LOFAR Magnetism KSP Meeting @ Sant'Antioco
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Capability of Wide-band Polarimetry for Probing the Intergalactic Magnetic Field (IGMF)

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Our Goal

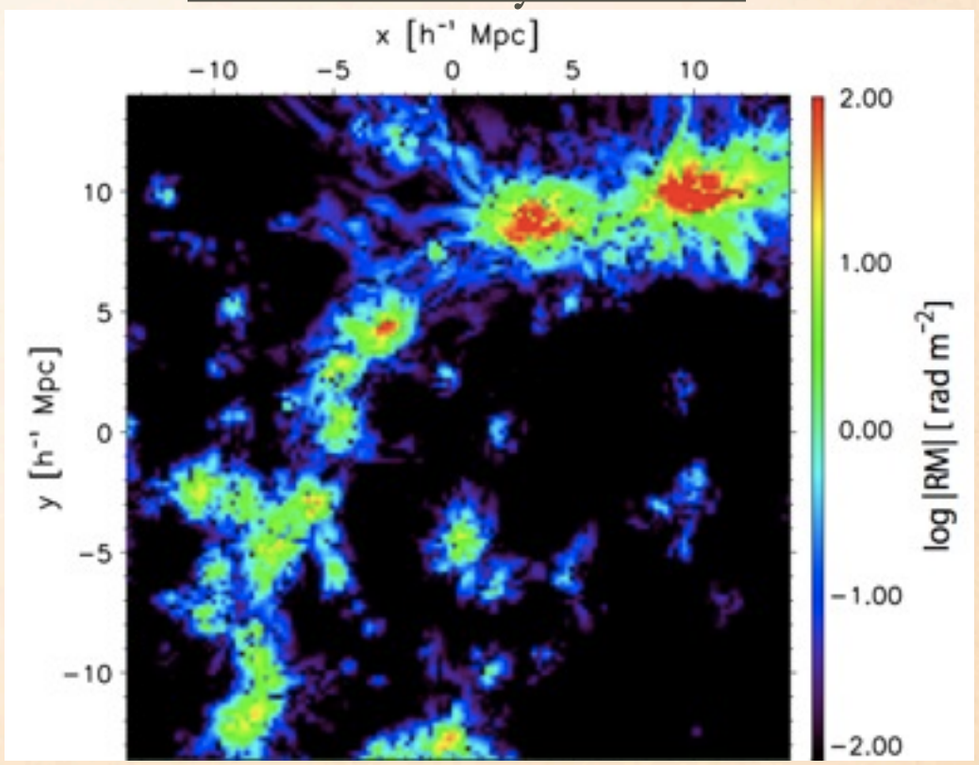
Find **IGMF in filaments of galaxies** by radio telescopes

- have never been observed
- affect to many cosmic phenomena
  - CMB fluctuation, propagation of UHECR, etc...
- may have information of early universe
  - based on ideas : the current comic magnetisms originate from primordial MF
- ~10-100nG, a few rad/m² in RM (Akahori & Ryu 2010)

In this study:

We forecast the capability for proving the IGMF in filaments assuming "LOFAR, ASKAP & GMRT" observation

Akahori & Ryu (2010)



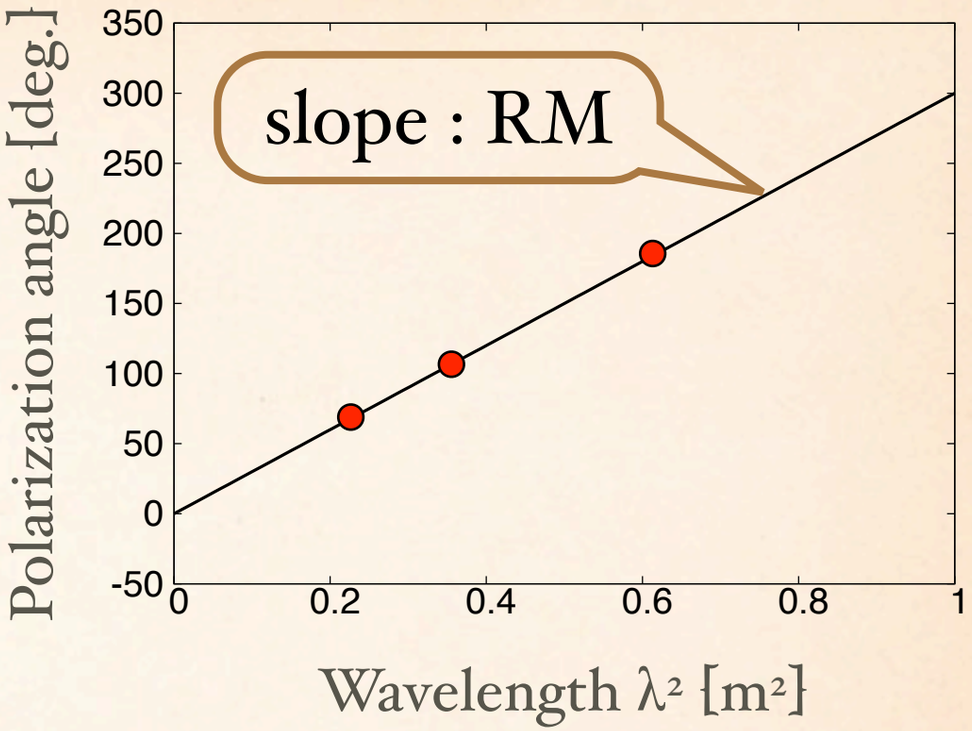
Observation

Faraday Rotation

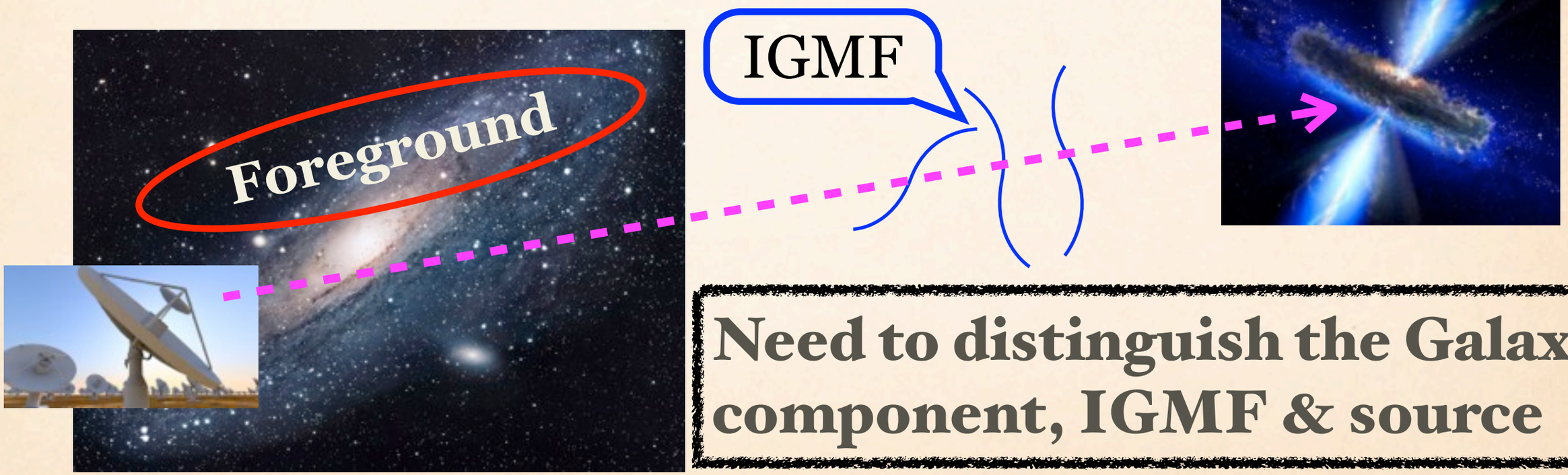
$$\chi = (RM)\lambda^2 + \chi_0$$

$$RM \simeq 0.81 \frac{\mathrm{rad}}{m^2} \int_0^{l_s} \left(\frac{n_e}{\mathrm{cm}^{-3}}\right) \left(\frac{B_\parallel}{\mu\mathrm{G}}\right) \left(\frac{dl}{\mathrm{Mpc}}\right)$$

Integration along a LOS



Situation needed for observing IGMF



Need to distinguish the Galaxy component, IGMF & source

Faraday Dispersion Function (FDF)

