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HIGH ENERGY GAMMA RAYS

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ABSTRACT

The Very High Energy Gamma Ray Astronomy (VHE) is a rapidly evolving branch of modern astronomy, which covers the range from about 50 GeV to several tens of TeV from the ground. In the past years, the second generation instruments firmly established a growing and varied list of sources including plerions, supernova remnants and active galactic nuclei, and started to study some fundamental questions such as the origin of cosmic rays or the emission mechanisms of the active galactic nuclei.

New results now include the first VHE unidentified sources as well as more puzzling sources such as the Galactic center. The arrival of new generation instruments (HESS, CANGAROO III, VERITAS, MAGIC) already gives a impressive look at the near future. Here we attempt to summarize the current status of the field. We briefly describe the instruments and analysis techniques, and give an outlook on the sources detected sofar.

1 The universe in gamma-rays

1.1 A little bit of history

Since their discovery by Victor Hess in 1912, one of the most puzzling (and still not completely solved) problems of astronomy is the *origin of Cosmic Rays*. These high energy particles mostly consist of charged nuclei and are spread over more than 10 orders of magnitude in energy up to 10^{20} eV (and possibly above). The search for the corresponding cosmic accelerators motivated the developement of *gamma-ray astronomy*, first from space and then from the ground. In contrast to the charged component of the cosmic rays, the gamma-rays are not deviated by the Galactic and extra-galactic magnetic fields and thus point back to their emission source. They are emitted by particle physics processes (non-thermal synchrotron radiation of accelerated electrons, inverse Compton scattering of cosmic rays off ambient photons, pion decay,. . .) occuring in high electromagnetic field acceleration regions, shocks in astrophysical plasmas or interaction of the cosmic rays with the interstellar medium. In the active galactic nuclei or other compact objects, they are thought to be emitted by the very central engine (instead of being secondary products) and can therefore probably provide the most valuable constraints on the emission models. Finally, they could also possibly originate from annihilation of neutralinos in dark matter clumps.

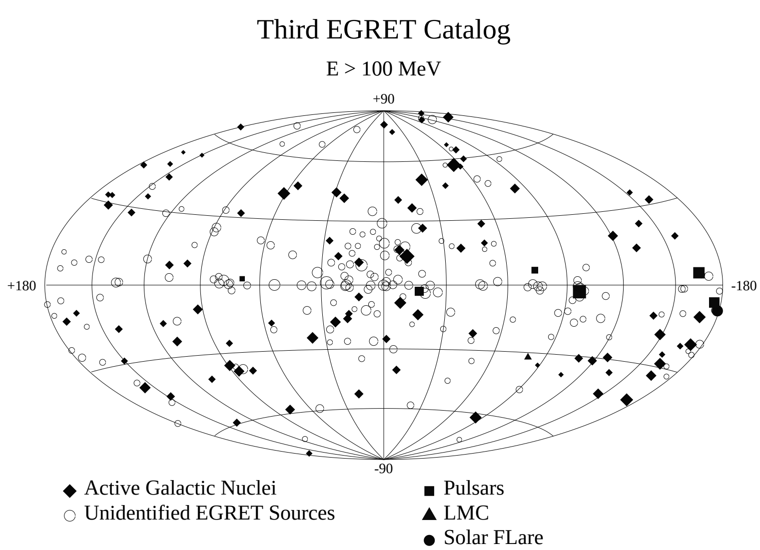

Figure 1: *Third Egret Catalog.*

After the pionneering work of SAS II and COS-B, a breakthrough was achieved in the 1990's by the EGRET detector onboard the CGRO satellite: this spark-chamber detector made the first map of the diffuse γ-ray emission from the

Galactic plane and detected 271 point-like source between 100 MeV and 10 GeV. The third EGRET catalogue [2] (Figure 1) contains 66 AGNs, 8 pulsars and 170 still-unidentified sources. A important fraction of these sources should be Galactic, and probably contribute to the bulk of cosmic-ray sources. The identification of these sources is one of the major chalenges of the 21^{th} century astronomy.

