Probing Intergalactic Magnetic Fields by Faraday Tomography

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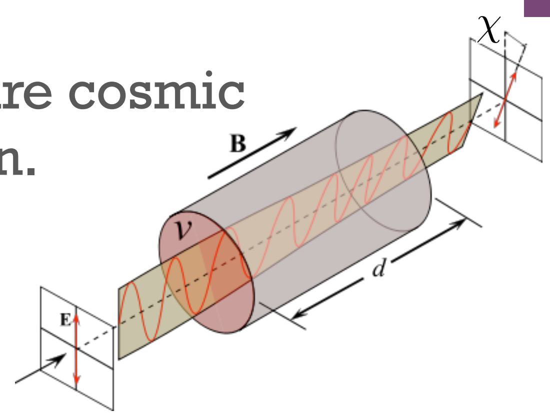
Introduction

- The origin and nature of intergalactic magnetic field (IGMF) is one of the outstanding problems of modern astronomy and cosmology.
  - The IGMF would become a seed fields of proto-galaxies.
    - These magnetic fields affect the current magnetic field structure of galaxies.
  - Exploring the IGMF includes the importance for finding the warm-hot intergalactic medium.

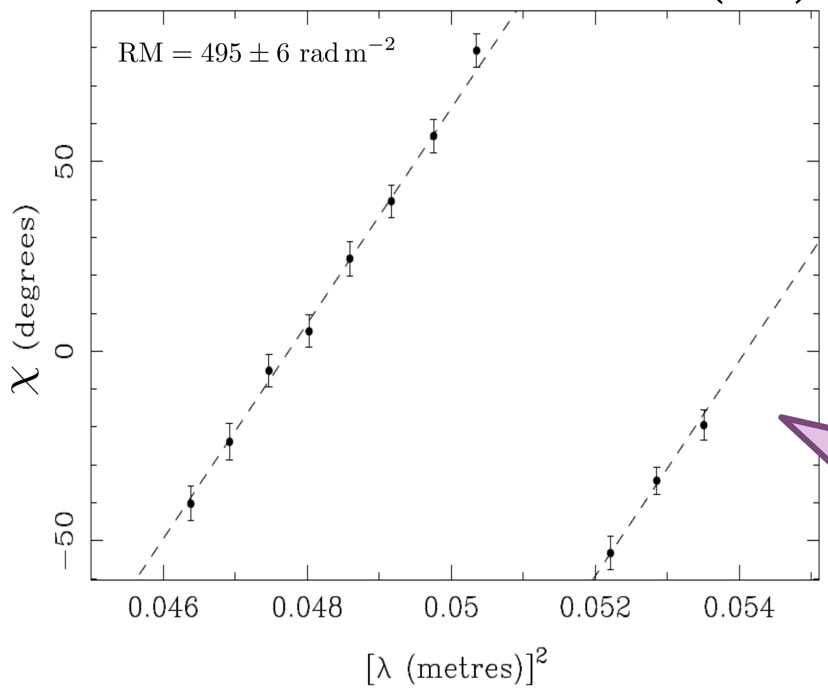
- In order to probe the IGMF, we consider so-called **Faraday tomography**.

To measure the IGMF

- One of the conventional methods to measure cosmic magnetic fields is to utilize Faraday rotation.



Pulsar B1154-62 Gaensler et al. (1998)



$$\chi = \chi_0 + \mathrm{RM}\lambda^2$$

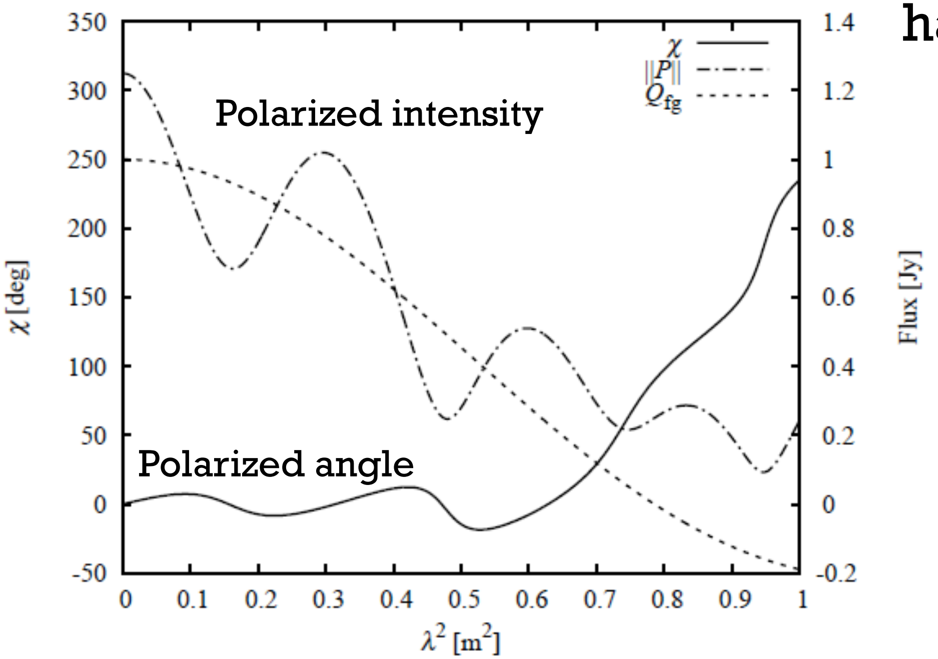
RM : Rotation measure

$$\mathrm{RM} = \frac{e^3}{2\pi m^2 c^4} \int_0^d n_e(s) B_{||}(s) ds$$

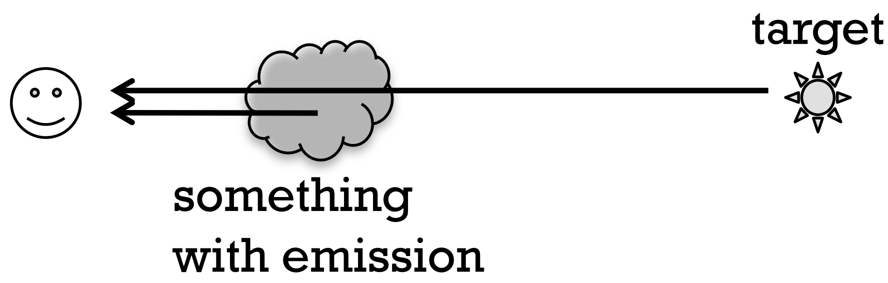
This method is successfully used to study magnetic fields of galaxies and galaxy clusters.

