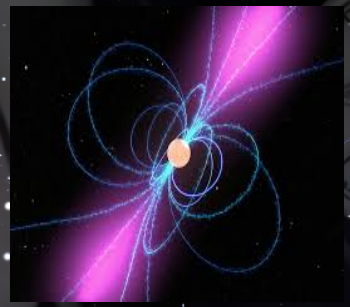

Vela

Detection of Pulsed > 50 GeV Emissions from the Vela pulsar with Fermi-LAT

Vela



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with

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(Leung+, ApJL in press, arXiv:1410.5208)

Outline

1. Introduction

   -Observations for the pulsed emissions above >10GeV

2. Fermi-data analysis of the Vela pulsar

   -Pulse search >50GeV

   -Phase-averaged spectrum

3. Emission model

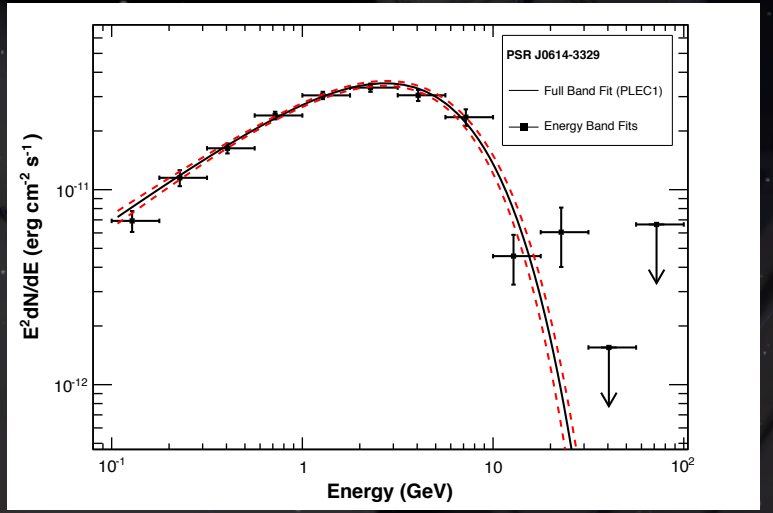
   -Switching pulsar magnetosphere

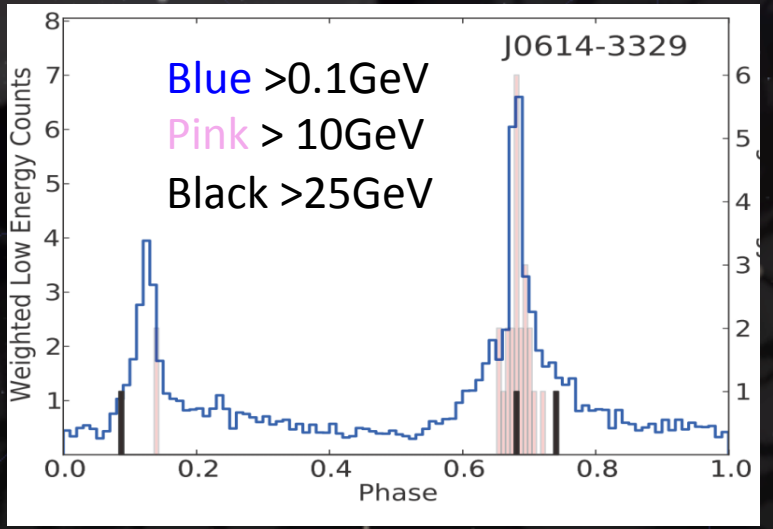
1 Introduction; Pulsed emissions at >10GeV

- High-Energy Pulsars

(Saz Parkinson et al. 2012)

- 20 (12) gamma-ray pulsars show evidence of the pulsations in the range >10GeV (>25GeV)





- Fermi-LAT detected >60GeV pulsed emissions of PSRs J0614-3329 (63GeV) and J1954+2836 (62GeV)

(Fermi collaboration 2013)

1 Introduction;
Pulsed emissions at >10GeV

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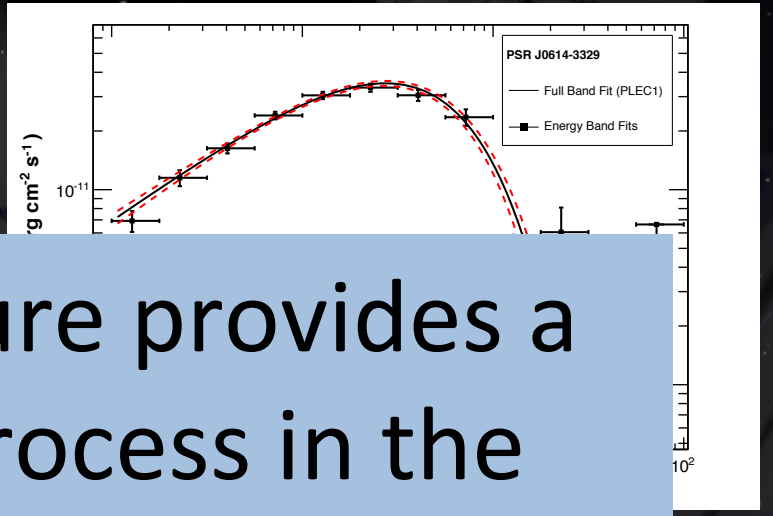
Observed cut-off feature provides a hint of the emission process in the pulsar magnetosphere.



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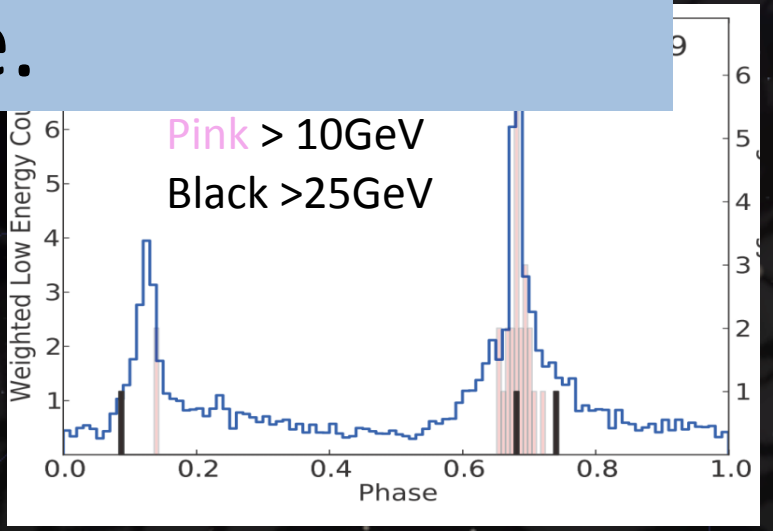


(Fermi collaboration 2013)

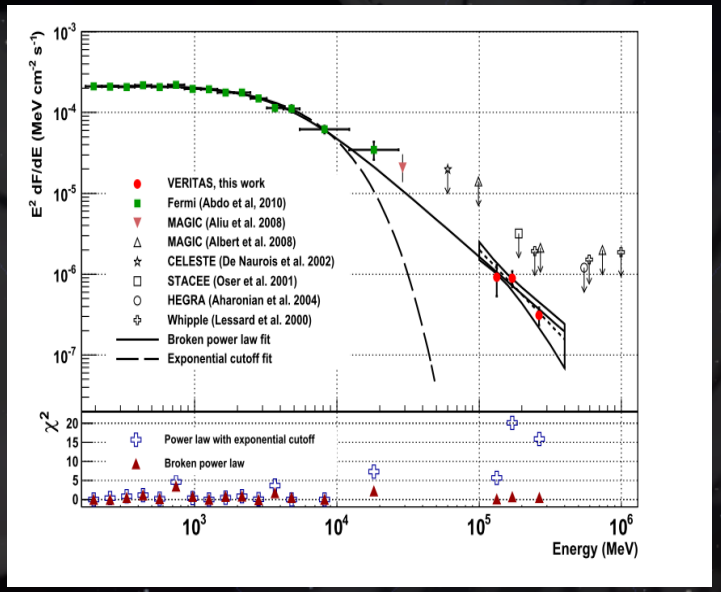
1 Introduction;
Pulsed emissions at >10GeV

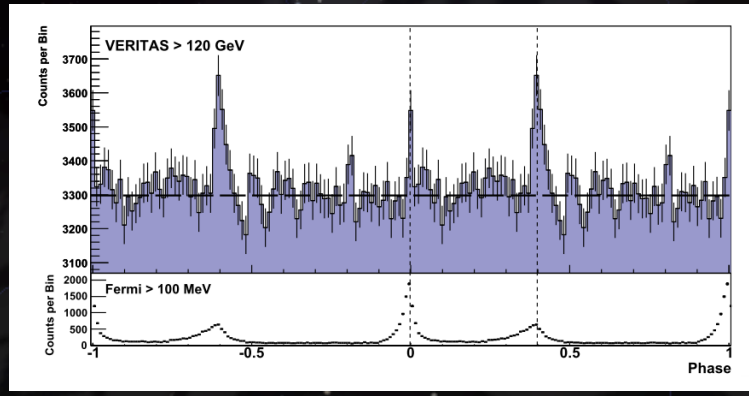
- Crab pulsar
  (see talks by Zanin and Sito)

- Pulsed emissions in 0.1-1TeV [VERITAS; (Aliu et al. 2011) and MAGIC (Aleksic et al. 2012) collaborations]

- No predictions by the standard curvature radiation models.

