The ASTRI Mini-Array: in search for hidden Pevatrons

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for the ASTRI Project

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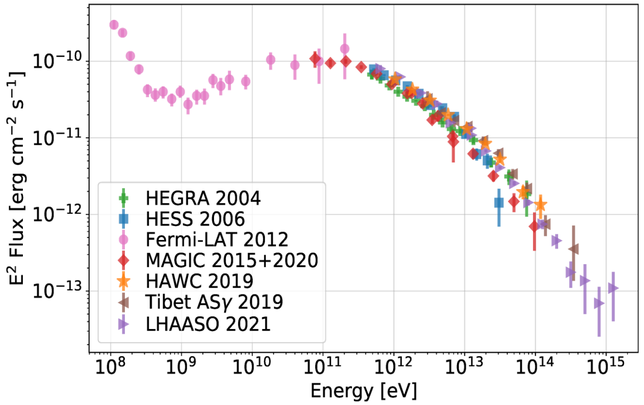
PeVatron context

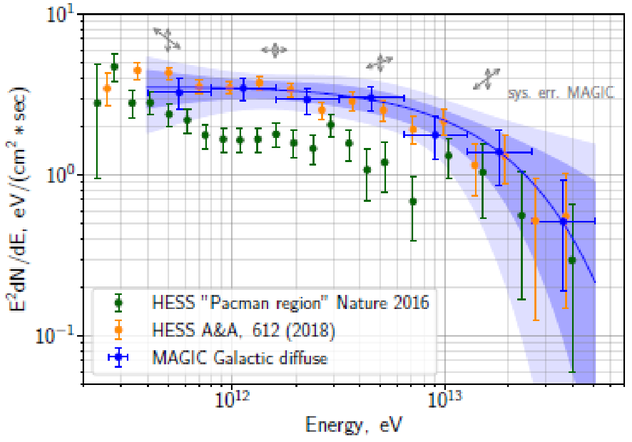
- In spite of the huge amount of collected data, Cosmic-Ray origin is still an open issue.
- Detection of hadronic PeVatrons (>100 TeV gamma-ray emission from protons with E>1 PeV) is the only direct proof of CR acceleration that we can have
- No Supernova Remnants (the main CR accelerator candidates) have been detected at these energies
- Recent data show several different kinds of sources emitting at E ≥ 100 TeV

Crab and PWNe



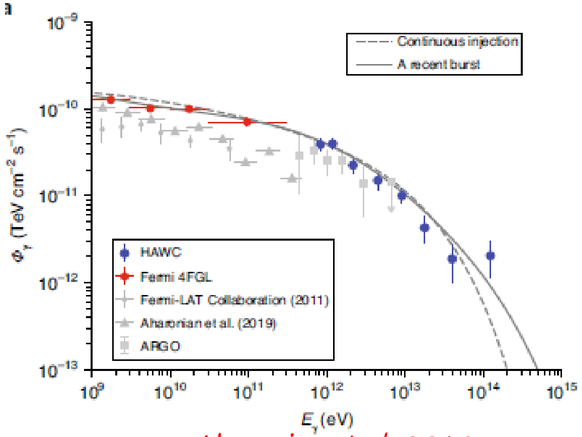
Tibet AS collaboration 2019, MAGIC collaboration 2020, LHAASO collaboration 2021, CAO et al. 2021, Amato & Olmi 2021

Galactic Center

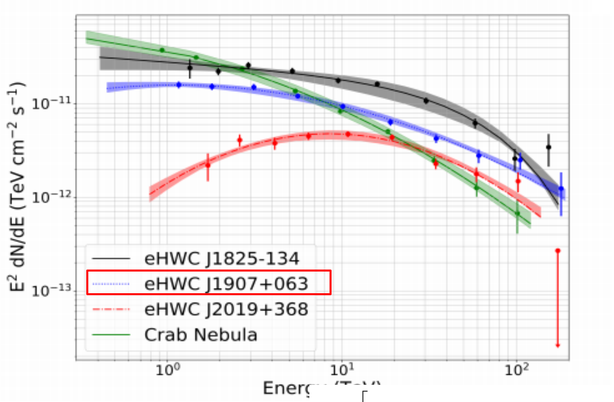


HESS collaboration 2016, 2018
MAGIC collaboration 2020

Massive Star clusters



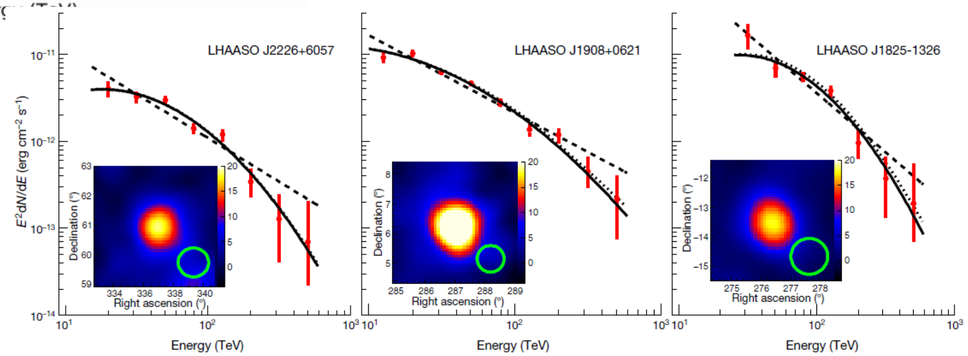
Aharonian et al. 2019
HAWC collaboration 2021



Abeysekara et al. 2020
Albert et al. 2020

HAWC and LHAASO sources

Cao et al. 2021



The ASTRI Project (Astrofisica con Specchi a Tecnologia Replicante Italiana)

