# Soft Gamma-ray Pulsars

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**Abstract:** We propose a model to explain the X-ray and soft gamma-ray spectra and light curves of a class of young pulsars: PSR B1509-58, PSR J1846-0258, PSR J1811-1925, PSR J1617-5055 and PSR J1930+1852.

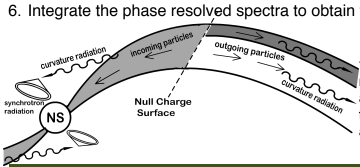
## Introduction:

The five young spin-down powered pulsars, PSR B1509-58, PSR J1846-0258, PSR J1811-1925, PSR J1617-5055 and PSR J1930+1852, have similar shapes of pulse profiles and spectra of non-thermal X-ray, which can be described by power law with photon index around 1.2. None of them has multi-GeV photon detected. We explain the non-thermal X-rays and soft gamma-rays of them based on the model in Wang et al., (2013).

The outer gap model predicts that most pairs created inside the gap are around the null charge surface, and the electric field separates the opposite charges to move in opposite directions (Cheng, Ho & Ruderman, 1986). Consequently, the region from the null charge surface to the light cylinder is dominated by the outflow of particles and that from the null charge surface to the star is dominated by the inflow of particles. Since the electric field decreases rapidly from the null charge surface to the star, the incoming radiation flux is weaker than that of the outgoing flux. These particles emit curvature photons, and the incoming curvature photons are converted by the strong magnetic field of the neutron star to pairs. We suggest that the outgoing curvature photons of the five pulsars are missed by the lines of sight, and the X-rays and soft gamma-rays of them are the synchrotron radiation of the pairs generated by the magnetic field.

## Simulation Method:

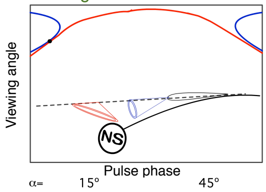
1. Trace the field lines and calculate the direction of the curvature radiation, $\vec{v}_{cur}$, at each step $\vec{r}$
2. Trace $\vec{v}_{cur}$ of the incoming curvature radiation to find the place, $\vec{r'}$, where the pair creation happens
3. Calculate the pulse phases and viewing angles, $(\psi, \zeta)$, along the hollow cone at $\vec{r'}$
4. Calculate the spectrum of the radiation that satisfies $|\zeta - \beta| < 0.5°$, where $\beta$ is the viewing angle
5. Trace the direction of synchrotron radiation to calculate the attenuation of the radiation caused by the pair creation, and remove the photons that covered by the star
6. Integrate the phase resolved spectra to obtain the energy dependent light curves




The sketch of the structure of the gap. Outside the null charge surface, the structure can be simplified as a two-layer structure (Wang et al., 2010, 2011). From the null charge surface to the stellar surface, the accelerating electric field is screened out.

## Pulse Phase of the Synchrotron Radiation:

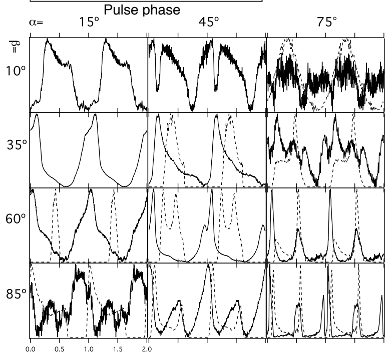
The pulse phase and viewing angle of the synchrotron radiation may be much different with the original curvature radiation.



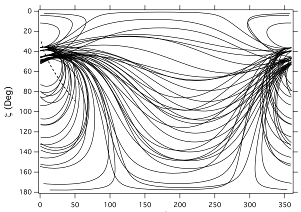

In the skymap, the highly beamed curvature radiation is represented by a **point**,

the hollow cone with a small pitch angle is represented by a '**circle**' surrounding the polar cap

the hollow cone with a large pitch angle is represented by a '**line**' that goes across the skymap.