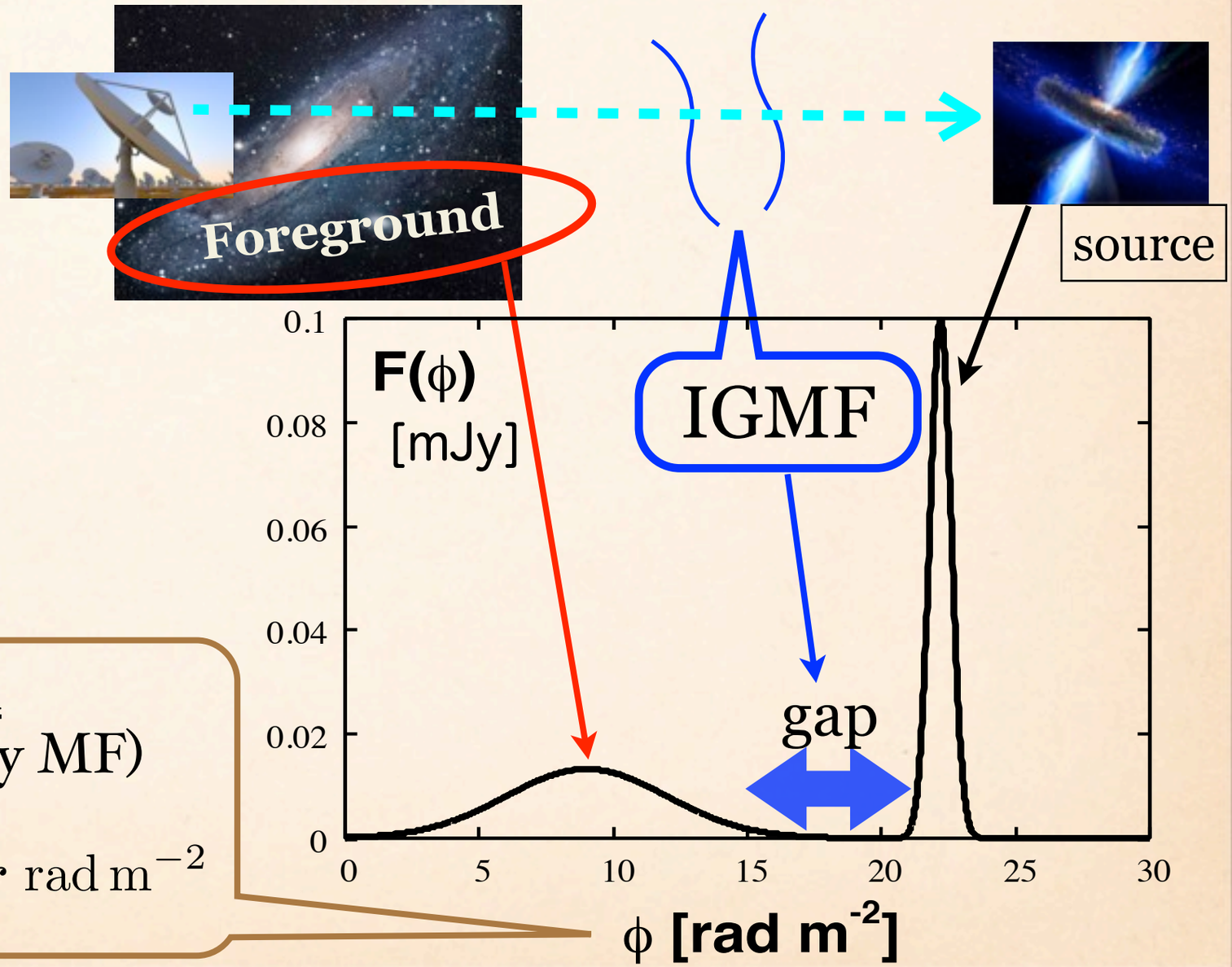
Distribution of MF & radio source along a LOS

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

Observed polarized intensity

Intrinsic polarized intensity

Relation between "observed PI" & "FDF"



Faraday depth
(~distance measured by MF)

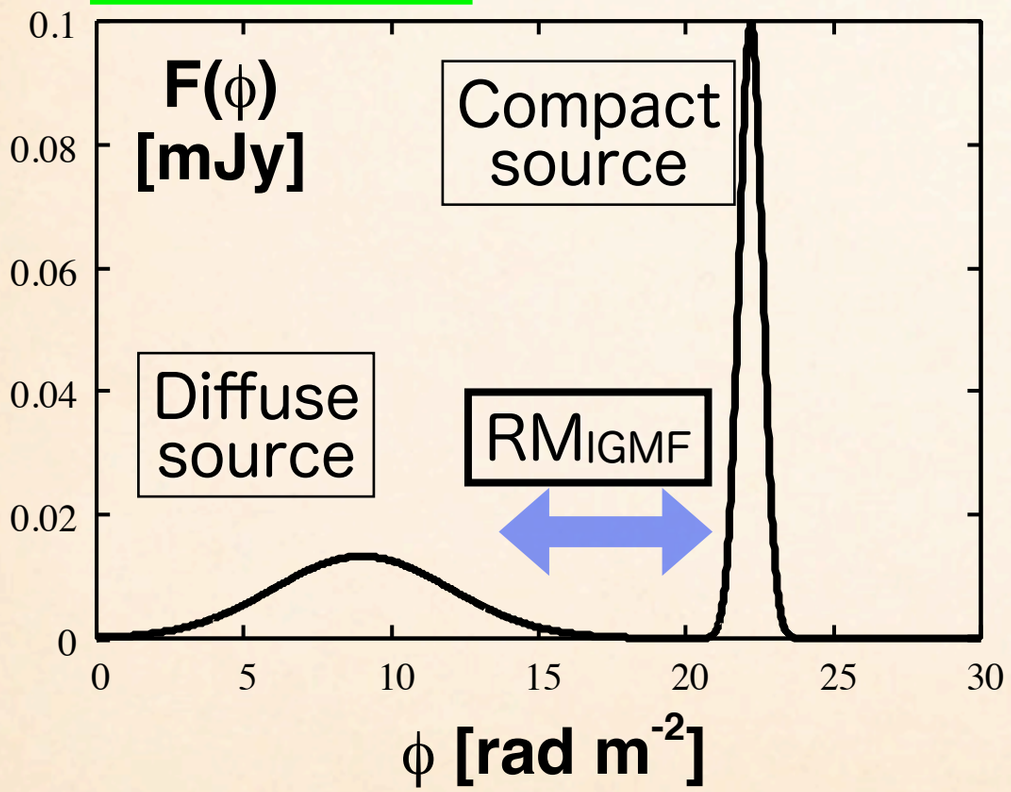
$$\phi(\boldsymbol{r}) = 0.81 \int_{\text{there}}^{\text{here}} n_{\text{e}} \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{r} \ \mathrm{rad\,m^{-2}}$$

QU-fitting

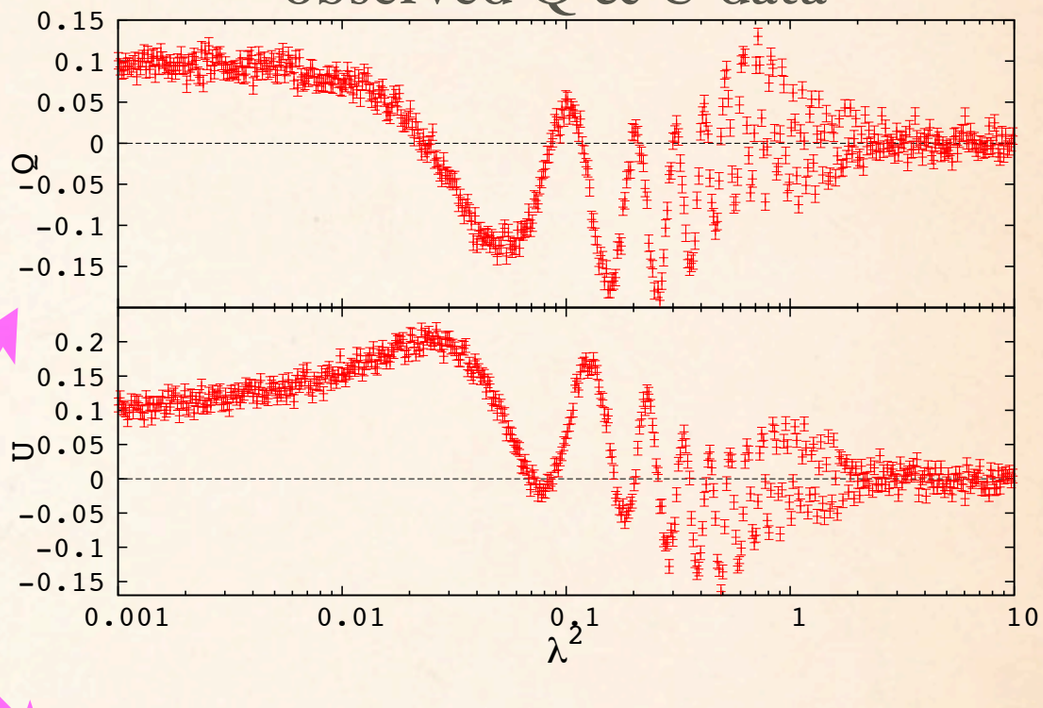
parameters per each source
φ : faraday depth of source
δφ: width of source
f : peak intensity of source
θ : intrinsic polarization angle

