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VHE astrophysics: recent developments

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Abstract. We review the current status, and some open issues, of VHE astrophysics.

Key words. Gamma rays: observations, supernova remnants, pulsars, pulsar wind nebulae, galaxies, active galactic nuclei; cosmic rays; dark matter

1. Introduction

The ground-breaking work of the imaging atmospheric Cherenkov telescope (IACT) Whipple led to the earliest detections of sources in the VHE (i.e., ~0.1-100 TeV) band, the Crab pulsar and nebula (Weekes et al. 1989) and the blazar Mrk 421 (Punch et al. 1992). These pioneering attempts initiated VHE astrophysics. Following on, the first generation of major IACTs – that included CAT (1996-2003), CANGAROO (1992-2001) and HEGRA (1993-2002), in addition to Whipple (1969-2003) itself – broadened the discovery potential of the new field by detecting several more blazars and Galactic sources. Thanks to reduced low-energy thresholds, improved sensitivities, wider-field cameras, and lighter mechanical structures, the current second-generation IACTs – i.e., H.E.S.S. (2003-), MAGIC (2004-), CANGAROO III (2004-), and VERITAS (2006-) – have taken VHE astrophysics into maturity.

In this paper we highlight some recent progress in VHE astrophysics obtained with the current generation of instruments.

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2. Galactic sources

In a seminal VHE survey of the Galactic plane, the southern-located H.E.S.S. telescope discovered 14 previously unknown sources (Aharonian et al. 2006a). Further Galactic sources, accessible from the northern hemisphere, were subsequently observed with the MAGIC telescope (e.g., Albert et al. 2007a). Proposed counterparts of such Galactic VHE sources include supernova remnants (SNRs), pulsar wind nebulae (PWNe), and accreting binaries. Whatever their detailed nature, it is expected that Galactic VHE sources are related to evolutionary endproducts of massive, bright, short-lived, stellar progenitors. Hence, these Galactic VHE sources are immediate tracers of the current star formation.

2.1. Supernova remnants

Galactic cosmic rays have long been suspected to be produced at supernova (SN) shock fronts via diffusive acceleration. If the observed VHE γ-rays were found to be generated through the hadronic channel, via π^0 decay following pp interaction with the dense molecular clouds embedding the short-lived SN progenitor, then the acceleration by SNe of nuclei to energies of the order of the knee in the CR spectrum would be virtually proven (e.g., Torres et al. 2003). However, it is difficult to disentangle the hadronic VHE component from the leptonic one, produced by inverse-Compton (IC) scattering of interstellar radiation field photons (in the inner Galaxy) or CMB photons (in the outer Galaxy) off ultra-relativistic electrons (e.g., Porter et al. 2006), by measuring γ-rays over only a decade or so in energy. The VHE data of RX J1713.7-3946 can be explained in terms of either channel, leptonic/hadronic if the relevant magnetic field is low/high (B~10/100 μG: Aharonian et al. 2006b and Berezhko & Völk 2006). Data in the ~0.1–100 GeV band, such as those to be provided by AGILE and GLAST, are clearly needed to discriminate between the two channels. (For Cas A the high magnetic field, B~1 mG, suggests a mostly hadronic [Berezhko et al. 2003] VHE emission [Oña-Wilhelmi et al. 2007].)

Whatever the details, the detection of photons with energy $\gtrsim$ 100 TeV from RX J1713.7-3946 is a proof of the acceleration of primary particles in SN shocks to energies well above 10^{14} eV. The differential VHE spectral index is ~2.1 all across this SNR, suggesting that the emitting particles are ubiquitously strong-shock accelerated, up to energies ~200/100 TeV for primary CR protons/electrons if the hadronic/leptonic channel is at work (Aharonian et al. 2007). This is getting close to the knee of the CR spectrum, ~$10^{15.5}$ eV, that signals the high-energy end of the Galactic CR distribution (e.g., Blasi 2005).

Circumstantial evidence supports a hadronic origin of the VHE emission. In several expanding SNRs the X-ray brightness profile behind the forward shock is best explained as synchrotron emission from energetic electrons in high magnetic fields, B~O(10^2) μG, i.e. ~100 times larger than typical interstellar medium (ISM) values. Such a large amplified magnetic field disfavors the IC interpretation of the VHE data. Furthermore, in the remnant H.E.S.S. J1834-087 the maximum of the extended VHE emission correlates with a maximum in the density of a nearby molecular cloud (Albert et al. 2006a) – which suggests hadronic illumination of the target molecular cloud.

