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The Cherenkov Telescope Array and its Key Science Projects

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Summary. — The Cherenkov Telescope Array (CTA) will be the next generation gamma-ray observatory, open to the scientific community, to investigate the very high-energy emission from a large variety of celestial sources in the energy range 20 GeV–300 TeV. The full array, distributed over two sites, one in the northern and one in the southern hemisphere, will provide whole-sky coverage and will improve the sensitivity of the current imaging atmospheric Cherenkov telescope arrays by a factor of 5–10. CTA will investigate a much higher number of sources of already known classes, reaching much larger distances in the Universe, performing population studies and accurate variability and spatially resolved analyses. New light will be shed on possible new classes of TeV sources and on fundamental physics. We review the main CTA technical characteristics as well as its Key Science Projects, which will focus on major scientific cases and will provide a clear advance beyond the current state of the art. CTA Key Science Projects will allow scientists to benefit from high-value legacy data-sets for both multi-wavelength and dedicated follow-up studies.

1. – CTA Project and Performance

The Cherenkov Telescope Array (CTA) is the next generation of ground-based imaging atmospheric Cherenkov telescopes arrays (IACTs, see [1] for a recent review) which will become fully operational at the beginning of the next decade [2-4]. CTA is designed to operate as an observatory open to the scientific community, capable of accessing almost the whole sky, since the full array will be distributed over two sites, one in the northern and one in the southern hemisphere. Moreover CTA will cover a large energy range, from 20 GeV up to 300 TeV and above, improving the sensitivity of the current imaging atmospheric Cherenkov telescope arrays (IACTs) by a factor of 5–10.

(*) See `http://www.cta-observatory.org/consortium_authors/authors_2017_06.html` for the full author list.

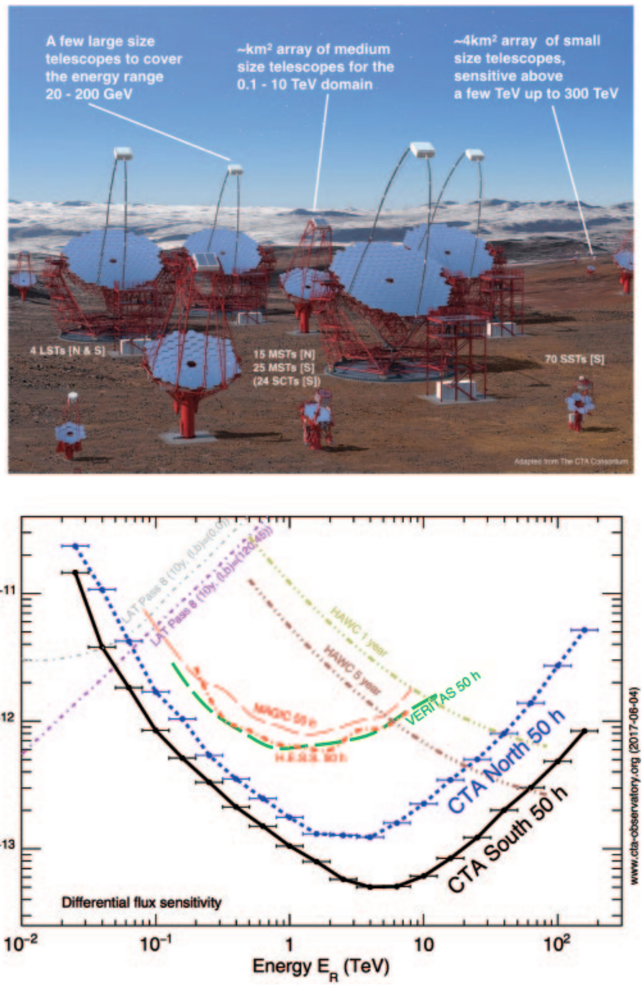

Fig. 1. – Top panel: artist's impression (not to scale) of the central zone of the Southern CTA array. Bottom panel: CTA differential energy flux sensitivity compared with the *Fermi*-LAT, H.E.S.S., MAGIC, VERITAS, and HAWC ones.

The wide energy range covered by the CTA requires different classes of telescopes. Figure 1 (top panel) shows an artist's impression (not to scale) of the central zone of the Southern CTA array. The large size telescopes (LSTs, $D \sim 23\,\mathrm{m}$) will lower the energy threshold with respect to the current IACTs down to a few tens of GeV, the medium size telescopes (MSTs, $D \sim 12\,\mathrm{m}$, SCTs, $D \sim 9.5\,\mathrm{m}$) will improve by a factor up to ten the sensitivity in the 0.1–10 TeV energy range, and the small size telescopes (SSTs, primary mirror $D \sim 4\,\mathrm{m}$) will enhance Galactic plane investigations in the energy range beyond 100 TeV. A few tens of telescopes (a few LSTs and several MSTs) will be installed at both sites, covering an area of $\sim 1\,\mathrm{km}^2$, with LSTs at the center. The CTA southern site, covering an area of about $4\,\mathrm{km}^2$, will be completed with 70 SSTs. A detailed review of the CTA project is given in [5].

