SF2A 2016
C. Reylé, J. Richard, L. Cambrésy, M. Deleuil, E. Pécontal, L. Tresse and I. Vauglin (eds)

GCT, THE GAMMA-RAY CHERENKOV TELESCOPE FOR MULTI-TEV SCIENCE WITH THE CHERENKOV TELESCOPE ARRAY

H. Sol[1], J.-L. Dournaux[2], P. Laporte[2] and the GCT Team and CTA Consortium[3]

Abstract. GCT is a gamma-ray telescope proposed for the high-energy section of the Cherenkov Telescope Array (CTA). A GCT prototype telescope has been designed, built and installed at the Observatoire de Paris in Meudon. Equipped with the first GCT prototype camera developed by an international collaboration, the complete GCT prototype was inaugurated in December 2015, after getting its first Cherenkov light on the night sky in November. The phase of tests, assessment, and optimisation is now coming to an end. Pre-production of the first GCT telescopes and cameras should start in 2017, for an installation on the Chilean site of CTA in 2018.

Keywords: high energy astrophysics, gamma-ray astronomy, Cherenkov telescope, prototype for CTA

1 Introduction

CTA, the Cherenkov Telescope Array, is the main global project of ground-based gamma-ray astronomy for the coming decades. Performance will be significantly improved relatively to present instruments, especially with an increase by a factor of ten of the sensitivity and a larger spectral range (Acharya et al. 2013). To achieve such goal, the CTA array will consist of several tens of Cherenkov telescopes of different types and sizes, with 23m, 12m and 4m telescopes respectively devoted to the low-energy sub-TeV domain down to 20 GeV, the intermediate TeV range, and the high-energy domain from a few TeV up to 300 TeV (see Fig. 1). To provide access to the whole sky, two arrays are going to be implemented, one in La Palma, Canary Islands, and one in Chile near Paranal. Pre-production and deployment of the first telescopes on sites are foreseen for 2017-2018. The production phase will then last a few years, with routine user operation expected to start in 2022 and for about 30 years. The nominal CTA southern array will include a sub-array of seventy 4m telescopes spread over a few square kilometres to study the sky at extremely high energies. The Gamma-ray Cherenkov Telescope (GCT) is one of the proposed telescope designs for that sub-array.

2 Which science at multi-TeV?

Large field of view instruments like MILAGRO and HAWC have shown that our cosmos harbours some sources emitting in the highest part of the electromagnetic spectrum, above tens of TeV. Extrapolating from present IACT (Imaging Atmospheric Cherenkov Telescopes) like HESS, MAGIC and VERITAS also suggests a variety of phenomena to study at such energies. However this electromagnetic cosmic window is still very poorly known due to limited current sensitivity and angular resolution. CTA, thanks to its large sub-array of 4m telescopes, will allow for the first time a detailed exploration and deep analysis of this extreme domain, from 3 to 300 TeV (Fig. 1). It combines the guarantee of important astrophysical results with a large discovery potential in cosmology and fundamental physics. We give three examples hereafter.

The search for PeVatrons, cosmic accelerators of particles at PeV energies (10^{15} eV) in our Galaxy and in the Large Magellanic Cloud (LMC), will be a key area in this regard, with the pending question of the origin of the most energetic galactic cosmic rays and their impact on their environment. Indeed, recent results by

[1] LUTH, Observatoire de Paris, PSL Research University, CNRS, Place J. Janssen, 92 195, Meudon, France
[2] GEPI, Observatoire de Paris, PSL Research University, CNRS, Place J. Janssen, 92 195, Meudon, France
[3] See http://www.cta-observatory.org for full author list and affiliations

