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

Martina Cardillo – IAPS/INAF

for the ASTRI Project

Ninth International Fermi Symposium

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

ASTRI-Horn Prototype

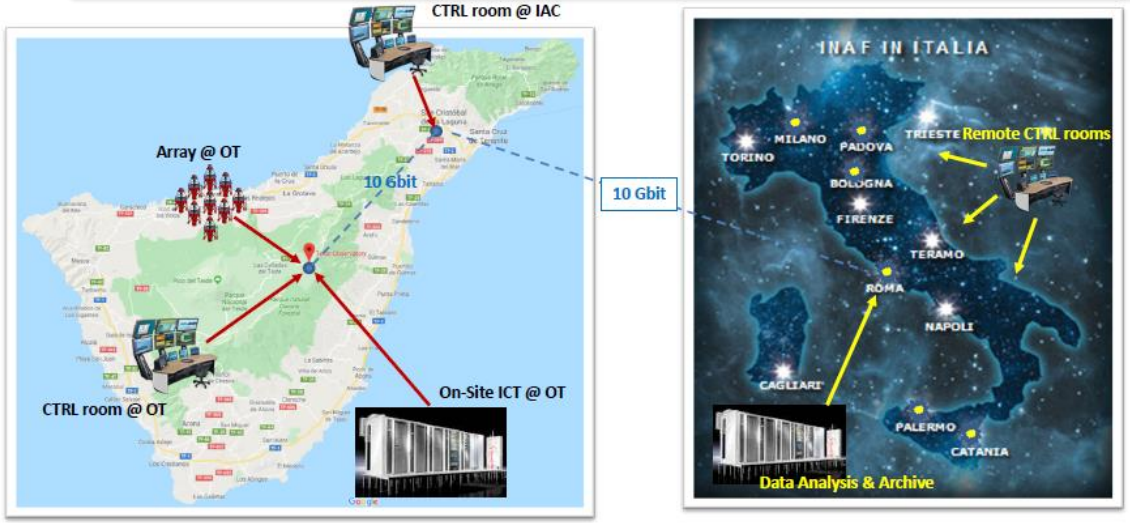
PI: Giovanni Pareschi
PM: Salvo Scuderi
PS: Andrea Giuliani

- 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

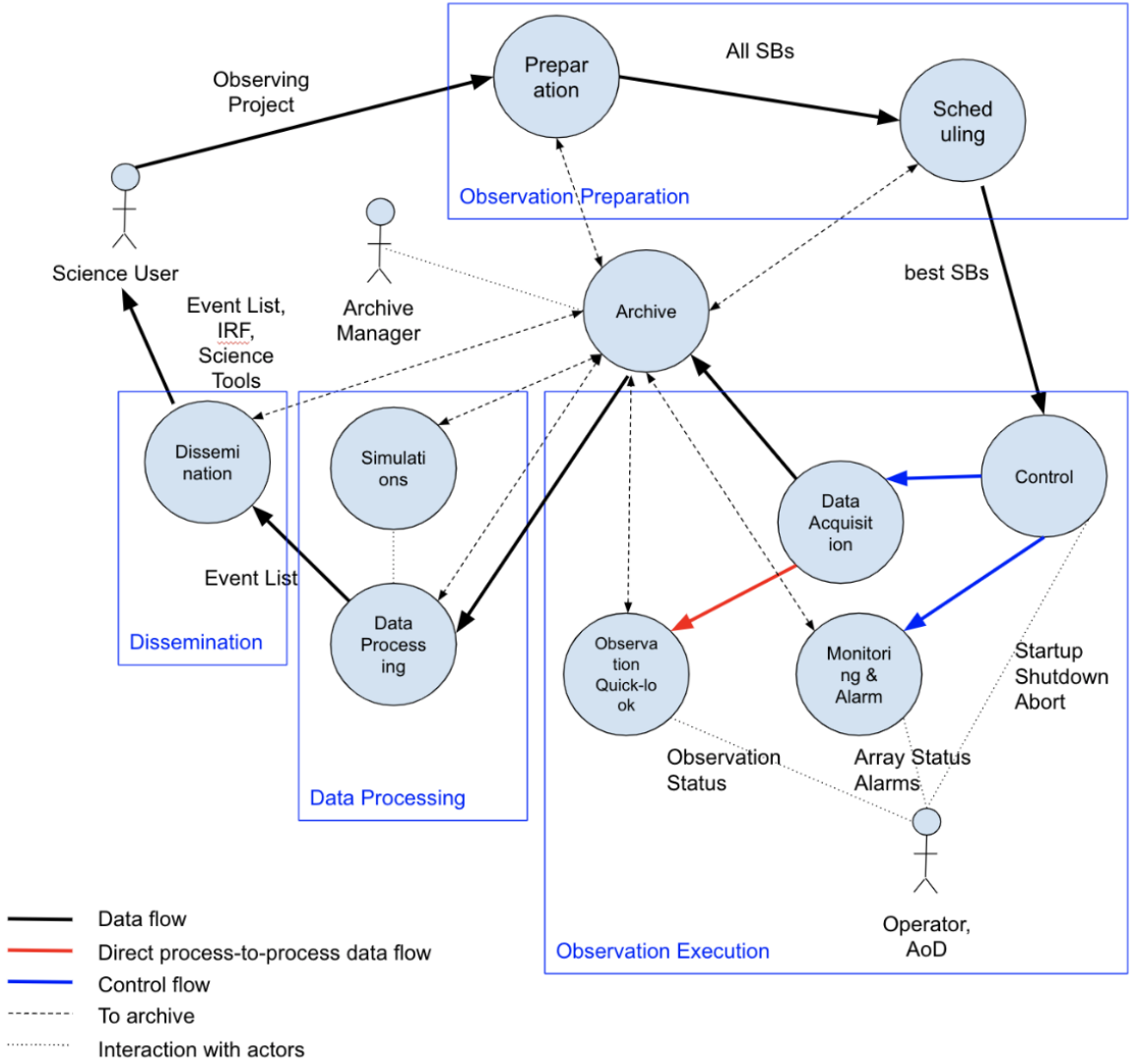
Array of 9 4m ASTRI telescopes at Teide

- 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



- It is being developed in order to be operated, after the commissioning phase, remotely.
- Data analysis will be performed off-site (3 TeraBytes/night)
- Possible synergies with current VHE Northern Arrays (e.g. MAGIC and LSTs)



