Pulsar Questions & GLAST

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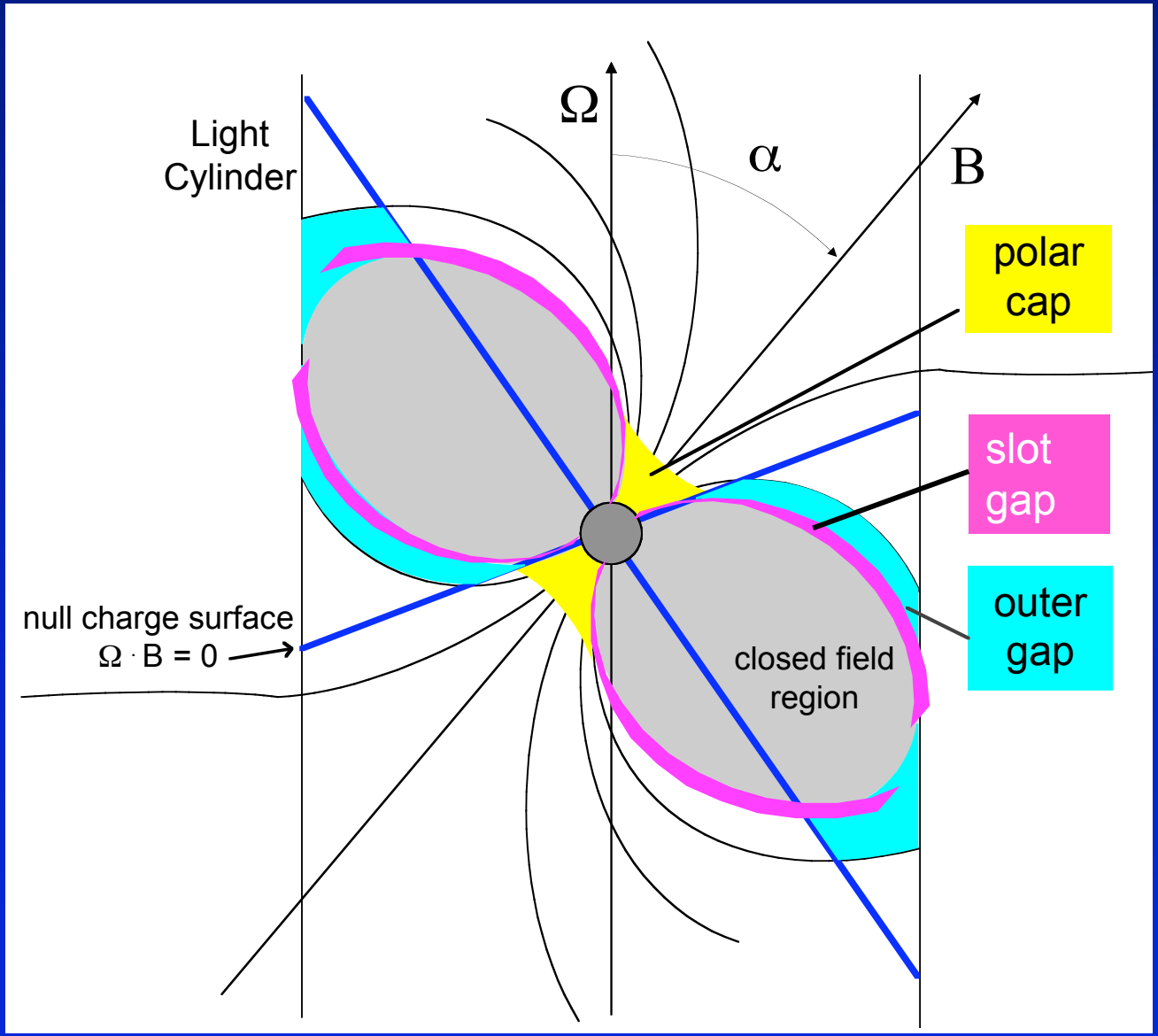
- Unresolved questions of pulsar physics
  - How and where are particles accelerated in the pulsar magnetosphere?
  - What are the high-energy radiation mechanisms?
  - Are processes the same for all pulsars?
  - Are there γ-ray millisecond pulsars?
  - What is the ratio of radio-loud to radio-quiet γ-ray pulsars?
- How can GLAST help to answer them?

How and where are particles accelerated in the pulsar magnetosphere?

- PROFILES → geometry of emission → Acceleration
- SPECTRAL CUTOFFS

Possible sites of particle acceleration



Ideal MHD in most of magnetosphere

$$E \bullet B = 0$$

Deficient charge supply

$$E \bullet B \neq 0$$

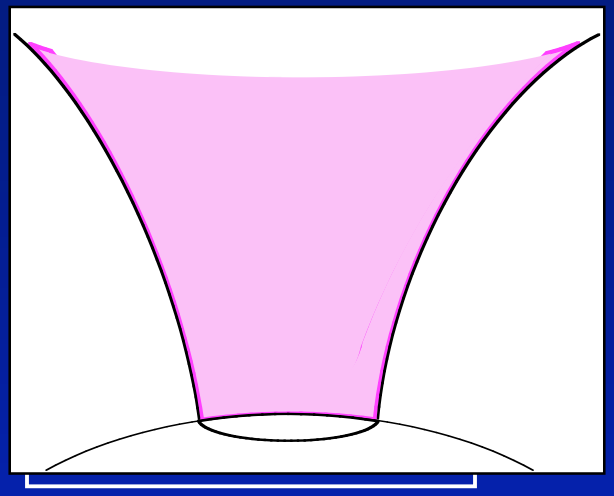
→ acceleration

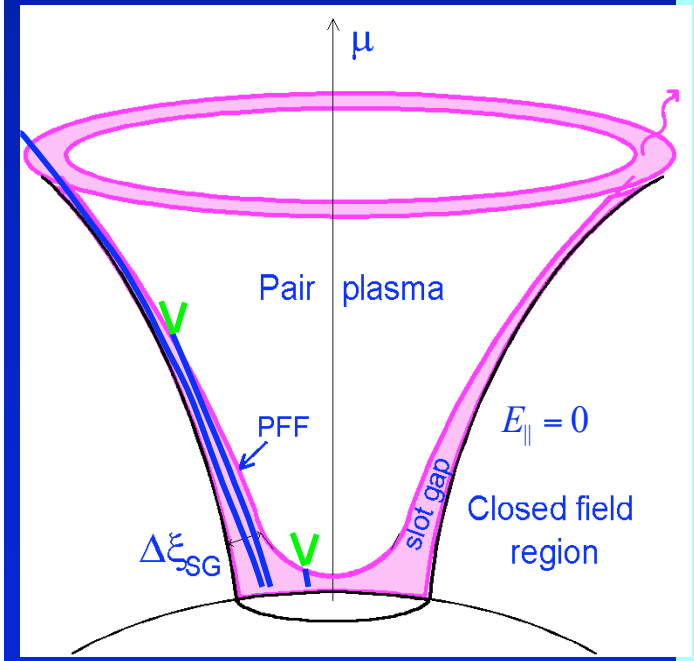
Solve Poisson's Eqn

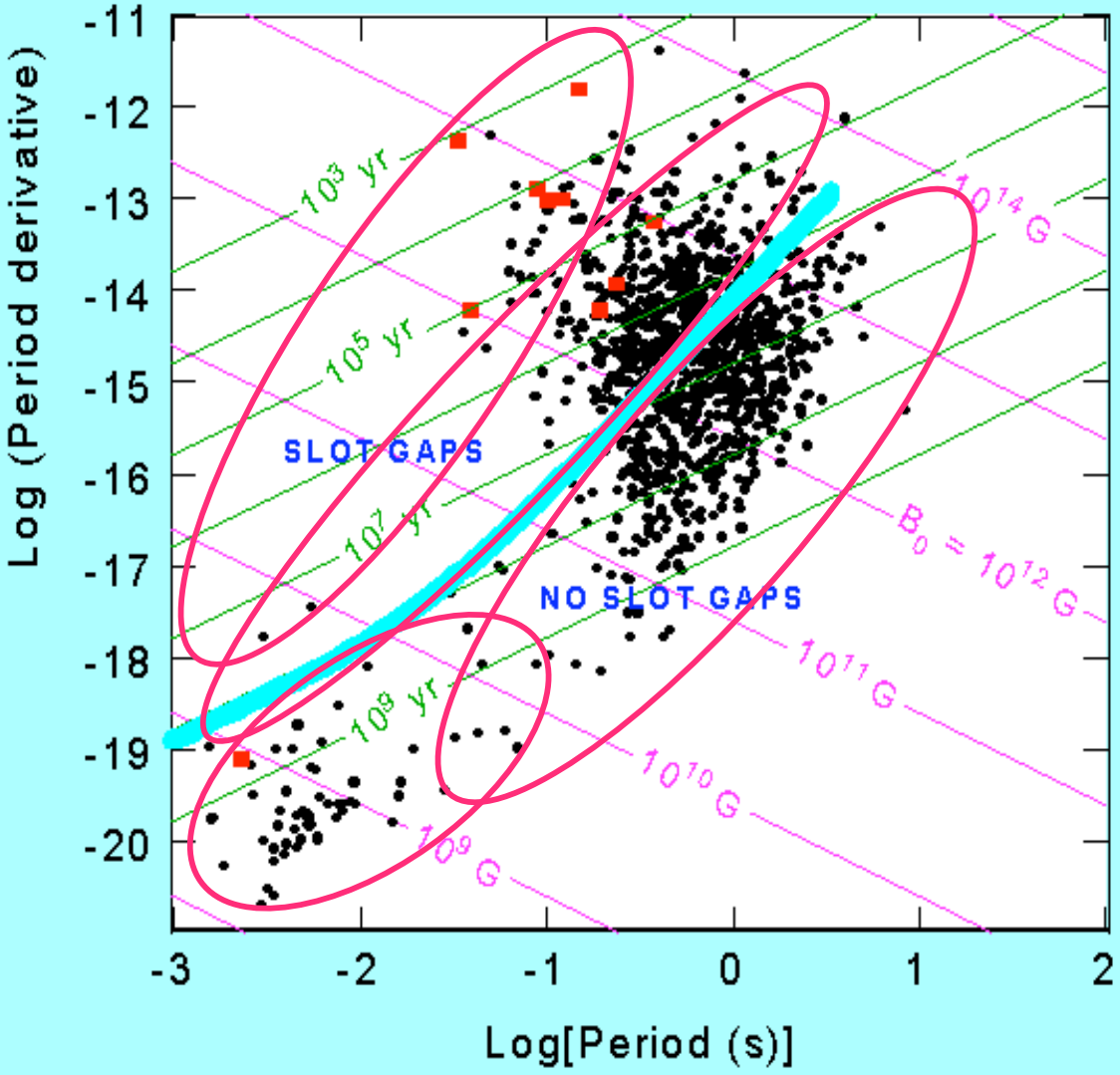
$$\nabla \cdot E_{\parallel} = 4\pi(\rho - \rho_{GJ})$$

Which pulsars have slot gaps?

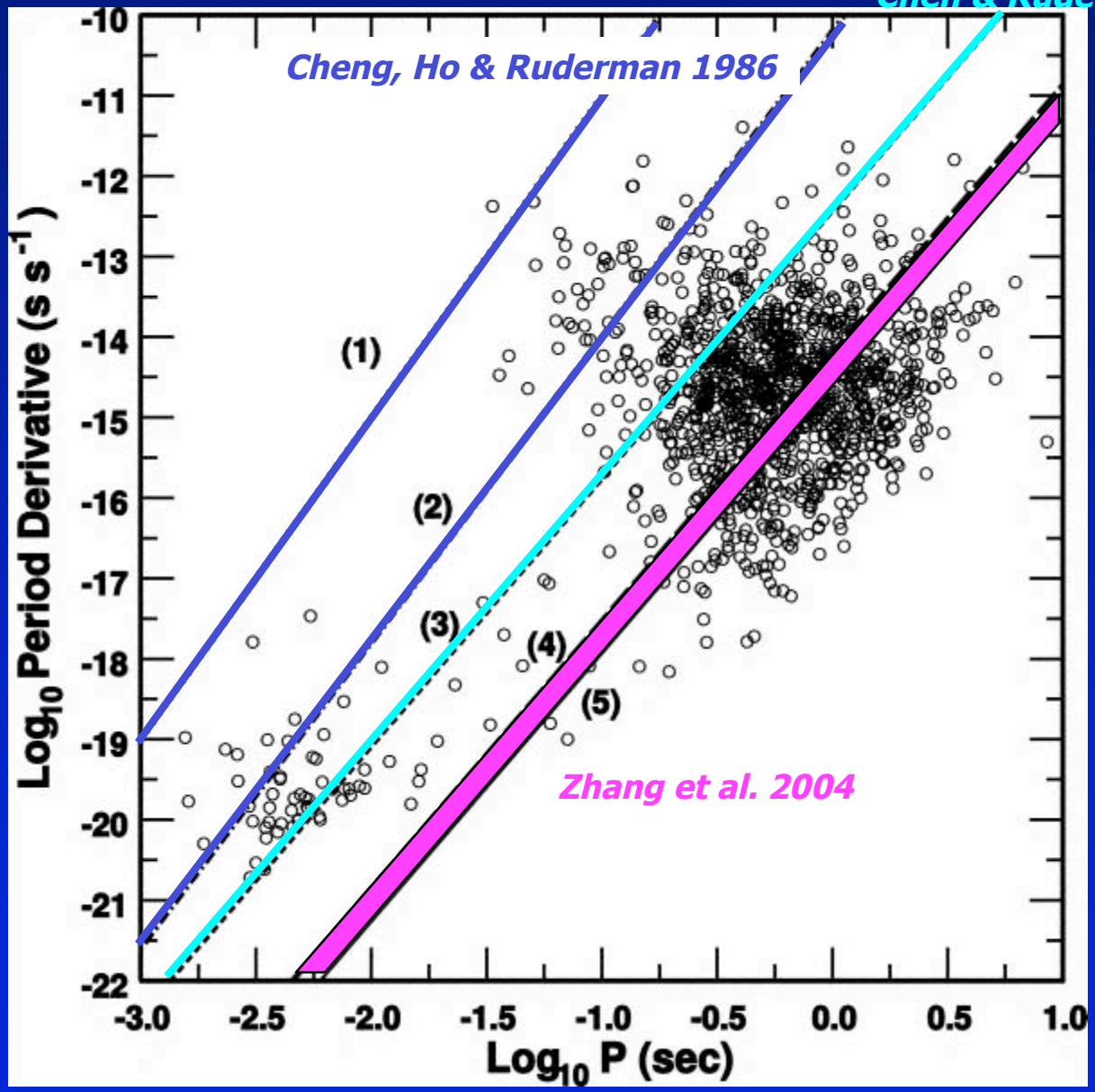
Harding, Muslimov & Zhang 2002





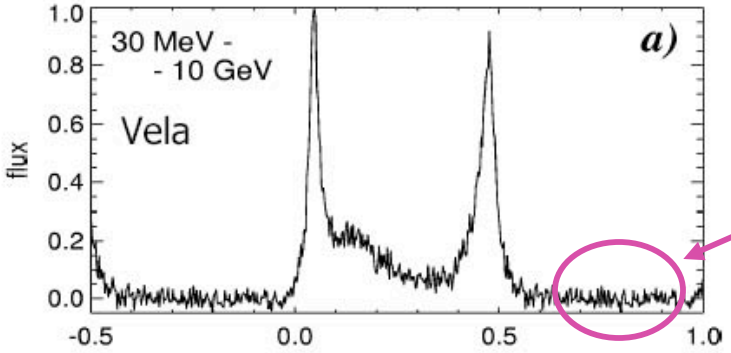


Which pulsars have outer gaps?

