GAMMA-RAY EMISSION OF PULSARS: STATUS AND MULTI-WAVELENGTH CONTEXT

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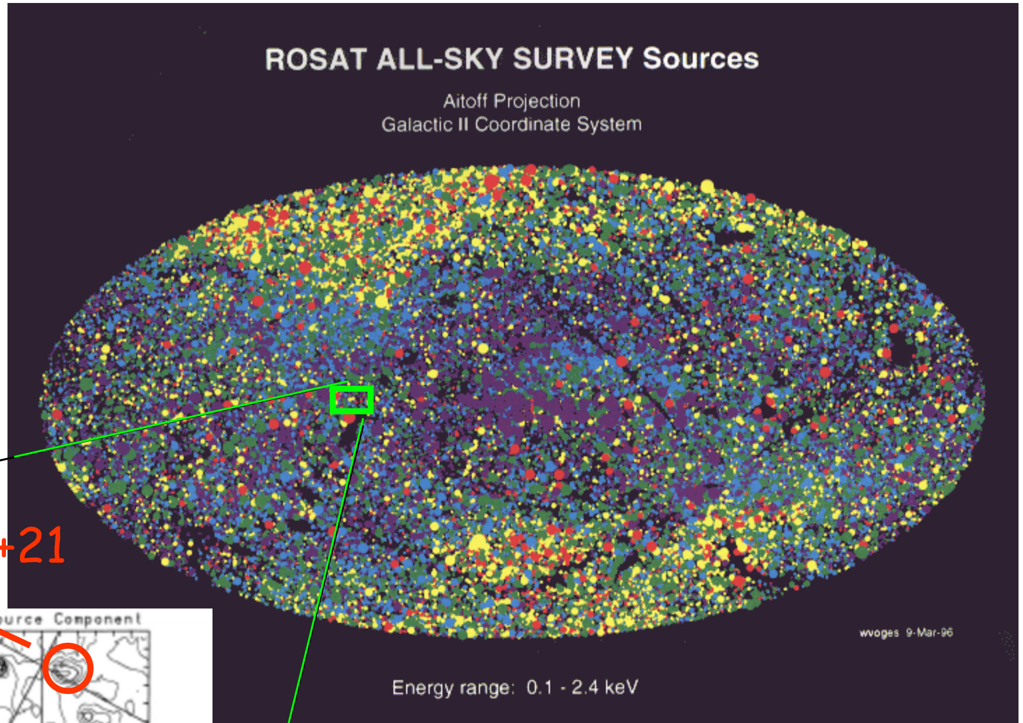
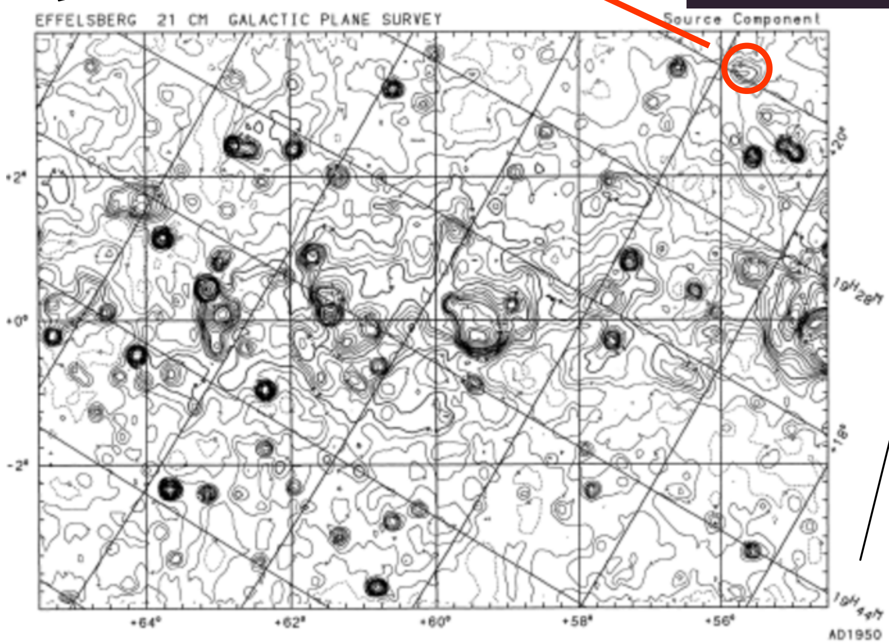
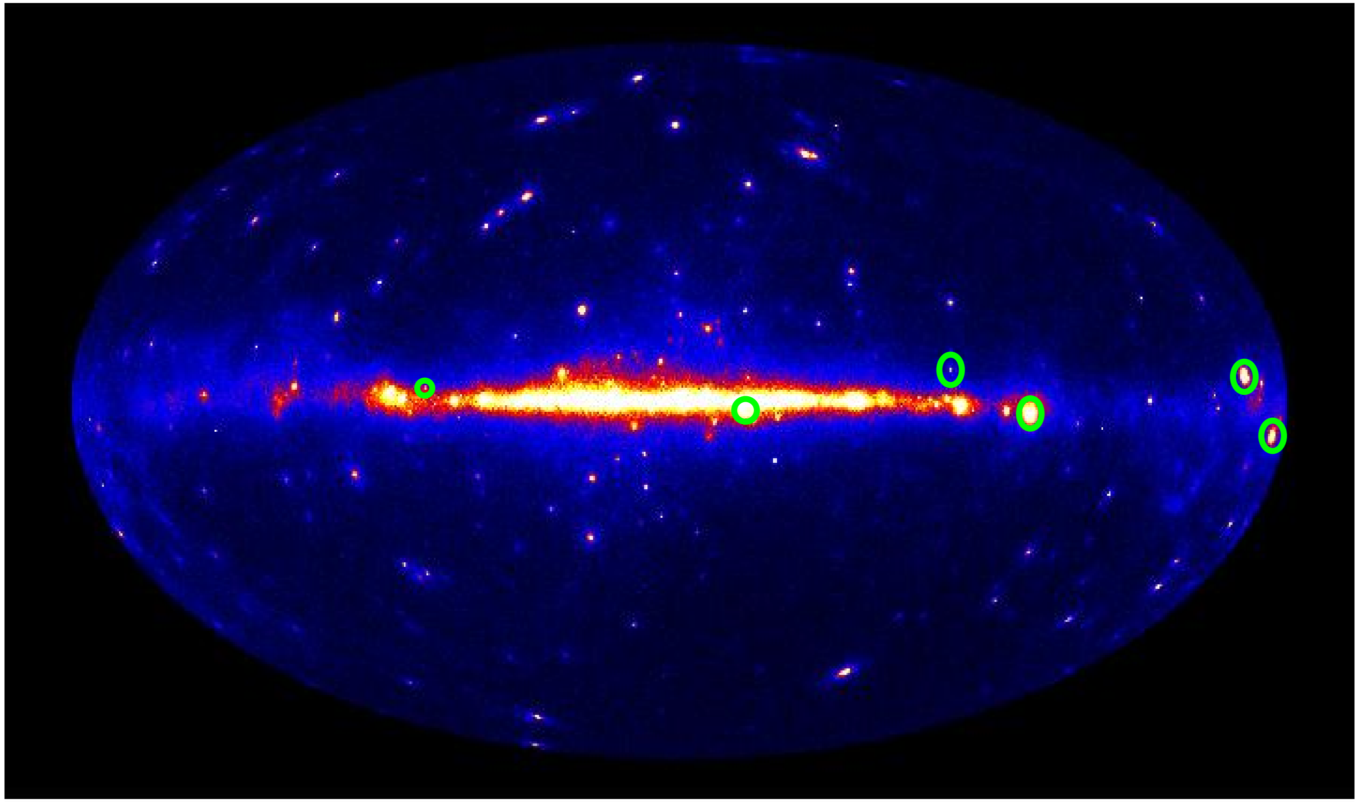


PSR B1919+21

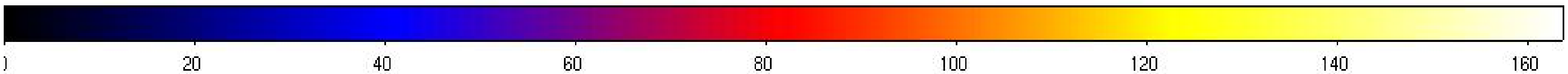


Pulsars are not the **most** prominent sources in radio or X-ray surveys

GLAST simulated all-sky map (>1GeV) after ~55 days of exposure: EGRET Pulsars



Credit: M. Razzano



Presently known pulsars

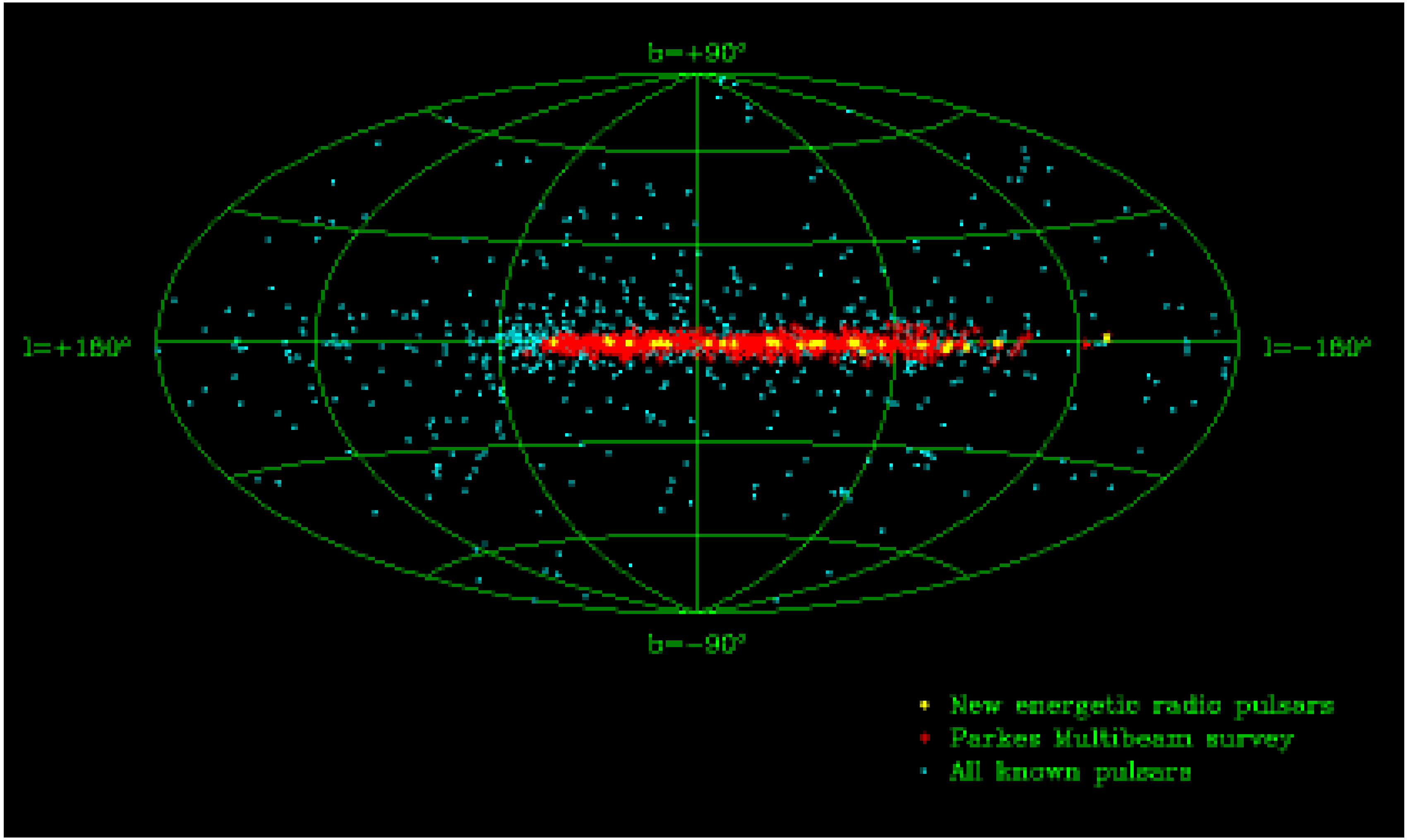


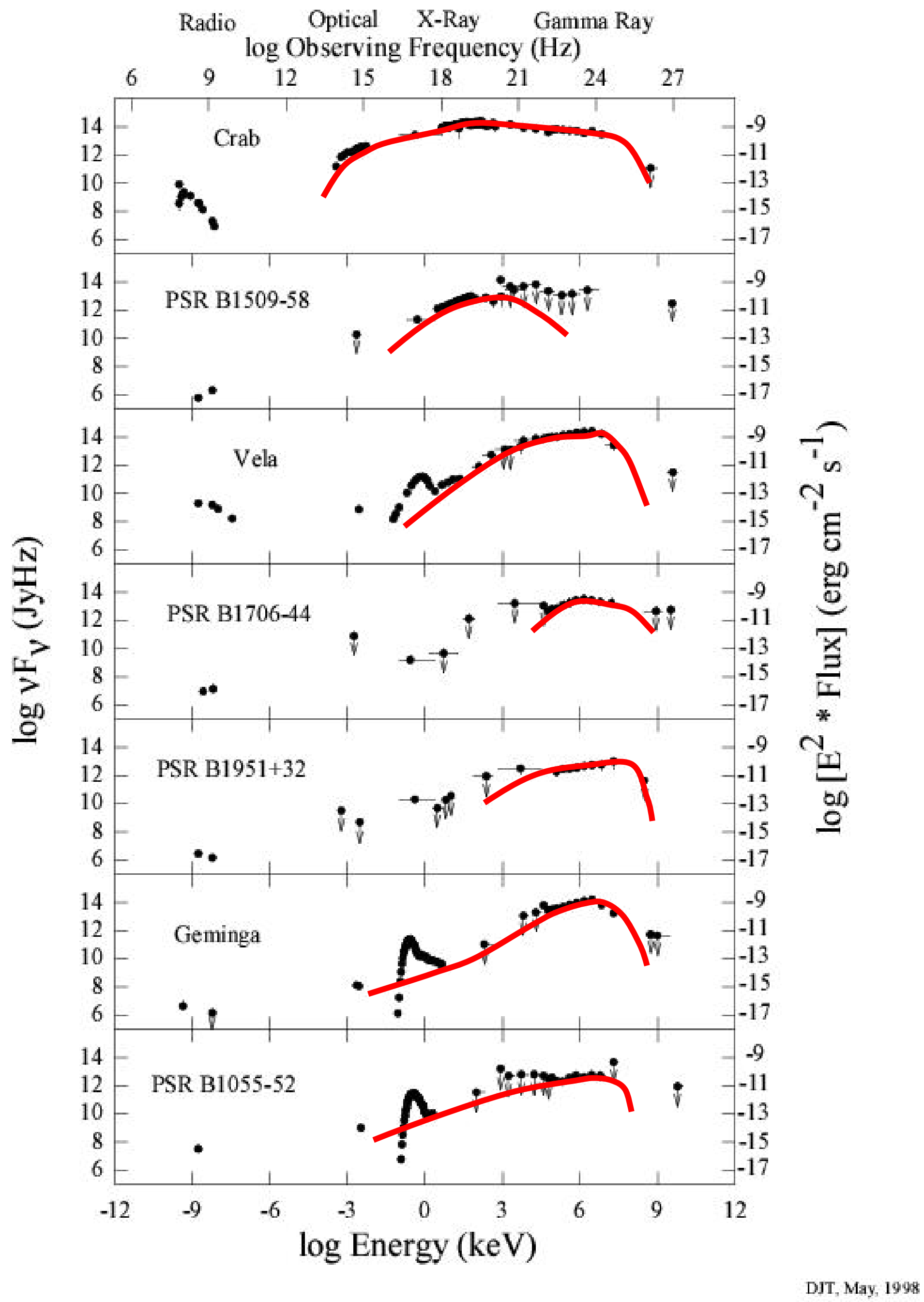
Table of detections

High-Energy Pulsars: Multiwavelength Detections								
PSR	P (ms)	$\dot{E}/d^2$ rank	radio	opt	X_{low}	X_{hi}	γ_{low}	γ_{hi}
high confidence γ-ray detections								
B0531+21 (Crab)	33.4	1	P	P	P	P	P	P
B0833-45 (Vela)	89.3	2	P	P	P	P	P	P
J0633+1746 (Geminga)	237.1	3	P?	P	P	P	?	P
B1706-44	102.5	4	P	?	D			P
B1509-58	150.7	5	P	D	P	P	P	
B1951+32	39.5	6	P		P		P	P
B1055-52	197.1	33	P	D	P		P	P
candidate γ-ray detections								
B0656+14	384.9	18	P	P	P		?	?
B0355+54	156.4	36	P		D			?
B0631+10	287.7	53	P		D			?
B0144+59	196.3	120	P					?
ms PSR γ-ray detection & candidates								
J0218+4232	2.32	43	P		P			P
B1821-24	3.05	14	P		P			?
Likely PSR - γ-ray source positional coincidence								
B1046-58	123.7	8	P		D			D?
J1105-6107	63.2	21	P		D			D?
B1853+01	267.4	27	P					D?

