Pulsar Scintillation as a Probe of Small-Scale ISM Magnetic Fields: An Innovative Method

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Motivation

1. Measuring B-field of the ISM in small scales (down to AU-scale), not attainable in the past, but was enabled by a novel method via pulsar scintillometry.

2. Resolve B-field in small-scale structure: 1-ms lens (width=0.6AU) in PSR B0834+06 data.

Introduction

Pulsar scintillation

Measuring magnetic fields

• Faraday rotation: polarization rotated as light passes through B-field. Angle of rotation $\Delta \chi = \lambda^2 \mathrm{RM}$

Method

• Rotation measure: RM = 0.81 $n_e B_{\parallel} dl$

Phase Retrieval

 From θ-θ map (turning quadratic to linear), we retrieve phases by eigenvector decomposition

- Similar to how stars twinkle (scintillate) by the atmosphere, pulsars scintillate by the ISM.
- Pulsar emission wavefront gets scattered by the inhomogeneities in the ISM, interference patterns observed on Earth.



• **Dynamic spectrum**: The intensity of the illuminated ISM (by pulsar) over time and frequency

• Measure angle of rotation by cutout and weighted mean



cutout and weighted mean of

lower

• Secondary spectrum: The power spectrum of the dynamic spectrum, showing parabolic arc structure.

Physical picture of pulsar scintillation

- Clear parabolic arc indicates 1D screen
- 1-ms feature shows double lensing in PSR B0834+06
- Corrugated sheet model: current sheet sustained by magnetic reconnection, not Kolmogorov turbulence.
- Scattered images act like lenses.



1-ms feature in θ - θ space 1-ms feature of B0834+06

Results & Discussion

-40.0 -37.5 -35.0 -32.5 -30.0

-42.5

Doppler Frequency f_D (mHz)

- Angle of rotation in upper and lower branch: consistent with 0, Arecibo might not resolve the RM structure.
- Measuring dominant upper branch RM and B-field $RM = (6.8 \pm 6.6) \times 10^{-3} rad m^{-2}$ $B_{\parallel} = 3.3 \pm 3.1 \ \mu G$ consistent with bound of pressure equilibrium: 6.4 μ G, and RM/0.81DM~2.45 µG



0.04phase (rad) 0.020.00-0.02320324frequency (MHz)

sheet instead of turbulence [1] structure of 1-ms lens and two images

[1] Jow et al. (2024) MNRAS.528.6292J [2] Zhu et al. (2023) ApJ, 950, 109

Observer

Concusion

0.06

- Using pulsar scintillation as a tool, we can systematically measure B-field of small scale structures, and the result is consistent with the theory as well.
- Better if we have larger telescope