To measure the IGMF

M. A. Brentjens and A. G. de Bruyn (2005)



In generally, the polarized angle has complex structure.



The polarized angle is integrated value from here to target.
It makes difficult to identify the RM.

Faraday tomography makes it possible to pick up the RM of each component.

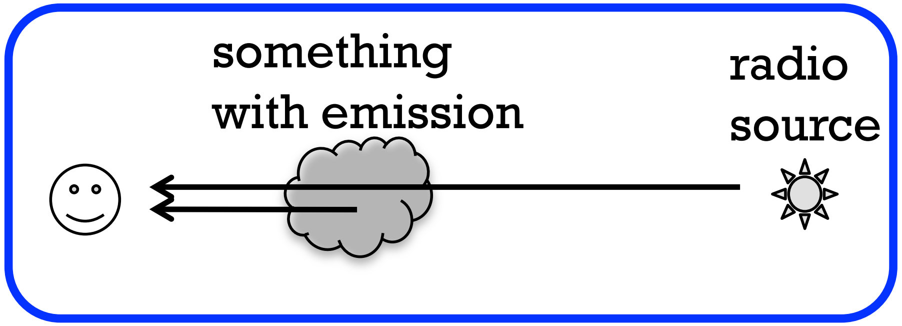
Faraday tomography

- The information of magnetic field is included in the **Faraday dispersion function** $F(\phi)$.

Brun, B. J. (1966)

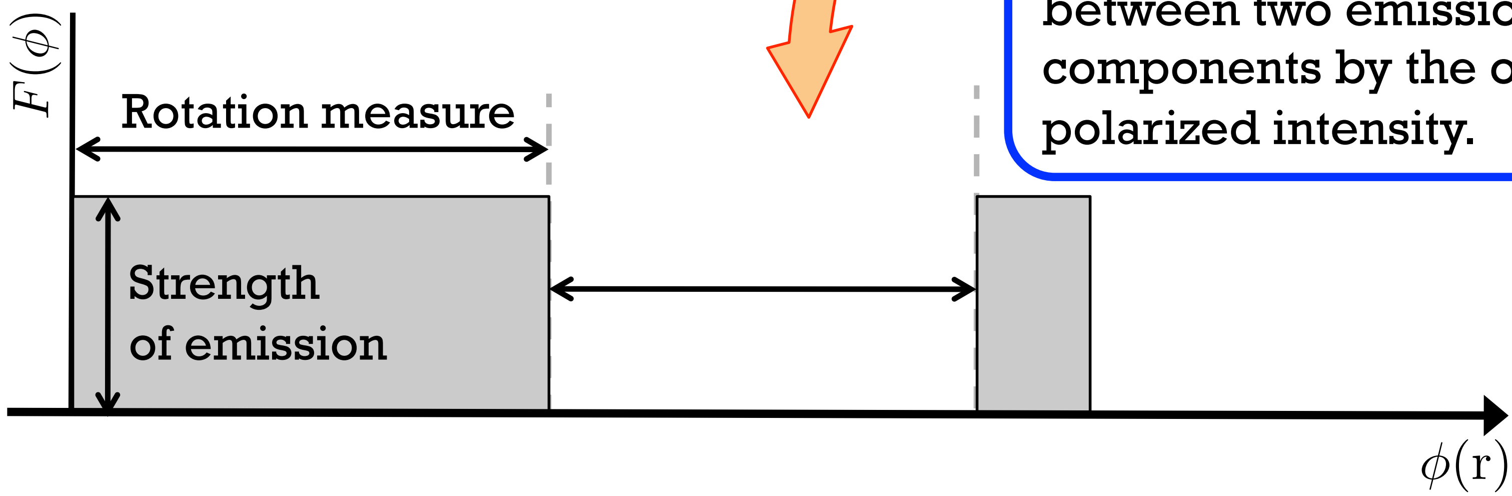
$$P(\lambda^2) = Q(\lambda^2) + iU(\lambda^2) = \int_{-\infty}^{\infty} F(\phi) e^{2i\phi\lambda^2} d\phi$$

$$\phi(\mathbf{r}) = 0.81 \int_{\text{there}}^{\text{here}} n_e \mathbf{B} \cdot d\mathbf{r}$$



This width represents the RM of IGMF.

We want to identify this width between two emission components by the observed polarized intensity.



Faraday tomography

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

The definition is similar to the Fourier transformation !!

Reconstruct

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

This method is called Faraday tomography.

- However, we can not observe the range $\lambda^2 < 0$.
- Also, observable range is finite.

We can not completely reconstruct FDF.

Faraday tomography

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W

In order to study how much FDF is reconstructed with limited range, we simulate Faraday tomography using some current/future interferometers.

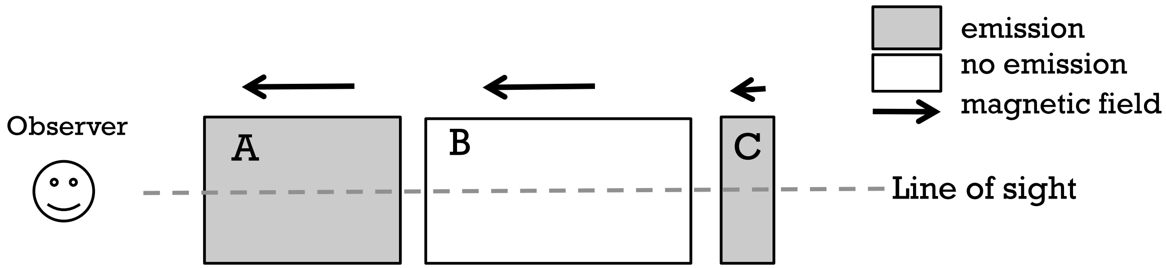
Step of simulation

Hypotheses

1, Magnetic fields pointing toward observer.
2, Contribution from our Galaxy is negligible.
3, Measurement errors are not considered.

① Set emission model.

