Faraday Rotation Measure due to the Intergalactic Magnetic Field

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1 Chungnam National University, Korea
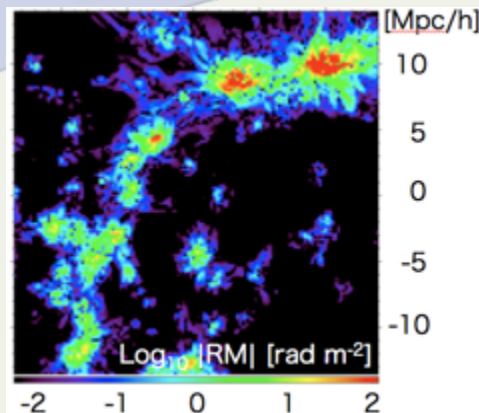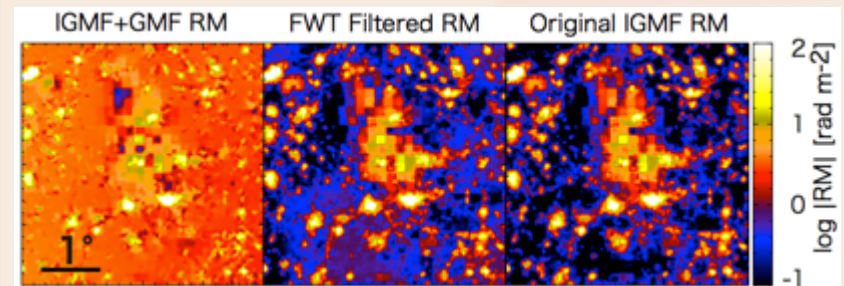2 Korea SKA SWG 3 Japan SKA SWG 4 ASKAP POSSUM
Collaborator: **Dongsu Ryu**

Contents

Intergalactic
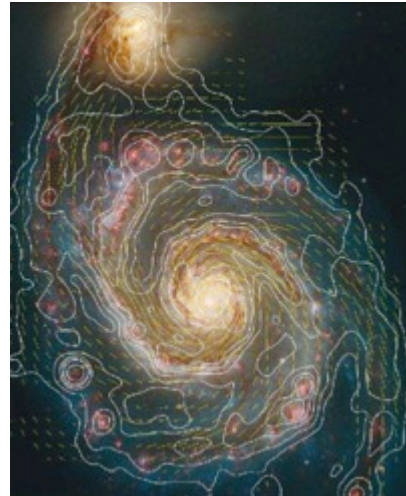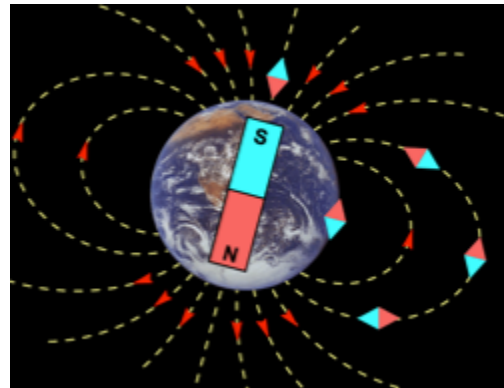Magnetic Filed
(**IGMF**)

Galactic
Magnetic Field
(**GMF**)

SKA
Korea,Japan

Small-scale
Turbulence
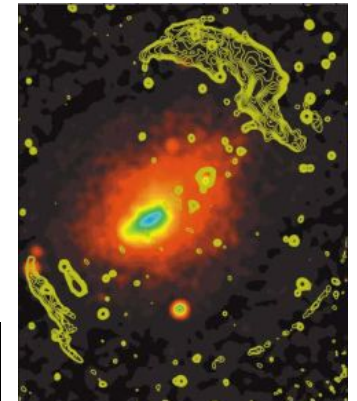Dynamo

20th century

Origin of Earth MF is one of the biggest issues in modern physics
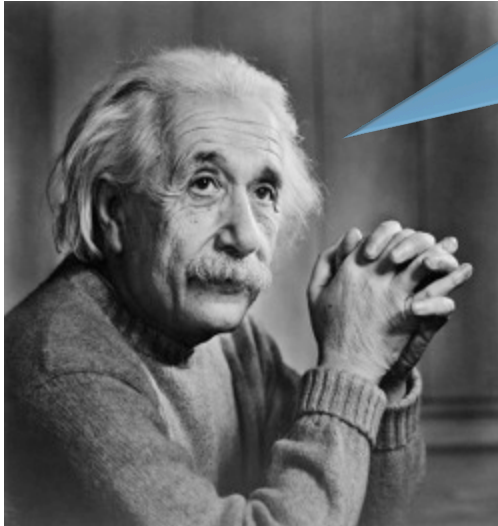
Roettiger+ (99)

Fletcher+ (10)

Origin of Cosmic MF is one of the biggest issues in modern physics

21th century

- UHECRs, seed field of galaxies, cosmology,···
- ICM: **|RM| ~100 [rad m^{-2}] IGMF ~1-10 [µG]**
- WHIM: **|RM| < 10 [rad m^{-2}] ? IGMF ~ ?**

