Future Pulsar Observations with H.E.S.S.

A. Konopelko
Max–Planck–Institut für Kernphysik, D-69029 Heidelberg, Germany

Abstract. Since their discovery at radio wavelengths pulsars have been persistent targets for widespread multiwave observations throughout optics, radio, X-rays, and high-energy γ-rays. Observations with the EGRET γ-ray telescope, on board Compton GRO satellite, confirmed the expectation of a pulsed high-energy emission up to a few GeV. Presently, at least seven objects are known as well established high-energy γ-ray pulsars. A few of those emit γ-rays well above 1 GeV. Forthcoming ground-based Čerenkov telescopes will enable observations of γ-rays well below 100 GeV, finally reaching the yet unexplored energy gap at tens of GeV. H.E.S.S. (High Energy Stereoscopic System) is one of such instruments which is planned to be operational in 2004. Here I summarize the basic scientific motivations, the H.E.S.S. sensitivity, and the first targets for future pulsar observations at high energies from the ground.

1. Introduction

It is generally accepted that pulsars are produced from massive progenitor stars with a masses of \( M \geq 8 M_\odot \) and typical radii \( R_\odot \approx 10^{11} \) cm, collapsing at the end of their evolution to neutron stars in an explosion, which ejects the outer envelope forming a supernova remnant. A pulsar is a rotating neutron star (Baade & Zwicky 1934) with a mass of \( M \approx 1.4 M_\odot \), a radius of \( R \approx 15 \) km, and a rotational period typically of order \( P \approx 1 \) s. Pulsars are slowing down and loosing their rotational energy with the rate

\[
\dot{E} = 4\pi^2 I \dot{P} / P^3
\]

(1)

where \( \dot{P} = dP/dt \) is the measured rate of a pulsar slowdown, and \( I = 10^{45} \) g cm\(^2\) is a generic moment of inertia of a pulsar. Assuming that the pulsar releases its mechanical energy in form of magnetic dipole radiation (Ostriker & Gunn 1969) one can estimate the pulsar surface magnetic field

\[
B_s \approx 3.2 \times 10^{19} (\dot{P} P)^{1/2},
\]

(2)

which appears to be very strong and for a typical pulsar is of the order of \( 10^{12} \) G. Assuming a constant magnetic field throughout the pulsar lifetime, the characteristic age of a pulsar can be determined from its rotational period and slow-down rate

\[
\tau = P/(2\dot{P}).
\]

(3)

The γ-ray luminosity of a pulsar, \( L_\gamma \) erg s\(^{-1}\), can be roughly estimated using the measured flux of high-energy γ-rays, \( F_\gamma \) photon cm\(^{-2}\) s\(^{-1}\):

\[
L_\gamma (> E_\gamma) \approx \omega d^2 F_\gamma (> E_\gamma) E_\gamma
\]

(4)

where \( \omega \) is the solid angle into which the pulsar beams and \( d \) is the distance to the pulsar. The γ-ray luminosity is widely supposed to be proportional to the total loss of pulsar rotational energy

\[
L_\gamma \approx \epsilon \dot{E}
\]

(5)

where \( \epsilon \) is the efficiency of converting the rotational energy of neutron star into γ-rays. On the other side the γ-ray flux of a particular pulsar can be estimated as

\[
F_\gamma \propto \epsilon (\dot{E}/d^2) E_\gamma^{-1} \text{ ph cm}^{-2} \text{ s}^{-1}.
\]

(6)

The conversion efficiency, \( \epsilon \), could be, in zero approximation, assumed as a phenomenological function of pulsar age, even though this function is not unique and not universal. The observed γ-ray flux depends at first on the size of the pulsar beam. Finally the spin-down powered pulsars can be characterized by a set of five parameters \((P, \dot{P}, B_s, \tau, E/d^2)\), which allow to predict approximate γ-ray luminosity of a particular pulsar for a given \( E/d^2 \) and \( \epsilon \). More accurate calculations of γ-ray fluxes, light-curves and energy spectra can be performed using elaborated models of spinning down pulsars.

