



Cherenkov Telescope Array: The next-generation ground-based gamma-ray observatory

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Abstract: High energy gamma-ray astronomy is a newly emerging and very successful branch of astronomy and astrophysics. Exciting results have been obtained by the current generation Cherenkov telescope systems such as H.E.S.S., MAGIC, VERITAS and CANGAROO. The H.E.S.S. survey of the galactic plane has revealed a large number of sources and addresses issues such as the question about the origin of cosmic rays. The detection of very high energy emission from extragalactic sources at large distances has provided insights in the star formation during the history of the universe and in the understanding of active galactic nuclei. The development of the very large Cherenkov telescope array system (CTA) with a sensitivity about an order of magnitude better than current instruments and significantly improved sensitivity is under intense discussion. This observatory will reveal an order of magnitude more sources and due to its higher sensitivity and angular resolution it will be able to detect new classes of objects and phenomena that have not been visible until now. A combination of different telescope types will provide the sensitivity needed in different energy ranges.

Introduction

The Cherenkov Telescope Array (CTA) [1] is a proposed advanced facility for ground based high-energy gamma ray astronomy, based on the observation of Cherenkov radiation. This approach has proven to be extremely successful for gamma rays of energies above a 100 GeV. The facility will consist of an array of telescopes enhancing the all sky monitoring capability. CTA is designed to be the next generation observatory after currently running Cherenkov telescope projects such as the H.E.S.S. experiment [2], MAGIC [3], VERITAS [4] and CANGAROO [5]. 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.

CTA will be about a factor of ten more sensitive than current experiments (see Fig.1). It will allow in-depth studies of known classes of gamma emitters and also detect new source classes that are below the sensitivity of current instruments. In its core energy range from about 100 GeV up

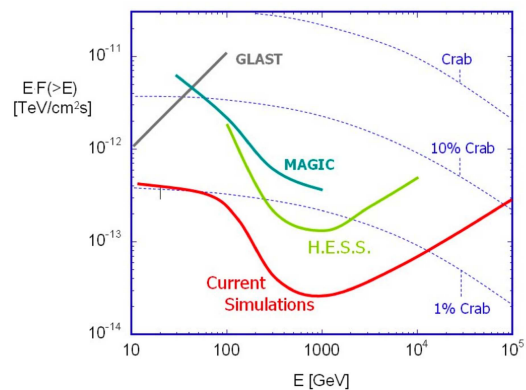


Figure 1: The figure illustrates the sensitivity that is aimed at with CTA. The exact values will finally depend on the real layout of the system.

to 10 TeV, CTA will reach millicrab sensitivity. The full energy range will be three to four orders of magnitude from some 10 GeV up to 100 TeV, which is crucial for the understanding of the physical processes. Together with multiwavelength observations from radio wavelengths to optical, X-ray and MeV energy range, CTA will reveal deep insight in the most violent and energetic physical processes in the universe. For selected sets of gamma-ray events, CTA will have an angular resolution by a factor of 5 better than current instruments because of the large amount of telescopes within the array. This angular resolution will be necessary for resolving the high density of galactic objects within the milky way. It allows also detailed morphological studies of extended objects. Due to its large detection area and lower threshold it will collect a much larger event statistics and improve the time resolution of transient objects down to the sub-minute scale. Some few telescopes can be used for monitoring transient objects. This will deliver interesting details about the acceleration process of particles in cosmic accelerators. All in all, CTA is expected to detect and observe about 1000 sources.

In March 2007 a European FP7 design study was applied for to examine the exact system layout and technical details of the CTA. 34 institutes in 15 countries (France, Germany, Italy, Spain, United Kingdom, Poland, Finland, Switzerland, Netherlands, Czech Republic, Armenia, Ireland, United States, Republic of South Africa) are participating in the CTA design study.

Physics prospects of CTA

The large list of the astrophysics cases for CTA can be roughly split into two parts, the galactic sources and the extragalactic sources. In this short overview we will only mention the most promising science cases.

