SKAで探る
背景クェーサー偏波の吸収線系による解消
と宇宙磁場研究

1. Square Kilometre Array Project
2. Depolarizing Intervening Galaxies

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1. SKA Project

Square Kilometre Array Project

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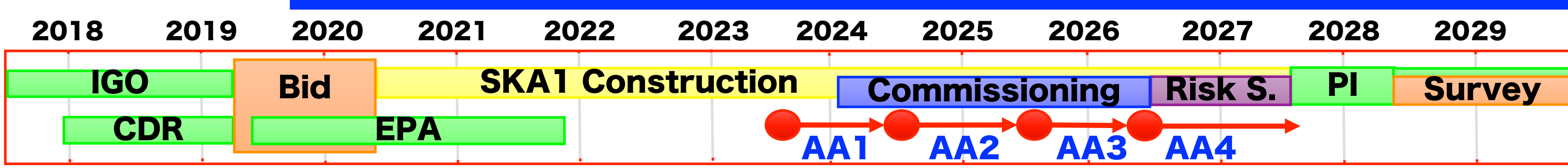
1. SKA Project
Project Overview

12 SKA members

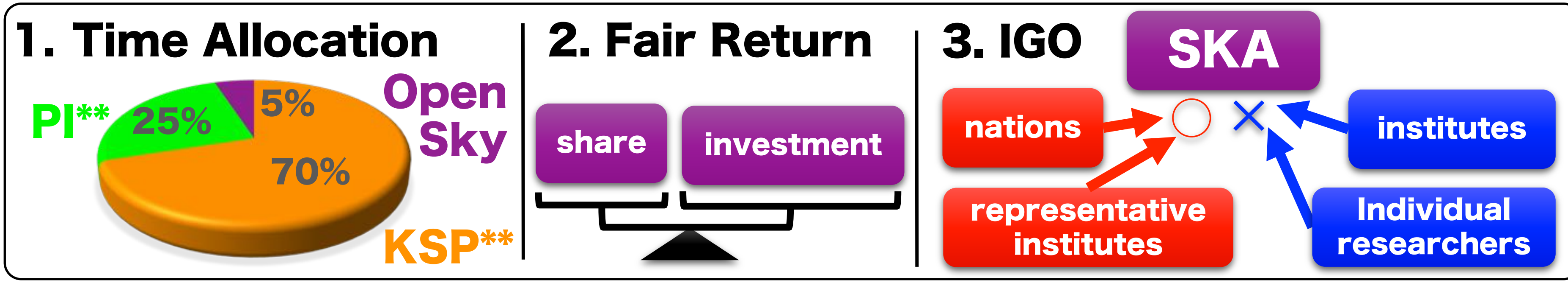
SKA = HQ +
2 telescopes

SKA1 timeline



Construction 691 M€$_{2017}$

1. SKA Project
Status of Japan



■ SKA members share 90%** of observing time

■ Japan's Plan

- **2-4%** contribution (TBD)
- **NAOJ SKA promotion office (submitted as category-A)**
- **An associate member**

■ Expected Return

- KSP/PI opportunities
- Science/engineering promotions
- Training of next generations
- International presence and status

4% ~ ½ of China
~ KSP 4, PI 4/yr

Widefield & multi-mode → multi-objective project

LOW
EoR deep
pulsar transients
cosmology

Band5
GC pulsars
magnetism ISM
MW-VLBI

4% can produce many results (papers) and students (PhD)

1. SKA Project
Science Objectives

SKA Science Book 2015

EoR(HI)
第一世代星の質量は？
宇宙再電離はどのように進んだ？

Pulsars
背景重力波は存在する？
アインシュタイン重力理論は正しい？

Transients
FRBの起源は何？
重力波はどこから来た？
宇宙人はいる？

Milky Way
ダークガス問題は解決？
銀河中心より向こう側はどうなっている？

Cosmology
銀河の水素量はどのくらい？
原始に宇宙の非ガウス性はあった？

Magnetism
磁場と乱流の宇宙進化は？
ミッシングバリオンは見つかる？

AGN
ジェットの構造は？
ブラックホールの成長とフィードバックの歴史は？

Star/Planet
原始惑星系円盤の氷雪帯内の構造は？
系外にアミノ酸は存在？

HOT Universe

ICM, IGM, CGM — Cosmic Magnetism — Radio galaxies
Fast Radio Burst, Transients — Quasars — AGN jets
Sun, Stars — **Pulsars**, Magnetars — Protostars — Late-type Stars
SETI ?? GHz

LOW | Band 1 | Band 2 | 3/4 | Band 5ab | 5c | Band 6

0.05 — 0.3 — 1.0 — 1.4 — 1.6 — 6.7 — 15 — 22 — 43 — Freq. (GHz)

MWA/LOFAR | ASKAP/MeerKAT/Parkes | JVN | VERA/KaVA

HI (Epoch of Reionization, Cosmic Dawn)
HI (Galaxies)
HI (Milky Way)
OH*
Glycin, Alanin, Urea, ...
HCN
CH_3OH*
H_2CO
NH_3
SiO*
H_2O*

