# Pulsar high-Energy radiation: A diagnostic tool for magnetic field structure in the magnetosphere

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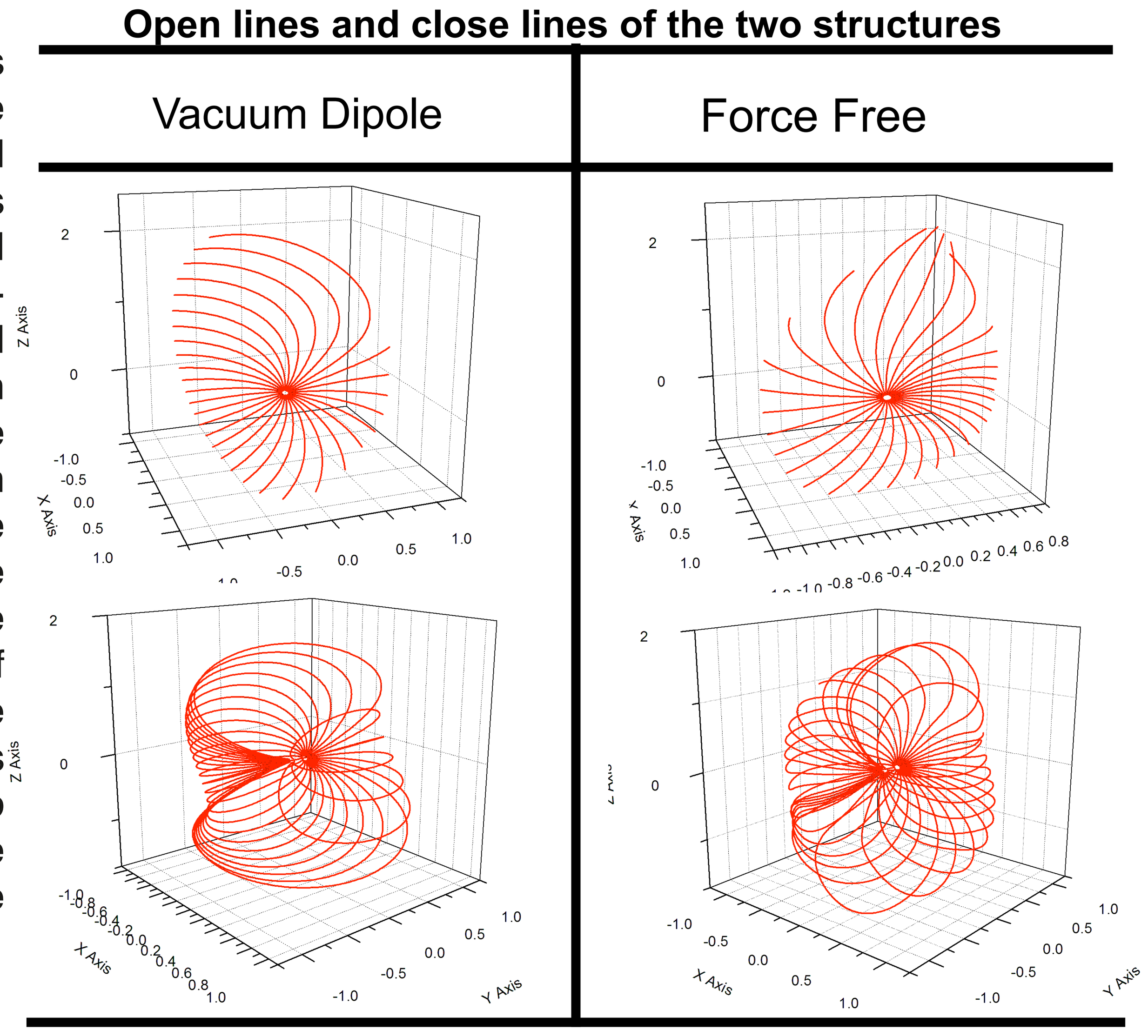
## ABSTRACT

We apply the outer gap accelerator model to calculate the pulse profiles, phase averaged and phase resolved spectra of Crab Pulsar, using force free field and vacuum dipole, and compare the results with observed data including very high energy data by Fermi and MAGIC.

