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# Pulsar Observations above 1 GeV with future Ground–based Gamma–Ray Telescopes

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**Abstract.** This paper explores the potential of present and future ground–based $\gamma$-ray telescopes to detect GeV to multi-GeV pulsed emission from EGRET pulsars. Five types of telescopes can in principle detect such emission: The two most promising are (1) the "5@5" stereo array (5 telescopes, each with a diameter of 20 m; proposed site: Chile, 5 km a.s.l.); (2) a single 30 meter dish at a conventional altitude (e.g. 2.2 km). These two detectors (in the conceptual phase) should be able to detect pulsed GeV emission within a few seconds, but may not realize before the launch of GLAST. Pre-GLAST results are however expected from experiments under construction: (3) MAGIC (17 m single dish, La Palma) and (4) H.E.S.S. (four 11 m diamter dishes, Namibia). (5) Existing solar type arrays: CELESTE (France - in operation) and STACEE (USA - in operation). To date no confirmed pulsed $\gamma$-ray emission from radio pulsars has been seen from any ground-based $\gamma$-ray telescope. In the case of the solar-type arrays, a clever triggering technique may reveal the spectral tail of the pulsed $\gamma$-ray emission from pulsars such as Crab and PSR B1951+32, but more luck is expected from the MAGIC and H.E.S.S. type arrays. This paper compares the pulsed rates and detection times required for MAGIC, H.E.S.S., and "5@5" given the trigger studies performed up to date. The performance of any of these telescopes is conservatively optimized if we employ the polar cap model for pulsed emission showing super exponential cutoffs between 5 GeV (Vela and Geminga) and 40 GeV (no cutoff was seen by EGRET up to 30 GeV for PSR B1951+32 and PSR B1706-44).

*Key words:* Gamma–Ray Pulsars, EGRET, Cerenkov Telescopes, MAGIC, H.E.S.S., "5@5"

## 1. Introduction

Pulsars are known to be compact objects with radii between 10 and 16 km, masses around a solar mass and spin periods between a millisecond and a few seconds. The spindown torque $I\dot{\Omega} \sim -K\Omega^n$ typically follows that for magnetic dipole radiation with $n \sim 3$, which confirms our believe in the existence of superstrong magnetic fields around $10^{12}$ gauss for the so-called canonical pulsars (periods above 20 or 30 ms), but field strengths near $\sim 10^9$ gauss for the older millisecond pulsars. Simple electrodynamics predict the existence of potential drops in excess of $10^{12}$ volt over the polar cap, which is also required to sustain the pair production process and radio emission in the magnetosphere. The observed pulsed MeV to GeV emission is then the consequence of a high multiplicity of electron-photon cascading on the strong magnetic field (see e.g. Daugherty & Harding 1996).

Roughly six or more $\gamma$-ray pulsars have been seen by the CGRO/EGRET instrument during its mission between 1991 and $\sim$ 1997 (Thompson 2001), and several hard-spectrum unidentified EGRET sources have also been seen which are thought to be $\gamma$-ray pulsars for which the EGRET statistics are too small to resolve the periodicity (see Grenier 2001 for a recent review). Furthermore, three high power, relatively young radio pulsars were recently discovered to be associated with unidentified EGRET sources (Halpern et al. 2001, D'Amico et al. 2001), which confirms this general belief, but detailed periodicity analyses lack to confirm these associations.

It is therefore important to observe such sources with next generation $\gamma$-ray telescopes, but the future space telescope GLAST should be able to determine whether some of the unidentified EGRET sources are indeed radio quiet pulsars, either due to unfavorable radio beaming or very high radio dispersion in a molecular cloud. Thompson (2001) recently reviewed the GLAST sensitivity for $\gamma$-ray pulsar detections.

This paper investigates the possibility for some classes of future ground-based $\gamma$-ray telescopes to detect pulsed emission, given the spectral information gained by EGRET. The discussion on the solar arrays is left for D. Smith (these proceedings). In fact, CELESTE may be the first ground-based telescope to detect pulsed emission under ideal atmospheric conditions, provided that a clever triggering scheme is designed.