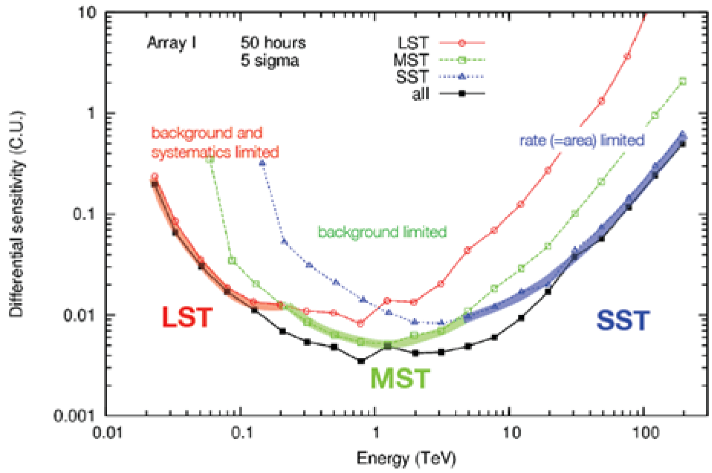

Fig. 1. Differential sensitivity of the future CTA array over its spectral range. The LST, MST and SST, respectively large sized, medium sized and small sized telescopes, dominate the sensitivity at low (in red), medium (in green) and high (in blue) energies (Bernlohr et al. 2013) .

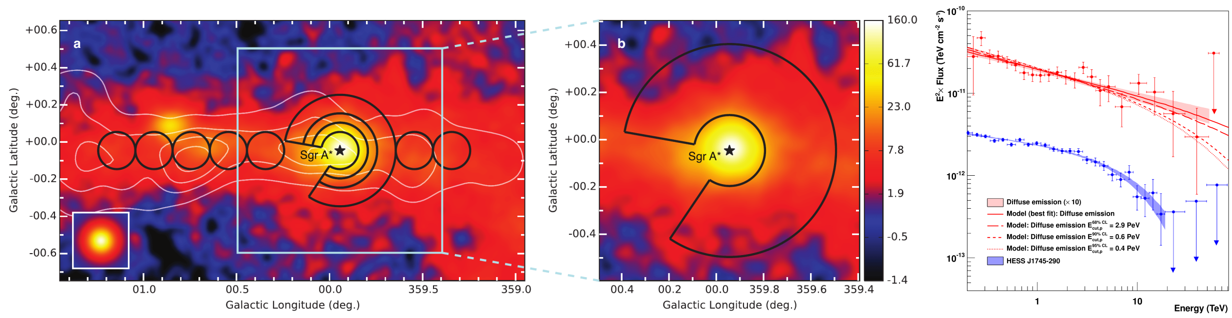

Fig. 2. Left: Very high energy (VHE) gamma-ray image of the Galactic Center region in coded colors. White contours indicate the density distribution of molecular gas. The zoomed view of the inner part shows the region used to extract the spectrum of the diffuse emission. **Right:** VHE gamma-ray spectra of the diffuse emission (in red; multiplied by 10) and of the central compact source HESS J1745-290 (in blue). Reproduced from Abramowski et al. (2016).

HESS suggest the first evidence of a cosmic hadronic PeVatron in the Galactic Center as illustrated in Fig. 2. Data show a power-law spectrum without any cutoff or break, up to tens of TeV, from the diffuse emission within the central 10 parsecs of the Milky Way (Abramowski et al. 2016). The galactic central black hole Sagittarius A* could be the source at the origin of this potential PeVatron, but this clearly deserves further investigation. Exceptionnally powerful VHE sources have also been detected in the LMC. Among them, 30DorC is the first unambiguous detection of a superbubble in the TeV range. It exhibits extreme conditions and could be another type of PeVatron to analyse with CTA (Abramowski et al. 2015). In the remote extragalactic space, the multi-TeV range will allow to explore the most powerful acceleration mechanisms in nearby Active Galactic Nuclei (AGN) and in AGN flares, and will open the search for signatures of hadronic versus leptonic processes around supermassive black holes (Sol et al. 2013). Studying the propagation along the line of sight of extremely high energy photons from cosmic sources will offer in addition the opportunity to analyse the diffuse extragalactic background light (EBL) and to probe the fine structure of spacetime, looking for potential clues of Lorentz Invariance Violation (LIV) and of axion-like particles (ALP). Indeed several versions of quantum gravity theories imply that LIV can significantly reduce the EBL opacity to gamma-rays above 10 TeV. The detection of such anomalies in the cosmic opacity could be reachable by CTA with the search for LIV upturn in the multi-TeV spectra of bright blazars (Tavecchio & Bonnoli 2016). Extending the spectral range up to extreme energies should also facilitate the studies of arrival time delays of VHE photons with their energy, which is another possible signature of LIV phenomena.

