Simulations of the SST-GATE optical performance

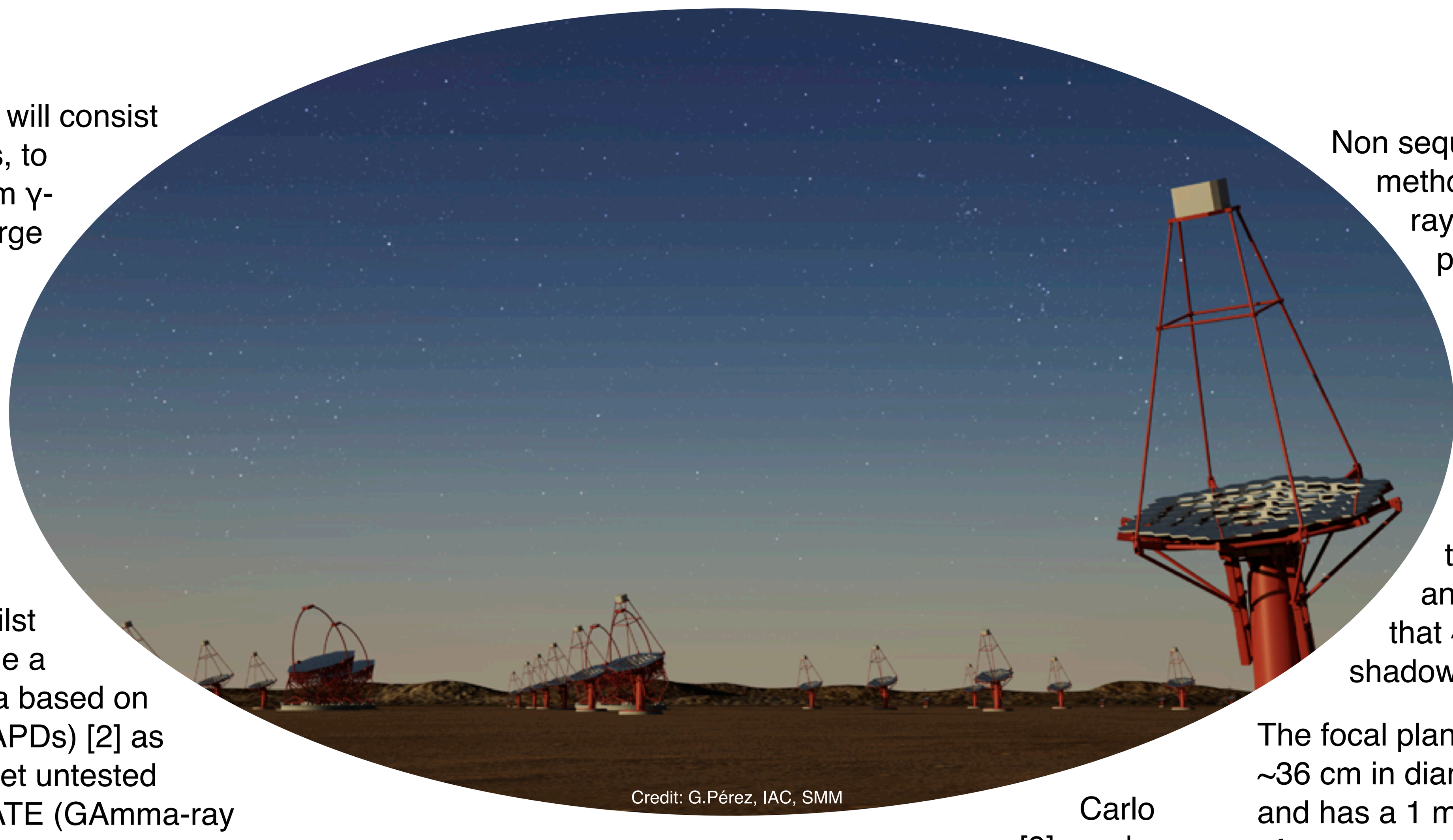
Cameron Rulten

LUTH, Observatoire de Paris, France.

