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H.E.S.S. AND CTA, PRESENT AND PERSPECTIVES IN GROUND-BASED GAMMA-RAY ASTRONOMY

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Abstract. Very high energy (VHE) gamma-ray astronomy emerged as a new branch of astronomy about ten years ago with the major discoveries achieved by the High Energy Stereocopic System (H.E.S.S.) operating in Namibia, quickly followed by the Major Atmospheric Gamma Imaging Cherenkov Telescopes (MAGIC) in the Canary Islands and the Very Energetic Radiation Imaging Telescope Array System (VERITAS) in the USA. These experiments succeeded to start exploring the cosmos at TeV energies, with the present detection of 178 sources in this range, mostly pulsar wind nebulae, supernova remnants, binary systems, blazars, and a variety of other types of sources. Based on these promizing results, the scientific community soon defined a next generation global project with significantly improved performance, the Cherenkov Telescope Array (CTA), in order to implement an open observatory at extreme energies, allowing a deep analysis of the sky in the highest part of the electromagnetic spectrum, from 20 GeV to 300 TeV. The CTA preparation phase is now completed. Production of the first telescopes should start in 2017 for deployment in 2018, in the perspective of an array fully operational at the horizon 2022.

Keywords: very high energy astrophysics, gamma-ray astronomy, cosmic accelerators, compact sources

1 Introduction

During the last decade, the IACT (Imaging Atmospheric Cherenkov Telescope) experiments H.E.S.S., MAGIC and VERITAS showed the richness of our cosmos when seen in the TeV range, with the detection of several tens of sources of various types, pulsars and pulsar wind nebulae (PWN), supernova remnants (SNR), binary stellar systems, star clusters, diffuse interstellar medium, galactic center, blazars, radio galaxies, starburst galaxies and a number of new VHE sources still unidentified. The sample of confirmed sources detected in the VHE range should soon reach 200 objects. Current experiments are continuously gathering new results. However their relatively poor sensitivity limits their possibilities of investigation. CTA, the next generation main instrument of ground-based gamma-ray astronomy will have improved performance, especially with an increase by a factor of ten of the sensitivity, a large spectral range, and a large field of view of about 8 degrees (Acharya et al. 2013). CTA array will consist of several tens of Cherenkov telescopes of different types and sizes, with 23m, 12m and 4m telescopes in order to cover a very large domain in energy from 20 GeV up to 300 TeV. Two arrays are going to be implemented, one in La Palma, Canary Islands, and one in Chile near Paranal to have access to the whole sky. Lifetime should be 30 years. At least a thousand of cosmic sources should be reachable with CTA. Production and deployment of the first telescopes on sites are foreseen for 2017-2018. Routine user operation open to general observer is expected to start in 2022.

2 A few recent H.E.S.S. discoveries in galactic science

With about 3000 hours of observation, the H.E.S.S. Galactic Plane Survey provided the first survey of the Milky Way at VHE energies with a resolution of about 0.1 degree and a sensitivity of 2% of the Crab nebula point source. It has recorded up to 77 VHE galactic sources, revealing a large variety of cosmic accelerators in our Galaxy (Lemoine et al. 2015). A diffuse large scale galactic gamma-ray emission has also been detected for the first time in regions off known VHE sources along the galactic plane (Abramowski et al. 2014). It can be

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interpreted as a mix of diffuse hadronic and Inverse-Compton VHE emission and contributions from unresolved sources, and clearly deserves further investigation.

An increasing sample of pulsar wind nebulae, the dominant class of TeV galactic sources, is now allowing the first statistical studies. A general picture is currently emerging, constraining further the theoretical models which still have difficulties to fully describe the current PWN populations and to study their link to young pulsars expected to power them and their interaction with the ambient interstellar medium.

Several new detections have also been achieved by H.E.S.S. in relation with supernova remnants. One example which perfectly illustrates the power of a multi-wavelength approach is the case of the complex region close to the SNR W41 in sky projection (Abramowski et al. 2015a). A new VHE source HESS J1832-093 has been discovered, located on the edge of the radio shell of a neighbouring remnant SNR G22.7-0.2 (see Fig. 1). The multi-lambda data suggest that this is the signature of escaping cosmic-rays illuminating a nearby molecular cloud. However there are some alternatives such as the presence of a PWN or of a VHE binary system. Deeper observations should allow to distinguish between the different scenarios.