QU-fitting

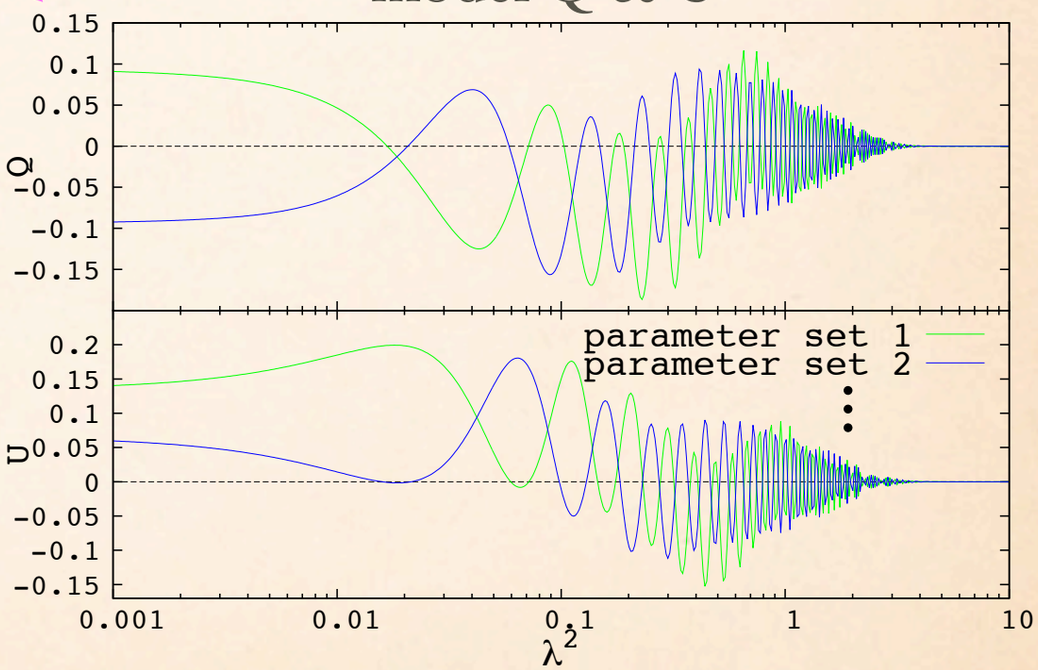
Model FDF



observed Q & U data



model Q & U



QU-fitting

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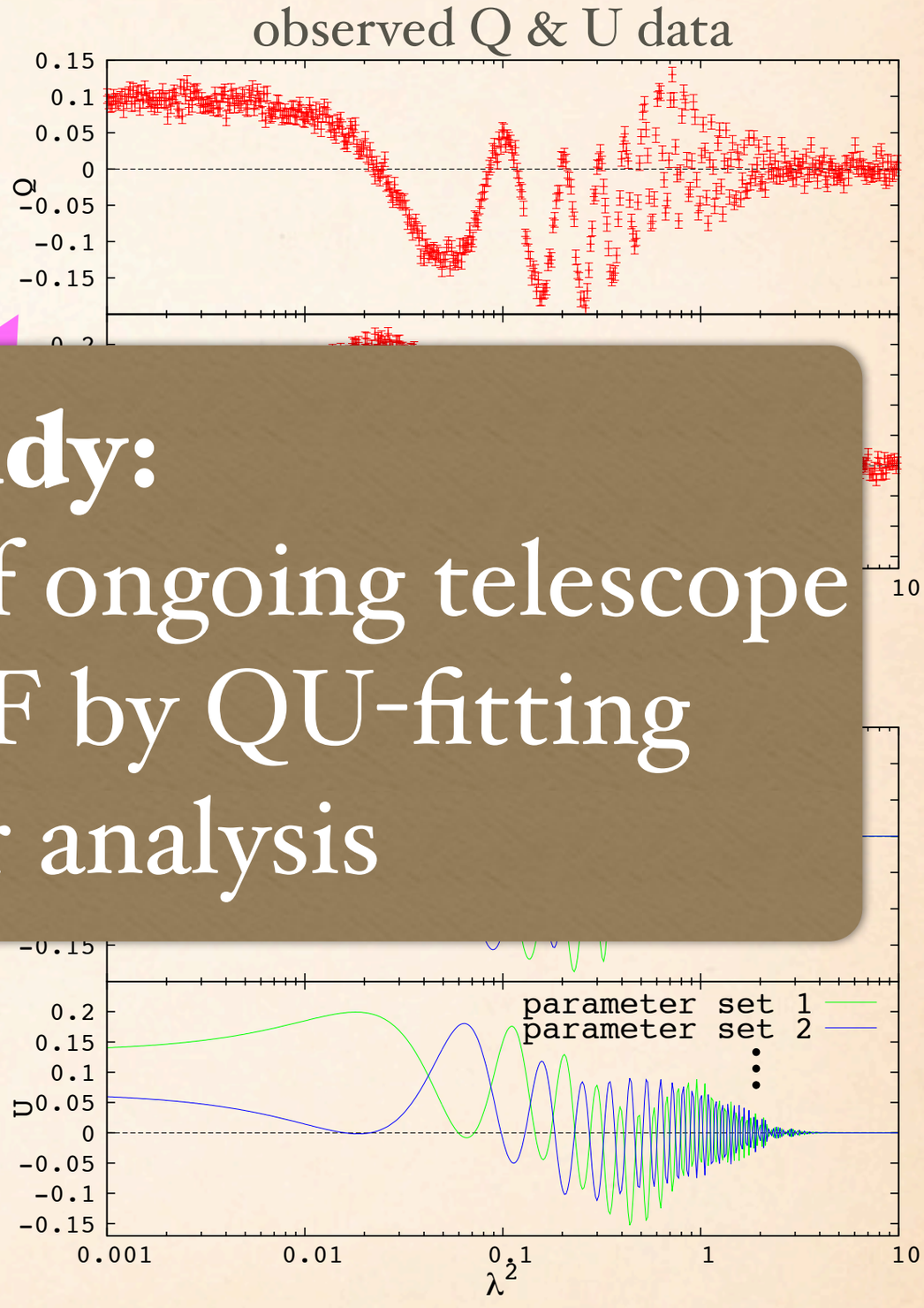
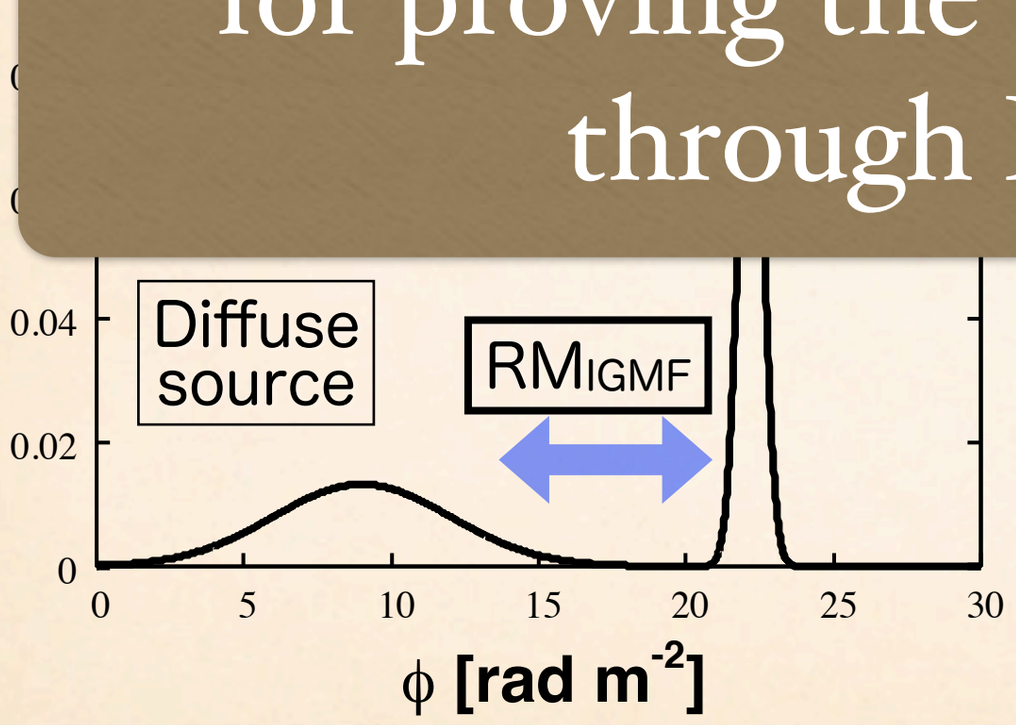


This Study:

Forecast the capability of ongoing telescope for proving the IGMF by QU-fitting through Fisher analysis



