



Telescopes for the High Energy Section of the Cherenkov Telescope Array

R. WHITE¹, F. DI PIERRO², T. GREENSHAW³, G. PARESCHI⁴, R. CANESTRARI⁴ FOR THE CTA CONSORTIUM

¹*University of Leicester, Leicester, UK*

²*Istituto di Fisica dello Spazio Interplanetario dell'Istituto Nazionale di Astrofisica, Torino, Italy*

³*University of Liverpool, Liverpool, UK*

⁴*INAF Osservatorio Astronomico di Brera, Merate, Italy*

richard.white@leicester.ac.uk

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Abstract: The Cherenkov Telescope Array (CTA) will provide an unprecedented level of sensitivity to very-high-energy (VHE) gamma rays across an energy range from below 50 GeV to above 100 TeV. To achieve this, large, medium and small size telescopes are required, covering the low, intermediate and high energy regimes, respectively. The small size telescope (SST) array will occupy an area on the ground of up to 10 km² and operate from around 1 TeV to several hundred TeV. It will allow CTA to probe the gamma-ray universe with the highest angular resolution yet obtained above the hard X-ray band, enabling morphological studies of PeV particle acceleration sites and discrimination between hadronic and leptonic cosmic-ray acceleration models. Under consideration for the SST are a Davies-Cotton design with a mirror diameter of about 7 m and a dual mirror telescope with primary mirror diameter of about 4 m. The status of the optical and mechanical designs of each of these alternatives is presented and the pros and cons of each approach discussed. Comments are also made on the cameras needed for each of these instruments.

Keywords: CTA, Imaging Atmospheric Cherenkov Telescope, gamma-rays, optics

1 Introduction

To extend the sensitivity of CTA to the highest energies, an array of small telescopes - the SST subsystem, will be utilised. The SST sub-system will operate from ≤ 1 TeV to 300 TeV and has a number of unique requirements:

- At the energies of interest to the SST sub-system astrophysical gamma rays are rare due to the power-law spectra of typical sources. Therefore the SST part of CTA must cover a large area (1 - 10 km²).
- Images due to gamma rays above 1 TeV are bright out to many hundreds of meters from the shower impact point and so only relatively small dish diameters (3 - 7 m) are needed to collect enough light to trigger each telescope (see Fig. 1).
- Although images are visible out to large impact parameters, they also shift away from the centre of the camera with increasing distance from the shower impact point so each SST camera must have a field of view (FoV) $> 7^\circ$ (see Fig. 1).
- An angular pixel size of 0.18 - 0.28 $^\circ$ is needed to resolve the width of gamma-ray images above 1 TeV (see Fig. 1).

- The fundamental limit of angular resolution for the IACT technique decreases with energy (1 arc minute at several TeV), see Fig. 2 [6]. The SST array offers the unique opportunity of high angular resolution at high energies. Monte Carlo simulations show that the angular resolution improve with telescope multiplicity and therefore an SST geometry in which a fixed area (i.e. fixed cost) is covered with small dishes placed closer together is favoured over fewer larger dishes placed further apart.

A SST sub-system that achieves these requirements will allow CTA to probe the gamma-ray universe with the highest angular resolution yet obtained above the hard X-ray band. Sensitivity at arc-minute scales above several TeV will enable morphological studies of PeV particle acceleration sites essential for discrimination between hadronic and leptonic cosmic ray acceleration models.

The SST sub-system will be capable of operation in conjunction with the other sections of CTA, or independently, in the case of a strong source, or a source with a hard spectrum.

