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A MAGIC view of the Very High-Energy gamma-Ray Sky

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Abstract. MAGIC is currently the largest single dish Cherenkov telescope operating since September 2004. Since then it has been delivering a wealth of exciting physics results from its observations in the Very High Energy (VHE) region of galactic and extragalactic sky. We present a review of the most recent experimental results obtained using MAGIC.

Key words. Gamma rays: observations – gamma-ray telescopes – Cherenkov telescopes – Galaxy: AGN

1. Introduction

The ground-based γ-ray astronomy based on the Imaging Atmospheric Cherenkov Telescopes (IACTs) aims at the observation of Very-High-Energy (VHE) γ-rays in the range 10 GeV-10 TeV. The VHE gamma-ray emission from astrophysical sources is connected to high energy processes accelerating charged particles. Leptonic models assume that the γ-ray photons are due to the inverse-Compton (IC) emission from accelerated electrons up-scattering seed photons to high energies; seed photons can originate from the electron acceleration through synchrotron emission or from ambient photons. In hadronic models interactions of highly relativistic jet outflow with ambient matter, proton-induced cascades, or synchrotron radiation of protons are responsible for the high-energy photons.

The VHE γ-ray sky counts few tenth of sources but its number is steadily increasing thanks to the high sensitivity of the IACTs in operation; among the most active we list MAGIC, H.E.S.S. and VERITAS.

The IACTs detect the extensive air shower produced after the interaction of a VHE γ-ray with the atmosphere. The charged particles (mainly electrons and positrons) in the air shower produce a short (few ns) Cherenkov flash. A Cherenkov telescope uses a large reflector area to sample the Cherenkov light dish, $\sim$ 100 m wide, and the photons are focussed to a photomultiplier-camera where an image of the atmospheric shower is formed. The analysis of the image results in the reconstruction of the incoming direction and the energy of the γ-ray and is also used to reject the much higher background of cosmic rays initiated showers (Albert et al. 2008).

The status of the VHE γ-ray sky at E>100 GeV is depicted on the galactic sky-map in figure 1, with 54 galactic and 28 extragalactic sources.

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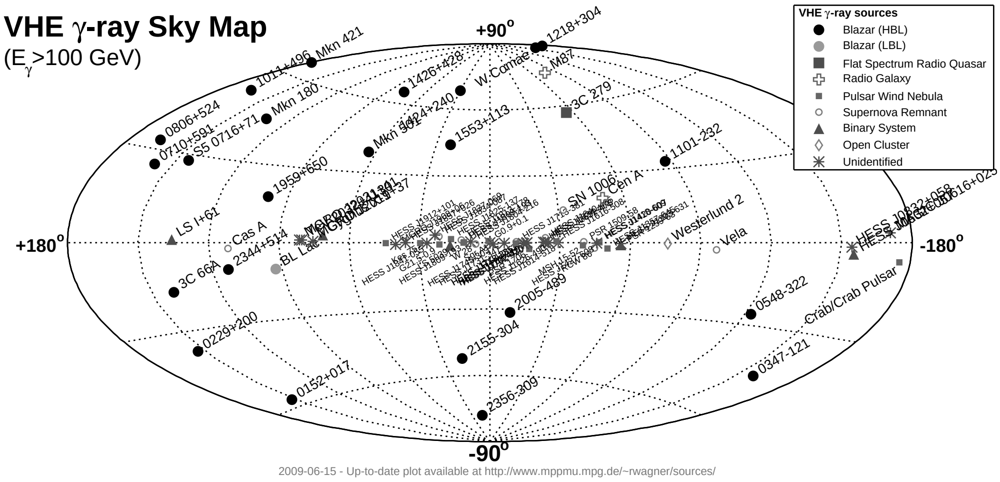

Fig. 1. Current catalog of VHE γ-ray sources detected by IACTs at E>100 GeV, July 2009.

