DISCOVERY OF AN INFRARED BOWSHOCK AROUND A PULSAR

Zhongxiang Wang
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Collaborators: D. L. Kaplan, P. Slane, N. Morrell, V. M. Kaspi
In ISM: \( C_s \sim 10 \left( \frac{T}{10^4 \text{ K}} \right)^{(1/2)} \) km/s \( \sim 1-100 \text{ km/s} \)

Requirements: an object ejects material and moves at a speed of \( V^* > C_s \)

Bow shocks are seen around wind-blowing massive stars, mass-ejecting giant stars, and pulsars

ra: standoff distance (Wilkin 1996)
Guitar (Hα) nebula (Chatterjee & Cordes 2002)

Pulsars:
- $V^*>100$ km/s
- Have a pulsar wind
- 5 detected at Hα, a few at X-ray or radio
Detection of a mid-IR bow shock in the field of PSR J1549-4848. Great, the first mid-IR bow shock driven by a pulsar!
Fit with the standard analytic form (Wilkin 1996) and determine the host object location:
- $ra = 2.9$ arcsec
- But the pulsar is 15 arcsec away from the contour region.
Seen with Spitzer/IRS

- Detected PAH and H$_2$ emission features, arising due to irradiation or shock collision

- Two dust emission components: T=55 K & 250 K, masses of $10^{29}$ and $10^{25}$ g, luminosities of $10^{32}$ and $6 \times 10^{31}$ erg/s (if distance ~ 1 kpc)

: Spitzer photometry

Δ: WISE 12 and 22 μm photometry

Solid curve: Spitzer/IRS spectrum
Crosscheck: Associated with a Star?

\[ r_a = \left( \frac{\dot{m}_w V_w}{4\pi \rho V_*^2} \right)^{1/2} \]

\[ n_H \sim 1 \text{ cm}^{-3} \]

- \( \dot{m}_w \sim 10^{-8} - 10^{-5} \text{ Msun/yr} \), mass lose rate
- \( V_* = 30 \text{ km/s} \), star velocity
- \( V_w = 10^3 \text{ km/s} \), for an O/B star’s wind velocity, or
  \[ V_w = 10 \text{ km/s}, \text{ for a giant star with mass ejection} \]
- \( r_a = 2.9 \text{ arcsec} \) at distance \( d = 1 \text{ kpc} \) (because \( G_b = 4.3 \text{ deg} \), and \( \text{H}_2 \) gas stays \(< 0.1 \text{ kpc} \) from the Galactic plane)
No detection of any sources in the $3\sigma$ contour region down to $R=23$ mag
NO CANDIDATE STAR HOST FOUND

- White dwarfs: 0.1 kpc
- Main-sequence: 2.5 kpc
- Giant stars: 10 kpc
- Impossible to have any massive stars or giant stars at a reasonable distance range in the field
- Note Gb=4.3 deg
PSR J1549-4848 has Spin-down rate $E_{\text{dot}} = 2.3 \times 10^{34}$ erg/s, distance = 1.5 kpc

1.6% of $E_{\text{dot}}$ is required, reasonable if the pulsar wind/emission illuminates the bow shock dust

Kinematic energy of the pulsar could also contribute to dust heating, e.g., if $V_p = 200$ km/s, $E_k = 6 \times 10^{33}$ erg/s

But, the pulsar is at least 15 arcsec (or 0.11 pc for distance 1.5 kpc) away from the apex of the bow shock
SIMULATIONS OF PULSAR WIND BOW SHOCKS (VIGELIUS ET AL. 2007)
Dash-dotted curve: jet-like outflow case
Pulsars are known to have jet-like outflows.
The guitar nebula pulsar has a X-ray jet, not fully understood.
A few line structures are seen associated with X-ray points sources in the Galactic center (pulsar jets?)
PSR J0357+3205 recently was found with a long X-ray tail.
The pulsar J1549-4848 might also have a jet-like outflow.

The outflow -ISM interaction drives the bow shock, which reflects the pulsar’s motion?

Radio VLBI imaging to detect proper motion of the pulsar is underway.

We have also proposed Chandra X-ray imaging to detect an X-ray nebula.
For details, see Wang et al. 2013, ApJ, 769, 122

THANKS FOR YOUR ATTENTION!