

# High-resolution Faraday Rotation measurements

for the MeerKAT MIGHTEE-POL Survey

Miguel Cárcamo



miguelcarcamov



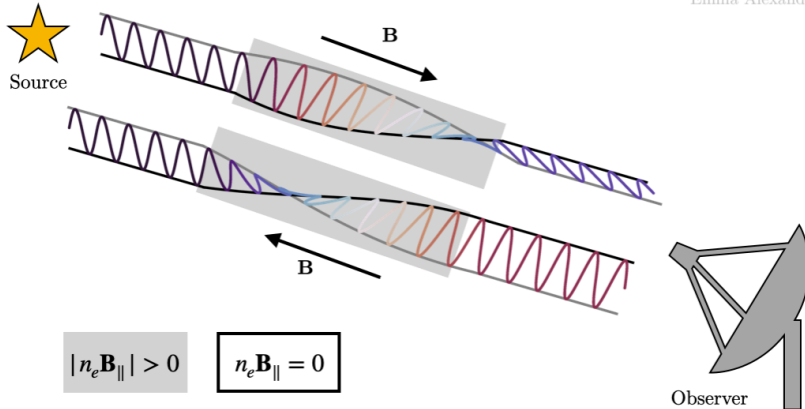
@miguel\_carcamov

Anna Scaife, Russ Taylor, Matt Jarvis, Micah Bowles, Srikrishna Sekhar, Lennart Heino  
and Jeroen Stil

National Astronomy Meeting, Warwick, UK - July 15, 2022

# STUDYING MAGNETIC FIELDS USING FARADAY ROTATION

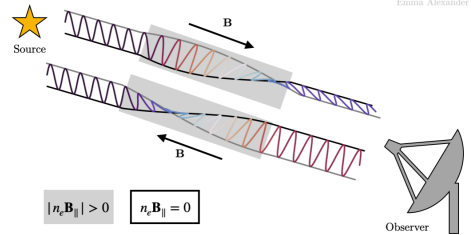
Emma Alexander



Faraday rotation illustration. Credit: Emma Alexander.

## Rotation Measure

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



Faraday rotation illustration. Credit: Emma Alexander.

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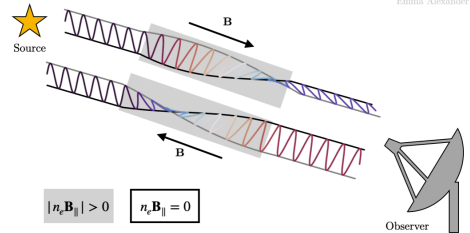
What we want

Radio

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

X-Ray

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



Faraday rotation illustration. Credit: Emma Alexander.



<http://github.com/miguelcarcamov/csromer>



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- Reconstruction of Faraday depth sources from linearly polarized data with CS



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- More than 100 wavelet filters provided by `Pywavelets`



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- Simulation of Faraday depth sources directly in  $\lambda^2$ -space





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- Subtraction of Galactic RM

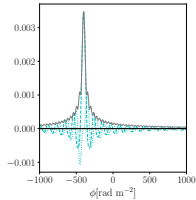
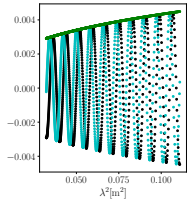


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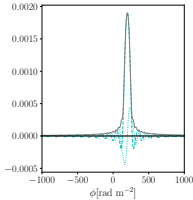
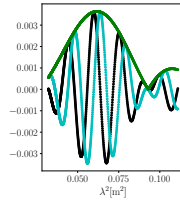
- Reconstruction of Faraday depth sources from linearly polarized data with CS
- More than 100 wavelet filters provided by `Pywavelets`
- Simulation of Faraday depth sources directly in  $\lambda^2$ -space
- Subtraction of Galactic RM
- Spectral index correction