## Introduction

Motivated by the recent progress of studies on the structure of pulsar magnetospheres and results of γ-ray instruments in high-energy bands, the magnetic field structure in pulsar magnetospheres is investigated with the high-energy emission model and observations. We apply the outer gap accelerator model to the Crab pulsar, and compute the spectra and pulse profiles of the high-energy emissions for the different magnetic field structures. To examine dependency of the emission properties on structure of the magnetosphere, we apply two extreme cases; (1) force-free field and (2) the vacuum dipole field. We find that both phase-averaged spectra calculated with the force-free field and the vacuum field are consistent with the present γ-ray data including very high energy data by Fermi and MAGIC, implying that the magnetic field structures may not be distinguished with the observed phase-averaged spectrum. On the other hand, it is found that the phase-resolved spectra calculated with the force-free field and the vacuum field show different properties each other. This indicates that the phase-resolved spectra can discriminate the field line structure, which is neither pure vacuum field nor pure force-free field. We discuss that a study of phase-resolved spectra with the different magnetic field structures will be an important tool to resolve the mechanism of the high-energy emissions from the pulsars.

**Open lines and close lines of the two structures**

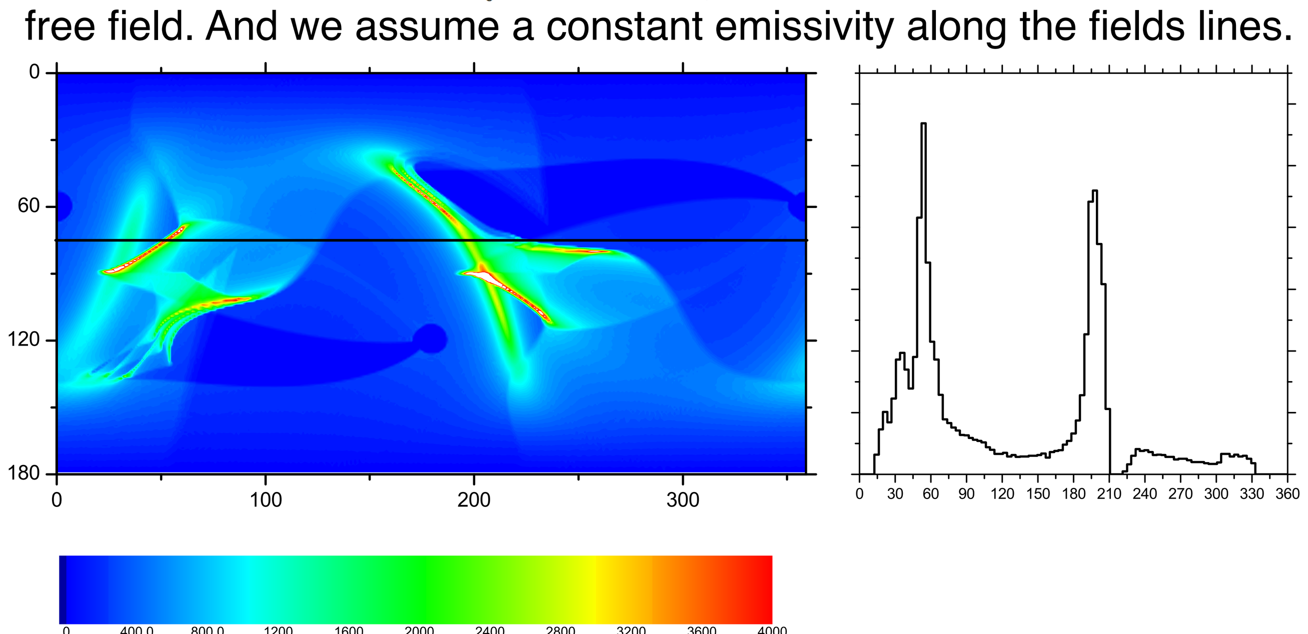



## Skymap and Light curve

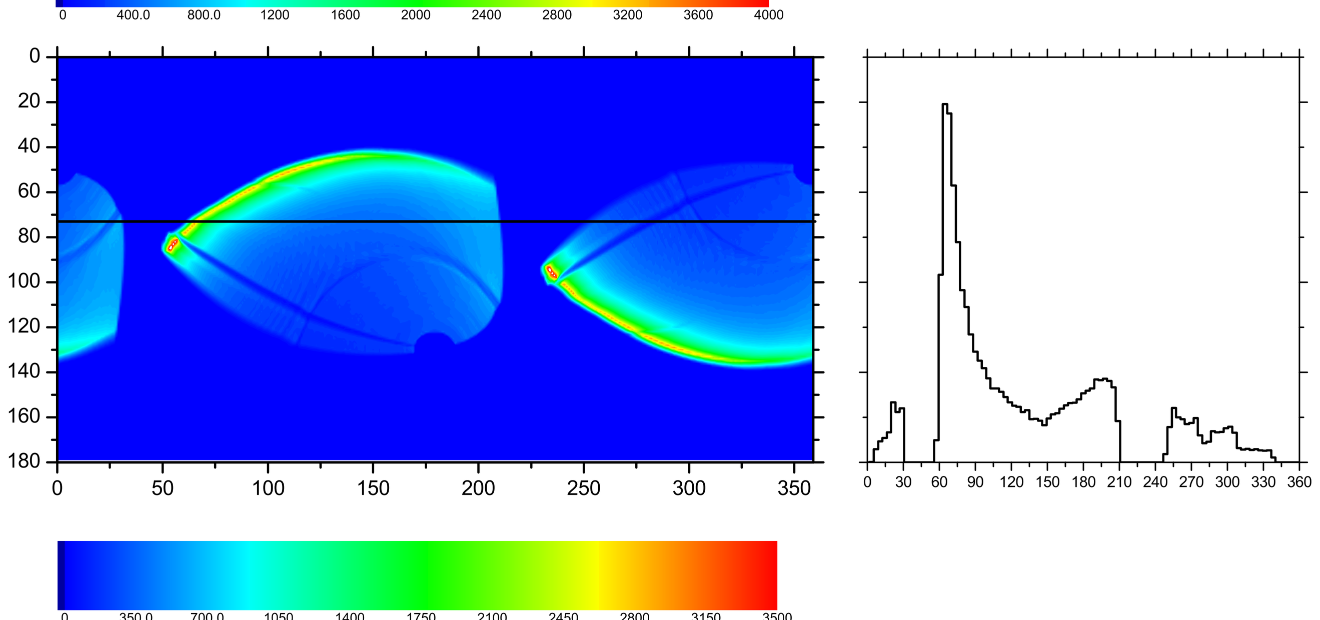
We modify the calculation method of the emission direction applied in Tang et al. (2008). In Tang et al. (2008), a rotating dipole field was defined in the corotating frame, in which the emission direction coincides with the local magnetic field direction, and a Lorentz transformation was performed to calculate the emission direction in the observer frame. Here, on the other hand, we discuss the emission direction in only observer frame with computation method of Takata et al. (2007). We assume that the curvature photons are emitted in the direction of the particle motion, which may be described as

$$\begin{cases} \vec{v} = v_p \vec{B}/B + \vec{v}_{drift} \\ |\vec{v}| = c \end{cases}$$

For the drift motion, we apply the coronation velocity $\vec{v}_{drift} = \vec{\Omega} \times \vec{r}$ for the vacuum case, while we calculate the velocity $\vec{v}_{drift} = c\vec{E} \times \vec{B}/B^2$ from the results obtained by Spitkovsky (2006) for the force free field. And we assume a constant emissivity along the fields lines.



The skymap (left panel) and pulse profile (right panel) for the vacuum dipole. The color in left panel refers intensity (arbitrary units) of emissions.