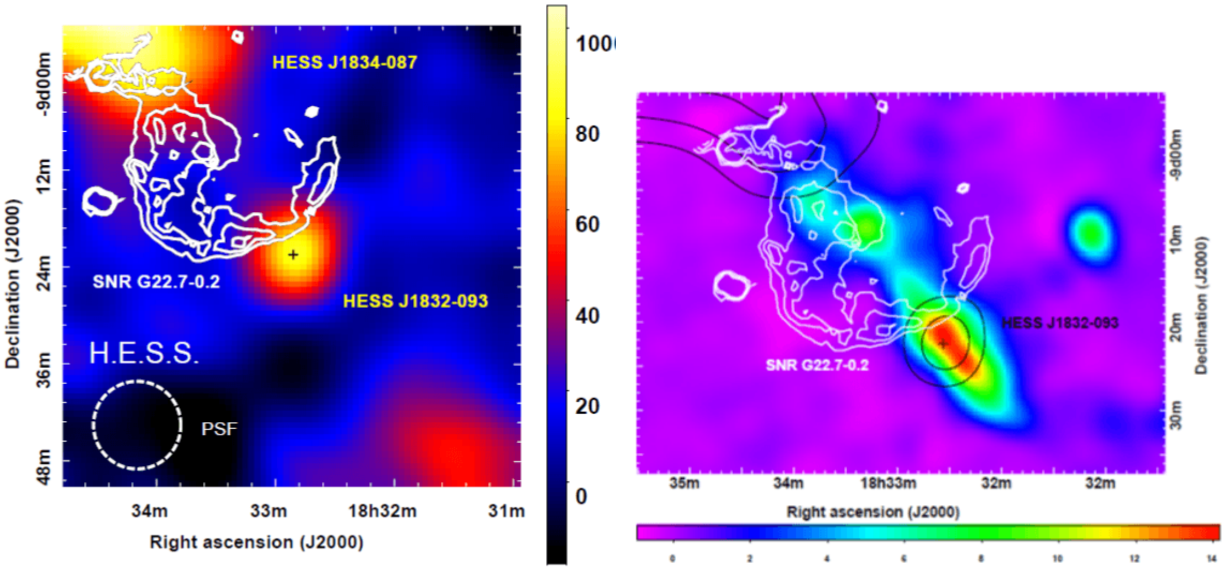

Fig. 1. Left: H.E.S.S. excess map of the region around the SNR G22.7-0.2 in coded colors. **Right:** Integrated ^{13}CO antenna temperature map in arbitrary units. Overlaid black contours show the gamma-ray excess. In the two maps white contours correspond to the 1.4 GHz radio map (Abramowski et al. 2015a)

The search with H.E.S.S. for PeVatrons, cosmic accelerators of particles at PeV energies (10^{15} eV), appeared to be quite promizing in our Galaxy and in the Large Magellanic Cloud (LMC). The experiment found the first evidence of a cosmic hadronic PeVatron in the Galactic Center with the obtention of a power-law spectrum without any cutoff or break, up to tens of TeV, from the diffuse emission within the central 10 parsecs of the Milky Way around the VHE point source of the Galactic Center (Abramowski et al. 2016). Exceptionnally powerful VHE sources have also been detected in the LMC (Abramowski et al. 2015b). Among them, 30DorC is the first unambiguous detection of a superbubble in the TeV range. It exhibits extreme conditions and could be another type of PeVatron deserving further analysis (see Fig. 2).

