

## Cosmic Rays from SNRs and TeV Gamma-Ray Astronomy

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**Abstract.** The origin of Galactic cosmic rays is still a burning question that forms a major motivation for developments in ground-based gamma-ray astronomy. SNRs are long-thought to be sites for the acceleration of Galactic cosmic rays, and evidence for gamma-ray and non-thermal X-ray production from some SNRs suggest that they may be capable of accelerating particles to multi-TeV energies. Yet, along with this, and in the same overall model framework (diffusive shock acceleration), is the need to accommodate upper limits at TeV energies imposed on other examples. This review will present an update on the status of SNR observations at TeV energies, their interpretation, and discuss the relevant parameters and issues of next generation ground-based instruments relating to their ability to confirm SNRs as Galactic cosmic ray sources.

*Key words:* Supernova remnants, gamma-rays,

### 1. Introduction

Supernova remnants (SNR), notably of the shell type, have long been considered the most likely accelerators of Galactic cosmic rays (CR) up to at least  $10^{14}$  eV and possibly the knee ( $E \sim 10^{15}$  eV). SNRs as a collective are able to meet the energetics of the observed CR flux at Earth, when considering CR escape and SNR birthrate issues. The average mechanical energy released by each SNR is  $\sim 10^{51}$  erg, and in the above context about 10% of this energy is required for CR acceleration to relativistic energies. The diffusive shock acceleration process invoked in SNR also naturally explains the  $dN/dE \sim E^{-2.0}$  spectrum obtained for the observed CRs at Earth after correction of propagation effects (ie. the source spectrum). The advent of sensitive space-based gamma-ray and X-ray detectors in recent years has provided the opportunity to identify likely sites of CR acceleration in our galaxy. (eg. Esposito et al. 1996, Slane 2001). However, in the context of our understanding of radiative processes from relativistic particles, the search

for gamma-radiation at multi-GeV to TeV energies (or Very High Energies, VHE) is also deemed vital to this effort. Within this energy regime it is the atmospheric Čerenkov imaging technique that appears to offer the best sensitivity to detect gamma radiation of such energies.

In this review I will present a summary of shell-type SNR observations at TeV energies, and then cover relevant issues for the next generation ground-based instruments now under construction to confirm or deny the theory that these objects are responsible for accelerating CRs.

## 2. VHE Gamma Ray Astronomy and Čerenkov Imaging

Non-thermal high energy radiation is presently the most accessible tracer of cosmic ray acceleration in the universe, by virtue of the physics associated with relativistic particles and high energy photons. The spectra of such radiations also closely reflects the spectra of parent particles, and so one is able to study particle acceleration processes.

The detection of VHE gamma-rays uses ground-based sampling of the extensive air shower (EAS). EAS comprise the secondary particles generated as primary gamma and cosmic rays interact with the Earth's atmosphere. The Čerenkov signature of EAS carries information about the primary particle's direction, energy and nature (hadronic or electromagnetic). Viewing the *angular distribution* of this signature with a sufficiently large (usually segmented) mirror ( $\geq 10 \text{ m}^2$ ) and focal plane array or camera of photomultiplier (PMT) pixels (ie. an imaging atmospheric Čerenkov telescope, IACT) allows to reconstruct primary parameters to high accuracy with a remarkably high effective collection area ( $\geq 10^5 \text{ m}^2$ ). Note that a number of experiments today are also making use of the *lateral distribution* to detect gamma-rays, a subject which is left at the moment for later discussion. The first reliable detection of the Crab Nebula by the Whipple Collaboration with the imaging technique (Weekes et al. 1989) was made using a single telescope employing a  $75 \text{ m}^2$  segmented mirror and 37 PMT camera. Since then, improvements have been realised such that cameras in use today by Whipple (Finley et al. 1999), CAT (Barrau et al 1998), HEGRA (Daum et al 1997), CANGAROO II (Yoshikoshi et al. 1999) and TACTIC (Bhat et al. 2000) now all exceed 200 pixels and achieve pixel sizes better than  $\sim 0.25^\circ$ . EAS Čerenkov images are often parameterised by the moments of an ellipse following Hillas (1985) although some improvements have been demonstrated (eg. LeBohec et al. 2000, Akhperjanian & Sahakian 1999). The primary aim is to preferentially select EAS images of a gamma-ray nature against those of the vastly outnumbering CR background, leaving a statistically significant excess of gamma-ray like events. A further significant improvement in the technique has been the use of stereoscopic imaging in which the EAS is viewed by at least two different telescopes separated by  $\sim 100 \text{ m}$ . This takes advantage of the uncorrelated nature of EAS image fluctuations, thereby achieving an improvement in angular resolution roughly proportional to  $1/\sqrt{n}$  with  $n$  the number of views attained for each EAS image (Hofmann et al. 1999). The HEGRA CT-System is currently the most sensitive example of such an array employing the stereoscopic technique. Today angular, energy resolution, energy threshold, and sensitivity of  $\lesssim 0.1^\circ$ ,  $\sim 15\%$ ,  $\sim 250 \text{ GeV}$  and  $\sim 1 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$  ( $>1 \text{ TeV}$ , 50 hours,  $5\sigma$ ) respectively are achieved by the best ground-based systems. Here we define the energy threshold at

