Cosmic Magnetism and SKA Phase 1

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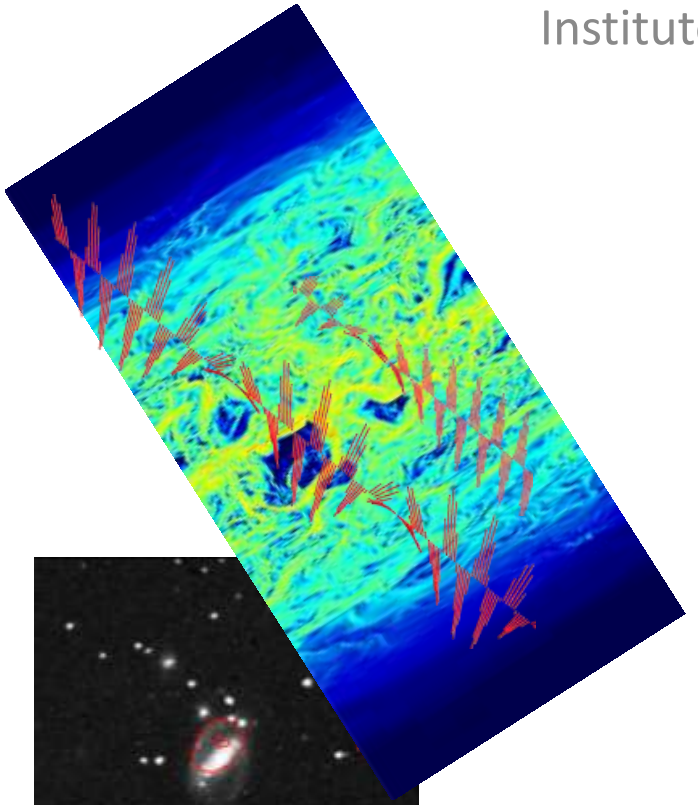
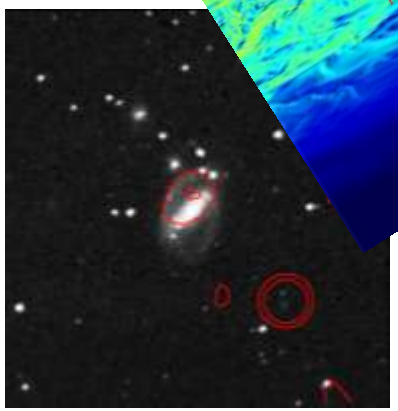
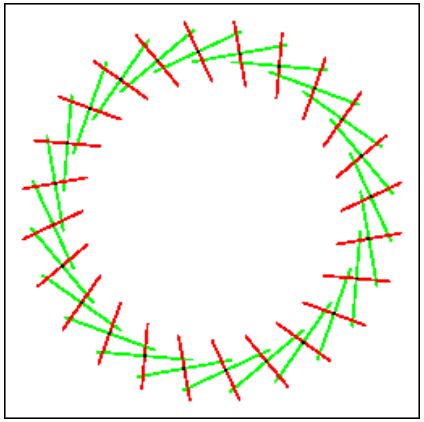
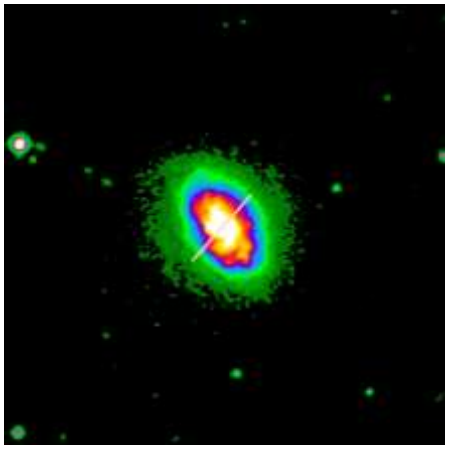
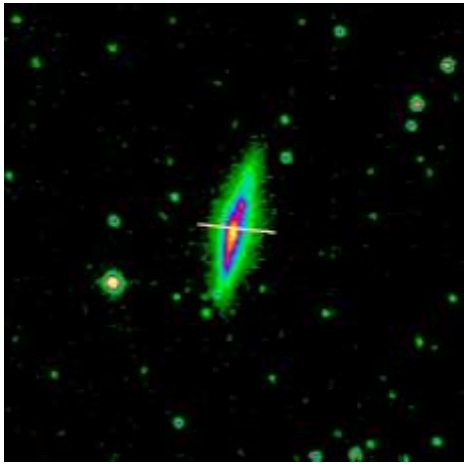
University of Calgary

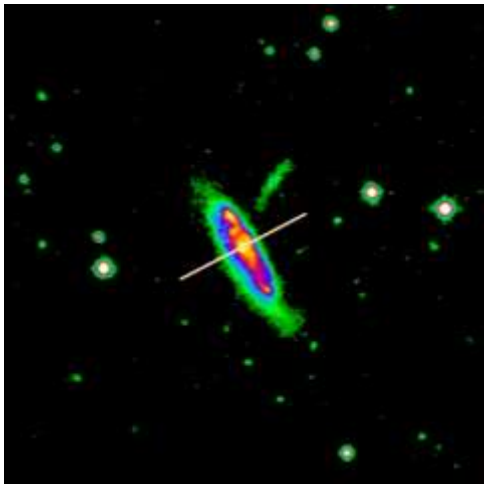












Astro2010 Science Priorities

- Cosmic dawn: First stars, galaxies and black holes
- New Worlds: Nearby habitable planets
- Physics of the Universe: Advancing understanding of fundamental physics of the universe

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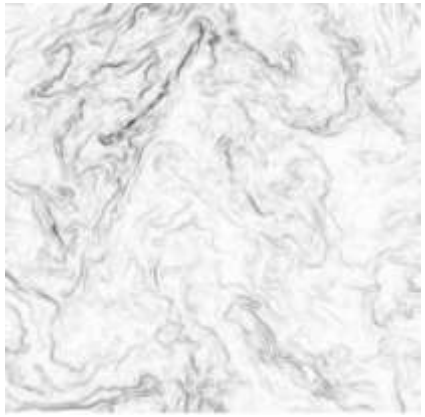
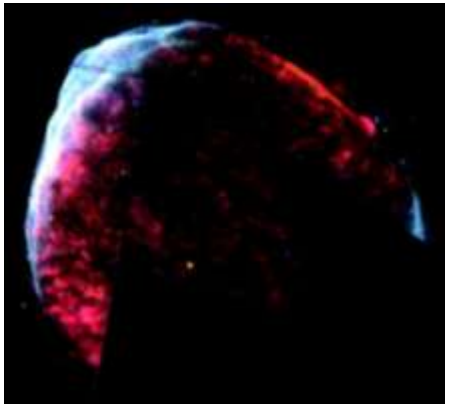
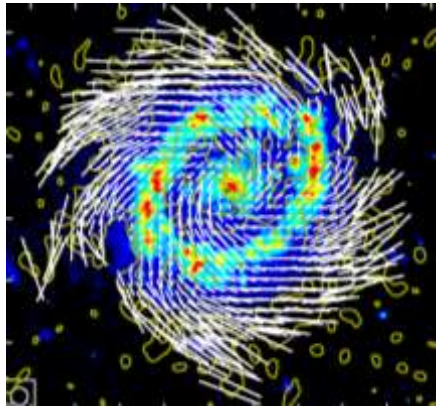
Cosmic Magnetism

Magnetism is crucial in :

- cloud collapse / star formation
- stellar activity / stellar outflows
- ISM turbulence / gas motions
- stability of galactic disks
- acceleration / propagation / confinement of cosmic rays
- heating in galaxy clusters
- AGNs / jets/ blackhole IGM feedback



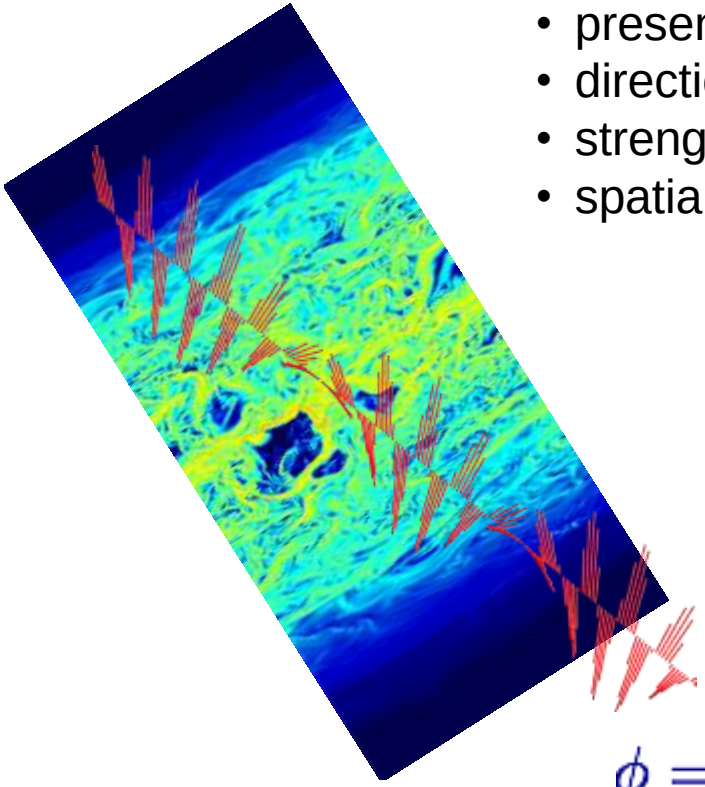




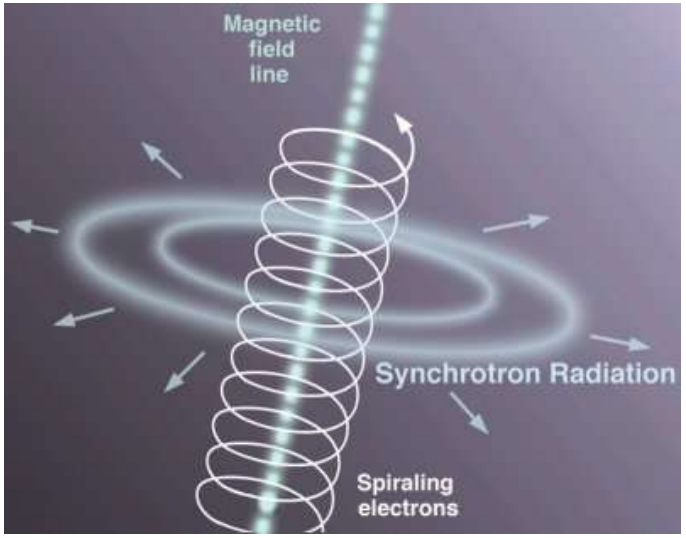
Magnetism is one of the fundamental forces in Nature

Radio Polarization probes magnetic fields

Polarization of Synchrotron Radiation



- presence of field
- direction of field
- strength of field
- spatial scale of field



