Probing Intergalactic Magnetic Fields with Square Kilometer Array

Keitaro Takahashi

29/11/2013

@Paris

Kumamoto University

Probing Intergalactic Magnetic Fields with Square Kilometer Array

+ Galactic CRs

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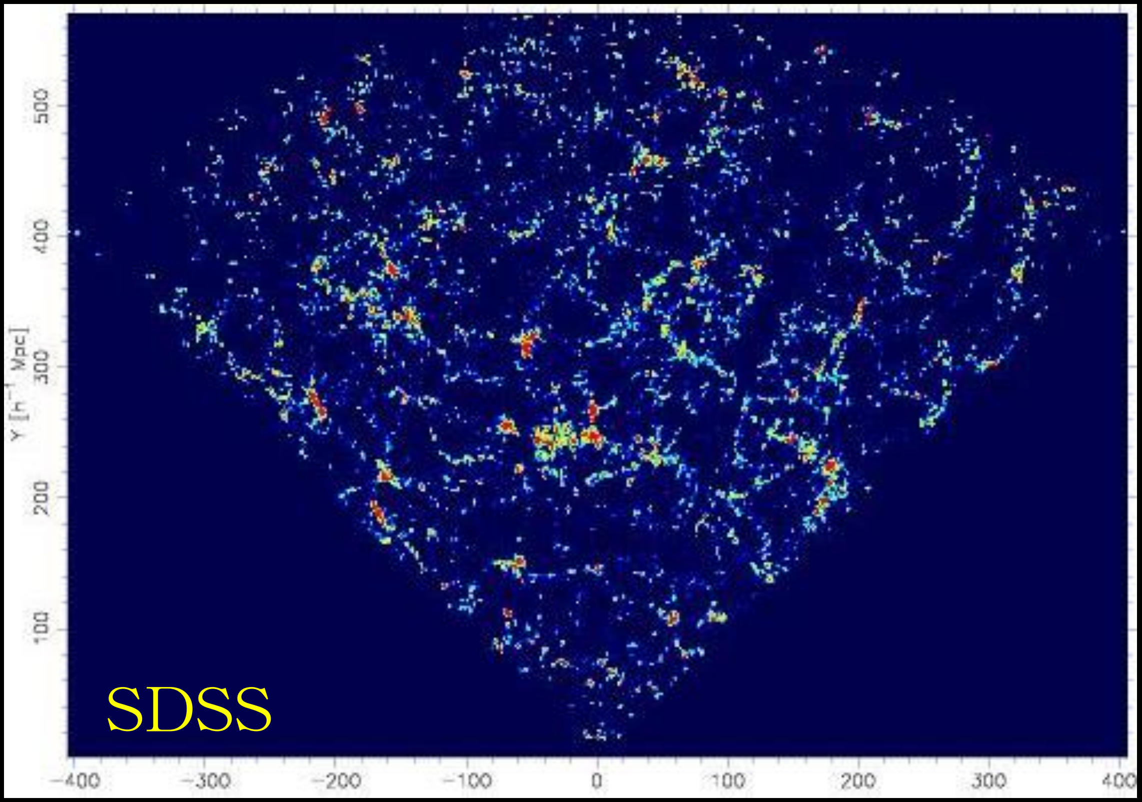
1. Intergalactic Magnetic Fields

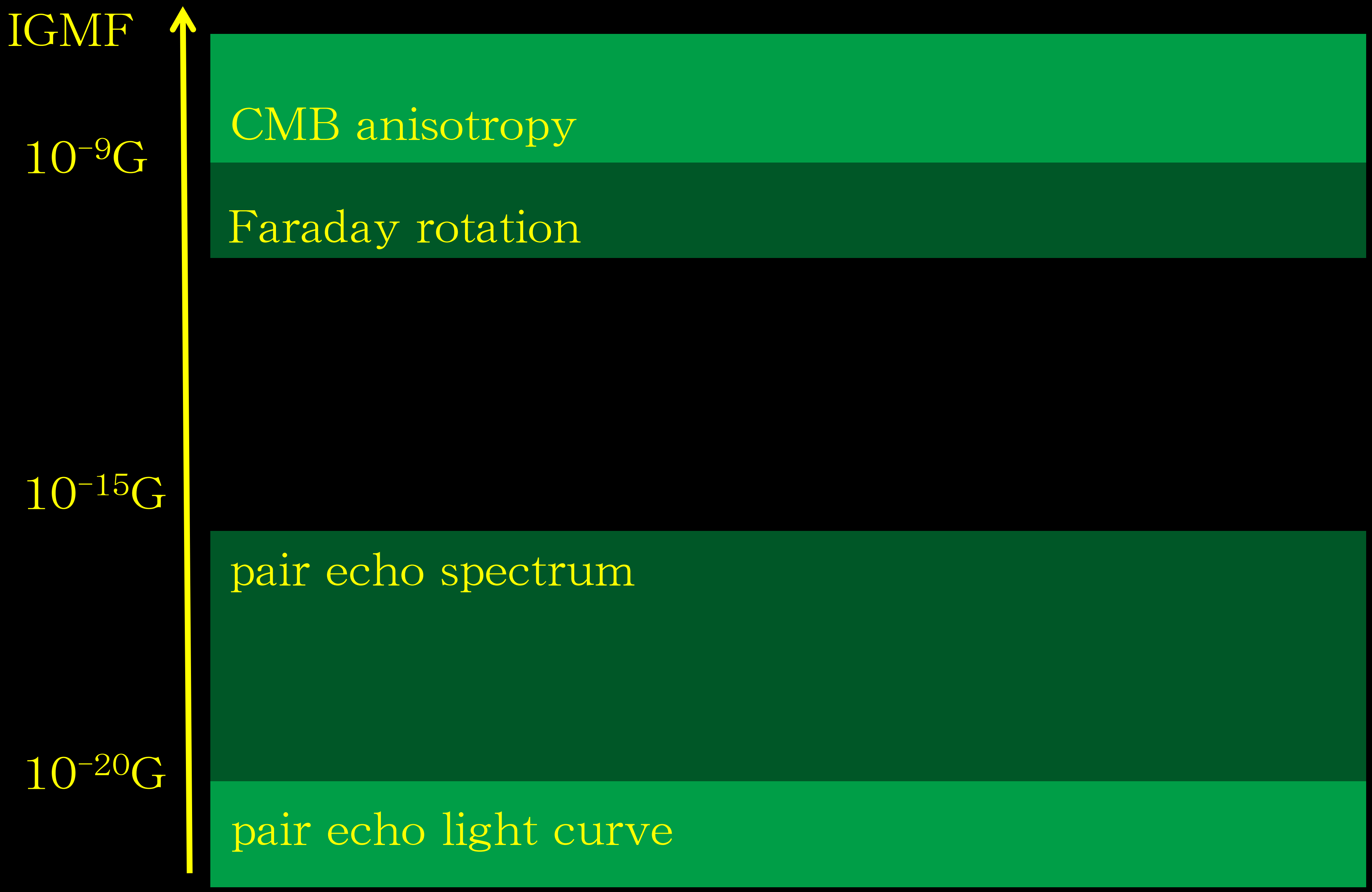
Intergalactic Magnetic Fields

IGMF

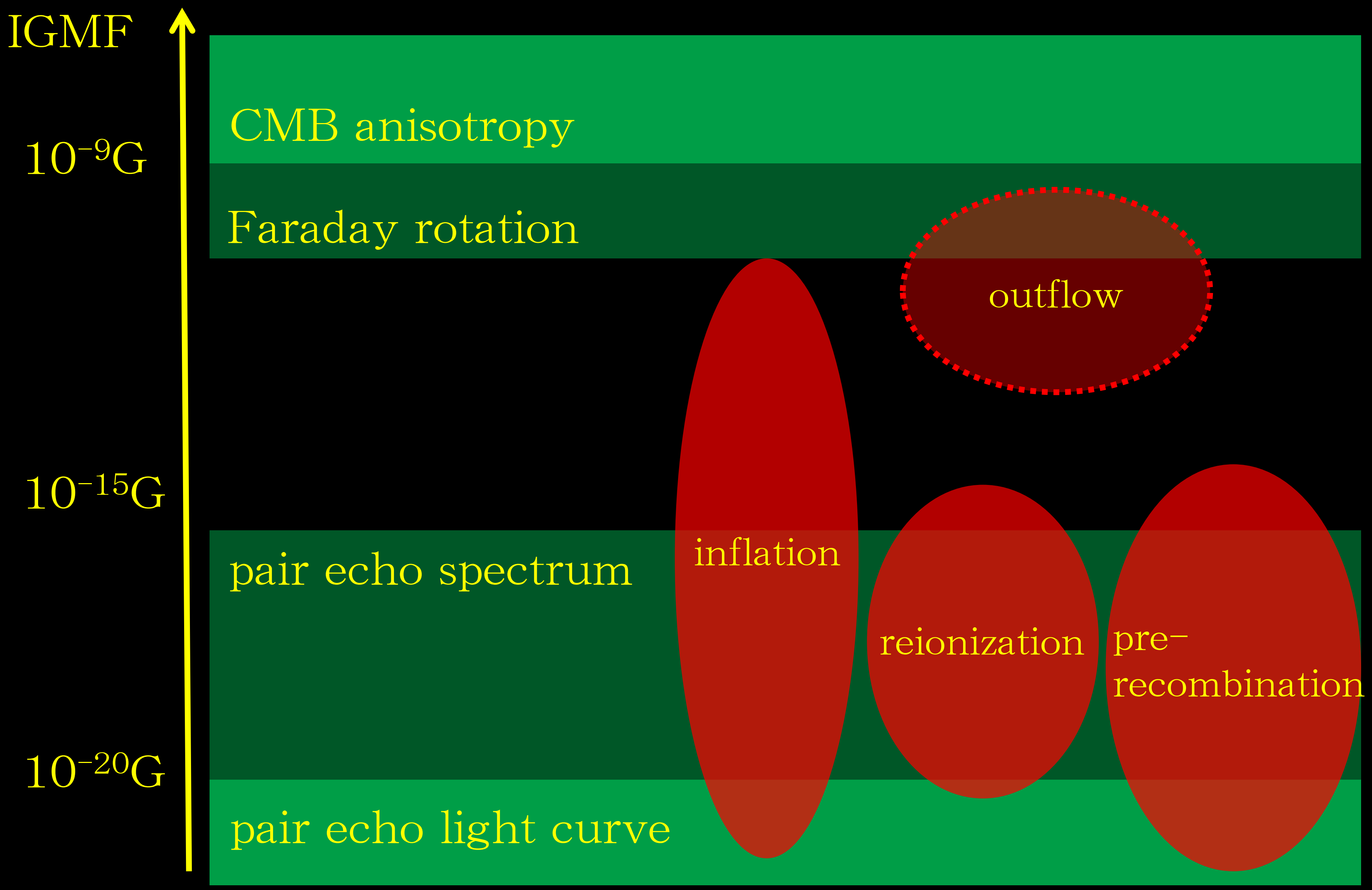
- B not associated with any object
- may be generated in early universe
- affect propagation of UHECR