that energy which maximises the differential trigger rate for gamma-rays, for a variety of source spectra. The achieved sensitivity is equivalent to  $\sim 1$  Crab at  $5\sigma$  significance, and has been sufficient to probe the TeV-output of the two BL-Lac blazars Mrk 421 and Mrk 501 on timescales of tens of *minutes* during flaring episodes. For further reviews of TeV observations and current instrumentation the reader is directed to Weekes (2000) and Fegan (2001).

### 3. Cosmic Ray Acceleration in SNRs

The considerable observational evidence at X-ray energies that SNRs are capable of accelerating CR electrons to multi-TeV energies, arises from the interpretation that their, in some cases entirely featureless X-ray spectra result from synchrotron emitting electrons (Koyama et al. 1995, Koyama et al. 1997, Slane et al. 2001). One can then make rather straightforward predictions concerning the GeV/TeV emission from such sources. The GeV/TeV emission arises from inverse Compton boosting of ambient photons (usually the microwave background) by the X-ray synchrotron-emitting high energy electrons (synchrotron/inverse Compton or S/IC theory), and that the ratio of the X-ray to gamma-ray flux is related to the shock-compressed magnetic field  $f_x/f_\gamma \sim B^2$ . Observations at TeV energies allow to determine and/or place constraints on  $B$ , which is an important parameter determining many features of shock acceleration. TeV observations can validate the S/IC framework since alternative explanations have been suggested for the hard X-ray emission in some cases (Laming 1998, Laming 2001). Recent results from CANGAROO suggesting the two SNRs, SN1006 and RXJ1713.7–3946 are TeV gamma-ray emitters (Tanimori et al. 1998, Muraishi et al. 2000), if confirmed could be considered strong evidence for the S/IC theory, although the hadronic channel (discussed shortly) may not be ruled out for SN1006 (Aharonian & Atoyan 1999).

The widely-accepted framework of diffusive shock acceleration that provides acceleration for such electrons however, must also do so for hadrons (Blandford & Eichler 1987, Völk 2001). Evidence for hadron acceleration in SNRs is unfortunately rather inconclusive in the face of that for electron acceleration. The predictions of Drury, Aharonian & Völk (1994) hereafter DAV, and also Naito & Takahara (1994) led to intense observation of SNRs by space and ground-based gamma-ray observatories. DAV showed that an appreciable gamma-ray flux may be obtained from the decay of  $\pi^0$  particles produced in the interaction of shock-accelerated hadrons with ambient matter nearby, ie. the so-called hadronic channel, which scales according to  $F_\gamma \sim E_{\text{cr}} n/d^2$ , for the SNR distance  $d$ , ambient matter density  $n$ , and energy available for particle acceleration  $E_{\text{cr}}$  (canonically believed to be  $\sim 10\%$  the total kinetic SNR energy).  $F_\gamma$  is also somewhat dependent on the spectral index of parent particles. Such fluxes were marginally close to sensitivities of instruments operating throughout the 1990's, when considering plausible values for the parameters just mentioned. However, apart from the results of EGRET (Esposito et al. 1996) which showed that the MeV/GeV emission from some likely SNRs candidates is consistent with the idea that they are areas of enhanced CR density, results from ground-based efforts have generally revealed TeV upper limits at levels of order 10% Crab flux. The exceptions have been recent evidence that Cas-A is an emitter of TeV gamma-rays (Aharonian et al. 2001a) and of course the two aforementioned CANGAROO results.

