On the Asymmetry of Pulsar Radio Emission from Both Poles

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Background

Pulsars are known as rotating magnetic dipoles in the universe. However, it is unclear whether the radio radiation from both magnetic poles is similar. Applying the rotating vector model (Radhakrishnan and Cooke, 1969, hereafter RVM) in PSR J1906+0746, which is a precession pulsar with interpulse, Desvignes et al. (2019) successfully unveiled its radio emission beam from both magnetic poles (see Figure 1). It can be clearly seen from the beam maps that the emission beams from both magnetic poles were dissimilar, other than they displayed a fan-like beam.

What's more, the pattern of pulsar radio emission beams has remained an elusive issue for almost six decades. As a representative of the narrowband model, the cone-core model (Rankin, 1993), consisting of two cones with some patchy and a core (see the left panel of Figure 2), is based on an empirical taxonomy of pulsar profiles. With the assumption of a regularly circular or elliptical radio beam, we can derive the beam radius from pulse profiles. On the other hand, Wang et al. (2014, hereafter W14) supposed that if the energy spectrum is broadband, a lime-darkening fan-like beam pattern can be observed (see the right panel of Figure 2), which is called the fan beam. This work also deduced the equations of pulse width and emission intensity.

Interpulse pulsars, which expose both magnetic poles to our line of sight, are valuable tools for studying the symmetry of magnetic poles. In this study, we aimed to compare the emission from both poles of each pulsar.

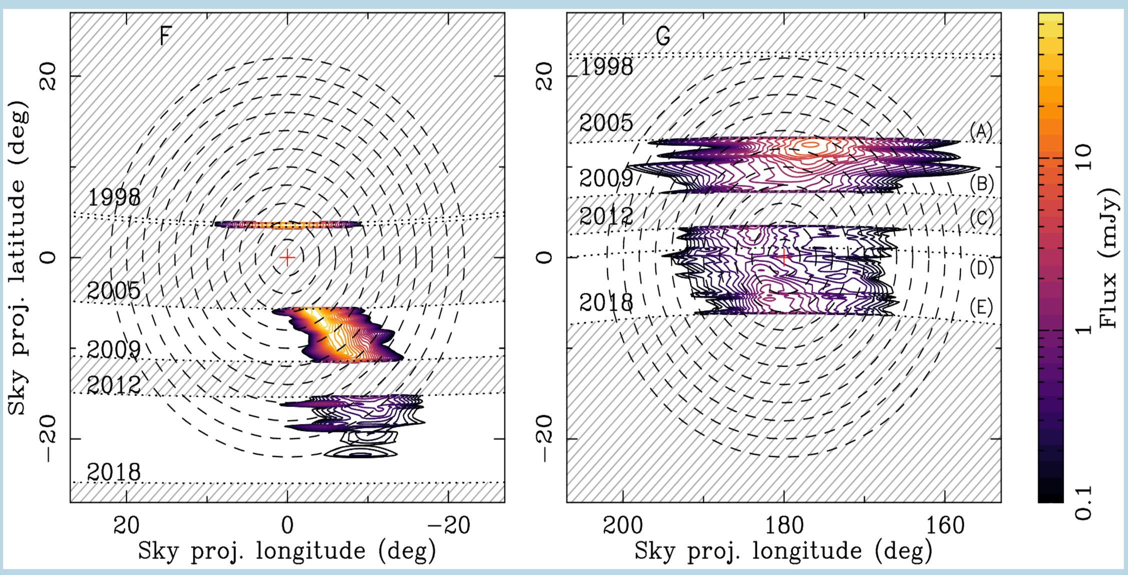

Figure 1. The radio beam maps of PSR J1906+0746(Desvignes et al., 2019)

