Inferring source polarisation properties from SKA observations

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Motivation and Overview:

Explore the evolution and generation of magnetic fields throughout the Universe with up-coming and future instruments

Especially study detectability of magnetic fields in galaxy clusters (largest gravitationally collapsed objects in the Universe with possibly very complicated magnetic field structures) with up-coming and future instruments (SKA and its pathfinders)

0) Synchrotron emission and Faraday rotation as magnetic field measure (RM)
1) Description of simulations (continuum and degree of polarisation)
2) RM Grid Statistics
3) Analysis of expected data (RM synthesis)
4) Results and Conclusions

Physical processes of importance:

Polarised synchrotron emission:

- **Highly relativistic electrons gyrating in magnetic field (EM radiation emitted by accelerated charge; beaming due to relativistic velocities)**
- **Synchrotron radiation spectrum of electron plasma : $S_v \sim v^{-\alpha}$ (low turn-over frequency, steepening at high frequencies)**
- **Intrinsic degree of polarisation (electron plasma with a power law energy distribution): Emission up to ~70% polarised (viewing angle perpendicular to homogeneous B-field; for typical power law indices)**

Faraday effect:

Effect of magneto-thermal electron plasma on transversing polarised radiation (scalar thermal electron density; line-of-sight B-field)

Simulating polarised sources

Simulate continuum emission:

Empirically: Assume luminosity functions for different source populations (i.e. AGN types, normal galaxies, starbursts), extrapolate and evolve; use linear theory to distribute (see e.g. Oxford team)

Numerically: Run large (hydro-dynamical) N-body simulations, distribute sources in a halo and environment dependent fashion

Model intrinsic degree of polarisation:

Empirically: Polarisation model prob based on observational results (see e.g. Tucci et al. – use a log-normal distribution at all frequencies; typically ~1%)

Theoretically/numerically: Model (analytically or numerically) sources (electron densities and B-field distributions)

# Modeling Faraday foreground screens (simple RM model)

Cluster model and distribution:

- Cluster modeling based on mass function and linear density perturbations

- Scaling relations to obtain cluster properties (e.g. cluster specific radii)

- Electron density modeled by a standard β profile

- RM radial distribution based on results from local Universe

  - Random uniform field amplitude matching local results

- Construct RM cluster "image" (still to include foregrounds and galaxies)

RM grid building:

- Model source catalogue as described

- Model polarisation as described

- Model observations
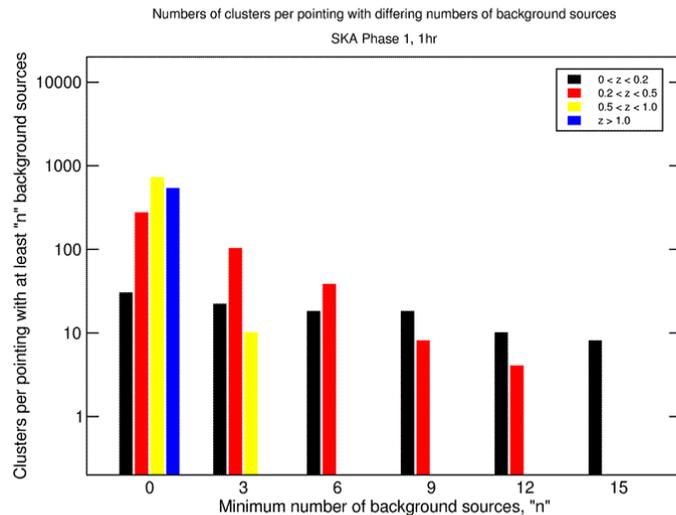
Simulating Faraday screens
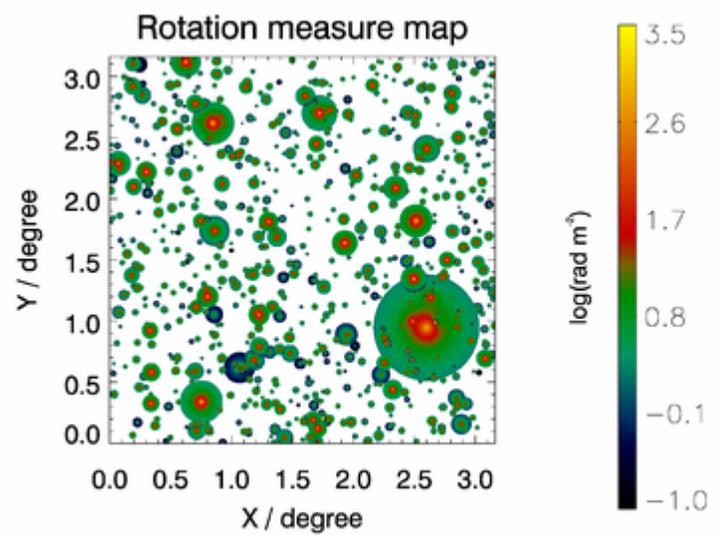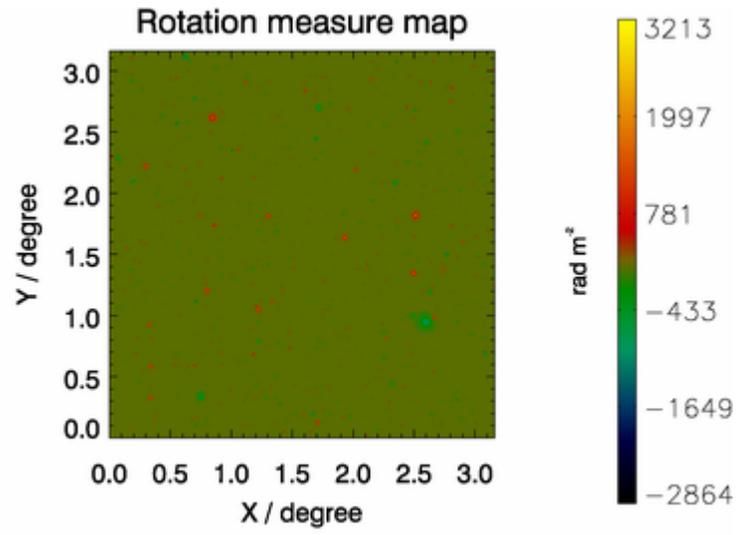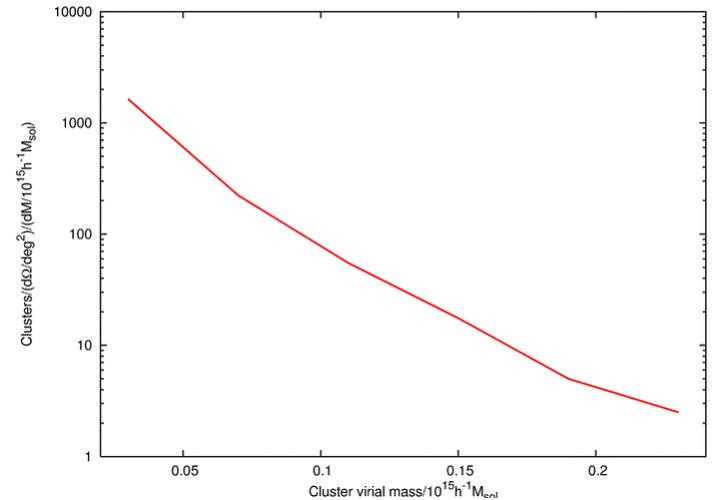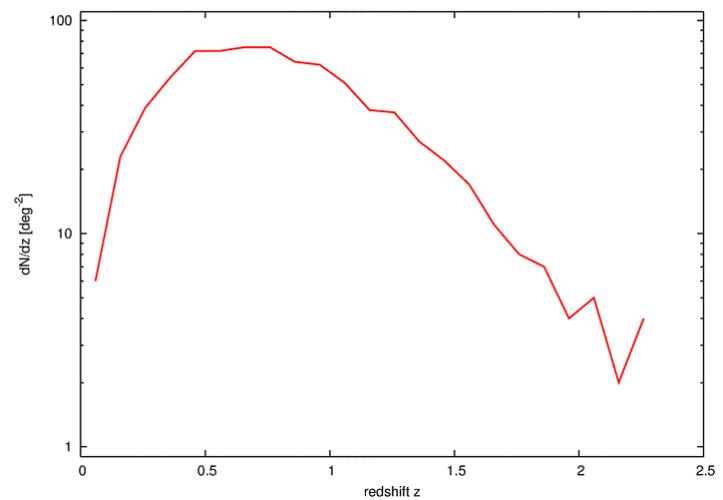
RM Grid Statistics
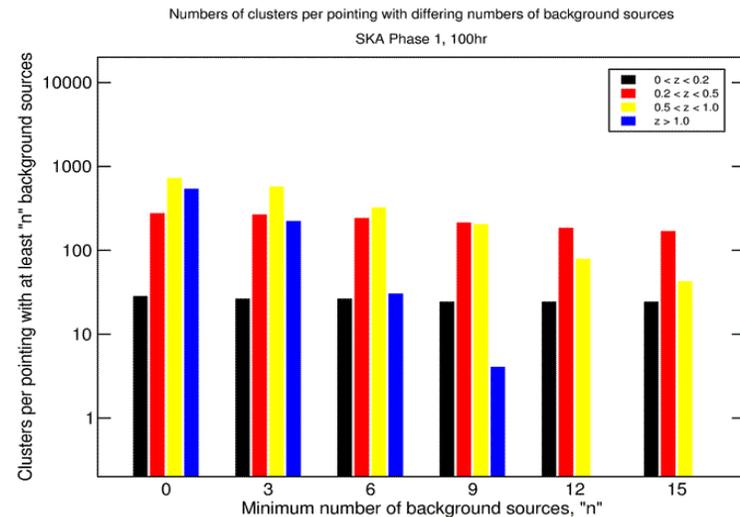### (cluster numbers and expected lines of sight through clusters)

