A Bow Shock Pulsar Wind Nebula: The Curious Case of Potoroo

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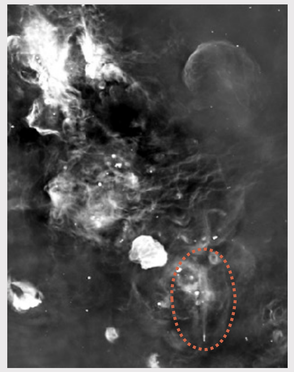


What are Bow Shock Pulsar Wind Nebulae?

Pulsars and their winds are remarkable **particle accelerators**, producing particles with energies up to a few PeV. In the case of young and energetic pulsars, a significant fraction of their rotational energy is converted into a magnetized ultra-relativistic particle wind. This wind generates **synchrotron emission** observable from radio bands to X-rays frequencies, forming what is known as **a pulsar wind nebula (PWN)**. While X-rays provide insight into the PWN's most recent history, radio observations trace its long-term evolution.

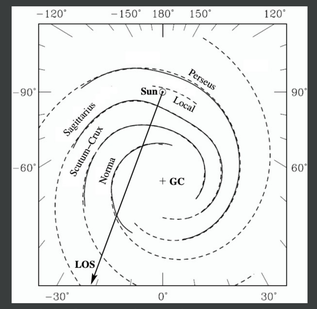
More exotically, if a pulsar is **moving supersonically** through the ambient medium, the pulsar creates a bow-shaped shock ahead and the magnetized wind outflow is confined by the ram pressure. An artist's impression of this phenomenon is shown in the top left image, while the bottom image presents **a bow-shock PWN** located in the plane of our Galaxy, named **Potoroo** (orange ellipse).

Top image: artist's impression of a pulsar surrounded by its bow shock (NASA). Bottom image: **ASKAP** radio continuum image of the **Galactic plane**. **Potoroo** is marked with an orange dotted ellipse.

Location and Distance to Potoroo

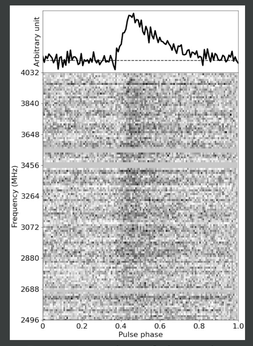
Potoroo was first observed during the Chandra X-ray Survey of the Norma Galactic spiral arm. The measurement of atomic hydrogen absorption indicates that Potoroo is located in a far Norma II region, behind the Galactic centre.

D_{min} = 10 kpc



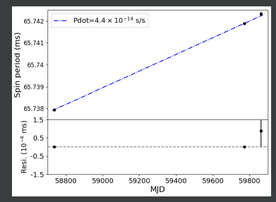
Model of our Galaxy. The arrow shows a line of sight toward the Potoroo region (Kothes & Dougherty, 2007)

Detection of Potoroo's Pulsar J1638-4713



Detection plot of the pulsar

Using the Parkes telescope, we discovered a highly scattered periodic signal from a pulsar at a frequency above 3 GHz. The pulsar has a spin period of 65.74 ms and the second-highest dispersion measure (DM = 1553 pc cm^{-3}) of all known radio pulsars.



Spin-down rate diagram of the pulsar

Future of PWNe

- Prior to the **Chandra Observatory** launch, only a handful of PWNe were detected. Currently, around **30 bow-shock PWNe** are known. The advent of advanced radio continuum surveys obtained with **ASKAP** and **MeerKAT** challenges the rarity of these objects.
- **Potoroo** is an excellent example of this growing class with remarkable characteristics that we follow up with further investigation: Potoroo was recently observed with **ATCA**, and its driving pulsar is part of our **Parkes monitoring program.**
- The recent detection of **ultrahigh-energy γ-ray emissions** linked to energetic pulsars and PWNe make them highly promising sources. Discovering more PWNe and gaining a better understanding could be crucial for unravelling **the origin of the highest energy cosmic rays in our Galaxy.**

References

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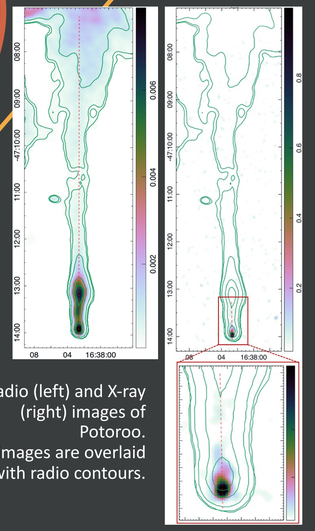
Potoroo Morphology



Radio (left) and X-ray (right) images of Potoroo.
All images are overlaid with radio contours.

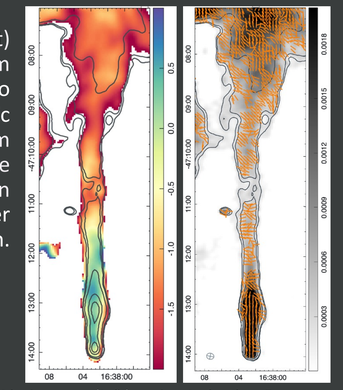
Potoroo exhibits a striking cometary structure which is a common shape for bow shock PWNe. The two distinct components are observable in both radio (left) and x-ray (right) images:
- compact and bright head
- elongated tail.

Potoroo has the greatest projected length among all the observed pulsar radio tails, measuring 21 pc! The size of the X-ray tail is shorter by a factor of 10.

Spectral Analysis and Polarisation

The spectral map of Potoroo (left) displays a flat radio continuum spectrum near the pulsar due to younger and more energetic electrons, while the spectrum becomes steeper with the distance from the pulsar where synchrotron radiation originates from the older electron population.

The overall radio spectral index of Potoroo, α = -1.27, falls far below the typical flat values for PWNe.



Spectral index map (left) and polarisation E-vectors overlaid over total intensity image (right)

Highly ordered polarisation E-vectors in the vicinity of the pulsar (right), indicate magnetic field vectors running in the tangential direction. The vectors switch orientation with the distance from the pulsar and become disordered, but radial tendencies can be seen even further.

Acknowledgements

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