Before proceeding with the discussion on H.E.S.S., MAGIC, and "5@5", we will compare the observable properties of $\gamma$-ray spectra above 1 GeV in terms of polar- and outer gap models.

## 2. Gamma-Ray Production in Pulsar Magnetospheres.

Basic pulsar electrodynamics involves a definition of a polar cap with associated potential drop $\Delta V \sim 0.2(\dot{E}/c)^{1/2} \propto B_s/P^2 > 10^{12}$ eV, with $B_s$ the surface field strength and $P$ the pulsar period. The Goldreich Julian pulsar current from the polar cap scales similarly as $I_{\rm GJ} \sim 2.4(\dot{E}c)^{1/2}$, and is responsible for the extraction of electrons and possibly Fe ions from the surface of the polar cap, where a component of the electric field parallel to **B** exists. The product $I_{\rm GJ}\Delta V \sim 0.5\dot{E}$ is then comparable to the magnetic dipole spindown power, so that the total energy loss rate is given by $\dot{E} = I\Omega\dot{\Omega}$ (the factor 0.5 in the particle luminosity is only an approximation to keep the total losses equal to $\dot{E}$).

It is therefore natural to follow the curvature $\gamma$-ray emission from accelerated electrons above the polar cap, resulting in a cone-like beam of $\gamma$-ray emission above the polar cap until magnetic pair production no longer dominates the pair production process. Daugherty & Harding (1996) were able to reproduce the observed pulse profiles and spectra for such processes, but a natural consequence of the polar cap process is a superexponential cutoff of the spectrum as discussed by Nel & de Jager (1995).

In competition with the polar cap model, is the so-called outer gap model, whereby a potential drop may develop around the $\mathbf{\Omega} \cdot \mathbf{B} = 0$ "null surface", which is at a much larger distance from the pulsar compared to the polar cap emission region. Spectra can be self-consistently derived for outer gaps (Hirotani 2001), but it remains to be shown how the outer gap geometry can be self-consistently unified with the electrodynamics. In this case we find that photon-photon pair production and the available acceleration potential determines the cutoff. Both a synchrotron and a VHE inverse Compton component can then escape from the outer gap to the observer. However, both the polar cap and outer gap mechanism may be operational simultaneously (Hirotani, 2001, personal communication).

It is well known that the conversion efficiency $\eta = L_\gamma/\dot{E}$ of spindown power to $\gamma$-rays increases with increasing age (or decreasing spindown power). Thompson (1997) found that the pulsed luminosity scales as pulsar current to the power unity, with $10^{13}$ volt as normalising constant and $\Omega = 1$ steradian beaming angle. This conclusion is empirical and model independent, although some scatter must be allowed to account for the unknown beaming fraction and uncertainties in pulsar distances. We can interpret and generalize this finding by considering the normalizing potential as the expected space-charge limited potential, $V_{\rm sc} \sim 10^{13}$ volt which is constant for young to middle-aged pulsars, but should decrease for older pulsars, since $V_{\rm pc}$ decreases with time. Combining three effects: (1) the observed scaling of $L_\gamma$ with current at earlier times, (2) the convergence of $\eta$ to unity with age and (3) the physical constraint that $V_{\rm sc} \leq V_{\rm pc}$, give the predicted luminosity as

$$L_\gamma = I_{\rm GJ}\Delta V_{\rm sc}(1 + \Delta V_{\rm sc}/\Delta V_{\rm pc})^{-1}. \quad (1)$$

As the pulsar grows older, we also expect the multiplicity for pair creation to decrease, with the resulting effect of spectra becoming harder with increasing age. In fact, the oldest pulsars may be too hard to be detectable by EGRET, but future multi-GeV ground-based telescopes and GLAST may detect such relics at or near their cutoffs (above $\sim 10$ GeV) as dictated by pair creation.

