TEV OBSERVATIONS OF SNRS AND UNIDENTIFIED SOURCES

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**Abstract**

A review of very high energy $\gamma$-ray astronomy is presented. Particular attention is paid to the atmospheric Cherenkov imaging technique whose employment has resulted in detections of both galactic and extra-galactic objects at energies above 300GeV. Next generation ground-based telescopes promise to increase our knowledge of extreme astrophysical objects as they begin to operate over the next few years.

1. **INTRODUCTION**

Very High Energy (VHE) $\gamma$-ray astronomy, or TeV $\gamma$-ray astronomy as it is sometimes known, traditionally describes observations in the energy range from 300GeV to 100TeV. Doing astronomy in this energy range was made possible by the development of the atmospheric Cherenkov imaging technique, which led to the detection of the first VHE source, the Crab Nebula, more than ten years ago (Weekes et al. 1989). Ground-based instruments operating in this energy region typically have large collecting areas, high angular resolution and good energy resolution (Ong 1998).

In the years since the detection of the Crab Nebula many other galactic and extra-galactic VHE $\gamma$-ray sources have been detected. There are observatories operating in the northern and southern hemispheres which have been able to independently confirm a number of the claimed de-
tectons. Ground-based telescopes have participated in multi-wavelength observations with satellite-based detectors, yielding many interesting results. To date only 1% of the VHE sky has been observed at these energies.

The coming years will bring a new generation of ground-based VHE $\gamma$-ray observatories that will build on the techniques developed over the past three decades. A number of large, next generation, Cherenkov telescopes are either starting to operate or being built around the world. The first decade of the new millennium promises many new exciting results in this field.

2. GROUND-BASED TELESCOPES

At very high energies, $\gamma$-rays and cosmic-rays interact with the atmosphere to produce Extensive Air Showers (EAS), showers of charged secondary particles which propagate through the atmosphere, reaching the ground if the energy of the primary particle is sufficiently high. Detecting these showers and inferring the composition, energy and arrival direction of the primary particle is the challenge of ground-based VHE astronomy. Fortunately, the mechanism by which the shower is produced is very well known and can be modeled for different primaries at any energy.

Directly detecting the secondary particles is possible for instruments placed at high altitude and for sufficiently energetic primaries. For lower energy primaries, the cascade of charged particles does not reach the ground but can be indirectly detected from the Cherenkov radiation emitted as the relativistic charged particles traverse the atmosphere at speeds in excess of the speed of light in air. The Cherenkov photons are strongly beamed in the arrival direction of the incident photon and form a narrow cone of light as they travel down through the atmosphere. A telescope with fast light detectors can sample the $\sim 5$ns pulse of Cherenkov light. The total number of photons recorded is roughly proportional to the energy of the primary, unless the telescope samples at the edge of the shower, where the number of photons falls off quickly.

Historically, the most successful ground-based detection method has been the Imaging Atmospheric Cherenkov Technique originally proposed in 1977 (Weekes & Turver 1977). A large telescope collects Cherenkov light from showers and focuses it onto a plane of photomultiplier tubes. Imaging the shower in such a fashion produces a “picture” of its development through the atmosphere. Typically, these images are characterized by a number of straightforward parameters (Hillas 1985) and it is on the basis of subtle differences in these parameters that hadronically pro-
duced showers can be differentiated from purely electromagnetic showers and rejection of cosmic-ray particles can be made. Although the isotropic background consists of $\sim 1000$ times more cosmic-rays than $\gamma$-rays, a single imaging atmospheric Cherenkov telescope (IACT) can reject 99.7% of the events caused by these background showers, leaving a statistically detectable $\gamma$-ray signal, if one is present and sufficiently strong. An array of such telescopes working in coincidence can reject substantially more (Daum et al. 1997).

Since the detection of the Crab Nebula in 1989, VHE gamma-ray astronomy has advanced in two major ways. First, the development of high resolution cameras has allowed better imaging of the showers and more refined rejection of hadronic background events. A number of observatories such as the Whipple 10m telescope, CAT, a French telescope in the Pyrenées (Barrau et al. 1998) and CANGAROO, a Japanese-Australian telescope in Woomera, Australia (Hara et al. 1993) employ this approach. The second major development is the combination of a number of IACTs to form an array that can view the shower development from a number of different points on the ground. Such stereoscopic viewing increases the suppression of hadronic background and allows for better reconstruction of the arrival direction and energy of the primary photon. To date the most significant example of such an array is HEGRA, five small imaging telescopes on La Palma run by an Armenian-German-Spanish collaboration (Daum et al. 1997).