Fisher Analysis

Fisher Matrix

$$\mathcal{F}_{jk} = \frac{1}{2}\frac{\partial^2 \chi^2}{\partial p_j \, \partial p_k}$$

~ C (Curvature)

Observed data

Model

$$\chi^2 = \sum_{l=1}^{N} \frac{[Y_l(p) - Z_l]^2}{\sigma_l^2}$$

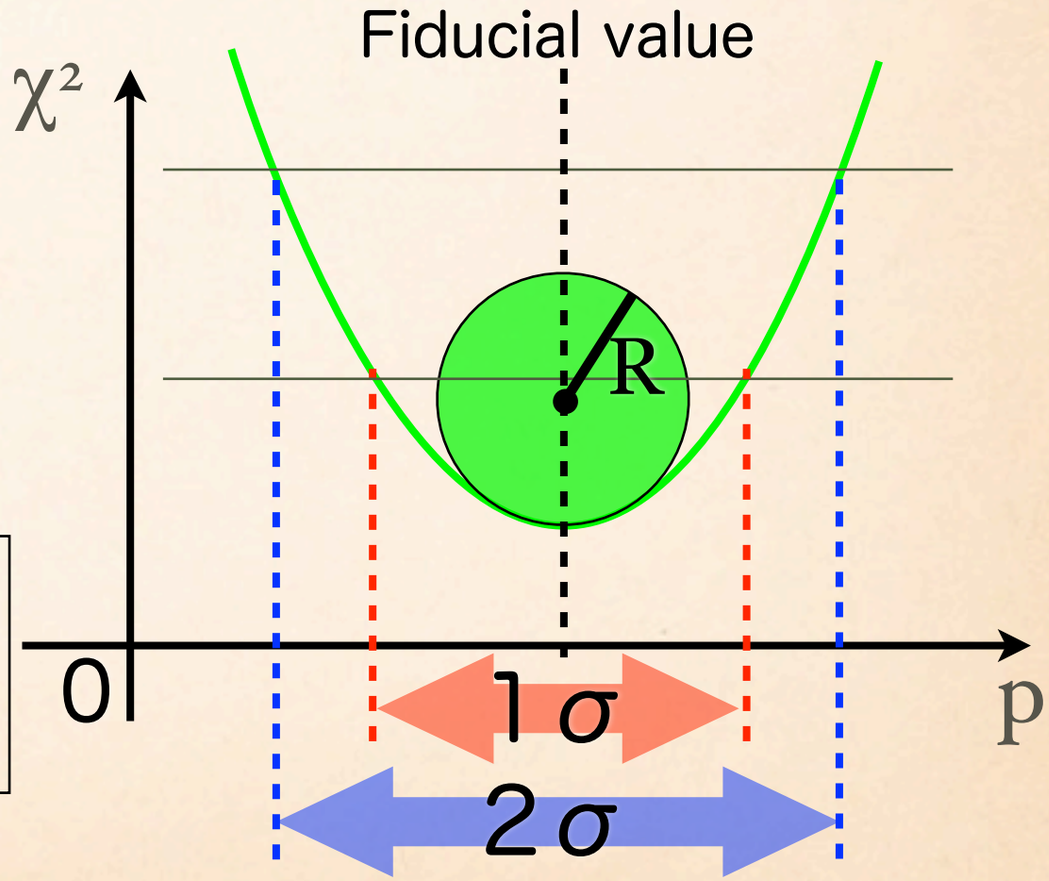
Curvature at the fiducial value in parameter space

Covariance Matrix

$$\sigma_{jk} = (\mathcal{F}^{-1})^{1/2}_{jk}$$

~ $(1/C)^{1/2}$ = R (Curvature Radius)

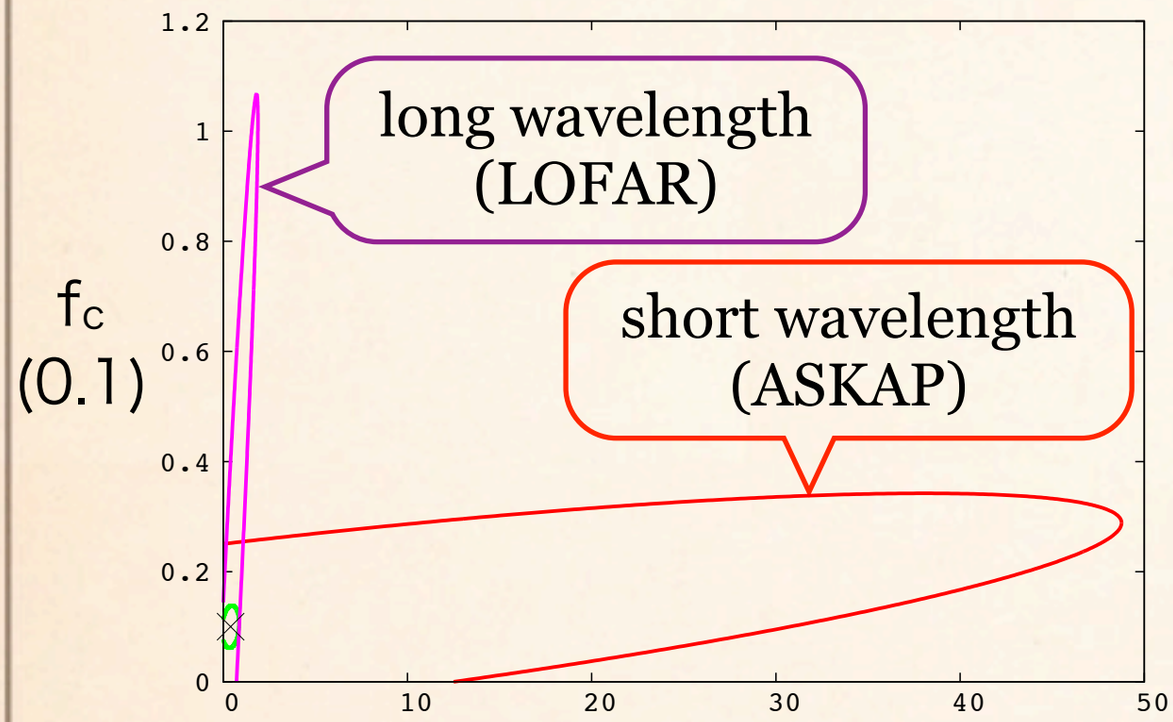
diagonal : 1-σ error of parameter
non-diagonal : correlation of error