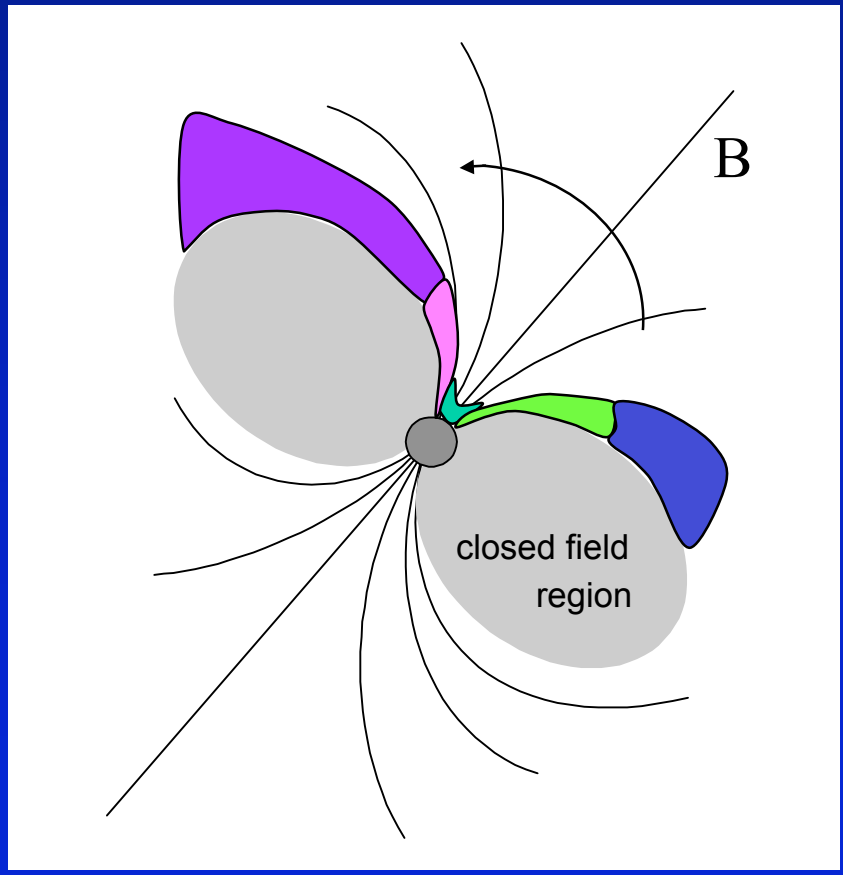


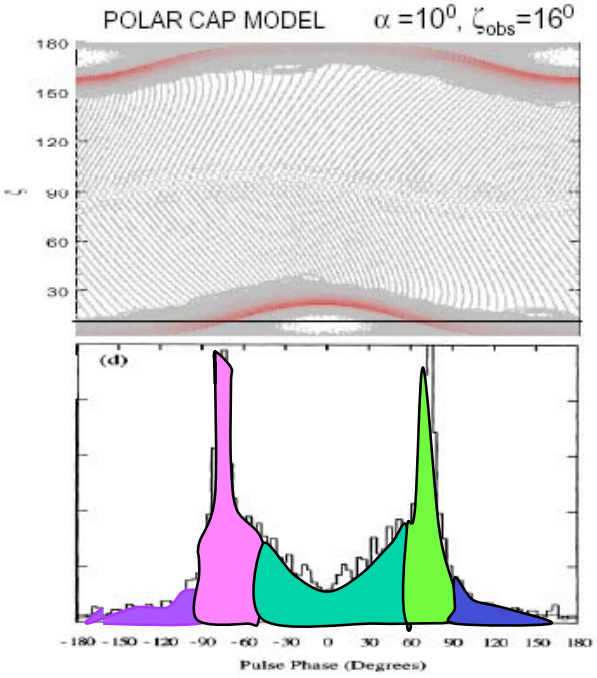
Polar cap model - low-altitude slot gap

Daugherty & Harding 1996



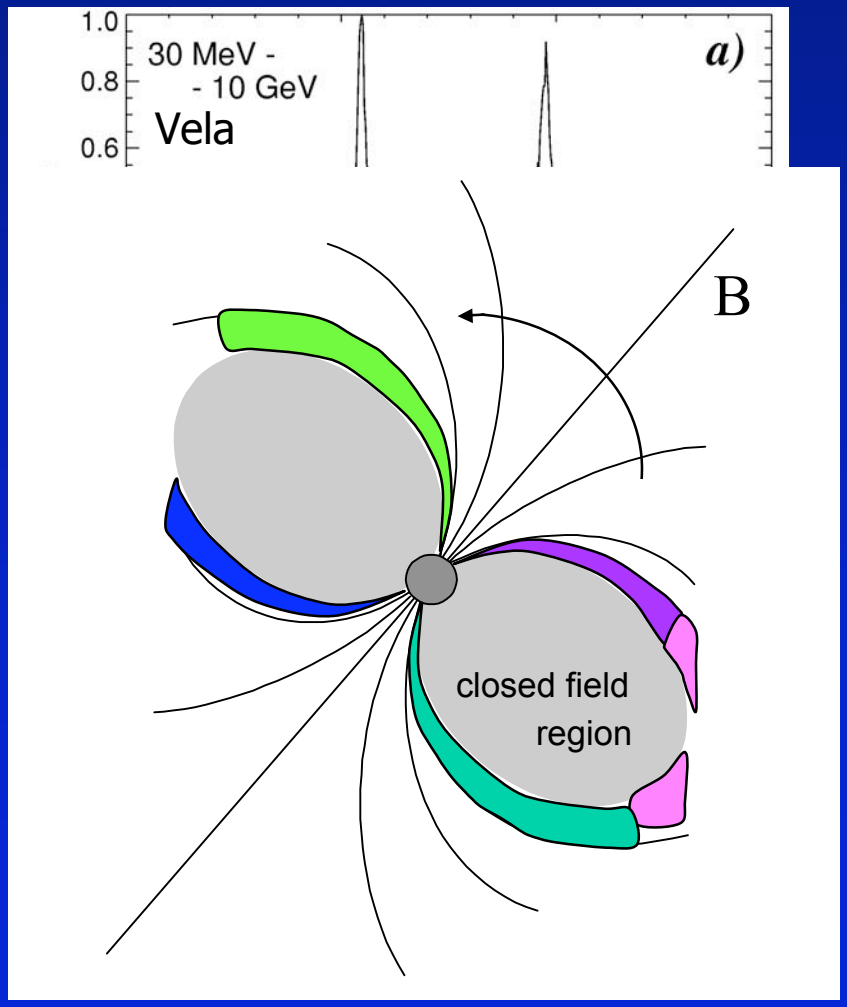
Measure off-pulse emission

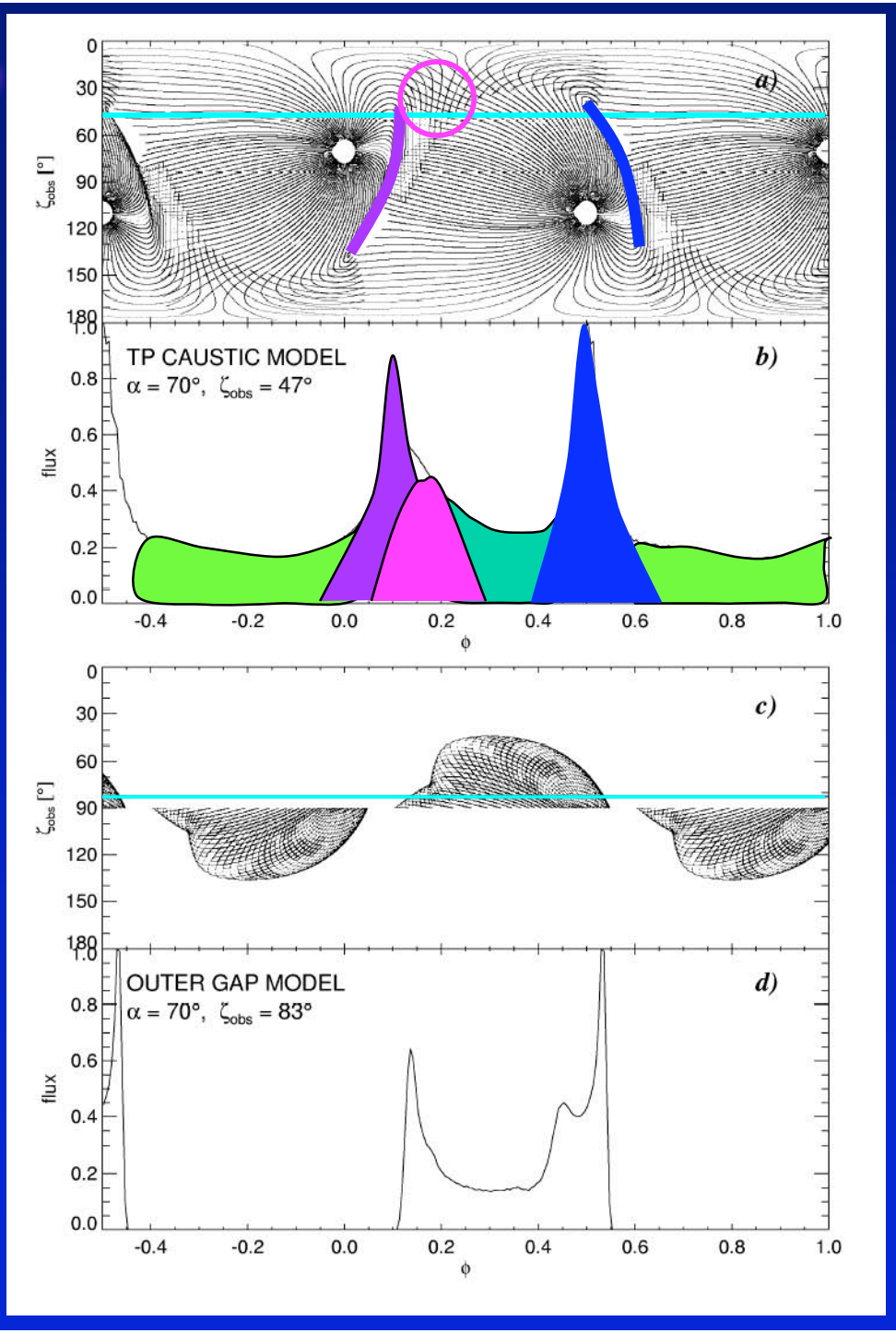




Slot gap and outer gap geometry

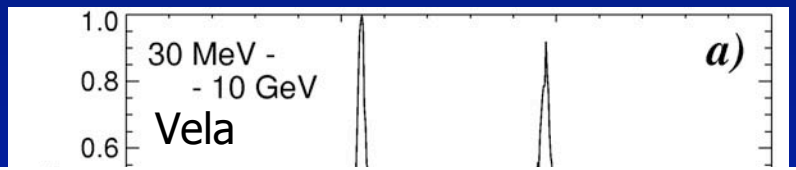
Dyks & Rudak 2003
Dyks, Harding & Rudak 2004