PI: Giovanni Pareschi
PM: Salvo Scuderi
PS: Andrea Giuliani

Scuderi et al. 2022, JHEAP, 35, 52

ASTRI-Horn Prototype

- INAF "Flag Project" funded by MIUR → end-to-end prototype for CTAO at Serra la Nave (Mount Etna, Sicily)
- First Crab detection above 5 sigma (Lombardi et al. 20)
- Structure and mirrors selected for CTA SSTs

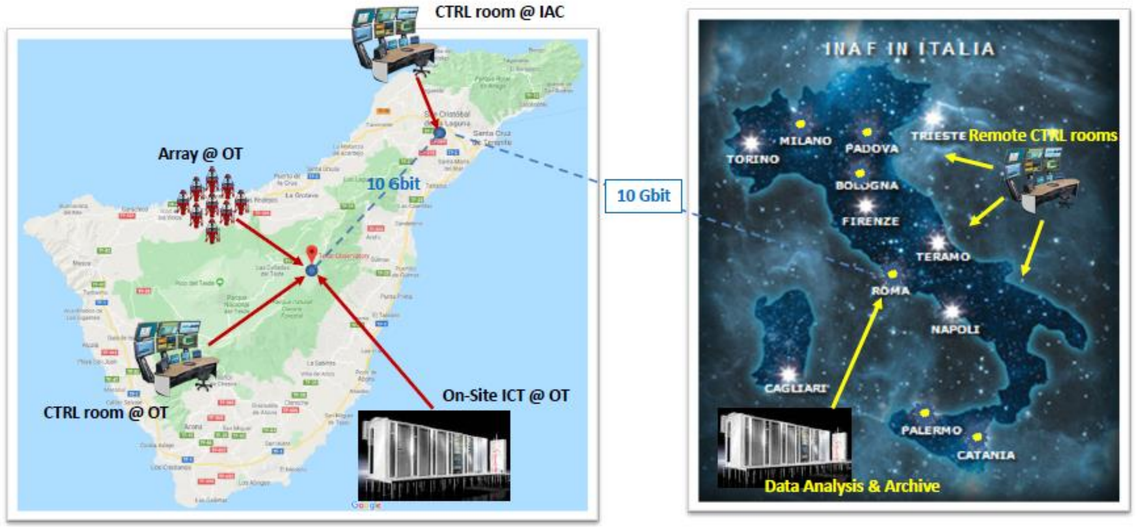
ASTRI Mini-Array

Array of 9 4m ASTRI telescopes at Teide

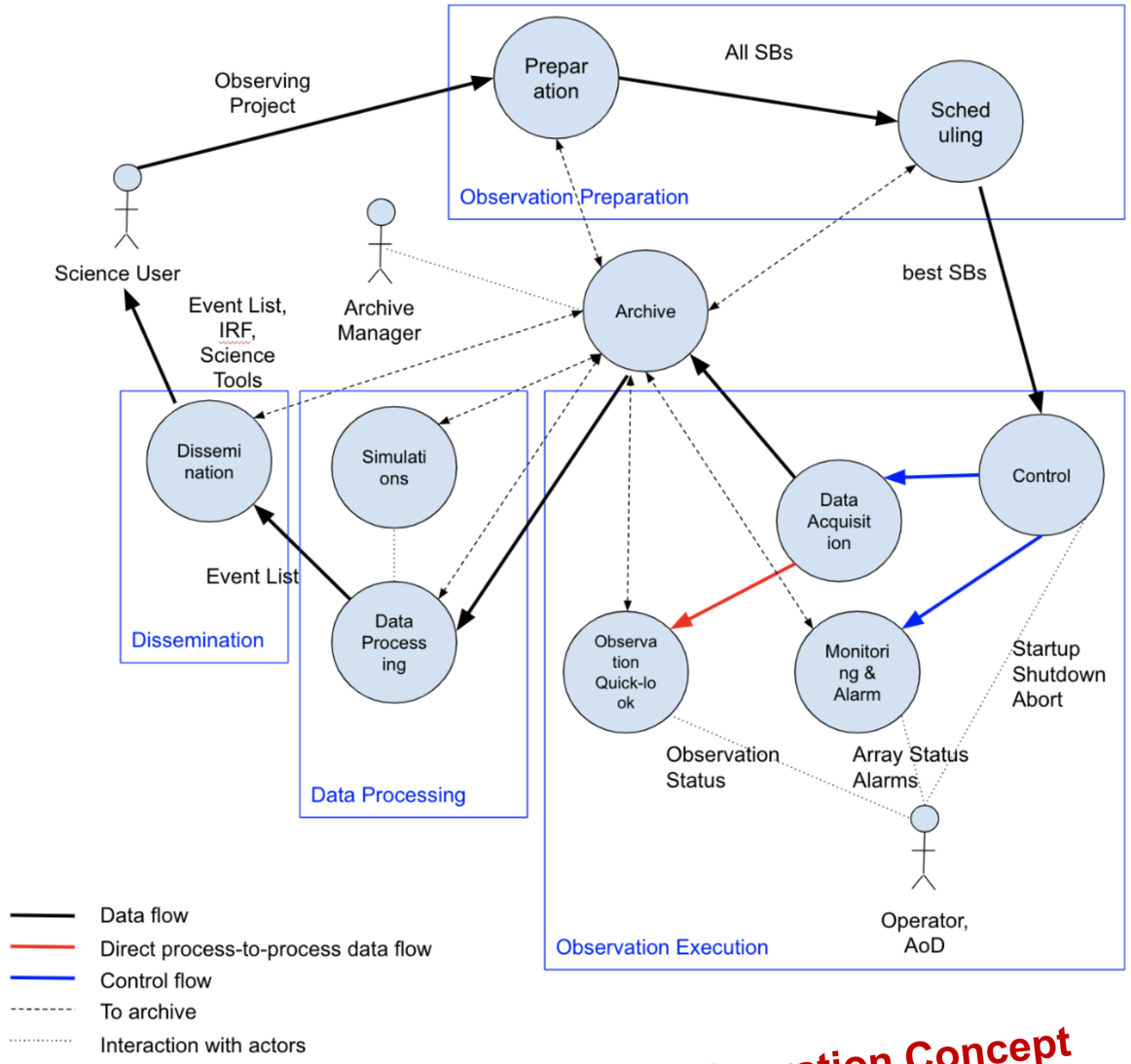
- INAF commitment with the Italian government and international partners (University of Sao Paulo/FPESP – Brazil, North-West University – South Africa, IAC – Spain) [more than 150 researchers]
- Dedicated Funding
- Being deployed at the Teide Observatory in collaboration with IAC

