Deep Chandra Observation of the PWN in SNR Kes 75

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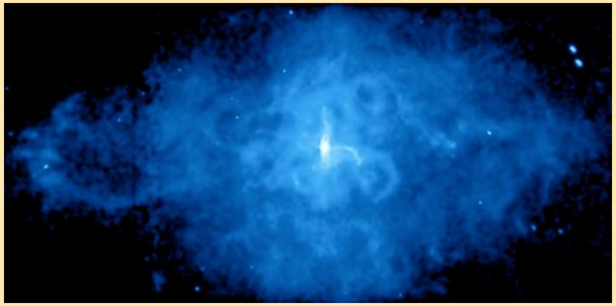
astro-ph/0804.3384

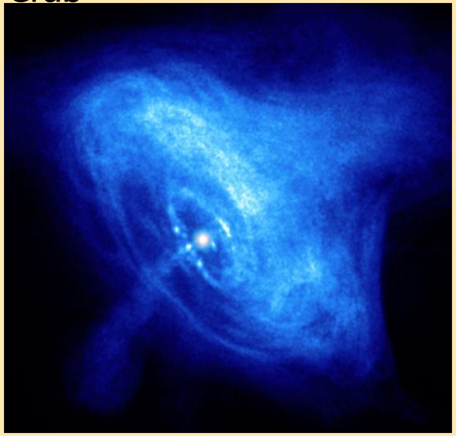
Pulsar Wind Nebula

3C58



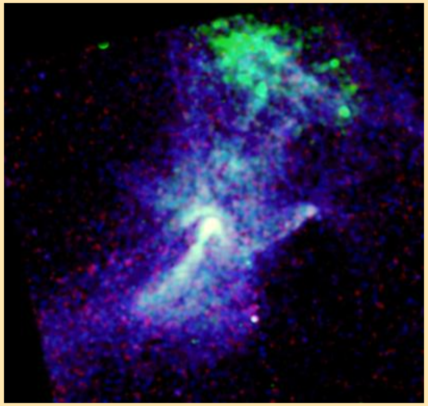
NASA/CXC/SAO/P.Slane et al.

Crab



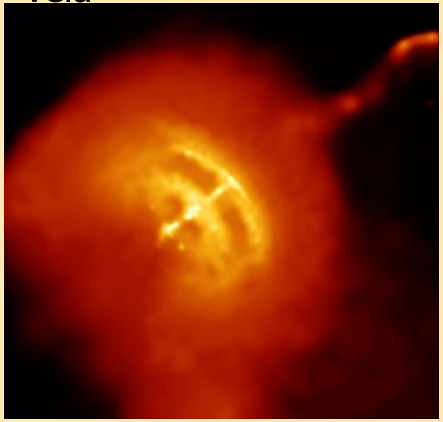
NASA/CXC/ASU/J. Hester et al.

B1509-58 / G320.4-1.2



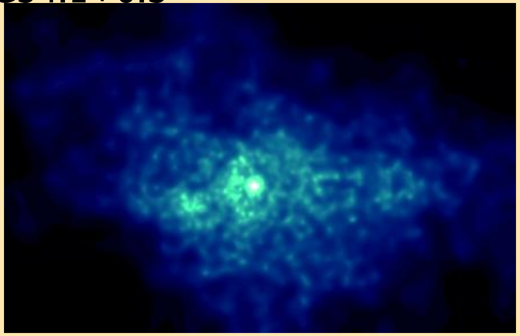
NASA/CXC/MIT/B.Gaensler et al.

Vela



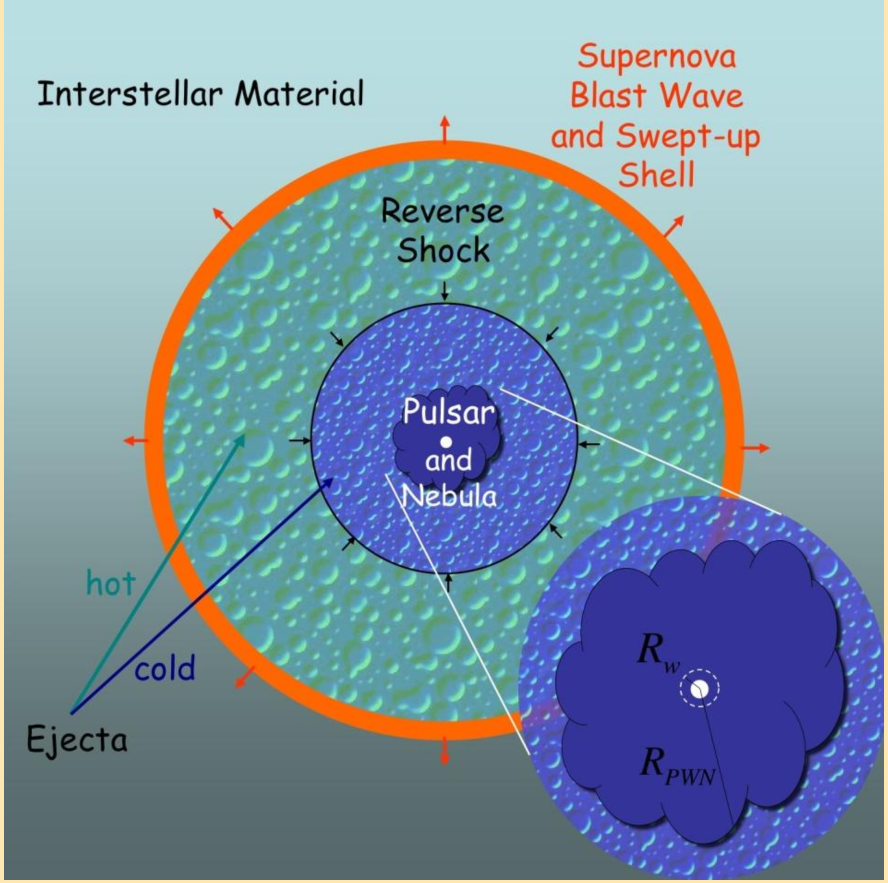
NASA/CXC/PSU/G.Pavlov et al.

G54.1+0.3



NASA/CXC/U.Mass/F.Lu et al.