2. The MAGIC Telescopes

MAGIC consists of two 17-m diameter telescopes, located on the Canary Island of La Palma (2200 m a.s.l.). Due to its large collection area and uniquely designed camera, MAGIC has reached the lowest energy threshold with a trigger threshold of 50 GeV at small zenith angles. MAGIC has a sensitivity of ~1.6% of the Crab Nebula flux in 50 observing hours. Its energy resolution is about 30% above 100 GeV and about 25% from 200 GeV onwards. The angular resolution is 0.1 deg. The second MAGIC telescope started operation in april 2009 (Sutton 2009). The telescopes system is improving the sensitivity to ~0.8% of Crab in 50 hours (Colin et al. 2009). In the following paragraphs the results obtained with the single MAGIC-I telescope will be outlined.

3. Galactic sources

The MAGIC telescope has discovered four new VHE galactic sources, detecting γs from the SNR IC-443 (Albert et al. 2007), the binary systems LSI+61 303 (MAGIC Coll. 2006) and Cyg X-1 (Albert et al. 2007), and the pulsed emission from the Crab pulsar; it has confirmed as TeV emitters several SNRs, the galactic center and the unidentified source TeVJ2032+4130, and has provided strong upper limits on the emission of PSR B1951+32/CTB80, Cyg X-3 and of two candidates of a possible new class of γ-ray sources, the Wolf-Rayet star binaries WR 146 and WR 147 (Albert et al. 2007).

3.1. The Crab pulsar

The Crab Nebula is the standard candle for VHE astrophysics and a big fraction of MAGIC observation time has been devoted to this object allowing a detailed study of the nebula between 60 GeV and 8 TeV (Albert et al. 2008). More recently, thanks to a special trigger setup, MAGIC has detected pulsed emission coming from the Crab pulsar above 25 GeV, with a statistical significance of 6.4σ. This result has revealed a relatively high energy cutoff, indicating that the emission occurs far out in the magnetosphere, hence excluding the polar-cap scenario as a plausible explanation for the high-energy origin (MAGIC Coll. 2008). This is also the first time that a pulsed γ-ray emission is detected from a ground-based telescope.

4. AGNs and MWL observations

Except for the radio galaxy M87, all currently known VHE γ-ray emitters AGNs are blazars.

An essential property of blazars is the high variability of their emission ranging from radio to γ-rays. For VHE γ-ray blazars, correlations between X-ray and γ-ray emission have been found on time scales ranging from $\approx$ 10 minutes to days and months (Fossati et al. 2008).

Coordinated simultaneous multi-wavelength (MWL) observations, yielding spectral energy distributions spanning over 15 decades in energy, have been recently conducted, and turn out to be essential for a deeper understanding of blazars. MAGIC participated in a number of MWL campaigns on known northern-hemisphere blazars, which involved the X-ray instruments *Suzaku* and *Swift*, the IACTs H.E.S.S. and VERITAS, the γ-ray observatories *Fermi* and AGILE and other optical and radio telescopes.

4.1. The region 3C66A/B

The MAGIC telescope observed the region around the distant blazar 3C 66A (z = 0.444) for 54.2 h in August-December 2007. The observations resulted in the discovery of a γ-ray source centered at celestial coordinates R.A. = 2h 23m12s and dec.= 43°0.′7 (MAGIC J0223+430), coinciding with the nearby radio galaxy 3C 66B. The energy spectrum of MAGIC J0223+430 follows a power law with a normalization of (1.7±0.3stat ±0.6syst)$\times 10^{-11}$ TeV^{-1} cm^{-2} s^{-1} at 300 GeV and a photon index $\Gamma = -3.10 \pm 0.31$stat ±0.2syst (Aliu et al. 2009). The position of the source found by MAGIC is not spatially compatible with 3C 66A at a level of 1.5σ. In addition the measured spectrum extending up to 2 TeV poses an additional drawback to the association of MAGICJ0223+430 with 3C 66A. Due to the energy-dependent absorption of VHE γ-rays with low-energy photons of the extragalactic background (EBL), the VHE γ-ray flux of distant sources is signicantly suppressed. Assuming a blazar-like emission mechanism and following the prescription of (Mazin&Raue 2007), a redshift upper limit of the source is derived to be $z < 0.17$. This redshift upper limit is incompatible with the association of MAGIC J0223+430 with 3C 66A, unless the redshift of 3C 66A is lower than the assumed value of z = 0.444 (Errando et al. 2009).