AstronomyOnline.org

Faraday Rotation

$$\phi = \phi_o + RM \times \lambda^2$$

$$RM = 0.81 \int n_e \bar{B} \cdot \overline{dl} \quad \text{rad m}^{-1}$$

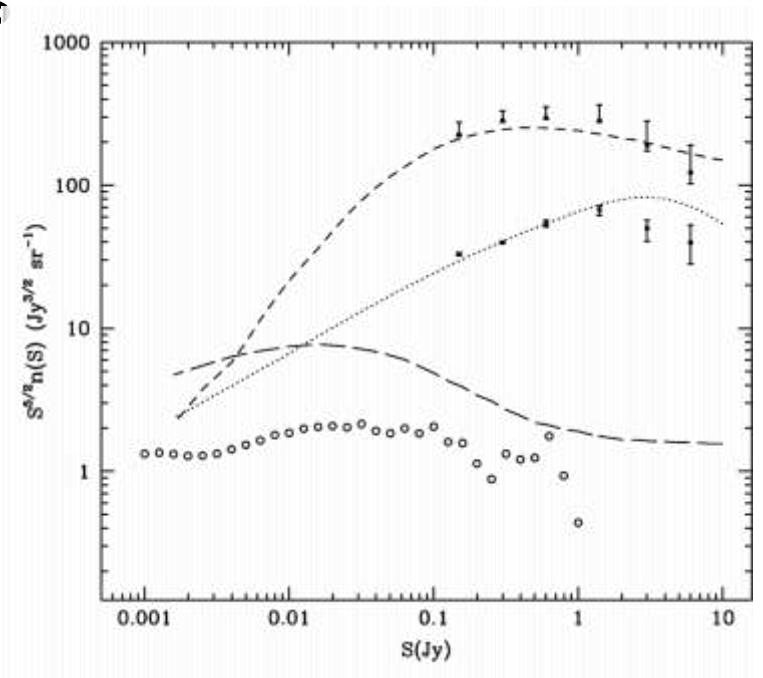
Astro2010 Science Priorities

- Cosmic dawn: First stars, galaxies and black holes

Continuum surveys with SKA Pathfinder & precursors and SKA

Polarization of NVSS Sources

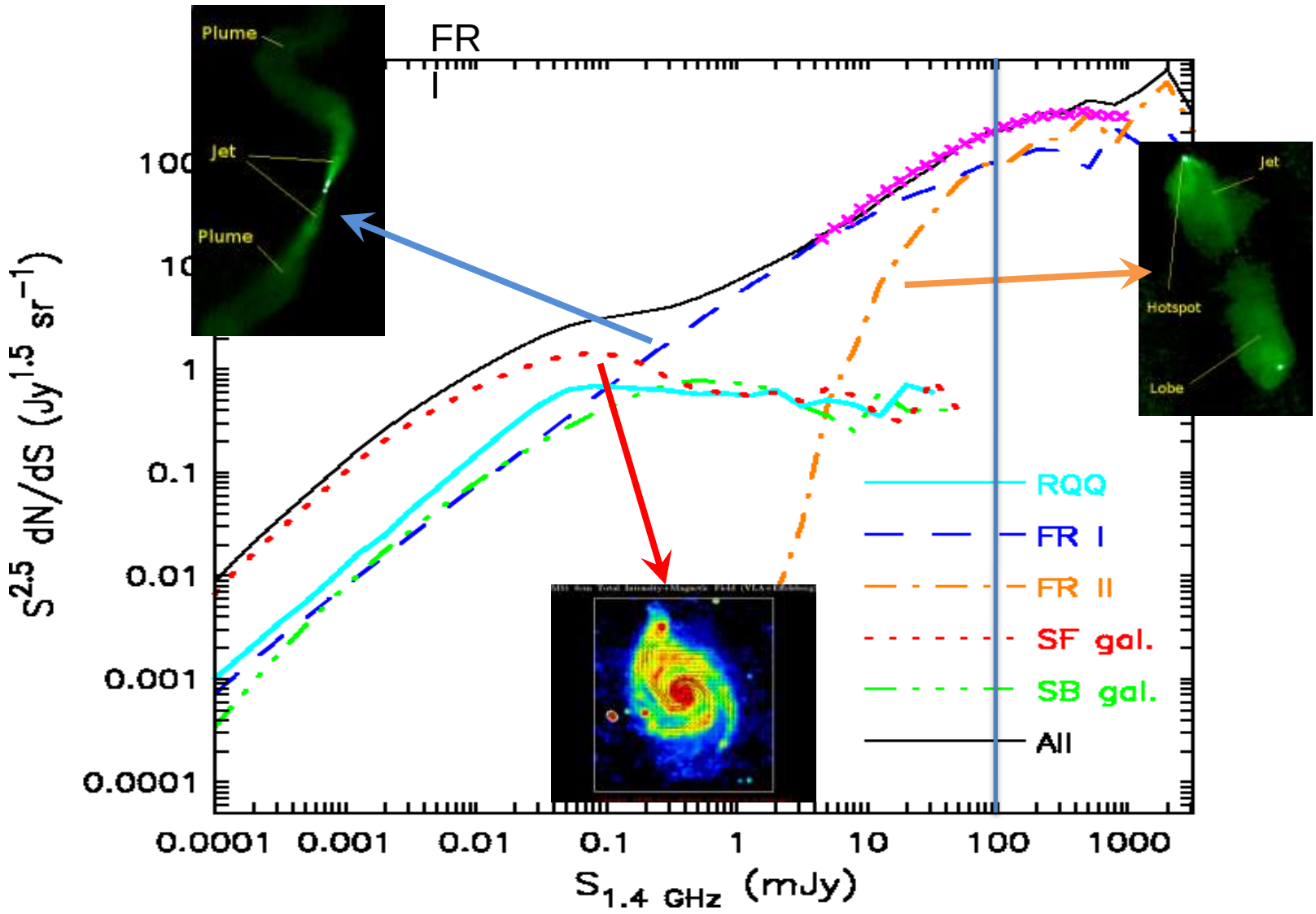
Approximately 10% of sources are detected in polarized emission



Studies of Π = P/I

- Mesa et al. (2002):
  - Median Π increases from ~1% at S > 800 mJy to 1.8% at S = 100-200 mJy
- Tucci et al. (2004):
  - Median Π increases from 1.1% at S > 800 mJy to 1.8% at S = 100-200 mJy for steep spectrum sources only

Radio Source Populations



Total intensity source populations counts: SKADS Simulation (Wilman et al. 2008)

Wide area Polarization surveys with SKA pathfinder and precursors

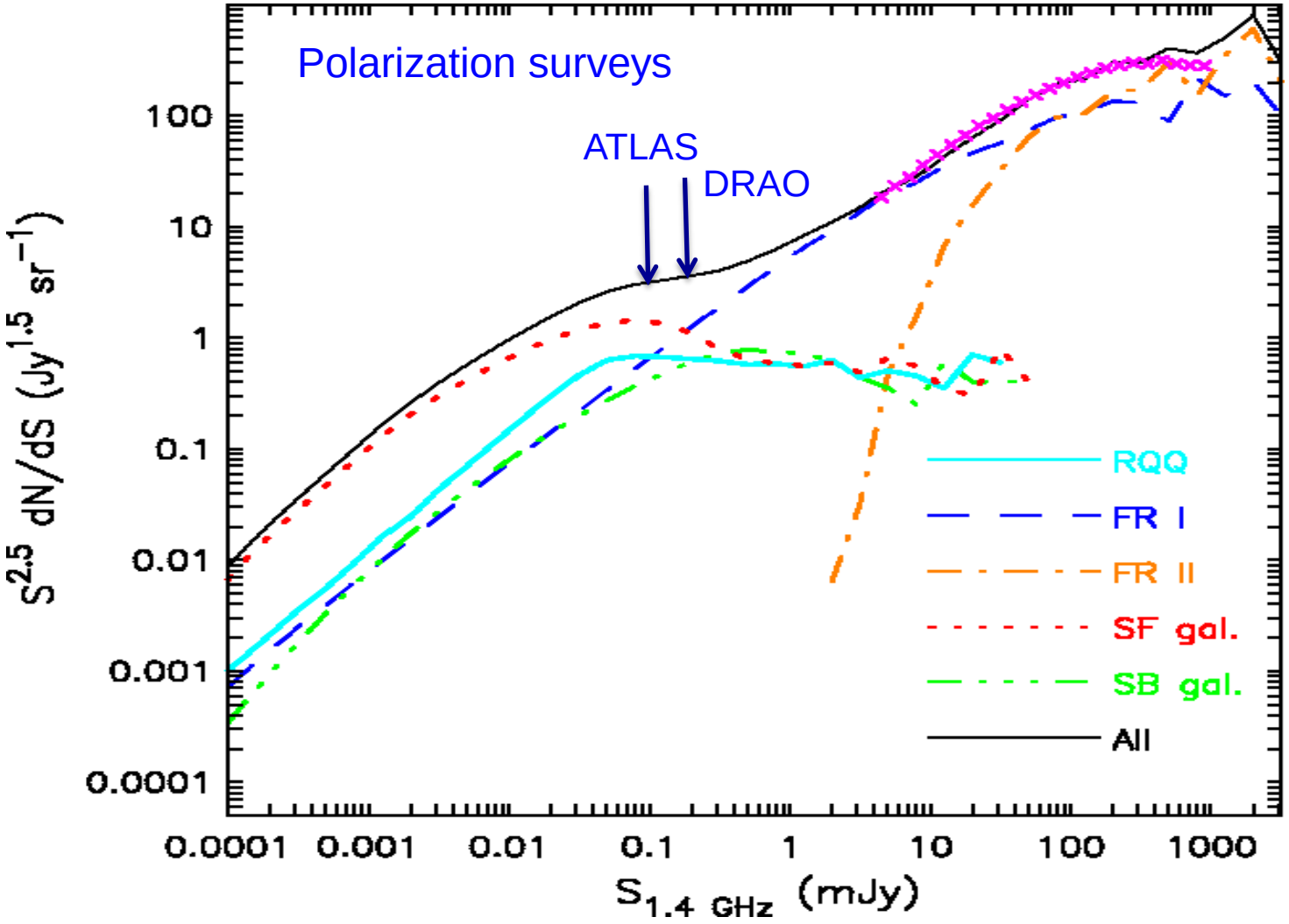
Telescope	Project	sensitivity	Sky coverage (sq deg)	completion
VLA	NVSS	300 μJy	33,000	1998
Arecibo	GALFACTS	90 μJy	12,700	2013
ASKAP	POSSUM	10 μJy	33,000	2015
MeerKAT	MIGHTEE	10 μJy	200	2016

Deep Polarization surveys with SKA pathfinder and precursors

Telescope	Project	sensitivity	Sky coverage (sq deg)	completion
DRAO	DRAO DPF	30 μJy	10	2011
ATCA	ATLAS	10 μJy	10	2011
EVLA	EVLA DPF	0.5 μJy	1	2011
MeerKAT	MIGHTEE	2 μJy	15	2016

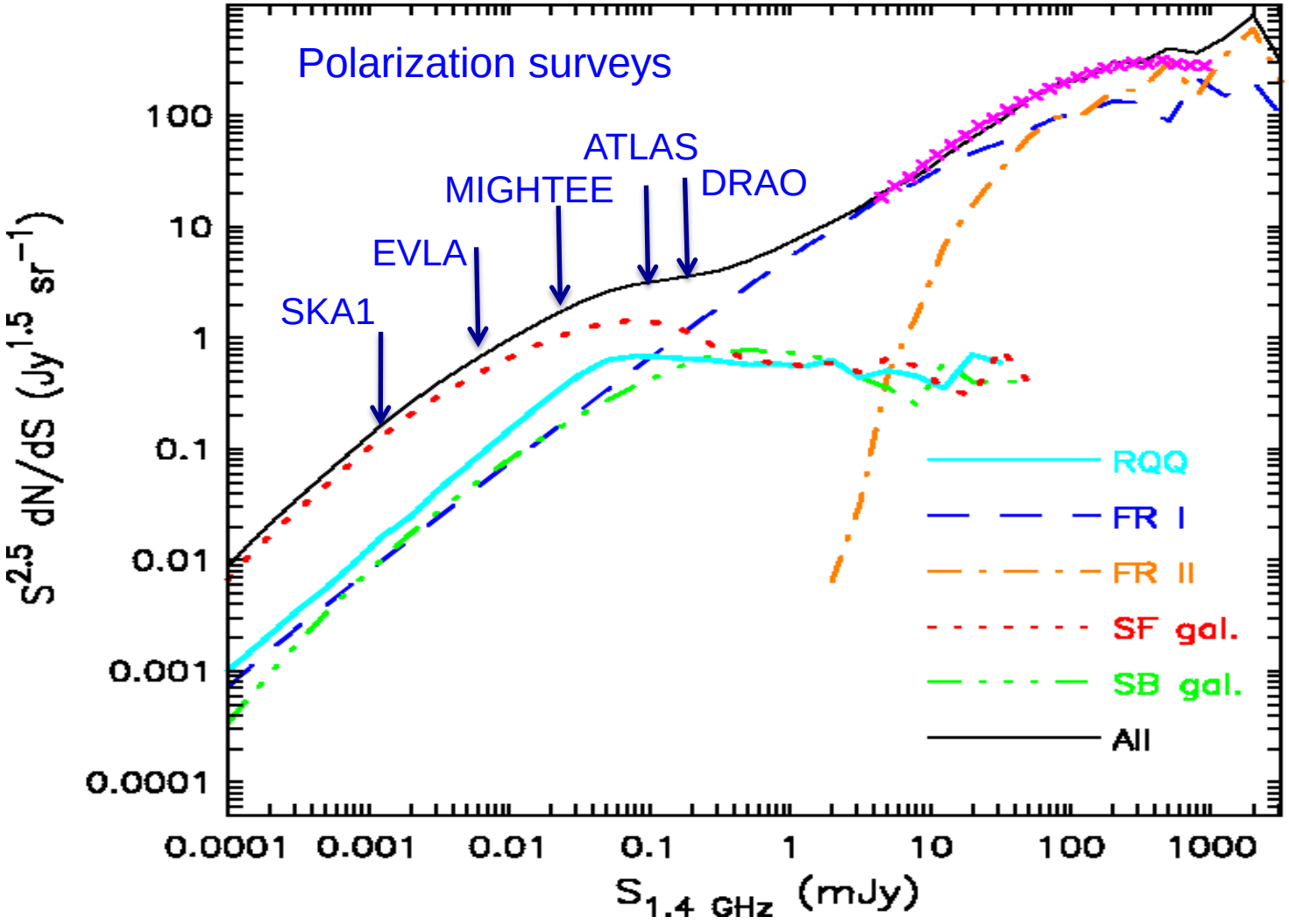
Radio Source Populations – Deep Polarization Surveys

