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

Martina Cardillo – IAPS/INAF
for the ASTRI Project

Ninth International Fermi Symposium
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

ASTRI Mini-Array (2022 -)
PI: Giovanni Pareschi

- 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)
# The ASTRI Mini-Array

ASTRI MA project, in progress

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

<table>
<thead>
<tr>
<th></th>
<th>ASTRI Mini-Array</th>
<th>MAGIC</th>
<th>VERITAS</th>
<th>H.E.S.S.</th>
<th>HAWC</th>
<th>LHAASO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>28° 18’ 04” N</td>
<td>28° 45’ 22” N</td>
<td>31° 40’ 30” N</td>
<td>23° 16’ 18” S</td>
<td>18° 59’ 41” N</td>
<td>29° 21’ 31” N</td>
</tr>
<tr>
<td></td>
<td>16° 30’ 38” W</td>
<td>17° 53’ 30” W</td>
<td>110° 57’ 7.8” W</td>
<td>16° 30’ 00’ E</td>
<td>97° 18’ 27” W</td>
<td>100° 08’ 15” E</td>
</tr>
<tr>
<td><strong>Altitude [m]</strong></td>
<td>2,390</td>
<td>2,396</td>
<td>1,268</td>
<td>1,800</td>
<td>4,100</td>
<td>4,410</td>
</tr>
<tr>
<td><strong>FoV</strong></td>
<td>9.6°</td>
<td>~ 3.5°</td>
<td>~ 3.5°</td>
<td>~ 5°</td>
<td>2 sr</td>
<td>2 sr</td>
</tr>
<tr>
<td><strong>Angular Res.</strong></td>
<td>0.05° (10 TeV)</td>
<td>0.07° (1 TeV)</td>
<td>0.07° (1 TeV)</td>
<td>0.06° (1 TeV)</td>
<td>(0.15–1)°(a)</td>
<td>~ 0.2°(b) (10 TeV)</td>
</tr>
<tr>
<td><strong>Energy Res.</strong></td>
<td>(12)% (10 TeV)</td>
<td>16% (1 TeV)</td>
<td>17% (1 TeV)</td>
<td>15% (1 TeV)</td>
<td>30% (10 TeV)</td>
<td>60% (10 TeV)(b)</td>
</tr>
<tr>
<td><strong>Energy Range</strong></td>
<td>(0.3-200) TeV</td>
<td>(0.05-20) TeV</td>
<td>(0.08-30) TeV</td>
<td>(0.02-30) TeV(c)</td>
<td>(0.1-100) TeV</td>
<td>(0.1-1,000) TeV</td>
</tr>
</tbody>
</table>
The ASTRI Mini-Array

- **Sensitivity:** better than current IACTs \((E > 10 \text{ TeV})\):
  - Extended spectra and cut-offs constraints

- **Energy/Angular resolution:** \(\leq 10\% / \leq 0.1^\circ (E \leq 10 \text{ TeV})\)
  - Characterize extended sources morphology

The ASTRI project in progress
Science with the 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)

And what if SNR do not were galactic CR sources?

- Galactic Center
- Superbubble
- Crab & PWNae
Candidate Pevatrons w ASTRI-MA

- 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 ($D \sim 8'$)
- With the same HESS $t_{exp}$, ASTRI-MA will secure the likely Pevatron nature of GC region
- Mapping of the whole GC region with a single observation (dimension $1.5^\circ \times 0.2^\circ$)
- Resolving different sources
Candidate Pevatrons w ASTRI MA

- 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)

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

Aliu et al. 2014

HAWC collaboration 2019

Abeysekara et al. 2017

ASTRI
Candidate Pevatrons w ASTRI MA

- 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

- Constraints on some physical parameters as maximum energy and diffusion coefficient
- Understanding 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°)

Distant Molecular clouds are the "only hope"!!

200h

MAGIC collaboration 2019

Aharonian et al. 2008
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

- Per year $\rightarrow$ ~ 1500 dark hours (moonless) $\rightarrow$ but:
  - bad weather, “calima”, maintenance...
  - $\sim$ 1000 hrs availables for scientific observations
  - on 3 years: $\sim$ 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:

<table>
<thead>
<tr>
<th>Sources</th>
<th>Seasons</th>
<th>Dark Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galactic Center</td>
<td>May-June-July</td>
<td>300</td>
</tr>
<tr>
<td>VER J1907</td>
<td>September-October</td>
<td>300</td>
</tr>
<tr>
<td>G106</td>
<td>November-December</td>
<td>400</td>
</tr>
</tbody>
</table>
## Schedule

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

### Key Dates:
- **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 commissioning → Oct 2023**
- **Ready for operations → Apr 2024**

S. Scuderi, Astrosiesta, 14/01/2021
Conclusions

What are the sources of Galactic Cosmic-Rays?
ASTRI Mini-Array has all the potentialities to answer this question

- Better (and improvable) sensitivity $\rightarrow$ detection with higher precision of sources above 100 TeV and constraints on physical parameters (e.g. diffusion coefficient)

- Better angular resolution $\rightarrow$ morphology characterization and strong constraints to gamma-ray emission/MC association

- Larger FoV $\rightarrow$ large field (e.g. Galactic Center region) and extended sources (e.g. TeV halo) in-depth analysis
Thank you very much!