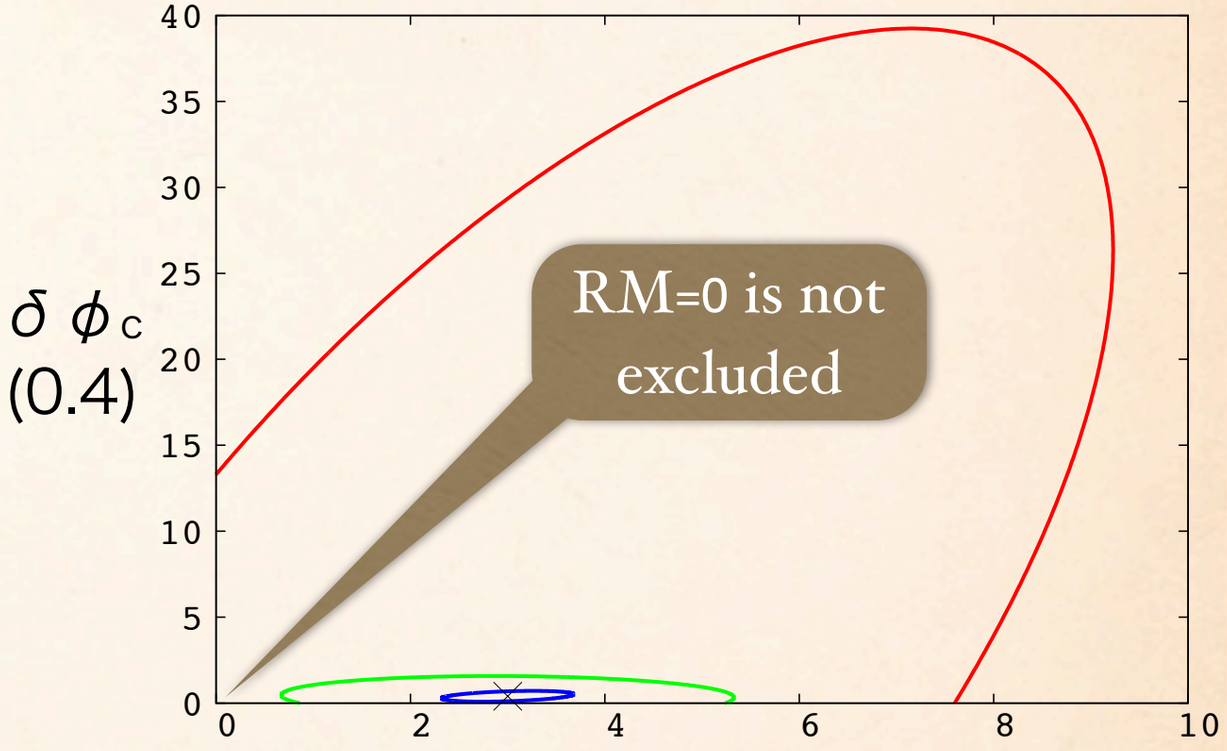


Results I

RM_{IGMF} =3.0 rad/m²
f=0.1 mJy

1-σ confidence region





L
A
AL
AGL

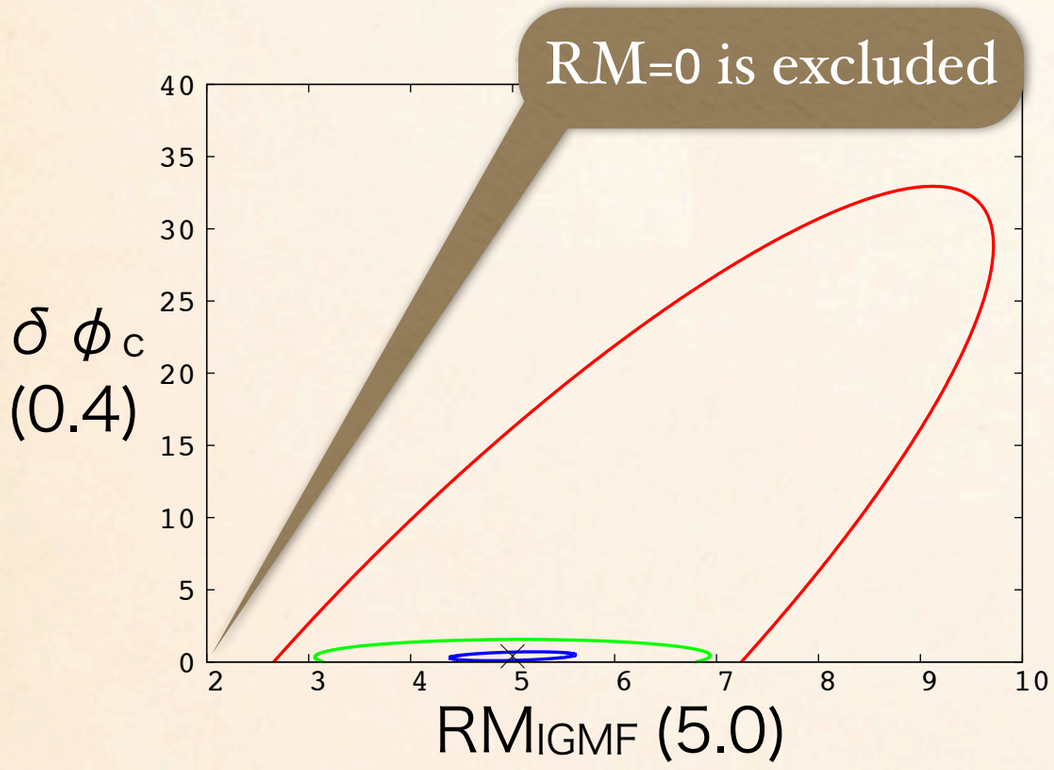
(A : ASKAP, G : GMRT, L : LOFAR)

Results II

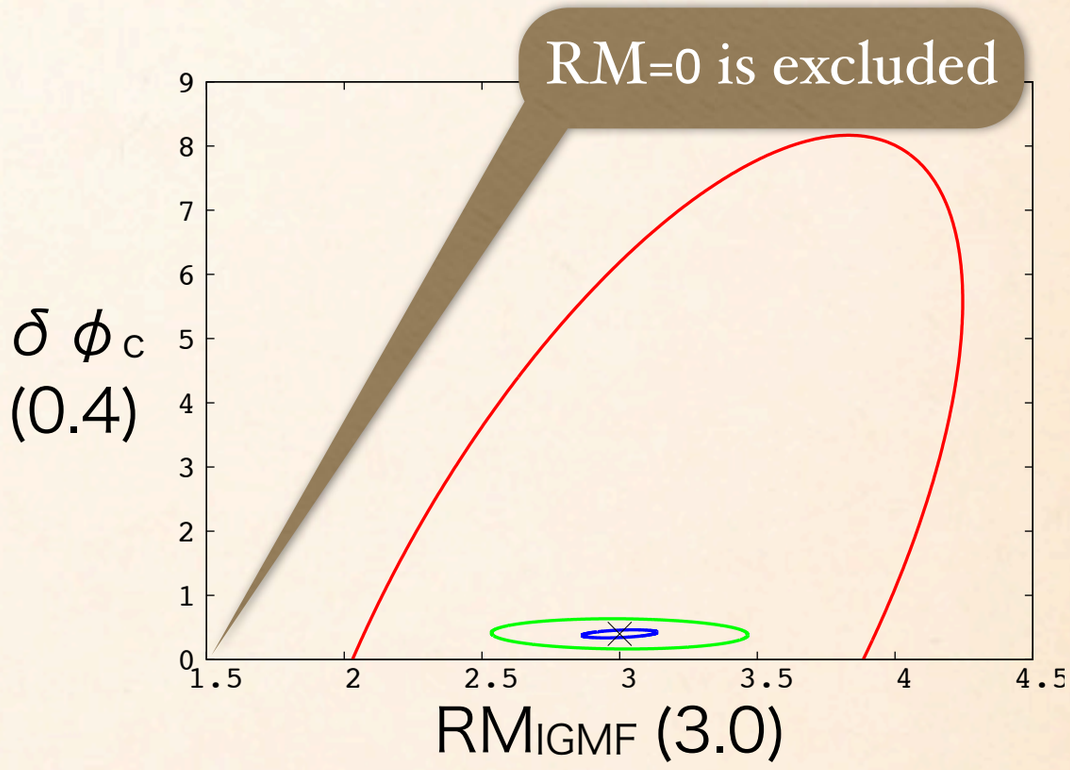
RM_{IGMF} =3.0 rad/m²
f=0.1 mJy

1-σ confidence region

RM_{IGMF} =5.0 rad/m²
f=0.1 mJy



RM_{IGMF} =3.0 rad/m²
f=0.5 mJy



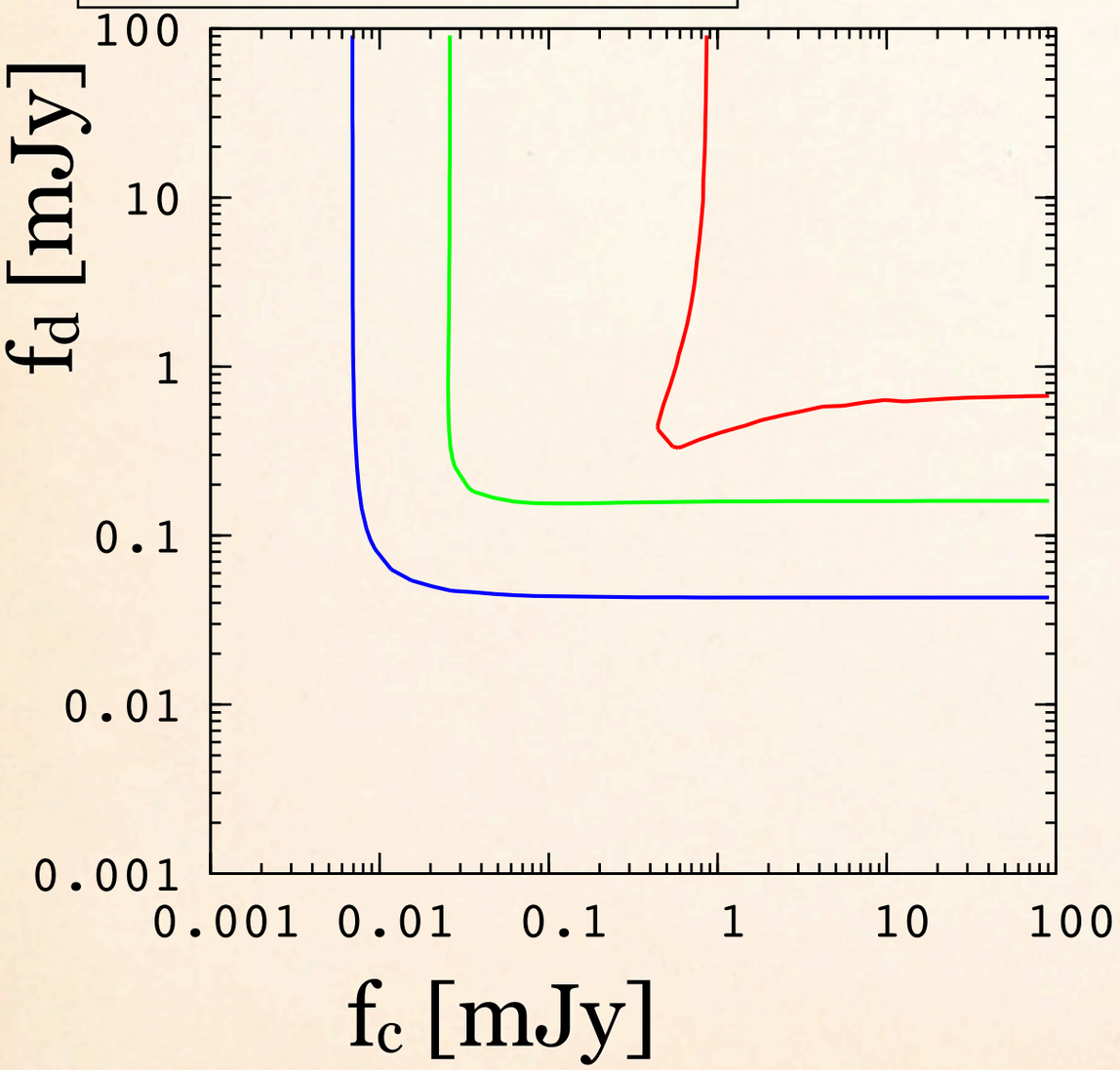
Larger RM_{IGMF} / Brighter source make it easier to detect the IGMF

