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The Next Generation of Cherenkov Telescopes.

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Abstract. In the last decade, Very High Energy ($E > 50GeV$) gamma-ray astrophysics has grown into a mature branch of astronomy having increased the number of discovered sources by about a factor of 10. These recent advances of TeV γ-ray astronomy have shown that the 10 GeV–100 TeV energy band is crucial to investigate the physics prevailing in extreme conditions as well as to test fundamental physics. Nevertheless, with the recent launch of two gamma ray dedicated satellites (AGILE and Fermi), the gamma-ray astronomy is now opening unprecedented opportunities of multiwavelength observations on a very wide energy range. In such an exciting scenario, a new generation of ground-based VHE gamma-ray instruments are needed in order to significantly improve: the sensitivity, the operational bandwidth, the angular resolution and the field of view.

Key words. TeV γ-ray astrophysics

1. Introduction

The results of the latest generation of ground-based gamma-ray instruments such as H.E.S.S., MAGIC, CANGAROO or VERITAS, have shown that the very high energy gamma-ray astronomy has grown to a genuine branch of astronomy. Cherenkov Telescopes are now allowing imaging, photometry and spectroscopy of sources of high-energy radiation with good sensitivity and good angular resolution. The number of known sources of very high energy gamma rays is continuously growing (now approaching 100), and source types include a lot of different classes of known objects as well as unidentified sources without obvious counterpart. The major scientific objective of Very High Energy (VHE) γ-ray astronomy is the understanding of the production, acceleration, transport and reaction mechanisms of VHE particles in astronomical objects. This is tightly linked to the search for sources of the cosmic rays connecting astrophysics with particle physics, so the physics program of the (e.g.) MAGIC telescope includes topics, both of fundamental physics and astrophysics. In the next 10 years, GLAST and (for less time) AGILE satellites will observe the Universe in the MeV-GeV band providing a unique opportunity for Cherenkov Telescopes to observe the same sources and to cross-calibrate instruments in the GeV band. In such a scenario the development of a next generation of Cherenkov Telescopes is mandatory in order to achieve 10 times the sensitivity of current instruments, an increased flexibility and an increased coverage from some 10 GeV to some 100 TeV.

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In the present work I briefly review both the scientific topics and potential developments of the field as well as to point out both the interests and the capacities (scientific and technical) of the VHE astrophysics community in INAF. For a larger review see Antonelli et al., (2009).

2. Science in the TeV band.

Since 2003, as the new generation experiments (HESS, MAGIC, CANGAROO and VERITAS) started to observe the gamma-ray sky, the number of VHE sources rapidly increased. New class of sources was detected at GeV-TeV energies both galactic (e.g. Galactic Center, Pulsar Wind Nebulae, Pulsars and Binary Systems) and extragalactic (e.g. Blazars, radiogalaxies, star-forming galaxies) as well as about a dozen of unknown new TeV sources. For example: the survey of the galactic plane performed by HESS (Aharonian et al., 2006) is absolutely remarkable revealing a large population of sources and a considerable number of new unidentified sources. It showed for the first time that an array of IACTs could be properly used as a real astronomical observatory able to survey a large portion of the sky with a high sensitivity. A new generation of ground-based VHE gamma-ray instruments is now going to be conceived in order to significantly improve the sensitivity, the observed energy band, the field of view, the signal sampling and to reduce the observing time. Many scientific drivers for such a new generation of Cherenkov telescopes can be identified. Among these the most outstanding are:
1) Galactic Astrophysics: An improved sensitivity in Tev γ-ray astronomy may lead to the identification of the sources of cosmic rays. In fact, on purely energetic grounds, it is relatively straightforward to single out supernova remnants (SNRs) as the most plausible candidate accelerators. Nevertheless, the only two messengers that would prove this association are gamma rays of unambiguously hadronic origin and neutrinos. Next-generation Cherenkov Telescopes will be the suitable instrumentation for this research allowing us to study in detail the acceleration sites and the propagation of these high-energy particles.
2) Extragalactic Astrophysics: The exploration at TeV energies of blazars spectral variability on very small timescales, will allow to establish the origin and the emission mechanisms of the TeV photons from relativistic jets. A higher sensitivity in Cherenkov Telescopes will allow the observations of fainter and farthest AGNs and Gamma Ray Bursts (GRB). This will permit to measure the extragalactic background light with unprecedented precision, constraining the star formation history of the Universe independently from galaxy counts (e.g. Aliu et al., (2008)). Observation of GRBs at these energies will be of fundamental importance to distinguish between all possible emitting mechanisms leading to a definitive comprehension of the emitting processes at work in these sources.
3) New Physics: The next generation of Cherenkov telescopes should have enough sensitivity to observe the γ-ray emission from the self–annihilation of the neutralino, which is the currently foremost elementary particle candidate for the cosmological Dark Matter. This could lead to the direct observation of the Dark Matter.

