GMRT/JVLA Deep Polarization Fields

Largest dish arrays in the world upgraded with wide-band correlators (SKA1 Full-Stokes Deep Field Pathfinders)

GMRT software correlator

- 230 hours of observing 2011/12
  - 0.61 GHz
  - 32 MHz bandwidth

JVLA Canadian WIDAR correlator

- 90 hours observing 2011/14
  - 4-6 GHz
  - 60 hours B & C configuration
  - 30 hours A configuration (in process)

GMRT/JVLA Deep Polarization Fields Team

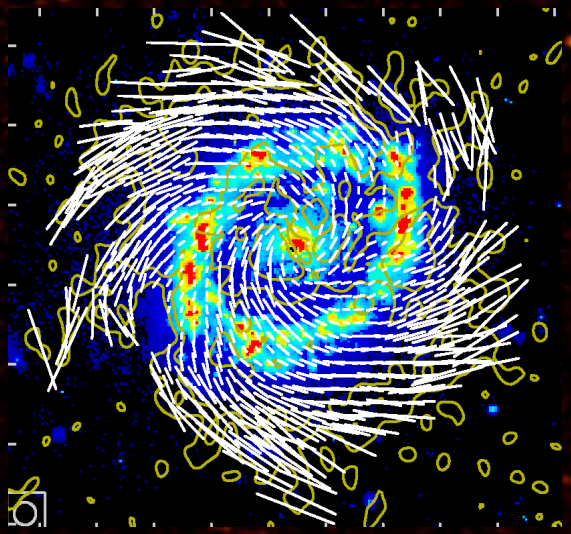
Julie Banfield	CSIRO
Sanjay Bhatnagar	NRAO
Jim Condon	NRAO
David Green	Cambridge University
Preshanth Jagannathan	University of Calgary
Nimisha Kantharia	NCRA
Roland Kothes	Herzberg Institute of Astrophysics
Rick Perley	NRAO
Jeroen Stil	University of Calgary
Russ Taylor (PI)	University of Cape Town & the Western Cape
Jasper Wall	University of British Columbia
Tony Willis	DRAO

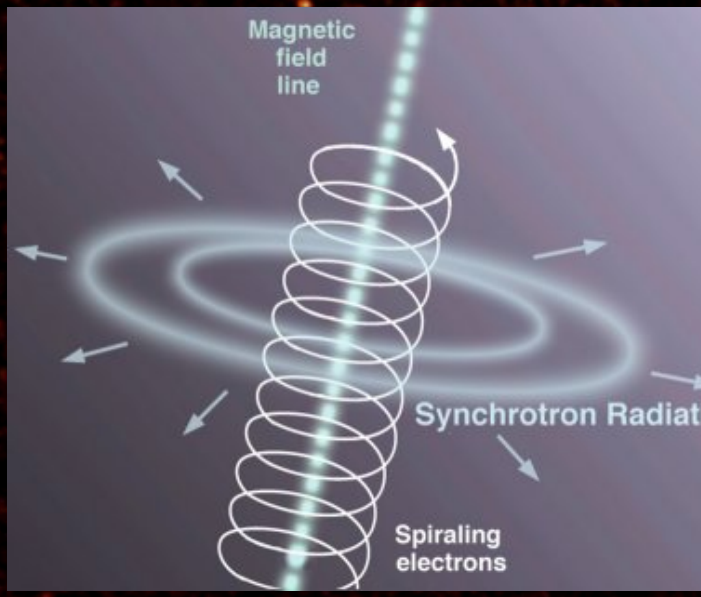
Why full Stokes?

Radio Polarization probes magnetic fields

Polarization of Synchrotron Radiation

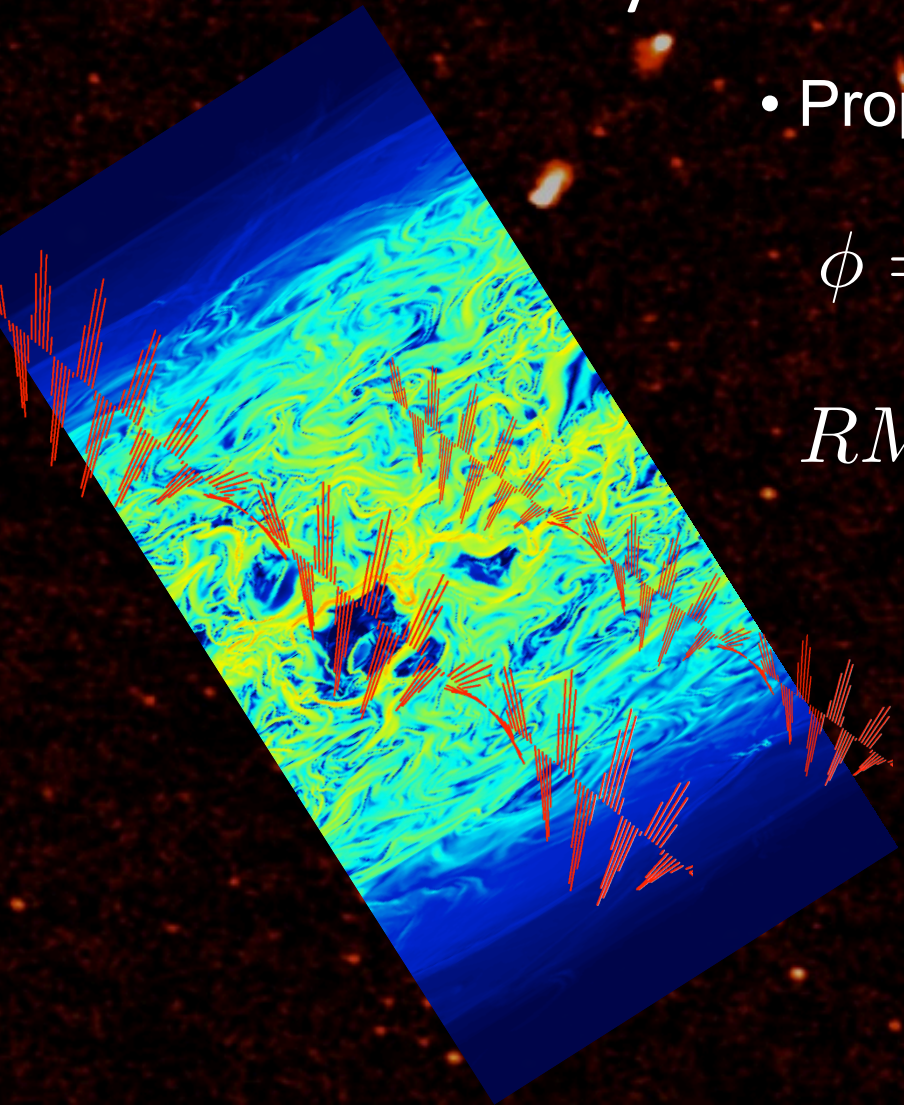
- presence of field
- direction of field
- strength of field
- uniformity and spatial scales of field





AstronomyOnline.org

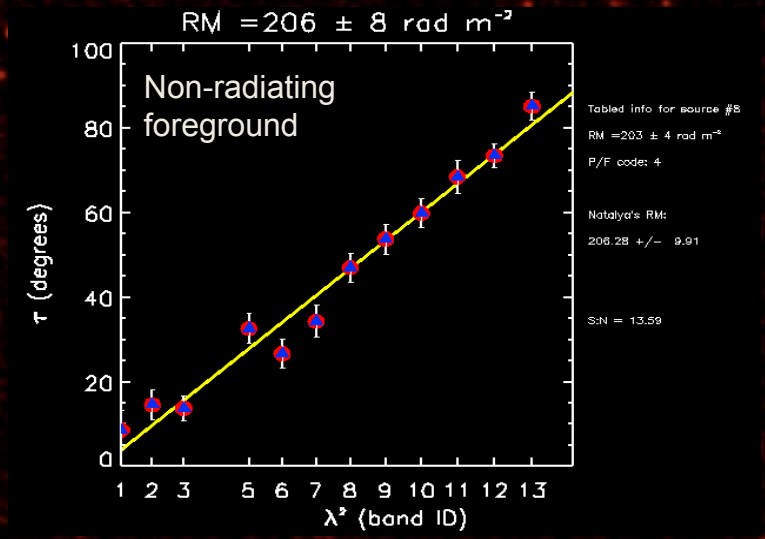
Why full Stokes?
Radio Polarization probes magnetic fields
Faraday Rotation



- Propagation through diffuse plasma

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

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



Some core questions in cosmic magnetism

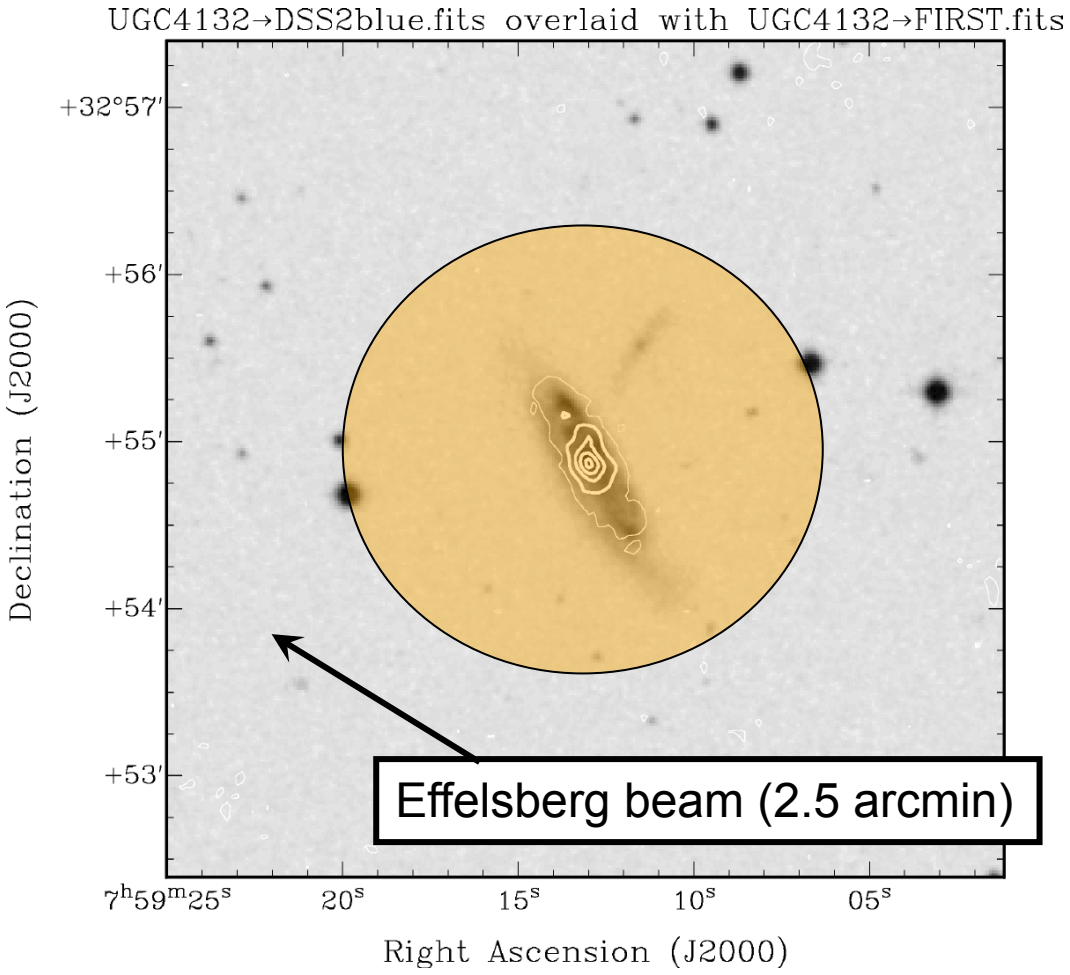
- Magnetism and galaxy evolution
  - When and how did coherent magnetic fields emerge in galaxies?
  - What is their relationship to and role in the star formation histo of the universe?
  - Role in global energetics and interactions with intergalactic environment
- Detection and characterization of the magnetic cosmic we
  - Can it be detected?
  - How did it arise?
  - What are its properties and how does it relate to large scale structure of matter?

Both require polarization observations of μJy radio sources

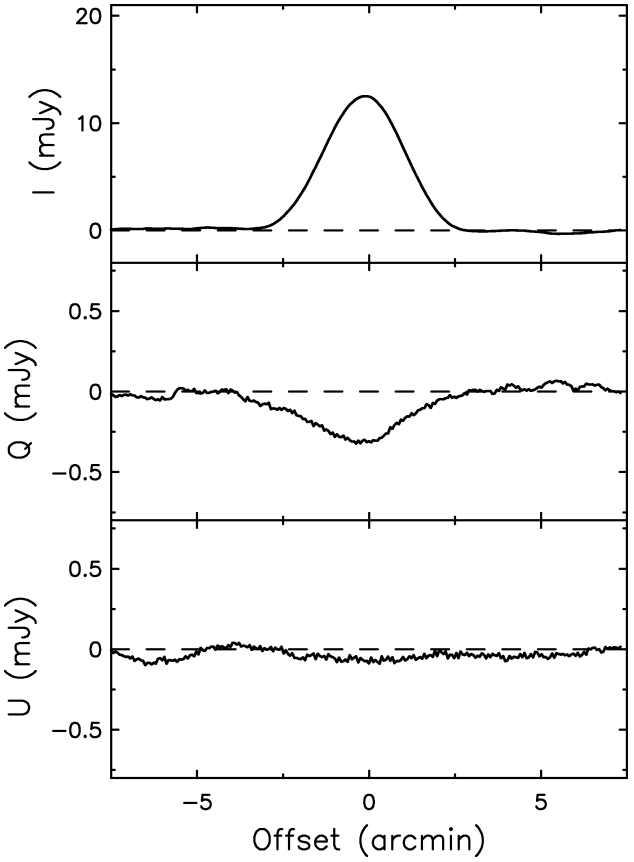
Effelsberg polarisation survey of local disk galaxies

Stil, Mitchell, Krause, Beck, & Taylor (2009)

UGC 4132: Milky Way size galaxy at 71 Mpc

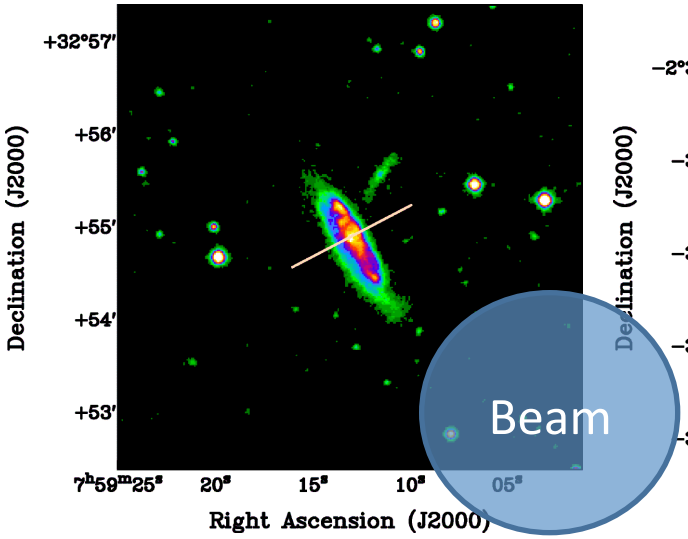


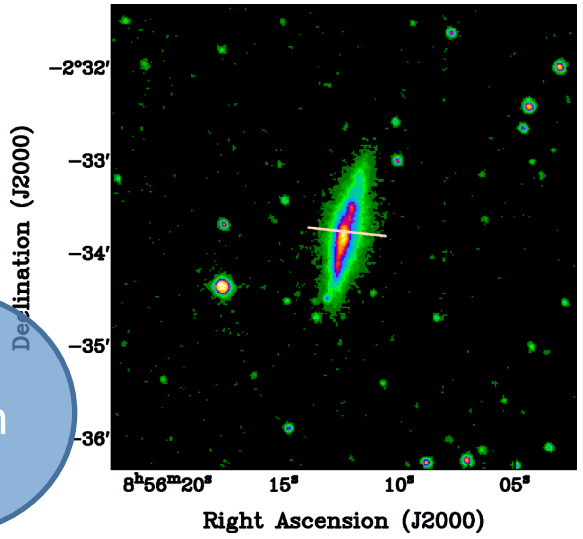
Polarization at 4.8 GHz

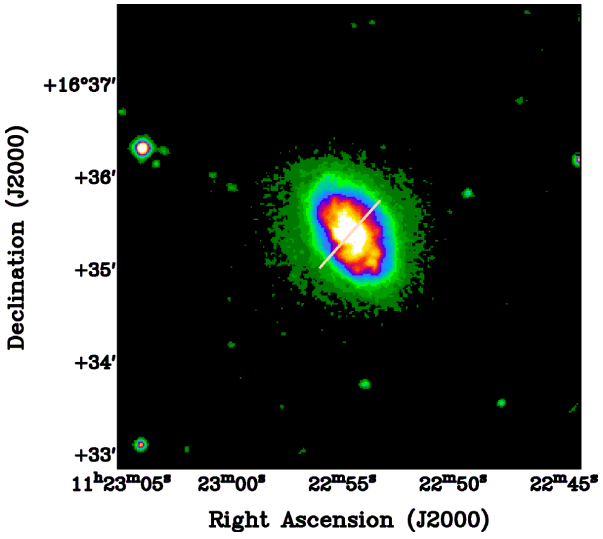


Effelsberg polarisation survey of disk local galaxies

Stil, Krause, Mitchell, Beck & Taylor (2009)