The CTA performance was accurately investigated by means of detailed and extensive Monte Carlo simulations over a period of more than ten years. These simulations allowed

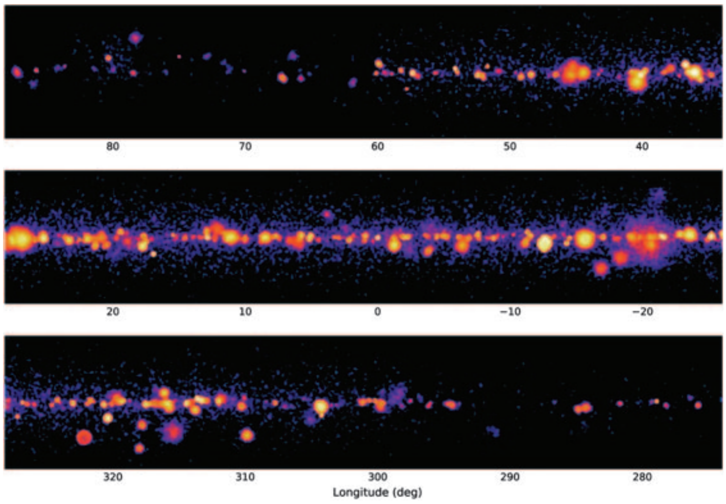

Fig. 2. – Simulated CTA image of the Galactic plane for the inner region $-90° < l < 90°$, adopting the actual proposed GPS observation strategy, and using a source model incorporating both supernova remnant and pulsar wind nebula populations and diffuse emission.

us to obtain a set of performance curves which can be publicly downloaded from the CTA webpages([1]). Figure 1 (bottom panel) shows, for both the northern and the southern arrays, the CTA differential energy flux sensitivity ($E^2 \mathrm{d}N/\mathrm{d}E$) in five independent logarithmic bins per decade of energy. The CTA curves are compared with the *Fermi*-LAT, H.E.S.S., MAGIC, VERITAS, and HAWC ones. Two unique characteristics of the CTA sensitivity can be appreciated: first, a factor from five to ten improvement in the domain of about 100 GeV to some 10 TeV; second, the extension of the accessible energy range from well below 100 GeV to above 100 TeV.

2. – CTA Key Science Projects

The CTA Core Program addresses a wide range of major questions in and beyond astrophysics, which can be grouped into three broad themes: 1) the origin and the role of relativistic cosmic particles; 2) the cosmic extreme environments; 3) new frontiers in physics. During the first decade of operation, about 40% of the time will be used by the CTA Consortium to exploit the Core Programme by means of a number of Key Science Projects (KSPs). The CTA Consortium selected the following KSPs, which can be gathered in major groups according to the main analysis method used to exploit a specific physics case.

- Dark matter: the dark matter program is particularly relevant for the CTA science and overlaps considerably in terms of observation fields with other science topics.
- Surveys: Galactic Centre (KSP #1), Galactic Plane (KSP #2), Large Magellanic Cloud (KSP #3), and Extra-galactic (KSP #4, 25% of the sky).

([1]) `https://www.cta-observatory.org/science/cta-performance/`.

- Transients phenomena: (KSP #5) both Galactic and extra-galactic, including GRBs.
- Pointed observations: Cosmic-ray PeVatrons (KSP #6), Star-forming Systems (KSP #7), Active Galactic Nuclei (KSP #8), and Cluster of Galaxies (KSP #9).

An exhaustive review of the CTA Key Science Projects is well beyond the scope of this paper, and we refer the readers to the *Science with the Cherenkov Telescope Array* paper [4].

As an example, we will briefly discuss the Galactic Plane Survey (GPS), since it exploits almost all the innovative CTA characteristics and performance (*e.g.*, the wide field of view, the extended energy range, and the improved sensitivity, energy and angular resolution). The survey will fulfil a number of important science goals, including: 1) providing a complete census of Galactic very-high-energy (VHE) gamma-ray source populations, namely supernova remnants (SNRs) and pulsar wind nebulae (PWNe), through the detection of hundreds of new sources, substantially increasing the Galactic source count and allowing more advanced population studies, 2) identifying a list of promising targets for follow-up observations, such as new gamma-ray binaries and PeVatron candidates, 3) determining the properties of the diffuse emission from the Galactic plane, 4) producing a multi-purpose, legacy data set, comprising the complete Galactic plane at very high energies, that will have long-lasting value to the entire astronomical and astroparticle physics communities, and 5) discovering new and unexpected phenomena in the Galaxy. In the south, CTA will go deeper in the inner region ($|l| < 60°$) by a factor of 5–20 compared to H.E.S.S. and will cover more uniformly a wider range of latitudes. An illustration is given in fig. 2. In the north, CTA will go deeper by a factor of at least ~ 5 compared to HAWC (5 year data set), at a factor 10–20 lower energy, with a factor ~ 5 better angular resolution. The typical observing time dedicated to the GPS is about 1000 and 600 hr in the South and in the North, respectively.

The Cherenkov Telescope Array will transform our understanding of the high-energy universe and will explore questions of fundamental importance in physics. As a key member of the suite of new and upcoming major astrophysical facilities and observatories, CTA will exploit synergies with gravitational wave and neutrino observatories as well as with classical observatories.

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