early Science

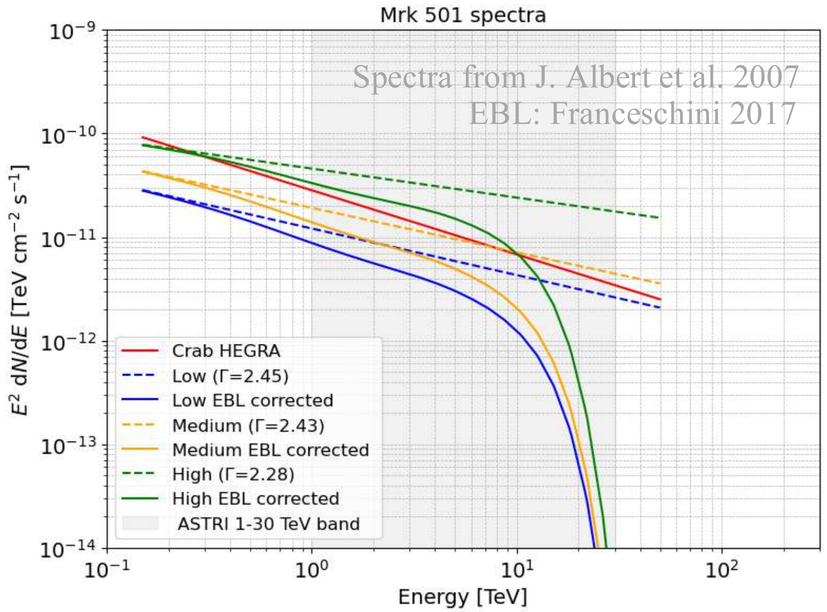
This summer, with at most two fully operational telescopes, our goal is to make the most of the available resources by combining scientific observations and technical operations. In this context, we aim to carry out a regular monitoring program of blazars.



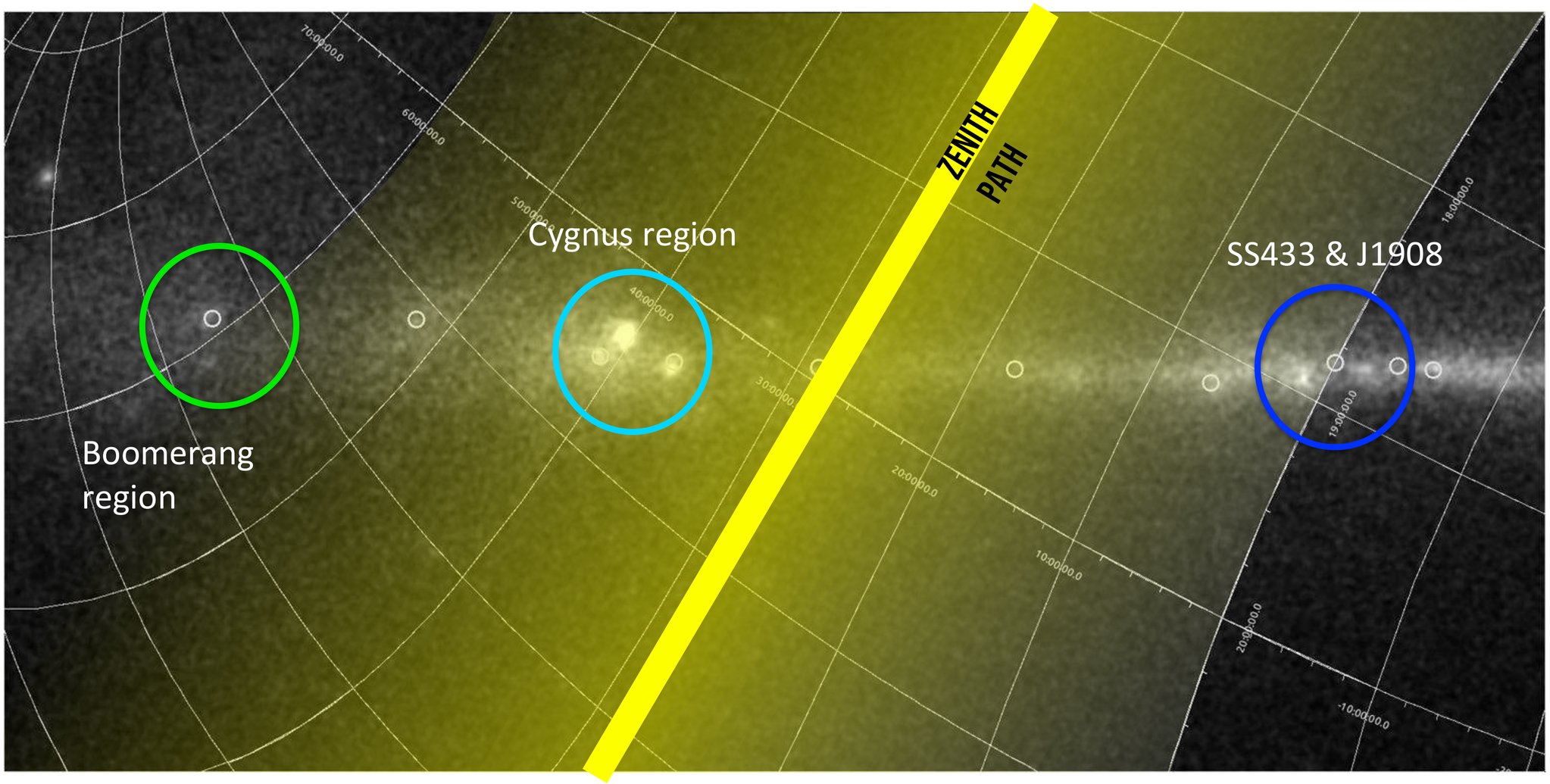


Flares in bright TeV blazars with *Swift* and the ASTRI Mini-Array

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)



ASTRI Early Science



ASTRI Science : overview

Origin of Cosmic Rays

- PeVatrons
- CRs Acceleration and Propagation
- Pulsar Wind Nebulae and TeV Halos

Fundamental Physics

- Intergalactic fields
- Blazars
- LIV, ALP and DM

Transient Follow-Up

Non gamma-ray science

The ASTRI Mini-Array of Cherenkov Telescopes at the Observatorio del Teide

JHEAP, 2022, 35, 52

ASTRI Mini-Array Core Science at the *Observatorio del Teide*

JHEAP, 2022, 35, 1

Galactic Observatory Science with the ASTRI Mini-Array at the *Observatorio del Teide*

JHEAP, 2022, 35, 39

Extragalactic Observatory Science with the ASTRI Mini-Array at the *Observatorio del Teide*

JHEAP, 2022, 35, 91

More at..

Astri web site : **http://www.astri.inaf.it/**

On socials, search for ***ASTRIgamma*** (FB and Instagram)

IRFs (gammapy compatible) available at :
https://zenodo.org/record/6827882