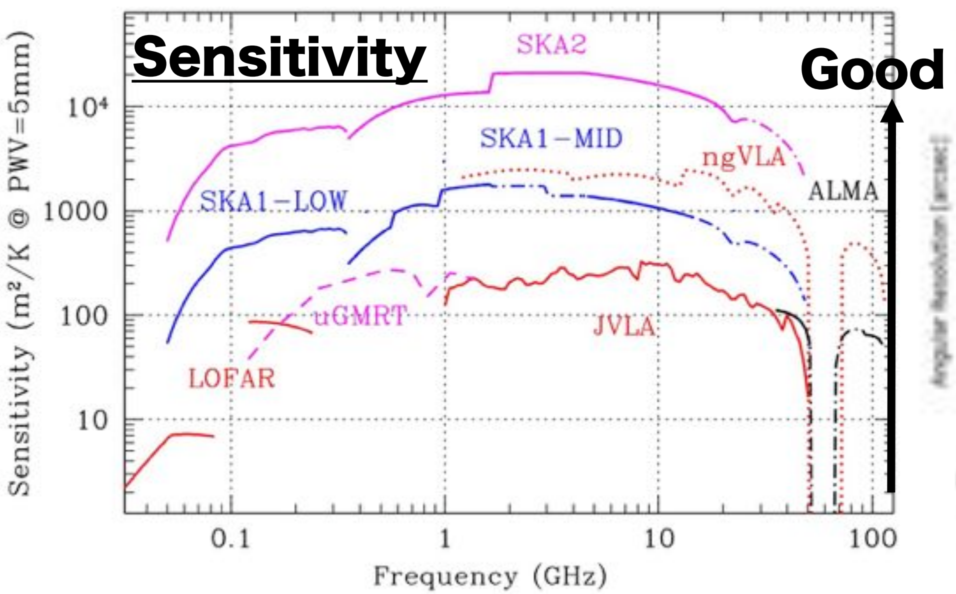
COLD Universe

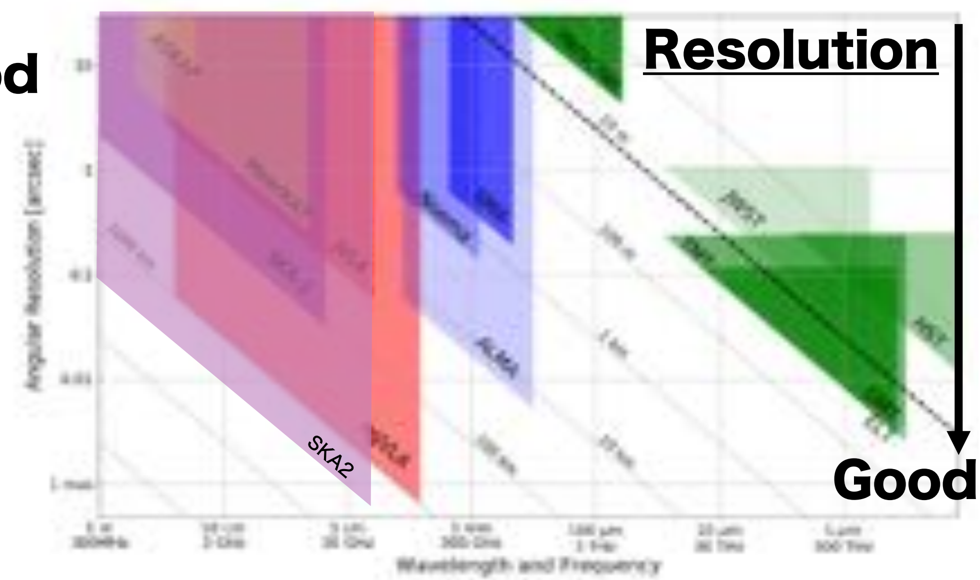
1. SKA Project

Science Specification

A/T in 100 m²/K, larger is better

	2010年代	2020年代	2010年代	2020年代
Telescope	**LOFAR**	**SKA1-LOW**	**JVLA**	**SKA1-MID**
Site	欧州 (**北半球**)	豪州 (**南半球**)	米国 (**北半球**)	南アフリカ共和国 (**南半球**)
Freq. (GHz)	0.03-0.22	0.050-0.35	0.058-50	0.35 - 15(24)
Antenna Φ • #	31m x 48, 40m x 14, 57m x 13	35m x 512	26m x 27	15m x 133 + 13.5m x 64
Array config.	-	3本アーム	3本アーム	コア + 3本アーム
Max. baseline	120 km	65 km	36 km	150 km
A/T @ 0.1,1.4 GHz	0.6	5.6	2	15

