MODELLING THE X-RAY EMISSION FROM THE COMPACT VELA PULSAR WIND NEBULA

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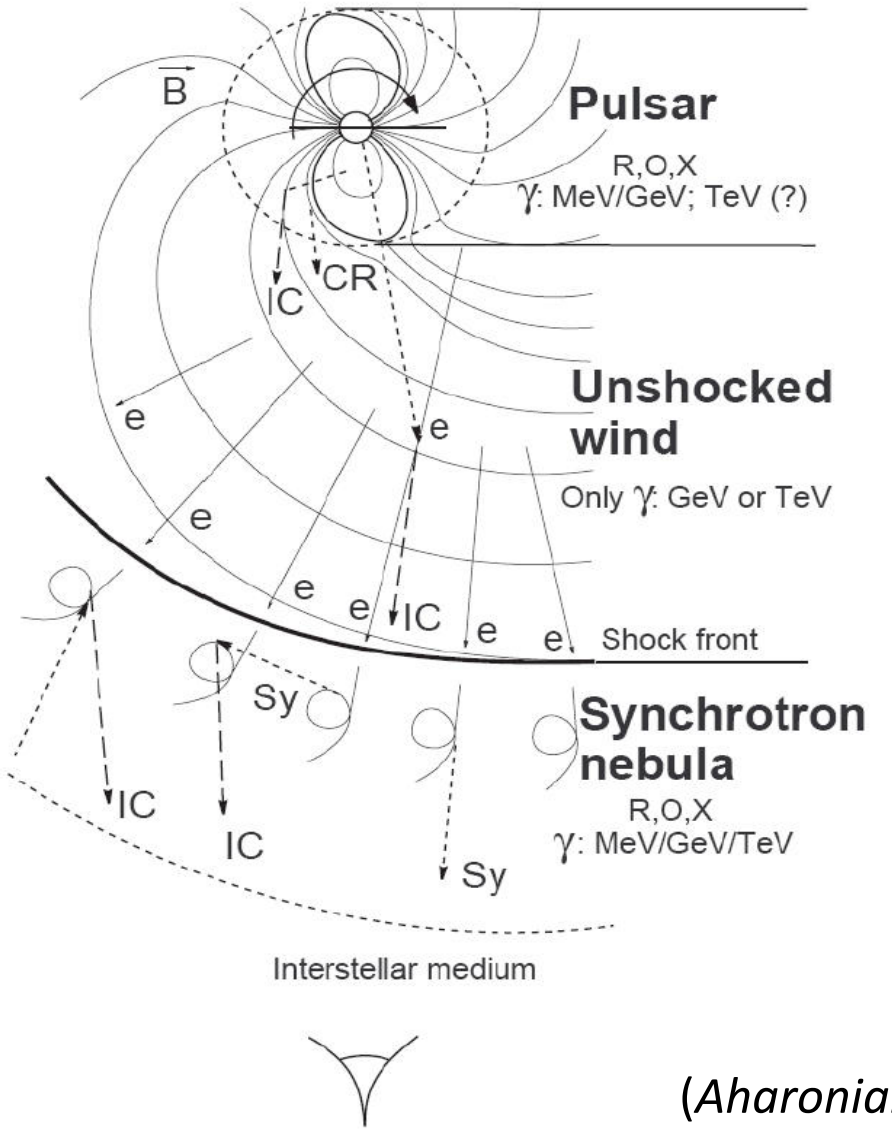
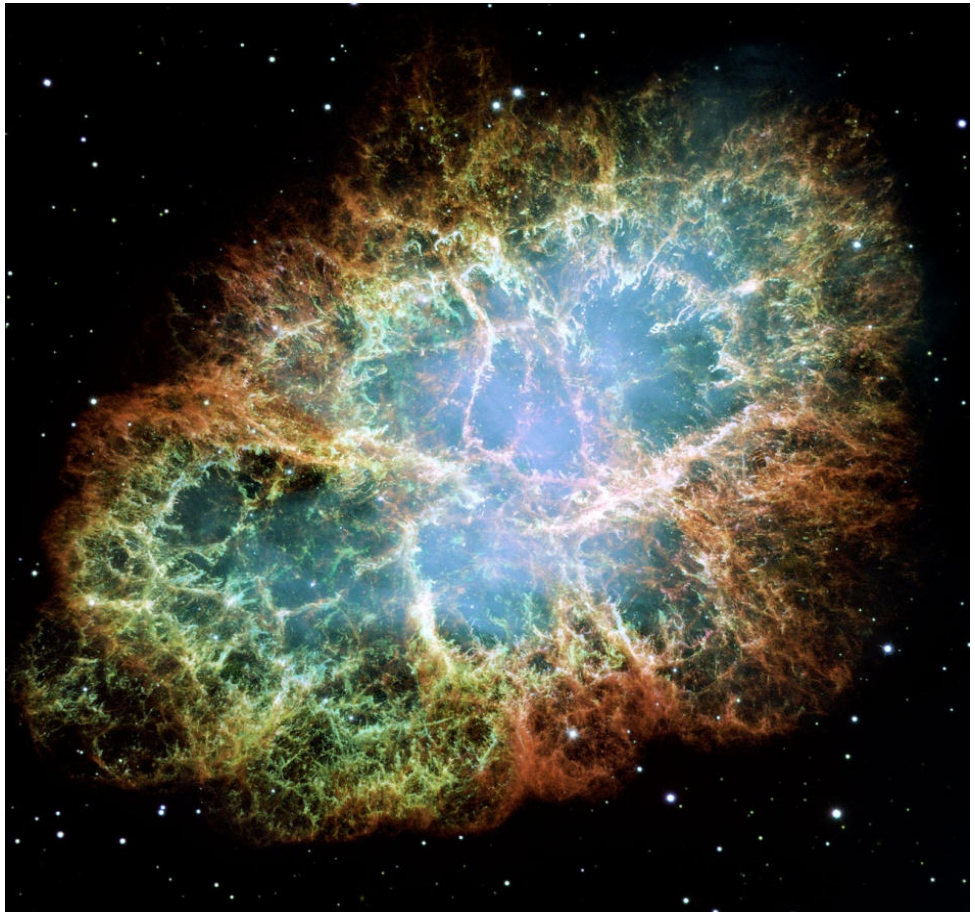
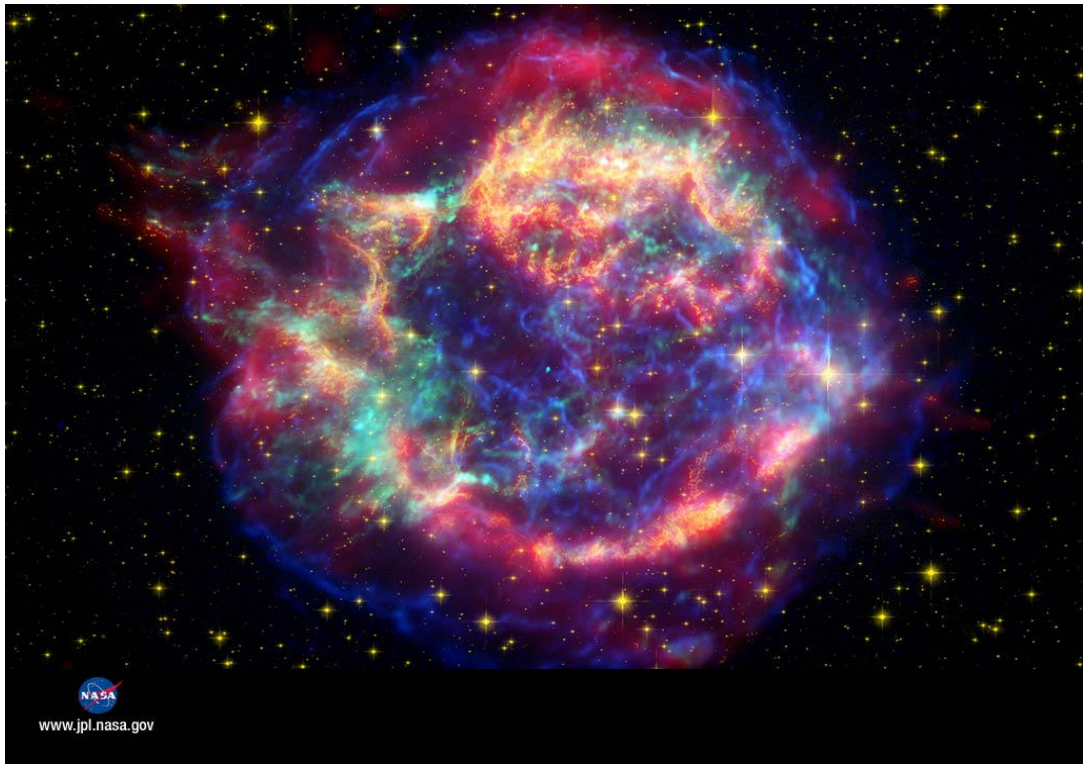
Pulsar Wind Nebulae (Plerions)



