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Update on the characterisation of the pGCT, a prototype of 4m dual-mirror Cherenkov Telescope

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Abstract. The Gamma-ray Cherenkov Telescope prototype (pGCT) is a prototype of an Imaging Atmospheric Cherenkov Telescope, developed as Small-Sized Telescope (SST) of 4m during the preparation of the Cherenkov Telescope Array (CTA). Based on a Schwarzschild-Couder dual-mirror optical design aiming to provide an optimised Point Spread Function (PSF) on a wide field, it had its first Cherenkov light on the Meudon site of the Observatoire de Paris in 2015. Since the decision of CTA to harmonize its future SSTs, the pGCT instrument and the experience gained with its development are now used by the Observatoire de Paris team to provide a test bench for Cherenkov astronomy and a pedagogical tool for educational purposes in Meudon. This paper briefly describes the design of the pGCT and presents the latest advances in the optics of the prototype and its characterisation, directly related to the implementation of new high-quality metallic mirrors carried out since 2020.

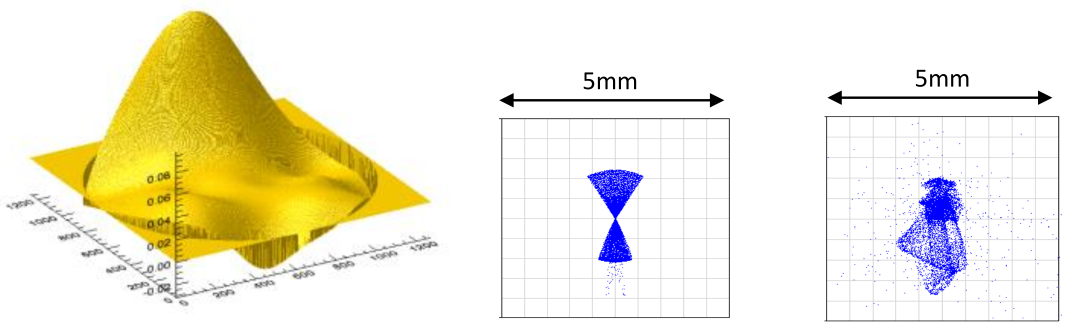
1. Introduction

The Gamma-ray Cherenkov Telescope prototype (pGCT) was originally designed for the CTA (Cherenkov Telescope Array) project. It has been manufactured mostly in the industry in 2013-2015, and then installed and finally inaugurated on the Meudon site of the Paris Observatory in 2015. Equipped with a CHEC camera prototype [1], it was the first CTA prototype to record its first Cherenkov light in November 2015 [2]. The 4-meter Schwarzschild-Couder optical dual mirrors adopted design is suitable for gamma-ray astronomy. The two mirror configuration results in a compact mechanical structure and the reduction of the plate scale allows the use of small Silicon Photomultiplier (SiPM) pixels and a light and compact camera. It also has the advantage to have a large field of view (FoV) greater than 8° and provides a good angular resolution for Very High Energy studies over the full FoV, ensuring an excellent tool for surveys and for observations of extended sources [3]. The pGCT has been designed in the spirit of cost-optimisation, easy assembly and maintenance, and upgradability possibilities, knowing that SiPM equipping the Cherenkov camera is a technology evolving rapidly. The pGCT is still in development due to the recent equipment in metallic mirrors of better quality than the first low-cost mirrors installed in 2015, the final goal being to reach a PSF defined as the diameter for 80% energy contained D80 of 3 mm on-axis, possibly adapted to a 2^{nd} generation of cameras with finer pixels.

Indeed, six panels compose the primary mirror that will be completed with new generation mirrors by the end of 2021. Those mirror panels have a very specific shape described by a sixteen-degree polynomial curve, manufactured following a specific industrial R&D process [4].

2. Update on the new high quality mirrors

The choice of metallic manufacturing mirror was made by the Paris Observatory team for the pGCT, in order to produce large mirrors with complex surface geometry, lighter compared to glass mirrors, with a deformation of 20 µm RMS (waviness) relatively to the ideal shape for the M1 aiming to a specular PSF of 2,2 mm at the center of the FoV (figure 1). However, the first generation of mirrors were affected by a poor micro-roughness of 55 nm RMS for the M1 panels and 53 nm RMS for the M2 which induced important halos of diffused light which degraded the total PSF obtained on sky. Both Zemax and ROBAST simulations showed that improving the micro-roughness from ~50 nm to 7 nm RMS had to drastically improve the final pGCT PSF [4].