The light curves of the synchrotron radiation (solid lines), which do not consider the attenuation of the original incoming curvature radiation, and the light curves of the outgoing curvature radiation (dashed lines), of different inclination angles and viewing angles. The two types of radiation have different scales in y-axis.




The skymap of the viewing angle $\zeta$ and the pulse phase $\psi$ of the synchrotron radiation (solid line) and the incoming curvature radiation (dashed line) originate from one magnetic field line, where the inclination angle=20Deg. The incoming curvature photons, which are represented by the points in the dashed line, are emitted by the particles moving from the null charge surface to the stellar surface along one magnetic field line. And the synchrotron photons are emitted from the places where pair creation happens. Along the directions of the curvature photons, there are many places where the condition of pair creation can be satisfied. The hollow cones of the synchrotron radiation are represented by the solid lines.

## Conclusion:

The lines of sight of these five pulsars are in the directions of incoming beams instead of outgoing beams, otherwise a characteristic power law with exponential cut-off spectrum with cut-off energy around a few GeV should be observed. The observed spectrum is the synchrotron radiation emitted by the pairs produced by the magnetic field that converts the major part of the incoming curvature photons.

THE DETAILS OF THE SIMULATION CAN BE FOUND IN :
Wang, Y., Takata, J., & Cheng, K.S., 2013, ApJ, 764, 51

## References:

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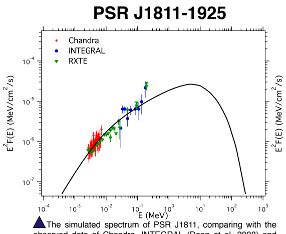
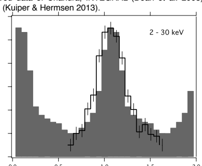
Wang, Y., Takata, J., & Cheng, K.S., 2013, ApJ, 764, 51

## Simulation Result:

### PSR J1811-1925

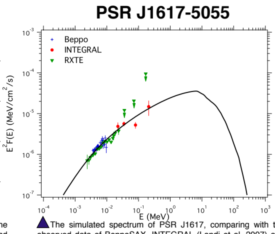



The simulated spectrum of PSR J1811, comparing with the observed data of Chandra, INTEGRAL (Dean et al. 2008) and RXTE (Kuiper & Hermsen 2013).

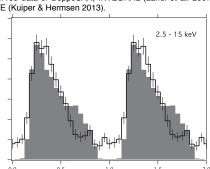



The simulated light curves of PSR J1811 (grey histograms), comparing with the observed data (solid lines) of RXTE (Gavriil et al. 2003).

### PSR J1617-5055

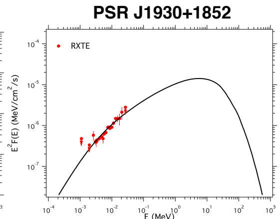



The simulated spectrum of PSR J1617, comparing with the observed data of BeppoSAX, INTEGRAL (Landi et al. 2007) and RXTE (Kuiper & Hermsen 2013).

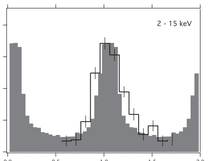



The simulated light curves of PSR J1617 (grey histograms), comparing with the observed data (solid lines) of XMM (Becker & Aschenbach 2002).

### PSR J1930+1852

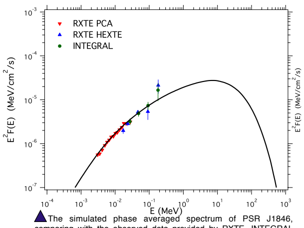



The simulated spectrum of PSR J1930, comparing with the observed data of RXTE (Kuiper & Hermsen 2013).



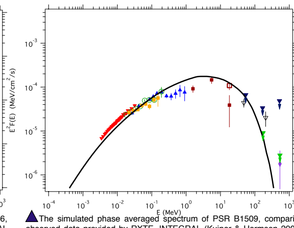

The simulated light curves of PSR J1930 (grey histograms), comparing with the observed data (solid lines) provided by RXTE (Lu et al. 2007).

