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VERY HIGH ENERGY γ-RAY ASTRONOMY: REVIEW OF THE LATEST RESULTS

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Abstract. The field of Very High Energy (VHE, E>100 GeV) gamma-ray astronomy has undergone a major revolution over the last four years, thanks to the results obtained by the new imaging Air Cherenkov Telescopes (IACTs). The latest generation of Cherenkov telescopes, such as H.E.S.S., VERITAS, and MAGIC, has increased the observation energy range from 100 GeV to multi-TeV, which allowed the field to enjoy a period of rapid growth, today boasting a source catalogue containing about 50 emitters of VHE gamma-rays from a variety of classes, including supernova remnants, blazars, pulsars, and microquasars. Other kinds of objects, such as pulsars, galaxy clusters or GRBs, are expected to produce also VHE gamma-rays. Furthermore, a large number of new unidentified sources without obvious counterparts at lower wavelength have been discovered. We will review the latest results published and discuss the most interesting cases.

1 Introduction

The window of ground-based gamma astronomy was opened in 1989 by the observation of a strong signal from the first TeV gamma source, the Crab Nebula, by the Whipple collaboration. Since then, increasing progress has been made in this new field of astronomy and discoveries of new sources have been made by newer ground-based VHE γ-ray instruments. Those instruments can be classify in two groups: Instruments with high sensitivity, the so-called imaging Cherenkov telescopes (IACTs) such as VERITAS (Holder et al. 2008), MAGIC (Bastieri et al. 2008), H.E.S.S. (Djannati-Ataï et al. 2008) and CANGAROO (Enomoto et al 2008), which operates in the energy range from 0.05 to 50 TeV, have large collection areas (>10^4m^2), good angular resolution (typically $\sim$0.05^o) and high capacity of background rejection using the *imaging* technique, but are limited by a small aperture (0.003 sr) and the request of observations under dark night conditions (10% duty cycle). IACTs allow to study in detailed the energy spectra and sources morphology, and are able to perform surveys of limited regions of the sky. The second group (Milagro (Abdo et al. 2007), Tibet (Amenomori et al. 2007) and ARGO) is characterized on the contrary by large aperture (> 2 sr) and high duty cycle (>90%) instruments, operating in a slightly higher energy range (1 - 100 TeV) but with limited angular resolution (0.3-0.7^o) and lower sensitivity than the one of the telescopes. These later instruments are optimum to carry on unbiased sky survey and study very extended sources not accessible by the imaging telescopes.

Over the last years, the number of known VHE gamma-ray sources increased rapidly: the last count gives more than 70 sources, among them 7 or more supernova remnants, about 20 pulsar wind nebulae and 20 unidentified sources, four binary systems, diffuse emission from clouds and 23 extragalactic sources. Fig. 1 shows the updated VHE γ-ray sky map (Wagner 2008).

A brief overview of the field is presented here. Since there will be another contribution dedicated to extragalactic sources, and due to the limited space, I will only cover the most relevant results on Galactic sources.

2 Galactic sources

The H.E.S.S. telescope has conducted recently an extension of the scan of the inner Galactic Plane Survey (GPS) (Aharonian et al. 2005), which has supposed a major breakthrough in the Galactic field. The survey, covering the yet unexplored range in longitude between [-85^o,60^o] and [-2.5^o,2.5^o] in latitude, has revealed more than two dozens of new VHE sources, consisting of shell-type SNRs, pulsar wind nebulae, X-ray binary

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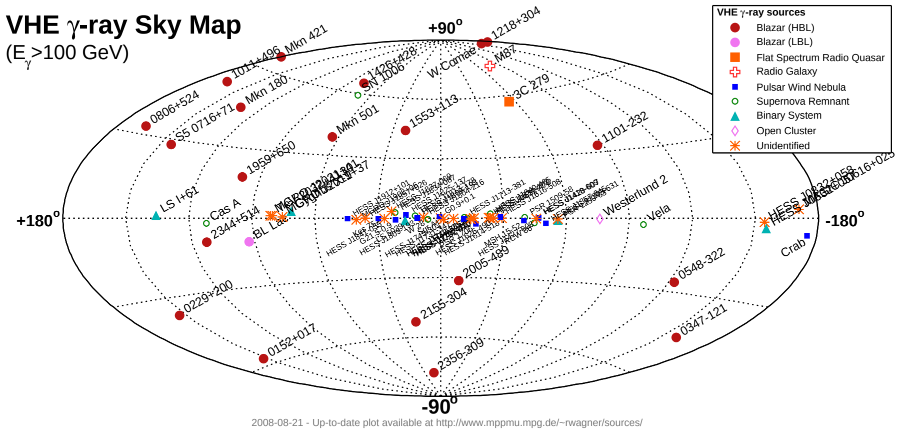

