MINISTERO DELL' ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA

INAF ISTITUTO NAZIONALE DI ASTROFISICA

NORTH-WEST UNIVERSITY YUNIBESITI YA BOKONE-BOPHIRIMA NOORDWES-UNIVERSITEIT

The ASTRI Mini-Array: a breakthrough in the Cosmic Ray study

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for the ASTRI Project

International Cosmic Ray Conference, July 16, 2021

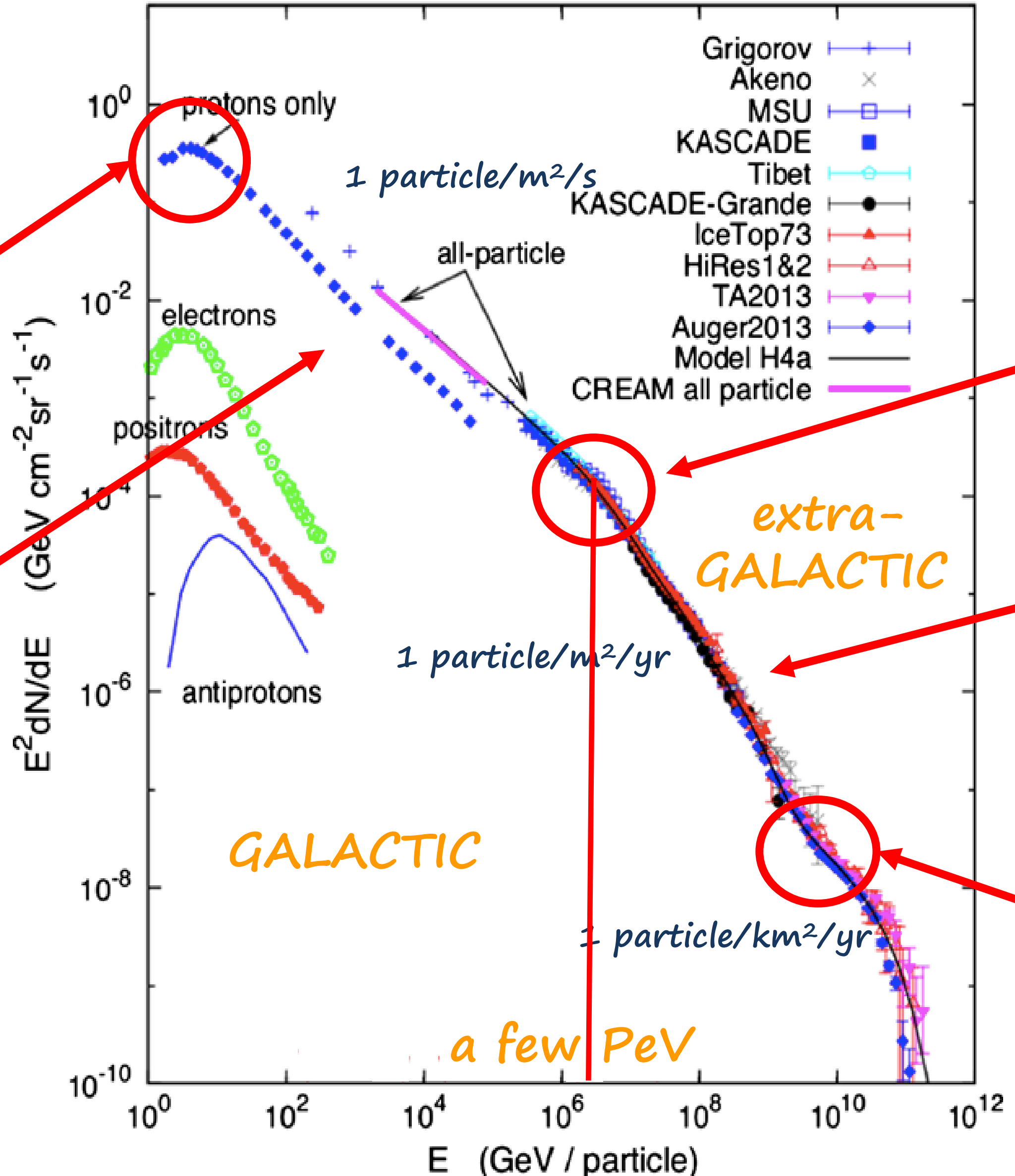
Cosmic Rays: Pevatron Context

Protons (85 %)
Nuclei (13%)
Electrons/Positrons (2%)

Solar modulation

power law $E^{-2,7}$

$W_{CR} \sim 1\ eV/cm^3$



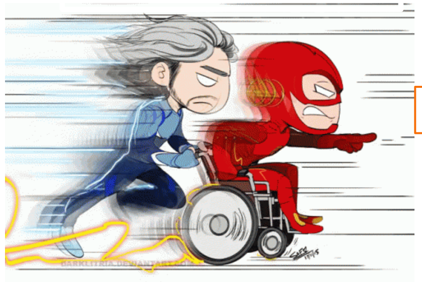
CR "Knee"

power law $E^{-3,1}$

CR "Ankle"

Cosmic Rays: Pevatron Context

ACCELERATION



DSA and NLDSA

$N(E)dE \propto E^{-\gamma_E}dE = 4\pi p^2 p^{-\gamma_p}dp$

$\gamma_E \leq 2$ | $\delta B/B > 1$

ESCAPE

"Help us Molecular Clouds: you are our only hope."

(Gabici 09, Celli 19, Mitchell 21)

Disagreement with DSA and NL-DSA results!!