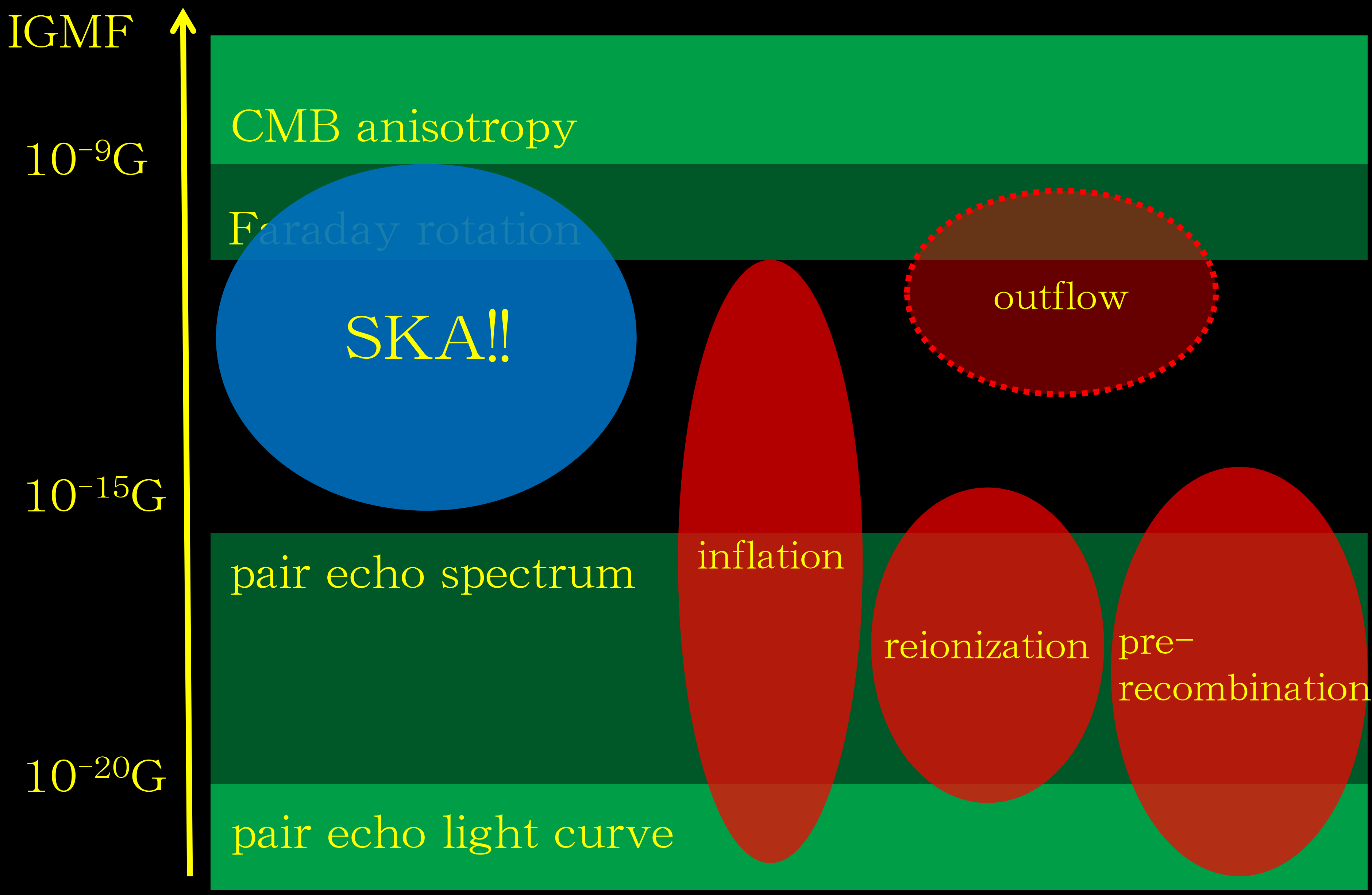
IGMF: constraint and prediction



IGMF: constraint and prediction



IGMF: constraint and prediction



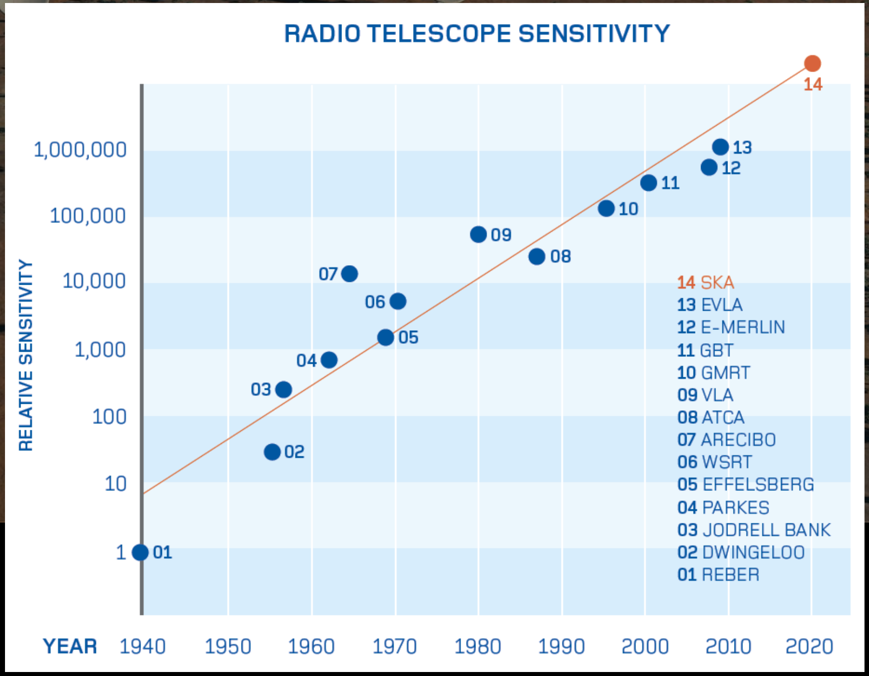
2. Square Kilometer Array

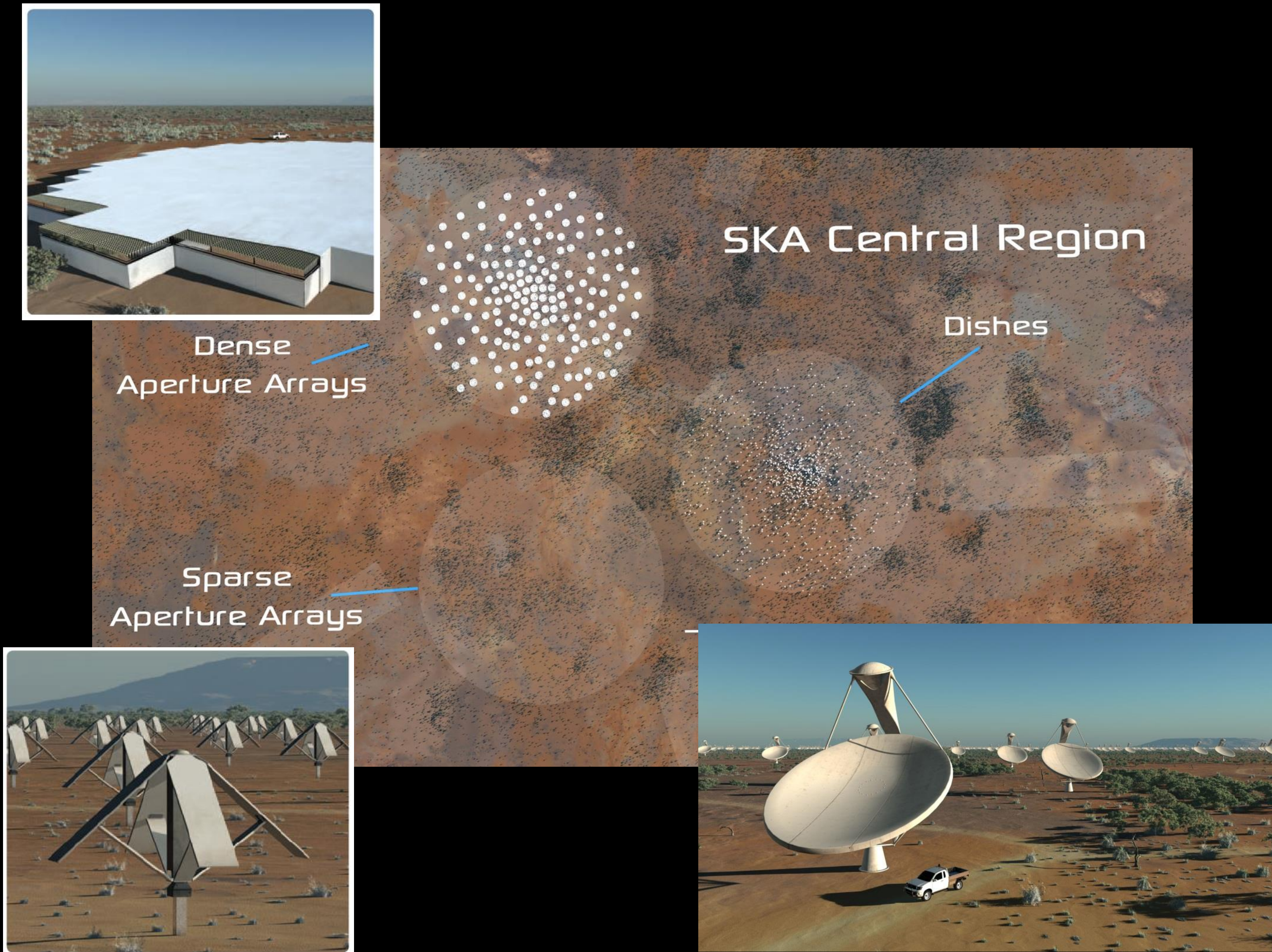
Square Kilometer Array

Next generation radio telescope

- high sensitivity, wide-band, large FoV
- high resolution
- band: 50-350MHz (SKA-low)
  - 0.35-10GHz (SKA-mid)
- baseline: maximum 3000km
- site: Australia (low) and South Africa (mid)

→ radio source: ×100
  sensitivity: EVLA×40




SKA Central Region
Dense Aperture Arrays
Dishes
Sparse Aperture Arrays

timeline

SKA phase 1
- 10% SKA
- 2016- construction
- 2019- observation

SKA phase 2
- full SKA
- 2019- construction
- 2024- observation

5 Key Sciences
- dark age and reionization
- pulsar: direct detection of GW and test of GR
- galaxy evolution and cosmology
- cosmic magnetism
- astrobiology

precursors, pathfinders

1% SKA

- low frequency ~ 100MHz
  - LOFAR
  - MWA
- mid frequency ~ 1GHz
  - ASKAP
  - MeerKAT

currently largest
starting observation

3. Faraday Tomography

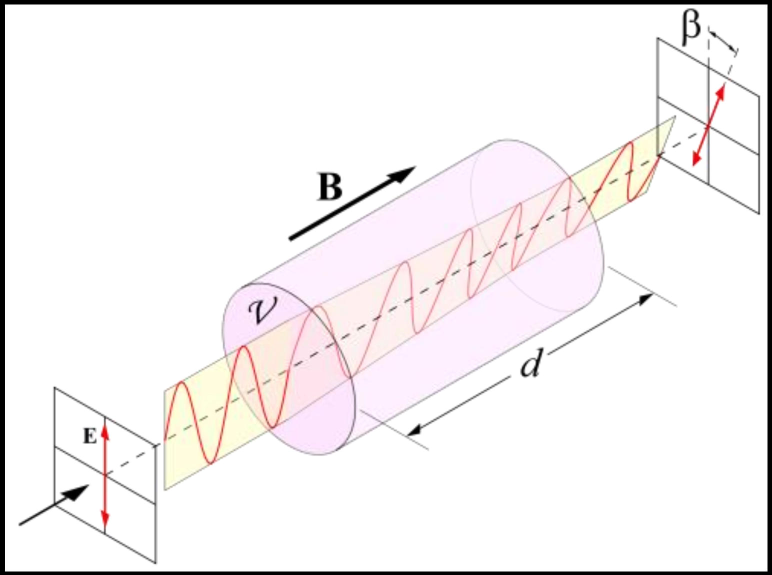
Faraday Rotation

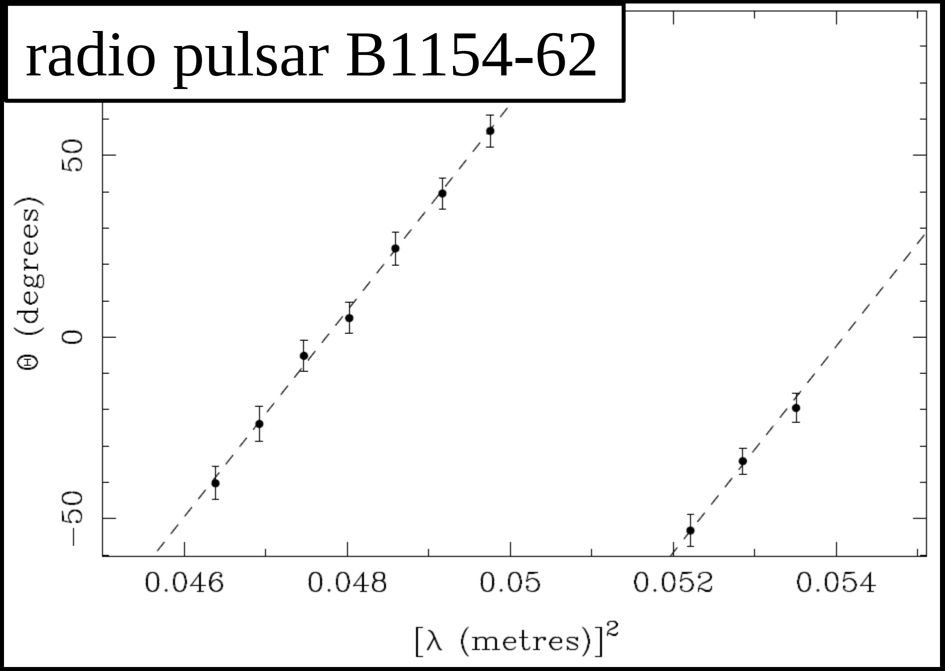
rotation of polarization angle in magnetized medium

