Gamma-Ray Pulsars:
Models and Predictions

Alice K. Harding

NASA Goddard Space Flight Center, Greenbelt MD 20771, USA

Abstract. Pulsed emission from γ-ray pulsars originates inside the magnetosphere, from radiation by charged particles accelerated near the magnetic poles or in the outer gaps. In polar cap models, the high energy spectrum is cut off by magnetic pair production above an energy that is dependent on the local magnetic field strength. While most young pulsars with surface fields in the range $B = 10^{12} - 10^{13}$ G are expected to have high energy cutoffs around several GeV, the gamma-ray spectra of old pulsars having lower surface fields may extend to 50 GeV. Although the gamma-ray emission of older pulsars is weaker, detecting pulsed emission at high energies from nearby sources would be an important confirmation of polar cap models. Outer gap models predict more gradual high-energy turnovers of the primary curvature emission around 10 GeV, but also predict an inverse Compton component extending to TeV energies. Detection of pulsed TeV emission, which would not survive attenuation at the polar caps, is thus an important test of outer gap models. Next-generation gamma-ray telescopes sensitive to GeV-TeV emission will provide critical tests of pulsar acceleration and emission mechanisms.

INTRODUCTION

The last decade has seen a large increase in the number of detected γ-ray pulsars. At GeV energies, the number has grown from two to at least six (and possibly nine) pulsar detections by the EGRET telescope on the Compton Gamma Ray Observatory (CGRO) (Thompson 2000). However, even with the advance of imaging Cherenkov telescopes in both northern and southern hemispheres, the number of detections of pulsed emission at energies above 20 GeV (Weekes et al. 1998) has remained the same (zero), or even decreased if one counts the "detections" of the non-imaging telescopes of the eighties. In the coming decade, this unexplored region above 20 GeV may hold the key to a question on which theorists have disagreed for at least two decades, that of how and where high energy emission emerges from the pulsar and how it relates to the radio emission. Furthermore, the known γ-ray pulsars are still a tiny fraction of the known radio pulsars, of which there are currently over 1000 (Camilo et al. 2000). The next-generation γ-ray telescopes, both in space and on the ground, will not only be breaching the unexplored territory

between 20 and 200 GeV, but are expected to make an unprecented increase in the γ-ray pulsar population. GLAST alone will probably detect several hundred or so radio-selected pulsars, with the predicted number being very model dependent. However, the number of radio-quiet γ-ray pulsars could dwarf the number of radio-selected γ-ray pulsars and even approach the total radio pulsar population.

I will give an overview of the current high-energy emission models and discuss their predictions for emission above 1 GeV. Because it is not yet clear how and where in the pulsar magnetosphere the non-thermal high-energy radiation originates, two competing models have developed. Polar cap models (Daugherty & Harding 1982, 1996; Usov & Melrose 1995) assume that particles are accelerated above the neutron star surface and that γ-rays result from a curvature radiation or inverse Compton induced pair cascade in a strong magnetic field. Outer-gap models (Cheng, Ho & Ruderman 1986, Romani 1996, Hirotani & Shibata 1999) assume that acceleration occurs along null charge surfaces in the outer magnetosphere and that γ-rays result from photon-photon pair production-induced cascades. These two types of models and their variations make contrasting predictions for the numbers of radio-quiet and radio-loud γ-ray pulsars and of their spectral characteristics.

HIGH-ENERGY EMISSION MODELS

Since we observe pulsed emission up to 10 GeV in γ-ray pulsars, there is no dispute that particles are accelerated to extremely relativistic energies in their magnetospheres. It is also generally agreed that the particle Lorentz factors must be in the range of at least $10^5 - 10^7$ and that these energies are the result of acceleration by large-scale electric fields. The source of the field is no mystery. Rotating, magnetized neutron stars are natural unipolar inductors, generating huge **vxB** electric fields. However, they are capable of pulling charges out of the star against the force of gravity (Goldreich & Julian 1969) and it is believed that the resulting charge density that builds up in a neutron star magnetosphere is able to short out the electric field parallel to the magnetic field ($E_{\parallel}$)(thus allowing the field to corotate with the star) everywhere except at a few locations. These spots where $\mathbf{E} \cdot \mathbf{B} \neq 0$ are thought to occur above the surface at the polar caps and along the null charge surface, $\mathbf{\Omega} \cdot \mathbf{B} = 0$, where the corotation charge changes sign. These are the purported sites of particle acceleration and have given rise to the two classes of high energy emission models.

