The ASTRI/CTA mini-array of Small Size Telescopes as a precursor of the Cherenkov Telescope Array

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https://www.cta-observatory.org/
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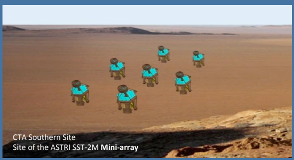
Abstract

ASTRI ("Astrofisica con Specchi a Tecnologia Replicante Italiana") is a flagship project of the Italian Ministry of Education, University and Research. Within this framework, INAF is currently developing a wide-field-of-view (9.6 degrees in diameter) end-to-end prototype of the small-size telescope (SST) of the Cherenkov Telescope Array, CTA, sensitive in the energy band from a few TeV up to hundreds TeV. The ASTRI telescope is based on a dual-mirror Schwarzschild-Couder (ASTRI SST-2M) optical design, with a compact (F# = 0.5) optical configuration named ASTRI SST-2M telescope. This allows us to adopt an innovative modular focal plane camera based on silicon photo-multipliers, with a logical pixel size of 6.2mm x 6.2mm. Moreover, planned, and already being developed, an SST mini-array based on 7 identical telescopes represents an evolution of the ASTRI SST-2M telescope. The University of Sao Paulo (Brazil) and North-West University (South Africa) have jointed INAF to collaborate to the mini-array implementation. The ASTRI/CTA mini-array will be part of the main CTA Observatory, representing a precursor around which the final array of CTA will grow up at the southern site. ASTRI/CTA mini-array, in addition to a technical assessment study (in the perspective of the full CTA implementation) it will be possible to perform an early scientific program. In particular we wish to start investigating the poorly known energy range beyond a few and 100 TeV, thus exploring e.g. the cut-off regime of cosmic accelerators.

The ASTRI/CTA mini-array concept



The ASTRI Project [1,2] is being developed following two major steps:

- ✓ the first step consists of the design, deployment and operation in Italy of an **end-to-end prototype** of a CTA [3] small-size telescope (in a dual-mirror optical configuration (SST-2M) and equipped with a modular SiPM-based camera) ➔ **inauguration 24 September 2014**;
- ✓ the second step consists of the deployment and the operation of a mini-array composed of **a few SST–2M telescopes** at the final CTA southern site in 2016, which could constitute the first *seed* of the future CTA Project.

The telescope end-to-end concept

End-to-end prototype

Energy threshold:

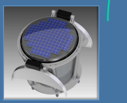
- ~ 1 TeV

Telescope properties:

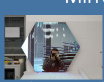
- Optical design = Schwarzschild-Couder
- Primary mirror, M1 = 4.3m Ø
- M1 type = Segmented (18 elements in 3 concentric rings)
- Secondary mirror, M2 = 1.8m Ø (2.2m Radius of Curvature)
- M2 type = Monolithic
- M1-M2 distance = 3m
- Effective area = 6.5m²
- F/D$_1$ = 0.5, F = 2.15m

Camera properties:

- Sensors type = SiPMs
- Number of logical pixels = 1984
- Pixel size = 0.17° (plate scale = 37.5mm/°)
- Field of View = 9.6°



Mirrors



Primary (18 segments)

Secondary (monolith)

The ASTRI mini-array operations in the context of CTA

The deployment and operation of the ASTRI SST–2M mini-array to be installed at the CTA southern site will verify the following array properties:

- ✓ the array performance (reliability and cost) at the chosen site;
- ✓ the trigger algorithms;
- ✓ ***the wide field of view performance to detect very high energy showers with the core located at a distance up to 250 m;***
- ✓ the HW/SW configurations for the array;
- ✓ the data-handling chain.

… and in particular…

through deep observations of a few selected targets, it will allow us to compare the actual performance with the Monte Carlo expectations, and ***to perform the first CTA science, by means of a few solid detections during the first year***

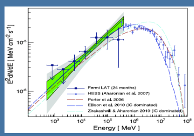
… assuming the following performance [4]…

- ✓ a ***limiting flux*** a factor 2 better than H.E.S.S. above a few TeV for an array composed of 7 telescopes
- ✓ an ***angular resolution*** of 0.08° at 10 TeV
- ✓ an ***energy resolution*** of the order of 15% at 10 teV

ASTRI/CTA mini-array preliminary scientific cases

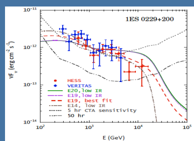
The CTA Southern site will provide an excellent view of most of the Galactic plane and of the Galactic Bulge. Several Galactic sources have been detected so far [5,6] above a few tens of TeV, including shell-type supernova remnants (SNR), pulsar wind nebulae (PWN, such as the Crab Nebula), binary systems, the Galactic Center, as well as a number of unidentified sources apparently emitting only above 100 GeV with no lower-energy counterparts.