RM through the ICM (Govoni+ 10) B~1-10 [µG]
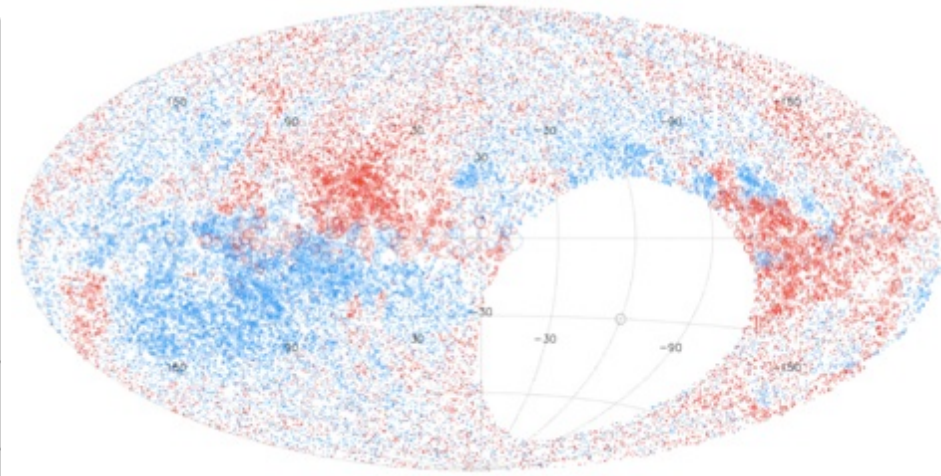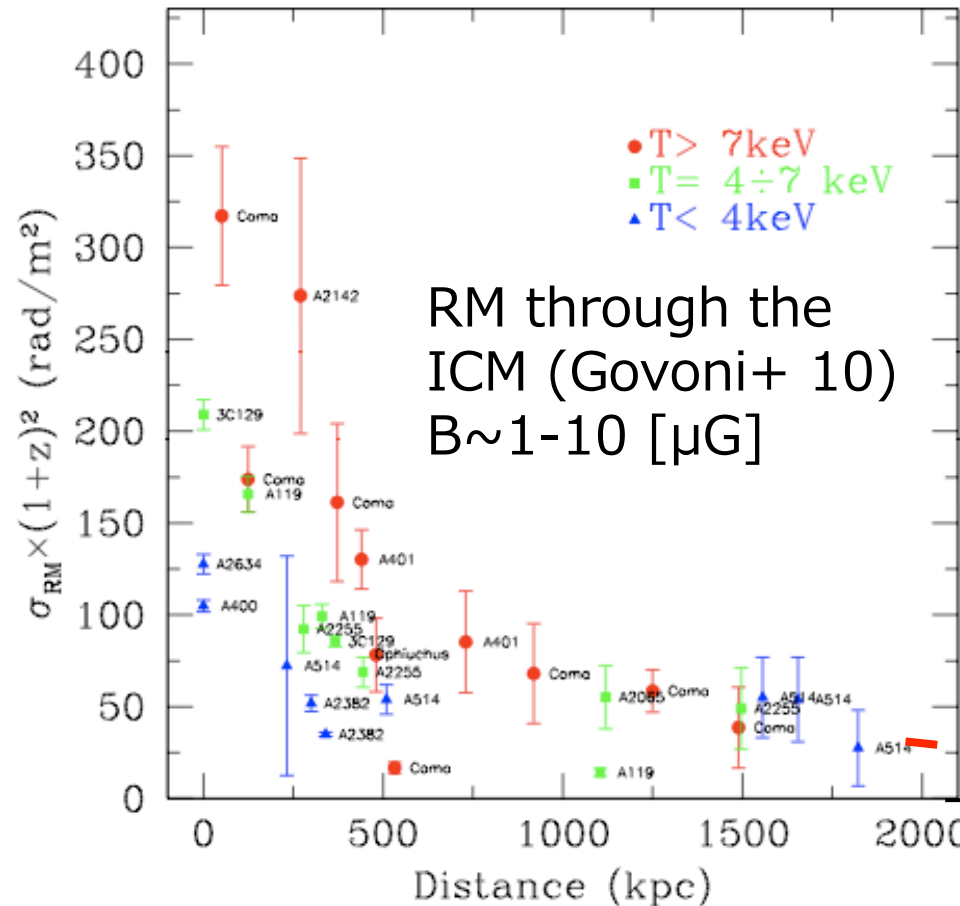
VLA RM map (~40k sources) Taylor, Stil, Sunstrum (09)

??

3 Mpc   5Mpc   10 Mpc ...

- Cosmological Seed Field
  Inflation
  Phase transition
  Recombination

- MHD in LSS
  Biermann effect,
  Turbulence dynamo

- IGMF

- Magnetic Field of Galaxies
  Instabilities,
  α-Ω dynamo
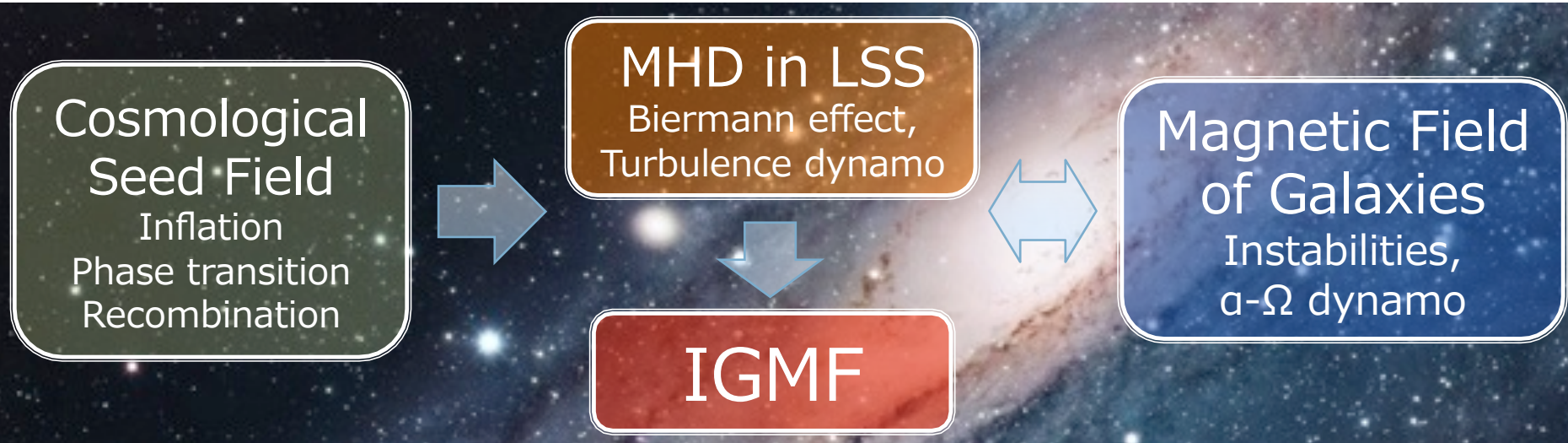
- **Scenarios for IGMF**
  - Cosmological
  - Astronomical
  - Magneto-hydrodynamical