- Indication of the Inverse-Compton scattering process in outer magnetosphere (Lyutikov 2012) or pulsar wind region (Aharonian et al. 2012).





(Aliu et al. 2011)

1 Introduction;
Pulsed emissions at >10GeV

1. How does the spectrum look like in 10-100GeV?

2. Can ground based telescopes measure the emissions from the high-energy pulsars?

3. What does the observation in 10-100GeV range tell us about the emission mechanisms?

2 Vela pulsar

1., P=0.089 s, Lsd~7x10^36 erg/s, d~0.25kpc.

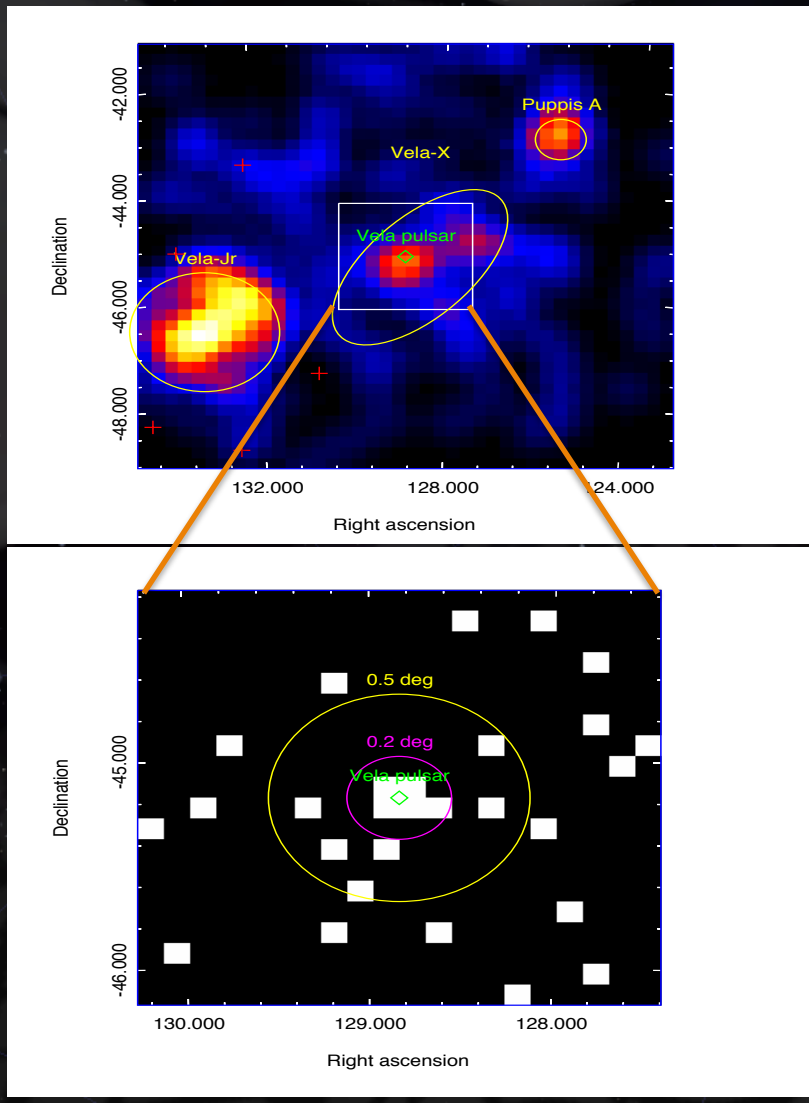
2., Brightest gamma-ray source (TS=72 in 30-100GeV).

3., Fermi-LAT detected pulsed emissions at > 37GeV
(Saz Parkinson et al. 2012)

4., H.E.S.S. collaboration (2014) found the pulsed emissions at >30GeV, with mean photon energy <40GeV>.

2 Vela pulsar;
I, Pulsation search in 50-300GeV

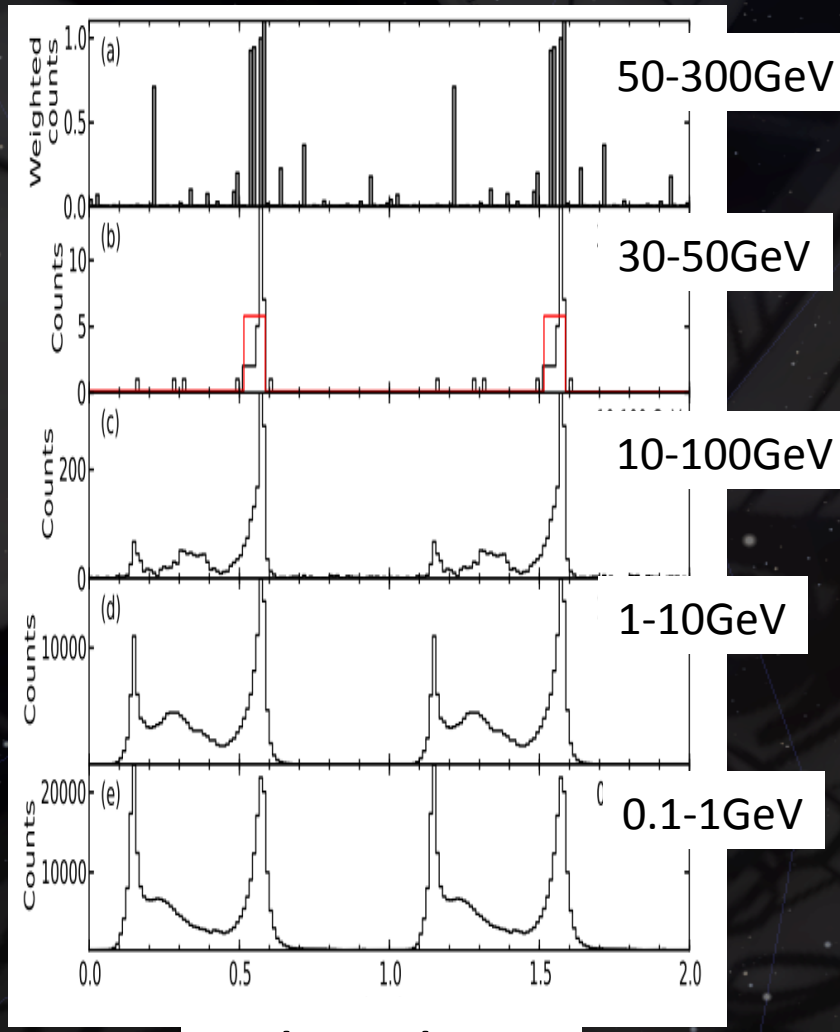
- Data span; 2008 August 4 to 2013 October 18.
- Photons within 4 degree from the Vela pulsar are weighted its source probability.



2 Vela pulsar;
I, Pulsation search in 50-300GeV

- More 50-300 GeV photons at *the second peak* in the lower energy bands.

- *Weighted* H-test (Kerr et al. 2011) for >50GeV pulsed emissions
  →H-Statistic is 15.4 ～3.1σ.