2.2. Pulsars and associated nebulae

Discrimination between different processes of pulsar magnetospheric emission (e.g., polar-cap vs outer-gap scenario) is one clear goal of VHE astrophysics. Polar-cap (e.g., Daugherty & Harding 1982, 1996) and outer-gap (e.g., Cheng et al. 1986; Romani 1996) models essentially differ by the location of the gap in the pulsar magnetosphere. In the former case this is close to the neutron star (NS) surface, whereas in the latter it is further away from it. Thus, the influence of the magnetic field (B~10^{11-13} G) is crucially different in these models. In polar-cap models, it produces absorption (due to γ+B $\rightarrow e^{\pm}$) leading to a super-exponential cutoff of the emission (mostly curvature radiation). In outer-gap models, only a (milder) exponential cutoff is present, and the highest photon energies depend on the electron energy: in these models a VHE IC component may thus arise from the upscattering, by such energetic electrons, of their emitted synchrotron photons or of the X-ray photons released by NS heating. Both models can deal with current observational constraints.

The current situation is exemplified be the cases of the Vela and PSR B1951+32 pulsars (Aharonian et al. 2006c; Albert et al. 2007b). In the latter case upper limits to the pulsed emission imply a cutoff energy E_c<32 GeV. In both, Vela and PSR B1951+32, IC emission at TeV energies as predicted by outer-gap models is severely constrained, although not all outer-gap models are ruled out. Deeper sensitivities can test the models further, and certainly no test of these models in the range 10–100 GeV has yet been achieved.

Millisecond pulsars, that have lower magnetic fields (B~10^{8-10} G), in polar-cap models could have $E_c \gtrsim$ 100 GeV (i.e., $E_c \propto B^{-1}$), hence their (pulsed) VHE emission could be substantial. Detecting it would be a test of the polar-cap theory (Harding et al. 2005) – however, no positive detection has been reported so far.

The Crab nebula, a steady emitter that is used as a calibration candle, has been observed extensively from the radio up to ∼70 TeV. No pulsed (magnetospheric) VHE emission was found in MAGIC data, that implies E_c<30 GeV (Albert et al. 2007c). The steady nebular spectrum, measured in the ∼0.03-30 GeV range by EGRET and in the ∼0.06-70 TeV by several IACTs, shows a bump that starts to dominate at ∼1 GeV and peaks at ∼50 GeV: this component results from IC scattering, by the synchrotron-emitting electrons, of softer photons in the shocked wind region – i.e., synchrotron, FIR/mm or CMB photons. In spite of its detected IC γ-ray emission, however, the Crab nebula is not an effective IC emitter as a consequence of its high nebular magnetic field (B∼0.4 mG).

PWNe – i.e., pulsars displaying a prominent nebular emission – currently constitute the most populated class of identified Galactic VHE sources (7 identifications – e.g., Gallant 2006). The VHE emission of PWNe is likely of leptonic origin. Let us consider the case of H.E.S.S. J1825-137, for which spectra have been measured in spatially separated regions (Aharonian et al. 2006d). In these regions, the VHE spectra steepen with increasing distance from the pulsar, and the VHE morphology is similar to the X-ray morphology: furthermore the low derived magnetic field (few μG) implies that synchrotron X-ray emission is due to electrons of energy higher than the γ-rays. This suggests that the observations can be interpreted in terms of very energetic electrons that efficiently lose energy via synchrotron losses, aging progressively more rapidly as they are farther away from the acceleration site, and produce VHE γ-rays via IC scattering.

2.3. TeV binaries

In both SNRs and PWNe particle acceleration proceeds on the parsec distance scales in the shocks formed in interactions of either SN ejecta or pulsar winds with the ISM. A different population of much more compact particle accelerators, which has been revealed by current IACTs, is formed by the TeV binaries (TVBs). These systems contain a compact object –either a NS or a black hole (BH)– that accretes, or interacts with, matter outflowing from a companion star: hence they are VHE-loud X-ray binaries (XRBs). Four TVBs have been detected so far: PSR B1259−63 (Aharonian et al. 2005a), LS 5039 (Aharonian et al. 2005b, 2006e), LS I +61 303 (Albert et al. 2006b), and Cyg X-1 (Albert et al. 2007d).

PSR B1259-63 is powered by the rotation energy of its young 48 ms pulsar, and strong VHE emission is observed from this system in pre- and post-periastron phases when the relativistic pulsar wind collides with the dense equatorial wind blowing from the companion Be star.