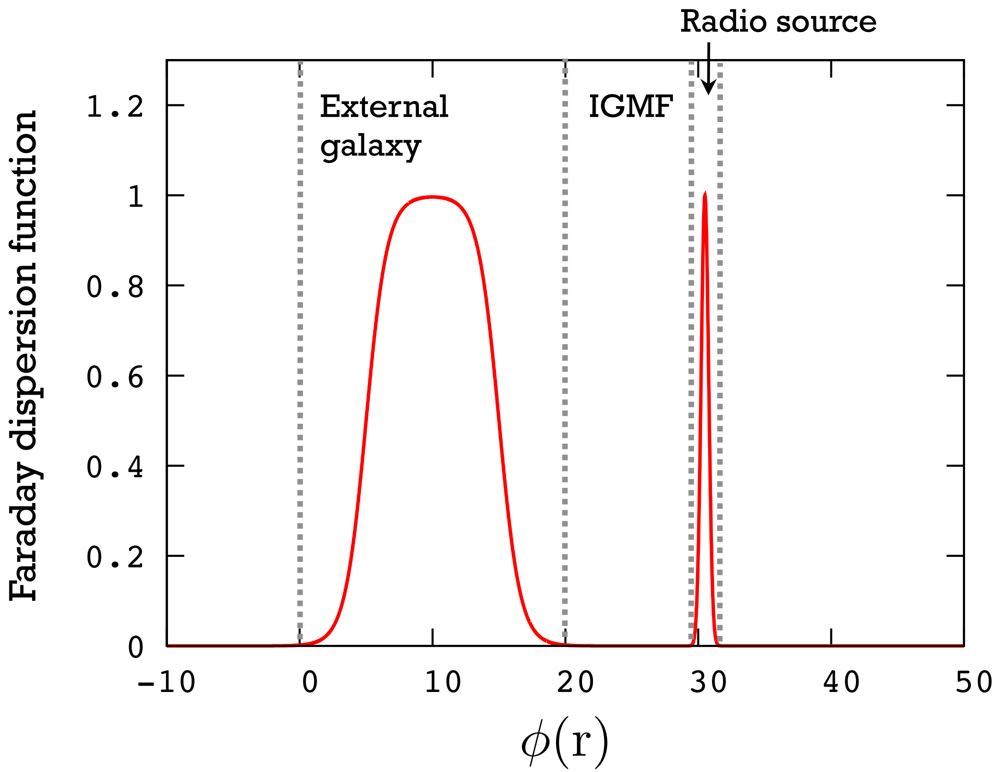
A : External galaxy
B : IGMF
C : Radio source



② Calculate $P(\lambda^2)$.

③ Simulate telescope capability.

④ Reconstruct $F(\phi)$.



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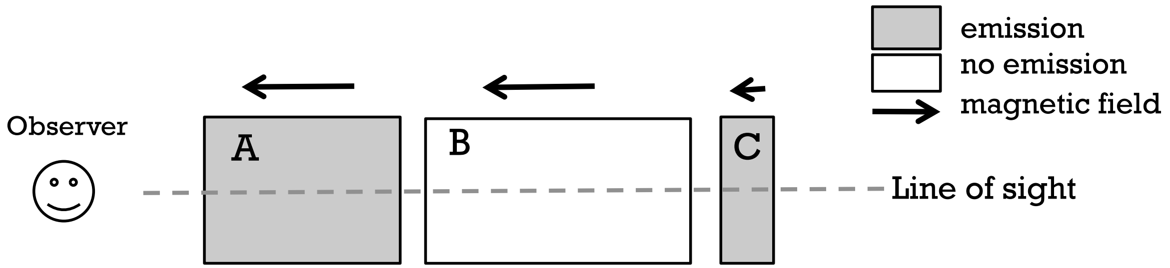

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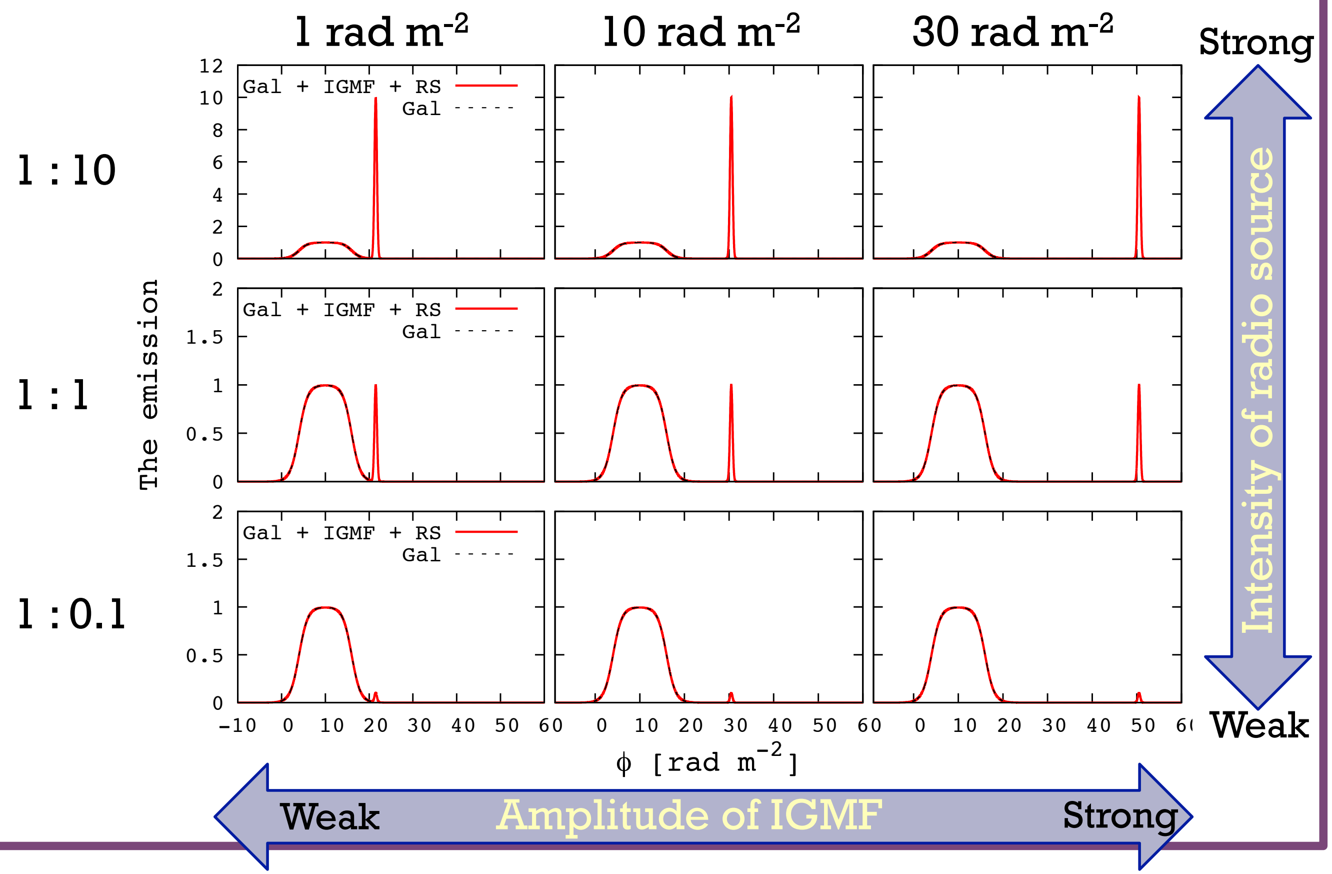

