UNIVERSITY of the
WESTERN CAPE

CRC
Centre for Radio Cosmology

Polarised synchrotron simulations for EoR experiments

The broad impact of Low Frequency Observing
Bologna, 19-23 June 2017

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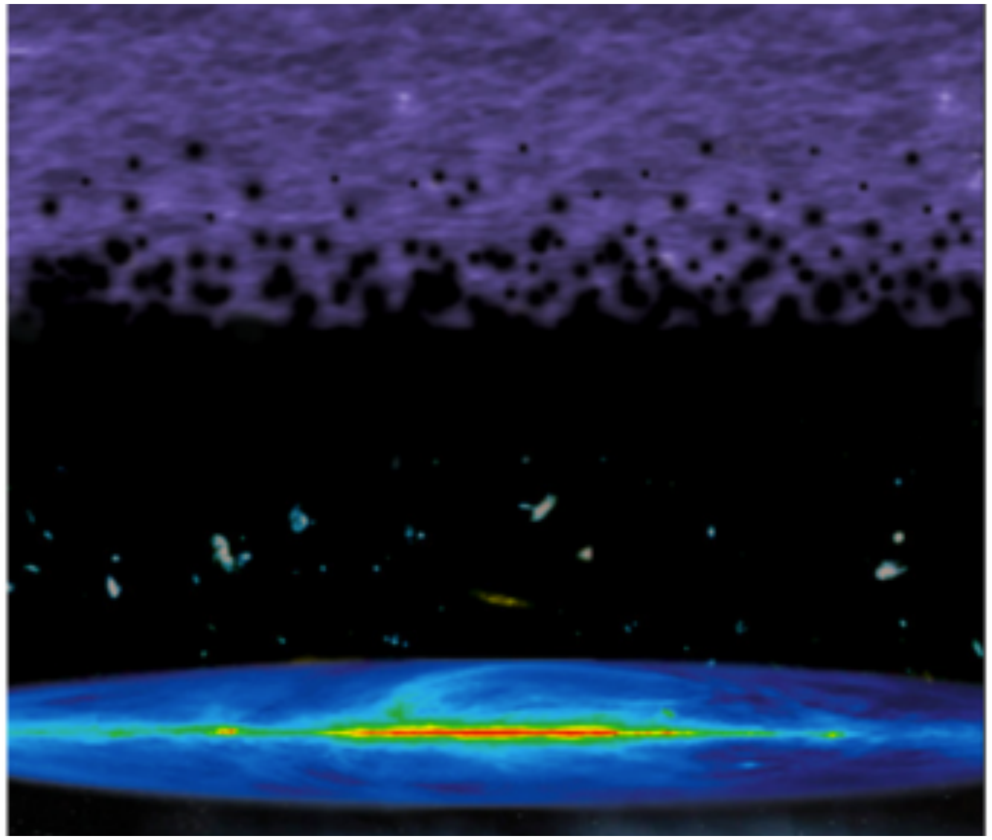
The challenge of foregrounds

The foregrounds are expected to be orders of magnitude larger than the EoR signal



credit: LOFAR

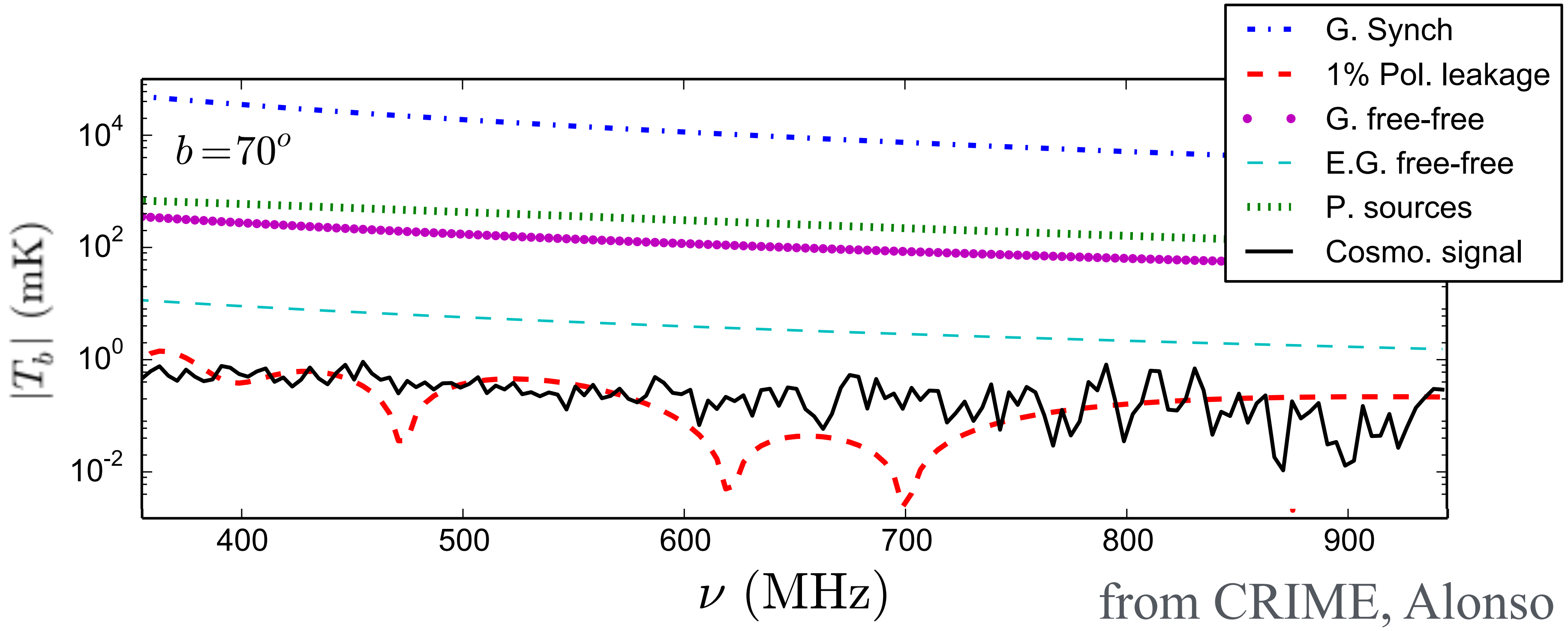
- Extragalactic Point Sources (PS)
  radio galaxies, AGNs, …