P = pulsed detection, P? = low significance pulsation, D = unpulsed detection

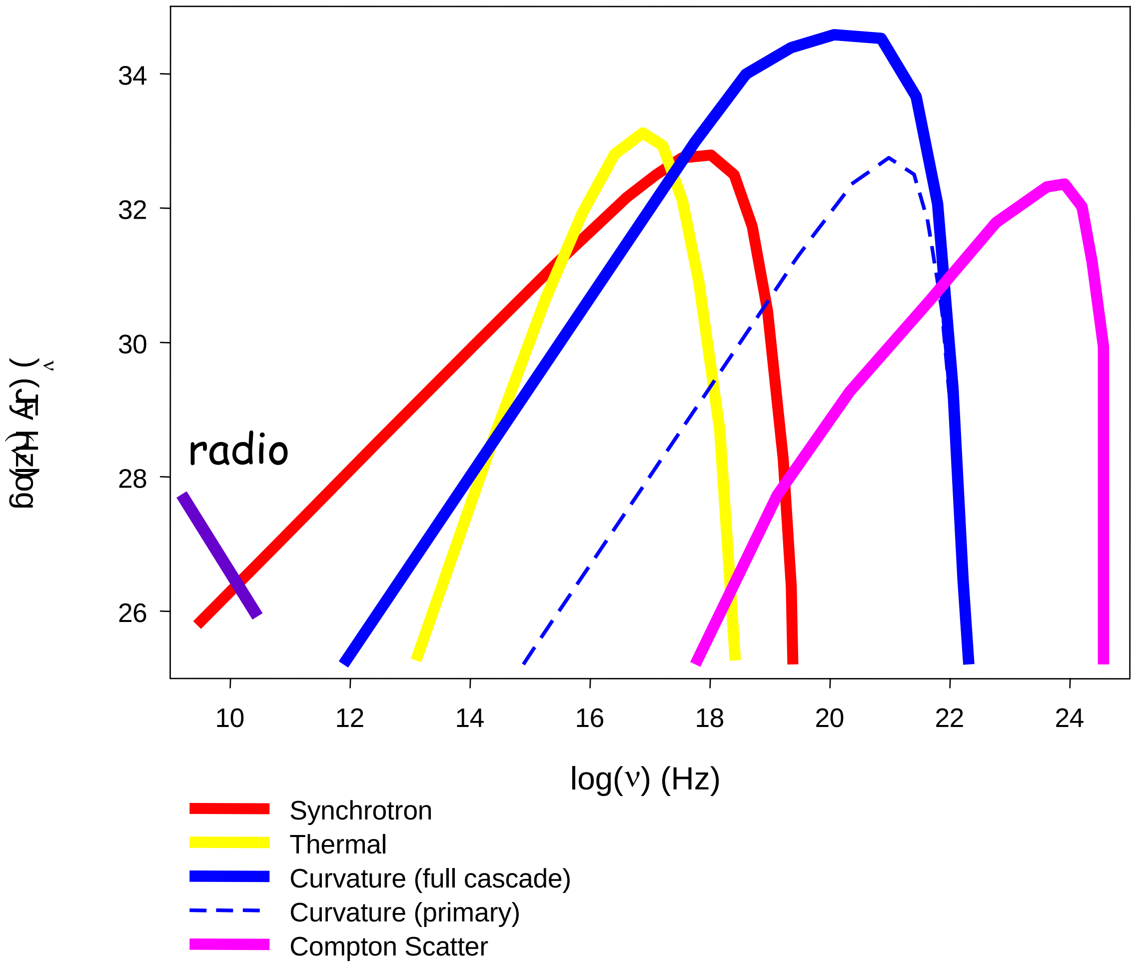
Multi-λ Spectra of γ-ray Pulsars (pulsed emission)

- Maximum of Emission in the hard X- and γ-ray range
- High energy spectral cut-off
- Distinct spectral components

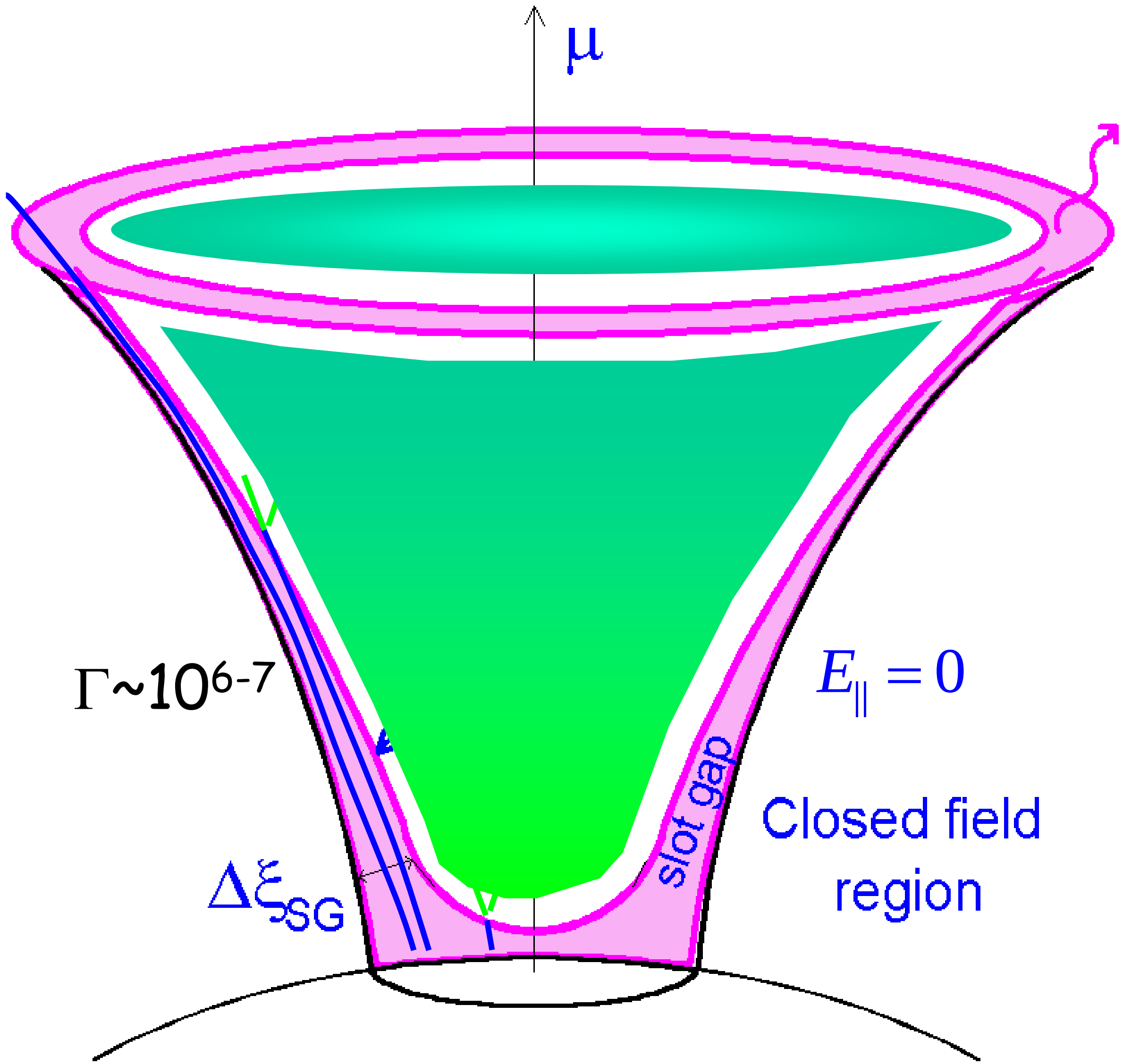


Phase Averaged Pulsar Spectrum
(Romani, 1996, ApJ 470, 469)
$\tau = 10^{4.5}$ y, B_{12}=3, E_c=3GeV

PSR spectral components (outer gap model)

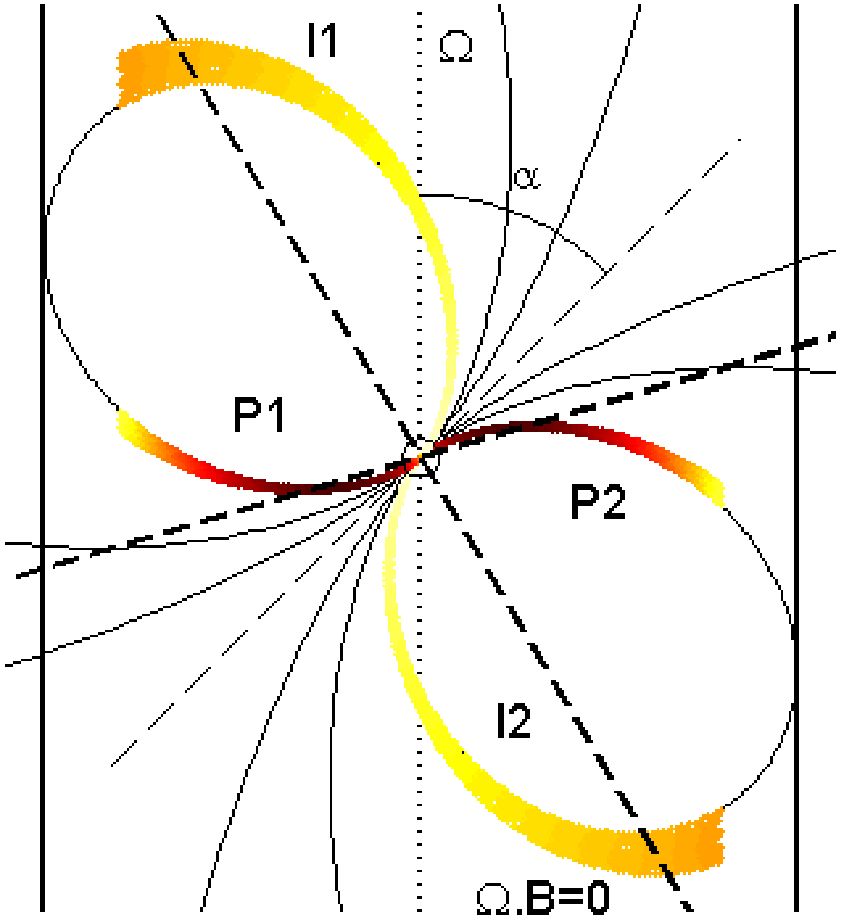


Slot gap model

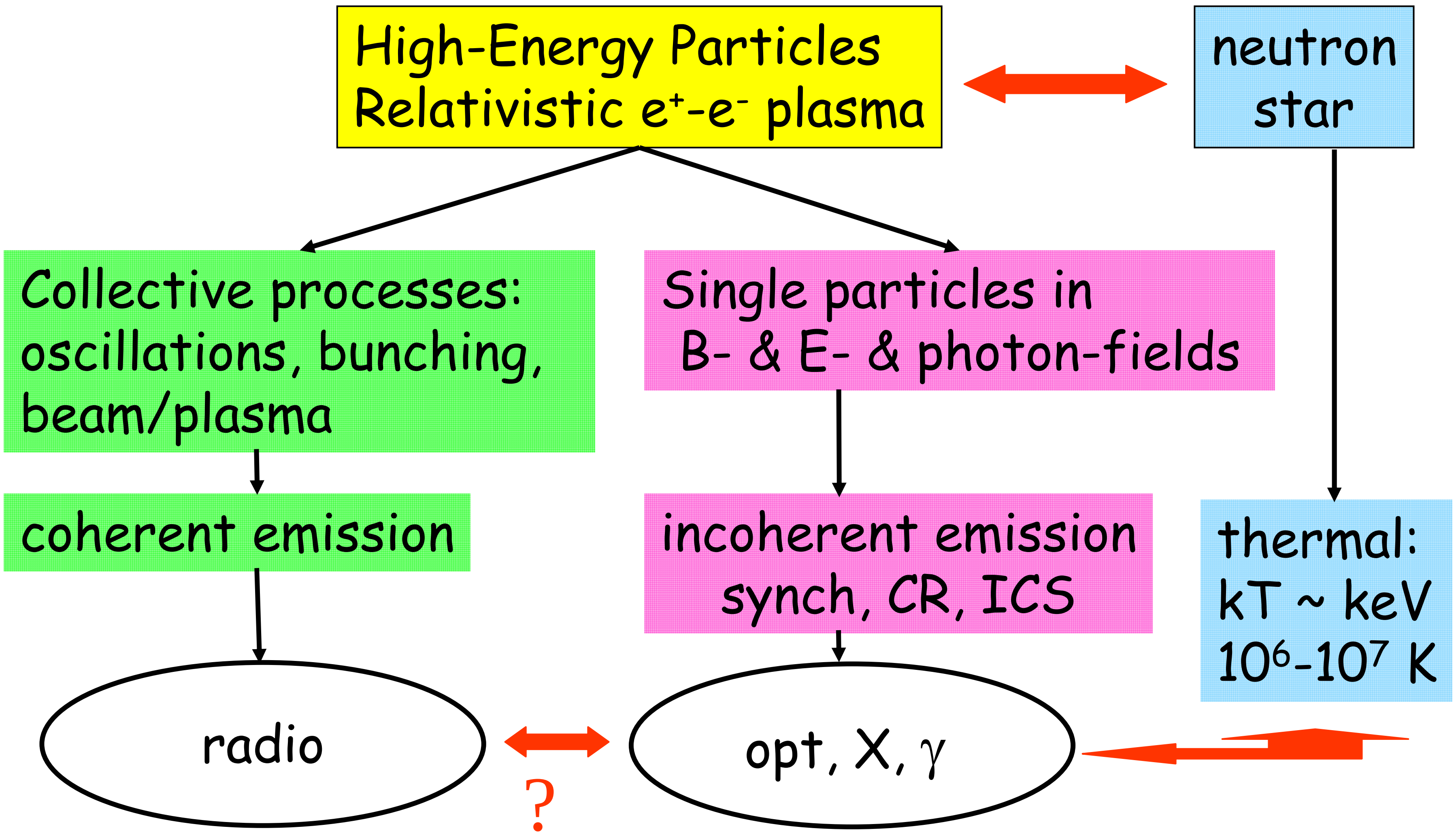


(Arons 1983, Muslimov & Harding 2003, 2004)