(*Aharonian and Bogovalov,* 2003)



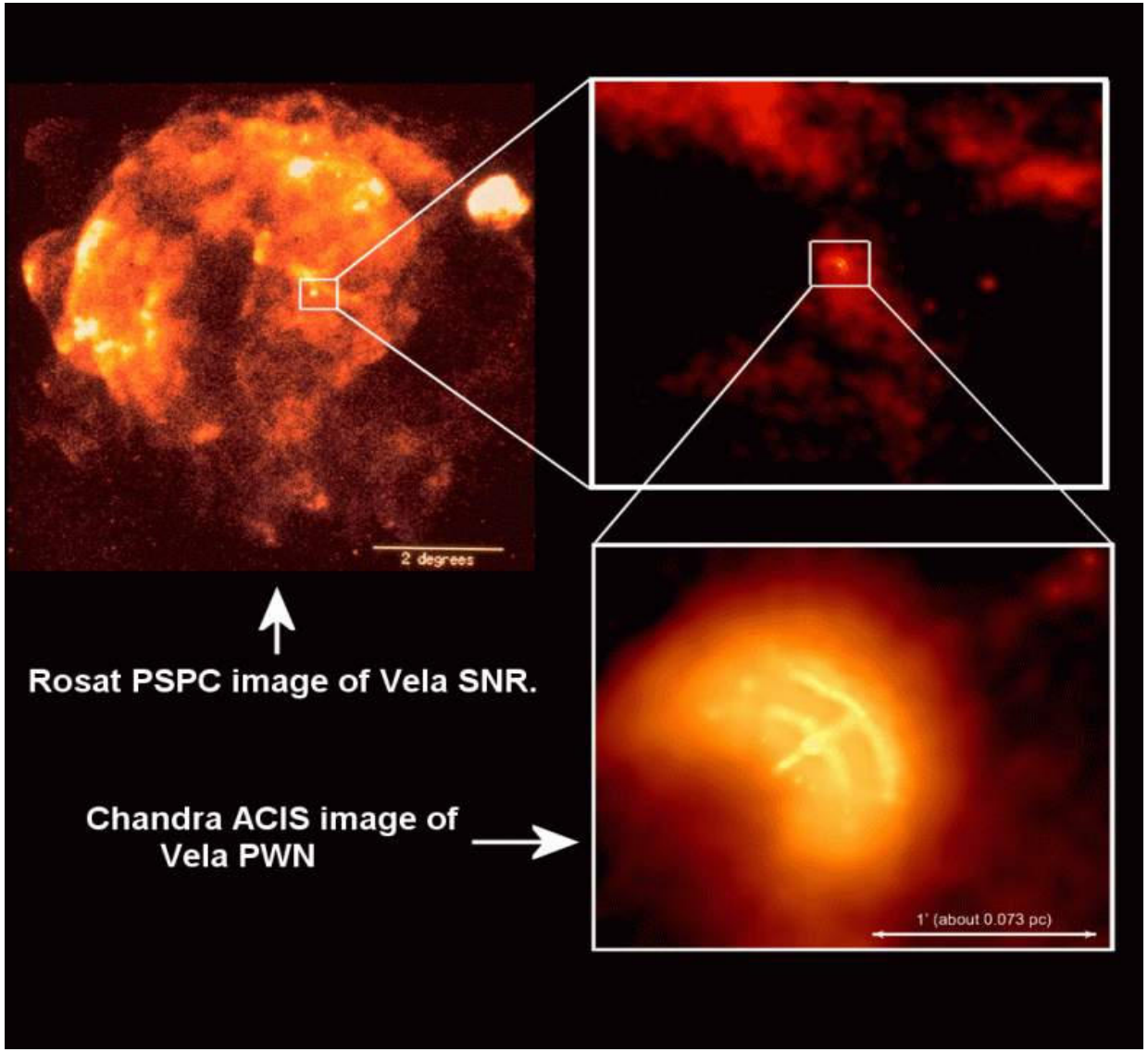

www.jpl.nasa.gov

Properties of PWN’e

- Observable at all wavelengths
- Filled appearance
- Flat radio spectrum
- X-ray spectrum has a steeper photon index
- Well defined magnetic field

(*Weiler and Panagia,* 1980; *De Jager and Djannati-Ataï*, 2009)

