Unveiling the intriguing nature of PSR J0855-4644: why no Gamma rays?

Chandreyeee Maitra
a) **Anisotropic wind structures** (tori/jet)
b) **Bow shocks**
c) **Anisotropies**

Gaensler & Slane 2008
Resolved sub arc second structures of the PWNe:

- Anisotropic wind structures (tori/jet)
- Bow shocks
- Anisotropies

Celebrating 20 Years of Chandra
Revolutionized the study of pulsar wind nebula!
Resolved sub arc second structures of the PWNe:

a) **Anisotropic wind structures** (tori/jet)

b) **Bow shocks**

**PWNe ZOO**

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

- Fast pulsar \( P = 65 \text{ ms}, \dot{P} = 7.26 \times 10^{-15}, \dot{E} = 1.1 \times 10^{36} \text{ erg/s} \) (from Parkes radio survey)

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

- Highest \( \dot{E}/d^2 \) system not seen by Fermi
Through the eyes of XMM-Newton

PWN revealed ~150" in extent
Through the eyes of Chandra: Structured PWN revealed!

- **Chandra: 38 ks ACIS-S observation**
  - What was thought to be X-ray pulsar: further resolved to 10′′ compact PWN (0.06 pc)
  - Two lobes symmetric about the pulsar
  - Very faint pulsar; contributes to 1% of flux of the XMM compact source, no non-thermal emission

- radio PSR
- jets
- double torus+one sided jet
Spatial modeling: torus & jet structures indicate **spin inclination** of the pulsar.

- Parameters: PA $\Psi$ (N to E), spin inclination $\zeta$, torus radius ($r$), postshock velocity $\beta$ (Ng & Romani 2004)
Spatial modeling: Can we answer why no Gamma ray emission?

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>position angle $\Psi$</td>
<td>$114.4 \pm 2.3 \pm 1.1 \pm 2.3^\circ$</td>
</tr>
<tr>
<td>spin inclination $\zeta$</td>
<td>$32.5 \pm 4.0^\circ \pm 1.7^\circ$</td>
</tr>
<tr>
<td>radius of each torus $R$</td>
<td>$2.1 \pm 0.06 \pm 0.08^\circ$</td>
</tr>
<tr>
<td>post-shock flow velocity $\beta$</td>
<td>$0.41 \pm 0.06 \pm 0.06$</td>
</tr>
<tr>
<td>separation between each torii $d$</td>
<td>$3.6 \pm 0.70 \pm 0.30$</td>
</tr>
</tbody>
</table>
Geometry of PSR J0855-4644: radio loud, $\gamma$ ray quiet with high $\dot{E}/d^2$

- Double torus fit to the PWN implies $\zeta < 37^\circ$
- Small viewing angles limits access to X-ray/ gamma ray beam ?
- Absence of $\gamma$ ray emission from a high $\dot{E}/d^2$ pulsar
- Radio & $\gamma$ ray emission sites different in RPPs
Independent constraints from predictions of geometric light curve models

- Geometric light curve models from (Dyks & Rudak 2003) TPC and OG (Romani 1996) and hollow-cone radio beam model (Radhakrishnan & Cooke 1969) generated to match the observed radio pulse profile for different combinations of $\alpha, \zeta$ ($5^\circ,5^\circ$ grid)

\( \alpha, \zeta 10^\circ \) grid

Predicted OG \( \gamma \)-ray (black), radio (magenta) light curves. \( \gamma \)-ray light curves have been normalized globally so that maximum is unity.
Independent constraints from predictions of geometric light curve models

- Radio visibility & peak multiplicity
- γ ray invisibility (non-detection)
- Radio profile fit

- Constrain on $\zeta, \alpha$
- $\beta = |\alpha - \zeta|$
Radio visibility & peak multiplicity: limits on $\beta$

As $\beta$ increases, radio beam progressively moves out of L.O.S and model predicts double peak, wide single peak, narrow single peak & no peak.