$$\Theta = \Theta_0 + \mathrm{RM}\,\lambda^2$$

slope: rotation measure

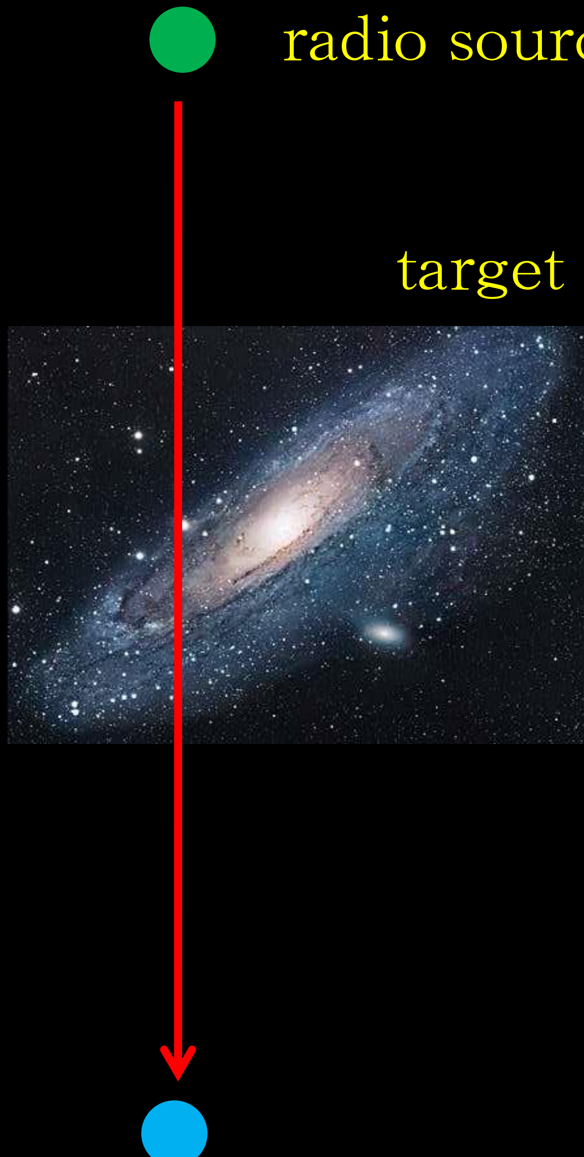
$$\mathrm{RM} = K \int n_e B_{||}\, dl$$



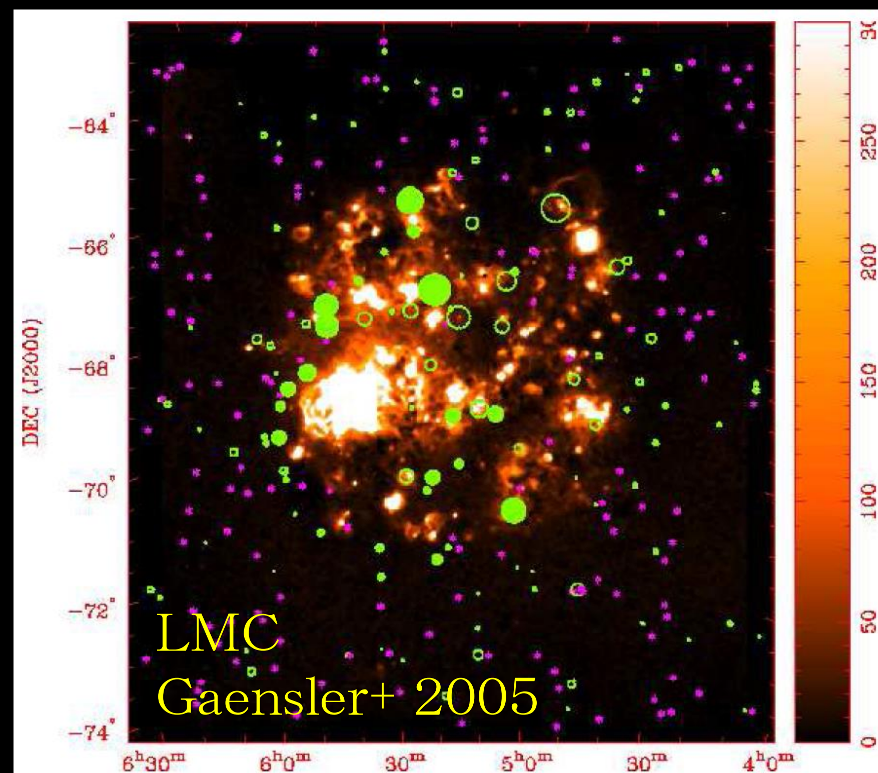


We can know only the integration along the line of sight.

Faraday Rotation

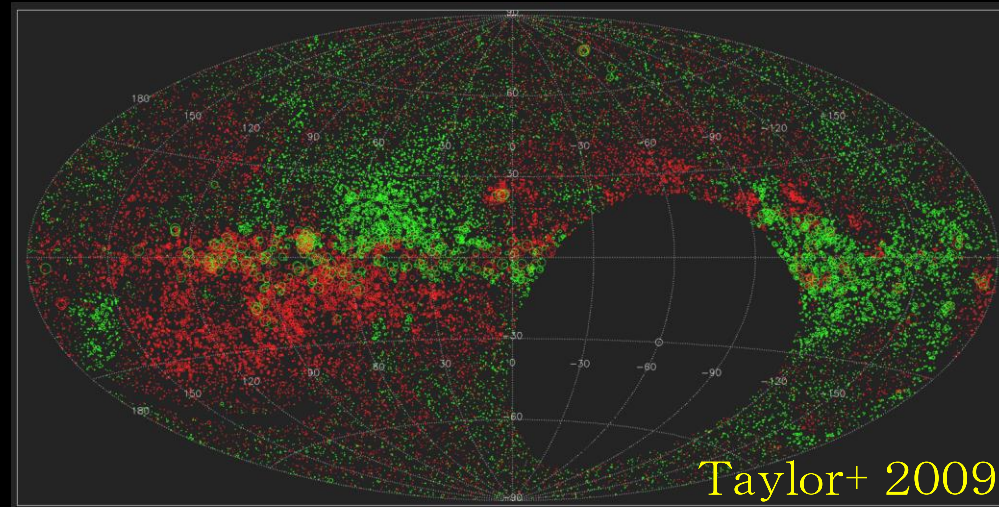


We can measure B by observing radio sources behind the target.

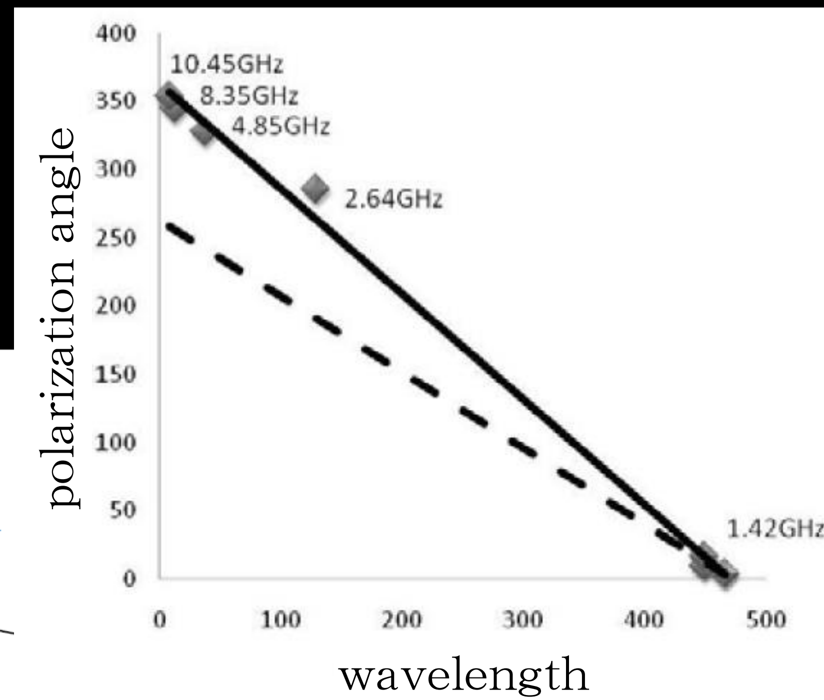


RM with SKA

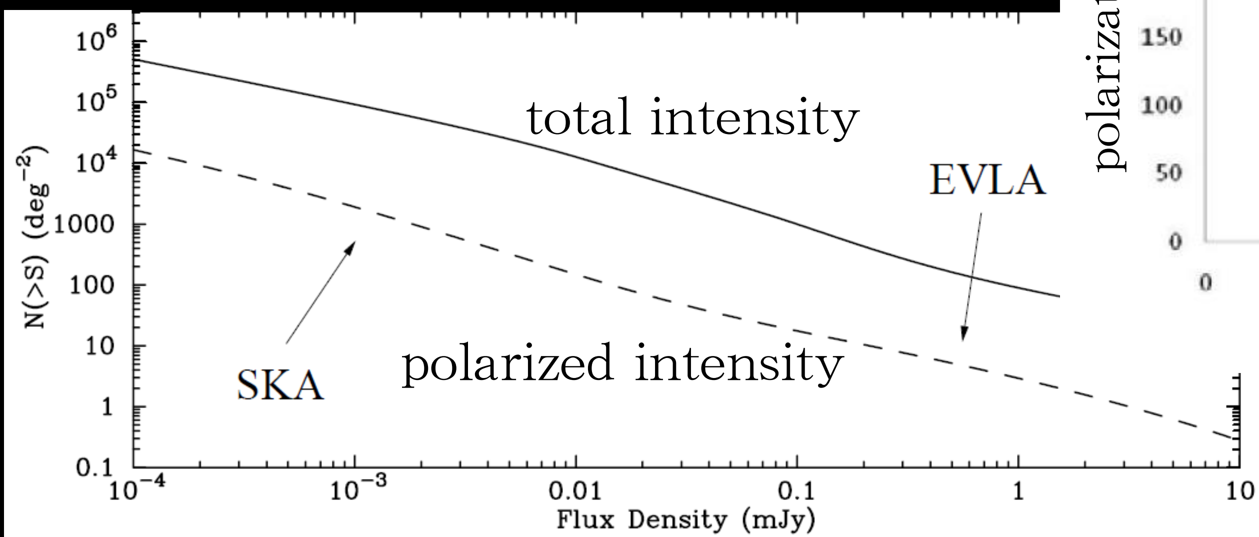
- currently 40,000 RMs
  → 10,000,000 RMs
- ultra-wideband
  0.05-10GHz
  → much accurate RMs