3 The early phase of the GCT project

The GCT is an alt-azimuth dual-mirror telescope based on a Schwarzschild-Couder (SC) optical design never built in astronomy before the advent of CTA. Such SC design offers many advantages for ground-based gamma-ray astronomy, with large field of view and reduced focal length allowing compact and lightweight telescope and camera equipped with Multianode Photo-multiplier (MAPM) or Silicon Photo-multiplier (SiPM) detectors. The camera has been developed by a collaboration involving teams from Australia, Germany, Japan, Netherlands and UK. Conception work and FEA simulations of the telescope started in Meudon in 2011 (Dumas et al. 2014; Dournaux et al. 2016a,b). The mechanical structure has been designed so as to facilitate production, transport, assembly and maintenance. It is composed of the telescope base (tower), the entrainment system (AAS), the dishes and arms supporting the mirrors (OSS), the camera support with the system of camera loading and unloading, and the counterweight. The 4m primary mirror is segmented in six aspherical petals, while the 2m secondary mirror is monolithic. Three on-board cabinets are implemented on the telescope for the telescope control system, as well as a chiller for the cooling of the camera (see Fig. 3).

To test the true performance of the SC design and validate the studies and processes, a complete prototype of the GCT telescope and cameras has been implemented. A first camera and its fast electronics was developed and built by the international collaboration and integrated in laboratory in UK. Foundations were completed in 2012 and a shelter installed early 2013 in Meudon. The manufacturing of the main telescope sub-systems was subcontracted to industries between 2013 and 2015. Meanwhile a control room has been arranged near the site on the Meudon campus.

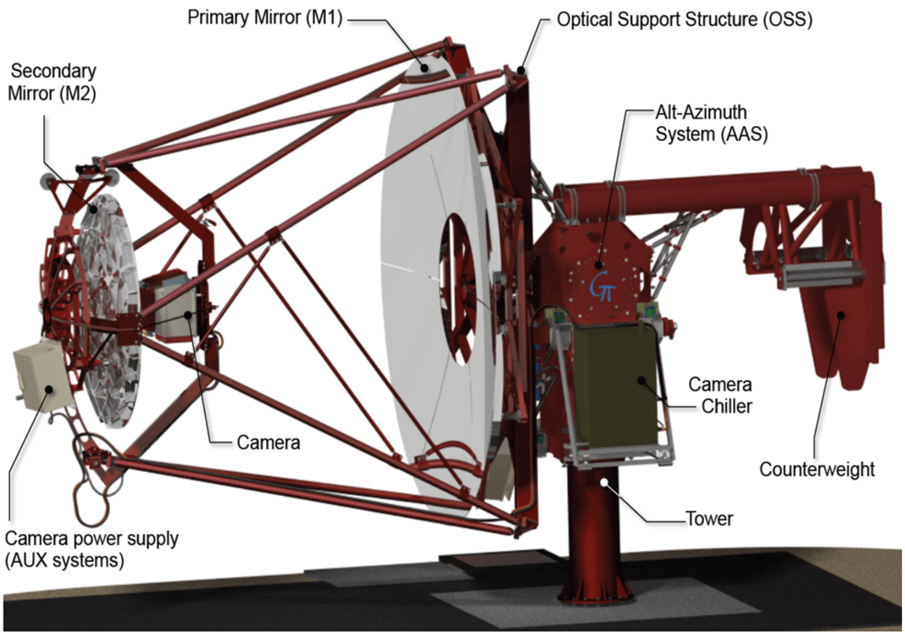

Fig. 3. A compact Schwarzschild-Couder telescope: the GCT design and its main sub-systems.