Pulsar Wind Nebula

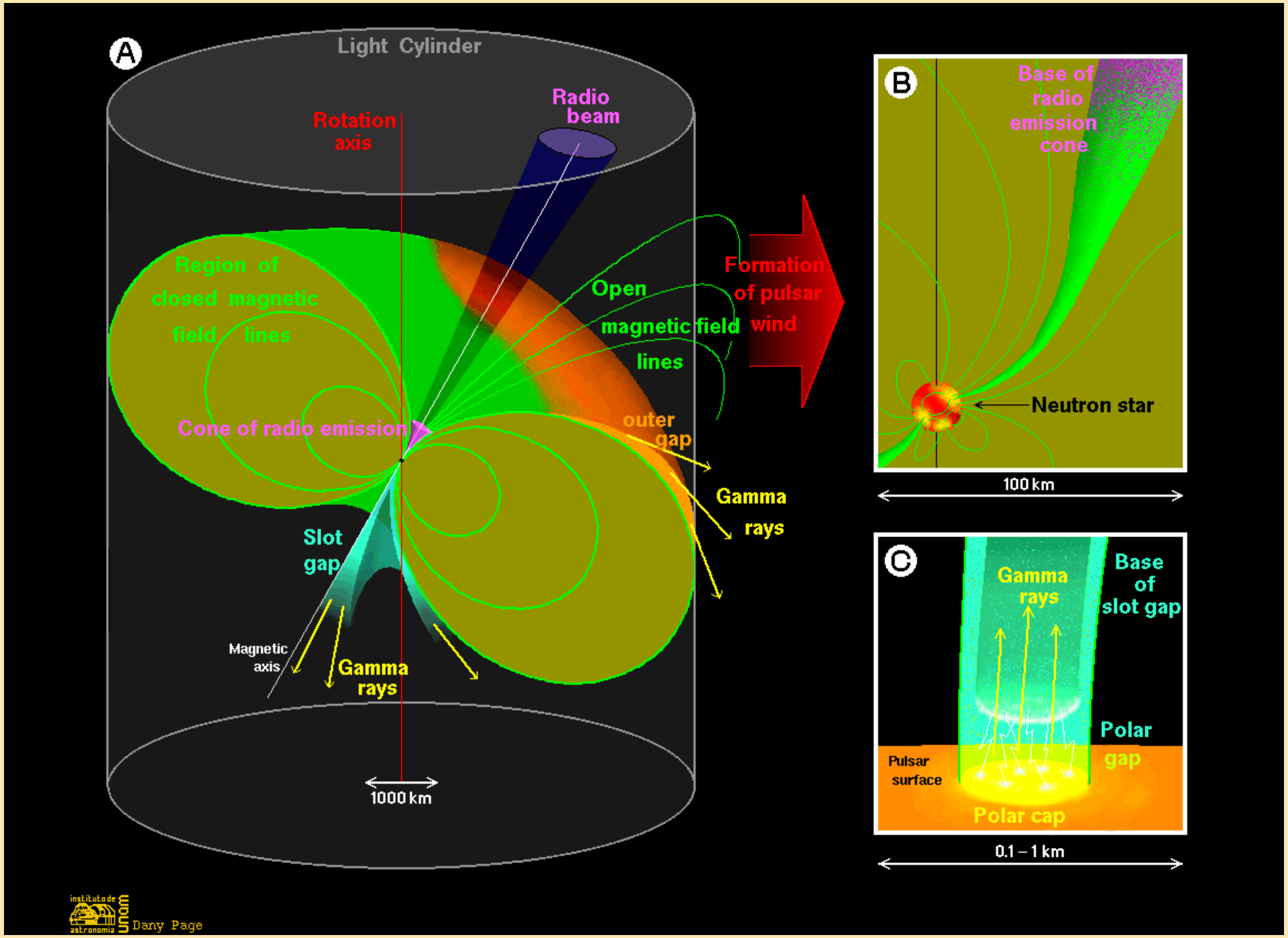


Gaensler & Slane 2006

Termination Shock
-- pressure balance

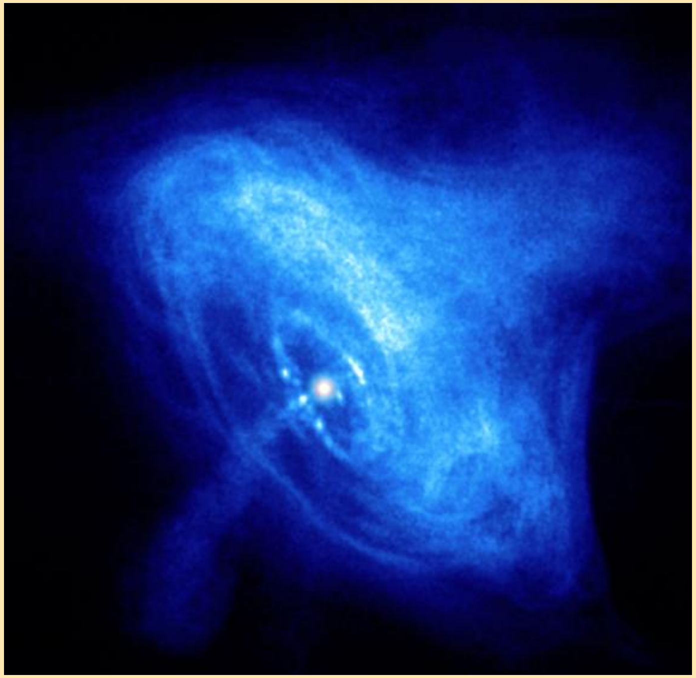
$$R^2 \approx \frac{\dot{E}}{4\pi c P_N}$$

Pulsar Wind

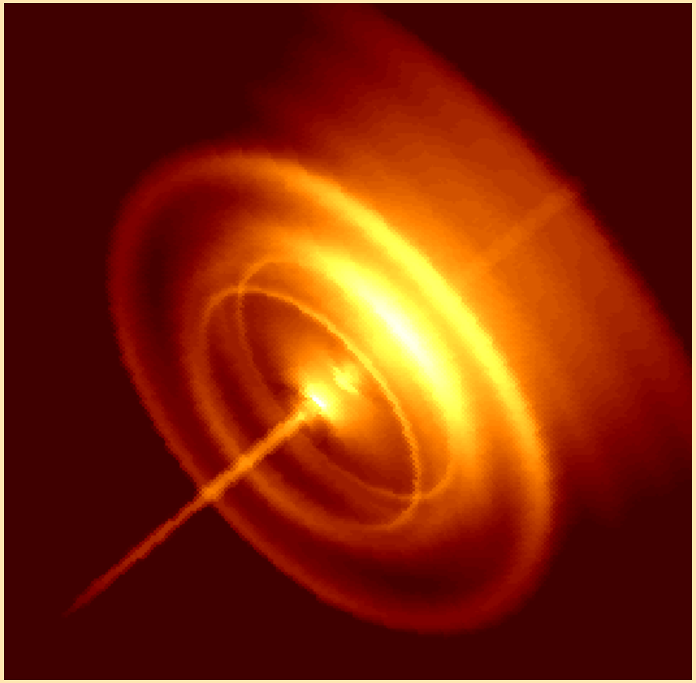


http://www.astroscu.unam.mx/neutrones/NS-Picture/MagSphe/MagSphe.html

Doppler Boosted Torus and Jets



NASA/CXC/ASU/J. Hester et al.