Throughout the last half-decade, over a dozen SNRs have undergone observation at TeV energies. Table 1 summarises results for some of these, and includes information considered indicators of the likelihood of TeV emission. We can see that a reasonable range of SNR ages and environments has been sampled although most are of the shell-type. Those SNRs exhibiting such properties as proximity, correct age (explained below), non-thermal X-ray emission, an EGRET source association and possible interaction with an adjacent molecular cloud (with high  $n$ ) would be considered prominent candidates for TeV gamma-ray emission.

SNR	radius [']	age <sup>a</sup> [kyr]	dist [kpc]	SNR type	TeV	EGRET	Non-th X-rays	SN type	Molec. cloud
W28	30	150	2.3	C	N	Y	N	II?	Y
W44	35x27	20	4.0	C	N	Y	N	II?	Y
W51	30	30	6.0	S?	N	M <sup>c</sup>	N	II?	Y
W63	95x65	24	2.0	S	N	M	N	II?	Y
$\gamma$ -Cyg	60	10	1.8	S	N	Y	N	II?	M
Monoceros	220	10	1.6	S	M	Y	N	II?	Y
Tycho	8	0.4	2.8	S	N	N	M	Ia	M
IC443	45	6.2	2.0	S	N	Y	N	II?	Y
Cas-A	4	0.3	3.4	S	Y	N	Y	Ib	M
SN1006	30	1.0	1.8	S	Y	N	Y	Ia	N
RXJ1713.7	65x55	40.0	6.0	S?	Y	N	Y	?	Y

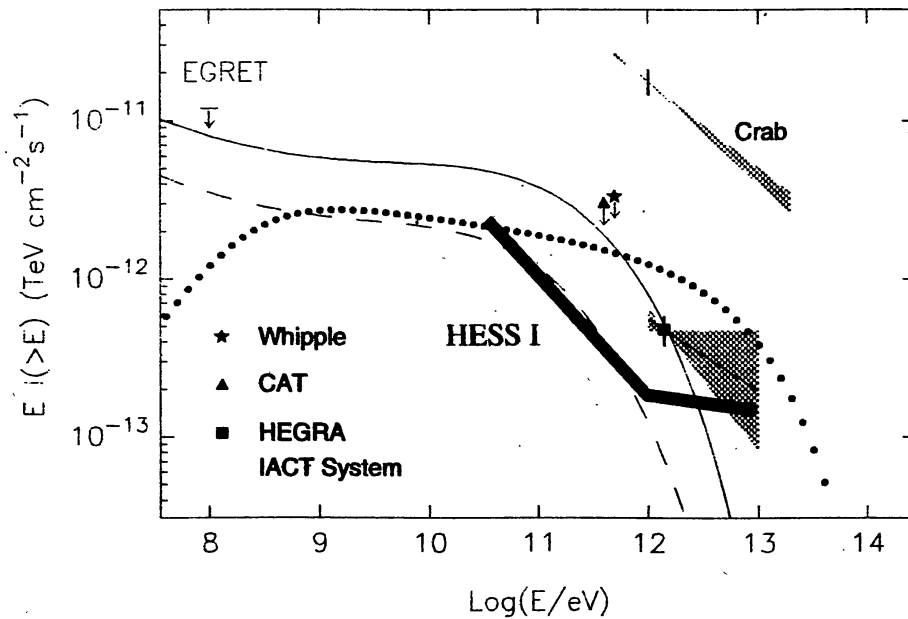
a: Upper Limits    b:  $\sim 50\%$  uncertainty    c: M=Maybe!