2 Vela pulsar;
II, Pulsation search in 50-300GeV

- We selected 50-300 GeV photons, which show source probability

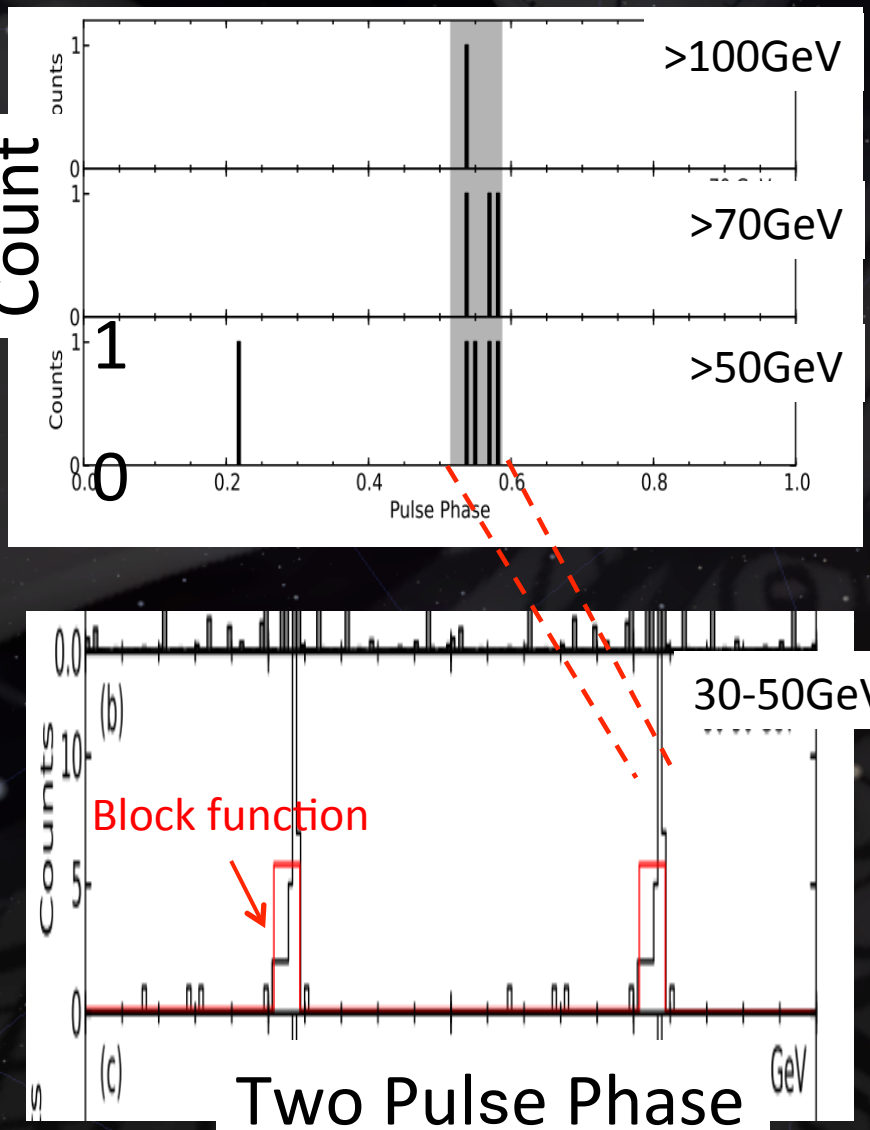
$$P_{PSR} > \max(P_{PWN}, P_{GAL})$$

→ 5 photons were left

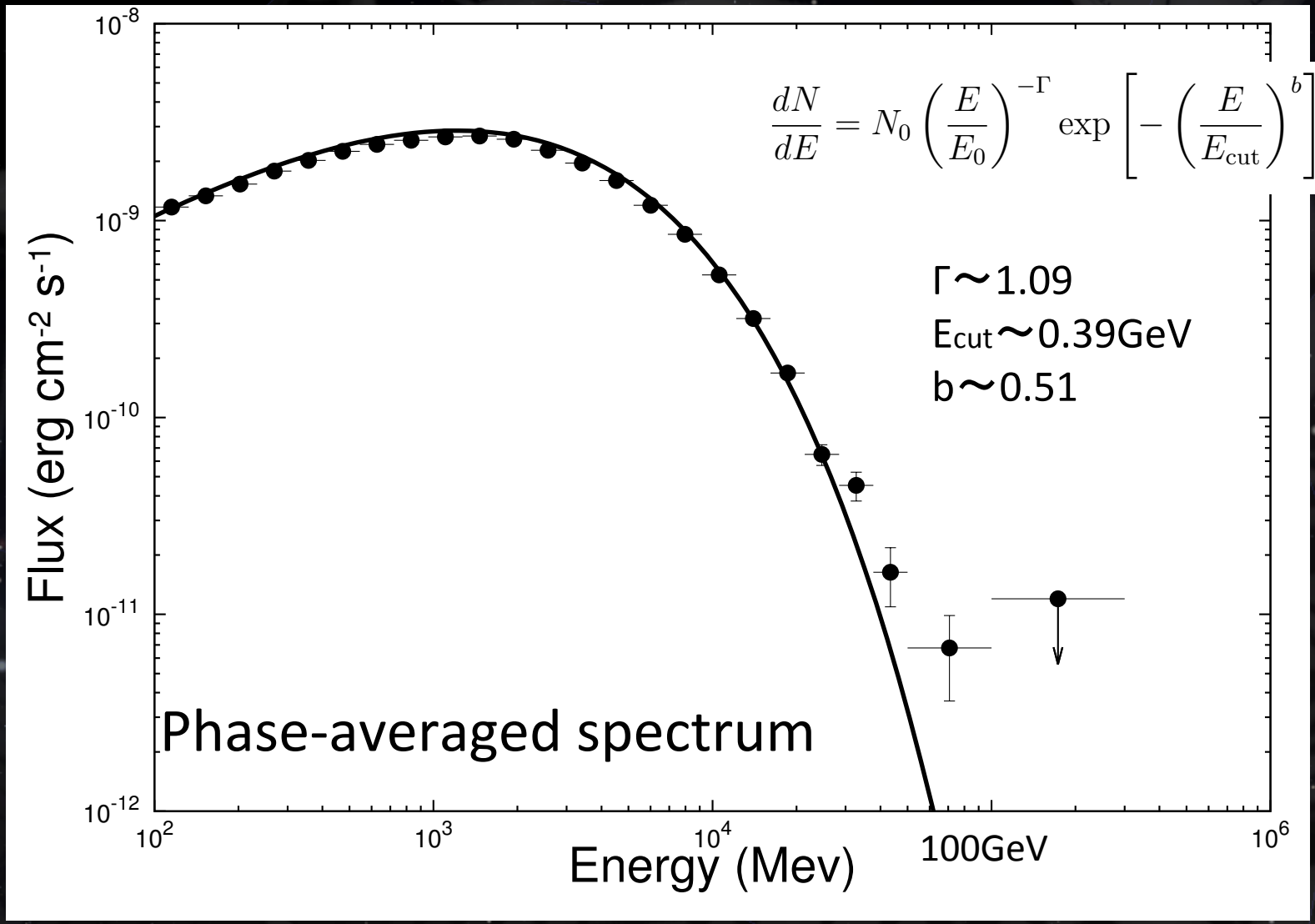
→ 4 out of 5 are detected at the second pulse

- We extracted the pulse profile in 30-50GeV with a block function (Bayesian block algorithm , Scargle et al. 2013)

- Likelihood ratio test gives the evidence of pulsation ～4σ for >79GeV and ～3.3σ for >90GeV