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}

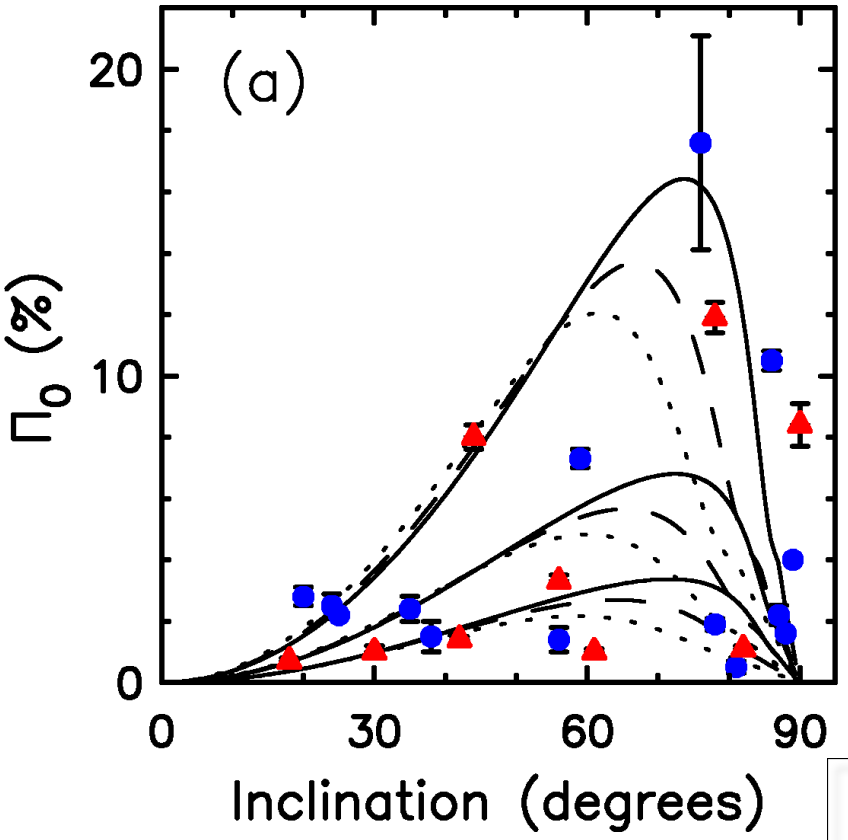
UGC 6936

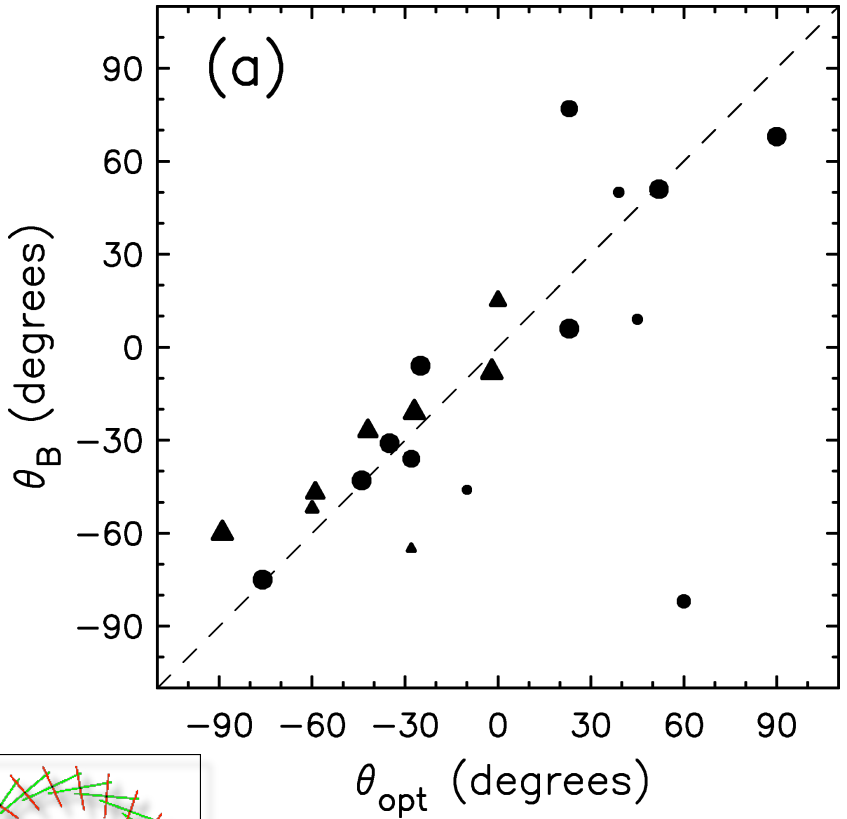
V_{hel} = 1473 km s^{-1}

distance = 18 Mpc

V_{rot} = 198 km s^{-1}

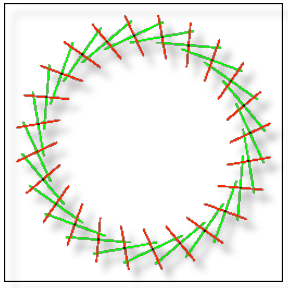
Integrated Polarization of Nearby Disk Galaxies





Model curves vary |B|, f_B, n_e

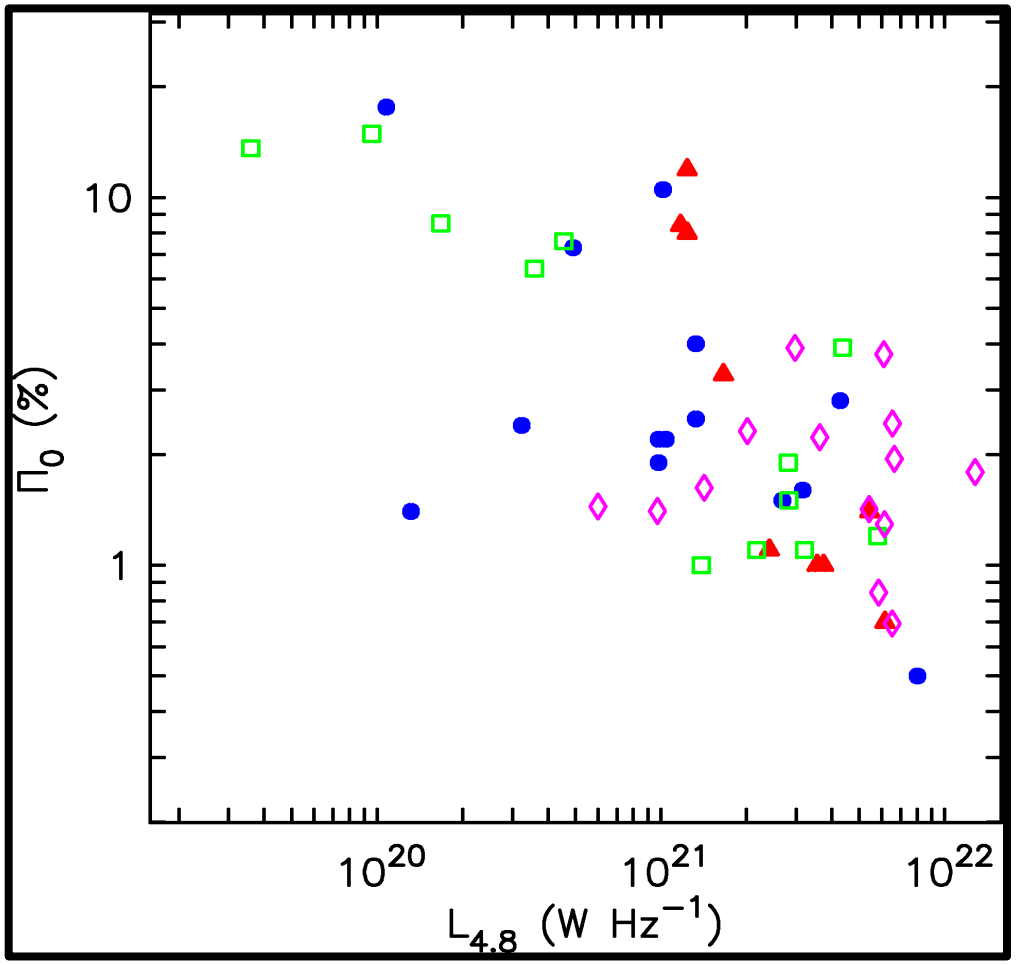
$f_B = B_{random}/B_{regular}$



Stil, Krause, Beck & Taylor (2009)

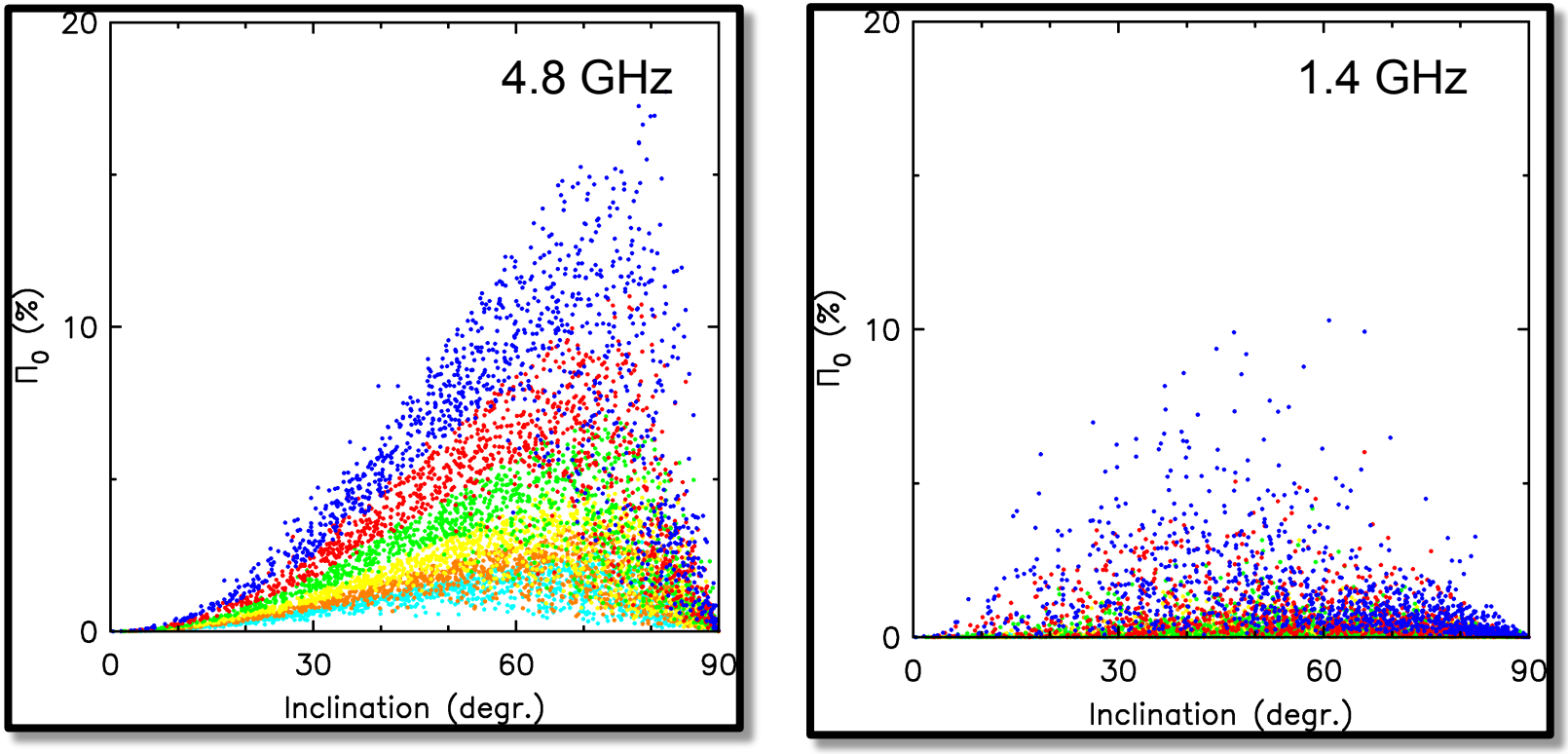
Integrated Fractional Polarization and Radio Luminosity

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



Statistical Integrated Polarization of Galaxies versus Frequency

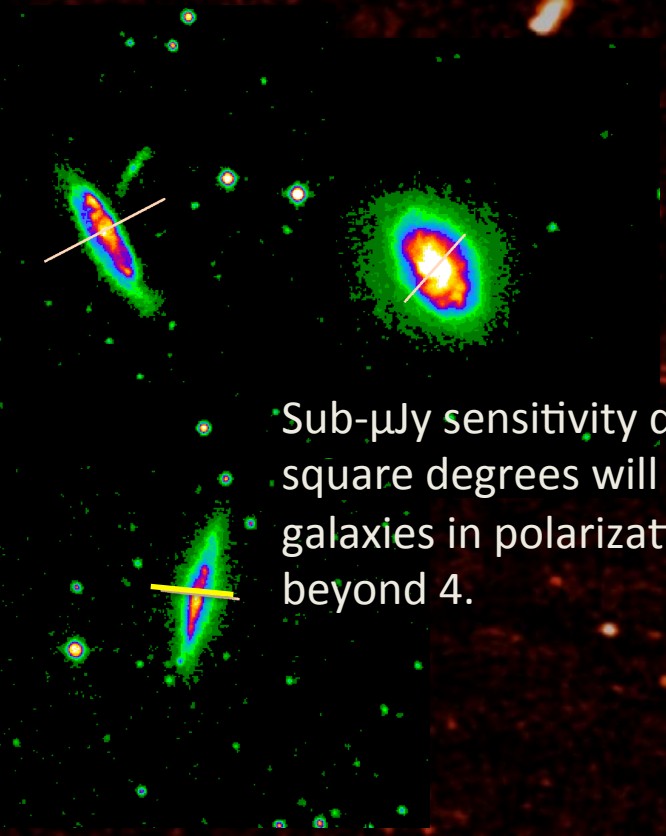
Simulation (20,000 random orientation disk galaxies)

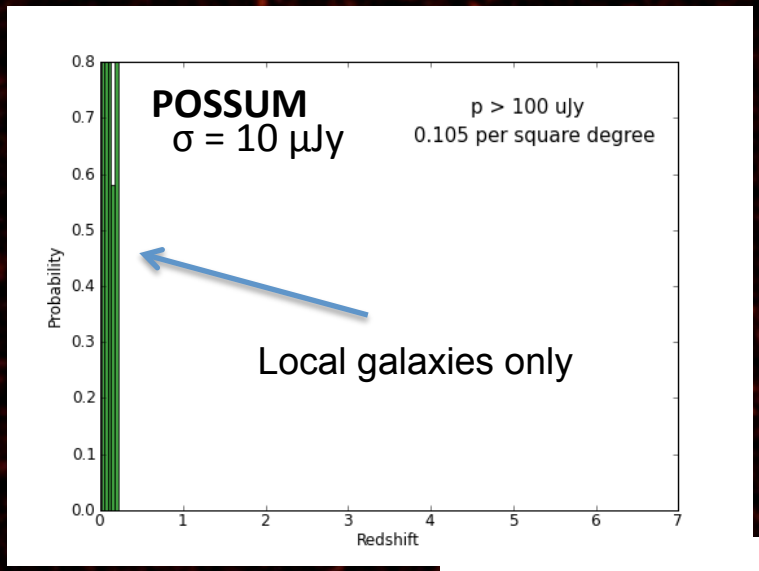


Variation of model parameters; No noise included

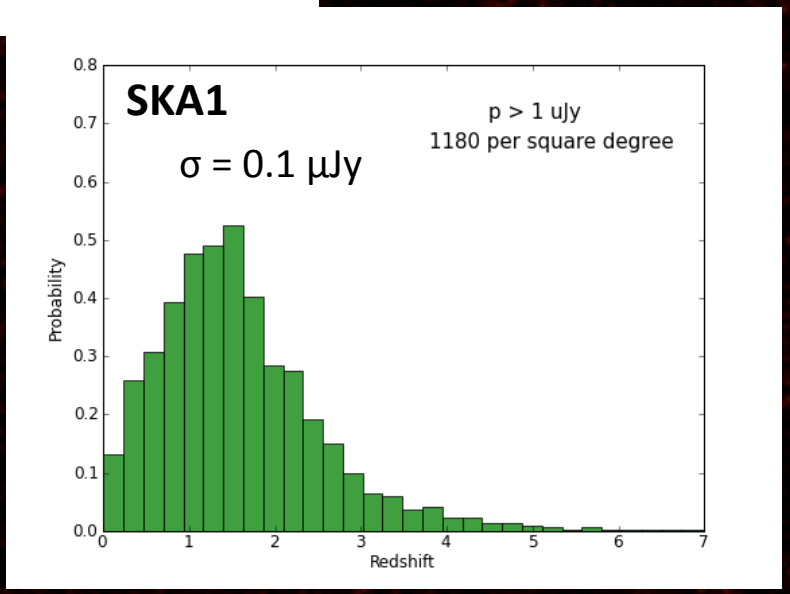
Stil (2009)

