High-resolution Faraday Rotation measurements

for the MeerKAT MIGHTEE-POL Survey

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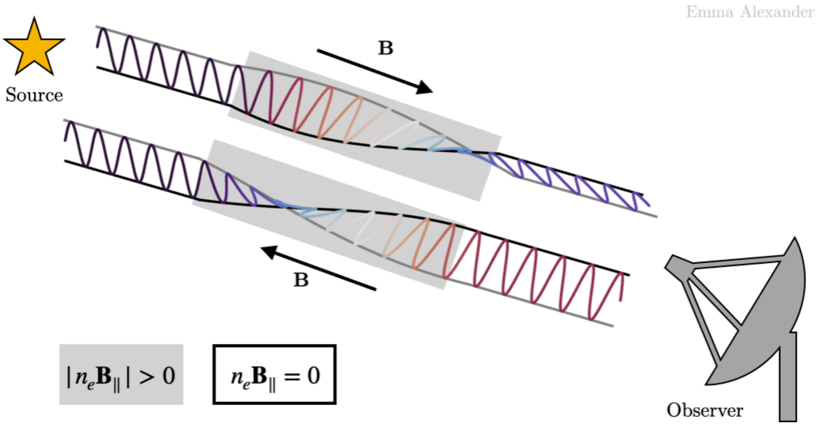
The University of Manchester

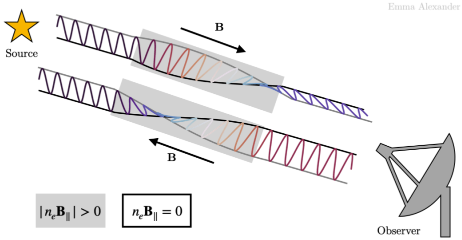
STUDYING MAGNETIC FIELDS USING FARADAY ROTATION



Faraday rotation illustration. Credit: Emma Alexander.

Rotation Measure

$$\mathrm{RM} = 0.81 \int_{\text{source}}^{\text{observer}} n_e(r) B_{||}(r) \cdot dr \text{ rad m}^{-2}$$



Faraday rotation illustration. Credit: Emma Alexander.

Rotation Measure

What we want

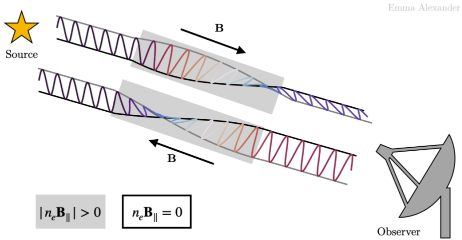
$$\mathrm{RM} = 0.81 \int_{\text{source}}^{\text{observer}} n_e(r) B_{||}(r) \cdot dr \text{ rad m}^{-2}$$

Radio

X-Ray

$$F(\phi) = \frac{1}{K} \int_{-\infty}^{\infty} W(\lambda^2) P(\lambda^2) e^{-2i\phi\lambda^2} \, d\lambda^2,$$

$$P(\lambda^2) = |P(\lambda^2)| e^{2i\chi(\lambda^2)} = Q(\lambda^2) + iU(\lambda^2).$$



Faraday rotation illustration. Credit: Emma Alexander.

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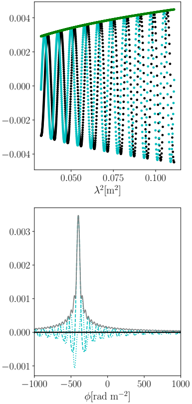
- Subtraction of Galactic RM
- Spectral index correction

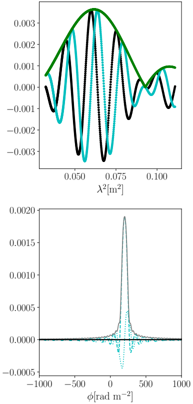
SIMULATION OF FARADAY SOURCES

- Simulation of thin, thick or mixed/complex sources
- Simulation of RFI flagging
- Noise application to simulated data