Abstract

The Cherenkov Telescope Array (CTA) [1] will consist of nearly 100 telescopes, of different sizes, to detect the Cherenkov light that results from γ-ray induced atmospheric air showers. A large number of these will be small-sized telescopes (SSTs) that will image the high-energy end of the electromagnetic spectrum (above ~1 TeV to beyond 100 TeV).

Several SST designs are currently being investigated, each of which aims to combine a large field of view (~9°) with a good imaging resolution of the shower whilst keeping costs to a minimum. These include a Davies-Cotton configuration with a camera based on Geiger-mode Avalanche PhotoDiodes (GAPDs) [2] as pioneered by FACT [3] and two novel as yet untested telescope designs, ASTRI [4] and SST-GATE (GAmma-ray Telescope Elements) [5], which are based on the Schwarzschild-Couder configuration [6]. Both of these use a secondary mirror to reduce the plate-scale and to allow for a wide field of view with a light-weight camera, which will use GAPDs or MAPMTs (Multi-Anode Photo Multiplier Tubes) for example.



SST-GATE telescope

The SST-GATE telescope is a cost-efficient telescope currently being constructed at the Paris Observatory in Meudon, France. It is envisaged that the telescope will be easy to install and maintain on the CTA site.

primary mirror diameter	4 m
secondary mirror diameter	2 m
effective collecting area	~8.2 m²
field of view	9°
plate-scale	39.6 mm / °
total weight	7.8 t

The optical system

The two mirror surfaces (Figure 1) can be characterised by a 16th order polynomial which is optimal in order to minimise the point spread function (PSF) over the whole field of view. The primary is comprised of 6 petals whilst the secondary is a formed monolithic. The telescope will carry the CHEC [7] camera currently under development.

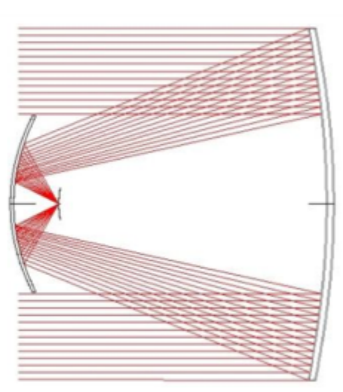


Figure 1: Light path for an on axis source at infinity simulated with Zemax. Credit: Jürgen Schmoll (Durham University)

Simulations of the optical performance

The optical performance of the SST-GATE telescope has been simulated with Zemax [8], the sim_telarray Monte Carlo program [9] used within the CTA consortium as well as with the ROOT based ROBAST ray tracing software [10] which was used in this research.

Using ROBAST, a 3 dimensional computer model was constructed (Figure 2) based upon the engineering specifications. In addition to the mirrors and ideal focal plane, the model includes the mast and truss structure supporting the secondary mirror and camera.

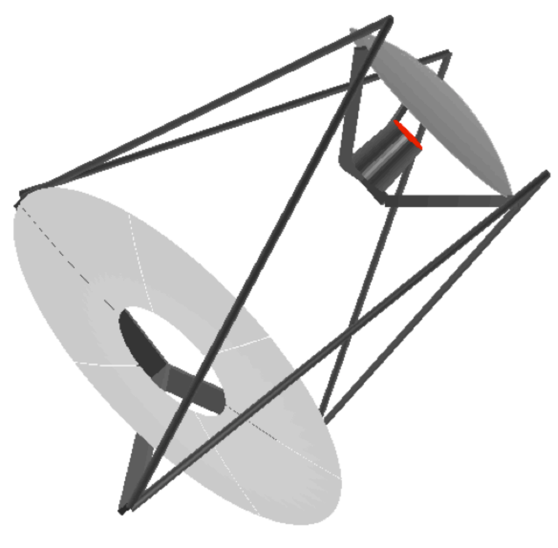


Figure 2: The 3 dimensional computer model constructed using ROBAST.