4 Assembly of the GCT prototype

Once the production and integration of every sub-system completed, the assembly of the telescope went very quickly in 2015 (see Fig. 4). The mechanical structure was installed in two days by a small team in April. Two days were also needed to mount the secondary mirror and two segments of the primary mirror on the telescope in August. The camera arrived in Meudon mid-November and was installed for the first time on the telescope in less than one week, with all connections operational (power and optical fibre, chiller pipes). The process of loading the camera on the telescope lasted by itself less than 15 minutes thanks to the specific loading-unloading mechanism. The Fig. 5 illustrates various steps of the prototype assembly.

Fig. 4. The GCT telescope and camera prototype assembled on the Meudon site (November 2015).

Fig. 5. Integration of the complete prototype. From left to right: (I) mounting the OSS on the tower and the AAS in April 2015, (II) the secondary mirror during its installation on the mechanical structure in August 2015, (III) first loading of the camera on the telescope in November 2015, (IV) the main cabinet for the slow control of the instrument.

5 First Cherenkov light and inauguration

The week following the installation of the camera on the telescope and after preliminary tests performed under the shelter, the instrument was tested on the Meudon night sky in the evening of November 26th, one day after the full moon. Clouds, city lights, and the almost full moon resulted in a night background rate estimate of about 500 MHz (photoelectrons/sec/pixel), typically 50 times higher than that expected on the Chilean site of CTA. Despite these difficulties, several Cherenkov events characteristic of an air shower signal were detected in a few minutes (Fig. 6). They were the first detection of air showers by a CTA prototype, and the very first Cherenkov light for a dual-mirror Schwarzschild-Couder telescope, never achieved before in astronomy. These results obtained during poor weather and light conditions, and before any optimisation of the instrument, appeared as very promising. They have been an important step towards the validation of the concepts and technologies, and for the preparation of CTA, recognised by the international community (Dournaux et al. 2016c). The GCT prototype was inaugurated a few days after its first light, in the presence of representatives of institutes and agencies and with the participation of CTA and VHE scientists (Fig. 6).

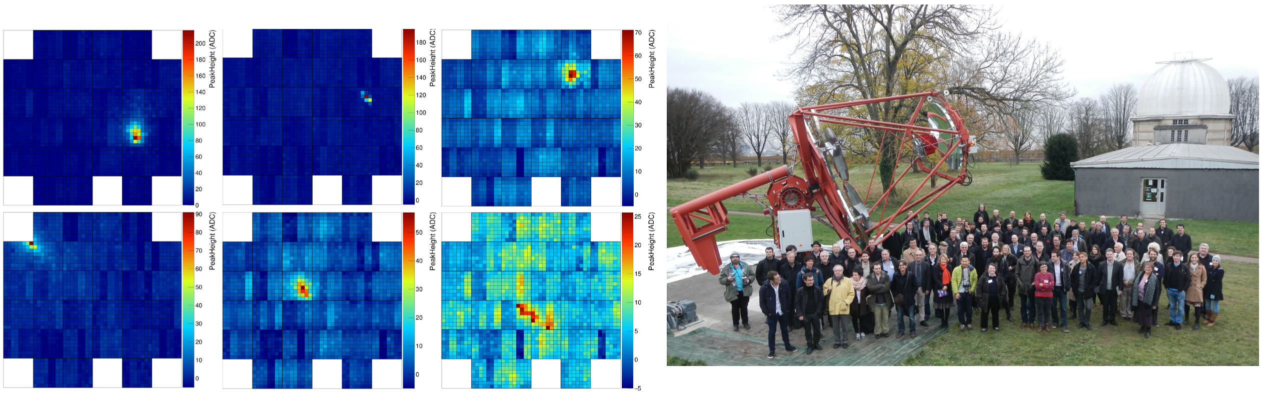

Fig. 6. Left: The first Cherenkov light, with integrated images of some atmospheric showers detected on the night sky in Meudon on November 26th, 2015 (extracted from Watson et al. (2016)). Such events typically last about ten nanoseconds (see for instance a short video available at cta.obspm.fr). **Right:** The inauguration of the GCT prototype on December 1st, one week after the first light. @The GCT Consortium