Fig. 1. The VHE γ-ray sky map

systems, a putative young star cluster, yet unidentified objects, the so-called dark sources, in which not obvious counterparts at other energy wavelengths are found (see e.g. Aharonian et al. (2006), Aharonian et al. (2008)), and the diffuse emission in the central 100 pc of the Milky Way, being able to locate the Galactic Center γ-ray source with a precision of 6", consistent with the black hole Srg A* but excluding the nearby remnant Sgr A East. MAGIC and VERITAS had contribute to the galactic field with the discovery of the γ-ray binary LSI +61 303 (Albert et al 2006), the stellar mass black hole binary Cygnus X-1 (Albert et al 2007), the supernova remnant IC443 (Albert et al. 2007) and they have confirmed several sources such as the first unidentified source, HEGRA TeV J2032+4130 (Aharonian et al. 2002).

The water Cherenkov detector Milagro has also survey the sky during 7 years of operation (2358 days of data to the North of 30^o longitude), announcing the discovery of three low-latitude sources and 4 lower significance hot-spots, as well as evidence for diffuse emission along the Galactic Plane. Fig. 2 shows the results of these observations. Note that the scan overlaps with the H.E.S.S. one between 35^o and 60^o, allowing a comparison between the sources detected in this region.

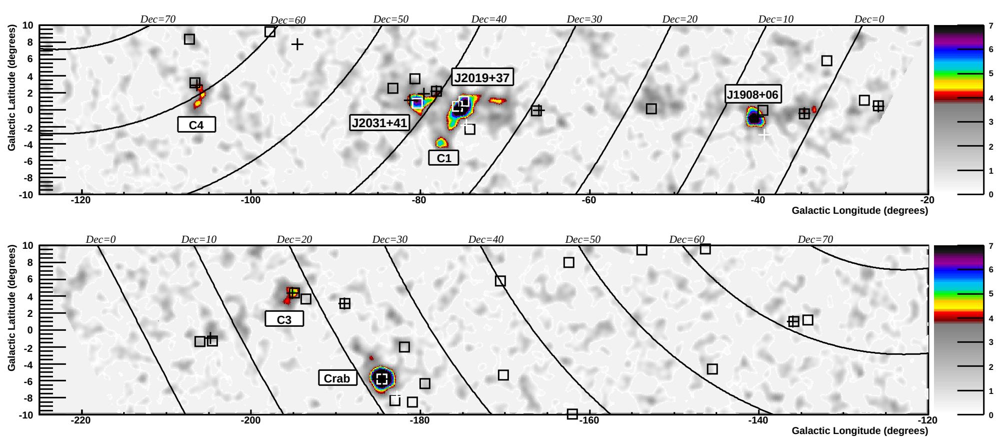

Fig. 2. Milagro observation of the Galactic Plane.

2.1 Supernova remnants

Shell-type supernova remnants (SNRs) are considered as prime acceleration sites for the galactic cosmic-rays, at most up 10^{15} eV. Up to 7 firm detections are seen in TeV γ-rays: IC 443, RX J0852-4622 (Katagiri et al 2005), RCW 86 (Hoppe & Lemoine-Goumard 2007), RX J1713.7-3946 (Aharonian et al. 2006), W28 (Aharonian et al. 2008), Cas A and SN 1006 (Melitta-Godo et al. 2008). Three of them have been resolved (RX J0852-4622, RCW 86 and RX J1713.7-3946) with unpreceding angular resolution, proving thus the acceleration of particle responsable of the VHE emission in the shell (see Fig. 3). Two mechanisms have been proposed to explain the VHE emission, through synchrotron radiation and Inverse Compton scattering produced by a population of electrons, or through collisions of accelerated protons with gas. The close correlation between γ-ray emission and X-ray emission, like in the case of RX J1713.7-3946, may favor a leptonic scenario, although it requires 10 μG magnetic field, while the filaments seen in X-ray images of SNR are often interpreted as evidence for rapid cooling of electrons as they move away from the shock fronts, which requires much higher fields in the 100 μG range. On the contrary, older SNRs such as IC 443 and W28, show a good agreement with dense molecular cloud, being so a strong argument for the presence of protons accelerated by the remnant.