2. Models of high-energy pulsars

There are two major classes of models dealing with high-energy γ-ray emission from the pulsars. They differ primarily by the initial assumptions on where the particle acceleration and radiation take place, either near the surface of neutron star at its polar caps or in the outer gaps, which may occur in the outer magnetosphere of a pulsar.
Pulsar. at relatively large distance from the surface of the neutron star (see Figure 1).

**Polar cap model.** A fast spinning, magnetized neutron star can generate a huge electric field, which induces an electrostatic potential $U \propto P^{-3/2}(\dot{P})^{1/2} \approx 10^{12}$V right above the polar caps of a pulsar. As suggested by Goldreich & Julian (1969) the corresponding electrostatic force may overcome gravity and pull out the charged particles from the surface of the neutron star, forming the current given by $I_{CJ} \propto B_s/P^2$. In addition charged particles may escape from the surface of the neutron star because its surface temperature $T_s = 10^5 - 10^6$K (Becker & Trümper 1997) may exceed the electron thermal emission temperature. The electrons can be accelerated in the regions above the poles where the open magnetic field lines originate (Sturrock 1971; Ruderman & Sutherland 1975). Those electrons may emit high-energy γ-rays in three major processes: (i) synchrotron emission induced by electrons spinning around the magnetic field lines; (ii) curvature radiation generated by the electrons moving along magnetic field lines; (iii) inverse Compton emission produced by high-energy electrons, which up-scatter low energy photons to γ-ray energies. The γ-rays interact with the pulsar magnetic field ($\gamma \rightarrow e^- e^+$) initiating the pair cascade ( Harding 1981; Daugherty & Harding 1982). The pair formation fronts occur at 0.5-1 stellar radii above the surface of the neutron star where the magnetic field is rather strong (for a typical pulsar $B \simeq 10^{12} G$). For such magnetic fields only the γ-rays below a certain energy (a few GeV for typical pulsars) may freely escape from the pair production region. The super-exponential cut-off in the high-energy γ-ray spectrum is an intrinsic feature of the polar cap model.

**Outer Gap model.** A vacuum gap may occur in the outer magnetosphere of a pulsar (Cheng, Ho & Ruderman 1986; Romani 1996), which is limited by the null charge surface $\Omega \cdot B \equiv 0$ and the light cylinder. Charged particles can flow out through the light cylinder, whereas they could not run through the null charge surface. The γ-rays (curvature or inverse Compton photons) penetrating into the vacuum gap can produce a pair ($\gamma \gamma \rightarrow e^- e^+$) by interacting with non-thermal X-rays or infrared photons, which fill the gap. The secondary electrons can be accelerated in the vacuum gap electric field and emit synchrotron and curvature γ-ray photons. The γ-rays of energy at least up to 10 GeV may escape from the vacuum gap. This model is suggestive of pulsed TeV γ-ray emission induced by the inverse Compton up-scattering of infrared photons by high-energy electrons (Romani 1996).

Table 1. High-energy γ-ray pulsars.

| Pulsar | $P(\text{ms})$ | $-\log \dot{P}$ | $\log B_s$ | $\log d$ (kpc) | $\log E/d^2$ | $R$ |
|--------|----------------|----------------|------------|---------------|-------------|-----|
| B0531+21 | 33 | 12.4 | 12.6 | 3.1 | 2.0 | −4.9 | 1 |
| B0833−45 | 89 | 12.9 | 12.5 | 4.1 | 0.5 | −5.5 | 2 |
| B1706−44 | 102 | 13.0 | 12.5 | 4.2 | 1.8 | −7.0 | 3 |
| B1509−58 | 150 | 11.8 | 13.2 | 3.2 | 1.4 | −7.0 | 4 |
| B1951+32 | 39 | 14.2 | 11.7 | 5.0 | 2.5 | −7.2 | 5 |
| J0633+1746 | 237 | 14.0 | 12.2 | 5.5 | 0.2 | −7.6 | 6 |
| B1055−52 | 197 | 14.2 | 12.0 | 5.7 | 1.5 | −8.9 | 29 |