Taylor+ 2009

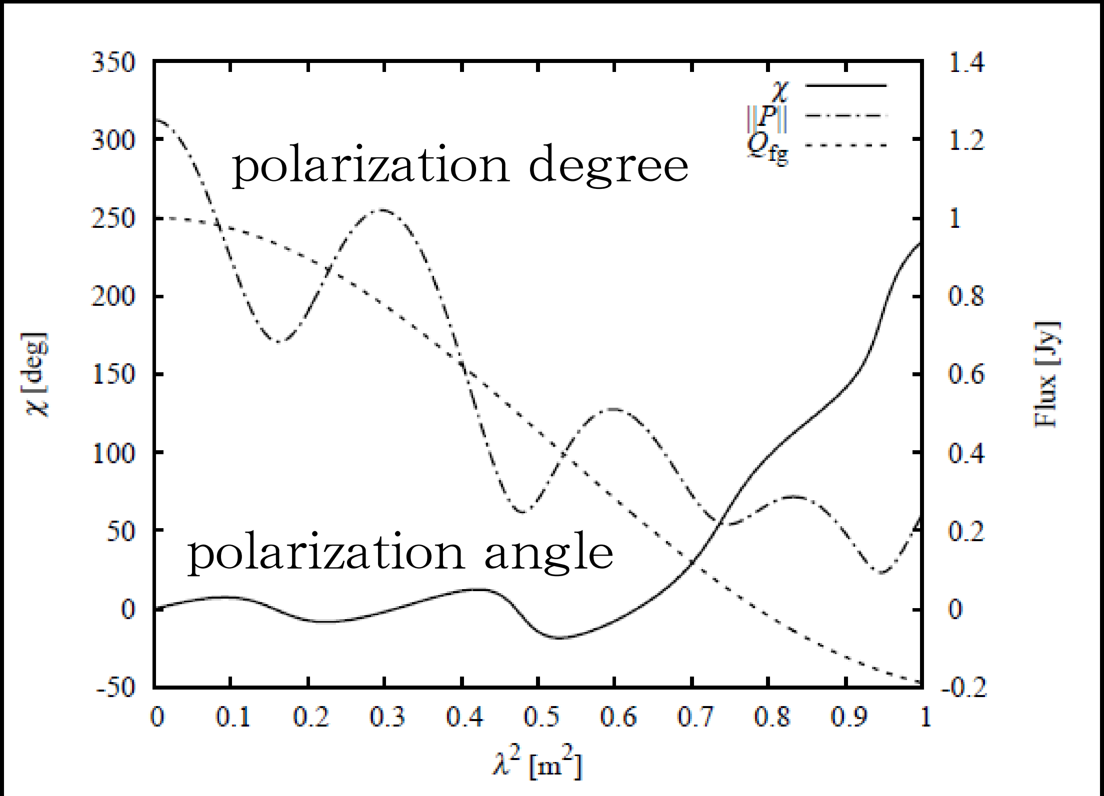


expected cumulative luminosity function

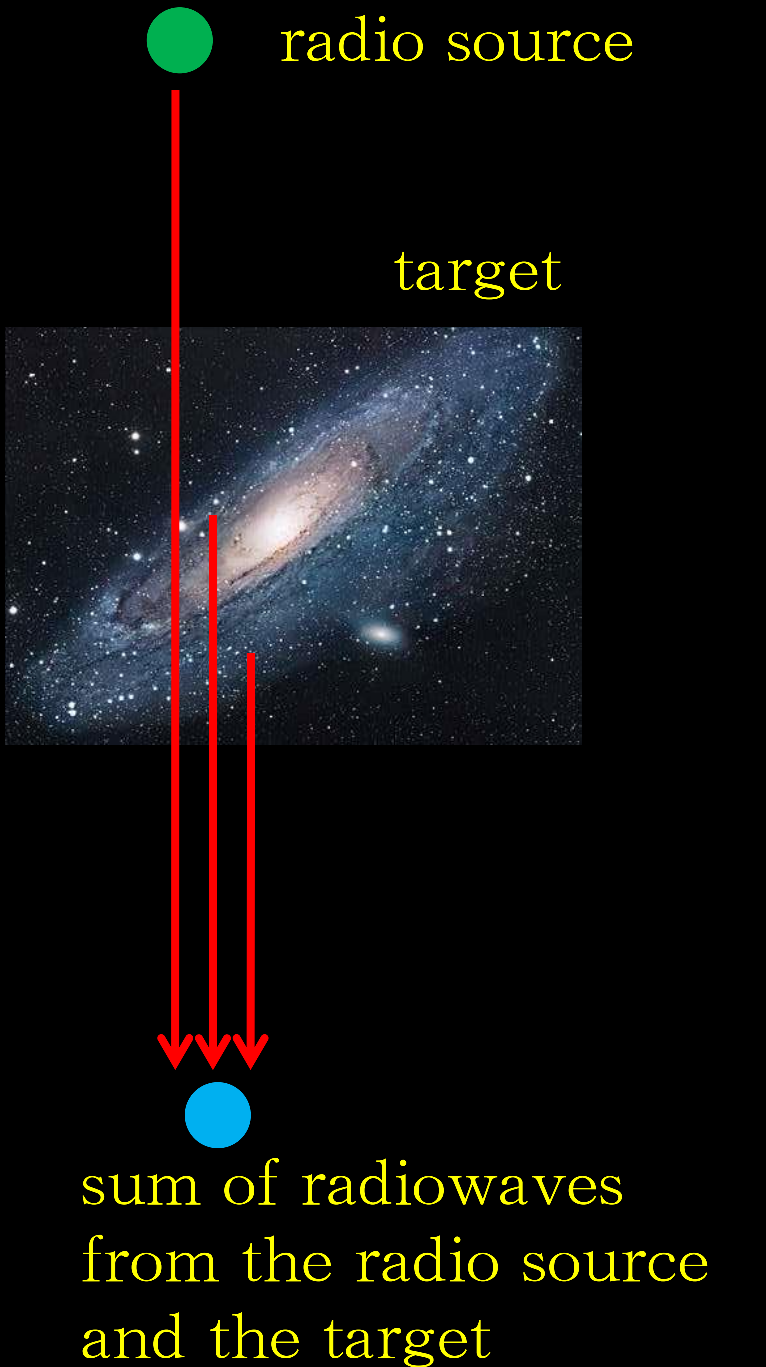


complication

Situation is not so simple…
- emission of the target itself
- Galactic magnetic fields



Brentjens & de Bruyn, A&A (2005)

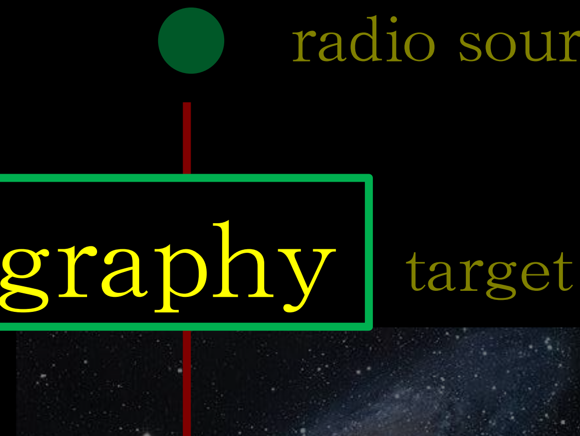


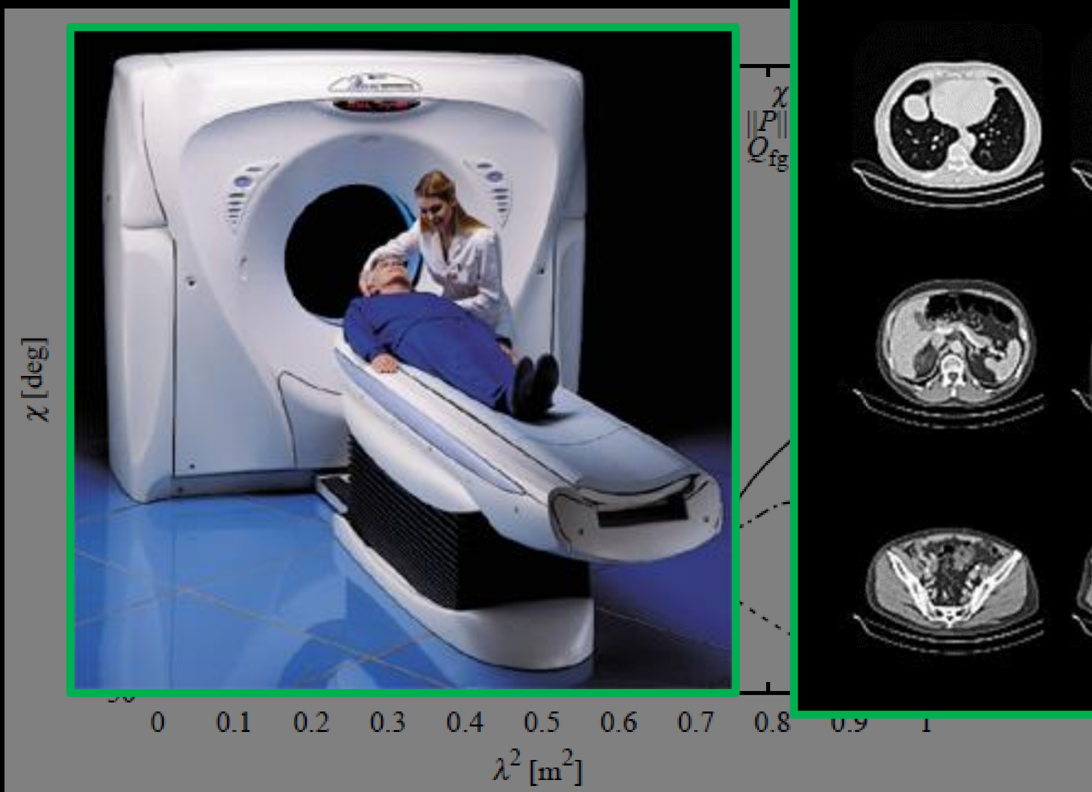
complication

Situation

- emissio…
- Galactic magnetic fields

Faraday Tomography





sum of radiowaves
from the radio source
and the target

Brentjens & de Bruyn, A&A (2005)

Faraday tomography

Burn (1966)

reconstruction of distribution of B and radio sources

polarization

$$P = pI = Q + \mathrm{i}U.$$

Q, U: Stokes parameters

Observed P is the integration of the sources along LOS.

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

F(ϕ) : Faraday dispersion function → source distribution

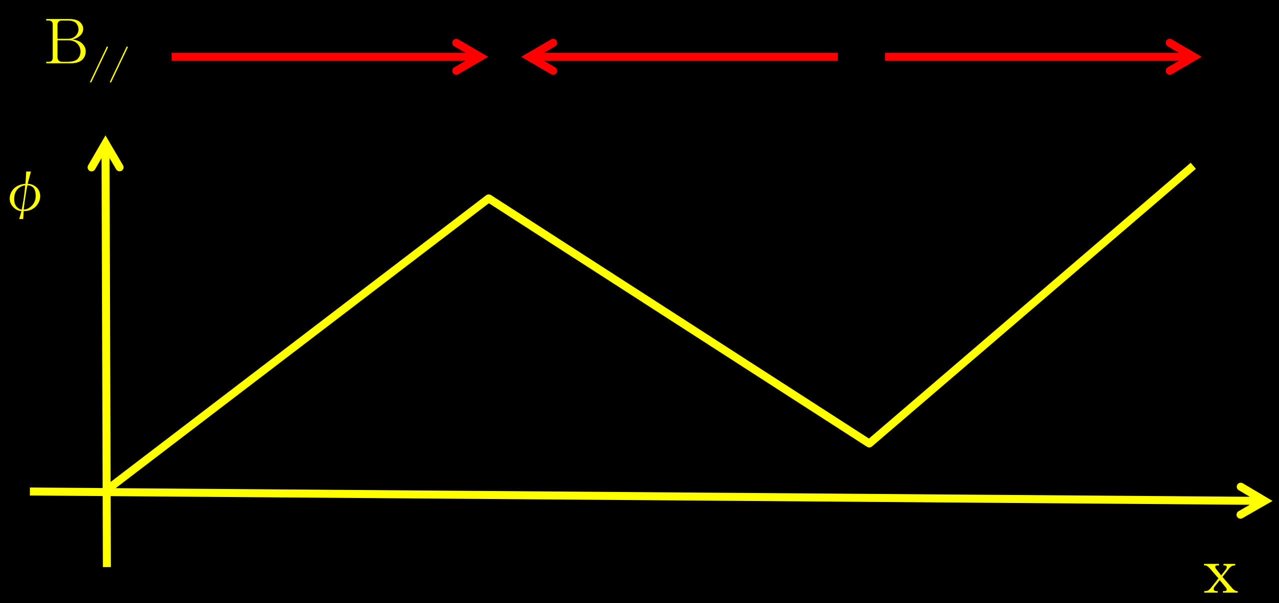
ϕ : Faraday depth → magnetic "distance"

$$\phi(\boldsymbol{r}) = 0.81 \int_{\text{there}}^{\text{here}} n_{\mathrm{e}} \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{r} \ \mathrm{rad\ m^{-2}}$$

We want to know F(ϕ) from P(λ^2)