PROPAGATION

$D(E) = D_0 E^{\delta}$

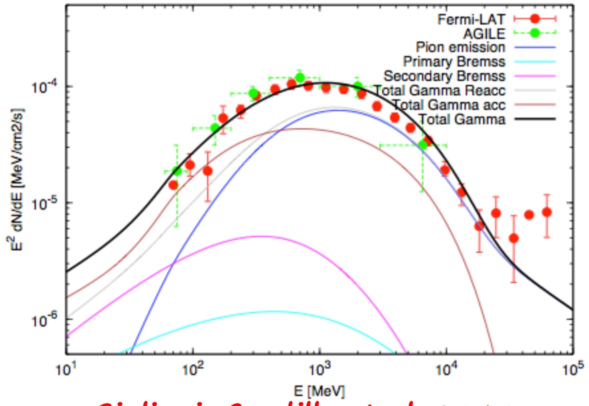
From B/C and anisotropy

$\delta \sim 0.3$ | $\gamma_E \sim 2.3 - 2.4$

ORIGIN ISSUE

Low-Energies

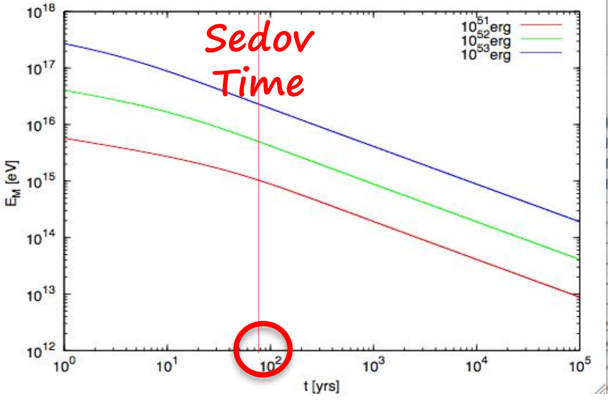
- ✧ We have the proof of CR energization from some middle-aged SNRs (W44, IC443, W51c):
  - ➢ Reacceleration? (Cardillo et al. 2016)
  - ➢ D(E) Suppression? (Celli et al. 2019)



Giuliani, Cardillo et al. 2010, Ackermann et al. 2013, Cardillo et al. 2014, Jogler et al. 2016

High-Energies

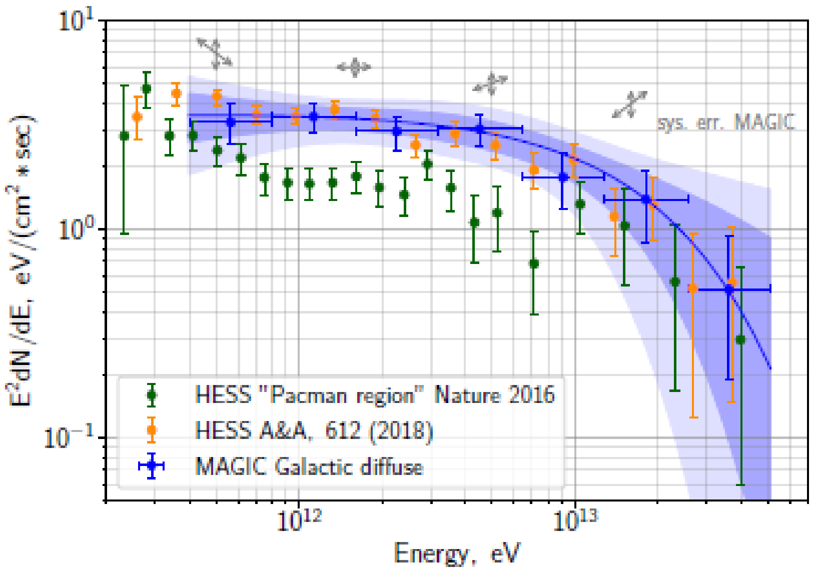
- ✧ No SNR at 100 TeV → Detection problem for pevatron SNRs (Cardillo et al. 2015)



Distant Molecular clouds are the "only hope"

And what if SNR do not were galactic CR sources?

CR origin: other sources

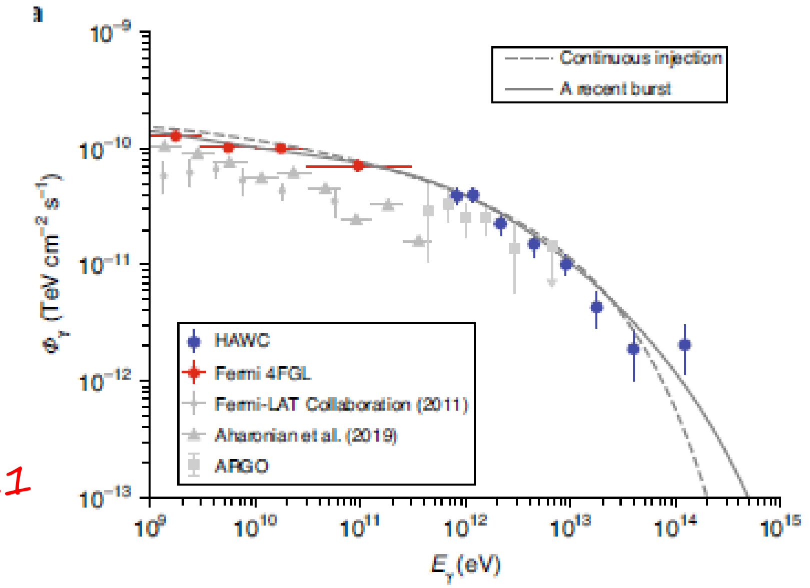


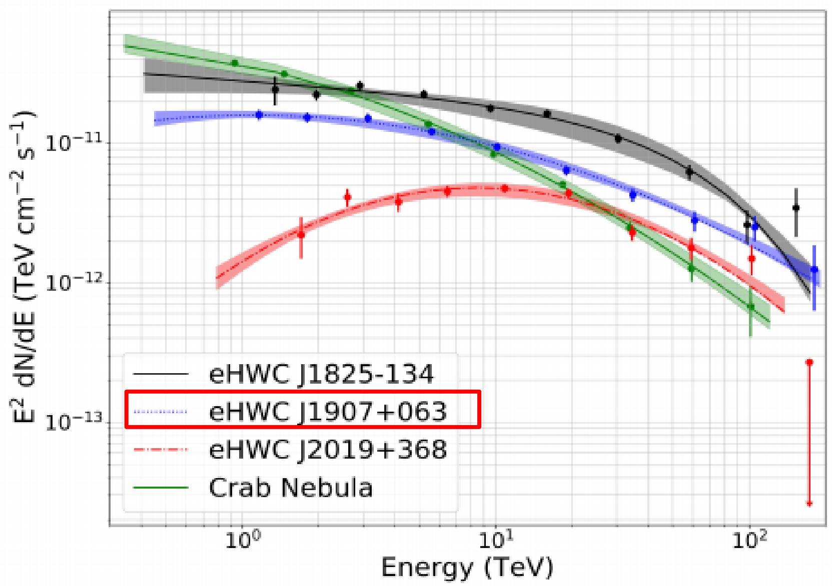
HESS collaboration 2016, 2018
MAGIC collaboration 2020