**Table 1.** The present status of prominent SNRs observed at X-ray to TeV gamma-ray energies with the column 'TeV' indicating a detection at TeV energies (Y: Yes, reported by least one research group) or upper limit only (N: No) at typically  $\sim 10\%$  Crab flux. The presence of non-thermal X-ray, EGRET (MeV/GeV) emission, and whether an interaction with a molecular cloud is suspected (high  $n$ , and OH maser emission) are important indicators of TeV emissivity. Also included is the SNR type (C-Composite, S-Shell) and supernova (SN) progenitor type, if known. References for each source are as follows; W28 (Rowell et al. 2000); W44, W51, W63,  $\gamma$ -Cyg, IC443 (Buckley et al. 1998); Monoceros (Lessard et al. 1999, Lucareli et al. 2000); Tycho (Aharonian et al. 2001b); Cas-A (Aharonian et al. 2001a); SN1006 (Tanimori et al. 1998); RXJ1713.7 (Muraishi et al. 2000). Where possible, radius, age and distance information are taken from Green (2000).

Attempts to explain these results overall, usually in combination with those at X-ray and EGRET gamma-ray energies are not trivial, involving many issues. In the context of accommodating upper limits, extrapolations from EGRET up to TeV energies when considering just the hadronic channel, appear to often imply rather steep particle spectra,  $\sim E^{-2.4}$  (Buckley et al. 1998). More than one process may be responsible for the EGRET emission in some cases. For example Gaisser et al. (1998) and Sturmer (1997) showed that the low energy gamma-ray emission may result from non-thermal electron Bremsstrahlung, again with rather steep particle spectra (together the IC and non-thermal Bremsstrahlung comprise the electronic channel of TeV gamma-ray production). Time evolution of SNR gamma-ray emissivity must also be considered, as DAV



showed that the peak gamma-ray emissivity of a SNR occurs during the so-called Sedov phase, corresponding to the time after which the swept-up mass exceeds that ejected by the blast. Later the non-linear model of Berezhko & Völk (1997) also confirmed this profile, albeit with some differences. Such information is likely important for those examples considered borderline Sedov (eg. Tycho's SNR, Aharonian et al. 2001b), or even too old where age limitations on maximum particle energies come into play (see Drury et al. 2000). Non-linear theory (Baring et al. 1999) also indicates that SNR expansion into high density environments may actually limit the maximum particle energies to  $\leq 1$  TeV, thereby anti-biasing SNR selection according to  $n$ . Complications are expected from SNR expanding into wind bubbles as expected from type Ib and II supernovae with massive progenitors (Berezhko & Völk 2000). And finally, aside from the above issues and those concerning shock acceleration itself (Kirk & Dendy 2001, Drury et al. 2001), we have also to deal with the rather large uncertainties (factors of least 2) in observable parameters such as  $d$ ,  $n$  and  $E_{cr}$  contributing to the wide parameter space, often a factor  $\sim 10$ , in which to accommodate models.



**Figure 1.** HEGRA Cas-A flux and  $1\sigma$  uncertainty on spectral index compared with the modelling of Atoyan et al. (2000). Hadronic (dotted) and electronic (IC+Bremsstrahlung, solid and dashed) channels are indicated. Reasonable scaling parameters for each channel were assumed. For comparison the Crab flux and error on spectral index are included. The Cas-A flux amounts to 3.3% Crab flux. The Whipple (Lessard et al. 1999) and CAT (Goret et al. 1999) upper limits are indicated. Note the estimated sensitivity of H.E.S.S. Phase I for point sources ( $5\sigma$  detection at 50 hrs observation shaded region), which will be more or less similar to that of VERITAS and CANGAROO III.