A generic model (polar cap and/or outergap) for the tails of pulsed differential spectra is then given by

$$dN/dE = K_1(E/E_n)^{-\Gamma_1}\exp(-(E/E_0)^b) + K_2(E/E_n)^{-\Gamma_2}\exp\left(-(E/E_2)^c\right) \quad (2)$$

The second component would be absent in the case of pure polar cap $\gamma$-ray emitters, with the additional signature of a super exponential cutoff ($b \geq 1$ and $K_2 = 0$). An outer gap origin can be interpreted in terms of a non-zero $K_2$, but with a slower roll-over ($b < 1$ and $c < 1$) compared to polar cap models, since the outer gap absorption process is controlled by photon-photon pair production, which has a weaker energy dependence compared to magnetic pair production above the polar cap.

All high energy spectra of pulsars are consistent with a relatively bright first component (large $K_1$), but VHE upper limits place only upper limits on $K_2$. Nel & de Jager (1995) was able to constrain some of the parameters from Eqn. (2), resulting in $b = 1.7$ for Vela but 2.2 for Geminga, with $K_2$ consistent with zero. If $b$ is consistently greater than 1, it would make ground–based detections even more difficult, since the collection area $A(E)$ increases with energy $E$, and a significant overlap of $A(E)$ and $dN/dE$ would be required for a detection. To obtain the most conservative rates, we will assume $b = 2$ for the unconstrained pulsars, which implies a typical polar cap scenario. A slower roll-over would increase the overlap and hence detection rate, but this may be too optimistic. Note that a steepening at $E_0$ for Vela and Geminga to a much steeper power law is also a possibility, but the limited statistics of EGRET above 10 GeV left little constraining data to investigate this possibility. The predicted detection rates would then increase in the case of a steepening, but we restrict ourselves to the most conservative assumption of a superexponential cutoff for each pulsar. Table 1 gives the spectral parameters for pulsars for $E > 1$ GeV which will be used below for the calculation of detection rates.

**TABLE 1: Assumed pulsed spectral parameters ($E > 1$ GeV).**

| Object | $K$ ($\times 10^{-8}$) (/cm$^2$/s/GeV) | $\Gamma$ | $E_o$ (GeV) | $b$ | $F(>1$ GeV) (/cm$^2$/s) |
|---|---|---|---|---|---|
| Crab | 24.0 | 2.08 | 30 | 2 | 22 |
| Vela | 138 | 1.62 | 8.0 | 1.7 | 148 |
| Geminga | 73.0 | 1.42 | 5.0 | 2.2 | 76 |
| PSR B1951+32 | 3.80 | 1.74 | 40 | 2 | 4.9 |
| PSR B1055-52 | 4.00 | 1.80 | 20 | 2 | 4.5 |
| PSR B1706-44 | 20.5 | 2.10 | 40 | 2 | 20 |

## 3. Detection Rates for Pulsed Emission.

Following the procedure described by de Jager et al. (2001), we will model the pulsar spectra above 1 GeV as a power law times an exponential cutoff with cutoff energy $E_0$. The strength of the cutoff is determined by the index $b$ as given by eqn. (2). The most conservative estimate for the detection sensitivity is to take $b > 1$, consistent with magnetic pair production above the polar cap, whereas a value of $b < 1$ will yield a very optimistic detection rate. The constant $K = K_1$ in eqn. (2) represents the monochromatic flux at the normalizing ($E_n \ll E_0$ in Table 1) energy near 1 GeV. Our conservative approach assumes that $K_2 = 0$, and thus no outer gap emission, whereas $b > 1$ also results in more realistic detection rates as discussed above. The same pulsar spectral parameters were used by Fonseca et al. (2001) and de Jager et al. (2001) for MAGIC and H.E.S.S. respectively. We will compare these lists and extend the calculations to the proposed "5@5" array.

