On the Spectral Shape of Gamma-ray Pulsars Above the Break Energy

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INTRODUCTION

◆ **Curvature radiation is the most favored gamma-ray pulsar emission mechanism [3, 7, 8, 9].**

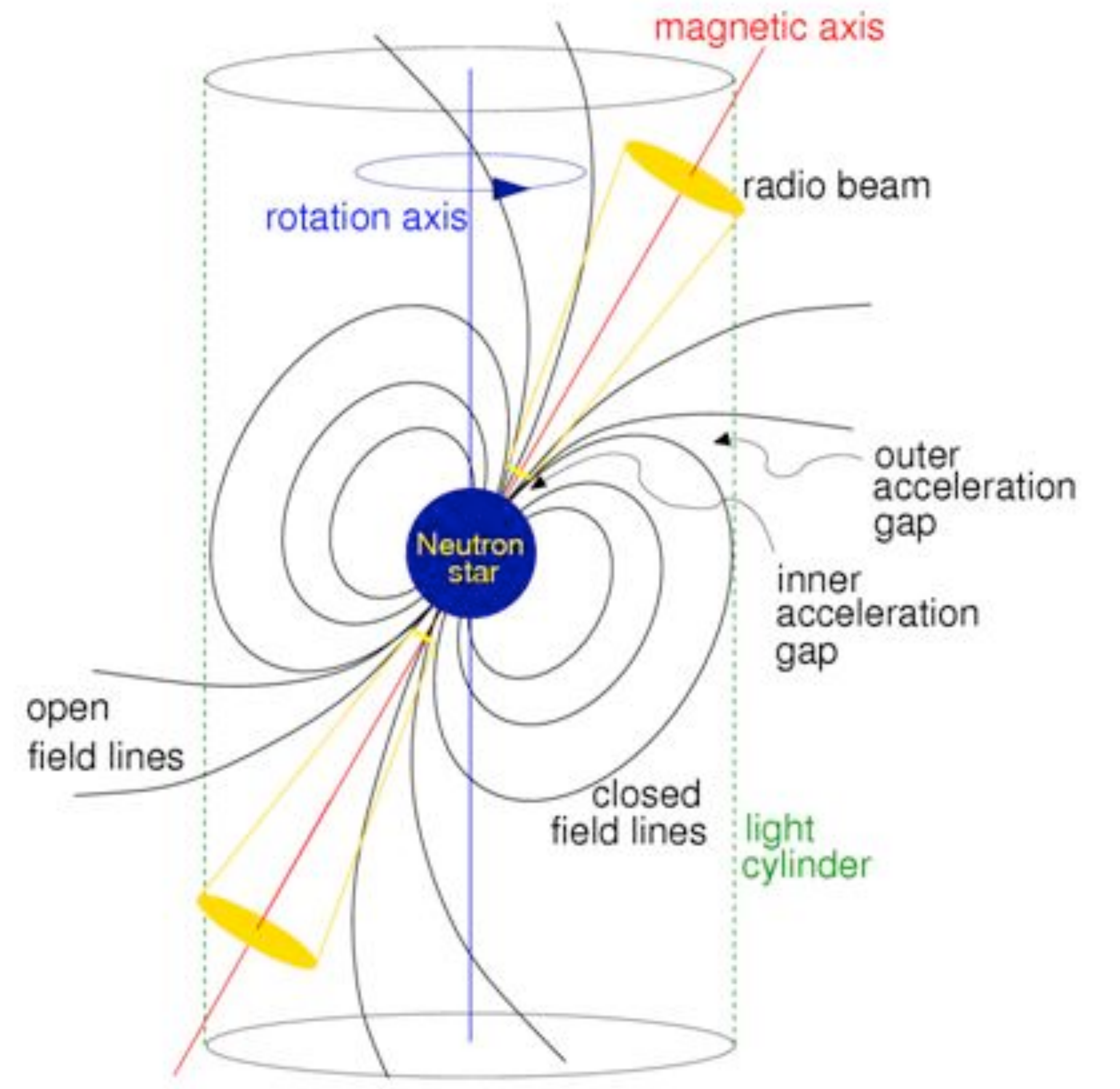

Figure 1 – The outer gap picture of gamma-ray pulsar emission. From Lorimer & Kramer (2004) [6].