Magnetism and Galaxy Evolution

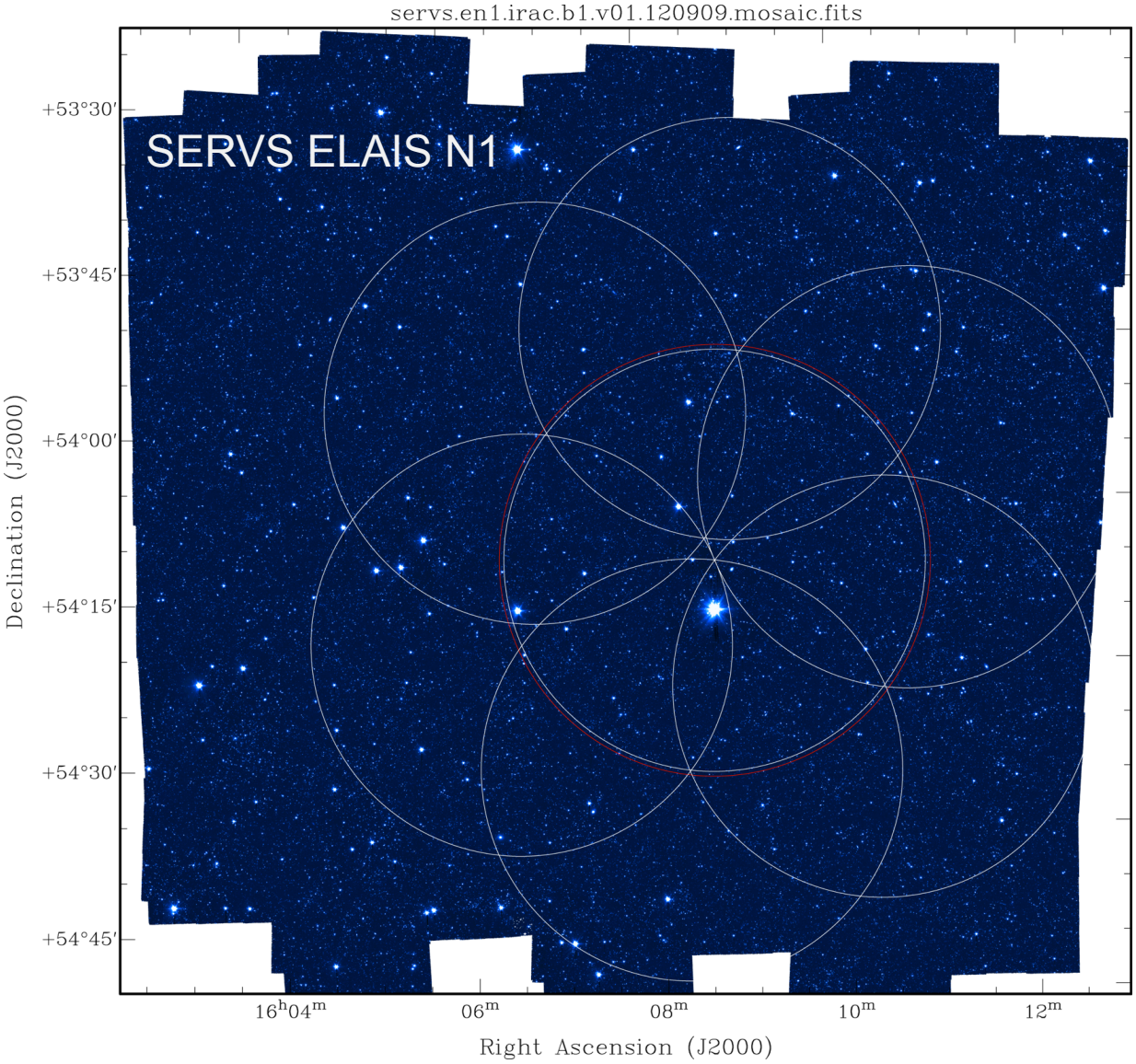




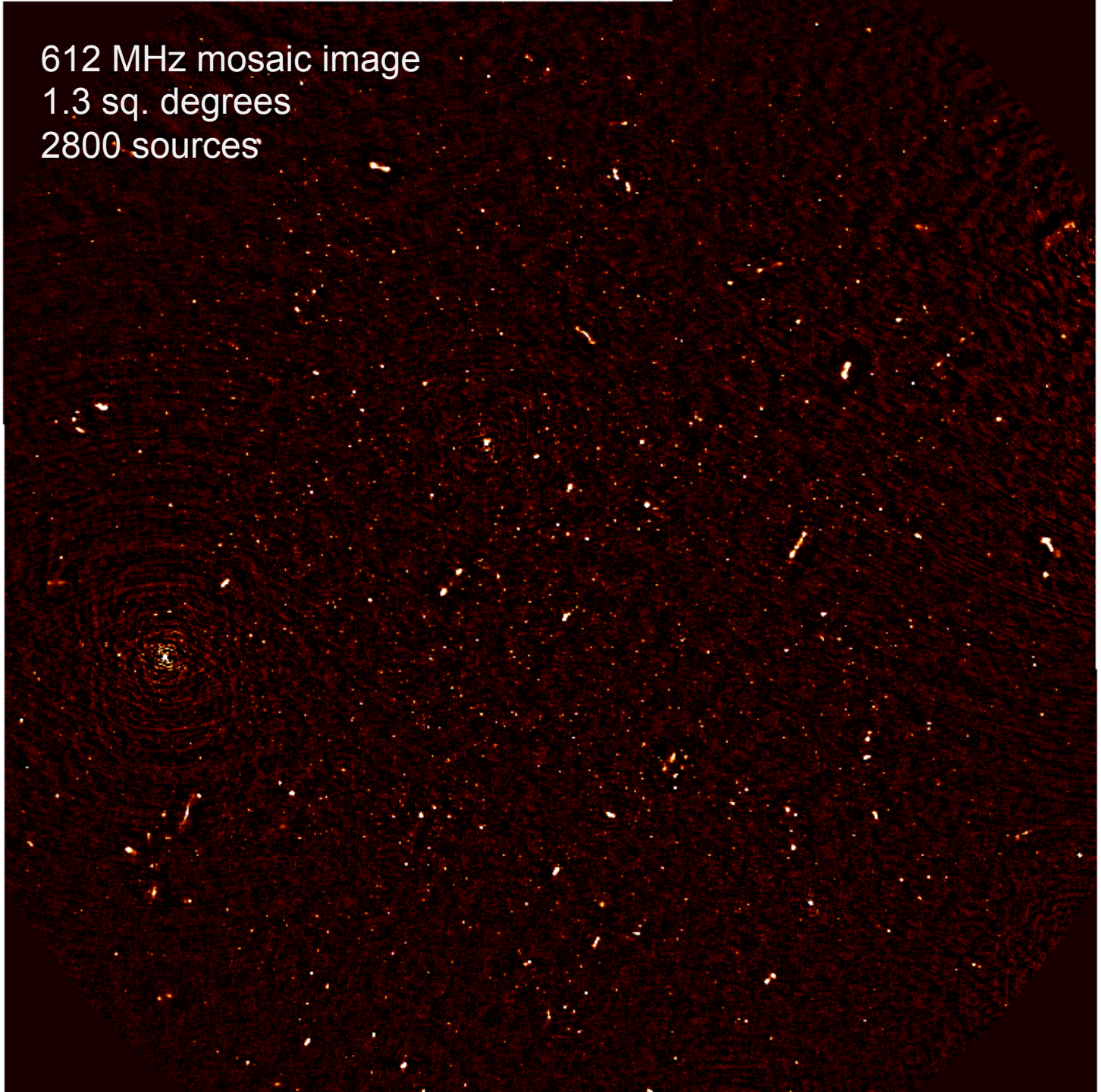
Sub-μJy sensitivity deep fields over several square degrees will detect thousands of galaxies in polarization out to redshifts beyond 4.

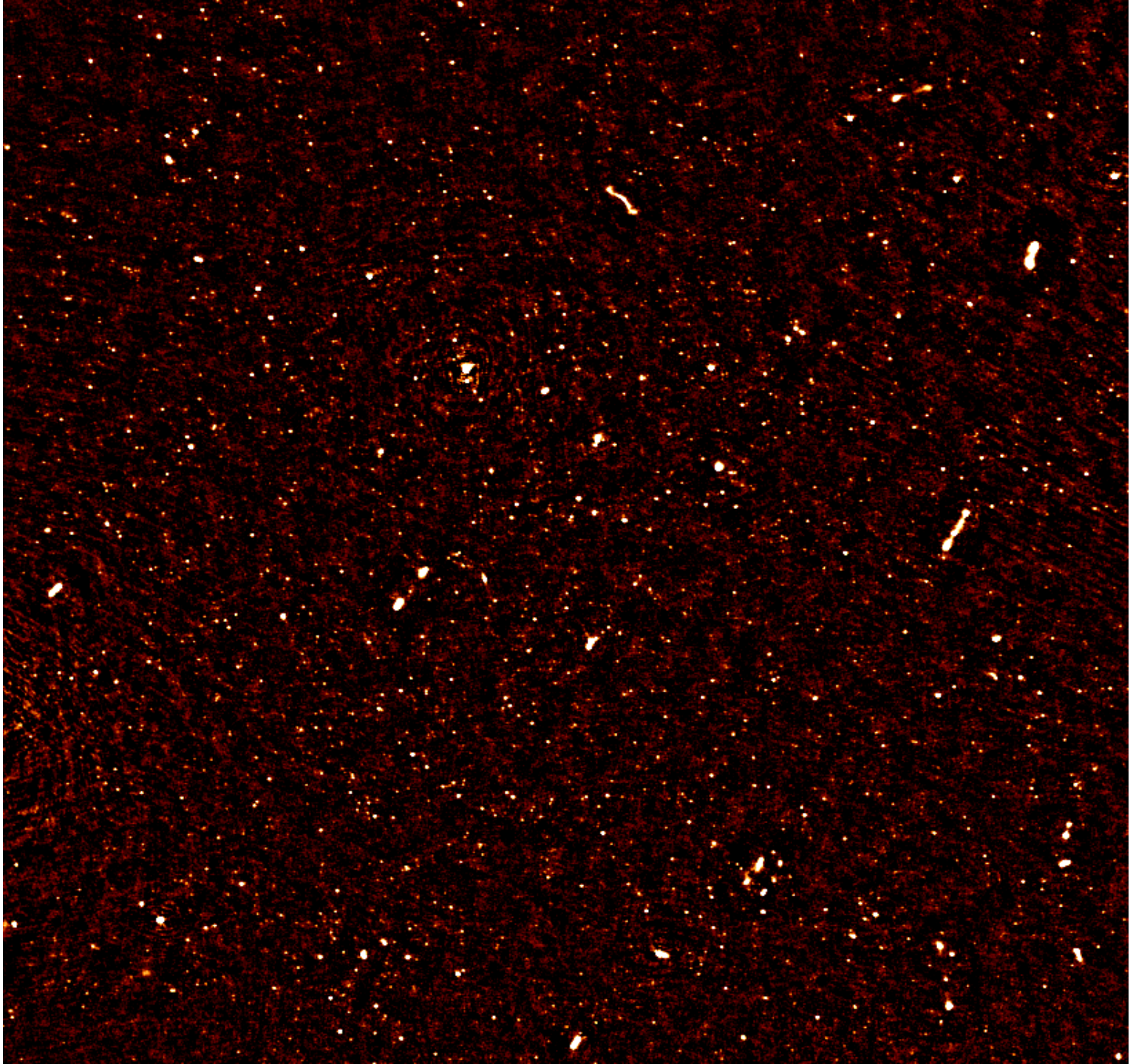


GMRT ultra-deep Polarization Field



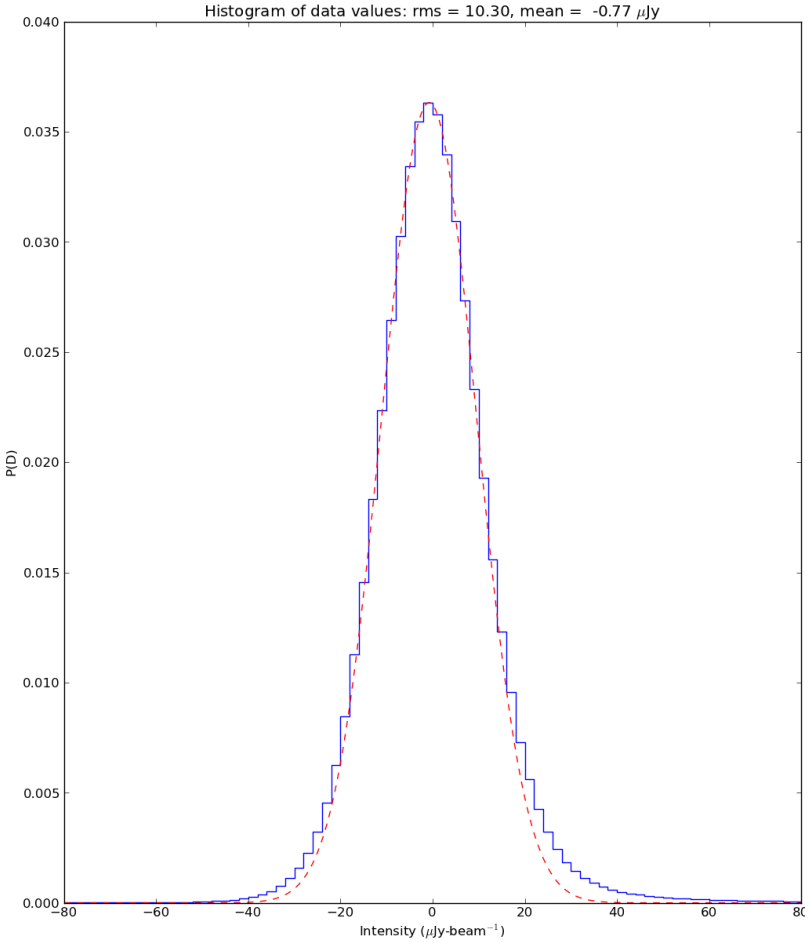
Spitzer Extragalactic Representative Volume Survey (Mauduit et al. 2012, PASP, 124, 714)