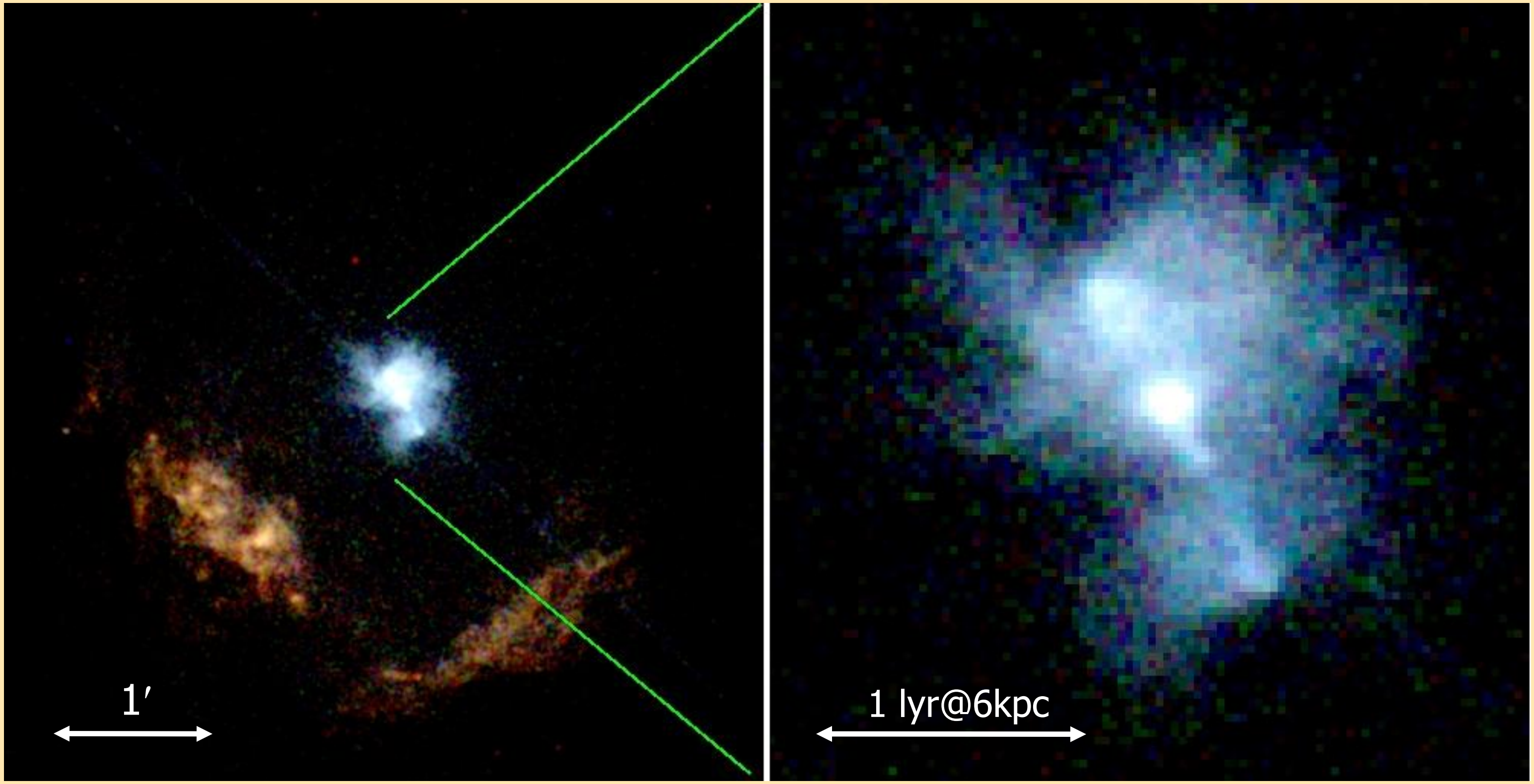
Kommisarov & Lyubarsky (2003)

Supernova Remnant Kes 75

- A young composite supernova remnant
  - 3′ diameter partial shell
- New distance measurement of 6kpc. (Leahy & Tian 2008)
- A central X-ray pulsar J1846-0258, no radio pulsation.
- Integral and HESS detection of the PWN.

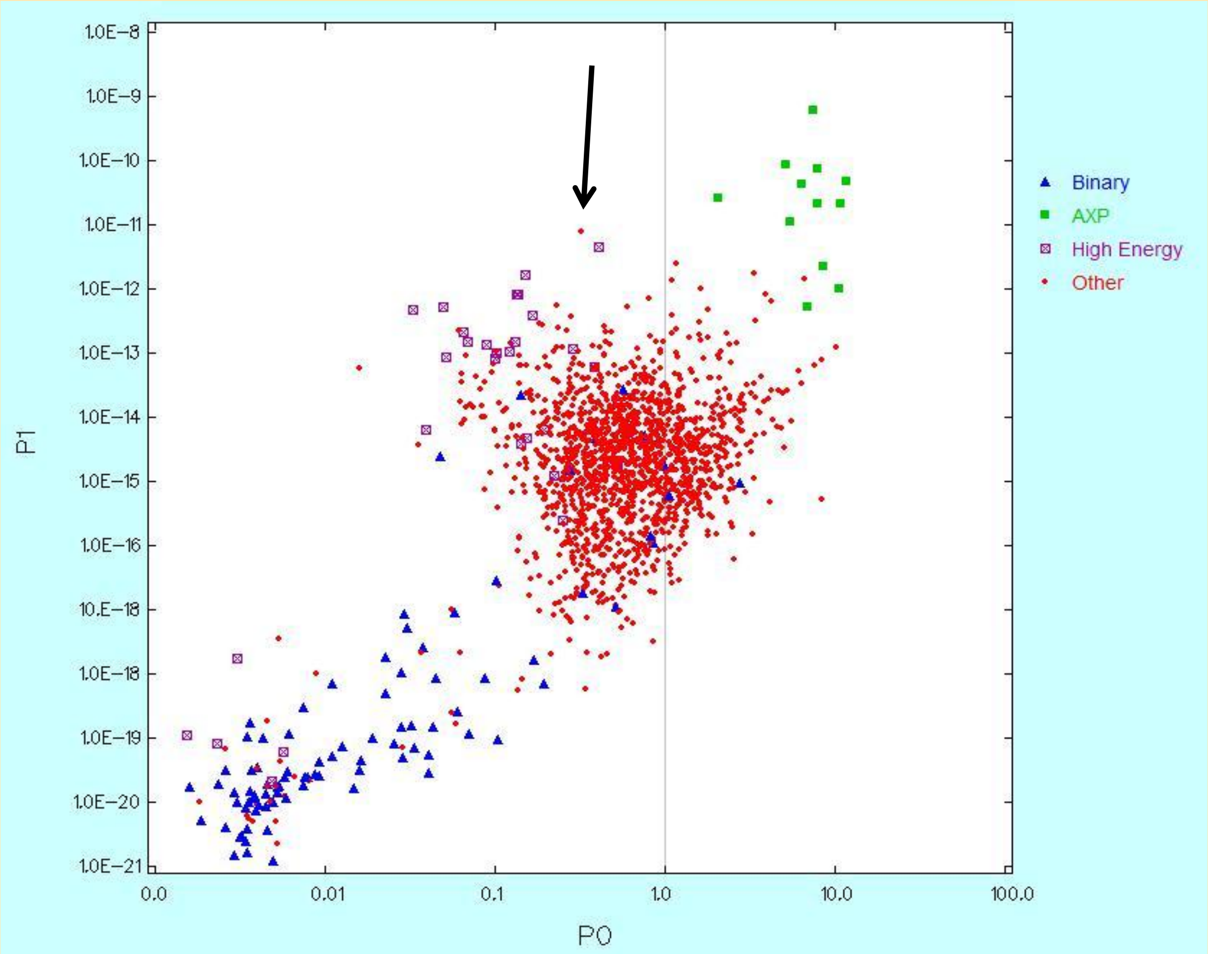
- Chandra ACIS Observations
  - 155ks on Jun 2006
  - 37ks on Oct 2000

