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THE CTA PROJECT

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Abstract. During the last few years, very high energy (VHE) gamma-ray astronomy has emerged as a truly observational discipline, largely driven by the European-led HESS and MAGIC experiments. More than 70 VHE gamma-ray sources have been detected, representing different galactic and extragalactic source populations such as young shell type supernova remnants, pulsars wind nebulae, giant molecular clouds, Wolf-Rayet stars, binary pulsars, microquasars, the Galactic Center, Active Galactic Nuclei and a large number of yet unidentified Galactic objects. The CTA project is aiming at building a very powerful multi-functional tool for spectral, temporal and morphological studies of galactic and extragalactic sources of VHE gamma-rays, with an unprecedented sensitivity (improved by one order of magnitude compared to the previous generation experiments) and a superior angular resolution. The current plan for CTA consists of two observatories, one in each Hemisphere, with 10 GeV-∼1 TeV and 10 GeV-100 TeV energy coverage in the Northern and Southern Hemisphere respectively. We will report on the scientific motivation, design status and expected performances of the CTA project, as well as on its current status.

1 Introduction

Since the pioneering work of the Whipple experiment in the 1980's, gamma-ray astronomy as emerged as a new window on the non-thermal Universe. Unprecedented sensitivity achieved by the third generation experiments such as HESS, MAGIC, VERITAS and CANGAROO led to the discovery of more than 70 Very High Energy sources, both galactic and extragalactic, and belonging to various categories such as young shell type supernova remnants, pulsars wind nebulae, giant molecular clouds, Wolf-Rayet stars, binary pulsars and microquasars. A large fraction of these object line up on the Galactic Plane, thus demonstrating the close correlation between these gamma-ray emitters and the distribution of matter in our Galaxy (see Fig. 1).

These spectacular astrophysics results, comprising high resolution spectra, precise imagery and timing measurement, have generated a considerable interest from the astrophysics and particle physics community and were recognized by the award of the Descartes Prize to the HESS collaboration for 2006. The very broad variety of achievable science has spawned the urgent wish for a next generation, more sensitive and more flexible facility, able to serve a very fast growing community of users. The proposed CTA facility - an array of Cerenkov telescopes built on proved technologies but at an industrial scale - is aiming at pushing the Atmospheric Cerenkov technique further on, with a factor of ten in sensitivity (Fig. 2, **left**) and a factor of five in angular resolution. This improvement, leading to the probable discovery of ∼1000 sources, is comparable with the gap between the EGRET and Fermi space telescopes and will allow in-depth studies of known classes of gamma emitters, together with a strong discovery potential for new classes of sources that are below the sensitivity of current instruments.

In order to cover the full sky, it is planned to build two stations, one in the northern hemisphere and the other one in the southern hemisphere. The full energy range will be three or four orders of magnitude, from about 10 GeV up to about 100 TeV (depending on the final design) with a milliCrab sensitivity in the core energy range.

CTA was considered as "Emerging Proposal" in the 2006 road-map report of the European Strategy Forum on Research Infrastructures (ESFRI) and is now included in the updated road-map. The construction of CTA as a next-generation facility for ground-based very-high-energy gamma-ray astronomy has been recently promoted to the status of "fully supported project" by the ApPEC/ASPERA committee.

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An important aspect of the CTA project is the time overlap with the Fermi space telescope, successfully launched in 2008 and which is now renewing our view of the GeV Universe. Multi-wavelength observations are indeed a key to the Non Thermal Universe, and this imposes a short schedule for the CTA design study and construction phase.

2 Science motivation

The large list of astrophysics cases for CTA, can be roughly split into *guaranteed science* and *new discovery potential*. Both parts cover both the galactic and extragalactic domains.

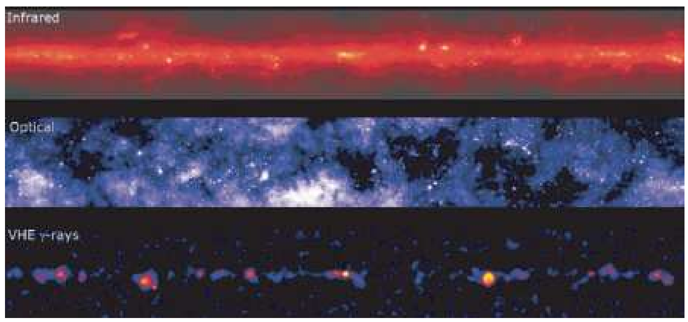

Fig. 1. The inner regions of the galactic plane seen in multi-wavelength observations. The H.E.S.S. observations at TeV energies reveal many sources, lining up on the plane, and mostly associated with supernova remnants and pulsar wind nebulæ.