Using the collection area $A(E)$ for a given type of telescope, the expected rate of triggers of pulsed Cerenkov showers is given by

$$R_p = \int A(E)(dN_\gamma/dE)dE.$$

The results for the six EGRET pulsars are shown in Table 1, indicated by "$R_p$" for each experiment.

It was shown by de Jager, Swanepoel & Raubenheimer (1989) and de Jager (1994) that the basic scaling parameter for any test for uniformity on the circle (given a test period) is given by $x = p\sqrt{n}$, where $p = R_p/(R_p + R_p) \sim R_p/R_b$ is the pulsed fraction, with $R_p$ the pulsed rate and $R_b$ the background rate. The total number of events is given by $N = (R_p + R_p)T$, with $T$ the observation time. In this case the test statistic for uniformity for the general Beran (1969) class of tests is given by $B = x^2\Phi_B + c$, where $\Phi_B$ is derived from the intrinsic pulse profile, and c is the noise term for $B$. It was shown by Thompson (2001) that the pulse profiles above 5 GeV consist mostly of one strong narrow peak, as opposed to two peaks at lower energies, which is a result of the spectral differences between the two peaks. We will assume that only a single peak survives at the highest energies, so that $\Phi_B = 5.8$ if we assume a 5% duty cycle, with $B = Z^2_m$ test statistic with $m = 10$ harmonics (see e.g. de Jager, Swanepoel & Raubenheimer 1989). For $m = 10$ we expect $c = 20$ due to background.

A value of $x = 3$ would imply a $\sim 3\sigma$ DC excess in a spatial analysis, but assuming that we have no imaging capability for $E_o$ near the detection threshold, we have to rely on a timing analysis, which would give $Z^2_{10} \sim 73$, or a chance probability of $P = 6 \times 10^{-8}$ if the period is known. The number of trials (with $\epsilon$ the test- and IFS dependent factor of oversampling - de Jager, Swanepoel & Raubenheimer, 1989) is given by

$$L = \epsilon\Delta\nu T = 4.3 \times 10^6 (\frac{\epsilon}{10})(\frac{\Delta\nu}{20 \text{ Hz}})(\frac{T}{6 \text{ hours}}),$$

which gives an insignificant probability of $PL \sim 0.3$ after multiplying with the number of trials for a $T = 6$ hour observation if searching for periods as short as 50 ms. Noting the $M = 1000$ most significant periods, an observation the following night under similar conditions should identify the correct period, but in this case with a higher significance of $PM \sim 6 \times 10^{-5}$. A confirming run on the third night should confirm the unique period from the previous night, but now at the level of $P$ with no extra trials.

Suppose that we can reduce the threshold only slightly, resulting in an increase from $x = 3$ to 4 on the superexponential slope. Then $Z^2$ increases to 112, giving $P = 8 \times 10^{-15}$ or $PL = 4 \times 10^{-8}$ instead of 0.3 on the first night, which changes the situation dramatically!

## 4. Detection capability of H.E.S.S. for pulsars.

The High Energy Stereoscopic System (H.E.S.S.) system of four telescopes (Hofmann et al. 2001) was designed to provide stereo imaging of $\gamma$-ray showers above 50 GeV. The stereo capability allows a significant rejection factor against background events. It is presently under construction in Namibia and will be capable of probing the Southern Sky, with the galactic center transit near the zenith. Whereas imaging is only possible above $\sim$ 50 GeV, it can trigger on events above $\sim 20 - 30$ GeV. The latter feature will be exploited in the discussion below, and even though imaging is not possible near threshold, the stereo capability still allows some background events to be rejected.