Polar cap models

Polar cap models for pulsar high energy emission date from the early work of Sturrock (1971) and Ruderman & Sutherland (1975), who proposed particle acceleration and radiation near the neutron star surface at the magnetic poles. There is a large variation among polar cap models, with the primary division being whether
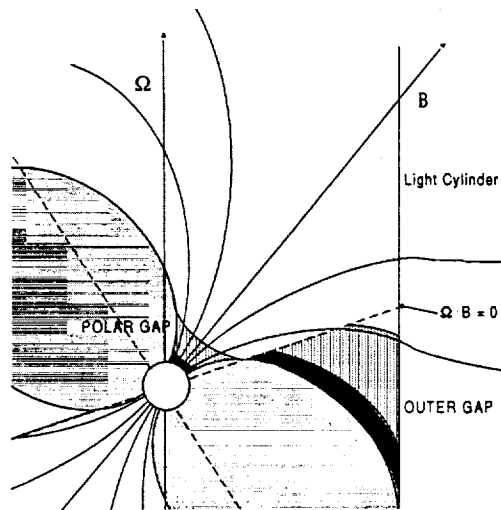
FIGURE 1. Schematic geometry of polar and outer gaps. Dark solid regions are thin gaps of younger pulsars. Hatched regions are thin gaps of older pulsars (see text).

or not there is free emission of particles from the neutron star surface. This question is still somewhat subject to debate, due to our incomplete understanding of the neutron star surface composition and physics. The subclass of polar cap models based on free emission of particles of either sign, called space-charge limited flow (SCLF) models, assumes that the surface temperature of the neutron star (many of which have now been measured in the range $T \sim 10^5 - 10^6$ K) exceeds the ion and electron thermal emission temperatures. Although $E_{\parallel} = 0$ at the neutron star surface in these models, the space charge along open field lines above the surface falls short of the corotation charge, due to the curvature of the field (Arons 1983) or to general relativistic inertial frame dragging (Muslimov & Tsygan 1992). The $E_{\parallel}$ generated by the charge deficit accelerates particles, which radiate inverse Compton (IC) photons by resonant scattering of thermal X-rays from the neutron star surface (when they reach energies $\gamma \sim 10^2 - 10^6$) and curvature (CR) photons (at energies $\gamma \lesssim 10^6$). Both IC and CR photons can produce e^+e^- pairs in the strong magnetic field. However, it is found (Harding & Muslimov 2000) that in all but the very high-field pulsars ($B \gtrsim 10^{13}$ G), the IC pair formation fronts do not produce sufficient pairs to screen the $E_{\parallel}$ or are unstable, due to returning positrons which disrupt $E_{\parallel}$ near the surface. (Harding & Muslimov 1998 [HM98]) found in this case that stable acceleration zones can form at 0.5 - 1 stellar radii above the surface, where the density of soft X-rays from the neutron star surface decreases and CR photons from both primary electrons and returning positrons produce stable pair formation fronts. The primary particle energies can then reach $\sim 10^7$ before pair production screens the field.

As the pulsar ages and its period increases, the cascade produces fewer pairs and it becomes more difficult to to produce a pair formation front and screen the $E_{\parallel}$. The acceleration zone grows longer and narrower as the particles must accelerate over larger distance to radiate pair-producing photons, until pair fronts can no

longer form and the pulsar dies as a radio pulsar. Thus, as shown in Figure 1, young pulsars will have thin accelerator gaps, while old pulsars will have thick gaps with cascades forming at higher altitudes.

The type of polar cap cascade which produces high-energy radiation depends on the primary radiation mechanism, which in turn depends on which photons (IC or CR) control the screening of the accelerating field. In pulsars where IC-controlled acceleration zones are stable, particle energies are limited to Lorentz factors $10^5 - 10^6$ (HM98) and IC is both the dominant primary radiation mechanism and the initiator of the pair cascade (Sturner et al. 1995). In pulsars where IC photons either cannot screen the accelerating field or IC-controlled zones are unstable, the primary particles continue accelerating up to Lorentz factors $\sim 10^7$. CR is then the dominant primary radiation mechanism and initiates the pair cascade. In the original version of the CR-initiated polar cap pair cascade (Daugherty & Harding 1982, 1996) the emergent cascade spectrum is dominated by synchrotron radiation from the pairs and has a very sharp high energy cutoff at several GeV due to pair production attenuation. Recently, Zhang & Harding (2000) noted that the pairs produced in polar cap cascades may resonant-scatter the soft thermal photons from the neutron star surface, losing most of the remaining parallel energy they could not lose via synchrotron emission.