1 R is a rank given according to the derived value of $E/d^2$.

2 PSR B1509−58 was seen only with COMPTEL (Kuiper et al. 1999) up to an energy of about 30 MeV, and not with EGRET.
null current sheet extending rather far from the surface of the neutron star beyond the light cylinder. Spectra of \( \gamma \)-ray emission computed using such a model might be challenging future observations at high-energies from the ground.

3. EGRET pulsars

The discovery of the first radio pulsar \( PSR B1919 + 21 \) (Hewish et al. 1968) has triggered further large-scale search for radio pulsars, which brought us a lot more detections. These days the catalogs of radio pulsars account for more than 1400 objects. About 50 of those have been seen in X-rays, but only 7 at high energies (\( E_{\gamma} \geq 30 \) MeV) (Kanbach 2002), recently observed with EGRET. It is remarkable that most of the EGRET pulsars have got a top rank when they are listed according to the value of \( E/d^2 \) (Table 1).

Most of the high-energy \( \gamma \)-ray pulsars have been seen at radio wavelengths, except Geminga (\( PSR J0633 + 1746 \)), which appears to be radio-quiet. The light-curves of pulsed high-energy \( \gamma \)-ray emission generally do not resemble the light-curves of radio emission, even though they can be rather similar, e.g. for the Crab pulsar (\( PSR B0531 + 21 \)). Three pulsars, Crab, Vela (\( PSR B0833 – 45 \)), and Geminga, have a double-peaked light-curve with a substantial contribution of a bridge (inter-peak) emission. The peculiar behavior of the light-curves reveals a complicated geometry of the pulsed emission, which is evidently not always similar to the light-curves at other wavelengths (for detailed discussion see Thompson 2000).

Six \( \gamma \)-ray pulsars show a clear evidence of the pulsed emission above 5 GeV. Spectral energy distributions (SED) of \( \gamma \)-ray emission from the high-energy pulsars (\( \nu F_{\nu} \), Jy Hz) peak in the hard X-ray or \( \gamma \)-ray range. The SED breaks at GeV energies, which is an established distinctive feature of \( \gamma \)-ray emission from the pulsars, which was predicted by the polar cap model.

The energy spectra of EGRET pulsars can be well fitted by power laws with spectral indices within the range \( \alpha = 1.4–2.1 \) plus a super-exponential cut-off at the energy about \( E_{\gamma} = 5 – 40 \) GeV (de Jager et al. 2001)

\[
dF_{\gamma}/dE = K \cdot E^{-\alpha} \exp(-E/E_0)^\beta, \quad \beta \approx 2 \quad (7)
\]

where \( E \) is in units of GeV. Parameters of the fit for six EGRET pulsars are summarized in Table 2.