Chandra Image of Kes 75



Three-color image of the deep (155ks) Chandra observation in 2006.
(red: 0.5-2keV, green: 2-3keV, blue: 3-5keV)

The Youngest Pulsar in our Galaxy



X-ray Pulsar J1846-0258

$P = 324\mathrm{ms}$

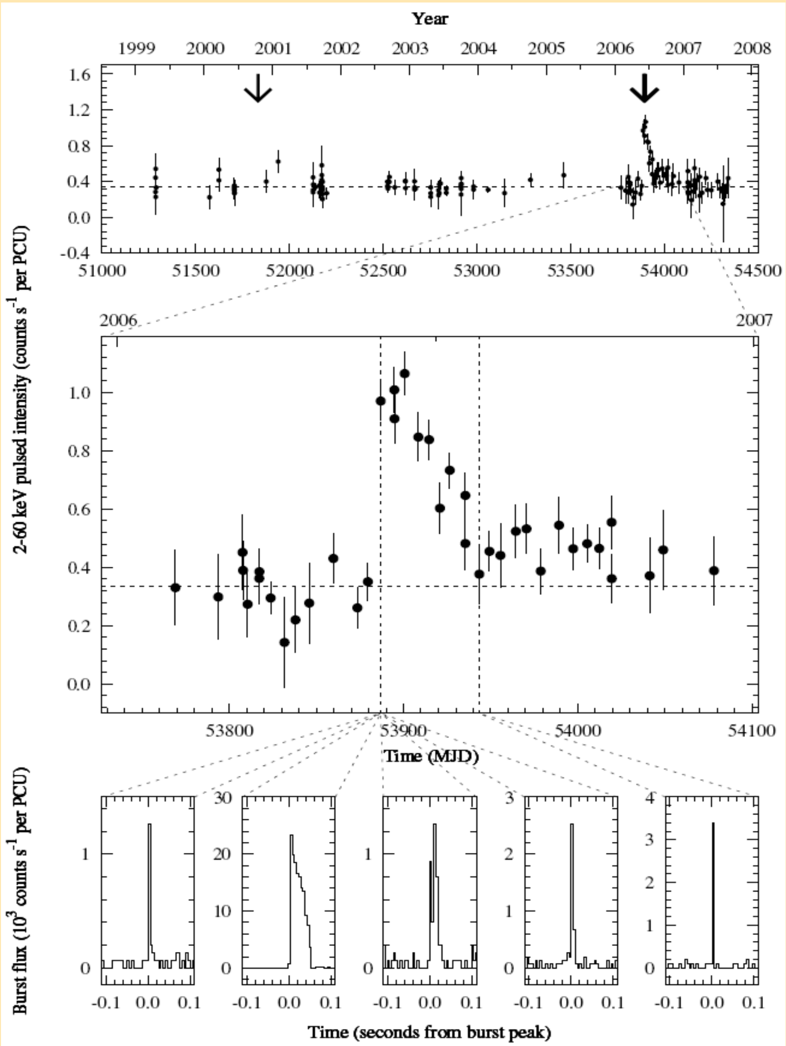
$\dot{P} = 7.1\times10^{-12}\mathrm{ss}^{-1}$

$n = 2.65$

$\tau = 884\mathrm{yr}$

$\dot{E} = 8\times10^{46}\mathrm{ergs\ s}^{-1}$

$B = 5\times10^{13}\mathrm{G}$

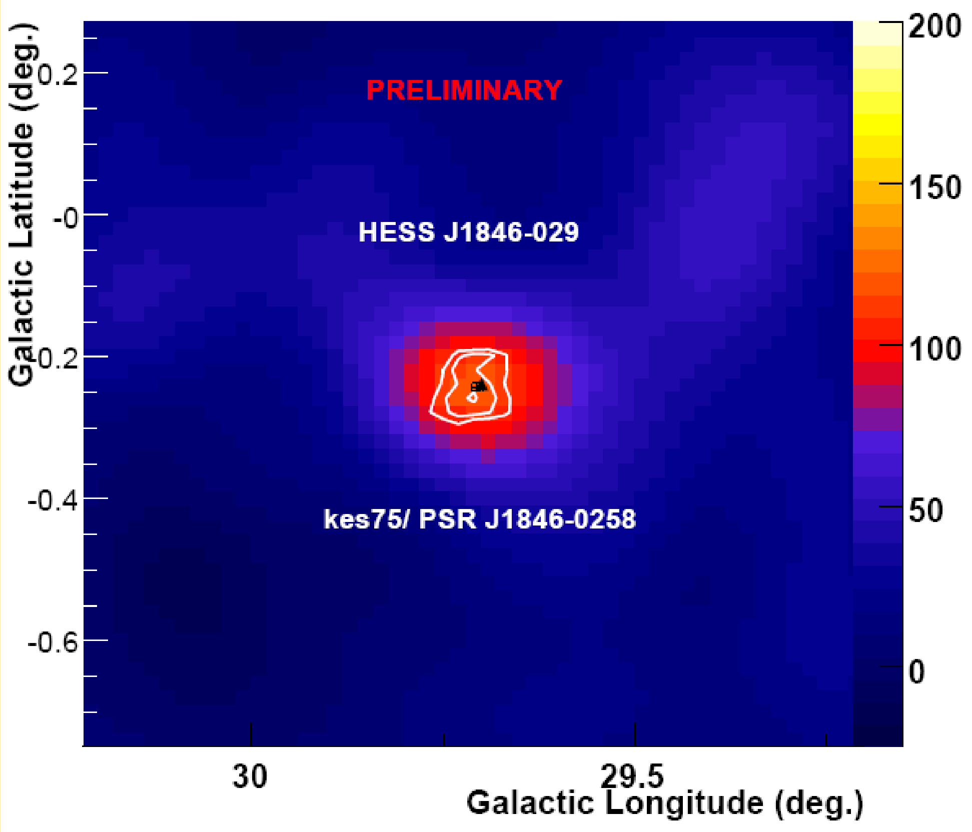


Gavrii et al. (2008)

Magnetar-like bursts

RXTE detected 5 magnetar-like bursts from PSR J1846-0258 in 2006. (Gavrii et al. 2008) 4 occurred 7 days before the Chandra observation, 1 occurred 50 days after.