The results of Cas-A observations nicely illustrate the present situation (Figure 1). Deep observations of Cas-A (over 200 hrs) by the HEGRA CT-System have revealed a TeV gamma-ray flux at a level  $\sim 3\%$  that of the Crab (Aharonian et al. 2001a). Atoyan et

al. (2000) used a tri-zone model to characterise areas of different magnetic field and electron transport in the range 0.1 to 1 mG for the electronic channel (IC + Bremsstrahlung), and a total energy of  $2 \times 10^{49}$  erg in CR hadrons. Here, we can clearly see the limitations of present-day ground-based instruments in sampling such a flux. Owing to the dependence of sensitivity with  $\sqrt{t}$  it is unlikely that further observations of Cas-A will be carried out. Most importantly, insufficient statistics prevent an accurate estimate of the spectral index, and hence discrimination between hadronic and electronic TeV channels is currently not available. Thus it is apparent that detailed studies of sources with fluxes around 10% Crab will only be accessible after significant improvements particularly in sensitivity. A reduction in energy threshold below the  $\sim 250$  GeV available today is also a strong motivation, as it would achieve a large dynamic spectral range, allow studies of SNR with lower energy cutoffs, and of course help in detection of the EGRET unidentified sources.

Overall, since it appears that many TeV upper limits lie not far from the conservative edge of parameter space, it is generally accepted that further reduction in constraints by about a factor 10 as could be obtained from the next generation instruments, would force uncomfortable modifications to current theory.

#### 4. Next Generation Instruments

Next generation instruments in ground-based gamma-ray astronomy aim to achieve roughly one order of magnitude improvement in sensitivity and energy threshold over present instruments.

A reduction in energy threshold has already been demonstrated by those experiments making use of existing solar power facilities with very large reflecting surface area ( $> 2000$  m<sup>2</sup>) to image the lateral distribution of EAS. Some hadronic background rejection is available based on the expected differences in uniformity of gamma-ray and CR signatures. The CELESTE group have been able to achieve a  $\sim 50$  GeV threshold detection of the Crab (de Naurois 2000) and Mrk 421 (Holder 2000). The Crab has also been detected by STACEE (Oser et al. 2001) and GRAAL (Diaz 2001) although at slightly higher energies. Another experiment of this type is Solar-2 (Tümer et al. 1999). Improvements in sensitivity will come from the addition of more mirrors, and possibly improvements in techniques to reject background events.

Direct sampling of EAS particles at ground-level is also possible at TeV energies. The water Čerenkov detector MILAGRO (McCullough 1999) and the air shower array in Tibet operating at very high altitude have produced detections of Mrk 501 (Atkins et al. 1999, Amenomori et al. 2000) and Crab (Amenomori et al. 1999). A nice feature of these detectors is their 24 hr duty cycle and nearly  $2\pi$  sr field of view, albeit with angular resolution and collecting area inferior to Čerenkov imaging systems. Future developments in these areas could however provide rather sensitive all-sky monitors at sub-TeV energies.

It appears likely that the most significant improvements will come from systems using the imaging technique described earlier. H.E.S.S. (Hofmann 1999), VERITAS (Lessard 1999) and CANGAROO III (Mori 2000) will employ the stereoscopic imaging technique

which permits an array of moderate-size telescopes to achieve arc-minute angular resolution. These systems consist of arrays of  $\geq 4$  telescopes each with  $\sim 100 \text{ m}^2$  segmented mirrors and imaging cameras of  $\geq 500$  pixels subtending  $\geq 3^\circ$  fields of view. MAGIC (Lorentz 1999) and MACE (Bhat 2000) will explore the use of very large segmented mirrors ( $>200 \text{ m}^2$ ) on a single telescope in order to push the energy threshold below 50 GeV, although additional telescopes may be added after experience with images properties at energies  $\leq 50 \text{ GeV}$  is gained. It is expected that H.E.S.S., VERITAS and CANGAROO III will achieve peak gamma-ray detection rates (for a range of spectral indices) at energies  $\sim 100 \text{ GeV}$  or slightly lower. Spectral studies should be possible from this threshold energy up to  $\sim 10 \text{ TeV}$ , an unprecedented dynamic range for this field. Table 2. summarises the salient features of these next generation imaging instruments, which will commence operation in the years 2002 to 2005.