The Vela Supernova Remnant

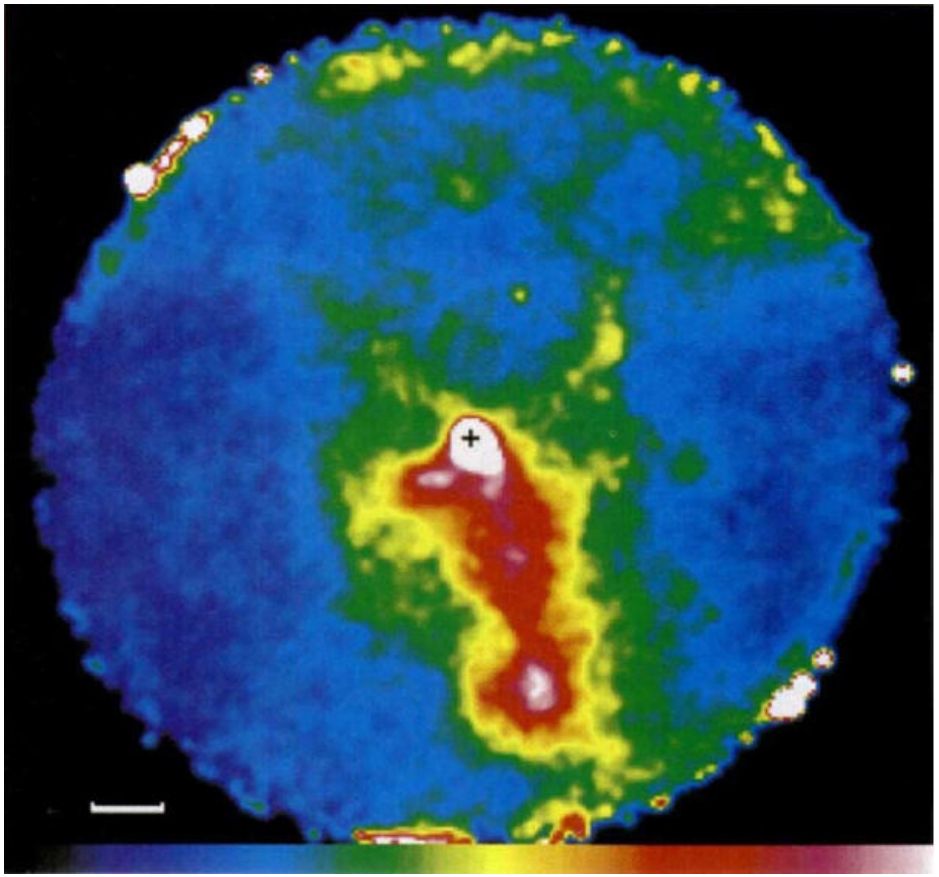


Properties

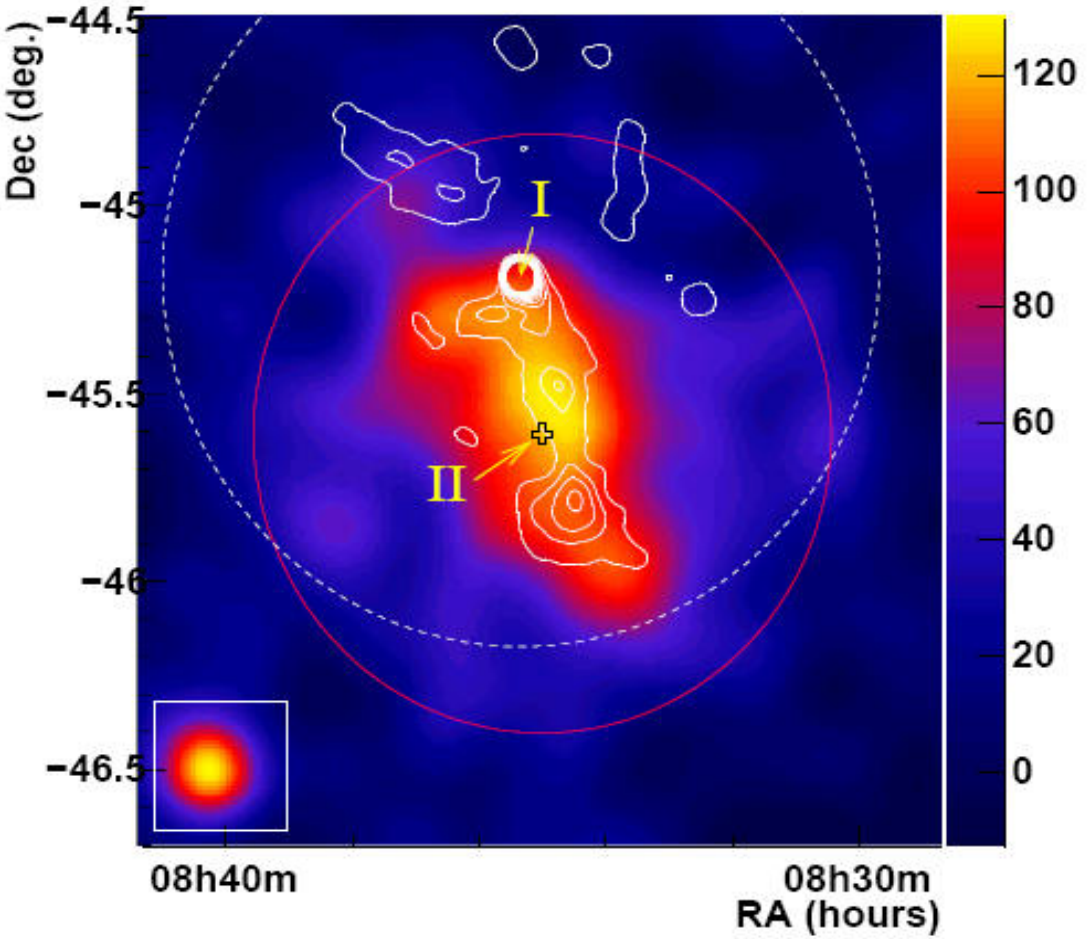
- Pulsar

Property	Value	Reference
Pulsar name	PSR B0833-45 (Vela)	*Large et al.* (1968)
Spin period (P)	89 ms	*Large et al.* (1968)
Distance to pulsar	$\sim$ 287 pc	*Dodson et al.* (2003b)