Operation Concept

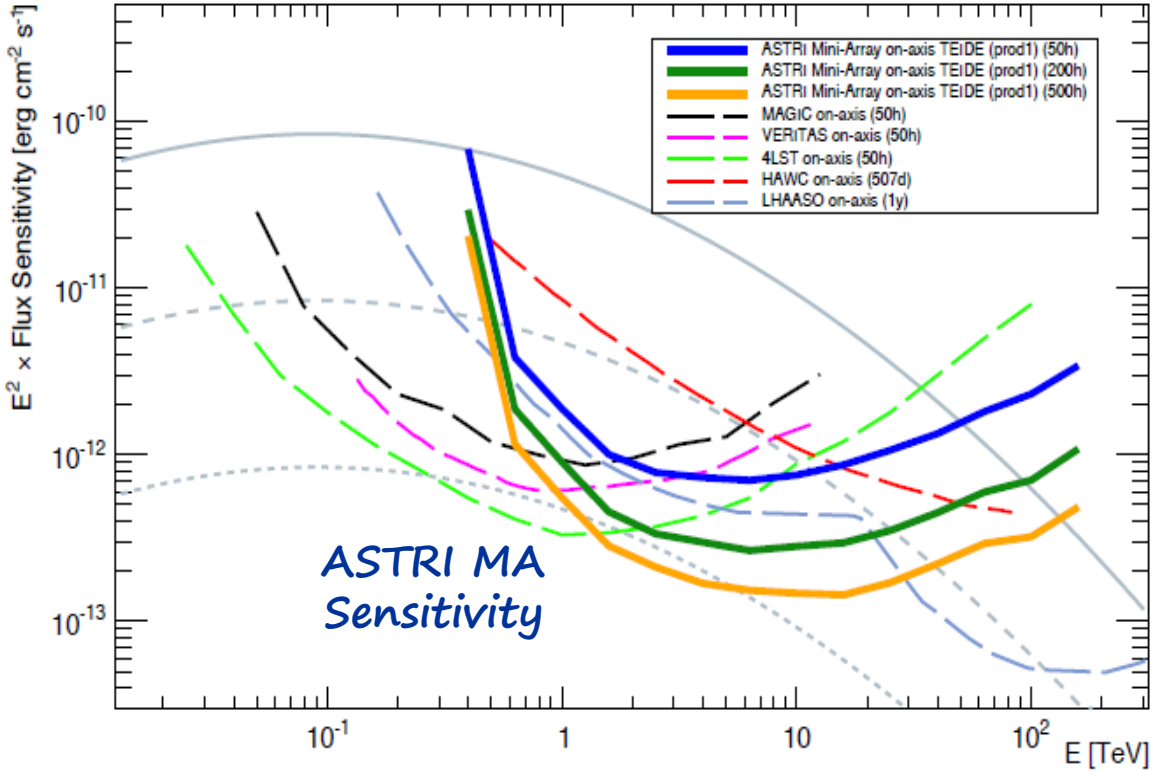
The ASTRI Mini-Array

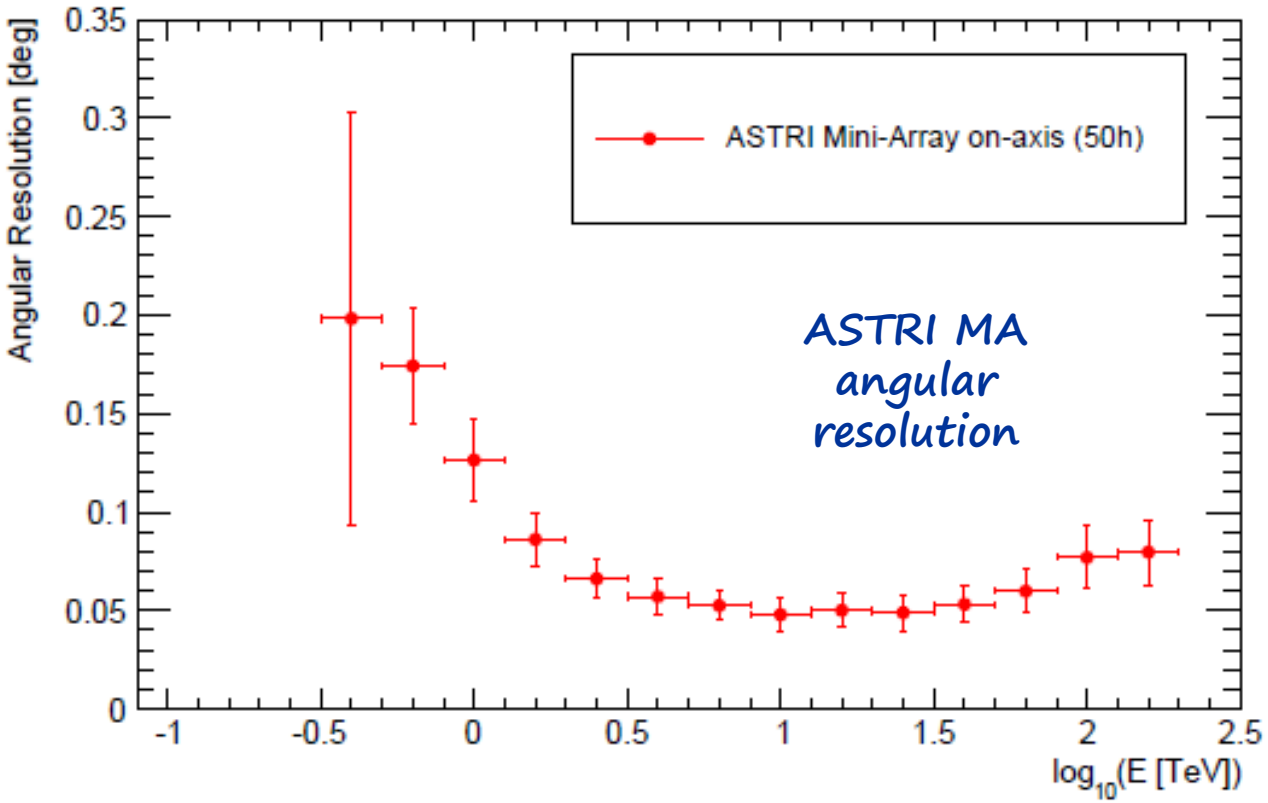
ASTRI MA project, in progress

	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

- Wide FoV with homogeneous off-axis acceptance
  - ✓ Multi-target fields, surveys, and extended sources
  - ✓ Enhanced chance for serendipitous discoveries

The ASTRI Mini-Array





- Sensitivity: better than current IACTs (E > 10 TeV):
  - ✓ Extended spectra and cut-offs contsraints

The ASTRI project in progress

- Energy/Angular resolution: ≤ 10% / ≤ 0.1° (E ≤ 10 TeV)
  - ✓ Characterize extended sources morphology