The ASTRI Mini-Array

Scuderi et al. 2022, JHEAP, 35, 52



- It is being developed in order to be operated remotely, after the commissioning phase
- Data analysis will be performed off-site (0.5 TeraBytes/night)
- Possible synergies with current VHE Northern Arrays (e.g. MAGIC and LSTs)



Operation Concept

The Role of the ASTRI Mini-Array

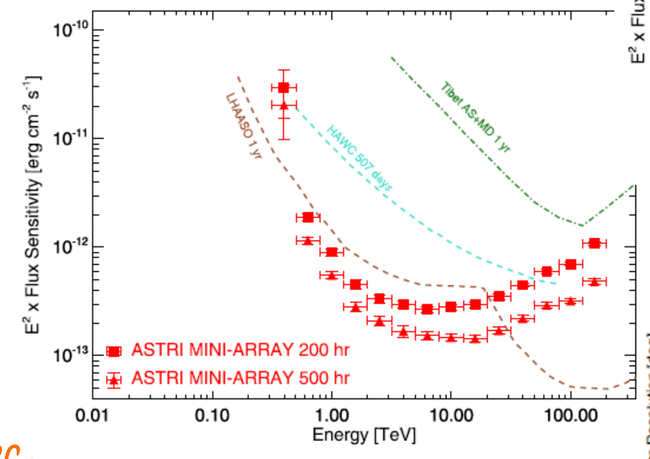
Vercellone et al., 2022, JHEAP, 35,1
Scuderi et al. 2022, JHEAP, 35, 52

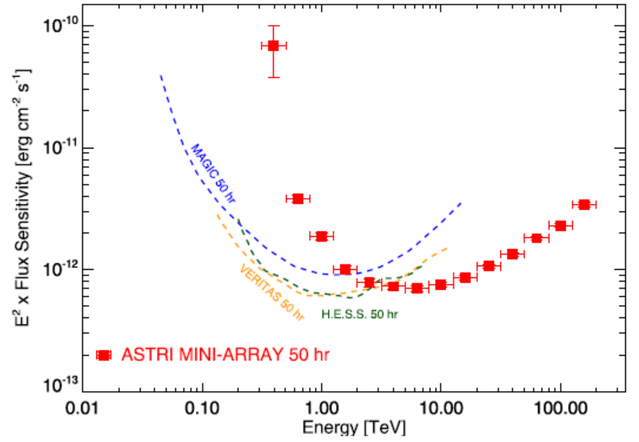
Despite these new detections at E>=100 TeV, we still have no clear evidence of pure hadronic emission (and consequently CR acceleration proof) at energies above several tens of TeV

The ASTRI Mini-Array may shed light on this open issue

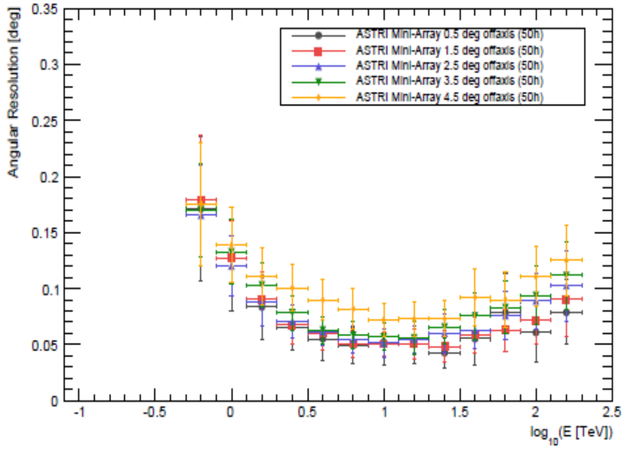
- Wide FoV with almost homogeneous off-axis acceptance
  - ✓ Multi-target fields, surveys, and extended sources
  - ✓ Enhanced chance for serendipitous discoveries
- Sensitivity: better than current IACTs (E > a few TeV):
  - ✓ Extended spectra and contsraints on cut-offs
- Energy/Angular resolution: ~10% / ~0.05° (E ~ 10 TeV)
  - ✓ Characterize extended sources morphology

