The Cherenkov Telescope Array

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Abstract

As an observatory for ground-based gamma-ray astronomy in the energy region from a few tens of GeV to a few hundred TeV, the Cherenkov Telescope Array (CTA) will be the major next generation facility of imaging atmospheric Cherenkov telescopes. The broad energy coverage will be accompanied by an order of magnitude improvement in flux sensitivity in the TeV region along with factor 2–5 improvements in angular and energy resolution compared to the current generation of instruments. These improvements in performance will come from the use of multiple designs of wide field-of-view telescope, each optimised for a particular energy region, arranged in extensive arrays. Full sky coverage will come from having arrays at two sites, one in the southern hemisphere and another in the northern. The CTA will operate as an open access observatory to the astrophysics community and run a Key Science Programme to provide legacy datasets and address topics of both high-energy astrophysics and fundamental physics. This proceedings will review the status of the CTA project as it enters its pre-construction phase.

1 Introduction

An imaging atmospheric Cherenkov telescope (IACT) is the most sensitive method of detecting astrophysical sources of very high energy (VHE, E> 10 GeV) gamma rays. The Cherenkov Telescope Array (CTA)[1] [1] will be the next generation IACT facility, providing the community with an open-access observatory for the observation of gamma rays with energies from a few tens of GeV to hundreds of TeV with unprecedented sensitivity and angular and energy resolution (see fig. 1). The CTA has set some very stringent requirements, including: the uncertainty on the effective collection area to be $< 12\%$; the systematic error on the absolute intensity of Cherenkov photons at each telescope (post calibration) must be $< 8\%$ such that the systematic error on the energy scale must not exceed 10%; and a final systematic error on the localisation of a point-like source of 3 arcseconds (under favourable observing conditions). Furthermore, the observatory will need to maximise the duty cycle and keep the maintenance burden low. This not only puts strict engineering requirements on the telescopes, but also requires a strong calibration programme and, as the atmosphere is such an integral part of the detection system for IACT, a suitably ambitious atmospheric monitoring strategy compared to that which has been seen before in ground based gamma-ray astronomy [2].

Whole sky coverage will be achieved by operating at sites in both hemispheres. For the southern site Chile (Cerro Armazones) has been selected for ongoing negotiations; with the array expected to cover an area of about $10\,\mathrm{km}^2$ and consist of O(100) telescopes of a range of sizes which will be optimised for the highest energy observations of the Galactic plane. The northern array is undergoing negotiations with the Observatory Roque de los Muchachos on La Palma, for a more limited site and number of telescopes covering an area of about $1\,\mathrm{km}^2$, that will be optimised for the low energy thresholds best suited to observing extragalactic sources. I discuss the types of telescopes in section 2 and the science programme in section 3.