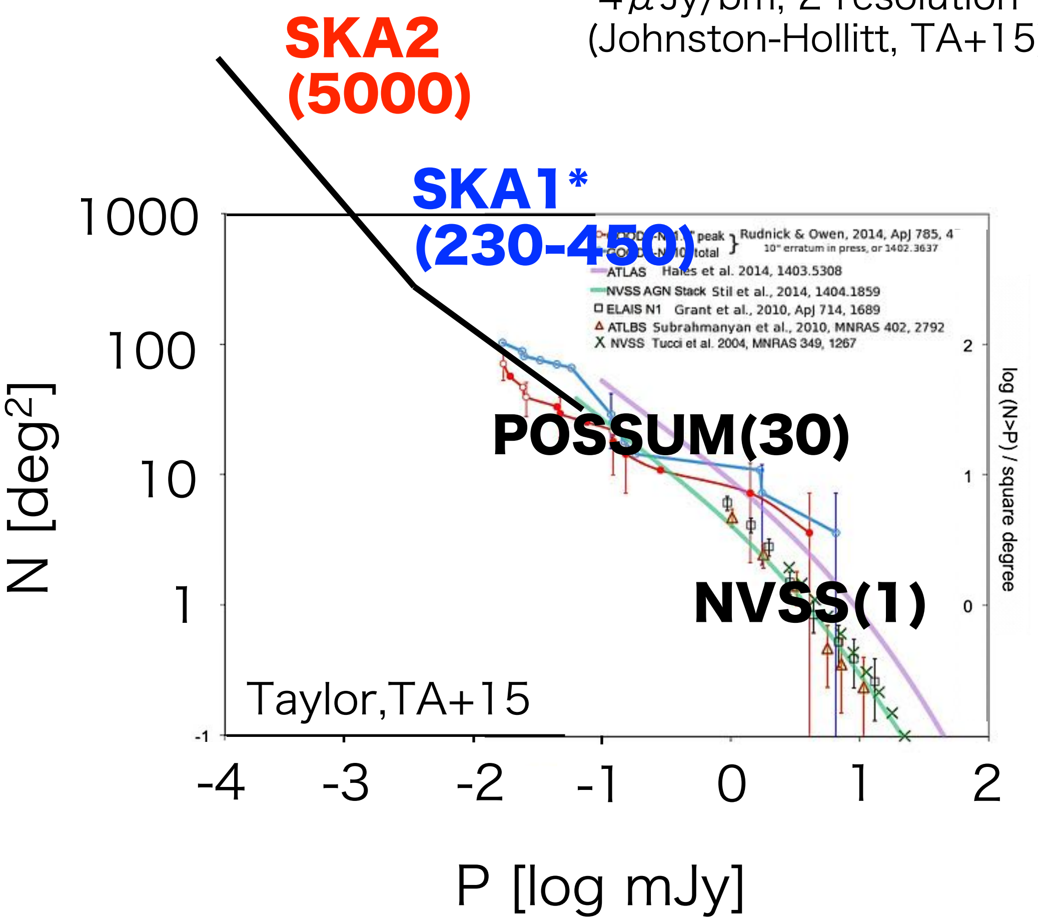


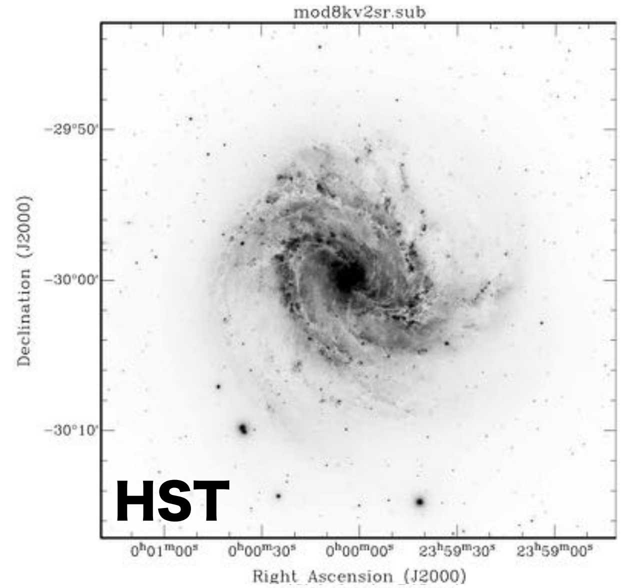


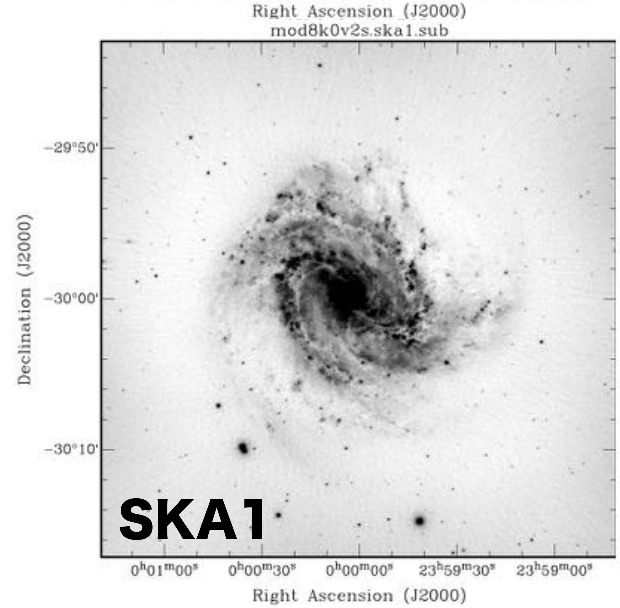
Advantages

Luminosity function of linearly-polarized extragalactic sources

*4μJy/bm, 2″resolution
(Johnston-Hollitt, TA+15)







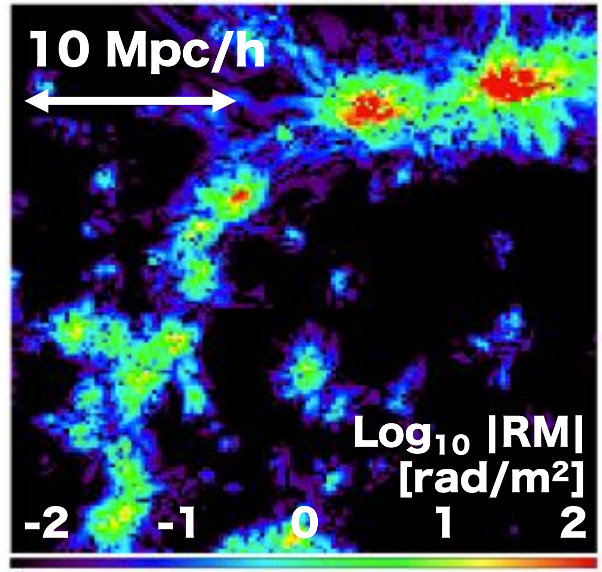
2. DINGs

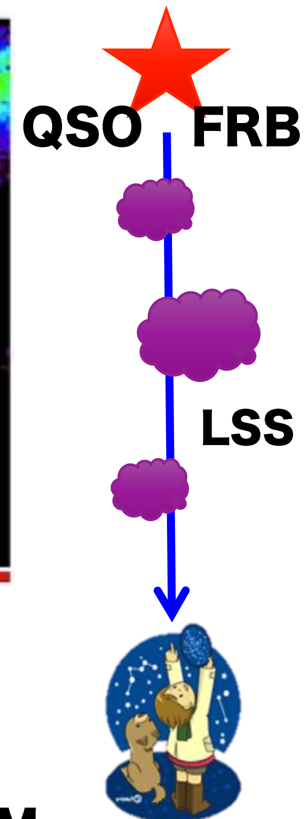
Depolarizing Intervening Galaxies

2. DINGs
WHIM and IGMF

Cosmic Baryon Budget

Std. Cosmology	Cosmic Baryon Budget
Observation	Galaxies, clusters, H_I, Lyα, O_{VI} / WHIM? / Mod. Gv.?





- **Warm-hot intergalactic medium (WHIM)**
  - In galaxy filaments. $T\sim10^{5\text{-}7}$ [K], $n\sim10^{-6}$–10^{-4} [cm^{-3}]
- **Inter-galactic magnetic field (IGMF)**
  - WHIM is most likely magnetized
  - **RM** ~ 1 rad/m^2 (local) and ~several rad/m^2 ($\int$dz, z=5)

$$RM_{LSS} = \int n_e B_{||} dl$$

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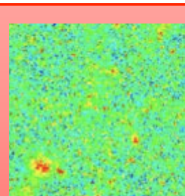
1. Introduction

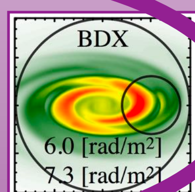
Find the signal of the IGMF

QSO/FRB
$\sigma_{INT}=\sigma_0(1+z)^{-2}$
$\sigma_0=10$ rad/m²

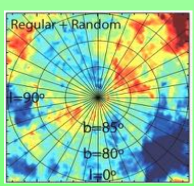
IGM
TA+11 map



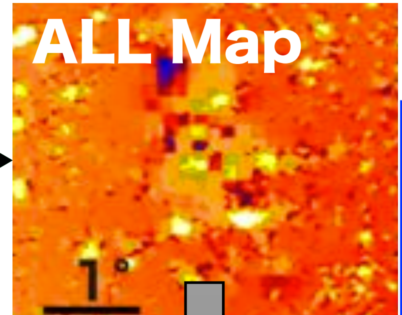
DING
50% MgII
TA+ in prep



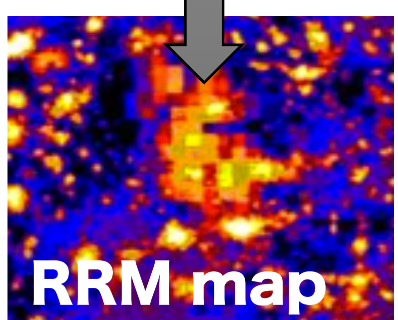
ISM
TA+13 map



ERR(ionosphere)
$\sigma_{ERR}=1$ rad/m²



- INT filter
- ICM filter
- DIG filter
- ISM filter
- ERR filter



High-z sources?
$\sigma_{INT}(z=2)\sim1$ rad/m²

Cluster removal
Criteria of S_X & T_X

Depolarization
Use no-DING LoS

Filter at ~1° -2°
High-b is better

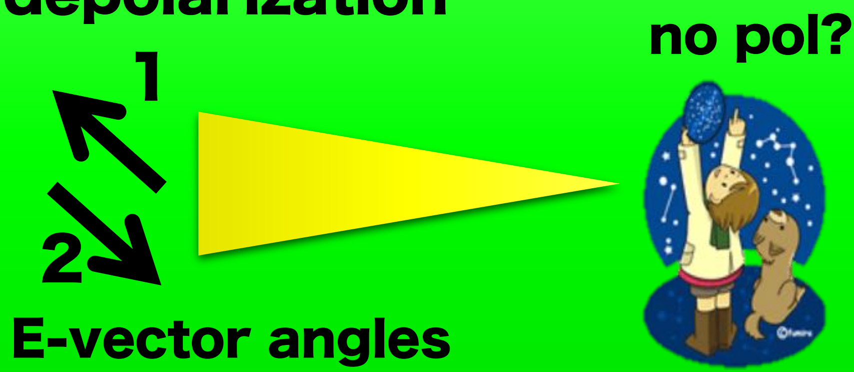
Bright sources?