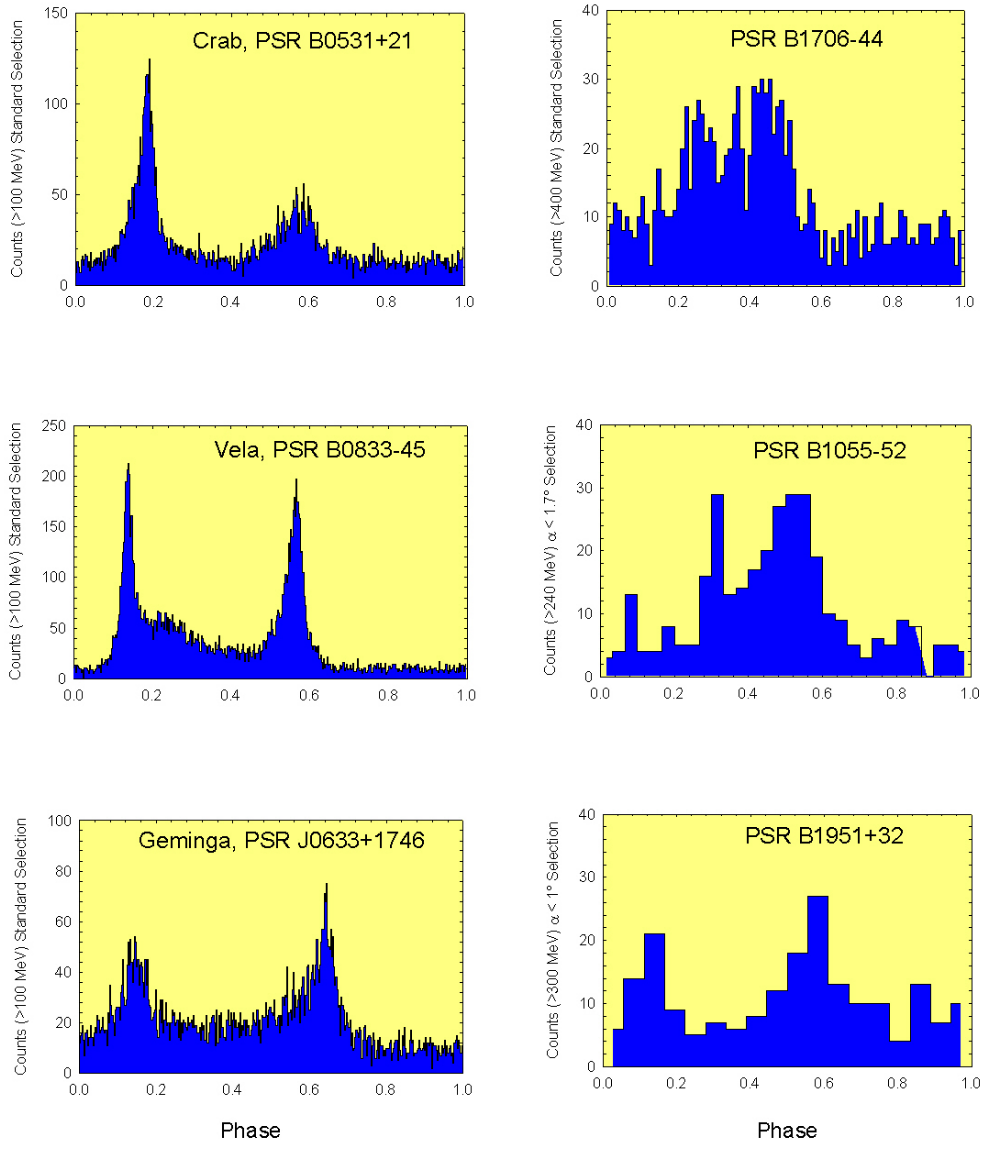
High-altitude slot gap - geometry



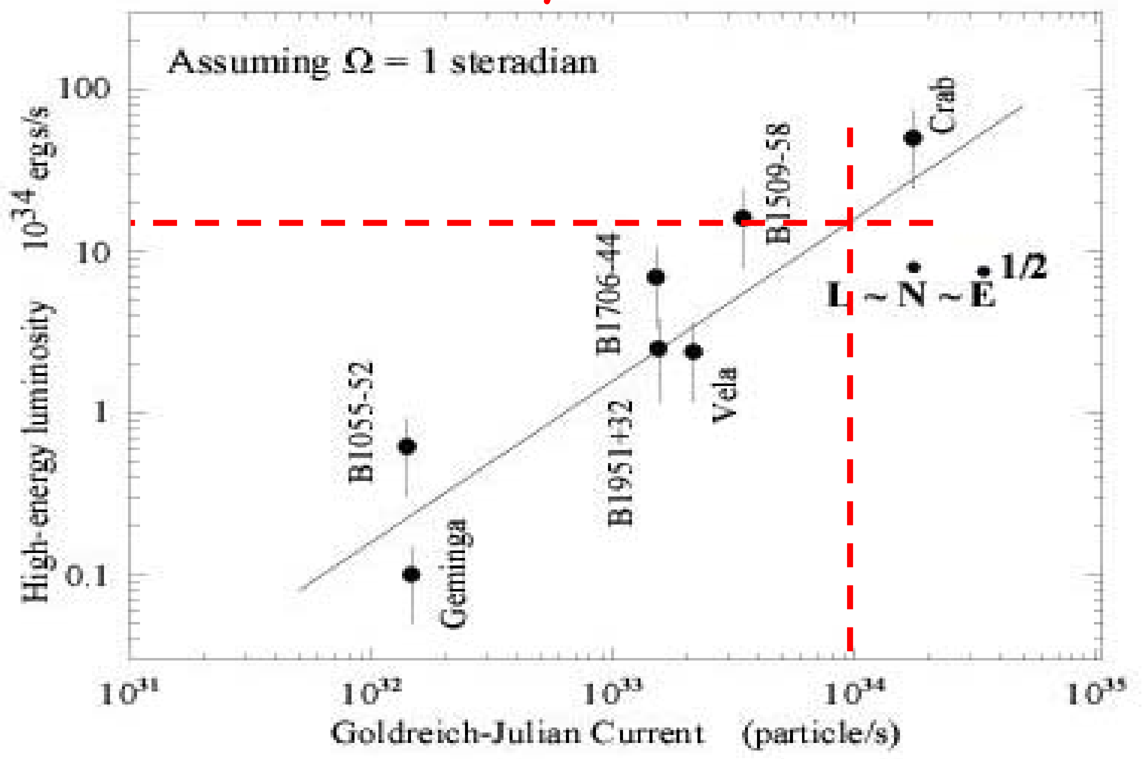
(Dyks & Rudak 2003, Dyks et al. 2004)


High-Energy Particles
Relativistic e+-e- plasma
neutron star
Collective processes: oscillations, bunching, beam/plasma
Single particles in B- & E- & photon-fields
coherent emission
incoherent emission synch, CR, ICS
thermal: kT ~ keV 10^6-10^7 K
radio
?
opt, X, γ

Gamma-Ray Details…



Luminosity

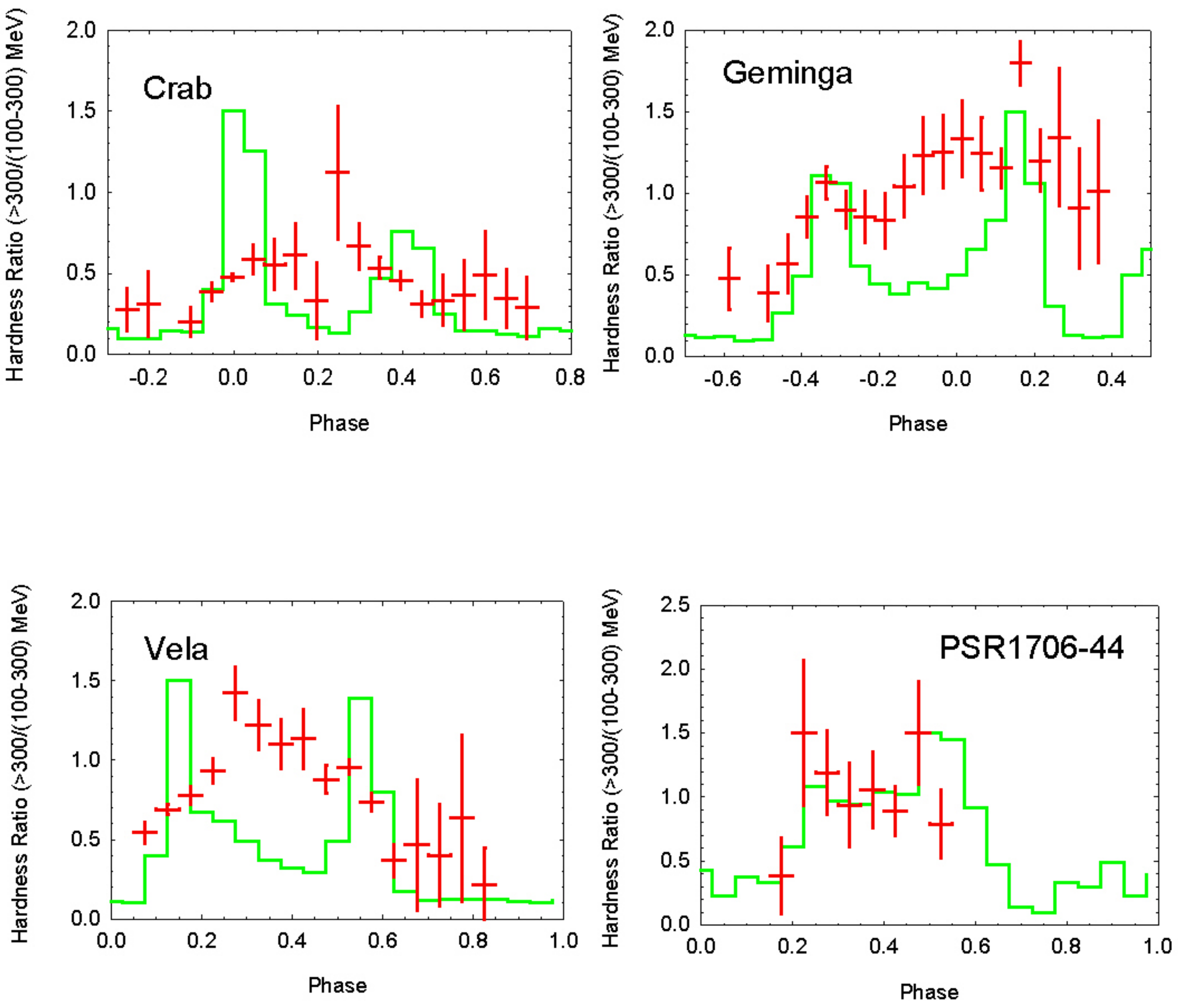


Each ‚Goldreich-Julian' particle releases ~ 15 ergs of γ-luminosity,

(e.g. in GeV photons this implies 6×10^3 photons/G-J particle)

If the accelerator provides particles of Lorentz factor ~ 10^7 (~10 erg) this implies a radiation efficiency of ~ 100%!

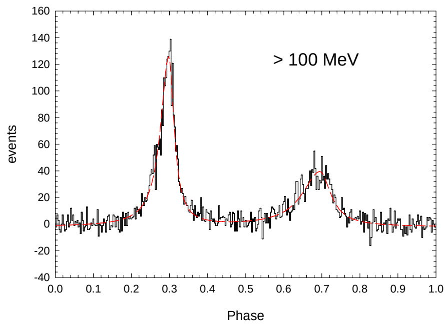
Hardness Ratio (>300 MeV) / (100-300 MeV)

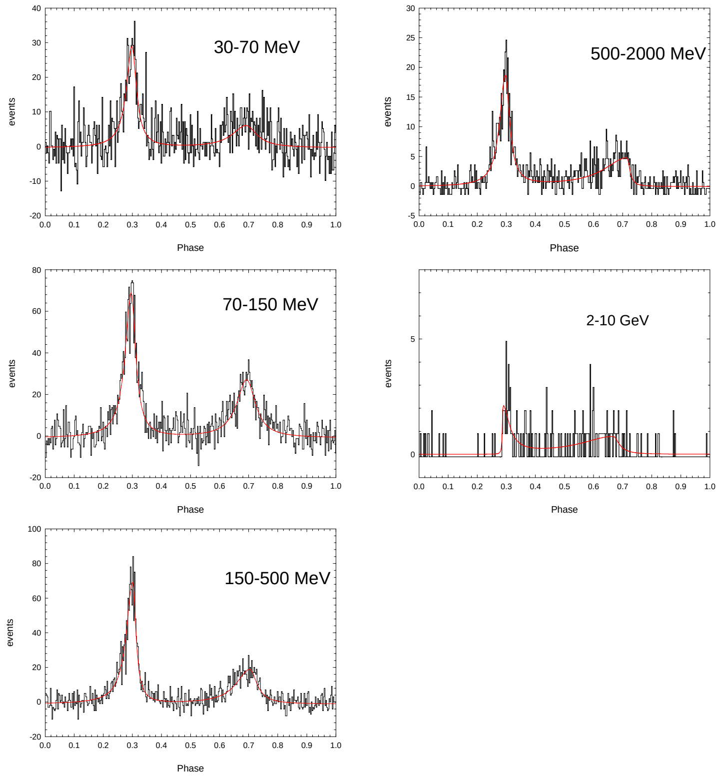


Pulse Components Crab and Geminga

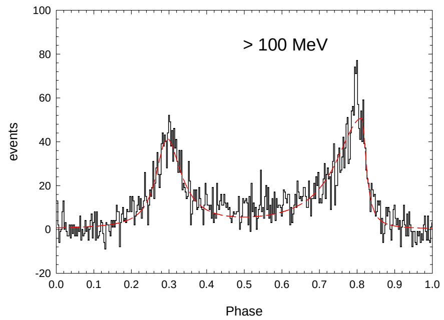
Fits with 2 asymmetric Lorentzian peaks P1, P2