F(ϕ) ⇔ P(λ^2) ～ Fourier transform

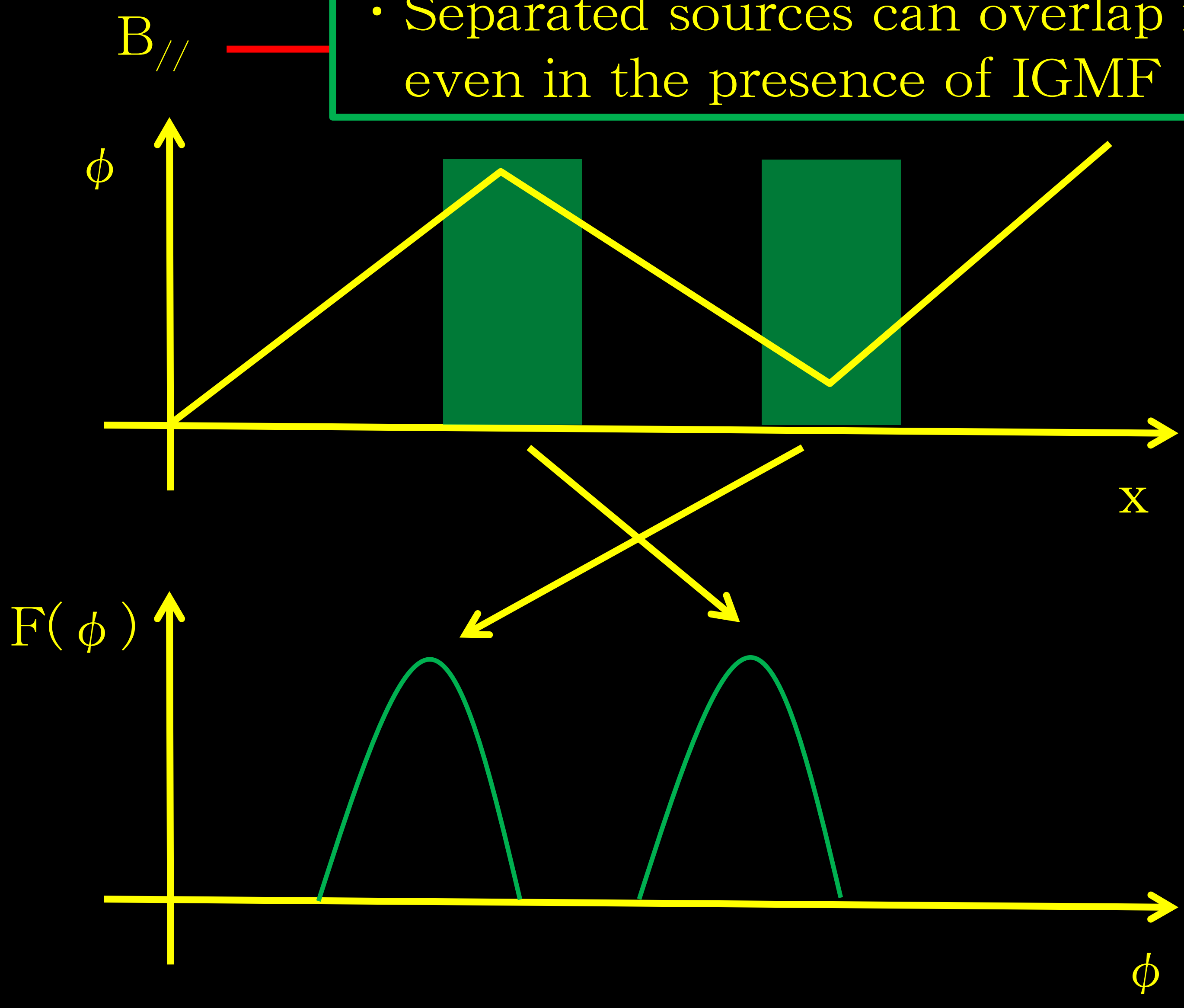
Faraday dispersion function



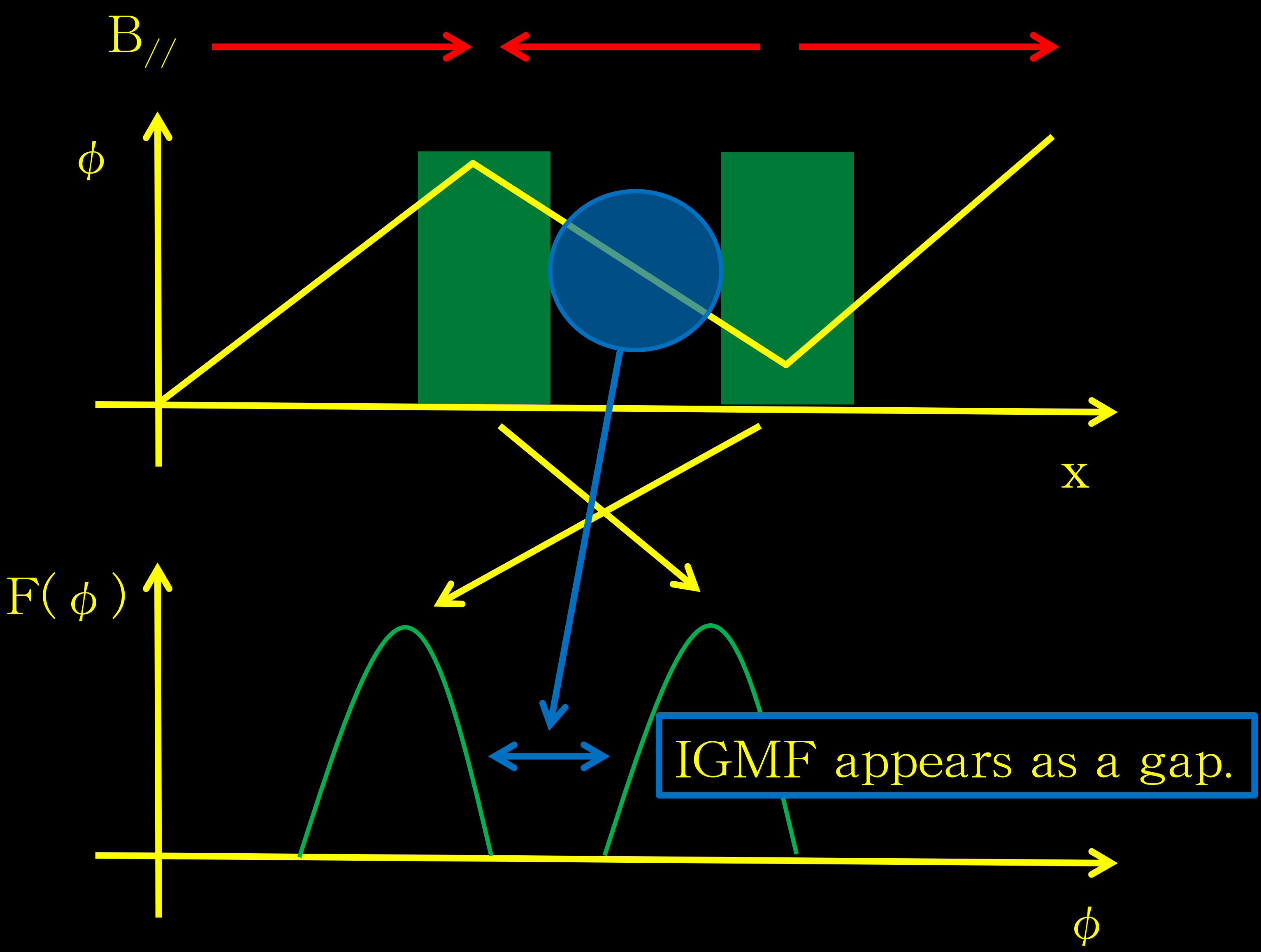
There is no 1-to-1 correspondence between x and ϕ in general.

Faraday dispersion function

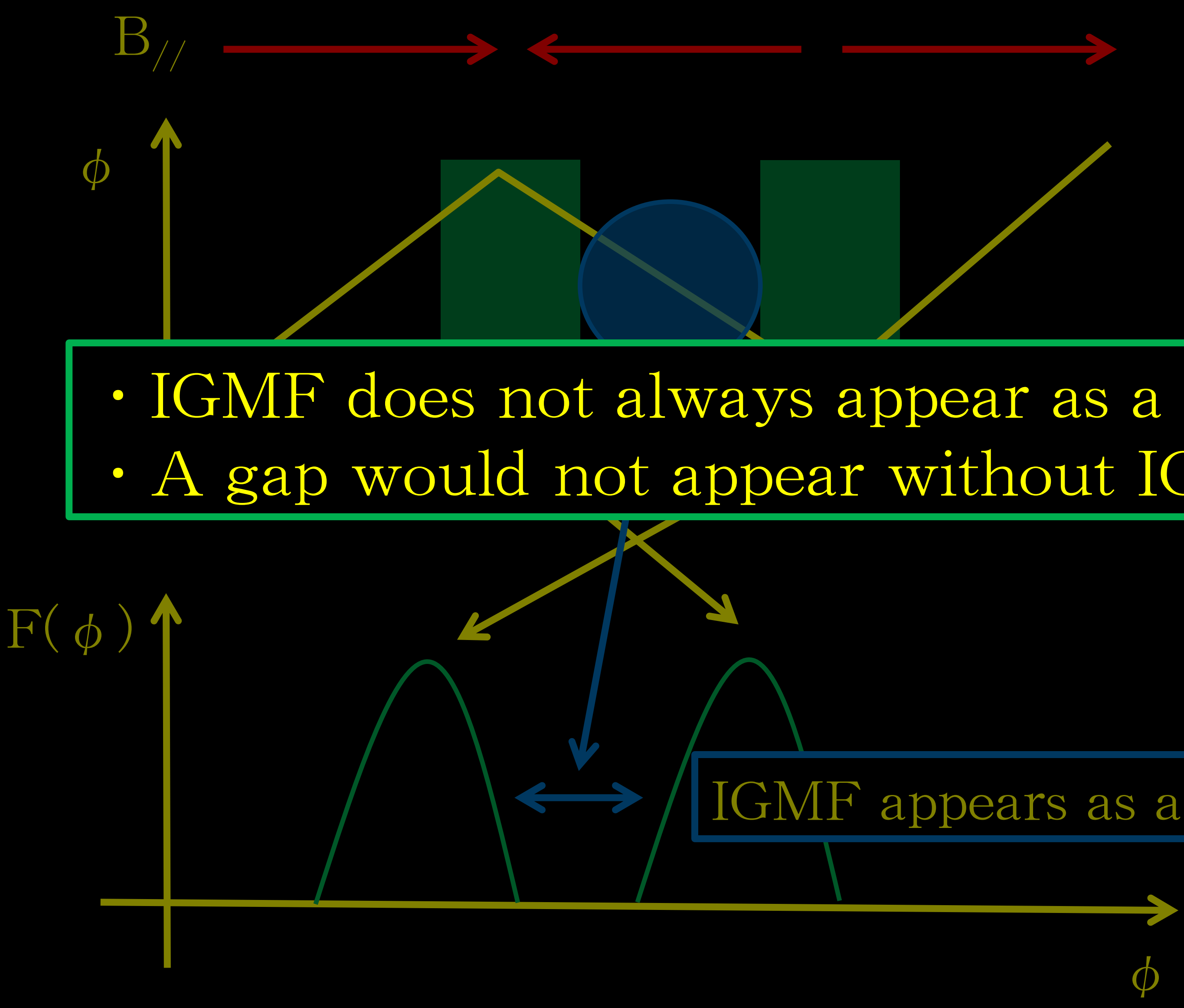
- Smaller-ϕ source is not necessarily closer
- Separated sources can overlap in ϕ space even in the presence of IGMF