In the galaxy many TeV gamma sources have already been discovered, mainly in the galactic scan by H.E.S.S. (see Fig.2). The sources are supernova remnants (SNRs), pulsar wind nebulae (PWNs), binary systems, the galactic center itself and diffuse gamma radiation from our galaxy. The galactic astrophysical subjects are manifold. One main

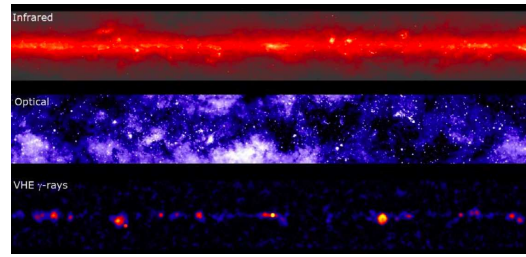


Figure 2: The milky way seen in multiwavelength observations. The H.E.S.S. observations at TeV energies reveal a plethora of sources. Most of them are supernova remnants and pulsar wind nebulae.

subject is the question about the origin of cosmic rays (CR).

The origin of the bulk of CR observed at earth remains unknown even almost one century after their discovery by Victor HESS in 1912. Several arguments hint to supernova remnants (SNRs) being the main candidate sources, but a solid evidence is still missing. The detection of TeV radiation from 30-100 SNRs that will be detected by an instrument with a higher sensitivity would be the ultimate proof of these sources to be the bulk producers of CR arriving at earth. The measurement of their spectra at 100 GeV up to 100 TeV region will reveal the physics of the particle acceleration mechanism and probe the 'knee' in the hadronic spectrum of CR at $3 \cdot 10^{15} eV$ using the gamma emission radiated during the acceleration process of particles at the shock front of the SNR with the interstellar medium. The diffuse gamma radiation from the region around the galactic center seems to originate from the interaction of cosmic rays with molecular clouds. Molecular clouds are a tool that allow to probe the cosmic ray spectrum in different locations in the galaxy. A new instrument like CTA has the necessary sensitivity to improve these measurements and even separate additional contributions to diffuse radiation due to more exotic physics.

In addition, also pulsar wind nebulae as well as binary systems might accelerate not only leptons but significantly also hadrons to multihundred TeV radiation and therefore contribute to the CRs. Purely leptonic acceleration models as well as hadronic acceleration models have been sug-

gested for both cases. Precise multiwavelength measurements from radio, optical, X-ray, MeV up to 100 TeV gamma radiation enable physicists to fit their models to the full wavelength range and verify or falsify one or another of these models. It is therefore crucial to measure an energy range as wide as possible from several tens GeV up to 100 TeV. CTA will provide this energy range.

Very interesting source classes are the various types of binary systems, Wolf-Rayet-Star binaries, Be-Star-Pulsar binary, Star-black hole binary, micro quasars etc. which are transient TeV gamma emitters. They are ideal objects to study various types of particle acceleration and Gamma ray absorption.

The low energy threshold together with a good sensitivity will allow to detect many extragalactic objects at high redshifts that are not visible at higher energies due to the so-called gamma ray horizon. High energy gamma rays are absorbed due to electron-positron pair creation with extragalactic background light in the universe. The study of the spectra and the energy cut-offs of active galactic nuclei (AGN) enables us to calculate and measure the spectrum of the so-called extragalactic background light (EBL). The main contributions to the EBL is redshifted starlight and its re-emission from dust in the universe. This measurement not only reflects the history of star formation in the universe but also contains information about the evolution of the universe expressed in the Hubble constant and cosmic constant.

Simultaneous multi wavelength campaigns of the transient AGN with instruments at other wavelengths will supply more information about leptonic and hadronic acceleration models in AGN jets by observing these objects in the multiwavelength band, same as for the galactic sources. It is not understood if the highest energy CR have been accelerated by these objects.

The final proof of hadronic acceleration can be only given by the detection of a neutrino signal from these sources. Therefore, multimessenger observations are important in gamma astronomy. The northern CTA observatory will observe the same hemisphere of the sky as the ICECUBE neutrino telescope. The future KM3NET neutrino telescope will observe the southern sky and will probably start operation around 2015.