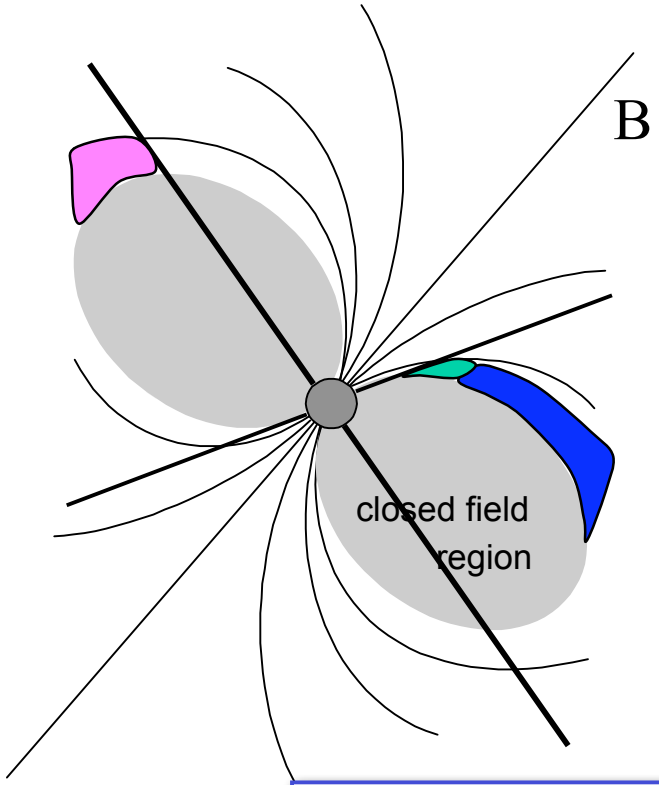


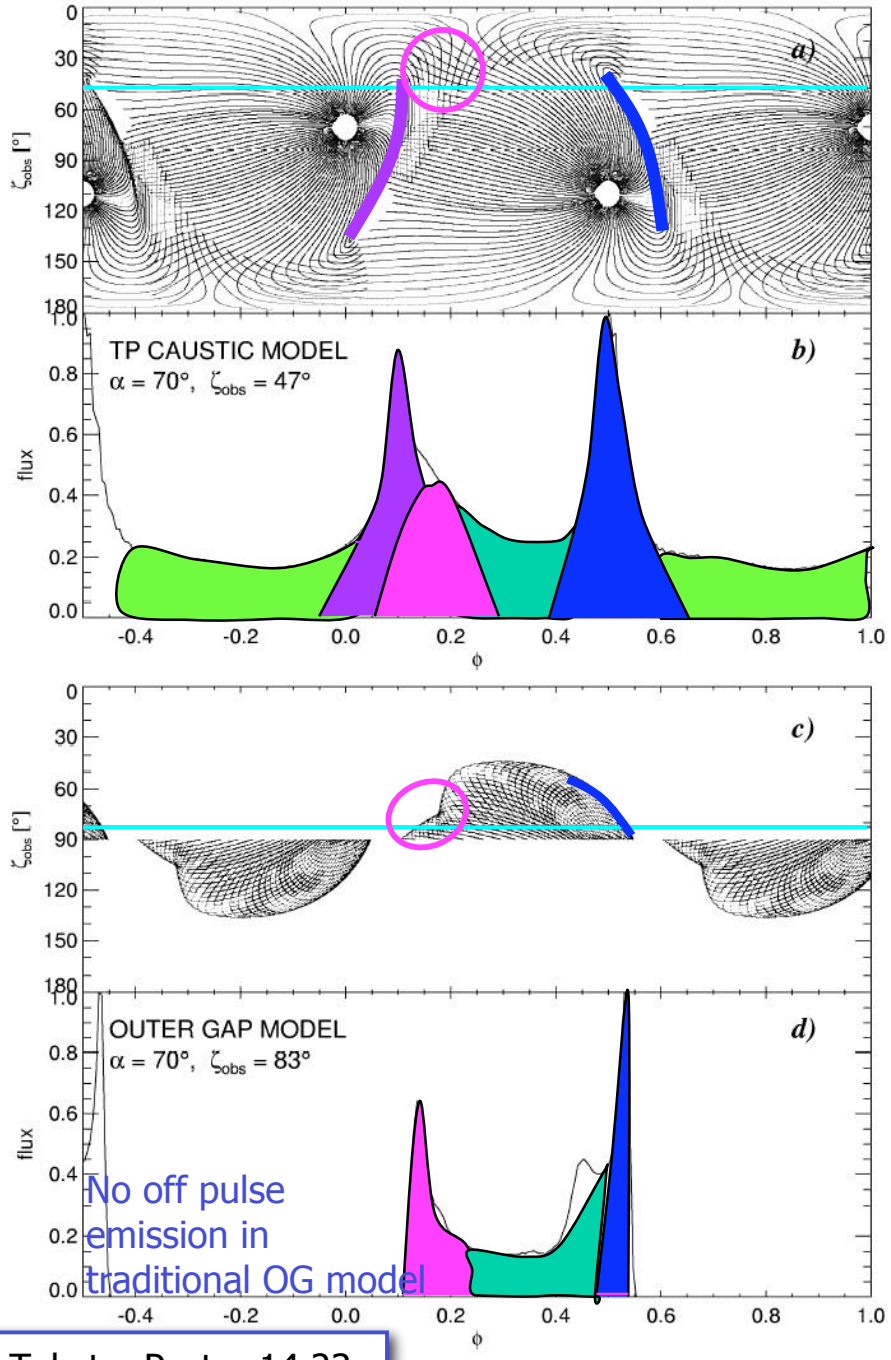


Slot gap and outer gap geometry

Cheng, Ruderman & Zhang 2000
Dyks, Harding & Rudak 2004



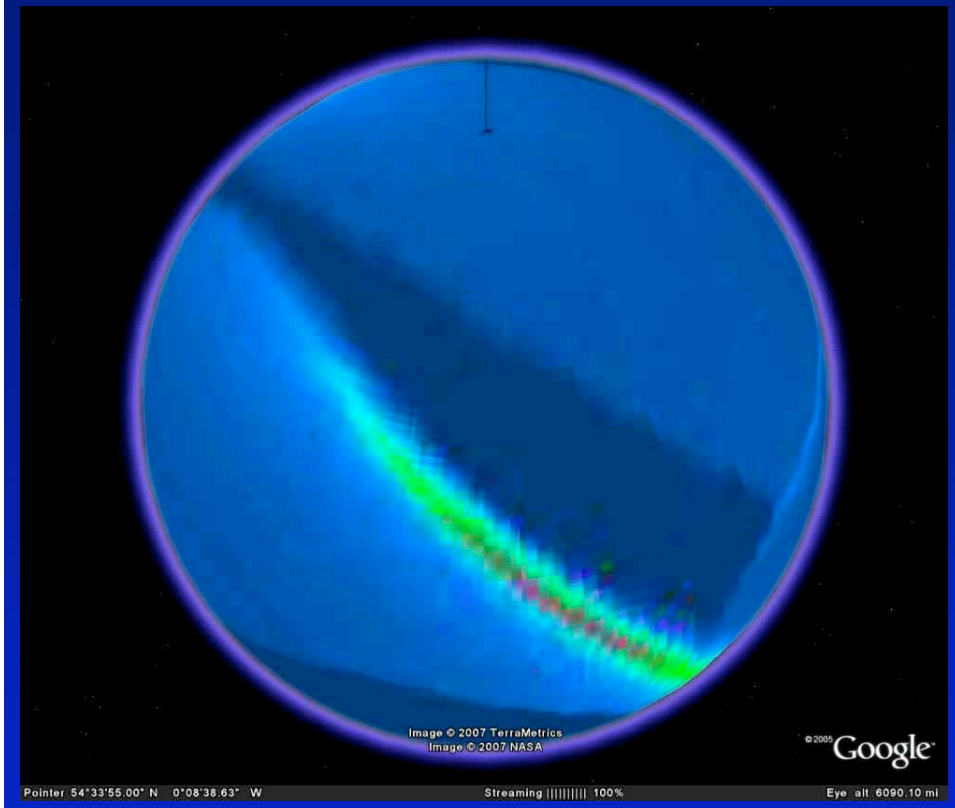




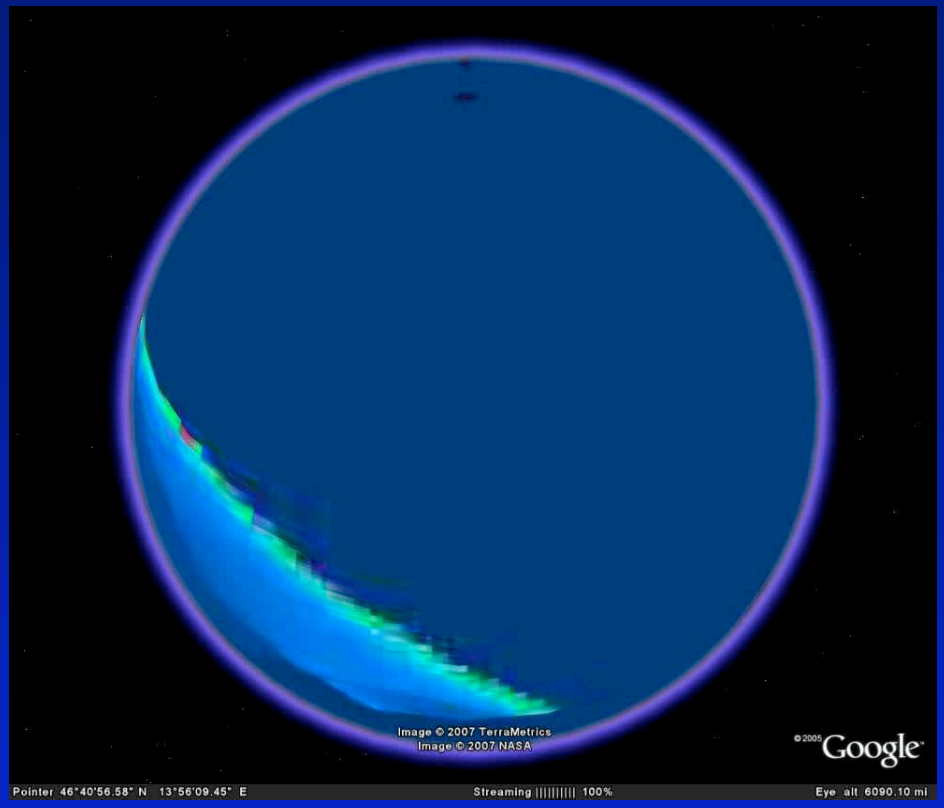
No off pulse emission in traditional OG model

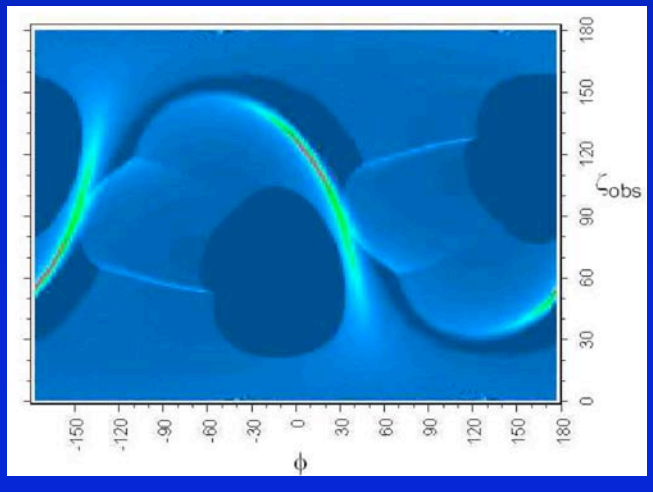
But see Hirotani, Poster 14.9, Takata, Poster 14.23

Slot gap

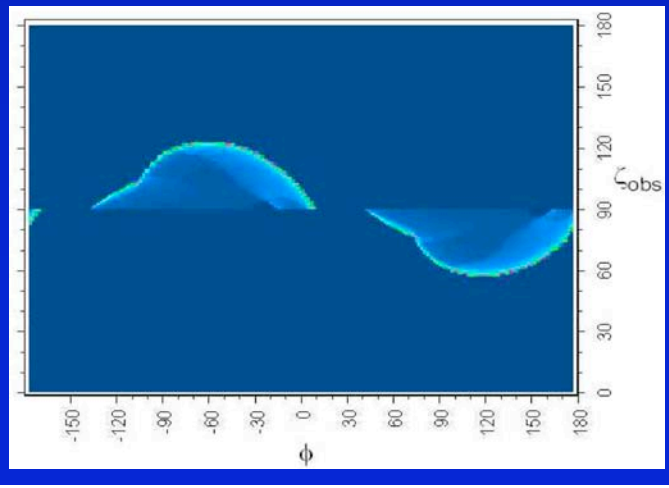


Outer gap

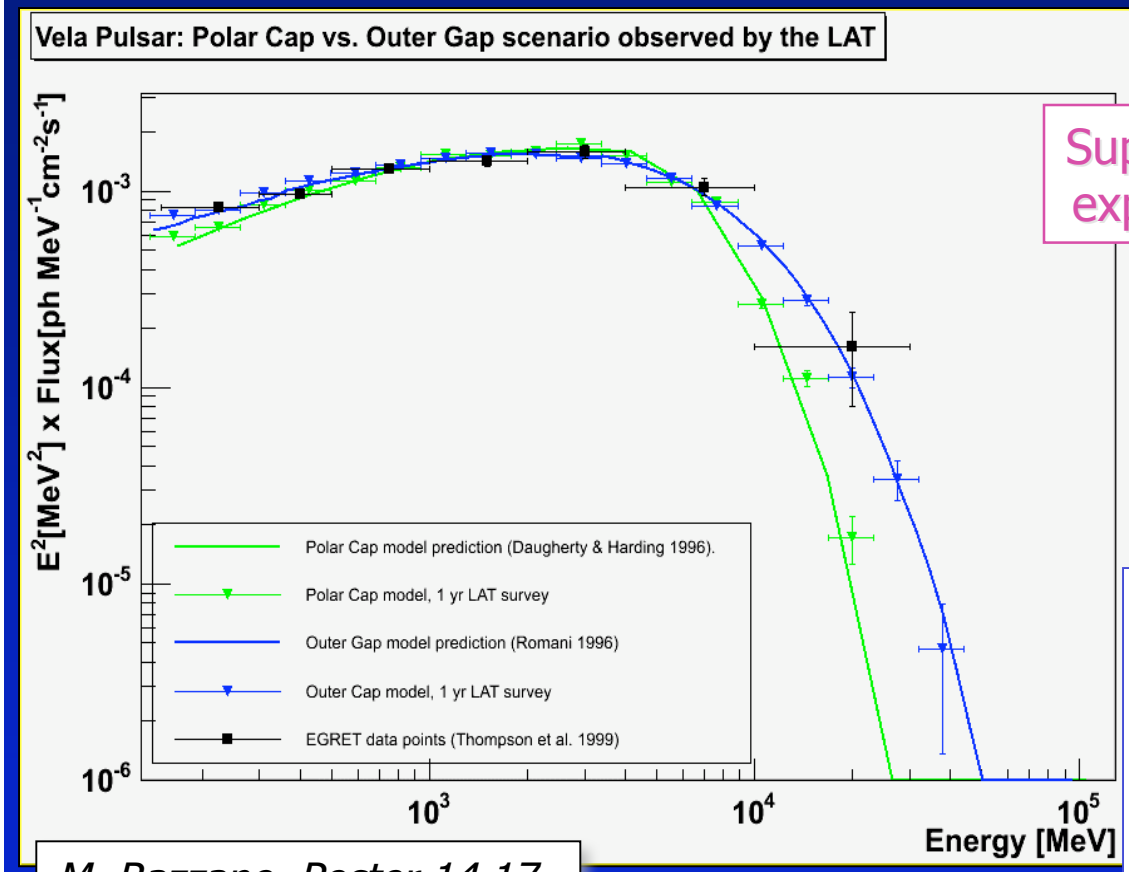




$\alpha = 60^{o}$

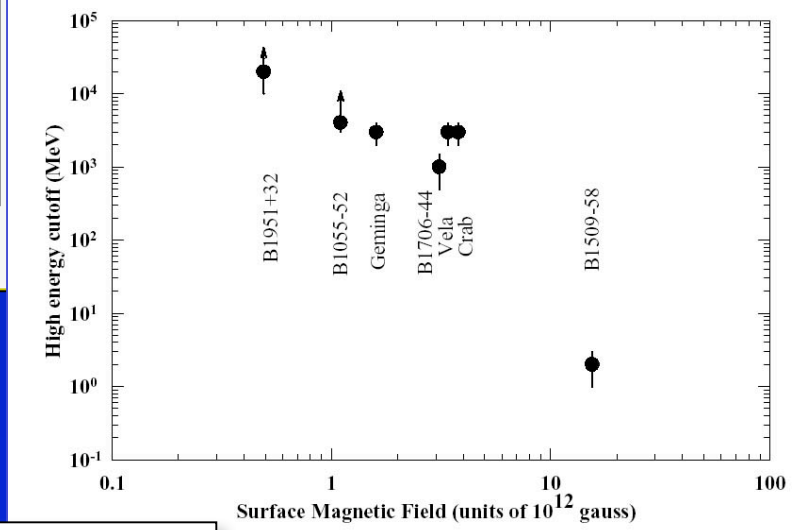


Measuring spectral cutoffs



Super-exponential (PC) or exponential cutoff (OG) ?