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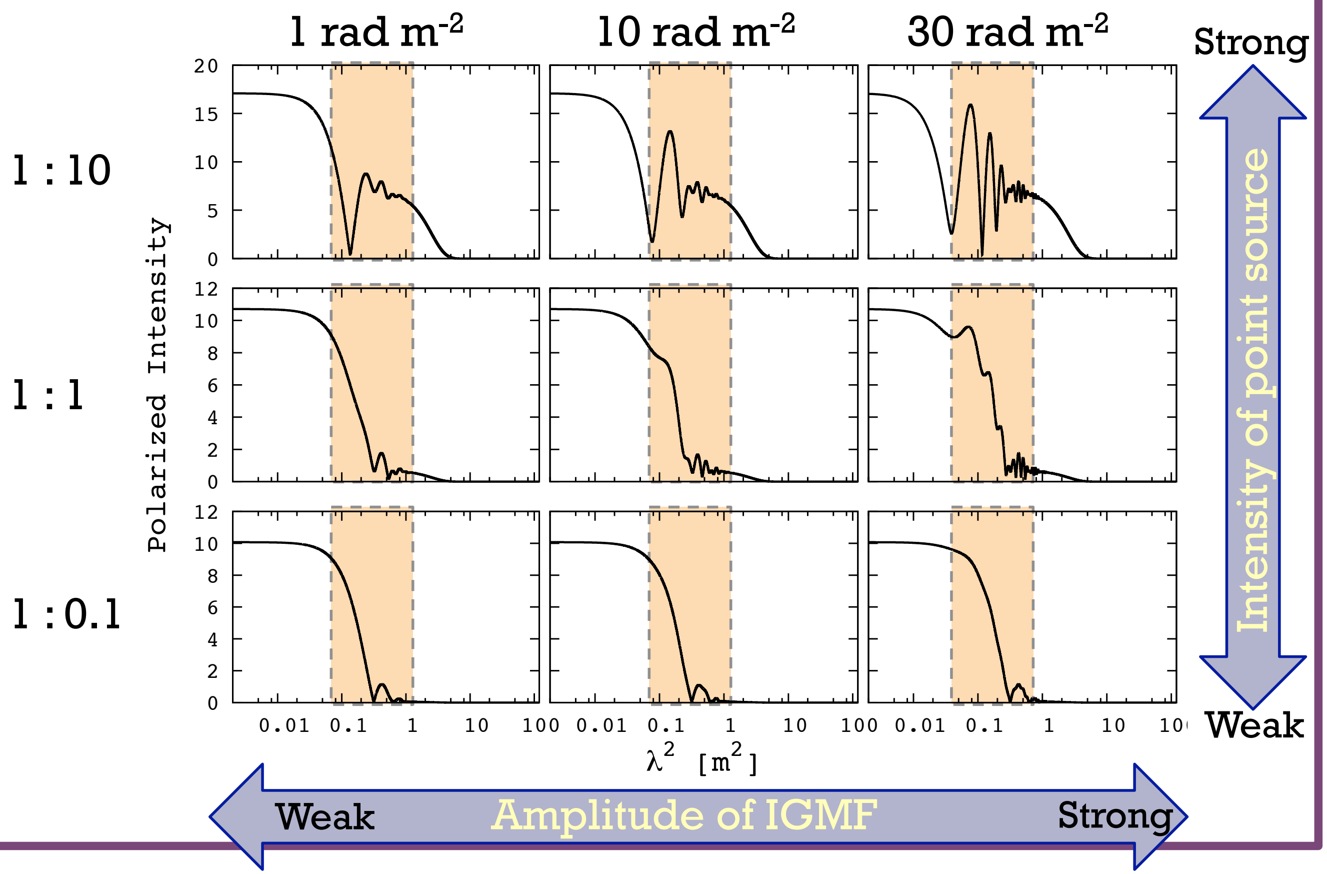
The middle wave bands have rich structure.



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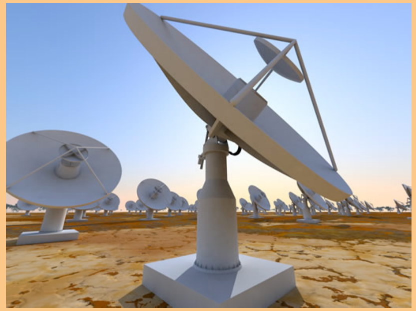
$$\tilde{P}(\lambda^2) = W(\lambda^2)P(\lambda^2)$$

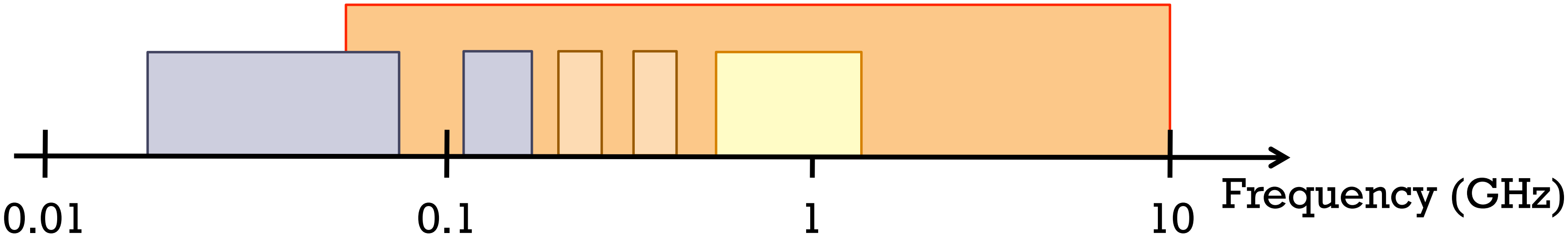
$$W(\lambda^2) = \begin{cases} 1 & \text{Observable} \\ 0 & \text{Not observable} \end{cases}$$

+

- We simulate following some interferometers.