Galactic Center

Superbubbles

Aharonian et al. 2018
HAWC collaboration 2021



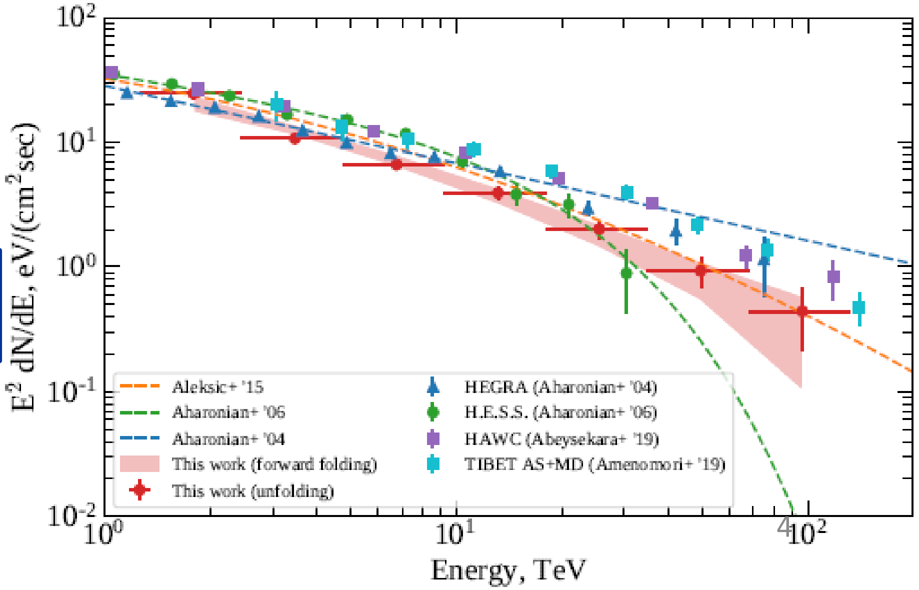


HAWC sources

Abeysekara et al. 2020
Albert et al. 2020

Crab and PWNae

Tibet AS collaboration 2019
MAGIC collaboration 2020
LHAASO collaboration 2021
CAO et al. 2021



The ASTRI Mini-Array

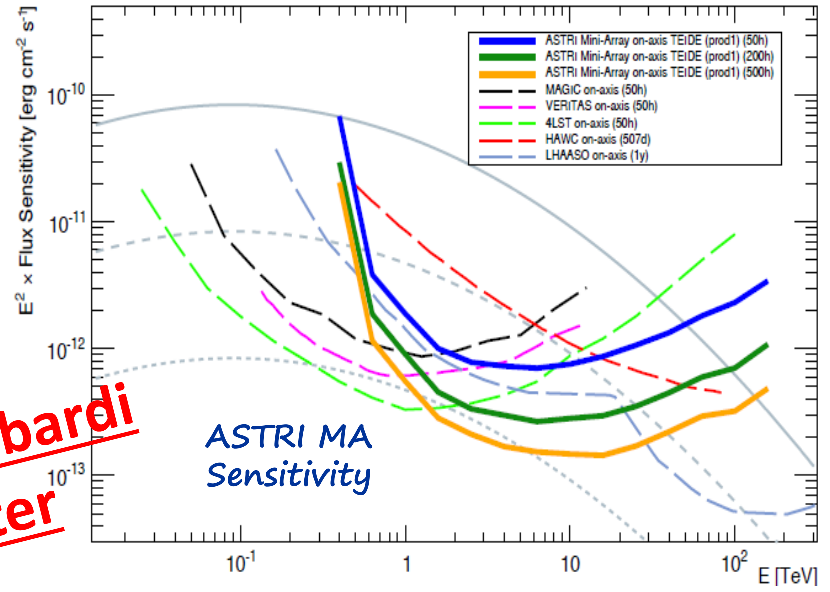
See Antonelli and Vercellone Talks

Mini-Array

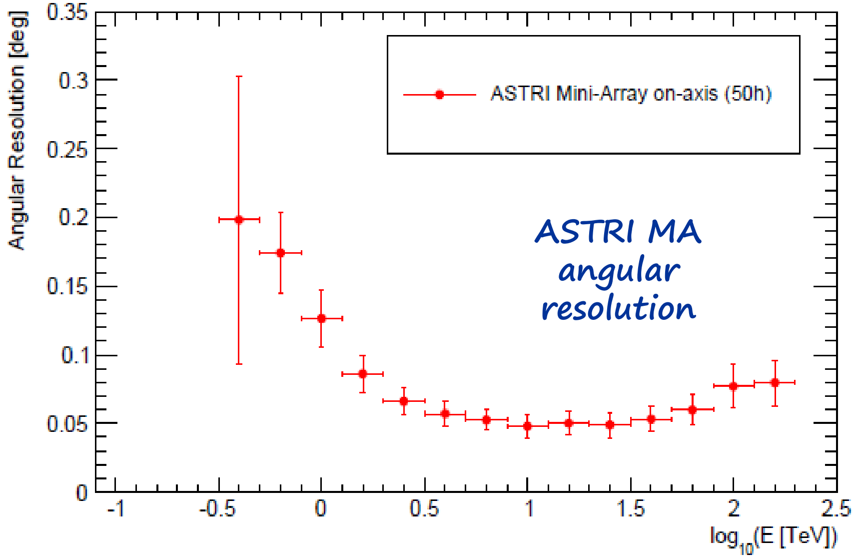
ASTRI MA project, in progress

	ASTRI Mini-Array	MAGIC	VERITAS	H.E.S.S.	HAWC	LHAASO
Location	28° 18′ 04″ N	28° 45′ 22″ N	31° 40′ 30″ N	23° 16′ 18″ S	18° 59′ 41″ N	29° 21′ 31″ N
	16° 30′ 38″ W	17° 53′ 30″ W	110° 57′ 7.8″ W	16° 30′ 00″ E	97° 18′ 27″ W	100° 08′ 15″ E
Altitude [m]	2,390	2,396	1,268	1,800	4,100	4,410
FoV	9.6°	~ 3.5°	~ 3.5°	~ 5°	2 sr	2 sr
Angular Res.	0.05° (10 TeV)	0.07° (1 TeV)	0.07° (1 TeV)	0.06° (1 TeV)	(0.15–1)°[(a)]	~ 0.2°[(b)] (10 TeV)
Energy Res.	(12)% (10 TeV)	16% (1 TeV)	17% (1 TeV)	15% (1 TeV)	30% (10 TeV)	60% (10 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

See Lombardi Poster



- 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 > 10 TeV):
  - ✓ Extended spectra and cut-offs contsraints
- Energy/Angular resolution: ≤ 10% / ≤ 0.1° (E ≤ 10 TeV)
  - ✓ Characterize extended sources morphology