***Supernovae Remnants*.** RX J1713.7-3946 is a young shell-like SNR which could be considered as an excellent laboratory to investigate the cosmic ray acceleration. The recent detection of this SNR by Fermi [7] and the combined study with H.E.S.S., show that the high-energy and very high-energy (VHE) emission could be interpreted in the framework of a leptonic scenario. The ASTRI SST–2M mini-array improved sensitivity in the 10-100 TeV energy range will allow us to investigate the possible cut-off at VHE predicted by the leptonic scenario and/or the spectral tail typical of hadronic models. Moreover, by combining the improved sensitivity with the optimal angular resolution, the ASTRI SST–2M mini-array might allow us to investigate the VHE emission in the different regions of this source, studying their spectra.

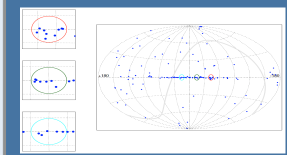


***The quest for Pevatrons*.** Tycho's SNR is the best candidate as Pevatron [8], but it will not be accessible from the CTA southern site. Interestingly, Kepler's SNR, which will be accessible to CTA, is very similar to Tycho's in many respects. The H.E.S.S. telescope observed Kepler's SNR for 13 hrs and provided upper limits on the energy flux in the range 230 GeV – 12.8 TeV of 8.6×10^{-13} erg cm^{-2} s^{-1} [9]. Indeed, theoretical models [10,11] predict that the high energy emission from Kepler's SNR should be only a factor 2-5 below the H.E.S.S. upper limits. Hence, the ASTRI SST–2M mini-array could be able to detect this young SNR by means of a deep observation.

***Blazars*.** 1ES 0229+200 is an extreme BL Lac object [12,13]. The emission spectrum measured as a result of the injection of VHE/UHE photons at the source is strongly suppressed above ~10 TeV for a wide range of EBL models, whereas a cosmic-ray-induced cascade displays a significantly harder spectrum above this energy.
As discussed in [13] a clear detection of VHE emission above a few tens of TeV from such a blazar could provide a striking evidence for non-standard phenomena, either an anomalous transparency of the Universe at these energies [14,15] or gamma-ray emission resulting from an
electromagnetic cascade initiated by ultra-relativistic protons accelerated in the blazar jet and beamed toward the observer.



A list of promising E-HBLs is currently under study [16] and will provide a fundamental *target list* for the future ASTRI SST–2M mini-array. The latter would also demonstrate the possibility that relativistic jets are the accelerators of the still enigmatic UHECR.



***New surprises*.** The large optical field of view of the ASTRI mini-array will allow us to monitor, during a single pointing, a few TeV sources simultaneously. Although the actual sensitivity will substantially drop for off-axis sources within the optical FoV, a few targets can be monitored simultaneously. Detection of hard and intense Galactic sources could be feasible, e.g. in the case of Vela–X and Vela–Jr. Moreover, it would be the chance to detect intense (a few Crab units) flares from hard-spectra serendipitous sources.

References: [1]-Pareschi et al., ICRC Proc. 2013 [2]-Vercellone et al., 2012, AIPC, 1505, 749. [3]-Actis et al., 2011, Exp. Astr., 32, 193. [4]-Di Pierro et al.,ICRC Proceeding 2013. [5]-Aharonian, et al., 2005, Science, 307, 1938. [6]-Hinton & Hofmann, 2009, ARA&A, 47, 523 [7]-Abdo et al., 2011, ApJ, 734, 28. [8]-Morlino & Caprioli, 2012, A&A, 538, A81. [9]-Aharonian et al., 2008, A&A, 488, 219. [10]-Berezhko et al., 2006, A&A, 452, 217. [11]-Morlino & Caprioli, 2012, AIPC, 1505, 241. [12]-Tavecchio et al., 2011, MNRAS, 414, 3566. [13]-Murase et al., 2012, ApJ, 749, 63. [14]-Horns & Meyer, 2012, JCAP, 02, 33. [15]-De Angelis et al., 2013, MNRAS ,432, Issue 4, p.3245. [16]-Tavecchio et al., 2013, Physical Review D, vol. 86, Issue 8, id. 085036.

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ASTRI/CTA mini-array flux sensitivity

Limiting flux

- a factor 2 better than H.E.S.S. above a few TeV for an array composed by 7 telescopes

Angular resolution

- a few (4-5) arcmin

Energy resolution

- of the order of 10-15 %