1.2 Atmospheric Cerenkov Imaging and other techniques

Above 10 GeV the rapid fall in of the flux limits the sensitivity of space detectors. The ground base detection relies on the sampling of the Cerenkov light emitted by the charged particles in the extensive air showers (Figure 2). The opening angle of the Cerenkov light makes the showers visible at great distances (up to 300 m) away from the detector and thus permits huge detection area ($> 10^9$ cm^2). The shape of the image is then used to discriminate between the high cosmic ray background (several hundreds Hz) and the γ candidates (representing at most 0.2% of the background for the strongest sources).

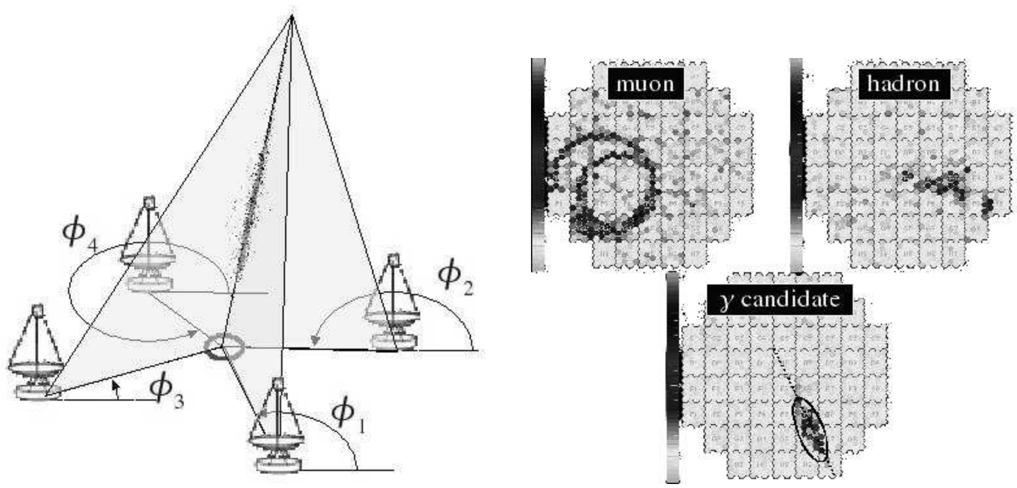

Figure 2: *The Atmospheric Cerenkov Imaging technique. Left: detection principle. Right: Typical images for muons, hadron and γ candidates.*

Between roughly 20 GeV and 100 GeV remains a quasi-unexplored region, where the Cerenkov light is too faint for existing Imaging Cerenkov Telescopes. Several Solar Farm experiments (Solar II, Stacee, Celeste) took the opportunity of the huge light collection area provided by the existing solar plants to lower the threshold down to 50 GeV, but they could never reach high-enough hadron rejection capabilities to be competitive.

The VHE catalogue (figure 3) was opened in 1989 by the discovery of the Crab Nebula [1] (see section 2.1) by the WHIPPLE collaboration. HEGRA introduced in 1995 the stereoscopic technique, which, by looking at the same shower from different points of view, gave a dramatic improvement in hadron and local muon rejection as well as in angular and energy resolution. After 15 years the VHE catalogue now consists of about 20 sources with very varied properties.