- **Turbulence in clusters**
  - **Kolmogorov-like power spectrum?** (Vogt & Ensslin 05; Guidetti+ 08; Bonafede+ 10)
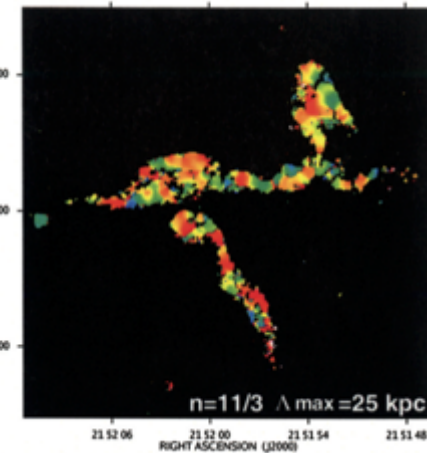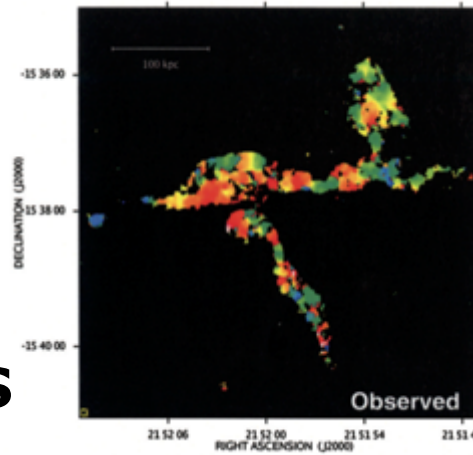
Observation and theoretical model of RM through Abell 2382 (Guidetti+ 08)

- Cosmological simulations
  - AMR-MHD (Dubois, Teyssier 08)
  - SPH-MHD (Dolag, Stasyszyn 09)
  - **MHD(passive) + turbulence dynamo model (Ryu, Kang, Cho, Das 08, science)**

100 h^{-1} Mpc

10^{-4} μG |B| 10 μG
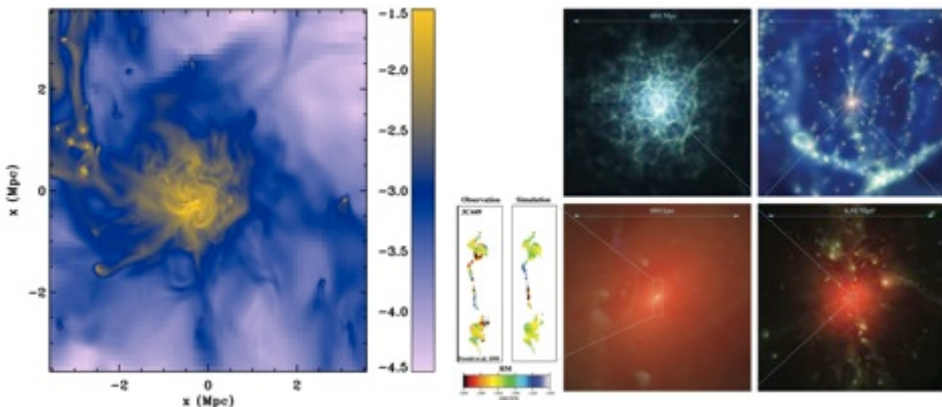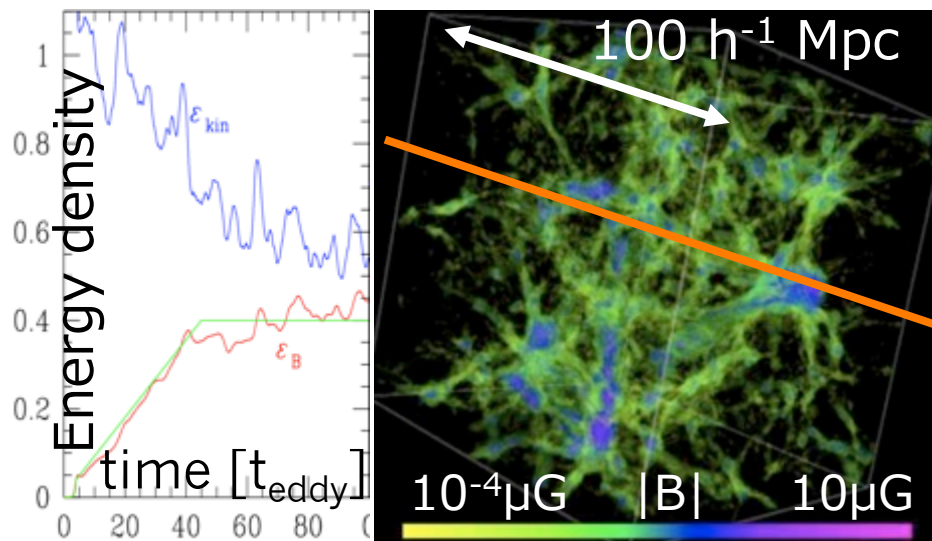
My Work

Faraday Rotation Measure (RM)
n_e [cm^{-3}], $B_{||}$ [μG], l [kpc]

$$\mathrm{RM} = 811.9 \int_0^L n_e B_{||} dl \quad \mathrm{rad\ m}^{-2}$$

⇔ current/future observations

$$\sigma_{RM} \sim 1.5 \left(\frac{\bar{n}_e}{10^{-5}\mathrm{cm}^{-3}} \right) \left(\frac{B_{rms}}{0.3\ \mu G} \right) \left(\frac{L_{int}}{300\mathrm{kpc}} \frac{L}{5\mathrm{Mpc}} \right)^{1/2} \mathrm{rad\ m}^{-2}$$

Cho & Ryu (09)