Outer gap models

The outer gap models for γ-ray pulsars are based on the existence of a vacuum gap in the outer magnetosphere which may develop between the last open field line and the null charge surface ($\mathbf{\Omega} \cdot \mathbf{B} = 0$) (see Figure 1) in charge separated magnetospheres. The gaps arise because charges escaping through the light cylinder along open field lines above the null charge surface cannot be replenished from below. The first outer gap γ-ray pulsar models (Cheng, Ho & Ruderman 1986 [CHR]) assumed that emission is seen from gaps associated with both magnetic poles, but this picture, although successful in fitting the spectrum of the Crab and Vela pulsars, did not reproduce the observed pulsar light curves. More recent outer gap models assuming emission from one pole can more successfully reproduce the observed light curves (Romani & Yadigaroglu 1995). Pairs from the polar cap cascades, which flow out along all the open field lines, will undoubtedly pollute the outer gaps to some extent, but this effect has yet to be investigated.

The electron-positron pairs needed to provide the current, and therefore allow particle acceleration, in the outer gaps are produced by photon-photon pair production. In young Crab-like pulsars, the pairs are produced by curvature photons from the primary particles interacting with non-thermal synchrotron X-rays from the same pairs. In older Vela-like pulsars, where non-thermal X-ray emission is much lower, the pairs were assumed to come from interaction of primary particle inverse Compton photons with infra-red photons. However, this original Vela-type model (CHR) predicted large fluxes of TeV emission, from inverse Compton scat-

tering of the infra-red photons by primary electrons, which violates the observed upper limits (Nel et al. 1993) by several orders of magnitude. Cheng (1994) revised the outer gap model for Vela-type pulsars by proposing another self-sustaining gap mechanism where thermal X-rays from the neutron star surface interact with primary particle radiation to produce pairs, replacing the infra-red radiation (which has also never been observed). Some of the accelerated pairs flow downward to heat the surface and maintain the required thermal X-ray emission. The modern outer gap Vela-type models (Romani 1996, Zhang & Cheng 1997) all adopt this picture.

As in polar cap models, it becomes more difficult for older pulsars to produce the pairs required to screen the field and "close the gap", so that young pulsars have thin gaps and old pulsars have thick gaps, as shown in Figure 1. However, unlike in polar cap (SCLF) models, pair production plays a critical role in production of the high energy emission: it allows the current to flow and particle accceration to take place in the gap. Beyond a death line in period-magnetic field space, and well before the traditional radio-pulsar death line, pairs cannot close the outer gap and the pulsar cannot emit high energy radiation. This outer gap death line for γ-ray pulsars falls around $P = 0.3$ s for $B \sim 10^{12}$ G (Chen & Ruderman 1993), putting Geminga just barely among the living. The observed non-thermal radiation in Crab-like pulsars is a combination of synchrotron emission and synchrotron self-Compton emission from pairs. In Vela-type pulsars, the non-thermal radiation is a combination of curvature and curvature self-Compton emission from the primaries at γ-ray energies, and synchrotron emission from the pairs at optical through X-ray energies. The high-energy spectra in both types of outer gap model have cutoffs around 10 GeV, due to the radiation-reaction cutoff in the primary particle spectrum, which are much less sharp than the attenuation cutoffs in polar cap model spectra.

PREDICTIONS FOR HIGH ENERGY EMISSION

Observations of pulsars in the unexplored energy region above 20 GeV and more sensitive measurements above 1 GeV may finally be able to discriminate in favor of polar cap or outer gap models (or eliminate both!). I will discuss three areas where future observations will be able to test distinctive predictions of the models: spectral high-energy cutoffs, luminosities and population statistics (which radio-selected pulsars are γ-ray loud, which γ-ray pulsars are radio quiet).