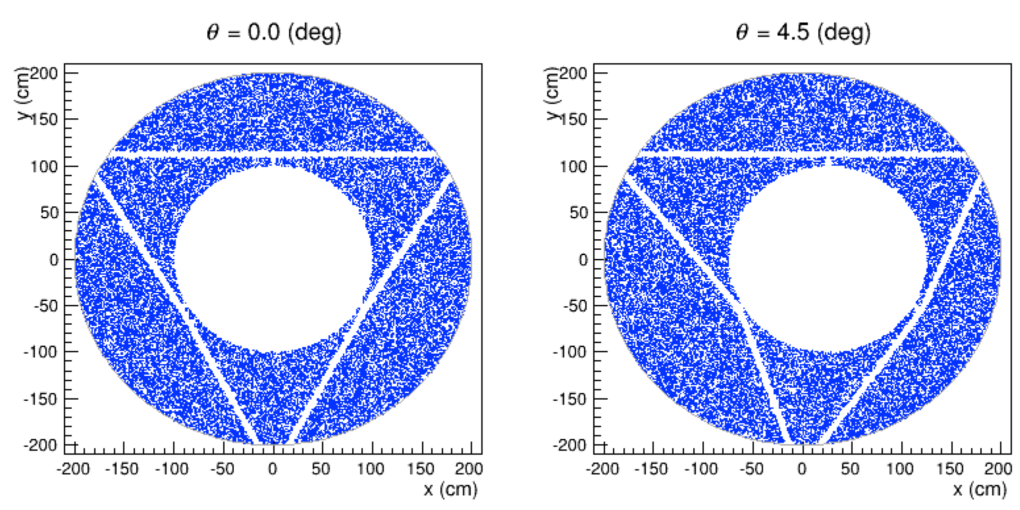


Figure 3: Shadowing as a result of the secondary mirror and support masts as seen on the primary mirror. The left panel illustrates the shadowing for an on-axis observation and the right panel for a wide field angle of 4.5°.

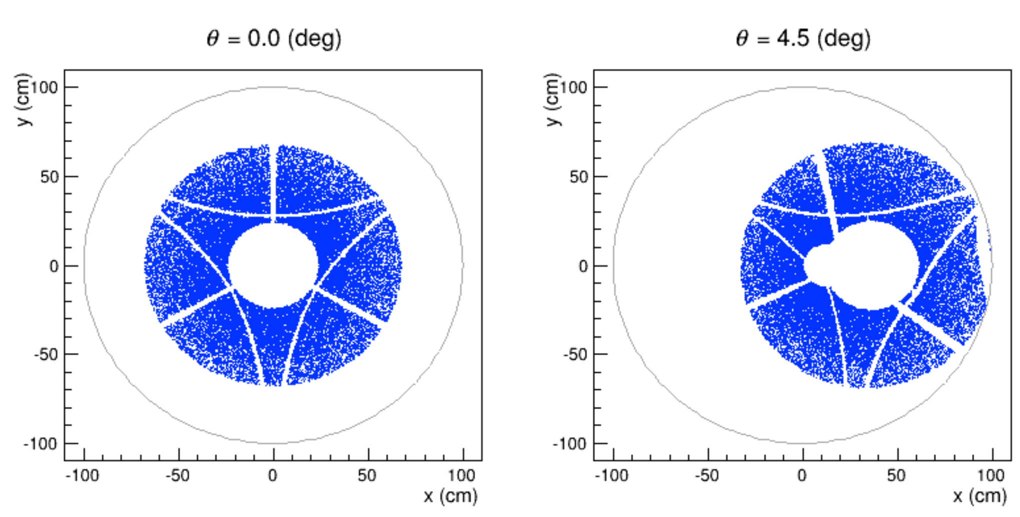


Figure 4: Shadowing as a result of the secondary mirror and its support masts and the camera and its support trusses as seen on the secondary mirror. The left panel illustrates the shadowing for an on-axis observation and the right panel for a wide field angle of 4.5°. The solid grey line shows the mirror circumference.