LS I +61 303 and LS 5039 may share a similar structure. The former is composed of a compact object and a Be star in a highly eccentric orbit. Its VHE emission, whose variability constrains the emitting region of LS I +61 303 to be larger than the binary system's size, appears correlated with the radio emission and does not peak at periastron, where $\dot{M}$ is expected to be largest. This picture favors an IC origin of VHE emission, as probably the most efficient at the relatively large scales of the system at peak emission.

The emission from Cyg X-1 is point-like and excludes the nearby radio nebula powered by the relativistic jet. Cyg X-1 is the first stellar-mass BH, and hence the first established accreting binary, detected at VHE frequencies.

2.4. Galactic center

The possibility of indirect dark matter (DM) detection through its annihilation into VHE γ-rays has aroused interest to observe the Galactic Center (GC). H.E.S.S. and MAGIC observed the GC, measuring a steady flux consistent with a differential power-law slope of ∼2.2, up to energies of ∼20 TeV with no cutoff (Aharonian et al. 2004; Albert et al. 2006c). Within the error circle of the measurement of the central source H.E.S.S. J1745-290 are three compelling candidates for the origin of the VHE emission: the shell-type SNR Sgr A East, the newly discovered PWN G 359.95−0.04, and the supermassive BH Sgr A* itself. Plausible radiation mechanisms include IC scattering of energetic electrons, the decay of pions produced in the interactions of energetic hadrons with the ISM or dense radiation fields, and curvature radiation of UHE protons close to Sgr A*. These considerations disfavor DM annihilation as the main origin of the detected flux, whereas a more conventional astrophysical mechanism is likely to be at work (e.g., Aharonian et al. 2006f). Furthermore, the lack of flux variability on hour/day/year timescales suggests that particle acceleration occurs in a steady object, such as a SNR or a PWN, and not in the central BH.

The GC diffuse emission correlates with molecular clouds and suggests an enhanced CR spectrum in the Galactic center (Aharonian et al. 2006g). Its morphology and spectrum suggest recent in situ CR acceleration: because the photon indexes of the diffuse emission and of the central source H.E.S.S. J1745-290 are similar, the latter source could be the accelerator in question.

3. Star-forming galaxies

Diffuse γ-ray emission from pp interactions of CR nuclei with target ISM and photons makes up ~90% of the >100 MeV luminosity of the Milky Way (Strong et al. 2000). However, the VHE flux from a galaxy like the Milky Way located 1 Mpc away would be well below current IACT sensitivities. Indeed, only loose upper limits on the VHE flux from normal galaxies have been obtained, even for local galaxies and for the VHE-bright starburst galaxies (e.g., Torres et al. 2004). Detailed models of VHE emission from NGC 253 (Völk et al. 1996; Paglione et al. 1996; Domingo-Santamaría & Torres 2005) and for Arp 220 (Torres 2004) are only loosely constrained by current upper limits (Aharonian et al. 2005c; Albert et al. 2007e).

4. Active galactic nuclei

Supermassive black holes (SMBHs) reside in the cores of most galaxies. The fueling of SMBHs by infalling matter produces the spectacular activity observed in active galactic nuclei (AGNs).

The current AGN paradigm includes a central engine, most likely a SMBH, surrounded by an accretion disk and by fast-moving clouds, which emit Doppler-broadened lines (Urry & Padovani 1995; Padovani 2007). In ~10 collimated jets that shoot out from the SMBH in opposite directions, likely perpendicular to the disk, at relativistic speeds.

If a relativistic jet is viewed at small angle to its axis the observed jet emission is amplified by relativistic beaming [1] and dominates the observed emission. Such sources are called blazars. Given the blazars' compactness (as suggested by their short variability timescales), all GeV/TeV photons would be absorbed through pair-producing $\gamma\gamma$ collisions with target X-ray/IR photons. Beaming ensures the intrinsic radiation density to be much smaller than the observed one, so that γ-ray photons encounter a much lower $\gamma\gamma$ opacity and hence manage to leave the source: reversing the argument, γ-ray detection is a proof of strongly anisotropic (e.g., beamed) emission.