2 Vela pulsar; Spectral analysis



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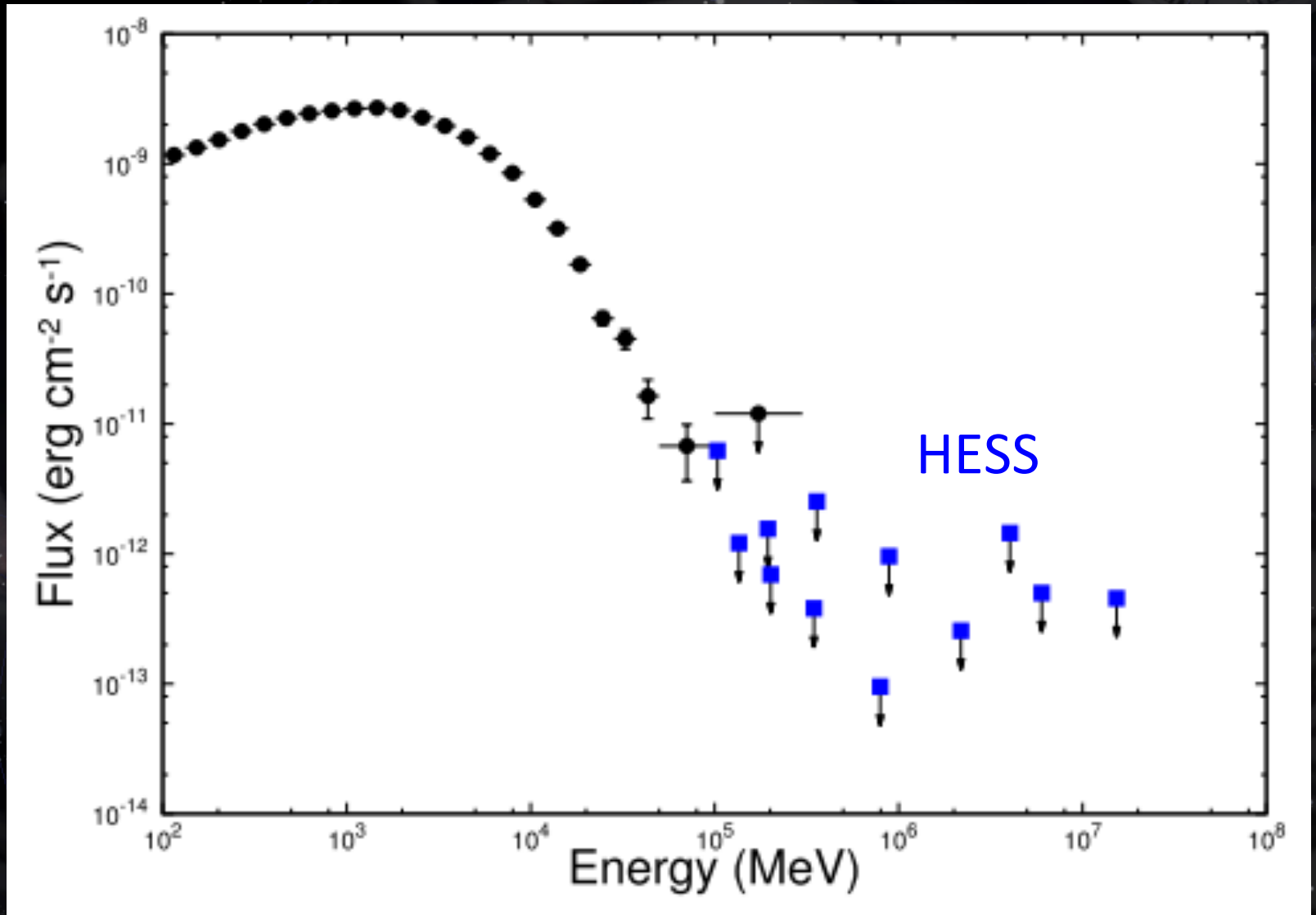
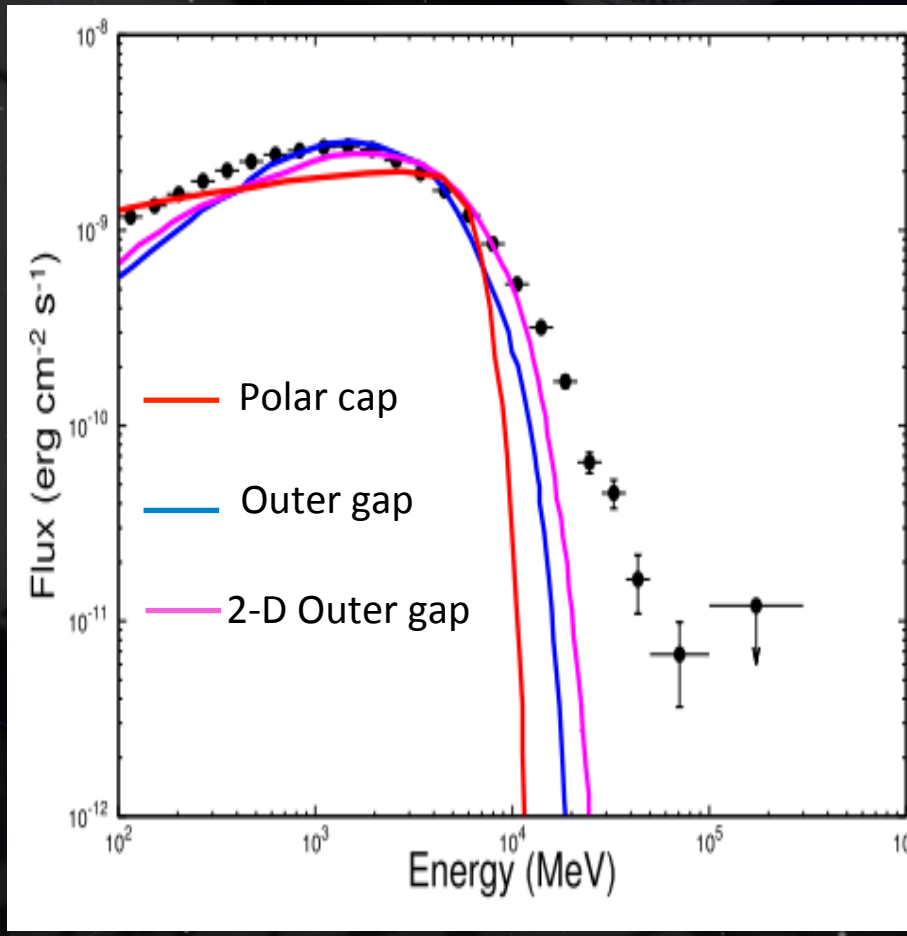


3 Model

- No previous “standard” model predicted 50-100GeV emissions with a flux level of $\sim 10^{-11} erg/cm^2 s$

-Predicted cut-off feature (a simple exponential cut-off) is too sharp

- The inverse-Compton scattering is very week (Takata et al. 2006).
- The curvature radiation process will be responsible for 10-100GeV emissions



3 Model
Switching Pulsar magnetosphere

- Pulsar magnetosphere is switching between stationary states

1, Observation

-Pulse to pulse variation, nulling and mode change of radio emissions

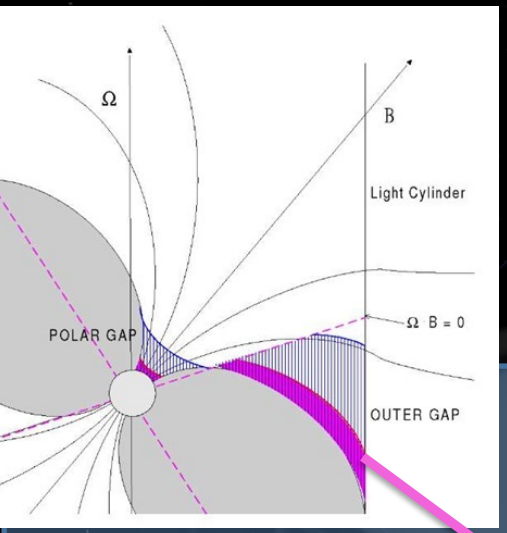
-Mode change of the X-ray emissions of PSR B0943+10 (Hermasen et al. 2013) and of the GeV emissions of PSR J2021+4026 (Abdo et al. 2013)

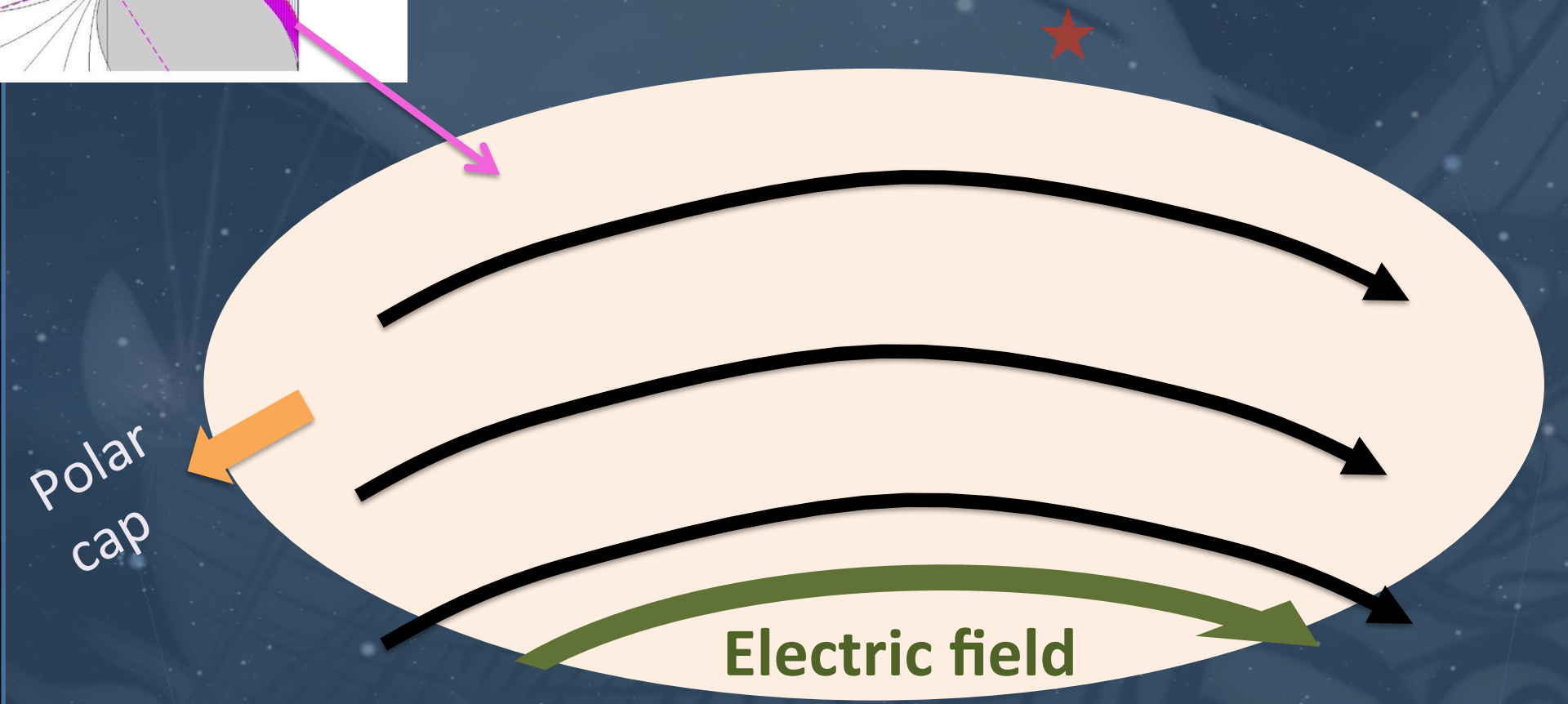
2, Theory

- Non-steady polar cap accelerator due to time-dependent pair-creation process (Levinson et al. 2005, Timokhin 2010).