The normalization constant \( K \) in Eqn. (1) corresponds to the photon flux at energy of 1 GeV, and is an approximate measure of the pulsar luminosity in high-energy \( \gamma \)-rays, \( L_{\gamma} \). One can expect that \( L_{\gamma} \) correlates with the total loss of the rotational energy of a pulsar \( (E/d^2) \). In Figure 2 the scatter plot of \( K \) over \( E/d^2 \) for six GeV EGRET high-energy \( \gamma \)-ray pulsars is shown. Even though the current sample of high-energy \( \gamma \)-ray is very poor one can see an evident trend, which can be fitted as \( L_{\gamma} \propto (E/d^2)^{1/3} \). Pulsar luminosity in high-energy \( \gamma \)-rays is determined not only by the total loss of its rotational power but in addition by the efficiency of energy conversion from slow-down into high-energy \( \gamma \)-rays (see Eqn. (1)). In fact, even a pulsar with a rather low value of \( E/d^2 \) and low Rank (see Table 1) could appear to be a powerful \( \gamma \)-ray emitter. For instance \( \gamma \)-ray pulsar \( PSR B1055 \) has rather low Rank – 52 has rather low Rank – 29. Naturally the efficiency \( \epsilon = L_{\gamma}/L \propto K/(E/d^2) \) could be a function of pulsar age. The efficiency of energy conversion from rotational slow-down into high-energy \( \gamma \)-rays can be determined at most by the increase of current flow out of the neutron star for elder pulsars (Harding 1981), or by the corresponding increase in size of a particle acceleration region in the magnetosphere around the star (Ruderman, Cheng 1988). The measure of conversion

---

**Table 2.** Spectral parameters\(^1\) of high-energy \( \gamma \)-ray pulsars\(^2\).

| Object         | \( K \times 10^{-8} \) | \( \alpha \) | \( E_0 \) | \( \beta \) |
|----------------|-------------------------|-------------|----------|-----------|
| \( B0531 + 21 \) | 24.0 2.08               | 30 2.0      |          |           |
| \( B0833 – 45 \) | 138.0 1.62              | 8 1.7       |          |           |
| \( B1706 – 44 \) | 20.5 2.10               | 40 2.0      |          |           |
| \( B1951 + 32 \) | 3.8 1.74                | 40 2.0      |          |           |
| \( J0633 + 1746 \) | 73.9 1.42              | 5 2.2       |          |           |
| \( B1055 – 52 \) | 4.0 1.80                | 20 2.0      |          |           |

\(^1\) see for details de Jager et al. (2001)

\(^2\) Spectral references from Macomb & Gehrels (1999)
efficiency as a function of pulsar apparent age is shown in Figure 3. The general tendency can be approximated by $\epsilon \propto \tau^{1.2}$.

For a better understanding of pulsar workings a substantially more representative sample of $\gamma$-ray pulsars is needed. Future observations from space with GLAST\footnote{GLAST: The Gamma ray Large Area Space Telescope} and from the ground with future Čerenkov instruments may significantly increase the sample of $\gamma$-ray pulsars.

de Jager et al (2001) have estimated the minimal exposure for a 5$\sigma$ detection of EGRET high-energy $\gamma$-ray pulsars. Pulsar PSR B1706 – 44 appeared to be the best candidate for the future observations with H.E.S.S. (for a description of the experiment, see Hofmann 2001). A 10 hours exposure with H.E.S.S. will enable to resolve a pulsed high-energy $\gamma$-ray emission above 30 GeV from PSR B1706 – 44.

4. Pulsar observations at very high energies

Based on the outer gap model of $\gamma$-ray emission (see discussion above) Romani (1996) predicted a pulsed very high energy (VHE) TeV emission through the inverse Compton (IC) up-scattering of synchrotron photons on the primary electrons accelerated in the strong electric field of a pulsar. It motivated numerous observations of pulsars with ground-based imaging and non-imaging Čerenkov telescopes (Ong 1998; Catanese & Wekes 1999). Note that the ground-based instruments are approaching the energy range covered by satellite detectors and already nowadays achieve an energy threshold as low as 60 GeV. Basic results of these observations are summarized in Table 2. Except for recent evidence for a detection of Geminga with still low level of confidence (Neshpor & Stepanian 2001) none of the observations have resolved a pulsed VHE $\gamma$-ray emission. The outer gap model could easily accommodate the non-detection of pulsed VHE $\gamma$-ray emission by assuming higher fluxes of the microwave seed photons which cause the pair production of TeV $\gamma$-rays within the vacuum gap (Hirotani & Shibata 2001). Predicted fluxes of pulsed IC TeV $\gamma$-rays rely heavily on the spectral energy distribution of the microwave seed photons, which is currently purely known. A detailed search for the IC component of VHE $\gamma$-ray emission from pulsars will be performed with the ground-based imaging Čerenkov telescopes of the next generation with drastically improved flux sensitivity.