- Galactic and Extragalactic free-free
  low frequency radio background produced by bremsstrahlung radiation from electron-ion collisions

- Galactic synchrotron (dominant foreground)
  cosmic ray electrons interacting with the galactic magnetic field.
  Linearly polarised.

e.g. Santos et al 2005, Jelic et al 2008, Geil et al 2011

Polarised Synchrotron emission



from CRIME, Alonso et al 2014

Why is it important?

- spectral smoothness key for proper foreground subtraction
- polarised synchrotron non trivial frequency structure
- can leak in the unpolarised part due to instrumental and calibration issues

Synchrotron generalities

e.g Burn (1966)

- Depends on B _|_ to the LOS modulated by the density of *cosmic electron*
- CR power law energy density: n(E) ~ E^-p

- Diffuse polarised emission:

$$P = \Pi_0 I e^{2i\phi} \qquad \text{with} \qquad \phi = \phi_0 + \psi(s, \hat{\mathbf{n}})\lambda^2$$

faraday rotation given by B// and the presence of *thermal electrons*

$$\psi = \frac{e^3}{2\pi(m_e c^2)^2} \int_{LOS} n_e B_{||} dr$$

faraday depth or
Rotation Measure (RM)

@ EoR frequencies P simulations are difficult:

- lack of correlation with total intensity
- not a lot of polarised data at low frequencies
- depolarisation effects prevent extrapolation from higher frequencies

Rotation Measure (RM) synthesis

e.g Bretjens&Bruyn (2005)
Heald, Brown&Edmonds (2009)

Use Fourier relation between polarised surface brightness (P) and surface brightness per unit of Faraday depth F

$$P(\lambda^2) = \int_{-\infty}^{+\infty} F(\psi) e^{2i\psi\lambda^2} d\psi$$

Inverting this formula:

- only positive lambda have physical meaning
- and incomplete sampling in lambda^2

Need to define a RM transfer function (RMTF) that gives the resolution in Faraday depth:

FWHM ~ (Delta lambda^2)^-1 total bandwidth
lack of sensitivity to structures extended in Faraday depth

Simulation strategy

Use RM synthesis framework:

- generate full-sky gaussian Q,U maps in RM space with specific power spectrum

$$\tilde{Q}(\theta,\phi,\psi) = \sum_{\ell m} \tilde{q}_{\ell m}(\psi) Y_{\ell m}(\theta,\phi)$$

$$\langle \tilde{q}_{\ell m}(\psi) \tilde{q}^{*}_{\ell' m'}(\psi) \rangle = (2\pi)^2 C_\ell \delta_{\ell\ell'} \delta_{mm'} = (2\pi)^2 A(\psi) \ell^{-\alpha(\psi)}$$

- transform back to frequency space using the Fourier relation between RM and lambda^2