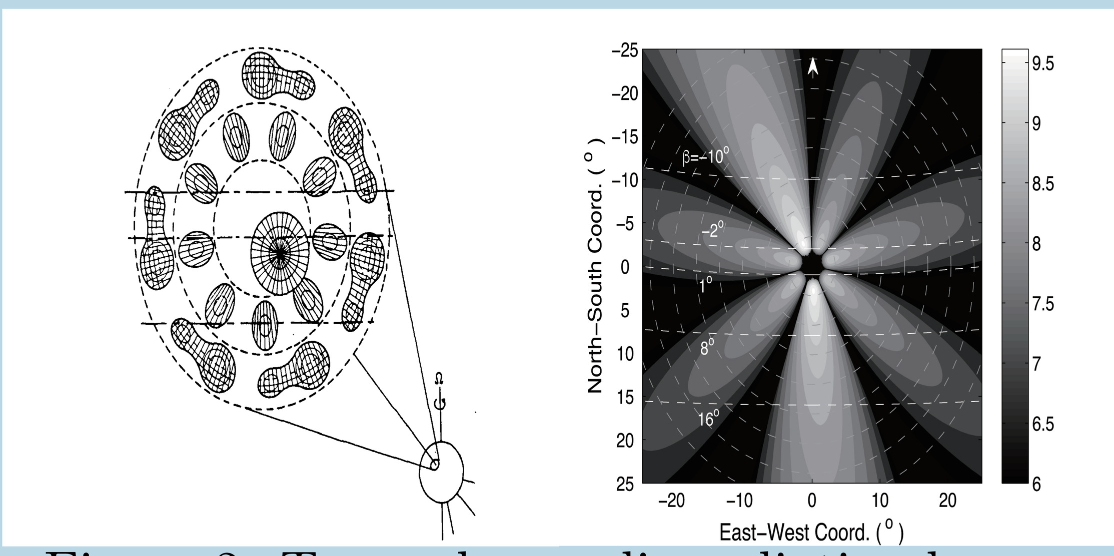

Figure 2. Two pulsar radio radiation beam models. Left: cone-core beam (Rankin, 1993), Right: fan beam(Wang et al., 2014), respectively.

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Observations and Methods

We collected pulsar samples with interpulse from various sources, including the FAST Pulsar Database (Wang et al., 2023), The Thousand-Pulsar-Array program on MeerKAT (Posselt et al., 2021), and archival data from the Parkes radio telescope (Johnston and Kerr, 2018). We selected these samples based on their regular polarisation position angle (PA), which can be well-fitted with RVM,

$$\mathrm{PA} = \mathrm{PA}_0 + \arctan\left(\frac{\sin\alpha\sin(\Phi-\Phi_0)}{\sin(\alpha+\beta)\cos\alpha - \cos(\alpha+\beta)\sin\cos(\Phi-\Phi_0)}\right)$$

, and see a double-pole interpulse geometry. In terms of RVM fitting, we employed the Dynesty sampler (Speagle, 2020) in the Python package Bilby (Ashton et al., 2019) to find high-likelihood samples.

To validate the fan beam model and the conical beam model, we measured the pulse widths of both mainpulse and interpulse. Then we converted them into magnetic azimuth width samples, $\Delta\phi_{\mathrm{M}}$ and $\Delta\phi_{\mathrm{I}}$, and beam radius samples, ρ_{M} and ρ_{I}, with

$$\cos\rho = \cos\alpha\cos(\alpha+\beta) + \sin\beta\sin(\alpha+\beta)\cos(\Phi-\Phi_0)$$

and

$$\cos\phi = \frac{\cos\alpha\cos\rho - \cos(\alpha+\beta)}{\sin\alpha\sin\rho}$$

, using the samples from RVM fitting(see Figure 3 as an example). The red dashed lines represent the equivalent lines, meaning that the fan-like beam width and/or conical beam radius of both poles are similar. Moreover, according to W14, we evaluated the fraction of emission intensity from both poles with

$$\mathrm{R_I} = \frac{\mathrm{I_{0,MP}}}{\mathrm{I_{0,IP}}} = \frac{\mathrm{I_{peak,MP}}}{\mathrm{I_{peak,IP}}}\left(\frac{\rho_{\mathrm{peak,MP}}}{\rho_{\mathrm{peak,IP}}}\right)^{-(2\mathrm{q}-6)}$$

. Notably, the power-law index q of the $\mathrm{I}-\rho$ relation is essential, so we focused on the $\mathrm{R_I}-\mathrm{q}$ relationship(see Figure 4 as an example), where the red dashed line represents $\mathrm{R_I} = 1$, i.e., the emission intensity from both poles is similar.