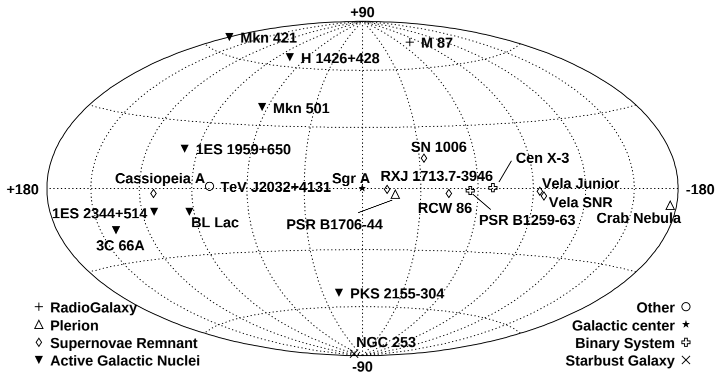

Figure 3: *The VHE sky c. 2004*

1.3 New instruments

Table 1: *Third generation instruments.*

Name	Location	# Telescopes	Diameter	FoV	Opening
CANGAROO III	Australia	4	10 m	4°	Completed
HESS	Namibia	4	12 m	5°	Completed
MAGIC	La Palma	1	17 m	4°	Commissionning
VERITAS	USA	4→7	12 m	3.5°	2006

After the success of the previous generation (WHIPPLE, HEGRA, CAT, CANGAROO-II), third generation instruments are now coming online. Their key properties are summarized in the table 1. Three of these projects are multi-telescope arrays combining the advantages of a big reflector inherited from WHIPPLE, a fine pixelization camera first developed by CAT, and stereoscopic observation pioneered by HEGRA. Their detection threshold lies around 100 GeV at zenith, and increases with zenith angle due to bigger atmospheric thickness. The latest experiment, MAGIC, is a bigger dish single telescope experiment which comprises a number of advanced technologies in the design of the mirror and the signal transmission, and aims to lower the detection threshold closer to the 20 GeV domain. Complementary to this, survey instrument with poor point-like sensitivity but nearly full sky coverage and duty cycle (Milagro, Tibet III) are providing the firsts VHE surveys at higher energies (above 2 TeV).

2 Galactic source

Nearly half of the known VHE sources belongs to our Galaxy. We will briefly recall the properties of some of them, focusing on the most recent results.

2.1 The Crab Nebula

This first discovered VHE source is a *plerion*, that is a synchrotron nebula fed by the electron wind of a central pulsar. A high resolution image of the Crab Nebula by the telescope Chandra is show in figure 4. Since its first discovery in 1989, the Crab Nebula showed no evidence for variability of any kind. It is therefore considered as the *standard candle* of high energy gamma-ray astronomy and can be used to compare and intercalibrate the instruments.

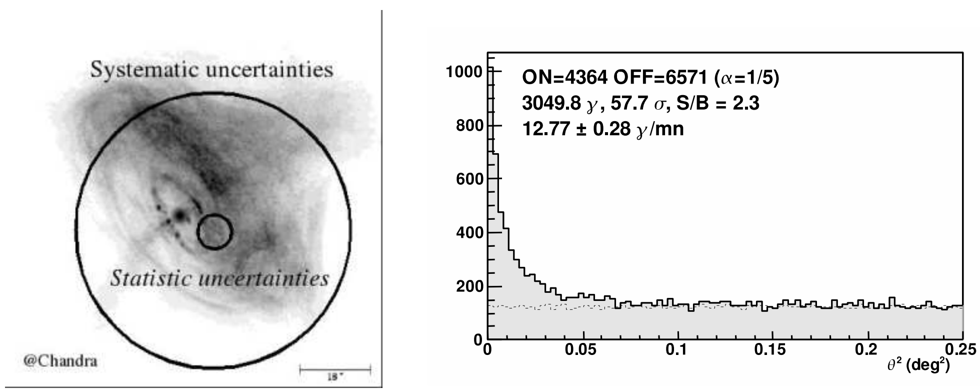

Figure 4: *The Crab Nebula. Left: high resolution X-rays image from Chandra, with confidence region from HESS. Right: Distribution of squared angular distance of the events to the direction of the Crab nebula as recorded by HESS, showing a highly significant excess in the direction of the source ($\theta^2 = 0$).*

New observation carried out by HESS using an uncomplete array of 3 telescopes yielded a highly significant signal, as show in the figure 4. The supreme achieved angular resolution gives a position compatible with the central pulsar, however a definite conclusion on the emission region will be possible only in a near future, when the systematic uncertainties will be reduced. The spectrum derived by HESS is found to be compatible with previously published results. MAGIC also reported a 10 σ detection of the Crab Nebula during the comissionning phase.