AGN exhibit very fast flux changes at all wavelengths that are especially difficult to explain for the TeV radiation. The large scales of the emission regions in the jet imply large gamma factors for the bulk motion.

Another type of very interesting transient objects are the so-called gamma ray bursts. These objects exhibit ultrafast X-ray and gamma-ray flux variability on second and subsecond time scale. As of today, no radiation at hundreds of GeV energies could be detected, it is believed mainly due to the gamma ray horizon.

Very distant transient objects with ultrafast flux variability can be used to test Lorentz invariance violation.

Furthermore, CTA has considerable discovery potential e.g. for the detection additional non-blazar AGN of pulsed gamma emission from pulsars, clusters of galaxies and the detection of a dark matter candidate, the neutralino.

Design of the CTA system

The exact design of CTA is being studied and not precisely defined as of now. First MC studies indicate some possible scenarios in which the sensitivity and angular resolution aimed for can be achieved. Fig. 3 illustrates the possible design, a combination of arrays of 2-3 different telescope sizes. A large number (several tens) of mid-size telescopes will provide for the millicrab sensitivity and high angular resolution in the core energy range from about 100 GeV up to 10 TeV. An extension of a few (4-9) very large diameter telescopes and many (up to 100) very small telescopes distributed over a large area enlarge the energy range from several 10 GeV up to 100 TeV.

In this way one achieves an energy coverage of 3-4 orders of magnitude while keeping the high sensitivity. This is crucial for detailed studies of the shape of the spectrum which contains a lot of information about the mechanism of particle acceleration and physics in the object.

In order to achieve full sky coverage it is planned to install two stations, one in the southern hemisphere and one in the northern hemisphere.

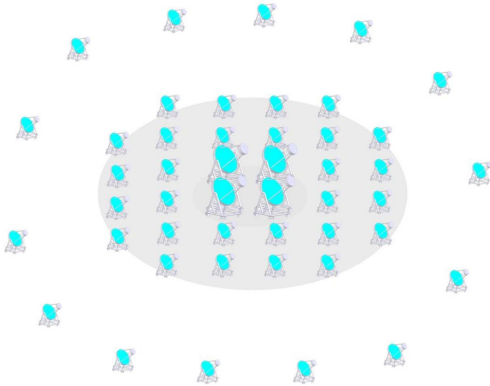


Figure 3: This figure illustrates possible telescope configurations which achieve the aimed sensitivity.

The design of the telescope camera and the performance predictions of CTA will be based on classical photomultipliers but an eye is kept also on the technical development of future photosensors (such as SiPM) with higher photon detection efficiency to lower the energy threshold of the system.

Detailed MC simulations will define the details such as FOV, optimal telescope sizes, camera pixel sizes and telescope spacing in the array.

The real challenge will be to reach the perfection and reliability of the hardware that is needed to run a large number of telescopes without major interruptions or failure in a quasi robotic modus since it is simply impossible to do frequent repairs on every telescope.

The design should start in 2008 and continue until the end of 2011. We aim to begin the construction of the full array around 2012. It is intended to have an overlap with the GLAST satellite project.

Conclusions

We present the new Cherenkov Telescope Array (CTA) project that unifies for the first time the research groups working in gamma ray astronomy in a common strategy, resulting in a new facility that is well beyond possible upgrades of existing instruments like H.E.S.S., MAGIC, VERITAS and CANGAROO. The new facility will be run as an observatory open to external astronomers. Its sen-

sitivity will be better by about one order of magnitude combined with a larger energy range coverage. It is expected that at the order of 1000 new sources and also new classes of sources classes will be discovered which have been not visible with today's instruments.

The physics of most objects can only be understood, if the whole multi-wavelength picture is generated. One of the main topics of CTA will be therefore the multi-wavelength and multi-messenger observation together with X-ray and gamma-ray satellites, optical and radio telescopes as well as with the forthcoming neutrino experiments.

Acknowledgements

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