Is there a real E_C vs. B_0 trend?



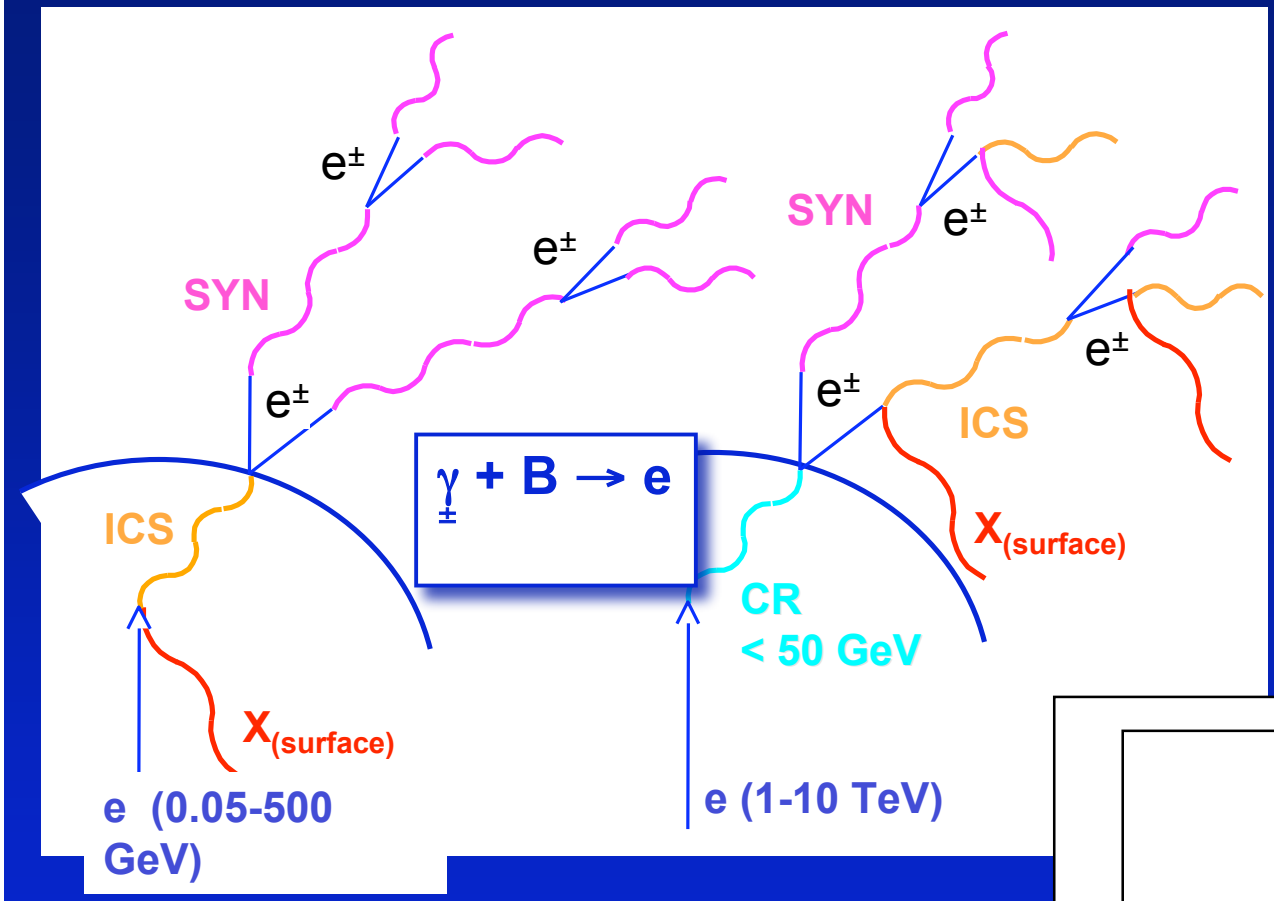
M. Razzano, Poster 14.17

Thompson 2003

What are the high-energy radiation mechanisms?

- MULTIPLE SPECTRAL COMPONENTS
- PHASE-RESOLVED SPECTRA

Polar cap cascades

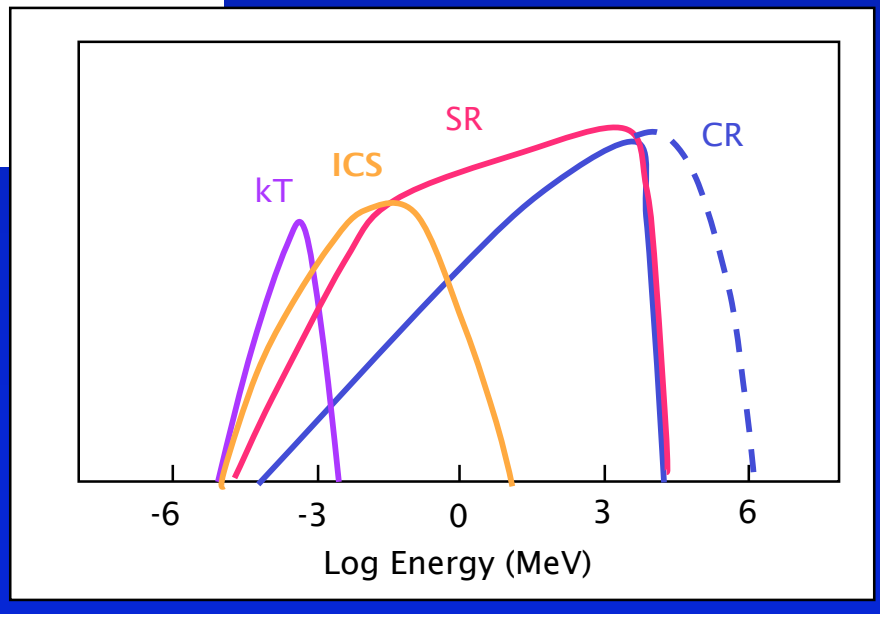


Daugherty & Harding 1982

Zhang & Harding 2000

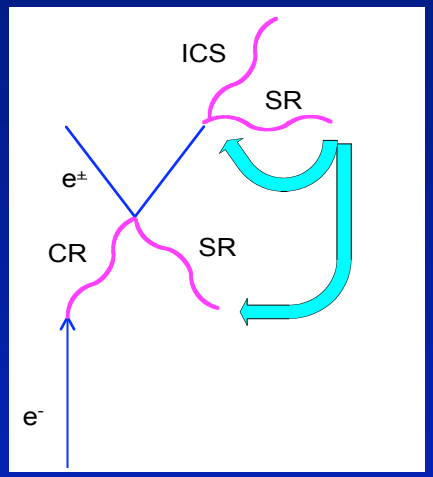
Sturner & Dermer 1994

Hibschmann & Arons 2001



Outer Gap Models – Pair Cascades

Crab-like

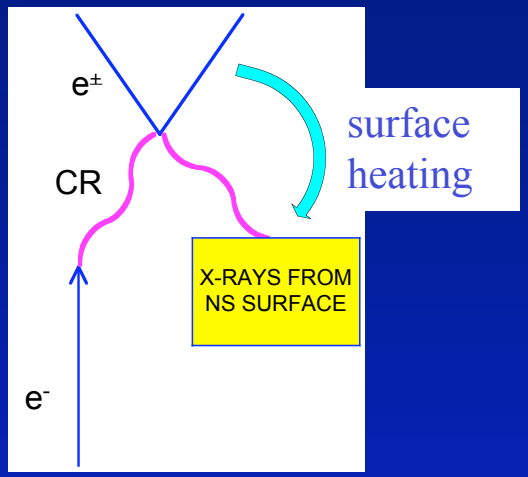


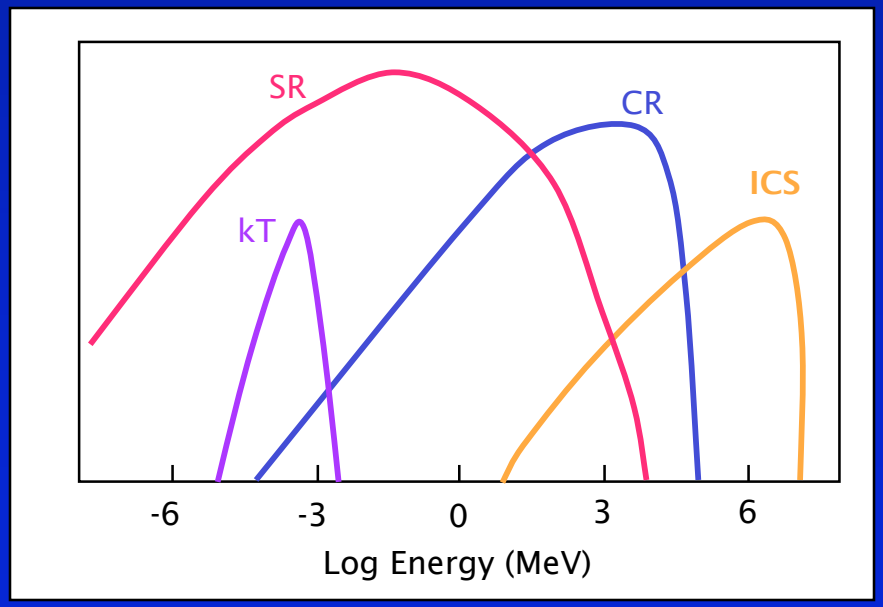
Cheng, Ho & Ruderman (1986)

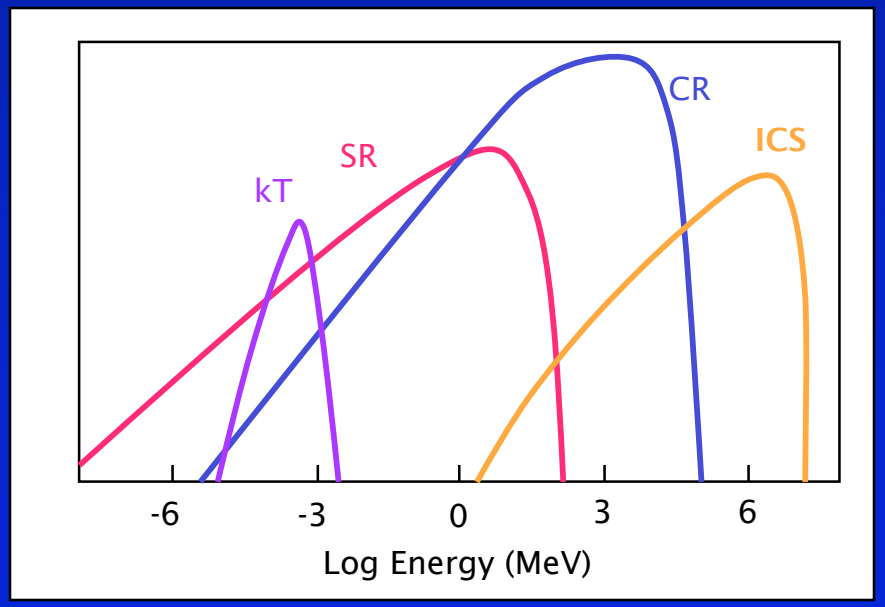
Cheng (1994)

Zhang & Cheng (1997)

Vela-like ($P < P_c = 0.13$ s)

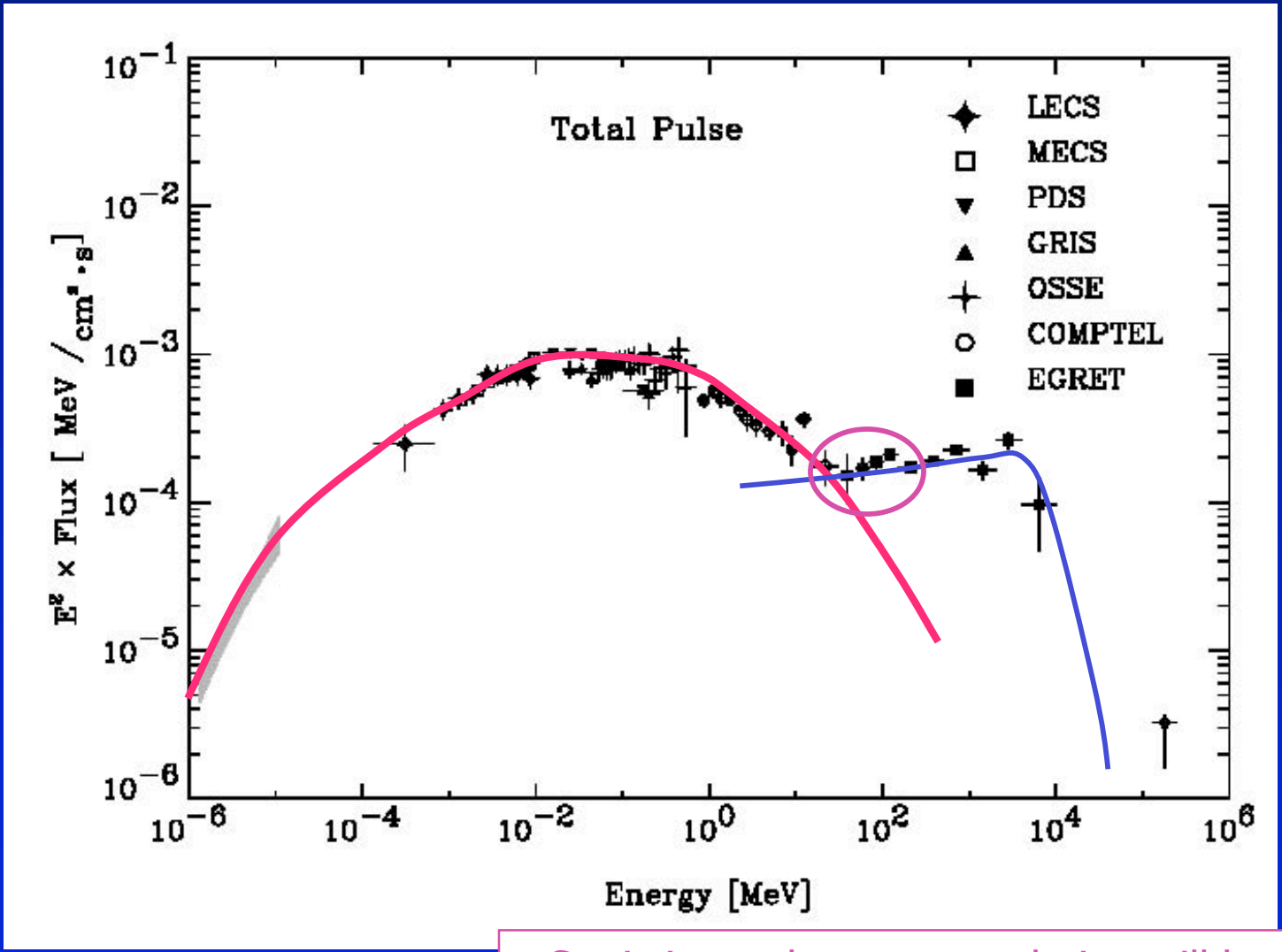






Romani (1996), Hirotani (1999…), Cheng, Ruderman & Zhang (2000)

Crab pulsar – multiple emission components?