HESS Detection



Djannati-Atai et al. (2007)

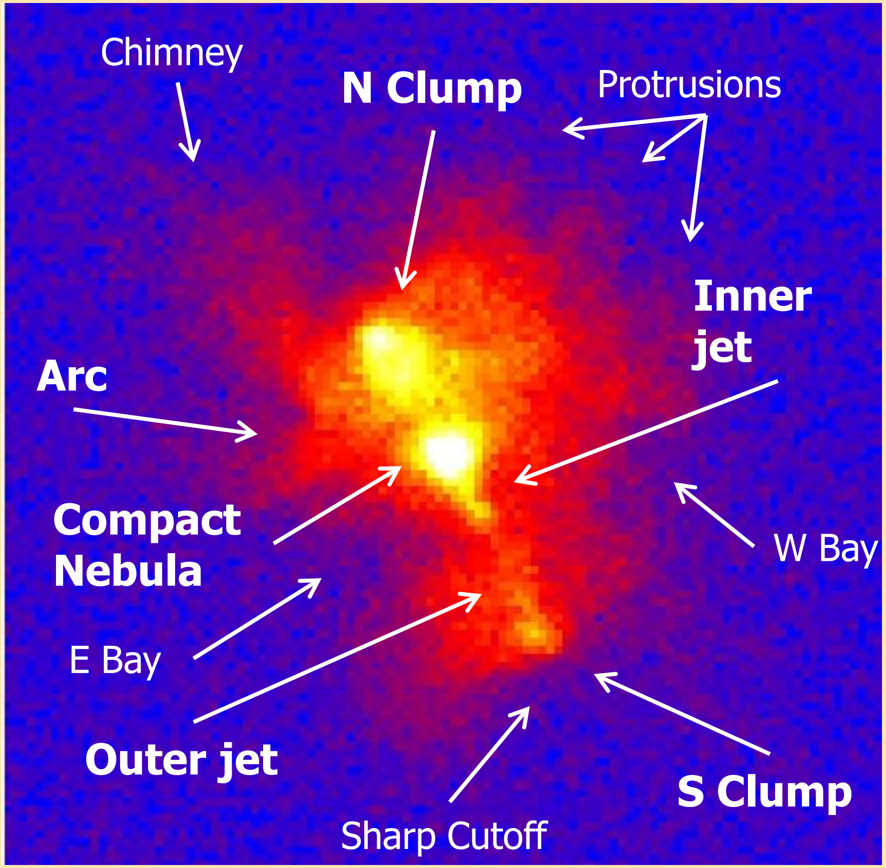
$$\frac{L_X}{L_\gamma} = \frac{\varepsilon_B}{\varepsilon_{\mathrm{ph}}}$$

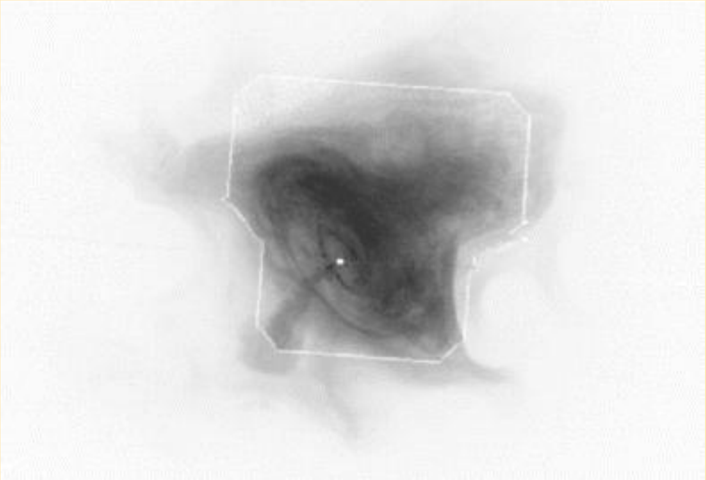
$$\Rightarrow B \sim 15\mu\mathrm{G}$$

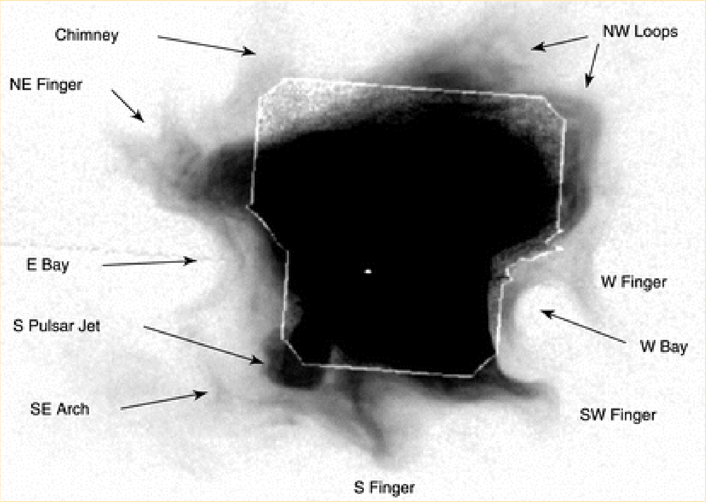
- Also supported by the similar size of the X-ray and radio PWN.

- No direct correlation between the nebular and neutron star field strength.