Science with the ASTRI Mini-Array

ASTRI Mini-Array

ASTRI Mini-Array Core Science at the Observatorio del Teide

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

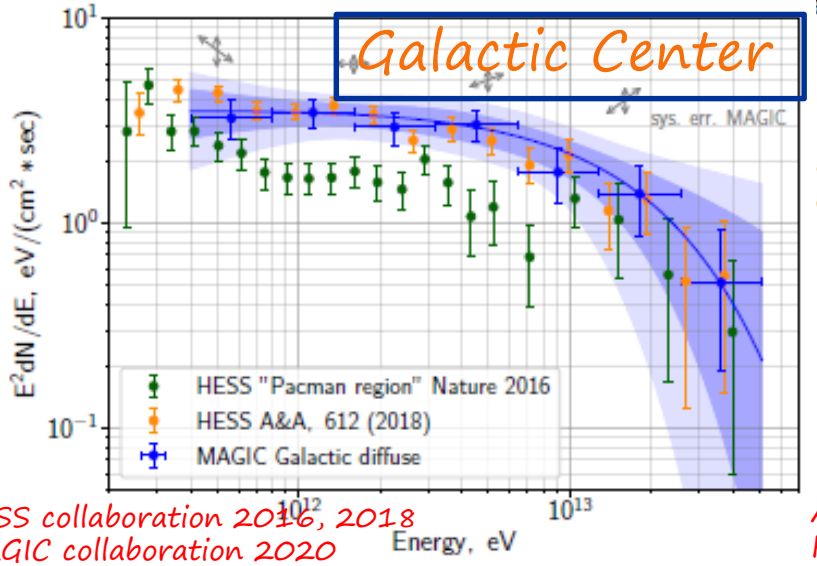
1. ASTRI Mini-Array expected Performances
2. ASTRI Mini-Array Core Science and Simulation Setup
3. Pillar-1: Origin of Cosmic Rays
4. Pillar-2: Cosmology and Fundamental Physics
5. Gamma-Ray Burst and Multi-Messangers Astrophysics
6. Non Gamma-ray Astrophysics
7. Multi-wavelength opportunities
8. Conclusions

CR origin: what we know

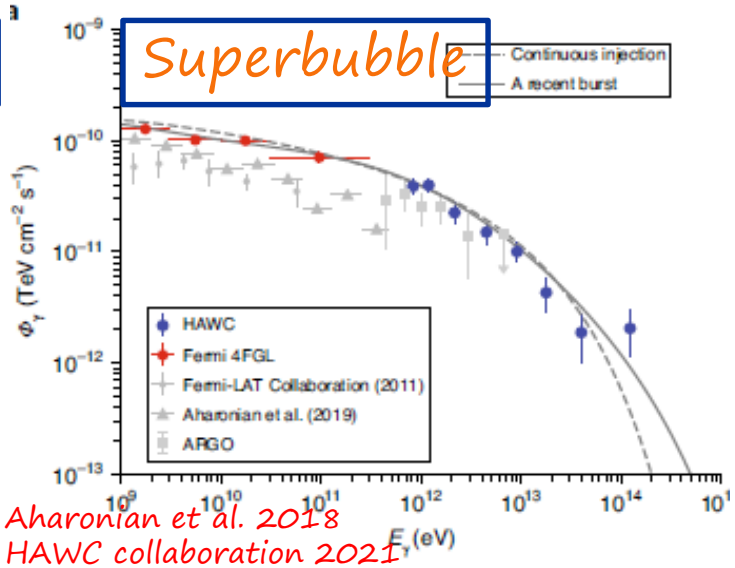
- ✧ **Lowest energies**: we have the proof of CR energization from some middle-aged SNRs (W44, IC443, W51c) [Giuliani, Cardillo et al. 2010, Ackermann et al. 2013, Cardillo et al. 2014, Jogler et al. 2016]:
  - ➢ **Reacceleration** (e.g. Cardillo et al. 2016) **or Diffusion coefficient Suppression?** (e.g. Celli et al. 2019, Mitchell et al. 2021)
- ✧ **Highest energies**: no SNR at 100 TeV
  - ➢ **Detection problem for pevatron SNRs** (e.g. Schure&Bell 2013, Cardillo et al. 2015, Cristofari et al. 2020)

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

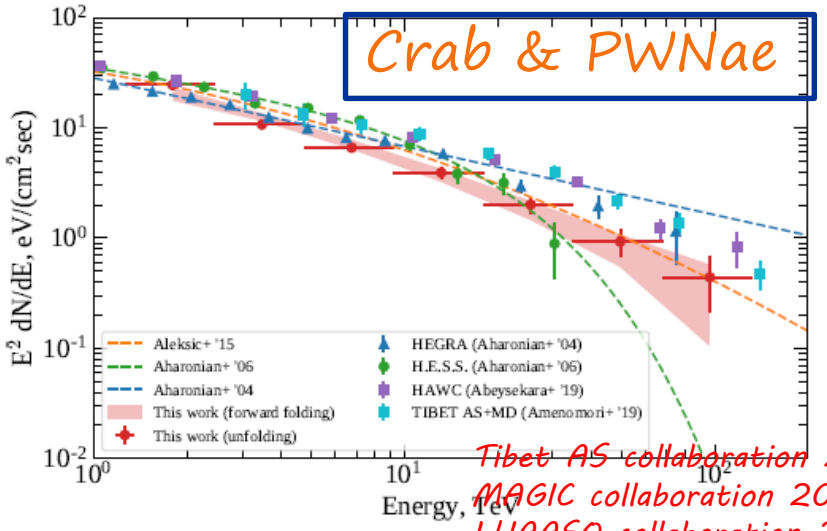
And what if SNR do not were galactic CR sources?