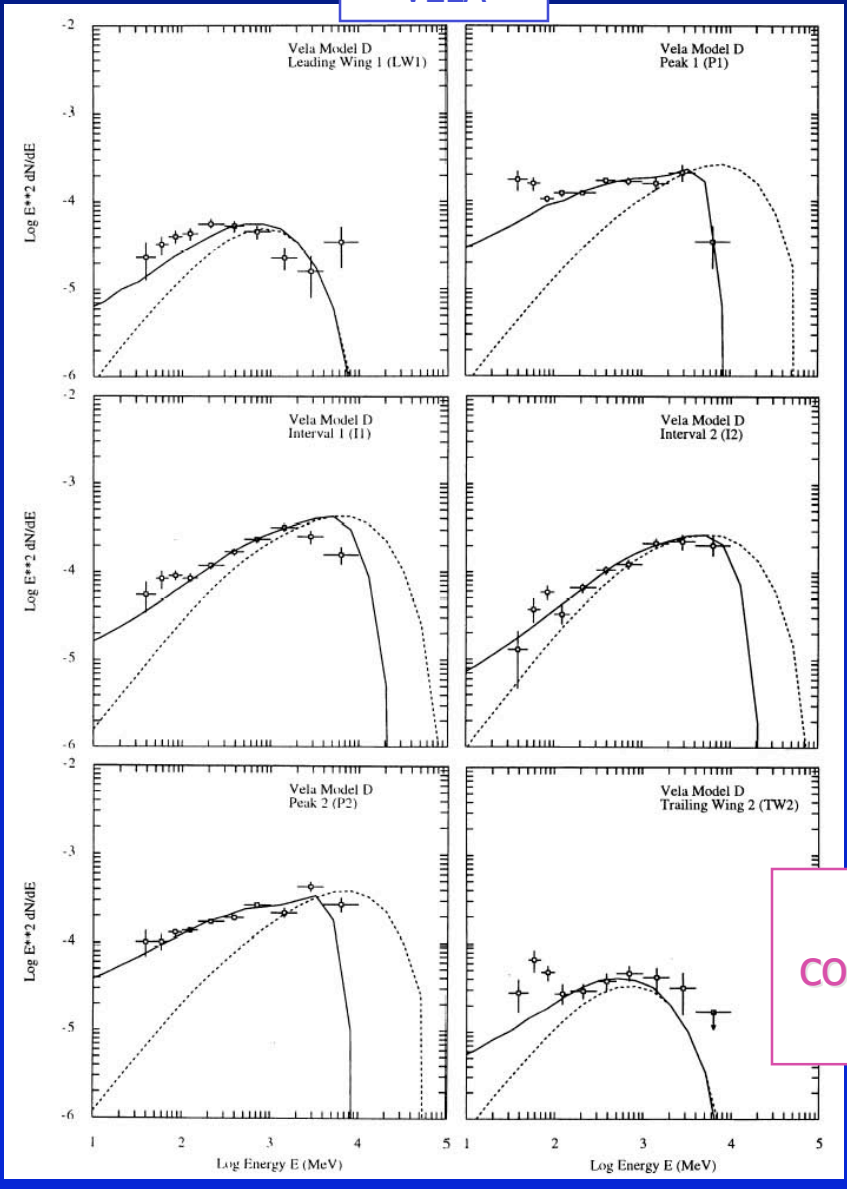


Kuiper et al. 2001

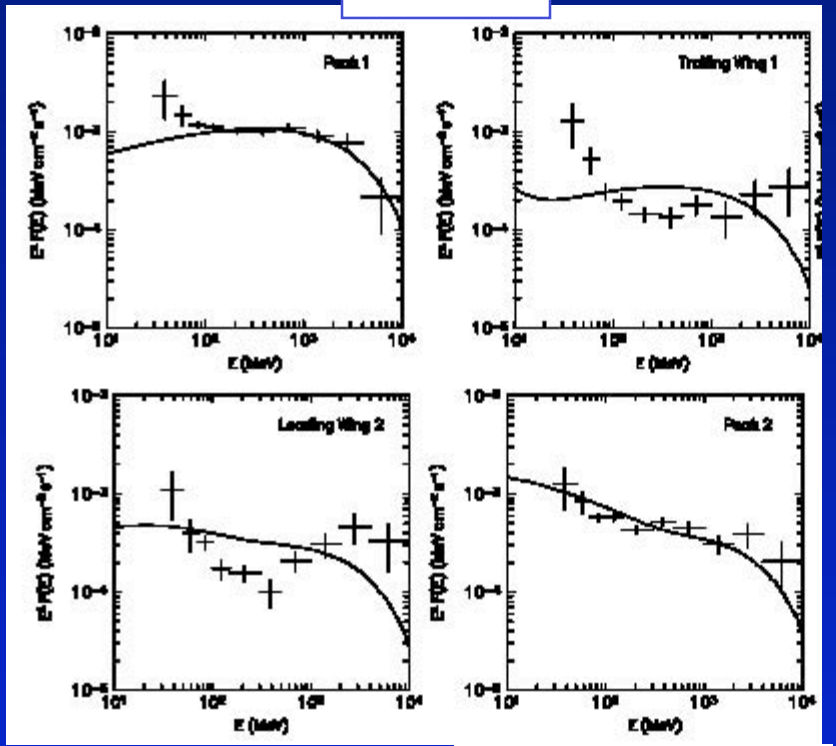
Statistics and energy resolution will be much better with GLAST

Distinguishing emission processes and models - Phase-resolved spectra

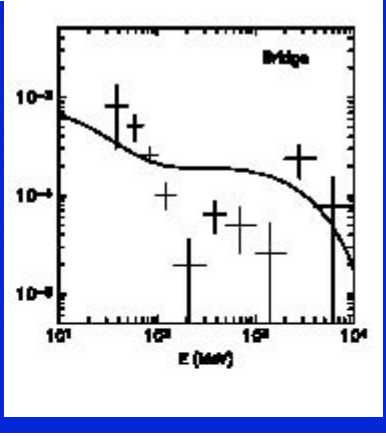
VELA



CRAB



Cheng et al. 2000



Measure spectral components, cutoff energy and shape with phase

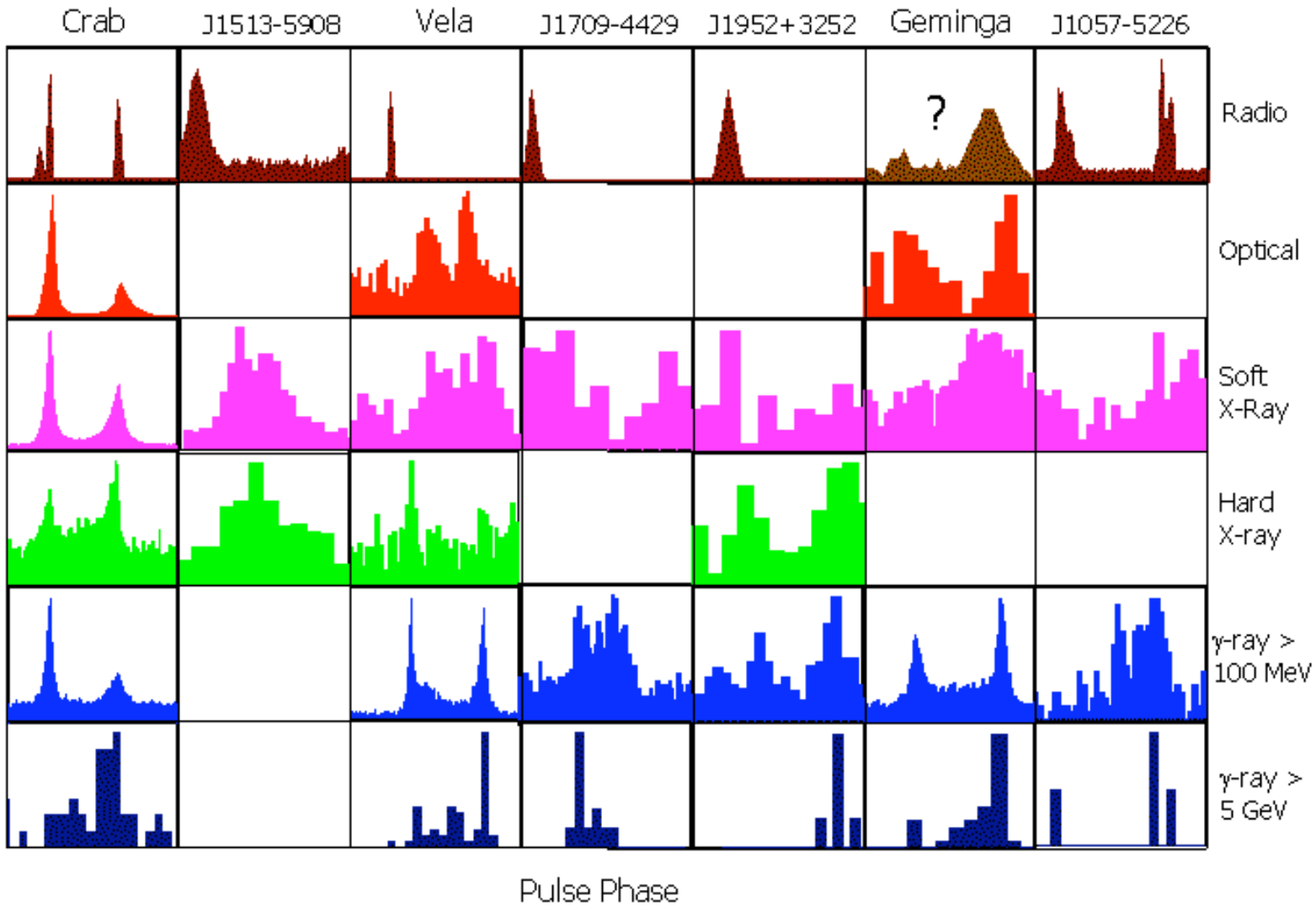
Daugherty & Harding 1996

Are processes the same for all pulsars?

PATTERNS IN

- Multiwavelength profiles
- Broad-band spectra

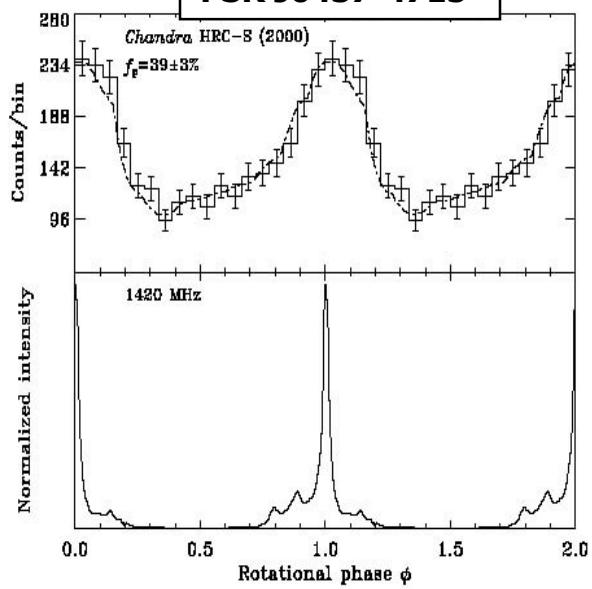
Patterns in multi-wavelength profiles?