5. Plerions

What sets the puzzle is that the Crab Nebula (Hillas et al. 1998; Aharonian et al. 2000), Vela (Yoshikoshi et al. 1997; Chadwick et al. 2000), and PSR B1706 – 44 (Kifune et al. 1995; Chadwick et al. 1998), are well established sources of DC GeV-TeV $\gamma$-ray emission in the 60 GeV - 50 TeV energy range. This steady flux emission might be associated possibly with the X-ray synchrotron nebula around the pulsar (de Jager & Harding. 1992; de Jager et al. 1996; Aharonian, Atoyan, Kifune 1997). However the spectral behavior of both, pulsed and unpulsed, components of high-energy $\gamma$-rays within the energy range from 10 GeV up to 100 GeV remains unknown. This energy range can be effectively studied from the ground with the forthcoming imaging atmospheric Čerenkov light telescopes (see for a review Catanese, Wekes 1999). Spectral measurements over this energy range will severely constrain the physics of particle injection and acceleration in a pulsar and within the surrounding pulsar nebula. Note that H.E.S.S. could

---

**Table 3. Summary of a search for pulsed VHE $\gamma$-ray emission from the ground.**

| Pulsar       | Telescope | $E_{\text{th}}$(GeV) | U.L.$^1$ | Ref. |
|--------------|-----------|----------------------|---------|------|
| B0531 + 21   | HEGRA     | $10^3$               | $\leq 5.6 \times 10^{-13}$ |      |
|              | Whipple   | 250                  | $\leq 4.8 \times 10^{-12}$ |      |
|              | STACEE    | 190                  | $\leq 1.2 \times 10^{-11}$ |      |
|              | CELESTE   | 60                   | $\leq 7.4 \times 10^{-11}$ |      |
| B0833 – 45   | CANGAROO  | $2.5 \times 10^4$    | $\leq 3.7 \times 10^{-13}$ |      |
|              | Durham    | 300                  | $\leq 1.3 \times 10^{-11}$ |      |
| B1706 – 44   | Durham    | 300                  | $\leq 7.8 \times 10^{-12}$ |      |
| B1951 + 32   | Whipple   | 260                  | $\leq 6.7 \times 10^{-12}$ |      |
| J0633 + 1746 | HEGRA     | $1.5 \times 10^3$    | $\leq 1.0 \times 10^{-12}$ |      |
|              | Whipple   | 500                  | $\leq 6.5 \times 10^{-12}$ |      |
|              | CrAO$^2$  | $10^3$               | $\approx 2.4 \times 10^{-11}$ |      |
| B1055 – 52   | Durham    | 300                  | $\leq 6.8 \times 10^{-11}$ |      |

$^1$ U.L. is an upper limit measured in photon cm$^{-2}$ s$^{-1}$.

$^2$ Neshpor & Stepanian (2001) claim the detection of Geminga pulsar at 4.4$\sigma$ confidence level.
detect a Crab like source of DC VHE \(\gamma\)-rays after a few minutes of observation (Konopelko 2000).