3 The Cherenkov Telescope Array project

The CTA project was launched ten years ago, motivated by the success of the new IACT instruments at that time (see Fig. 3). Supported at the european level and by national agencies, the CTA consortium now brings together 32 countries, with almost 200 institutes and 1300 members. On June 14th, 2016, the CTA council selected the city of Bologna in Italy to host the CTA headquarters and DESY-Zeuthen near Berlin to host the Science Management Centre. Massive simulations (Bernlohr et al. 2013) have been done to optimize the layout and its performance in terms of sensitivity, spectral resolution and angular resolution (see Fig. 4). A special issue of Astroparticles Physics, volume 43, has been devoted to the CTA science case in 2013, with a large part

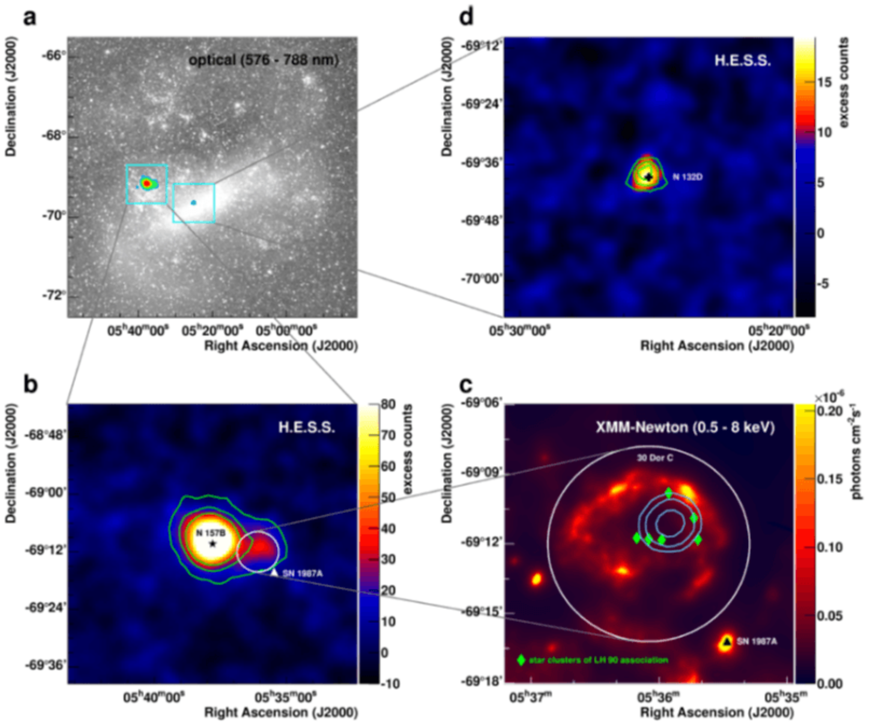

Fig. 2. Powerful TeV emitters detected in the Large Magellanic Cloud: N123D, an old TeV radio-loud SNR, possibly interacting with dense shocked interstellar cloud (upper right); N157B, a PWN associated to the most powerful known pulsar PSR J0537-6910 (lower left); 30DorC, the first unambiguous detection of superbubble in VHE (lower right). With its size of about 47 pc, 30DorC harbours extreme conditions and appears as a possible PeVatron (Abramowski et al. 2015b).

dedicated to galactic science.

Several prototypes of telescopes and cameras have been implemented in the world especially in France, Germany, Italy, Poland, Switzerland and UK and are under construction in Spain and USA. Their first Cherenkov light has been obtained by the 4m prototype built and installed at the Observatoire de Paris in Meudon at the end of 2015 (Sol et al. 2016). The prototyping and assessment phase is coming to an end and the pre-production of first telescopes and cameras to be installed on the two CTA sites is starting. First partial operations of the arrays and commissioning data can be expected in about two years. A number of key science projects (KSP) which have been worked out by the CTA consortium for the guaranteed time will soon be published. The first call for general observer proposals will be launched when the arrays are near completion. The CTA Observatory will provide support and services to the user (softwares, instrument response functions, data management and pipelines, dissemination, data archive, observer access).