Spectral shape and cutoffs

Polar cap models predict that the γ-ray spectra cutoff very sharply (as a "super-exponential") due to one-photon pair production attenuation, at a field-dependent energy, while outer gap model spectra cut off more slowly (as a simple exponential) due to a particle acceleration limit. The highly relativistic particles emit photons
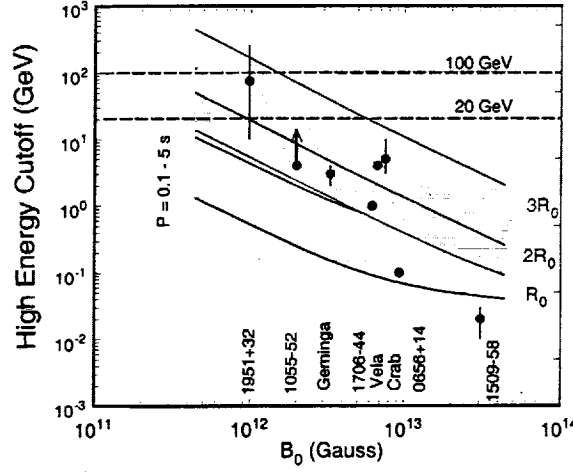
FIGURE 2. Calculated high-energy spectral cutoff energies due to magnetic pair production attenuation vs. surface field strength for a range of periods at different photon emission radii. Also shown are measured turnover energies of detected pulsars.

at very small ($\theta \sim 1/\gamma$) angles to the open magnetic field lines. The photons of energy ϵ (in units of mc^2), emitted near the neutron star surface, are initially below the threshold for one-photon pair production ($\epsilon_{th} = 2/\sin\theta$), but may reach threshold by increasing θ in the course of propagating across curved field lines. The polar cap model γ-ray spectrum will exhibit a cutoff at the pair escape energy (cf. Harding et al. 1997 [HBG97]), i.e. the highest energy at which photons emitted at a given location can escape the magnetosphere without pair producing. A rough estimate of this cutoff energy, assuming emission along the polar cap outer rim, $\theta \simeq (2\pi R/cP)^{1/2}$, at radius R, is

$$E_c \sim 1.9\,\text{GeV}\,P^{1/2}\,B_{o,12}^{-1}\left(\frac{R}{R_o}\right)^{7/2}, \qquad B_{12} \lesssim 4.4 \tag{1}$$

$$E_c \sim 0.4\,\text{GeV}\,P^{1/2}\left(\frac{R}{R_o}\right)^{1/2}, \qquad B_{12} \gtrsim 4.4 \tag{2}$$

where P, R_o, B_o and B are the neutron star period, radius and surface and local magnetic fields in units of 10^{12} G. Figure 2 shows a more accurate calculation of the predicted high-energy cutoff energy as a function of surface field strength for different radii of photon emission, computed by numerically propagating photons through a neutron star magnetosphere and taking into account general relativistic effects of a Schwarzschild metric (as in HBG97). Also plotted are the observed high-energy cutoff energies of eight γ-ray pulsars, assuming that the very steep spectrum with index 3 measured for PSR0656+14 (Ramanamuthy et al. 1996) is actually the cutoff. The cutoff energy for the highest field pulsar, PSR1509-58, falls
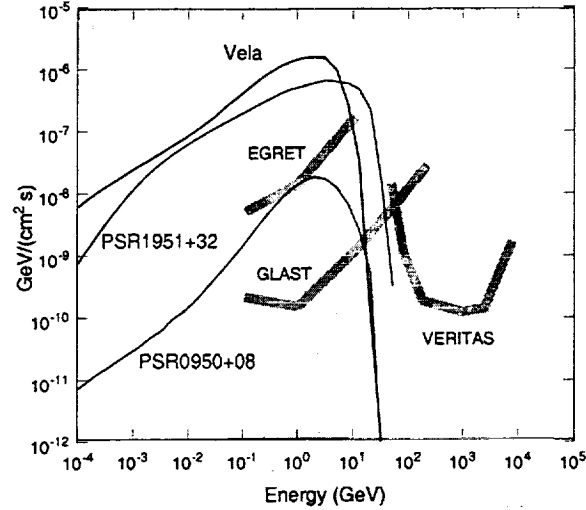
FIGURE 3. Polar cap model spectra of three different pulsars and sensitivity thresholds of various detectors. Vela and PSR1951+32 have been detected by EGRET as γ-ray pulsars.

below the predicted pair escape energy at the surface. However photon splitting, in which a single photon splits into two lower energy photons, becomes the dominant attenuation process in fields above $\sim 2\times10^{13}$ G and lowers the photon escape energy (HBG97). There seems to be an increasing cutoff energy with decreasing surface field in the observed pulsars, with a dependence even stronger than predicted by the polar cap model for a constant emission radius. However, some increase in emission radius is expected due to the trend for larger acceleration zones in older pulsars, but work to quantify this trend is still in progress.