The PWN Features

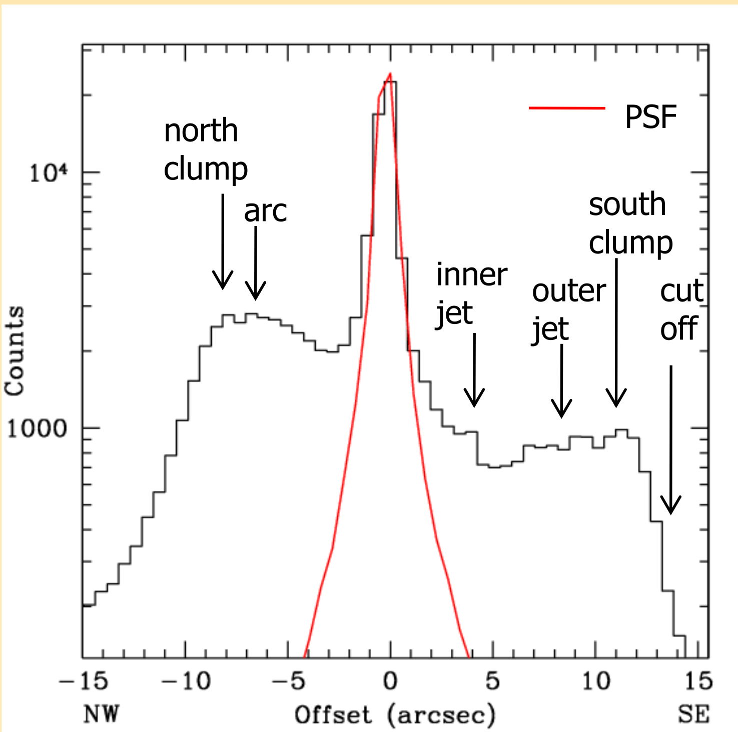




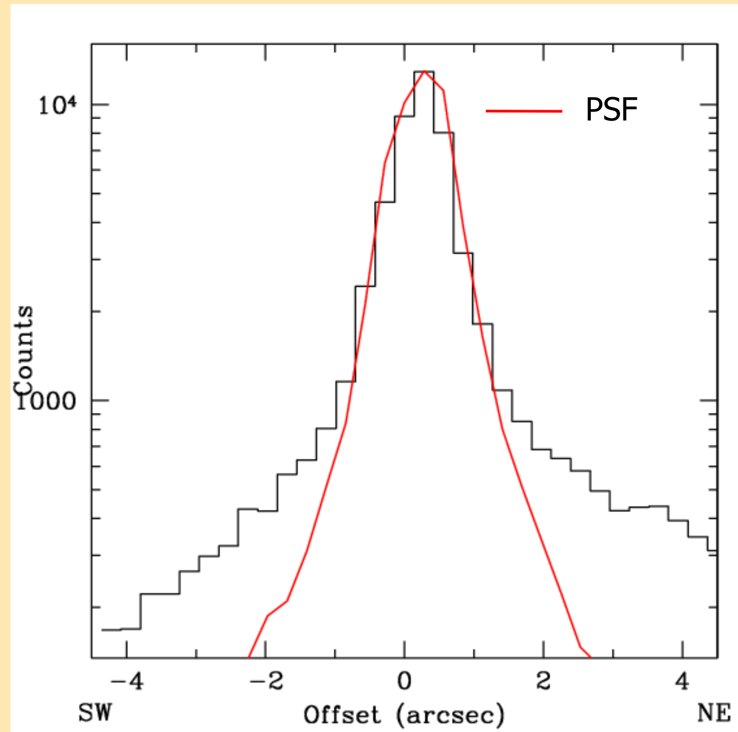


Seward et al. (2006)

Count Profiles

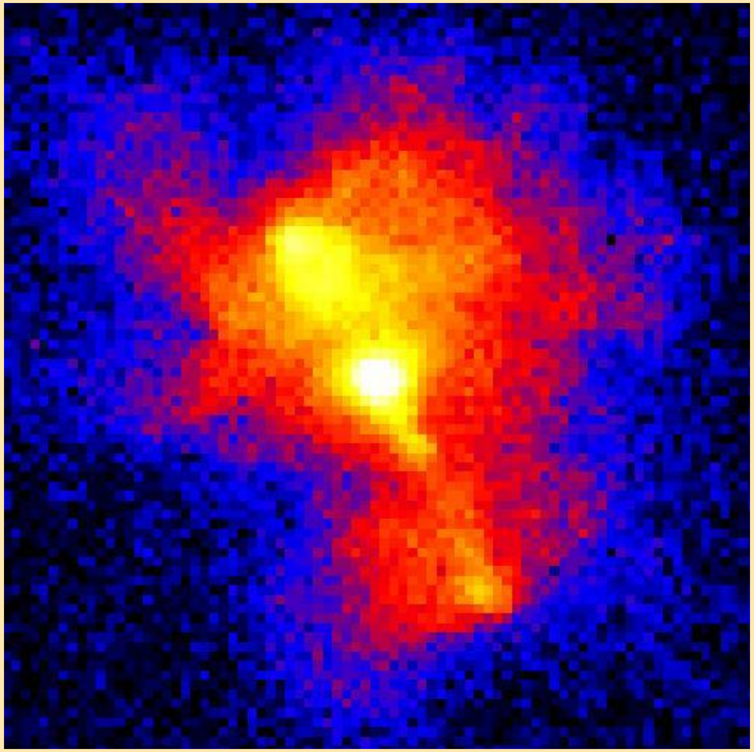


Count profile along the jet direction, showing the clumps, arc and jet features.

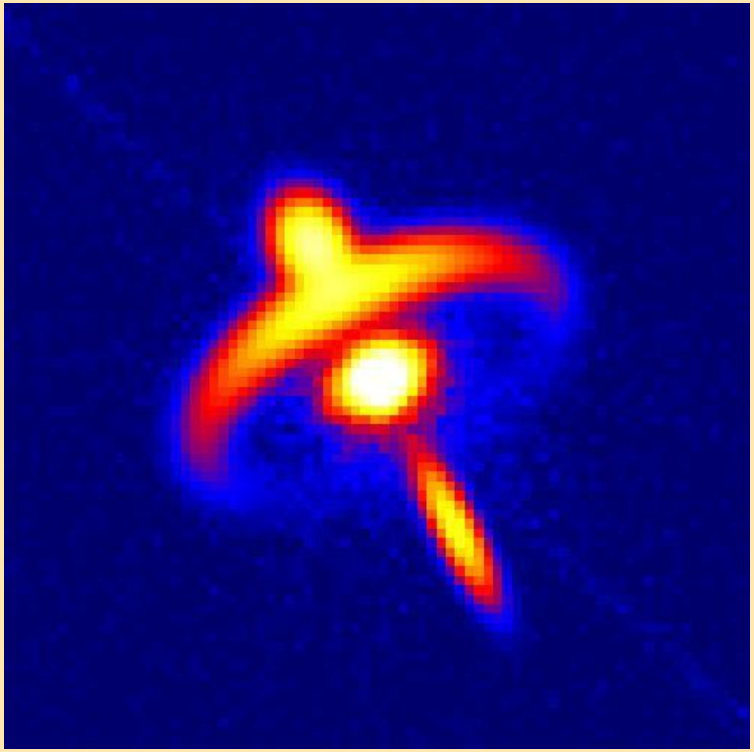


Count profile perpendicular to the jet direction, showing the compact nebula around the pulsar.