Figure 1  Left, the Whipple observatory 10m imaging atmospheric Cherenkov telescope. Right, at the focus, a 490 pixel high resolution camera operating since 1999.
3. SUPERNOVA REMNANTS

3.1. PLERIONS

The Crab Nebula has been detected in VHE $\gamma$-rays by many independent Cherenkov observatories in the northern hemisphere and by one in the southern. Routine observations of the Crab Nebula by IACTs continue and it has come to be regarded by the VHE community as the “standard candle” and is often used to provide a check on the calibration of new instruments. Modern IACTs can detect the Crab Nebula at the 5-6$\sigma$ level after one an hour of observations, a testament to how far the field has advanced since the original detection in 1989, which was a 9$\sigma$ excess based on 60 hours of observations. Recently the STACEE and CELESTE collaborations, have published significant detections of the Crab Nebula in the energy region $E > 190 \pm 60$GeV (Oser et al. 2000) and $E > 50$GeV (De Naurois et al., 2000) respectively, an energy range that extends lower than other ground-based instruments. At the other end of the VHE spectrum, the Crab was the first $\gamma$-ray source source detected by an air shower array, when it was seen by the Tibet Air Shower Array at $E > 3$TeV (Amenomori 1999).

The energy spectrum between 300GeV and 50TeV has been well established by a number of groups (Hillas et al. 1998, Aharonian et al. 2000). To date no pulsation has been seen in the VHE $\gamma$-ray signal from the Crab (Gillanders et al. 1997; Burdett et al. 1999; Aharonian et al. 1999). The VHE flux is thought to arise, in the most part, from inverse Compton scattering of synchrotron photons by relativistic electrons, so called synchrotron self-Compton or SSC emission (De Jager & Harding 1992; Hillas et al. 1998). By fitting the SSC model to the energy spectrum that results from combining the X-ray, EGRET and VHE data, a magnetic field of 160$\mu$G is derived (Hillas et al. 1998).

No other plerions have been detected by IACTs in the northern hemisphere; however the situation is different in the southern hemisphere where the CANGAROO group have detected two. In 1993 they reported the detection of PSR 1706-44 based on 60 hours of observations (Kifune et al. 1995). Confirmation by the Durham group based on 10 hours of observation was subsequently made (Chadwick et al. 1997). The VHE source is associated with a pulsar of period 102ms and appears to be associated with a supernova remnant. No pulsations have been detected in the VHE data. The CANGAROO group has also reported the detection of a VHE signal in the neighborhood of the Vela pulsar. The detection is at the 6$\sigma$ level based on $\sim 120$ hours of observation and the measured flux above 2.5TeV is $0.25 \times 10^{-11}$cm$^{-2}$s$^{-1}$. The VHE signal, which is offset from the location of the pulsar by 0.14$^\circ$, is thought to originate
Table 1  TeV Observations of Plerions

| Object Name     | Exposure time (hours) | Flux/Upper Limit x 10^{-11} cm^{-2} s^{-1} |
|-----------------|-----------------------|--------------------------------------------|
| Crab Nebula     | \( \rightarrow \infty \) | 7.0 (> 400GeV)                             |
| CANGAROO        |                       |                                            |
| PSR 1706-44     | 60                    | 0.15 (>1TeV)                               |
| Vela Pulsar     | 116                   | 0.26 (E/2 TeV)^{-2.4} TeV^{-1}             |
| Durham          |                       |                                            |
| PSR 1706-44     | 10                    | 1.2 (>300GeV)                              |
| Vela Pulsar     | 8.75                  | <5.0 (>300GeV)                             |

from a synchrotron nebula, powered by a population of relativistic electrons which were created in the supernova explosion and which have survived since then due to the low magnetic field in the nebula. The nebula is assumed to be centered on the birthplace of the pulsar, which was ejected at the time of the supernova explosion.