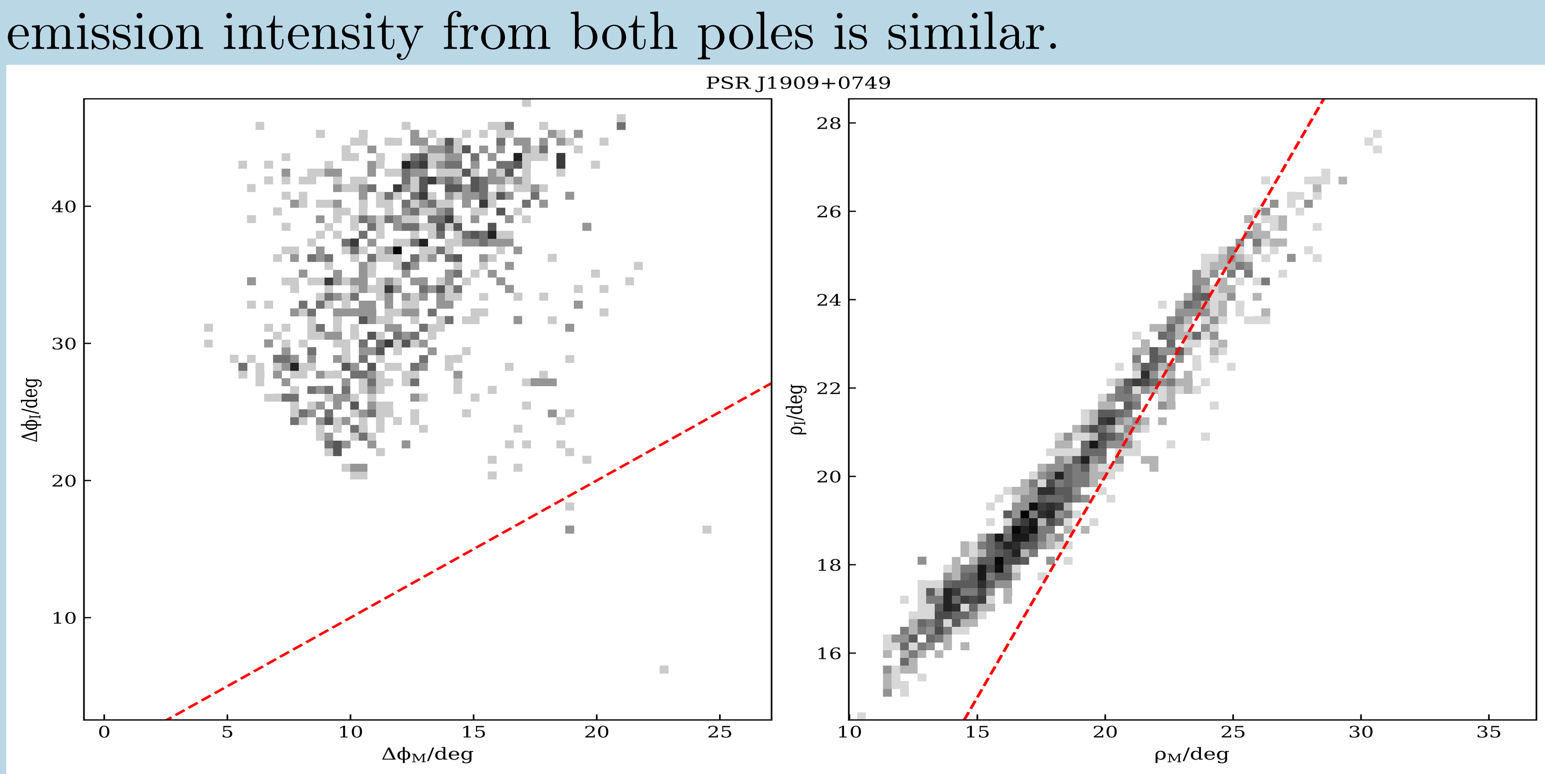

Figure 3. 2-D histograms of $\Delta\phi_{\mathrm{M}}$ and $\Delta\phi_{\mathrm{I}}$ samples (left panel), ρ_{M} and ρ_{I} samples (right panel).