Surface magnetic field (B_S)	$\sim 3 \times 10^{12}$ G	*Mori et al.* (2004)
Rate of energy loss ($\dot{E}$)	$\sim 7 \times 10^{36}$ erg/s	*Manzali et al.* (2007)
Characteristic age of pulsar (τ_c)	$\sim$ 11 400 yrs	*Manzali et al.* (2007)

- Displaced PWN



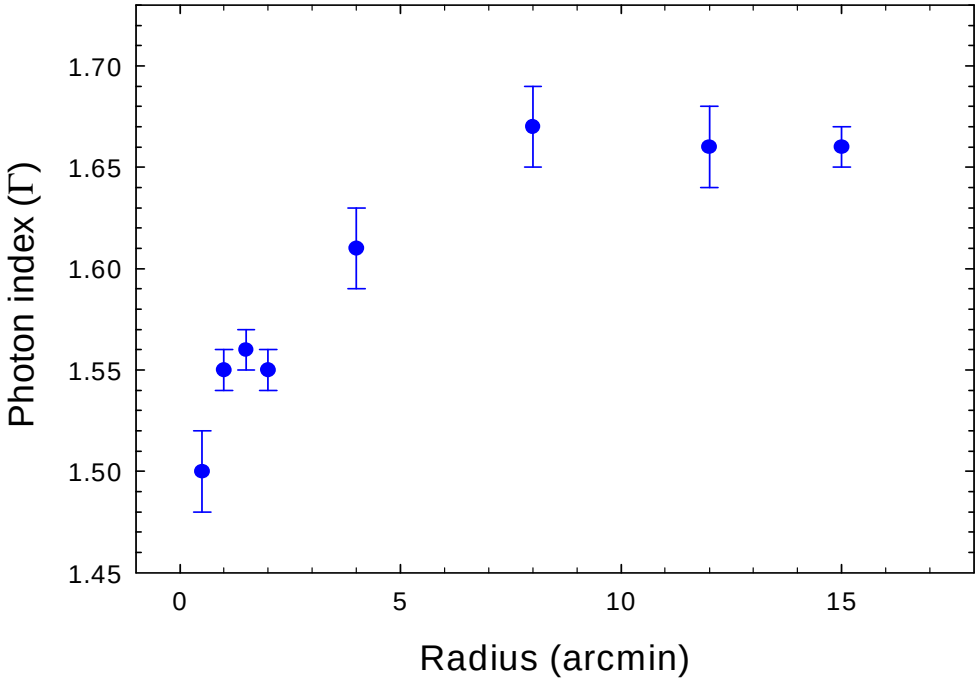
(0.9-2 keV: *Markwardt and Ögelman*, 1995)