Science with the ASTRI Mini-Array

Mini-Array

ASTRI Mini-Array Core Science at the Observatorio del Teide

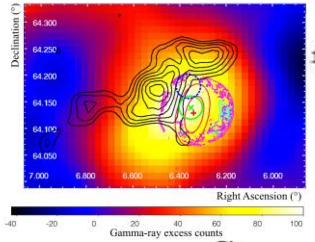
See Vercellone Talk

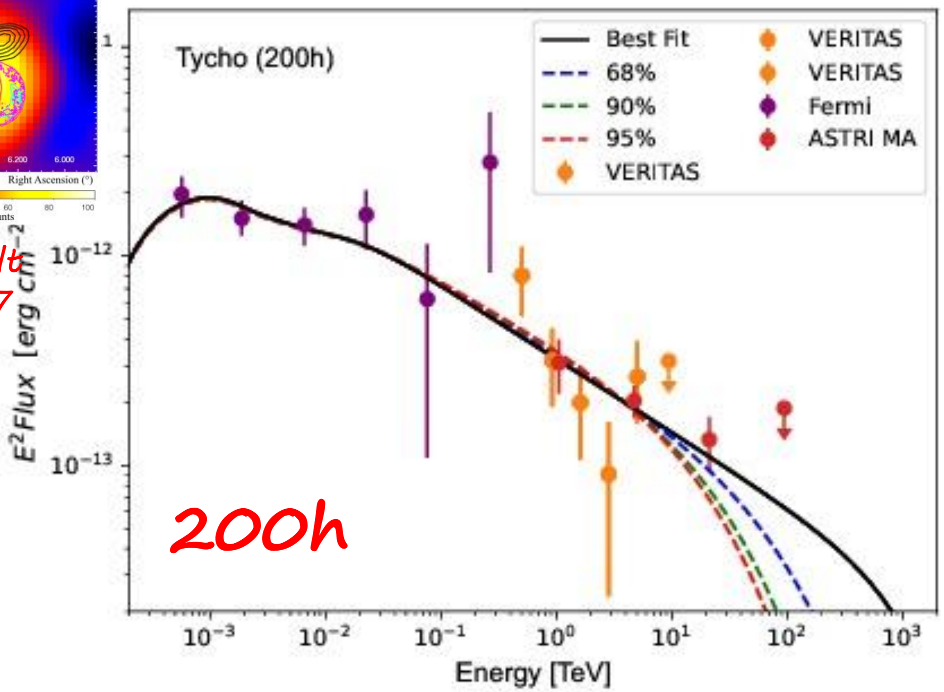
The ASTRI Project, in progress

Martina Cardillo
Elena Amato, Aleksandr Burtovoi, Antonio Alessio Compagnino, Silvia Crestan, Antonino D'Ai , Michele Fiori, Andrea Giuliani, Alessandra Lamastra, Saverio Lombardi, Giovanni Morlino, Lara Nava, Barbara Olmi, Giovanni Piano, Fabio Pintore, Patrizia Romano, Francesco Gabriele Saturni, Antonio Tutone, Stefano Vercellone, Luca Zampieri, Patrizia Caraveo, Giovanni Pareschi

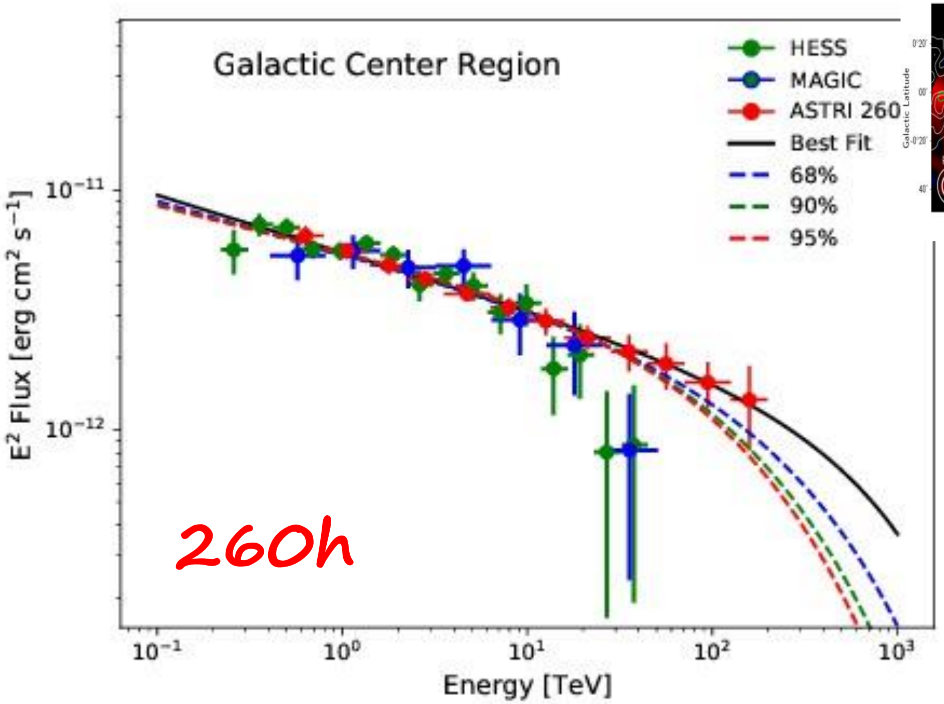
1. ASTRI Mini-Array expected Performances
2. ASTRI Mini-Array Core Science and Simulation Setup
3. Pillar-1: Origin of Cosmic Rays
4. Pillar-2: Cosmology and Fundamental Physics
5. Gamma-Ray Burst and Multi-Messangers Astrophysics
6. Non Gamma-ray Astrophysics
7. Multi-wavelength opportunities
8. Conclusions

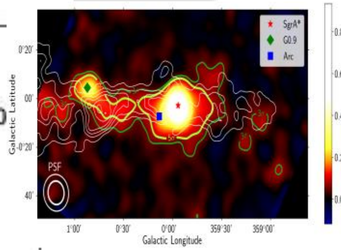
Candidate Pevatrons w ASTRI-MA





Archambault et al. 2017





Acciari et al. 2020

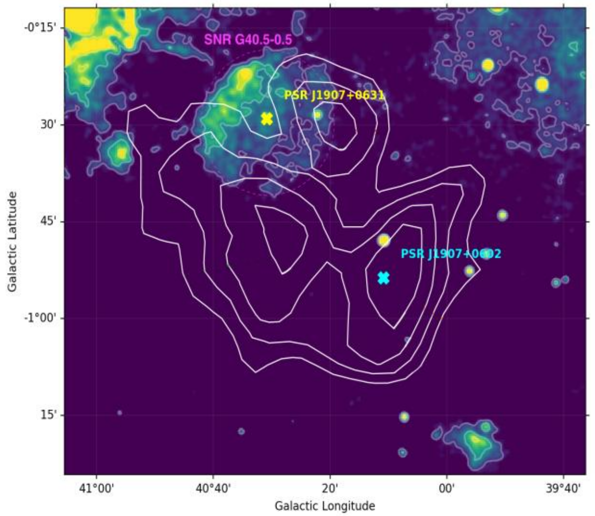
- 100 TeV detection with 500h of exposure
- Critical contribution to Pevatron emission from Tycho SNR even without a 100 TeV detection
- ASTRI MA can resolve the source (D~8')
- With the same HESS texp, ASTRI-MA will secure the likely Pevatron nature of GC region
- Mapping of the whole GC region with a single observation (dimension 1,5°x0,2°)
- Resolving different sources