◆ **Single zone curvature models predict a gamma-ray spectrum of a power law with an exponential cutoff (PLEC) above a critical energy [5].**

◆ **Geometric and relativistic effects cause wide beams to converge/diverge at different phases, creating peaks (caustics), bridges, and off-peak regions.**

Figure 2 – Caustics formed in water due to ripples in the surface. From Gregory Massal Photography.

◆ **Thus there is likely no one-to-one mapping between emission zone and observed phase.**

◆ **To demonstrate this, we show that phase resolved spectra favor power-law times a *sub*-exponential cut-off (PLSEC).**

$$\frac{dF}{dE} = A(E/E_0)^{-\Gamma} e^{-(E/E_c)^b}$$

Equation 1 – Functional form of a PLSEC. This reduces to a PLEC when *b*=1.

◆ **We argue that the sum of many cutoff energies produces the observed sub-exponential cutoff.**

◆ **Therefore, each pulse phase is the superposition of many PLECs each with their own cutoff energy.**

REFERENCES

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OVERVIEW

It is well known that, for bright gamma-ray pulsars with high statistics above a few GeV, the phase averaged spectral energy distribution (SED) is harder than a simple exponential cutoff above the break. We perform phase-resolved spectral analyses of bright gamma-ray pulsars and demonstrate that, even over narrow phase ranges, the SEDs of gamma-ray pulsars above the break energy are harder than a simple exponential cutoff. We argue within a radiation-reaction limited curvature framework that this is indicative of non-stationary emission or emission from multiple zones. Further, we address a common problem faced when fitting hard spectral tails with a power-law times a sub-exponential function. Namely, that the sub-exponent parameter does not describe any parameters of physical models of pulsar emission. We introduce a simple analytical fit function to solve this problem.