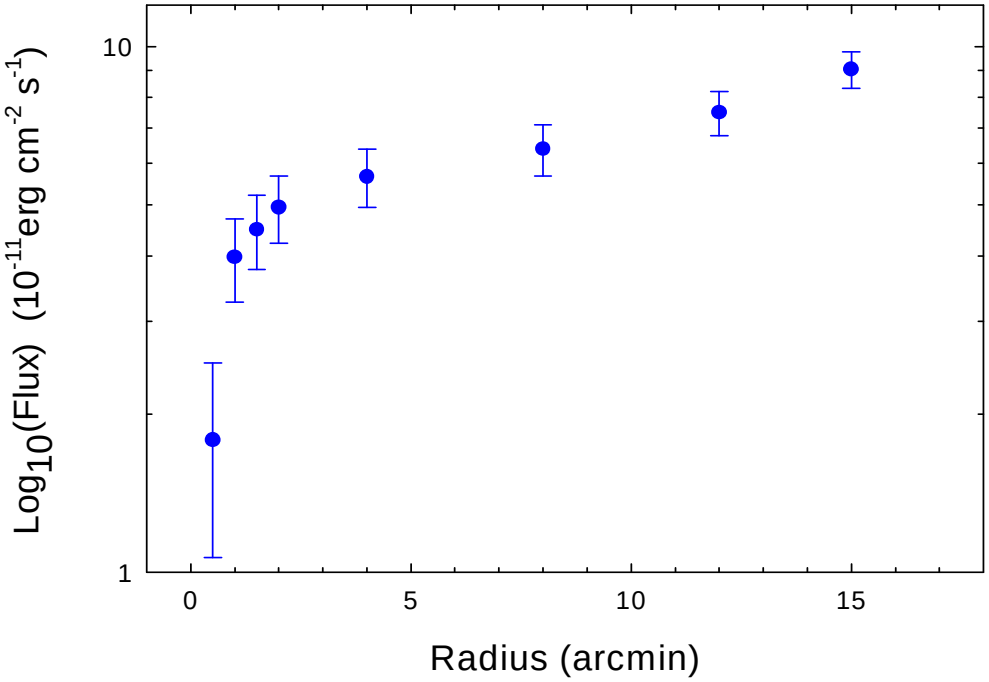


(0.55-65 TeV: *Aharonian et al.*, 2006)

The Model

- Mangano *et al.* (2005): *XMM-Newton* (3-10 keV)
  - photon index a function of distance from pulsar
  - synchrotron cooling
- Model X-ray emission from compact nebula





Lepton Injection Spectrum

- Broken power-law

$$Q(E_{\rm e}) = \begin{cases} Q_0 (E_{\rm e}/E_{\rm b})^{-p_1} & \text{if } E_{\rm e} < E_{\rm b} \\ Q_0 (E_{\rm e}/E_{\rm b})^{-p_2} & \text{if } E_{\rm e} \geq E_{\rm b} \end{cases}$$

- Determining Q_0

$$\int_{E_{\rm b}}^{E_{\rm max}} Q(E_{\rm e}) E_{\rm e} {\rm d}E_{\rm e} = \eta \dot{E}$$

$$\int_{E_{\rm b}}^{E_{\rm max}} Q_0 \left(\frac{E_{\rm b}}{E_{\rm e}}\right)^{p} E_{\rm e} dE_{\rm e} = \eta \dot{E}$$

- Time-independent

- $p \neq 2$

$$Q(E_{\rm e}) = \frac{\eta \dot{E}}{E_{\rm e}^{p}} \frac{(2-p)}{\left[E_{\rm max}^{2-p} - E_{\rm b}^{2-p}\right]}$$

- $p = 2$

$$Q(E_{\rm e}) = \frac{\eta \dot{E} E_{\rm e}^{-2}}{\ln(E_{\rm max}/E_{\rm b})}$$

- Position of PWN shock: r = 0’.35 (*Ng and Romani*, 2004)
- Γ = 1.5 at r = 0’.5 (*Mangano et al.*, 2005)
- Negligible energy loss: p = 2
- Limited dependence on E_b
- Energy loss mechanisms
  - synchrotron
  - adiabatic

Constraints on the Model

- Spherical symmetry

$$\mathbf{v} \sim v\hat{\mathbf{e}}_{\mathrm{r}} \qquad\qquad \mathbf{B} \sim B\hat{\mathbf{e}}_{\phi}$$

- Conservation of magnetic flux in a steady-state MHD approximation

$$\nabla \times (\mathbf{v} \times \mathbf{B}) = 0$$

(*Kennel and Coroniti*, 1984)