2.2 Galactic Pevatrons: the Supernova remnants

The supernova remnants are though to be the site of acceleration of the Galactic cosmic rays up to 10^{15} eV. However the naive picture according to which the TeV spectrum would give a clear signature of π° decay has not turned true, and the situation is still under debate.

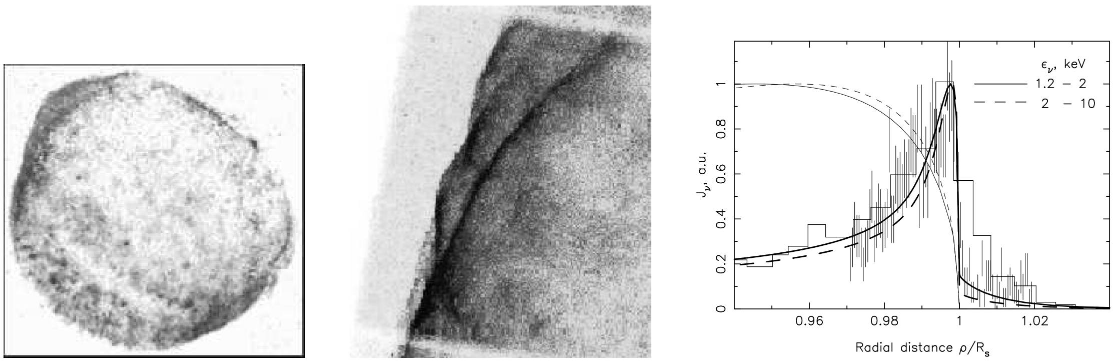

Figure 5: *Left: The SN 1006 supernova remnant seen by Rosat. Middle: zoom on the north west region by Chandra [3]. Right: section of one of the filaments showing the shock thinckness.*

The detection of the supernova remnant SN 1006 by CANGAROO-II in 1996 and 1997 was originally attributed to an inverse Compton emission of accelerated electrons, without the need of nuclear cosmic rays. The situation changed in 2003 with the obervation by Chandra [3] of very thin filaments of intense non thermal synchrotron X-ray emission. This has been interpreted as the effect of magnetic field amplification made possible by a accelerated population of nuclear cosmic rays [4]. In this scheme of high magnetic field ($\geq 100\mu G$), the TeV emission would be mainly due to π° decay.

HESS reported a non detection of SN 1006 and derived an upper limit at the level of 10% of the published CANGAROO-II flux. This discrepancy raises a lot of questions: As the emission of a SNR is not expected to vary significantly on so short timescales, could the emission come rather from a extragalactic background source? Only new observations will solved this point.

CANGAROO-II recently reported the detection of two other supernova remnants, RCW 86 and RX J0852.0-4622. The supernova remnants are now firmly established as sources of 100 TeV electrons, but the debate concerning the nuclear cosmic rays acceleration is not closed yet. We expect the situation to improve very quickly with the results of the third generation instruments.

2.3 An exotic system: PSR B1259-63

PSR B1259-63 is a very unique system in our Galaxy, consisting of a 47.7 ms pulsar in highly ($\epsilon \approx 0.87$) excentric orbit around a massive star SS 2883 (figure 6). Every

3.4 years at the *periastron*, the distance of the pulsar to the star is only $23R_\star$, $R_\star$ being the radius of the star. An interaction between the pulsar wind and the stellar disk surrounding SS 2883 could, according to several models (e.g. [5]), lead to the production of high energy gamma-rays.