In the galaxy, many TeV gamma sources have been discovered, in particular during the H.E.S.S. survey of the inner galactic regions (see Fig. 1). These sources mainly belong to the categories of supernova remnants (SNRs), pulsar wind nebula (PWNs), binary systems and diffuse emission attributed to the interaction of cosmic rays with the interstellar medium, with some still unidentified sources and a few additional peculiar sources, such as the Galactic Center. The variety of sources allows to address various physics subjects such as acceleration of charged particles in astrophysical sources which is linked to the origin of cosmic rays (CR) mystery. Indeed, almost one century after their discovery by Victor HESS in 1912, the sources of the bulk of CR observed at earth are still not firmly identified, although many arguments point towards supernova remnants as prime candidates. The solid detection of TeV radiation from a population of SNRs and the precise measurement of their spectra from below the GeV domain (with the Fermi Space Telescope) up to 100 TeV will help disentangling between the leptonic and hadronic acceleration scenarios and thus make a decisive contribution to the solution of this mystery. The upper energy range, close to the *knee*, is of particular interest in this regard.

Pulsar Wind Nebula form the most numerous class of known Very High Energy emitters, some of them being amongst the most efficient known accelerators. Third generation instruments have in some cases observed an energy-dependent morphology in these systems, and thus started to investigate the details of particle acceleration and cooling. The major task for CTA regarding PWNs will be to probe the physics of pulsar wind by the mean of better sensitivity and angular resolution.

Pulsar magnetospheres are also known to act as efficient cosmic accelerators, yet there is no accepted model for this particle acceleration, a process which involves electrodynamics with very high magnetic fields as well as the effect of general relativity. Two broads categories of models (*polar-cap* and *outer-gap* models), differ by the location on the magnetosphere where the particle acceleration takes place, and predict different behavior in the 10-50 GeV domain. The recent discovery of pulsation from the Crab nebula by the MAGIC collaboration (Teshima, M., 2008) above 25 GeV, with a dedicated trigger setup, stresses the discovery potential of a more sensitive instruments such as CTA in this domain.

Amongst Very High γ-ray emitters, four are binary systems, consisting of a compact object (neutron star or black hole) orbiting around a massive star. In these objects, the periodic change of environment along the orbit can induce a modulation of the acceleration efficiency and of the cooling mechanisms, thus resulting in a modulation of the spectral signature, as was observed in LS 5039 by the H.E.S.S. experiment (Aharonian, A. *et al*, 2006). This offers a unique view on the system, allowing to probe how the acceleration mechanism react to changing environment. Moreover, microquasars can be understood as scaled down version of the giants Active Galactic Nuclei, however with much smaller dynamical time scales. Microquasars therefore offer a chance to understand the physics of accretion and ejection in accreting black holes.

The increased sensitivity and energy coverage of CTA will increase the number of VHE γ-ray blazars and allow the detection of more distant ones. By disentangling between intrinsic spectral curvature and propagation effects, this will provide a handle on the extragalactic diffuse gamma-ray background, which is closely related to the formation of large structures in the Universe. Modeling of accretion and ejection mechanisms will also benefit from the improved sensitivity as it will allow to sample faster variability.

In addition to detailed study of the aforementioned sources of TeV γ-rays, CTA offers a significant discovery potential in fundamental physics: weakly interacting dark matter particles are expected to concentrate at the center of massive structures, where their annihilation could lead to a detectable gamma-ray signal. Prime targets for CTA in these regards are Globular Clusters or Dwarf Galaxies where less conventional sources are expected to hide a possible annihilation signal. Improved angular resolution will limit the confusion problem, whereas increased energy coverage will increase the reachable mass range and allow the detection of spectacular spectral features that are needed to reject conventional signal explanations. Other potential discovery from CTA would be the detection of non-Newtonian gravity through its effect on the time of propagation of very high energy photons. This would require a large sample of highly variable blazars at different distances, in order to investigate relation between propagation time lags and distance.