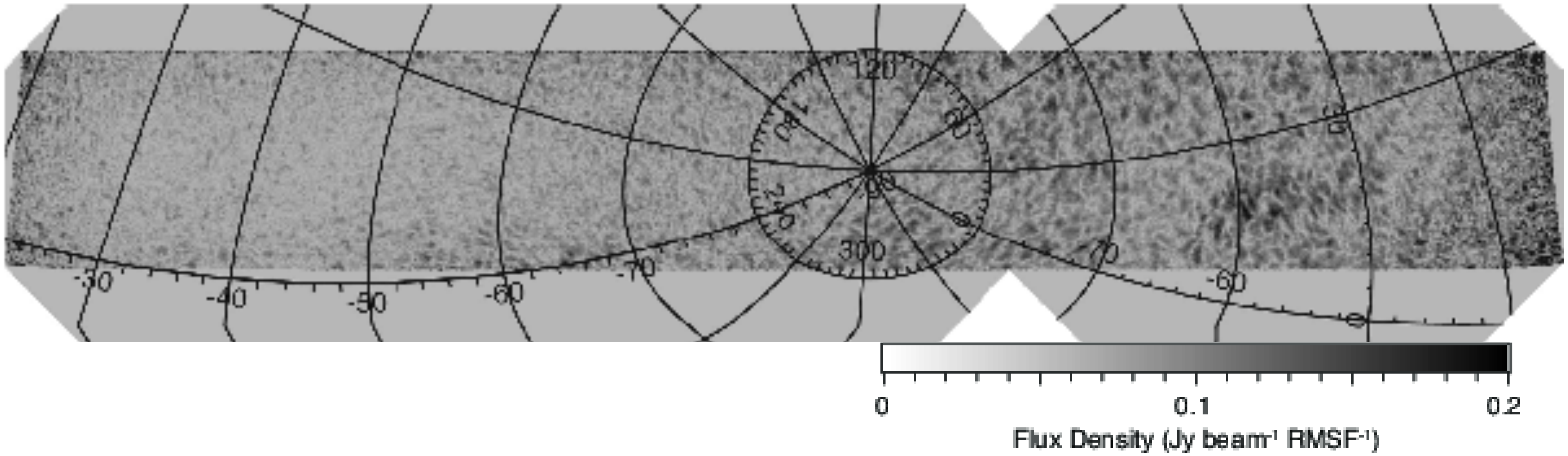
$$Q(\theta,\phi,\lambda^2) = \int \tilde{Q}(\theta,\phi,\psi) e^{2\pi i \lambda^2 \psi} d\psi$$

we use MWA data to constraint free parameters

(but we can use other data)

MWA data @189 MHz

G. Bernardi et al. 2013



- MWA 32 element 2400 degrees
- RM synthesis

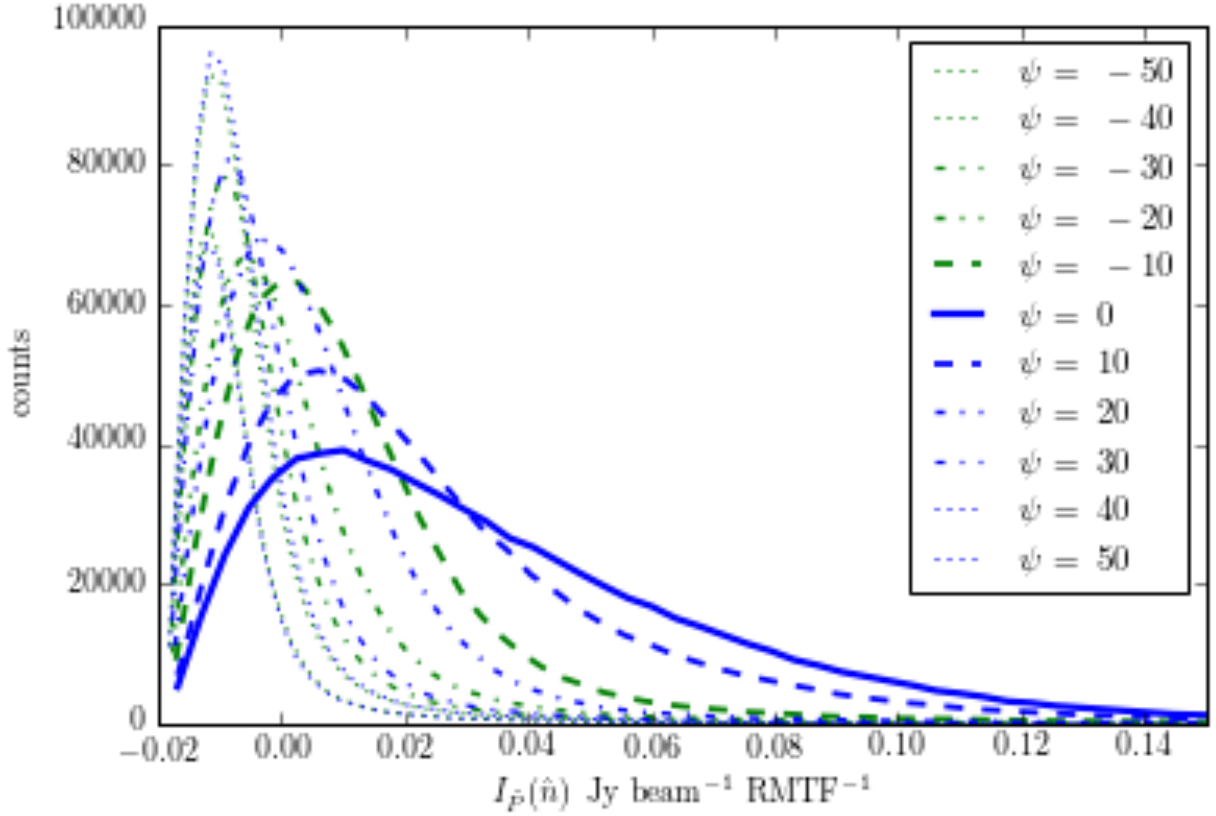
cube of polarised images at selected faraday depth