Switching outer gap

Injection rate of the particles controls the gap size and gamma-ray spectrum.





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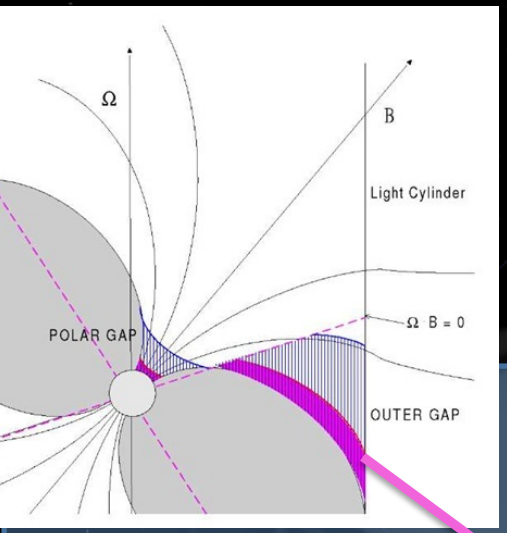

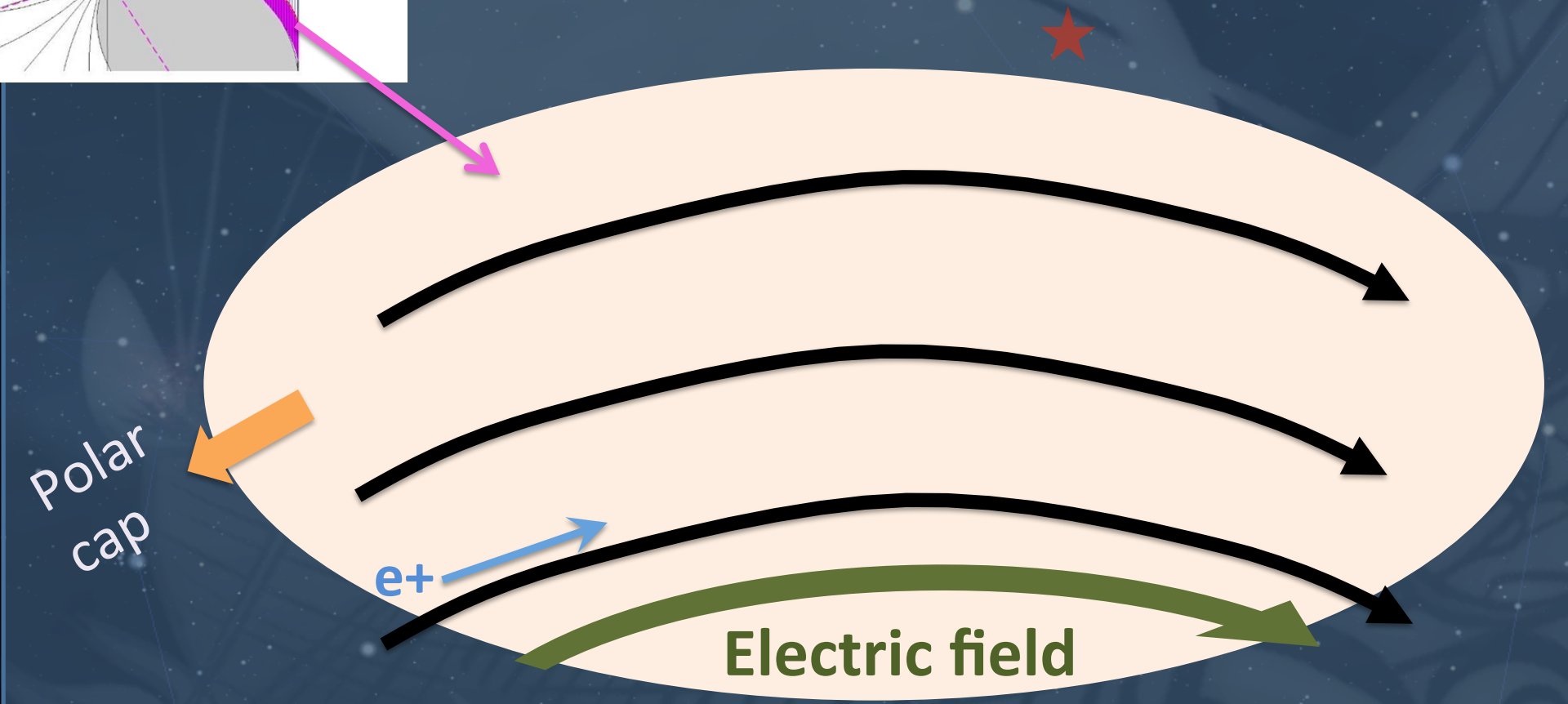

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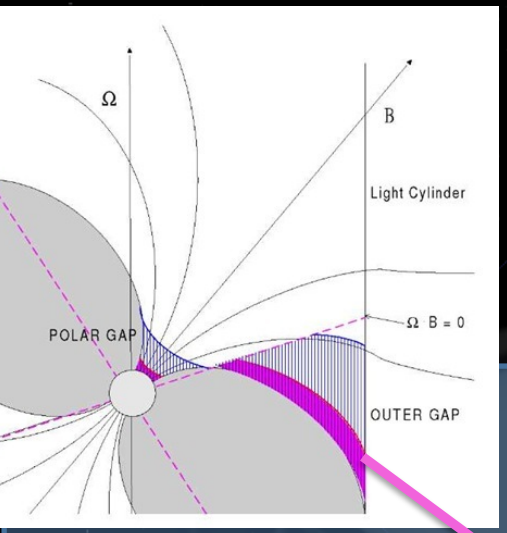

