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The Cherenkov Telescope Array: the Project and the Challenges

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Abstract. The Cherenkov Telescope Array (CTA) is a new observatory for γ-ray astronomy at very high energies - between tens of GeV to hundreds of TeV -, with unprecedented sensitivity, energy coverage and angular resolution.

This contribution describes the current status of the project and the challenges involved in this international facility, including the scientific aspects of this new window to the Universe and technical issues associated to the design of the observatory.

1. Introduction

In the last decades we have seen major developments in γ-ray astronomy, both from ground-based and space observatories. Space instruments are now able to observe at energies up to some tens of GeV, where they become statistics-limited due to their small collecting areas (Pinkau 2009). In the very high energy range, above 100 GeV, Imaging Atmospheric Cherenkov Telescopes (IACTs) are highly successful for the detection of γ-rays from ground, since the first measurements of TeV emissions from the Crab nebula at the Whipple observatory (Weekes et al. 1989).

IACTs observe Extensive Air Showers (EAS); γ-ray photons striking the atmosphere will produce a cascade of relativistic electrons, positrons and secondary γ-rays via pair production and bremsstrahlung. Among those, charged relativistic particles generate a wide pool of Cherenkov light that reaches the ground in a short pulse of a few nanoseconds. To detect these faint Cherenkov bursts IACTs have a large tessellated primary mirror focussing the light into a photomultiplier camera with fast electronics. Stereoscopic methods, using several telescopes that observe the same shower on coincidence, allow the determination of the γ-ray direction and improve the sensitivity and resolution of the observations. Major observatories based on IACT currently in operation are: MAGIC, H.E.S.S., VERITAS and Cangaroo (Völk & Bernlöhr 2009).

Astronomy at this very high energy γ-rays range probes the non-thermal Universe, where mechanisms other than thermal emission by hot bodies are needed to concentrate very large amounts of energy into a single quantum of radiation. The current catalogue includes 110 sources, encompassing 40 extragalactic sources, mainly AGNs of different types, and 70 galactic objects: Supernovae Remnants, Pulsar Wind Nebulae, binary systems and unidentified sources in the Galactic plane without counterpart at other wavelengths (Weekes 2008).

2. The project

The CTA observatory project is conceived as an open facility to serve several science communities including high energy astrophysics, cosmology and fundamental physics. Due to its unique features, CTA has been ranked as one of the top priorities in major roadmaps that highlight the trends in future science infrastructures (ASPERA [1], ASTRONET [2], ESFRI [3], US National Academy Decadal Survey [4]). Although born in Europe, the project is now fully international with the participation of more than 700 scientists from over 20 countries worldwide. Structured as an international consortium, CTA has completed the initial design study (CTA Consortium 2010) and started, in October 2010, the preparatory phase which includes prototyping of key systems.

In order to provide full sky coverage, the CTA observatory consists of two large arrays, in the Southern and Northern hemisphere respectively. The Southern site, devoted to observe the central part of the Galactic plane and the dominant part of the Galactic sources, will be designed to cover the full spectral range, while the Northern site, specialized in extragalactic astronomy, will not cover the highest energy range.

Due to the wide energy range covered by CTA, a unique telescope design would not be efficient. To optimize the observatory three energy ranges have been identified and specific telescope designs are being developed for each energy range to improve the sensitivity:

Low-energy range: Below primary energies of 100 GeV the detection of the faint Cherenkov light becomes the limiting factor. In the current design, a few very large, closely packed, telescopes of about 20 to 30 m dish diameter are foreseen. Based on the experience with MAGIC the telescopes will have a parabolic primary mirror (Acciari et al. 2009).

Core energy range: The technology to observe primary γ-rays from 100 GeV to 10 TeV is well understood, based on H.E.S.S. and VERITAS experience. The appropriate solution seems to be a grid of telescopes in the 10 to 15 m class with an spacing between in the 100 m range. This part of the array will be the workhorse of the observatory. A Davies-Cotton reflector (Davies & Cotton 1957) is foreseen; although this design is not isochronous, it provides very good off-axis properties and a wide field of view.

High-energy range: Above primary energies of 10 TeV the key limitation is the number of detected γ-ray showers, therefore, the array will have to cover a large area. As the Cherenkov light yield is large at high energies, an option is to implement a large number of small size telescopes covering an area of about 10 km^2. Telescopes based on Davies-Cotton or Schwarzschild-Couder (Vassiliev et al. 2007) designs are being considered. This last design, with a secondary mirror, presents two major advantages: it is isochronous and has a small focal field, suitable to incorporate small cameras.