Instrument	Site	Mirror(s)	Camera pixels (resol.)	Energy Thres. (GeV)	Epoch begin
CANGAROO III	Woomera	4x10m	4x512 (0.12°)	100	2003
MACE	India	1x17m	1x>800 (0.1, 0.2°)	10	2005
MAGIC Phase I	La Palma	1x17m	1x577 (0.1°)	30	2002
H.E.S.S. Phase I	Namibia	4x12m	4x960 (0.16°)	100	2002
VERITAS	Arizona	7x11m	7x499 (0.15°)	75	2005

**Table 2.** Summary of next generation atmospheric Čerenkov imaging systems approved and/or under construction. Details of each project can be found from references cited in the text.

Along with ground-based techniques, the development of the next space-based instruments at gamma-ray energies GLAST (Gehrels 2000) and X-ray energies (for example XMM-Newton and *Chandra*) will advance significantly our understanding of SNRs. Arc-second resolution now available from these X-ray satellites is allowing detailed spatial and spectral studies of SNRs and comparisons with radio data, thereby improving greatly the likelihood of disentangling thermal and non-thermal X-ray components.

GLAST will sample the high energy gamma-ray sky at sensitivities and angular resolution an order of magnitude better than that of EGRET. A major goal of GLAST will be to shed light on the  $>150$  unidentified EGRET sources (Hartman et al. 1999), a number of which are considered SNRs (Romero et al. 1999), and also for related sources such as giant molecular clouds. Certain questions however will not be easily accessible to GLAST. The origin of the Galactic CRs up to the knee will be a question best addressed by ground-based methods operating at higher energies since the electronic and hadronic channels described above require multi-TeV energy particles to produce TeV

gamma-rays. The huge collecting area afforded by ground-based techniques gives them a sensitivity advantage over satellite-based gamma-ray systems, although the latter of course operate with much larger fields of view ( $\geq 0.5$  sr) and duty cycles. In the context of probing spectral and morphological properties in SNRs requiring high statistics over a broad energy range, the ground-based systems are ideal instruments.

## 5. Issues for Future SNR Studies at GeV/TeV Energies

Summarised here are a number of issues considered important for studies of SNRs by the next generation ground-based imaging instruments. Many of the groups building such instruments have, or are now devoting significant effort to these with the use of Monte Carlo simulations in order to optimise astrophysics potential.

1. **SNR Detectability:** The problem is that SNR will invariably be extended sources. Included in figure 1. is an example sensitivity curve for H.E.S.S. phase I observing *point* sources, which will be more or less similar to that for VERITAS and CANGAROO-III. The minimum detectable flux from an extended source  $F_{\text{ext}}$  of size  $\sigma_{\text{src}}$  may be expressed, assuming Gaussian source morphology:

$$F_{\text{ext}} \sim F_{\text{pt}} \sqrt{(2\pi k\sigma_{\text{src}}^2 + s)/(2\pi k\sigma_o^2 + s)} \quad (1)$$

for  $F_{\text{pt}}$  the point source sensitivity,  $\sigma_o$  the point spread function of the instrument,  $s$  the number of signal counts, and  $k$  the background count density (total background counts  $b = k\pi\sigma^2$ ), after gamma-ray selection. This equation accounts for the increase in statistical uncertainty of the background with size, contribution from the signal, and results from rearrangement of Eq. 5 in Li & Ma (1983), setting  $\text{ON}=b+s$ ,  $\text{OFF}=b$  and  $\alpha = 1.0$ . For example a SNR of radius  $\sigma_{\text{src}} \sim 0.5^\circ$  viewed by an instrument with  $\sigma_o = 0.1^\circ$ , an increase in minimum detectable flux by a factor  $\sim 5$  is expected for signals with  $s=200$  and  $b=800$  counts<sup>†</sup>. Equation 1 neglects contributions from systematic uncertainties in estimating  $b$  arising from, for example instrument performance and sky condition changes during data taking. Such errors increase with  $\sigma_{\text{src}}^2$  making this potentially a dominant term if they exceed  $\sim$  few percent and the source is large. Instrument performance nevertheless is often able to meet this criterion via diligent screening of data quality.