The spectral energy distributions (SEDs) of blazars are generally characterized by two broad humps, peaking at, respectively, IR/X-ray and GeV-TeV frequencies (Ulrich et al. 1997). Analyses of blazar SEDs (Fossati et al. 1998; Ghisellini et al. 1998) have suggested that: *(i)* higher/lower-luminosity objects have both humps peaking at lower/higher frequencies (they are called, respectively, LBLs and HBLs); *(ii)* the luminosity ratio between the high- and low-frequency bumps increases with luminosity; *(iii)* at the highest luminosities the γ-ray output dominates the total luminosity.

The mainstream interpretation of the blazars SEDs is synchrotron-Compton emis-

[1] Defining the relativistic Doppler factor as $\delta \equiv [\Gamma(1-\beta\cos\theta)]^{-1}$ (with $\beta = v/c$ the jet speed normalized to the speed of light, $\Gamma = 1/\sqrt{(1-\beta^2)}$, and θ the angle w.r.t. the line of sight), the observed and intrinsic luminosities at a given frequency f are related by $L_f^{\rm obs} = \delta^p L_f^{\rm em}$ with p~2-3, and the variability timescales are related by $\Delta t_{\rm obs} = \delta^{-1} \Delta t_{\rm em}$. For $\theta \sim 0°$ and $\delta \sim 2\,\Gamma$ the observed luminosity can be amplified by factors ~400–10^4 (for, typically, Γ~10 and p~2-3); whereas $\theta \sim 1/\Gamma$ implies $\delta \sim \Gamma$, with a luminosity amplification of ~10^2–10^3.

sion, i.e. synchrotron emission (peaked in the IR/X-ray range) from a time-varying population of ultra-relativistic electrons moving in a strong magnetic field, and IC emission (peaked in the ~100 MeV–100 GeV range) from soft photons scattering off energetic electrons. Depending on the relative efficiency of the relativistic particles' cooling through scattering with photon fields that are internal to jet or external to it, the synchrotron and Compton components peak at, respectively, UV/X-ray and GeV–TeV energies (synchrotron-self-Compton [SSC] scheme: e.g., Maraschi et al. 1992) or at IR/optical and MeV–GeV energies (external-IC [EIC] scheme, see Dermer & Schlickeiser 1993). Hybrid SSC/EIC models have also been proposed (Ghisellini 1999). Alternative models of VHE emission involve, e.g., two electron populations, one –primary– accelerated within the jet and the other –secondary– generated by electromagnetic cascades initiated by primary protons/nuclei that had been accelerated in the jet (Mannheim 1993); or a population of extremely energetic protons emitting by synchrotron radiation (Aharonian 2000).

The emitting particles are accelerated within the relativistic jets which transport energy from the central SMBH outwards (Rees 1967). In the popular SSC framework this process is approximated with a series of relativistically moving homogeneous regions (blobs), where particle acceleration and radiation take place (e.g., Maraschi et al. 1992). The X-ray and γ-ray emission, with its extremely fast and correlated multi-frequency variability, indicates that often a single region dominates the emission.

VHE data are of crucial importance to close the SSC model. Even in the simplest one-zone SSC model of blazar emission, knowledge of the whole SED up to the VHE regime is required for a complete description of the emitting electrons' distribution and environment (e.g., Tavecchio et al. 1998). The parameters that specify the properties of the emitting plasma in the basic SSC model are: the electron distributions normalization, low- and high-energy slopes, and min/break/max energy, and the plasma blobs magnetic field, size and Lorentz factor. Knowing only the IR/X-ray peak would give info on the shape (i.e., the broken-power-law slopes) of the electron distribution but would leave all other parameters unconstrained (e.g., Tavecchio et al. 1998). However, accurate knowledge of blazar emission mechanism(s) requires *simultaneous* broadband γ-ray and X-ray (i.e., IC and synchrotron) data. In fact, a simultaneous SED can act as a snapshot of the emitting population of particles at a given time.

Blazar observations have been a top priority for VHE astrophysics ever since the discovery of TeV emission from Mrk 421 (Punch et al. 1992). To date, firm blazar TeV detections include 15 HBLs and 1 LBL. (One further non-blazar AGN, M 87, has also been detected, see Aharonian et al. 2006h).)