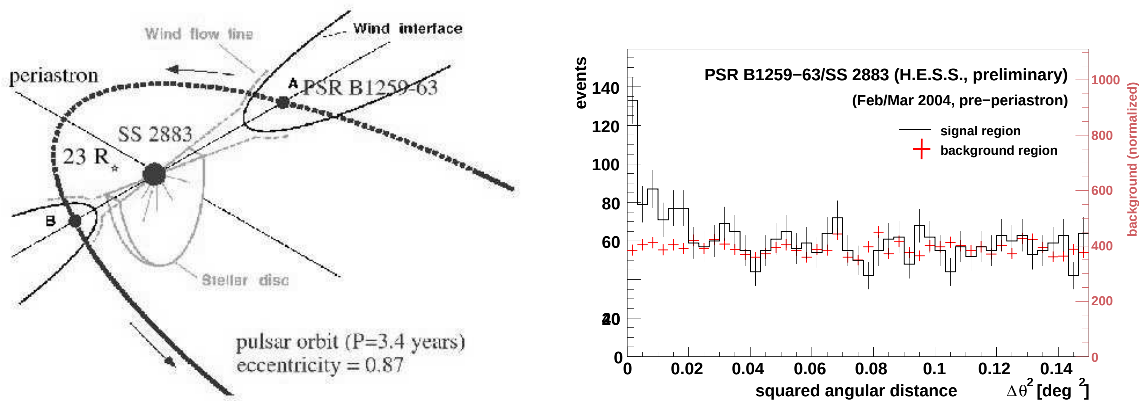

Figure 6: *Left: schematics of the PSR B1259-63 binary system. Right: signal observed by HESS*

HESS observed PSR B1259-63 during 10 hours around its periastron (March, 7th 2004). An significant excess at the 8.2 σ has been detected, and further work on the modeling is under way.

2.4 The Galactic center

The CANGAROO-II experiment first announced the discovery of a TeV gamma-ray signal from the Galactic center [6]. Soon after, WHIPPLE brought a marginal confirmation [7]. The very soft and somewhat unusual spectrum measured by CANGAROO-II, $\propto E^{-4.6}$ and the compatibility of the position with the center of the Galaxy led many authors to interpret this signal in terms of neutralinos annihilation [8]. For a very massive WIMP (of mass m_χ) annihilating mostly into W^+W^-, $Z^\circ Z^\circ$ and $q\bar{q}$ pairs, a reasonable description of the decay spectrum is given by the parametrisation of the form:

$$\frac{dN}{dE} = \frac{0.73}{m_\chi} \times \frac{e^{-7.8E/m_\chi}}{E_0 + (E/m_\chi)^1.5} \quad (1)$$

If the signal observed by CANGAROO-II was due to annihilation of neutralinos, the mass of the later would be in the range $1 - 3$ TeV.

As shown in the figure 7, recent results obtained by HESS [9] with a much better angular resolution (better than 0.1°) are incompatible with CANGAROO-II,

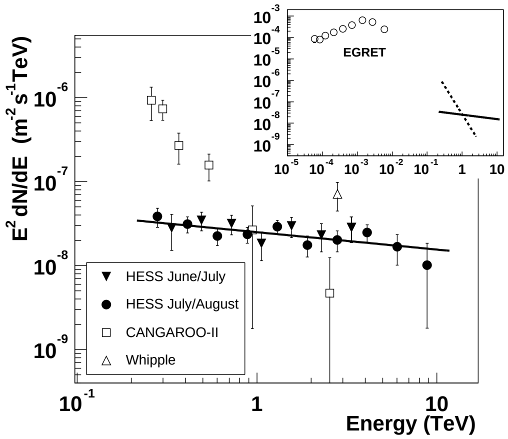

Figure 7: *CANGAROO-II and HESS spectra of the Galactic Center.*

and would give, if the signal was due to neutralinos, a lower limit of 7.5 TeV on the neutralino mass at 99% CL. However, the Galactic center is a very crowded region, with several potential sources in the CANGAROO-II and even in the HESS confidence level region. New observations with the complete HESS array should for instance clearly exclude the supernova remnant SgrA East which lies only 1.7′ away from the Galactic center.

More conventional model for the emission of central black hole Sgr A* include Advection Dominated Accretion Flow (ADAF), or diffuse emission due to interaction of accelerated protons and nuclei with the high density ambient matter.