Weakest source with detectable polarization

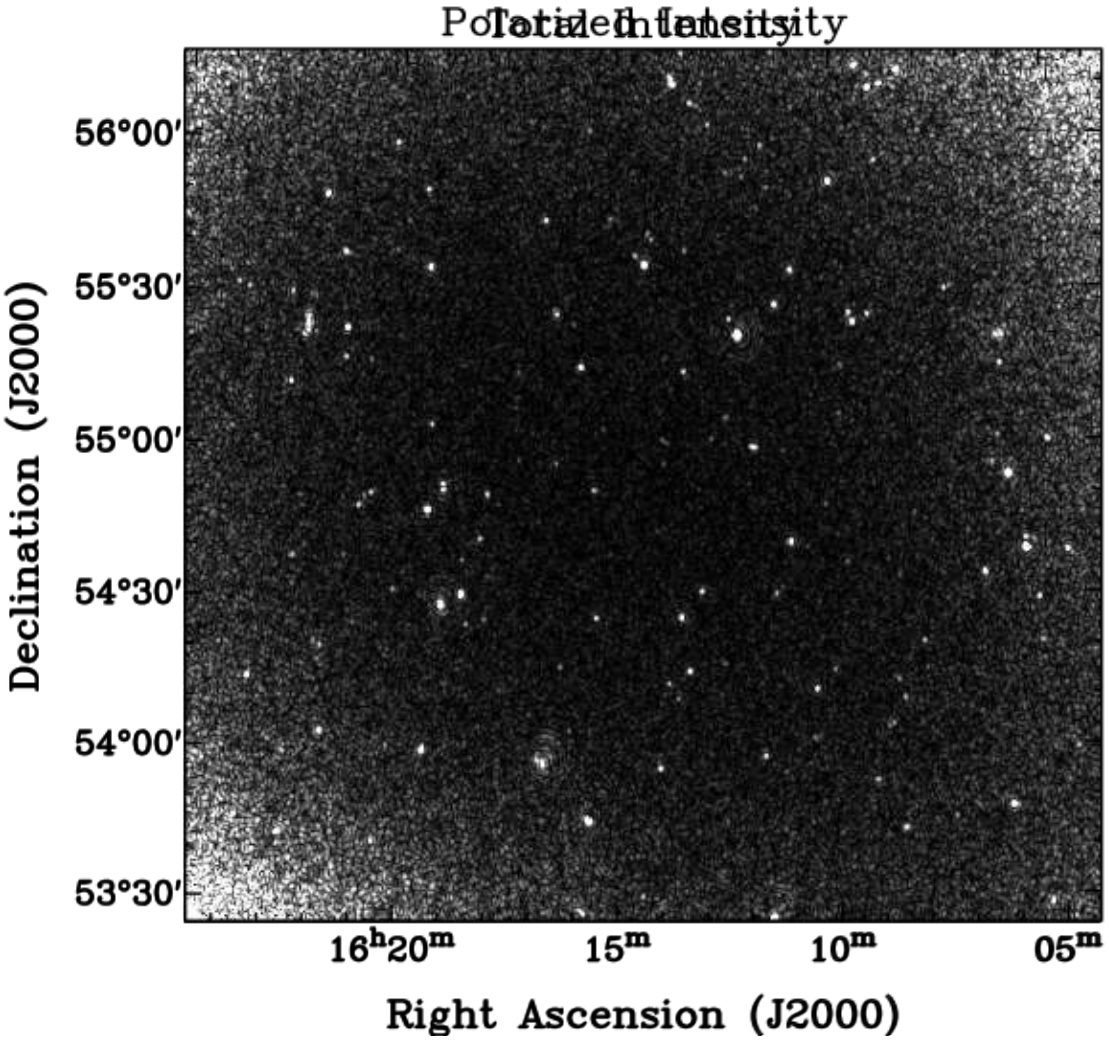


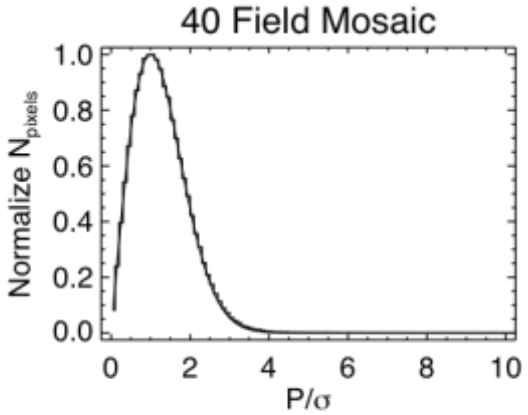
Radio Source Populations – Deep Surveys

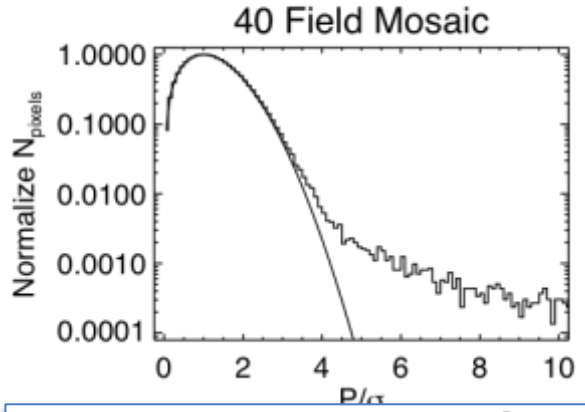
Weakest source with detectable polarization



DRAO ELAIS N1 Deep Polarimetry







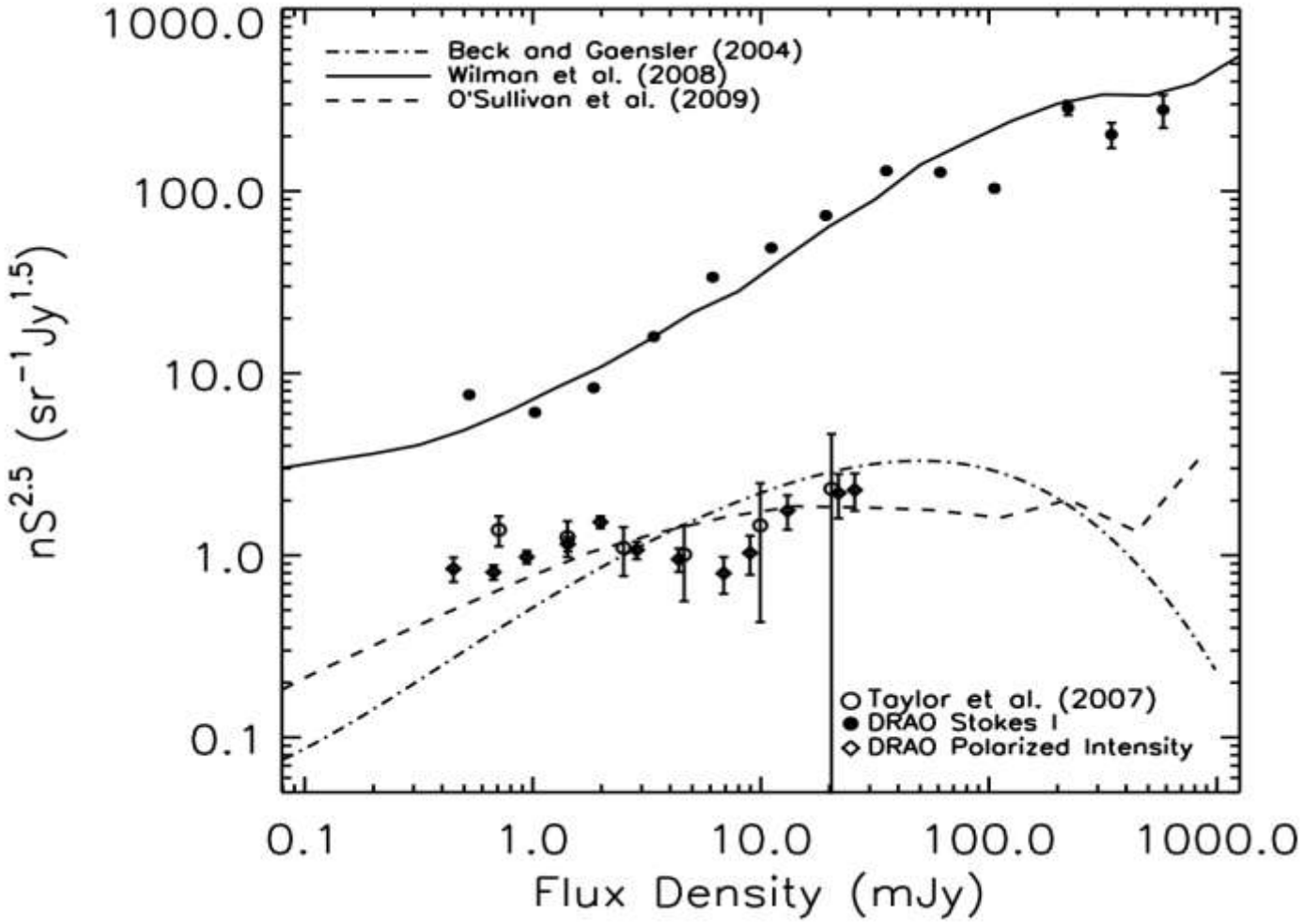
$$f(p|0) = \frac{p}{\sigma} e^{-\frac{p^2}{2\sigma^2}}$$

$$\sigma = 42\,\mu Jy$$

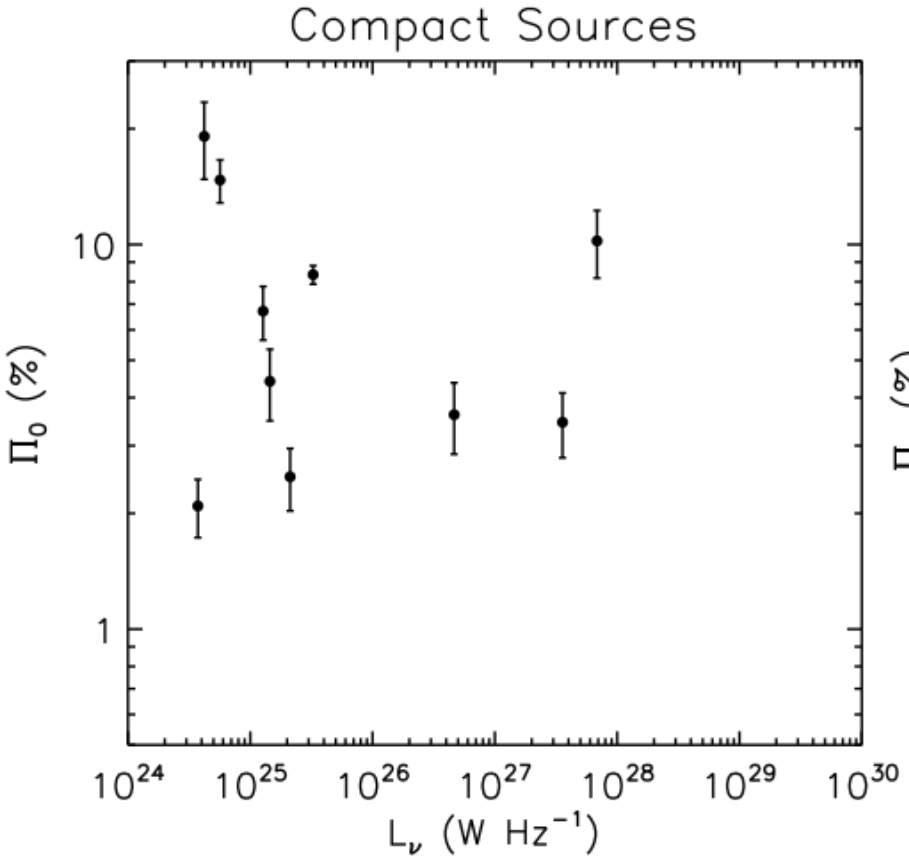
Excess of Faint Polarized Source

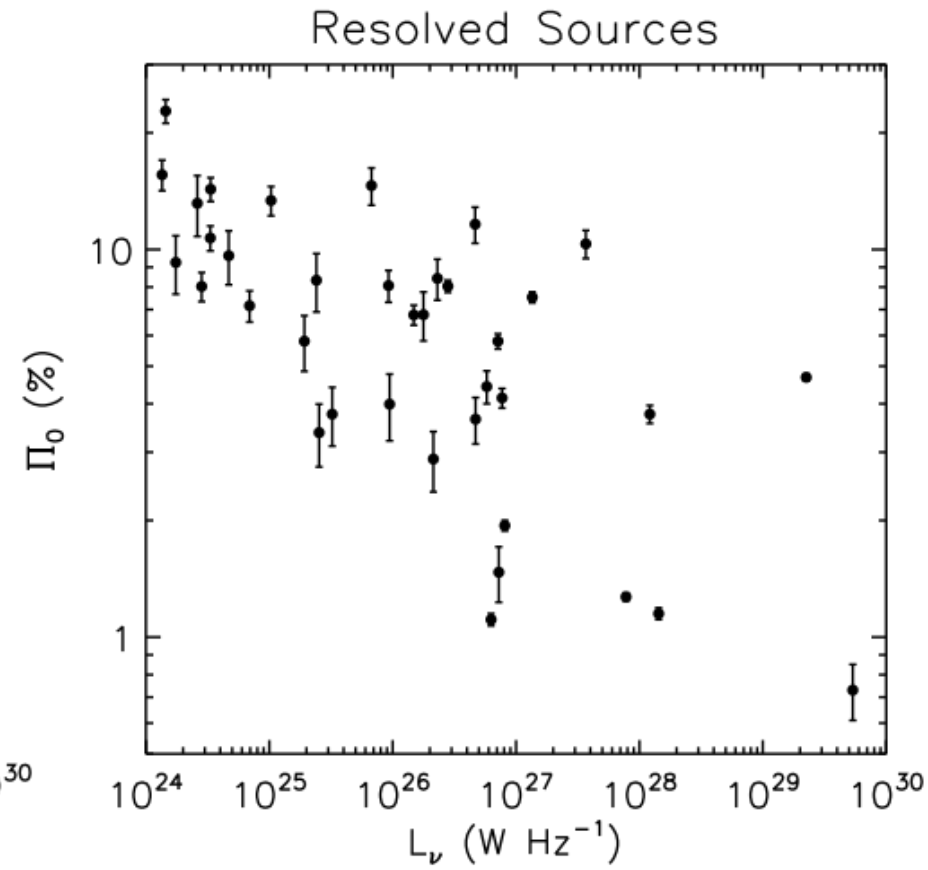
Observations from first 40 DRAO EN1 fields (5800 hours)

SKADS Stokes I simulations (Willman et al 2008)