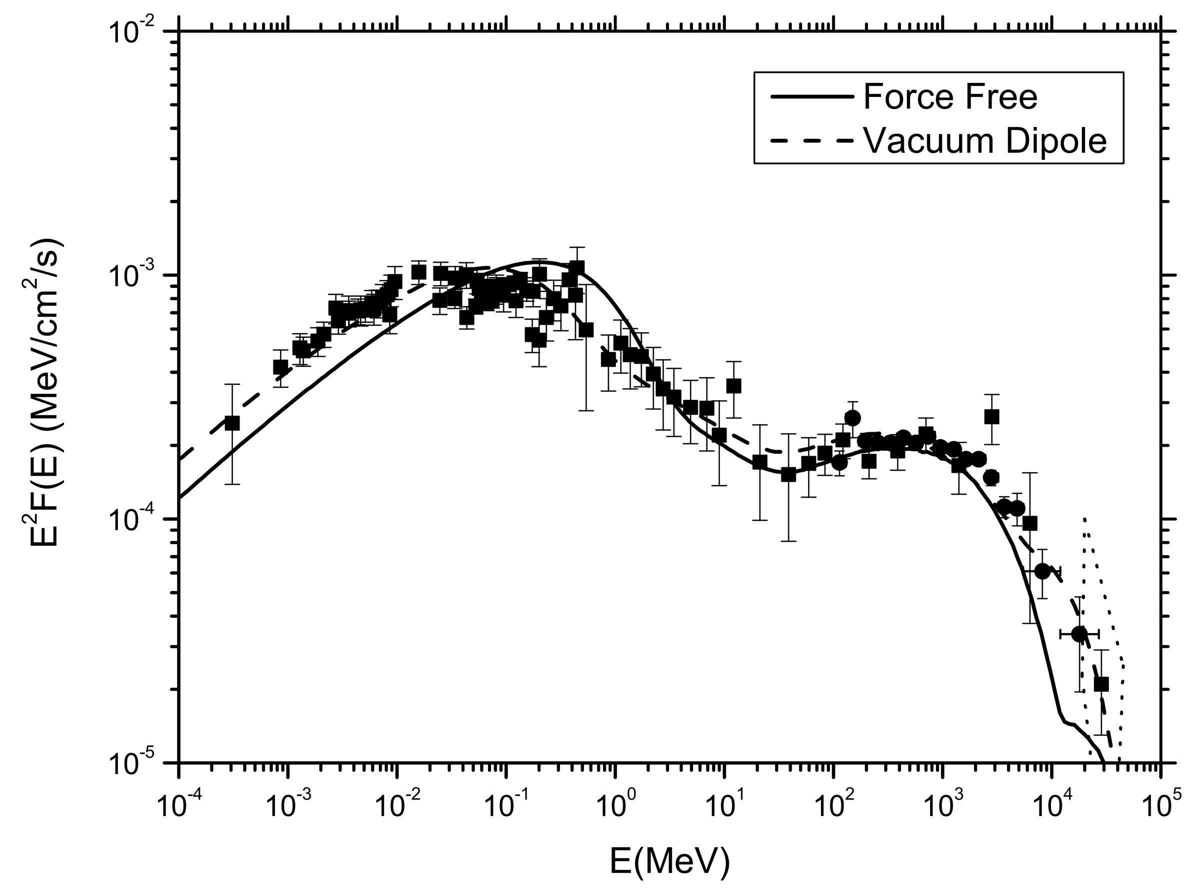


The skymap (left panel) and pulse profile (right panel) for the force-free field. The color in left panel refers intensity (arbitrary units) of emissions.

For more details about the calculation of light curve of force-free fileld, please refer to the poster of X.-N. Bai and A. Spitkovsky.