Figure 2  VHE emission in the neighborhood of the Vela Pulsar as detected by the CANGAROO experiment. The contours show the number of excess events per deg^2. The present location of the pulsar is marked with a star.
3.2. SHELL-TYPE

It has long been hoped that VHE $\gamma$-ray astronomy could provide a probe of the origin of cosmic-rays with $E < 10^{14}$eV. Supernovae are regarded as the most likely producers of these cosmic-rays as they are the only galactic objects capable of supplying the power required to account for the observed cosmic-ray energy spectrum. Furthermore, diffusive shock acceleration (Blanford & Ostriker 1978, Bell 1978) provides a natural mechanism to convert the kinetic energy of the SNR shock-front into a spectrum of accelerated charged particles with $dN/dE = E^{-2.1}$. This source spectrum, after correcting for diffusion in the galaxy (Swordy et al. 1990), fits the locally observed spectrum of $E^{-2.7}$. If this mechanism is correct, then interactions between the relativistic charged particles and the interstellar medium surrounding the SNRs should produce $\gamma$-rays through the decay of secondary $\pi^0$ particles (Drury, Aharonian & Völk 1994 – DAV). These models predict that fluxes of $\gamma$-rays should be high enough to be visible to the current generation of satellite-based and ground-based detectors. Detection of the signature $\pi^0$ bump at MeV energies and a spectrum extending to tens of TeV would be a clear indication that cosmic-ray acceleration does take place in SNRs. However, the experimental situation is complicated by the presence of a population of $\gamma$-rays produced by the inverse-Compton reaction of relativistic electrons and the cosmic microwave background. Separating these two components requires that the spectrum be measured continuously from 10 MeV to 10 TeV.

For most of its history, VHE $\gamma$-ray astronomy provided no detections of shell-type supernova remnants. Observations of SNRs that are considered to be good candidates for neutral pion decay have been undertaken by numerous groups. In particular, observations of W44, W51, $\gamma$-Cygni, W63 and Tycho’s SNR, selected due to their possible association with molecular clouds which should provide an enhanced target for $\pi^0$ decay, their possible associations with EGRET sources and their small angular extent (Buckley et al. 1998), have failed to produce detections in VHE $\gamma$-rays (Table 2). Buckley et al. 1998 suggest that, assuming the EGRET emission is from these shell-type SNRs and that $\pi^0$ decay dominates, the spectra of cosmic-rays produced would have to be softer than suggested by DAV. The required differential source spectrum is $E^{-2.5}$ for $\gamma$-Cygni and $E^{-2.4}$ for IC443. Even if no reference is made to the EGRET data, the VHE upper-limits for some of the objects (IC443) push the allowable parameter space of DAV. Gaisser et al. (1998) performed fits of the EGRET and Whipple results concluding that the EGRET data must be
dominated at lower energies by electron bremsstrahlung but the source spectrum must still be steep to account for the Whipple upper limits.

Table 2  TeV Observations of Shell-type SNR

| Object Name | Exposure time (hours) | Flux/Upper Limit \( \times 10^{-11} \text{cm}^{-2}\text{s}^{-1} \) |
|-------------|----------------------|--------------------------------------------------|
| CANGAROO    |                      |                                                  |
| RXJ 1713.7-3946 | 66               | 0.53 (\( \geq 1.8 \) TeV)                       |
| SN1006      | 34                  | 0.46 (\( \geq 1.7 \) TeV)                       |
| W28         | 58                  | <0.88 (> 5 TeV\(^a\))                           |
| HEGRA       |                      |                                                  |
| Cas A       | 232                 | 0.058 (> 1 TeV)\(^b\)                           |
| \(\gamma\)-Cygni | 47              | <1.1 (>500 GeV)\(^c\)                           |
| Durham      |                      |                                                  |
| SN1006      | 41                  | <1.7 (>300 GeV)                                 |
| Whipple     |                      |                                                  |
| Monoceros   | 13.1                | <4.8 (>500 GeV)                                 |
| Cas A       | 6.9                 | <0.66 (>500 GeV)                                |
| W44         | 6                   | <3.0 (>300 GeV)                                 |
| W51         | 7.8                 | <3.6 (>300 GeV)                                 |
| \(\gamma\)-Cygni | 9.3             | <2.2 (>300 GeV)                                 |
| W63         | 2.3                 | <6.4 (>300 GeV)                                 |
| Tycho       | 14.5                | <0.8 (>300 GeV)                                 |
| CAT         |                      |                                                  |
| CasA        | 24.4                | <0.74 (>400 GeV)                                |