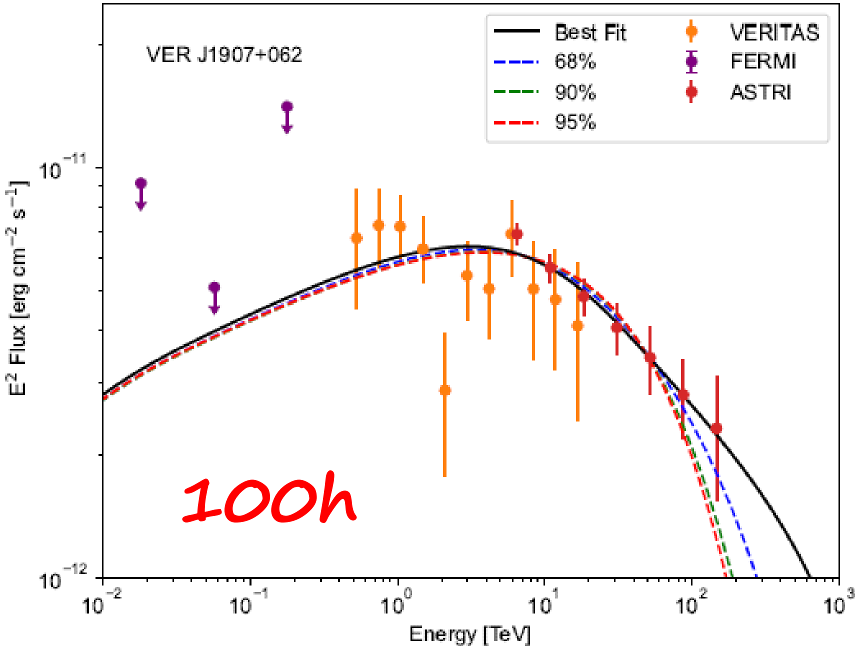
Candidate Pevatrons w ASTRI MA

eHWC 1907+063

Mini-Array

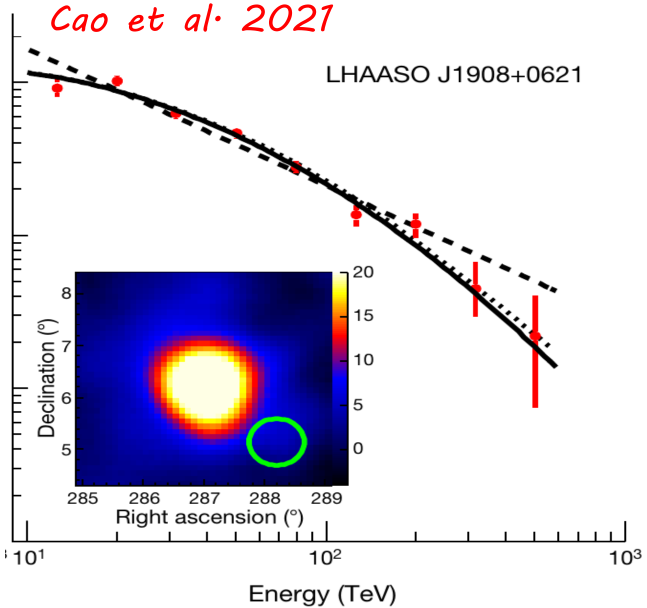
Aliu et al. 2014





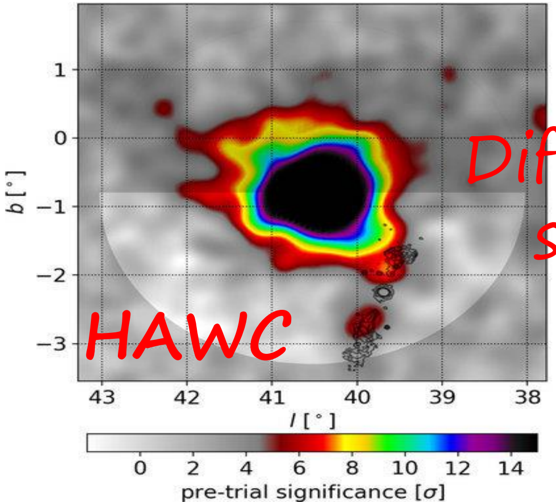
- Morphology from VERITAS (Aliu et al. 2014)
- PL spectrum from HAWC (Abeysekara et al. 2017)
- Detection @100TeV w ASTRI MA (100h exp)
- With ASTRI MA we put a lower limit to a possible cut-off @ 1,6 PeV with 95% confidence (50 TeV without ASTRI MA)

Cao et al. 2021

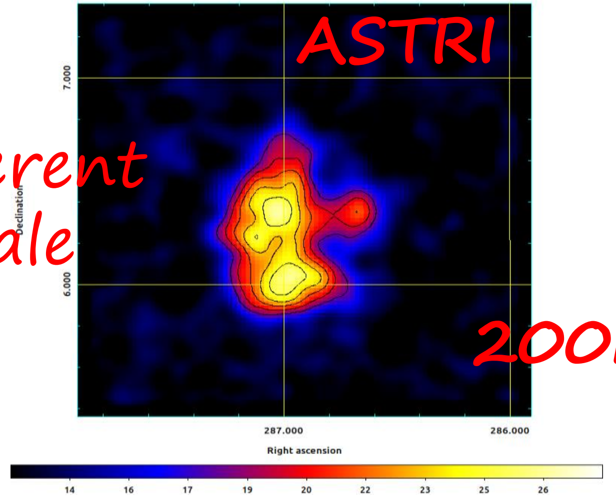


ASTRI MA, in the near future, will be the only instrument able to resolve TeV extended sources