Faraday dispersion function

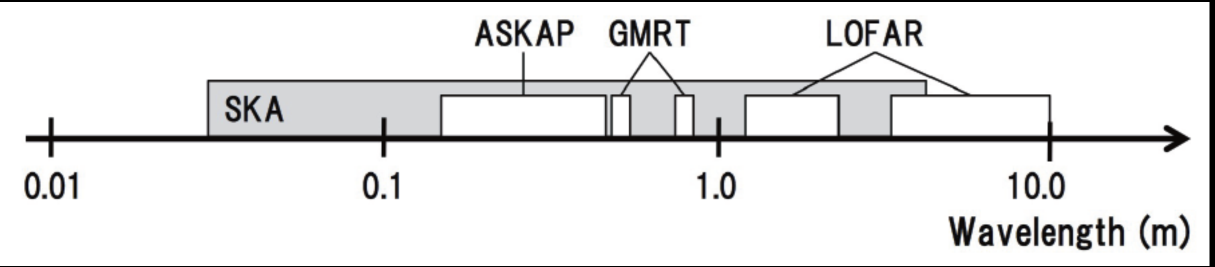


Faraday dispersion function



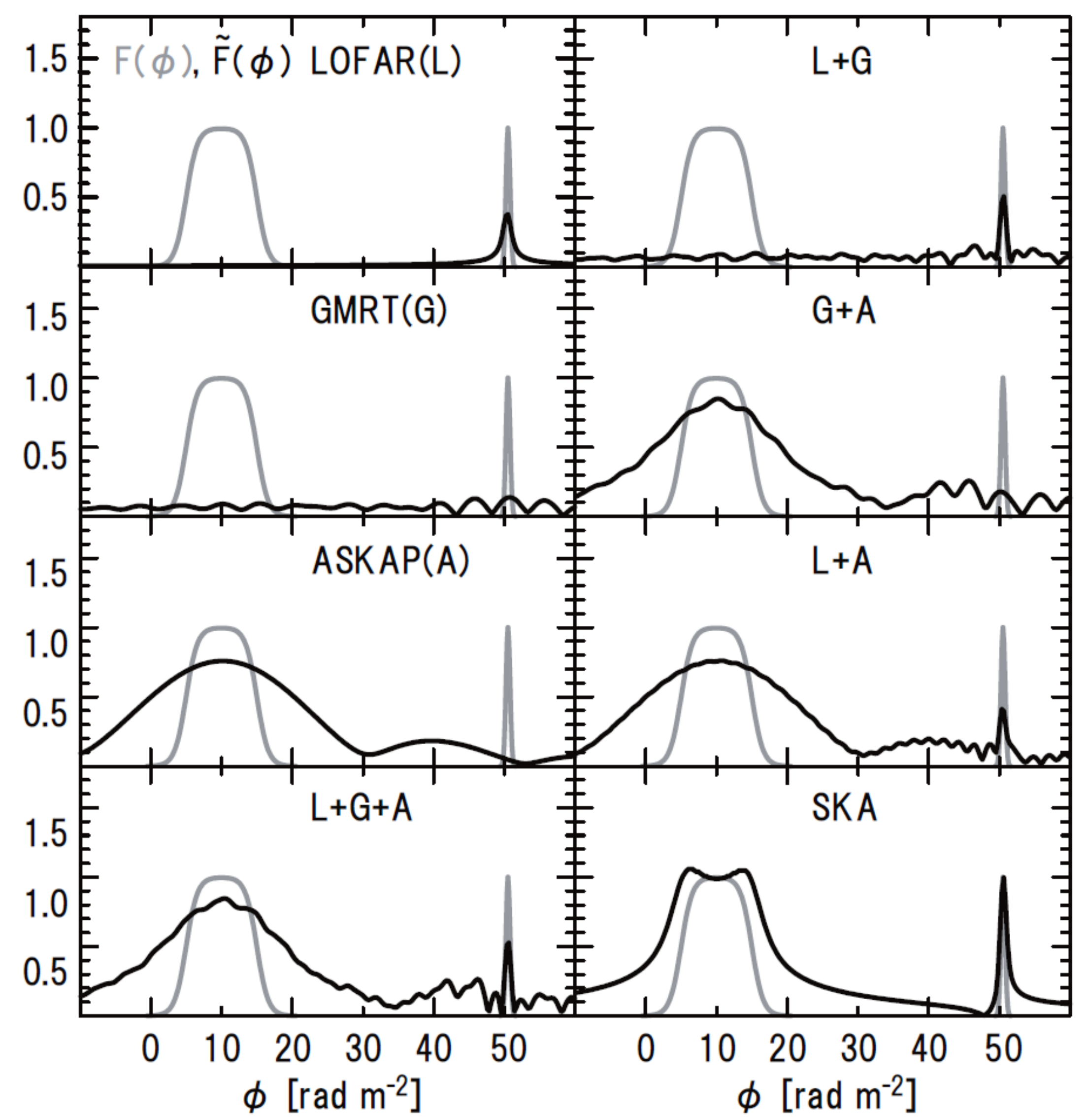
- IGMF does not always appear as a gap
- A gap would not appear without IGMF

tomography



Akahori, KT+ 2013

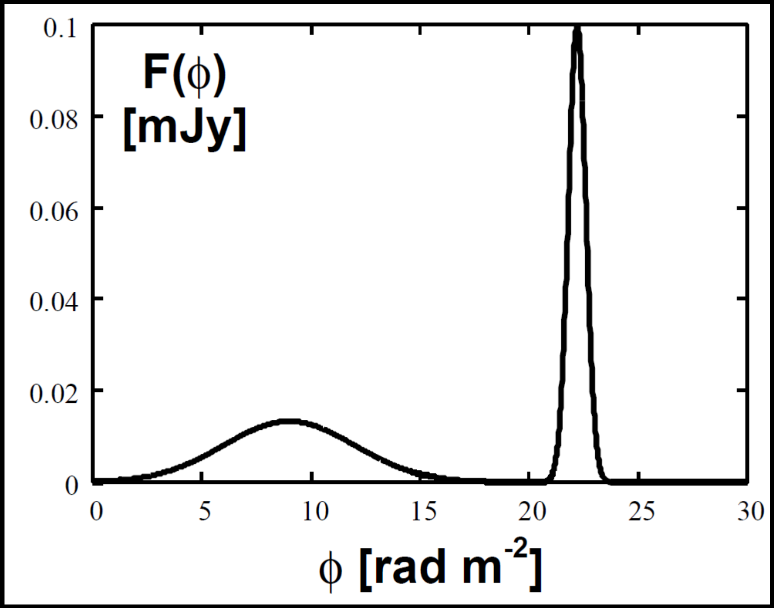
- AGN behind a galaxy
- How precise F(ϕ) can be reconstructed
- identify the gap?
- large λ^2 (LOFAR) → small structure
- small λ^2 (ASKAP) → large structure

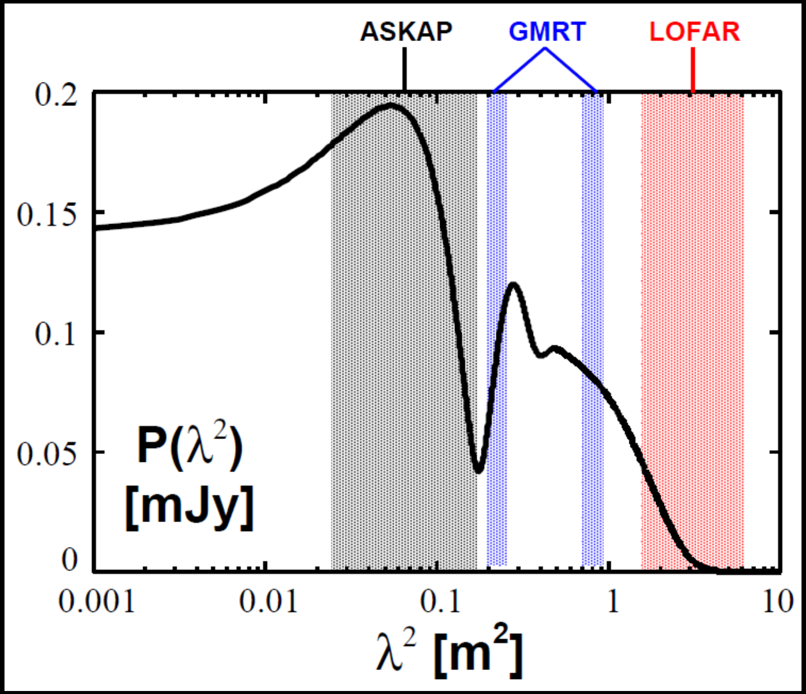


Akahori, KT+ 2013

sensitivity on IGMF

Ideguchi, KT+ 2013



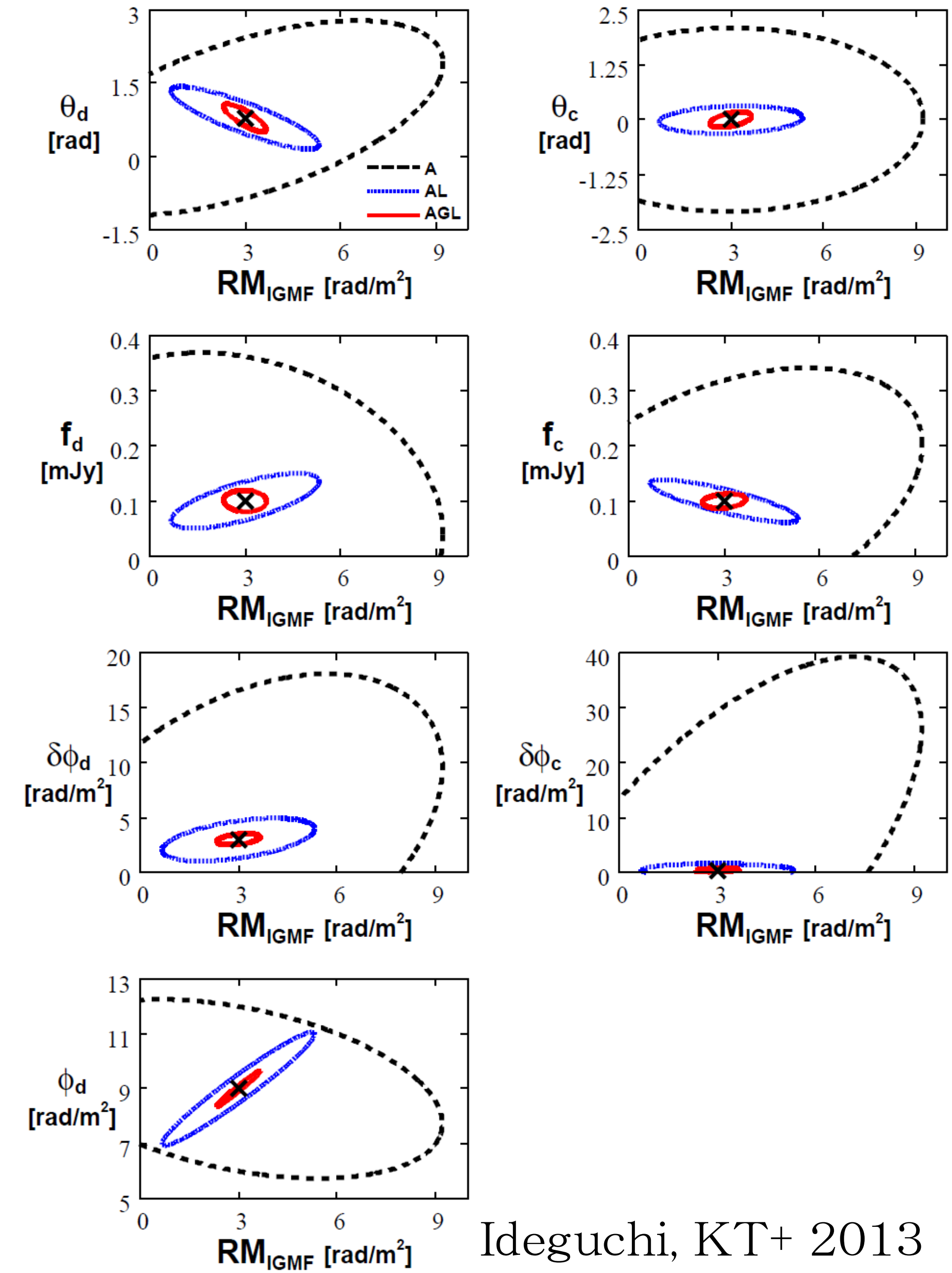


- source model F(ϕ): 2 Gaussian sources
  brightnesses, widths, intrinsic polarization angles
  IGMF
- fiducial model → mock data
- fit the mock data with the model
  → constraints on model parameters

sensitivity on IGMF

With two 1mJy sources, we can detect IGMF as small as 3 rad/m^2 with a combination of LOFAR, GMRT and ASKAP.