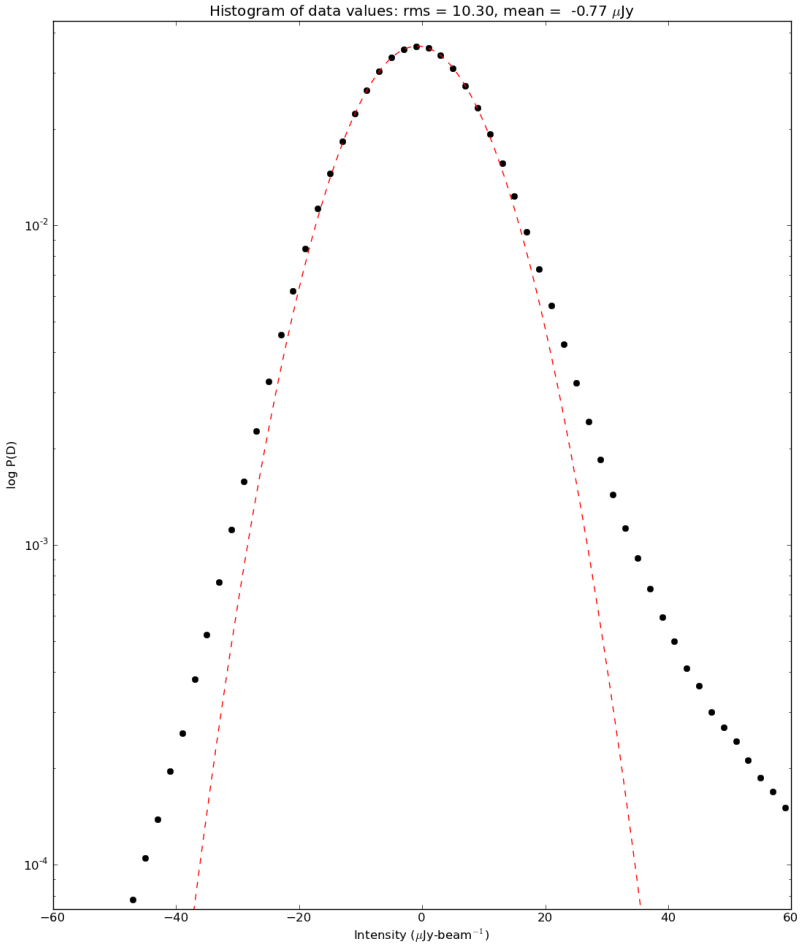

612 MHz mosaic image
1.3 sq. degrees
2800 sources

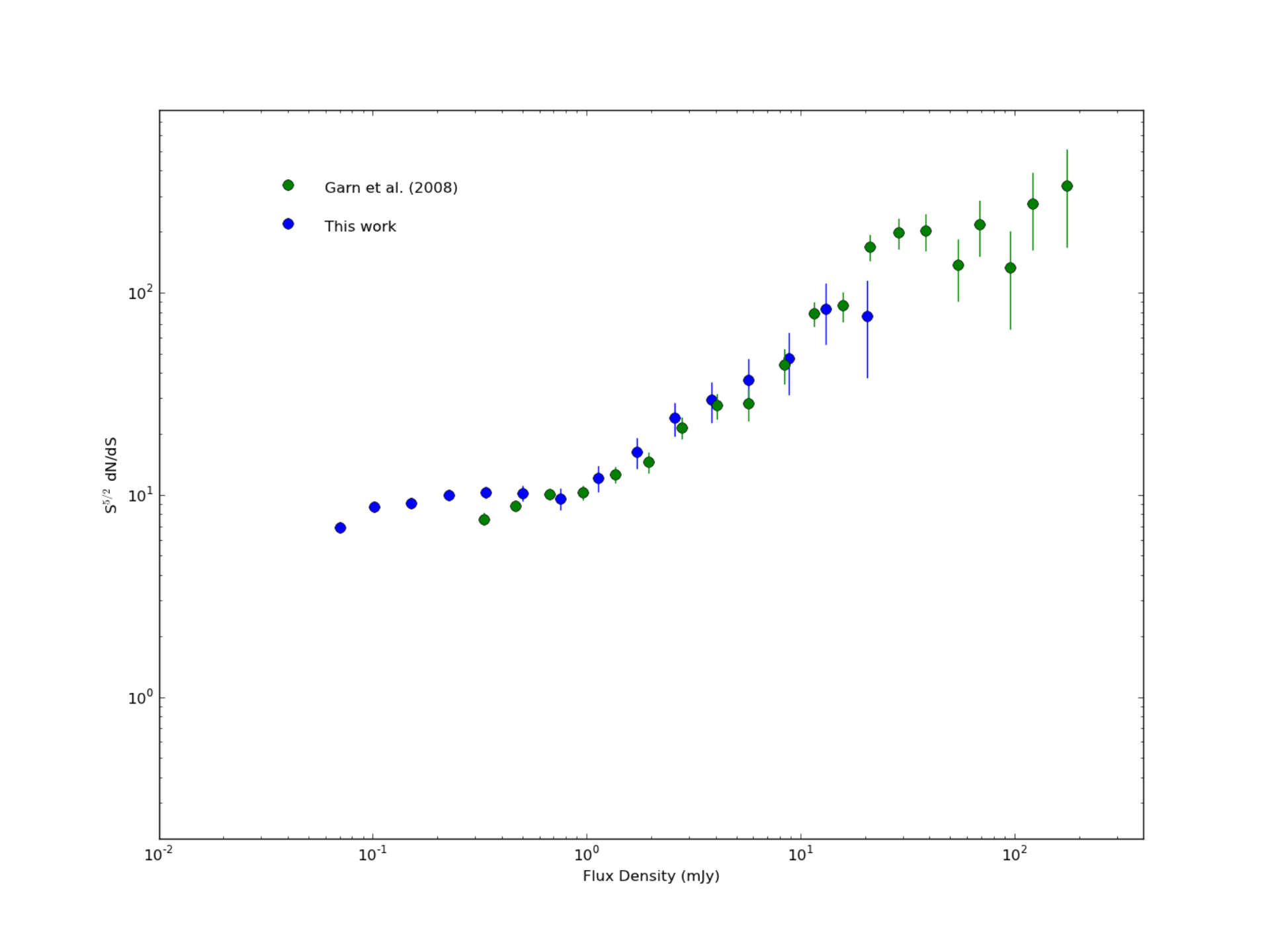


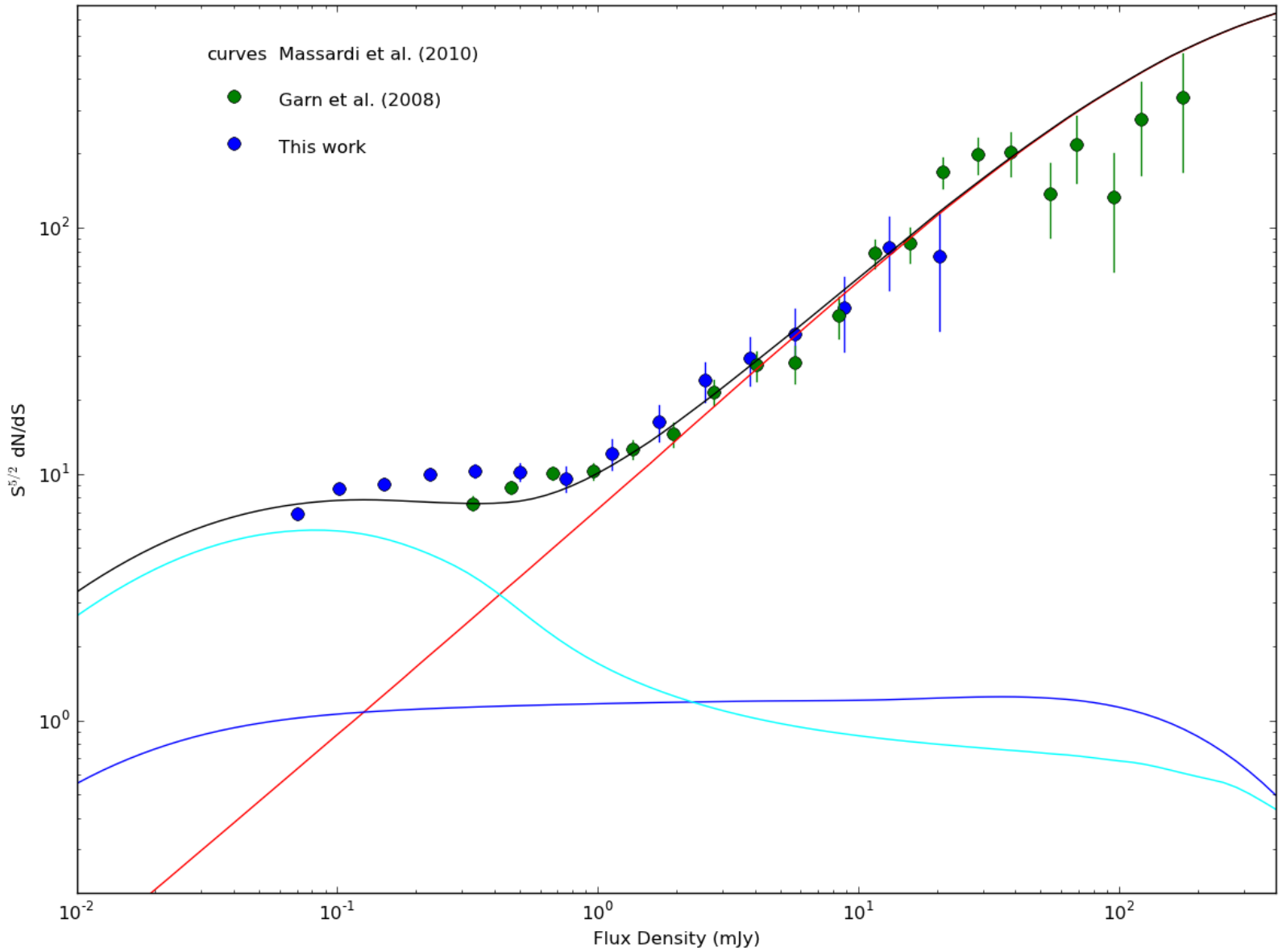
Stokes I P(D) rms = 10.3 μJy

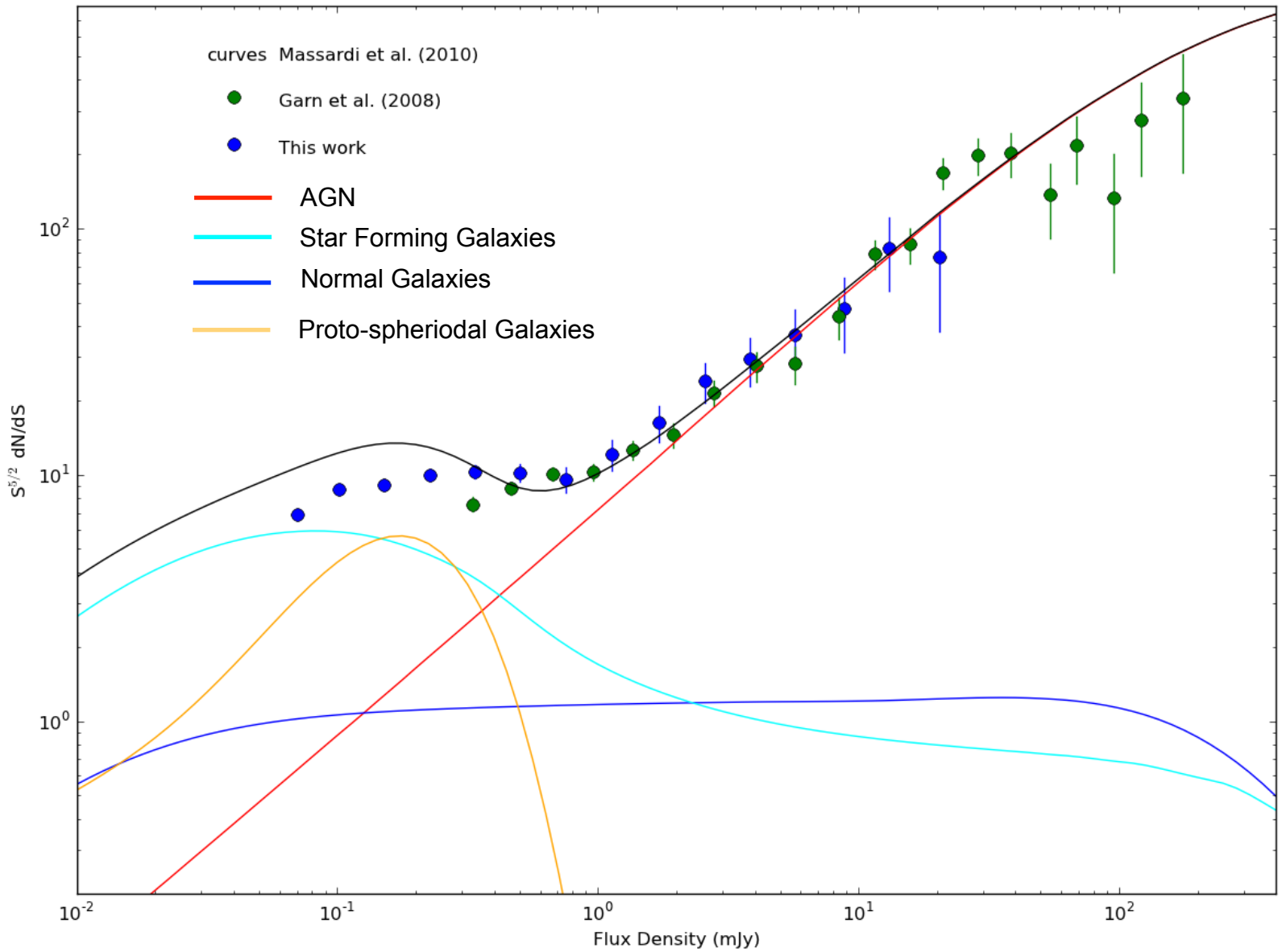
(5.2μJy @ 1.4 GHz)



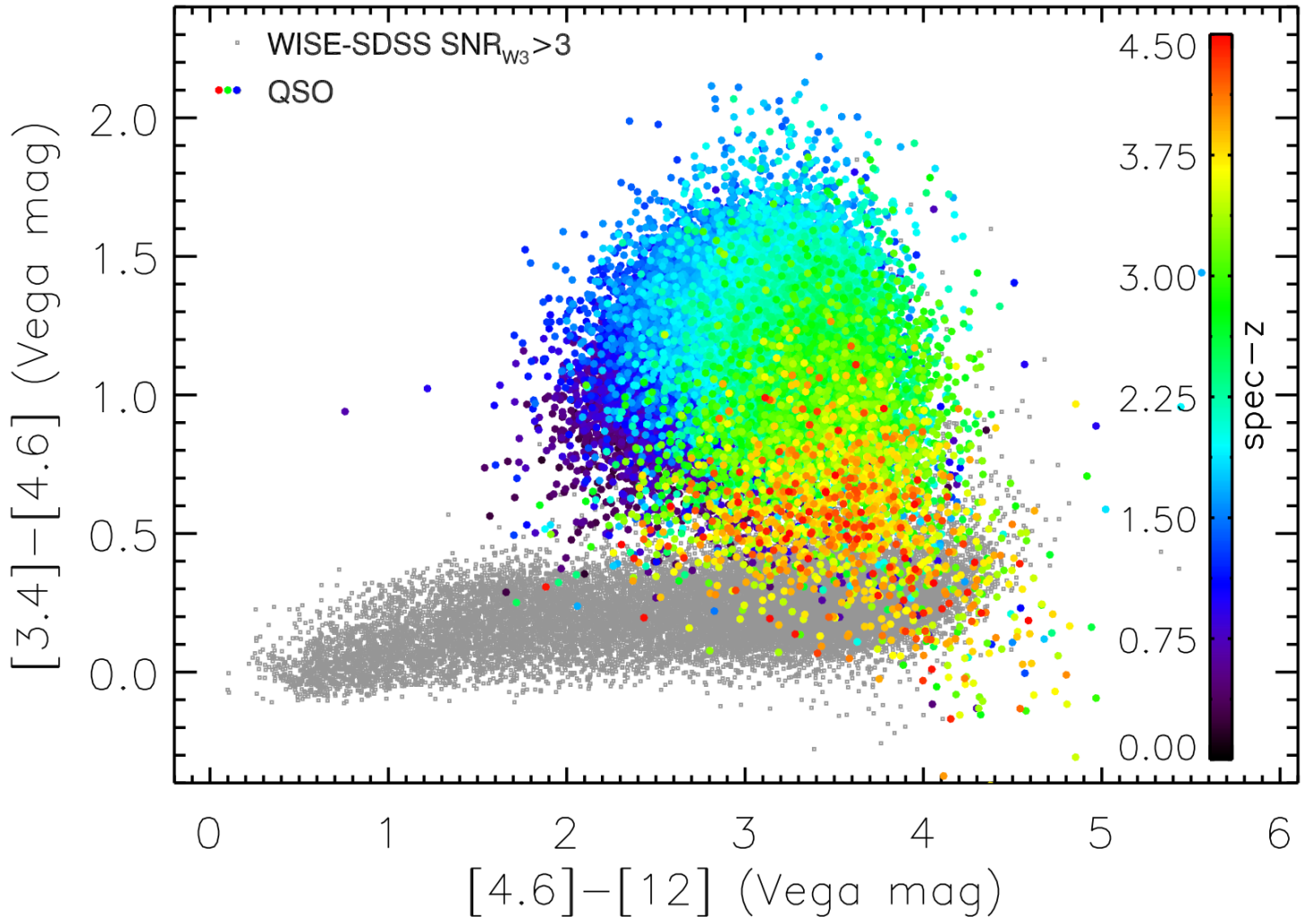



Garn et al. (2008)
This work
$S^{5/2}$ dN/dS
10^2
10^1
10^0
10^{-2}
10^{-1}
10^0
10^1
10^2
Flux Density (mJy)


curves Massardi et al. (2010)
Garn et al. (2008)
This work
$S^{5/2}$ dN/dS
10^2
10^1
10^0
10^{-2}
10^{-1}
10^0
10^1
10^2
Flux Density (mJy)