Non sequential ray tracing was performed using two methods: parallel rays and a random cone i.e. rays randomly distributed within a cone from a point at a given height.

Using the photons focused at the ideal focal plane, various performance parameters were then calculated.

The first simulation conducted was to determine the amount of light lost due to the telescope masts and trusses (see Figures 3 and 4). From these simulations it is estimated that ~13% of the photons are lost due to shadowing from the masts and trusses.

The focal plane is ~36 cm in diameter and has a 1 m radius of curvature. Currently these simulations assume an ideal focal plane whilst work is still ongoing to create (and include) a computer model of the CHEC camera.

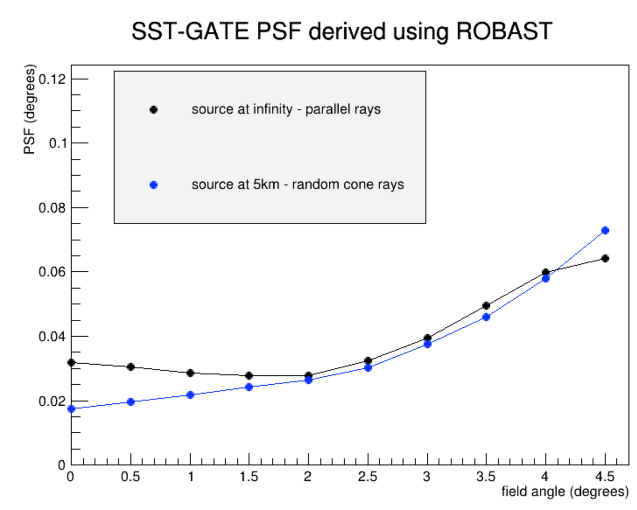


Figure 6: The PSF, defined as the radius within which 80% of the photons are contained, calculated for different field angles.

Figure 5 illustrates the simulated image spot seen on the focal plane for different field angles. Using these spot images a PSF for each field angle was derived and is shown in Figure 6. The PSF calculated here is defined as a radius within which 80% of the photons are contained. For all field angles simulated the PSF is smaller than the assumed pixel size.

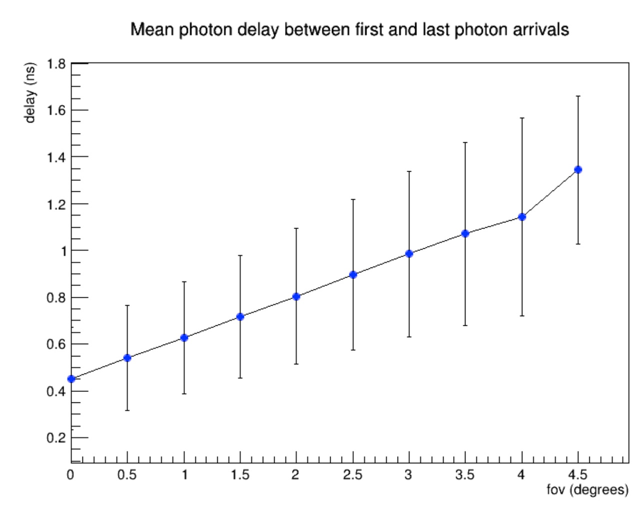


Figure 7: The average delay between the first and last photon arrival time on the focal plane tracing photons using a random cone. The error bars show the spread.

The final simulation conducted was to determine the average delay between the photon arrival times at the focal plane. This was calculated by finding the average delay between the first photon and the last photon, traced along the path from the primary mirror to the focal plane. Figure 7 shows that for all field angles, the delay is less than 1.6 ns which is within the SST design requirements for the CTA.