ASTRI Mini-Array Sensitivity



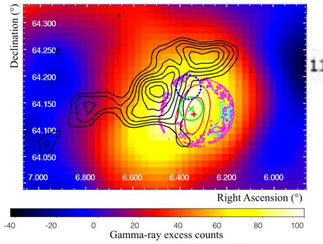


ASTRI Mini-Array Angular Resolution

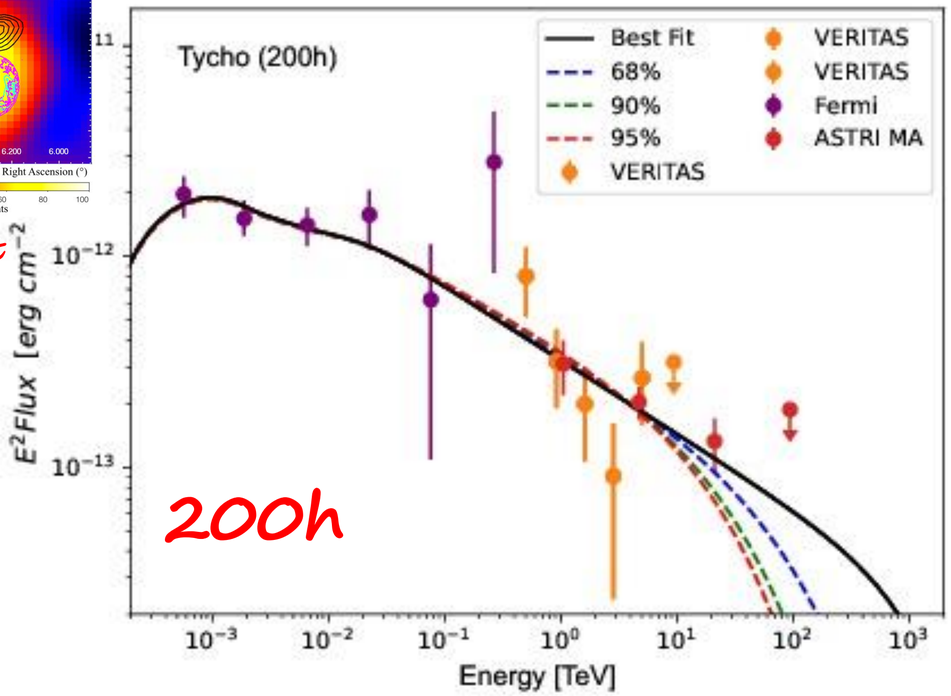


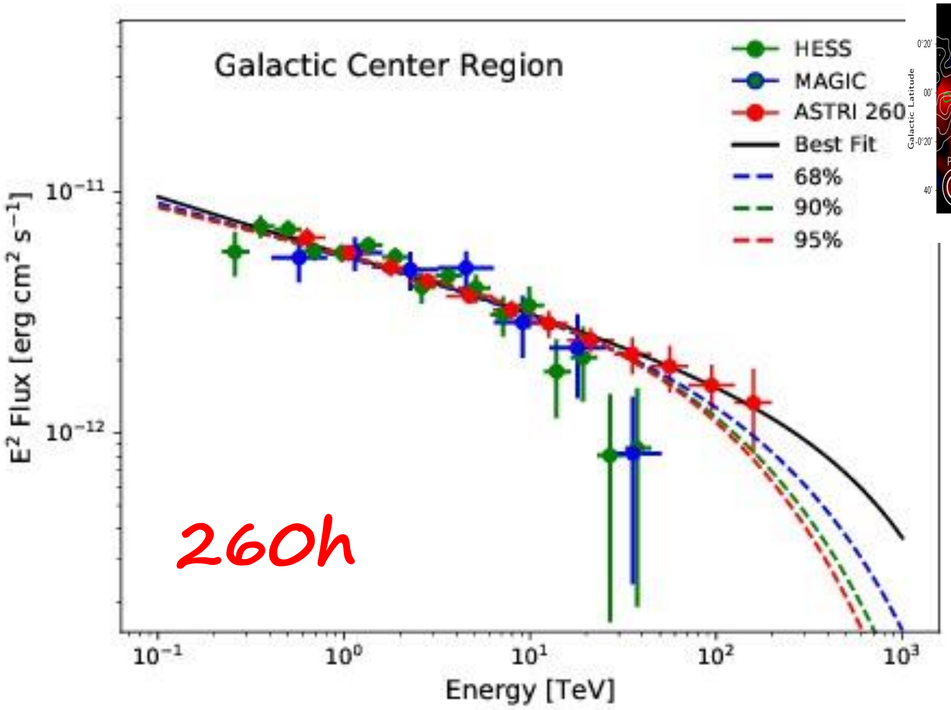
Candidate PeVatrons with ASTRI MA:
SNR Tycho and the GC Region

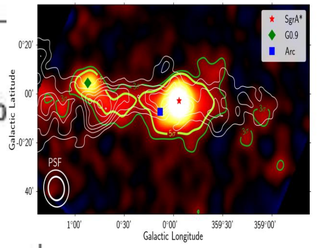
Vercellone et al., 2022, JHEAP, 35,1



Archambault et al. 2017







Acciari et al. 2020

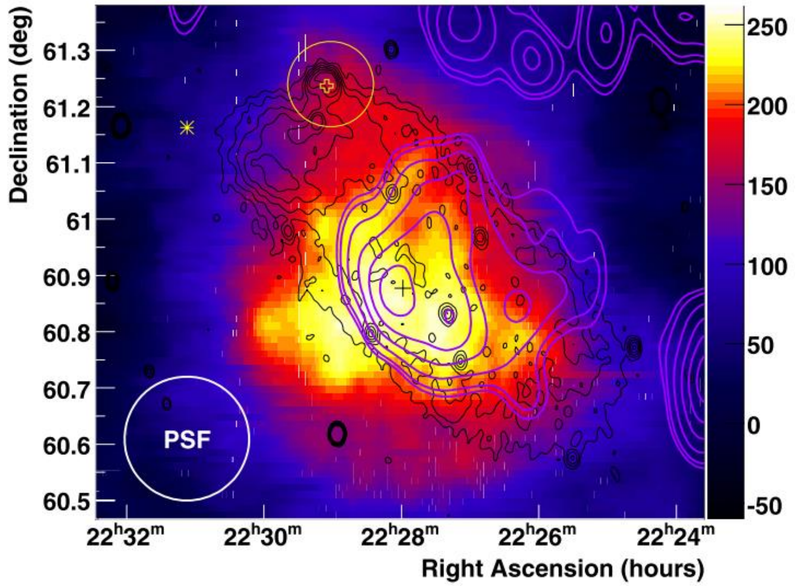
- 100 TeV detection with 500h of exposure
- Critical contribution to Pevatron emission from Tycho SNR even without a 100 TeV detection (cut-off constraints)
- ASTRI MA can resolve the source (D~8')