2 A Davies-Cotton SST

Traditionally IACTs with dish diameters of under ~ 12 m are constructed with a Davies-Cotton geometry. This op-

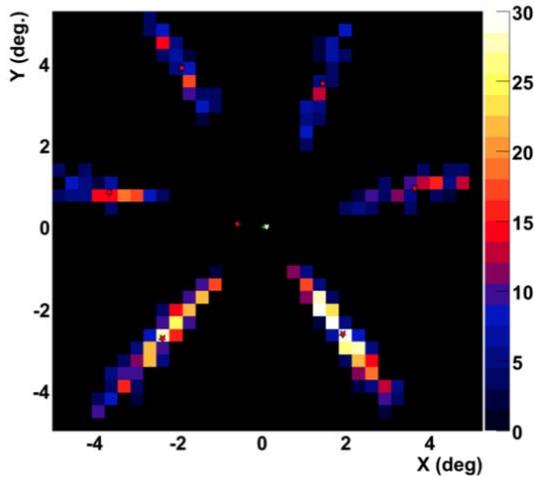


Figure 1: Images from a simulated 14 TeV gamma-ray in 10° FoV cameras with 0.25° pixels. Each dish has a diameter of 3 m diameter and the telescopes are ~ 500 m from the shower core. The z-scale is in units of photoelectrons/pixel. Taken from [4].

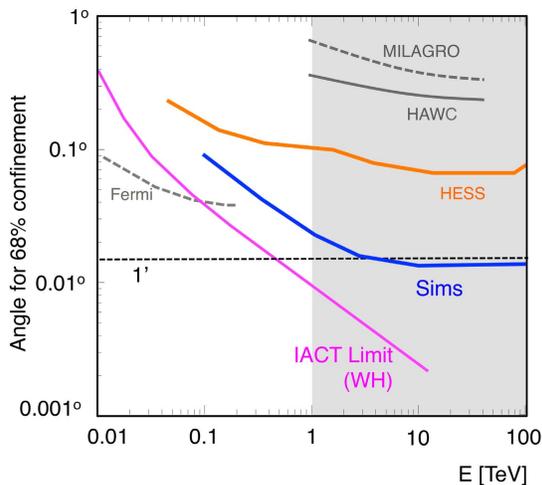


Figure 2: The angular resolution of gamma-ray instruments including a simulation of a high-energy IACT array, taken from [5] and the fundamental limit of angular resolution for IACTs from [6].

tion forms the baseline solution for the SST, and has the advantage of being tried and tested.

The CTA Medium Sized Telescope (MST) will use a 50 mm pixel pitch (including the PMT and associated light guide). It is desirable both in terms of cost and maintenance to use the same physical PMT size for all telescopes. Several Davies-Cotton designs for the SST based on this

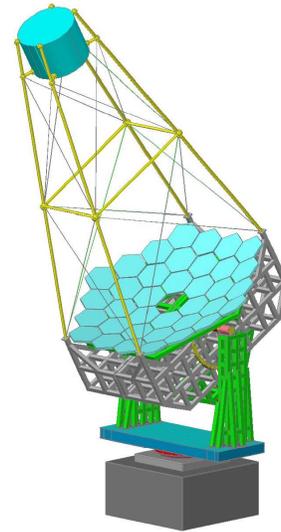


Figure 3: The Polish Davies-Cotton SST design with 11.46 m focal length and 7.64 m dish diameter.

requirement are under investigation by Polish, Italian and Argentinian collaborators [8].

A structural Davies-Cotton SST prototype is planned in Poland with a 11.46 m focal length and 7.64 m diameter dish as shown in Fig. 3. A 0.25° pixel based on the 50 mm physical pixel size results in ~ 1000 (1600) pixels for a 8° (10°) FoV and a 1.6 m (2.0 m) wide camera. Under the current cost model ~ 35 such telescopes could be built.

A Davies-Cotton SST dish would consist of hexagonal segments tiled to approximate a circle. A segment size of ~ 0.85 m (face-to-face) is under investigation by Italian groups. Larger sizes degrade the PSF, and are impossible to manufacture with the required radius of curvature using cold-slumping. A smaller segment size (and the additional mounts and actuators) increases the cost of the telescope.

3 Optimisation

The Davies-Cotton design for the SST is the baseline solution, but is not without challenges and may not be optimal. Mirror segments of the required radius and desired size are difficult to produce using traditional methods, supporting a 1000-1600 kg camera at 11.5 m is non-trivial, and the cost of the telescope is dominated by the large camera.