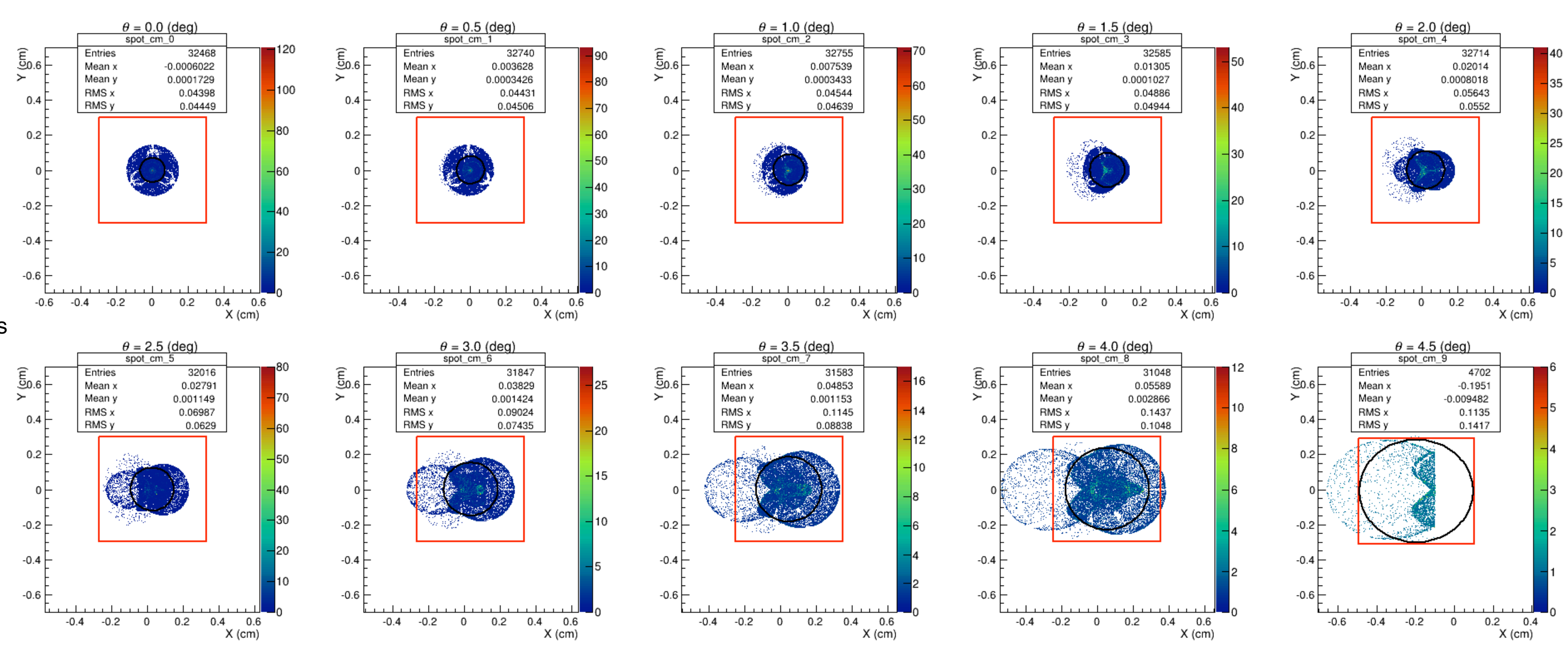


Figure 5: The image spot seen on the ideal focal plane for different field angles from 0° to 4.5° in 0.5° steps. The red box illustrates the dimensions of a 6mm x 6mm square pixel and the solid black circle shows the derived PSF.

Current status and future work

This research is currently being used to optimise the optical design of the SST-GATE prototype telescope which includes a comprehensive tolerance analysis not shown here. In addition, this work provides an independent analysis to verify results obtained using other tools. Furthermore, these results will have an impact on the final methods used for mirror alignment and telescope pointing. With this in mind, this work is being extended to determine the spot size imaged on top of a camera lid as well performing a ray trace from LEDs positioned on the camera face, needed for camera calibration and alignment.

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