-50 < RM < +50 rad m^-2
in step of 1 rad m^-2
RMTF 4.3 rad m^-2

➡ describe MWA statistical behaviour and extend it to full-sky

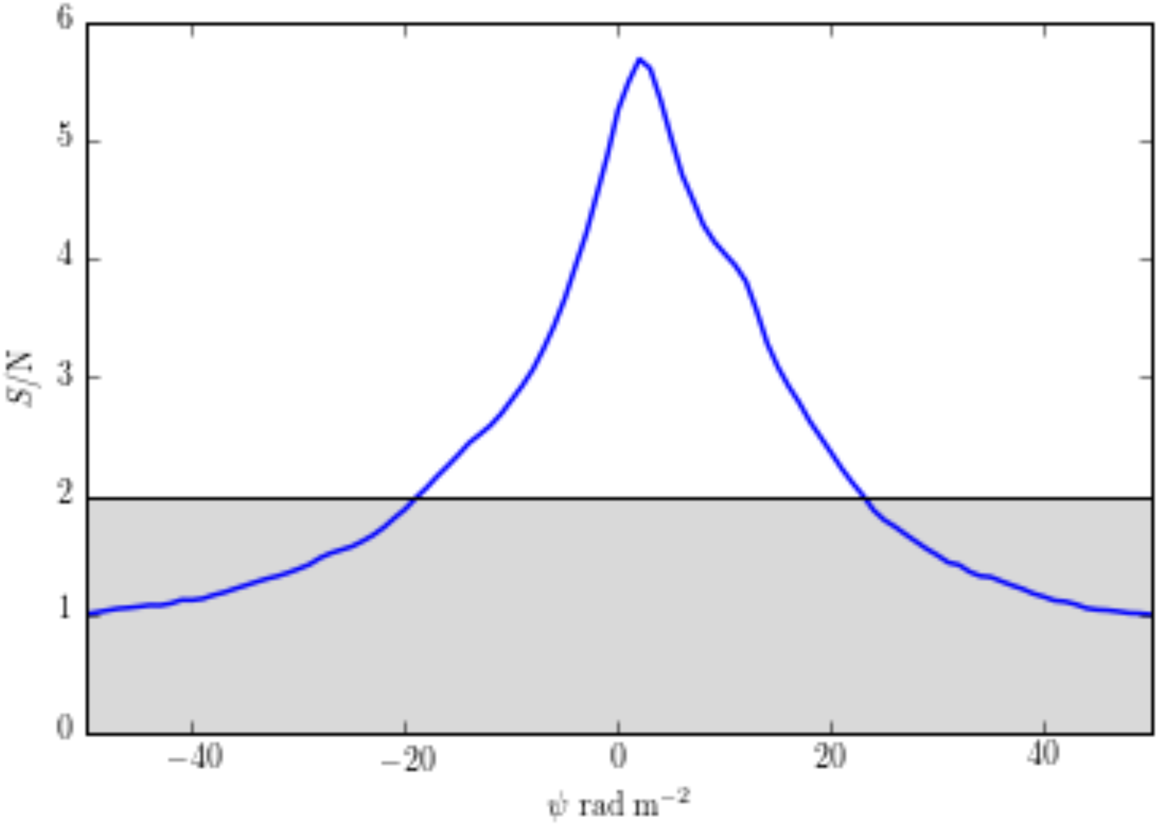
- CONs: fine and local structures impossible to catch
- PROs: using genuine polarisation data instead of intensity