SKA Phase 1:

1hr integration

100hrs integration

T_{sys} = 50 K, A/T = 1200 for 20 sqdeg

490 15 m dishes

Bandwidth: 400 MHz

RM Grid Statistics

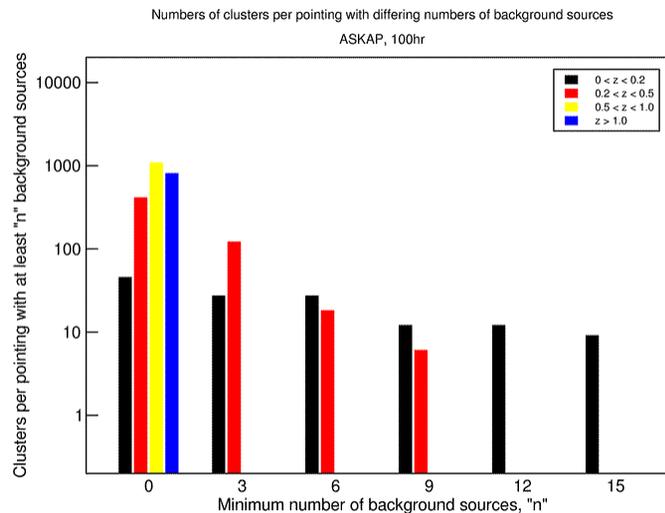**(cluster numbers and expected lines of sight through clusters)**

ASKAP:

1hr integration

Numbers of clusters per pointing with differing numbers of background sources

ASKAP, 1hr

100hrs integration

Numbers of clusters per pointing with differing numbers of background sources

ASKAP, 100hr
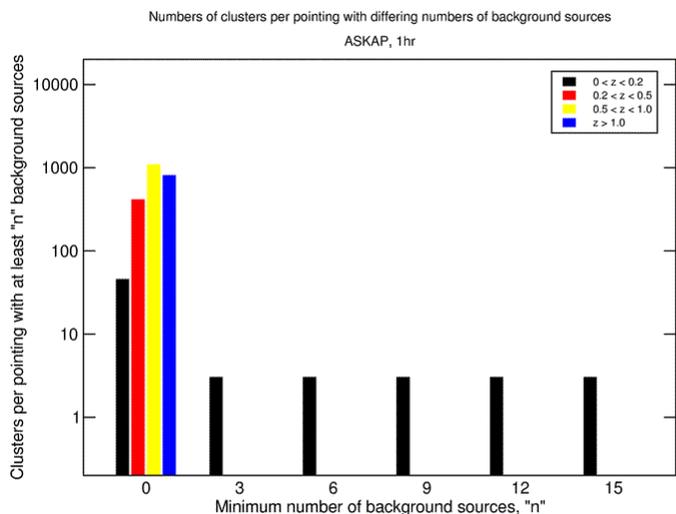
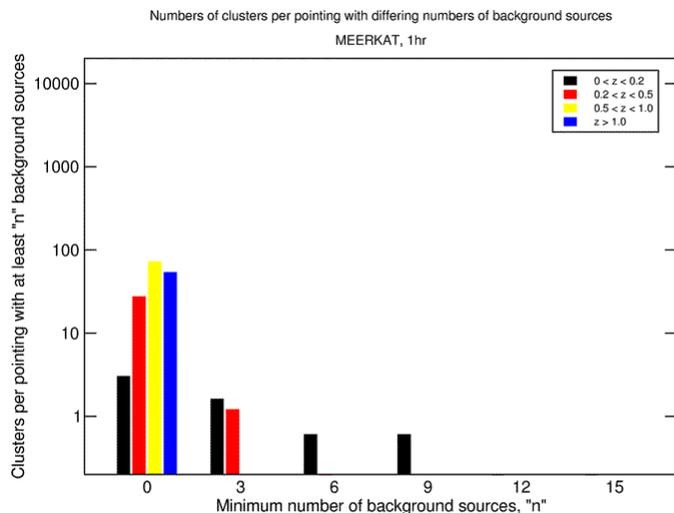T_{sys} = 35 K, Area: 5089 sqm