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

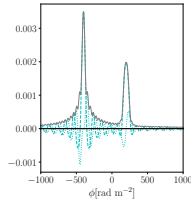
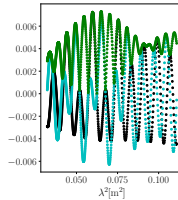
# THIN, THICK, MIXED SOURCES



(a) Thin source

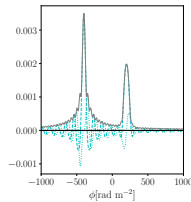
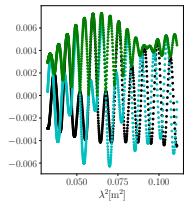


(b) Thick source

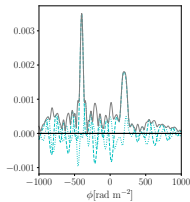
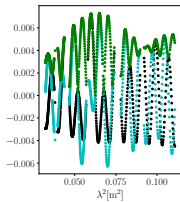


(c) Mixed source

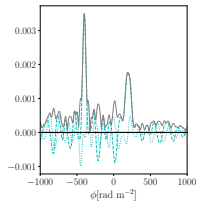
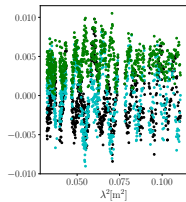
# RFI & NOISE EXAMPLE



(a) Complete dataset



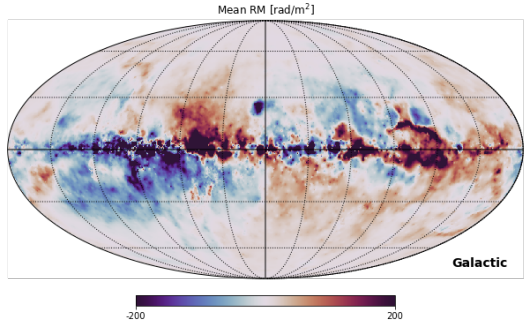
(b) 20% data removed



(c) 1.4 mJy/beam noise

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

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



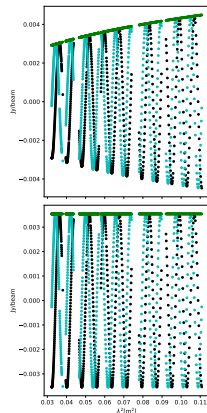
Mean Galactic RM (Hutschenreuter et al., 2022)

# SPECTRAL INDEX CORRECTION

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

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

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



$\lambda^2$ -space before and after spectral index correction

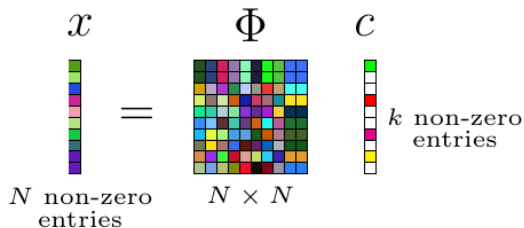
# COMPRESSED SENSING RECONSTRUCTION

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

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

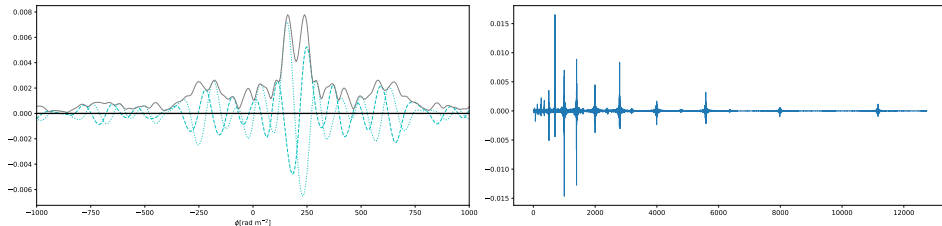
- $A$ : Measurement matrix (Fourier transform)
- $b$ : Observed data
- $x$ : Signal or a sparse representation of it.