Spatial Modeling



2006 observation in 1-7keV



Best-fit torus+jet model

Best-fit torus Parameters

Parameter	Value
Position angle	$207° \pm 8°$
Inclination	$62° \pm 2°$
Radius	$10.1'' \pm 0.4''$
blur	$1''$ (fixed)
β	0.76 ± 0.03
Point Source	61.6×10^3 cts
Torus	26.2×10^3 cts
Compact Nebula	9.1×10^3 cts
Northern Jet	12.2×10^3 cts
Southern Jet	6.4×10^3 cts

Interpretation:

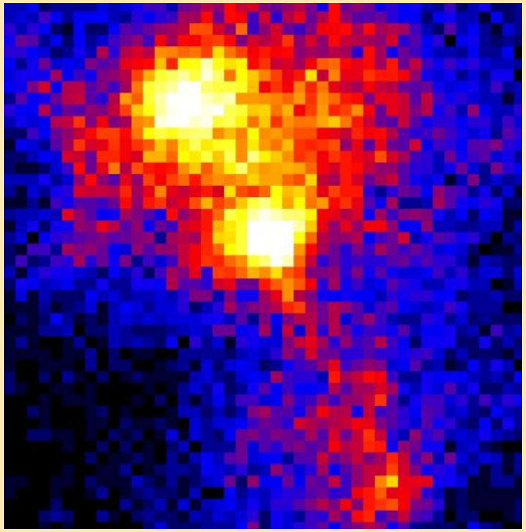
•The arc could be the termination shock => confinement pressure ~10^{-11} dyne cm^{-2}, consistent with the nebular magnet pressure, but 2 orders lower than thermal pressure in the SNR limbs (Morton et al. 2007).

•The compact nebula could be due to repeated bursts.

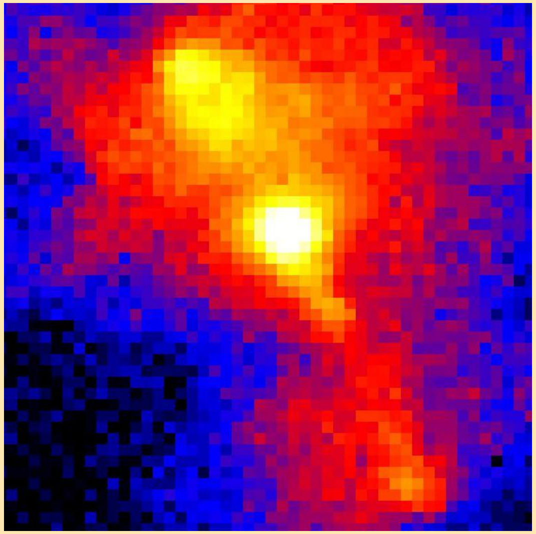
•The clumps cannot be Doppler boosted jets.