FoV: 30 sqdeg

Bandwidth: 300 MHz

RM Grid Statistics
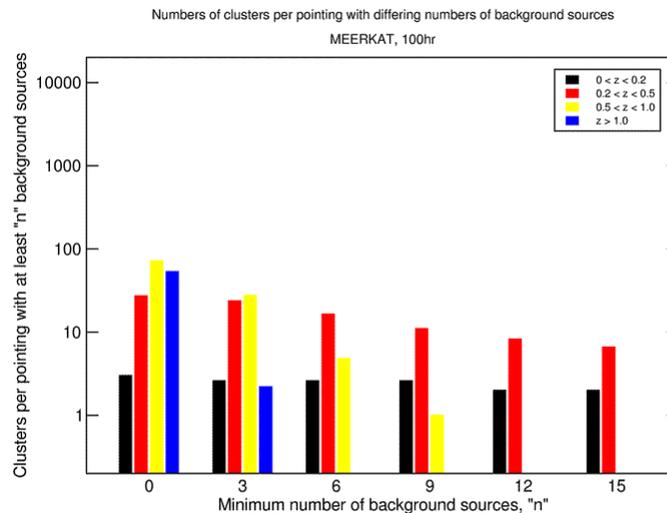### (cluster numbers and expected lines of sight through clusters)

MEERKAT:

1hr integration

100hrs integration

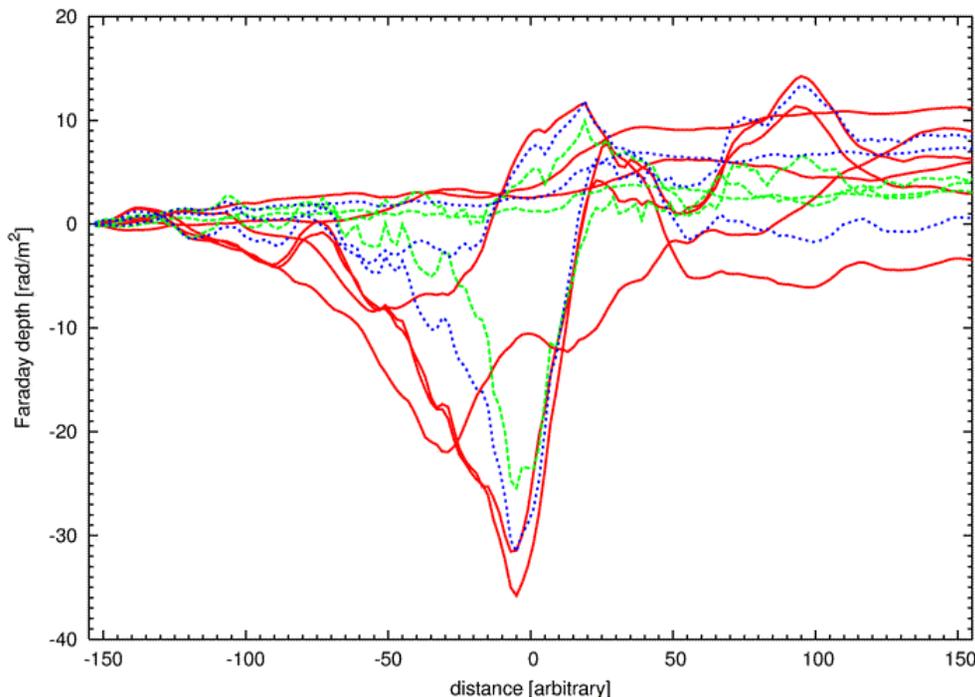T_{sys} = 27 K, Area: 14139 sqm

FoV: 2 sqdeg

Bandwidth: 512 MHz

Faraday screens with turbulent fields I

- **Electron gas density: $(1+r^2)^{-3\beta/2}$, $\beta=0.6$**

- **Magnetic field from random vector potential, modulated by $(1+r^2)^{-3\mu/2}$, $\mu=0.3$, so average energy density ratio stays constant with radius**