2. DINGs

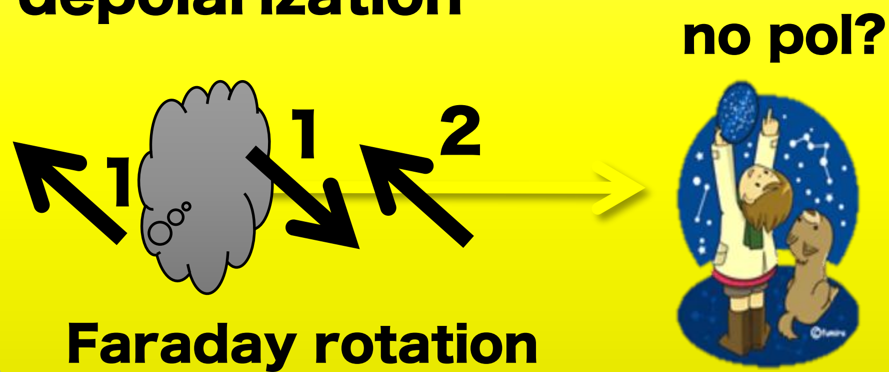
How DP arises?

Burns 66; Sokoloff+98
Arshakian & Beck 11

Wavelength-independent depolarization

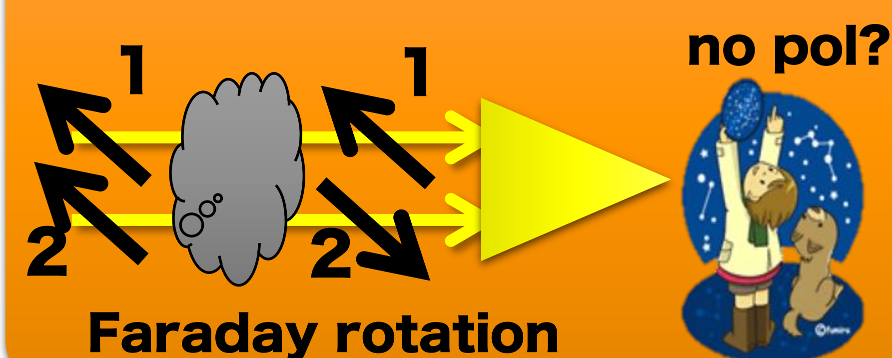


Differential Faraday rotation depolarization

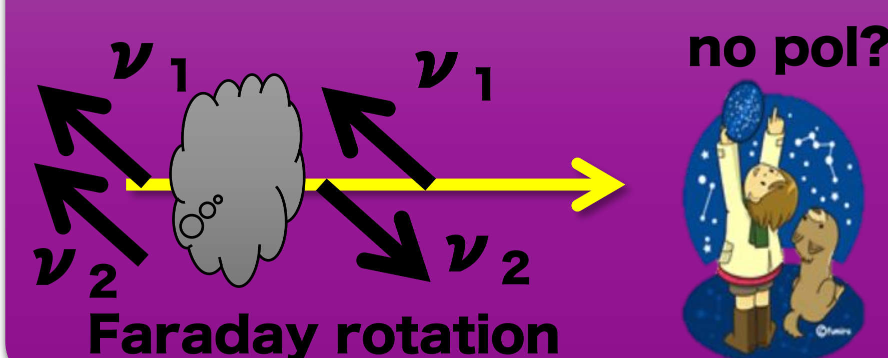


Beam Depolarization

NVSS =45″ , ASKAP ~10″ , SKA1 Band2 ~1″

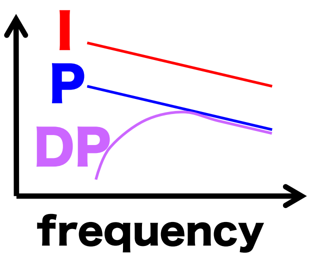


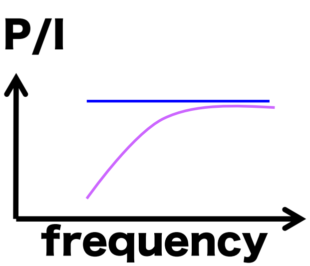
Bandwidth Depolarization

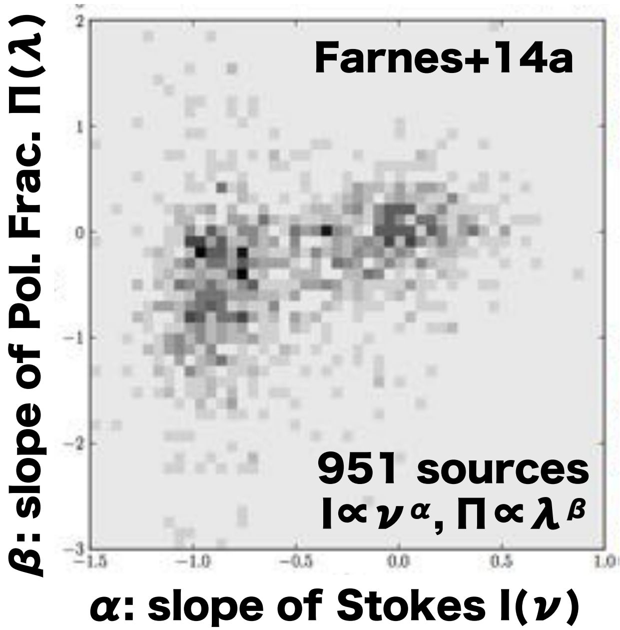


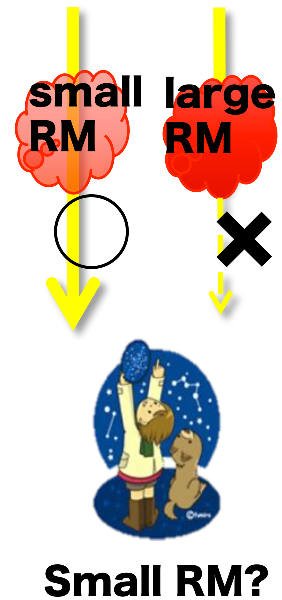
2. DINGs
What DP induces?

