Broadband Polarimetry with the SKA

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@SciBry #skascicon14
For the Twitterati …

Go Wide Band, or Go Home
Radio polarimetry: a highly sensitive probe of density, magnetic field and turbulence at all redshifts

→ **Cosmic Magnetism**: a fundamental unsolved problem and one of five SKA Key Science Projects

Faraday rotation: $\theta \propto \lambda^2$ → the “RM grid”

... but many sources do not show pure rotation
- $\theta$ does not have linear dependence on $\lambda^2$
- $Q$ vs $\lambda^2$ and $U$ vs $\lambda^2$ are not pure sinusoids
- fractional polarisation not constant vs $\lambda^2$
- none of this is apparent over a narrow bandwidth!

In “Faraday depth” space, $\lambda^2$ analogous to $u$-$v$ plane
- small baseline range → crude images, missing physics
- small $\lambda^2$ range → crude polarimetry, missing physics!

**RM grid**: foreground magnetism, ensemble properties

**Broadband polarimetry**: intrinsic properties, individual sightlines

$v = 1400 \text{ MHz, } \Delta v = 350 \text{ MHz}$

$v = 1200 \text{ MHz, } \Delta v = 1000 \text{ MHz}$
Supermassive Black Holes and their Environments

How do AGN outflows entrain thermal gas?
- pollution of IGM with metals & magnetic fields
- feedback on star formation & black hole growth
- deceleration of AGN jets
- acceleration of highest-energy cosmic rays

Spatially resolved polarimetry of radio galaxies (Guidetti et al. 2011, 2012; O’Sullivan et al. 2013)
- thermal sheaths draped over lobes
- compression & mixing of surrounding thermal gas
- Cen A: thermal gas inside lobes, $n_e \approx 10^{-4}$ cm$^{-3}$

Broadband polarimetry with the SKA
- differentiate between depolarisation mechanisms
- resolved images of cores, lobes, host galaxies
→ comprehensive view of entrainment, outflows, ionised gas and magnetic fields in AGN

Polarimetry of Centaurus A (O’Sullivan et al. 2013)
Faraday Rotation from Magnesium II Absorbers towards Polarized Background Radio Sources

Figure 5. ECDFs of the absolute value of the NVSS RMs for (i) Top panel: flat- (black), and steep- (red) spectrum sources. The solid lines show the sources without MgII absorption, while the dashed lines show the sources with absorbing system along the line of sight, (ii) Middle panel: flat-spectrum sources only, (iii) Bottom panel: steep-spectrum sources only. In (ii) and (iii), the black solid lines show the sources without MgII absorption along the line of sight, the red dashed lines show the sources with absorbing system, and the blue dotted lines show the sources with absorbing systems.

Figure 6. ECDFs of the NVSS polarized fraction,⇧, for flat- (black), and steep- (red) spectrum sources. The solid lines show the sources without MgII absorption, while the dashed lines show the sources with absorbing system along the line of sight.

Figure 7. ECDFs of the Farnes et al. (2014) polarization spectral indices,⇧, for flat- (black), and steep- (red) spectrum sources. The solid lines show the sources without MgII absorption, while the dashed lines show the sources with absorbing system along the line of sight.

We therefore highlight that without the introduction of either multiple simplifying assumptions or very long baseline interferometric data, the same physical line of sight cannot be trivially probed using merely the alignment of radio and optical counterparts.

We therefore suggest an improved measure of the same emitting region, and by extension the same physical line of sight. This can be provided by the total intensity spectral index,⇧. A prototypical model of an extragalactic radio source is one that consists of at least two emitting regions: (i) a flat-spectrum core (⇧ ⇐ 0), and (ii) steep-spectrum jets/lobes (⇧ ⇐ 0.7). The spectral index therefore serves as a powerful discriminator of the physical emitting region that is largely independent of both resolution and projection effects.

Although unresolved radio sources can contain emission from both the core region and the jets/lobes, the spectral index allows us to determine from which physical region the emission is dominated. Consequently, flat-spectrum sources can be used as a proxy for the optical and radio counterparts being aligned (i.e. a core-dominated source), while steep-

Intervening systems to polarised background sources
- amplitude of turbulence in galactic disks & halos
- dynamo time scales and coherence lengths
- covering fraction & spatial extent of intervenors
... all as a function of redshift

Faraday rotation toward polarised quasars (Bernet et al. 2008, 2012; Farnes, Gaensler et al. 2014)
- excess RM when Mg II absorption present
- strong, coherent galactic magnetic fields at z ~ 1.5
- partial covering of background sources?

Broadband polarimetry with the SKA
- break degeneracy between different models
- resolution needed to match optical/radio sightlines
→ ionised gas in ordinary galaxies at all redshifts

Physical Properties of Absorbing Systems

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Evolution of Active Galaxies over Cosmic Time

- Physical properties of AGN population
  - jet power, field strength, outflow rate, thermal density, spectral turnover, etc.
  - evolution over cosmic history
    → K-correction into source rest frame
  - luminosity, size, spectrum: relatively trivial

- Broadband polarimetry of AGN
  (Mantovani et al. 2009; Farnes, Gaensler & Carretti 2014)
  - sources depolarise, repolarise and oscillate
  - almost no sources show “flat” spectra!

- Broadband polarimetry with the SKA
  - large sample of polarisation SEDs
  - angular resolution needed to separate components
    → cosmic evolution of AGN & their magnetised outflows

Polarisation SEDs (Farnes et al. 2014b)
**Broadband Polarimetry with SKA**

- **Frequency:** SKA1-SURVEY Band 2 (650-1670 MHz)
  - optimises survey speed, $\lambda^2$ coverage, redshift range ($z \sim 0.5$–1.5)
- **Resolution:** 1" → optimises number of extended polarised sources
- **Survey strategy:** two passes → 5 $\mu$Jy/beam over 30 000 deg$^2$
- **Predicted yield:**
  - AGN lobes: bin by $z$ (x10), power (x10), morphology (x10)
  - intervenors: bin by $z$ (x10), EW (x5), impact parameter (x5)
  - SEDs: 500 000 K-corrections in redshift range $z \sim 0$–2
- **SKA1 Early Science:** convert ASKAP POSSUM (1200–1500 MHz, 10" resolution, 10 $\mu$Jy/beam) into broadband survey
- **SKA2:** broader frequency band (350–1500 MHz) → extend to $z \sim 4$

- AGN outflows & feedback
- Normal galaxies over cosmic time
- Evolution of radio galaxies

*Broad band bandwidths provide unique physical insights*