4 Conclusion and perspectives

Full operations of CTA are planned for 2022 and should last at least until 2050. CTA high sensitivity will ensure access to VHE sources in all parts of our Galaxy, while present instruments are basically limited to nearby sources, or extremely bright ones. Further improvement in angular and spectral resolution will provide detailed maps and high-quality spectra. Several observational modes will be operational (targetted sources, surveys, observing with full array or with sub-arrays, alarms and targets of opportunity). Fast re-positionning of the telescopes and good temporal resolution, below the minute scale, will be very adapted to study transient phenomena and to get light curves over several time scales. In this regard, a global alarm network is being developped between the large research infrastructures of the coming decades in astrophysics and astroparticle physics.

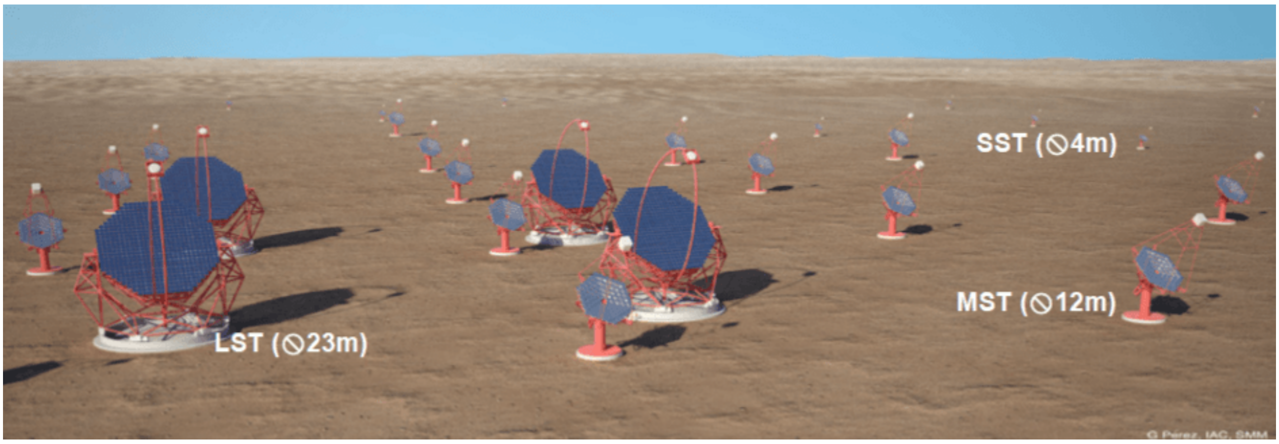

Fig. 3. Artist's view of the future southern Cherenkov Telescope Array with telescopes of three different sizes, covering a large spectral range from 20 GeV to 300 TeV.

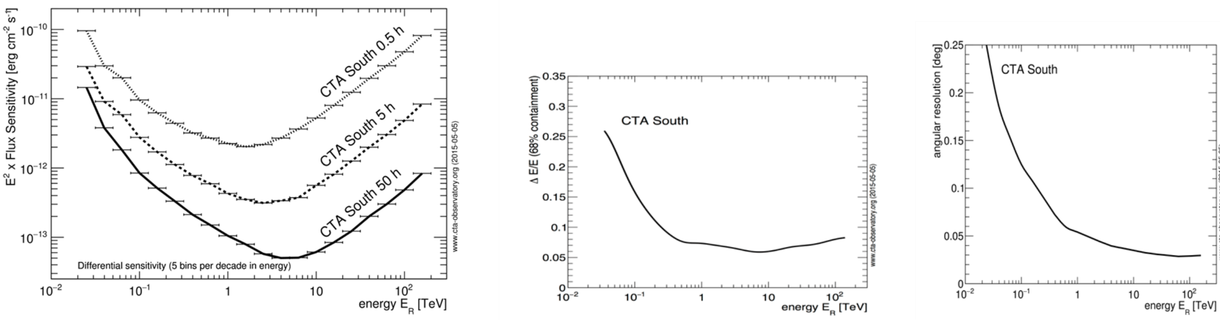

Fig. 4. Left: Differential sensitivity aimed for the nominal southern CTA array. **Middle:** Typical spectral resolution with the same array. **Right:** Typical angular resolution with the same array. (Extracted from *http : //portal.cta − observatory.org/CTA_Observatory/performance/SitePages/Home.aspx*).

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