MWA data characterisation



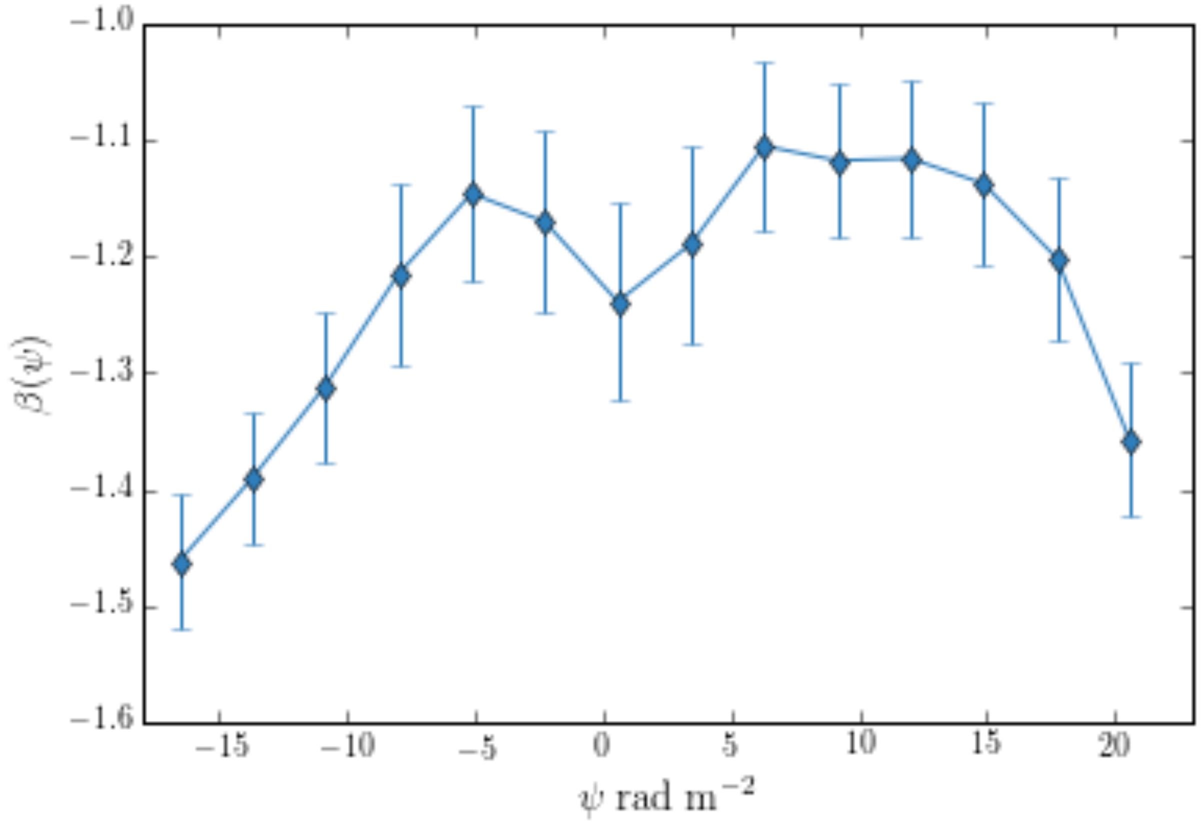
- At fixed RM, the data can be approximated with a Rayleigh distribution R(sigma)
- the value of sigma fix the global level of the final map $A(\psi)$

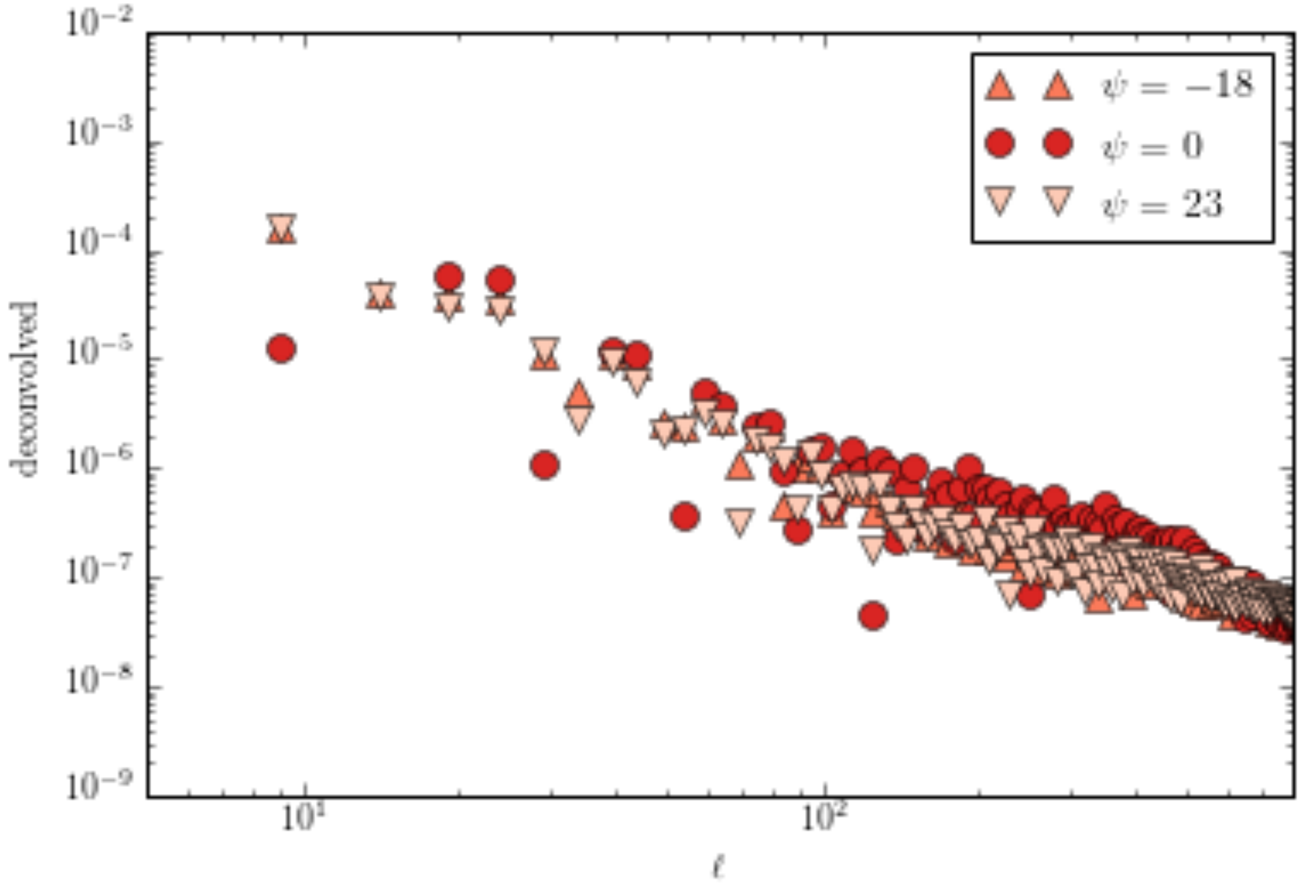
- maps at RM=+50, -50 as proxy for the noise
- retain only maps with S/N greater than 2: the interval -18< RM <+23