$$x = \sum_i^N c_i \phi_i.$$

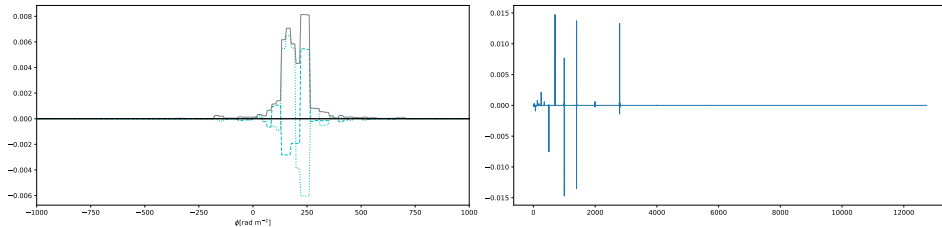




# COMPRESSED SENSING EXAMPLE

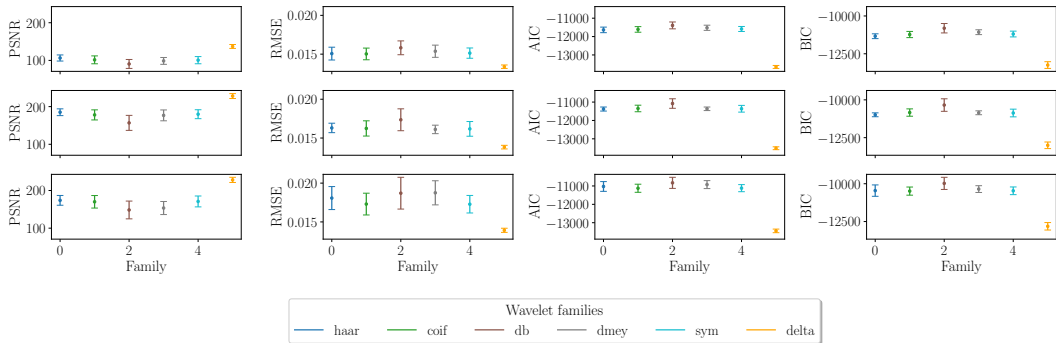


(a) Dirty FD spectrum and coefficient representation



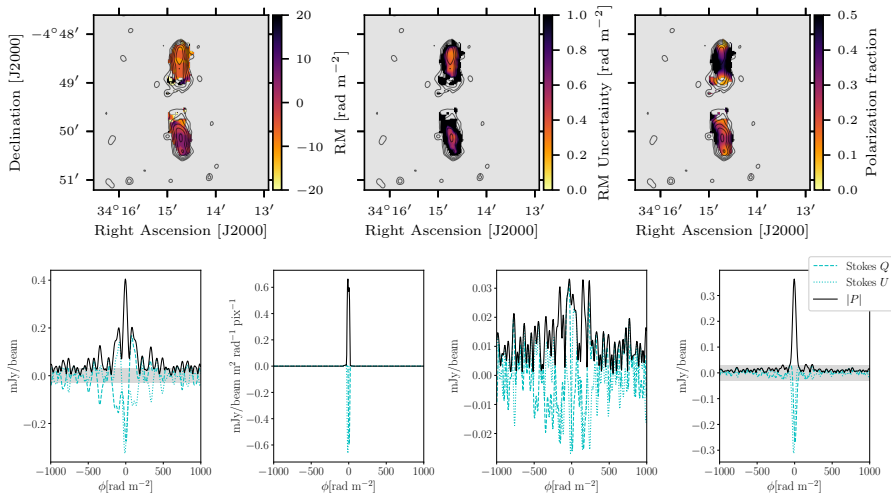
(b) Reconstructed FD spectrum and sparse representation (note sparsity of coefficients!)

# WAVELET AND PERFORMANCE EVALUATION



Peak signal-to-noise ratio, root mean squared error, Akaike AIC and BIC for thin, thick and mixed sources.

# PRELIMINARY RESULTS IN THE XMMLSS-12 EARLY SCIENCE FIELD



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

- 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`