PHASE RESOLVED SPECTRA

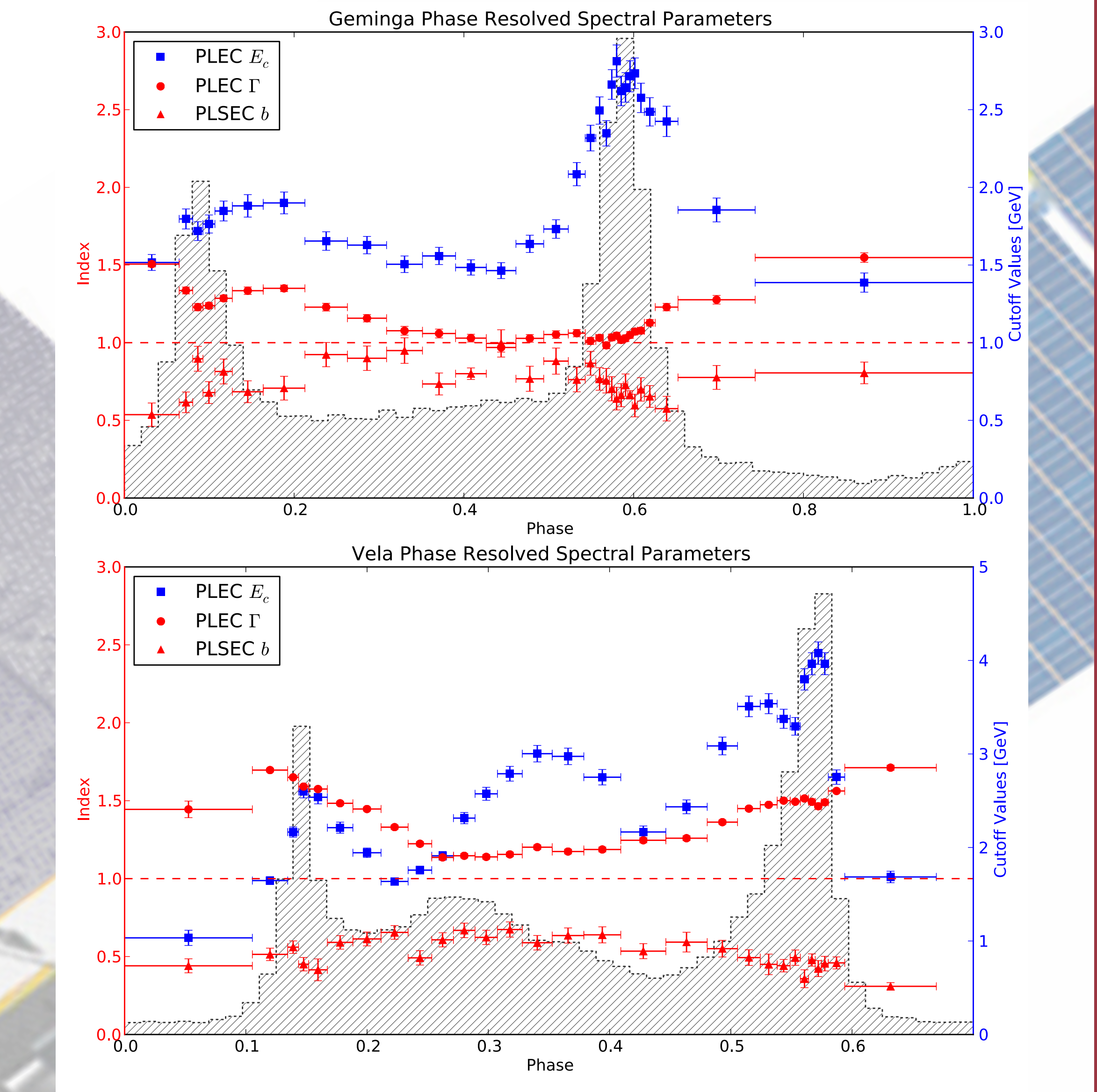

Figure 3 - The phase-resolved spectral parameters of the Geminga pulsar (top) and Vela pulsar (bottom). The shaded histogram in each figure shows the phasogram of the corresponding pulsar.