- **lower limit on $\beta$:** single radio peak $\beta \geq 10^\circ$ (depends also on $\alpha$)
- **lower limit on $\beta$:** radio visibility $\beta \leq 30^\circ$

$10^\circ \leq \beta \leq 30^\circ$
Independent constraints from predictions of geometric light curve models

- Radio visibility & peak multiplicity
- $\gamma$ ray invisibility (non-detection)
- Radio profile fit

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

$\beta = |\alpha - \zeta|$
\( \gamma \) ray invisibility (non detection)
limits on \((\alpha, \zeta)\)

For OG: \( \gamma \) ray visible only at large \((\alpha, \zeta) \leq (55^\circ, 55^\circ)\).
For TPC: \( \gamma \) ray visible almost at all angles, but low level emission are small \((\alpha, \zeta)\)

\(\alpha, \zeta\) is not detected

\((\alpha, \zeta) \leq (55^\circ, 55^\circ)\)
\[10^\circ \leq \beta \leq 30^\circ\]
\[(\alpha, \zeta) \approx (55^\circ, 55^\circ)\]
Independent constraints from predictions of geometric light curve models

- Radio visibility & peak multiplicity
- $\gamma$ ray invisibility (non-detection)
- Radio profile fit

- Constrain on $\zeta$, $\alpha$
- $\beta = |\alpha - \zeta|$
\[ \log_{10} \chi^2 / N_{\text{dof}}(\alpha, \zeta) \] map showing the best fit with the yellow cross

Best-fit radio light curves over plotted on the data

Best-fit at \((\alpha, \zeta) = (22^\circ, 8^\circ)\) map showing the best fit with the yellow cross

Alternative fit at \((\alpha, \zeta) = (9^\circ, 25^\circ)\) with almost comparable \(\chi^2\).

\[ \chi^2 / N_{\text{dof}} \sim (285/255 \ & 294/255) \]
Geometry of PSR J0855-4644


Spatial modeling by double torus

Radio profile fitting

$10^\circ \leq \beta \leq 30^\circ$

$(\alpha, \zeta) \sim (22^\circ, 8^\circ)$
Geometry of PSR J0855-4644


Spatial modeling by double torus

Non-detection of non-thermal X-rays from PSR

Radio profile fitting

$10^\circ \lessapprox \beta \lessapprox 30^\circ$

$(\alpha, \zeta) \sim (22^\circ, 8^\circ)$

Non-detection of gamma rays in a high $\dot{E}/d^2$ pulsar
THANK YOU!
David Smith, Mathew Kerr (private comm)
Faint soft pulsar & its bright & hard nebula

\[ kT = 0.20 \pm 0.05 \]
\[ \Gamma = 1.12 \pm 0.25 \]

\[ L_{x \text{ (0.5-8)}} = 1.3 \times 10^{30} \text{ erg s}^{-1} \]
Reff ~ 1.5 km: emission from hot spot of neutron star

\[ L_{x \text{ (0.5-8)}} = 3.3 \times 10^{31} \text{ erg s}^{-1} \]
non-thermal emission
\[ \eta \equiv \dot{E} / L_x \sim 10^{-5} \]
compact nebula ~0.06 pc (d=900 pc)
Spectroscopy of PWN structures

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

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

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

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

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

- **West Lobe**
  - $\Gamma = 1.30 \pm 0.33$
diffuse emission

2-8 keV smoothed at larger scales overlaying XMM contour
Emission from rotation powered pulsars

- **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**

- **Slot gap or Two-Pole-Caustic (TPC) model**: (Dyks & Rudak 2003)

- Models of outer-gap emission of gamma rays predict $\zeta > 45$ deg and large $\alpha - \zeta > 30$ deg (Romani & Yadigaroglu 1995 & references): **Constraint on pulsar geometry**
Independent constraints from predictions of geometric light curve models

- \( P=65 \text{ ms} \) and \( \nu=1.2 \text{ GHz} \) sets the beam width for radio as
  
  \[ \text{Radio beam width from a single altitude } \sim \Theta \text{pc} \propto P^{-1/2} \]

- Beam width in conjunction with \( \zeta \) sets radio visibility of the pulsar

- **Derive** \( \alpha, \zeta \) **based on radio visibility, and gamma ray non-visibility** ->

**Geometry**

- Geometric model, so does not predict flux, but match normalized pulse shape to the observed profile