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The ASTRI Program

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Abstract. The ASTRI (*Astrofisica con Specchi a Tecnologia Replicante Italiana*) program was born as a collaborative international effort led by the Italian National Institute for Astrophysics (INAF) to design and realize, within the Cherenkov Telescope Array (CTA) framework, an end-to-end prototype of the Small-Sized Telescope (SST) in a dual-mirror configuration (2M). While the activities concerning the characterization of the prototype are under completion, the program entered a new phase. With the final aim of contributing at the production of the SST telescopes for the CTAO Southern site, we started the development of nine telescopes based on the evolution of the ASTRI prototype design to work as pathfinder for the CTAO. Furthermore, together with the CHEC (*Compact High Energy Camera*) collaboration, the ASTRI team presented a proposal, that will be evaluated with other proposals, to deliver to CTAO the complete set of SST telescopes.

1 Introduction

The Cherenkov Telescope Array Observatory [1] (CTAO) will be the largest ground-based very high-energy gamma-ray detection observatory in the world, with more than one hundred telescopes located in the Northern and Southern Hemispheres (La Palma, Canary Islands and currently proposed at the Atacama desert, Chile). The energy coverage, in the Southern CTA array, will extend up to 300 TeV thanks to a large number (up to 70) of small size telescopes (SST), with their primary mirrors of about 4 meters in diameter and large field of view of the order of 9 degrees.
In the CTA project framework Italy is planning an important contribution in the development of the telescope array through the ASTRI program. The program was born in 2011 with the final aim to contribute to the production and delivery of a number of SST telescopes for the CTAO Southern site. The effort is led by INAF in synergy with the Universidade de Sao Paulo (Brazil) and the North-West University (South Africa). The ASTRI program envisages three distinct but continuous phases. The first phase is the design, realization and deployment of a prototype of the SST telescopes named the ASTRI SST-2M. The prototype telescope has been built; it is now installed in Italy at the INAF Observing Station on Mt. Etna (Sicily) and is completing its science verification phase. The second phase of the project goes one-step further towards the CTAO construction through the implementation of an array of SST pathfinders. The third phase is the contribution to the construction of the final CTAO array. Dedicated funds from the Italian government and the international partners are already available for the implementation of the last two phases.

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2 The ASTRI Prototype

The ASTRI SST-2M telescope [2] is characterized by an optical system based on a dual-mirror modified Schwarzschild-Couder design and by a curved focal plane covered by silicon photomultiplier sensors managed by a fast front-end electronics. The telescope has an alt-azimuthal mount with a segmented primary mirror of 4.3m diameter and a monolithic secondary mirror of 1.8m diameter. The focal plane of the prototype Cherenkov camera is populated with 21 Hamamatsu SiPM of the LCT5 series and the read-out electronics is based on CITIROC ASICs that implement a custom peak-detector operation mode to acquire the SiPM pulses. A comprehensive description of the technical characteristics of the telescope can be found in [3, 4] for the electromechanical structure, and in [5, 6] for the optics, while the camera and its electronics is thoroughly described in [7, 8]. Analogously, the control/acquisition hardware and software are described in [9], the data analysis software in [10], and the data archiving system in [11].

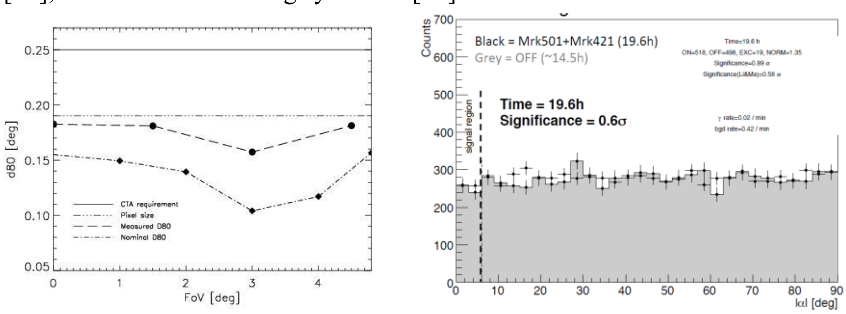

Figure 1. Left : Comparison of D80 (diameter of the circle corresponding to an encircled energy of 80%) as a function of field angle (off-axis) between its ideal (dot-dashed curve) and measured at ASTRI SST-2M (dashed curve) values. SiPM pixel size (dashed horizontal line) and CTA requirement (solid horizontal line) are also shown. The requirement of a flat PSF of ~10 arcmin along a large field of view (~10°) is clearly fulfilled. **Right** : $|\alpha|$ distribution of the stacked Mrk421 and Mrk501 signal and background estimation from data taken in June/July 2018, after an 80% efficiency-based gamma/hadron discrimination parameter cut (in the whole energy range). The region between zero and the vertical dashed line (at 6 deg) represents the fiducial signal region.

The telescope prototype is mainly a demonstrator used to validate the novel technology. However, it has been developed following an end-to-end approach that comprises all the work that should be done to obtain scientific products through Cherenkov observations [12].

The telescope prototype was installed in September 2014 at the INAF Catania Astrophysical Observatory on the slopes of the Etna volcano and, since then, has been operated on regular basis. A complete set of functional and verification tests was performed for the mechanical structure and for the optics. In particular, the pointing and tracking performance has been measured [1] and the results show that they are well within the CTA requirements of online and post calibration astrometric accuracy (1 arcmin and 7 arcsec respectively). The optical performance was also extensively studied. Figure 1 (left side) shows the most important result obtained, that is, the first validation ever of the SC optical design [6]. In addition, dedicated measurements show that the optical Point Spread Function is very stable against time and telescope elevation [13]. A somewhat unexpected result, coming from the mirrors' reflectivity characterization, was the fast ageing of their coating likely due to the aggressive volcanic atmosphere [2].