\(^a\) A different definition of Energy Threshold is used  
\(^b\) Evidence for emission at the 4.9\(\sigma\) level (Pühlhofer et al. 2001)  
\(^c\) Limits converted from Crab units using flux of Hillas et al. 1998  

Recent observations of shell-type SNRs by the CANGAROO group have resulted in the detections of SN1006 (Tanimori et al. 1998) and RXJ1713.7-3946 (Muraishi et al. 2000). Observations of SN1006 in 1996 and 1997 show a significant excess from the NW rim of the SNR. The excess is consistent with the location of non-thermal X-rays detected by ASCA (Koyama et al. 1995). Similarly, RXJ1713.7-3946 has recently had a ROSAT and ASCA X-ray source associated with it (Pfeffermann & Aschenbach 1996). The TeV \(\gamma\)-ray signal from these objects, if confirmed, would not necessarily imply that they are accelerators of hadronic cosmic-rays. It is considered likely that the \(\gamma\)-rays are linked through inverse-Compton scattering with a population of rel-
Figure 3 MeV - TeV observations of shell-type SNR. Whipple upper limits marked as (W), associated EGRET fluxes as points or EGRET upper-limits (E). Also shown are CASA-MIA (CM), Cygnus (C) and AIROBICC upper-limits. The solid curve shows the extrapolation of the DAV model from the EGRET integral data points at 100 MeV, shown as a triangle. The dashed curve show the reasonable flux ranges of the DAV model without making any assumptions about the EGRET data.
ativistic electrons which are also responsible for producing the X-rays. In any case, further observations and the determination of the energy spectrum with more sensitive instruments will be required either to confirm or to completely rule out the presence of a hadronic component to the TeV signal.

The latest shell-type SNR to be detected at TeV energies is Cassiopeia A, recently announced as a source by the HEGRA collaboration (Pühlhofer et al. 2001). Based on 232 hours of observations they report an excess at the 4.9σ level, and calculate a flux of $F = 5.8 \pm 1.2,_{stat} \pm 2,_{syst} \times 10^{-13} \text{cm}^{-2}\text{s}^{-1}$ at ($E > 1$ TeV). Whether the $\gamma$-rays from Cas A arise from inverse-Compton interactions or through neutral pion decay has not yet been determined. There are reasons to think that both components may be present at some level. First, Cas A is associated with a bright source of hard X-rays which indicates a population of non-thermal electrons with energies up to 100 TeV (Allen et al. 1999). Second, Cas A is situated in a region of high ambient matter density which has been associated with the wind system left over from the progenitor. Measurement of the energy spectrum will be required before any determination between the two components can be made.

4. UNIDENTIFIED SOURCES

IACTs are most sensitive when observing on-axis point sources, i.e. when pointing directly towards an object of small angular extent. Observations of extended sources or of sources where the location is not well known are possible, however, as IACTs do have good sensitivity across most of their field of view. It is therefore possible to create a two dimensional VHE map of the sky within, typically, $0.5 - 1.0^\circ$ of the center of the field of view. The angular resolution of a single IACT is 0.15° (Lessard et al. 2000), and better for an array of IACTs, providing the ability to resolve the location of a source within the field of view to high accuracy.

VHE observations of unidentified EGRET sources are usually made on the basis of their luminosity, spectrum and size of their error box or if they have a good candidate association, such as an SNR or pulsar which allows sensitive, point source observations to be made.