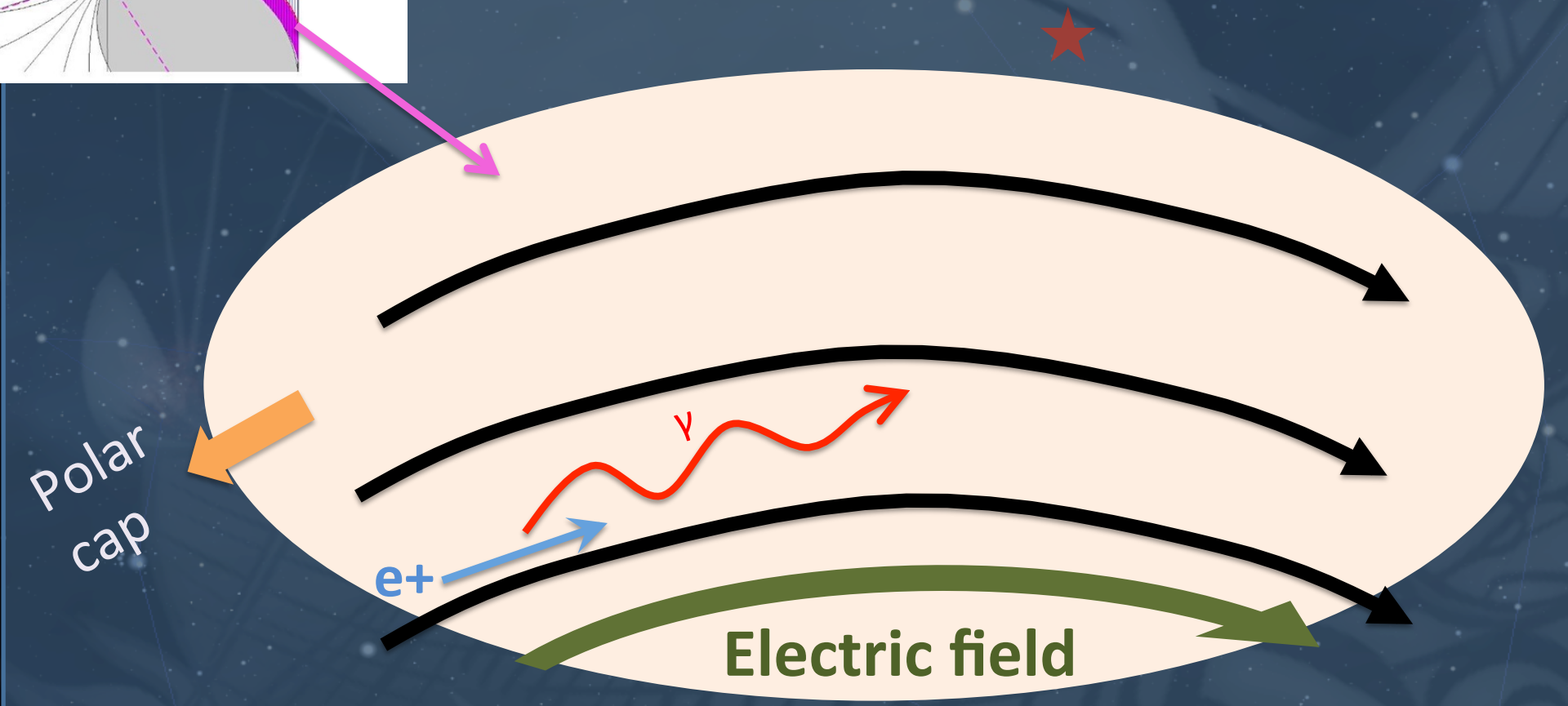

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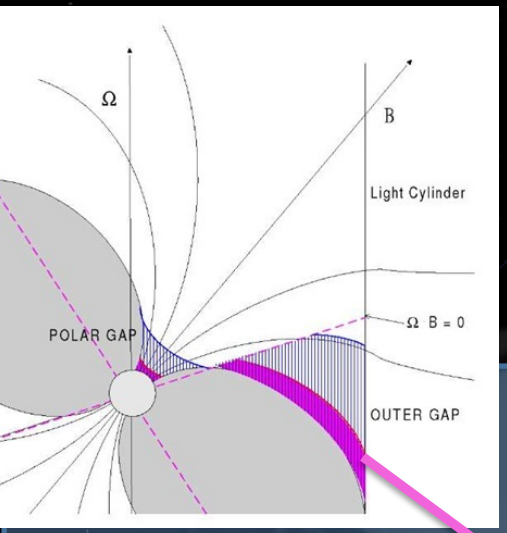

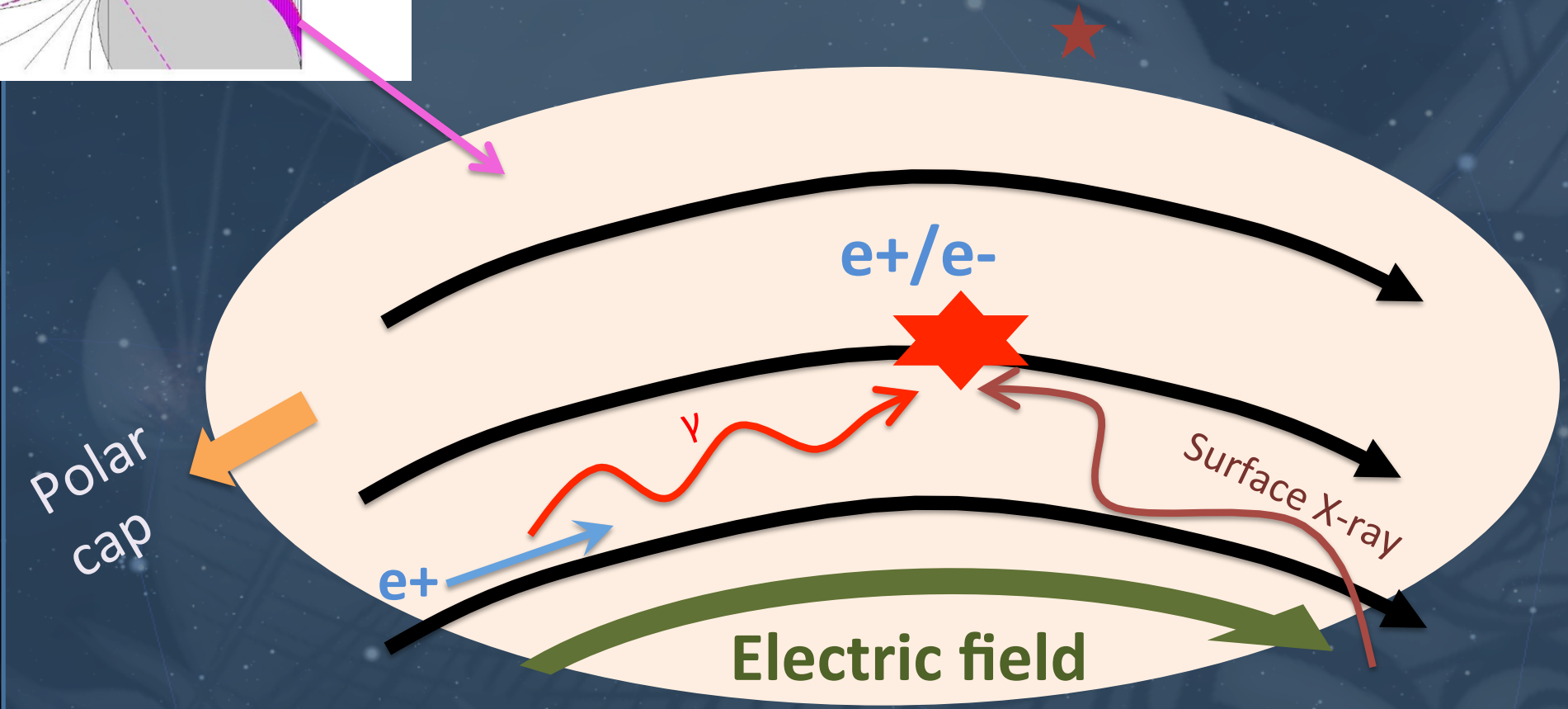

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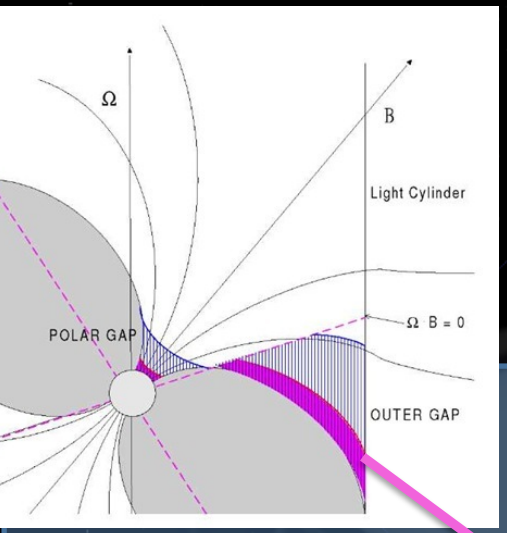
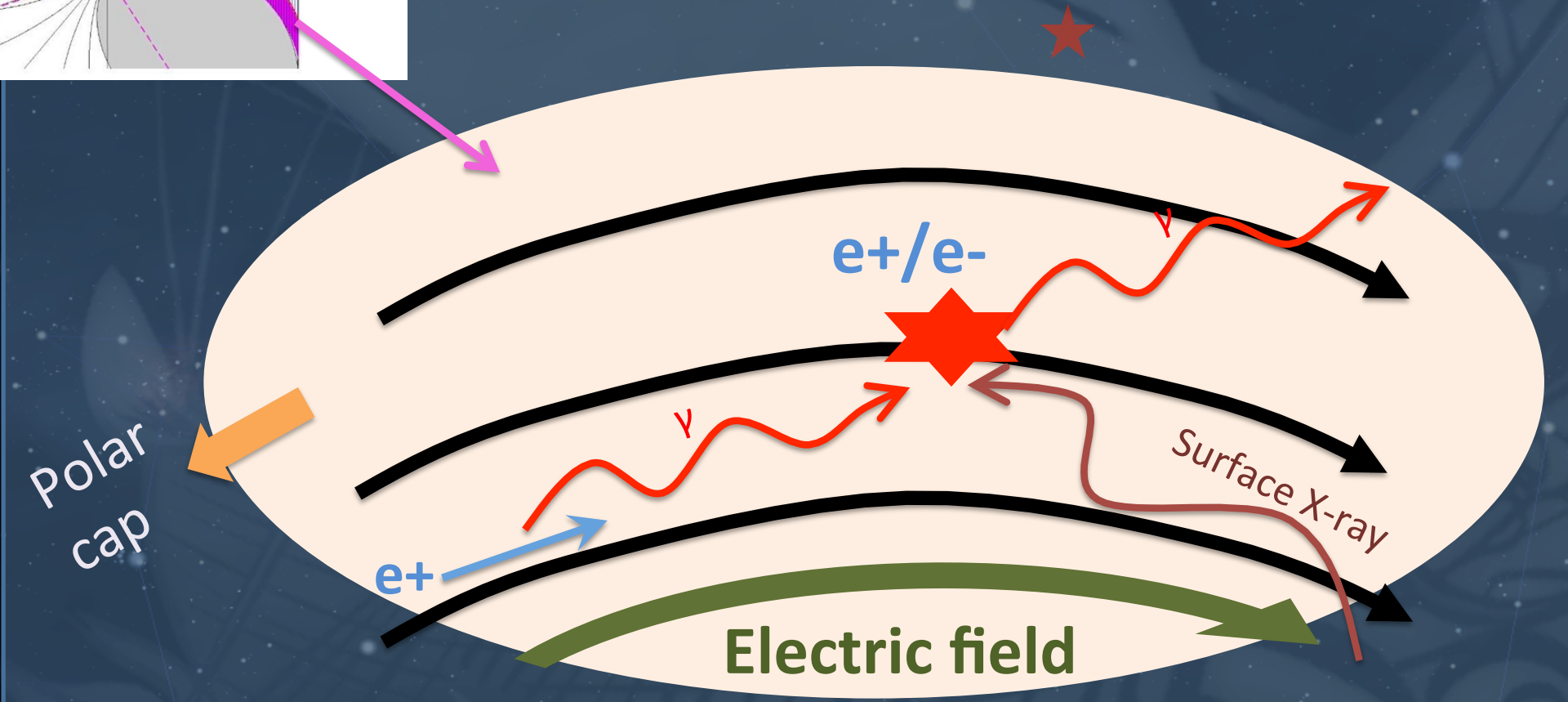
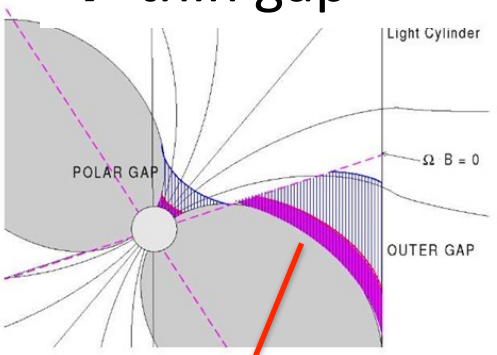


