Study on polarization high-energy photons from the Crab pulsar

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Abstract We explain the main futures of polarization data of optical bands of the Crab pulsar with the spectrum and the light curve using recent version of outer gap model. We calculate the polarization characteristics predicted by the synchrotron emission which explains the Crab spectrum from optical to MeV bands. We found that emissions from inside of the null charge surface and from higher order generated pairs are required to explain the Crab polarization data, which can not be reproduced by the emissions from the secondary generated pairs, which mainly contribute to spectrum and light curve. With polarization position angle swing, we constrain that the viewing angle, which is ambiguous with spectrum and light curve, from the rotation axis is greater than 90degree for the Crab pulsar.

1. Introduction (Why the polarization?)

Observational fact; 7 young pulsar such as Crab emit the gamma-ray photons.
Questions; How and where are the particles accelerated and the gamma-rays radiated in the pulsar magnetosphere ? ***Polar cap model vs. Outer gap model.***

H o w e v e r , a f t e r a b o u t 4 0 y e a r s s i n c e t h e d i s c o v e r y o f t h e g a m m a – r a y p u l s a r , w e s t i l l d o n o t u n d e r s t a n d w h e r e t h e a c c e l e r a t i n g e l e c t r i c f i e l d a r i s e

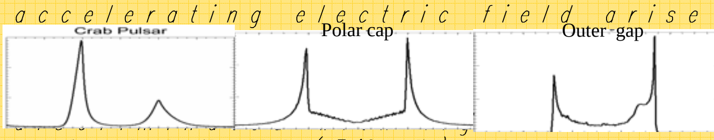
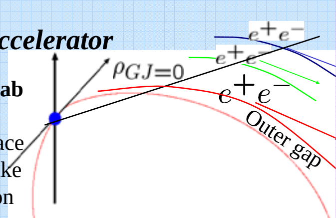


Fig1. Observed and predicted light curves for polar cap and outer gap, which have successfully explained observed main features.

Why polarization?; Polarization measurement increases the observed parameters, polarization degree (P.D.) and polarization angle (P.A.) swing.
Present Crab optical polarization data with spectrum and light curve will play an important role to discriminate the various models.

So far, no one has explained Crab optical polarization data with spectrum and light curve.

2. Emission model with outer gap accelerator



A, K.S. Cheng et al (2000) model for the Crab pulsar

- Outer gap starting from the null charge surface
- Secondary pairs by the primary photons make optical-MeV spectrum (Fig.3) with synchrotron process.

B, Present outer gap model

- Emissions from the inside of the null charge surface predicted by 2-D electrodynamical model, (Takata et al. 2004).
- Emissions from the higher-order generated pairs.

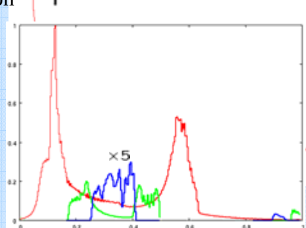


Fig2. Contribution of emissions from inside null surface and higher order generated pairs on the light curve.

3 Polarization calculation

At each point, we calculate

- synchrotron emissivity with the particle distribution of

$$\frac{dN_e}{dE_e} \propto E_e^{-p} \qquad p=2$$

- stokes parameters

$$Q^i = \Pi_{sc} I^i \cos 2\chi^i \quad V^i = 0$$

$$U^i = \Pi_{sc} I^i \sin 2\chi^i \quad \chi^i\text{; Position angle}$$

-each radiation is assumed to be linearly polarized with $\Pi_{sy} = \frac{p+1}{p+7/3}$

Model Parameters

- Inclination angle between the rotational and magnetic axes
- Viewing angle of the observer
- Critical radial distance (Rc) below which no outwardly secondary pairs are produced.

4. Results

Best fit parameters;

- inclination angle 50deg,
- viewing angle 98.5deg,
- Rc=0.68Rn, where Rn is the radial distance to the null charge surface.

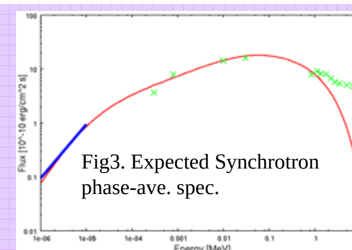


Fig3. Expected Synchrotron phase-ave. spec.

A, Spectrum

1, Fig1 shows synchrotron spectrum from the pairs, which explain the data from the optical to MeV bands, above which inverse-Compton process is important.

B, Polarization; comparison with data

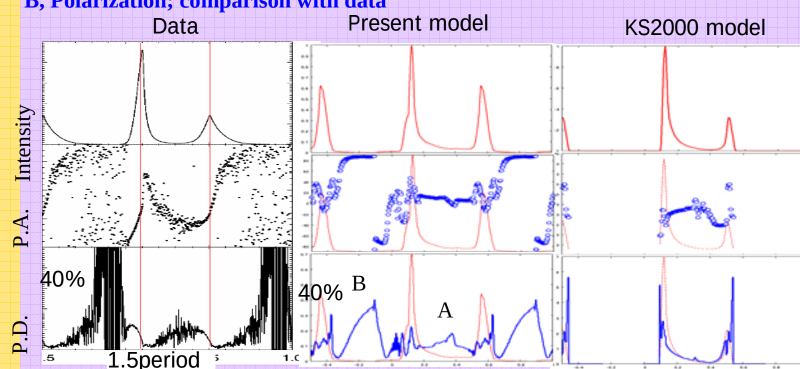


Fig.4 Polarization of the Crab pulsar. Left; data (Kanbach 2004). Middle; present outer gap model, Right; traditional outer gap model

2, Traditional outer gap (KS2000) model can not explain Crab optical data,
-there are no P.D. component between two peaks,
-no off pulse emissions.
3, Present outer gap model explains the main features of Crab optical data
-Higher generated pairs make the P.D. component (A in Fig 4) between two main peaks (Fig2).
-Emissions inside null charge surface make P.D. component (B) at off pulse phase
-Predicted polarization swing is also consistent with data.

C, Viewing angle

4, Position angle swing determines the viewing angle.
-Fig5 shows the polarization characteristics for the viewing angle 81.5degree, which is symmetry with 98.5degree relatively to the equatorial plane.
-The two observer have same spectrum and light curve, but P.A. swings are difference between two observer due to the difference of the projected direction of the magnetic field lines on the sky.

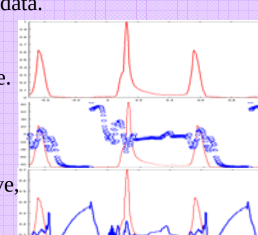


Fig.5 Polarization for viewing angle of 81.5degree. P.A. swing is inconsistent with data

5. Conclusion

The present outer gap model has successfully explained the Crab optical polarization data with the spectrum and the light curve. The emission of secondary pairs outside of the null charge surface is major part in the spectrum and light curve. On the other hand, the higher generated pairs and the emission from the inside of the null charge surface explain polarization data with minor contribution to the spectrum and light curve. With the polarization angle swing, the viewing angle greater than 90degree is prefer for the Crab pulsar.

1, Takata J., Shibata S., Hirotani K., 2004 MNRAS 354, 1120
2, Cheng K.S., Ruderman M., Zhang L.2000, ApJ, 537, 964
3, Kanback, et al 2005 astro-ph/0511636