Collaboration

				
	LOwer Frequency ARray (LOFAR)	Giant Metrewave Radio Telescope (GMRT)	Australian SKA Pathfinder (ASKAP)	Square Kilometre Array (SKA)
Frequency Range (GHz)	0.030 - 0.080 0.120 - 0.240	0.305 - 0.345 0.580 - 0.640	0.700 - 1.800	0.070 - 10.00



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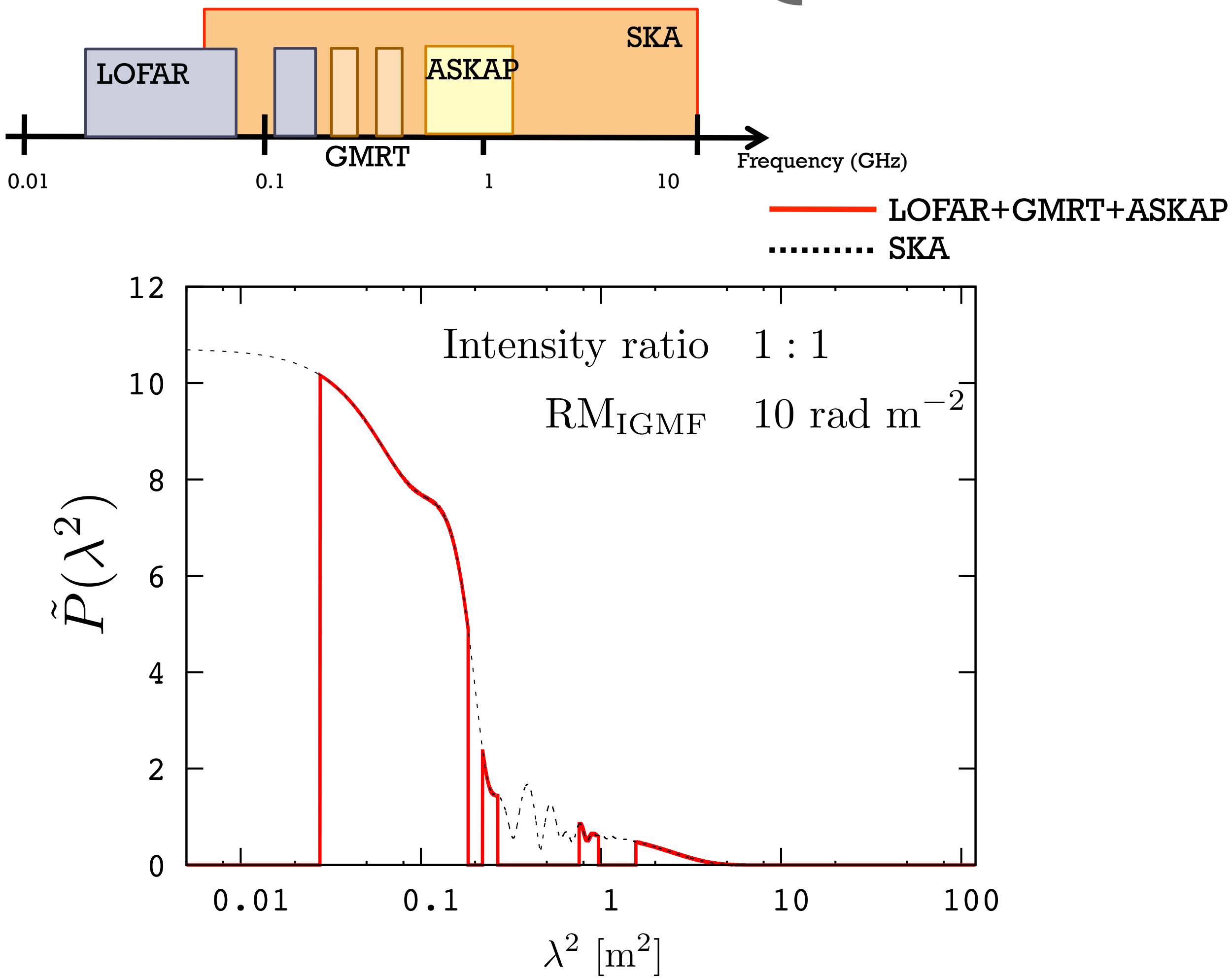

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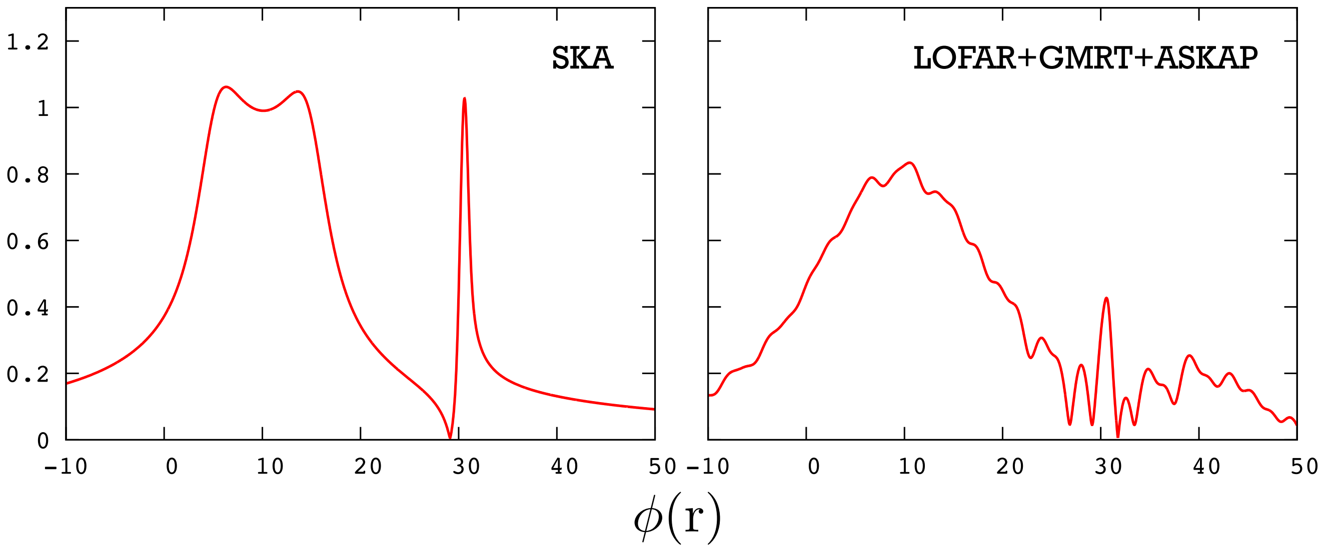
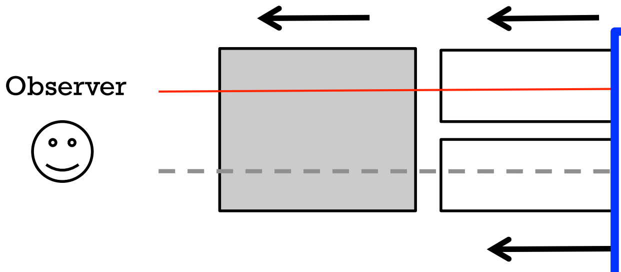


FDF has skirts around the peak.