[1] www.cta-observatory.org

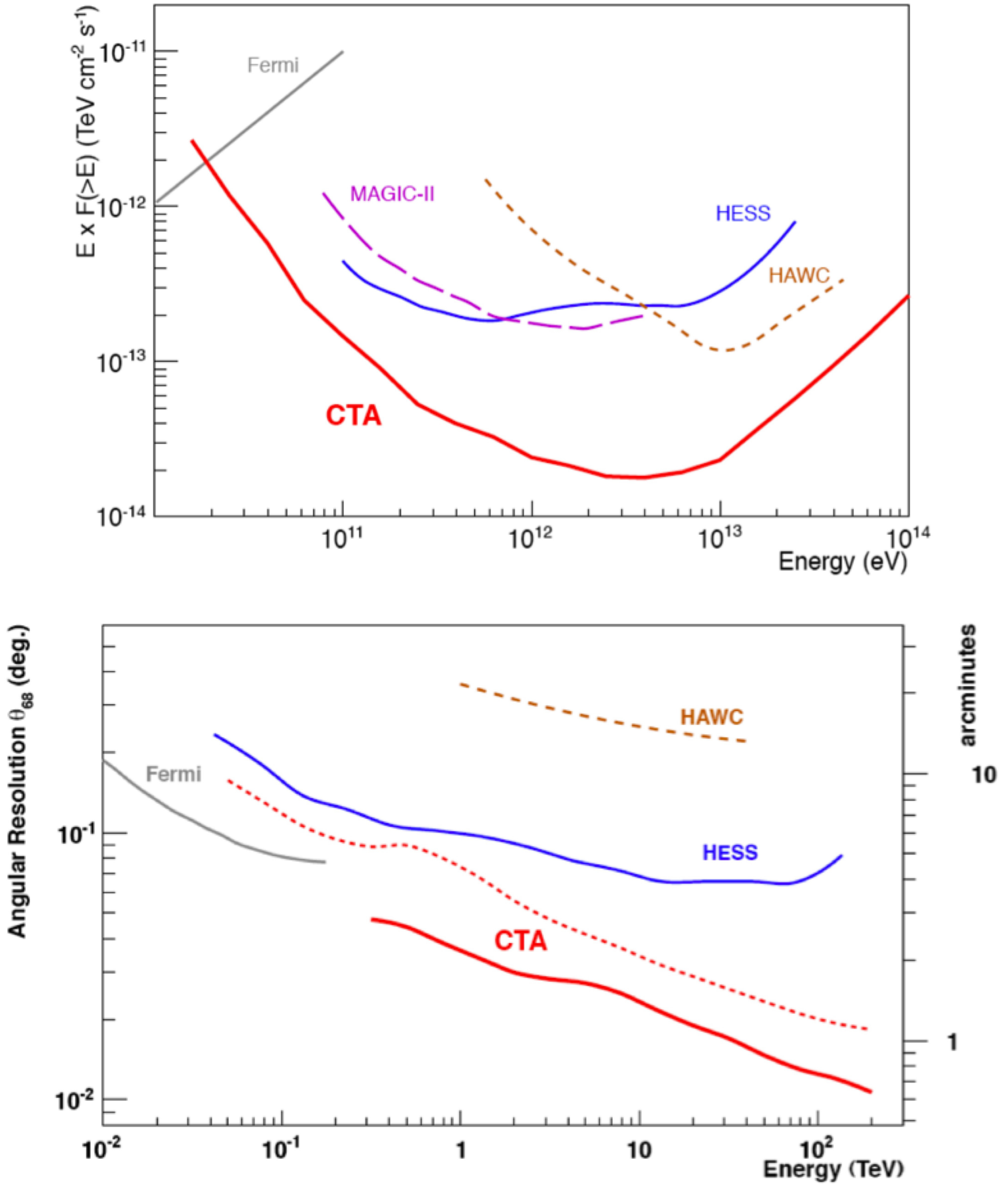

Figure 1: An indication of the performance requirements of CTA with regard to integral sensitivity (top) and angular resolution (bottom) as a function of photon energy.

2 The Array

To cover the large dynamic range of nearly 5 decades in energy is not practical with a single telescope and camera design combination, so the CTA has been sub-divided into the three telescope class sizes, as seen in figure 2.