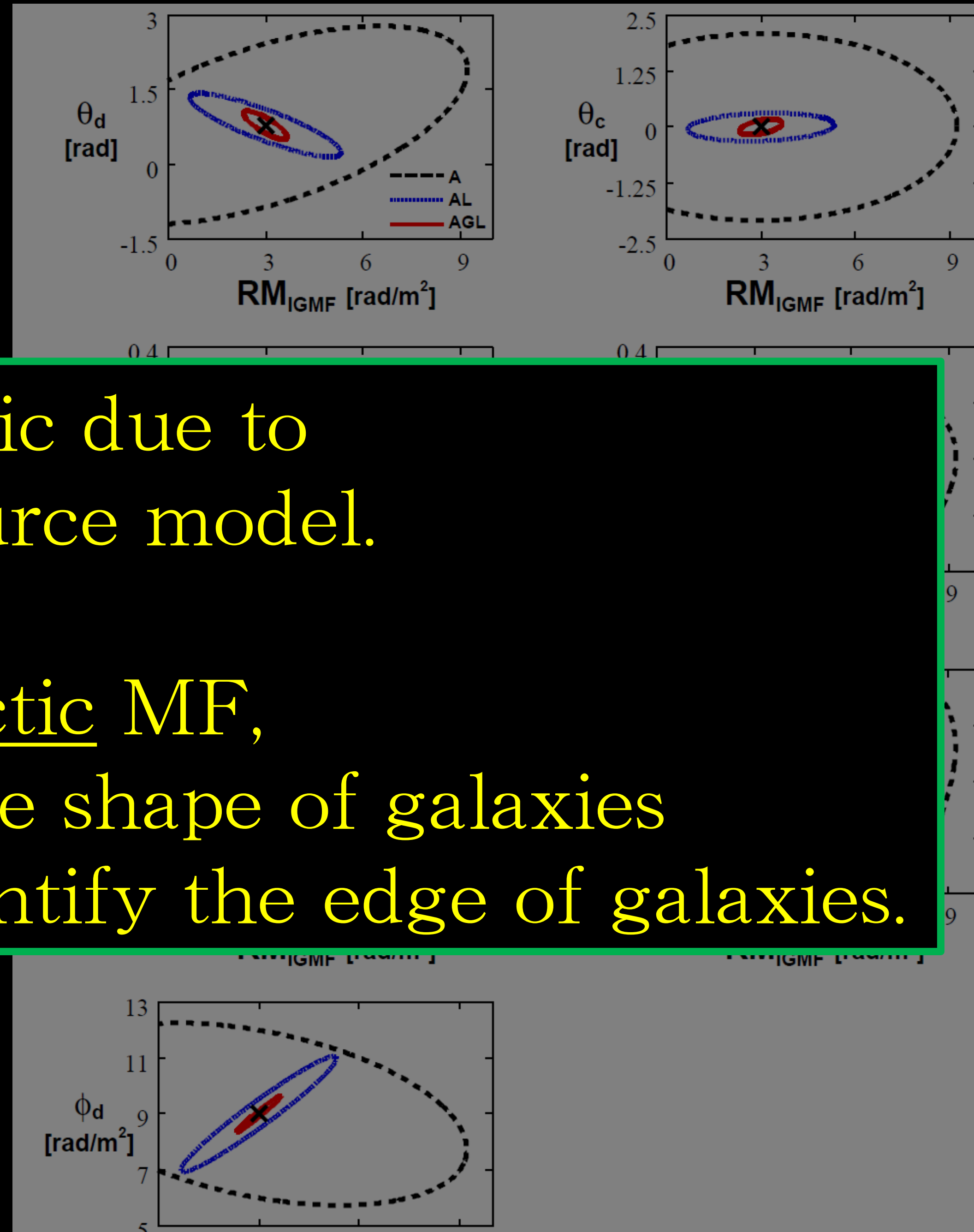
3 rad/m^2
$\rightarrow 10^{-13}$ Gauss!!
(n=0.1/cc, d=100Mpc)



Ideguchi, KT+ 2013

sensitivity on IGMF

With two 1mJy sources,
we can detect IGMF



Maybe too optimistic due to
the very simple source model.

To know intergalactic MF,
we should know the shape of galaxies
in ϕ space and identify the edge of galaxies.

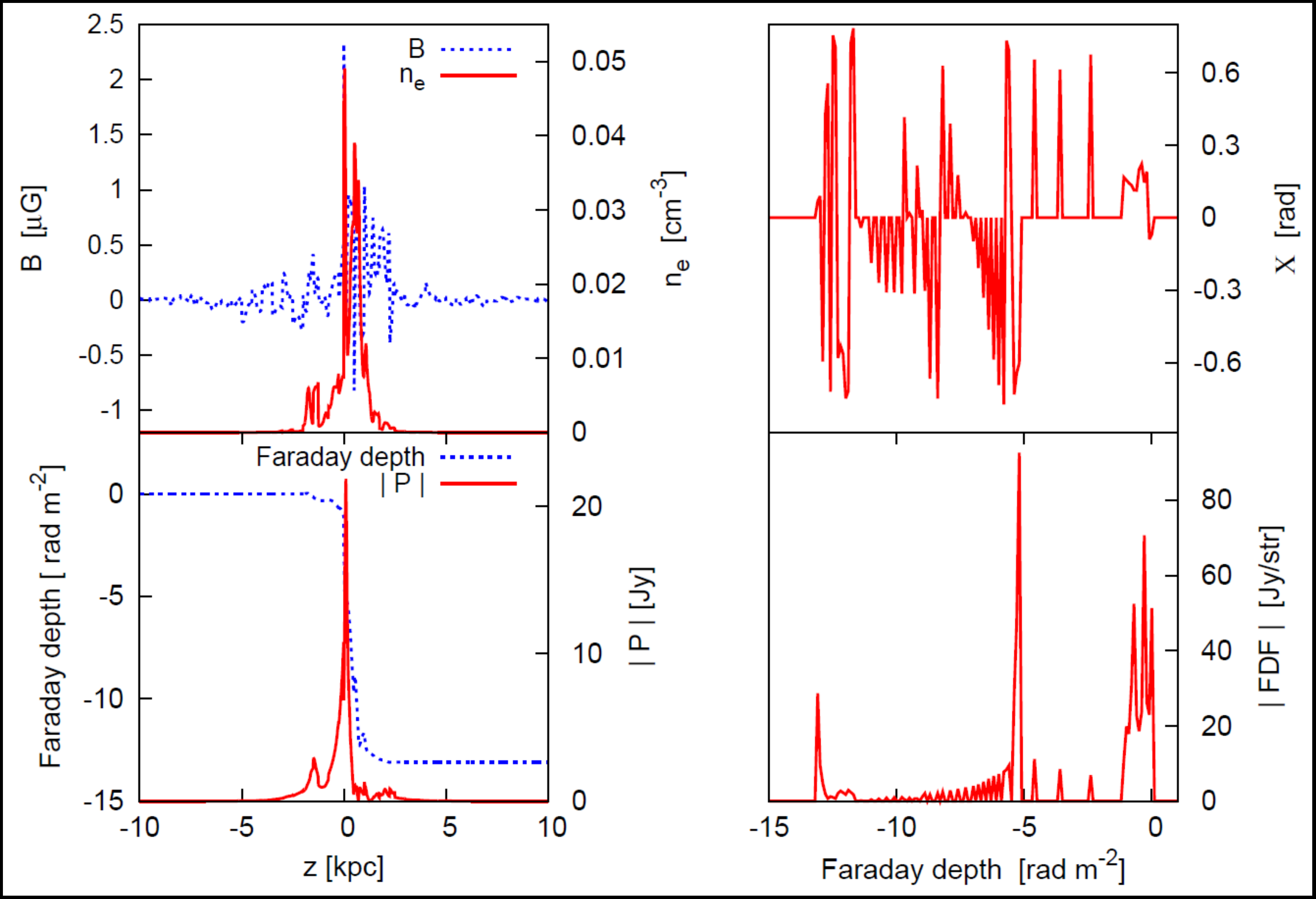
Ideguchi, KT+ 2013

shape of galaxies

Ideguchi, KT+ in prep

Galactic model of Akahori+ 2013 → B, ne, CRs

consider observation of a face-on galaxy



shape of galaxies

Ideguchi, KT+ in prep

Galactic model of Akahori+ 2013 → B, ne, CRs
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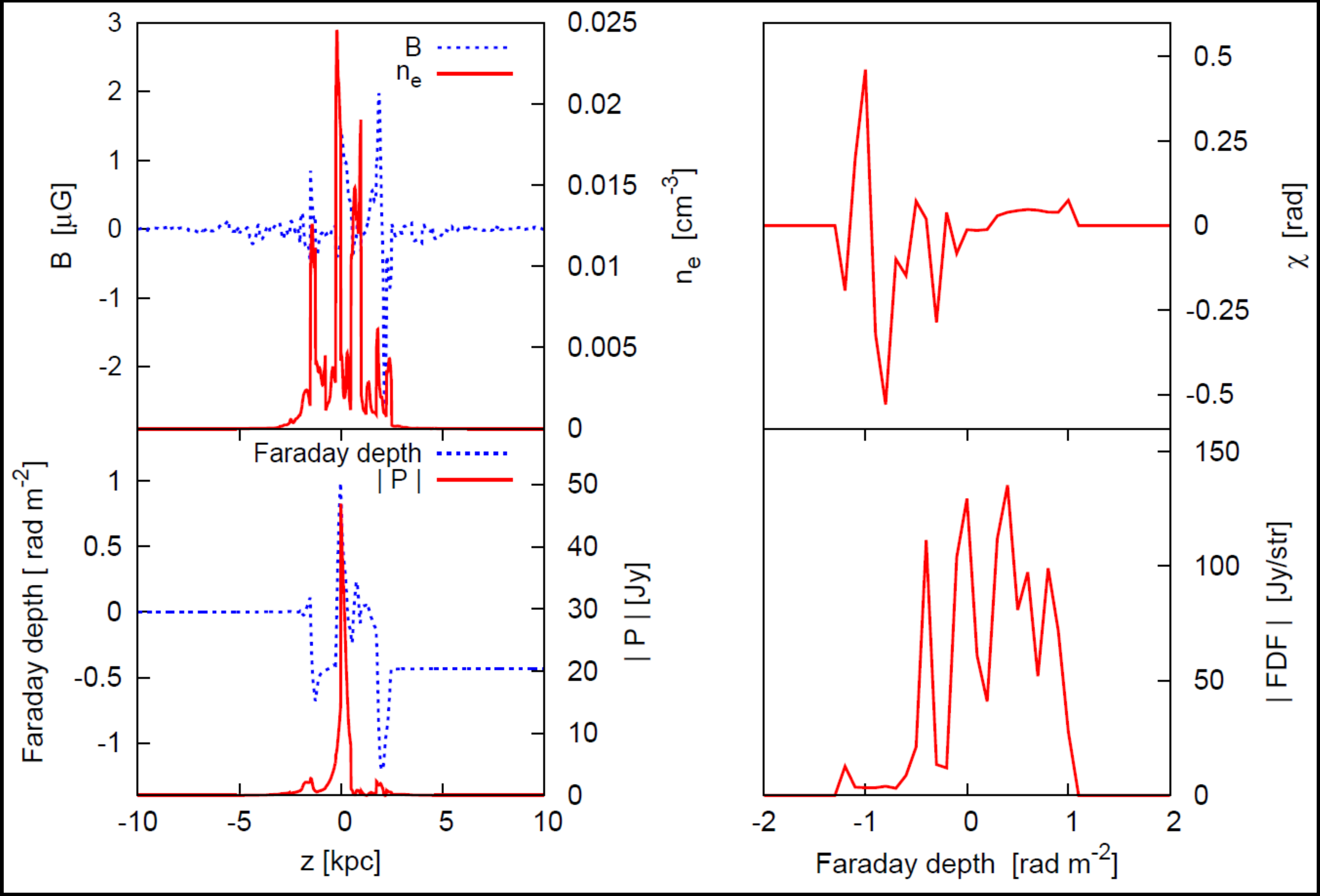
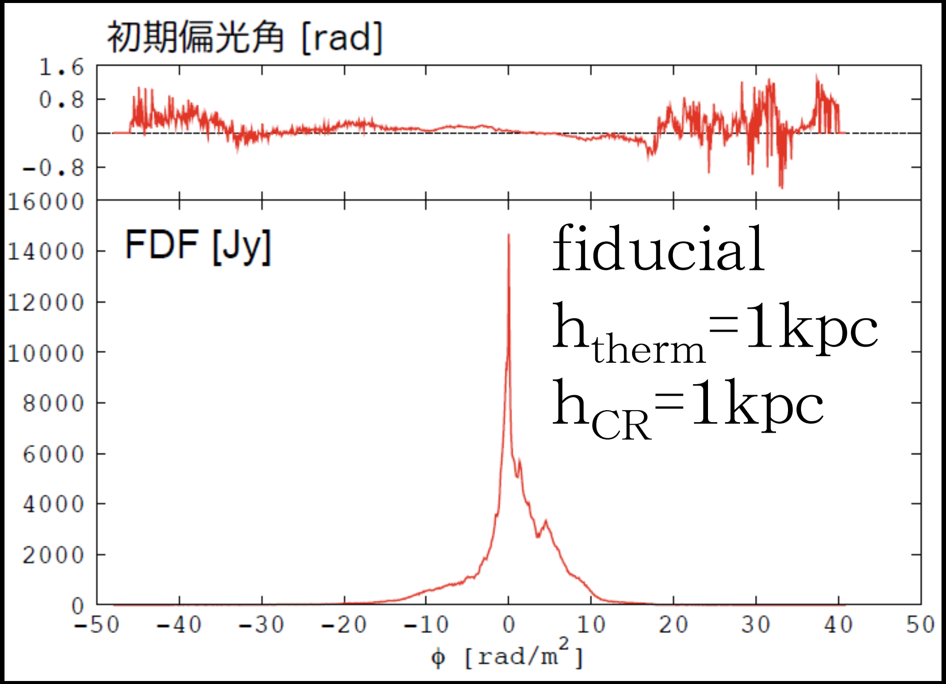
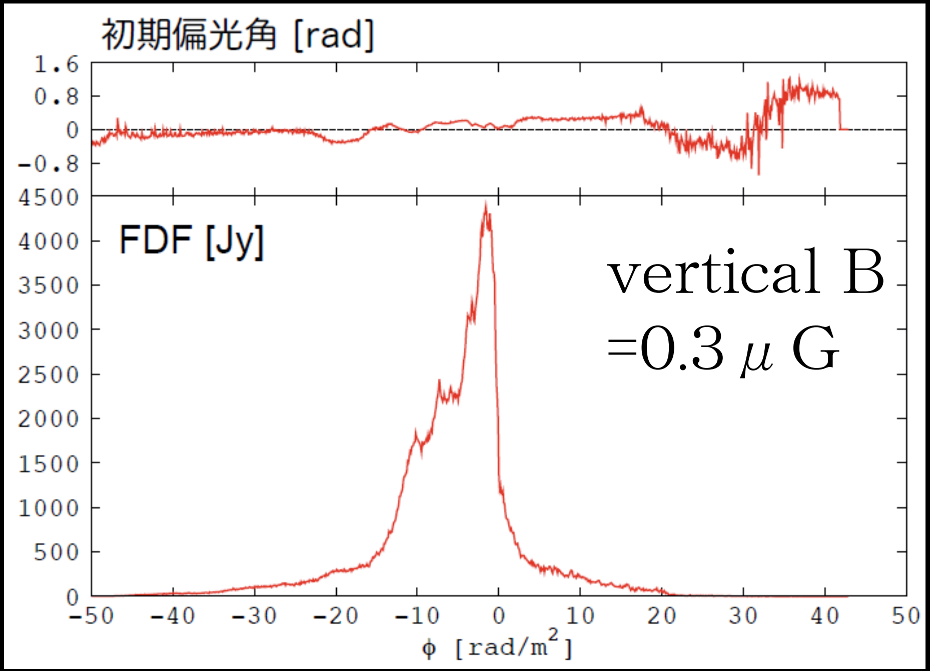