Results III

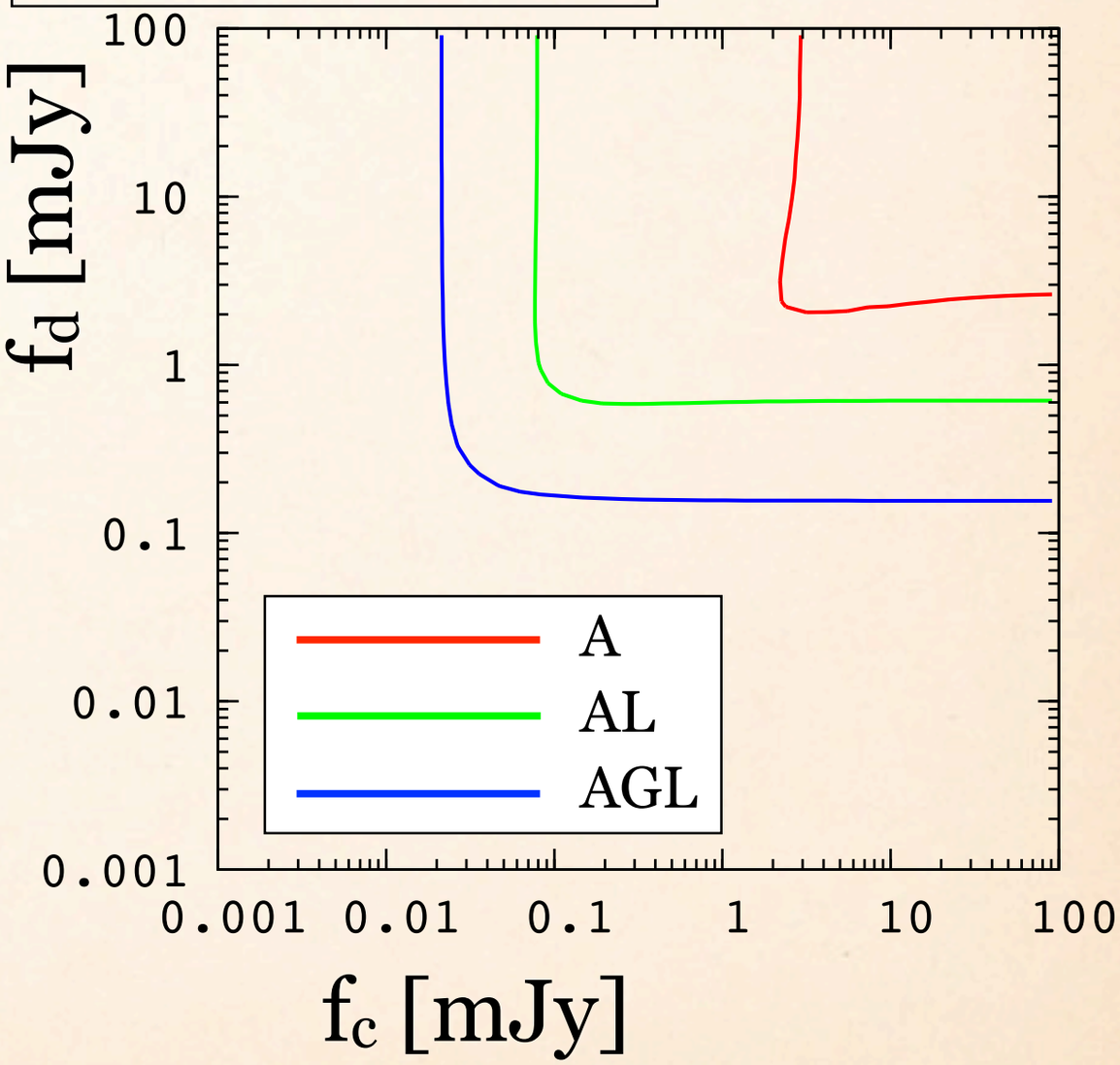
Necessary source intensities for detecting IGMF (3-σ CL)

IGMF is detected in the up-right regions of the lines

RM=3.0 rad/m²



RM=1.0 rad/m²



(A : ASKAP, G : GMRT, L : LOFAR)

Results III

Necessary source intensities for detecting IGMF (3-σ CL)

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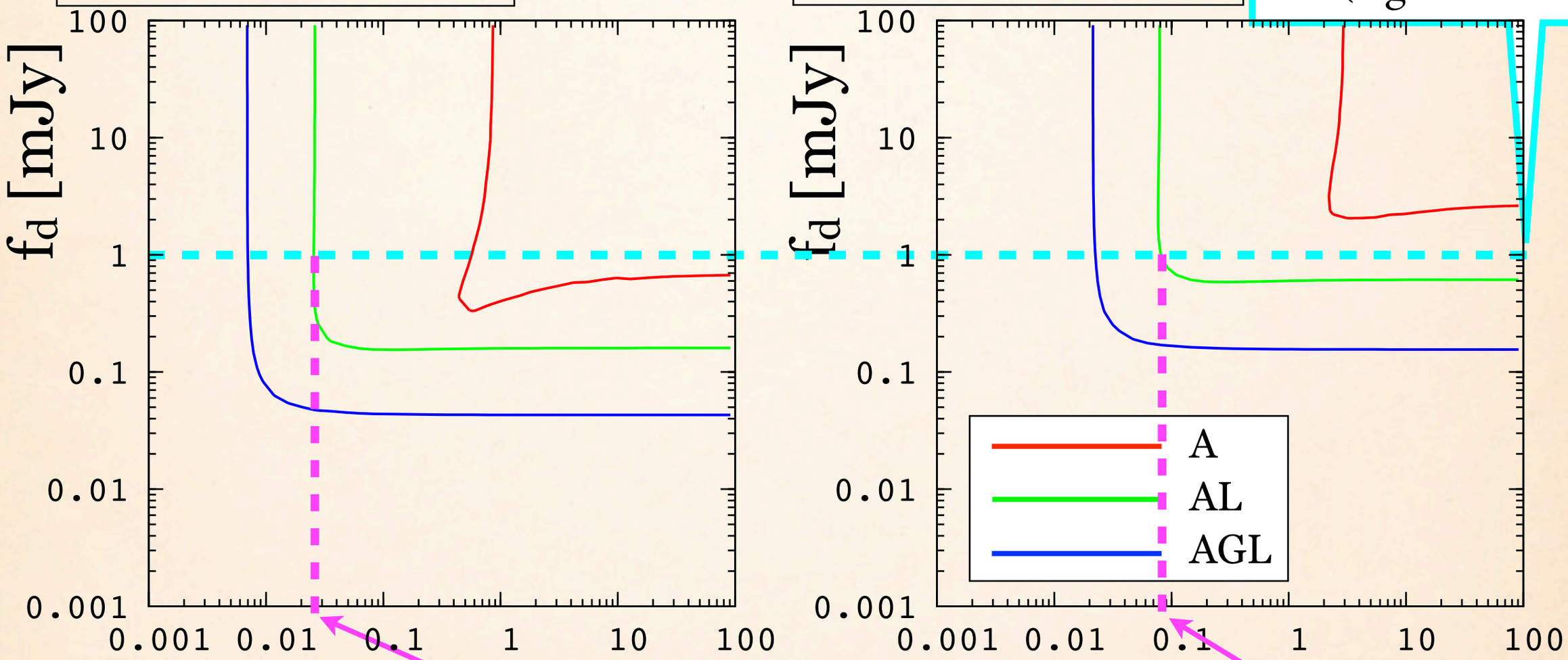
RM=3.0 rad/m²