From Figure 2, it appears that long period pulsars with low magnetic fields ("old" pulsars) will be the best candidates for detection above 20 GeV. However, there are two effects which work against detection of these pulsars at γ-ray energies. One is that the curvature radiation energy of the primaries decreases with increasing period, due to both an increasing radius of curvature of the last open field line and a decreasing particle acceleration energy. The maximum CR energy starts to move below the photon escape energy and thus determines the cutoff energy. Figure 3 shows cascade model simulations of high-energy spectra for three pulsars of different types. The model spectrum of Vela, a young pulsar with a high magnetic field and the brightest steady γ-ray source seen by EGRET, shows the sharp "super-exponential" ($\exp(-\alpha)$, where the attenuation coefficient α is itself an exponential of the photon energy) high-energy cutoff below 10 GeV. There is some evidence that the observed high-energy cutoffs are indeed steeper than a simple exponential of the photon energy (Nel & De Jager 1995). The spectrum of PSR1951+32, having a short period but surface field of only 9.8×10^{11} G and no detected high-energy cutoff below 10 GeV, has a predicted sharp cutoff around 20 GeV. The spectrum of PSR0950+08, an older pulsar with period $P = 0.253$ s and age $\tau \sim 10^7$ yr, shows a more gradual high-energy cutoff around 2 GeV, the curvature radiation

critical energy, which steepens at the pair escape energy around 20 GeV. This pulsar was not detected by EGRET, but should be easily detectable by GLAST. If the present version of the polar cap model is correct, then pulsed emission will be difficult to detect with the next generation air-Cherenkov detectors, even from short-period, low-field pulsar like PSR1951+32, unless energy thresholds below 50 GeV and preferably 20 GeV can be achieved.

The picture is quite different in outer gap models (and much more hopeful for ground-based observers). When the high-energy photons are emitted in the outer magnetosphere, where the local magnetic field is orders of magnitiude lower than the surface field, one-photon pair production plays no role in either the pair cascade or the spectral attenuation. In this case the high-energy cutoffs in the photon spectrum come from the upper limit of the accelerated particle spectrum, due radiation reaction. The shape of the cutoff is thus a simple exponential, more gradual than in polar cap model spectra. Figure 4 shows the broad-band outer-gap model spectrum of Vela (Romani 1996), superposed on the measured spectrum from optical to VHE γ-rays and the polar cap model spectrum (Harding & Daugherty 1996). The more gradual high-energy cutoff of the outer gap spectrum relative to that of the polar cap spectrum is apparent. However, due to the large errors of the EGRET data points above 1 GeV, the measurements at present to not definitely discriminate between model spectra. GLAST should have the energy resolution and dynamic range to measure the shape of the cutoffs seen by EGRET and should be able to rule out either the simple exponential or super-exponential shape. In addition, GLAST will detect enough γ-ray pulsars with different field strengths to look for a correlation between surface field strength and cutoff energy.

Outer gap models predict an emission component at TeV energies due to inverse Compton scattering by gap-accelerated particles. The original predictions of Cheng et al. (1986) were not verified by observations of ground-based detectors (Nel et al. 1993), requiring a revision of the Vela-like model (Cheng 1994). However, even later models which predicted lower TeV fluxes (Romani 1996) are above CANGAROO upper limits on pulsed emission from Vela (see Fig. 4). The most recent outer gap models (Hirotani 2000), have predicted TeV inverse-Compton fluxes which are below the present observational upper limits, but which should be detectable with the next generation of TeV detectors. Unfortunately, while a TeV emission component is an essential prediction of all outer gap models, the inverse Compton flux level depends on the pulsed emission spectrum in the infra-red (IR) band which is notoriously difficult to measure in most pulsars. Unmeasured IR turnovers can decrease the scattered TeV significantly (Romani 2000, priv. comm.).