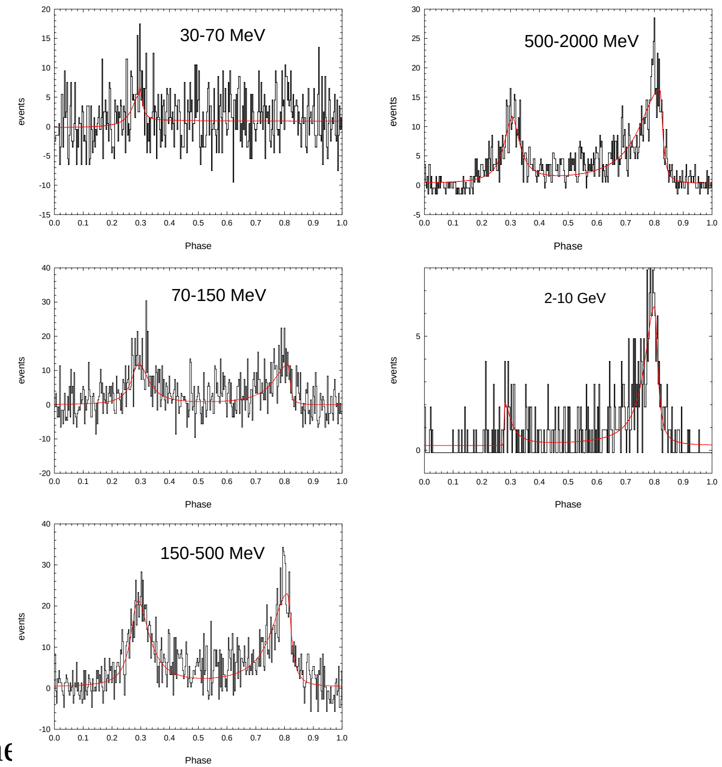
Crab, PSR B0531+21



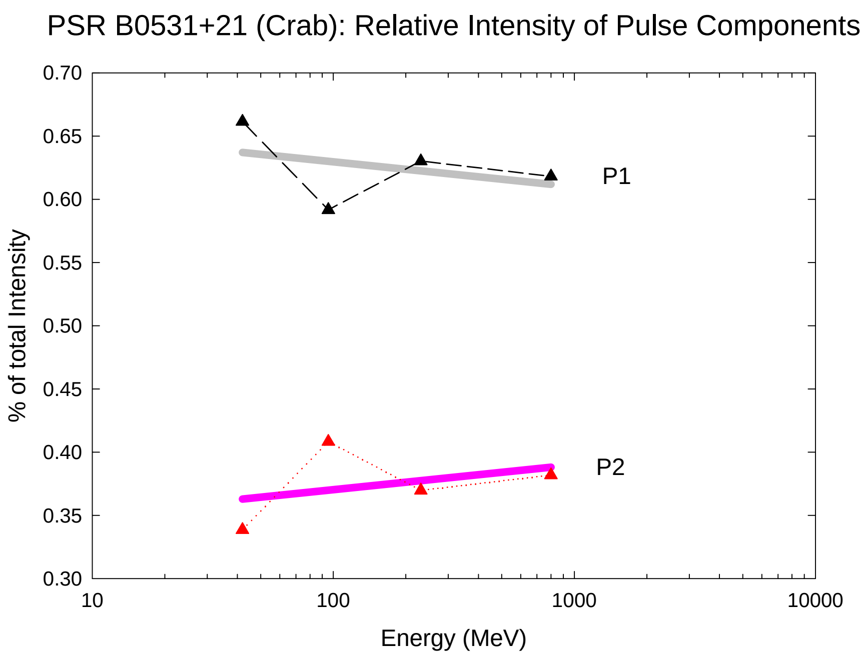


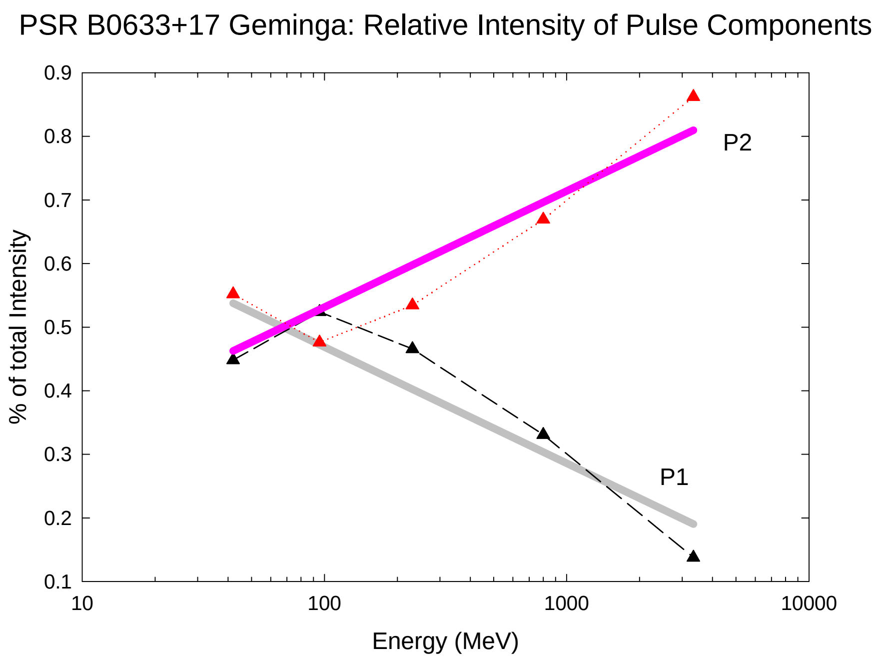
PSR B0633+17 Geminga

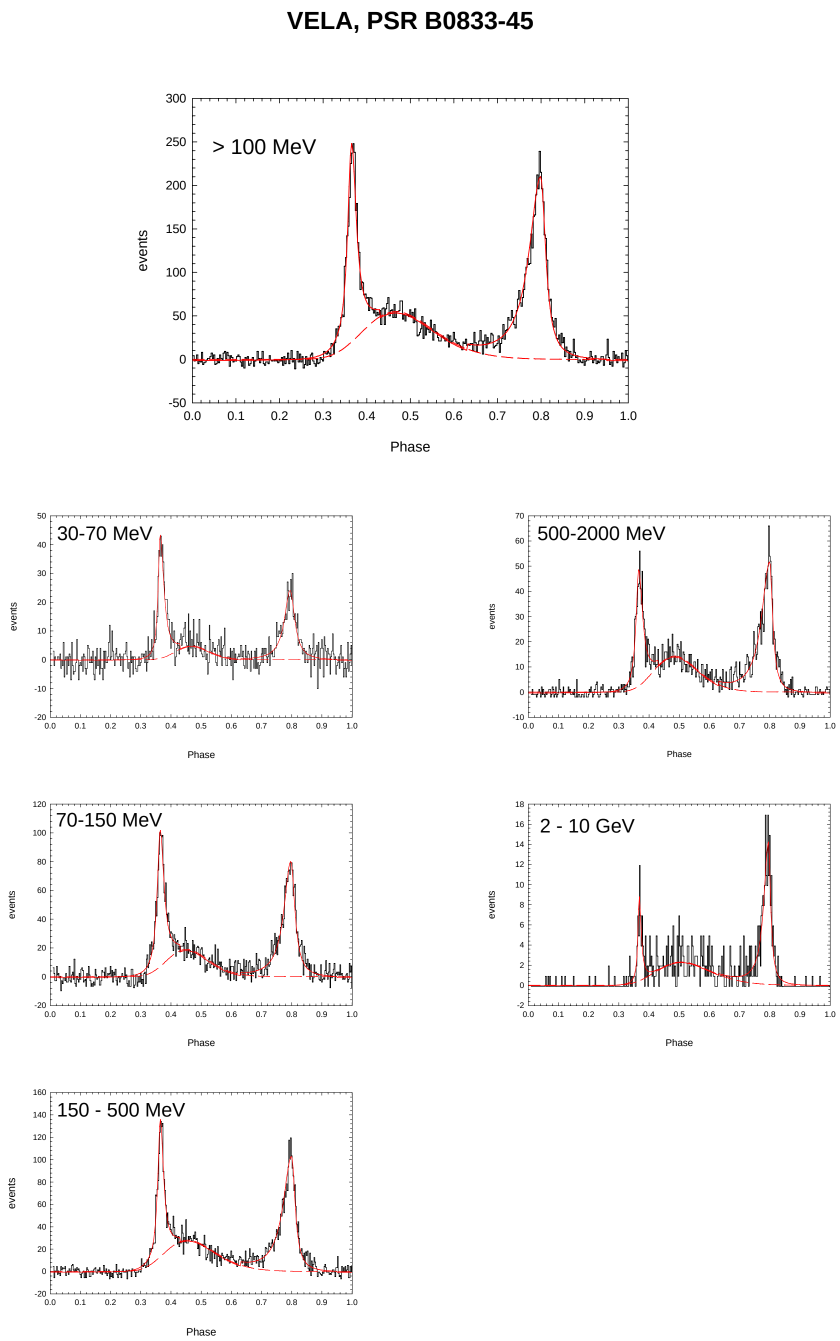




Spectra of Components in Crab and Geminga

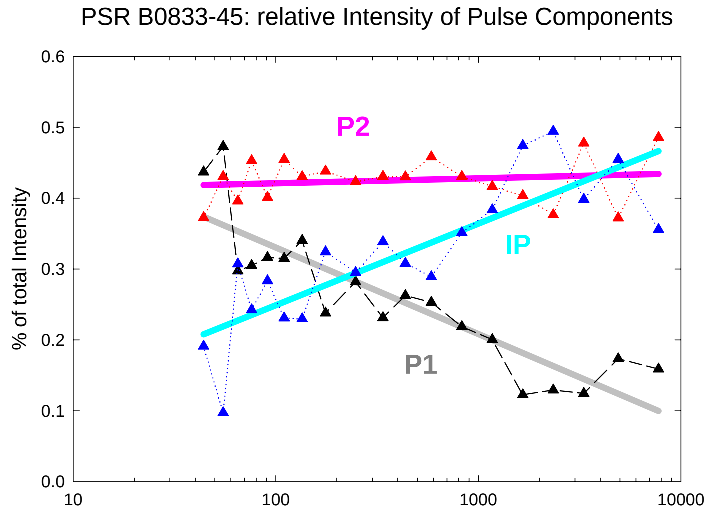


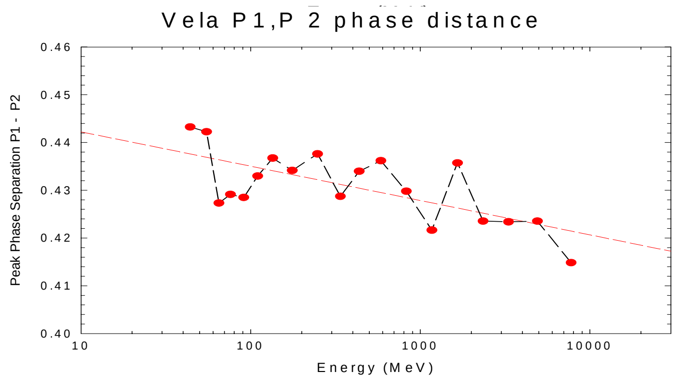




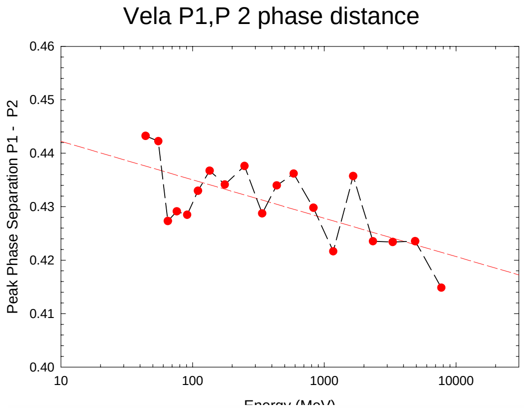
Pulse Components Vela

Empirical Fit with 2 asymmetric Lorentzian peaks and a log-normal distribution: P1, P2, IP