4.2. 3C 279 and the γ-ray horizon

Observations of 3C 279 during the WEBT multi-wavelength campaign in 2006 revealed a 5.77σ post-trial detection on 2006 February 23rd supported by a marginal signal on the preceding night (MAGIC Coll. 2008). The observed VHE spectrum can be described by a power law with a differential photon spectral index of Γ = 4.1 ± 0.7stat ± 0.2 syst between 75 and 500 GeV. The measured integrated flux above 100 GeV on February 23rd is (5.15 ± 0.82 stat ± 1.5syst)$\times 10^{10}$ photons cm^{-2} s^{-1}. This detection extends the test on the transparency of the universe up to z = 0.536. VHE observations of such distant sources were until recently impossible due to the expected strong attenuation of γ-rays by the EBL, which influences the observed spectrum and flux, resulting in an exponential decrease with energy and a cutoff in the γ-ray spectrum. The reconstructed intrinsic spectrum is difficult to reconcile with models predicting high EBL densities, while low-level models are still viable. Assuming a maximum intrinsic photon index of $\alpha = 1.5$, a upper EBL limit is inferred, leaving a small allowed region for the EBL. The recent findings suggest a higher transparency of the universe to VHE photons than expected from current models of the EBL.

4.3. M 87

M 87 is the first non-blazar radio galaxy known to emit VHE γ-rays, and one of the best-studied extragalactic black-hole systems. To enable long-term studies and assess the variability timescales and the location of the VHE emission in M 87, the H.E.S.S., MAGIC and VERITAS collaborations established a regular, shared monitoring of M 87 and agreed on mutual alerts in case of a signicant detection. During the MAGIC observations, a strong signal of 8σ significance was found on 2008 February 1st , triggering the other IACTs as well as Swift observations. The analysis

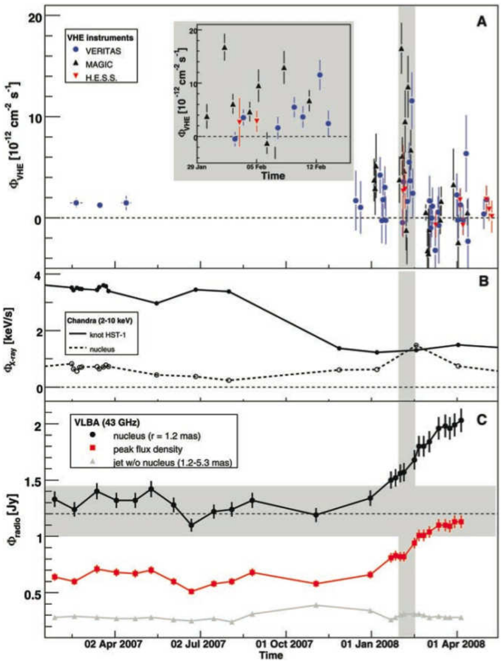

Fig. 2. Combined M87 light curves from 2007 to 2008 (VERITAS et al. 2009). Panel A: VHE γ-ray fluxes ($E > 0.35$ TeV), showing the H.E.S.S., MAGIC, and VERITAS data. Panel B: Chandra X-ray measurements (2 to 10 keV) of the nucleus and the knot HST-1. Panel C: Flux densities from the 43-GHz VLBA observations.

revealed a variable night-to-night γ-ray flux above 350 GeV, while no variability was found in the 150-350 GeV range (Albert et al. 2008). This variability is of the order of or even below one day, suggesting the core of M 87 as the origin of the TeV γ-rays. Simultaneous Chandra observations, found HST-1, the innermost knot in the jet, in a low state, while the nucleus showed an increased X-ray activity as shown in figure 2. The radio activity in 2007 2008, resolving the inner region of M87 down to some 10s Schwarzschild radii, allows for speculation about the origin of the VHE γ-ray emission. A model suggesting HST-1 to be the origin of the γ-ray emission seems less likely in the light of the 2008 result (VERITAS et al. 2009).

5. Conclusions

After almost 4 observation cycles, the MAGIC view of the TeV γ-ray sky contributed to many physics insights, confirming the rich potential of VHE γ-ray astrophysics. MAGIC has contributed to MWL campaigns with other telescopes and observatories and new coordinated campaigns are planned in the near future covering the spectrum from radio to TeV energies.

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