The intriguing double torus-jet PWN around PSR J0855-4644

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Vela cocoon
E < 1.3 keV
E > 1.3 keV
HESS

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Polar cap (Daugherty & Harding 1996): Particle acceleration & radiation at the magnetic poles: Radio

Outer Gap (Romani 1996): Particle acceleration & radiation between caustic and light cylinder: X-rays and Gamma rays

Models of outer-gap emission of gamma rays predict $\zeta > 45$ deg and large $\alpha - \zeta > 30$ deg (Romani & Yadigaroglu 1995 & references)
Resolved sub arc second structures of the PWNe:

a) **Anisotropic wind structures** (tori/jet)
b) **Bow shocks**
c) **Signatures of PWN interaction with ambient med**

The classic PWN

Weisskopf 2000
Resolved sub arc second structures of the PWNe:

a) **Anisotropic wind structures** (tori/jet)
b) **Bow shocks**
c) **Signatures of PWN interaction with ambient med**

**PWNe ZOO**

Pavlov & Kargalstev 2006
PSR J0855-4644: nearby fast spinning, energetic radio pulsar

- Fast pulsar $P = 65$ ms $\dot{E} = 1.1 \times 10^{36}$ erg/s (Parkes radio survey)

- Distance $< 1$ Kpc (X-ray Nh); second most energetic pulsar after Vela at this distance

- Radio loud, Gamma ray quiet $\rightarrow$ high $\dot{E}/d^2$

- Why no gamma rays? Geometry?
Through the eyes of XMM-Newton

R1=15"

X-ray counterpart of pulsar?

Through the eyes of Chandra: Structured PWN revealed!

**Chandra: ACIS-S observation**
- What was thought to be X-ray pulsar: further resolved (< 0.05 pc)
- Axisymmetric structures like jets/torii:
- Further signatures of young energetic pulsar
- Very faint pulsar; factor of 10 fainter than nebula
Energy resolved images

B
0.5-2 keV
Energy resolved images

A

2-8 keV
A close look at the PWN:

a) only third source after \textit{Vela} & \textit{PSR J2021+3651} to show this morphology

b) Nearby object: opportunity to study physics of equatorial & polar outflows in PWNe
Count profile
Spectroscopy

Confirming the XMM results

XMM (R: 15 ″): NH=(0.64±0.12) x 10^{22} \text{ cm}^{-2}
Chandra (R: 15 ″): NH=(0.70±0.20) x 10^{22} \text{ cm}^{-2}

Reducing systematic uncertainties —— Thermal emission 50 times less

- Compare the spatially resolved structures of the PWN
- pulsar vs the axisymmetric structures
Spectroscopy of PWN structures

- **Pulsar**
  - $K_T = 0.20 \pm 0.05$

- **Total nebula**
  - $\Gamma = 1.12 \pm 0.25$

- **Inner nebula**
  - $\Gamma = 1.20 \pm 0.16$

- **Annular nebula**
  - $\Gamma = 0.90 \pm 0.26$

- **East Blob**
  - $\Gamma = 0.93 \pm 0.38$

- **West Blob**
  - $\Gamma = 1.30 \pm 0.33$
Spatial modeling: Can we answer why no Gamma ray emission?

Constraints from imaging & spectroscopy
- One sided outer jet means intrinsically one sided outflow or it cannot be seen. Latter implies either high doppler boosted velocity or low spin inclination \( \zeta \).
- Lack of non-thermal X-rays from pulsar implies, viewing of surface emission only —from the OG model it implies low spin inclination \( \zeta \).

Morphological fitting of ‘double torus’ using Ng & Romani 2004 model.
- Parameters PA \( \Psi \) (N to E), spin inclination \( \zeta \), torus radius \( r \), postshock velocity \( \beta \).
- To investigate effect of systematic errors east jet structure masked.
- Pulsar modeled with PSF, double tori model convolved with PSF.
Results

- Spin inclination angle $\zeta = 34.6^\circ \pm 1.4^\circ \pm 4.5^\circ$
Geometry of PSR J0855-4644

- Double torii fit to the PWN implies $\zeta < 40°$
- Standard gamma ray OG models imply $(\alpha, \zeta) < (40, 40°)$, supported by absence of non-thermal X-rays
- Small viewing angles limit access to X-ray/gamma ray beam? Absence of gamma ray emission from a high $\dot{E}/d^2$ pulsar

Investigate further by phase plots/light curves from radio model
Phase plots and light curves generated assuming the radio emissivity model with P=65 ms (beam width depends on P) & gamma ray emissivity model.

Results obtain for both PC and OG model to match the observed radio pulse profile for different combinations of $\alpha$, $\zeta$.

Derive $\alpha$, $\zeta$ based on radio visibility, and gamma ray non-visibility constrain

$\beta = |\alpha - \zeta|$.

Model does not predict flux, but match normalized pulse shape to the observed profile.

Comparison with observation

\[ \zeta < |40| \, ^\circ \]
\[ \beta = |\alpha - \zeta| < 20 \, ^\circ \]

alpha, zeta 10,30
alpha, zeta 20,30
alpha, zeta 20,40
PSR J0855 radio pp

Diagram showing normalized intensity (Norm Int) vs. phase, with various labeled curves and annotations.

Spatial modeling by double torii

Non-detection of non-thermal X-rays

- $\zeta < |40| \, ^\circ$
- $\beta = |\alpha - \zeta| < 20 \, ^\circ$ & OG model of pulsar emission

Radio pulse shape modeling & non-detectibility of gamma rays

Non-detection of gamma rays in a high $\dot{E}/d^2$ pulsar
THANK YOU