- RMS of RM through a filament **~1 [rad m^{-2}]** (present-day, local universe)
- Coherence length~ **a few*100 kpc**, **random walk**
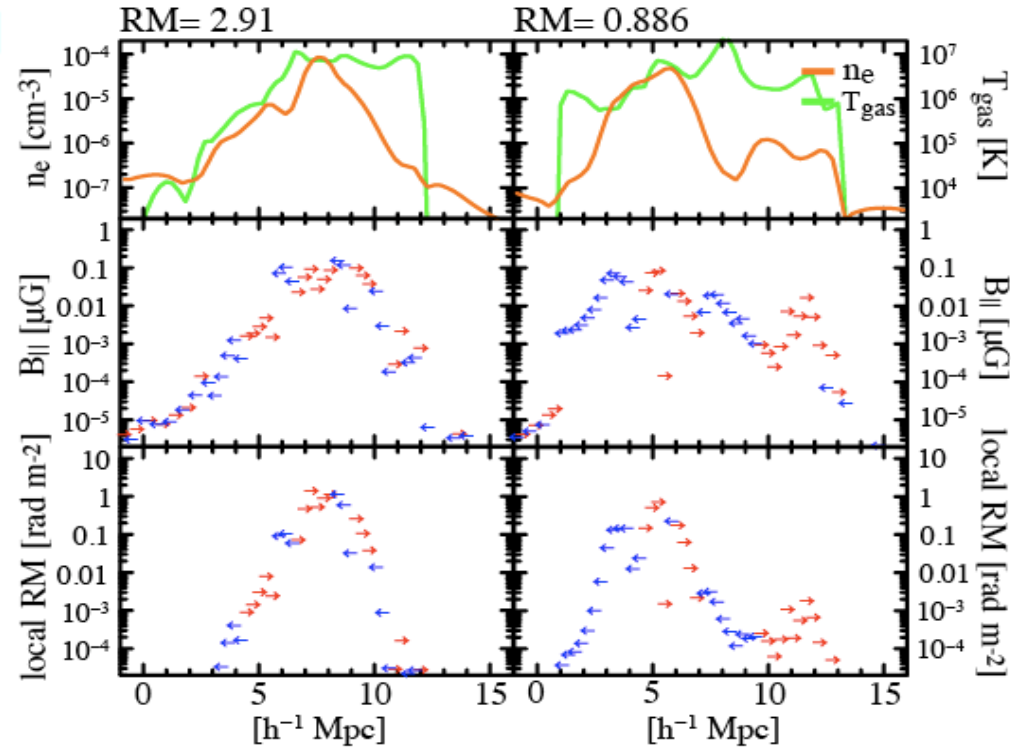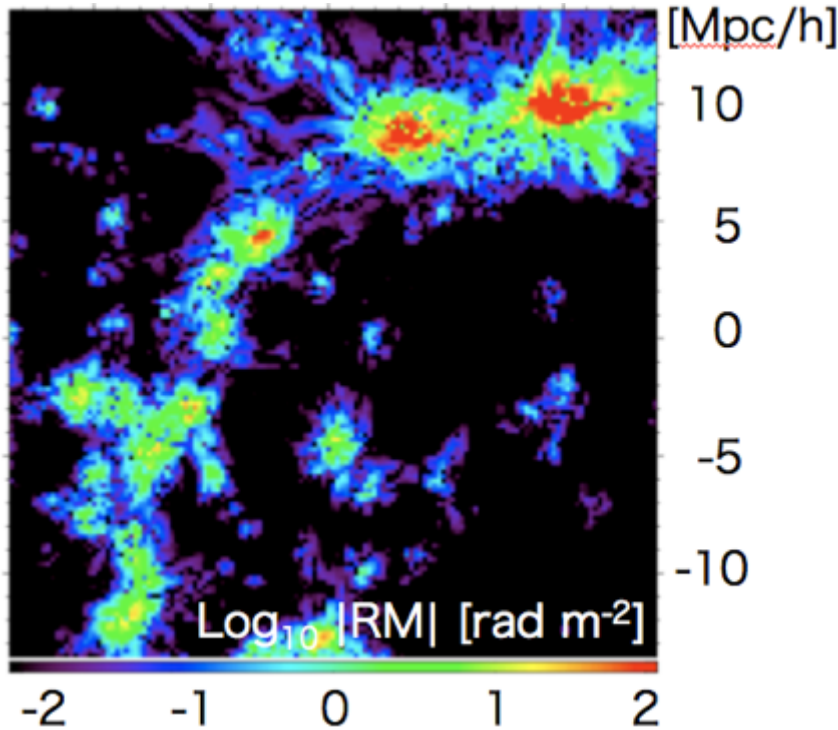
RM map of the
large-scale structure

Line-of-sight profiles
through a single filament

Akahori & Ryu (2010), ApJ, 723, 476

2011.08.22-26

■ RMS of RM through filaments **~several-10 [rad m⁻²]**
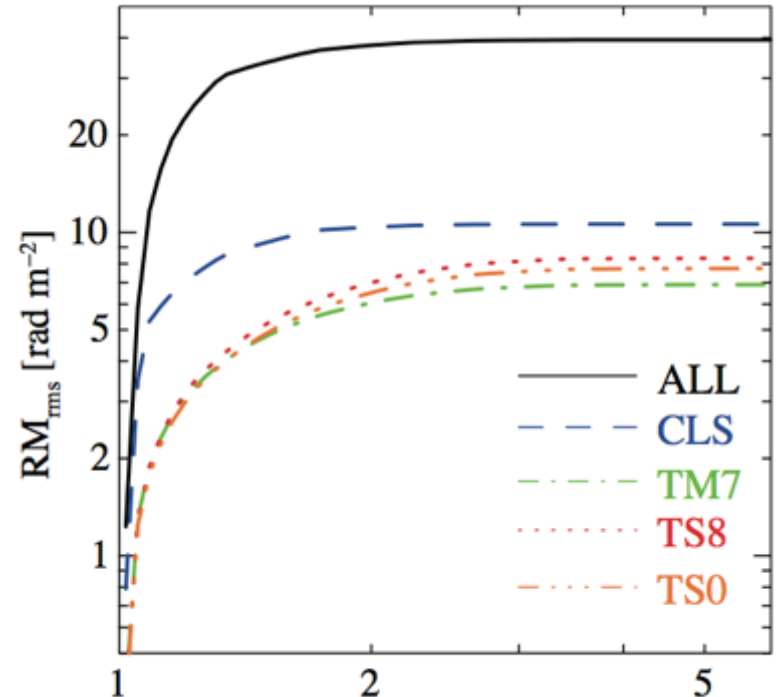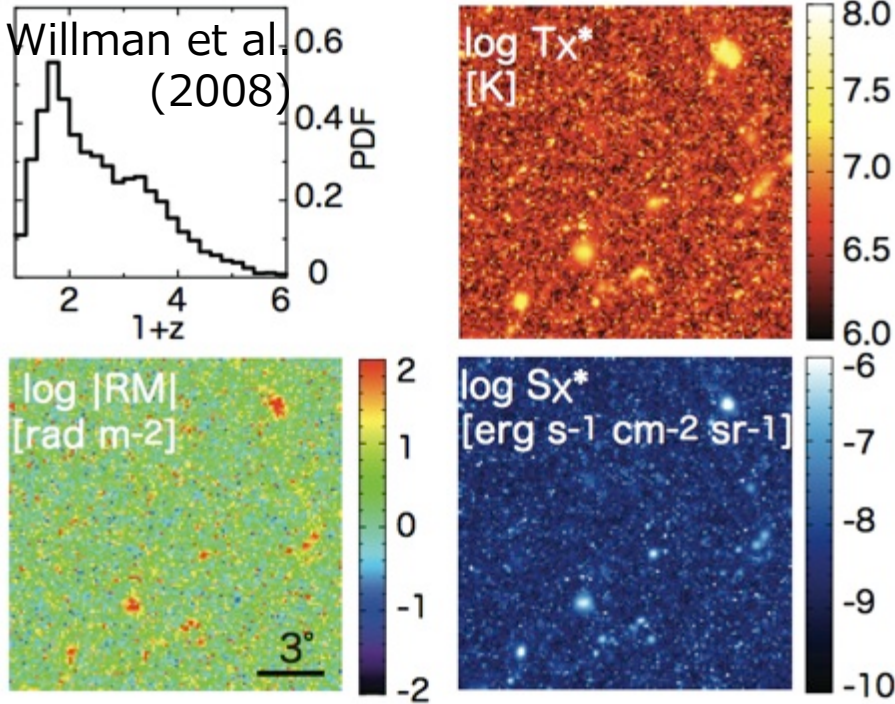
RM, Sx, Tx maps (z<5),
200 deg² field-of-view
(2048*2048, one pixel one source)