HESS collaboration 2016, 2018
MAGIC collaboration 2020

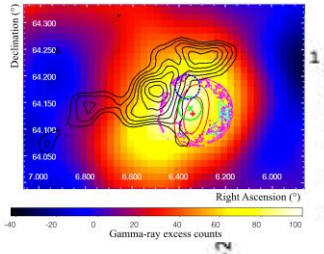


Aharonian et al. 2018
HAWC collaboration 2021

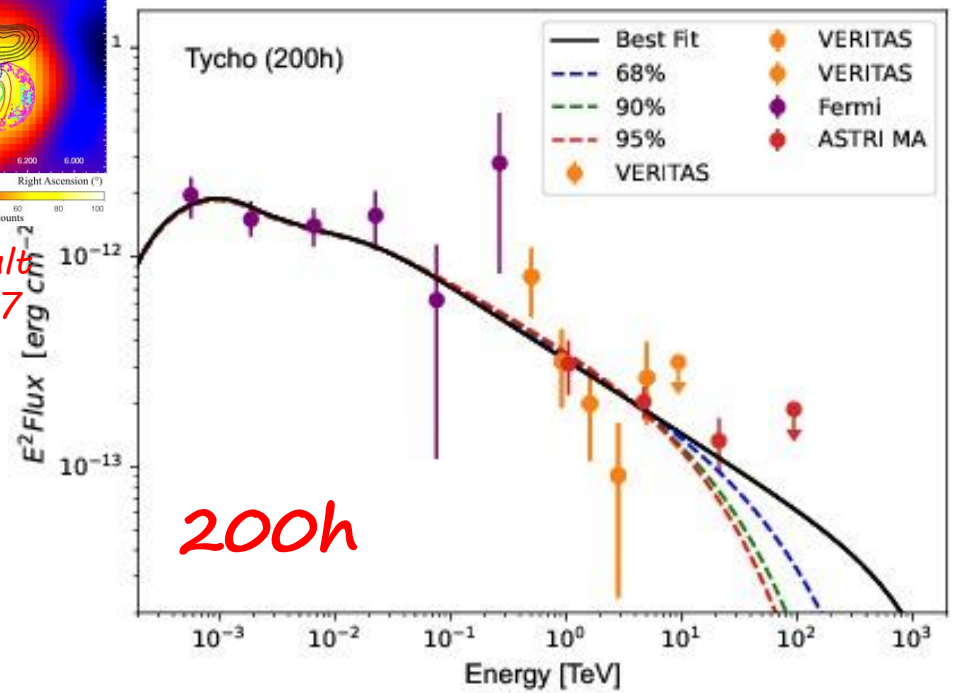


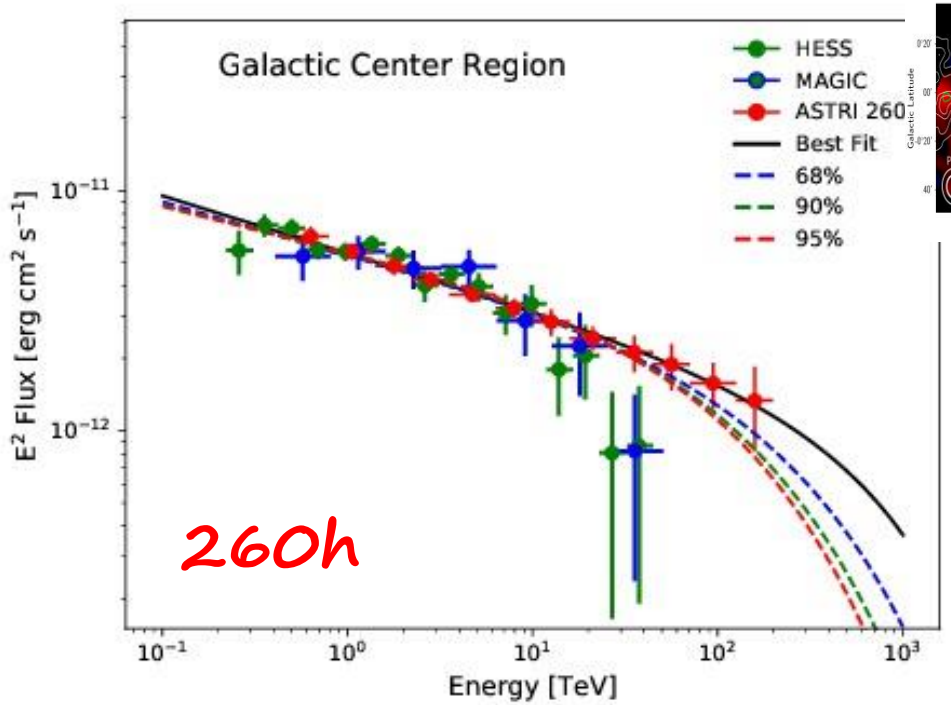
Tibet AS collaboration 2019
MAGIC collaboration 2020
LHAASO collaboration 2021

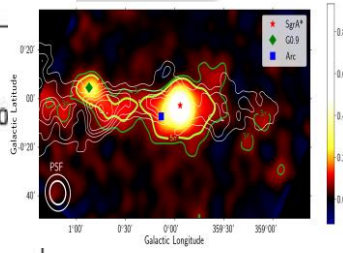
Candidate Pevatrons w ASTRI-MA



Archambault et al. 2017







Acciari et al. 2020

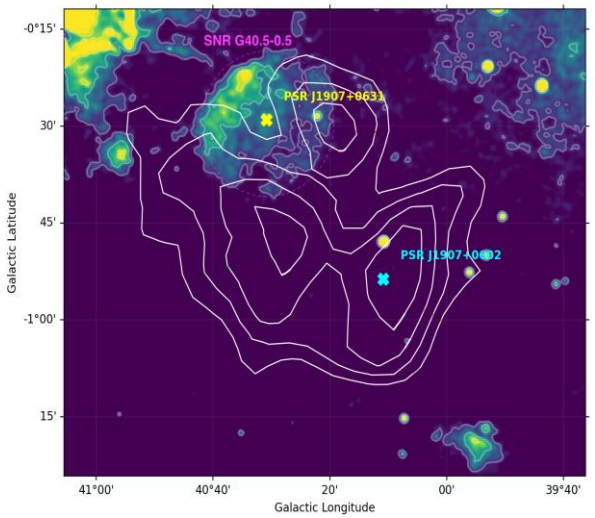
- 100 TeV detection with 500h of exposure
- Critical contribution to Pevatron emission from Tycho SNR even without a 100 TeV detection
- ASTRI MA can resolve the source (D~8')

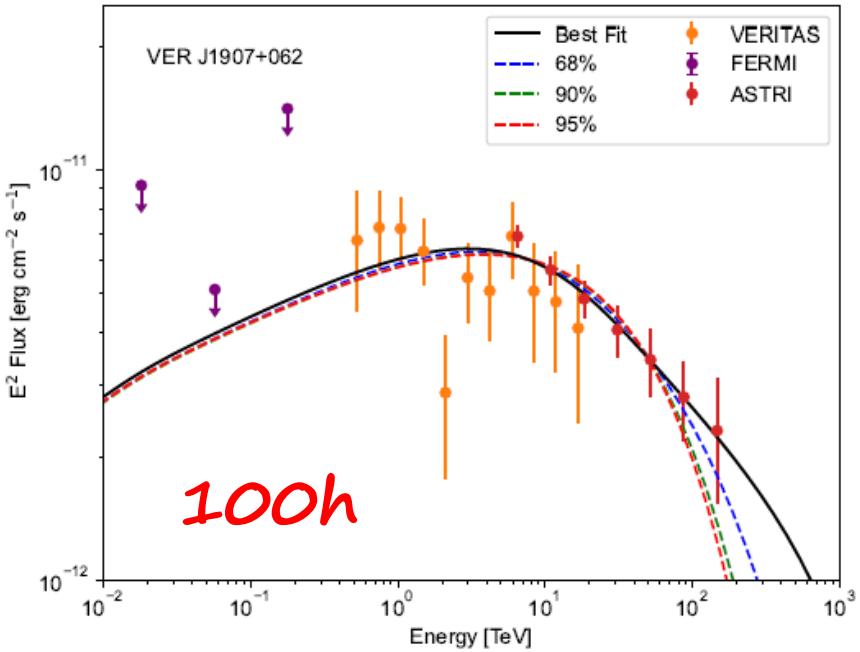
- With the same HESS texp, ASTRI-MA will secure the likely Pevatron nature of GC region
- Mapping of the whole GC region with a single observation (dimension 1,5°x0,2°)
- Resolving different sources

