Likelihood Analysis of High-Energy Pulsar Emission Models

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Abstract. The high-quality Fermi LAT observations of gamma-ray pulsars open a new window to understanding the generation mechanisms of high-energy pulsar emission. To explore this, we have simulated high-energy light curves from geometrical representations of the outer gap and slot gap emission models with the vacuum retarded dipole magnetosphere model. These simulated light curves are compared with the LAT light curves of the Vela and Geminga pulsars via maximum likelihood, using a Markov Chain Monte Carlo method to explore the models' phase space.

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1. INTRODUCTION

High-energy (HE) pulsar emission is believed to be caused by the acceleration of charged particles in charge-depleted magnetospheric gaps between the neutron star surface and light cylinder ($R_{\rm lc}$). *Fermi* Large Area Telescope (LAT, [1]) observations of GeV pulsar emission are consistent with radiation originating in the outer magnetosphere, as in the slot gap (SG, [2]) and outer gap (OG, [3]) emission models. The geometry of a system will potentially determine observed features in HE pulsar light curves. We therefore compare light curves simulated from SG and OG geometrical models with the LAT light curves of the Vela and Geminga pulsars to determine their emission geometries.

2. LIGHT CURVES AND LIKELIHOOD FITTING

Using two years of LAT data, we constructed $E > 100\,$MeV fixed-count light curves of the Vela and Geminga pulsars. We simulated HE pulsar light curves as in [4], modifying the geometry to represent the OG and SG emission zones. The retarded vacuum dipole field, defined in the observer's frame, is transformed to the co-rotating frame (CF) [5] and photons are emitted tangent to the B field in the CF prior to calculating the aberration. We assume constant photon emission rate along the field lines in the CF. For a given inclination angle α, gap width w in open volume units ($r_{\rm ovc}$, [4]), and maximum emission radius $r_{\rm max}$ ($R_{\rm lc}$ units), the code produces light curves at all observer angles (ζ). Our simulations have resolution 1° in α and ζ, $0.01\,r_{\rm ovc}$ in width, and $0.1\,R_{\rm lc}$ in $r_{\rm max}$. We used a Markov Chain Monte Carlo maximum likelihood routine [6] to traverse the 4-D parameter space and find parameters that produce well-fitting light curves.

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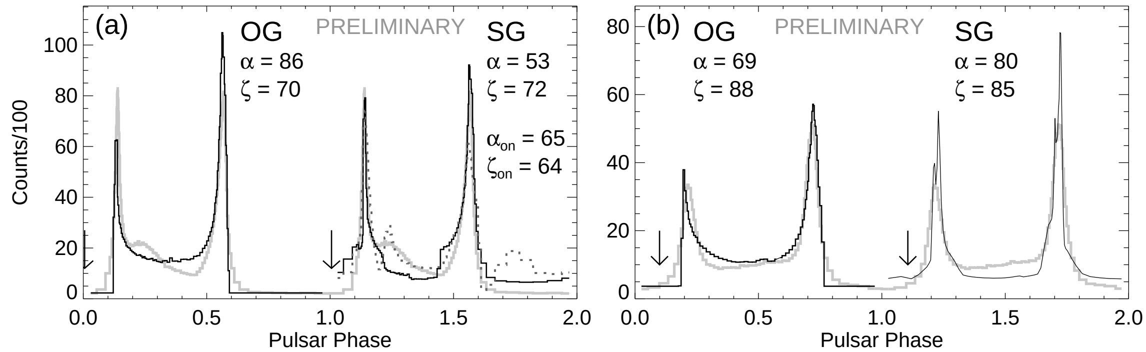

FIGURE 1. *(a)* LAT light curve (light grey) and best-fit simulated light curves (black) for the Vela pulsar, with the OG on the left and SG on the right. The dark grey dotted line shows the best fit to Vela's peak emission ("on"). Arrows mark the model location of the magnetic pole. *(b)* Same as *(a)*, for Geminga.

3. RESULTS AND CONCLUSION

Vela's geometry is constrained to $\beta = \zeta - \alpha \leq 6.5^\circ$ and $\zeta \sim 64^\circ$ from multiwavelength observations. For the OG, we find the best model parameters, 3σ confidence intervals, and reduced χ^2 to be (α, ζ, w, $r_{\rm max}$; $\chi^2_{\rm r}$) = (86^{+4}_{-14}, 70^{+6}_{-2}, $0.04^{+0.01}_{-0.02}$, $1.3^{+0.1}_{-0.4}$; 489), consistent with [7]. For the SG, the parameters are (53^{+15}_{-3}, 72^{+3}_{-3}, $0.01^{+0.01}_{-0.01}$, $1^{+0.1}_{-0.05}$; 2221). Because modifications to the SG can decrease off-pulse emission, we also fit the peak emission alone, for which the SG instead finds the parameters (65^{+9}_{-6},64^{+4}_{-12},$0.1^{+0.04}_{-0.08}$,$1^{+0.1}_{-0.05}$; 418). Geminga has no multiwavelength constraints; we find the OG parameters (69^{+3}_{-23}, 88^{+2}_{-3}, $0^{+0.07}_{-0}$, $0.9^{+0.3}_{-0.05}$; 138), and SG parameters (80^{+9}_{-10}, 85^{+5}_{-6}, $0.01^{+0.07}_{-0.01}$, $1.1^{+0.2}_{-0.1}$; 326).

The OG fits are better due to the lack of off-peak emission. However, all fits are poor, and the large χ^2 values make it difficult to draw strong conclusions from the statistics. We have shown that the OG and high-altitude SG geometrical models can both produce light curves similar to those of Vela and Geminga. More physical models within these geometries may lead to a better understanding of the pulsar HE emission mechanism.

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