RM=1.0 rad/m²

Intensity of the Galaxy (high latitude)



~0.03mJy [RM=3]

~0.09mJy [RM=1]

(A : ASKAP, G : GMRT, L : LOFAR)

QU-FITTING

WITH

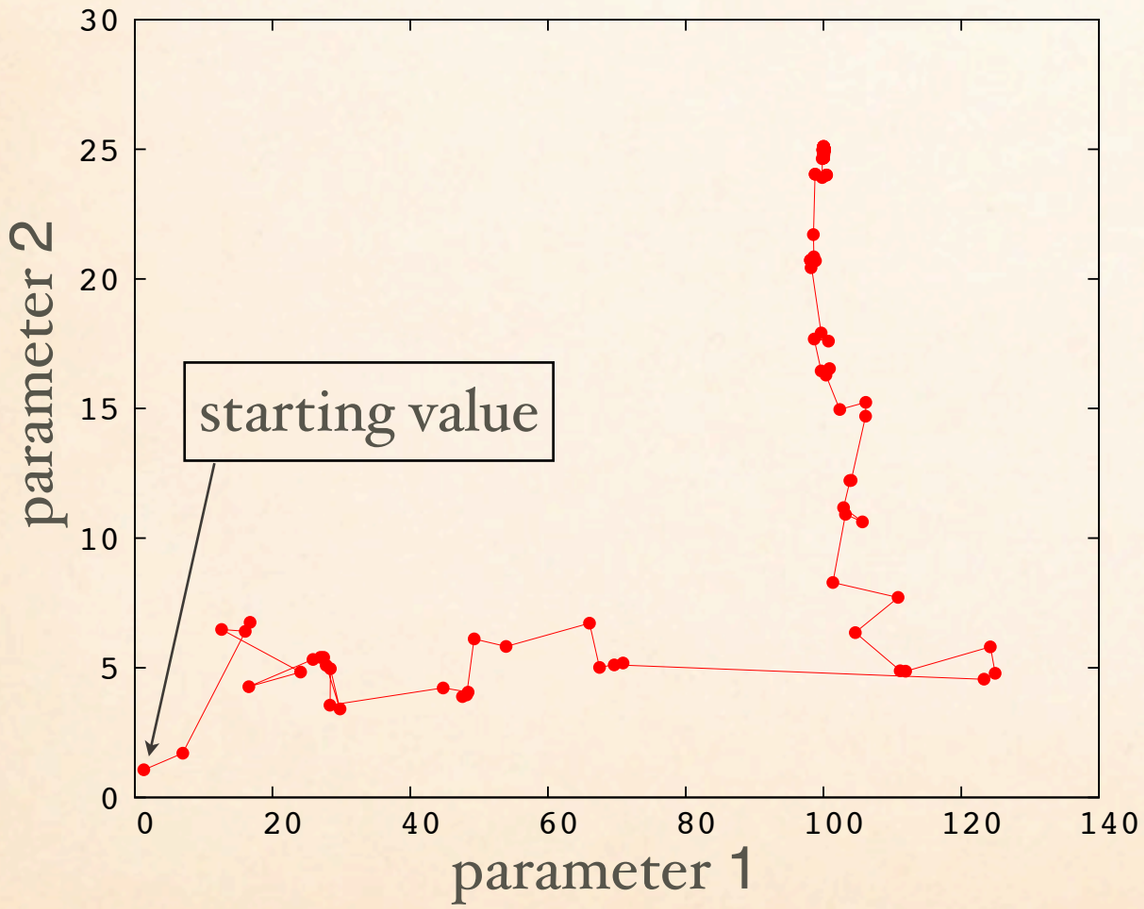
MCMC

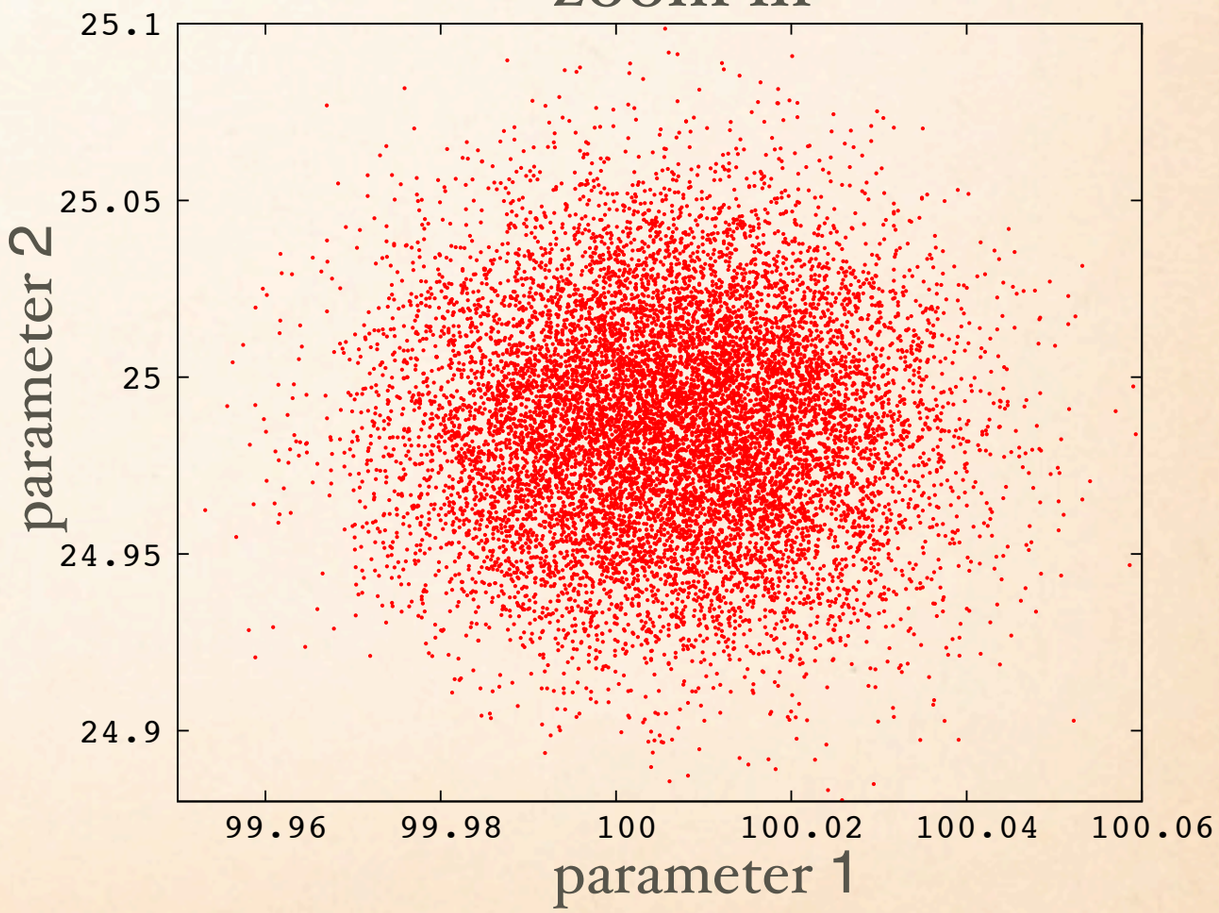
MCMC Markov Chain Monte Carlo method

(often used in cosmology field to estimate cosmological parameter)

Advantage

- extremely fast in calculation even with many parameters
  - It takes a few seconds for QU-fitting assuming 1000ch observation & 8 parameters
- can evaluate error
  - statistical discussion would be possible