Candidate Pevatrons w ASTRI MA

eHWC 1907+063

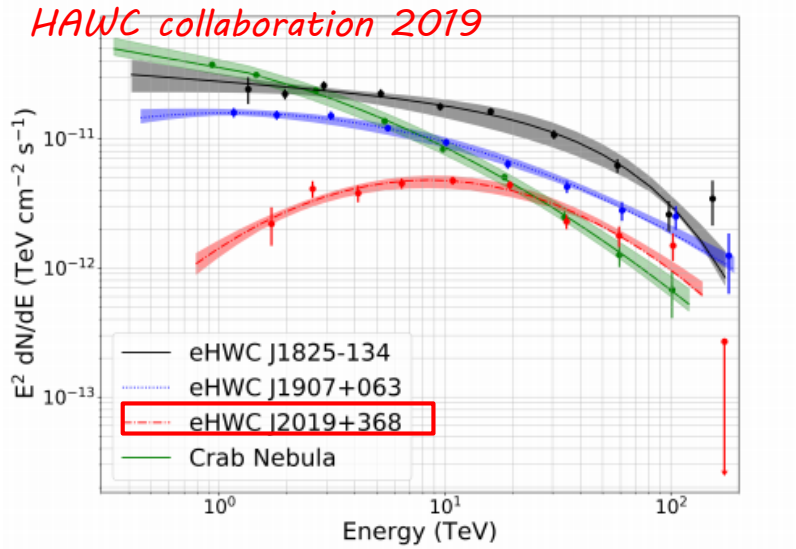
Aliu et al. 2014





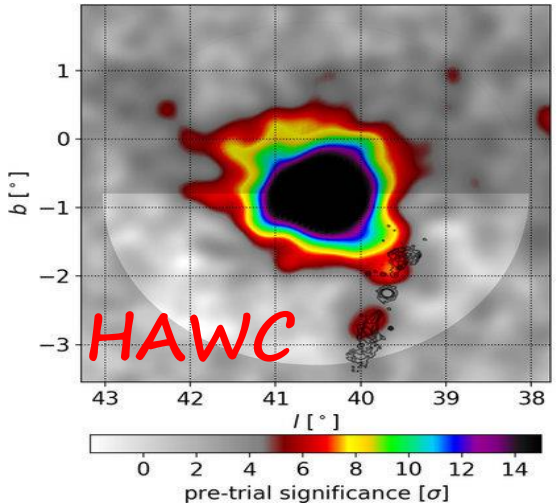
- Morphology from VERITAS (Aliu et al. 2014)
- PL spectrum from HAWC (Abeysekara et al. 2017)
- Detection @100TeV w ASTRI MA (100h exp)
- With ASTRI MA we put a lower limit to a possible cut-off @ 1,6 PeV with 95% confidence (50 TeV without ASTRI MA)