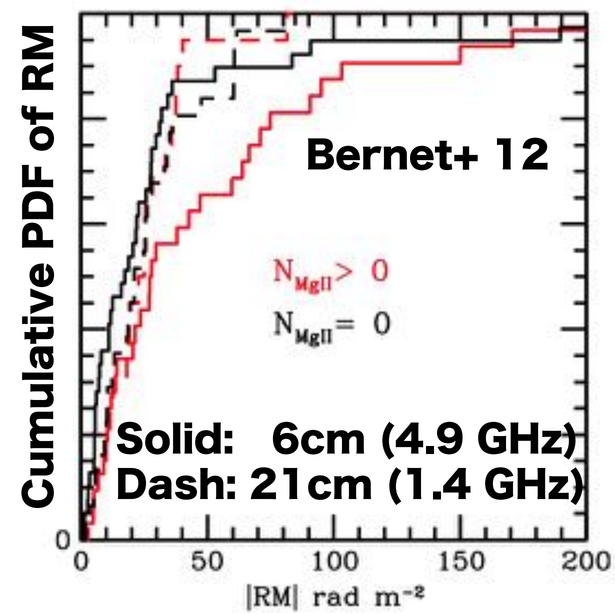
■Two λ-independent quantities becomes λ-dependent quantities











1. Polarization fraction

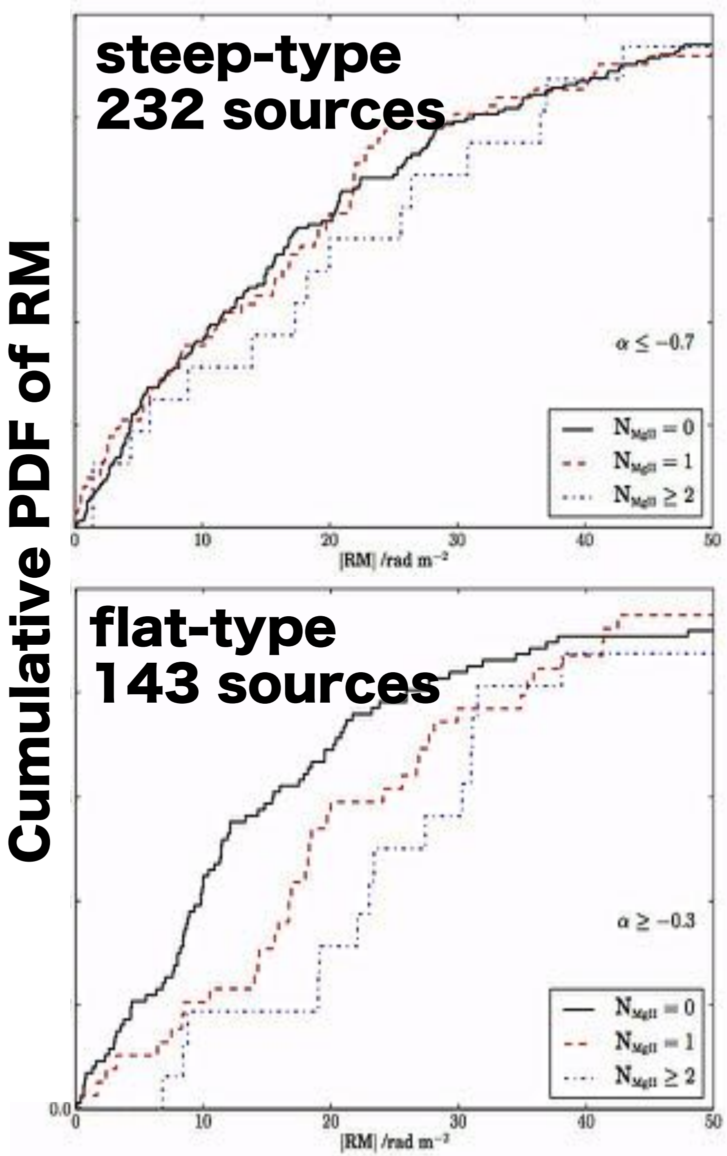
I & P have the same spectral indices. DP reduces P, so that P/I decreases in wavelength

2. Faraday RM

P through a larger RM is more depolarized than that through a smaller RM. DP biases RM.

2. DINGs
Intervening Galaxies

Farnes+14b



- **Steep-type sources**
  - $\alpha_{\text{Stokes I}}$ <= -0.7, unresolved lobes?
  - Large DP (β<0)
  - No clear RM from Mg systems
- **Flat-type sources**
  - $\alpha_{\text{Stokes I}}$ >= -0.3, AGN cores?
  - Weak DP (β~0)
  - 6.9 ± 1.7 rad/m^2/DING at observer

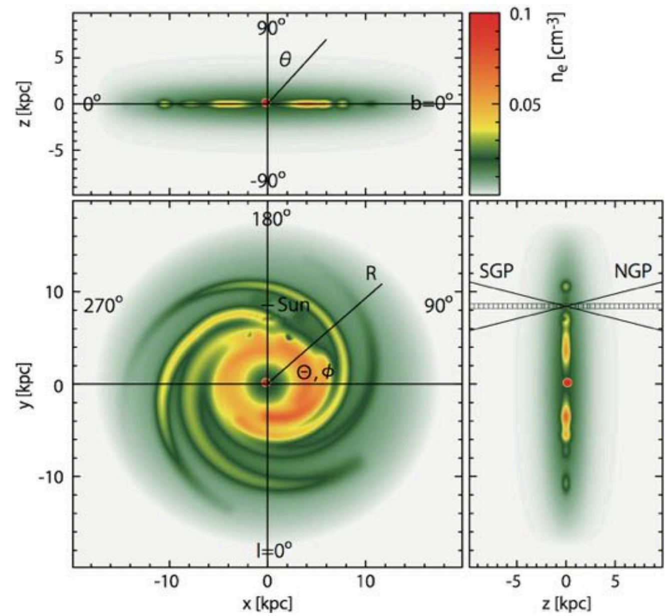
Question/Motivation

- Why only “steep-type” shows large DP?
- Why only “flat-type” shows excess RM?
- Dependence on z, beam, frequency

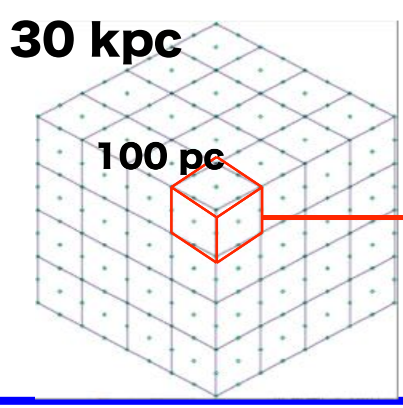
→ Let’s do simulations!

2. DINGs
Models of Galaxies

- **Global (coherent) components**
  - Modified NE2001 (h=1.8 kpc)
  - Disk(ASS/BSS) + Toroidal + X/OFF
- **Local (turbulent) components**
  - Given M, β, l_{coh}~10-15 pc, we input data at the saturation stage of isothermal compressible MHD turbulence
- **Wind components (minor)**
  - Just incorporated. No figures, Sorry!