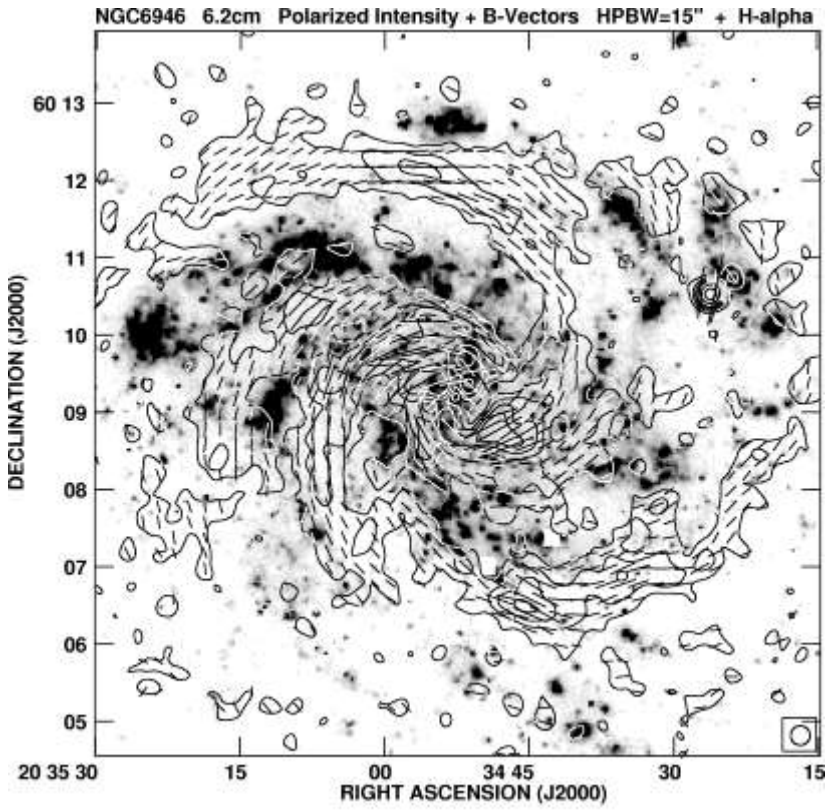


DRAO Fractional Polarization versus $L_{1.4}$

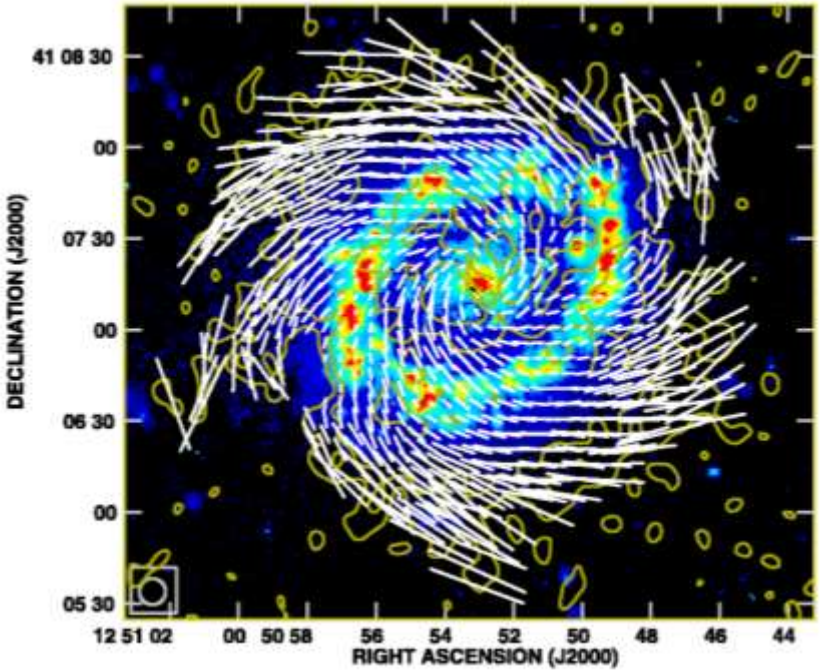




Polarized Synchrotron Emission from Spiral Galaxies



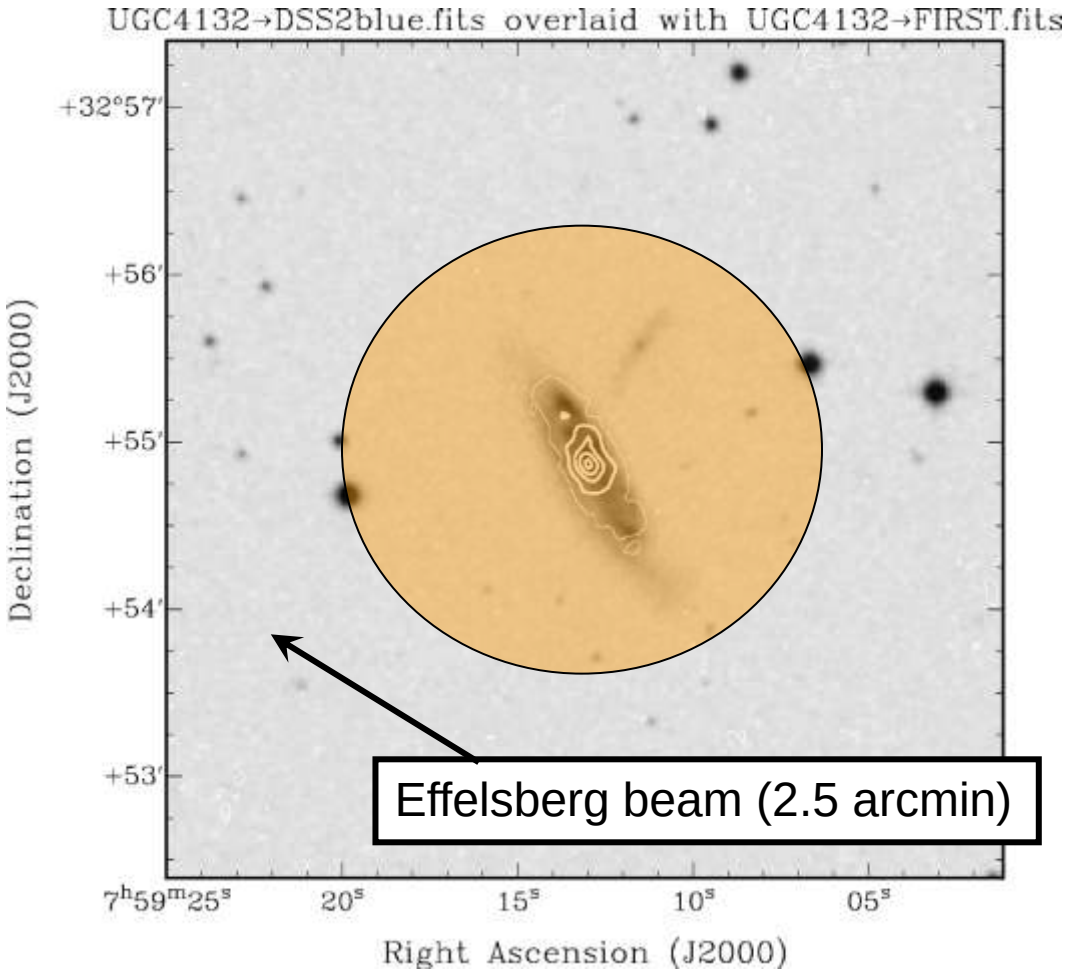
NGC 6946 (Beck 2007)
B vectors on Hα
SW side depolarized at 1.4 GHz



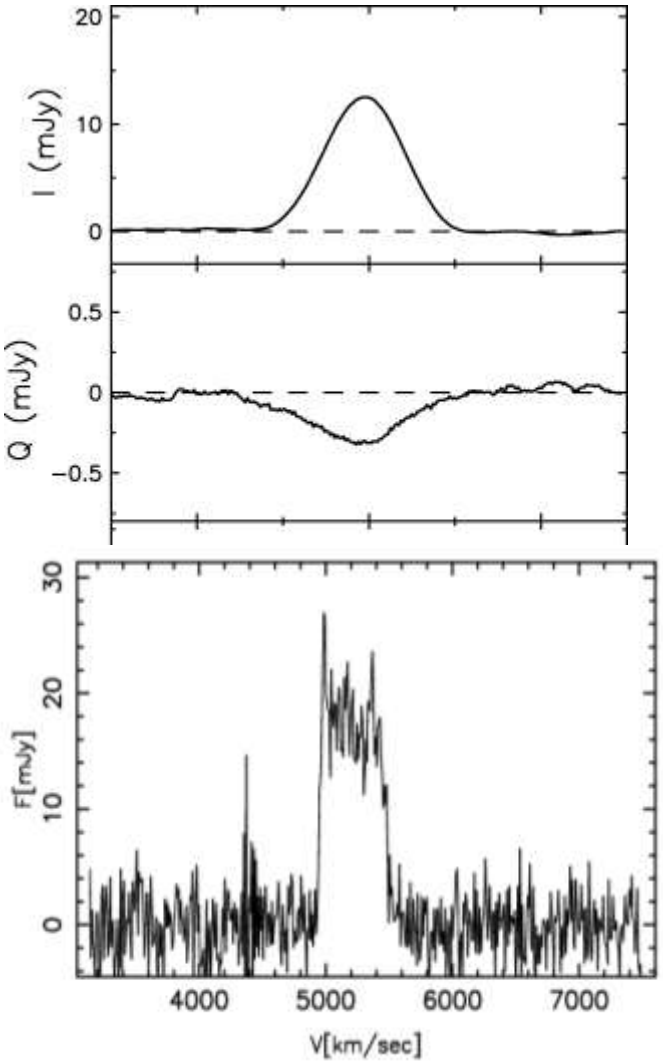
NGC 4736 (Chyzy & Buta 2008; ApJ 677, L17)
B vectors on Hα

Effelsberg polarisation survey of disk galaxies
Stil, Mitchell, Krause, Beck, & Taylor

UGC 4132: Milky Way size galaxy at 71 Mpc

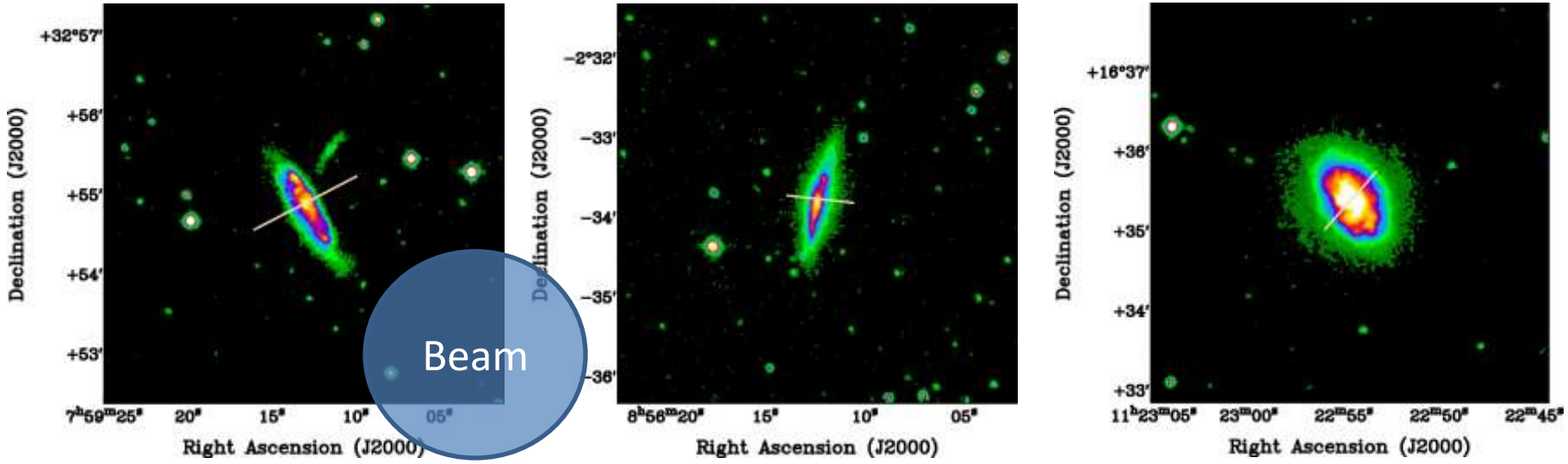


UGC 4132 4.8 GHz



HI line Springob et al. (2005)

Effelsberg Northern Galaxy Polarisation Survey
Stil, Mitchell, Krause, Beck, & Taylor



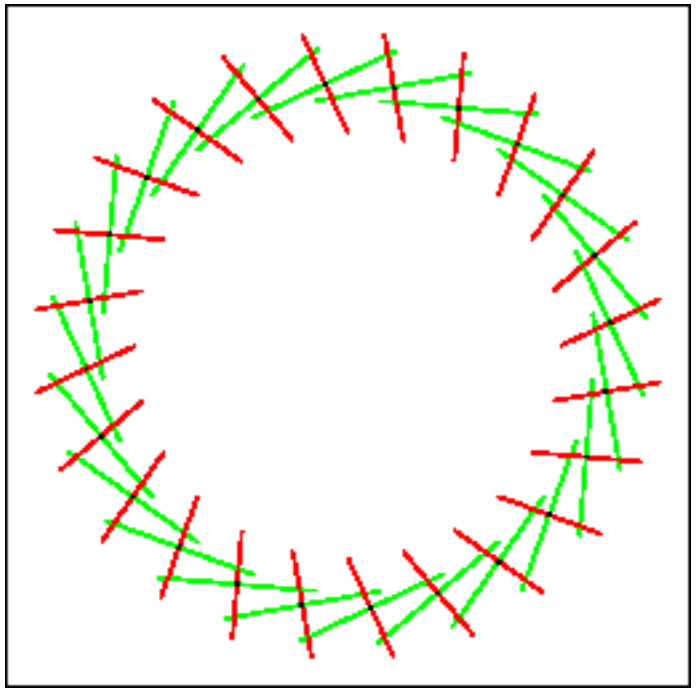
UGC 4132
V_{hel} = 5219 km s^{-1}
distance = 74 Mpc
V_{rot} = 257 km s^{-1}

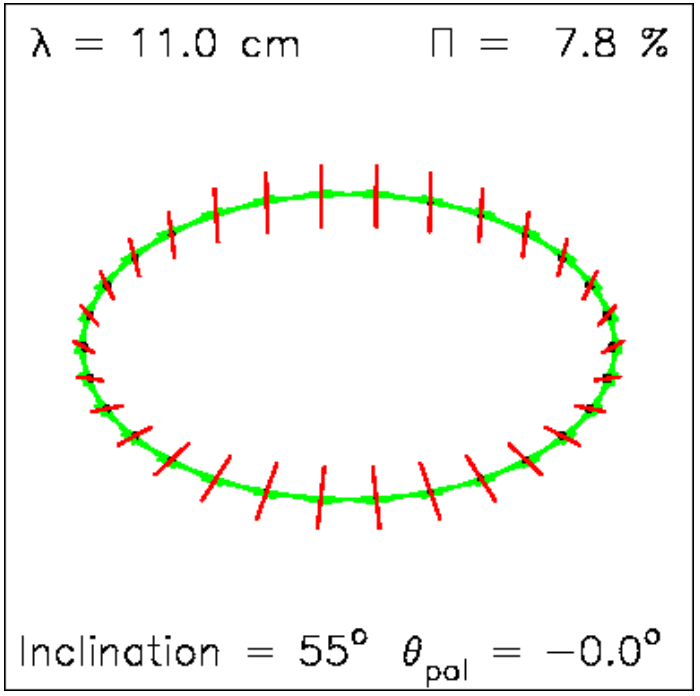
UGC 4680
V_{hel} = 1631 km s^{-1}
distance = 27 Mpc
V_{rot} = --- km s^{-1}

UGC 6936
V_{hel} = 1473 km s^{-1}
distance = 18 Mpc
V_{rot} = 198 km s^{-1}

- Can observe hundreds of galaxies with a large single-dish telescope:
- Local comparison sample for unrelsolved high-z galaxies