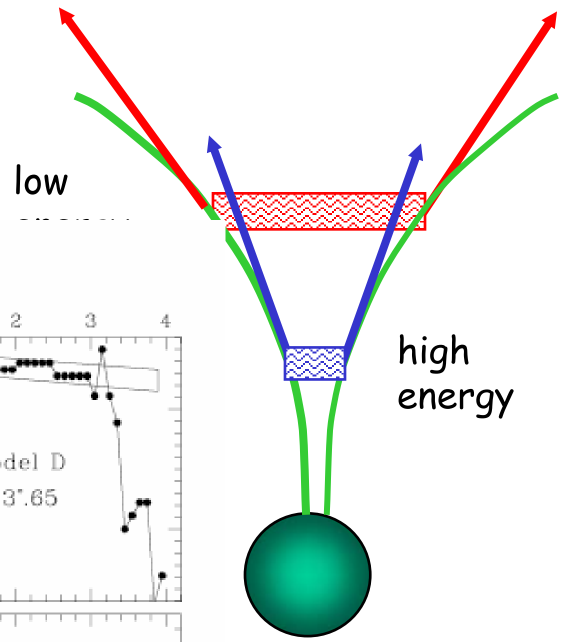


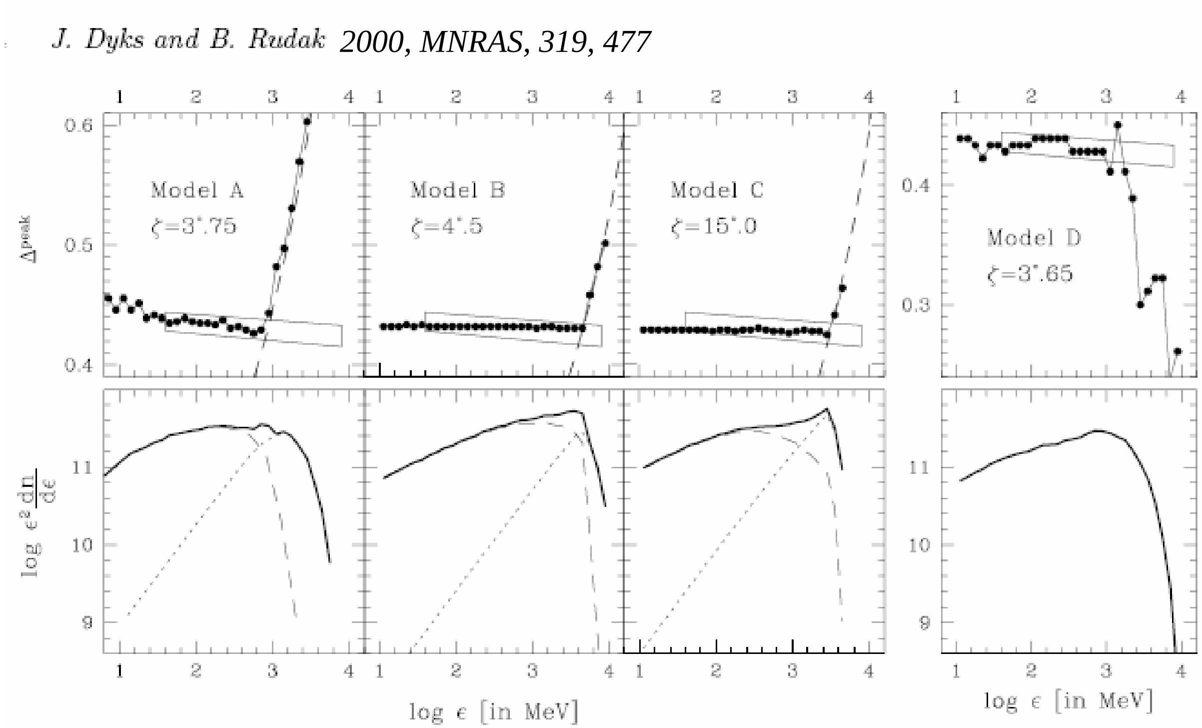


Peak separation Vela

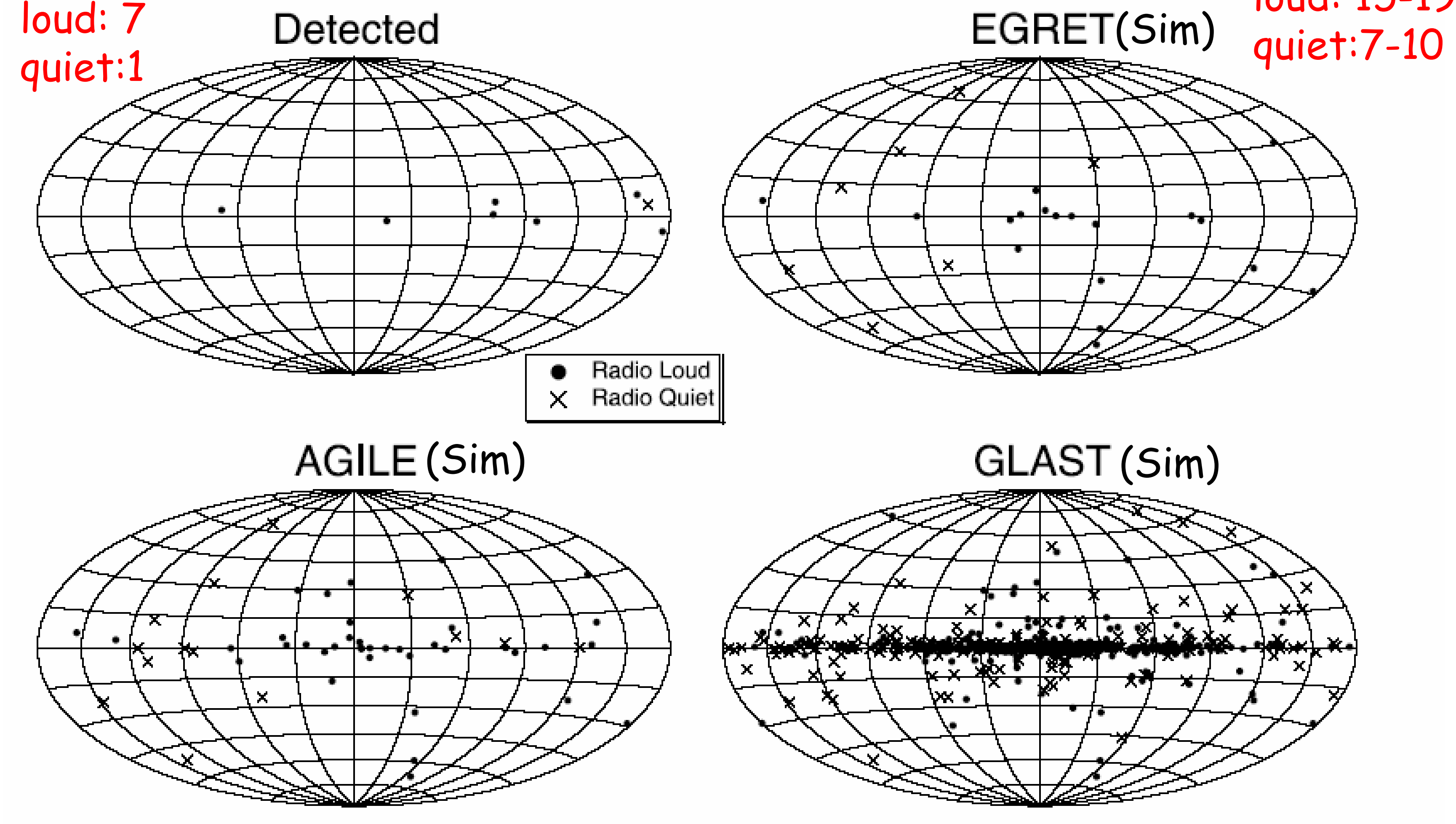


Fit (30-10000 MeV):
$\Delta\phi = 0.449 - 7.19\times10^{-3}\log(E_{MeV})$





Population Synthesis of observable γ-ray pulsars

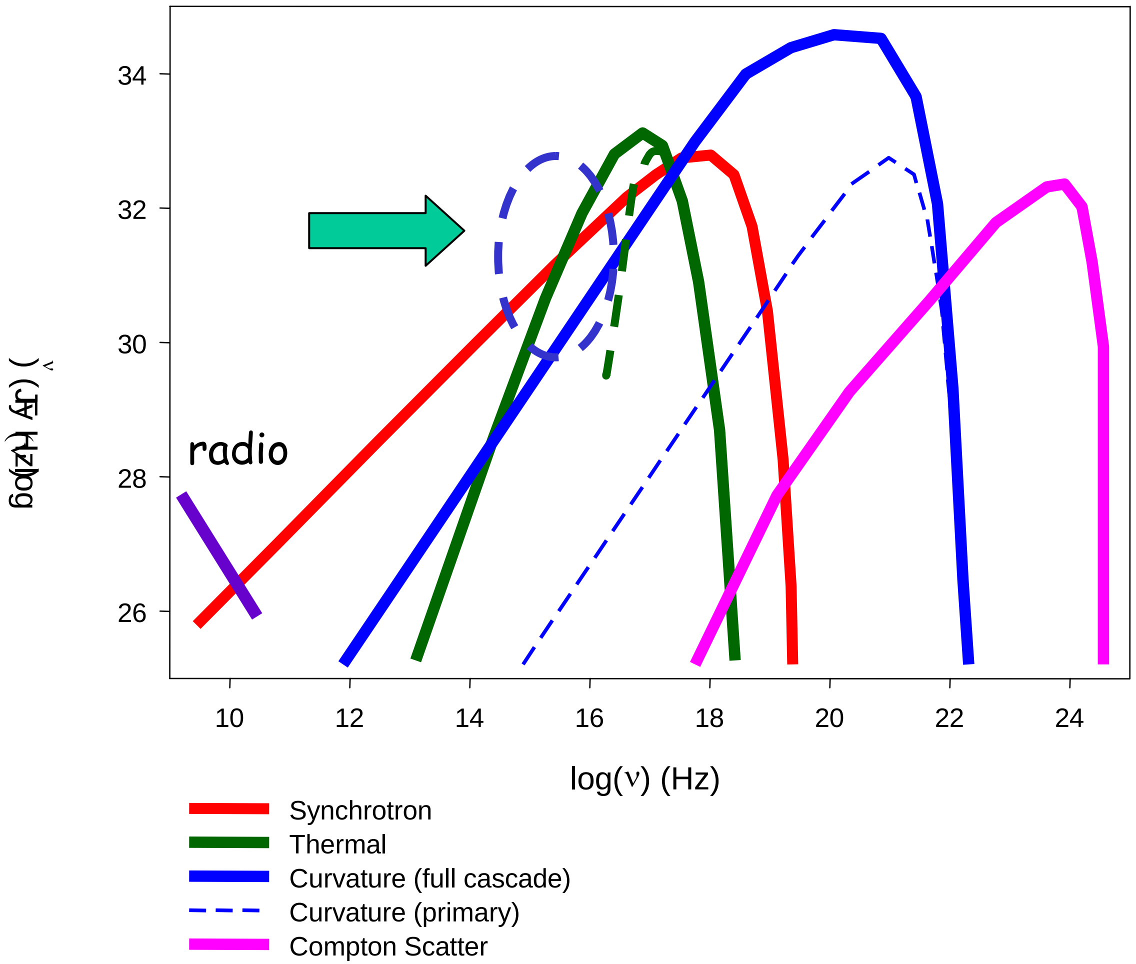


(Gonthier et al., 2004)

loud: 37
quiet:13

loud: 344
quiet:276

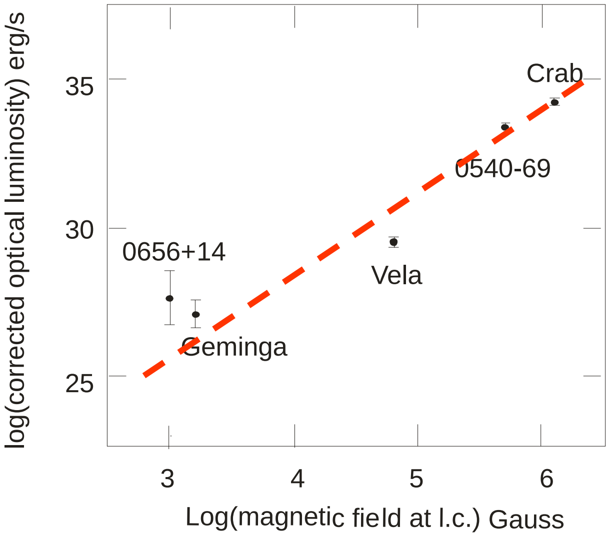
Pulsars in the optical range

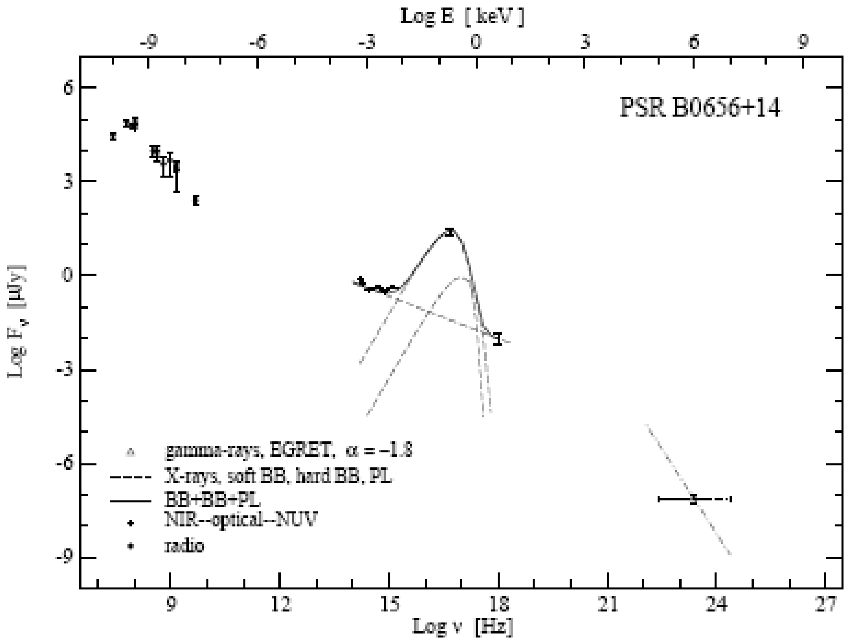


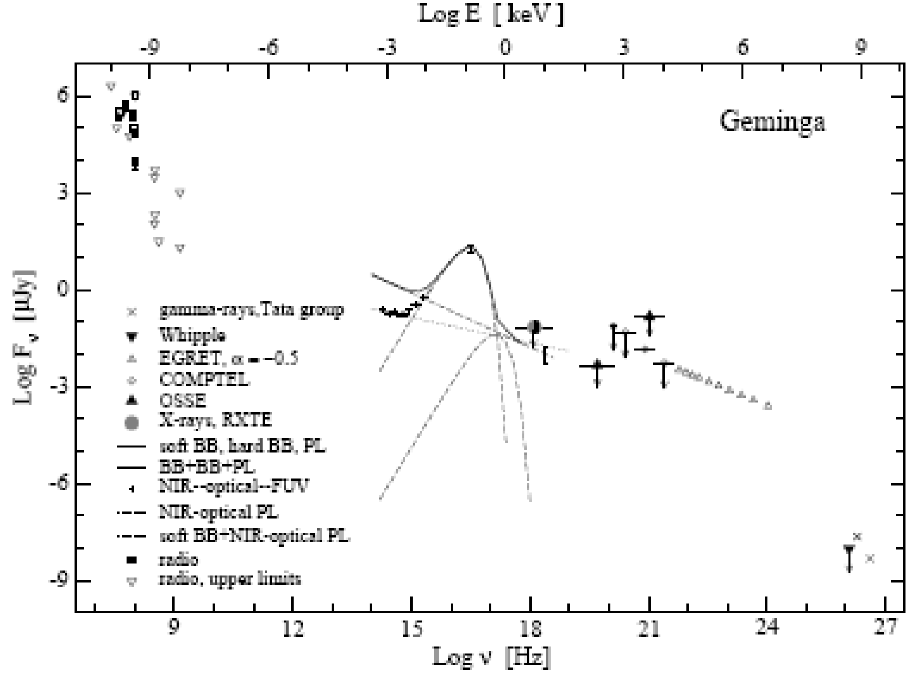
Optical Emission

Shearer, 1999

Name	D (kpc)	P (ms)	$\dot{P}$ 10^{-14} s/s	B_S log(G)	B_{LC} log (G)	Opt. Lum μCrab	Peak Lumin. μCrab
Crab	2	33	40	12.6	6.1	10^6	10^6
Vela	0.5	89	11	12.5	4.8	27	21
PSR0545-69	49	50	40	12.7	5.7	1.1 10^6	1.4 10^5
PSR0656+14	0.76(?)	385	1.2	12.7	3.0	1.8	0.3
PSR0633+17	0.16	237	1.2	12.2	3.2	0.3	0.1