Since the first Cherenkov light obtained in May 2017, the camera has performed several observational campaigns at the telescope, most of them devoted to engineering tests and some to scientific observations of the brightest sources (Crab nebula, Mrk421, and Mrk501) observable from the prototype site. Figure 1 (right side) shows the results of the analysis of the stacked shower data on the two Markarians obtained in June/July 2018. We collected ~20 hours on the objects and ~15 hours of off data. No detection has been obtained. This is not unexpected due to the reduced efficiency of the telescope mirrors, and the low flux of the objects (<0.1 Crab units). The scientific observations obtained up to now allowed us to test the end-to-end concept of the prototype from the photon capture to the data analysis [10]. A complete report of the camera performance in the laboratory and on sky can be found in [8].

3 The ASTRI Pathfinder

The next step of the program is the production of a set of nine end-to-end ASTRI telescopes named ASTRI pathfinder based on the ASTRI design to be placed at the CTAO Southern site. The pathfinder is proposed as a precursor of the final array to prove technology and to test operational and maintenance procedures. In particular, the activities in which the pathfinder can give a fundamental contribution to the development of the CTAO are: the assessment of the array trigger; the test of the array control software and general operations; the test of the AIV procedures on site (time, personnel, infrastructure, and tools); the test of the array performance against Monte Carlo simulations and the test of the implementation of the intensity interferometry capability.
The implementation of the pathfinder will happen within the framework of CTAO development. In particular, it will have to pass, before deployment, all the CTAO technical reviews. If the currently proposed CTAO Southern site in Chile will be confirmed shortly, the current schedule will allow us to place the first complete pathfinder telescope at the end of 2020.

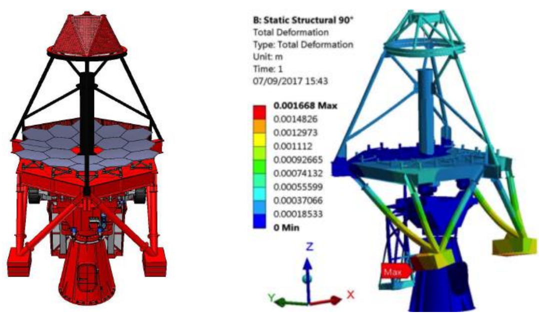

Figure 2. Left: the design of the ASTRI structure for the array of pathfinders (courtesy of GEC). Right: example of Finite Element Analysis for the new structure (courtesy of GEC).

Activities for the production of the array of pathfinders started already. In particular, the procurement of the telescope mirrors and the camera ASICs, items whose design is well consolidated and then considered at low risk, is well under way. Half of the primary mirror segments are ready and the secondary mirrors will be completed by the end of 2018. The production of the new version CITIROC 1A of the camera ASIC is also half way. Details of the procurement activities is given in [2]. On the other hand, the electromechanical structure and the Cherenkov camera are instead going through a phase of design consolidation and optimization. This is necessary to take into account the lessons learnt with the prototype, the technology improvements and the consolidation of CTA requirements due to the final choice of the South site. Figure 2 shows the consolidated design of the electromechanical structure. The main changes in the telescope design are the optimization of several parts of the mechanical structure to allow us lowering the total weight while keeping the stiffness unchanged. Furthermore, the stability of the measured optical PSF against gravity and time allowed a design without a permanent active mirror control. The optimized design is described in detail in [14]. Analogously, we will proceed in the design consolidation of the camera.
As it is conceived with an end-to-end approach, the pathfinder can be used not only for technological and operational aspects but also to make astrophysical observations. Preliminary Monte Carlo simulations (Figure 3) shows that the ASTRI pathfinder could surpass the H.E.S.S. sensitivity above 10 TeV, extending up to about 100 TeV with an energy resolution of about 10 – 15 % [10]. The ASTRI pathfinder will exploit its better sensitivity and extended spectral range to investigate the emission of prominent sources such as extreme blazars, nearby well-known BL Lac objects and radio galaxies, galactic pulsar wind nebulae, supernova remnants, the Galactic Centre and the search for cosmic ray (CR) PeVatrons.

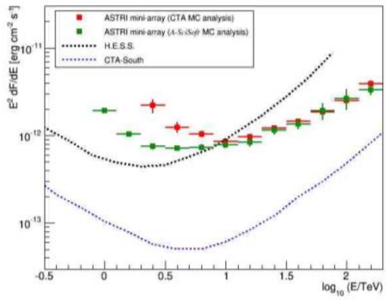

Figure 3. ASTRI pathfinder (9 telescopes, relative distance ~250 m, and square layout) differential sensitivity curves (5σ 50 hours) achieved with the A-SciSoft MC analysis (green points) and with the CTA MC analysis [10]. The differential sensitivities of CTA-South (blue line) and H.E.S.S (black line) are shown for comparison.

4 CTAO

Three different SST prototypes are currently being developed within the CTA Collaboration, namely the single mirror SST-1M [15] telescope and the dual-mirror GCT [16] and ASTRI telescopes. Recently, the CTAO project office started a harmonization process that includes the evaluation of these designs through an external panel of experts to be concluded by next Spring.

The ASTRI and the CHEC collaborations decided to answer jointly to this call proposing a design based on a combination of the developed work of the ASTRI project and the CHEC prototyping effort. The aim is to deliver to CTAO the complete set of SST telescopes including the pathfinder described previously as precursor of the final array. The telescope structure, including mirrors, will be the current ASTRI design while the final camera will be an improved version of the current CHEC camera [17]. The telescopes of the array of pathfinders will be part of the final delivery to CTAO while the CHEC-like cameras will replace the ASTRI-like cameras in the array of pathfinders.

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