Profiles of millisecond pulsars

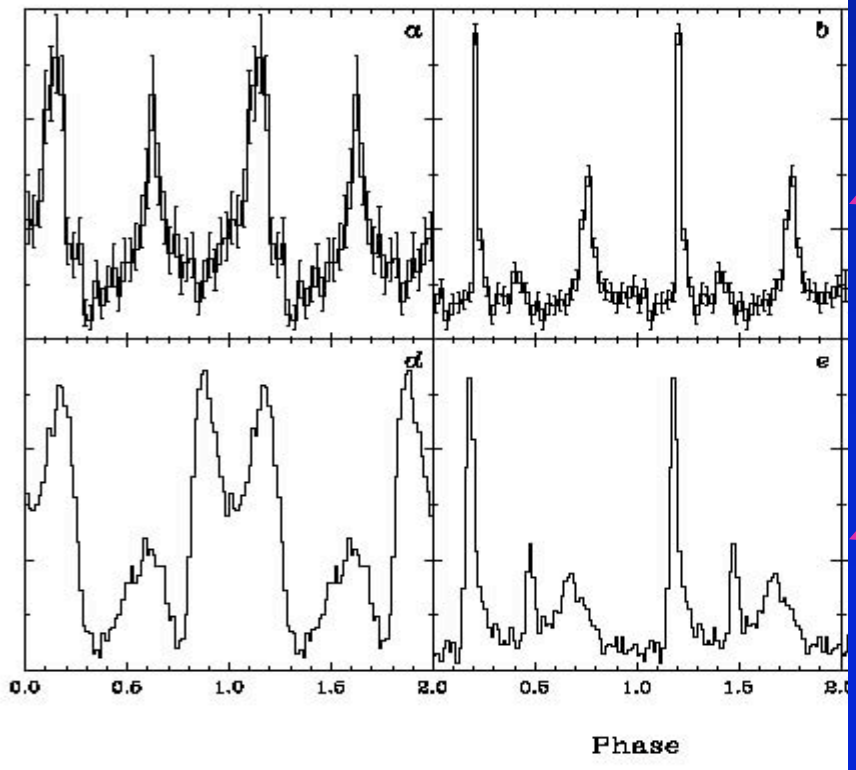
X-ray peaks (mostly) in phase with radio peaks

PSR J0437-4715



PSR J0218+4232

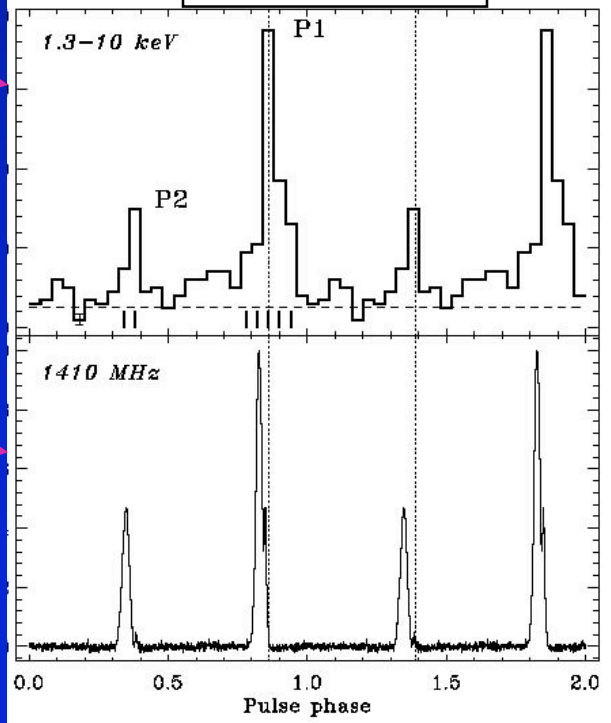
PSR B1821-24



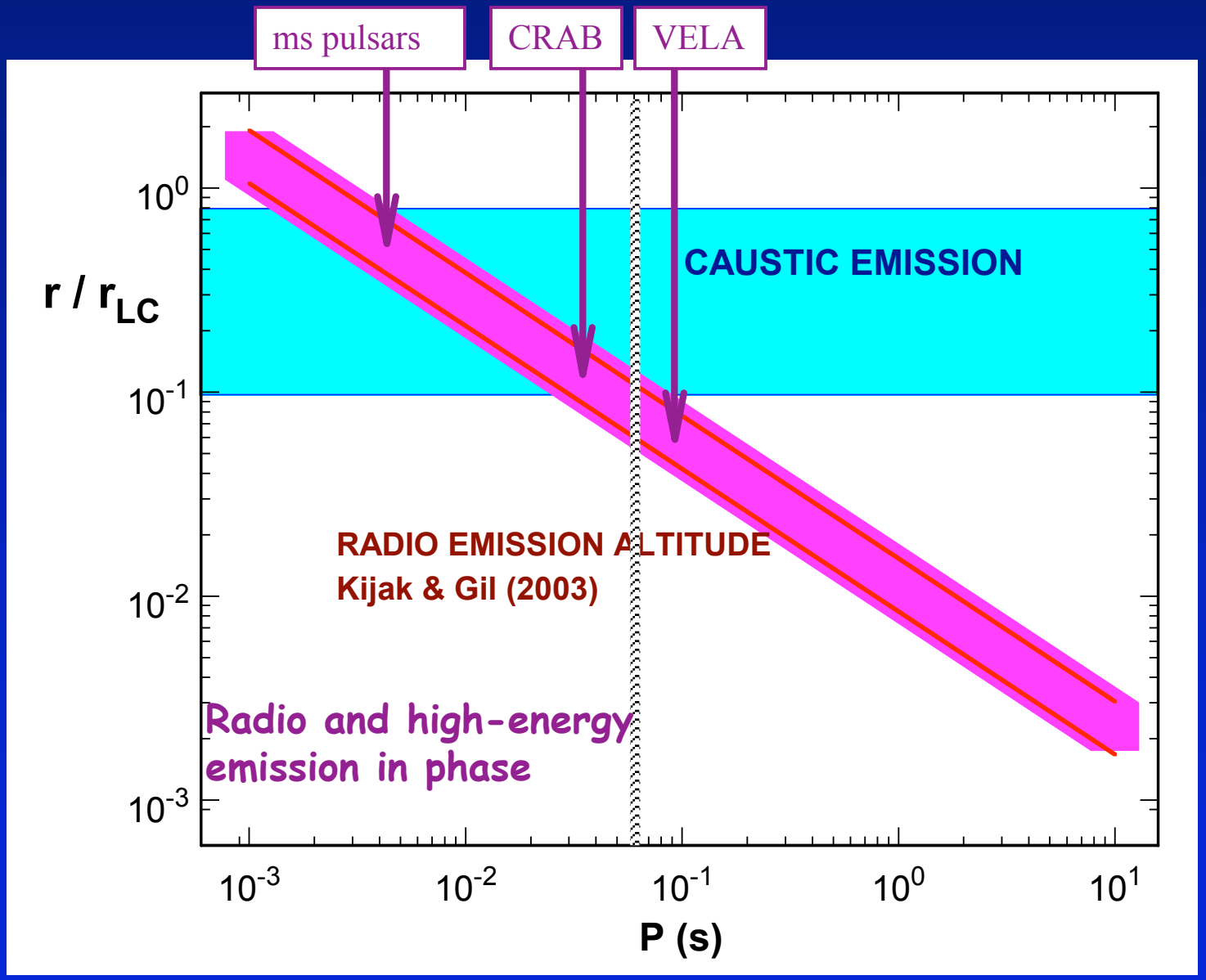
X-Ray

Radio

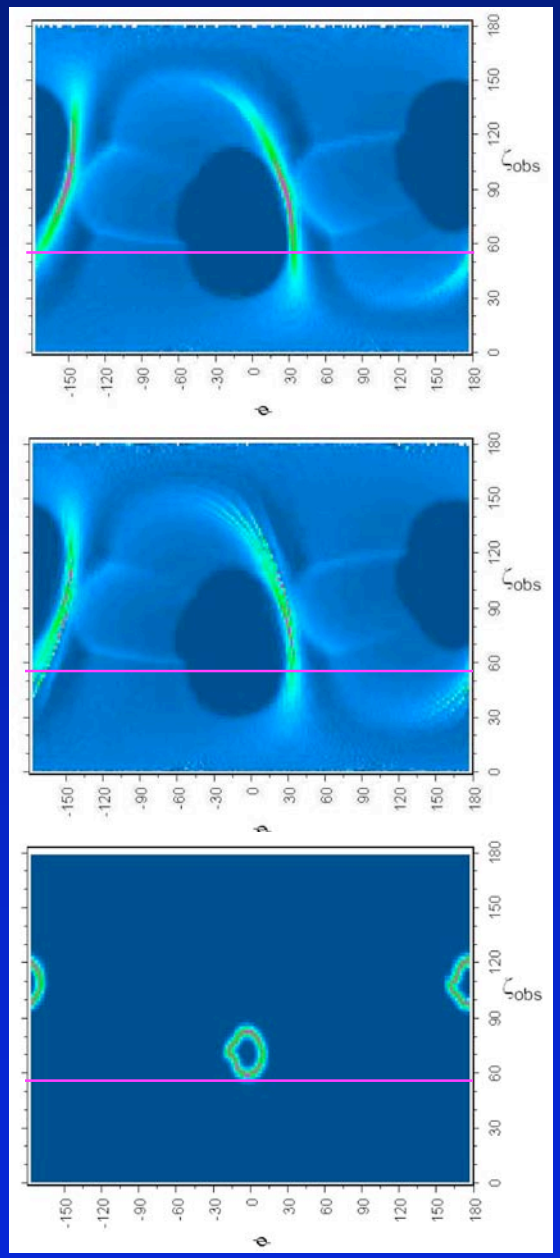
PSR B1937+21

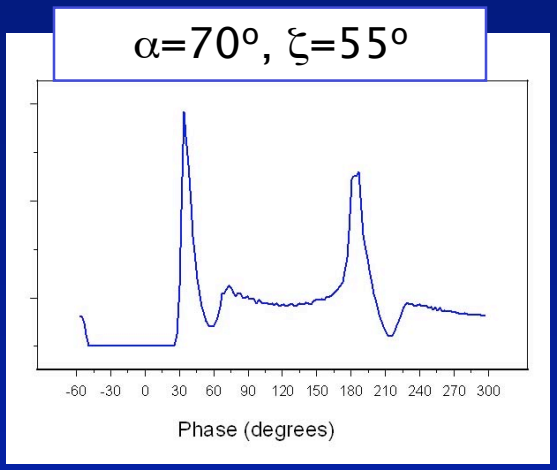


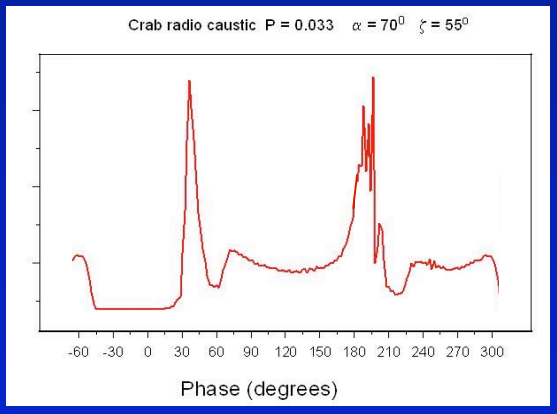
Radio caustic emission?

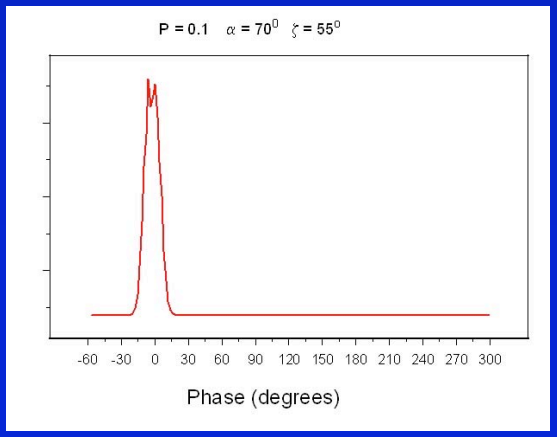


Relative HE and radio emission altitude









Crab and Vela

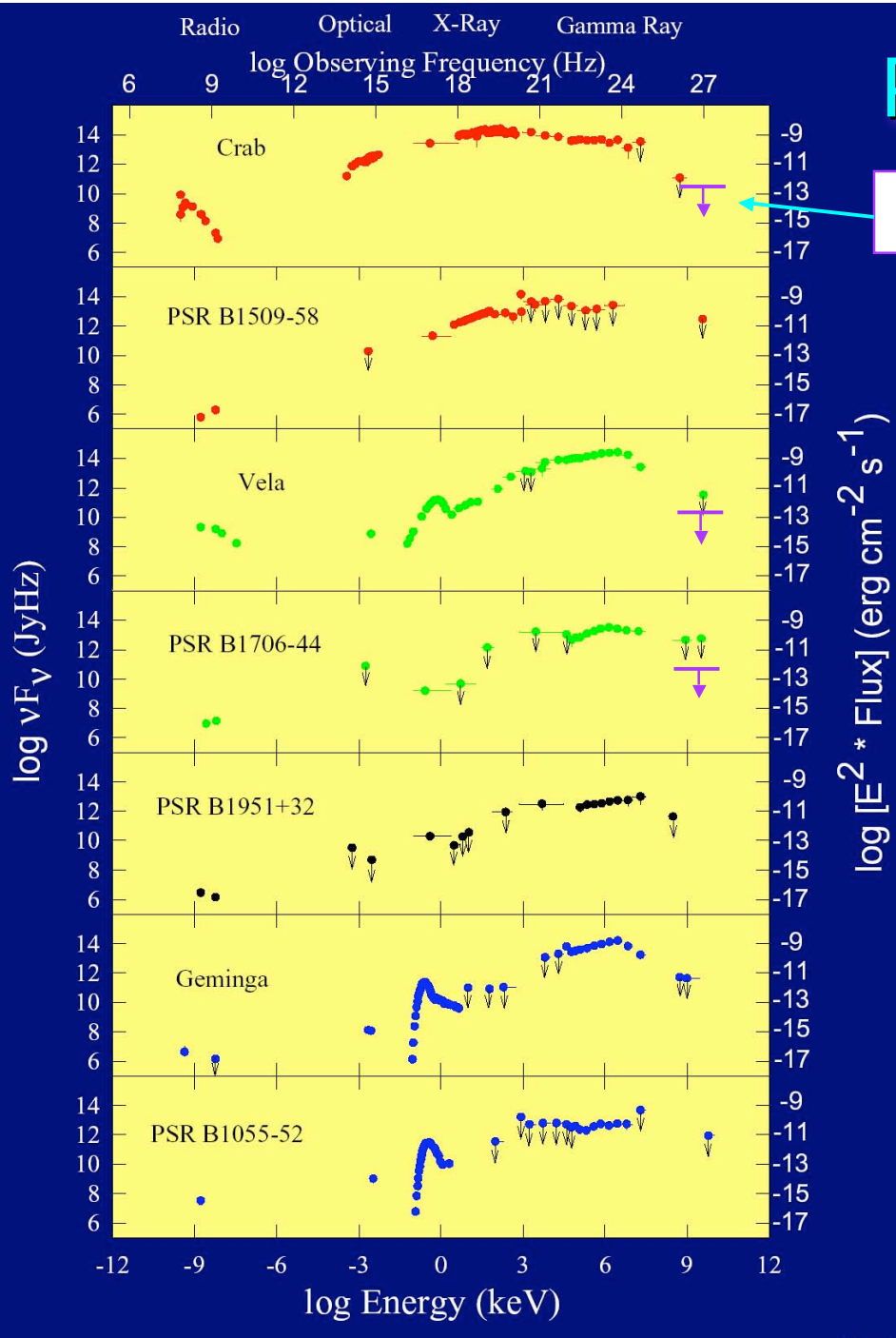
Slot gap γ-rays

Crab

High-altitude (0.2-0.6 R_{LC}) radio cone

Vela

Low-altitude (0.08 R_{LC}) radio cone



HESS

Patterns in broad-band spectra

- Power peak
  - Young pulsars in X-rays
  - Older pulsars in γ-rays
- No pulsed emission above 20 GeV
- High-energy turnover
- Increase in hardness with age

Are there γ-ray millisecond pulsars?