MWA data characterisation

- Consider P maps as a function of RM
- Power Spectrum reconstruction with *HEALPIX (Gorski et al. 2005)* and *MASTER (Hivon et al. 2002)*



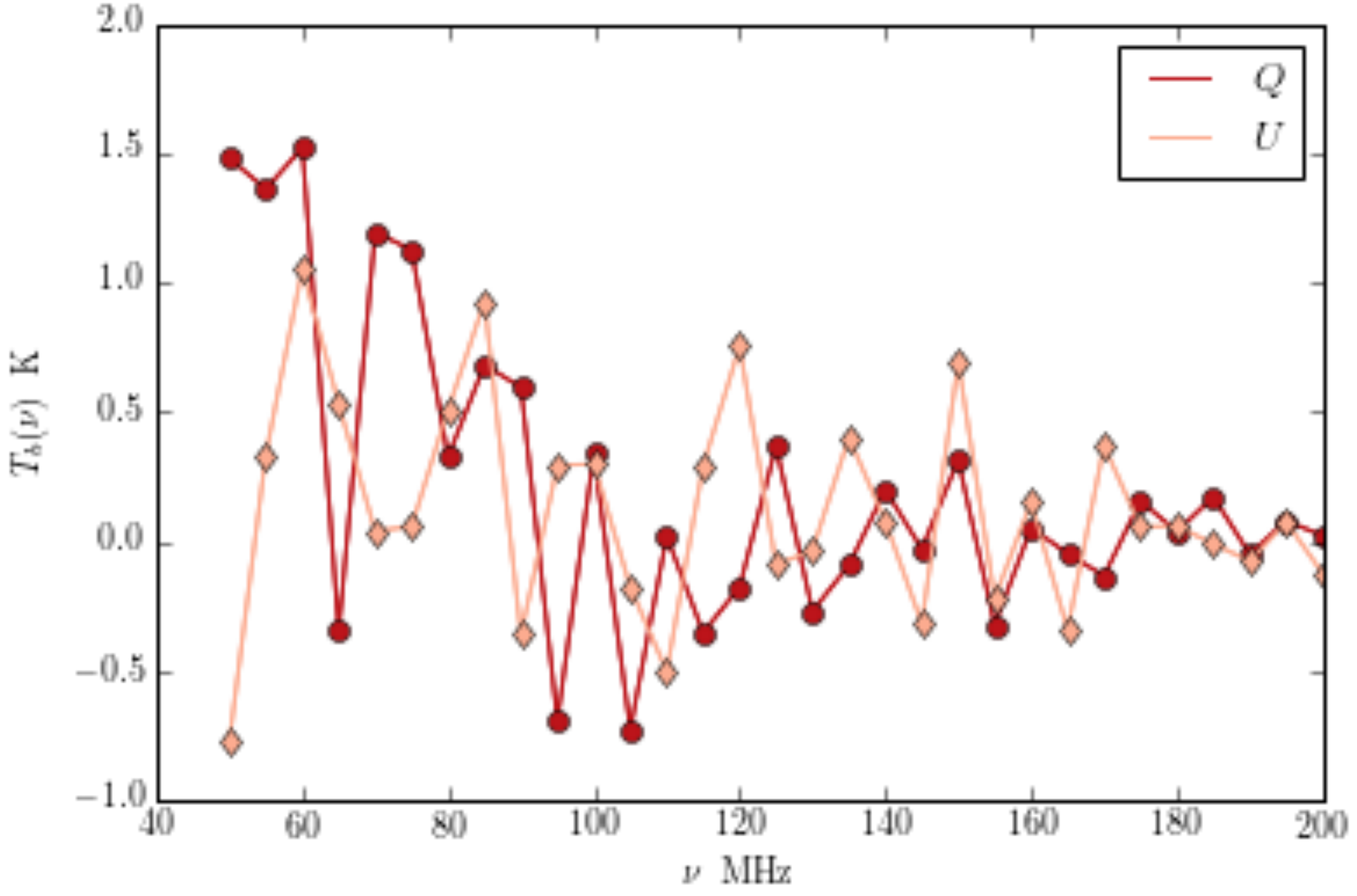


- Fit a power law behaviour considering *cosmic variance* on large scale