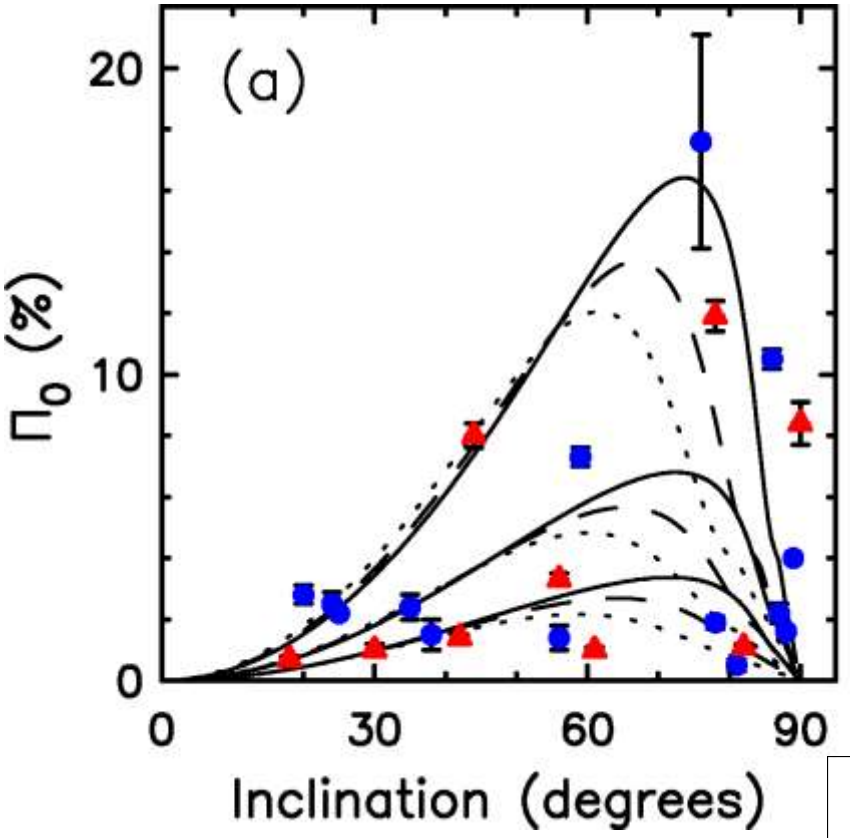
Integrated Polarization of Spiral Galaxies

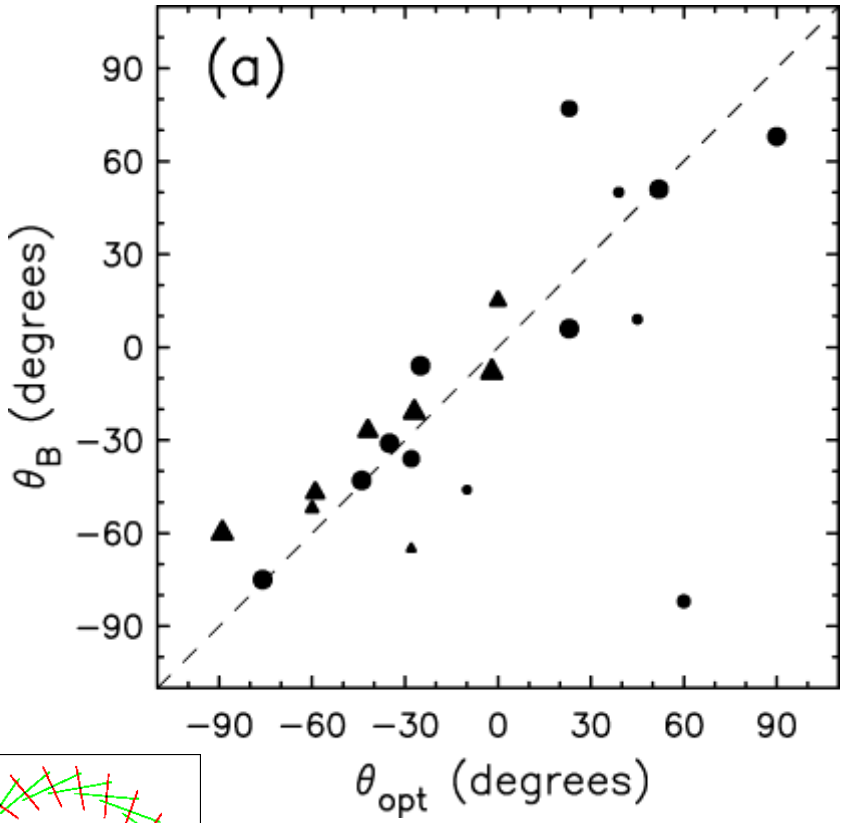


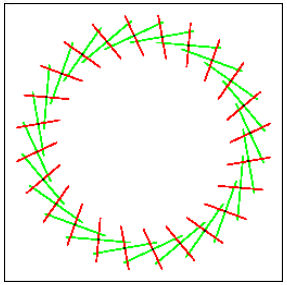


Detect presence and properties of a global magnetic field

Integrated Polarization of Nearby Disk Galaxies







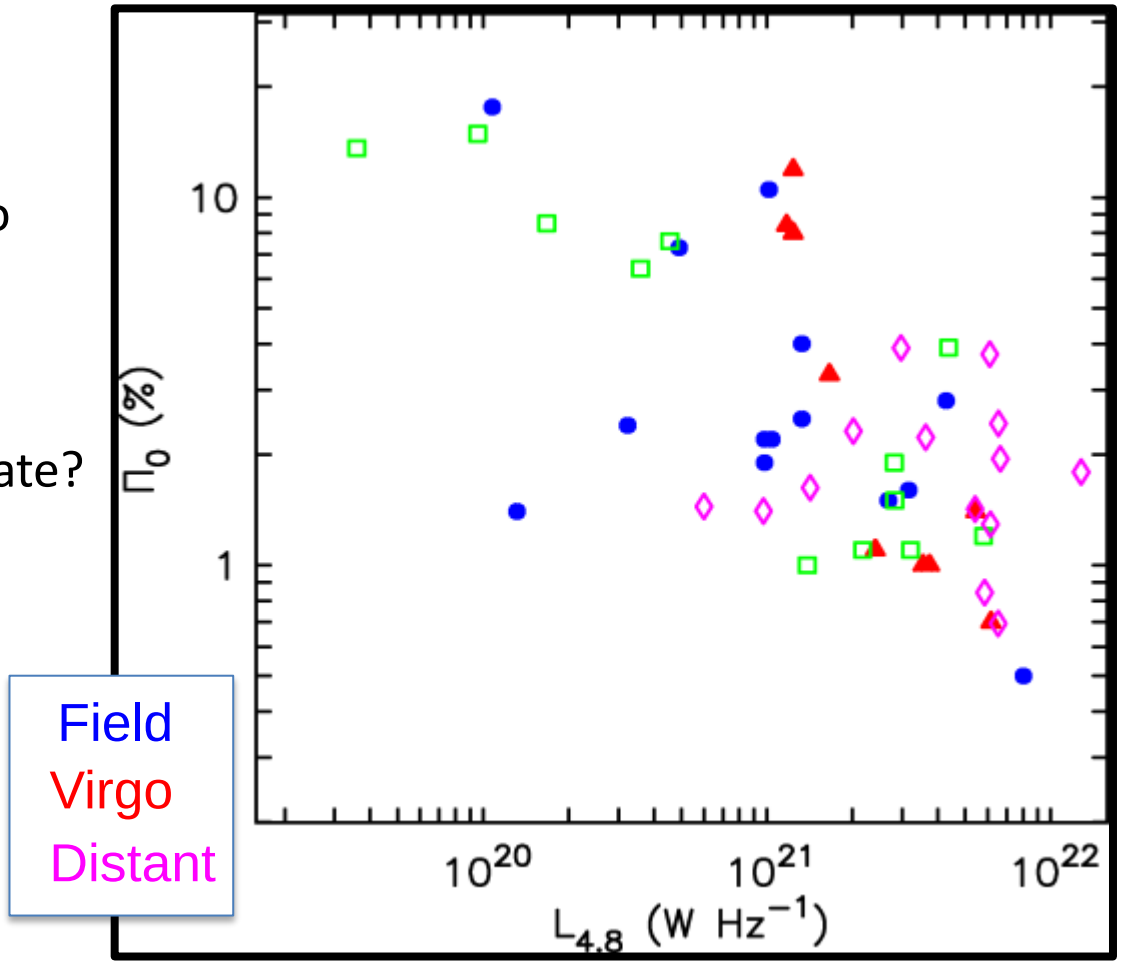
Model curves vary |B|, f_B, n_e

$f_B = B_{random}/B_{regular}$

Stil, Krause, Beck, & Taylor (2009)

Fractional Polarization and Radio Luminosity

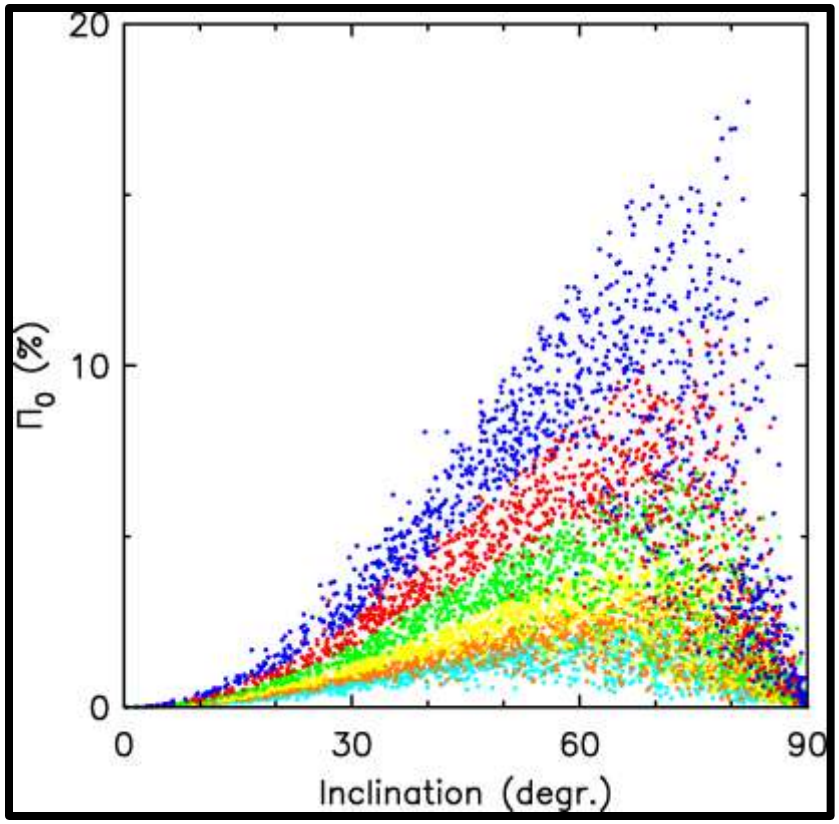
- Highly ordered large-scale magnetic fields restricted to galaxies with a low radio luminosity (L < L*).
- Relation to star formation rate?

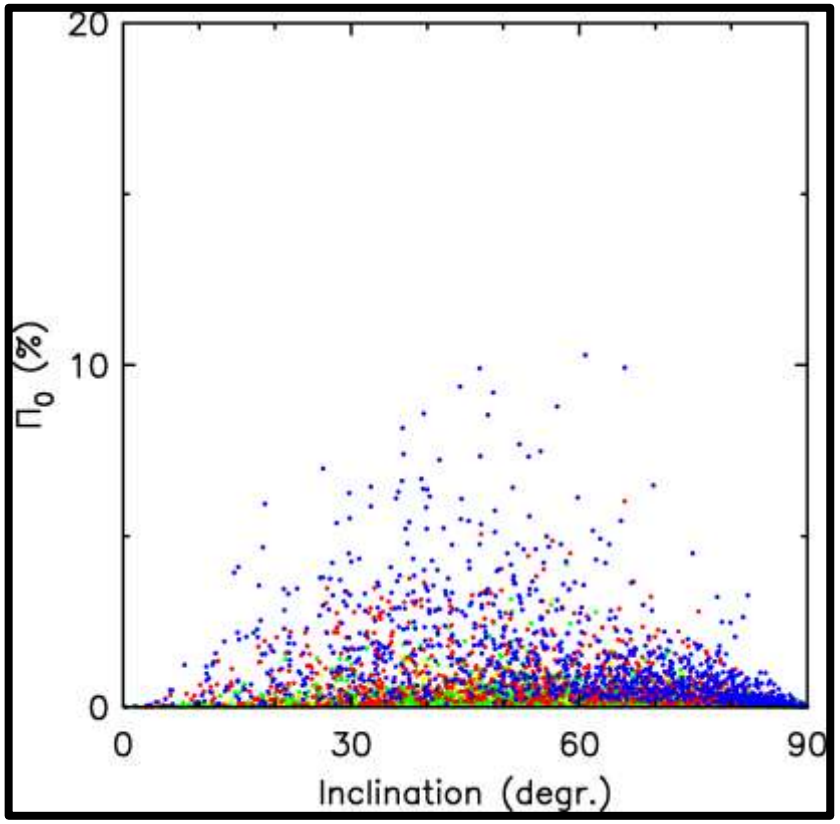


Stil, Krause, Beck, & Taylor (2009)