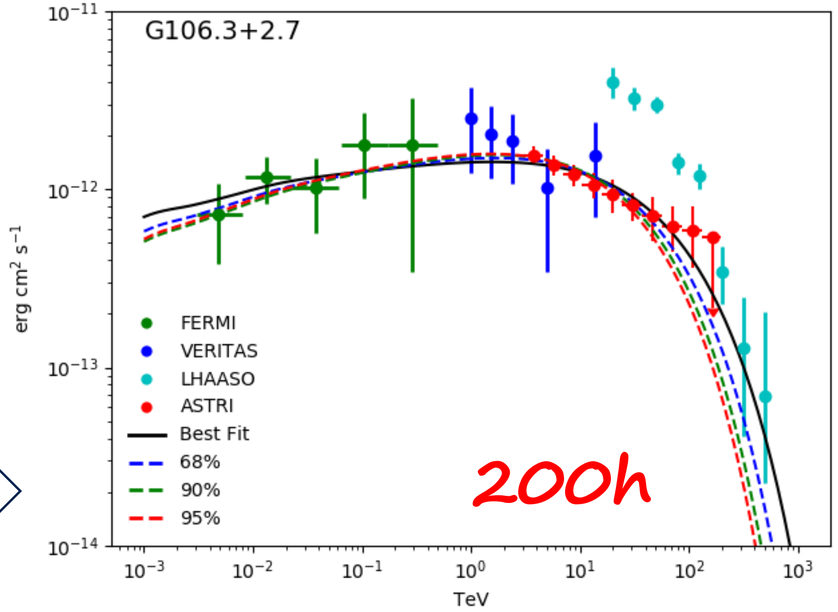
- With the same HESS texp, ASTRI-MA will secure the likely Pevatron nature of GC region
- Mapping of the whole GC region with a single observation (dimension 1,5°x0,2°)
- Resolving different sources

Candidate PeVatrons with ASTRI MA:
SNR G106.3+2.7

Vercellone et al., 2022, JHEAP, 35,1

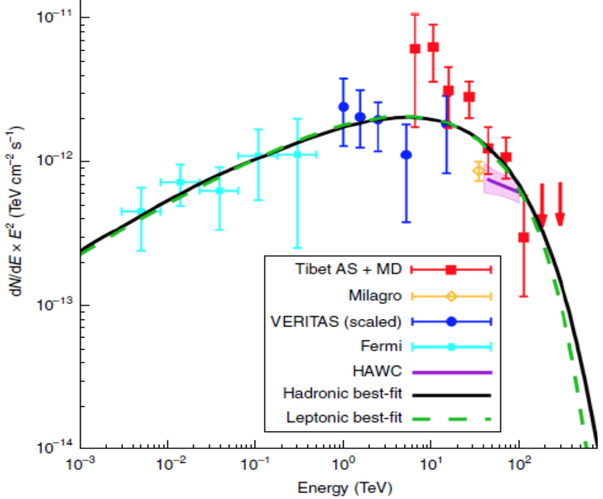
ASTRI Mini-Array



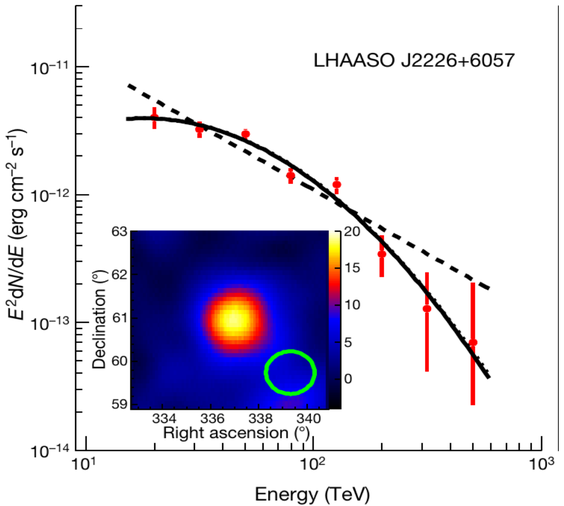


- Morphology and spectrum from VERITAS [LHAASO points added in a second moment]
- Detection @100TeV w ASTRI MA (200h exp) with high significance

Tibet AS collaboration 2021



Cao et al. 2021



With the ASTRI-MA angular resolution:

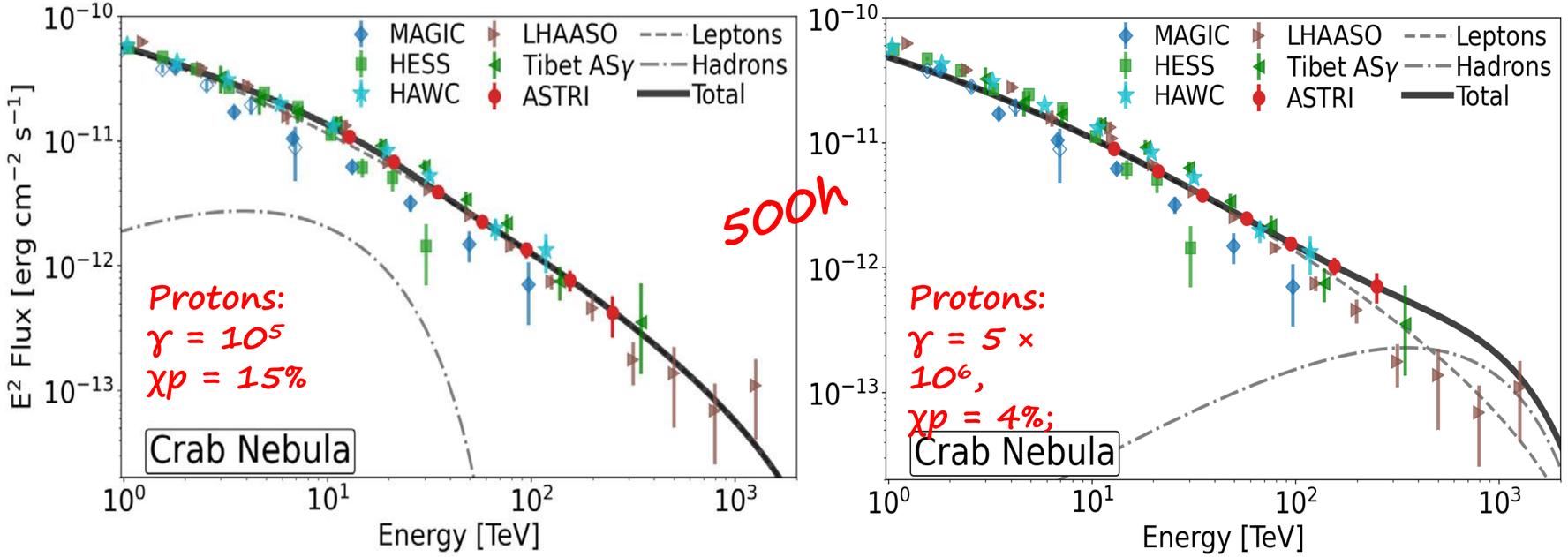
- association of the SNR with the Molecular cloud, separating it from the pulsar
- different morphologies at different energies

Candidate PeVatrons with ASTRI MA:
Crab Nebula (and Pulsar Wind Nebulae)

Vercellone et al., 2022, JHEAP, 35,1

Mini-Array

Crab Nebula detected in the gamma-ray band above PeV energies
→ particle acceleration but hadrons or leptons?



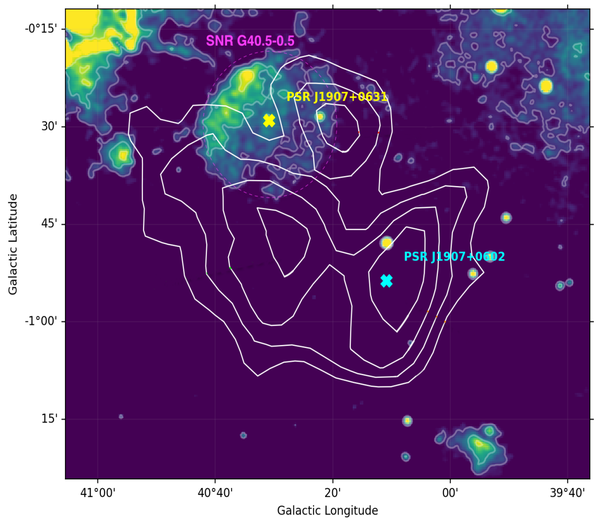
The ASTRI Mini-Array sensitivity will allow us to constrain the hadronic contribution in the Crab Nebula (and similar sources)

Different fraction (χp) and energies (γ) of hadrons implies different behavior at the highest energies

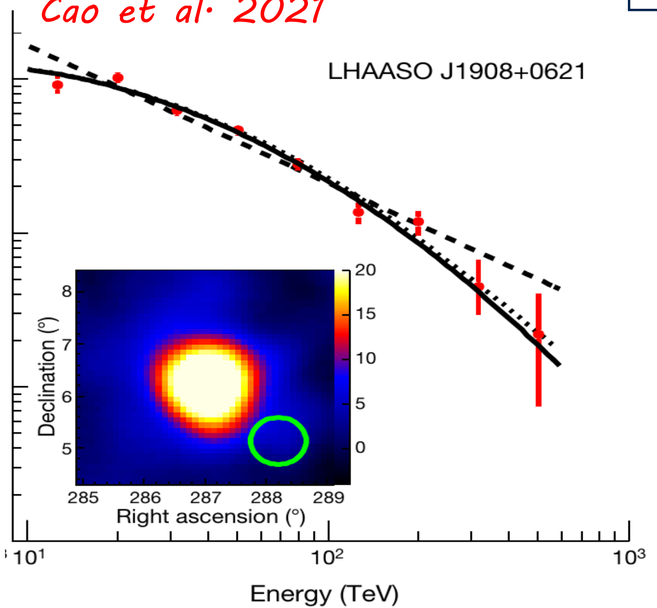
Candidate PeVatrons with ASTRI MA:
eHWC 1907+063