RMS of RM(<z)
(average of 200 maps = average
of 2048*2048*200 pixels)

Akahori & Ryu (2011),
ApJ, 738, 134

$$\mathrm{RM} = \frac{e^3}{2\pi m_e^2 c^4} \int_0^{l_s(z_s)} (1+z)^{-2} n_e(z) B_\parallel(z) dl(z)$$

■ Peak at **0.1-0.2° scales**

Data：Mao+ (10), Stil+ (11)
solid=VLA, circles =ACTA+WSRT
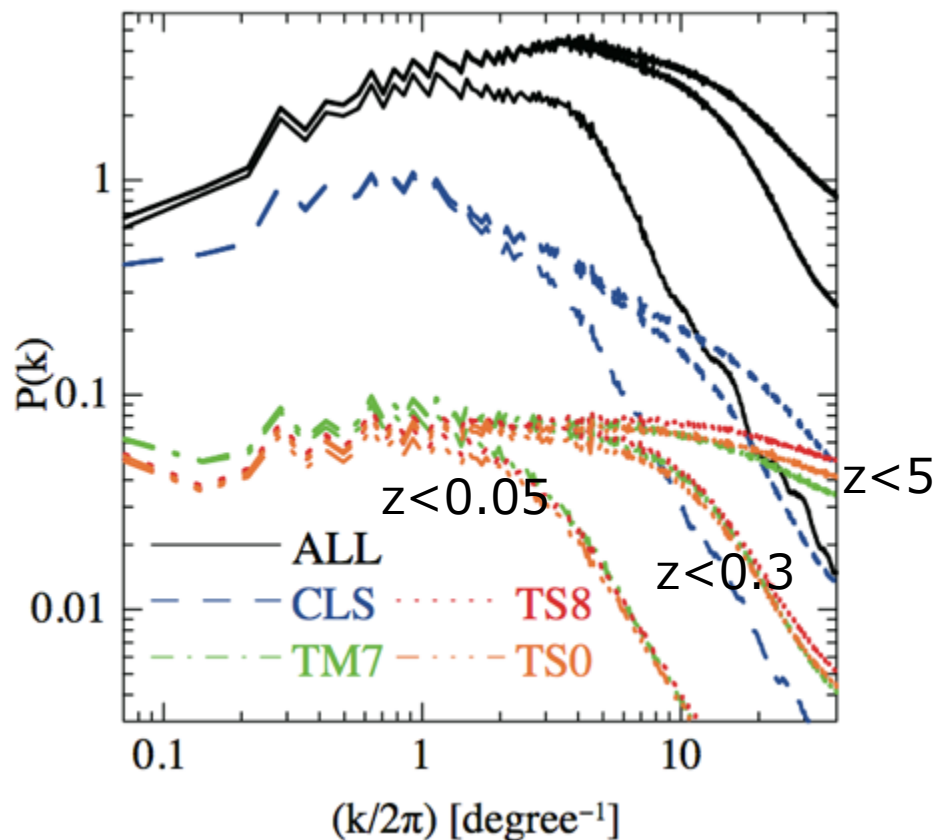
Power spectrum of RM map (ave. of 200 maps)

2nd order structure function of RM map (ave. of 200 maps)

Akahori & Ryu (2011), ApJ, 738, 134

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- Analytical model of the Galaxy "HAMMURABI"
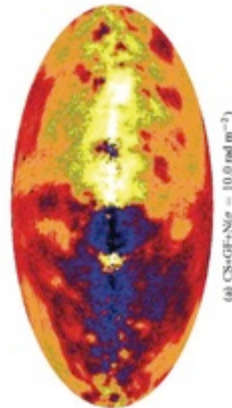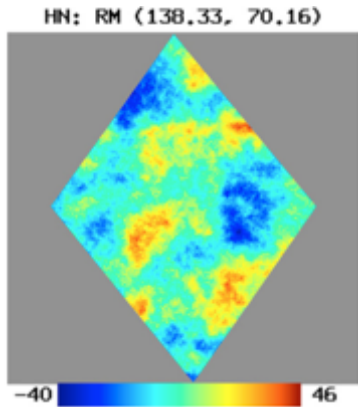
RM map toward (l,b)=(140,70) with 1.5º×1.5º FOV (Sun, Reich 09)

All-sky RM map (Stasyszyn+ 10) using cosmological SPH-MHD simulation (Dolag + 09) + HAMMURABI (Waelkens+ 09)