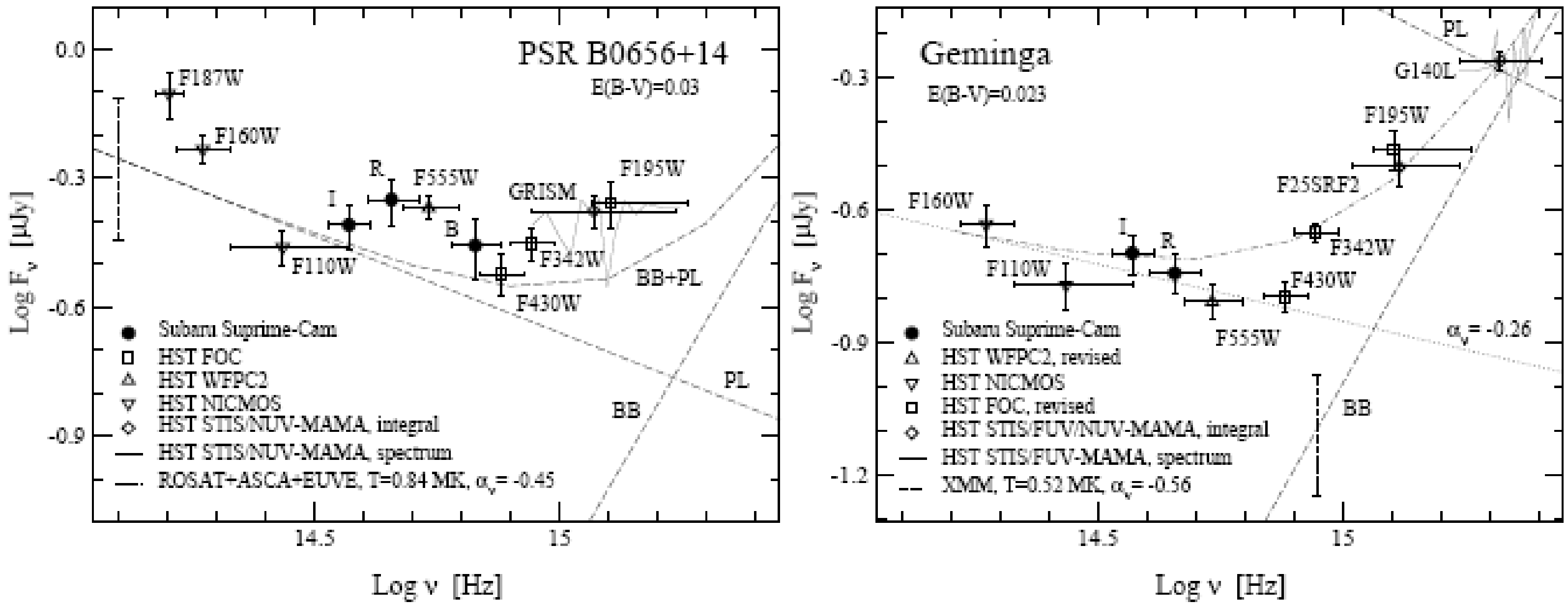




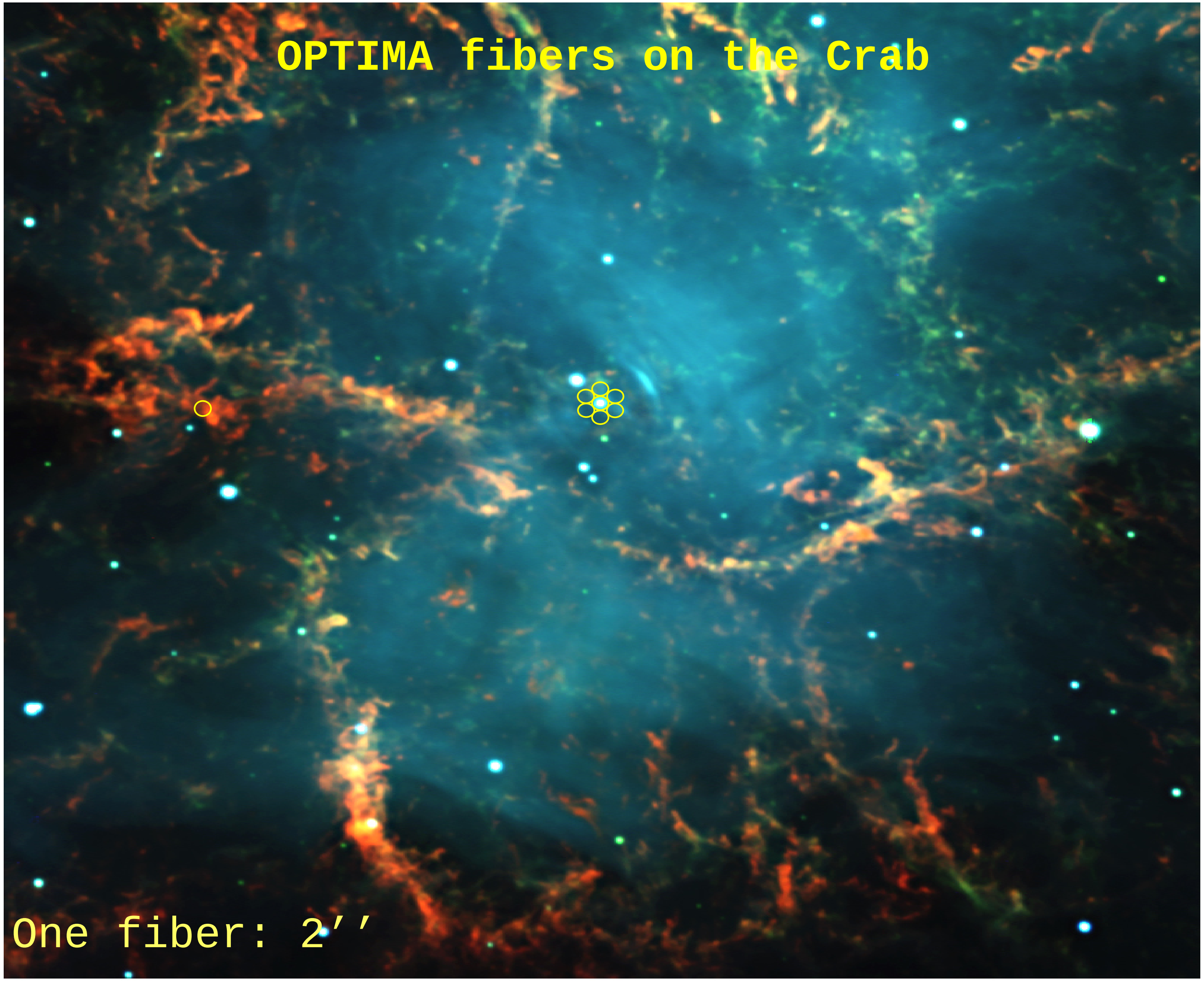


Observations with the SUBARU telescope

Shibanov, et al.,, astro-ph/0511311



Shibanov, et al.,, astro-ph/0511311



The Crab Nebula in Taurus (centre) (VLT KUEYEN + FORS2)

ESO PR Photo 40g/99 (17 November 1999)

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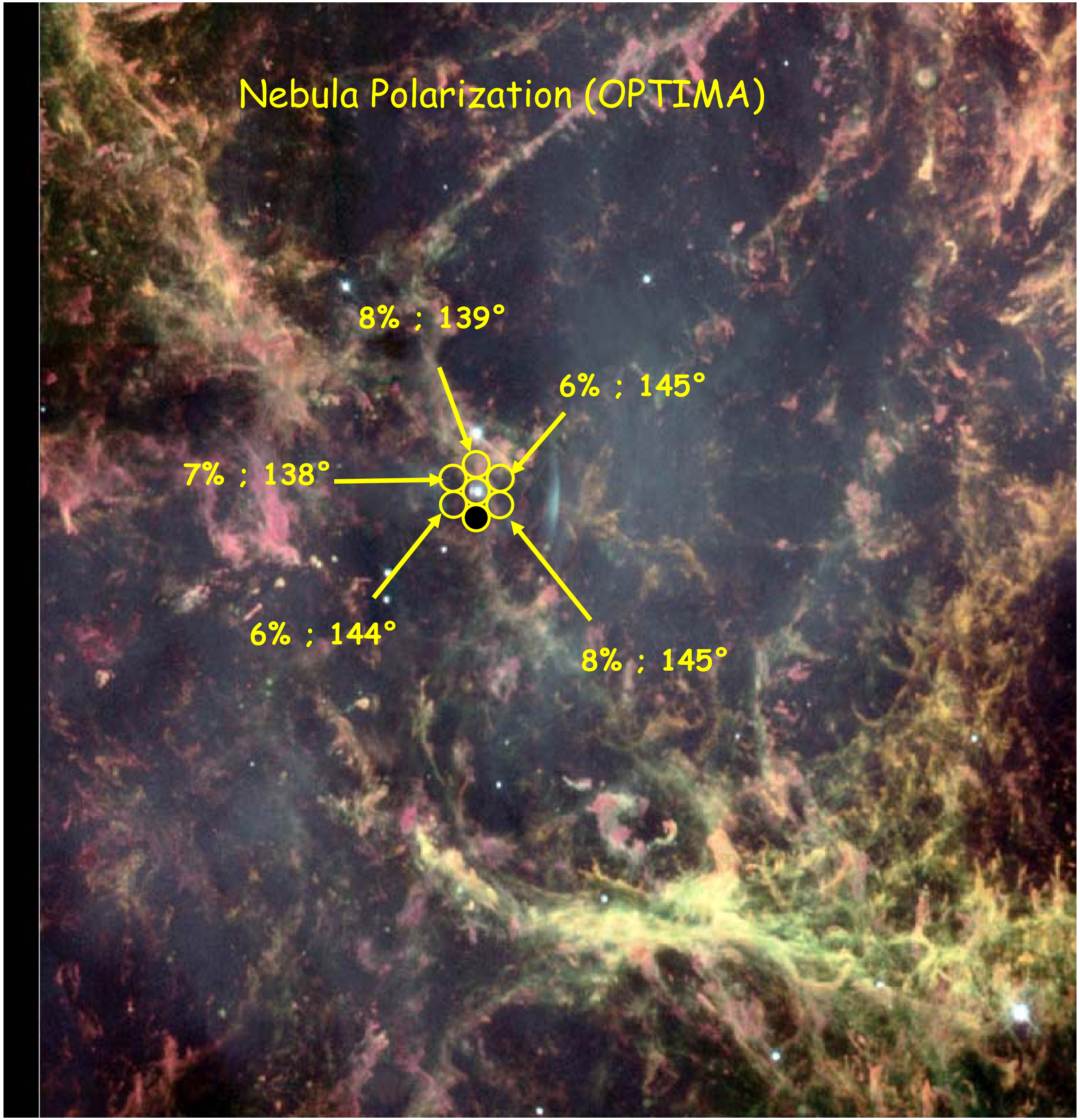
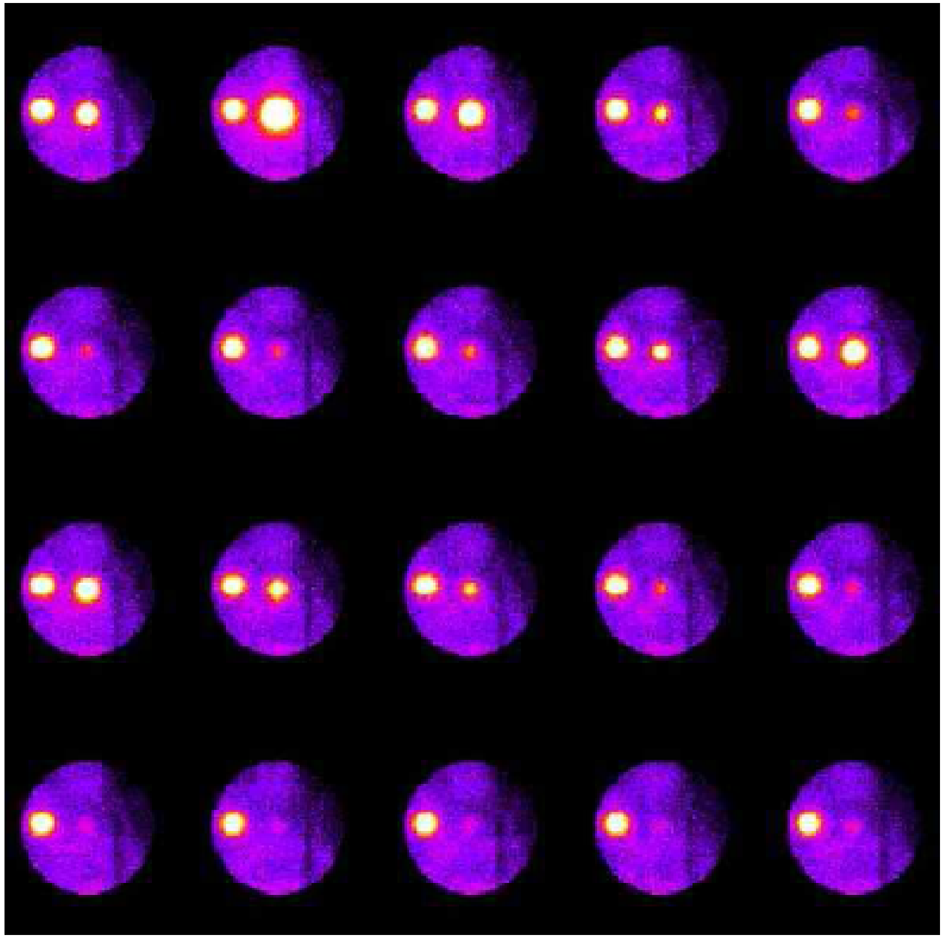
Polarization
close to pulsar:
degree: 8-13%
angle ~ 140°
(Schmidt&Angel, 79)