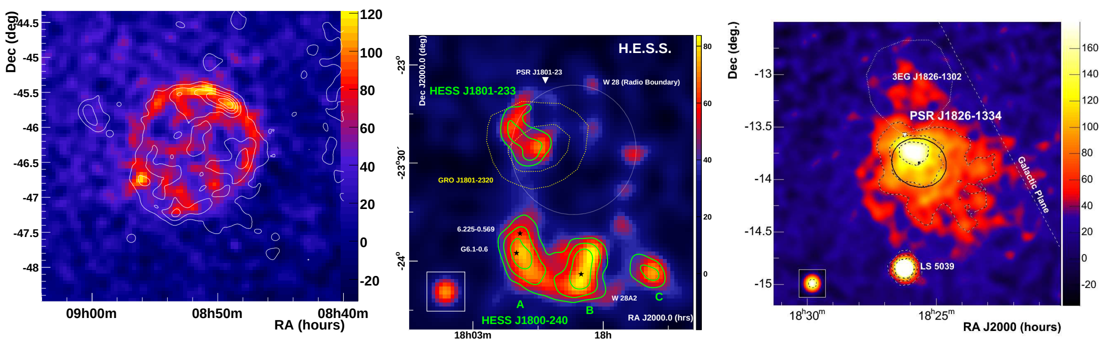

Fig. 3. Left: RX J0852-4622, together with X-ray contours from the ROSAT All Sky Survey >1.3 keV. **Middle:** the VHE emission from W28, coincident with an enhancement of ^{12}CO (J=1-2) data. **Right:** the PWN J1825-137

2.2 Pulsar wind nebulae

Pulsar wind nebulae represents the major Galactic source population revealed by the H.E.S.S. scan, being the Crab Nebula the first VHE γ-ray source. But they differ from the Crab Nebula in that they are typically very extended sources (few tens of pc), associated with very young, energetic pulsars, and the TeV emission is mostly displaced with respect to the pulsar position. HESS J1825-137 (in Fig. 3) can be considered as the prototype of such objects. The VHE emission and morphology can be explained by cooling of particles suffering radiative energy losses as they flowing away from the pulsar, resulting in the shrinking of the source towards the pulsar with increasing energy.

2.3 Unidentified sources

A large number of TeV γ-ray sources remain unidentified, that is, do not have a plausible counterpart at lower energies, where both, leptonic and hadronic models, predict in general synchrotron emission from charge particles, although highly suppressed in the latter case. They show rather hard spectral index and are mostly extended (see i.e. Fig. 4). In some cases, this could be due to lack of deep observations at other wavelength, but on some other cases, the VHE emission could be identify with pure protons accelerators, or explained with a leptonic population with a cutoff in the TeV range, in which case, in the KN regime high energy γ-rays can still be produced, but the synchrotron radiation peaks below the X-ray range and escapes detection. The scan performed by Milagro shows 3 new sources which remained unidentified, MGRO J2019+37 and MGRO J2031+41, on the Cygnus region, and MGRO J1908+06, located around 40^o on the Galactic plane. Fig. 4 shows the differential flux at 20 TeV of the H.E.S.S. and Milagro sources in the overlapping region of their scan. The two horizontal blue lines show the Milagro sensitivity at 20 TeV for a declination of 0 and 10^o, corresponding to the range of longitude of the H.E.S.S. sources above 35^o longitude.

HESS J1908+063 has been identified with MGRO J1908+06 but the two other Milagro sources are still being investigated by MAGIC and VERITAS.

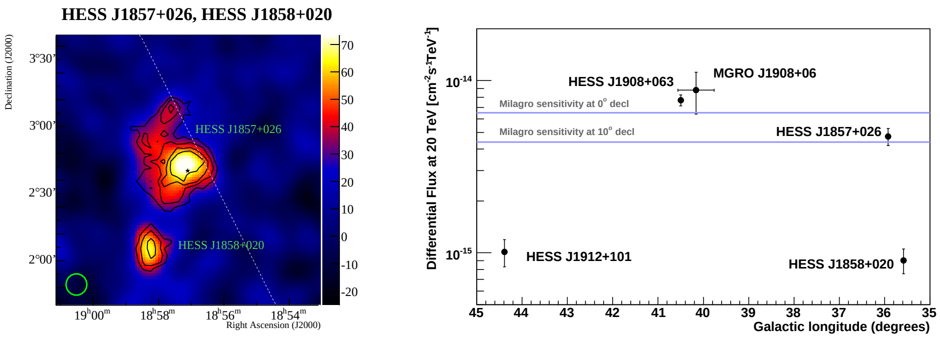

Fig. 4. On the left, one of the unidentified source discovered during the GPS, on the right, sources detected by Milagro and H.E.S.S. in their Galactic Plane Scan

3 Summary

The field of VHE astronomy has been consolidated in the last years, and has opened and answered many scientific topics. The future generation of telescopes Cherenkov, MAGIC II and H.E.S.S. II, and CTA in the following years, are expected to increase the sensitivity 10 orders of magnitude and extend the energy coverage from 1 GeV to 100 TeV, providing thus, together with HAWC (based on Milagro technology) full-sky coverage at sensitivity better than 0.1 Crab.

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