- SENSITIVITY ABOVE 10 GeV

High energy emission from millisecond pulsars

- Polar cap
  - A few higher B ⟹ slot gap emission
  - Most lower B ⟹ unscreened $E_{||}$ over whole PC

Continuous acceleration to high altitude -> particles reach radiation reaction limit

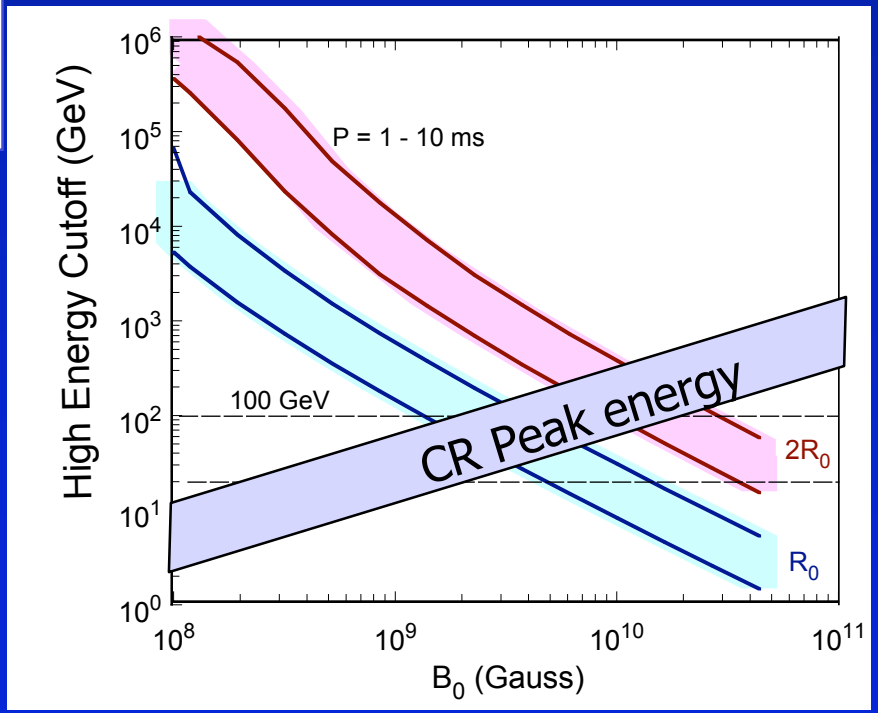
$$\gamma_{CRR} = \left(\frac{3}{2} \frac{E_{||} \rho_c^2}{e} \right)^{1/4} \approx 3 \times 10^7$$

Short P
smaller ρ_c

$$\varepsilon_{peak}^{CR} = 2 \frac{\lambda_C \gamma_{CRR}^3}{\rho_c} \approx 10 - 100 \text{ GeV}$$

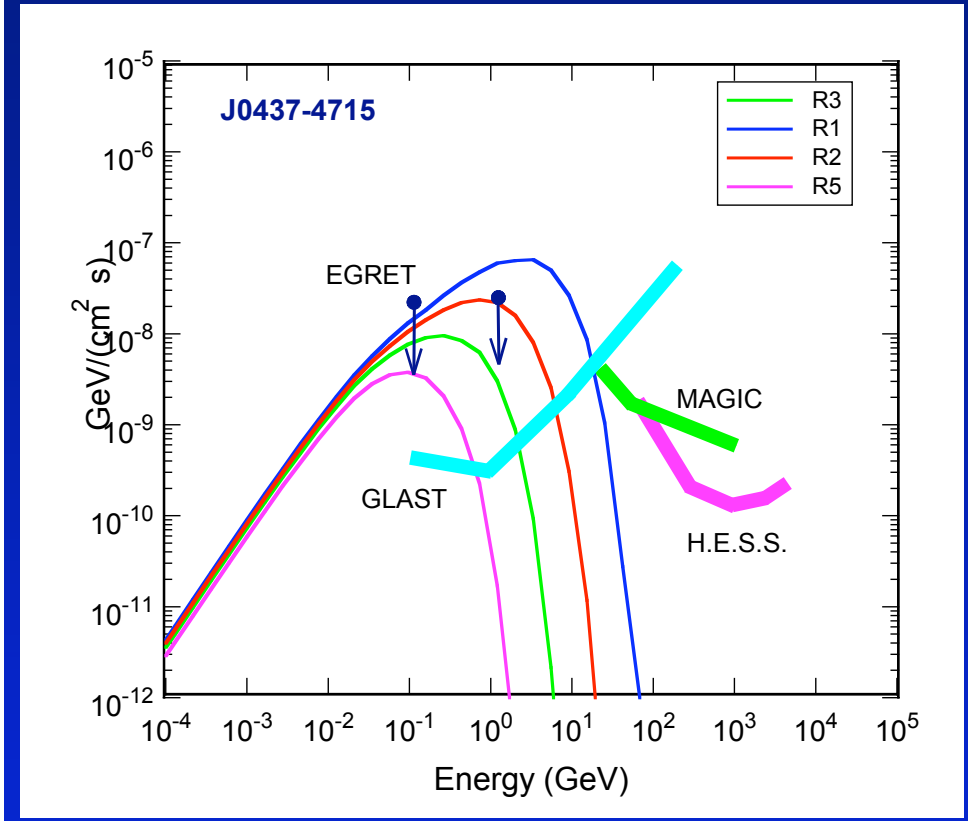
Lower B_o

Pair production cuts off spectrum at higher energy

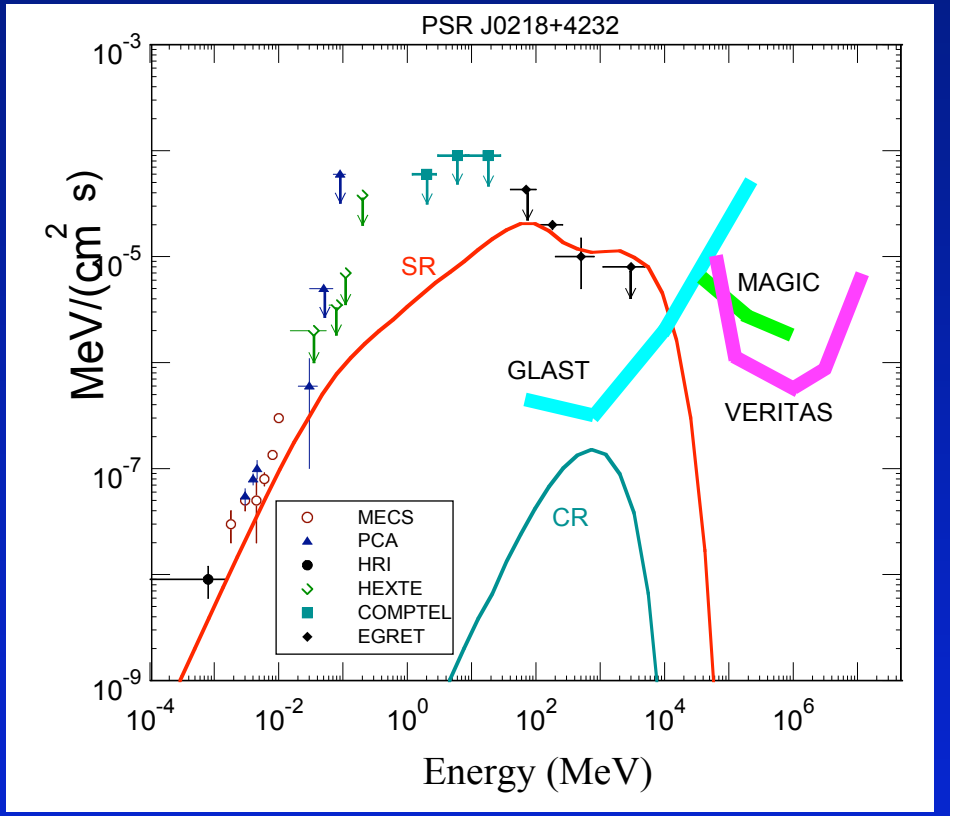


Emission from millisecond pulsars in polar gap model

Harding, Usov & Muslimov 2005



Kuiper et al. 2003



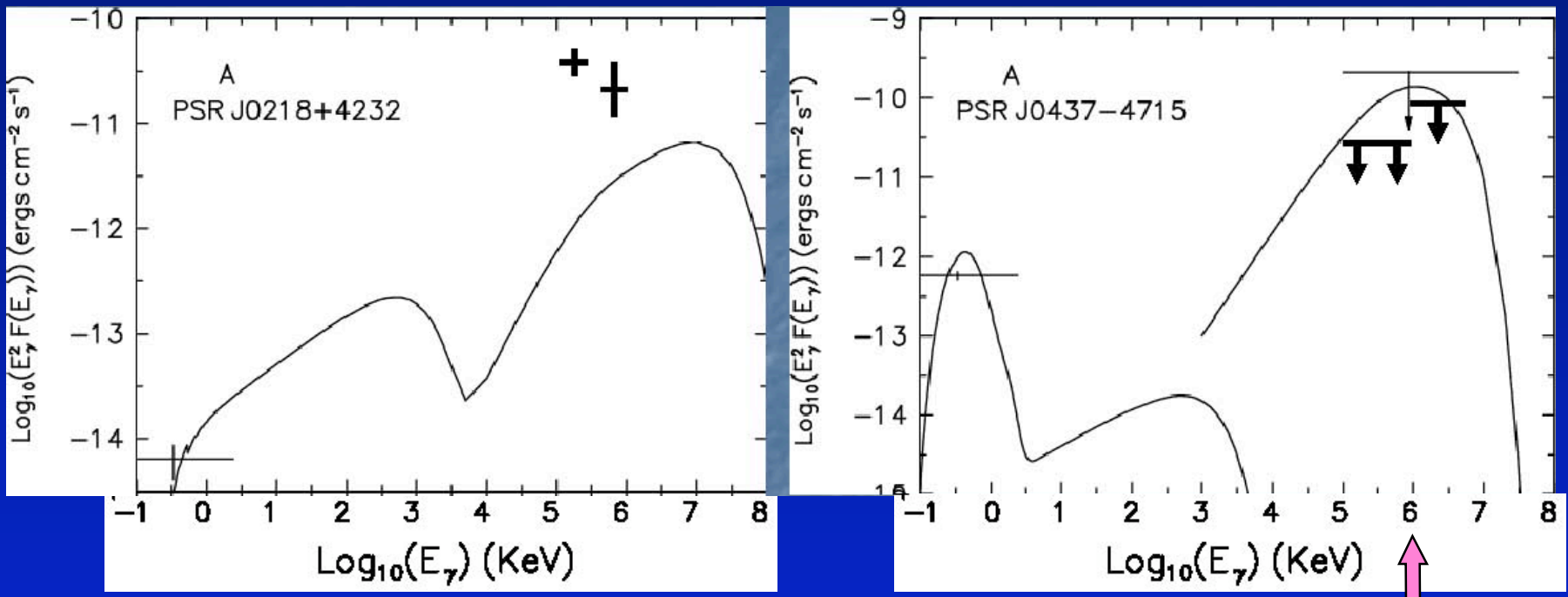
Curvature radiation from high altitudes

Viewing angle is critical

Synchrotron radiation from resonant absorption of radio emission (Lyubarsky & Petrova 1998)

Emission from millisecond pulsars in outer gap model

Zhang & Cheng 2003



CR peak energy for outer gap accelerator (Hirotani)

$$\varepsilon_{peak}^{CR} \approx 2\ \mathrm{GeV}\ B_8^{3/4} P_{ms}^{-1} \left(\frac{r}{R_{LC}}\right)^{-3/4} \left(\frac{W_\perp}{r}\right)^{3/2}$$

is smaller than at polar cap since $E_{||}\rho_c$ is smaller

→ **MSP emission above 10 GeV must come from polar cap**

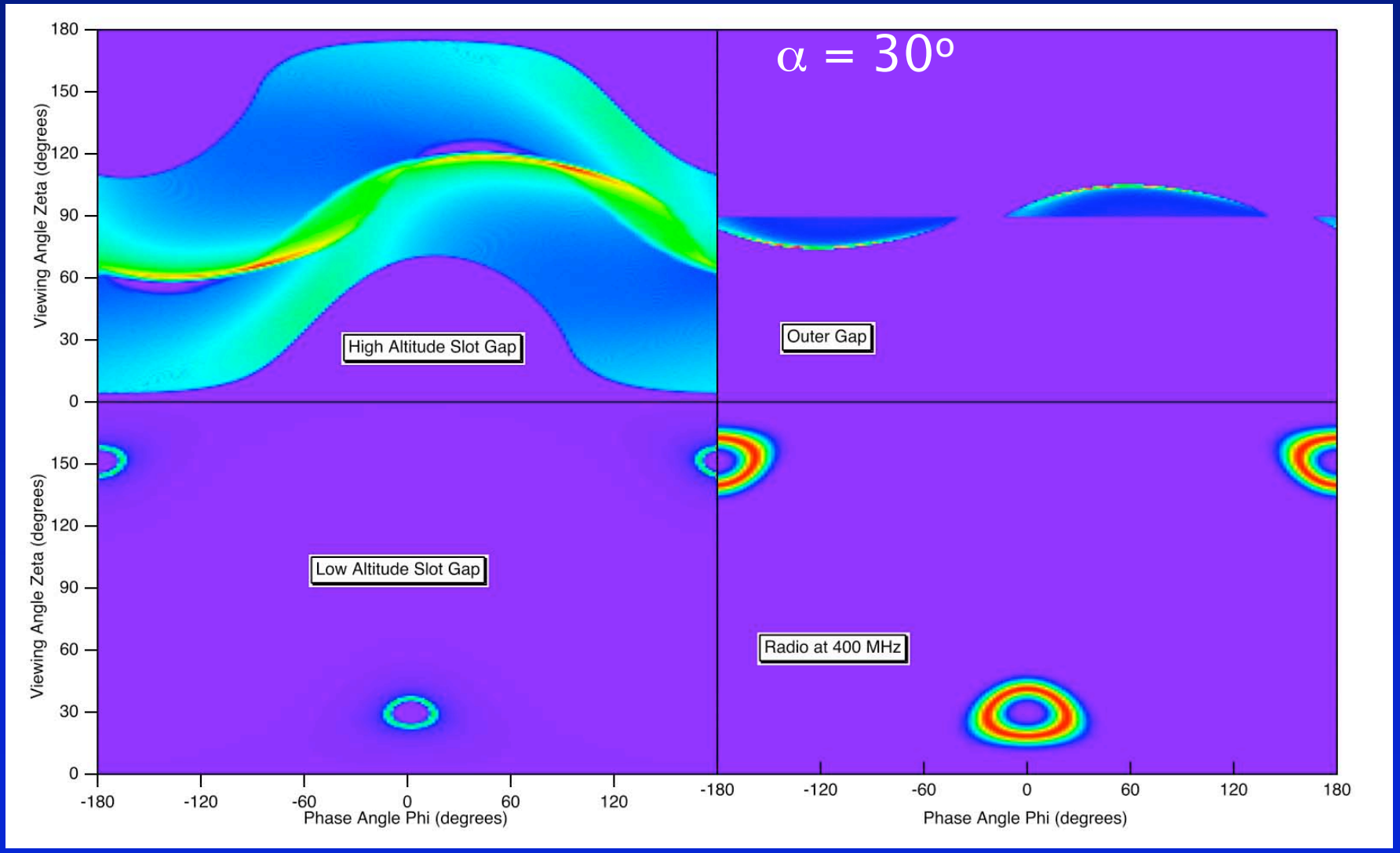
Cascade from OG particles moving toward NS surface

HE pulses out of phase with radio?