- But, unsolved issues…

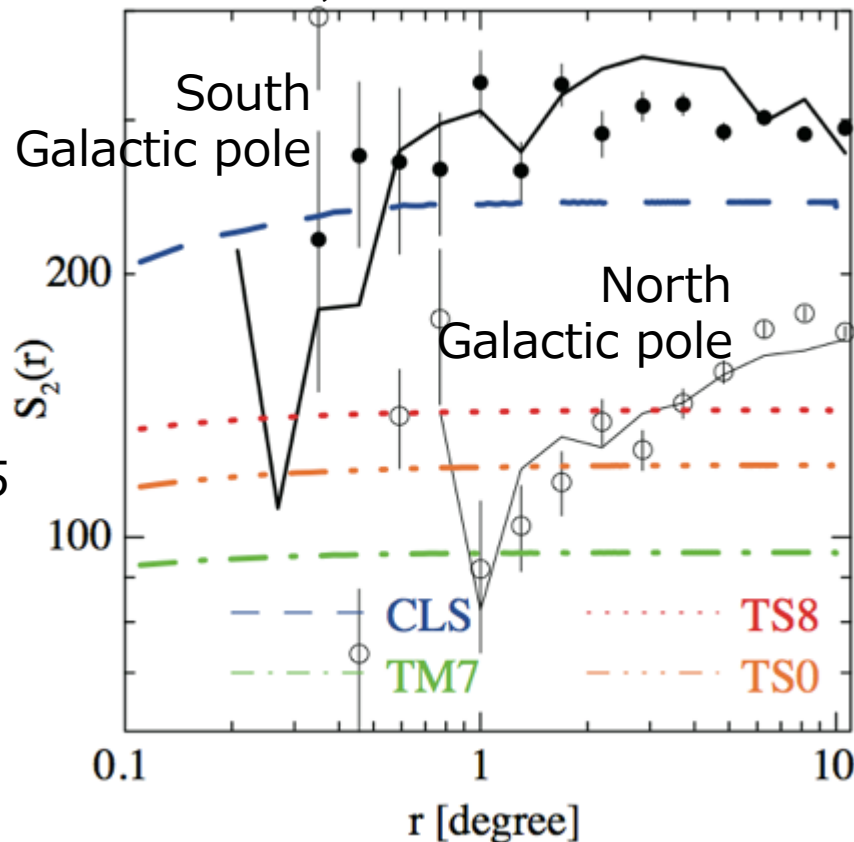 ✓ Coupling factor for the thermal electron density fluctuation

  ✓ Suppose uniform |b|~a few μG at disk, halo, everywhere

  ✓ Suppose random phase (no sheet/filamentary structures)

| Analytic model for regular component | ➕ | Results of MHD simulation for random component | **My Approach** |

2011.08.22-26

- Random component → **we stack the boxes of MHD turbulence simulations**
  - Simulations by Kim+ (93); Wu+ (09)

$V_{rms} = 15 - 50$ [km/s]
(Tufte+ 99; Haffner+ 03, 10)

Schematic picture of the stacking

Examples of line-of-sight properties toward NGP

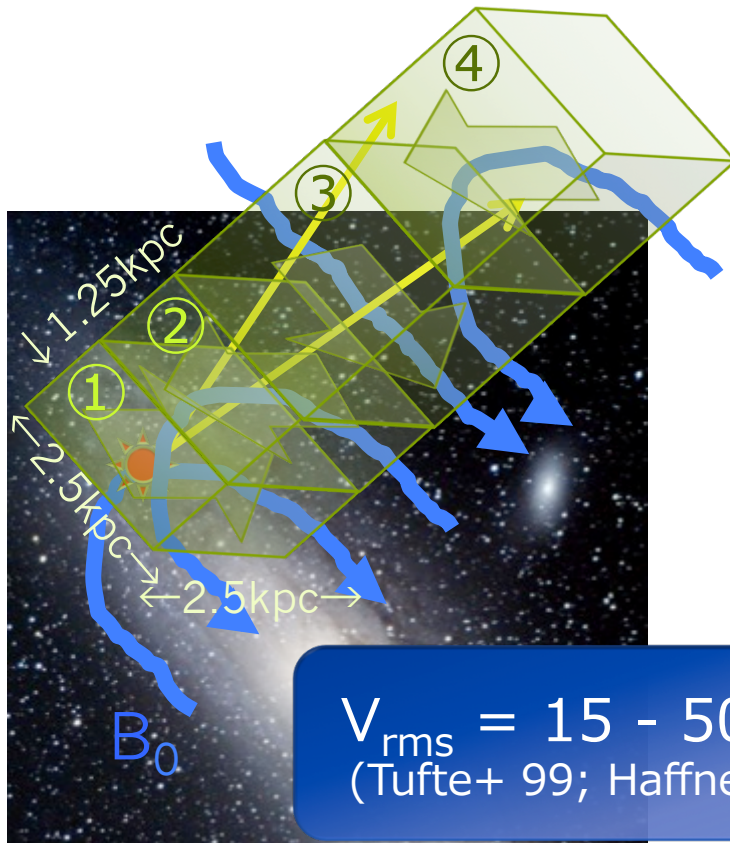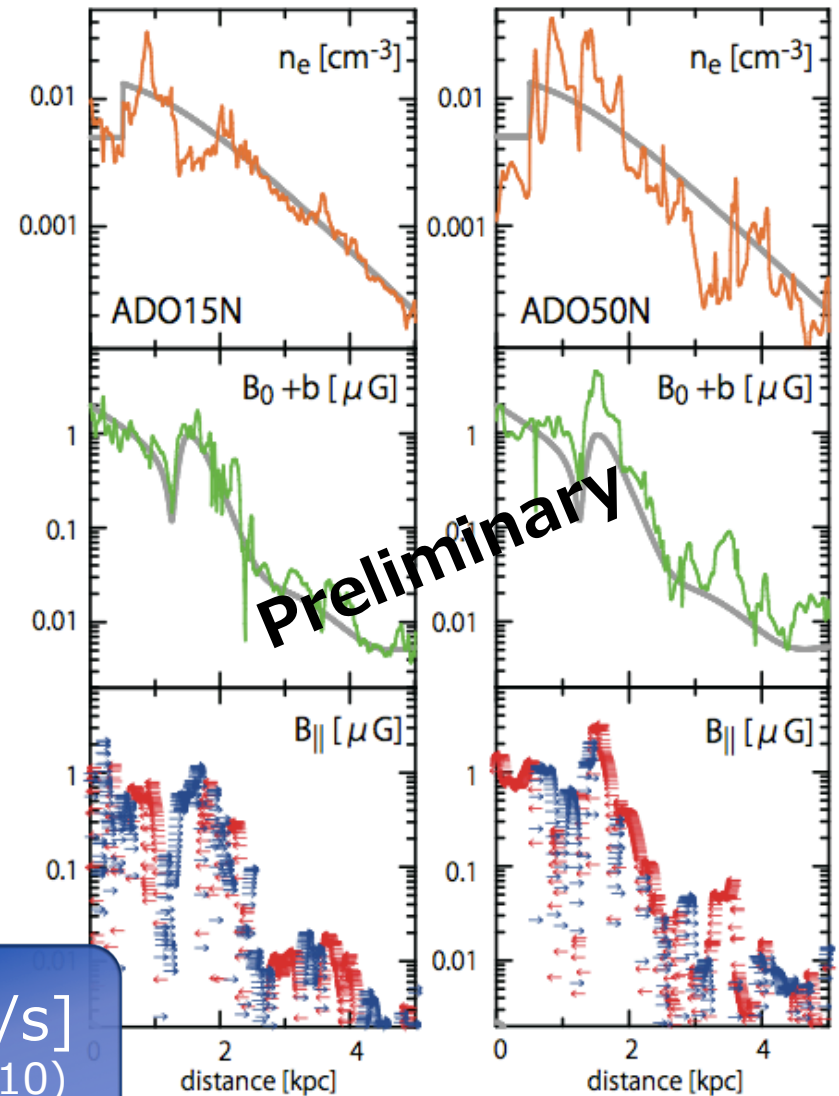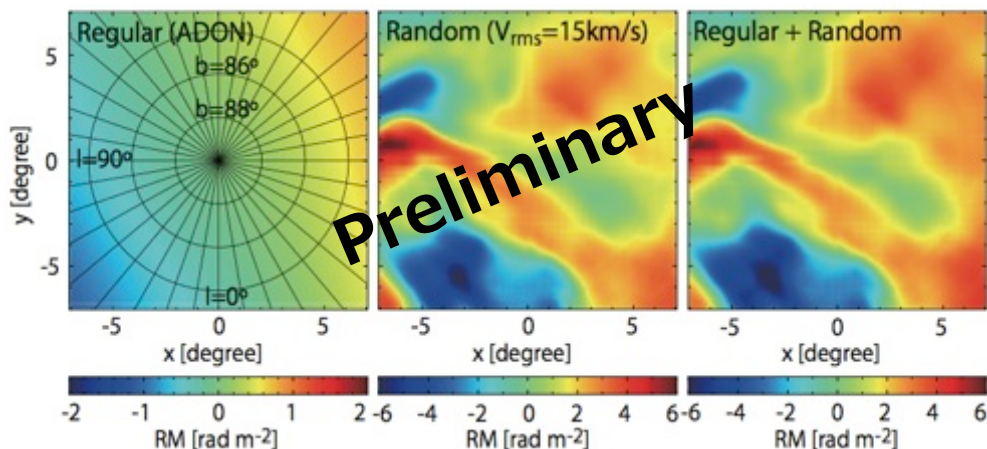- Filamentary structure of RM