- **Integrated rotation measure along line of sight**

Change of Faraday depth for different lines through a cluster of medium mass and for different values of the spectral index of the power spectrum (see also Murgia et al. 2004; Govoni et al. 2006 for observations of fields in clusters)

Faraday screens with turbulent fields II

n=2

Kolmogorov (n=11/3)
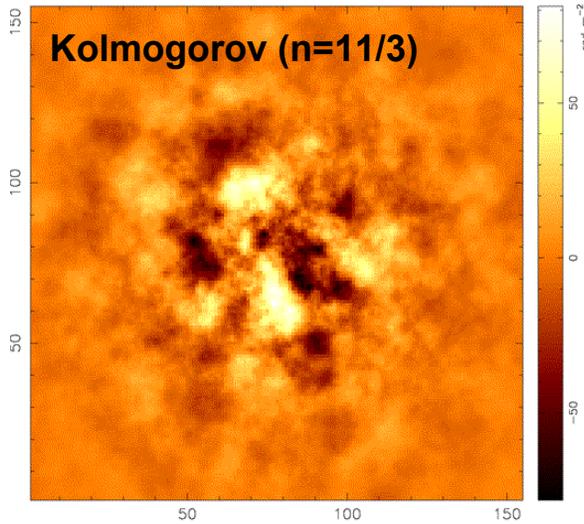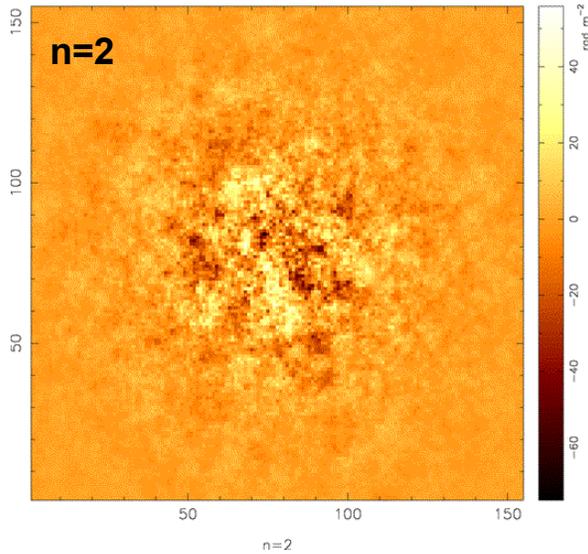
Rotation measure structures for different values of the spectral index; normalised to have the same total magnetic field energy

Power spectrum of multi-scale tangled divergence-free cluster magnetic field model:
$$k^2 P(B) = k^{-(n-2)}$$

n=3

n=4
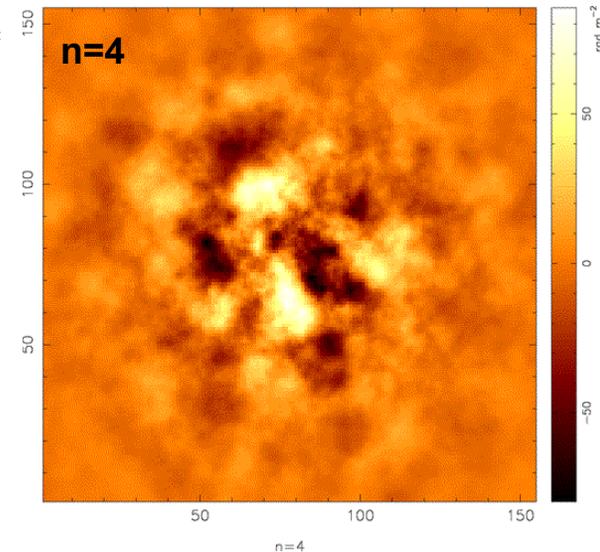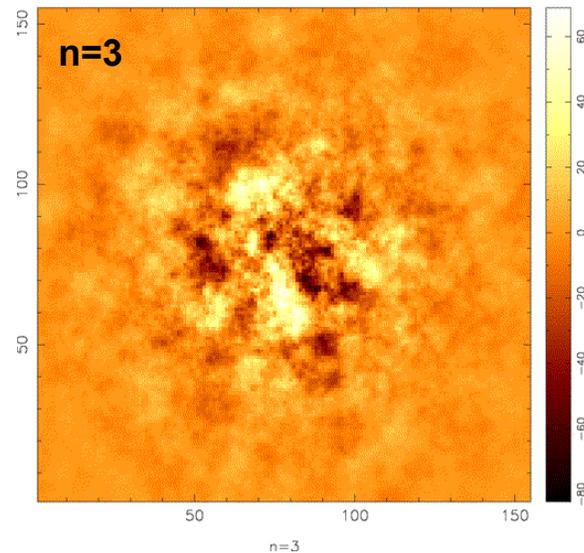
Depolarisation