6. Millisecond pulsars

Most of the radio pulsars detected so far have their rotational periods within the range from 10 ms to 10 s, whereas a few of them form a separate sample of millisecond pulsars with rotational periods in the range from 1 ms to 10 ms. \(PSR\ 1937 + 214\) is the first detected millisecond pulsar, and has a rotational period of 1.5 ms (Backer et al. 1982). For such a short period it has a surprisingly small value of \(P \approx 10^{-19}\). Using the relation given by Eqn.(3), one can estimate the pulsar age as \(\tau \geq 10^7\) years. Being rather old, the millisecond pulsars do not fit the general scheme of pulsar evolution, and most probably are re-accelerated by some external mechanism (e.g. by accretion from a companion star in a binary system). The millisecond pulsars should have smaller surface magnetic field (see Eqn.(3)), \(B_s \sim 10^9\ G\), and that makes them particularly interesting with respect to the high-energy \(\gamma\)-ray emission. Given such a low magnetic field, the cut-off energy of curvature photons due to the pair production (see discussion in section 2) shifts to higher energies, and the maximum radiation of the millisecond pulsars should correspond to photons with energy \(\sim 10^{11}\ eV\) (Usov 1983). The value of the photon flux above 100 GeV, estimated for \(PSR\ 1937 + 214\) by Usov (1983), is approximately an order of magnitude higher than that of the Crab pulsar, \(J_c(\geq 100\ GeV) \approx 2 \times 10^{-10}\ ph\ cm^{-2}\ s^{-1}\). Recent detailed calculations of the energy spectra of high-energy and very high energy \(\gamma\)-ray emission from millisecond pulsars (Bulik, Rudak, Dyks 2000) in general have confirmed early expectations.

Pulsar \(J0437 - 4715\) (\(P = 5.75\ ms, d = 140\ pc\)) is a prime candidate for observations in the energy range above 100 GeV. Its integral \(\gamma\)-ray flux above 100 GeV is expected to be as high as \(\geq 10^{-11}\ ph\ cm^{-2}\ s^{-1}\) (Bulik, Rudak, Dyks 2000), which is above the sensitivity limit of H.E.S.S. (Konopelko 2000). Assuming rather conservative \(\gamma\)-ray flux for \(J0437 - 4715\) one needs a 50 hour exposure with H.E.S.S. in order to detect the pulsed \(\gamma\)-rays. Another millisecond pulsar, \(PSR\ B1821 - 24\), is a good candidate for pulsed high-energy \(\gamma\)-ray emission seen by EGRET, and it is certainly a valuable target for future observations with H.E.S.S.

7. Young pulsars

In addition to seven well established high-energy \(\gamma\)-ray pulsars EGRET discovered a large number of unidentified \(\gamma\)-ray sources at low Galactic latitudes (see Kanbach 2002). The recent Parkes multi-beam radio surveys allowed to resolve a number of young energetic radio pulsars with some of those being in rather good positional coincidence with unidentified EGRET \(\gamma\)-ray sources (Torres, Butt, Camilo 2001). Such associations resemble in many ways the established EGRET \(\gamma\)-ray pulsars. For instance pulsar \(PSR\ B1046 - 58\) could be a counterpart of high-energy \(\gamma\)-ray source \(3EG\ J1048 - 5840\) (Kaspi et al. 2000). It has the ninth highest value of \(E/d^2\), and its \(\gamma\)-ray light-curve morphology is similar to other known \(\gamma\)-ray pulsars, namely, two narrow peaks separated by \(\sim 0.4\) in the light-curve phase. \(3EG\ J1048 - 5840\ has a rather flat energy spectrum \((\alpha \approx 2.0)\) without clear evidence for a cut-off. Two other young radio pulsars \(PSR\ J1420 - 6048\ (P=68\ ms)\) and \(PSR\ J1837 - 6004\ (P=96\ ms)\) are located \(\sim 10'\ away from the position of the EGRET unidentified sources \(3EG\ J1420 - 6038\) and \(3EG\ J1837 - 6006\), respectively (D’Amico et al. 2001). In the energy range from 100 MeV to 10 GeV, the spectra of these two sources can be fitted with power laws of photon spectral index \(\alpha = 2.02\) and 1.82, respectively, which are inside the spectral index range of the known \(\gamma\)-ray pulsars. A 20 hour exposure with H.E.S.S. for this source may be sufficient for a clear detection of very high energy \(\gamma\)-ray emission (de Jager et al. 2001) from both of these pulsars, assuming the energy cut-off at 40 GeV. About 30 young energetic radio pulsars are currently known as positional associations with unidentified EGRET \(\gamma\)-ray sources (D’Amico...
In addition some of those pulsars are within the X-ray nebula, which confirms that they are plerions (see Roberts, Romani, Kawai 2001), and may well be in addition the sources of DC high-energy γ-ray emission coming from the X-ray nebula, surrounding the pulsar. Such sources could be effectively studied at very high energies from the ground with an instrument like H.E.S.S.