Abeysekara et al. 2017



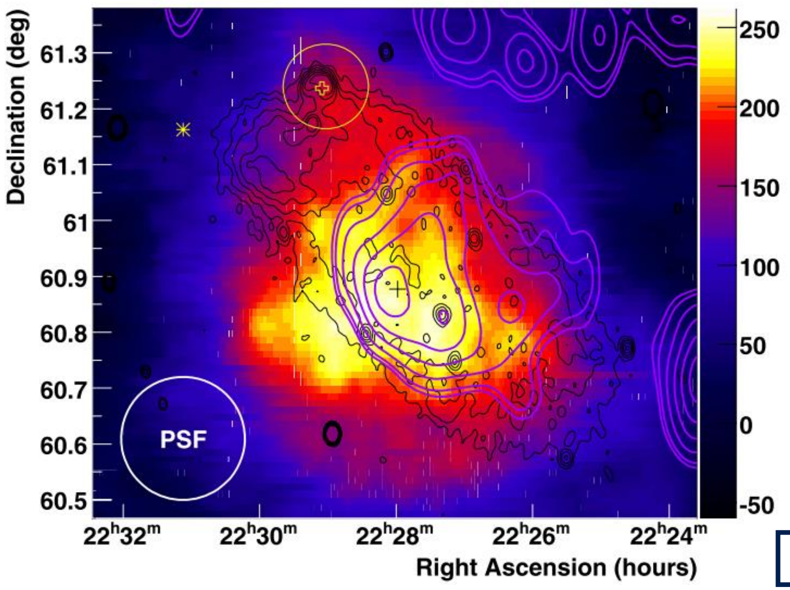
Different scale

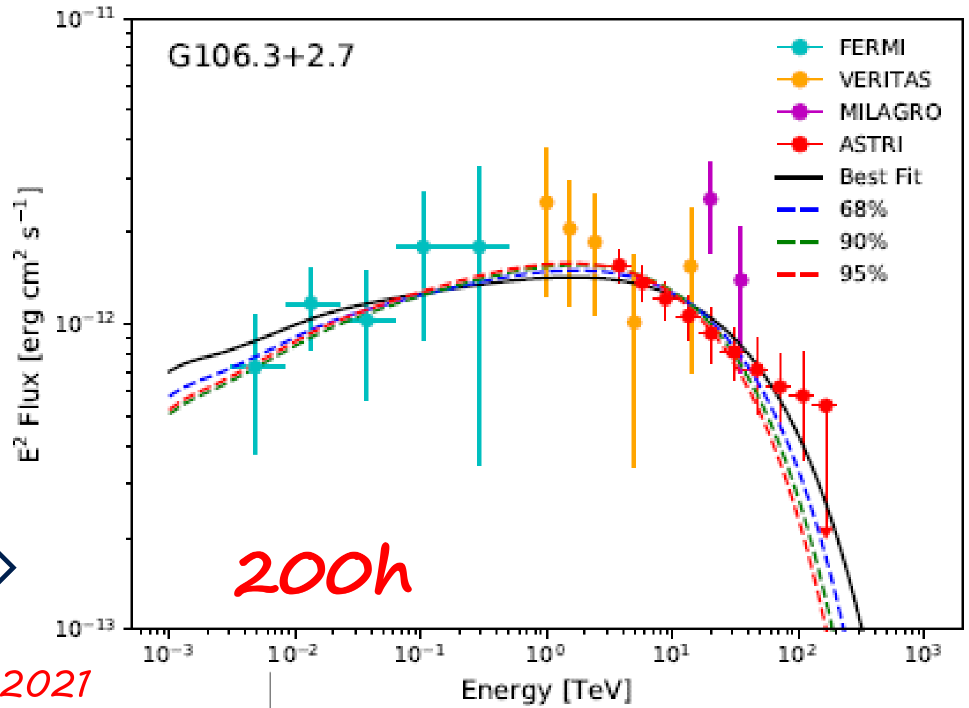


Candidate Pevatrons w ASTRI MA

G106.3+2.7

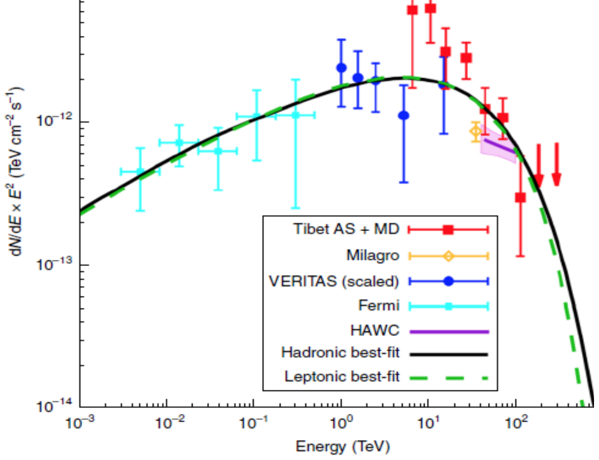
Mini-Array



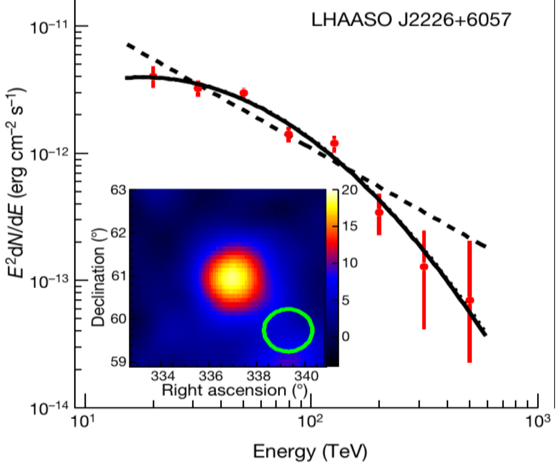


- Morphology and spectrum from VERITAS
- Detection @100TeV w ASTRI MA (200h exp)
- Our best fit constrains the proton maximum energy at ~500 TeV (lower limit @ 400TeV with 69% confidence