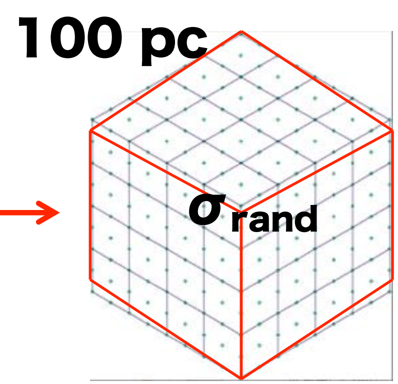
Global grids = coherent fields



n_{e_reg} (x,y,z)
$B_{\_reg}$ (x,y,z)

M_{rms} (x,y,z)
β_0 (x,y,z)

Local grids = turbulent fields



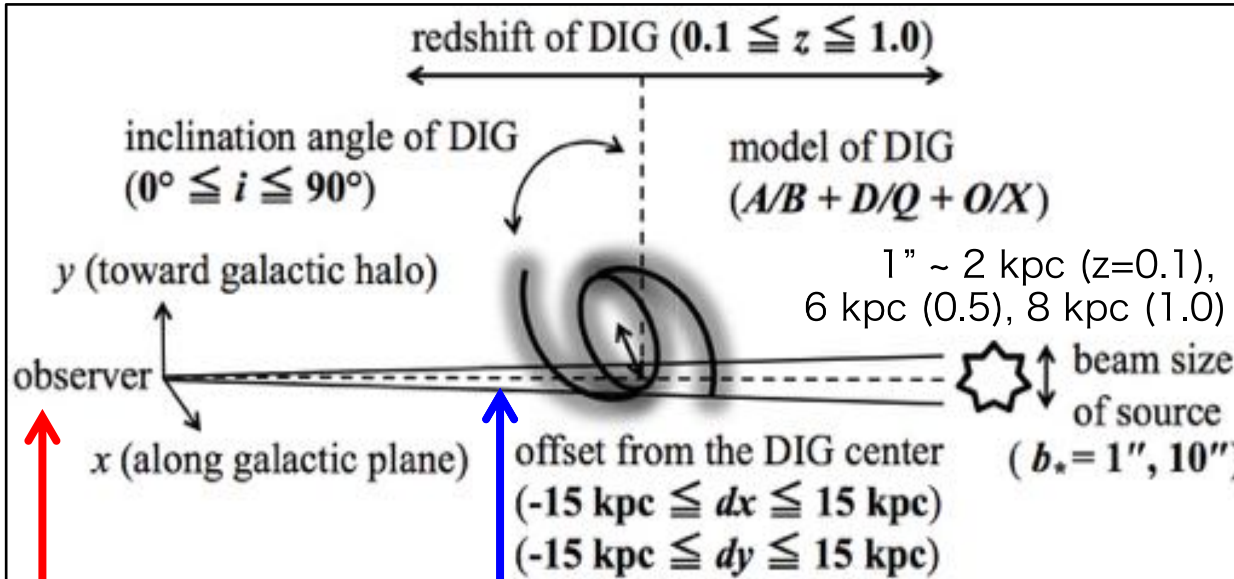
$l_{coherent}$ << box size
→ Gaussian → Burn's DP

σ_{rand} RM dispersion for this local grid

$$p \propto \exp(-2\sigma_{\rm rand}^2 \lambda^4)$$

Calculation

- **Source**
  - 1″ or 10″ size
  - Uniform
  - $\alpha_I = \alpha_P = -1$
  - 100% pol.
- **DING**
  - z, i, models, beam offset
- **Observation**
  - Stokes Q, U
  - Classical style: RM is from the pol. angle gradient



~50% MgII system of SDSS Quasars (Zhu & M’enald 13)