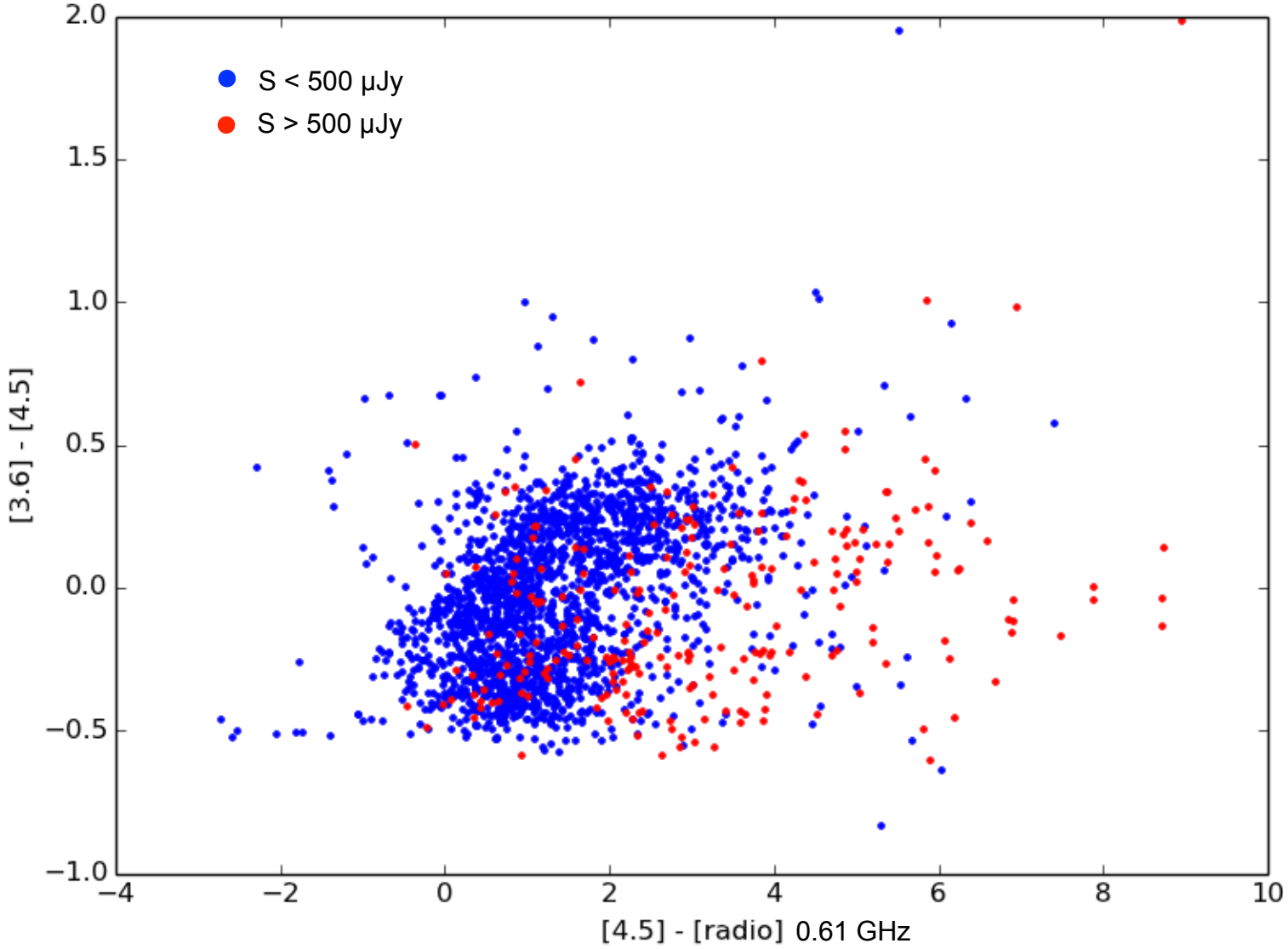

curves Massardi et al. (2010)
Garn et al. (2008)
This work
AGN
Star Forming Galaxies
Normal Galaxies
Proto-spheriodal Galaxies
$S^{5/2}$ dN/dS
Flux Density (mJy)
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

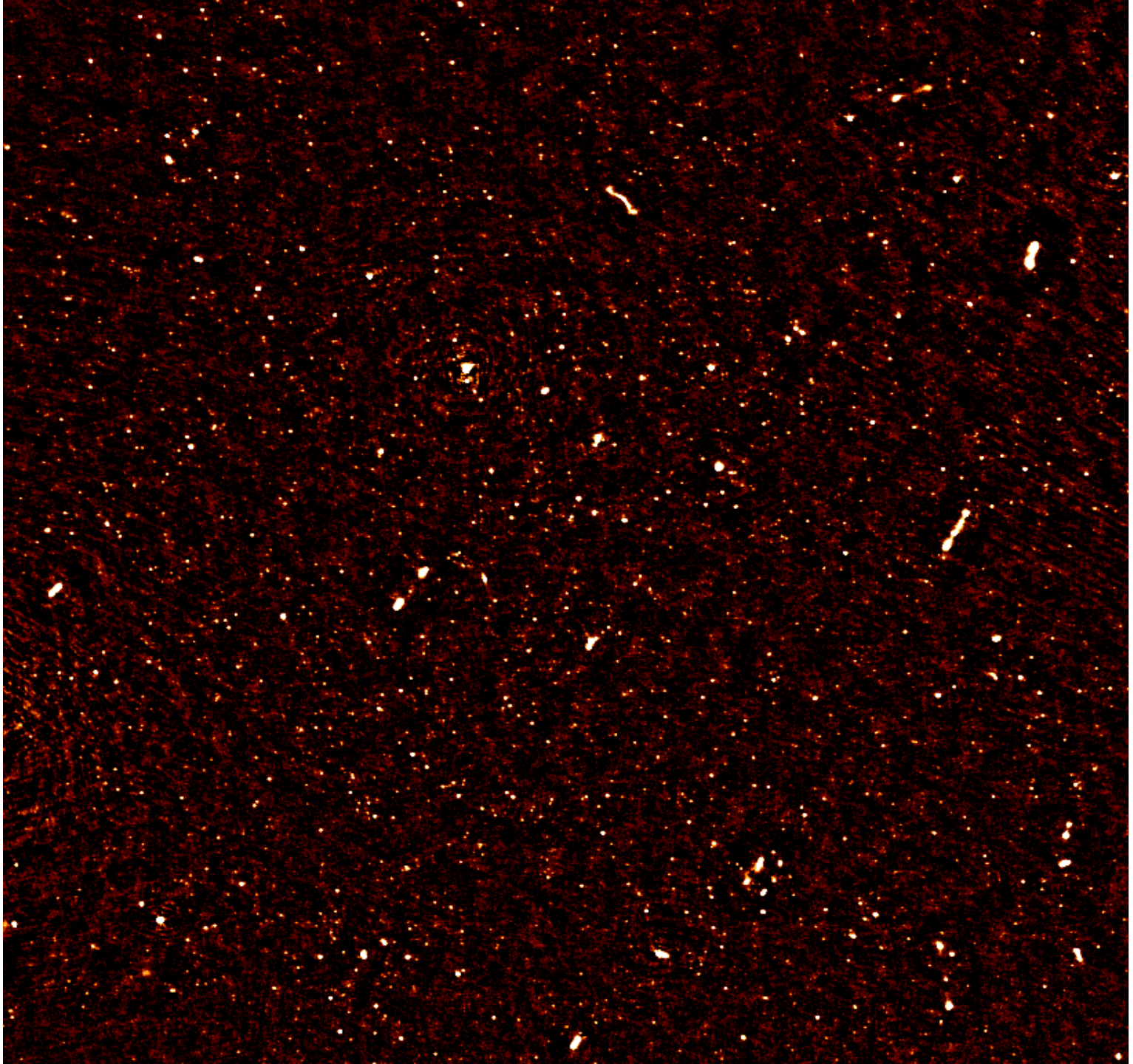
WISE W1-W2 colour classification



Lin et al. 2013, AJ, 145, 55.

SERVS-radio colours

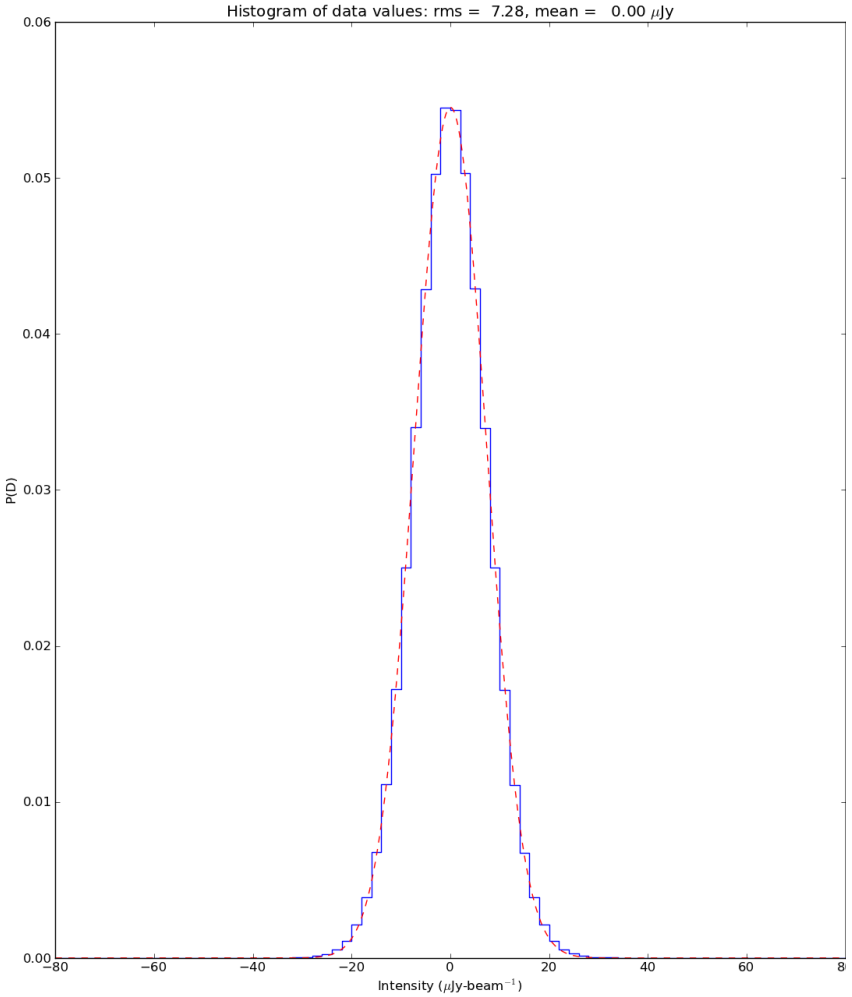


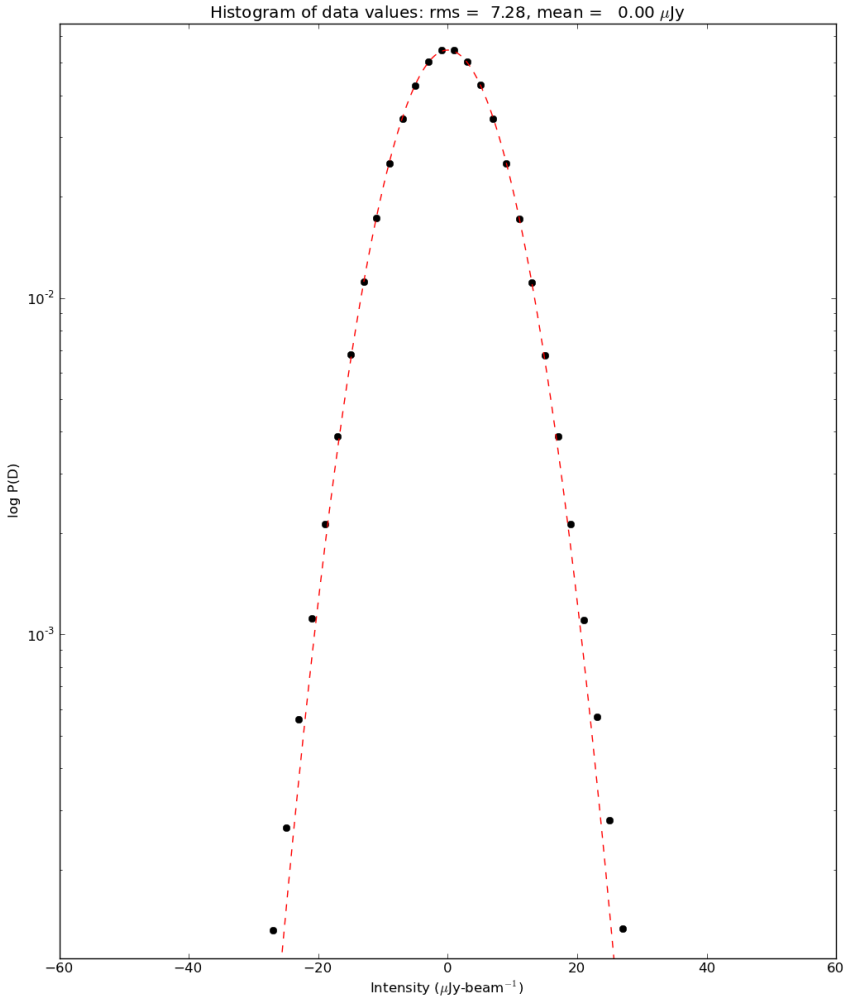


Stokes Q P(D)

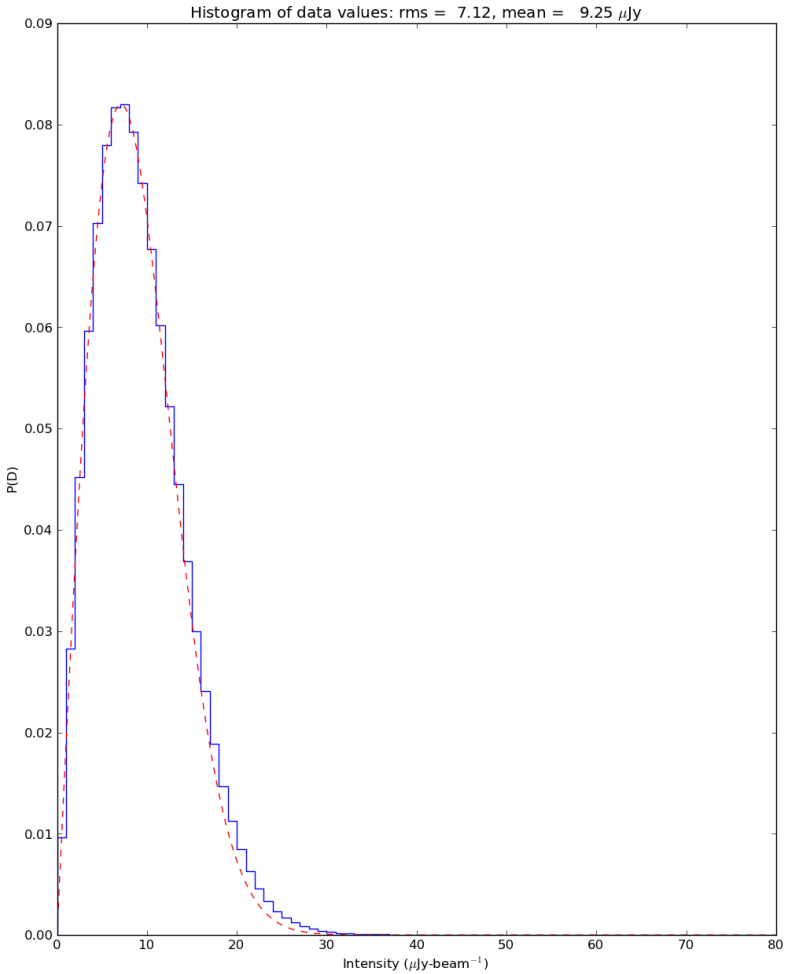
rms = 7.28 μJy

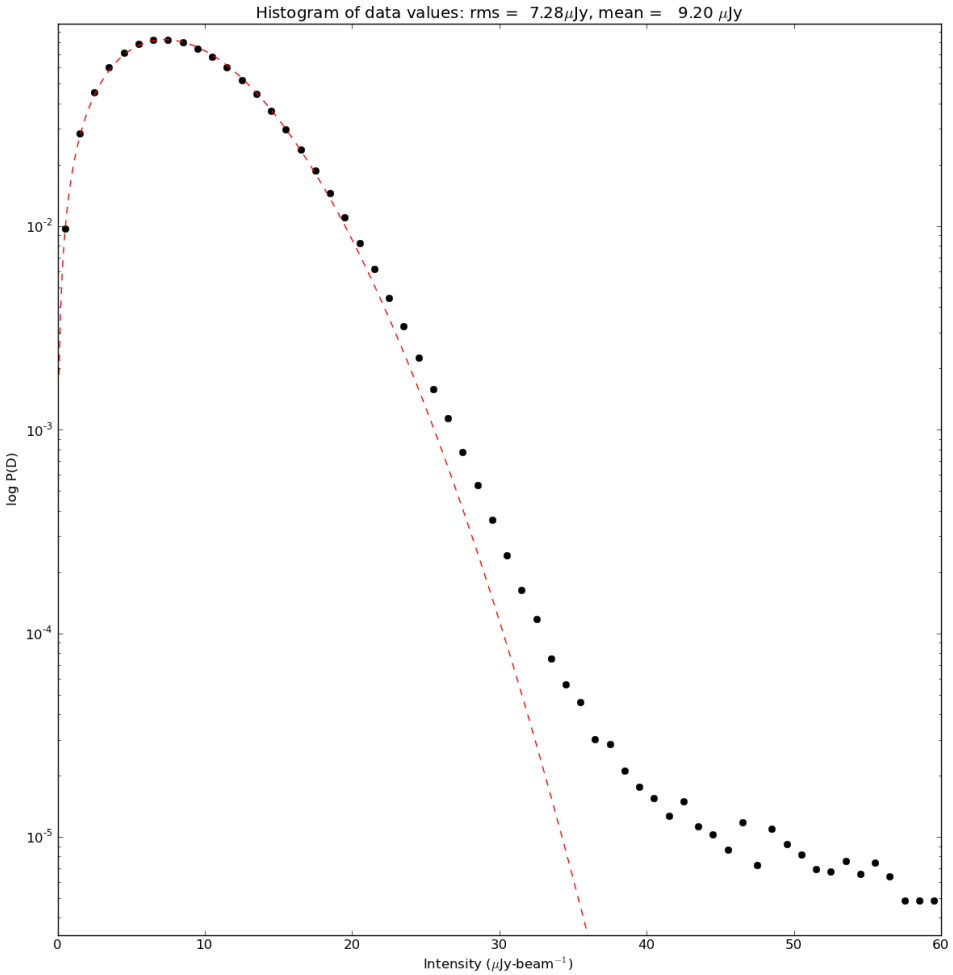
(3.7μJy @ 1.4 GHz)