Results of previous observations of unidentified EGRET sources with the Whipple 10m telescope (Buckley et al. 1997) and new results from ongoing observations are given in table 3. No unidentified sources have been detected in VHE $\gamma$-rays but for many of them, upper limits have been placed on VHE emission from within the EGRET error circle.
Table 3  TeV Observations of Unidentified Sources

| Object Name      | Exposure time (mins) | Flux Upper Limit $\times 10^{-11} cm^{-2}s^{-1}$ |
|------------------|----------------------|-----------------------------------------------|
| J0241+6119       | 972                  | 1.02$^a$                                      |
| J0433+2907       | 499                  | 4.4$^a$                                       |
| J0545+3943       | 108                  | 6.72$^a$                                      |
| J0618+2234       | 1188                 | 0.911$^a$                                     |
| J0635+0521       | 108                  | 5.59$^a$                                      |
| J0749+17         | 486                  | 0.813$^a$                                     |
| J1746-2852       | 270                  | 0.45$^b$                                      |
| J1825-1307       | 702                  | 1.55$^a$                                      |
| J1857+0118       | 351                  | 2.79$^a$                                      |
| J2016+3657       | 287                  | 5.8$^a$                                       |
| J2020+4026       | 513                  | 0.990$^a$                                     |
| J2227+6122       | 274                  | 6.0$^a$                                       |

$^a$Integral Flux Above 400 GeV.

$^b$Integral Flux Above 2.0 TeV.

5. THE NEXT GENERATION

The future of ground-based $\gamma$-ray astronomy lies with the next generation of observatories that will build on the advances made to date. Significant discoveries will come from extending the energy range observable from the ground and by improving the flux sensitivity.

Extending the observable energy range below 200 GeV will be achieved by building instruments with larger mirror area to gather more light from the shower. Two approaches have been suggested. The first uses existing solar furnace facilities which have fields of large heliostats that lie unused at night. The arrival of the Cherenkov wavefront at groups of heliostats is precisely measured and this information is used to differentiate $\gamma$-rays from cosmic-rays (Ong 1998). STACEE (Chantell et al. 1998), CELESTE (Quebert et al. 1995) and Solar-2 (Tümer et al. 1999), each of which use this technique, have started operating in the last few years and hope to observe at $\sim$20-30 GeV. MAGIC (Barrio et al. 1998) takes a different approach; by extending the size of a traditional IACT to 17m they plan to achieve a significantly lower energy threshold than is possible with current generation telescopes.

At the other end of the VHE spectrum, air shower arrays on very high mountains, such as the Tibet Air Shower Array (Amenomori 1999) and Cherenkov telescopes operating at large zenith angles have been
joined by MILAGRO (Sinnis et al. 1995), a water Cherenkov detector in New Mexico that views all of the visible sky with 45° of the zenith and operates 24 hours a day and hopes to achieve a better energy overlap with traditional ground-based techniques.

Figure 4  Point source sensitivity of some of the current and next generation of γ-ray instruments; Whipple (Weekes et al. 1989), MAGIC (Barrio et al. 1998), STACEE & CELESTE (Chantell et al. 1998 & Quebert et al. 1995), HEGRA (Daum et al. 1997), GLAST (Gehrels & Michelson 1999), EGRET (Thompson et al. 1993) and MILAGRO (Sinnis et al. 1995).

To significantly increase flux sensitivity and angular resolution while achieving a broad operating energy range of 100GeV to 10TeV a number of groups have undertaken to build arrays of large (∼ 10 – 12m) IACTs operating in coincidence. VERITAS (Bradbury et al. 1999), a system of seven 10m telescopes in Arizona will build on the experience gained by the Whipple group. HESS (Hoffmann 1997), an array of four (and possibly sixteen when completed) of 12m telescopes in Namibia will extend the ideas pioneered by HEGRA. The Japanese-Australian CANGAROO group are building an array of four 10m telescopes at the site of the present CANGAROO experiment, one telescope has been completed. Collectively, these three arrays and the MAGIC telescope
are often referred to as the Next Generation Gamma-Ray Telescopes (NGGRTs).

Figure 4 shows how all of these upcoming experiments will overlap with the EGRET and Whipple sensitivities and also with the sensitivity of the upcoming GLAST mission. It is evident that the NGGRTs will provide some overlap with GLAST and the solar arrays, and at the high energy side with the Tibet Air Shower array and MILAGRO.

The future of ground-based $\gamma$-ray astronomy will be very interesting. Continued cooperation with space-based missions will ensure that the energy range from 1MeV to 10TeV will be well covered in both the northern and southern hemispheres. Better flux sensitivity will mean that new sources will be discovered; excellent angular resolution will ensure that accurate source locations and associations will be found. Detailed energy spectra in this range will allow for better models of the emission regions.