$$\mathrm{RM_{rest}} \approx 812 \int n_e B_{\|} dl \ \ \mathrm{rad\ m^{-2}}$$

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

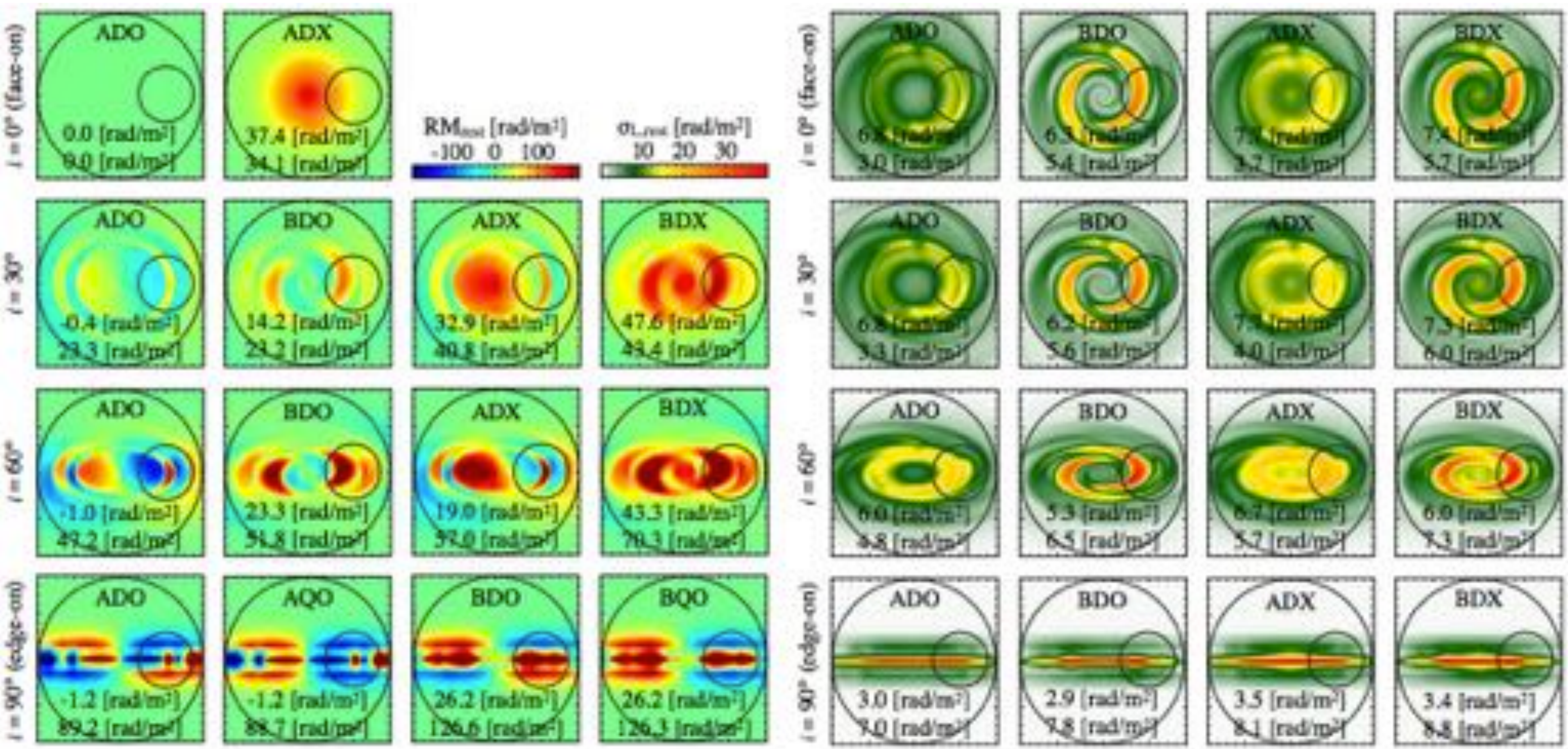
Consider the redshift of the source

$$\chi(\lambda) = \frac{1}{2}\arctan(U(\lambda)/Q(\lambda)) \qquad \mathrm{RM_{obs}} = \frac{d\chi(\lambda^2)}{d\lambda^2}$$

DING's RM

○: 10", z=0.1, dx=0 kpc
○: 1", z=0.5, dx= 5 kpc

- **RM strongly depends on MF configuration**



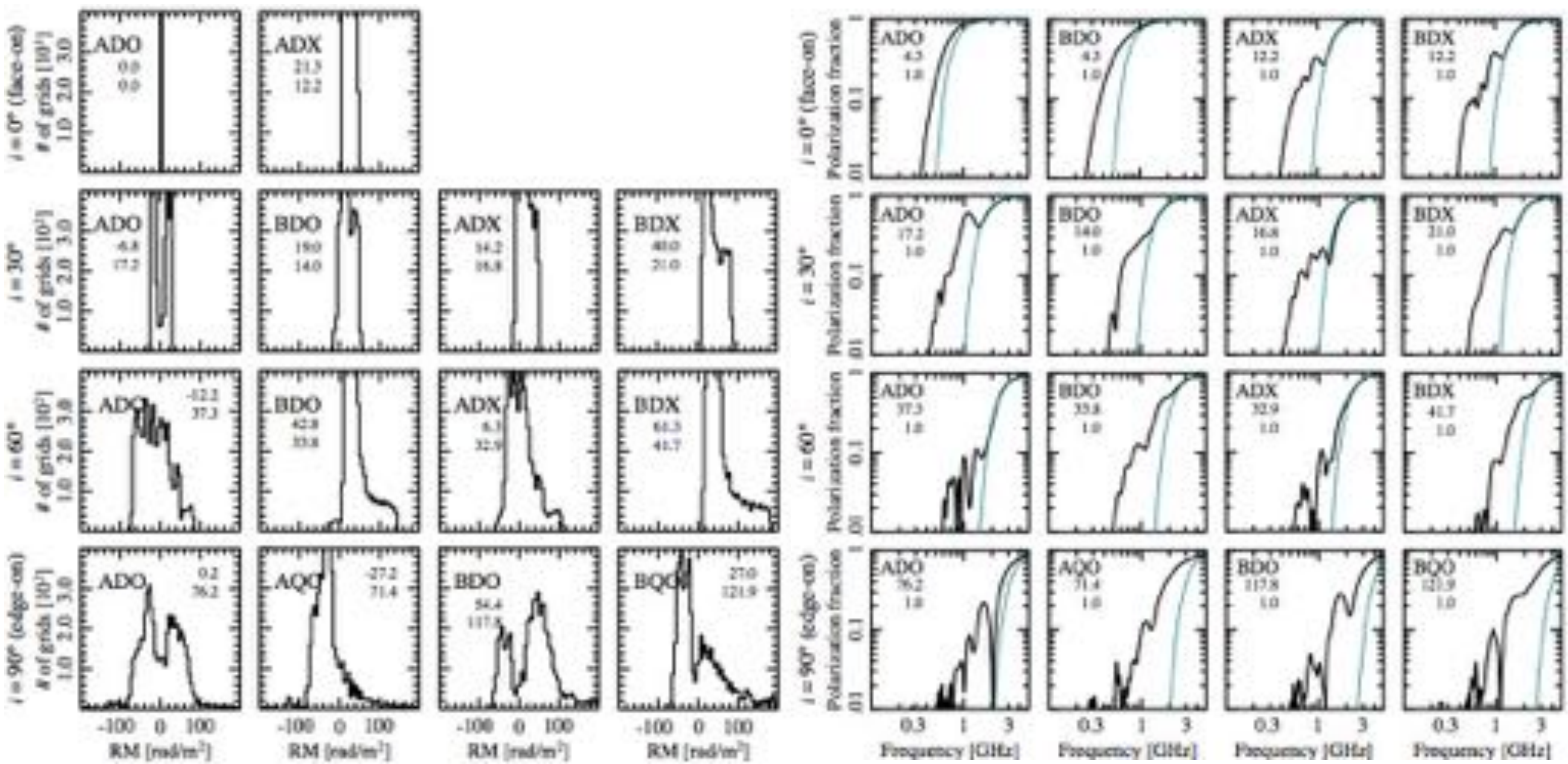
Mean : 0-200 rad/m² **Dispersion: 5-40 rad/m²**