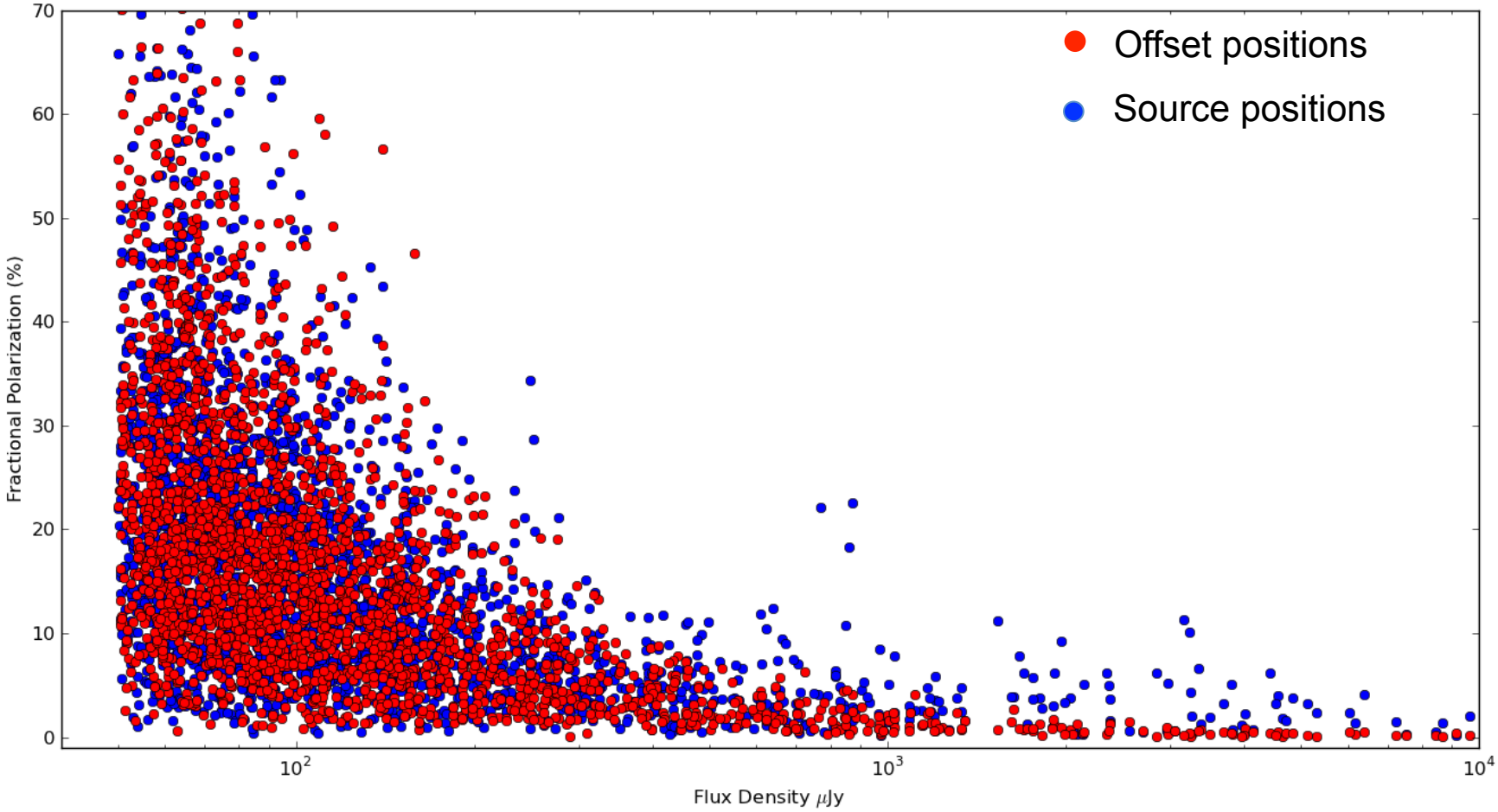


Polarized Intensity P(D)



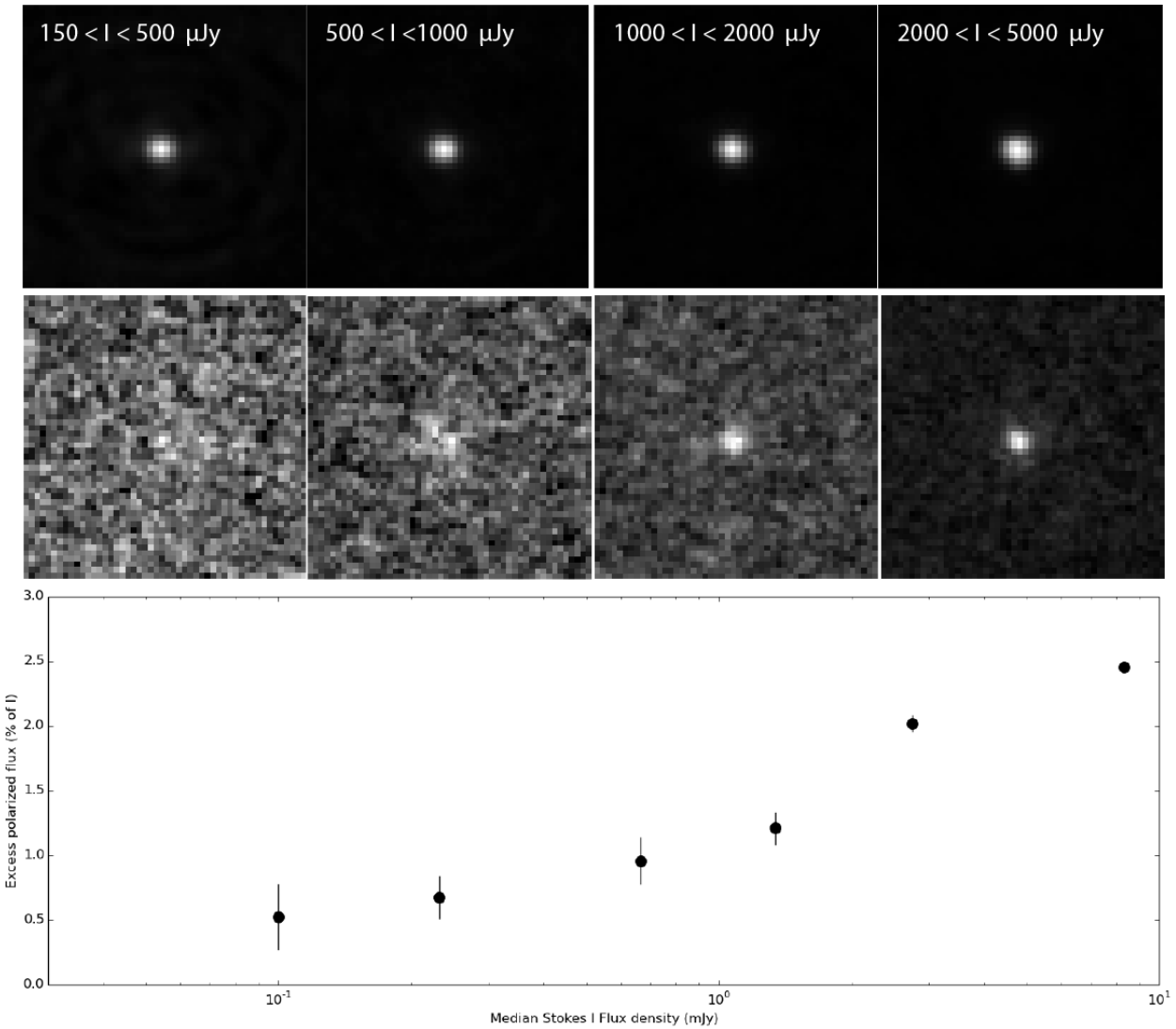


Fractional Polarization Distribution

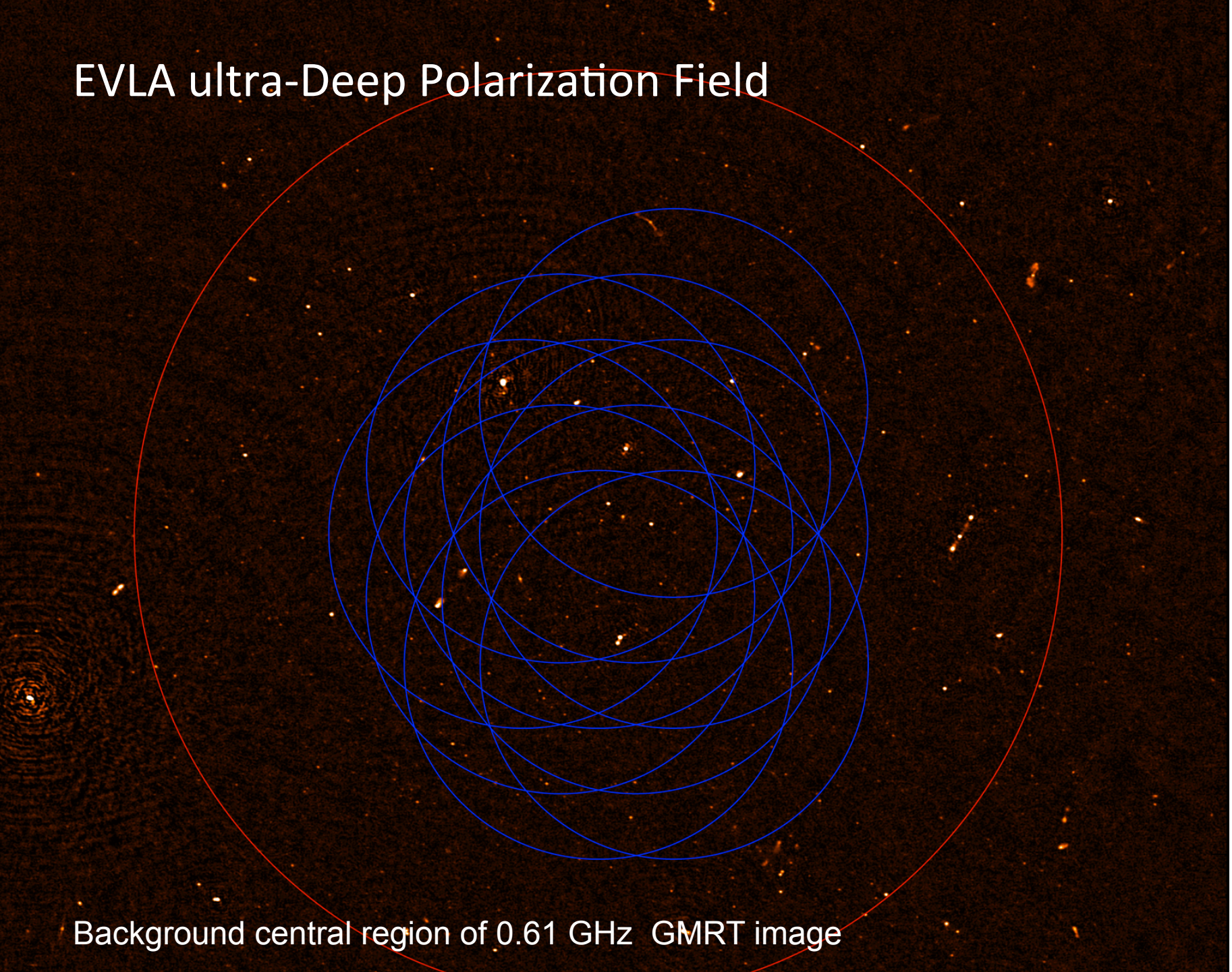


Which points are real signal?

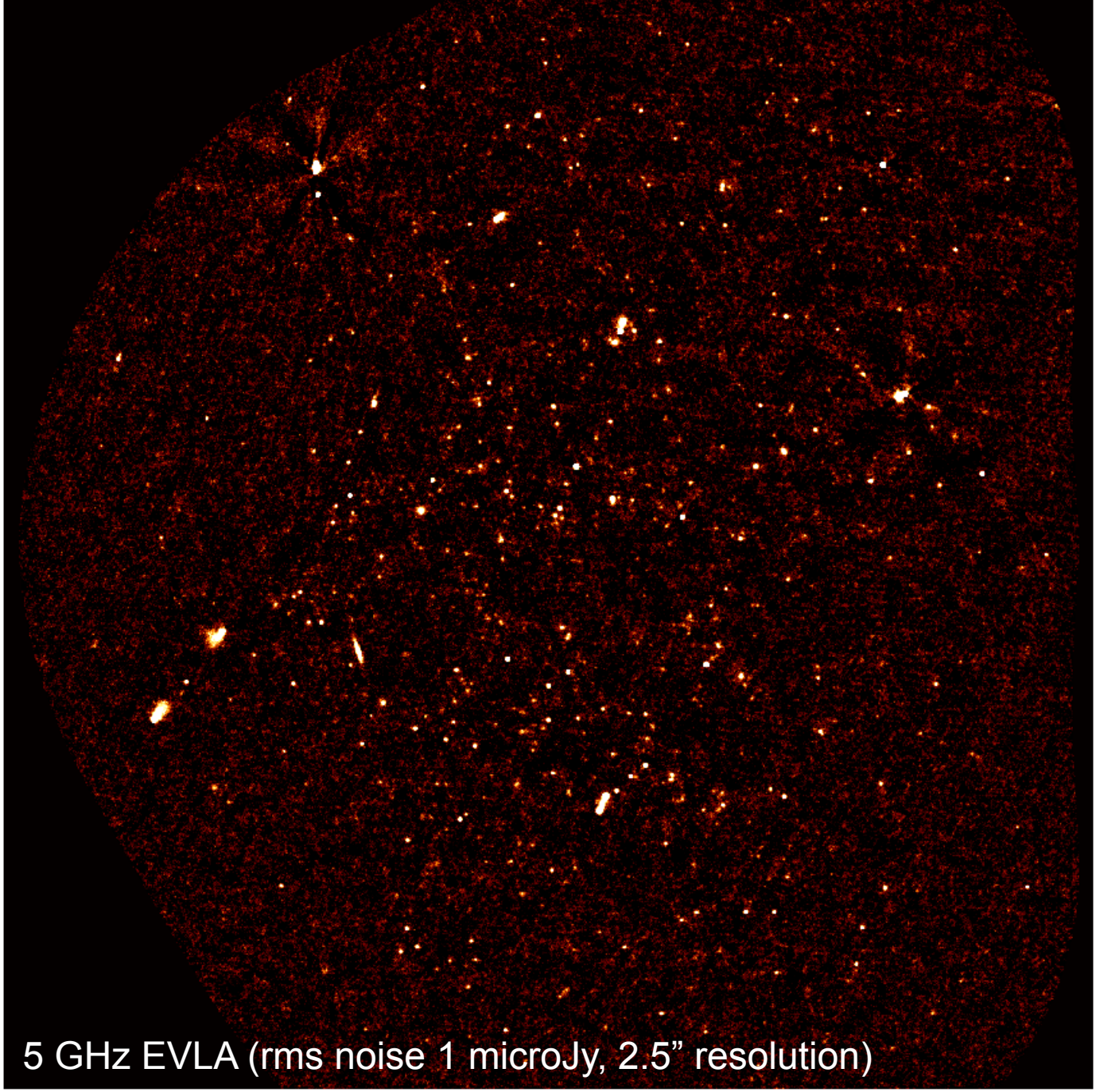
Polarization Stacking in Stokes I flux density