What is the ratio of radio-loud to radio-quiet γ-ray pulsars?

- MORE PULSAR DETECTIONS
- BLIND SEARCHES
- (What does 'radio-quiet' mean?)

γ-ray and radio emission patterns



Gonthier et al. Poster 14.32

Predicted GLAST pulsar populations

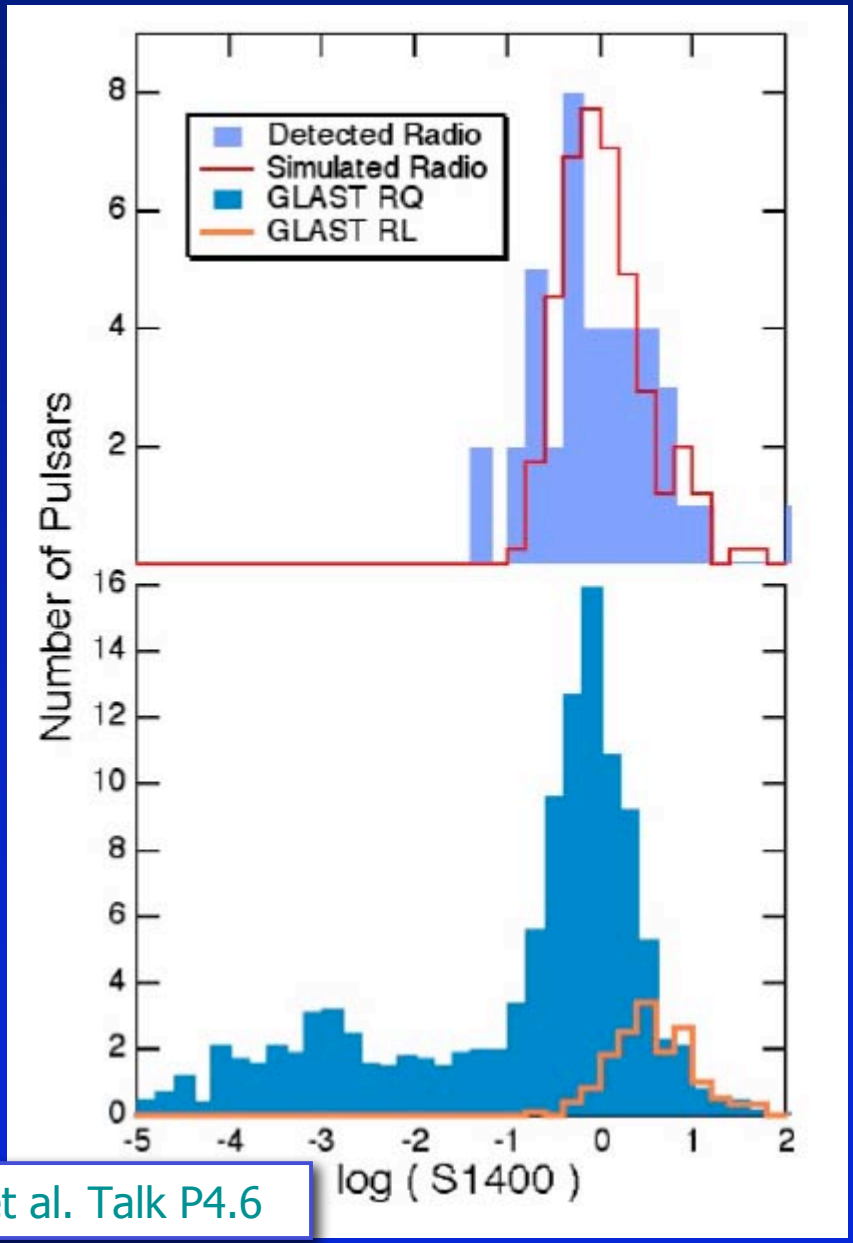
	Normal pulsars		Millisecond pulsars	
	Radio-loud	**Radio-quiet**	**Radio-loud**	**Radio-quiet**
Low Altitude Slot gap	81	43 (28)	16	99-131 (35)
High Altitude Slot gap	5	49		
Outer gap	1 78	258 740		

Few radio-loud pulsars for high-altitude accelerators

( ) – bright enough for GLAST blind pulsation search

Gonthier et al. Poster 14.32
Jiang & Zhang 2006
Story et al. Talk P4.6

Detecting radio-quiet millisecond pulsars



Follow-up radio observations of GLAST sources

⇓

Radio period

⇓

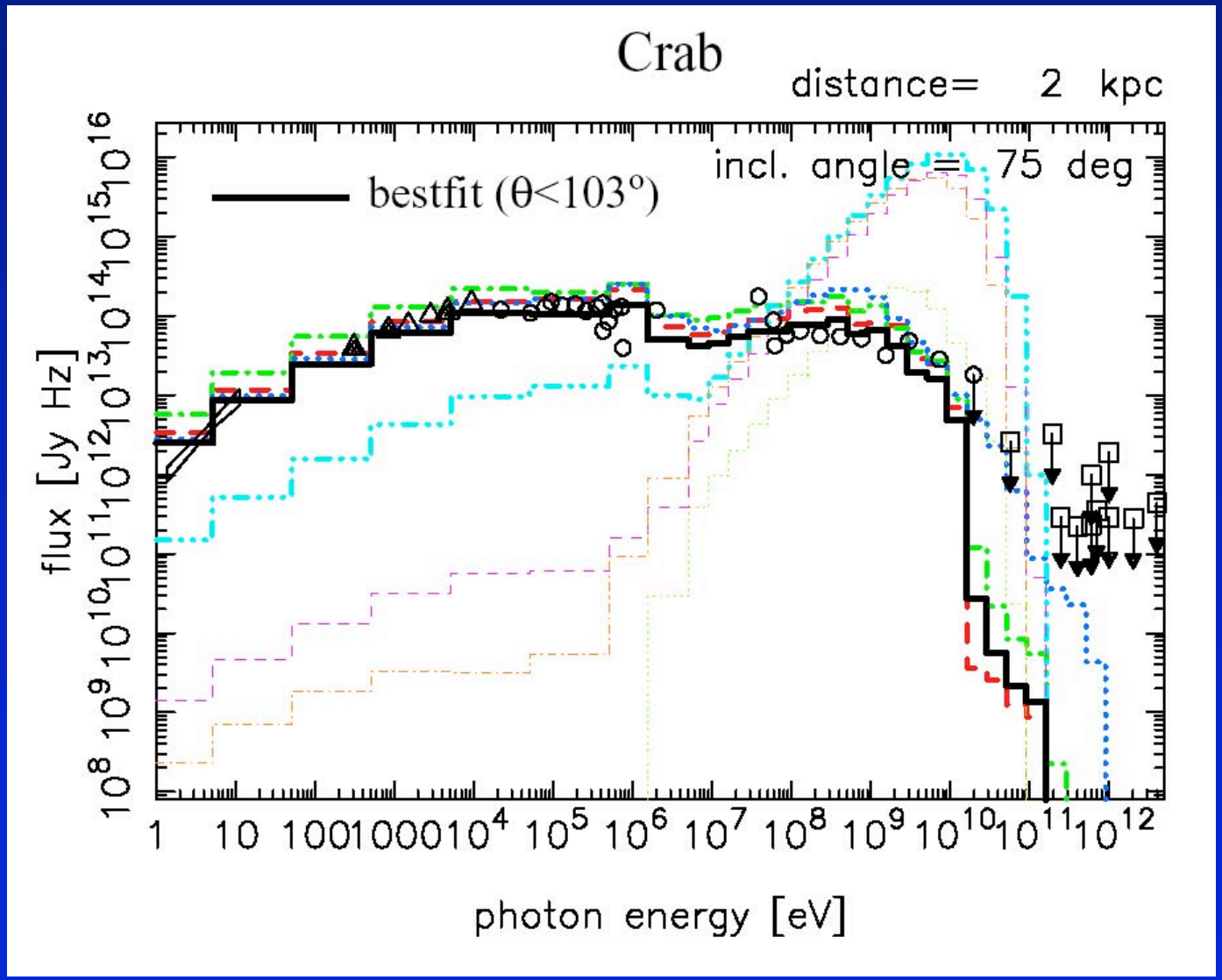
γ-ray period

Story et al. Talk P4.6

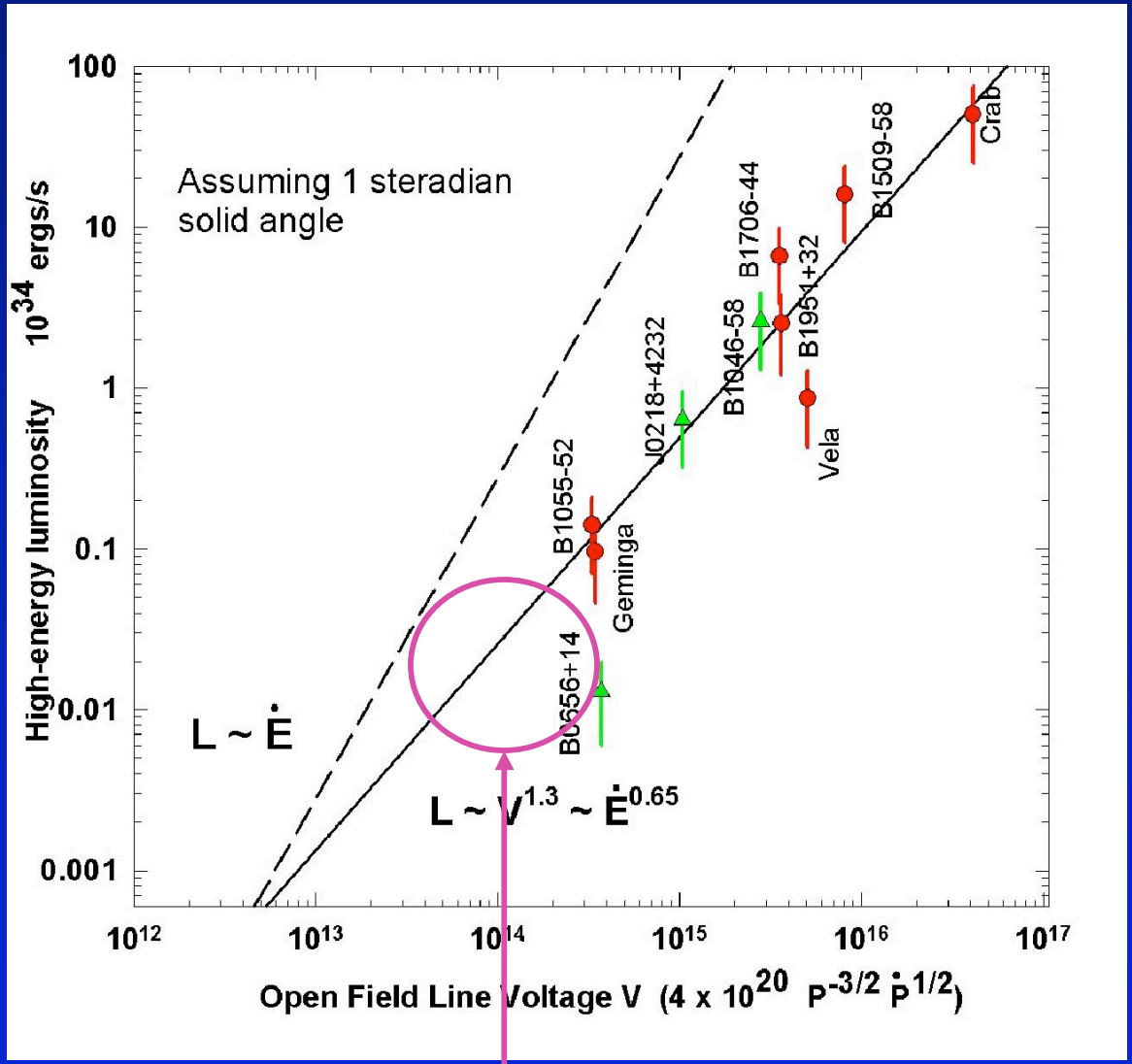
Summary

- Better definition of pulse profiles
  - Geometry of acceleration and emission
- Spectral components and cutoffs
  - Emission location and mechanisms
- Phase-resolved spectroscopy of more sources
  - Emission components, phase dependence of cutoffs
- Improved sensitivity above 10 GeV
  - Millisecond pulsars?
- Detection of more radio-loud and radio-quiet pulsars
  - Population trends: L_γ vs. L_{SD}, Spectral index vs. age
  - Ratio of radio-loud/radio-quiet pulsars discriminates between high and low altitude accelerators

Spectra are sensitive to viewing angle



What is the limit to γ-radiation efficiency?



GLAST will explore this region