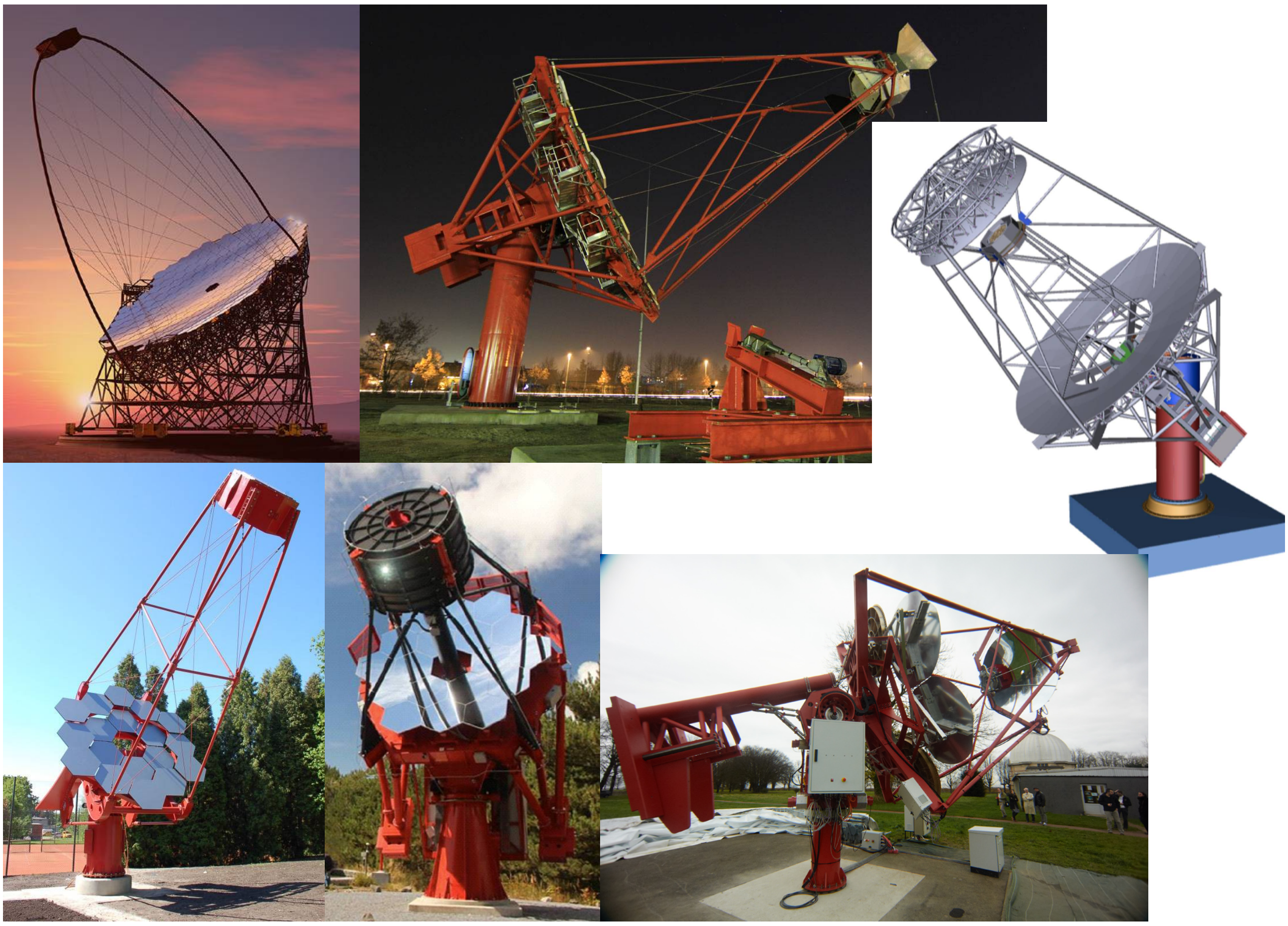

Figure 2: The CTA telescope designs. Clockwise from top left: LST (conceptual), MST (prototype, Berlin), SCT (conceptual), SST:GCT (prototype, Paris), SST:ASTRI (prototype, Sicily), SST-1M (prototype, Krakow).

2.1 The Large Sized Telescopes

The relative abundance of gamma-ray photons below 100 GeV means this part of the array can consist of a few large sized telescopes, with four 23 m diameter large sized telescopes (LSTs) [3] set in a compact central sub-array envisaged for both the northern and southern hemisphere arrays of the CTA observatory. They will be constructed of light carbon-fibre based structures to enable fast repositioning to catch transient high energy sources (such as gamma-ray bursts) as quickly as possible. Since the low energy sources are generally point-like objects, the LSTs will have the smallest field of view cameras in the array, of about 4.5°. A prototype LST has had ground broken at La Palma and will gradually morph into the first LST of the array.