Variability

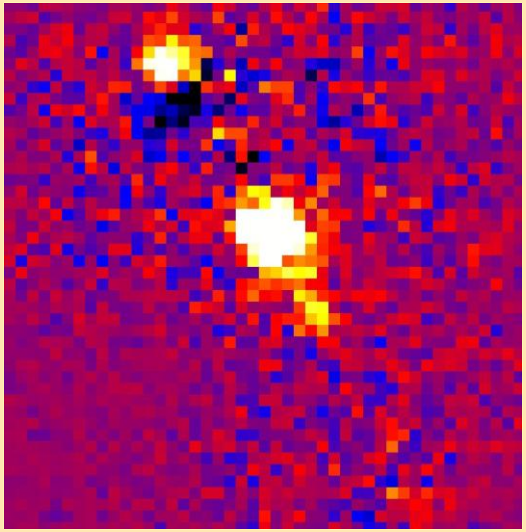
2000



2006

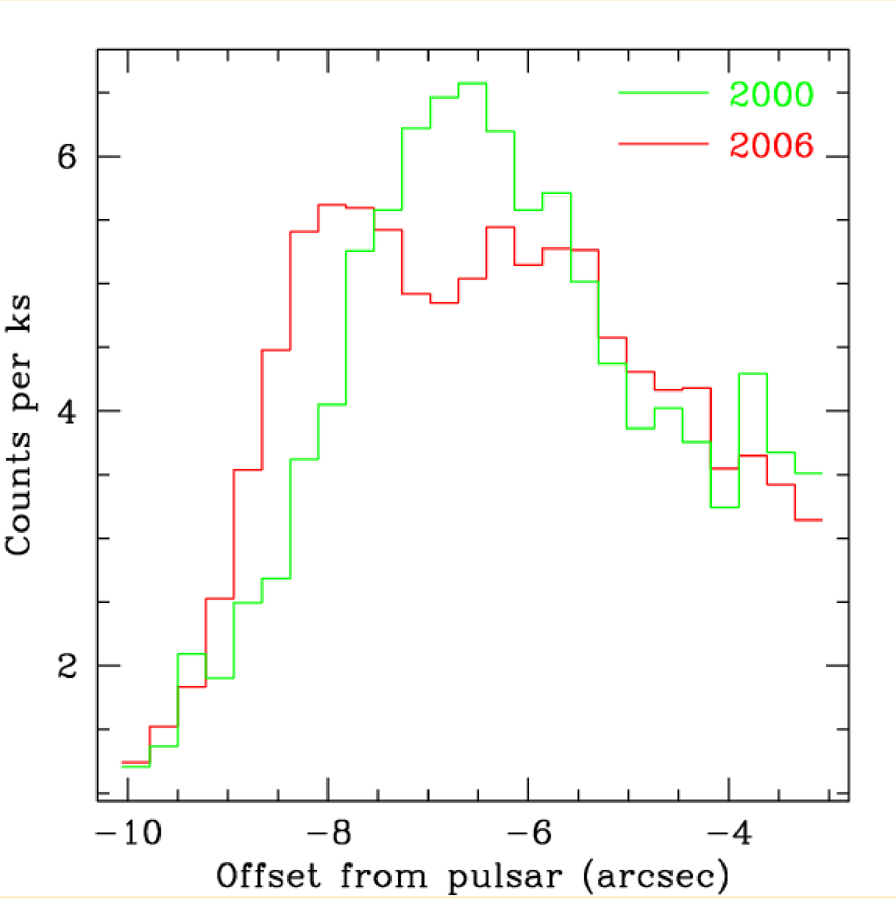


2006-2000

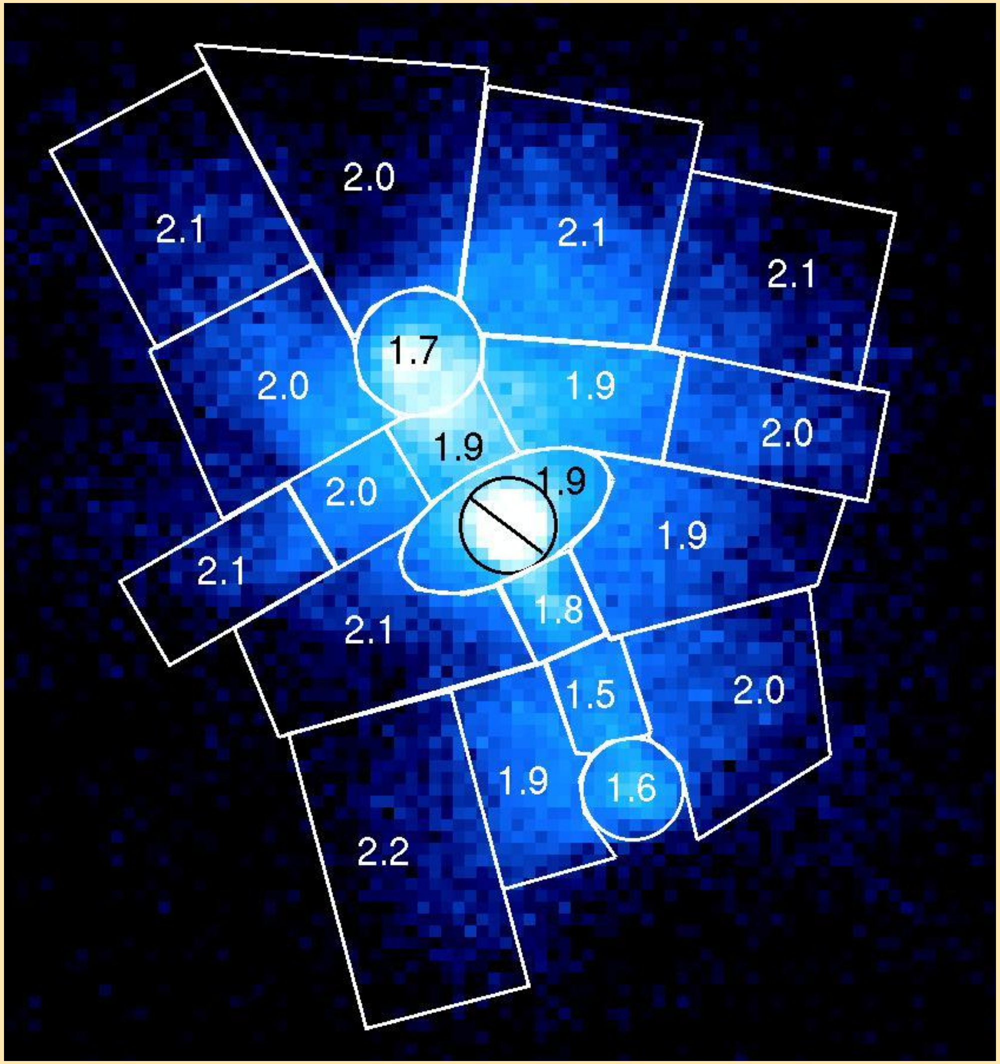


- Brightening of the pulsar and the inner jet.
- Peak of the northern clump has shifted.
- No flux or spectral changes for the overall PWN.

The Northern Clump

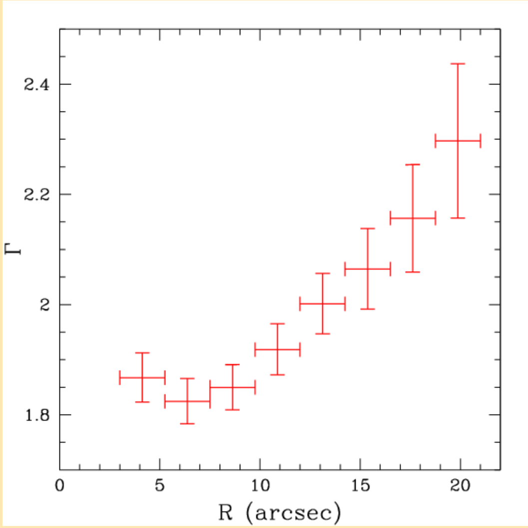


- Total flux is conserved
- No spectral variation



Spectral Map

- Regions along the jet direction are systematically harder.
- Softening as moving away from the pulsar.



Spectral fits to the jet regions

Region	2000 Γ	2000 f^{unabs}	2006 Γ	2006 f^{unabs}
northern clump	1.6 ± 0.1	28.2 ± 1.4	1.6 ± 0.07	28.7 ± 0.7
inner jet	1.6 ± 0.5	2.2 ± 0.4	1.7 ± 0.2	4.3 ± 0.2
outer jet	1.1 ± 0.3	6.0 ± 0.6	1.3 ± 0.2	5.4 ± 0.3
southern clump	1.7 ± 0.3	5.9 ± 0.7	1.5 ± 0.2	4.8 ± 0.3

flux is in the unit of 10^{-11}ergs s^{-1} cm^{-2} in 0.5-10keV

- The inner jet doubles the flux between epochs.
- The outer jet seems to have a harder spectrum than the inner jet .

Physical Interpretation of the Jet

- Lack of a counterjet in the north due to Doppler boosting => bulk flow velocity $v_j > 0.4c$
- X-ray emissivity => $B_j \sim 120\mu G$
- $t_{synch} \gg t_{flow}$
- Variability is unlikely related to the recent bursts.
- The clumps could be shock interaction between the jet and the ambient medium.
- MHD instabilities in the northern clump.

Pulsar Spectrum

Model	Γ	$f_{\rm PL}^{\rm unabs}$	kT (keV)	$f_{\rm BB}^{\rm unabs}$
2000				
PL	1.1 ± 0.1	0.61 ± 0.03	...	...
PL+BB	$1.0^{+0.8}_{-0.3}$	0.61 ± 0.04	0.4 ± 0.4	$0.01^{+0.03}_{-0.01}$
2006				
PL	1.86 ± 0.02	3.7 ± 0.1	...	...
PL+BB	1.9 ± 0.1	3.1 ± 0.6	0.9 ± 0.2	0.32 ± 0.04

flux is in the unit of 10^{-11}ergs s^{-1} cm^{-2} in 0.5-10keV

- Spectrum softened significantly; flux increased by a factor of 6.
- PL+BB is statistically a better fit for 2006 data, but BB component is not observed in 2000. => thermal afterglow
- In quiescence η_{psr}=0.3% , typical among young pulsars.

Summary

- Nebular B-field ≈ 15μG.
- The arc could be interpreted as a termination shock; the clumps may be shock interaction between the jet and the surrounding.
- The jet has a flow velocity $v_j \geq 0.4c$ and $B_j \sim 120\ \mu G$.
- The northern clump and the inner jet show strong variability.
- The pulsar flux increased by 6 times, with a larger photon index ($\Gamma=1.1 \rightarrow 1.9$) and a new thermal component in the spectrum.