Using an additional topological software trigger, recently tested with the HEGRA system of 5 imaging atmospheric Cerenkov telescopes (Lucarelli et al. 2001) and selecting events by image size and angular shape, de Jager et al. (2001) were able to reject $\sim$ 99.2% of the triggered background events, while retaining 95% of the source events below 50 GeV. From a total background rate of about 1 kHz (Konopelko 2001), the resulting rate is $R_b = 8$ Hz. This allowed de Jager et al. (2001) to calculate detection sensitivities for periodicities as shown in Table 2 assuming a threshold of $x = 3$, and solving for $T$ (in 10-hour shifts) assuming the spectral parameters from EGRET as listed in Table 1. It is clear the H.E.S.S. will only be able to detect pulsed emission if $E_0$ exceeds 30 GeV, which is realized at least for PSR B1706-44 in the Southern Hemisphere.

## 5. Detection capability of MAGIC for pulsars.

The MAGIC 17 meter single dish telescope (Barrio et al. 1998) is presently under construction in La Palma. The larger mirror collection area allows MAGIC to go further down in threshold energy, compared to the H.E.S.S. and VERITAS arrays. It would be possible to trigger on pulsar signals with energy near 10 GeV, but at the cost of a larger background compared to H.E.S.S. The reduction in threshold energy is extremely important, since the telescope response must overcome the superexponential cutoffs expected near 10 GeV. MACE is the proposed counterpart for MAGIC in India (Bhat, 2001) and is expected to become operational on Mount Abu by $\sim$ 2005.

Based on the collection efficiencies calculated by Barrio et al. (1998), De Jager (1998) showed that MAGIC can detect pulsations from EGRET pulsars in the 10 - 30 GeV range. E. Lorenz (1998, personal communication) also suggested a size- and distance cut on background showers, while retaining $\gamma$-rays below $\sim$ 30 GeV. This feature will be discussed below.

The pulsed $\gamma$-ray rate $R_p$ was calculated by Fonseca et al. (2001) after integrating the product of the energy dependent collection area $A(E)$, with the differential pulsed spectrum, which includes the cutoff. The collection area for MAGIC was calculated for a special ring of 30% (0.8° trigger radius) QE PMTs. (In reality the 30%+ QE PMTs will occupy only the central 0.5 degree radius - E. Lorenz, 2001, personal communication). Four-nearest neighbor pixels were used in the trigger after adding the NSB, with a calculated collection area of $A(E) \sim 100$ m$^2$ for $E \sim 10$ GeV. The background rate $R_b$ was calculated ***assuming incident cosmic ray showers for all energies at large acceptance angles relative to the pointing direction and core positions relative to the telescope, until convergence in $R_b$ is seen.*** The convergent background rate $R_b \sim 200$ Hz (depending on the trigger condition).

Table 2 shows the expected pulsed rates (for a DC excess of $x = 3\sigma$) and required observation times for MAGIC, assuming a very moderate cut from 200 Hz background to 50 Hz (Fonseca et al. 2001) which may be achieved from size- and distance information alone. Significant rejections are still expected if gate time (optical fibre communication) and pattern information (second level trigger) are also employed (E. Lorenz, 2001, personal communication). The final goal is to have the background consisting of mainly cosmic ray electron showers.

From Table 2 it is clear that a detection of Crab and PSR B1951+32 can be realized within one night. These two pulsars also transit close to La Palma, so that the minimum threshold energy can be realized at transit.

**TABLE 2: Pulsed rates and observation times.**

| **Object** | H.E.S.S. ($R_p$, $T$) ($hr^{-1}$, 10-hr days) | MAGIC ($R_p$, $T$) ($hr^{-1}$, hours) | 5@5 ($R_p$, $T$) (Hz, s) |
|---|---|---|---|
| Crab | (100, 3) | (730, 3) | (10, 2) |
| Vela | (8, 400) | (500, 7) | (50, 0.1) |
| Geminga | ($\ll 1$, $\infty$) | (30, $10^3$) | (13, 1) |
| PSR B1951+32 | (180, 1) | (530, 6) | (4, 14) |
| PSR B1055-52 | (8, 420) | (130, 100) | (3, 36) |
| PSR B1706-44 | (240, 1) | (870, 2) | (9, 3) |