2.2 The Medium Sized Telescopes

The mid-range energies of 0.1–10 TeV will be covered by the medium sized telescopes which are 12 m diameter modified Davies-Cotton design structures with large $\sim 8^{\circ}$ degree field of view cameras optimised for survey observations [4]. The southern site will contain approximately 25 MSTs, whilst the northern one requires only a smaller number of about 15. A prototype MST has been constructed in Berlin and there are two camera technologies also being tested [5], [6]. There is also a proposed extension of the MST sub-array with a 10 m dual reflector Schwarzschild-Couder design that will have much finer resolution through the use of silicon photomultiplier (SiPM) technology, with a prototype telescope under construction at the VERITAS site in southern Arizona [7].

2.3 The Small Sized Telescopes

The extremely low flux of photons of a few tens to a few hundreds of TeV, but related very large number of Cherenkov photons that such air showers produce, mean that for the highest energy part of the array a large number of small sized telescopes (SSTs, $\sim$4 m diameter) [8] can be spread over a very large area of a few km^2. Whilst only proposed for the southern array there will be still be a large number required, approximately 70, to achieve the required sensitivity. This large number of telescopes needs novel thinking for a suitably economic design of telescope and so three prototype systems have been proposed for CTA. Each concentrates on using inexpensive SiPM units for the camera photodetectors, with one design going the traditional Davies-Cotton single reflector route and two, similarly to the SCT, exploring different, but complementary, realisations of the never before used dual mirror Schwarzchild-Couder design of telescope.

3 The Key Science Projects

The large number of telescopes in the array mean that multiple observing strategies can be utilised depending on a wide variety of science cases. The full array can take very deep exposures of sources for maximum flux sensitivity at the milli-Crab level; whereas sub-arrays can observe several objects simultaneously for maximum flexibility; or use overlapping, divergent pointings, for maximum coverage at minimal sensitivity loss compared to full array observations.

The increased field of view of the CTA cameras and the increased sensitivity gain means that more of the sky can be surveyed and in a much shorter time, improving source numbers to study TeV source populations in a non-biased way. The improved angular resolution to the arcminute scale means that extended sources such as supernova remnants and starburst galaxies can be resolved. The broad energy coverage means higher redshift objects can be accessed at the low energy end pushing out the gamma-ray horizon both in terms of source physics and the use of TeV gamma-rays as probes of the cosmological environment. At the high energy end the search for cosmic-ray PeVatrons will be aided by the improved flux sensitivity and energy resolution of the array. An enhanced energy resolution will also aid in the investigation of fundamental physics topics such as the search for dark matter annihilation lines. The increased flux sensitivity and long life of the observatory will provide enhanced time domain astronomy spanning from the second to multi-year timescales. With such a wealth of science topics available CTA has organised itself according to three science themes:

- Understanding the origin of cosmic rays and their role in the universe.
- Understanding the nature and variety of particle acceleration around black holes.
- Searching for the ultimate nature of matter and physics beyond the Standard Model.

A number of Key Science Projects (KSPs) related to galactic [9], extragalactic [10] and fundamental physics [11] have been proposed that will make up a significant fraction (50%) of the observatory's observing programme. The KSPs are to be chosen based on the scale in terms of the number of observing hours required; the need for a coherent approach across multiple targets and/or pointings;

and the technical difficulty of performing the required analysis and hence reliance on consortium expertise. These KSP datasets are intended to become legacy datasets of high value to the wider community.

It is not just in the KSPs that the community is considered, though. In a new, and welcome, departure for the operation of a ground-based IACT facility, in the region of half of the available observing time will for the first time be offered to the community of scientists in the participating CTA countries as time that can be openly competed for. After some (to be determined) proprietary period all CTA data will become public. The CTA Observatory (CTAO) will provide support to non-expert users regarding proposal preparation and submission tools to the time allocation committee. CTAO will provide the calibrated, reconstructed and reduced event data in a standard format (e.g. FITS) and the software to analyse data. A help-desk that will provide user documentation, knowledge and training is also foreseen.

4 Summary

CTA will be an open observatory comprising arrays of IACTs of unprecedented flux sensitivity, angular and energy resolution and broad energy range. Siting CTA telescopes at sites in the northern and southern hemispheres will provide access to the full TeV sky. CTA will dramatically enhance surveying capability, monitoring capability and flexibility of operation. This will serve a wide user community, with provision of data products and tools for non-expert users.

References

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