3. The Cherenkov Telescope Array

The next decade can be considered the golden age of the gamma-ray astronomy with two gamma ray dedicated satellites (AGILE and Fermi) in orbit. Moreover, thanks to many X-ray experiments already in orbit (e.g. Swift, Chandra, Newton-XMM, etc.) and to many other new ground-based optical and infrared instruments, it will be possible to observe the Universe for the first time all over the electromagnetic spectrum almost at the same time. In such a scenario a new generation of ground-based VHE gamma-ray instruments with enhanced characteristics is needed. The VHE astrophysics community is moving towards such a new generation of Cherenkov esperiments both in Europe and USA. Big projects such as the Cherenkov Telescopes

Array (CTA)[1] in Europe and the Advanced Gamma-ray Imaging System (AGIS)[2] in USA are now being planned.

The European CTA is conceived to allow both detection and in-depth study of large samples of known source types, and to explore a wide range of classes of suspected gamma-ray emitters beyond the sensitivity of current instruments. CTA will be a combination of the well proven technology of Cherenkov telescopes (with some tens deployed over a large area) and of new wide-field gamma detectors. CTA sensitivity will be about a factor 10 more sensitive than any existing instrument (see Fig.1) in its core energy range, from about 100 GeV to several TeV. The covered energy range will be three to four orders of magnitude (see Fig.1) enabling to distinguish between key hypotheses such as the electronic or hadronic origin of highest energy gamma rays. CTA will reach angular resolutions in the arc-minute range, a factor 5 lower than current instruments. With its large detection area, CTA will resolve flaring and time-variable emission on sub-minute time scales which are currently not accessible. Extrapolating from the intensity distribution of known sources, CTA is expected to enlarge the catalogue of objects detected from currently about 100 objects to about 1000 objects.

CTA, will be, for the first time in this field, operated as a true observatory, open to the entire astrophysics (and particle physics) community, and providing support for easy access and analysis of data. Data will be made publicly available and will be accessible through Virtual Observatory tools. The large amount of data obtained and open to public access will also allow data mining in addition to targeted observation proposals favouring multi-wavelength studies. The CTA project aims to emerge as a cornerstone in a networked multi-wavelength, multi-messenger exploration of the Non-thermal Universe. For this reason also issues such as data reduction and dissemination have to be conceived and developed within

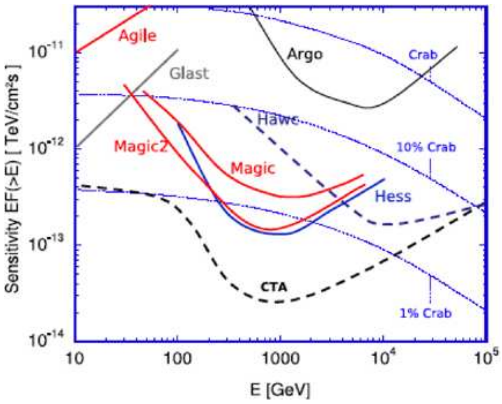

Fig. 1. Sensitivities of some present and future HE gamma detector, measured as the minimum intensity source detectable at 5 sigma. The performance for EAS and satellite detector is based on one year of data taking; for Cherenkov telescopes it is based on 50 hours of data [from De Angelis et al., (2008)].

the CTA project. CTA has been included in the 2008 roadmap of the European Strategy Forum on Research Infrastructures (ESFRI) . It is one of the seven most important projects of the European strategy for astroparticle physics published by ASPERA , and highly ranked in the "strategic plan for European astronomy" of ASTRONET.