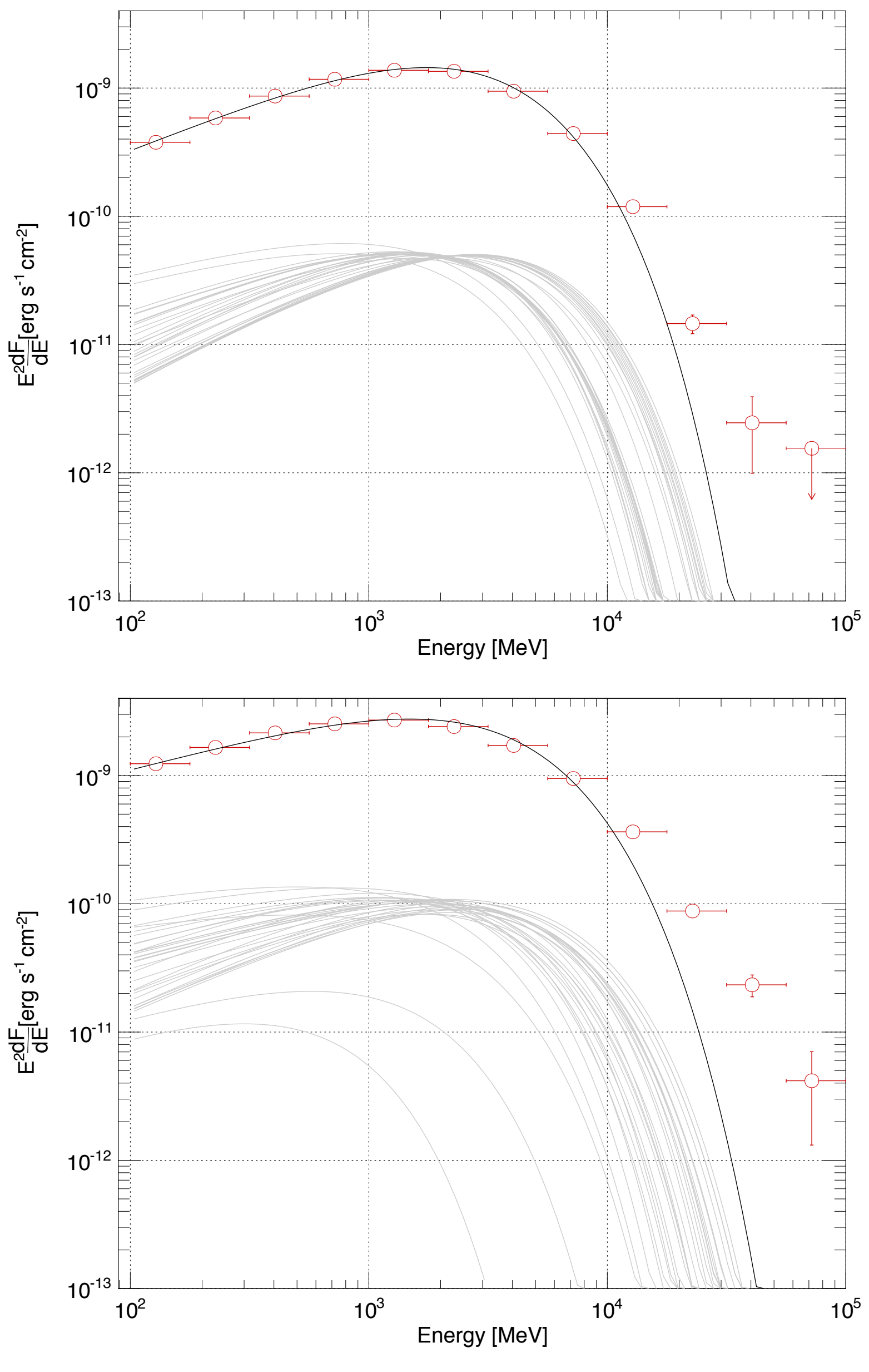

Figure 4 - The phase-resolved (grey lines) and phase averaged (red circles) spectra of the Geminga pulsar (top) and Vela pulsar (bottom). The black line is the sum of all the phase resolved spectra. Each grey line is a PLEC while they do add together to produce a rounder tail, it is not hard enough to explain the observed spectral shape, as was argued in [2]. The PLECs shown in this figure are the same PLECs shown in Figure 3.

DISCUSSION & CONCLUSIONS

◆ **Figure 3 shows that at each phase, the spectrum of bright gamma-ray pulsars favors a sub-exponential break over a simple exponential break.**

◆ **The PLSEC shape is easily produced by summing PLECs with different break energies [1, 2].**

◆ **Different acceleration zones will have different break energies.**

◆ **This is evidence that the emission observed at a given phase originates from several different particle acceleration zones.**

◆ **Another interpretation is that an unstable gap potential causes various cutoff energies to be observed from a single zone [4].**

A NEW FIT FUNCTION

◆ **When fitting pulsar spectra with a PLSEC, the *b* parameter has no physical significance.**

◆ **The *b* parameter is also highly degenerate with E_c.**

◆ **To resolve this problem, we introduce a new fit function which is the sum of *N* PLECs with different cutoff values, which we call SUMPLEC.**

$$\frac{dF}{dE} = \frac{A}{N}\sum_{i=1}^{N}\left\{\frac{(E/E_0)^{-\Gamma} e^{-\left(E/E_c^i\right)}}{\left(E_c^i\right)^{1-\Gamma} - \left(E_{low}\right)^{1-\Gamma}}\right\} \quad , \quad E_c^i = 10^{\left(\alpha+\frac{i}{N}\beta\right)}$$

Equation 2 – The SUMPLEC fit function. The denominator normalizes the area under each PLEC.