Deformation from the ideal shape measured for one M1 segment (X,Y,Z in mm) — Ideal PSF — PSF with real M1 segment, assuming perfect polishing

Figure 1. On the left: Large scale shape of one M1 segment. In the centre: Ideal simulated PSF (D80 = 1.8mm on-axis). On the right: PSF for the real large scale shape of one M1 segment, assuming ideal M2 (D80 = 2.0mm on-axis).

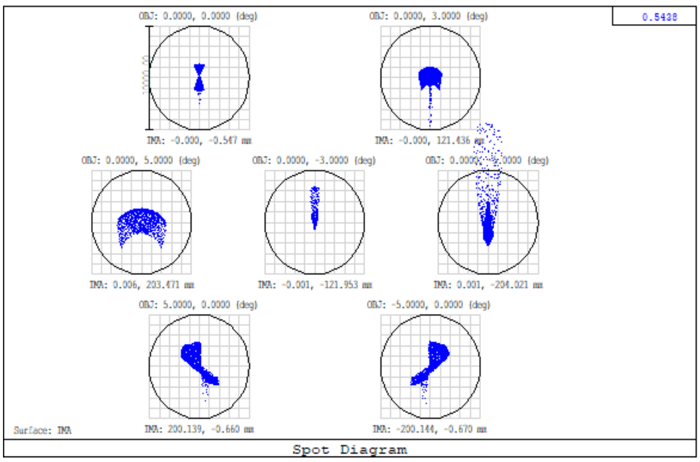


Figure 2. Ideal PSF theoretical spot diagram for one M1 segment depending of the angles to the centre of the field of view.

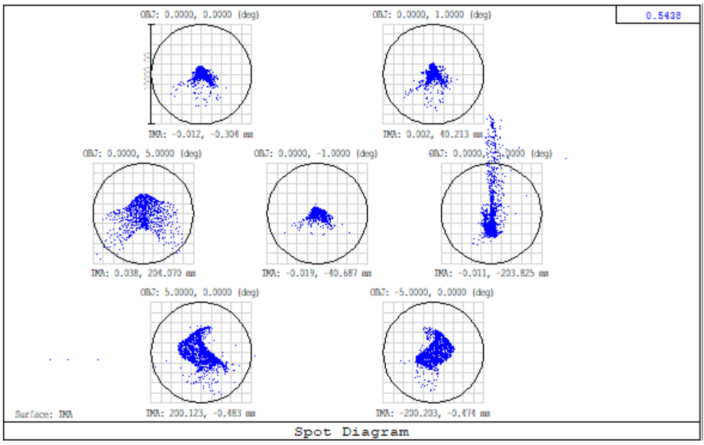


Figure 3. PSF simulated spot diagram for one real new M1 segment, assuming an ideal M2).

In 2020, a new generation of M1 metallic mirrors with high quality polishing has been received and tested on the prototype. The comparison between the PSF theoretical spot diagram (figure 2) and the PSF simulated spot diagram with one of the new mirror (figure 3) points the high quality of the expected final PSF global shape. Those panels are made in continuous bulk aluminum, covered with a 100µm nickel layer and finally coated with an optical treatment. This manufacturing process established with the ALSYOM company enables to reach the expected specifications of 7nm RMS micro-roughness (High-Spatial Frequency Roughness) and a specular reflectivity (between 300 nm and 550 nm) upper than 85% on average.

3. Results obtained on sky for the current PSF profiles

Measurements with different M1 panels have been achieved on Polaris in 2018 and 2021, which allows to compare the optical quality and shows the improvement between the old and new panels. As shown in figure 4 below, the decomposition of stellar images into two 2D Gaussian components (a narrow one and a diffuse one) results in an old “narrow” component (around D80 = 7,3mm) corresponding now to the new “extended” one (D80 = 7,2 mm) induced by the remaining diffusion of the M2.

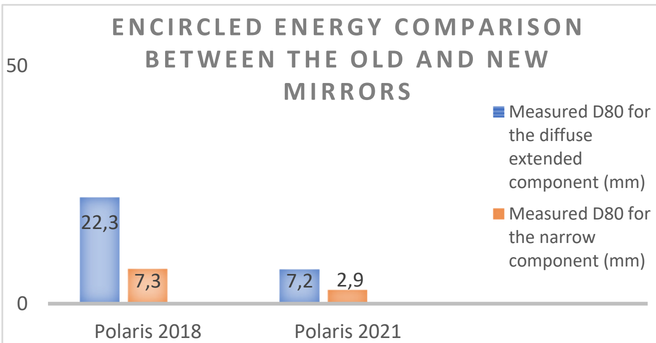


Figure 4: Decomposition of stellar images into two 2D Gaussian components, illustrating the significant improvement of the PSF between 2018 (with old M1) and 2021 (with new M1). The diffusion by the M1, responsible of the large halo in 2018, almost completely disappeared in 2021.