Galactic RM toward NGP

- For $V_{rms} \sim 50$ km/s, the STD of Galactic RM toward GPs is close to the observed value $\sim$several [rad m^{-2}] (Mao+ 10)

Akahori, Ryu, Kim, Gaensler, in prep.

Model	900 deg^2		
	$\langle RM \rangle$	σ_{RM}	rms
AD/QO15N	0.48(1.80)	2.43(0.85)	2.99(1.08)
ADO15S	0.32(2.43)	3.70(1.04)	4.39(1.24)
AQO15S	−0.58(2.56)	2.93(0.96)	3.79(1.44)
AD/QO50N	0.11(4.50)	5.52(2.99)	6.60(4.02)
ADO50S	1.64(9.19)	7.58(4.95)	10.0(8.29)
AQO50S	1.01(7.76)	6.95(4.61)	8.97(7.09)
AD/QP15N	−3.02(1.26)	1.76(0.53)	3.60(1.09)
ADP15S	4.19(2.38)	3.66(0.98)	5.81(1.95)
AQP15S	3.60(2.08)	1.89(0.74)	4.18(1.98)
AD/QP50N	−2.70(4.55)	5.98(3.27)	7.36(4.51)
ADP50S	4.32(9.04)	7.71(4.88)	10.4(8.69)
AQP50S	4.41(8.10)	7.29(5.29)	9.48(8.18)
BD/QO15N	0.26(1.69)	2.32(0.87)	2.97(1.06)
BDO15S	0.33(2.45)	3.48(0.91)	4.08(1.06)
BQO15S	−0.28(3.07)	2.90(1.02)	4.03(1.66)
BD/QO50N	−0.73(4.73)	5.88(3.54)	6.99(4.60)
BDO50S	0.33(8.01)	7.21(4.55)	9.12(7.32)
BQO50S	−0.66(5.88)	7.51(6.29)	8.93(7.15)
BD/QP15N	−3.48(1.30)	1.75(0.51)	3.95(1.23)
BDP15S	3.71(2.30)	3.45(0.98)	5.31(1.95)
BQP15S	3.19(3.19)	2.56(1.28)	4.63(2.66)
BD/QP50N	−3.55(4.12)	5.93(3.22)	7.31(4.64)
BDP50S	4.21(8.01)	7.26(4.66)	9.60(8.01)
BQP50S	3.29(6.59)	8.22(7.17)	10.1(8.41)