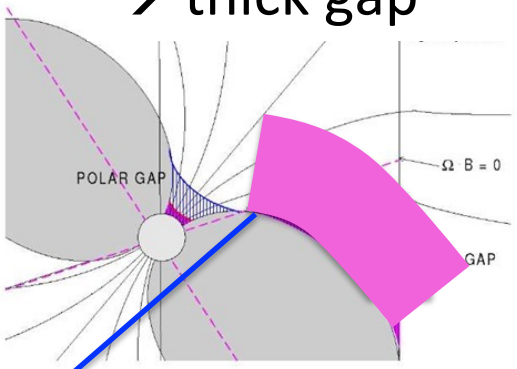


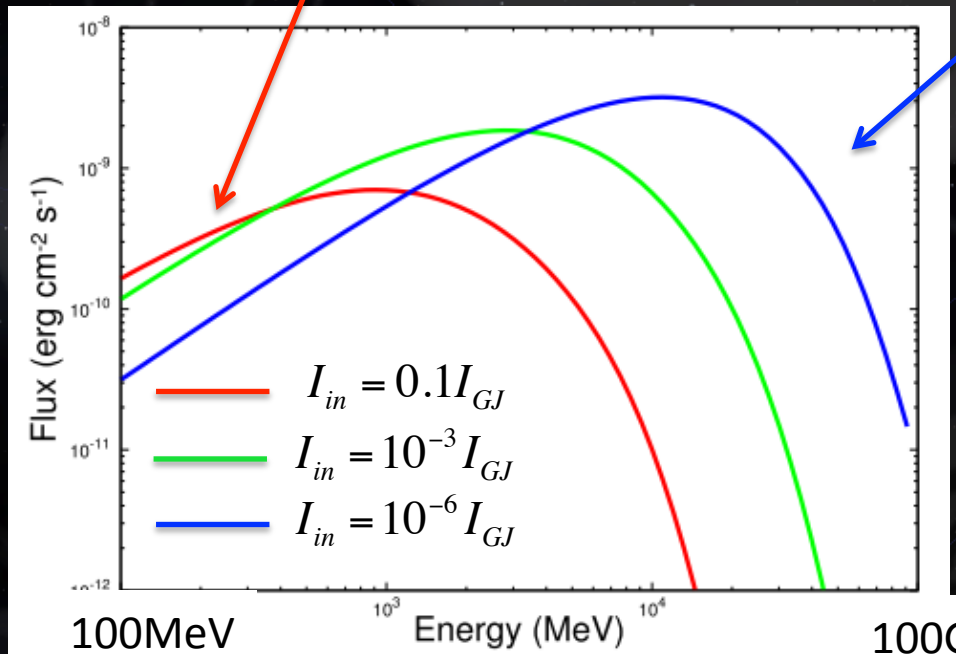
- The outer gap region develops until the pair-creation process makes a Goldreich-Julian current (Hirotani 2006+; Takata et al. 2004+)

large injection
→ thin gap



Small injection
→ thick gap





- **3-D local model**

- Dipole magnetic field

- Poisson equation and particle continuity equation

- Pair-creation process

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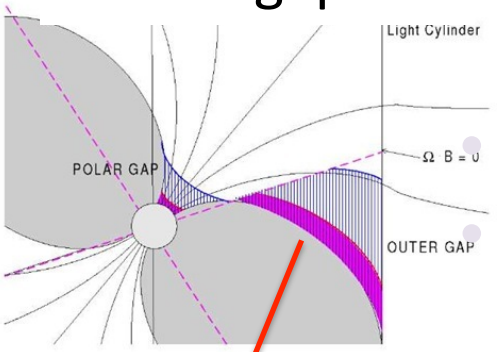

Switching
(~s scale)

Small injection
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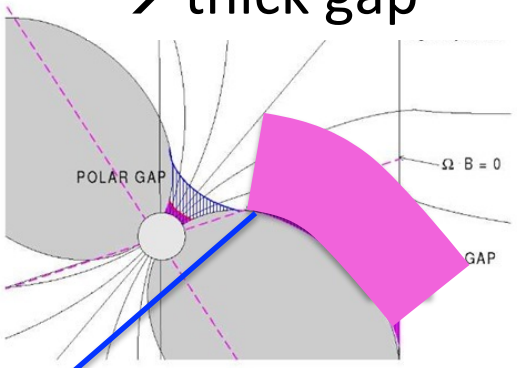