It is difficult to find the edge of the external galaxy component.

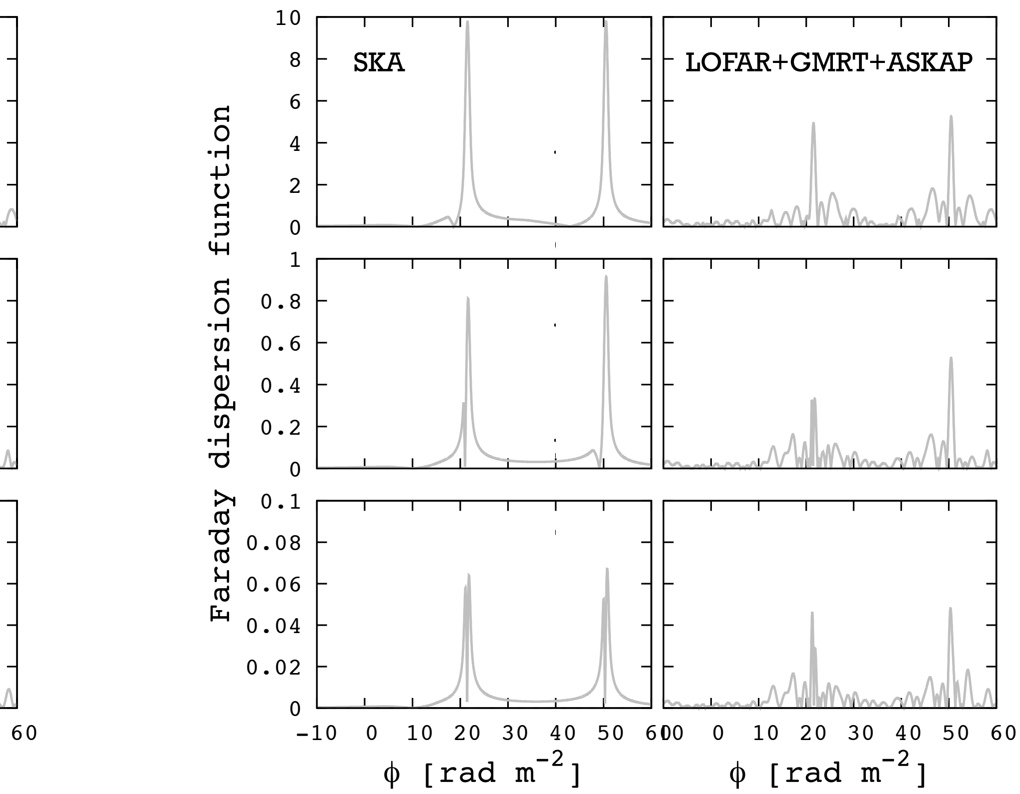
However, we can find the IGMF with following methods.

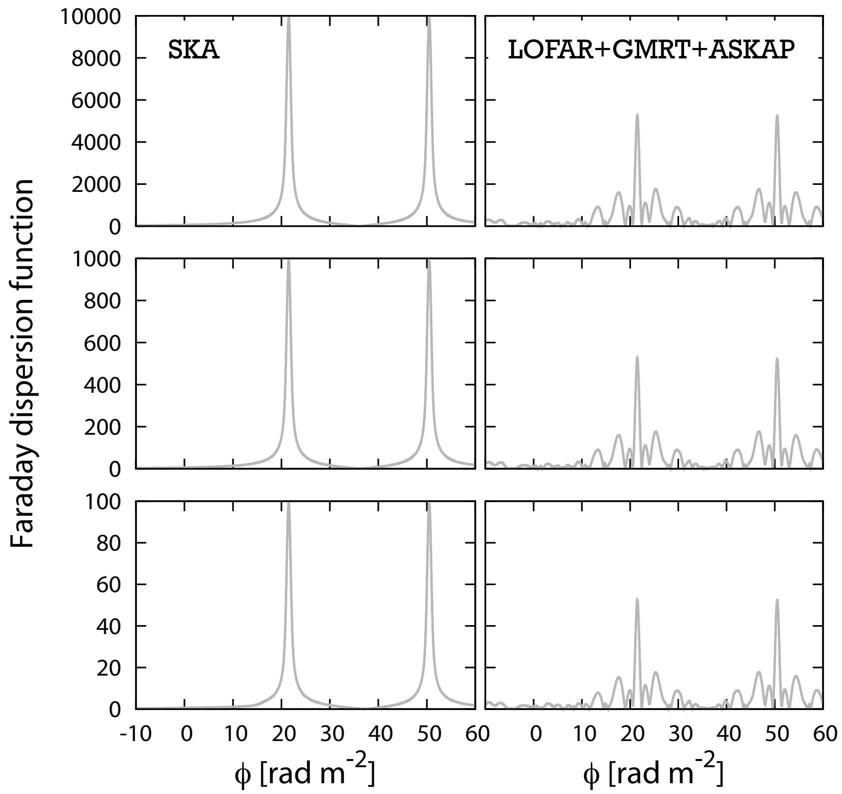
Pair sources ⟶ residual



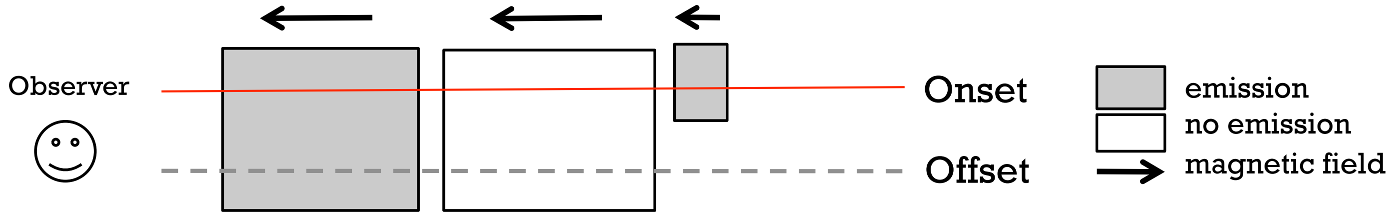
This observation do not significantly depend on the intensity ratio.