and *noise* on small scales *(Tegmark 1997)*

Full-sky extrapolation

- We obtained $A(\psi)$ from MWA data
- Fit power law to extract the one for Q, U $\ell^{-\alpha(\psi)}$

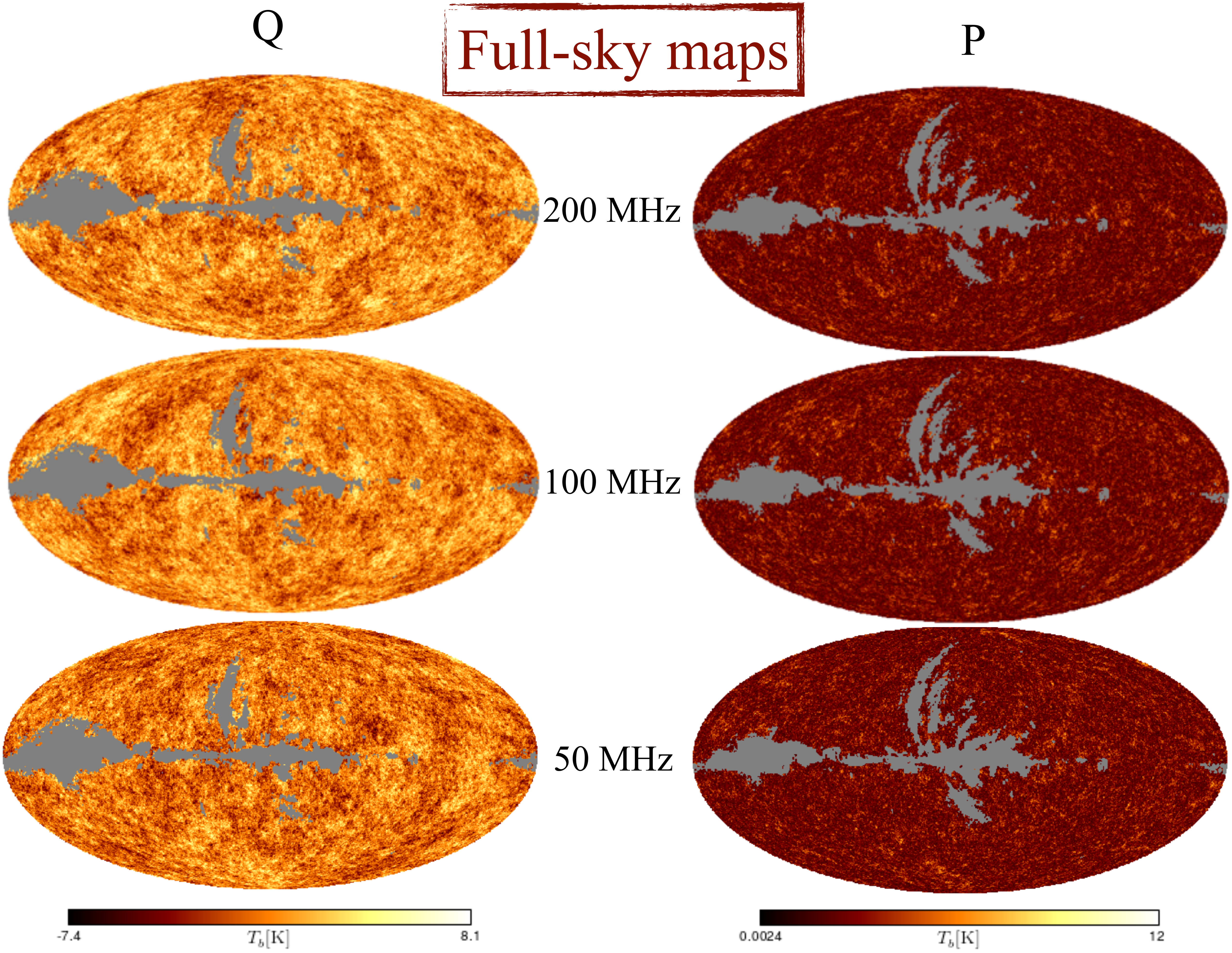
we simulate a RM-cube and then transform back to frequency space