Vercellone et al., 2022, JHEAP, 35,1

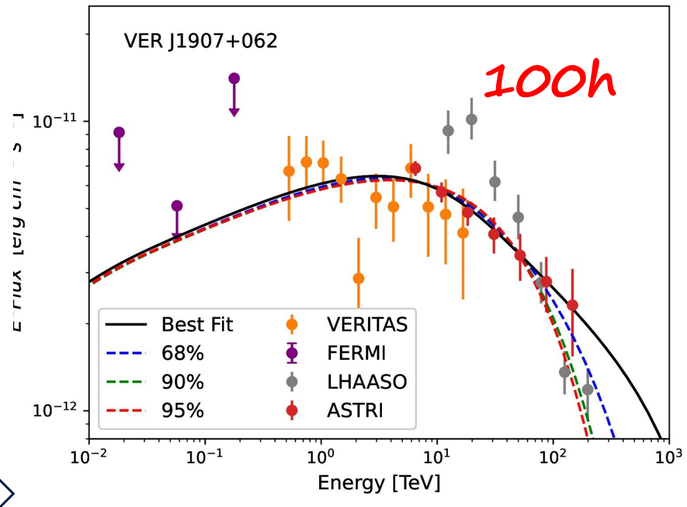
Aliu et al. 2014



Cao et al. 2021

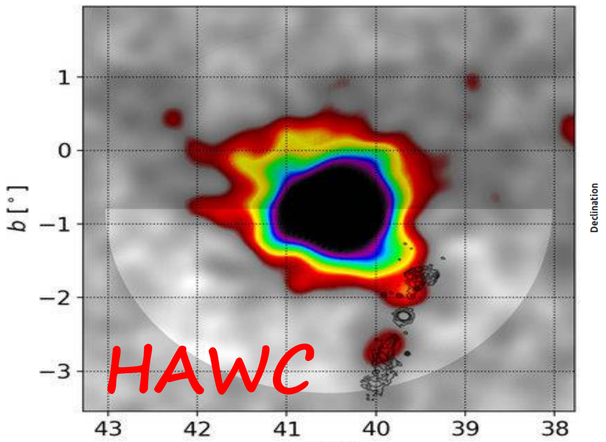


ASTRI MA

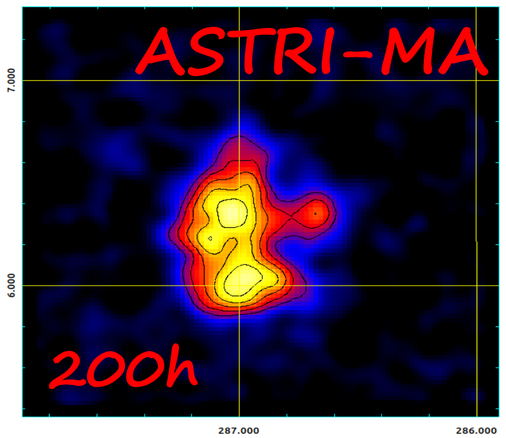


- Morphology from VERITAS (Aliu et al. 2014)
- PL spectrum from HAWC (Abeysekara et al. 2017) [LHAASO points added in a second moment]
- Detection @100TeV w ASTRI MA (100h exp) with high significance
- **ASTRI MA, in the near future, will be the only instrument able to resolve TeV extended sources**

[Different scale]

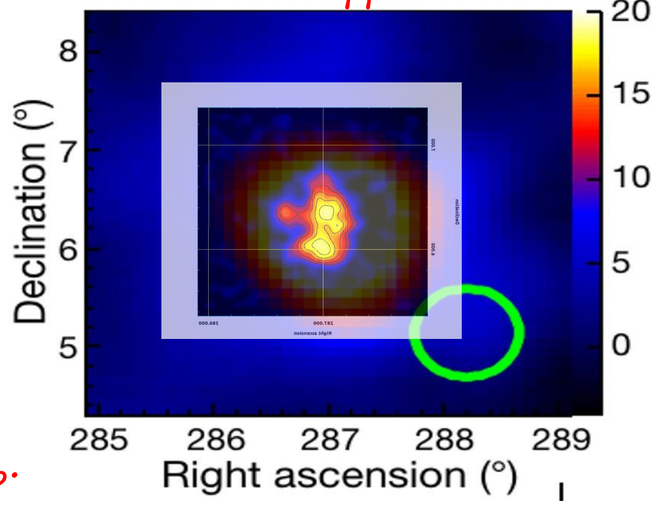


Abeysekara+ 2017



Crestan+ in prep.

ASTRI-MA overlapped w LHAASO

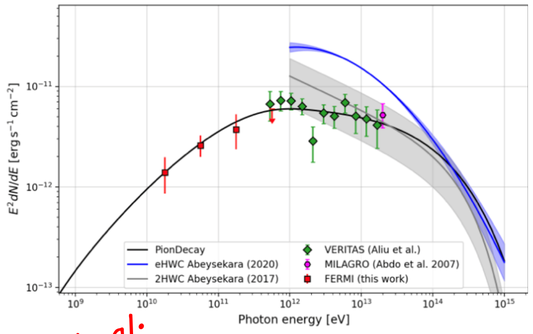


Candidate PeVatrons with ASTRI MA:
eHWC 1907+063: X-ray follow up

Mini-Array

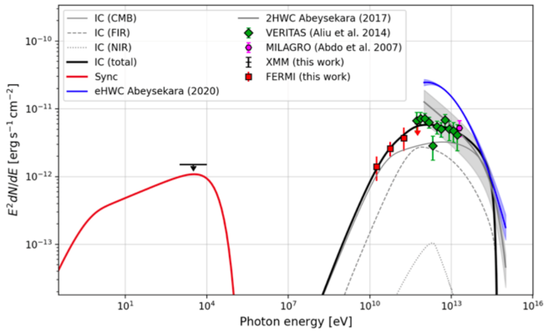
Deep study of gamma-ray emission from this source