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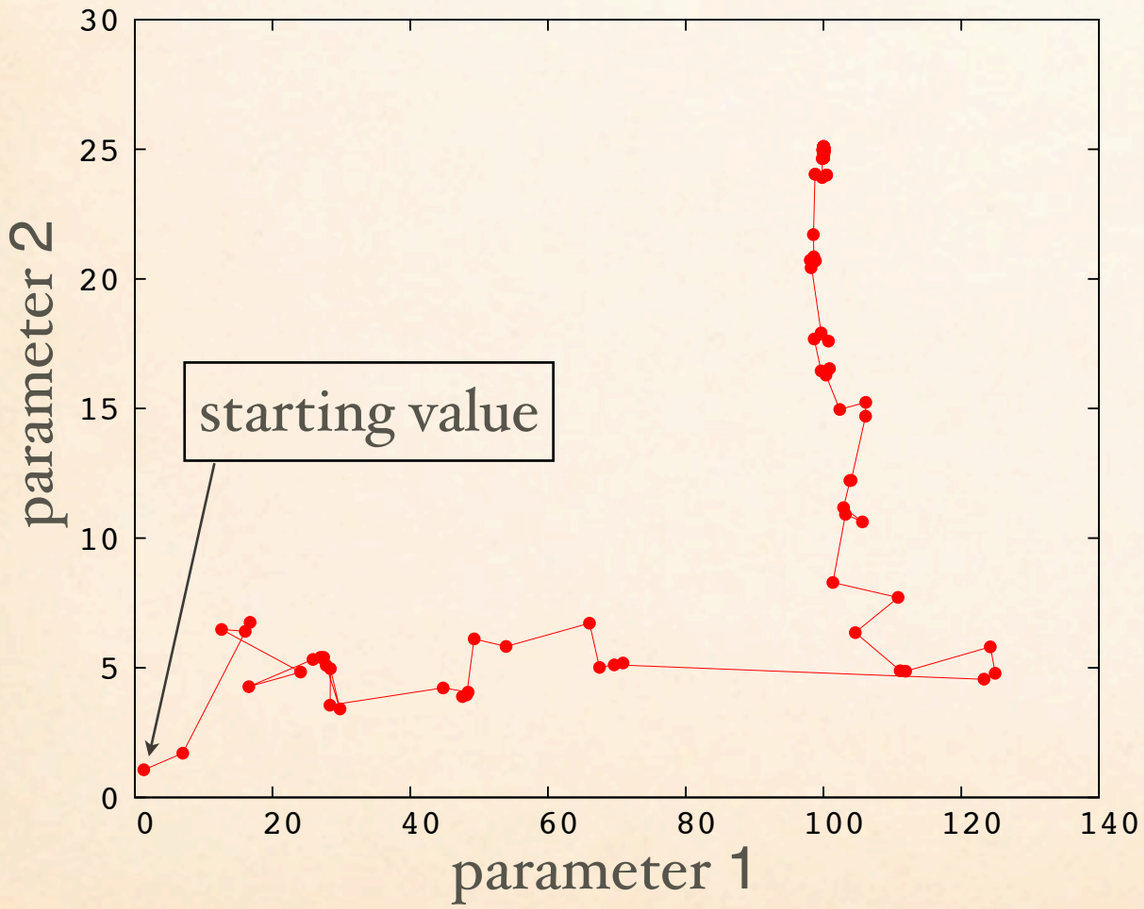
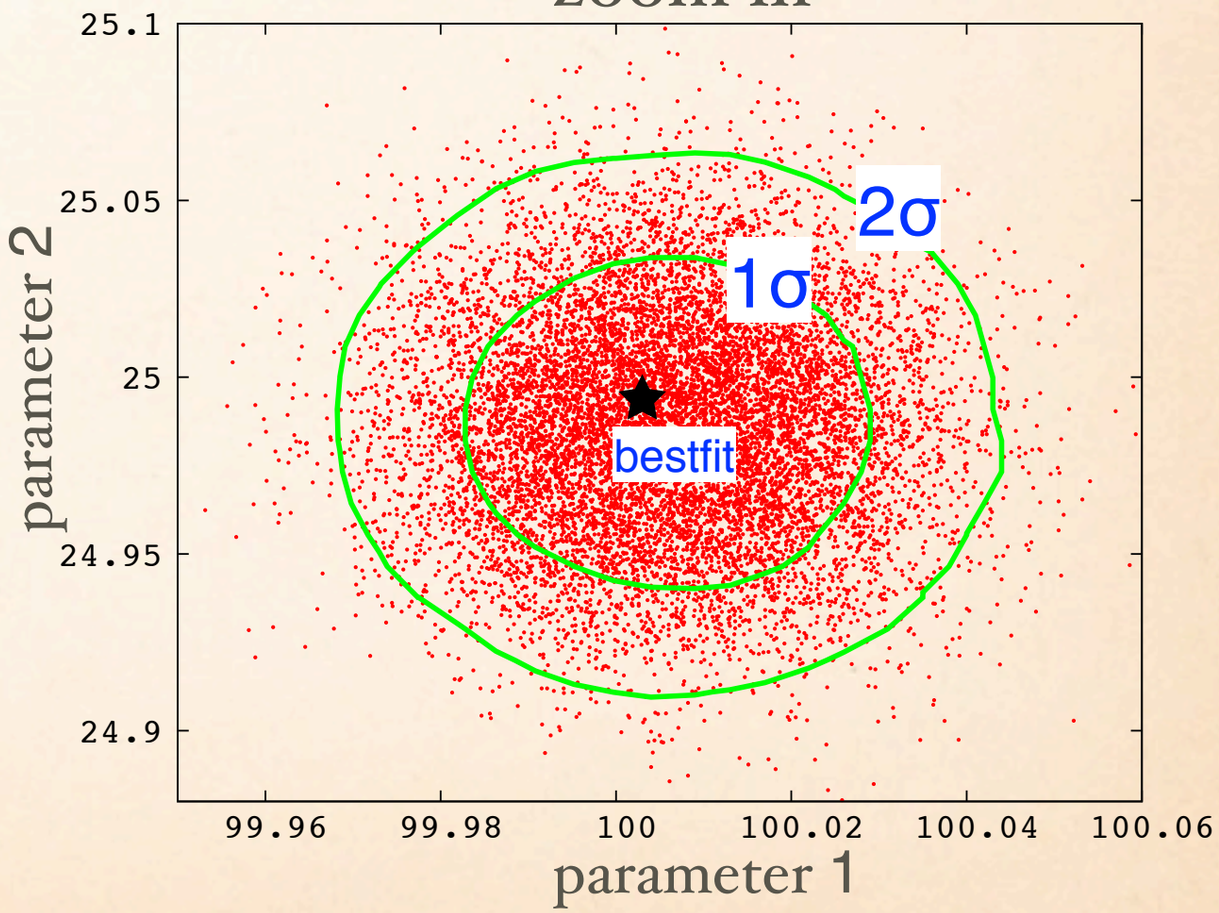


zoom in



POSSUM : POlarization Sky Survey of the Universe's Magnetism

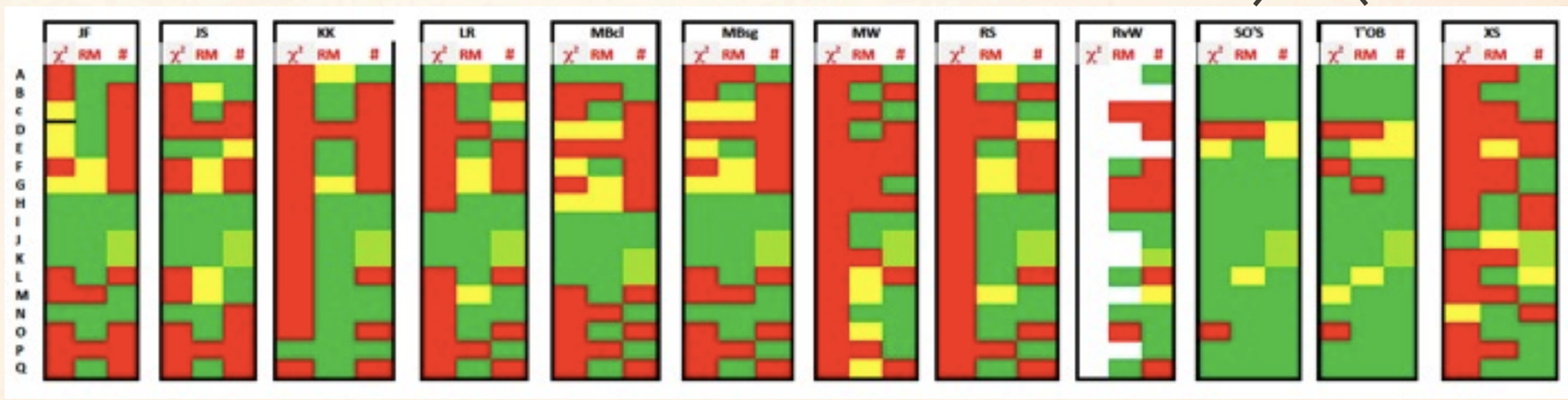
(One of the ASKAP survey)

POSSUM benchmark test

evaluate how collect to reconstruct FDFs

QU-fitting

green : good
yelllow : fair
red : bad



- QU-fitting got good scores (even without MCMC)
- By using MCMC,
  - ✓ we make it faster to execute QU-fitting
  - ✓ & make it possible to evaluate parameters errors
- We are involved with a development of POSSUM pipeline

SUMMARY

- We forecast the capability of ongoing telescope for proving IGMFs of filaments by QU-fitting through Fisher analysis

- Assuming very simple model as the Galaxy component and RM of the IGMF is a few rad/m^2, the IGMF can be detected by observing some compact source with intensities more than 0.03mJy by LOFAR & ASKAP

- QU-fitting with MCMC would be very useful for finding FDF with more accuracy in a sense of finding likely parameters. In addition, statistical dicussions would be possible by this method.