2.5 TeV 2032+42 : First TeV unidentifed source

During the year 2002 the first unidentified TeV source, **TeV 2032+42** was detected by HEGRA [10]. This extended and faint source (3% of the Crab flux), having no radio or X-rays counterparts, exhibits a hard spectrum and has been confirmed by WHIPPLE analysis of archival data at a slighlty higher level. There are now some indications that this is not an isolated case, but rather a hint of a bright future.

3 A quick look outside the Galaxy

Almost all known extragalactic TeV sources are active galactic nuclei (AGN) belonging to the class of **Blazars**. They consist of a super-massive ($\approx 10^9\, M_\odot$) black holes surrounded by an accretion disk, from which two giant ultrarelativistic jets of plasma escape up to Megaparsec distances. For the blazars, one of theses jets points towards the earth and completely outshines the rest of the AGN.

Amongst other properties, the TeV emission of the Blazars is characterized by a dramatic variability on all time scales, the flux been sometimes multiplied by a factor 2 in times as short as 20 minutes.

Two principle classes of models aim to explain the emission mechanism of the Blazars: The leptonic SSC (*Synchroton Self Compton*) and EC (*Extrernal Compton*) models attribute the TeV emission to inverse Compton emission of accelerated electrons respectively on the synchroton X photons or on the environment photons. The second class of models is based on proton acceleration and hadronic cascades in the jets.

Very detailed observations of the correlation and timelag between the X-ray and γ-ray emissions are required to discriminate between the models. Recently organized multi-wavelength observation campains, combining the radio, optical, X-rays and γ-rays observations, tend to give a more comprehensive picture in favour of the leptonic models.

Very recent observations of giant flares of Markarian 421 by HESS and MAGIC confirm that the new generation instruments now reached the required sensitivity to study the time-variability of the Blazars at the minute timescale, and will probably solve this acceleration problem in a short time-scale.

4 Conclusion

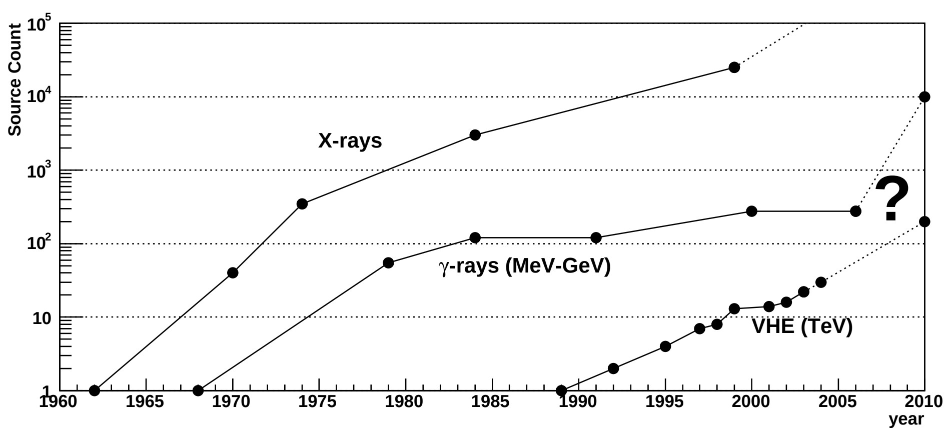

Figure 8: *Moore's law of astonomy: Source count vs time for X-ray, γ-ray and high energy γ-ray astronomy.*

In the last years, the VHE astronomy left the field of experiment to become a real branch of astonomy. The VHE catalogue already contains a big variety of sources and steadily increases. The similar evolution of the source count versus time for X-ray, γ-ray and high energy γ-ray astronomy (Figure 8) gives hints about a very bright future. The increase of statistics about extragalactic sources will also make new measurements possible: The interaction of the γ-rays with intergalactic infra-red and visible photons (through electron-positron pair creation) can be exploited to do a tomography of the ambiant star light at cosmological distances. This very delicate measurement would require a significance number of AGN with similar spectral features to disentangle the intrinsic properties of each source from the effect of comic absorption.

5 Acknowledgements

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