Along the line of sight:
- scrambled/tangled magnetic fields (emission)
- Differential Faraday rotation (source structure and geometry)

By the telescope beam:
-(Rapid) change of polarisation angle on the sky smoothed out by synthesised beam pattern and/or source illumination

By the channel bandwidth:
-Resolution of Faraday rotation feature (wavelength and bandwidth dependent)

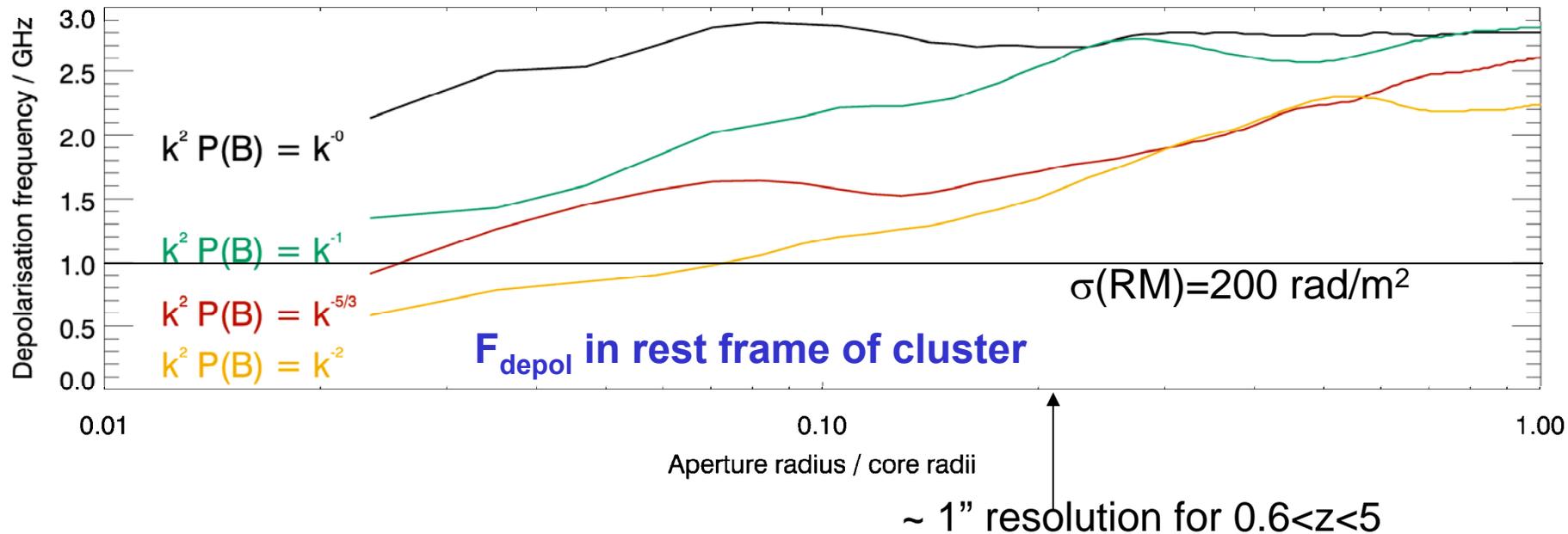**By temporal changes in the earth's atmosphere:**
-Ionospheric Faraday rotation (time varying turbulent screen)