2. **Energy Resolution and Sensitivity:** With point source sensitivities approaching  $10^{-13}$  erg cm<sup>-2</sup> s<sup>-1</sup>, and energy resolution  $\leq 15\%$ , the spectra of sources with  $\sim 10\%$  Crab flux will be determined by H.E.S.S., VERITAS, CANGAROO-III etc. after reasonable observation time. It should therefore be possible to discriminate the hadronic and electronic components of TeV emission, given sufficient statistics at certain energy

<sup>†</sup> Here I have assumed  $b=800$  background counts fall within the region  $\sigma_o = 0.1^\circ$  over 10 hours observation time, derived from a post-gamma-ray shape-selected trigger rate of 5 Hz (assuming a shape selection efficiency for background is 1%) over a region of radius  $1.5^\circ$ , as might be expected for H.E.S.S. and the like. Then,  $s=200$  is chosen to give a  $\sim 5\sigma$  point source significance.



domains where spectral differences are maximised. IC and also Bremsstrahlung spectra are quite sensitive to SNR age and magnetic field values due to electron cooling, leading to characteristic IC 'turnovers' in spectral index which appear at multi-GeV to multi-TeV energies. The hadronic component will reflect more just the upper energy limit to particle energies. Spectral differences may therefore be most apparent at the low and high energy end of instrument sensitivities, highlighting the need to achieve a wide dynamic range. The effect of electron cooling for example due to the high  $B$  field is evident in figure 1.

3. **Angular Resolution:** The hadronic channel for TeV emission in SNRs will generally trace regions of high ambient density and regions where the SNR shock has interacted with a molecular cloud, leading to distinct morphological TeV features. The electronic channel morphology on the other hand will depend strongly on the magnetic field. For example Aharonian & Atoyan (1999) argue that for SN1006, the electronic IC TeV emission would essentially fill the SNR under current assumptions about the magnetic field  $B \leq 10 \mu\text{G}$ . Instrument angular resolution will play an important role in discriminating between TeV components. Since the angular resolution is mildly energy-dependent (a factor  $\sim 2$  improvement is generally achieved at the high energy end), it may be possible to perform such studies better at energies well away from threshold, aligning with the arguments concerning spectral differences in point 2 above.
4. **Field of View and Acceptance** SNR sizes generally exceed comfortably the instrument point spread function. A wide radius ( $\geq 1.5^\circ$ ) achieving a roughly flat gamma-ray acceptance is therefore desirable. This aspect is also very important in searches for the EGRET unidentified sources, where positional uncertainties of  $\leq 1^\circ$  are noted.

## 6. Conclusions

Over the past decade, ground-based observations of SNRs at TeV gamma-ray energies have been carried out in an attempt to establish them as the primary sites of Galactic CR's. With the exceptions of three cases, studies of SNRs at TeV energies have revealed non-detections with upper limits at levels of the order 10% Crab. Such limits do constrain models on CR production in SNRs, but generally lie close to the conservative edge of the rather large parameter space available. The next generation ground-based instruments employing the imaging atmospheric Čerenkov technique from  $\sim 50$  GeV to 10 TeV are expected however in conjunction with new X-ray satellites and the forthcoming space-based gamma-ray instrument GLAST, to sample the sky at sufficient sensitivity and resolution to provide serious constraints on the theory that SNRs are responsible for Galactic CRs. Negative results from SNR observations with these ground-based instruments, would confront us with a number of not necessarily exclusive consequences, assuming that we retain the diffusive shock acceleration framework: (1) Limiting the energy content in accelerated particles, particularly hadrons, in SNRs to  $E_{\text{cr}} \leq 10^{49}$  erg; (2) CR source spectra generally steeper than that predicted from current theory, (3) our understanding of SNR dynamics is clearly lacking, (4) and/or that alternative

sources contribute significantly to CR acceleration. For the last point Galactic sources such as pulsar-driven nebulae or plerions and microquasars/X-ray binaries, all of which appear capable of maintaining particle acceleration at sufficient luminosity for very long times, may be alternatives. Definite answers concerning these type of questions should be available not long after 2002, when the first of the next-generation instruments is fully online.

**Acknowledgements** I would like to thank the organising committee of the GAME 2001 workshop for the invitation, and gratefully acknowledge receipt of a von Humboldt Fellowship. F.A. Aharonian, D. Horns and H.J. Völk are thanked for helpful comments.

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