Polarization of Unresolved Galaxies as a Function of Frequency

Simulation



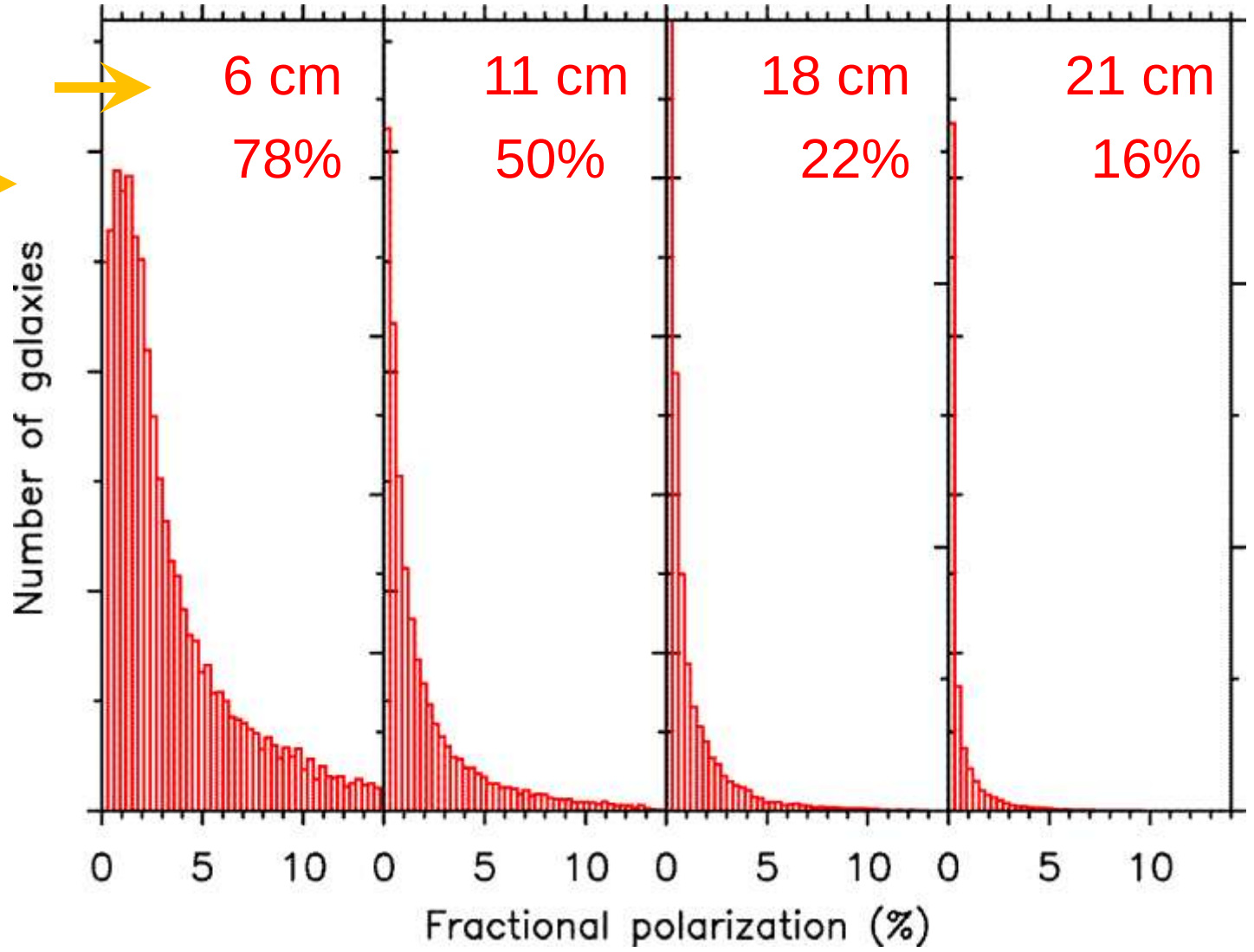


Variation of model parameters; No noise included

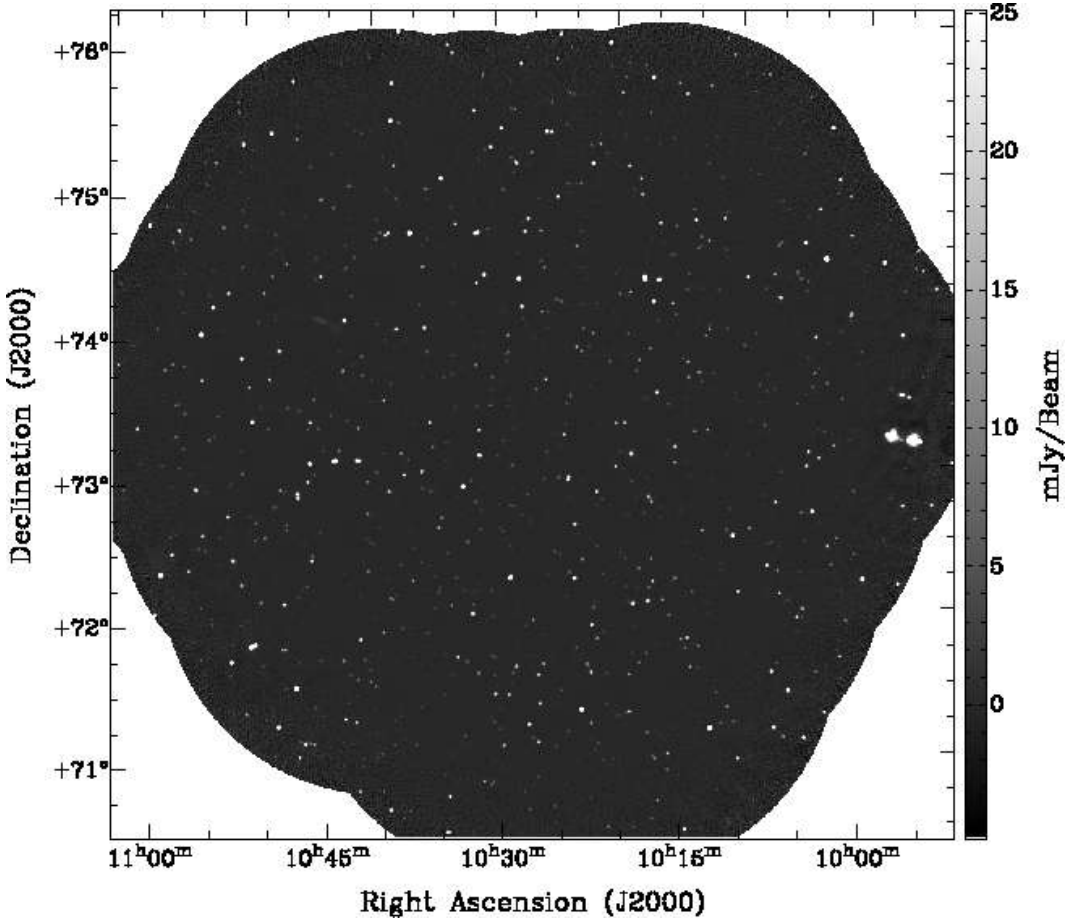
Statistics of B_{rand}/B_{reg} from 4.8 GHz, inclination < 50^o

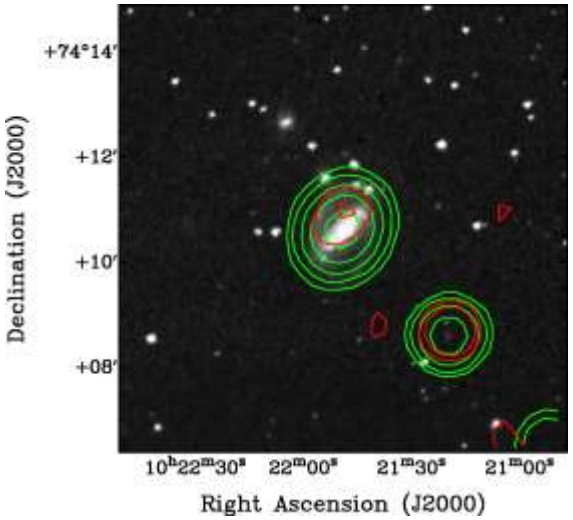
Distribution of Π = p/I

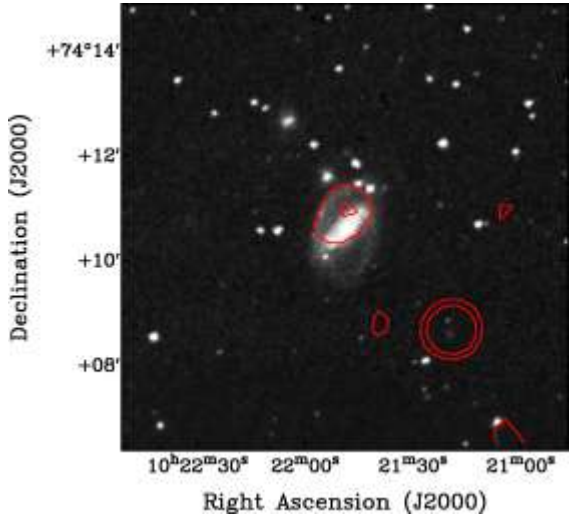
Simulation of 20,000 randomly oriented galaxies



UGC 5582 in DRAO Spider Deep Field (2.7 % pol. at 1.4 GHz)