Comparing field power spectra

Beam depolarisation for different power spectra

$k^2 P(B) = k^{-0}$

$k^2 P(B) = k^{-1}$

$k^2 P(B) = k^{-5/3}$

$k^2 P(B) = k^{-2}$

$\sigma(RM)=200$ rad/m^2

F_{depol} in rest frame of cluster

Aperture radius / core radii

~ 1" resolution for 0.6<z<5

- **Depolarisation frequency may provide an independent constraint on the power spectrum of the magnetic field**

- **Does need careful consideration for experiment design**

MCMC RM synthesis

Methodology:

Use a Bayesian analysis in combination with a MCMC sampling method to explore the posterior.
Assume source and screen models and apply model parameter priors (i.e. knowledge gained from past observations and simulations).
Test for model preference by selection criterions to discriminate between different realistic/possible models.
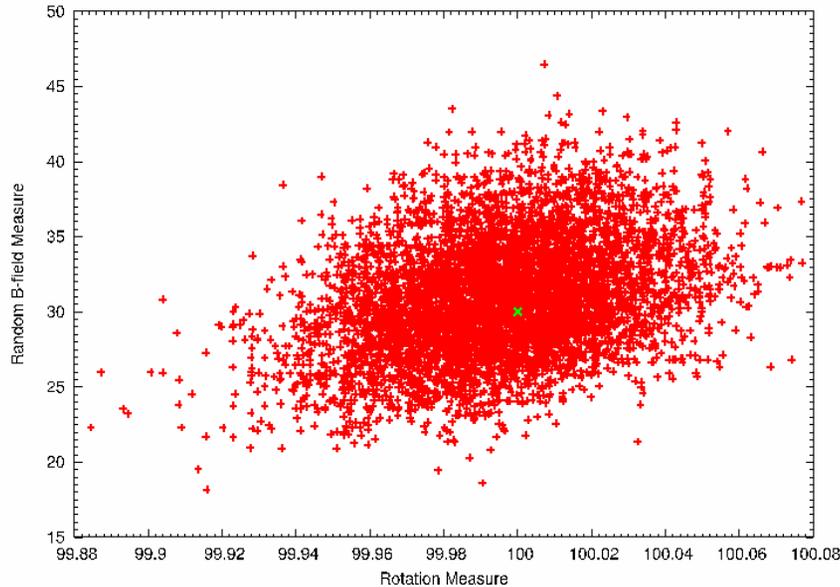
Bayes' theorem:

$$P(\theta|D,H) = [P(D|\theta,H)\ P(\theta|H)] / P(D|H)$$

MCMC: prescription for efficiently sampling from the parameter hypercube
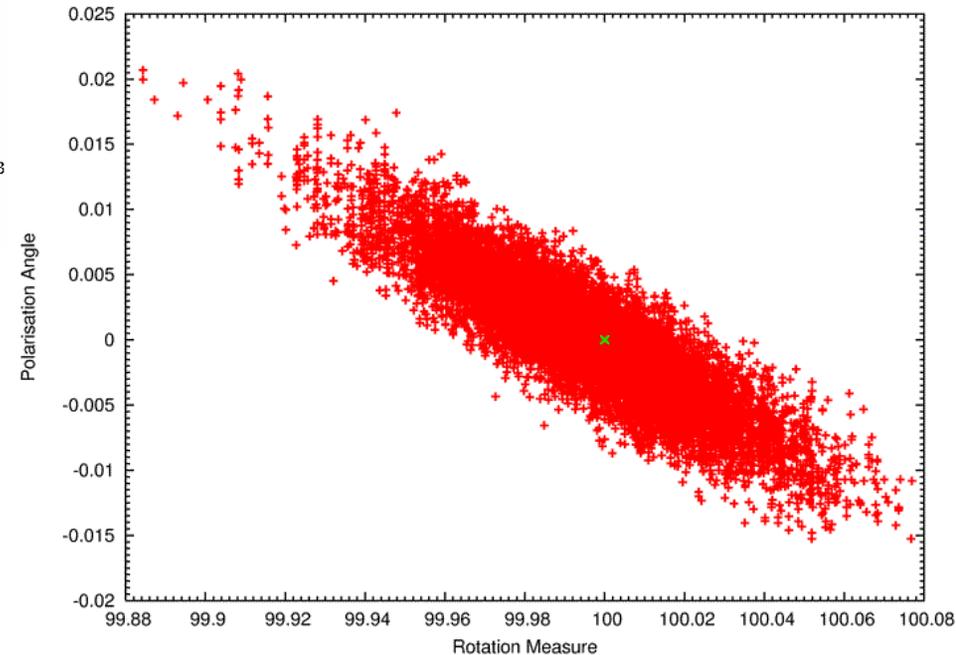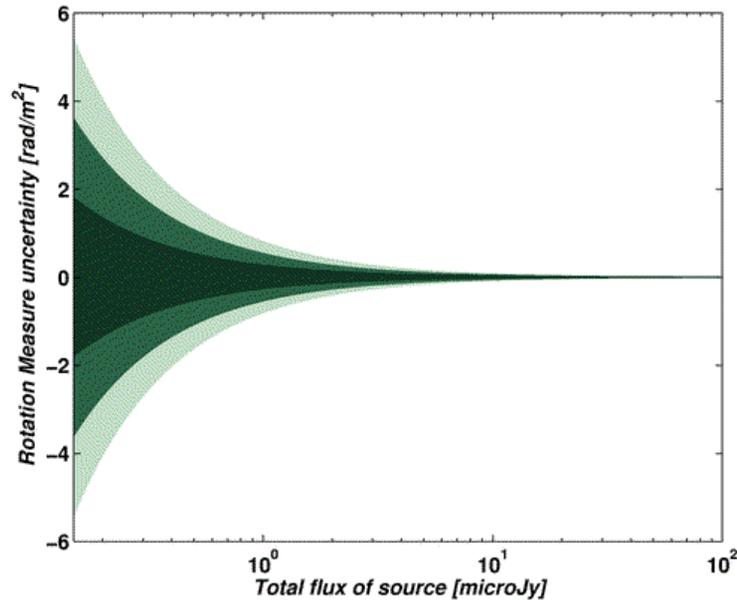
Sampling the posterior