### PSR J1846-0258



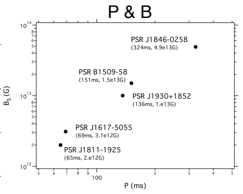

The simulated phase averaged spectrum of PSR J1846, comparing with the observed data provided by RXTE, INTEGRAL (Kuiper & Hermsen 2009).

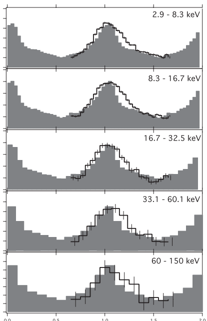
### PSR B1509-58



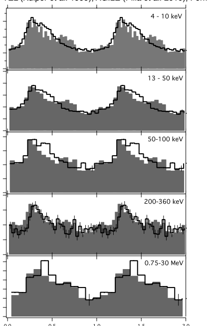

The simulated phase averaged spectrum of PSR B1509, comparing with the observed data provided by RXTE, INTEGRAL (Kuiper & Hermsen 2009), EGERT, COMPTEL (Kuiper et al. 1999), AGILE (Pilia et al. 2010), Fermi (Abdo et al. 2010),

### P & B




The simulated energy dependent light curves of PSR J1846 (grey histograms), comparing with the observed data (solid lines), which are provided by RXTE and INTEGRAL (Kuiper & Hermsen 2009).




The simulated energy dependent light curves of PSR B1509 (grey histograms), comparing with the observed data (solid lines), which are provided by, COMPTEL (Kuiper et al. 1999), OSSE (Matz et al. 1994) and BeppoSAX (Cusumano et al. 2001).

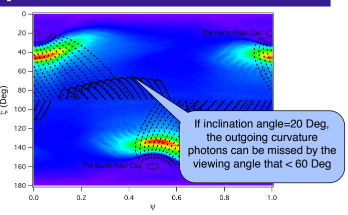
Fitting Parameters

| | $\alpha$ | $\beta$ | $\eta$ | $f$ |
|---|---|---|---|---|
| PSR B1509-58 | 30 | 15 | 0.25 | 0.3 |
| PSR J1846-0258 | 10 | 35 | 0.20 | 0.5 |
| PSR J1930+1852 | 20 | 41 | 0.02 | 0.28 |
| PSR J1617-5055 | 15 | 25 | 0.50 | 0.21 |
| PSR J1811-1925 | 10 | 35 | 0.10 | 0.2 |

$\alpha$: inclination angle (Deg)
$\beta$: viewing angle (Deg)
$\eta$: density of the inflow of the particles in $\rho_{GJ}$
$f$: size of the gap

## Where are the GeV curvature photons?

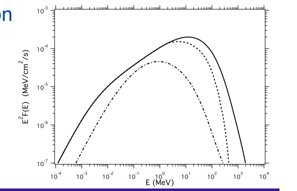
The outgoing GeV curvature photons are missed by the viewing angle. If the viewing angle or inclination angle increases, the GeV curvature photons can be seen.




The skymap of the viewing angle and the pulse phase of the outgoing curvature photons (solid lines) emitted from the null charge surface to the light cylinder, the incoming curvature photons (dashed lines) emitted from the null charge surface to the stellar surface, and the synchrotron photons (color) emitted from the places, where the pair creation happens. The inclination angle =20Deg.

## Why is the cut-off energy of the spectrum so low?

This is because of the attenuation of the synchrotron photons caused by the magnetic pair creation.




The solid line is the one without considering the attenuation of the synchrotron photons by the magnetic pair creation.
The dashed line is the spectrum of the survival synchrotron photons from the magnetic pair creation.
The dot-dashed line is the contribution of the synchrotron radiation of the pairs converted from the synchrotron photons.

## How to constraint the inclination and viewing angles?

1. The "ring" in the SNR — If the ring is circle, the viewing angle can be determined directly.

2. The energy of the peak of the spectrum — Different inclination angles and viewing angles lead to different energies of the peak of the spectrum due to different optical depths of the magnetic pair creation.

3. The shape of the light curve

4. The phase lag of the peak of the X-ray radiation to the radio radiation