3 The CTA design study

The CTA consortium is performing a Design Study (DS) for the optimization of the performance of the planned observatory and to study its possible implementation. The primary targets of the DS are:

- to narrow down the multidimensional space of design options and technology options, optimizing the relation between performance and cost of the facility,
- to lay out a clear path for how such a facility can be constructed and operated using proved industrial technologies, and ensuring high performances and availability of the system,
- to build and test prototype telescope(s) that are suitable for mass production for a large array of telescopes

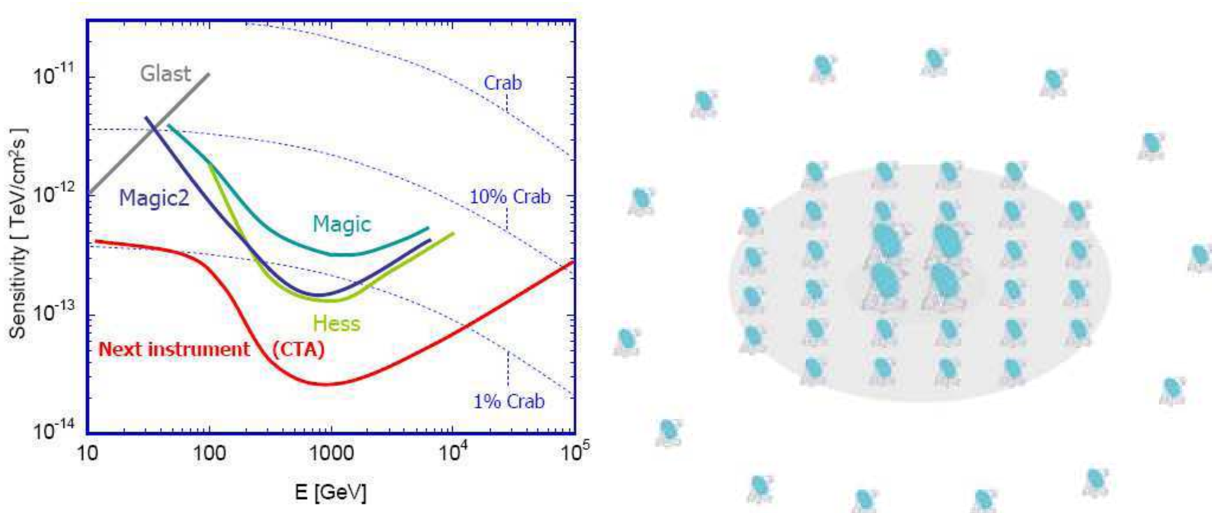

Fig. 2. Left: Sensitivity aimed with CTA, compared with the existing experiments and with the flux of the Crab Nebula (standard candle for Very High Energy Gamma-Ray Astronomy). The exact value will depend on the real layout of the system. **Right**: Possible layout for the CTA southern array.

A duration of about four years is foreseen for the Design Study and prototyping. Examples of the system optimization include telescope layout (Fig. 2, **right**), field of view and pixel size, as well as full integration of electronic components into a single ASIC. In a possible design scenario, the southern hemisphere array of CTA will consist of two types of telescopes with different mirror size in order to cover the full energy range. The low energy instrumentation might consist of 23-28 m telescopes with a moderate field of view (FoV) of the order of 3-4 deg, while the high energy instrumentation above about 100 GeV will be equipped with large cameras with up to 6-8 deg FoV, installed in 12-15 m telescopes. This will not only allow effective surveys of the galactic plane and the investigation of extended sources and diffuse radiation, but will also result in an improved high energy performance with an expected additional improvement in count rate with respect to small FoV instrumentation. The northern hemisphere array will consist of the low energy instrumentation only, and focuses on the observation of extragalactic objects. For future upgrades the implementation of high QE photon detectors might be envisaged, which possibly results in an even higher sensitivity.

While in 2008 the focus is on the optimization of possible layouts of the telescope system and on the evaluation of possible technical implementations, the year 2009 will be used to construct and test components of prototypes. During 2010-2011 prototype telescope(s) shall be constructed and finally tested in the field, before the actual construction of the array from 2010 for fully operational system in 2018.

4 Conclusions

The new Cerenkov Telescope Array (CTA) project intends to build in a short time scale a large facility that is well beyond possible upgrades of existing instruments. Its much improved sensitivity, it's unprecedented angular resolution and its larger energy coverage will guarantee a high level of science return, together with a large discovery potential in fundamental physics. Of the order of $\sim$1000 sources are expected, including new types of sources that are below the capabilities of current instruments. Being run as an observatory open to external astronomers, CTA will bring one more piece to the multi-wavelenth coverage of the Universe, and intends to become one of the major player in astronomy for the next decade.

5 Acknowledgments

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References

"The Cherenkov Telescope Array project". http://www.cta-observatory.org/

"The H.E.S.S. project". http://www.mpi-hd.mpg.de/hfm/HESS

"The MAGIC Telescope". http://wwwmagic.mppmu.mpg.de/

"The VERITAS project". http://veritas.sao.arizona.edu/

"The CANGAROO telescope system". http://icrhp9.icrr.u-tokyo.ac.jp/

Teshima, M. 2008, ATel #1491

Aharonian, A. *et al* 2006, A&A, 460, 743-749