4. The INAF Perspective for the new generation of IACTs.

The INAF contribution to CTA is reflecting its background and know-how in the field of VHE astrophysics, VHE technologies, space- and ground-based observatories management and operations, multiwavelength observations and data analysis (see Antonelli et al., (2009) for detailed description). In particular, INAF scientists and associated are mainly participating to CTA in the following topics:

Astrophysics and Astroparticle Physics. INAF scientists are actively involved in the theoretical investigations in the field of High-Energy Astrophysics. In particular, different groups have focused on particular topics of interest for the CTA. INAF scientists from many different institutes are actively

[1] http://www.cta-observatory.org/

[2] http://www.agis-observatory.org/

working in the development of theoretical models of emission processes in relativistic jets, in the organization of high energy and multifrequency observations of GRB, AGN and Blazars and in modelling their Spectral Energy Distributions. Other groups are active in theoretical modelling and in organizing high energy and multifrequency observations of Galactic Compact Objects and GRBs. Some scientists are focusing their research on modeling particle acceleration in SNRs, plerions, relativistic shocks for applications to PSR systems, cosmic-ray origin and propagation models, AGNs, and galaxy clusters. Another group is involved in studying Dark Matter and fundamental physics.

Optimisation of the array layout. In INAF there is a good expertise in simulations and studies to characterize and to optimize the instruments performances in the TeV energy band with particular attention to the large field of view telescopes.

Telescope Optics and Mirrors. INAF groups have conceived and developed the glass mirrors of the MAGIC II telescope (Pareschi et al., 2008). The same groups are also involved in the development of new production techniques for the realization of the CTA mirrors (Vernani et al., 2008). In particular, they are already involved, in collaboration with industrial partners (Media Lario), in the development of reflecting panels based on the new approach of the cold slumping of thin glass sheets from a master, a technique suitable for the mass and low cost production of the CTA mirrors. In INAF there is also a relevant experience in ray-tracing from optic systems as well as a deep experience in simulation of Cherenkov light produced by atmospheric Air Shower with particular regard to the wide field.

Photon detectors and focal plane. Other groups are active in the design of sensors and relative electronics for high energy detectors operating in both space-borne and ground-based experiments.

Observatory operation. CTA will be not operated as an experiment but as an open observatory to serve a wider astronomical and physics community. INAF has a wide expertise in running astronomical observatories in Italy and abroad. Several INAF scientists and engineers have been and are still involved in operating telescopes and instruments, in setting up and running scientific Announcements of Opportunity, in the management of observing proposals and in data distribution from both ground- and space- based observatories. INAF scientists are also participating in the definition of the requirements of the CTA site and infrastructures.

Data handling, data processing and, data access. Many INAF groups have been deeply involved in data analysis and processing from instruments and experiments at all wavelengths. INAF scientists are contributing to the CTA system design in defining data format, design and development of quick look analysis, pipeline processing and data storage systems as well as to the science analysis tasks.

5. Conclusions

A new generation of ground-based very high energy gamma-ray instruments is now in a design-study phase. It will be based on a solid and well proven technology so, a factor of 10 in sensitivity could be achieved with an installation cost of the array relatively low. Such an investment will guarantee an outstanding scientific return to the whole astrophysical community by solving fundamental astrophysical questions and stimulating and driving multi-wavelength and multimessenger studies. INAF will play a leading role in this scenario.

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