## 6. Detection capability of "5@5" for pulsars.

The placement of five large telescopes in stereo at an altitude of 5 km has three advantages: (a) it succeeds in reducing threshold energy due to the larger mirror area (the MAGIC concept), (b) a further reduction in threshold energy due to reduced atmospheric absorption, and (c) improved energy and spatial resolution due to stereo imaging (Aharonian et al. 2001). Raising the array from the 2.2 km altitude of La Palma to Atacama desert of Northern Chile would reduce the threshold energy from $\sim$ 30 GeV to $\sim$ 5 GeV. The infrastructure may be provided by the proposed Atacama Large Millimeter Array (ALMA) at the same site.

Aharonian et al. (2001) have shown that the photon density of a 10 GeV shower would increase by a factor $\approx 2$ in the core of the shower relative to the corresponding density on La Palma. Furthermore, the angular resolution at 5 GeV would be $\approx 0.4°$, improving to 0.3° at 10 GeV, making a spatial identification also possible. The collection area at 2 GeV is already more than 100 $m^2$, and with an electron background rate of $\approx$ 26 Hz, typical EGRET GeV sources can be detected within a few seconds! Solar modulation will cause the background rate to change with time, but solar modulation models can predict this variation accurately which would give a reliable prediction for the background rate if the trigger is properly understood.

Using the collection area vs energy $A(E)$ for the trigger condition selected by Aharonian et al., the detection rate can be determined by integrating the quantity $(dN/dE)A(E)0.67$ over energy (with the factor 0.67 determined by the $1\sigma$ point spread function) to give the pulsed rate $R_p$ (in Hz) as shown in Table 2. Following the same procedure as for

MAGIC and H.E.S.S., the required observation time $T$ (in seconds) was determined and listed in Table 2.

It is clear that all pulsars can be detected within a few seconds, provided that the atmospheric conditions are favorable and that the zenith angle is not too large.

## 7. Conclusion

By employing a special non-imaging "pulsar trigger", ground-based telescopes under construction can trigger on the low energy $\gamma$-ray showers near threshold, at the cost of photons with energies above $\sim$ 50 GeV. There are two reasons for this: Higher energy photons should pair produce on the strong magnetic fields (unless an outer gap scenario is in operation, but our main goal is to detect EGRET-type photons below 30 GeV). Secondly, a significant background component is rejected in association with such a discrimination.

If, however, the pulsed $\gamma$-rays are produced in an outer gap, such $\gamma$-rays can escape from the lower $B$-field region, unless prevented by $\gamma\gamma$-pair creation on soft X-rays in the outer gap, but this cutoff would not be as fast as for magnetic pair creation. The design of a special pulsar trigger should be based on the most conservative spectral expectations, which, in this case, is represented by a polar cap mechanism as discussed previously.

Whereas a stereo system like H.E.S.S. rejects a significant fraction of background events, its limited mirror area per telescope requires a pulsar cutoff $E_0 > 30$ TeV. MAGIC with its larger mirror area has the advantage of a lower threshold energy, allowing it to probe lower cutoff pulsars, but more effort must be put into background rejection, which is possible given all the hardware- and software features.

MAGIC should have PSR B1951+32 and Crab detectable from La Palma within $\sim$ 1 night – one pulsar for each season. For H.E.S.S. in Namibia, PSR B1706-44 should be detectable in the pulsed and unpulsed (plerionic?) mode within a single night if $E_0$ is not much lower than 40 GeV. These studies concentrated on pulsed detections in the non-imaging mode, but some of the tails of the pulsed spectra may still be detectable in the imaging mode, which would offer an opportunity to study the images near threshold, by exploiting the test statistic for uniformity as a measure of the signal strength. This may allow us to improve the quality of imaging closer to the threshold of detection. This compares with the "in-flight" calibration performed by EGRET by exploiting a test statistic for pulsed events from Crab and Vela, and such "pulsed" sky maps are free of systematics compared to the sky maps constructed for DC sources (on-line routine checks are of course performed to search for spurious oscillations in the recording system.)