Simulations:
SKA AA observation of galaxy through screen;
SKA AA specifications as in Schilizzi et al.

Thinned and marginalised posterior sample distributions -> confidence intervals

Prior assumptions:
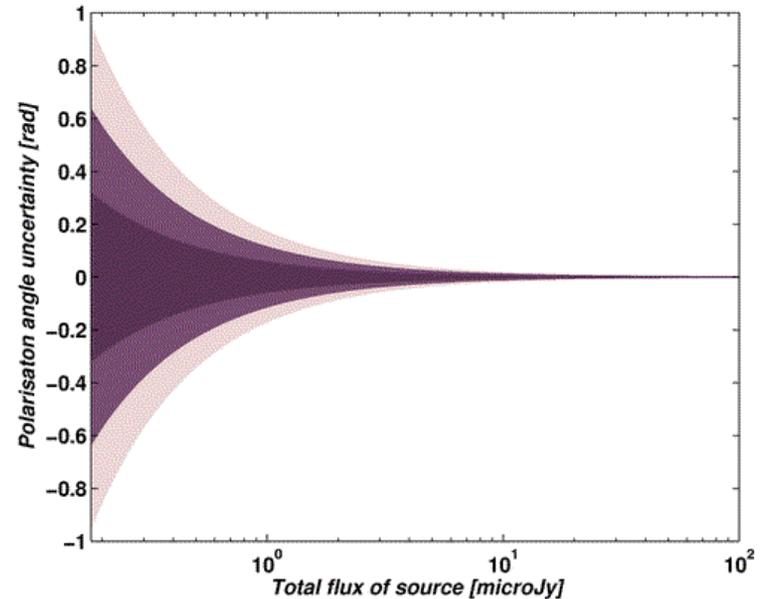**Model, redshift (e.g. SZ cluster detection followed up in optical)**

MCMC RM synthesis results

Uncertainties of foreground screen RM and radio galaxy intrinsic polarisation angle for single lines of sights

Different colour shades represent different levels of confidence

Conclusions

- **SKA pathfinders will be powerful instruments for studying B-field in clusters nearby and at moderate redshifts**
- **Full SKA is needed to go out to high redshifts**
- **Need to have prior knowledge on cluster positions and redshifts**
  - **SZ and X-ray surveys and their follow-up will deliver this for clusters**
- **Developed a capable and efficient analysis tool**
- **Need to model full data processing pipeline and include Galactic and atmospheric screens**
- **Moreover need to include in our simulations**
  - **Model cluster embedded sources and the interaction of extended sources with IGM (FR-I's and FR-II's)**
  - **Further improve cluster field modeling and make predictions about evolution of sources (some predictions from cosmological MHD simulations; 12 redshift slices from z=5 to z=0)**