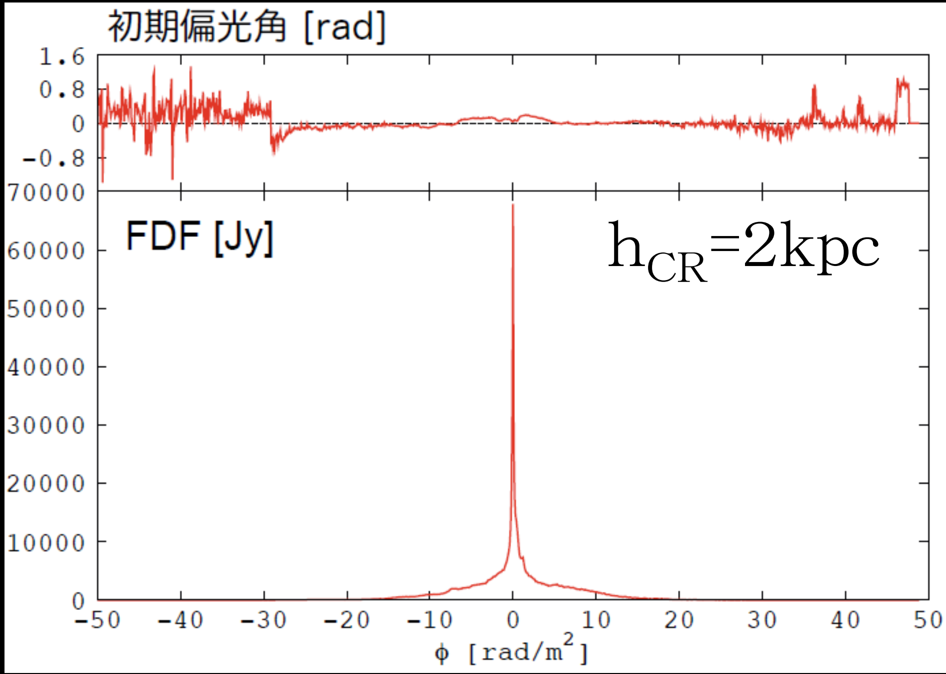
shape of galaxies

properties of galaxies
→ F(ϕ)

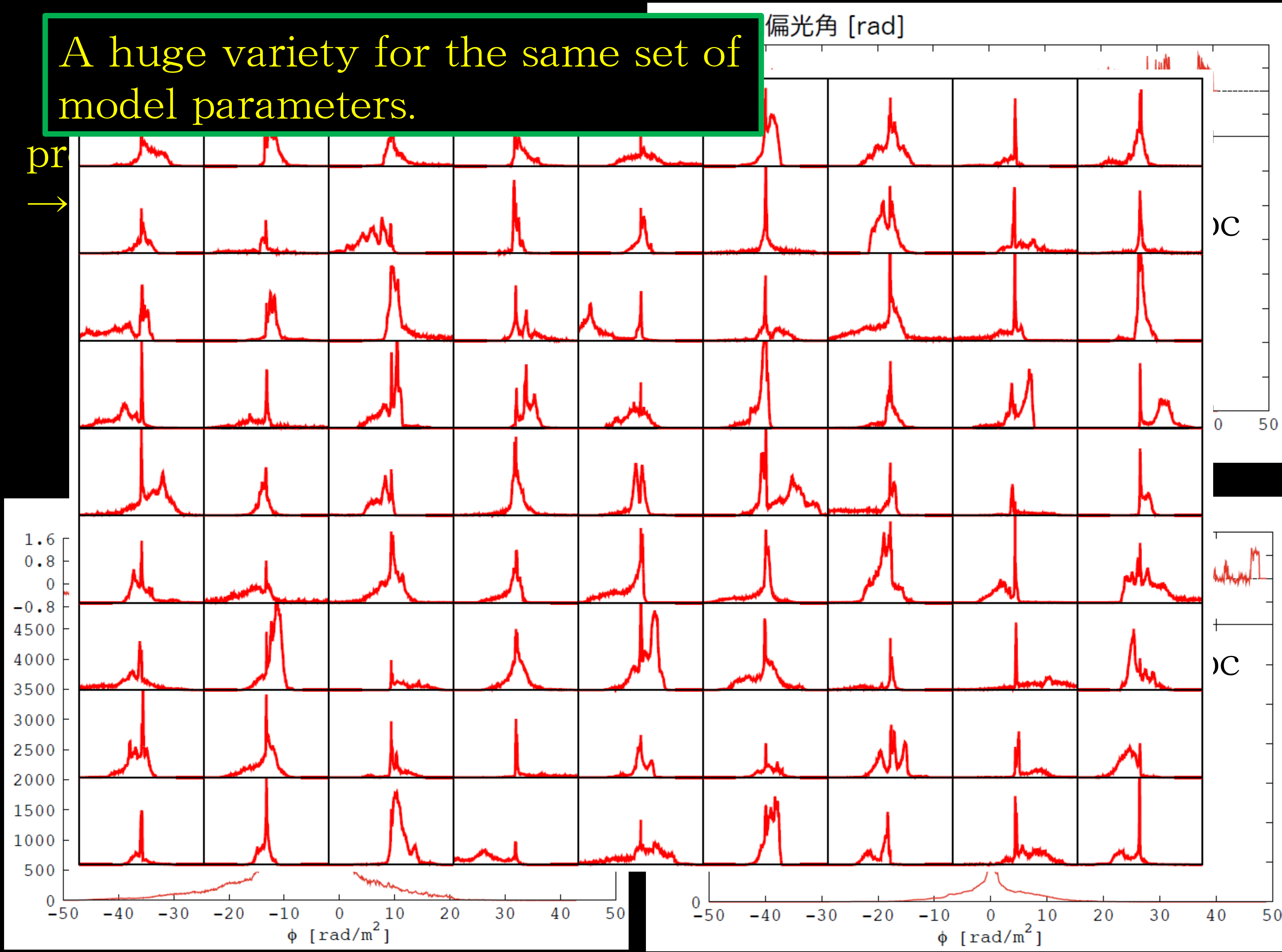
- vertical magnetic fields
- distribution of CR
- distribution of thermal e^-
- turbulence



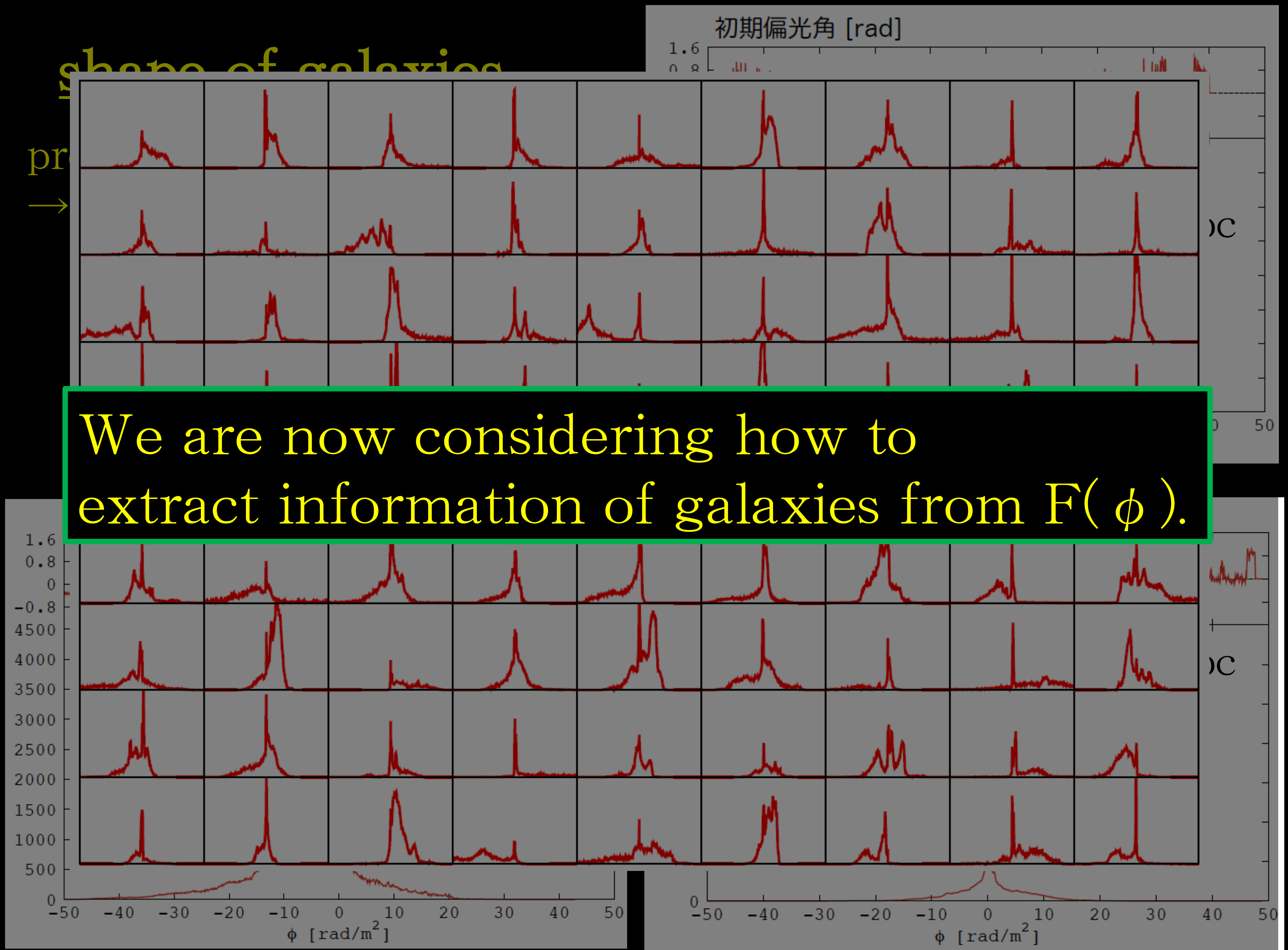




A huge variety for the same set of model parameters.



shape of galaxies



We are now considering how to extract information of galaxies from F(ϕ).

Summary

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Wide-band radio observation is a powerful tool to probe IGMF, galactic B, ne, CRs.