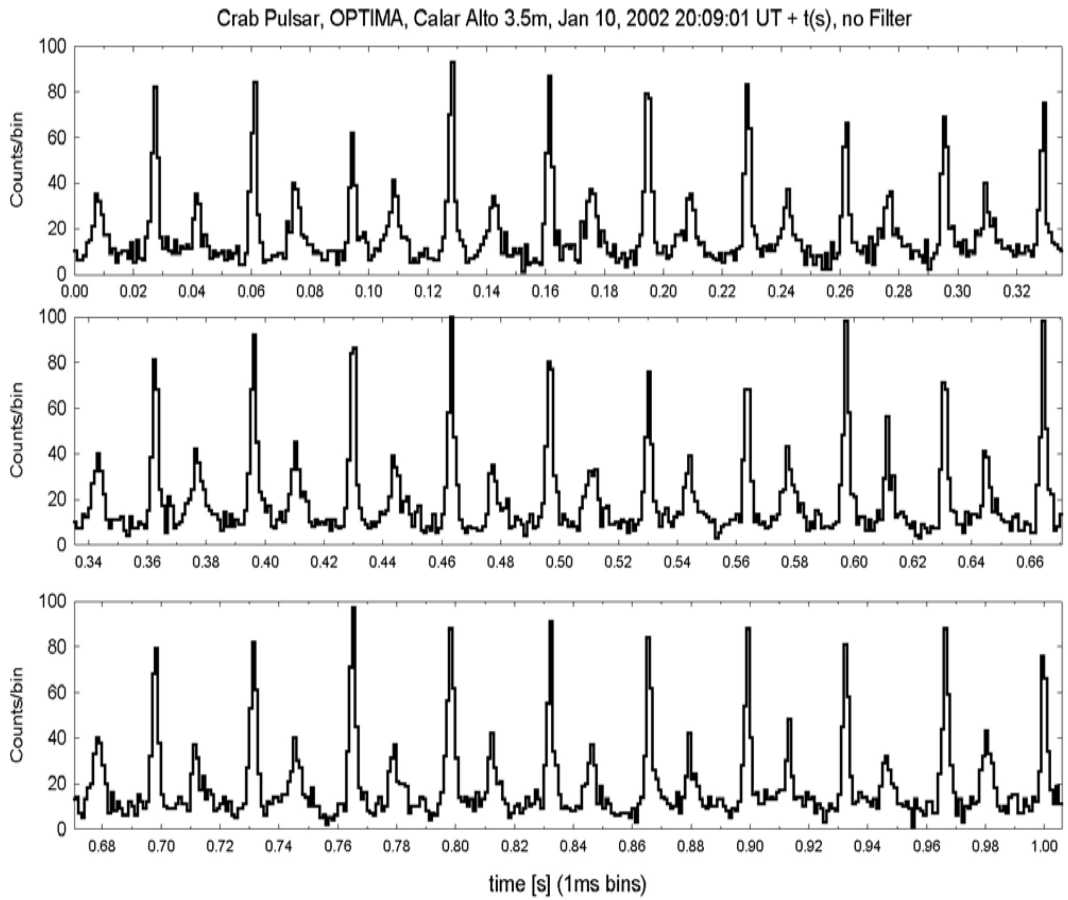


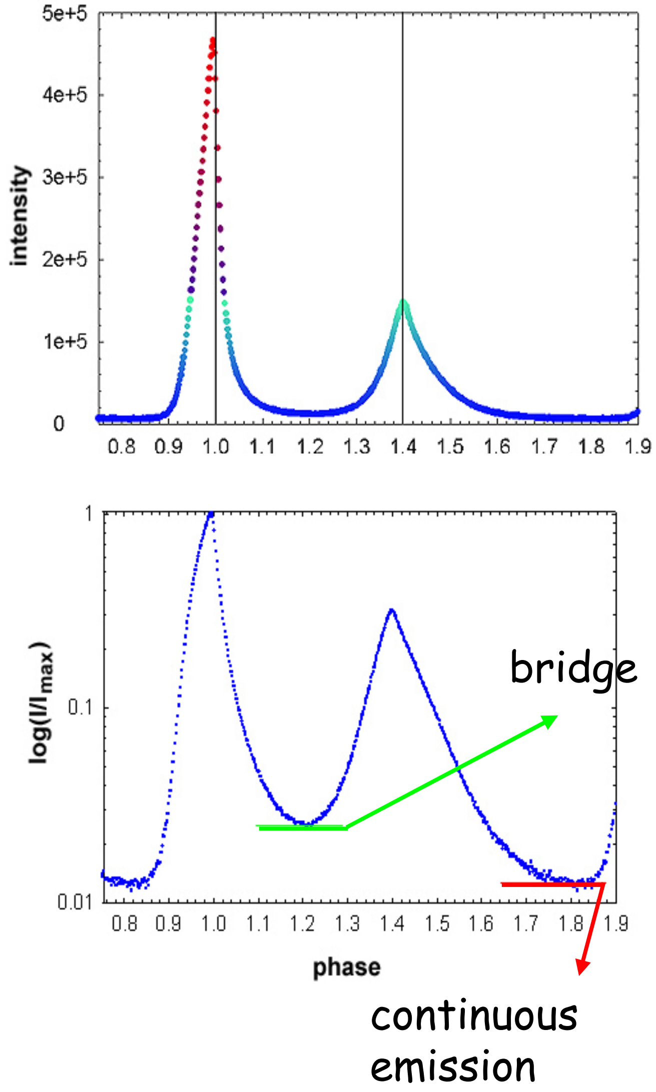
The Crab is visible at all phases



Shearer, 2002

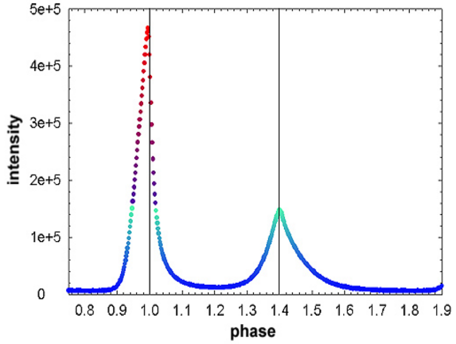
Crab single rotation and summed lightcurve





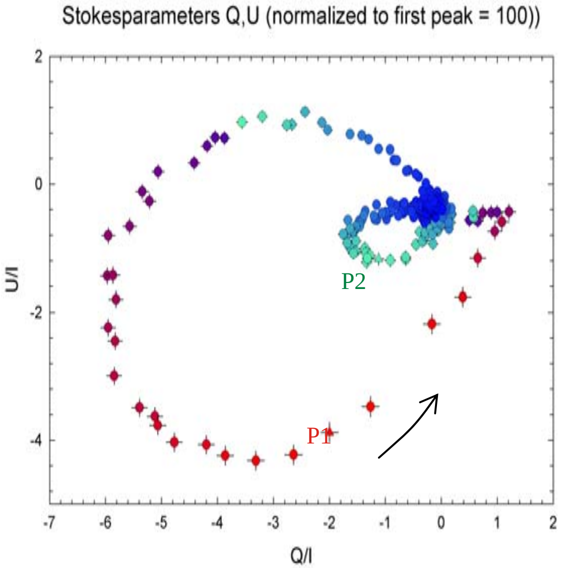
single rotation variability studies

Crab Polarization (OPTIMA)

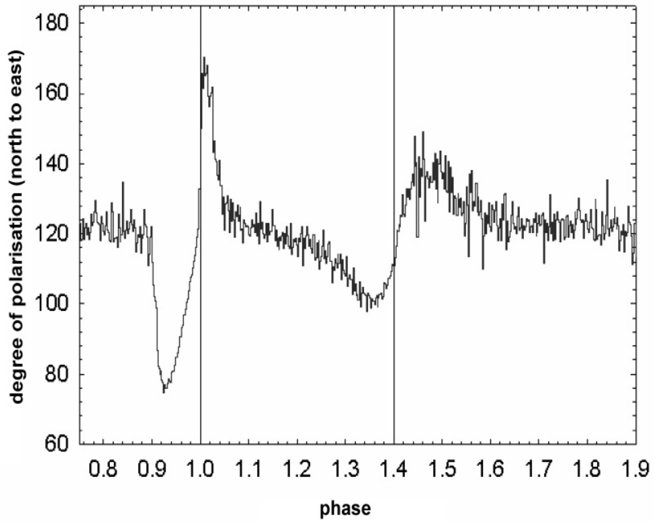


Measure lightcurves for different positions of the rotating polarisation filter at $[\phi_0, \phi_0+90°]$ and $[\phi_0+45°, \phi_0+135°]$.

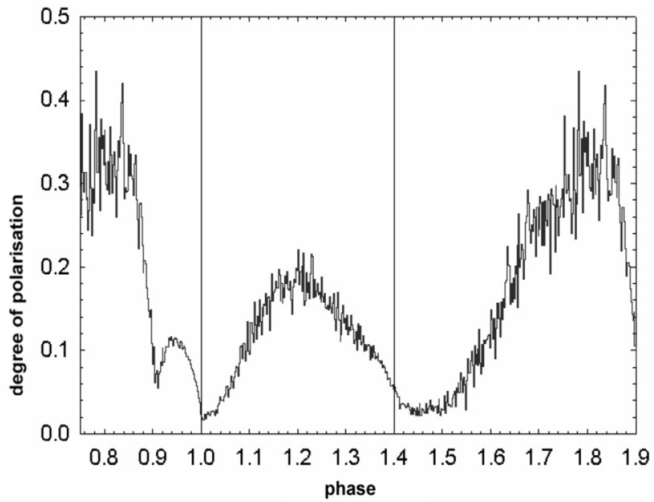
Calculate Stokes-Parameters:
Q=I(0°)-I(90°), U=I(45°)-I(135°)



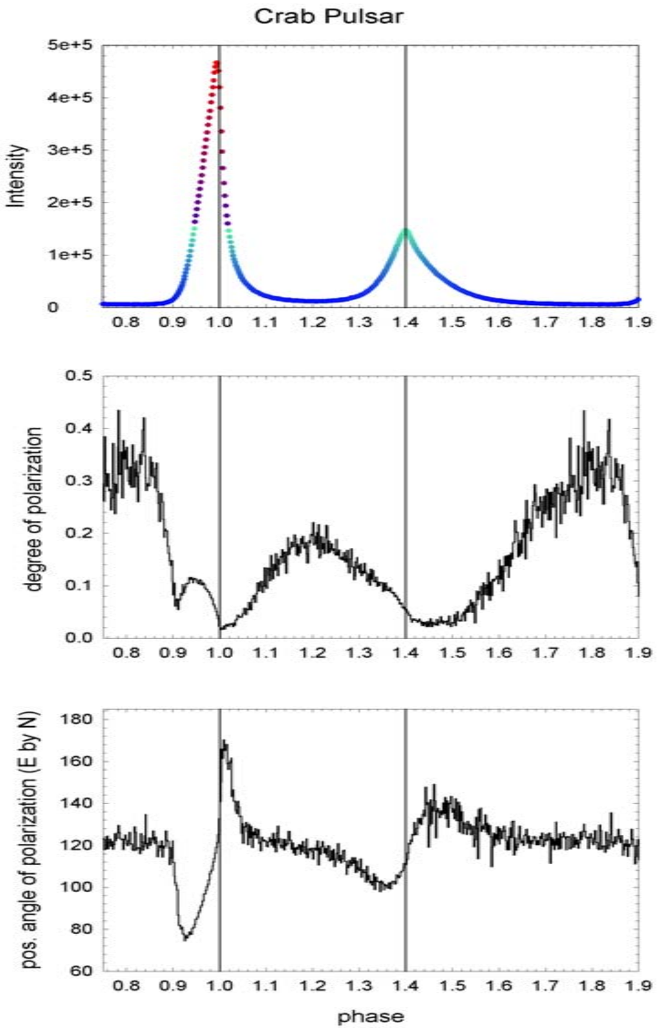
angle of polarization: $\Theta = \frac{1}{2} \cdot \arctan \frac{U}{Q}$



degree of polarization: $V = \frac{\sqrt{Q^2 + U^2}}{I}$

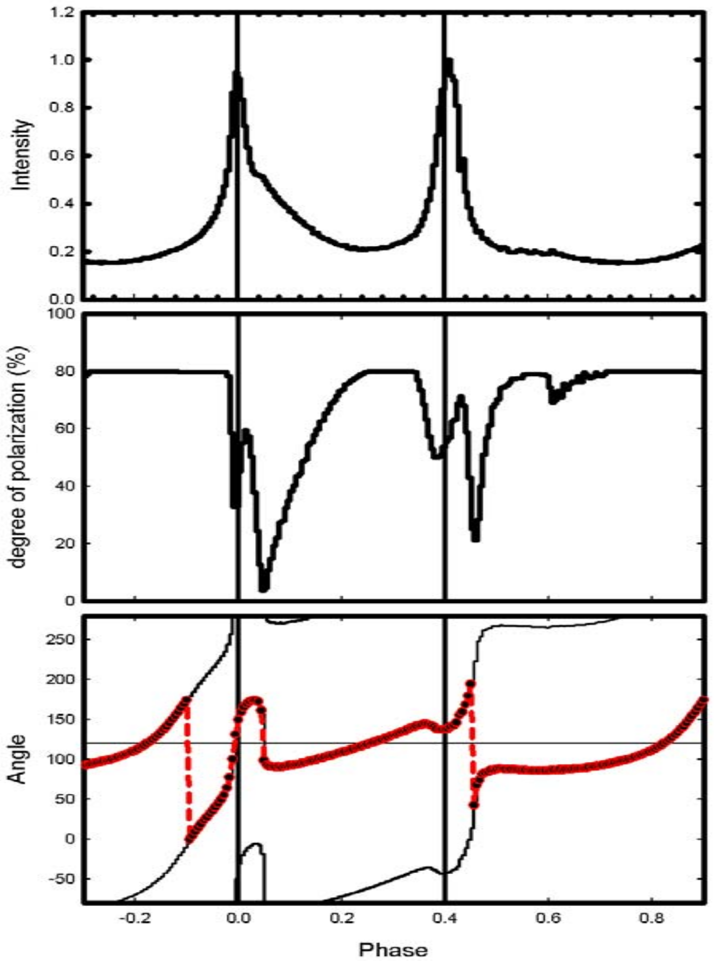


~ Correspondence of Polarization Characteristics (note also striped wind model, Petri and Kirk, 2005)