One method to optimise the SST is to consider alternative photodetectors. SiPMs (GaPDs) are more efficient than PMTs, weigh less, are impervious to day-light and require no high voltage. They have long since been considered for IACTs, but traditionally exhibit performance problems and have a high cost per unit area. Recently, however, the FACT collaboration proved that an IACT SiPM camera is realistic, and have overcome many technical issues [2]. In such a scenario DC optics could be used in conjunction with a

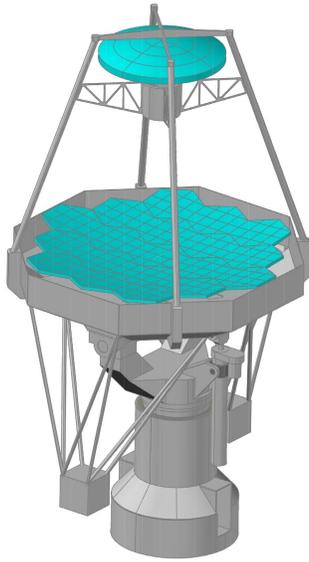


Figure 4: The Italian secondary optics SST design with a ~ 4 m diameter primary and a ~ 2 m secondary.

SiPM camera. It may be possible to envisage a ~ 4 m DC dish and a 0.7 m camera with 20 mm pixels constructed from SiPMs with solid light cones (assuming 5 mm SiPMs with the required performance and cost become available on the timescale of CTA).

Another approach to optimise the SST is to address the cost imbalance between structure and camera in the DC design. The camera can be made drastically less expensive by reducing the plate scale to the point at which alternative photodetectors become affordable. This can be achieved with a secondary optics (SO) system. By reducing the camera cost to a similar level as the structure cost, many more telescopes can be built resulting in either a larger area on the ground (higher sensitivity) or tighter spacing (higher angular resolution).

4 A Secondary Optics SST

UK and Italian SO SST optical designs have been produced and independently converged to similar results. In the near future Italian and Anglo-French structural prototypes are planned, featuring aspherical mirrors with a segmented ~ 4 m diameter primary and a (possibly monolithic) ~ 2 m secondary with $f/d \sim 0.5$ resulting in a plate scale of ~ 37.5 mm/°. The PSF (80% containment) is below the size of a single pixel across the entire FoV in both cases.

A 9.6° FoV can be implemented with a 0.35 m camera. The focal plane is curved (radius 1 m) and must be approximated with photodetectors. The 64 channel Hamamatsu H10966 Multi Anode PMT (MAPMT) can be used with a physical pixel of $\sim 6.5 \times 6.5$ mm² ($\sim 0.18^\circ$). Alternatively,

the Hamamatsu S11828-3344M SiPM array of 4×4 pixels, each of size 3×3 mm². In this case 4 SiPM pixels would be combined to form a 6×6 mm² (0.16°) camera pixel, and light collectors used to reduce dead space. The SO solution results in a curved focal plane and so the smaller SiPM array allows for a more accurate representation of the curvature. There are still questions over the performance of both the MAPMT and the SiPM array and these are under investigation within CTA.

Camera prototypes for the SO SST structures based on MAPMTs and SiPMs are planned by UK-US and Italian CTA groups. There are several front-end electronics solutions under development within CTA. The Target modules, based around the Target ASIC under development at SLAC [1, 9] offer a compact solution with a potentially low cost. Using the Target modules it would be feasible to construct a camera for the SO SST with electronics integrated into the compact camera. Alternatively the Flash-Cam project underdevelopment within CTA offers a potentially cost effective flash ADC based approach [7]. In this scenario signals would be amplified in the camera and transported in analogue form to the digitisation electronics located behind the primary reflector (potentially in the telescope counterweight as shown in 5). This approach would avoid a densely packed camera and the power dissipation problems associated with it, but would introduce a level of signal degradation and additional failure points at the cable interfaces.

Assuming a similar cost model to the Davies-Cotton SST, and that Target-based electronics are used, around ~ 60 SO SSTs could be built.