EVLA ultra-Deep Polarization Field

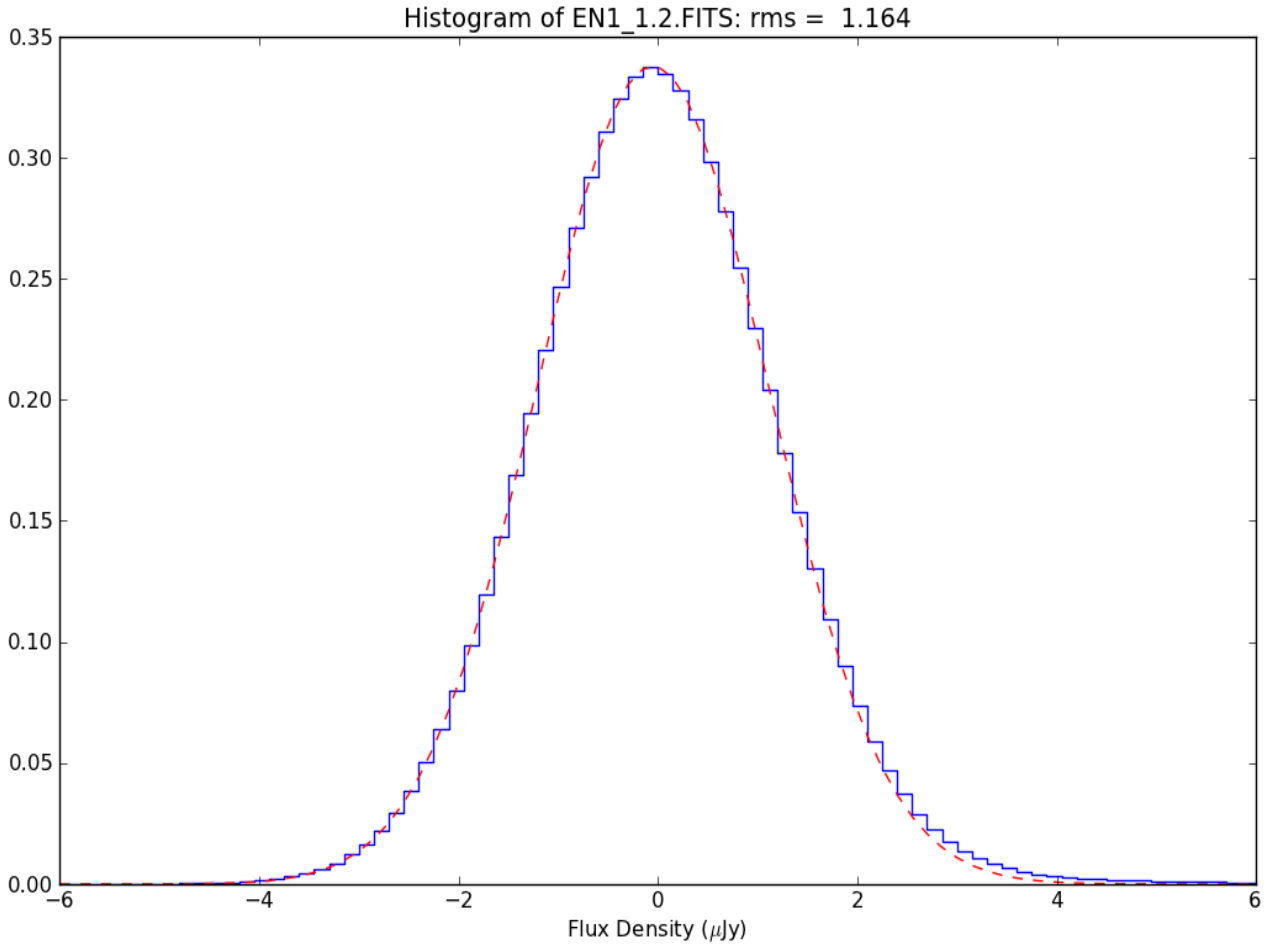


Background central region of 0.61 GHz GMRT image


5 GHz EVLA (rms noise 1 microJy, 2.5” resolution)
9.07e-07
1.91e-06
2.93e-06
3.94e-06
4.95e-06
5.96e-06
6.97e-06
7.99e-06
8.99e-06

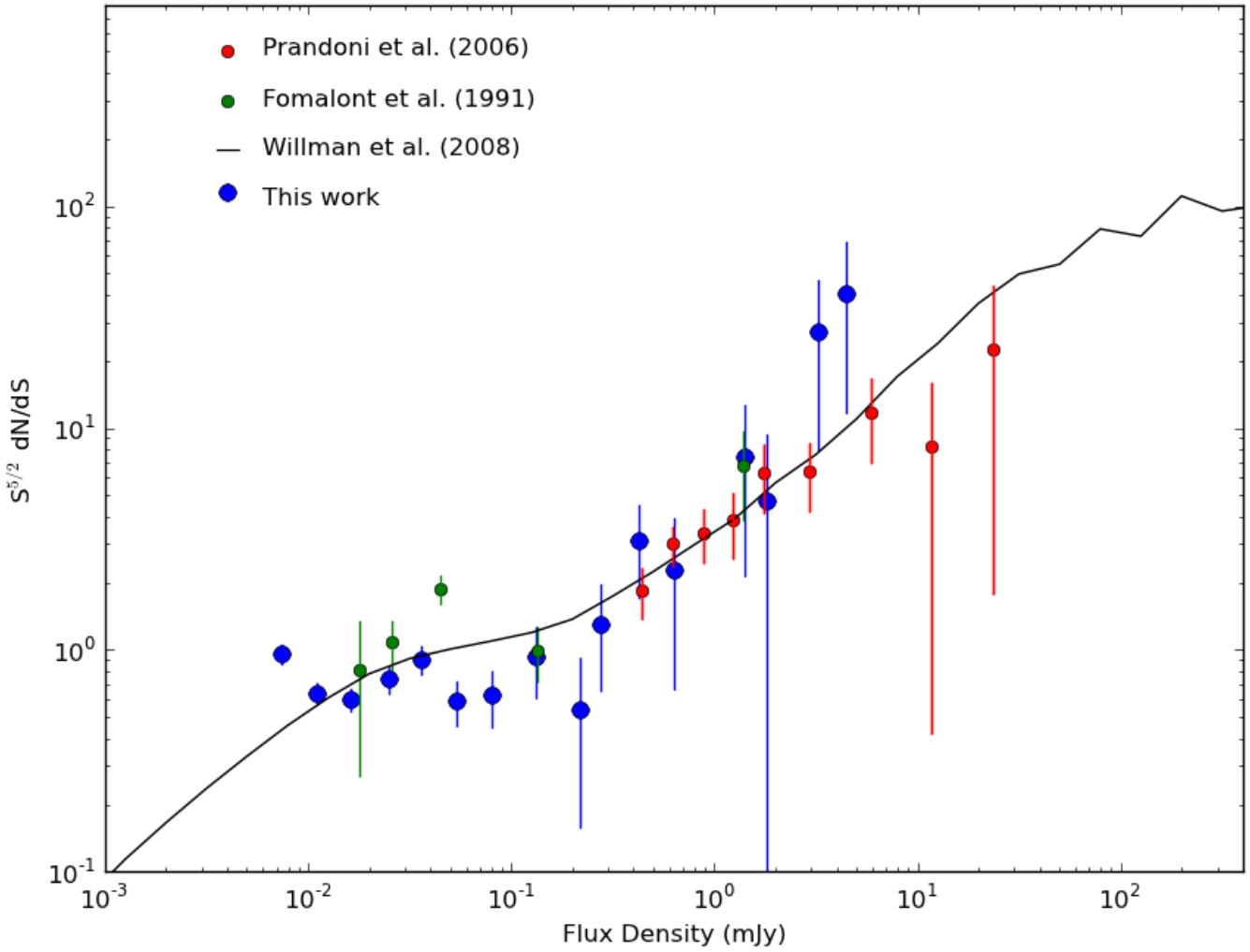
Amplitude distribution in Stokes I (mfs)

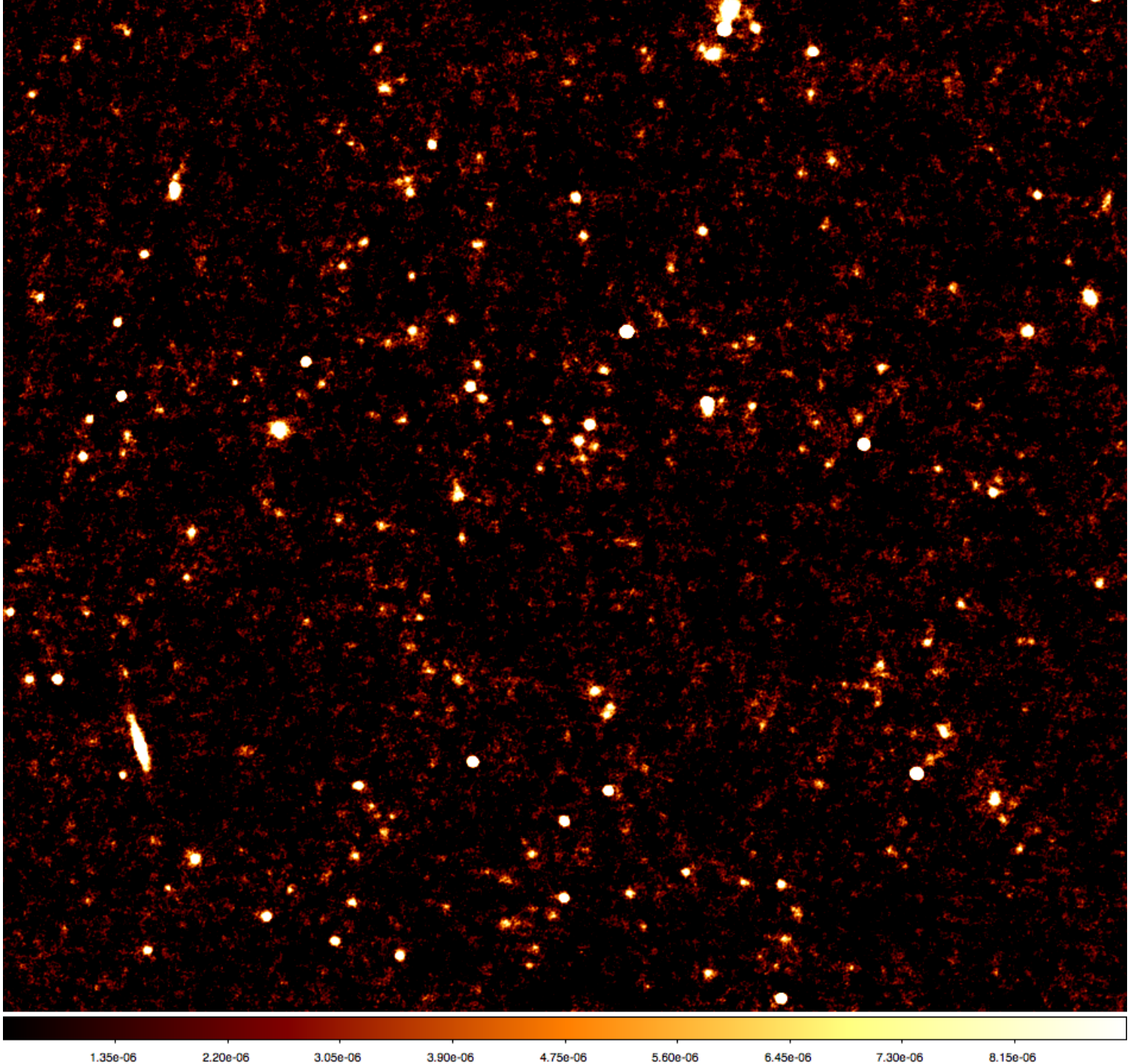
Red curve: Gaussian with σ = 1.164 μJy

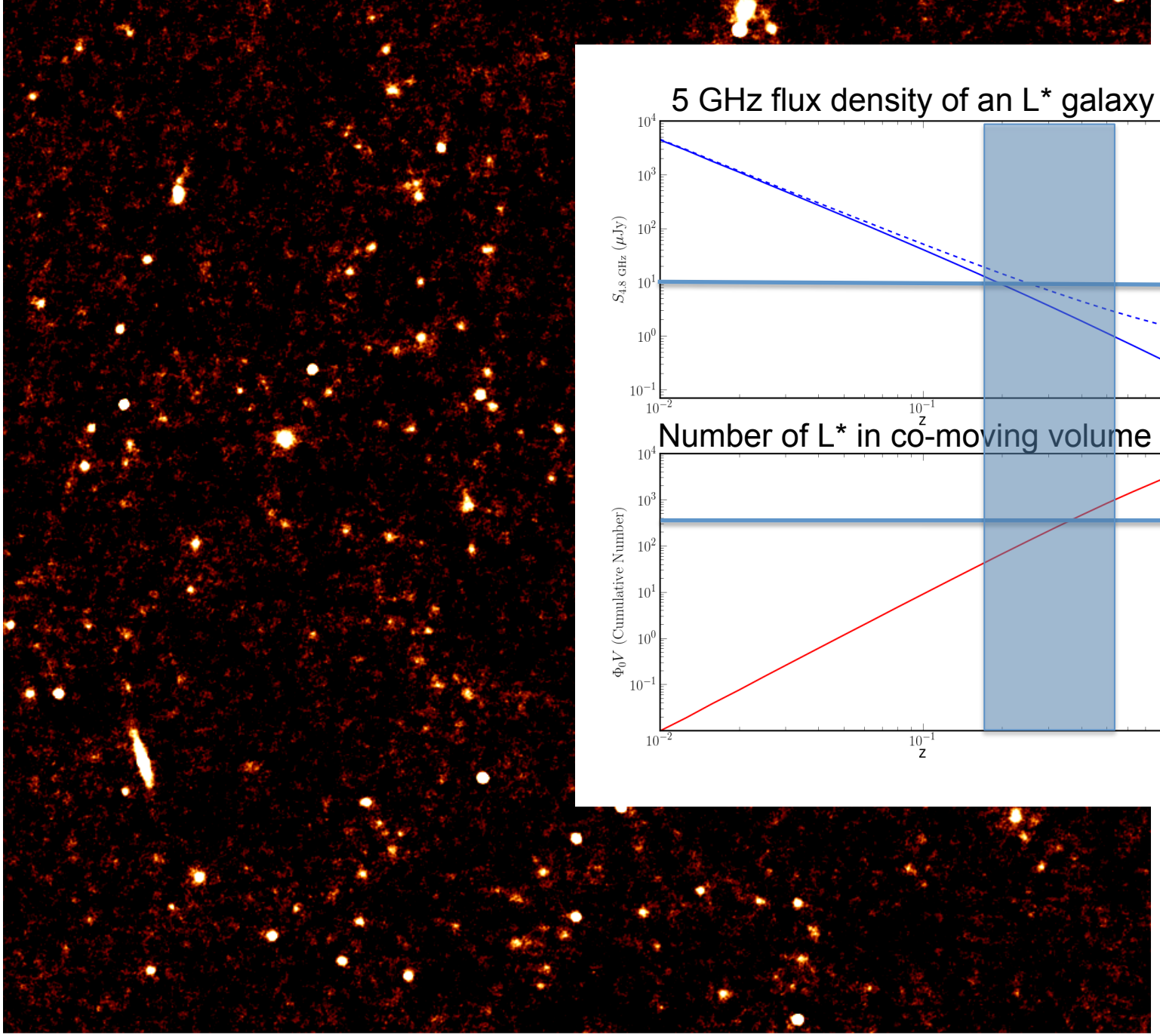


5 GHz Source Counts Stokes I

483 source detected (SAD) (~4500 per sq deg)