- *Single-component models cannot explain both data and morphology (critical parameters).*
- *Good fit with reasonable parameters for a composite (hadronic + leptonic) model*

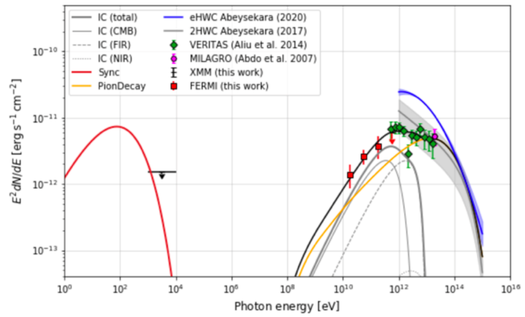


Crestan et al. 2021

Hadronic scenario

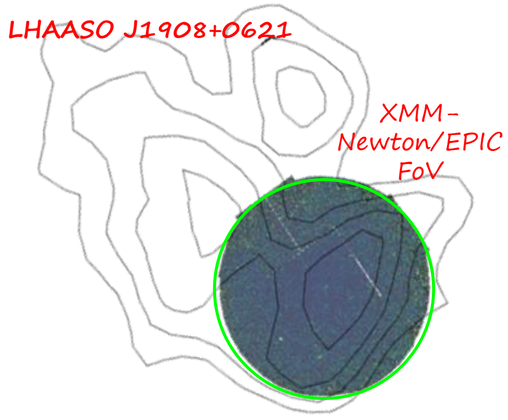


Leptonic scenario



Composite scenario

⇨ ***It is very important to constrain the leptonic contribution in the X-ray band (1-10 keV).***



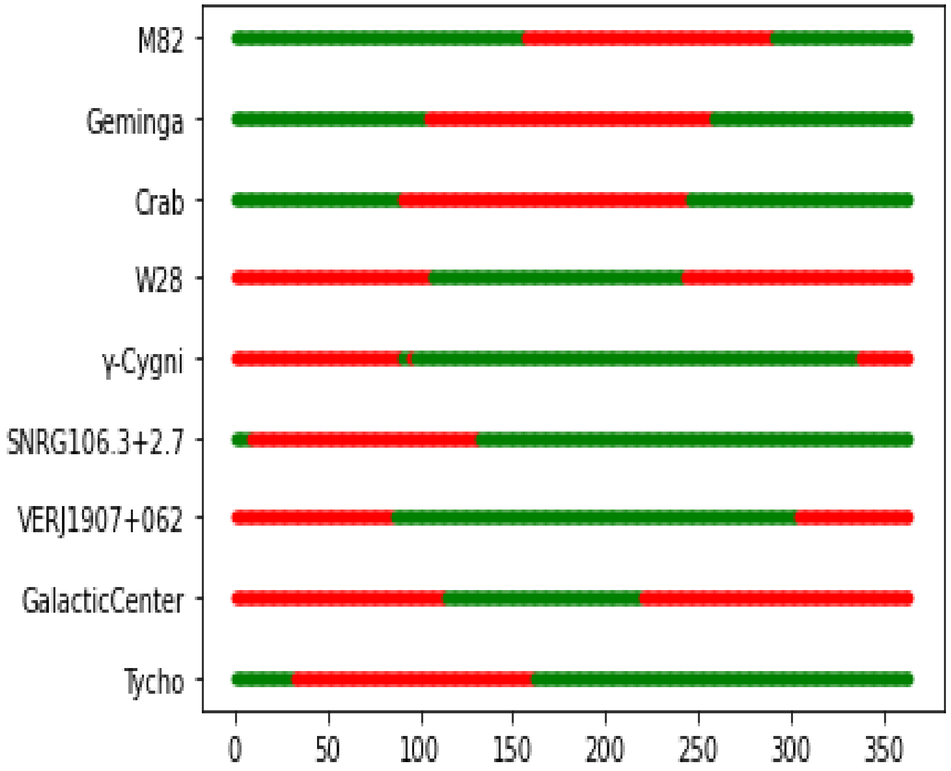
XMM-Newton archive → no evidence for X-ray diffuse emission → we rescaled the resulting upper limit to the VHE emission area **(black arrow in the SED plots).**

⇩

Same idea applied to all the VHE sources → ***proposal for XMM-Newton data in order to map the sky region containing the most promising sources with a mosaic***

ASTRI MA observation Strategy

"Pillar Sources" well distributed during the year



Green = more than 2 hrs per night available

- 1500 dark hours per year becaming 1000 hrs available for scientific observations taking into account bad weather, "calima", maintenance… (~ 3000 hours of data taking in 3 years)
- High zenith angles (up to 60°)
- even moonlit night (a quarter)

We plan to have deep exposures on few selected regions, as an example :

Sources	Seasons	Dark Hours (3 years)
Galactic Center	May-June-July	300
VER J1907	September-October	300
G106	November-December	400

Conclusions

What are the sources of Galactic Cosmic-Rays?

ASTRI Mini-Array has the needed potential to answer this question

- Improved sensitivity w.r.t. current IACTs at energies above a few TeV → detection of sources above 100 TeV and constraints on physical parameters (e.g. diffusion coefficient)
- Excellent angular resolution at very high-energies → morphology characterization and strong constraints to gamma-ray emission/Molecular Cloud association
- Large FoV → large field (e.g. Galactic Center region) and extended sources (e.g. TeV halo) in-depth analysis

1 telescope operative → early 2023 (already on-site!!)

3 telescopes operative → by summer 2023

Complete Array→ by 2025


Thank you very
much!