T_b as a function of frequency for a random LOS in the range 50-200 MHz for Q and U

Note: we exclude 10% of the sky using WMAP Q and U @23 GHz

Full-sky maps



Conclusions

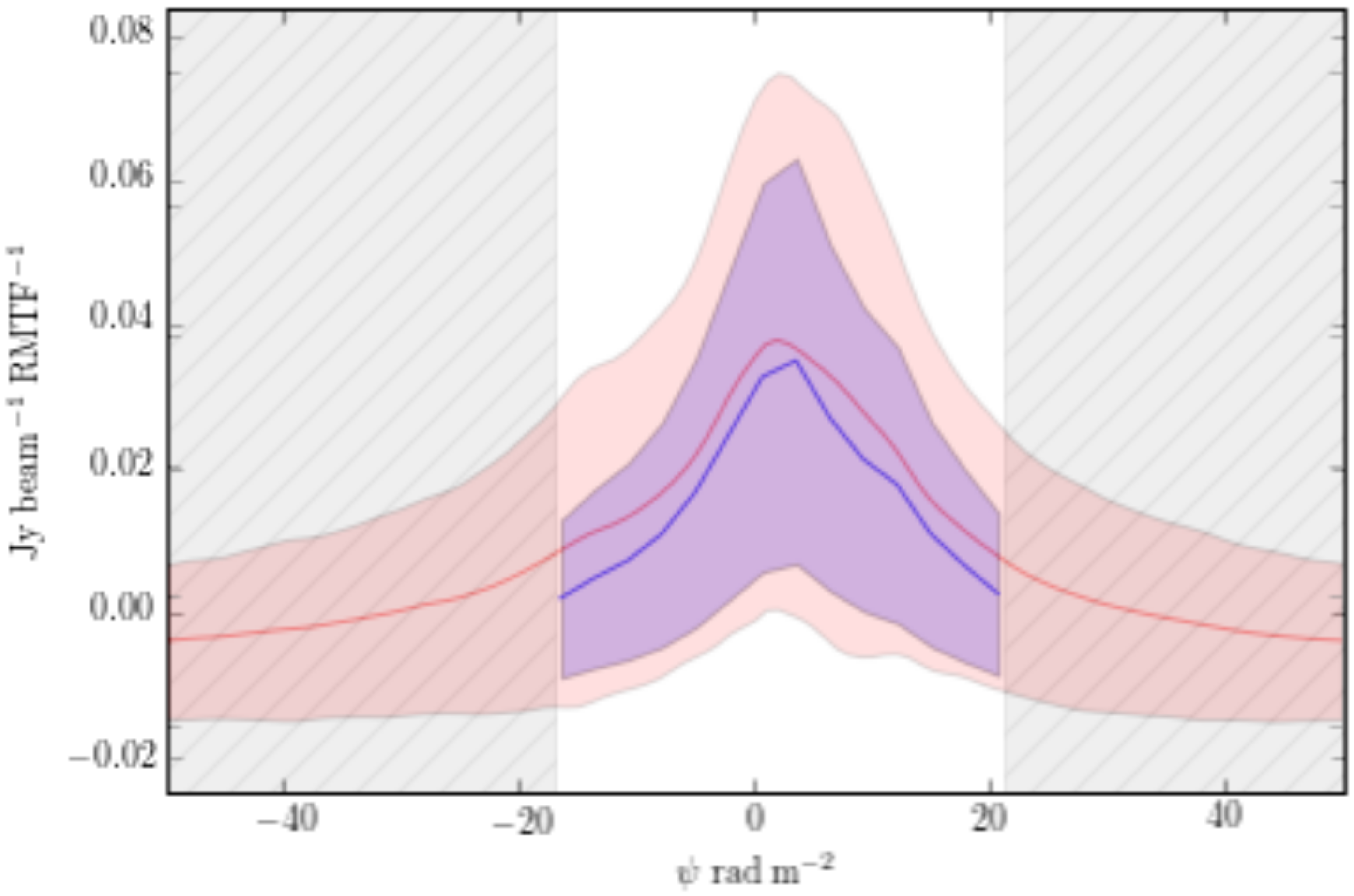
- Polarised foregrounds are a potential issue for EoR signal detection (even if now less worrying than before?)
- Lack of data and de-correlation from intensity make simulations a complicated task
- We use RM synthesis MWA data @ 189 MHz
- Characterise some global statistical properties and extend them to simulate a full-sky RM-cube
- Transform back the RM-cube to frequency space

To do:

- Including forthcoming larger area observations
- Find data to better characterise the galactic plane
- Test the maps in cleaning pipelines (to have a better understanding on how much we should fear polarised synchrotron)

Backup

Simulation checks



Mean and std of the P maps as a function of RM for the data (in red) vs. simulation (in blue)

Full-sky extrapolation

- MWA data characterised by power law P but we generate Q, U
- simple brute force Monte Carlo method to find the power law for Q, U given the one for P

Example: beta=-1.2