8. H.E.S.S.

H.E.S.S. (High Energy Stereoscopic System) is one of the next generation ground-based instruments for very high energy γ-ray astronomy (Hofmann 2001). In its 1st phase it will consist of four 12 m Čerenkov telescopes deployed in the Khomas Highland of Namibia. H.E.S.S. will have an energy threshold in the range of 50 - 100 GeV (Konopelko 2000), an angular resolution for individual photons of 0.1°, and an energy resolution better than 20%. According to the current sensitivity estimate, H.E.S.S. will need a 50 hour exposure to detect a γ-ray point source with photon fluxes \( \mathcal{J} \simeq 10^{-11} \text{ph cm}^{-2} \text{s}^{-1} \) and \( \simeq 10^{-13} \text{ph cm}^{-2} \text{s}^{-1} \) above 100 GeV and 1 TeV, respectively. The first observations with two telescopes are being currently planned in early 2003. The complete system is due in 2004. The visibility of H.E.S.S. along with a few selected pulsars as the potential targets for future observations is shown in Figure 4.

9. Summary

Pulsars are objects with an extreme physics environment. They are offering physics processes to be studied by plasma electrodynamics, nuclear physics, cosmic ray physics, etc. Understanding the pulsar physics could substantially benefit from the enrichment of the presently very small sample of high-energy γ-ray pulsars. Measurements of energy spectra for already established, as well as for newly discovered γ-ray pulsars, will constrain the modeling of high-energy emission and in particular the location of the emitting regions with respect to the neutron star. Future observations at high-energies, which can be effectively done with the ground-based Čerenkov instruments, will stretch the existing models and will help to understand the physics of millisecond pulsars. Observations of associations of the energetic young radio pulsars at low Galactic latitudes with unidentified EGRET γ-ray sources will allow to prove that pulsars are in general powerful emitters of high-energy γ-rays. Finally, a rich sample of γ-ray pulsars can be used for better understanding the conversion of pulsar rotational energy into γ-ray emission, which is determined by the size and geometry of emitting regions.

H.E.S.S. is one of the forthcoming ground-based Čerenkov detectors, such as CANGAROO, MAGIC, and VERITAS, and the present discussion is entirely relevant for the future observations with any of those instruments.

Acknowledgements. I would like to thank Werner Becker, Alice Harding, Okkie de Jager, Gottfried Kaubach, John Kirk, Yury Lyubarsky, Roger Romani, Bronislaw Rudak, Vladimir Usov, and Heinz Völk, for discussions on pulsar physics.