- Velocity profile

$$\mathbf{v} = v_{\mathrm{s}} \left(\frac{r_{\mathrm{s}}}{r}\right)^{\delta} \hat{\mathbf{e}}_{\mathrm{r}}$$

- Magnetic profile

$$B(r) = B_{\rm s}\left(\frac{r_{\rm s}}{r}\right)^{\delta-1}$$

- Maximum lepton energy
  - gyroradius limit

$$E_{\rm max} = e\varepsilon B_{\rm s} r_{\rm s}$$

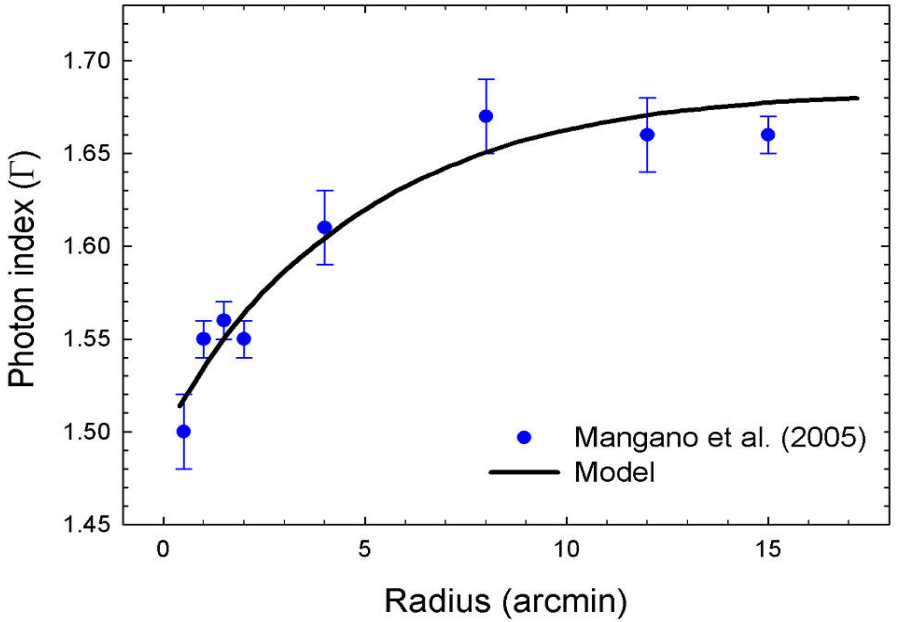
- Minimum lepton energy
  - E_b = 100 GeV

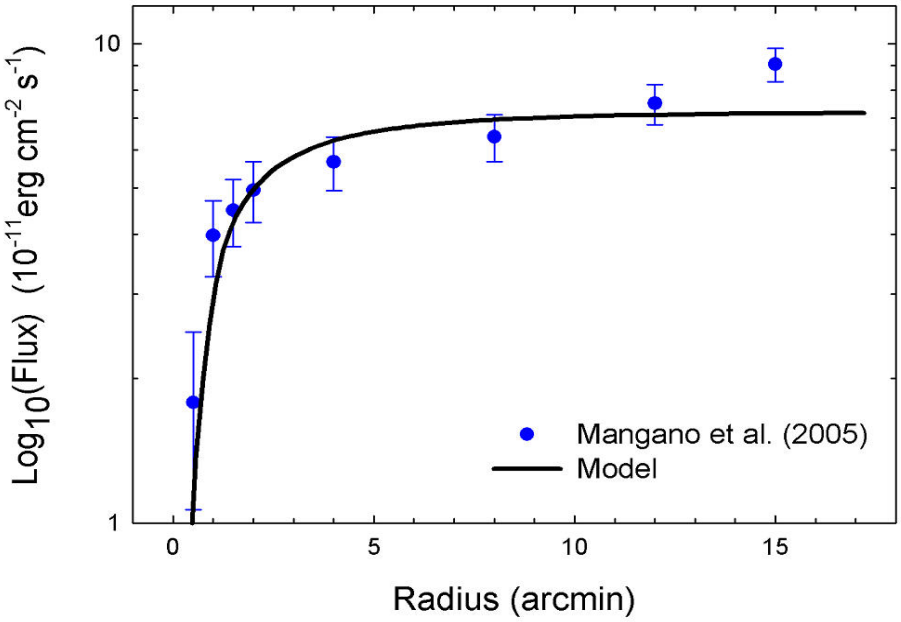
Free parameters

Parameter	Description
η	conversion efficiency of pulsar-spin down power to lepton luminosity
B_s	magnetic field strength at PWN shock
δ	radial profile parameter
ϵ	containment factor