Luminosities

Predicted γ-ray pulsar luminosities and which radio-selected pulsars will be γ-ray pulsars will also discriminate between polar cap and outer gap models. In polar cap models, the γ-ray luminosity is roughly proportional to the polar cap current
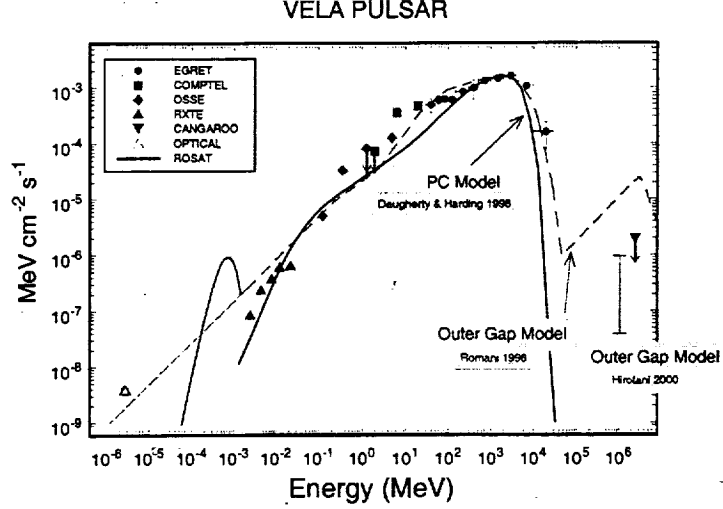
VELA PULSAR

FIGURE 4. Observed optical to VHE γ-ray spectrum of the Vela pulsar with polar cap (solid line) and outer gap (dashed line) model spectra. Data points are from the compilation by Thompson (2000).

of primary particles, $N_p \propto B_o P^{-2}$. The CR-initiated cascade model of Zhang & Harding (2000) predicts that,

$$L_\gamma^{ZH}(I) = 9.4 \times 10^{31} \, B_{12}^{6/7} P^{-13/7} \, \text{erg s}^{-1} \tag{3}$$

$$L_\gamma^{ZH}(II) = 1.6 \times 10^{31} \, B_{12} P^{-9/4} \, \text{erg s}^{-1} \tag{4}$$

where Regime I applies to young pulsars satisfying

$$B_{12}^{1/7} P^{-11/28} > 6.0 \tag{5}$$

and Regime II applies to older pulsars. The ICS-initiated polar cap cascade model of Sturner & Dermer (1994) predicts that

$$L_\gamma^{SD} = 10^{32} \, B_{12}^{3/2} P^{-2} \, \text{erg s}^{-1} \tag{6}$$

The predicted γ-ray luminosity in the outer gap models, on the other hand, is not as directly tied to the polar cap current, but rather depends on the fraction of open field lines (and thus fraction of the polar cap current) that is spanned by the outer gap accelerator. The model of Romani & Yadigaroglu (1995) predicts

$$L_\gamma^{RY} = 2.5 \times 10^{32} \, B_{12}^{0.48} P^{-2.48} \, \text{erg s}^{-1} \tag{7}$$

while the outer gap model of Cheng & Zhang (1998) predicts

$$L_\gamma^{CZ} = 6.3 \times 10^{33} \, B_{12}^{0.3} P^{-0.3} \, \text{erg s}^{-1}. \tag{8}$$

The known γ-ray pulsars, assuming a constant solid angle for all sources, follow the luminosity dependence, $L_\gamma \propto L_{SD}^{1/2} \propto B_0 P^{-2}$, where L_{SD} is the spin-down luminosity. The polar cap models thus more naturally explain this observed dependence.

Polar cap models predict that all pulsars are capable of γ-ray emission at some level. Which pulsars are detected as γ-ray pulsars is thus a matter of sensitivity. Outer gap models predict a "death line" for γ-ray emission in pulsars, which is a division in period-surface magnetic field space between young pulsars capable of sustaining pair production (and thus activity) in the outer gaps from the older pulsars which cannot (Ruderman & Halpern 1993, Chen & Ruderman 1993). Thus, a critical test of outer models is the non-detection of pulsars with ages much exceeding that of Geminga.