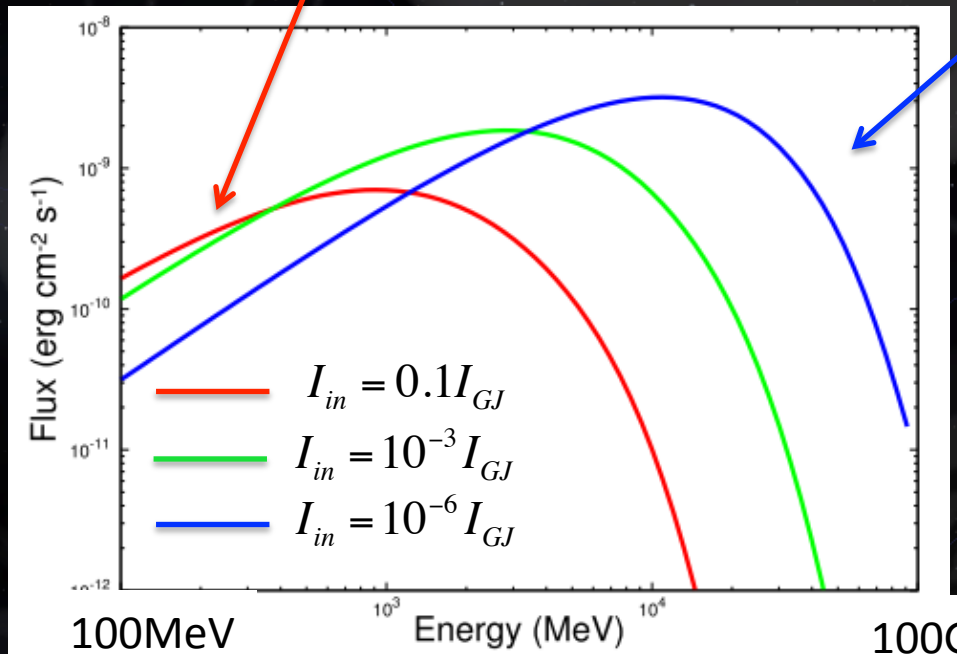

- **3-D local model**
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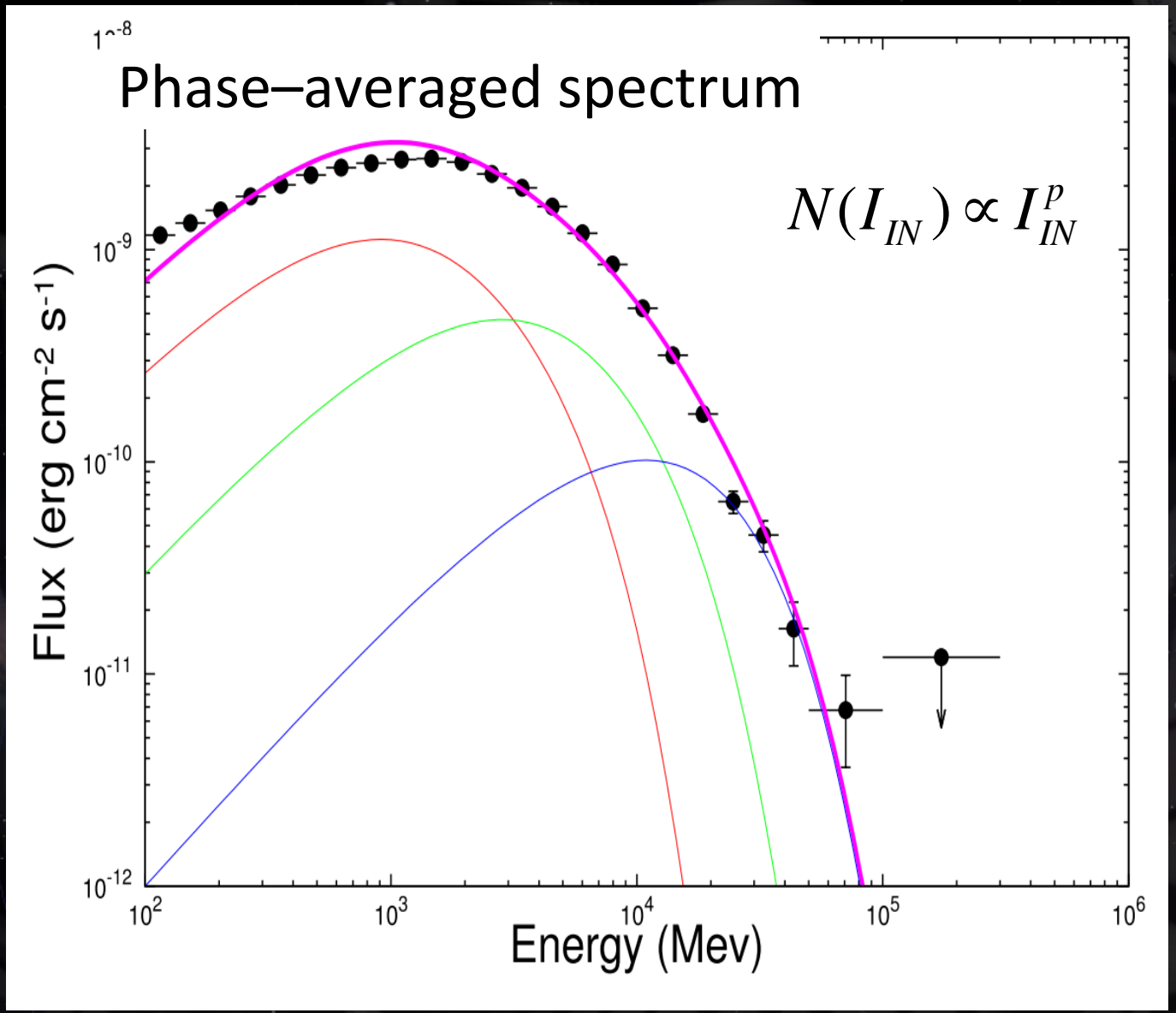
- **Pair-creation process**

3 Model

Switching outer gap

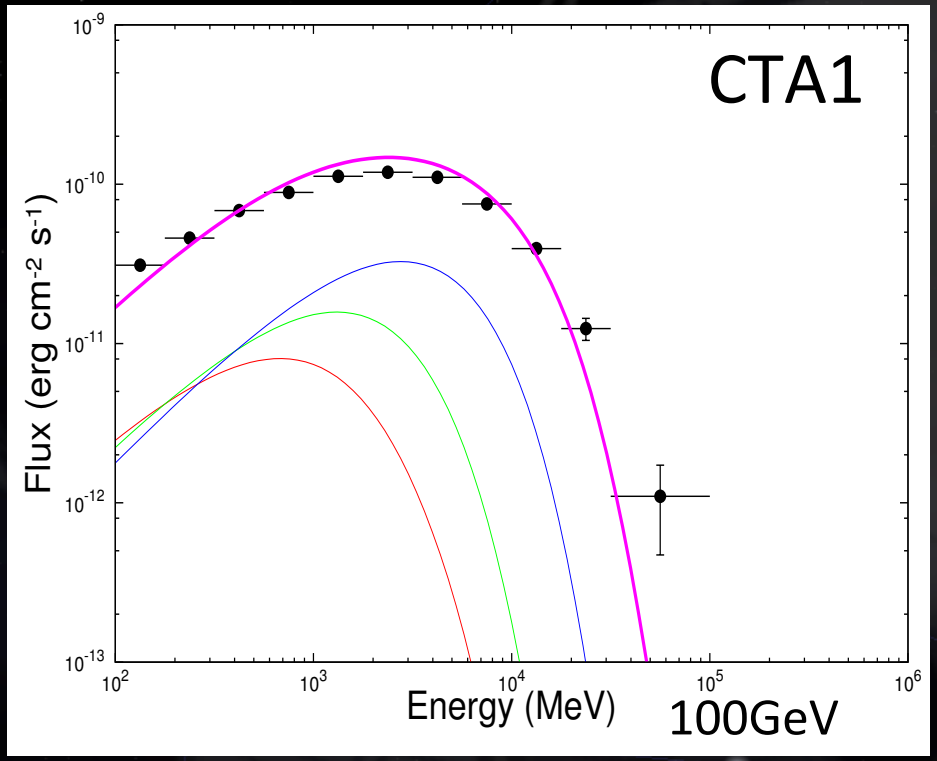


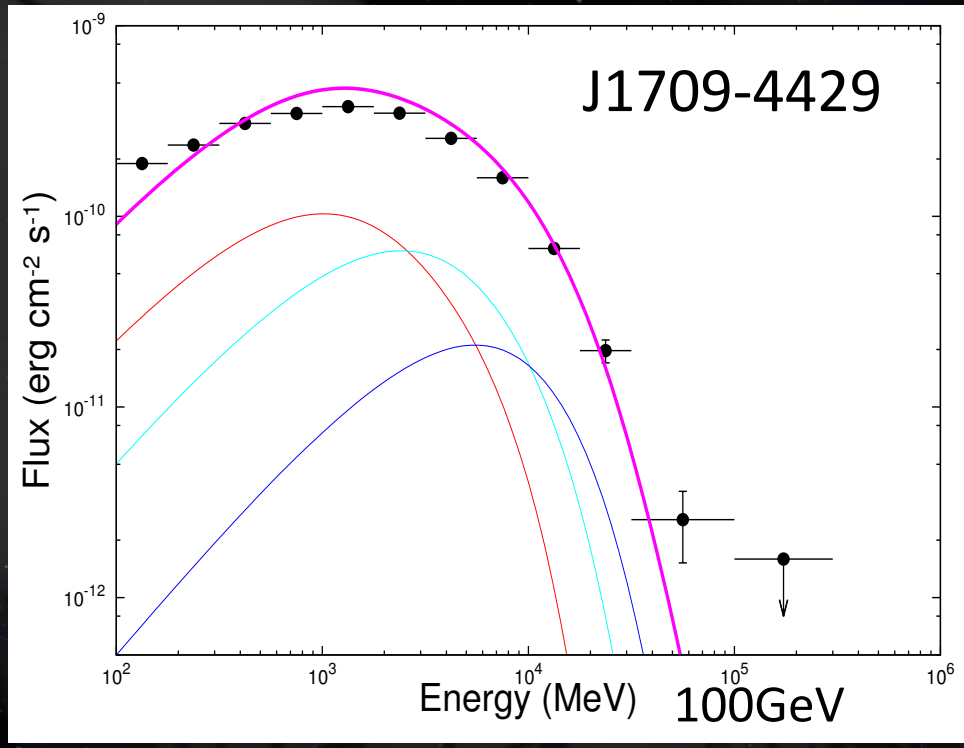
>0.1GeV

>20GeV

3 Model

Switching outer gap





Summary

- Fermi enables us to study the pulsed emissions above 10GeV

- Pulsed >50GeV emissions from the Vela pulsar.
  →More photons are concentrated at second peak in lower energy bands .

- Flux at 50-100GeV is of order of $\sim 10^{-11} erg/cm^2 s$
  →Target for pulsed emissions at >100GeV.

- Switching outer gap

→ Is gamma-ray emission correlated with radio emissions?

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- Switching pulsar magnetosphere

→ Is gamma-ray emission correlated with radio emission?

→ "Non-thermal" X-ray/radio correlation discovered by Lommen et al (2007).