Tibet AS collaboration 2021



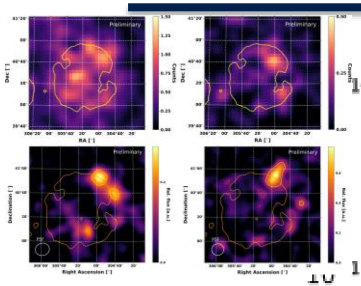
Cao et al. 2021



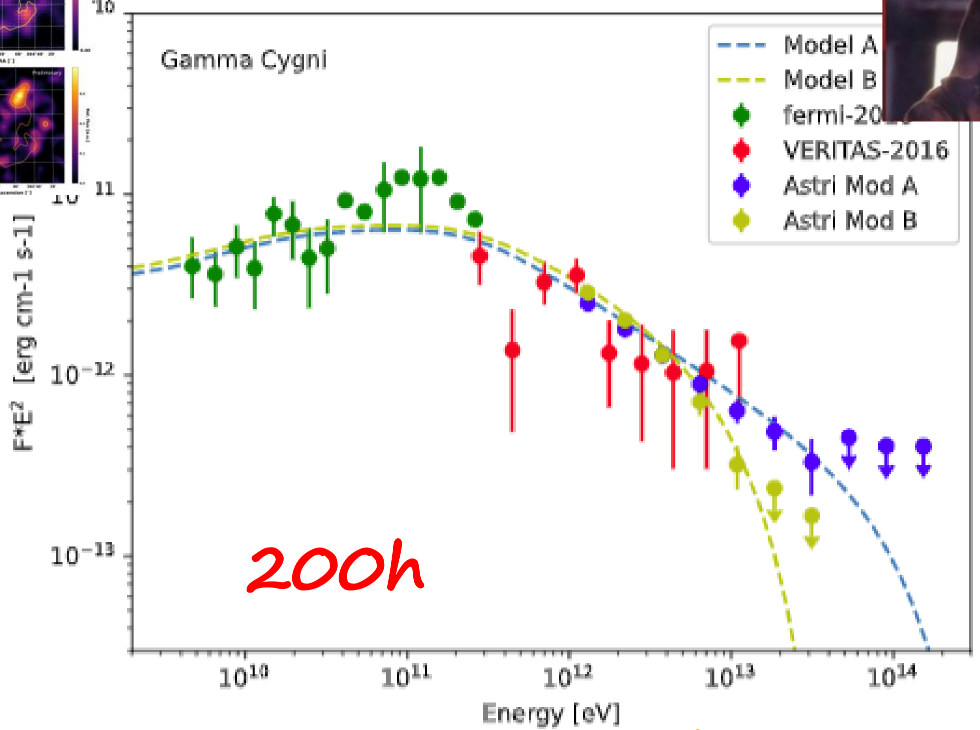
Moreover, with the ASTRI-MA angular resolution:

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

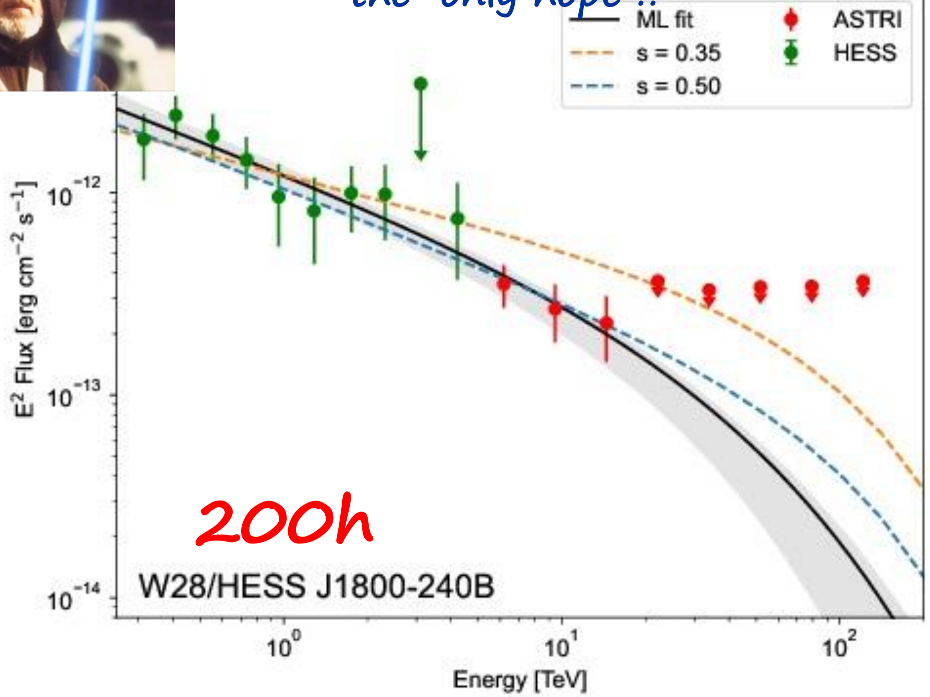
CR propagation with ASTRI-MA

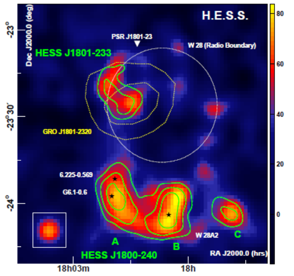


MAGIC collaboration 2019



Distant Molecular clouds are the "only hope"!!



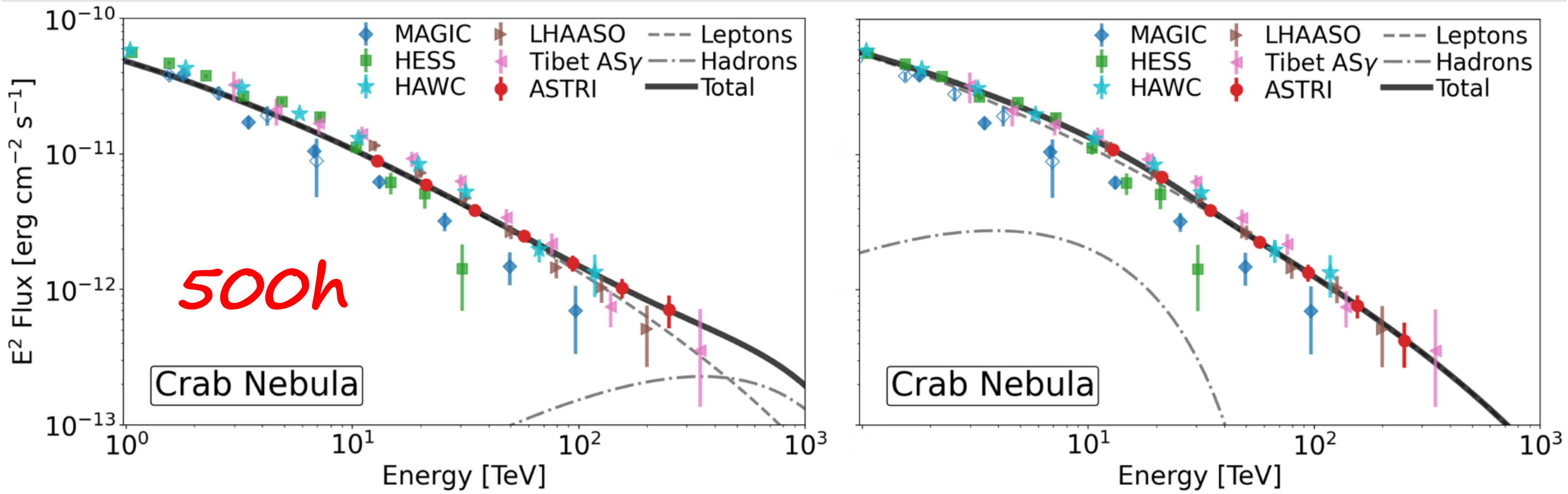


Aharonian et al. 2008

- Contraints on some physical parameters as maximum energy and diffusion coefficient
- Undestanding the break in the middle aged SNRs
- Resolving the VHE emission morphology