6 Test phase and assessment

After the commissioning of the complete prototype, several tests and developments were performed in 2016 both for the camera and for the telescope. Following the Design Verification Document and conformity matrix, about 300 tests were necessary in mechanics, optics, electronics and RAMS to check that the telescope structure, mirrors, slow control and security meet all specifications and CTA requirements. A preliminary virtual model of the telescope has been developed with the TPOINT software, after pointing observations of bright stars and planets with a CCD camera installed at the focal surface. Residual misalignments and flexures can then be deduced and modelled, which allows for further correction of geometrical effects and tube flexure.

The test phase is now coming to an end. Most of the time it has validated the performance, as for instance the alignment accuracy of axes as well as azimuth and elevation angular velocities (see Fig. 7), maximum power, pointing accuracy, emergency stop, etc. No technological barrier and specific risks have been identified. Some components not yet implemented on the prototype need to be added, like actuators and baffles for the mirrors, and some others need to be slightly modified for various reasons, like the camera support to improve the telescope-camera interface after some change in the mechanical structure. A special attention is payed to mirrors in order to select the best industrial solution before starting mass production. Work is now in progress to optimise the detailed design plans for GCT-1, the first GCT telescope to be built in pre-production for the southern array of CTA, based on knowledge and expertise gained during the prototyping and assessment phase.

Detailed simulations of the instrument performance are now available (Costantini et al. 2016) and both telescope and camera are better known and calibrated than last year. Slow control for the telescope and data handling for the Cherenkov camera have been improved. A second observational campaign with the Cherenkov camera is planned in Meudon before the end of 2016. It should complete our knowledge of the overall behaviour of the equipment while operating on the night sky.

7 Conclusion and perspectives

The international GCT consortium aims to build 35 telescopes equipped with Cherenkov cameras as in-kind contribution to the CTA Observatory. For the telescope structure, slow control and secondary mirror, the intent is to launch a call for tender in early 2017 and to select an industrial prime for the production of a first telescope unit GCT-1, in order to install it in Chile in the first part of 2018. It will allow validation of the whole industrialisation process as well as of assembly and operation on site. A number of other telescope units will be ordered afterwards following the schedule presented in Fig. 8, when France decides to start the funding of the construction phase of CTA. The project ensures the participation of the French CTA community and its direct involvement on site from the beginning of the implementation of the southern array. It should contribute to the first partial operations of the CTA array under construction in about two years from now, with the obtention of the first experimental data. Full operations of CTA are foreseen for the horizon 2022 and for 30 years.