The known TeV blazars are variable in flux in all wavebands. Even simple one-zone homogeneous SSC modeling predicts the X-ray and TeV flux variability to be closely correlated, both emissions being linked to the same electron population. Observational evidence, although still statistically limited, supports this prediction (e.g., Pian et al. 1998). (Some TeV flares that show no simultaneous X-ray counterpart may be explained as IC radiation from an additional, very compact and dense, electron population – see Krawczynski et al. 2004.) Blazar variability, in flux and spectrum, has been observed at VHE frequencies down to minute timescales. For Mkn 501, observed with the MAGIC telescope at >100 GeV during 24 nights between May and July 2005, the integrated flux and the differential photon spectra could be measured on a night-by-night basis (Albert et al. 2007f). During the observational campaign, the flux variations (from ~0.4 to ~4 crab units) were correlated with the spectral changes (i.e., harder spectra for higher fluxes), and a spectral peak showed up during the most active phases. A rapid flare occurred on the night of 10 July 2005, showing a doubling time as short as ~2 minutes and a delay of ~3 minutes as a function of energy of the emitted photons.

One further aspect of TeV spectra of blazars is that they can be used as probes of the Extragalactic Background Light (EBL), i.e. the integrated light arising from the evolving stellar populations of galaxies (see Hauser & Dwek 2001). The TeV photons emitted by a blazar interact with the EBL photons and are likely absorbed via pair production. Whatever its intrinsic shape at emission, after travelling through the EBL-filled space, a blazar spectrum will reach the observer distorted by absorption. This effect, which is stronger for more distant objects (e.g., Stecker et al. 1992), is the most likely origin of the avoidance zone (i.e., no flat spectra at high redshift) in the observed spectral slope vs redshift plot. The strength of the absorption is measured by $\tau_{\gamma\gamma}(E)$, the optical depth for attenuation between the blazar, located at a distance $D(z)$, and the Earth (Fazio & Stecker 1970; Stecker et al. 1992). Usually, either *(i)* the shape and intensity of EBL(z) is assumed, and the TeV spectrum is corrected before the SSC modeling is performed (e.g., de Jager & Stecker 2002; Kneiske et al. 2004); or *(ii)* based on assumptions on the intrinsic VHE spectrum, EBL(z) is solved for: e.g., based on analysis of the observed hard VHE spectra of the distant blazars 1ES 1101-232 and H 2359-309, a low EBL energy density at $z\lesssim 0.2$ has been derived (Aharonian et al. 2006i). The two approaches can be used in combination to estimate the distance to the VHE source (Mazin & Goebel 2007).

5. Gamma-ray bursts

There is a prevailing consensus that the basic mechanism of GRB emission is an expanding relativistic fireball (Rees & Meszaros 1992, Meszaros & Rees 1993, Sari et al. 1998), with the beamed radiation (δ~O(10^2) due to internal/external shocks (prompt/afterglow phase, respectively). If so, the emitting particles (electrons and/or protons) are accelerated to very high energies.

In the fireball shock framework, several models have predicted VHE emission during both the prompt and afterglow phases of the GRB (e.g., Meszaros 2006). This can occur as a result of electron self-IC emission from the internal shock or the external forward/reverse shock. Seed photons can be produced locally (through synchrotron, or be the leftover of the initial radiation content responsible for the acceleration of the fireball) or can be produced in, e.g., the shell of a previously exploded SN. In the latter case, the SN photons may also act as targets for the $\gamma\gamma$ absorption, and in this case the VHE emission could be severely dimmed. If the emission processes are indeed synchrotron and IC, then a blazar-like SED is predicted, with a double-peak shape extending into the VHE band. In such theoretical freedom, VHE observations of GRBs could help constraining GRB models.

MAGIC observed part of the prompt-emission phase of GRB 050713a as a response to an alert by the Swift satellite (Albert et al. 2006d) However, no excess at >175 GeV was detected, neither during the prompt emission phase nor later – but the upper limits to the MAGIC flux are compatible with simple extrapolations of the Swift $\Gamma\simeq 1.6$ power-law spectrum to hundreds of GeV. In general, however, the cosmological distances of these sources prevent VHE detection (see Albert et al. 2007g): the average redshift of the GRBs for which MAGIC was alerted (and whose z are known) is $\bar{z}$=3.22, whereas at 70 GeV the cosmological γ-ray horizon is $z\sim 1$. Complementary Whipple data (Horan et al. 2007) and MILAGRO data (Abdo et al. 2007) provide upper limits on, respectively, the late VHE emission (~4 hr after the burst) from several long-duration GRBs, and on the prompt/delayed emission from several, reputedly nearby ($z\lesssim 0.5$), short-duration GRBs.

6. Dark matter

Evidence for departure of cosmological motions from the predictions of Newtonian dynamics based on visible matter, interpreted as due to the the presence of DM, are well established – from galaxy scales (e.g., van Albada et al. 1985) to galaxy-cluster scales (e.g., Sarazin 1986) to cosmological scales (e.g., Spergel et al. 2003).