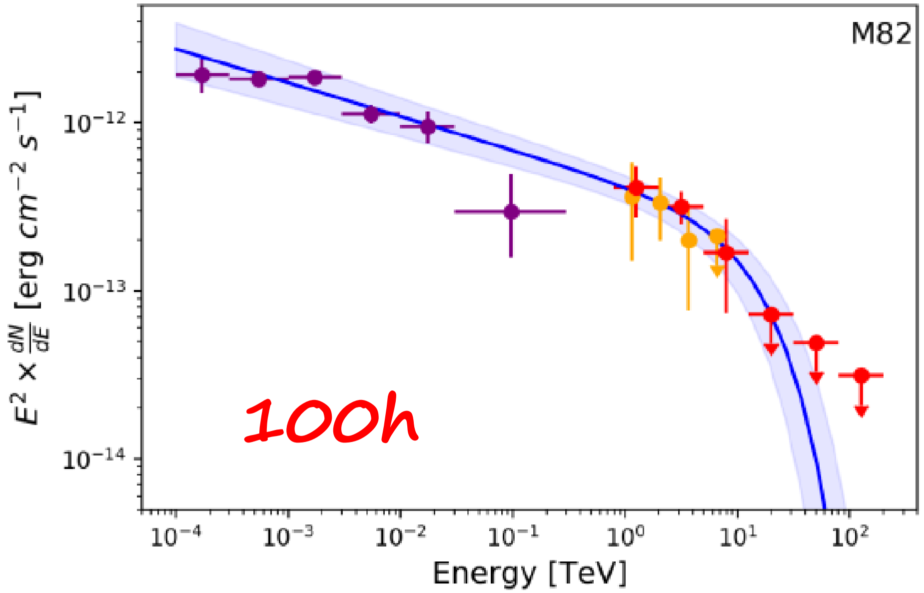
- Understanding the energy dependence of the diffusion coefficient in the vicinity of W28
- Resolving the gamma-ray emission from the two nearest clouds (Dclouds <0,5°)

Crab Nebula et al. w ASTRI MA



PWNae:
detection of Crab emission up to 330 TeV will allow to understand its gamma-ray emission origin: hadronic or leptonic

TeV Halo and positron excess:
good morphology reconstruction and spectral behavior of Geminga, the likely nearest source of positron excess
(thanks to larger FoV and better angular resolution)

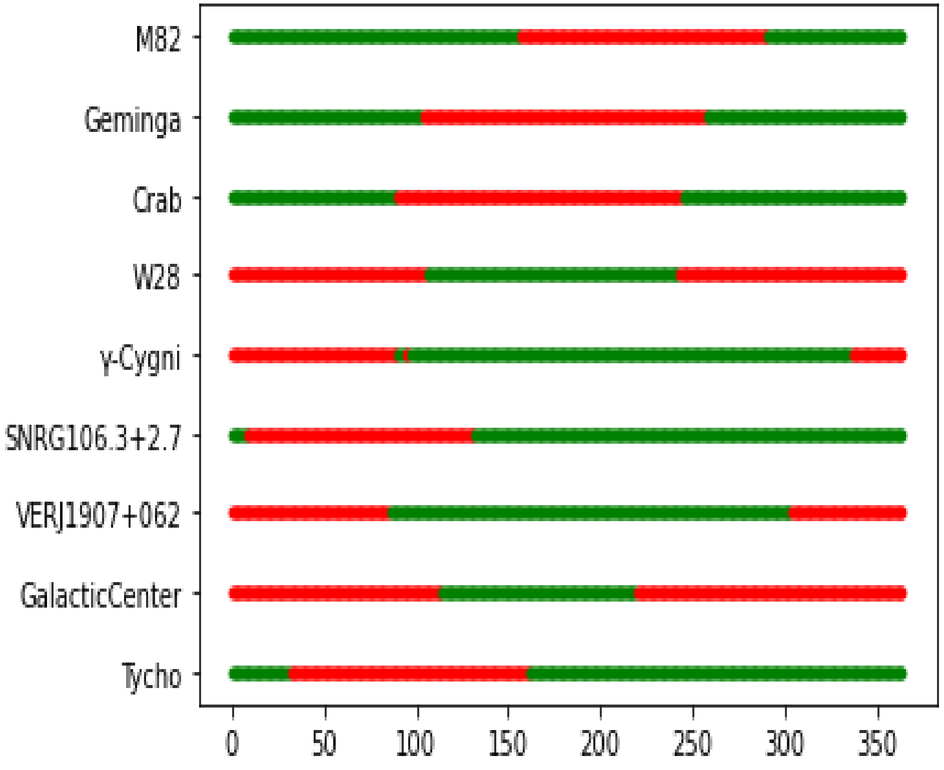


UHECRs:
Better understanding of the presence of a CO due to gamma-gamma absorption (constraints on neutrino flux)

Observation Strategy

Mini-Array

"Pillar Sources" well distributed during the year



Green = more than 2 hrs per night available

- Per year → ~ 1500 dark hours (moonless) → but : bad weather, "calima", maintenance...
  - ~ 1000 hrs availables for scientific observations
  - on 3 years : ~ 3000 hours of data taking
- High zenith angles (up to 60°)
- even night with the moon (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 all the potentialities to answer this question

- *Better (and improvable) sensitivity → detection with higher precision of sources above 100 TeV and constraints on physical parameters (e.g. diffusion coefficient)*
- *Better angular resolution → morphology characterization and strong constraints to gamma-ray emission/MC association*
- *Larger FoV →large field (e.g. Galactic Center region) and extended sources (e.g. TeV halo) in-depth analysis*

AIV 1st telescope start → Spring 2022

AIV 3st telescopes start → End 2022

Complete Array→ 2024


Thank you very much!