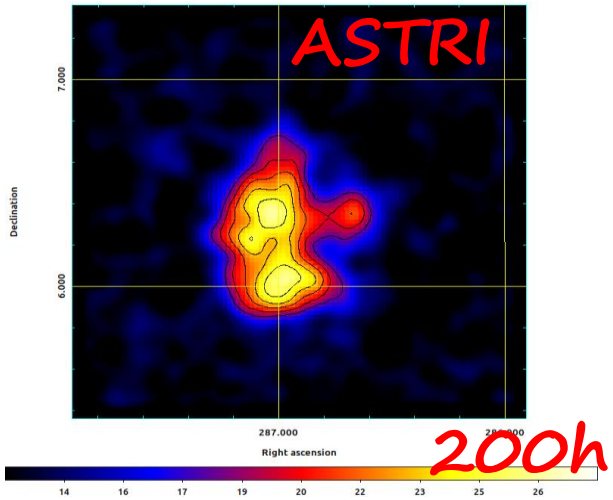
HAWC collaboration 2019



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

Abeysekara et al. 2017

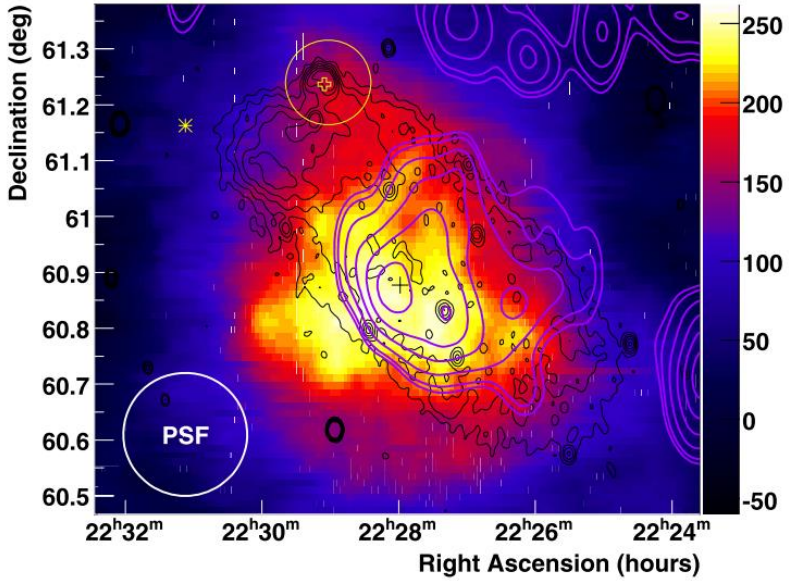


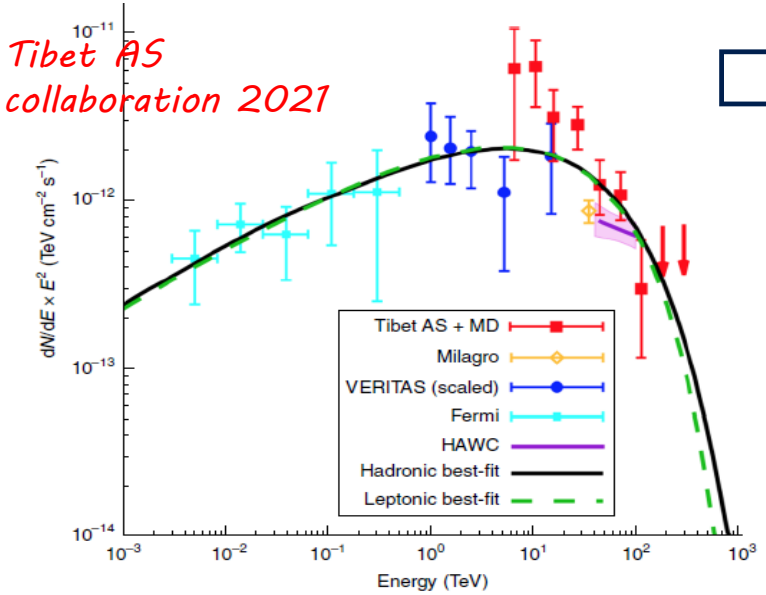


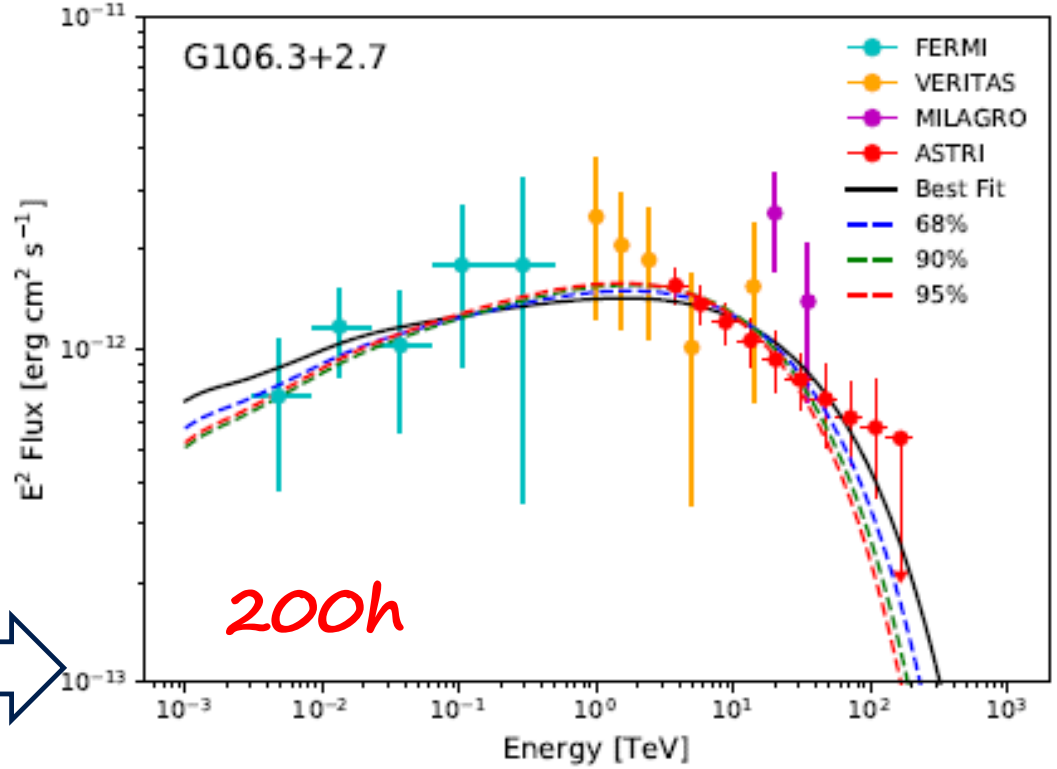
Candidate Pevatrons w ASTRI MA

G106.3+2.7

ASTRI Mini-Array





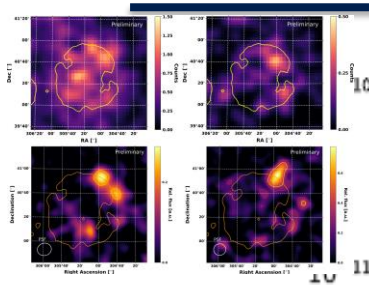


- Morphology and spectrum from VERITAS
- Detection @100TeV w ASTRI MA (200h exp)
- Our best fit constrains the proton maximum energy at ~500 TeV (lower limit @ 400TeV with 69% confidence

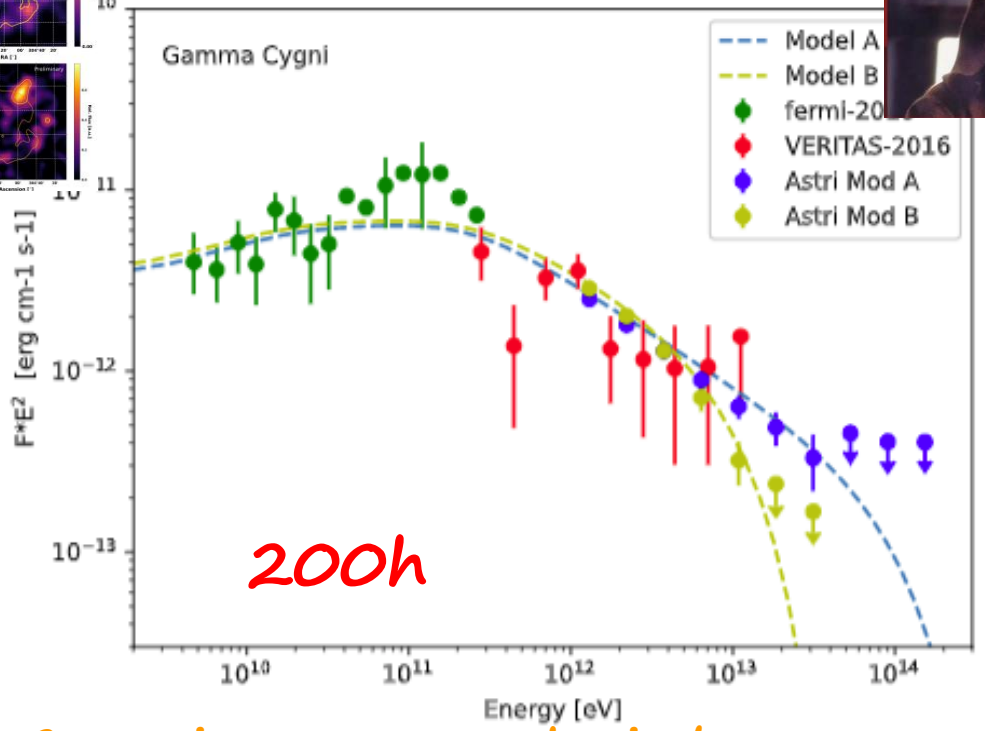
Moreover, with the ASTRI-MA angular resolution:

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

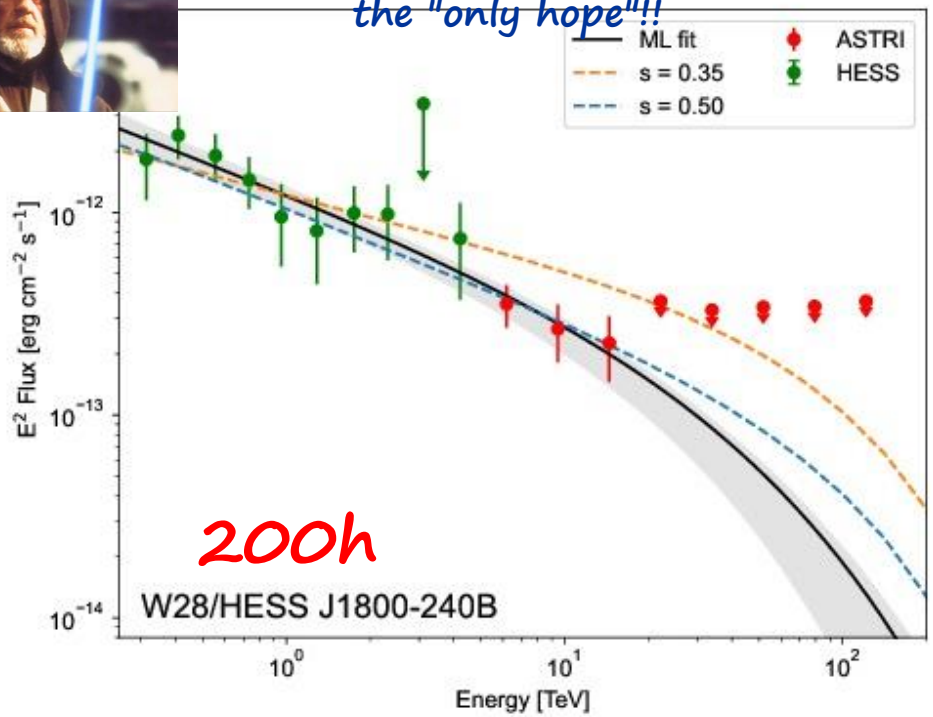
CR propagation with ASTRI-MA

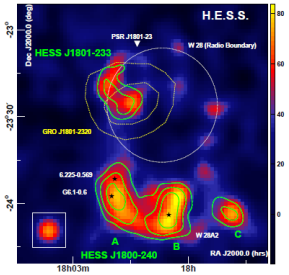


MAGIC collaboration 2019



Distant Molecular clouds are the "only hope"!!

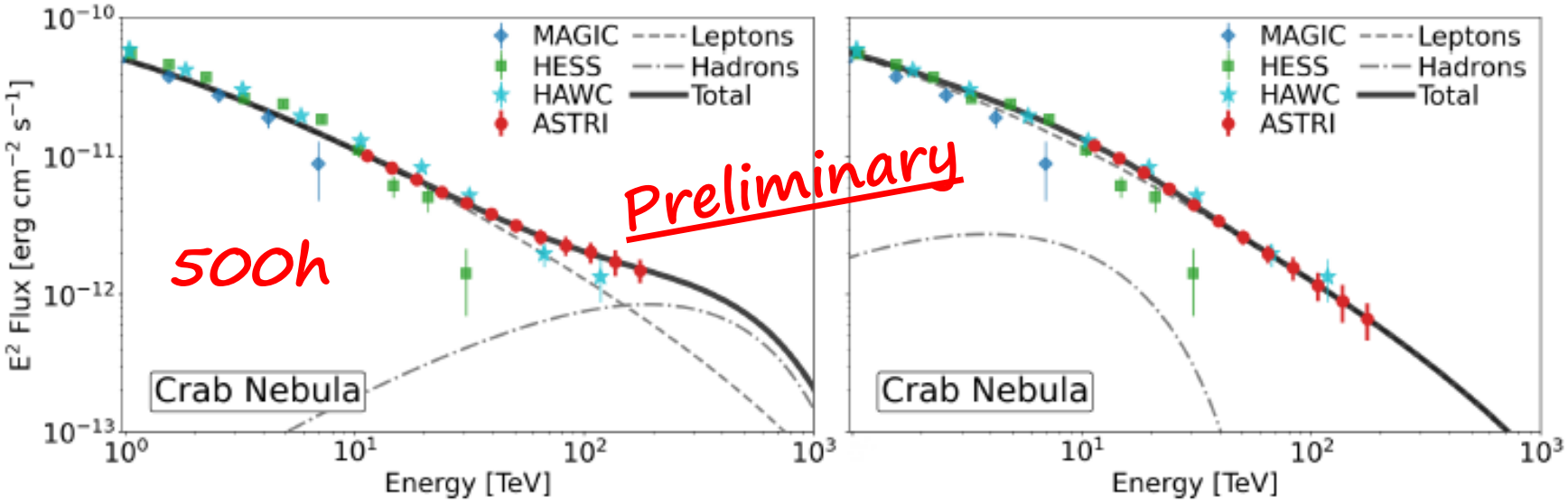




Aharonian et al. 2008

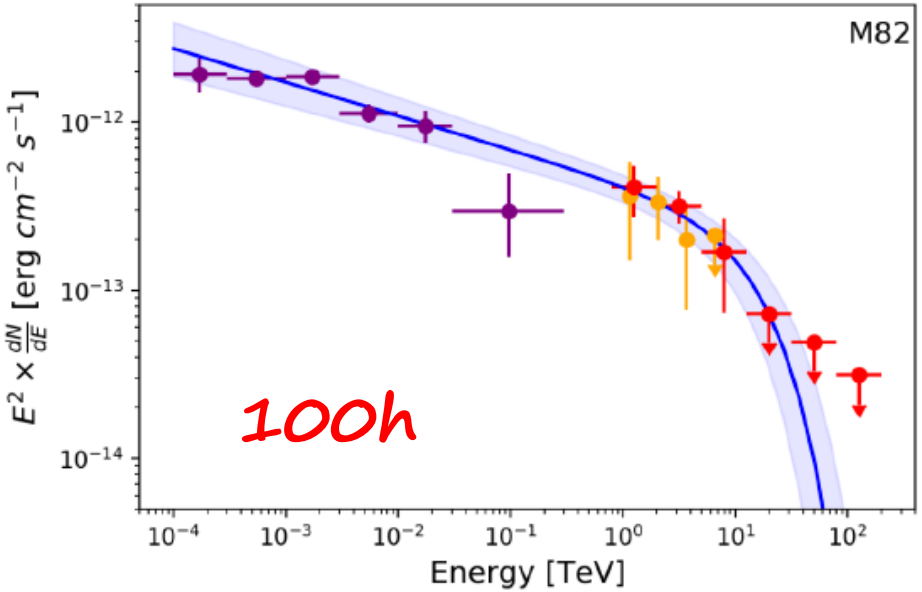
- Contraints on some physical parameters as maximum energy and diffusion coefficient
- Undestanding the break in the middle aged SNRs
- Resolving the VHE emission morphology
- Understanding the energy dependence of the diffusion coefficient in the vicinity of W28
- Resolving the gamma-ray emission from the two nearest clouds (Dclouds <0,5°)

Crab Nebula et al. w ASTRI MA



PWNae:
detection of Crab emission up to 100 TeV will allow to understand its gamma-ray emission origin: hadronic or leptonic