Population statistics and radio-quiet pulsars

Polar cap and outer gap models predict different ratios of radio-loud to radio-quiet γ-ray pulsars, primarily due to the different geometry of the high-energy emission regions and its location relative to the radio emission region. Numerous studies of radio emission morphology of many pulsars (e.g. Rankin 1993, Gil & Han 1995) argue in favor of an origin in the polar regions, within tens of stellar radii of the neutron star surface. Thus, polar cap γ-ray emission is expected to have a much higher correlation with radio emission. In fact, the radio emission is physically linked to the γ-ray emission in polar cap models if pairs from the high-energy cascades are a necessary requirement for coherent radio emission. On the other hand, the high energy emission in the outer gap is generally radiated in a different direction from the radio emission, which allows these models to account for the observed phase offsets of the radio and γ-ray pulses. At the same time, there will be fewer radio-γ-ray coincidences and thus a larger number of radio-quiet γ-ray pulsars. In Romani & Yadigaroglu's (1995) geometrical outer gap model, the radio emission originates from the magnetic pole opposite to the one connected to the visible outer gap. Many observer lines-of-sight miss the radio beam but intersect the outer-gap γ-ray beam, having a much larger solid angle. When the line-of-sight does intersect both, the radio pulse leads the γ-ray pulse, as is observed in most γ-ray pulsars.

Simulations of the radio and γ-ray pulsar populations in both models reflect these intuitive ideas. In a study of outer gap emission based on the model of Yadigaroglu & Romani (1995) find that the number of radio-quiet (Geminga-like) pulsars detectable as point sources by EGRET (17) is much larger than the number of radio-loud γ-ray pulsars (5). Cheng & Zhang (1998) find an even larger ratio of radio-quiet to radio-loud γ-ray pulsars, ~ 6, in their outer gap model. On the other hand, a study of the polar cap γ-ray pulsar population by Sturner & Dermer (1996) find that radio-quiet pulsars constitute only 25% of the γ-ray pulsars detectable by EGRET. Gonthier et al. (2000) have also found a small ratio of radio-quiet to radio-loud pulsars detectable by EGRET in the polar cap model, $\sim 10\%$. However,

they have also computed the number of detections expected for GLAST and find that the situation is reversed, with about 160 radio-loud and 280 radio-quiet pulsars detectable, at least as point sources. This is due to the stronger dependence of the predicted γ-ray luminosity on P and $\dot{P}$ relative to the radio luminosity. All of the population studies of polar cap γ-ray pulsars have assumed that both γ-ray and radio emission is beamed with the same direction and solid angle, and studies including geometry of beams are needed to refine the estimates.

Recently, another possible population of radio-quiet γ-ray pulsars has been suggested by Zhang & Harding (2000, see also Harding & Zhang 2000). According to the polar cap model (e.g. Daugherty & Harding 1996), γ-ray emission occurs throughout the entire pulse phase. Primary electrons that initiate pair cascades at low altitude continue to radiate curvature emission on open field lines to high altitudes beyond the cascade region, producing a lower level of softer off-beam emission. Due to the flaring of the dipole field lines, this emission may be seen over a large solid angle, far exceeding that of the main beams. Since the radio emission is expected to originate within ten stellar radii of the neutron star surface, it is quite probable to see off-beam γ-ray emission and miss the radio beam. Zhang & Harding (2000) estimate that the probability of detecting such off-beam emission is about an order of magnitude higher than that of the on-beam emission. At least some of the radio-quiet Gould Belt sources detected by EGRET could therefore be such off-beam gamma-ray pulsars.

SUMMARY

I have outlined the current predictions of high-energy pulsar emission models which can potentially be tested by future instruments having both higher sensitivity and larger energy range. Probably the most discriminating tests will be measurement of pulsar spectra at energies from 1 GeV to 10 TeV. In this range, polar cap models predict steep spectral cutoffs due to magnetic pair production attenuation and essentially no detectable emission above about 50 GeV from any pulsar. While GLAST should be able to measure the shape of these cutoffs, it is also important for Air Cherenkov detectors to achieve sensitivity at low energies. Outer gap models predict not only more gradual spectral cutoffs around 10 GeV, but an inverse Compton component with a peak in power around 1 TeV. The predicted flux of this inverse Compton emission is somewhat model dependent, but should be detectable by future Air Cherenkov detectors. The presence of such a component would be very difficult, if not impossible, to explain in polar cap models. Distributions of radio-loud pulsars detected as γ-ray pulsars by GLAST will be able to test predicted γ-ray luminosity dependence on pulsar parameters. In particular, detection of γ-ray pulsars older than about 0.5 Myr will argue strongly for polar cap models. The number of radio-quiet pulsars detected by GLAST will be an important diagnostic. Although both polar cap and outer cap models now expect more radio-quiet γ-ray pulsars detectable with GLAST sensitivity, the outer

gap models will always predict larger ratios of radio-quiet to radio-loud pulsars due to geometry.

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