By putting five MAGIC telescopes in stereo to form a "super-H.E.S.S." at an altitude of 5 km above sealevel would reduce the threshold to 5 GeV, with significant triggers as low as 1.5 GeV. No special trigger would be required for "5@5" and it would be able to detect all EGRET pulsars within a few seconds (given a favorable declination). This would give a much faster detection compared to GLAST, but at the cost of a limited field of view and declination strip. Such a detector should be able to survey all GeV EGRET sources inside the declination strip and establish their periodic status within a few seconds.

Lorenz & Mirzoyan (2001) suggested an upgraded version for MAGIC, consisting of a 30-meter class telescope at a lower altitude (e.g. La Palma). Such a "super-MAGIC" would collect $(30/17)^2 = 3$ times more photons from the same shower compared to MAGIC, and, combined with the developments in high QE PMT's (near 50%), may reach a similar status compared to "5@5".

Whereas H.E.S.S. and and especially MAGIC are expected to probe some EGRET pulsars and a number of unidentified EGRET sources, GLAST is expected to survey the pulsar sky before either 5@5 or the 30-meter telescope becomes a reality, but improvements in high quantum efficiency photon detectors should improve the numbers presented in Table 2 significantly.

## References


Aharonian, F.A., Konopelko, A.K., Völk, H., & Quintana, H. 2001, Astroparticle Physics, 15, 335.

Barrio, J.A. et al. 1998, MPI-PhE/98-5.

Beran, R.J. 1969, Ann. Math. Statist., 40, 1196.

Bhat, C.L. 2001, in Proc. International Symposium, Heidelberg 26-30 June 2000, Germany, Eds. F.A. Aharonian, H.J. Völk American Institute of Physics 558, 582.

D'Amico, N. et al. 2001, ApJ, 552, L45.

Daugherty, J.K. & Harding, A.K. 1996, ApJ, 458, 278.

de Jager, O.C., Swanepoel, J.W.H. & Raubenheimer, B.C. 1989, A&A, 170, 187.

de Jager, O.C. 1994, ApJ, 436, 239.

de Jager, O.C. 1998, in Proc. 16th ECRS, ed. J. Medina, University of Alcalá, 311.

de Jager, O.C., Konopelko, A., Raubenheimer B.C., & Visser, B. 2001, in Proc. International Symposium, Heidelberg 26-30 June 2000, Germany, Eds. F.A. Aharonian, H.J. Völk American Institute of Physics 558, 613.

Fonseca, V. et al. 2001, ICRC, OG Session, in press.

Grenier, I. 2001, in Proc. International Symposium, Heidelberg 26-30 June 2000, Germany, Eds. F.A. Aharonian, H.J. Völk American Institute of Physics 558, 191.

Halpern, J.P. et al. 2001, ApJ, 552, L125.

Hirotani, K. 2001, ApJ, 549, 495.

Hofmann, W. et al. 2001, ICRC, OG Session, in press.

Konopelko, A. 2001, in Proc. International Symposium, Heidelberg 26-30 June 2000, Germany, Eds. F.A. Aharonian, H.J. Völk American Institute of Physics 558, 569.

Lorenz, E. & Mirzoyan, R. 2001, in Proc. International Symposium, Heidelberg 26-30 June 2000, Germany, Eds. F.A. Aharonian, H.J. Völk American Institute of Physics 558, 586.

Lucarelli, F., et al. 2001, ICRC, OG Session, in press.

Nel, H.I. & de Jager, O.C. 1995, Astr. Space Science, 230, 299.

Thompson, D.J. 1997, in Neutron Stars and Pulsars, ed. Shibazaki, N. et al. (Tokyo Univ. Acad. Press), 273.

Thompson, D.J. 2001, in Proc. International Symposium, Heidelberg 26-30 June 2000, Germany, Eds. F.A. Aharonian, H.J. Völk American Institute of Physics 558, 103.