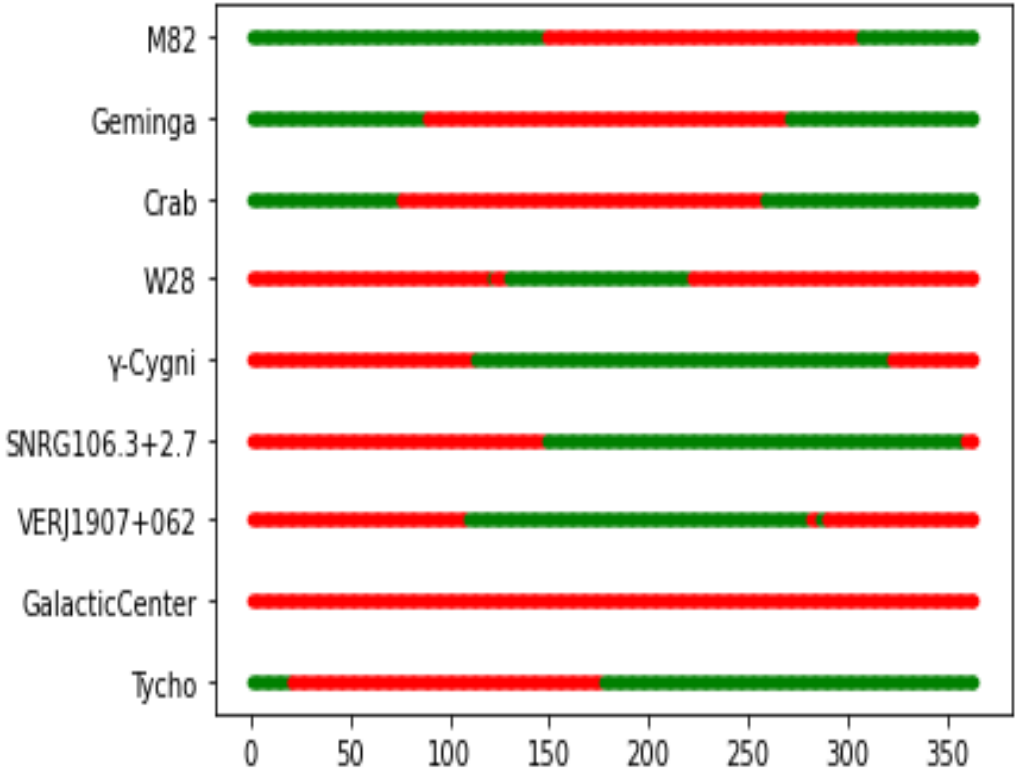
TeV Halo and positron excess:
good morphology reconstruction and spectral behavior of Geminga, the likely nearest source of positron excess (thanks to larger FoV and better angular resolution)



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

Observation Strategy

"Pillar Sources" well distributed during the year



Green = more than 3 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
Galactic Center	May-June-July	300
VER J1907	September-October	300
G106	November-December	400

Schedule

Site ready to host 1st telescope → Jul 2021

Infrastructure ready → Dec 2021

1st telescope ready to ship → Jul 2021

1st camera ready to ship → Mar 2022

AIV 1st telescope start → Feb 2022

Ready for commissinig → Oct 2023

Ready for operations → Apr 2024

Title: ASTRI mini-array schedule
Date: Tue 12/01/21
Page 1 of 1

ASTRI Mini-Array Construction Project

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D	Task Name	Start	Finish	Duration
0	ASTRI Mini-Array	Wed 22/06/16	Tue 02/04/24	2030 days
1	Infrastructure	Mon 16/03/20	Thu 16/12/21	459 days
2	Safety and Security System	Mon 15/02/21	Thu 18/11/21	199 days
3	Telescope	Wed 22/06/16	Tue 17/10/23	1910 days
4	ICT	Wed 04/12/19	Tue 30/11/21	520 days
5	Software	Thu 04/07/19	Mon 29/05/23	1018 days
6	MCCS	Thu 20/02/20	Wed 23/11/22	720 days
8	On Site Integration & Verifica	Thu 23/09/21	Tue 02/04/24	659 days

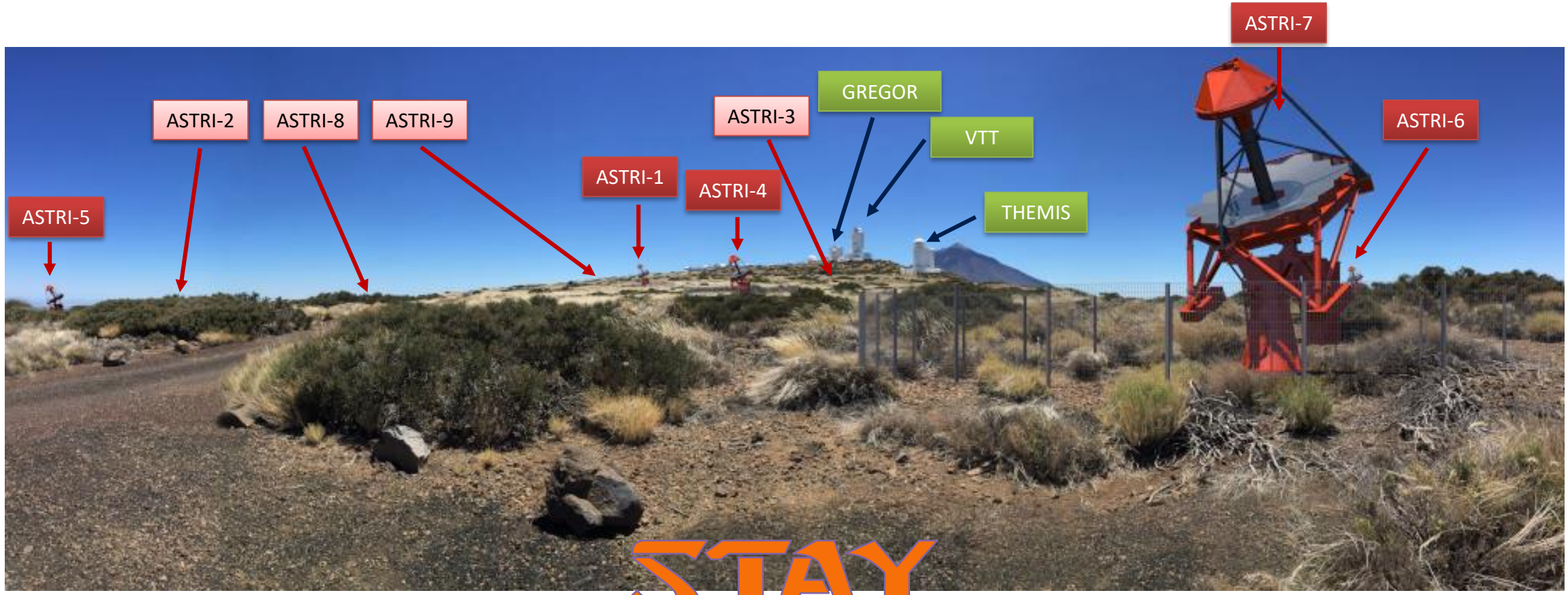
Conclusions

ASTRI Mini-Array

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


ASTRI-7
ASTRI-2
ASTRI-8
ASTRI-9
ASTRI-3
GREGOR
VTT
ASTRI-6
ASTRI-1
ASTRI-4
THEMIS
ASTRI-5

STAY TUNED!!!


Thank you very much!