2. DINGs
PDF & Pol. fraction

1", z=0.5, dx=5 kpc

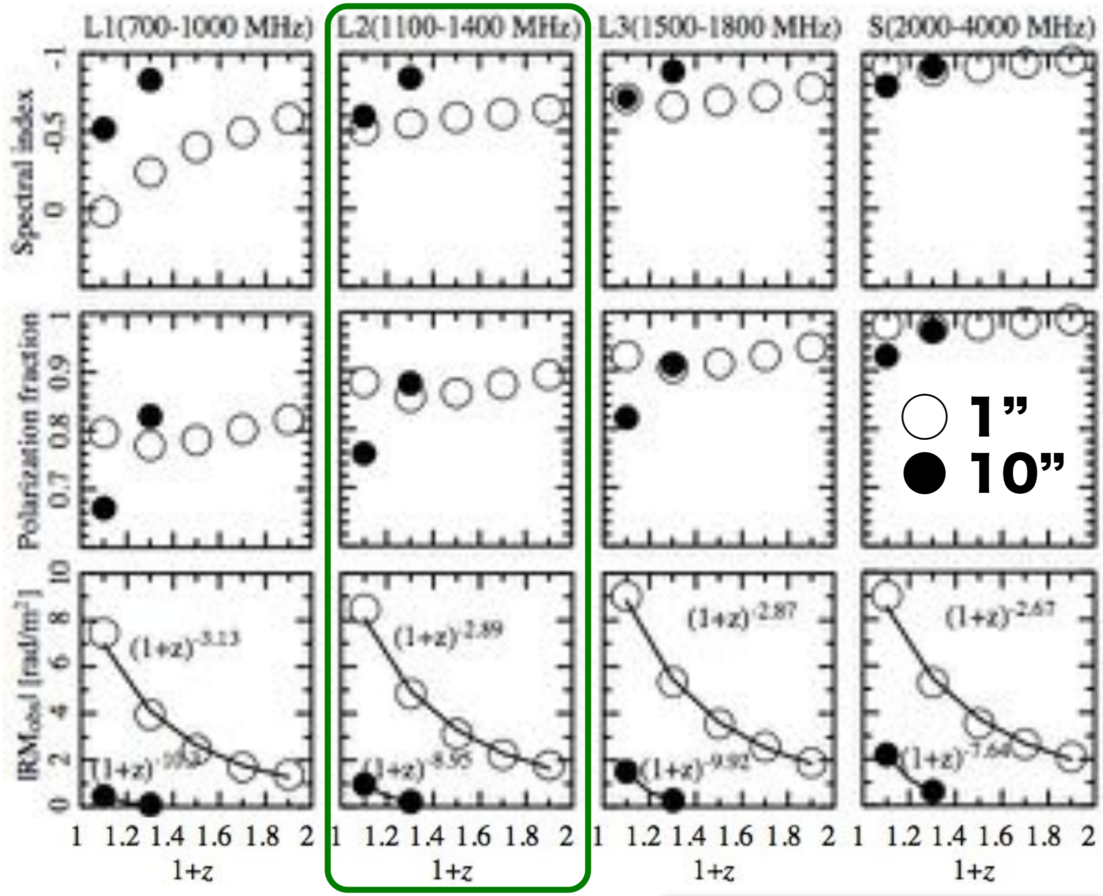
- PDF of RM within a beam does not follow the Gaussian
  → the resultant **DP does not follow the Burn's law**

$$P/I \propto \exp(-2\sigma_{\mathrm{RM}}^2 \lambda^4)$$

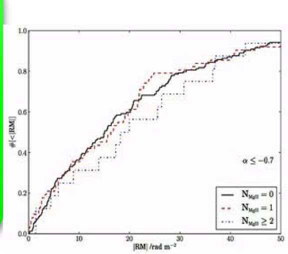


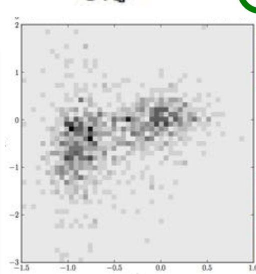
2. DINGs
Monte-Carlo Simulations

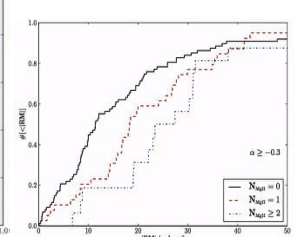
- **100k realizations**
  - Inclination, B-shape, offset are chosen randomly
- **Results**
  - Freq. dependent
  - Trends broadly consistent with Farnes+14ab



●10”(lobe=steep)
DING’s DP 10-25%
RM < 1 rad/m^2







○1”(core=flat)
DING’s DP ~10 %
RM ~ 2-8 rad/m^2

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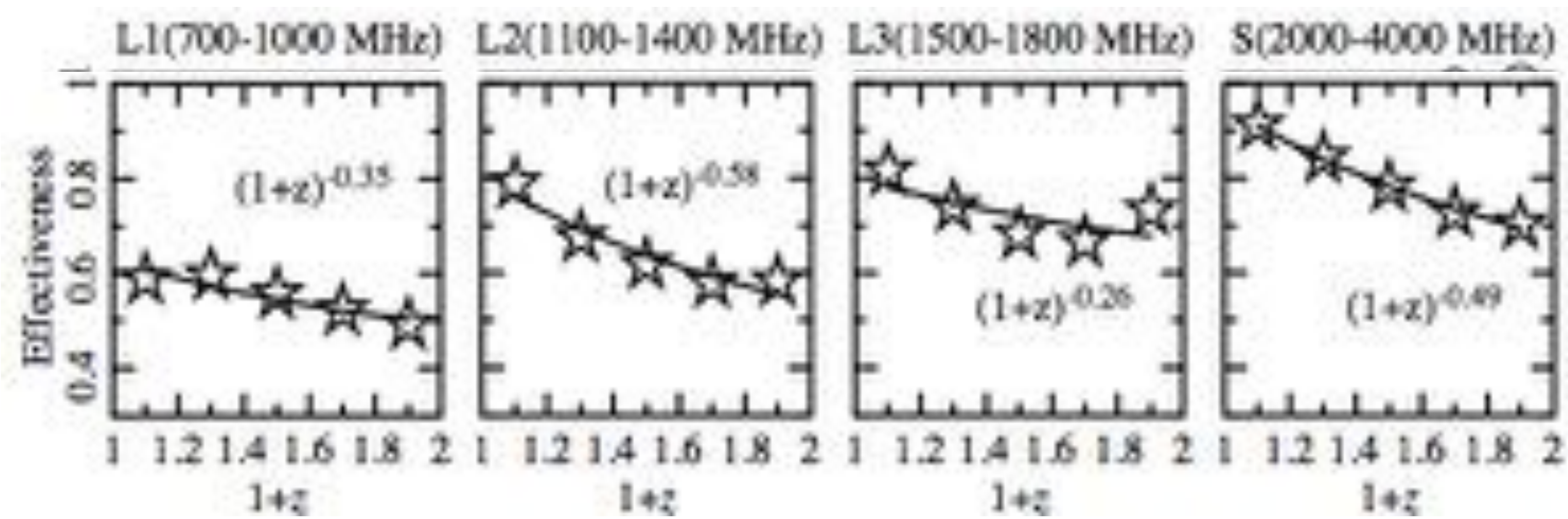
2. DINGs
Bias effect on RM

- **If we increase the intrinsic RM by 5 times, the observed RM does not increase by 5!**
  - The “effectiveness” is 0.5 – 0.9 as func. of λ and z_{DING}



Estimated DING’s RM

8 rad/m² → **60 rad/m²** (z)

Intrinsic DING’s RM

10 rad/m² → **100 rad/m²** (z)

Summary

■SKA will appear soon

- The world-largest cm-m wavelength interferometer
- EoR and Pulsars + diverse science objectives
- Japan may join SKA as an associate member of a 2-4% share

■Depolarizing Intervening Galaxies (DINGs)

- Absorber systems (do/don't) contribute to RM measurement of background polarized sources
- DINGs simulation: a Milky Way model (Akahori+13)
- DING's DP/RM depend on the source size. The results seem to be consistent with Farnes+14 work
- We tend to underestimate the evolution of galaxies

Understanding DING's DP

→

Understanding the cosmic evolution of Galactic turbulence and magnetic field

Discovery of the WHIM and the IGMF → Testing the standard cosmology!