If we calculate the residual between two FDFs,
we get information of the IGMF between the two sources.





Onset / Offset → residual



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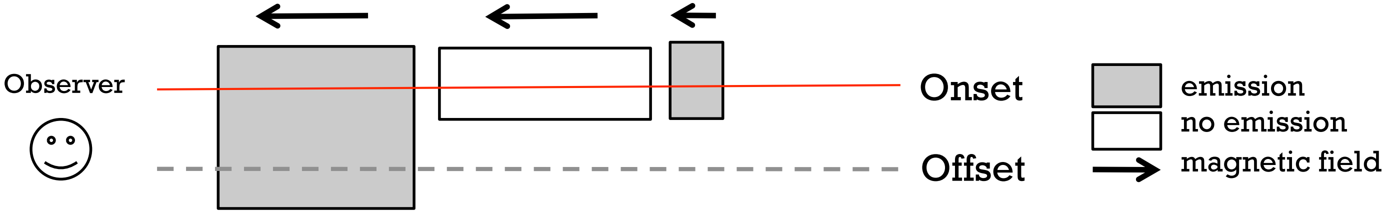
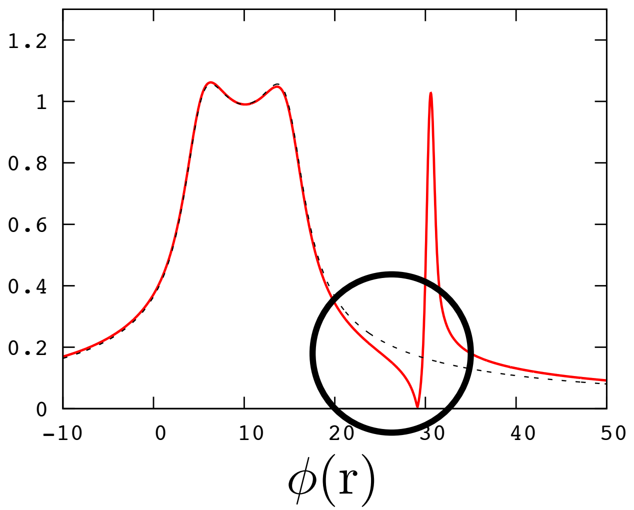
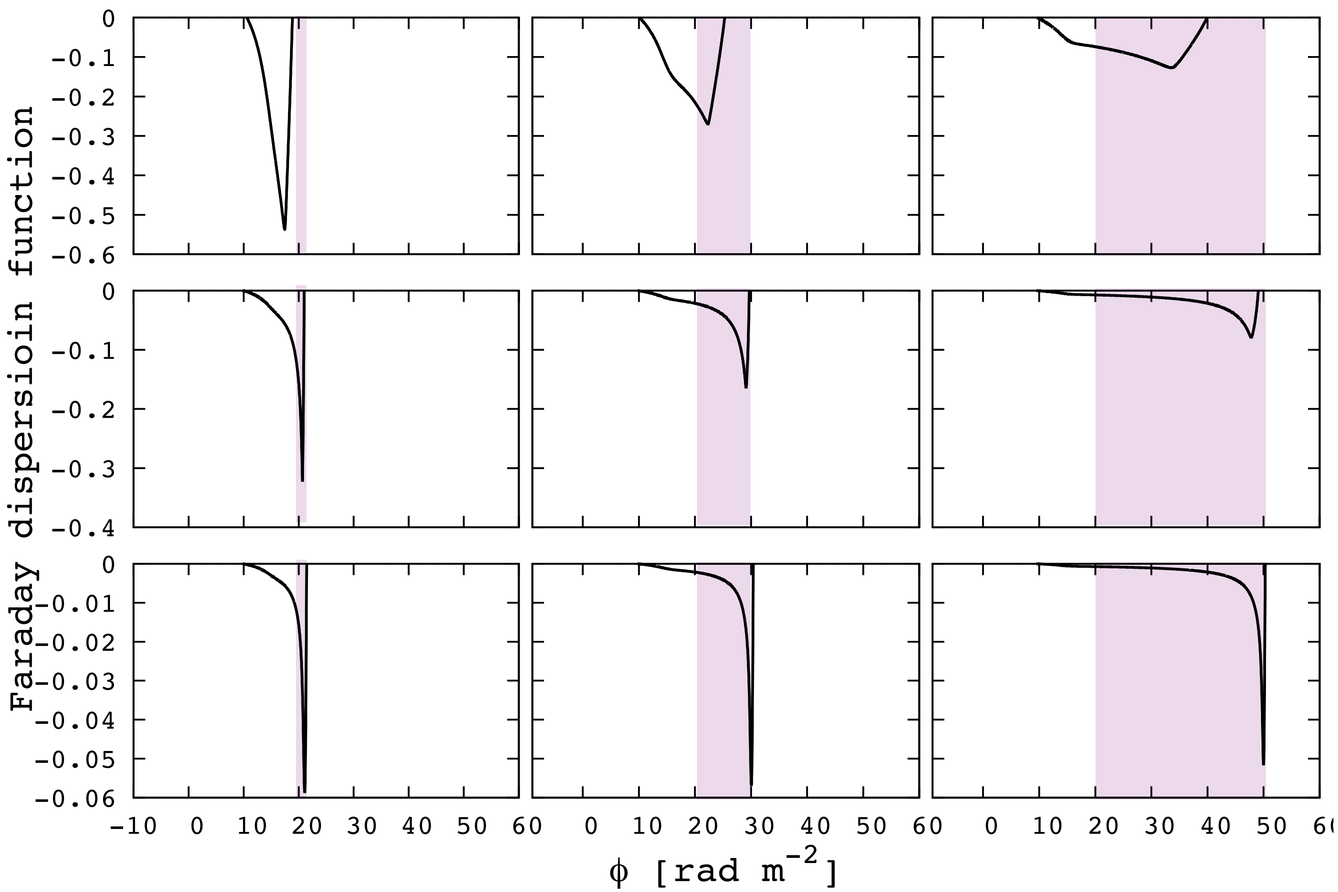


SKA observation



There is the dip between the external galaxy and radio source.