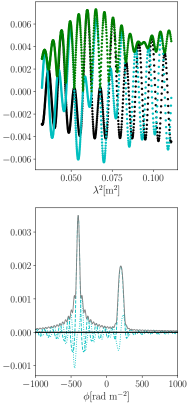
THIN, THICK, MIXED/COMPLEX SOURCES



(a) Thin source

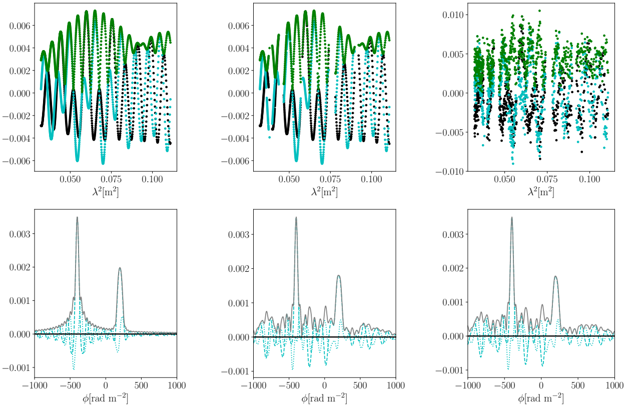


(b) Thick source



(c) Complex source

RFI & NOISE EXAMPLE



(a) Complete dataset

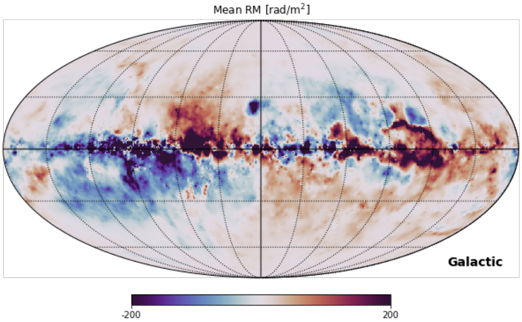
(b) 20% data removed

(c) 1.4 mJy/beam noise

GALACTIC RM DEROTATION

- The framework applies the derotation directly in λ^2-space as a phase shift.

$$\hat{P}(\lambda^2) = P(\lambda^2)e^{-2i\phi_{\mathrm{GAL}}\lambda^2}$$

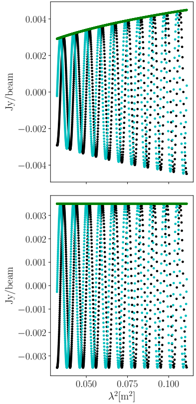


Mean Galactic RM (Hutschenreuter et al., 2022)

SPECTRAL INDEX CORRECTION

$$F(\phi) = \frac{1}{K}\int_{-\infty}^{\infty} W(\lambda^2)\frac{P(\lambda^2)}{s(\lambda^2)}\mathrm{e}^{-2i\phi\lambda^2}\,\mathrm{d}\lambda^2$$

$$s(\lambda^2) = \frac{I(\lambda^2)}{I(\lambda_0^2)} = \left(\frac{\lambda^2}{\lambda_0^2}\right)^{-\alpha/2}$$



- Brentjens and de Bruyn, 2005
- For real data we can use FITS/CASA spectral index images

λ^2-space before and after spectral index correction

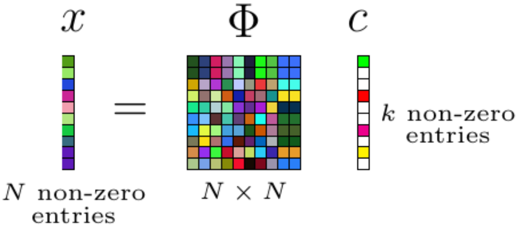
COMPRESSED SENSING RECONSTRUCTION

- Technique that aims to solve inverse problems
- Finds the sparsest signal that is consistent with the measurements and to a specific constraint.

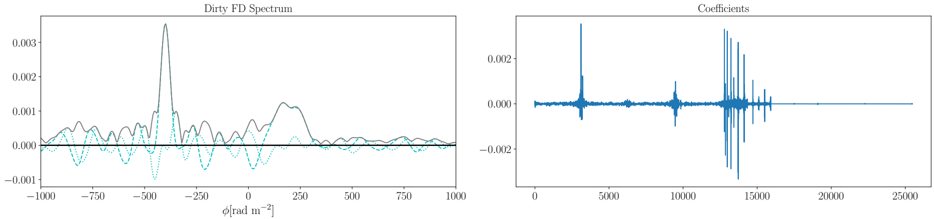
$$\phi = \arg\min_{x} ||Ax - b||_2^2 + \lambda ||x||_1$$

- A: Measurement matrix (Fourier transform)
- b: Observed data
- x: Signal or a sparse representation of it.

