Radio-Wave Scintillation : Microscopy of the ISM

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Introduction to interstellar scintillation
Scintillation reveals stress nuggets
What causes the stress nuggets ?
Prospects for the future
Holography & Cyclic Spectroscopy

Introduction to scintillation

Ionised gas

 $\delta \varphi \sim 1$ for $N_e \sim 10^{11}$ cm⁻² Fresnel-scale $\sim 10^{10}$ cm

AU

Density fluctuation spectrum close to Kolmogorov Log P(k)

pc

Logk





Properties of scattering material

☑ D ~ 3 pc

- Pulsars reveal similar material is present out to ~ kpc distances (Stinebring)
- Size ~ $10^{13} 10^{15}$ cm
- \odot P_{gas} ~ 10⁵ K cm⁻³ \gg P_{ISM}
- Solution Number density $\sim 10^4 \text{ pc}^{-3}$
- \bigcirc Anisotropy of scattered image, $A \gg 1$



Image anisotropy

 A ≥ 10 from pulsar dynamic spectra (Cordes et al 2006) Rickett Poster

Image anisotropy

A ≥ 30 from pulsar dynamic spectra (Brisken et al 2011)



Image anisotropy

\bigcirc A \geq 100 from the kinematics of J1819+3845



Image anisotropy A ≥ 100 from the kinematics of J1819+3845



What do stress nuggets look like?



A ~ 10

 $\overline{A} \gg 10$

 $P_{?} \gg P_{B} \gg P_{gas} \gg P_{ISM}$

What causes stress nuggets?



Implications

Spherical lens .: self-gravitating
Neutral gas clouds
Dynamically significant
Hypersonic .: not a thin-disk population
Not in current inventory
Dark matter : cold, dense gas

Australian SKA Pathfinder



Australian SKA Pathfinder



Australian SKA Pathfinder

VAST : Variable And Slow Transient survey
PIs : Tara Murphy & Shami Chatterjee
Daily sky survey at ~ 1 GHz
Monitor ~10⁵ radio quasars (S/N = 25)
Expect ~ 10² Extreme Scattering Events /yr
Hundreds of Intra-Hour Variables

Holography of the ISM

- Want a detailed 3D image of the ionised ISM toward a pulsar
- Scattering by ISM creates structure in E-field
- Measure structure of E-field
- Image N_e by Fourier Transform

But need phase information

Solution: cyclic spectroscopy P. Demorest 2011

When to use Cyclic Spectroscopy?

If your signal statistics are stationary, use the power spectrum

If your signal statistics are cyclo-stationary, use the cyclic spectrum

Cyclic Spectroscopy

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Radio Frequency

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Cyclic Spectroscopy



Impulse response of ISM



Intrinsic pulse profile of B1937+21



Summary

Scintillation reveals AU-scale stress nuggets

- High gas pressures, and strong, ordered B-fields
- Solution ≥ 10⁵ × more numerous than stars
- Appears to be a magnetotail phenomenon
 - Prime movers are hypersonic neutral clouds
 - New, dark Galactic population
- Heaps of new data to come from ASKAP VAST
- New insights to come from holography
 - Holography facilitated by Cyclic Spectroscopy