◆ **The parameters *A*, Γ, α, and β are free to float.**

◆ **This formula is motivated by physical outer gap emission scenarios where α and β correspond to the minimal and maximal cutoff energies.**

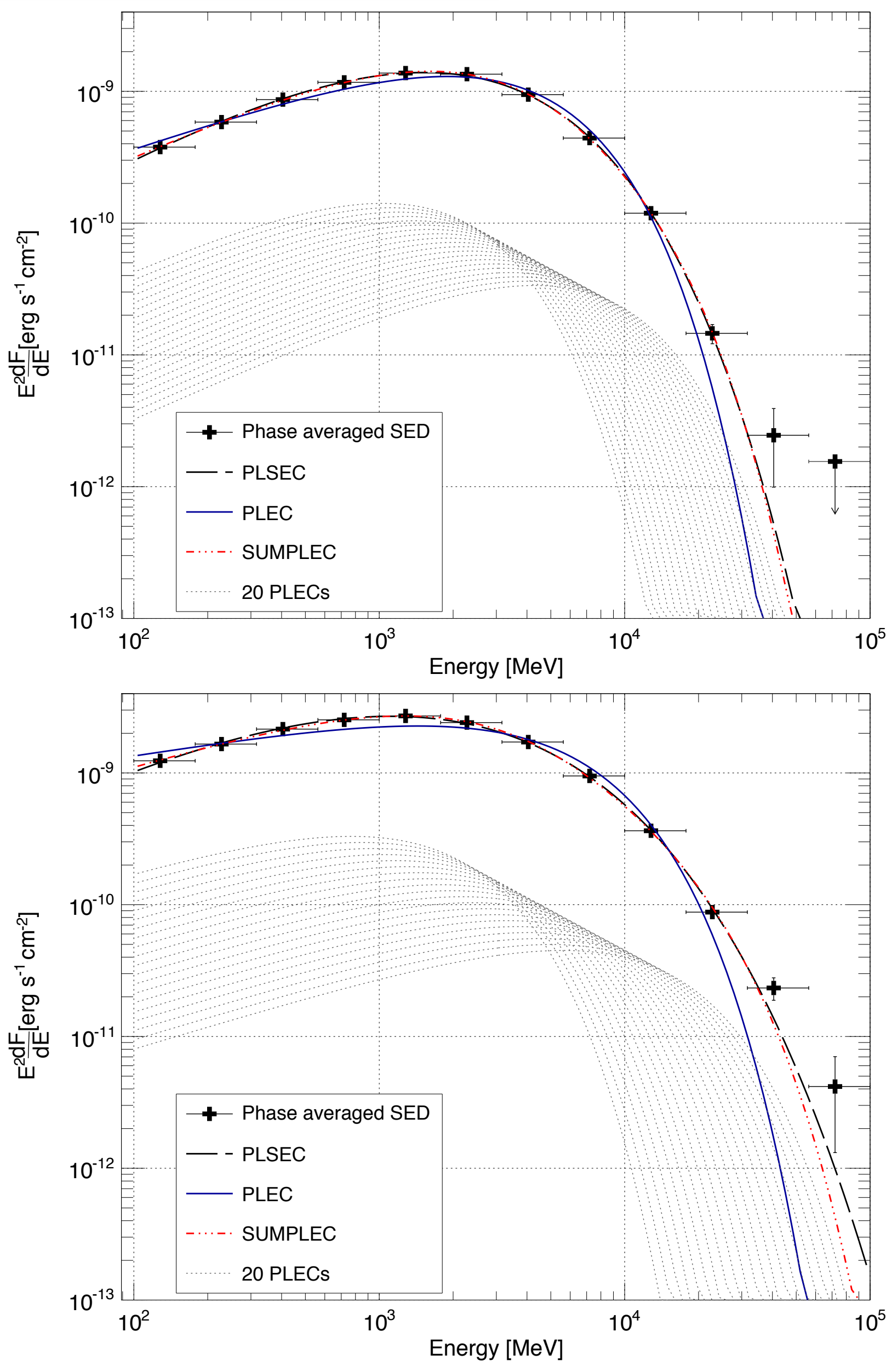

Figure 5 – Phase averaged SEDs for the Geminga (top) and Vela (bottom) pulsars. Each SED is fit with the PLEC, PLSEC, and SUMPLEC fit functions.

◆ **Using SUMPLEC, we found that for Geminga, the cutoff values span the range 1.22 ± 0.11 GeV to 5.1 ± 0.2 GeV. For Vela, the cutoff values span the range 1.35 ± 0.13 GeV to 9.8 ± 0.5 GeV.**

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