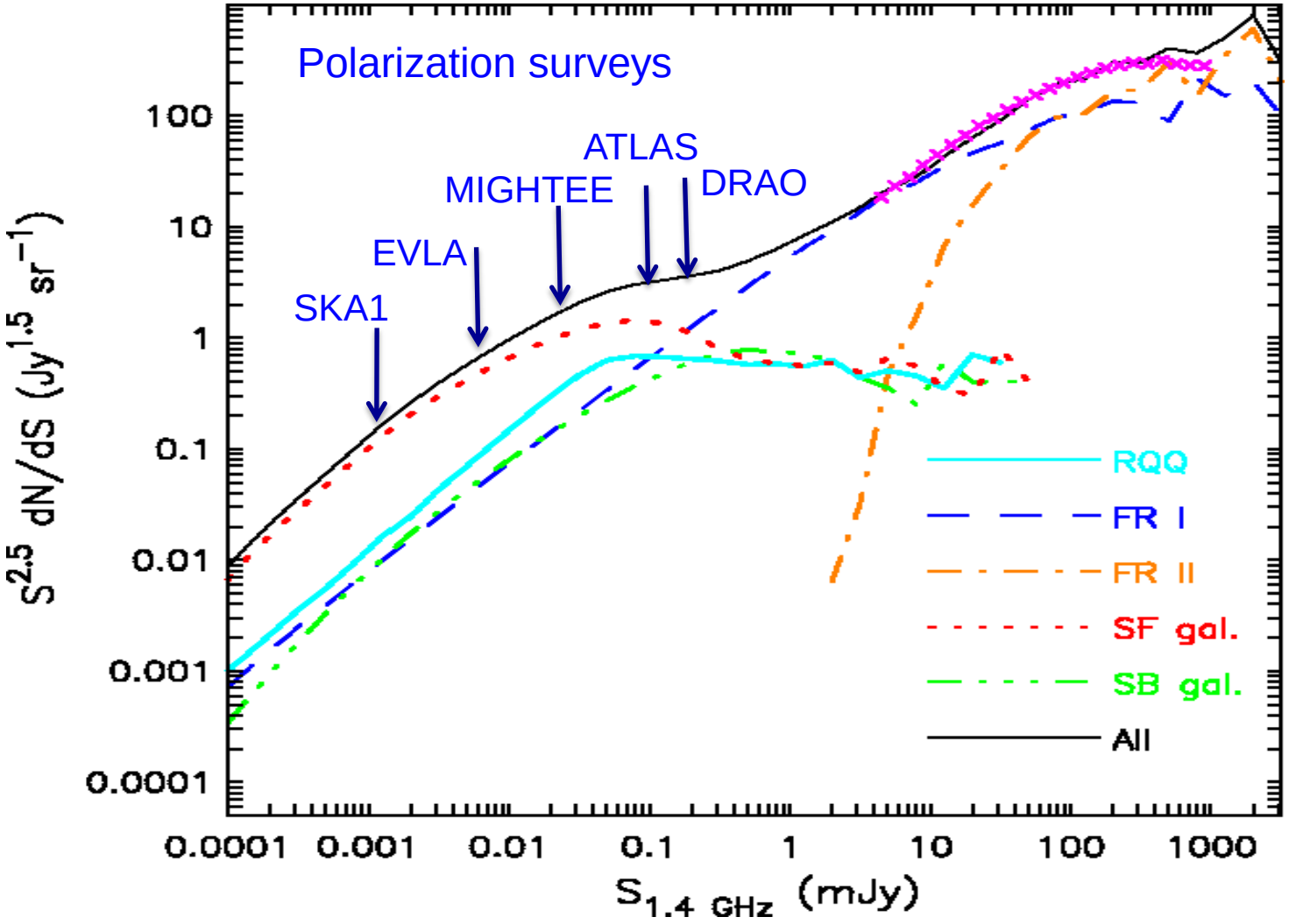




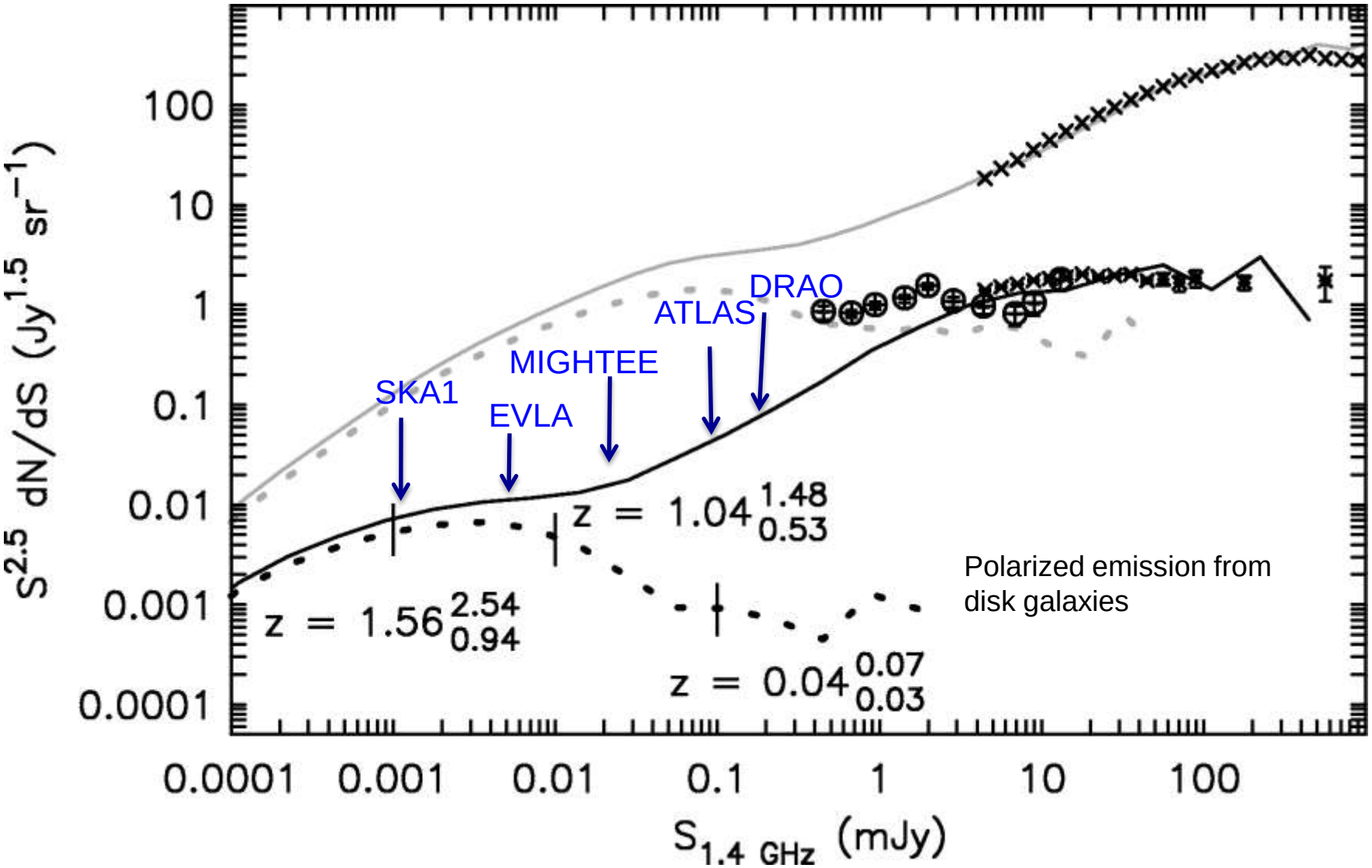


Radio Source Populations – Deep Surveys

Weakest source with detectable polarization



Galaxies in the Polarized Source Counts

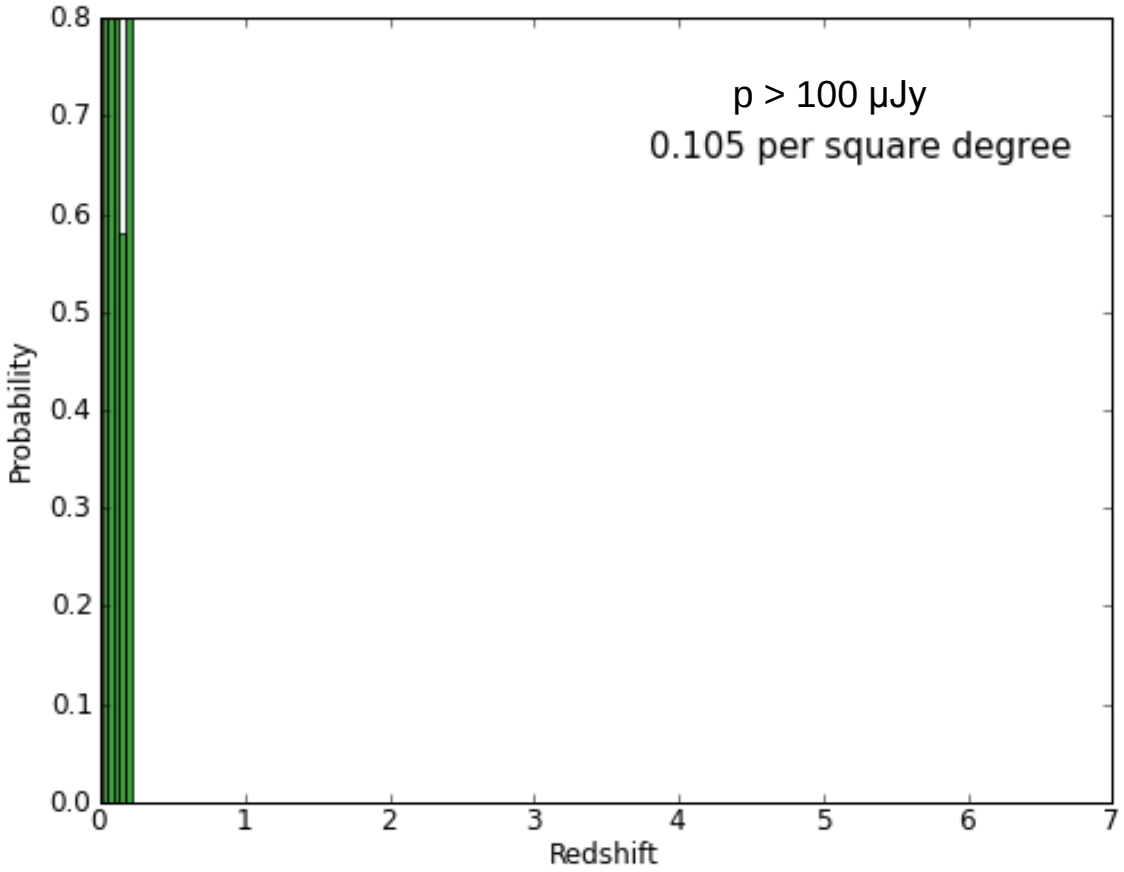


Galaxy Redshift Depth of a Deep Polarization Surveys

ATLAS
POSSUM

σ = 10 μJy

ATLAS will detect a few local galaxies



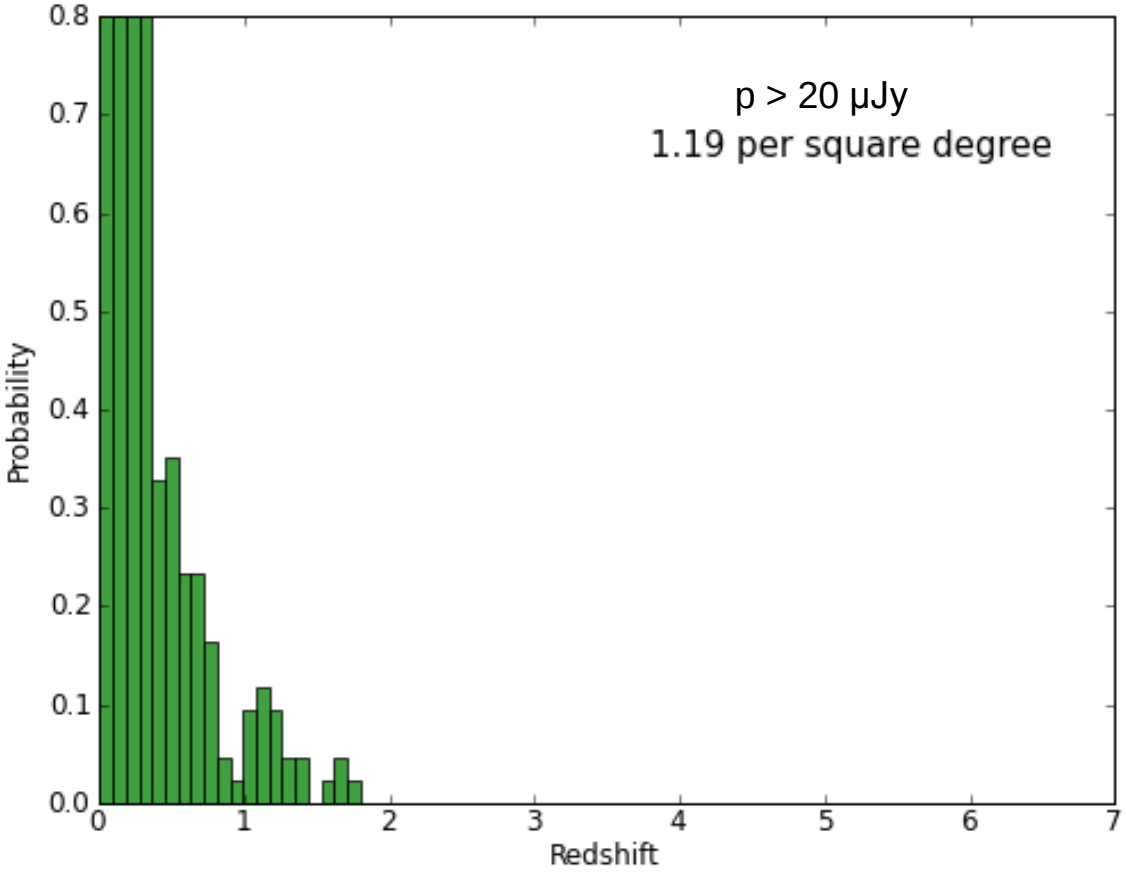
POSSUM will detect a several thousand local galaxies