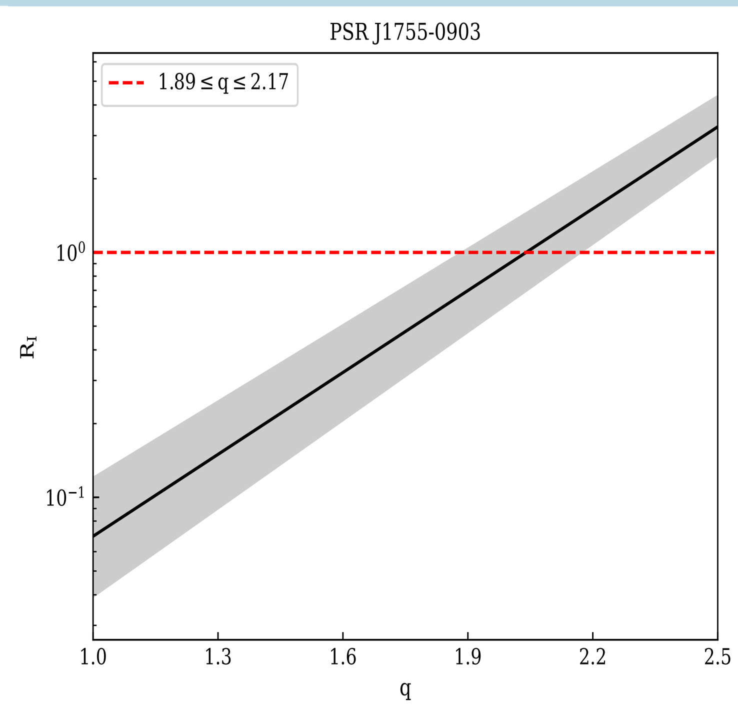

Figure 4. The $\mathrm{R_I}-\mathrm{q}$ relation.

Results and Conclusion

The results of all 17 pulsar samples are shown in the table below. The column labeled "P" lists the periods of each pulsar. The third column indicates if the emission from both poles of each pulsar is from the same region (**S**) or a different region (D) (the emission region can be located near the equator or the rotating axis of the star). The fourth to seventh columns show whether the radiation heights, intensity, magnetic azimuth widths, or beam radius of both poles of each pulsar are either comparable (**Y**) or dissimilar (N).

Jname	P (ms)	Position (**S**/D)	CH? (**Y**/N)	CI? (**Y**/N)	CW? (**Y**/N)	CR? (**Y**/N)
J0627+0706	475.9	D	N	N	N	N
J0905−5127	346.3	D	N	N	**Y**	**Y**
J0908−4913	106.8	**S**	N	N	N	N
J1126−6054	202.7	**S**	**Y**	**Y**	N	N
J1413−6307	394.9	**S**	N	**Y**	N	N
J1549−4848	288.4	**S**	N	N	N	N
J1611−5209	182.5	**S**	N	N	**Y**	**Y**
J1722−3712	236.2	D	N	**Y**	**Y**	N
J1739−2903	322.9	**S**	N	**Y**	N	N
J1755−0903	190.7	**S**	N	**Y**	N	N
J1843−0702	191.6	D	N	**Y**	N	N
J1849+0409	761.1	D	N	N	N	**Y**
J1909+0749	237.2	**S**	N	**Y**	**Y**	**Y**
J1913+0832	134.0	**S**	N	N	N	N
J1935+2025	80.1	D	N	N	N	N
J2047+5029	445.9	**S**	N	N	N	N
J2208+4056	636.0	**S**	N	N	N	N

Conclusion: Out of 17 pulsars, 11 can be observed from the same region of both magnetic poles. Among them, only 2 pulsars have comparable magnetic azimuth width and beam radius, and only 1 pulsar has comparable emission height, while 5 pulsars have comparable emission intensity. The results suggest that there is no evidence to support the claim that the emission from both magnetic poles of each pulsar is similar, even if they originate from the same emission region.