5 Secondary Optics Technical Challenges

There are several technical challenges associated with the use of SO for the SST, not least of which is the novelty of the design. To date a SO IACT has never been built. Beyond this:

- **Mirrors:** The unusual shape and size means that cold-slumping can not be used. Alternative techniques including hot slumping are under investigation.
- **Photodetectors - MAPMTs:** The 64 channel H10966A has a single HV supply. The device must be able to operate in star light otherwise a large fraction of the camera will have to be regularly disabled. The MAPMT must also be able to operate at large incidence angles of up to $\sim 60^\circ$.
- **Photodetectors - SiPMs:** These devices are typically over sensitive in the red and under sensitive in the blue. They also require compensation for temperature effects.
- **Electronics:** The small camera volume means reduced space for electronics presenting cabling, con-

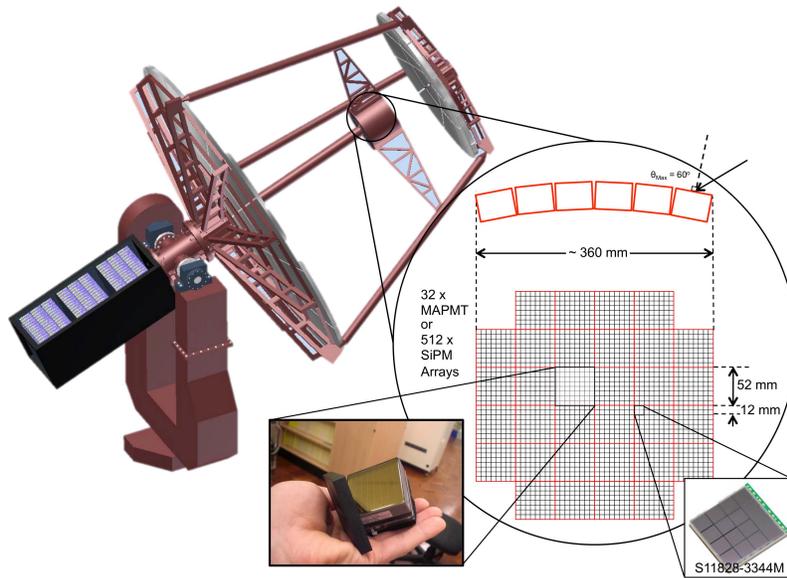


Figure 5: The Anglo-French secondary optics design with possible camera tiling and photodetectors.

neer and power dissipation problems. Gamma-ray images at the highest energies can take hundreds of nanoseconds to traverse a camera. This presents readout and dead-time challenges.

- **Alignment:** The successful operation of a secondary optics SST requires millimeter alignment precision between the mirror segments of the primary and secondary reflectors and the focal plane.
- **Maintenance:** The SST subsystem will be the largest array of IACTs ever built. The expected lifetime of CTA is the order of 20 years. Each telescope must be built with reliability and maintenance in mind to realise this goal.

6 Conclusion

CTA will consist of at least three types of telescope, each aimed at a particular energy range. Above 1 TeV the performance of the array will be dominated by the SST subsystem, consisting of 30 - 60 telescopes covering 1 - 10 km², each with a $>7^\circ$ FoV. Covering a larger area increases sensitivity whilst spacing the telescopes closer together improves angular resolution. A Davies-Cotton telescope design has the advantage of using proven technology, but the assumed cost is dominated heavily by the camera. One method to address this is to use secondary optics. In this way the plate scale is reduced and smaller, cheaper-per-pixel, photodetectors become available. Decreasing the SST cost allows more telescopes to be built and can be used to increase sensitivity and improve angular resolution.

Prototypes of both Davies-Cotton and SO SST designs are planned, and detailed designs are underway. Components for the SO camera are currently being tested, and two full camera prototypes using alternative photodetectors are planned.

An optimised SST array will provide CTA with unprecedented sensitivity and angular resolution in the energy range 1 TeV - 300 TeV.

Acknowledgements

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