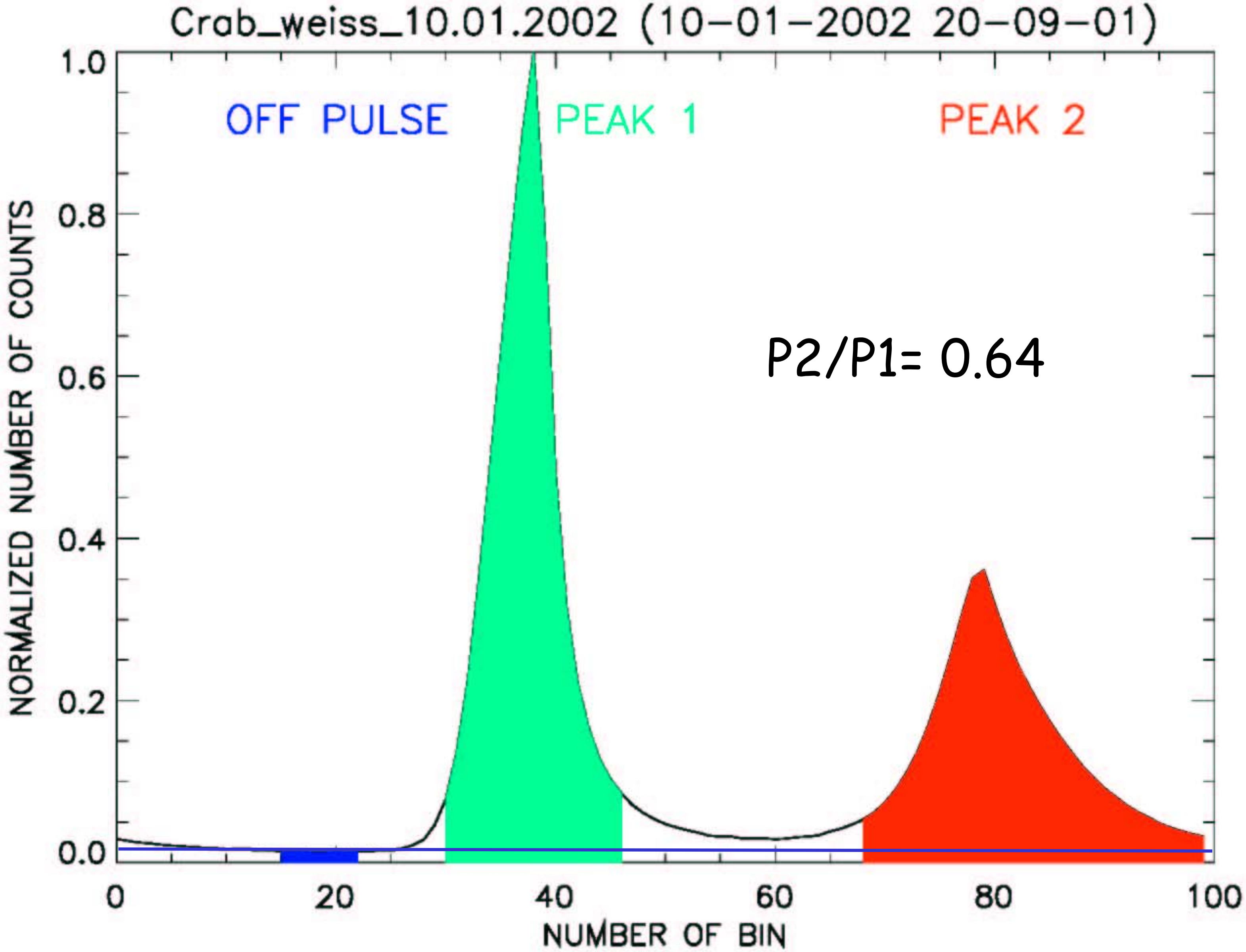
Measurement

Model: Dyks et al., 2004

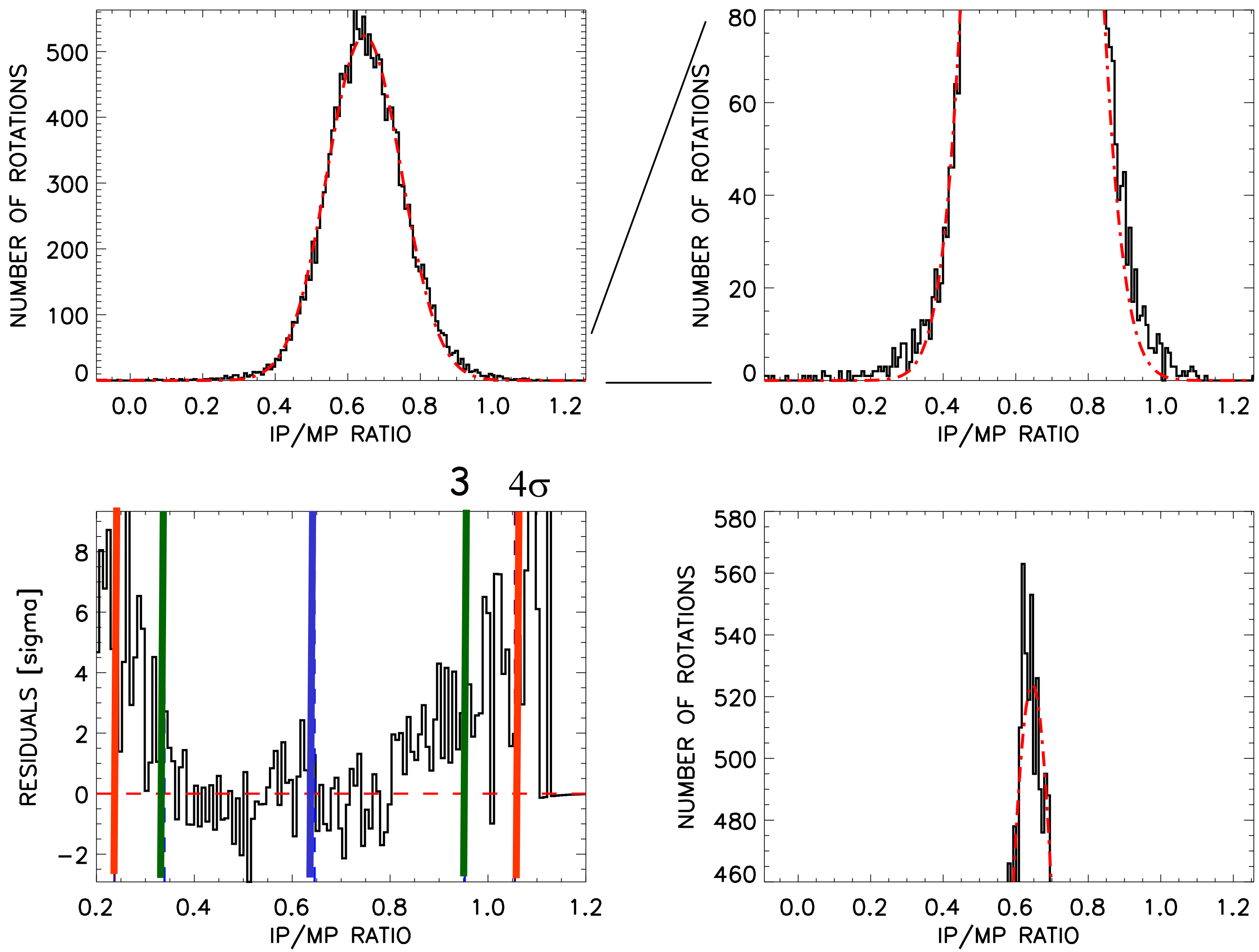


Two Pole Caustic Model
(Dyks etal, 2004)

Crab: single pulse statistics (A. Slowikowska et al.)

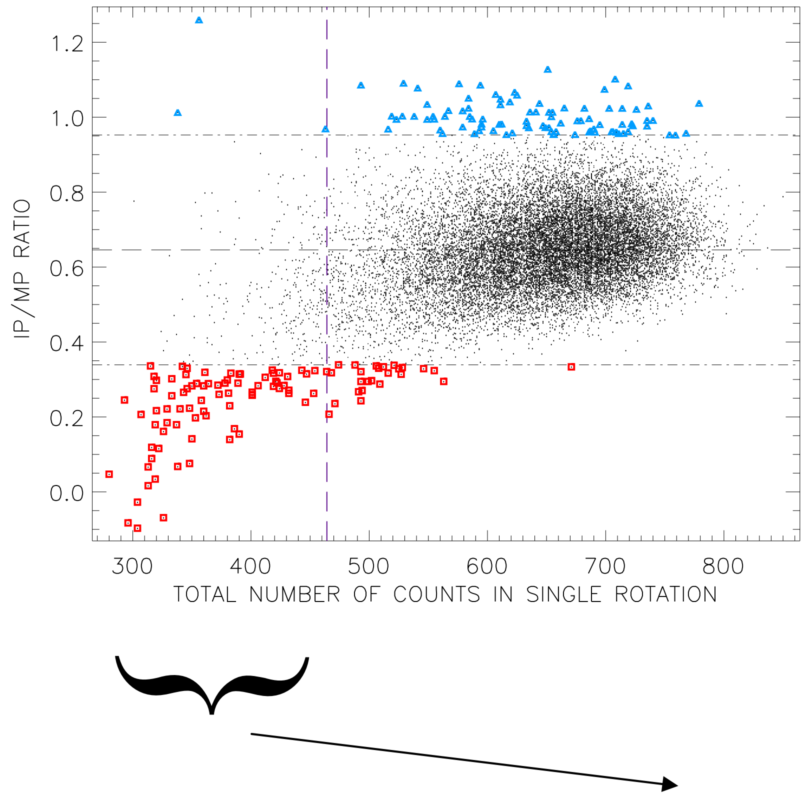


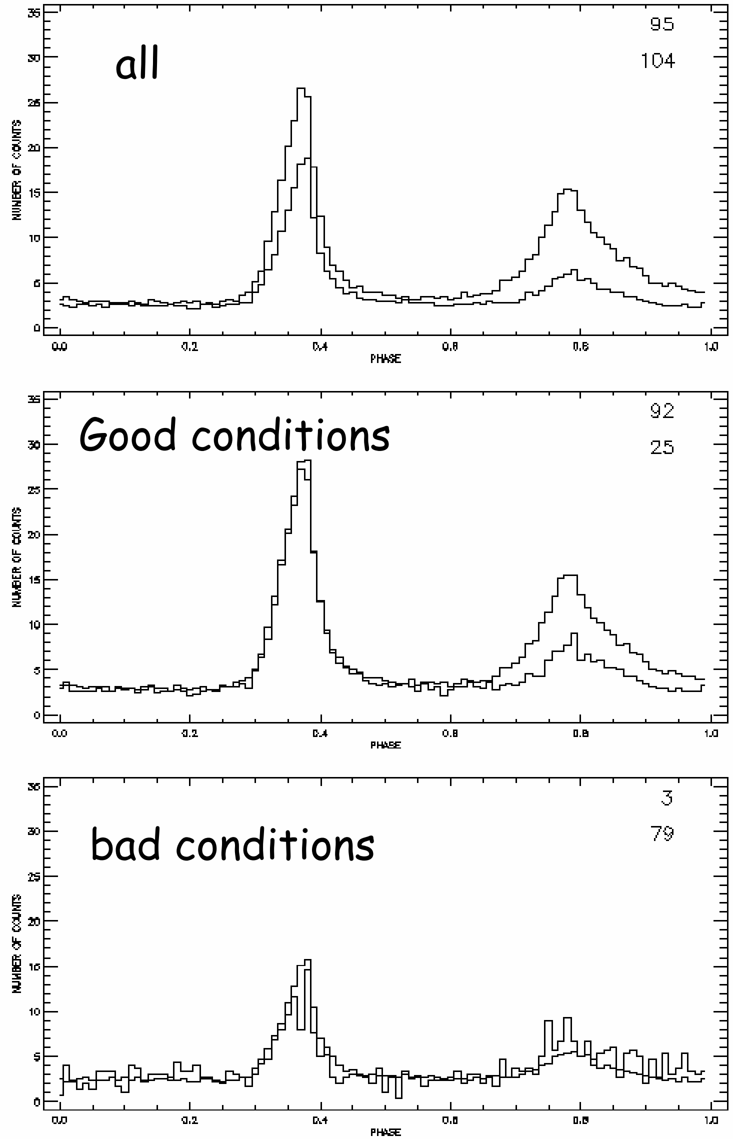
Peak ratio statistics



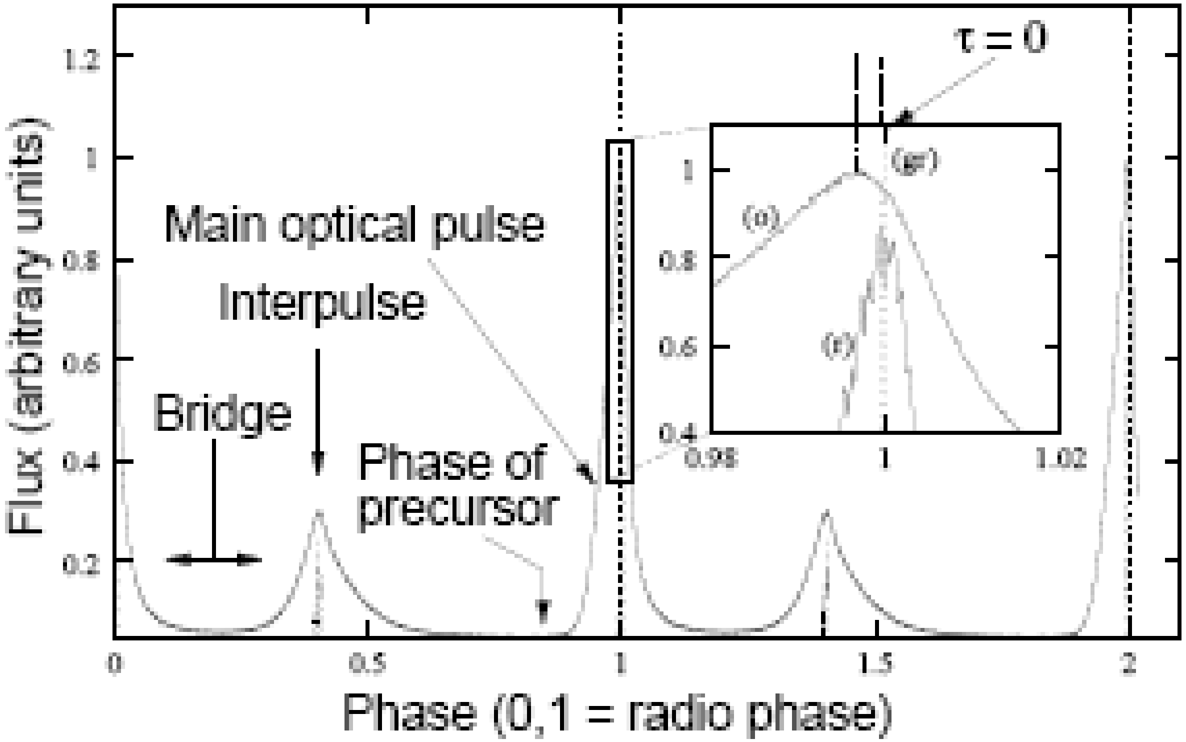
High= 568.67, P2 / P1= 0.626, σ= 0.119, χ^2 / d= 1.65

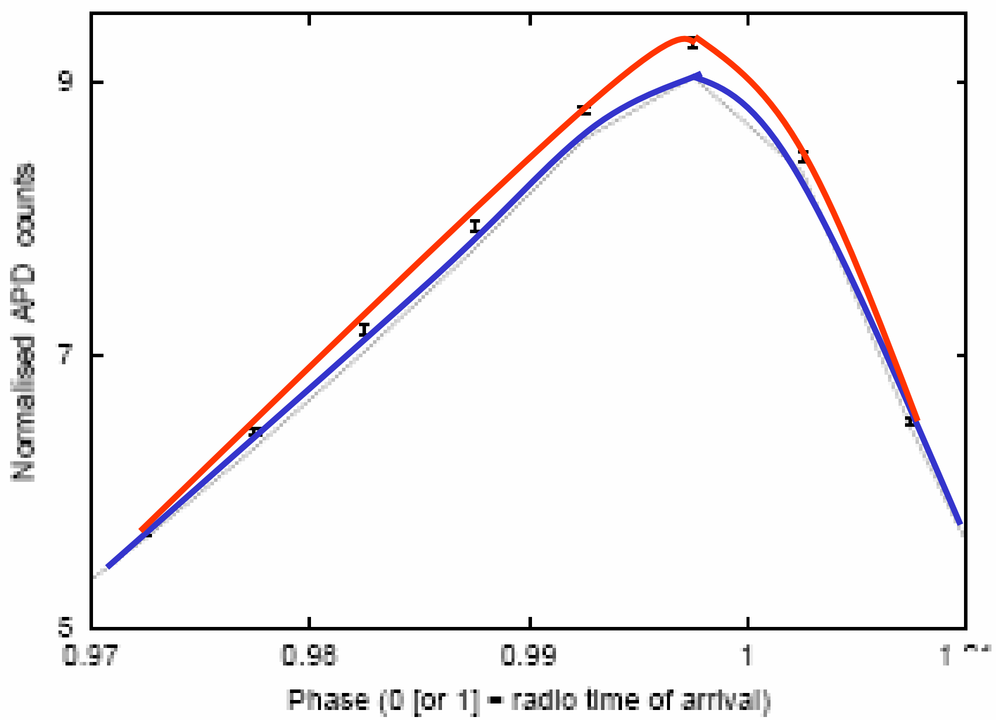
Check for atmospheric transparency
and aperture loss due to seeing variations



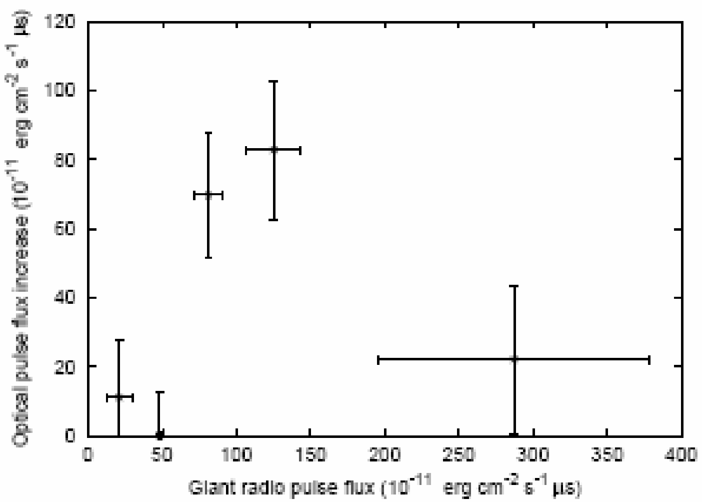


Correlation of otical flux and Giant Radio Pulses (Shearer et al., Science, 301, 493, 2003)





The main peak of the Optical emission is ~3-5% brighter in a Rotation that shows A GRP !



Conclusions:

High energy emission in young radio pulsars is the dominant radiation process and some details are already detectable in the brightest objects

(GLAST will detect `many` more radio pulsars Where many could be 50-100 depending on model)

Coupling between incoherent high-energy radiations and coherent radio emissions in Crab (rad-opt) and Vela (talk by A. Lommen) start to become visible.

We should be on our way to a comprehensive model of pulsar emissions…