

Gamma-Ray Light Curves from Pulsar Magnetospheres with Finite Conductivity

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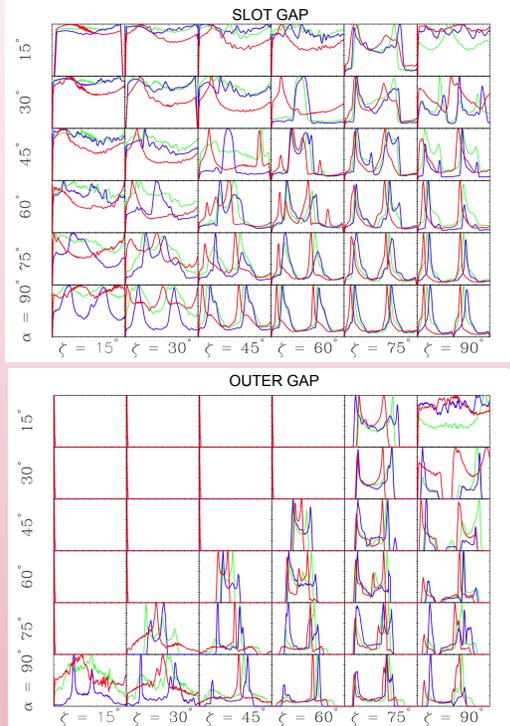
We compute model gamma-ray pulsar light curves for magnetospheres with finite conductivity. We show light curve atlas' using both geometric slot gap and outer gap emission models, as well as the particle trajectories resulting from model electric fields and curvature radiation losses.

Abstract – The Fermi Large Area Telescope has provided an unprecedented database for pulsar emission studies that includes gamma-ray light curves for over 100 pulsars. Modeling these light curves can reveal and constrain the geometry of the particle accelerator, as well as the pulsar magnetic field structure. We have constructed 3D magnetosphere models with finite conductivity, that bridge the extreme vacuum and force-free solutions used in previous light curves modeling. We are investigating the shapes of pulsar gamma-ray light curves using these dissipative solutions with two different approaches: (1) assuming geometric emission patterns of the slot gap and outer gap, and (2) using the parallel electric field provided by the resistive models to compute the trajectories and emission of the radiating particles. The light curves using geometric emission patterns show a systematic increase in gamma-ray peak phase with increasing conductivity, introducing a new diagnostic of these solutions. The light curves using the model electric fields are very sensitive to the conductivity but do not resemble the observed Fermi light curves, suggesting that some screening of the parallel electric field, by pair cascades not included in the models, is necessary.

Models for high energy pulsar emission have assumed either vacuum retarded dipole (Deutsch 1955), force-free (Contopoulos et al. 1999, Spitkovsky 2006) or pseudo-force-free (Romani & Watters 2010) magnetic field geometry. However, these field structures are not fully self-consistent with the currents and electric fields that must exist to produce the high-energy radiation. Recently, new resistive magnetosphere models have become available (Kalapotharakos et al. 2012, Li et al 2012, see poster by Kalapotharakos). These models allow for an electric field parallel to the magnetic field by means of an Ohm's law that relates current to the E and B fields through a finite conductivity. We use these model fields to generate gamma-ray light curves assuming two approaches.

1. Light curves using geometrical emission models

We have generated model light curves using geometrical versions of the slot gap (SG) and outer gap (OG) high energy emission models (Dyks et al. 2004, Venter et al. 2009). In the SG geometry, emission occurs in a narrow gap of width $w = 0.05$ along the last open field line from the neutron star surface to a maximum radius $r_{\max} = 1.2 R_{LC}$, where $R_{LC} = c/\Omega$ is the light cylinder radius, and maximum cylindrical radius $r_{cyl} = 0.95 R_{LC}$. In the OG geometry, emission occurs on the inner edge of a gap of width $w = 0.05$ along the last open field line above the null charge surface, to $r_{\max} = 1.5 R_{LC}$ and with $r_{cyl} = 0.97 R_{LC}$.

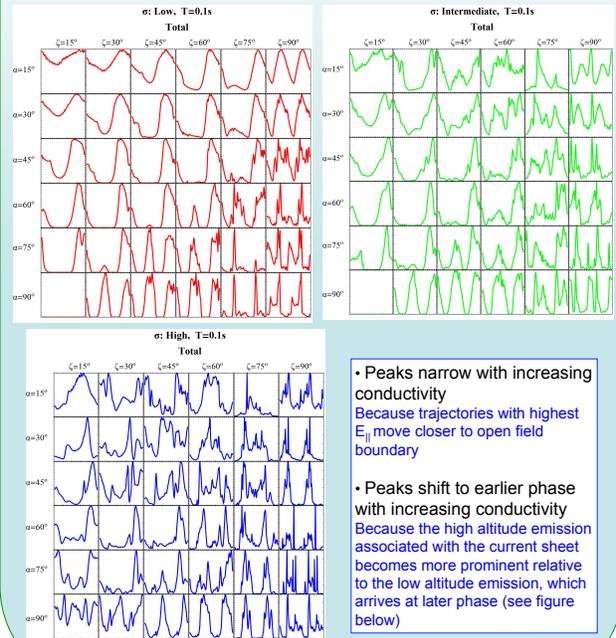


Light curves for different pulsar inclination α angle and observer angle ζ with respect to the rotation axis and for constant conductivity values $\sigma = 0.002\Omega$ (black), 1.0Ω (red) and 24Ω (green). Phase 0 is magnetic pole.

- Light curve peaks shift to later phase (both peaks in the SG case, but only the second peak for the OG case) with increasing σ
- Peaks broaden with increasing σ
Because the increased sweepback of field lines with higher conductivity, causes the open volume to expand and shift to later phase.

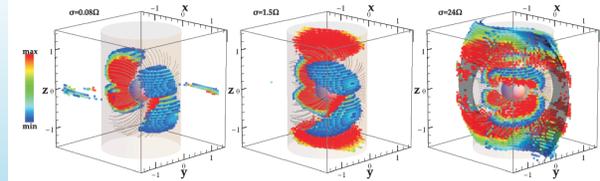
2. Light curves using particle trajectories

We have used both the electric and magnetic fields from the resistive models to compute the light curves, using an approximate particle trajectory that decomposes the motion into drift and parallel velocities so that the total velocity is c . The Lorentz factor along the trajectory is computed from the energy gain from E_{\parallel} and loss from curvature radiation.



- Peaks narrow with increasing conductivity
Because trajectories with highest E_{\parallel} move closer to open field boundary
- Peaks shift to earlier phase with increasing conductivity
Because the high altitude emission associated with the current sheet becomes more prominent relative to the low altitude emission, which arrives at later phase (see figure below)

Peak emission distribution



The regions of the magnetospheres that produce the peaks of the pulses for $\alpha = 90^\circ$. The color scale indicates the corresponding emissivity. For $\sigma = 24\Omega$ a significant part of the emission comes from a region near the current-sheet outside the light-cylinder (gray surface in the right-hand panel).

References

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