DM particle candidates should be weakly interacting with ordinary matter (and hence neutral). The theoretically favored ones, which are heavier than the proton, are dubbed weakly interacting massive particles (WIMPs).

WIMPs should be long-lived enough to have survived from their decoupling from radiation in the early universe into the present epoch. Except for the neutrino, which is the only DM particle known to exist within the Standard Model of elementary particles (with a relic background number density of $\sim$50 cm^{-3} for each active neutrino species) but which is too light ($m_\nu \lesssim 1$ eV) to contribute significantly to Ω_m given the current cosmological model, WIMP candidates have been proposed only within theoretical frameworks mainly motivated by extensions of the Standard Model of particle physics (e.g., the R-parity conserving supersymmetry [SUSY]). Among current WIMP candidates (see Bertone et al. 2005), the neutralino, which is the lightest SUSY particle, is the most popular candidate. Its relic density is compatible with *W*MAP bounds (see Munoz 2004).

WIMPs could be detected directly, via elastic scattering vith targets on Earth, or indirectly, by their self-annihilation products in high-density DM environments. DM annihilation can generate γ-rays through several processes. Most distinctive are those that result in mono-energetic spectral lines, $\chi\chi \to \gamma\gamma$, $\chi\chi \to \gamma Z$ or $\chi\chi \to \gamma h$. However, in most models the processes only take place through loop diagrams; hence the cross sections for such final states are quite suppressed, and the lines are weak and experimentally challenging to observe. A continuum γ-ray spectrum can also be produced through the fragmentation and cascades of most other annihilation products. The resulting spectral shape depends on the dominant annihilation modes (see Bergström & Hooper 2006), whereas the normalization depends on the WIMP's mass and velocity-averaged annihilation cross section as well as on the DM density profile.

Once the astroparticle model has been chosen (e.g., Bergström et al. 1998), the biggest uncertainties are of astrophysical nature. Superposed to any VHE emission from the decaying DM (cosmological, non-baryonic signal), galaxies can display a VHE emission from astrophysical sources associated with the visible matter distribution (astrophysical, baryonic signal). The ratio of the former to the latter is maximized in small, low-*L*, low-SFR galaxy. This is because the dark-to-visible mass ratio as well as the central DM density increase with decreasing luminosity (Persic et al. 1996). Clearly, distance dilution of the signal opposes detection, so galaxies candidate for indirect DM detection should be chosen among nearby objects. In conclusion, the best observational targets for DM detection are the Milky Way dwarf spheroidal galaxies (e.g., Draco, Sculptor, Fornax, Carina, Sextans, Ursa Minor). A further issue, stemming from the ρ^2 dependence (as a result of annihilation) of the normalization integral of the γ-ray emission, concerns the shape of the inner halo profile, i.e. whether the latter is cuspy or cored. Cuspy profiles are produced in cosmological N-body simulations of halo formation (Navarro et al. 1997), whereas cored profiles are suggested by the measured rotation curves of disk galaxies (Borriello & Salucci 2001) – also in low-surface-brightness galaxies, where the local self-gravity of baryons is virtually negligible (de Blok et al. 2001).

These considerations (and uncertainties) have been incorporated in detailed predictions of the γ-ray flux expected from the annihilation of the neutralino pairs. Outlooks for VHE neutralino detection in Draco by current IACTs are not very promising: for a neutralino mass m_χ=100 GeV and a variety of annihilation modes, and in the favorable case of a maximal (cuspy) inner halo profile, VHE detection (by MAGIC in 40hr observation) can occur if average value of the neutralino's cross section times velocity is $<\sigma v> \gtrsim 10^{-25}$ cm^{3}s^{-1}, which is somewhat larger than the maximum value for a thermal relic with a density equal to the measured (cold) DM density (but may be fine for non-thermally generated relics) in the allowed SUSY parameter space. The prospects are better in the HE range (100 MeV–10 GeV): for a maximal (cuspy) halo, 1 yr of GLAST observation should be able to yield a detection if $m_\chi \lesssim 500$ GeV and $<\sigma v> \sim 3\times10^{-25}$ cm^{3}s^{-1} (Bergström & Hooper 2006).

No evidence of DM annihilation γ-rays has been unambiguously claimed so far. An apparently extended signal from the direction of

NGC 253 has been definitely interpreted as due to hardware malfunction (Itoh et al. 2007).

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