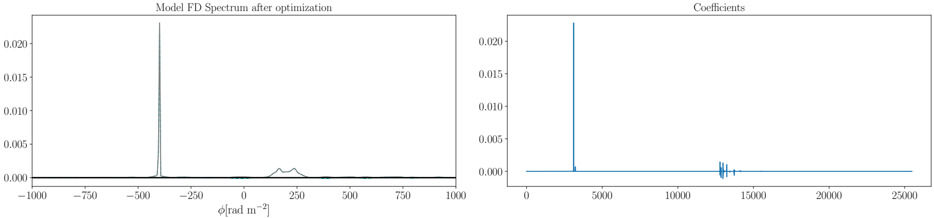
$$x = \sum_{i}^{N} c_i \phi_i .$$



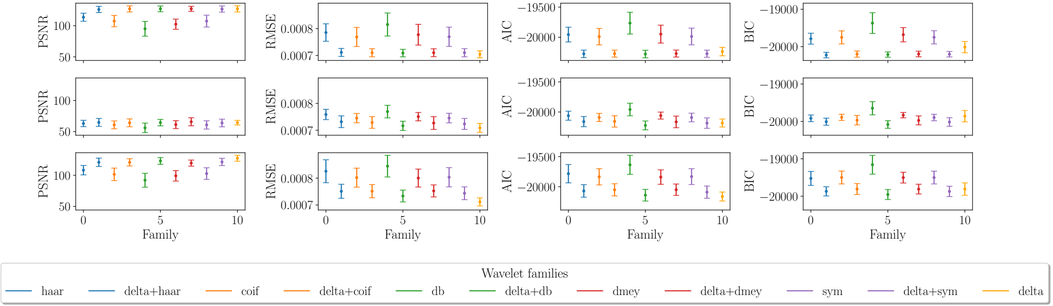
COMPRESSED SENSING EXAMPLE



(a) Dirty FD spectrum and coefficient representation

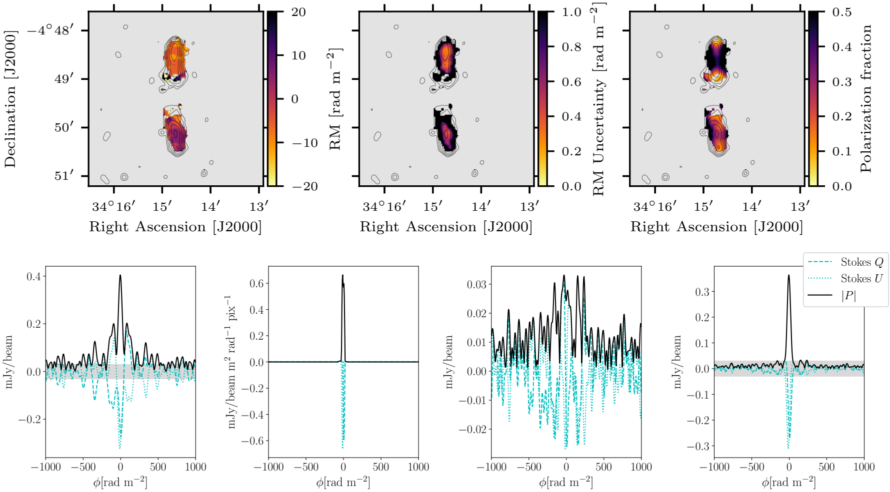


(b) Model FD spectrum and sparse representation (note sparsity of coefficients!)



Peak signal-to-noise ratio, root mean squared error, Akaike and Bayesian Information criterias for thin, thick and mixed sources.

PRELIMINARY RESULTS IN THE XMMLSS-12 EARLY SCIENCE FIELD



(a) Dirty, model, residuals and restored Faraday depth spectra.

CONCLUSIONS

- We have already demonstrated this method with real data (Cárcamo et al., 2022) (`arXiv 2205.01413`).
- We need to apply this method to all the MIGHTEE-POL survey maps
- Add `cs-romer` RM and RM uncertainties to the MIGHTEE catalog
- Compare the RM values with QU-fitting and naive RM-Synthesis
- We need to incorporate big data and big computing packages such as `dask` and `cupy` to `cs-romer`