References

Aharonian, F., et al. 1999, \textit{A\&A}, 346, 913
Aharonian, F., et al. 2000, \textit{ApJ}, 539, 317
Aharonian, F., Atoyan, A., Kifune, T. 1997, \textit{MNRAS}, 291, 162
Akerlof, et al., 1993, \textit{A\&A}, 274, L17
Baade, W., Zwicky, F. 1934, \textit{Proc. Nat. Acad. Sci. USA}, 20, 254
Backer, D.C., et al. 1982, \textit{Nature}, 300, 615
Becker, W., Trümper, J. 1997, \textit{A\&A}, 326, 682
Bulik, T., Rudak, B., Dyks, J. 2000, \textit{Mon. Not. R. Astron. Soc.}, 317, 97
Catanese, M., Weekes, T. 1999, \textit{Pub. Astron. Soc. of Pacific}, 111, 764, 1193
Chadwick, et al., 1998, \textit{Astropart. Phys.}, 9, 131
Chadwick, et al., 2000, \textit{ApJ}, 537, 414
Cheng, K.S., Ho, C., Ruderman, M.A. 1986, \textit{ApJ}, 300, 500
D’Amico, N., et al. 2001, \textit{ApJ}, 552, L15
D’Amico, 2001, \textit{Talk at Gamma Ray Astrophysics Symposium}, Baltimore
Daugherty, J.K., Harding, A.K. 1982, \textit{ApJ}, 252, 337
de Jager O.C., et al. 1992, \textit{ApJ}, 396, 161
de Jager O.C., et al. 1996, \textit{ApJ}, 457, 253
de Jager O.C., Konopelko, A., Raubenheimer, B.C., Visser, B.
2001, \textit{Proc. ICRC}, Hamburg, vol. 6, 2432
de Naurois, et al. 2002, \textit{ApJ}, 566, 343
Goldreich, P., Julian, W.H. 1969, \textit{ApJ}, 157, 869
Harding, A.K. 1981, \textit{ApJ}, 245, 267
Harding, A. et al. 2000, \textit{Proc. Int. Symp. High Energy Gamma Ray Aston.}, Heidelberg, \textit{Eds. F.A. Aharonian, H.J. Völk, AIP Conf. Proc.}, vol. 558, 115
Hewish, A., et al. 1968, \textit{Nature}, 217, 709
Hillas, A.M., et al. 1998, \textit{ApJ}, 503, 744
Hirotani, K., Shibata, S. 2001, \textit{ApJ}, 558, 216
Hofmann, W. 2001, \textit{Proc. 27th ICRC}, Hamburg, vol. 7, 2785
Kanbach, G. 2002, \textit{This proceedings}
Kaspi, V.M., et al. 2000, \textit{ApJ}, 528, 445
Kifune, T., et al., 1995, \textit{ApJ}, 438, L91
Kirk, J., Skjæeraasen, O., Gallant, Y. 2002, \textit{submitted to A\&A}.
Konopelko, A., 2000, \textit{Proc. Int. Symp. High Energy Gamma Ray Aston.}, Heidelberg, \textit{Eds. F.A. Aharonian, H.J. Völk, AIP Conf. Proc.}, vol. 558, 569
Kuiper, L., et al. 1999, \textit{A\&A}, 351, 119
Lessard, et al., 2000, \textit{ApJ}, 531, 942
Macomb, D.J., Gehrels, N. 1999, \textit{ApJS}, 120, 335
Neshpor, Yu., Stepanian, A., 2001, \textit{Astron. Letters}, 27, 12, 794
Ong, R. 1998, \textit{Phys. Reports}, 305, 93
Osher, et al., 2001, \textit{ApJ}, 543, 949
Ostriker, J.P., Gunn, J.E. 1969, \textit{ApJ}, 157, 1395
Roberts, M., Romani, R., Kawai, N. 2001, \textit{ApJS}, 133, 451
Romani, R. 1996, \textit{ApJ}, 470, 469
Ruderman, M., Cheng, K.S. 1988, \textit{ApJ}, 335, 306
Ruderman, M.A., Sutherland, P.G. 1975, \textit{ApJ}, 196, 51
Srinivasan, R., et al. 1999, \textit{ApJ}, 489, 170
Sturrock, P.A., 1971, \textit{ApJ}, 164, 529
Thompson, D.J. 2000, Proc. Int. Symp. High Energy Gamma Ray Ast., Heidelberg, Eds. F.A. Aharonian, H.J. Völk, AIP Conf. Proc., vol. 558, 103
Torres, D., Butt, Y., Camilo, F. 2001, ApJ, 560, L155
Usov, V.V. 1982, Nature, 305, 409
Yoshikoshi, et al., 1997, ApJ, 487, L65