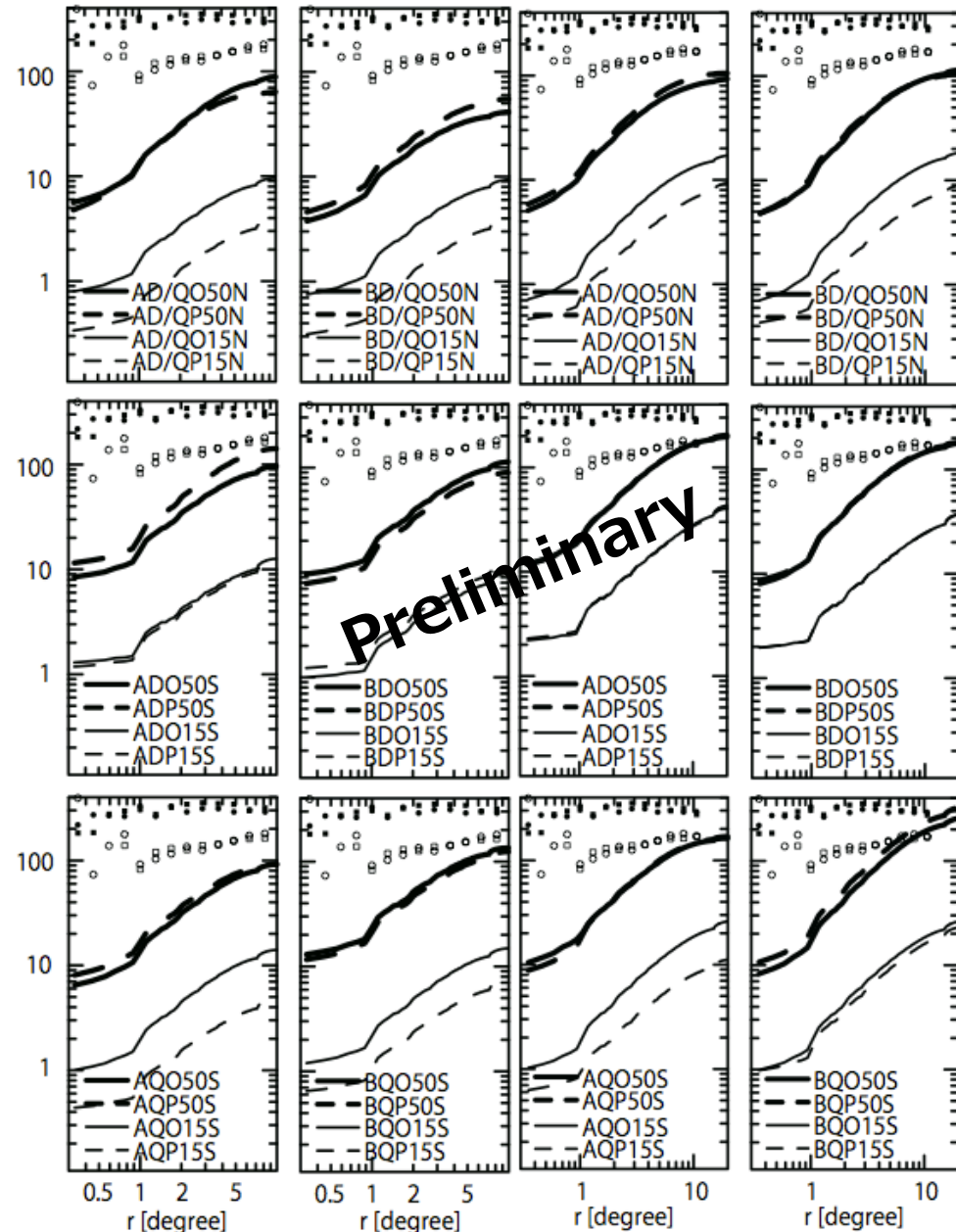Average, STD, RMS of RM
(for 200 maps)

- Even V_{rms} ~50 km/s, the predicted SF has values substantially smaller than the observed ones at separation angles of <~ several-10 degree

- The IGMF significantly contributes to RM toward high Galactic latitude, particularly at < degree

2nd order structure function of RM map (ave. of 200 maps)

Akahori, Ryu, Kim, Gaensler, in prep.

Preliminary

- Korea SKA SWG (~20 scientists)
  - Regular Meetings (2011. 4, 8, ⋯)
  - **SKA Workshop 2011**
    - **Nov. 30 – Dec. 2, @KASI, Korea**
    - **http://canopus.cnu.ac.kr/ea-ska/**

- Japan SKA Consortium
  - SWG, IWG
    - **"Cosmic Magnetism" sub SWG**
    - Monthly meetings, 13 scientists
    - Coordinator: Takuya Akahori

- Korea-Japan Collaborations
  - Synchrotron radiation
  - Faraday tomography
  - High-pass filter
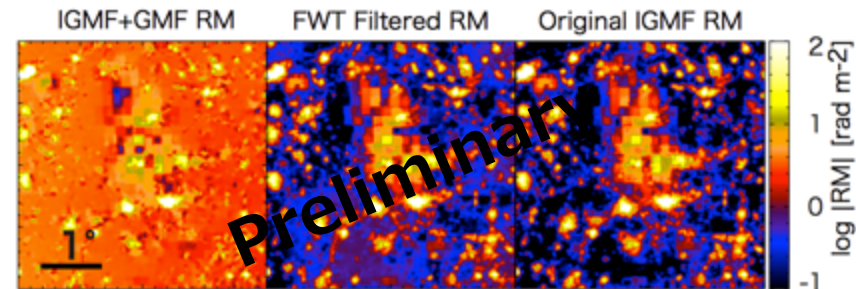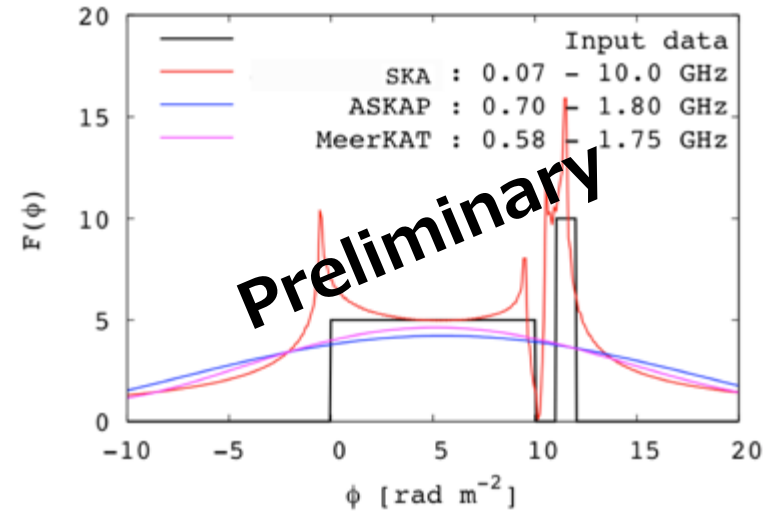
Kumazaki, Akahori, Takahashi, Ryu, in prep.
Akahori & Ryu (2010), SKAJP workshop 2010

Summary

- Intergalactic Magnetic Field (IGMF)
  - MHD turbulence plays an important role
- IGMF-RM
  - **1-10 [rad m^{-2}]**
  - **Peak at 0.1-0.2º**
- GMF-RM toward Galactic poles
  - **Several [rad m^{-2}] (V$_{rms}$=50km/s)**
  - **IGMF-RM contribution at < 1º**
- Future
  - Korea-Japan participation in SKA
    - Synchrotron radiation
    - Faraday tomography
    - High-pass filter