Status of the Small-Sized Telescopes of the Cherenkov Telescope Array

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The extreme Universe viewed in very-high-energy gamma rays 2018
Oct 12, 2018
Small-Sized Telescopes (SSTs)
1. Introduction to CTA Science

1.1 Key Characteristics & Capabilities

![Image of diagram showing energy flux sensitivity and angular resolution comparisons]

**Figure 1.1**

Comparisons of the performance of CTA with selected existing gamma-ray instruments. Top: differential energy flux sensitivities for CTA (south and north) for five standard deviation detections in five independent logarithmic bins per decade in energy. For the CTA sensitivities, additional criteria are applied to require at least ten detected gamma rays per energy bin and a signal/background ratio of at least 1/20. The curves for Fermi-LAT and HAWC are scaled by a factor of 1.2 to account for the different energy binning. The curves shown give only an indicative comparison of the sensitivity of the different instruments, as the method of calculation and the criteria applied are different. In particular, the definition of the differential sensitivity for HAWC is rather different due to the lack of energy reconstruction for individual photons in the HAWC analysis.

Bottom: angular resolution expressed as the 68% containment radius of reconstructed gamma rays (the resolution for CTA-North is similar). The sensitivity and angular resolution curves are based on the following references: Fermi-LAT [1], HAWC [2], H.E.S.S. [3], MAGIC [4], and VERITAS [5]. The CTA curves represent the understanding of the performance of CTA at the time of completion of this document; for the latest CTA performance plots, see [https://www.cta-observatory.org/science/cta-performance](https://www.cta-observatory.org/science/cta-performance)
Baseline Layout of CTA with 70 SSTs

- Achieves a vast effective area of \(~5 \text{ km}^2\) with 70 SSTs
- Extends the highest-energy frontier to **300 TeV** and beyond
Southern Site – Paranal, Chile

Very Large Telescope

Proposal Site
(~2150 m a.s.l.)

E-ELT
Where do PeV cosmic rays come from? Do PeVatrons accelerate CRs up to Knee?

~3 PeV cosmic-ray protons $\rightarrow$ ~300 TeV gamma rays through $\pi^0$ decays
CTA Key Science Projects for PeVatron Search
Galactic center is the best PeVatron candidate so far (possible CR cutoff energy of a few PeV)

Deep survey of ~800 hours is planned (inc. dark matter search)
Galactic Plane Survey (GPS)

https://twitter.com/CTA_Observatory/status/996680795631816704
Galactic Plane Survey

HAWC
(> 20 TeV Data)

Galactic Center
RX J1713

Any other PeVatron candidates by CTA?


https://twitter.com/CTA_Observatory/status/996680795631816704
50-hrs exposure for RX J1713.7-3946 and other candidates each after GPS
- More photons in > 10 TeV region to study spectral cutoff and hadronic component
- Higher angular resolution and sensitivity may be able to reveal escaping cosmic rays
SST Design Proposals

- Need 70 SSTs with less expensive technologies (4-m optics & compact camera)
- Large FOV (8–10°) to detect photons with large core distances
- SiPM cameras with 1296–2368 pixels and compact front-end electronics
Optical Systems for >8° FOV

Schwarzschild–Couder (ASTRI and GCT)

Davies–Cotton (SST-1M)

Primary

Secondary

Credit: SST-1M/CTA
SiPM Cameras

- Use of SiPMs enables us to build compact cameras with high pixel density
- Dedicated compact and modular readout
- Very NSB tolerant and long SST-only observations (> 5 TeV) are possible
SST-2M GCT (Gamma Cherenkov Telescope)

- Built at Meudon site of the Paris Observatory’s (very bright sky)
- 6 segmented aspherical primary mirrors and semi-monolithic secondary
- Star images by a CCD camera show 6–7 mm PSF size (narrow component) while wide component (scattering by micro roughness) needs to be improved with new Al mirrors
**SST-2M GCT Camera**

- Updated the first prototype camera with SiPM arrays
  - Better photon detection efficiency, uniform pixel gain, and better charge resolution
  - New sampling and trigger ASICs for better dynamic range, lower noise, improved trigger efficiency, etc
- Lab tests and on-telescope observations
CTA's first ever Cherenkov images taken on Nov 26, 2015
- CR hadron observations with the first camera and telescope prototype at Paris Observatory
- The second camera to be tested on the ASTRI telescope prototype in 2018
Built at INAF-Catania mountain station on Mt. Etna (very active volcano)

- 18 segmented aspherical primary mirrors + monolithic aspherical secondary

ASTRI prototype telescope is the first realization of the Schwarzschild–Couder optics with full mirror configuration
SST-2M ASTRI Camera

- $8 \times 8$ ch MPPC $\times 37 = 2368$ MPPC pixels at the focal plane
- Dedicated SiPM-readout ASICs (CITIROC) used in front-end electronics
- Compatible design with SST-2M GCT

Image credit: CTA/ASTRI
Achieved first light of air-shower images on May 25, 2017

Observed Crab and Mrk 501 but not significant yet

Also able to image stars by measuring pixel amplitude variance (proportional to star flux)
SST-1M

- Conventional Davies–Cotton optics with 18 segmented spherical mirrors (less expensive than Schwarzschild–Couder)
- Fully automated system installed at IFJ, Krakow, Poland
- Optical performance has been verified with star images
SST-1M Camera

- 8.9° FOV with 1296-pixel SiPMs and light concentrators
- Dead-time free fully digital camera (DigiCam)
- Not compatible with SST-2Ms but use similar technologies with MST FlashCam
SST-1M First Light

- Achieved first light on Aug 31, 2017
- Prototype detected the Crab nebular with 4.2σ excess in test observations
- New observation campaigns are ongoing in 2018

CTA Prototype Telescope, the SST-1M, Catches its First Glimpse of the Sky

On Thursday, 31 August, 2017, a prototype telescope proposed for the Cherenkov Telescope Array (CTA), the SST-1M, recorded its first events while undergoing testing at the Institute of Nuclear Physics Polish Academy of Sciences (IFJ-PAN) in Krakow, Poland. The SST-1M is proposed as one of CTA’s Small-Sized Telescopes (SSTs), which will cover the high end of CTA’s energy range, between about 1 and 300 TeV (tera-electronvolts).

A crew in Krakow worked for two days to install the camera on the telescope and spent another two days monitoring it to ensure it could be safely switched on in the high humidity conditions. Watch the camera installation in the video below.
SST Harmonization Started

- Three different approaches are matured and have verified the concept of SSTs
- But it is time to consolidate the optics and camera designs before SST pre-production phase
- “SST harmonization” process started in May 2018 to simplify the southern array with easier maintainability and less construction cost
- Final SST design proposals to be submitted Oct 2018
- Review and evaluation of “the” final SST design will follow in 2019
- Only single acronym, the “SST”, will be used afterwards :-)

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Site hosting agreement for CTA south to be signed
ASTRI Mini Array

- 9 ASTRI telescopes to be built as ASTRI Mini Array in parallel to the SST harmonization
- Stereo imaging, array trigger, array control etc. will be thoroughly tested
- ASTRI and GCT cameras can be mounted
Summary

- CTA Small-Sized Telescopes will explore the highest-energy gamma-ray frontier from the ground
  - Core energy coverage of 5–300 TeV
  - 70 telescopes in CTA South
  - Wide-FOV optical system and SiPM camera
  - PeVatrons and cosmic-ray origins
- Three SST designs; GCT, ASTRI, and SST-1M
  - Verified their functionalities in labs and by first light
  - Harmonization process is ongoing
  - Bigger single SST group will be formed and quickly move toward pre-production and completion