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References

Aharonian, F.A., et al. (1999), *A&A*, 346, 913
Aharonian, F.A., et al. (2000), *ApJ*, 539, 317
Allen, G.E., Gotthelf, E.V., Petre, R. (1999), *Proc. 26th Internat. Cosmic Ray Conf. (Salt Lake City)*, 3, 480
Amenomori, M., et al. (1999), *ApJ*, 525, L93
Barrau, A. et al. (1998), *Nucl. Instrum. Methods A*, 416, 278
Barrio, J.A., et al. (1998), “The MAGIC Telescope”, *design study, MPI-PhE/98-5*
Bell, A.R. (1978) *MNRAS*, 182, 147
Blanford, R.D. & Ostriker, J.P. (1978), *ApJ*, 221, L29
Bradbury, S.M., et al. (1999), *Proc. 26th Internat. Cosmic Ray Conf. (Salt Lake City)*, 5, 280
Buckley, J.H., et al. (1997), *Proc. 25th Int. Cosmic Ray Conf. (Durban)*, 3, 237
Buckley, J.H., et al. (1998), *A&A*, 329, 639
Burdett, A., et al. (1999), *Proc. 26th Internat. Cosmic Ray Conf. (Salt Lake City)*, 3, 448
Chadwick, P.M. et al. (1997), *Proc. 25th Int. Cosmic Ray Conf. (Durban)*, 3, 189
Chantell, M.C., et al. (1998), Nucl. Instrum. Methods A, 408, 468
Daum, A., et al. (1997), Astropart. Phys., 8, 1
De Jager, O.C. & Harding, A.K. (1992), ApJ, 396, 161
De Naurois, M., et al. (2000), Proc. Int. Symp. on High Energy Gamma-Ray Astro. (Heidelberg), in press.
Drury, L.O'C., Aharonian, F.A., Völk, H.J. (1994), A&A, 287, 959
Gaisser, T.K., Protheroe, R.J., Stanev, T. (1998), ApJ, 492, 219
Gehrels, N. & Michelson, P. (1999), TeV Astrophysics of Extragalactic Sources; Astropart. Phys., 11, 277
Gillanders, G., et al. (1997), Proc. 25th Int. Cosmic Ray Conf. (Durban), 3, 185
Hara, T. et al. (1993), Nucl. Instrum. Methods A, 332, 300
Hillas, A.M., et al. (1985), Proc. 19th Int. Cosmic Ray Conf. (La Jolla), 3, 445
Hillas, A.M., et al. (1998), ApJ, 503, 774
Hoffmann, W., (1997), Proc. Workshop on TeV γ-ray Astrophys. (Kruger Park), 405
Kifune, T., et al. (1995), ApJ, 438, L91
Koyama, M., et al. (1995), Nature, 378, 255
Lessard, R.W., et al. (2000), Astropart. Phys., in press
Muraishi, H., et al. (2000), A&A, 354, L57
Ong, R.A. (1998) Phys Rep, 305, 93
Oser, S., et al. (2000), ApJ, in press
Pfeffermann, E. & Aschenbach, B., (1996), Röntgenstrahlung from the Universe, In. Conf. on X-ray Astron. and Astrophys., MPE Report, 263, P267
Pühlhofer, G. et al. (2001), Proc. Int. Symp. on High Energy Gamma-Ray Astro. (Heidelberg), in press.
Quebert, J., et al. (1995), Towards a Major Atmospheric Cherenkov Detector - IV (Padova), 428
Sinnis, G., et al. (1995), Nucl. Phys. B (Proc. Suppl.) 43, 141
Swordy, S.P., et al. (1990), ApJ, 349, 625
Tanimori, T., et al. (1998), ApJ, 497, L25
Thompson, D.J., et al. (1993), ApJS, 86, 629
Tümer, T., et al. (1999), TeV Astrophysics of Extragalactic Sources; Astropart. Phys., 11, 271
Weekes, T.C., et al. (1989) ApJ, 342, 379
Weekes, T.C. & Turver, K.E. (1977), Proc. 12th ESLAB Symp. (Frascati) ESA SP-124, 279