## Spectrum

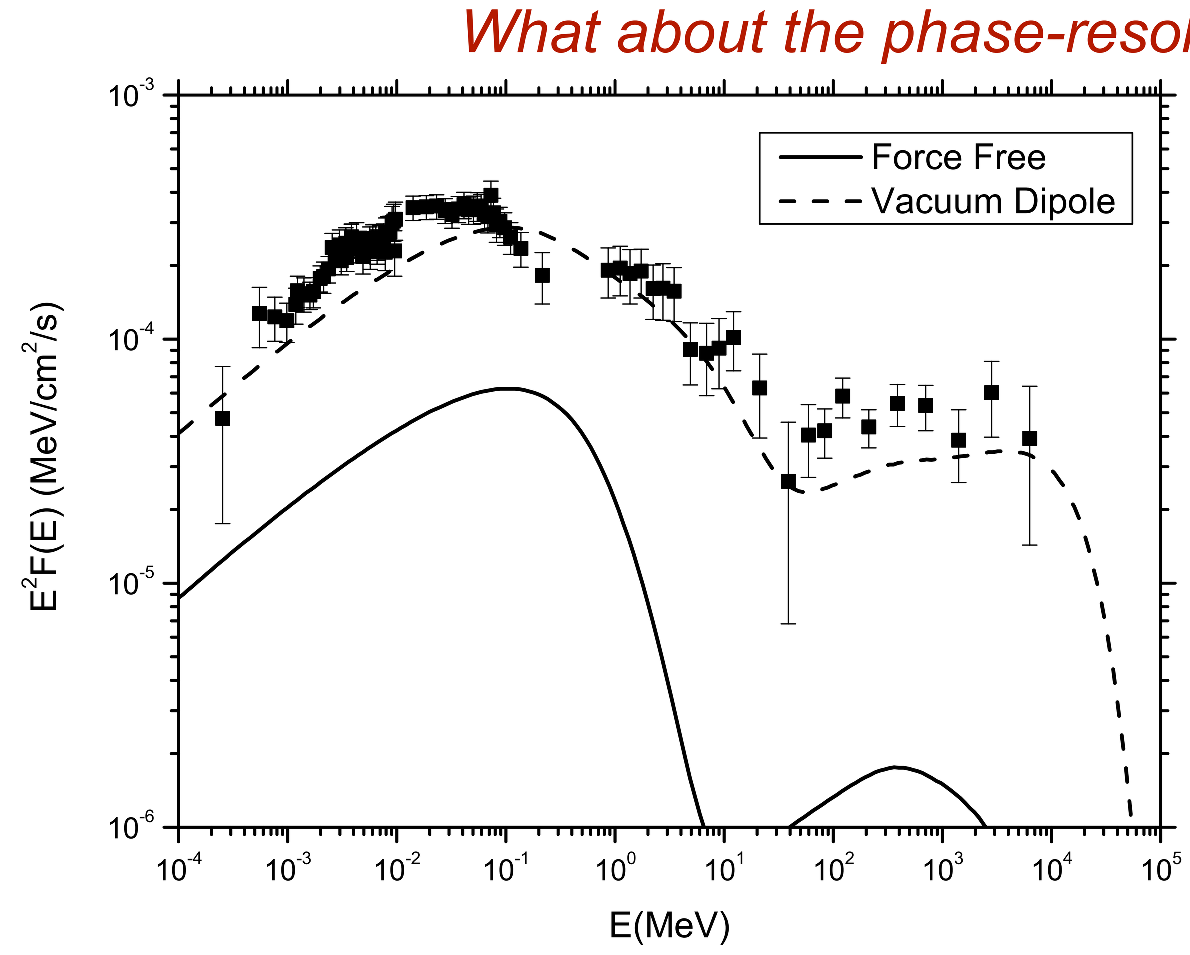
Our computation method for the high-energy emissions follows the outer gap accelerator scenario investigated by Tang et al. (2008). We apply the force-free field obtained by Spitkovsky (2006).




Phase-averaged spectrum of the Crab pulsar. The solid line and the dashed line are results for the force-free field and for the vacuum dipole field, respectively. The data were taken from Kuiper et al. (2001) for X-ray energy bands, Loparco et al. (2009) for results of the Fermi tele- scope, and Aliu et al. (2008) for the results of the MAGIC telescope

It can be found that both phase-averaged spectra calculated with the force-free field and the vacuum field are consistent with the present γ-ray data.

*What about the phase-resolved spectra??*




Phase-resolved spectrum of the second peak of the Crab pulsar. The solid line and the dashed line are results for the force-free field and for the vacuum dipole field, respectively. The data were taken from Kuiper et al. (2001). The phase-resolved spectra in γ-ray bands were measured by EGRET (Energetic Gamma Ray Experiment Tele- scope).

The phase-resolved spectra calculated with the force-free field and the vacuum field show different properties each other. And the spectrum of the second peak cannot be fitted well using the force-free field is consistent with the light curve.

### The parameters used to calculate the pulse profiles and spectra

| | Inclination angle | Viewing angle | $f(R_{lc})$ | a | sin beta($R_{lc}$) | $R_{cut}$ |
|---|---|---|---|---|---|---|
| Force-Free | 50 deg | 73 deg | 0.28 | 0.91 | 0.032 | 1 $R_{lc}$ |
| Vacuum Dipole | 60 deg | 75 deg | 0.2 | 0.96 | 0.046 | 1 $R_{lc}$ |

For more details about the calculation of spectrum and the parameters listed in the table above, please refer to Tang et al. (2008).

## Conclusion

It seems that the outer gap accelerator does not work well for the force-free magnetosphere. And It is interesting to perform a further study to make a modified outer gap model for force free field. Here we just want to show that different field structures can make a same phase-averaged spectrum but different phase-resolved spectra. The phase-resolved spectra measured by Fermi will probably enable us to diagnose a more detail the field line structure in the acceleration and emission region.

## Reference

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