Galaxy Redshift Depth of a Deep Polarization Surveys

MIGHTEE

σ = 2 μJy

MIGHTEE will detect about 10 galaxies to z > 1

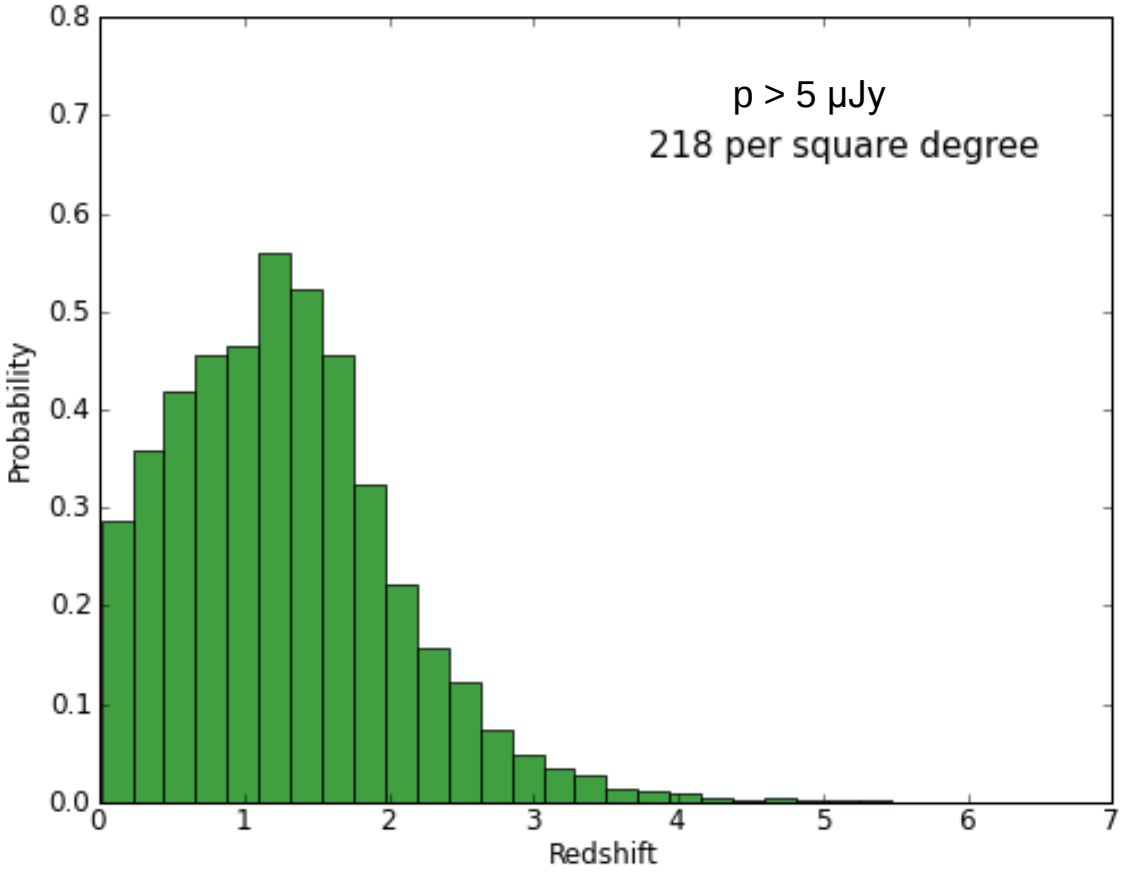


Galaxy Redshift Depth of a Deep Polarization Surveys

EVLA will detect a few 100 galaxies out to z > 2

EVLA

σ = 0.5 μJy



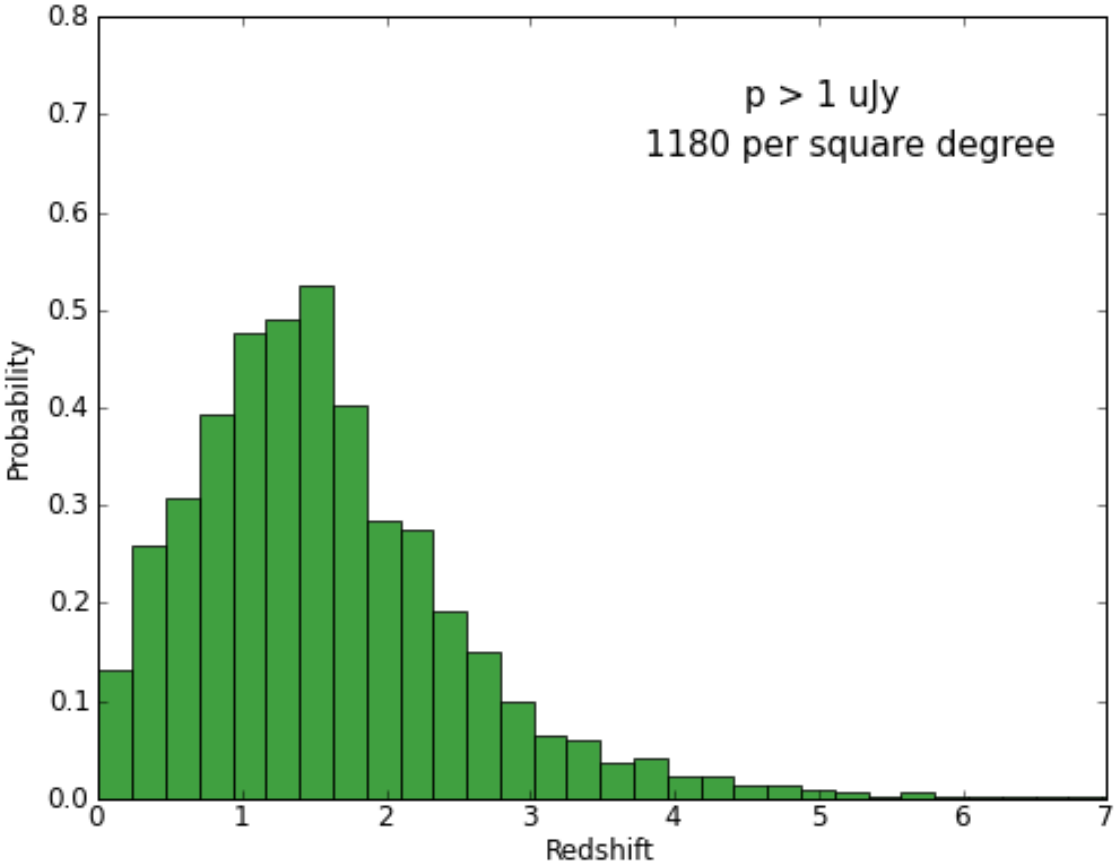
Separation ~ 0.1 deg

Galaxy Redshift Depth of a Deep Polarization Surveys

EVLA will detect a few 1000 galaxies out to z > 4

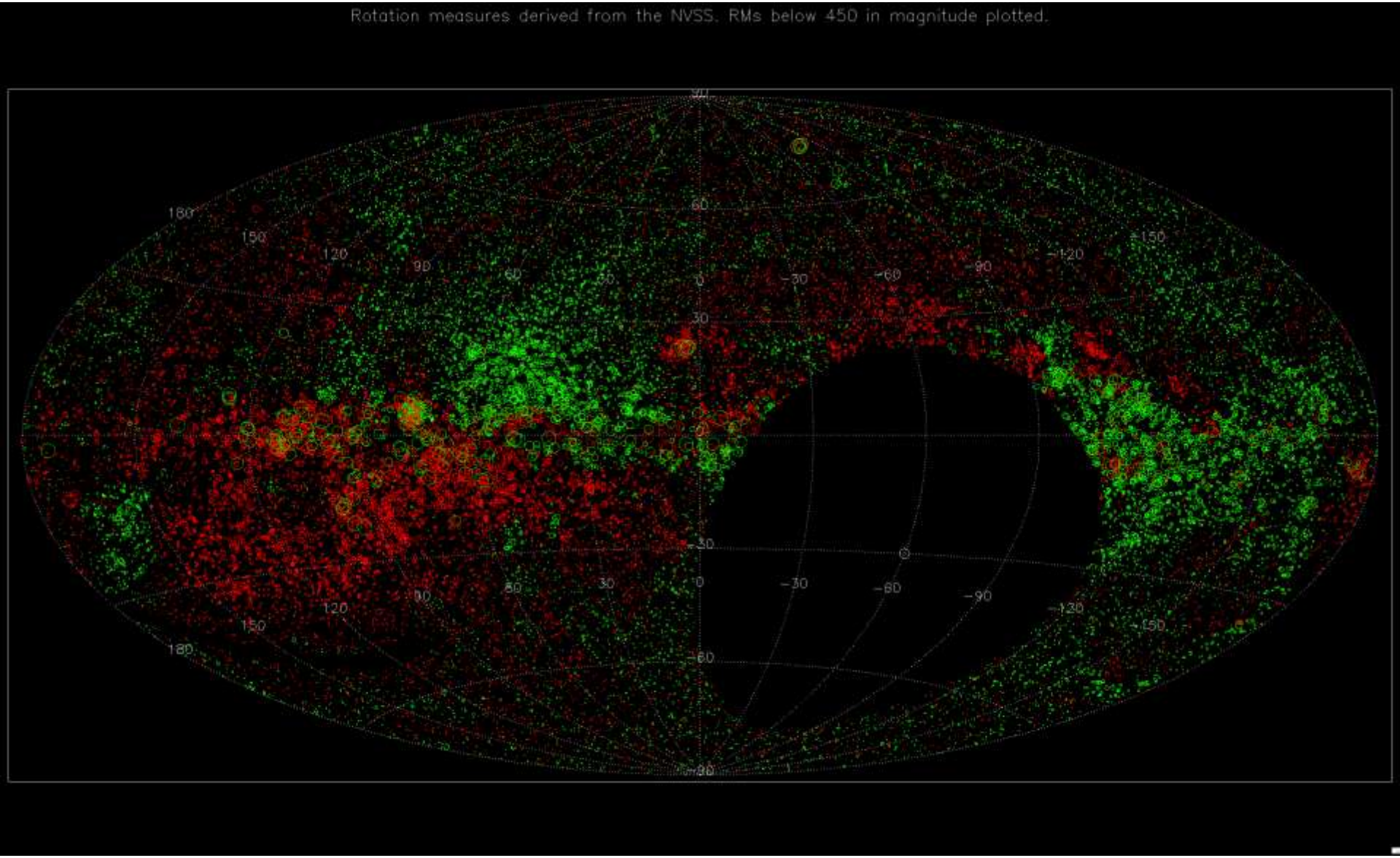
SKA1

σ ~ 0.1 μJy

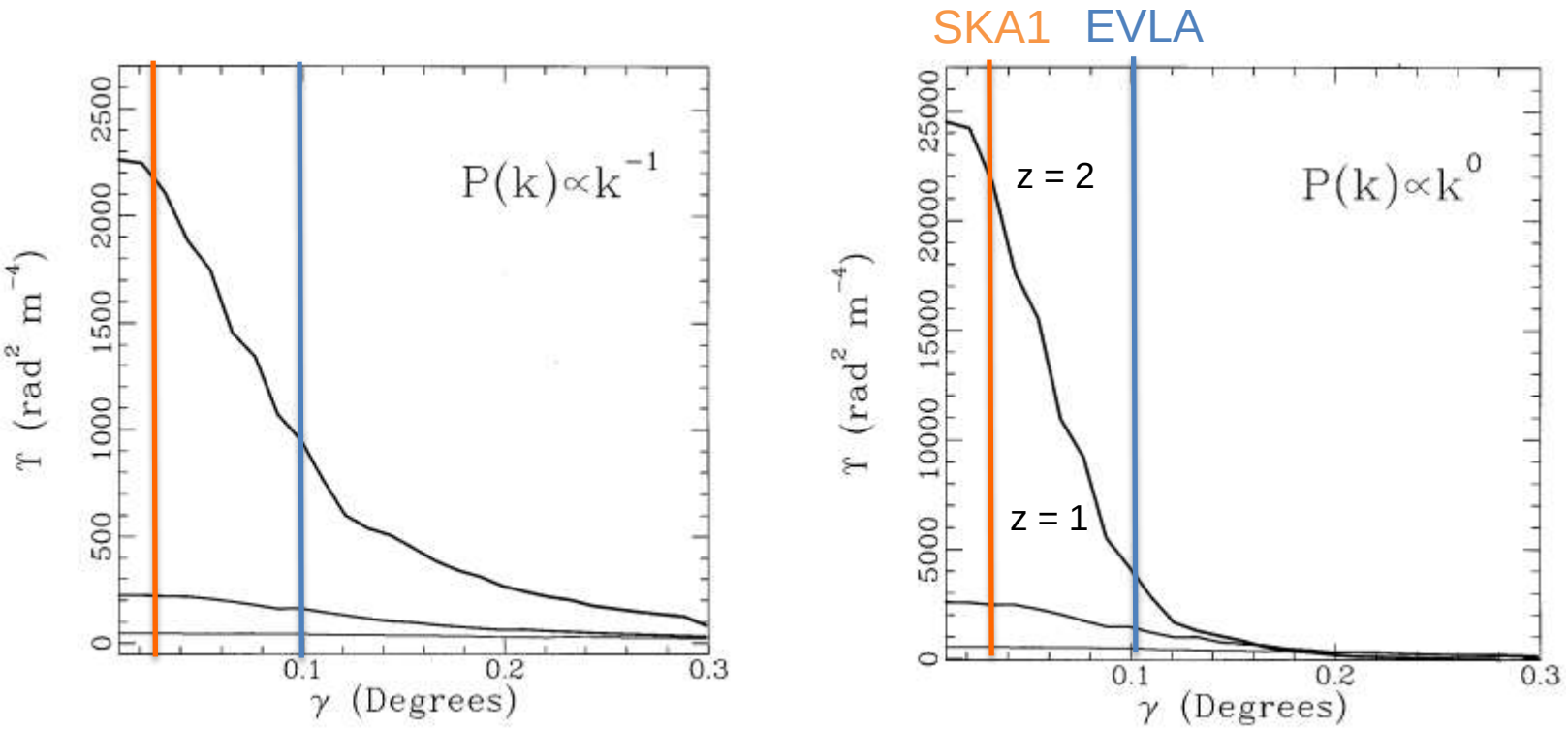


Separation ~ 0.03 deg

Using Large Scale catalogues to probe the deep sky



Primordial (pre-galaxy formation) Cosmic Magnetic Field Fluctuations

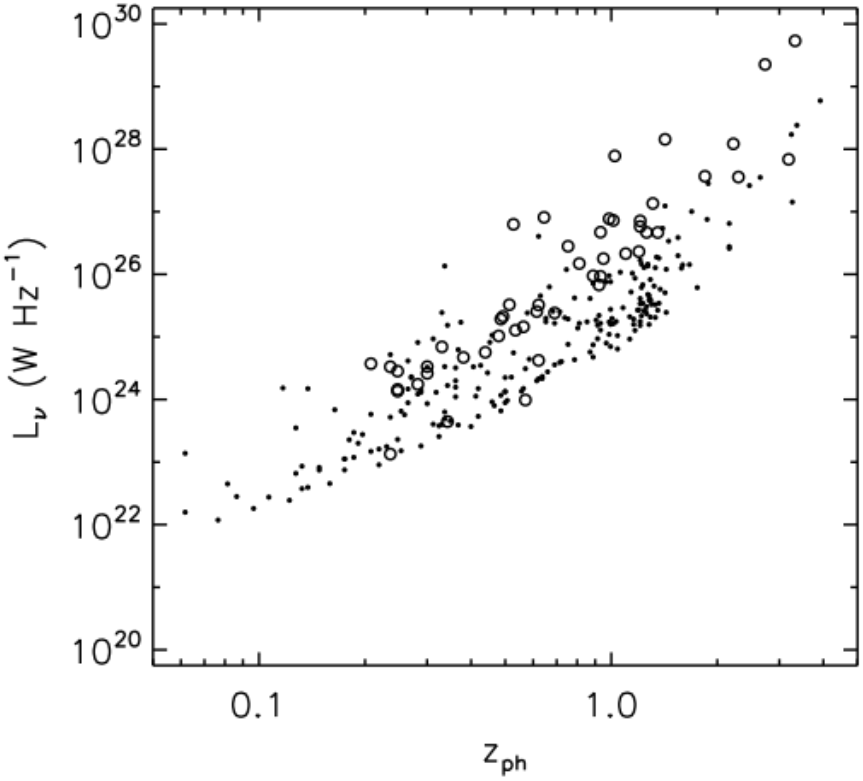


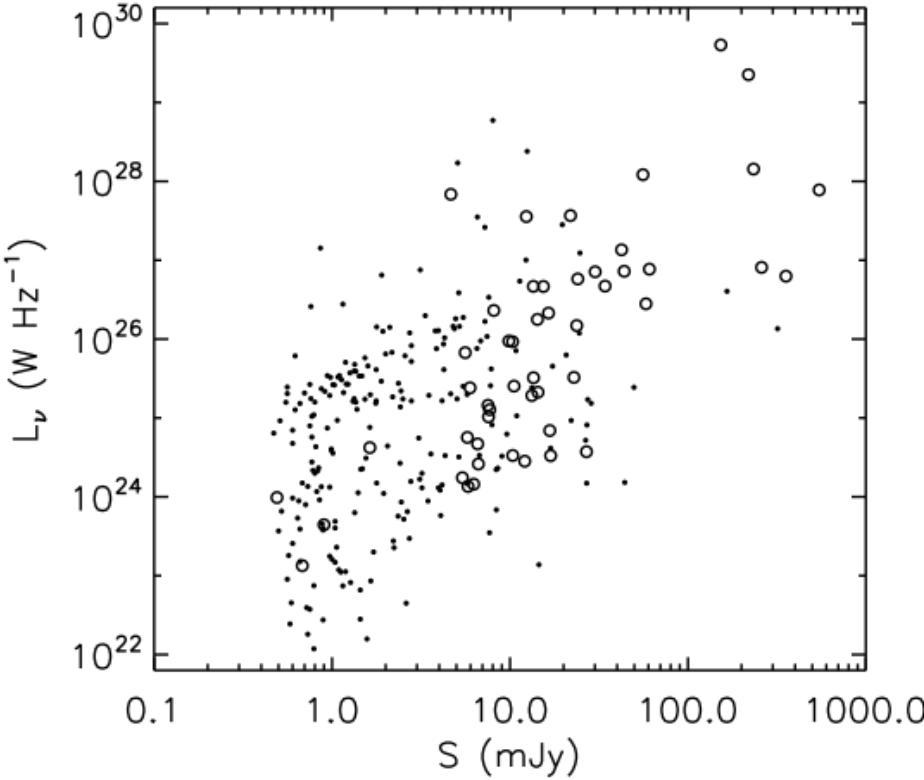
Simulations Faraday Rotation Measure 2-point correlation function from primordial cosmic magnetic field fluctuations (Kolatt 1998)

SKA1 Deep Polarization field

- 0.1 μJy sensitivity over a few sq degrees
- Observing frequencies 1 - 2 GHz
- Resolution about 1 arc-seconds (baseline ~40 km)
- RM accuracy ~1 rad m^{-2}
- Wide-field, broad-band full Stokes Imaging
- Wide-field imaging dynamic range > 10^{5-6}

- Cosmic evolution of magnetic fields in disk galaxies to redshift > 4
- Detect and study structure of primordial cosmic field fluctuations through RM 2-point correlation function


10^{30}
10^{28}
10^{26}
10^{24}
10^{22}
10^{20}
L_ν (W Hz^{-1})
0.1
1.0
z_{ph}


10^{30}
10^{28}
10^{26}
10^{24}
10^{22}
L_ν (W Hz^{-1})
0.1
1.0
10.0
100.0
1000.0
S (mJy)