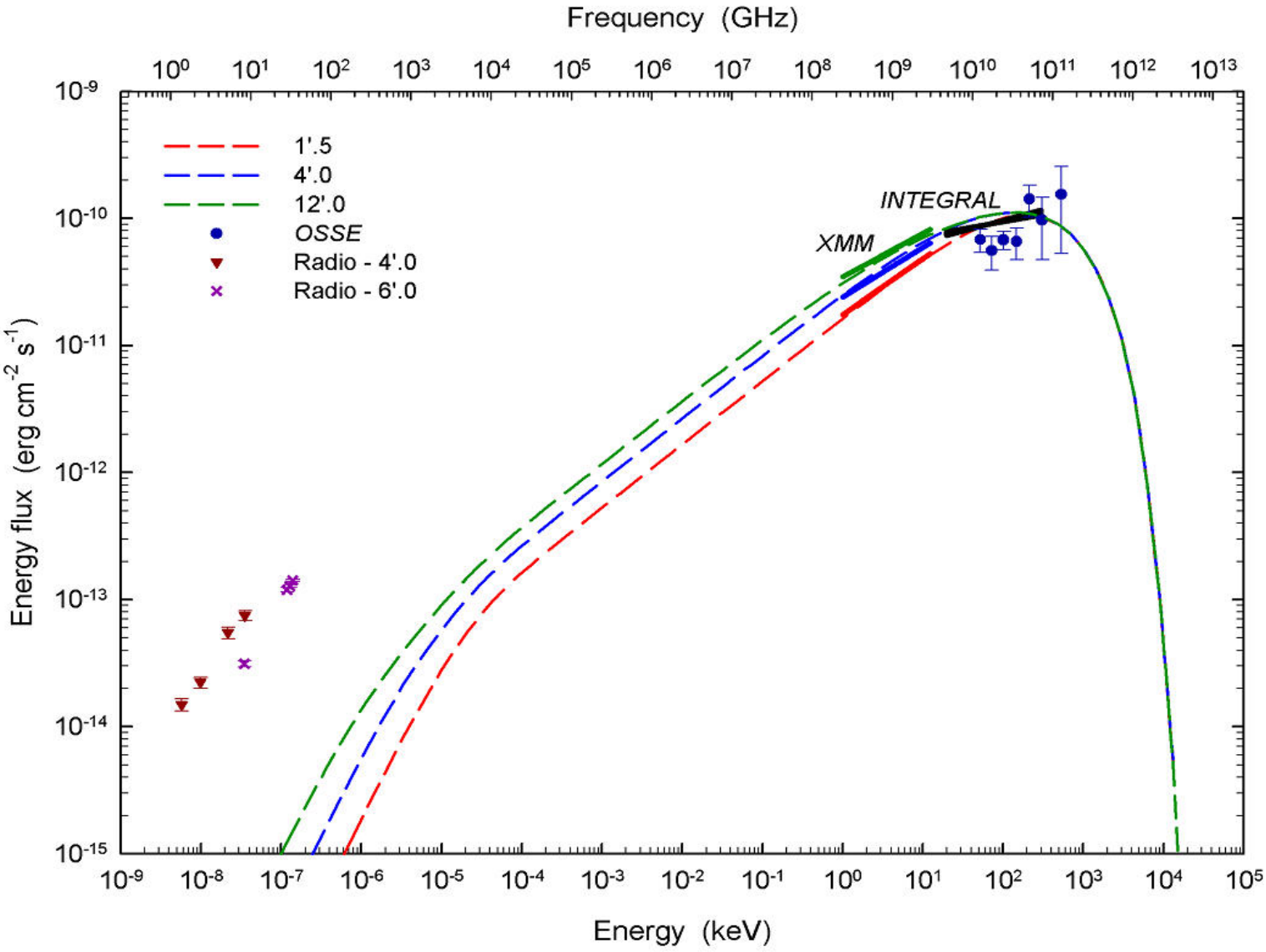
Results and Discussions

Parameter	68 % confidence interval	Best-fit values
η	$0.04 - 0.4$	0.07
δ	$0.4 - 0.6$	0.55
ϵ	$0.1 - 0.5$	0.2
B_s (μG)	$40 - 200$	100
σ_s	> 0.005	$0.03 - 0.3$





Synchrotron spectra



Discussions and Conclusions

- η
  - this study: $\eta > 0.04$
  - *De Jager et al*. (2008): $\eta = 0.003$
  - particle escape from PWN
  - reverse shock?
  - other mature PWN'e?