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γ-ray emission from Outer-Gap of pulsar magnetosphere

Takata, J.[I], Shibata, S.[II], Hirotani, K.[III]

(I) Graduate School of Science and Engineering, Yamagata University
(II) Department of Physics, Yamagata University
(III) NASA/Goddard Space Flight Center

Email : takata@ksirius.kj.yamagata-u.ac.jp

Abstract We develop a model for gamma-ray emission from outer magnetosphere of pulsars (the outer-gap model). The charge depletion causes a large electric field along the magnetic field, which accelerates electrons and positrons. We solve electric field with radiation and pair creation processes self-consistently, and calculate curvature spectrum (MeV-GeV) and Inverse Compton (IC) spectrum (TeV). We apply this theory to Vela and B1706-44, for which their surface magnetic field, observed thermal X-ray, etc. are similar to each other, but observed MeV-GeV spectra are different in some degree. It is found that the observed peak energies of the gamma-ray are well explained for both pulsars. By inclusion of emission outside the gap, the spectrum is in better agreement with the observation. The difference in the observed spectra is due to difference in Goldreich-Juliun (GJ) density in the gap. The expected TeV spectra are is much smaller than the 700GeV-TeV emission observed CANGAROO [1] team in the direction of B1706-44.

1. Basic equations [2]

We deal with one-dimensional geometry for simplicity.

•Poisson equation:

$$\frac{dE_{||}}{ds} = 4\pi e\left(N_{+} - N_{-} - \frac{\rho_{GJ}}{e}\right),$$

where $E_{||}$: electric field along the magnetic field line, $N_{\pm}$: number densities of positron and electron, ρ_{GJ}: GJ charge density, s : arc length from the surface along the last-closed magnetic field line.

•Continuity eq. for particles & gamma-ray photons

$$\pm B\frac{d}{ds}\left(\frac{N_{\pm}}{B}\right) = \frac{1}{c\cos\Psi}\int_{0}^{\infty} dE_{\gamma}[\eta_{p+}(E_{\gamma})G_{+}(E_{\gamma})+\eta_{p-}(E_{\gamma})G_{-}(E_{\gamma})].$$

$$\pm B\frac{d}{ds}\left(\frac{G_{\pm}(E_{\gamma})}{B}\right) = \frac{-\eta_{p\pm}(E_{\gamma})G_{\pm}(E_{\gamma}) + \eta_{c}(E_{\gamma})N_{\pm}}{c\cos\Psi},$$

where $G_{\pm}$: distribution function of outward (+) and inward (-) propagating gamma-ray, η_p : pair creation rate, η_c : emissivity for curvature radiation, Ψ : angle between the particle motion and the poloidal plane.

2. X-ray and Infrared(IR) Field

X-ray field are necessary to calculate the pair-creation rate via photon-photon collision. This is obtained from the observed X-ray flux, but depends on an assumed distance. IR field is inferred from optical-radio (Vela) and X-radio (B1706-44) fluxes with a single power-low, because there is no available IR observation for both pulsars.

3. Model parameters

The observed parameters are shown Table 1. The model parameters are as follows:

•(j_0, j_1, j_2): Total current density, positrons and electrons current densities coming into the gap through the inner and outer boundaries, respectively.

•Inclination angle: we adopt 45 deg., though Romani & Yadigaroglu (1995)[3] predicted 65 deg. for Vela.

•The emission solid angle : we assume $\delta\Omega = \pi\frac{W_{gap}}{R_{lc}}$, where R_{ls}, W_{gap} are the light radius and the gap width, respectively

• The cross section of the gap : it must be smaller than R_{ls}^2 .

Table 1 :pulsar properties

pulsar	distance kpc	Ω rad/s	B_{12} $10^{12}G$	kT_s eV
Vela	0.50	70.6	3.4	150
B1706-44	1.8(DM)/2.5(HI)	61.6	3.1	143

(DM) : Dispersion measure, (HI) : HI absorption

4. Results

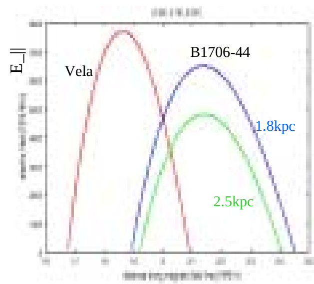

Fig.1 Electric field in the gap

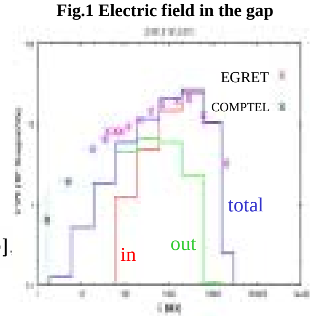

Fig.2 MeV-GeV spectrum of Vela

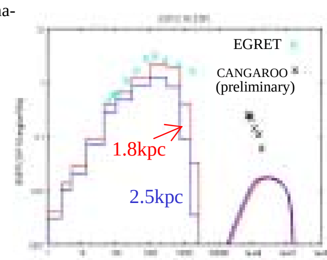

Fig.3 MeV-TeV spectrum of B1706-44. Dependence on distance is shown.

(1) The observed peak energies are reproduced with (0.201, 0.191, 0.001) for both pulsars. Because Vela has a shorter period and larger GJ density in the gap, the electric filed of Vela is larger than B1706-44 (Fig.1). As a result, the peak energy of Vela is higher than B1706-44.

The gap width is characterized by mean free path the electron-positron pair $W_{gap}^2 \propto \frac{1}{\int \eta_p \eta_c dE_\gamma}$, which is shorter than the light radius.

(2) Particles escaped from the gap still radiate curvature photons. This effect was not take into account previous model. By inclusion of this emission, the spectrum (E>100MeV) is in better agreement with the EGRET observation[4] than previous model (Fig.2). The emission below MeV will be obtained by inclusion of synchrotron emission by pairs.

(3) In general, the spectrum becomes harder and gamma-ray fluxes increase, if we adopt a nearer distance to the pulsar. Comparing the spectrum of B1706-44 with observations[5], the small distance, 1.8kpc, is preferable (Fig.3).

(4)Both pulsars, IC [6] TeV fluxes are estimated to be ~ 10^{-12} erg/cm^2/s, though the estimation depends on inferred IR fluxes. The sharp-cut off exists in spectrum around 10TeV which is incomparable with unidentified 700GeV-TeV radiation in the direction of B1706-44 .

5. Conclusion

We obtained the 100MeV-GeV spectra in good agreement with observations for Vela & B1706-44. We found that both pulsars have almost the same current running through the gap in unit of the GJ value. The difference observed spectra is due to difference in GJ density in the gap.

References

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