The diffuse component due to the old secondary mirror M2 is still very notifiable on the PSF measured in 2021. Regarding the improved results achieved with new M1 panels, improving the micro-roughness of the M2 should reach the aimed final D80 of 3mm, similar to the current specular component around 2,9mm.

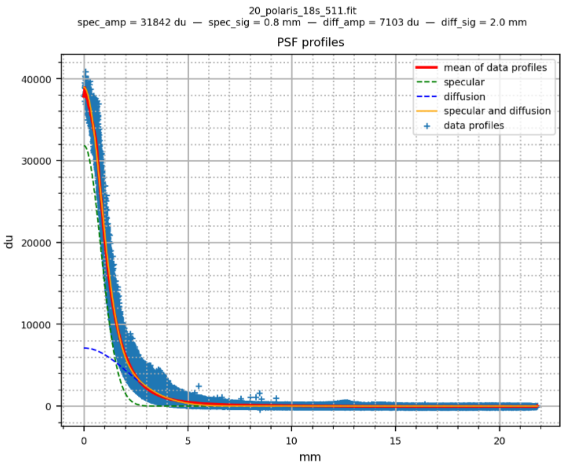


Figure 5. D80 PSF profiles of Polaris obtained with new M1 in 2021, fitted by the sum of two 2D Gaussian components.

The study of the PSF profile obtained in July 2021 (figure 5) shows that the mean of data points (in red) is very well fitted by two 2D Gaussian profiles, a narrow one corresponding to the expected specular PSF with D80 = 2.9 mm, plus a more extended one mostly due to the diffusion by the old M2 with D80 = 7.2 mm, as described in the graphs below (figure 6). The new M1 mirrors combined with the 2015 secondary mirror provide stellar profiles with a total D80 = 6.9 mm, which precisely corresponds to what was expected for such a hybrid configuration.

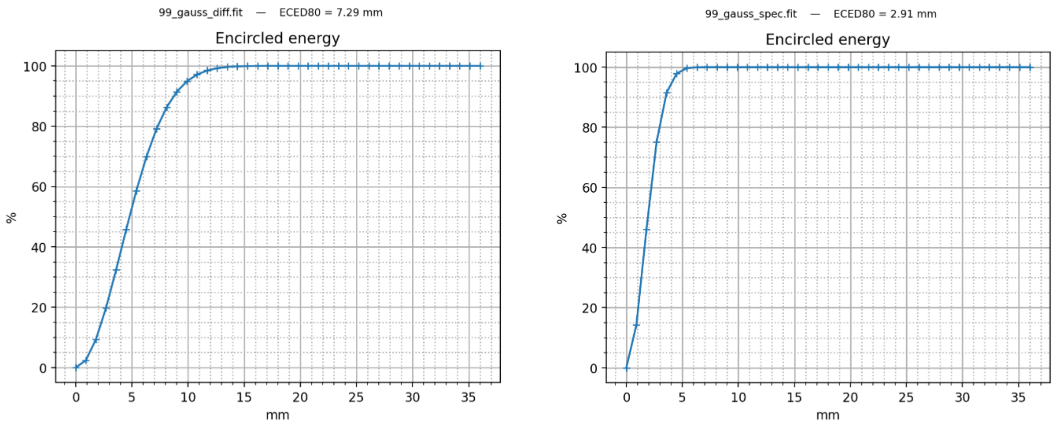


Figure 6. Encircled Energy D80 for the diffuse component on the left graph (7,29mm) and the specular component on the right graph (2,91mm) for the current hybrid configuration with new M1 and old M2 of the pGCT.

Figure 7. Visual of one of the new M1 panel received in 2021, while being mounted on the pGCT.

4. Conclusion

The GCT Consortium has initially designed (in-house) a full prototype that is operated since 2015 at the Observatoire de Paris. The telescope structure design has been optimized for mass production using the lessons learnt from the prototyping phase and industrial inputs. New high-quality segments of the primary mirror have been recently installed on the telescope. They completely solve the problem of diffusion faced with our first generation of mirrors. The secondary mirror is now under construction following the same manufacturing process established by the ALSYOM company. A quality similar to the new M1 is expected, which should complete the optimization of the optical system and reach a final PSF close to the current specular value of D80 = 2.9 mm. Once completed with its new optical system, the pGCT will be used as an educational tool and as a test bench.

5. References

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