Expected area as IGMF contribution



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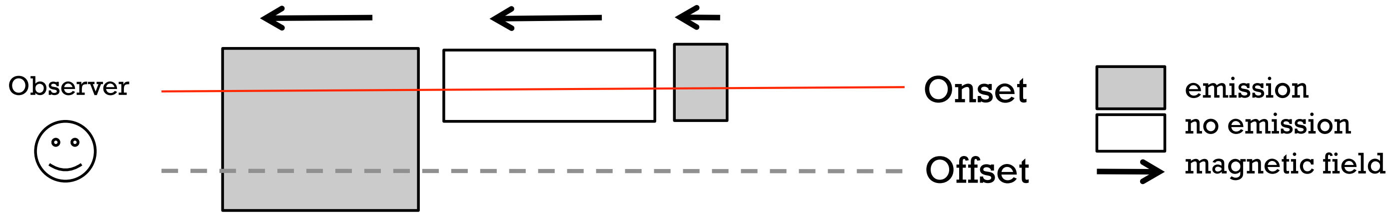
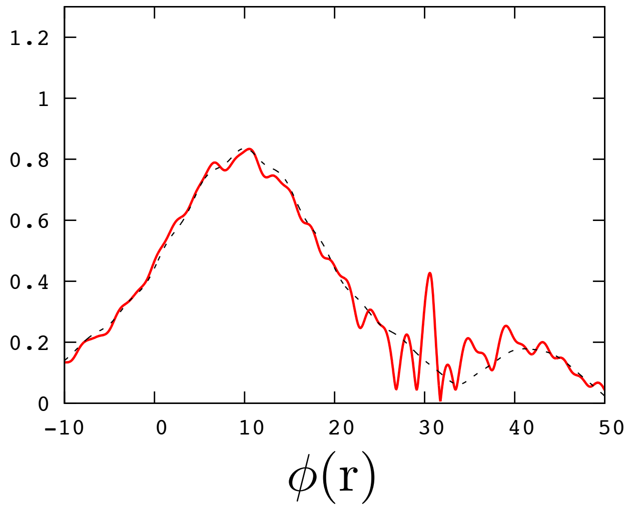
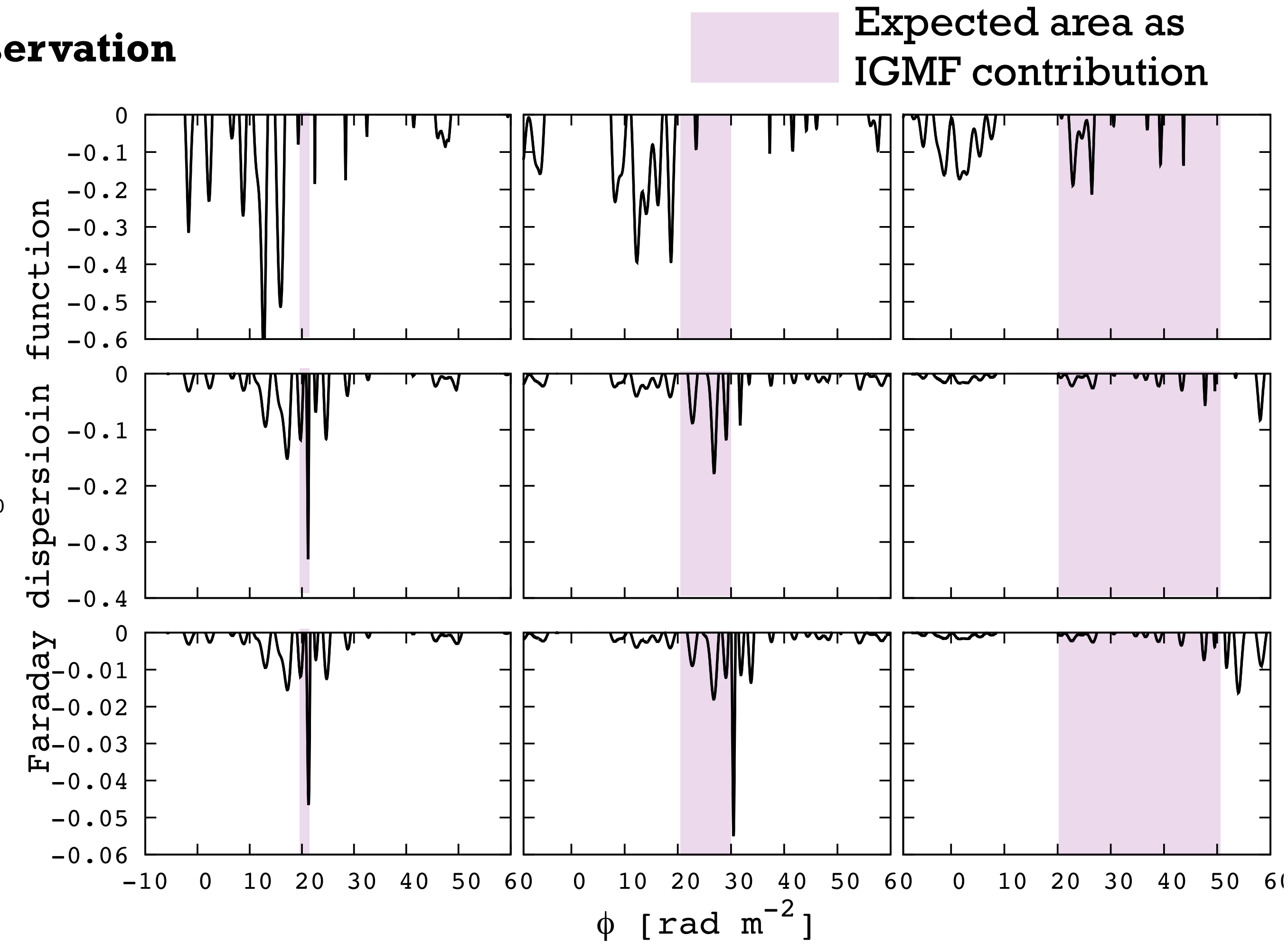


LOFAR+GMRT+ASKAP observation





Summary

- We simulate the polarized intensity observation with current / future interferometers to probe the intergalactic magnetic field using Faraday tomography.
- We find that
  - The middle wave bands is important to detect IGMF, because the range have rich structure.
  - The IGMF will be detected with SKA observation.
  - Using pair source observation, we will obtain the IGMF with SKA and collaborating observation.