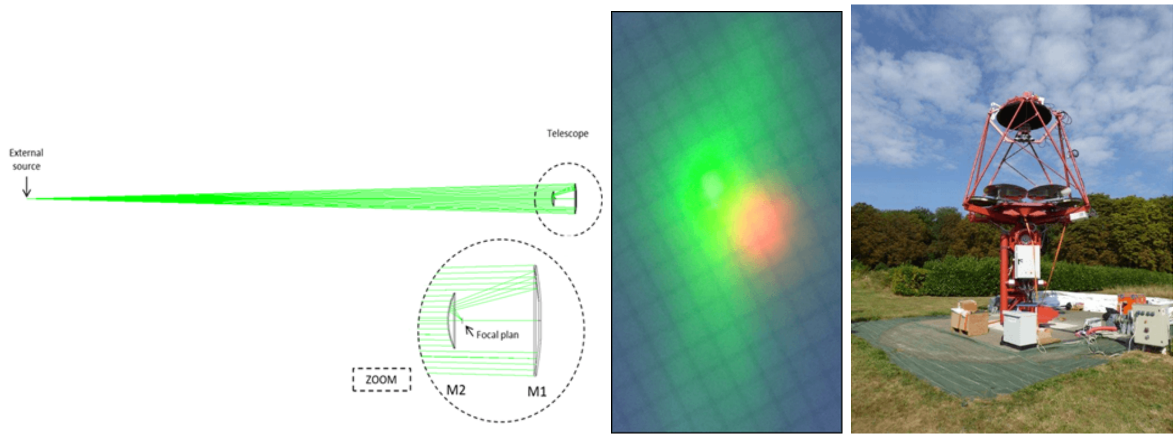

Fig. 7. Left: Test of the alignment of the mechanical and optical axes. A green laser at 77 m distance illuminates segments of the primary mirror and materialises the optical axis on the focal surface. A red laser is attached along the mechanical axis. **Middle:** Image of the two axes on the focal surface, with squares of side 5 mm. Axes are coincident within tolerance, prior to any adjustment of the mirror alignement with actuators. **Right:** Testing the motorisation and entrainment of the telescope. Here the telescope is at 91 degrees in elevation.

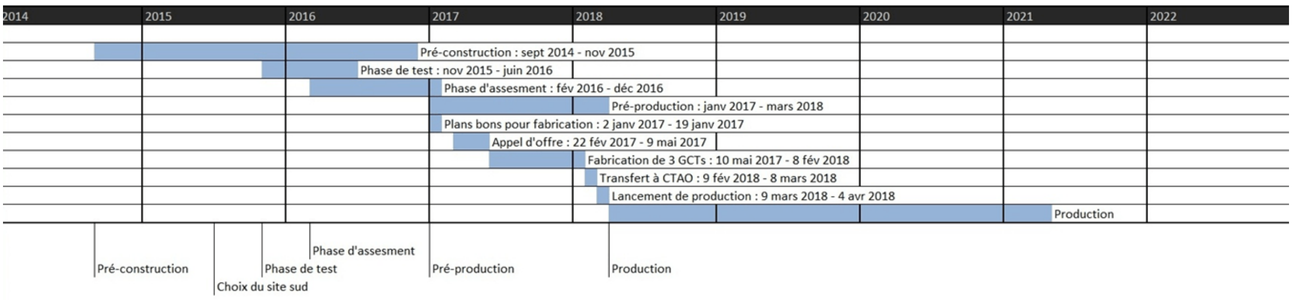

Fig. 8. Indicative agenda of the GCT array implementation for the CTA production and deployment.

Acknowledgements: We gratefully acknowledge support from the agencies and organisations listed under Funding Agencies at this website: `http://www.cta-observatory.org/` and the Programme National Hautes Energies (PNHE) of the CNRS.

References

Abramowski, A., et al, 2015, Science, 347, 406

Abramowski, A., et al, 2016, Nature, 531, 476

Acharya, B.S., et al, 2013, Astroparticle Physics, 43, 3

Bernlohr, K., et al, 2013, Astroparticle Physics, 43, 171

Costantini, H., Dournaux, J.-L., Ernenwein, J.-P., Laporte, P., Sol, H., et al, 2016, Proceedings of the Gamma 2016 symposium, Heidelberg (in press; arXiv:1610.01427v1)

Dournaux, J.-L., Amans, J.P., Dangeon, L., Fasola, G., et al, 2016a, Proceedings SPIE 9912 (in press)

Dournaux, J.-L., Gironnet, J., Huet, J.M., Laporte, P., et al, 2016b, Proceedings SPIE 9912 (in press)

Dournaux, J.-L., De Franco, A., Laporte, P., White, R., Greenshaw, T., Sol, H., et al, 2016c, Nuclear Instruments and Methods in Physics Research A, `http://dx.doi.org/10.1016/j.nima.2016.05.059`

Dumas, D., Huet, J.-M., Dournaux, J.-L., et al, 2014, Proceedings SPIE 9145

Sol, H., Zech, A., Boisson, C., et al, 2013, Astroparticle Physics, 43, 215

Tavecchio, F., Bonnoli, G., 2016, A&A, 585, A25

Watson, J.J., De Franco, A., Abchiche, A., et al, 2016, Proceedings of the Gamma 2016 symposium, Heidelberg (in press; arXiv:1610.01452v1)