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[1] http://www.aspera-eu.org/

[2] http://www.astronet-eu.org/

[3] http://ec.europa.eu/research/infrastructures

[4] http://sites.nationalacademies.org/bpa/BPA_049810

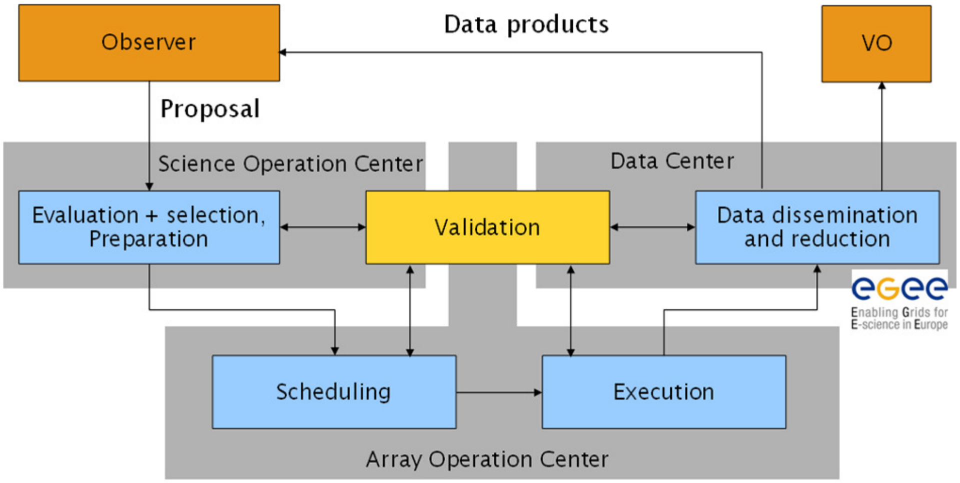

Figure 1. Data flow diagram of the CTA observatory

The CTA observatory is defined as an open facility promoting collaboration and data sharing. Scientists will issue observing proposals that will go through a selection process evaluated by an external committee. Selected proposals will be scheduled for observation depending on priorities and on observing conditions within a flexible schedule. After execution of the observations the data will be reduced and the results will be delivered to the scientist and also stored in the project archive. Finally, after a guarantee period, data will be available to the science community via standard Virtual Observatory facilities.

It is foreseen that the complete cycle will be implemented in three main centres:

1) **Science Operations Centre** responsible for the scientific outcome. It receives the proposals, performs the science planning and evaluation.

2) **Array Operations Centre** responsible for the execution of the observing plan, performs the scheduling and execution of the observations. The actual control system will be based on the ALMA architecture.

3) **Science Data Centre** performs the data reduction procedures and distribute the results. Processing pipelines implemented in grid architectures, data distribution and archive based on Virtual Observatory technology.

The selection of the site is a critical task. The requirements aim at sites with very good sky quality at latitudes around 30° North and South, respectively, and an altitude between 1500 and 4000 m in a flat area of about 10 km^2 for the Southern array and about 1 km^2 for the Northern site. In addition, the site must have adequate infrastructure available in terms of access roads, power grid, high speed internet connectivity and safety conditions. A critical aspect of the project is to minimize the environmental impact of the telescope arrays.

The following sites are currently being considered for the Southern array: (1) Khomas Highlands in Namibia (23° S, 1800 m) close to H.E.S.S. observatory, (2) North of La Silla in Chile (29° S, 2400 m) and (3) in Argentina El Leoncito in Argentina (32° S, 2600 m), or Puna Highlands (30° S, 3700 m).

Pre-selected sites for the Northen array are (1) Canary islands observatories in Spain (26° N, 2400 m) and (2) San Pedro Mártir, Baja California in Mexico (31° N, 2800 m).

3. Goals and challenges

CTA will offer a new way to explore the Universe at very high energies with many important scientific goals. These include astrophysics questions as the understanding of the origin of cosmic rays and their impact on the constituents of the Universe or the study of particle accelerators such as pulsars, supernova remnants and γ-ray binaries. In addition, we expect that CTA will substantially contribute to the understanding of the ultimate nature of matter and to the search for new physics beyond the standard model, including dark matter through its possible annihilation signatures.

At the technical level the project builds on the experience of current IACT observatories, therefore, no major risks are expected. However, to fulfill the scientific objectives, the project aims at unprecedented capabilities in performance with an increase of a factor of 10 in sensitivity compared to current observatories and an angular resolution in the arc-min range over the wide energy coverage from some tens of GeV to beyond 100 TeV. The foreseen performance requires an optimal design of the telescopes and a major effort is required concerning the industrial production of the large telescope arrays. Fast electronics and photon detectors with improved quantum efficiency are being investigated to fulfill the required sensitivity.

As a conclusion, CTA will advance the state of the art in astronomy at the highest energies. For the first time it will bring together all the groups working in Europe in the field, integrating as well partners from USA, Japan and other countries to form a worldwide collaboration aimed at building the first open Cherenkov observatory.

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