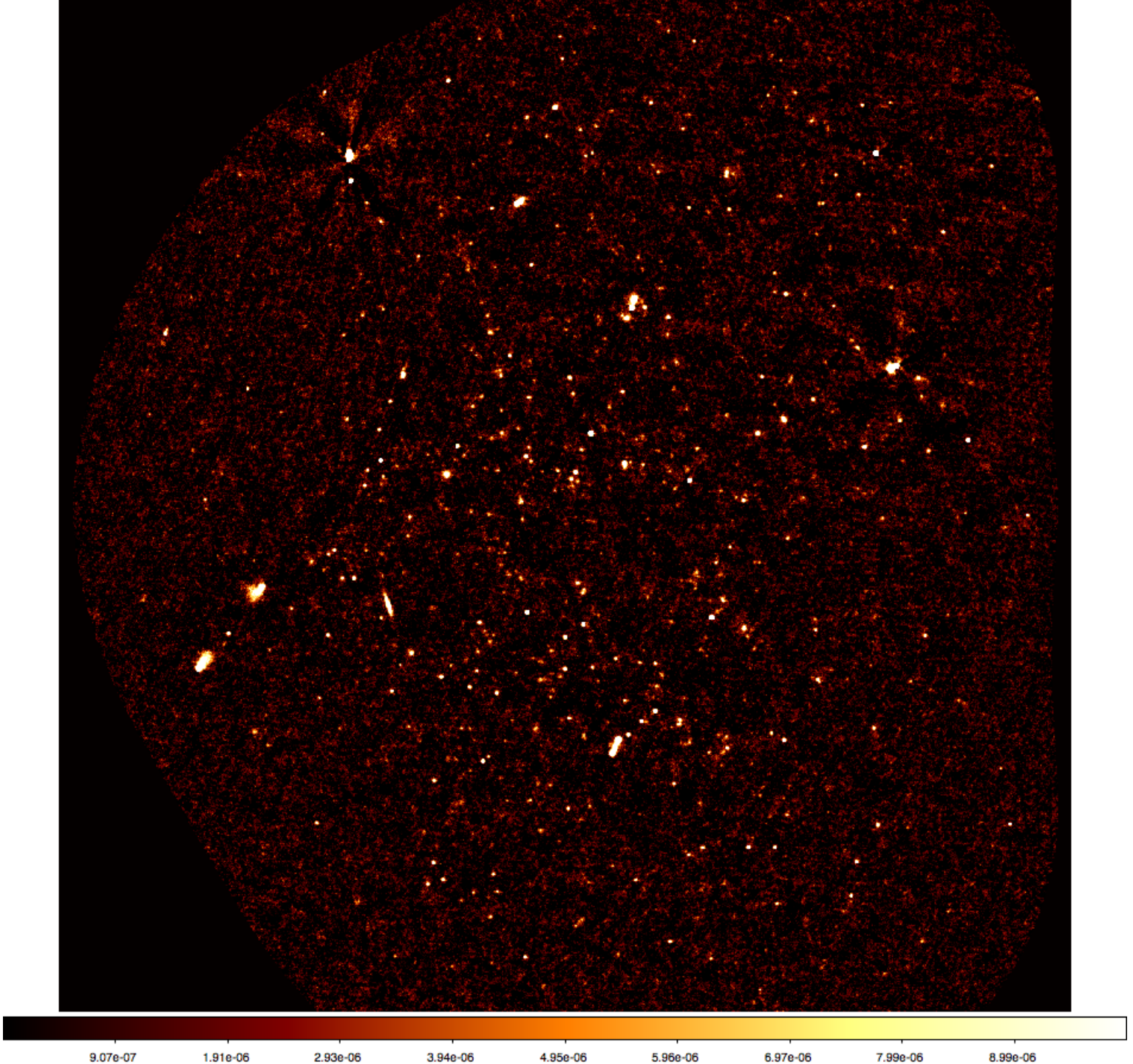


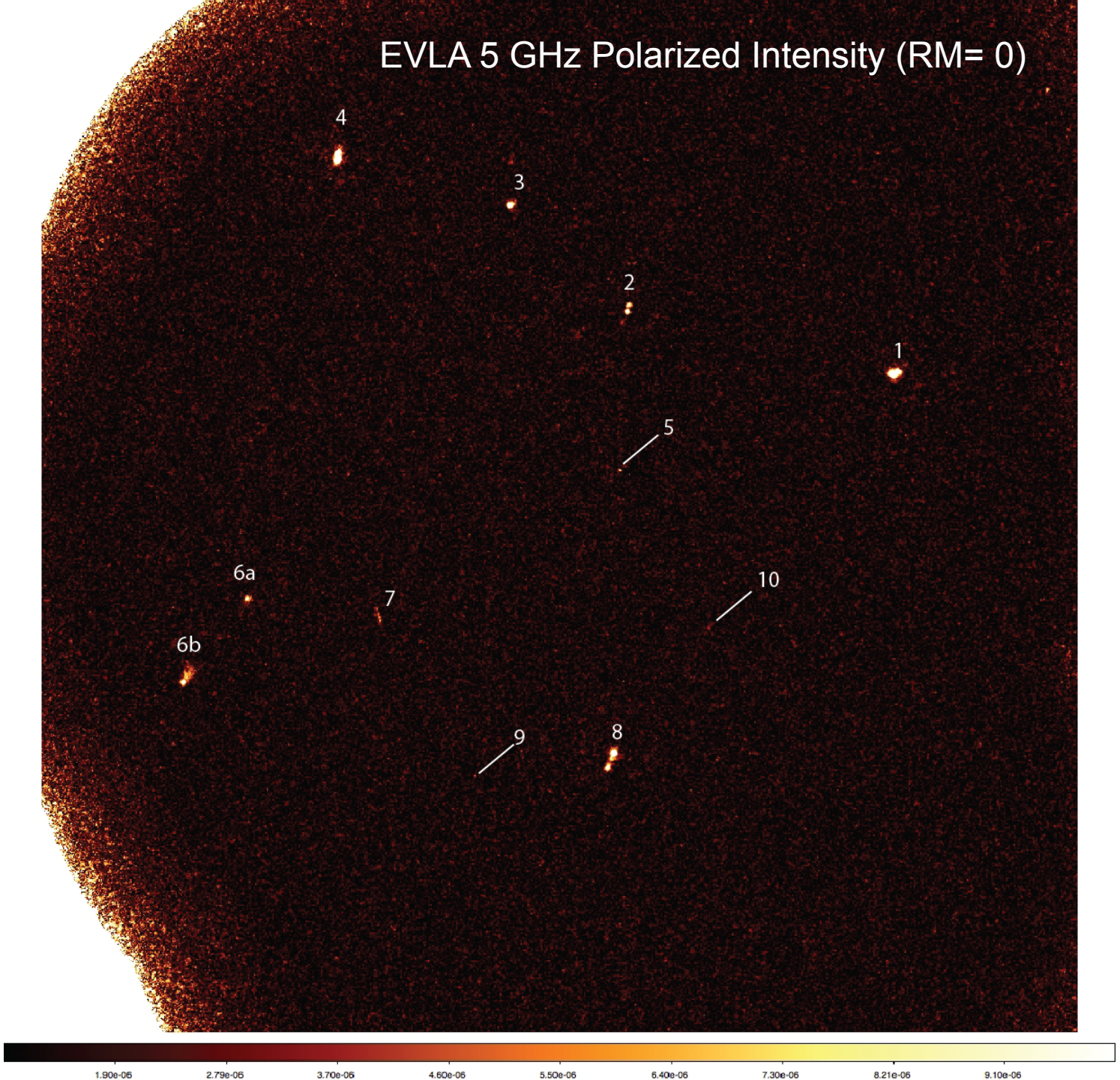

1.35e-06
2.20e-06
3.05e-06
3.90e-06
4.75e-06
5.60e-06
6.45e-06
7.30e-06
8.15e-06



5 GHz flux density of an L* galaxy

Number of L* in co-moving volume


9.07e-07
1.91e-06
2.93e-06
3.94e-06
4.95e-06
5.96e-06
6.97e-06
7.99e-06
8.99e-06


EVLA 5 GHz Polarized Intensity (RM= 0)
4
3
2
1
5
6a
7
10
6b
9
8
1.90e-06
2.79e-06
3.70e-06
4.60e-06
5.50e-06
6.40e-06
7.30e-06
8.21e-06
9.10e-06

Polarized source counts

Theoretical curves

- Red (total counts)
- Green (FR II radio galaxies)
- Yellow (FR I radio galaxies)
- Blue (normal galaxies)

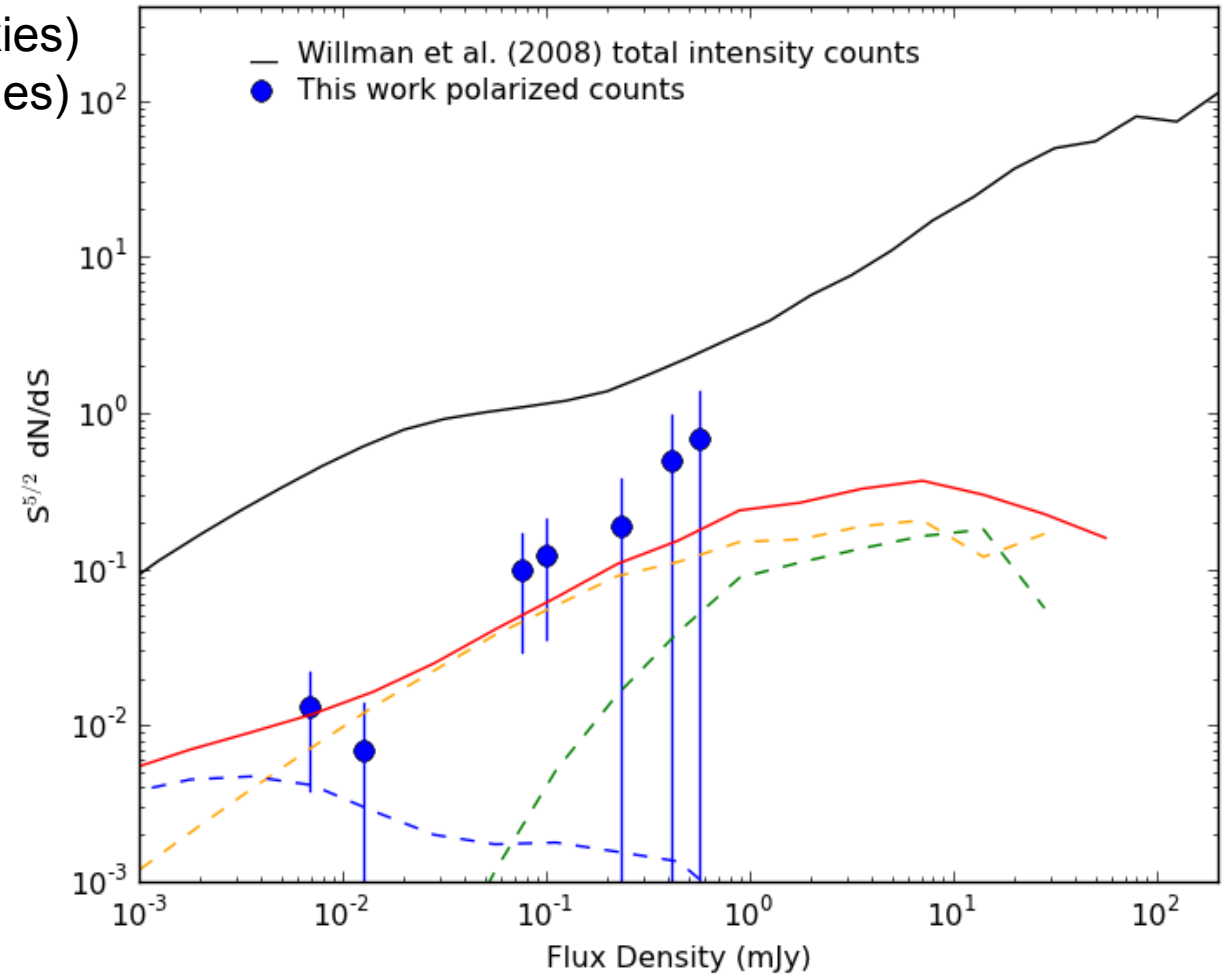
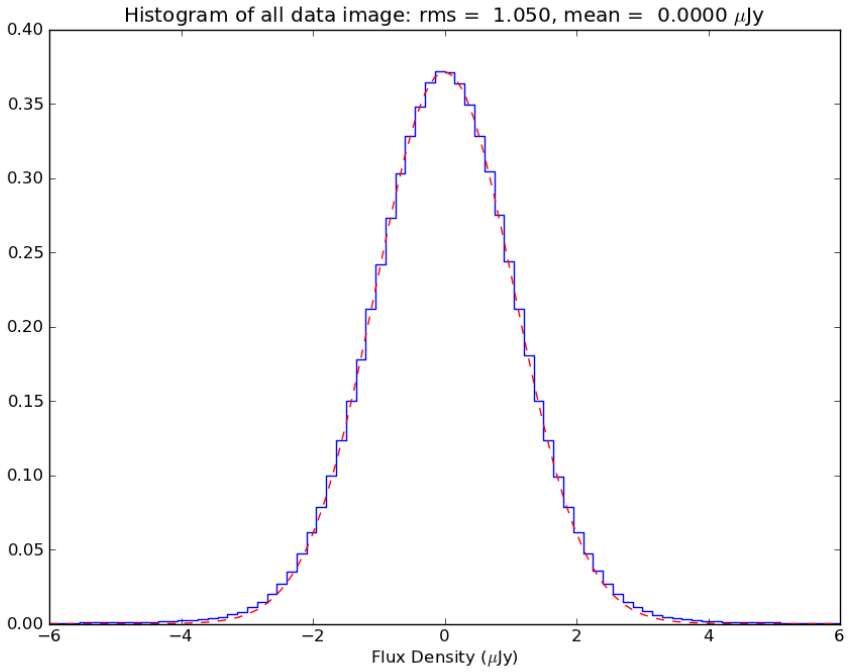


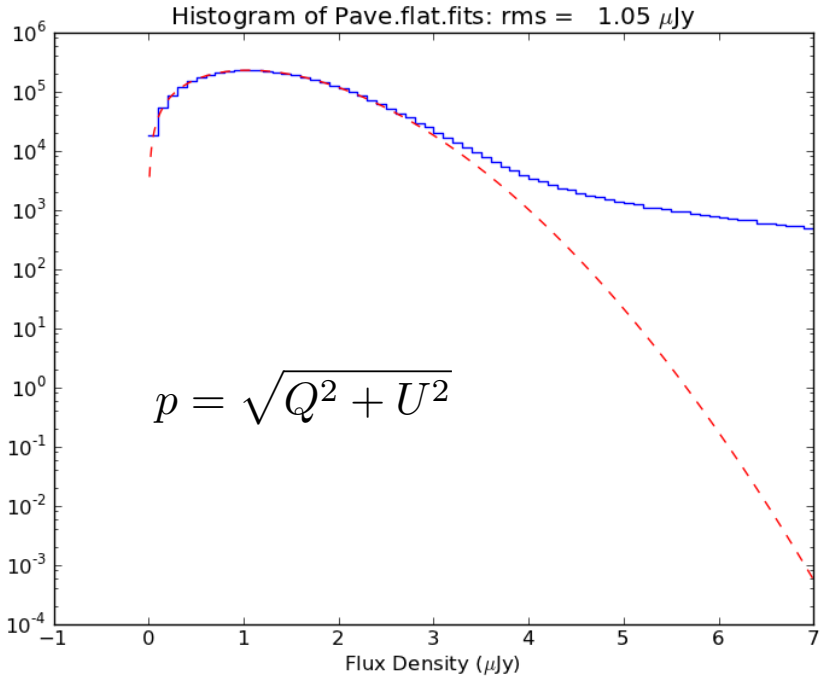
Image Pixel Amplitude distributions

Stokes Q



Gaussian Distribution σ = 1.05 μJy

Polarized Intensity

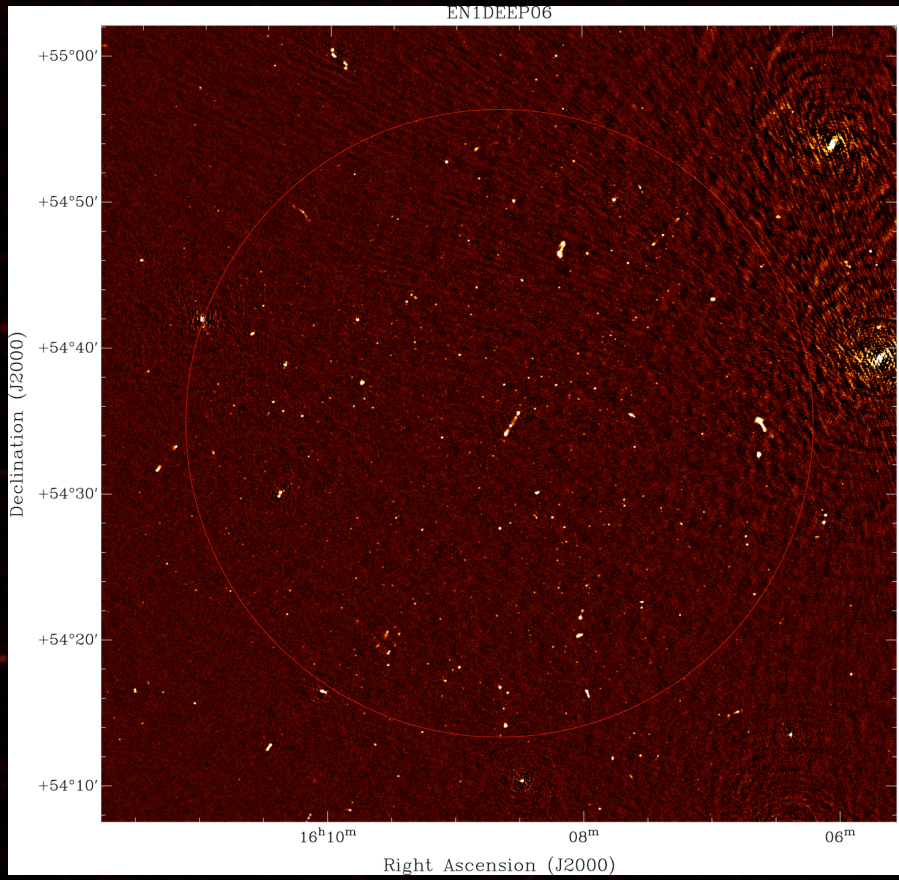


Rayleigh Distribution for σ = 1.05 μJy

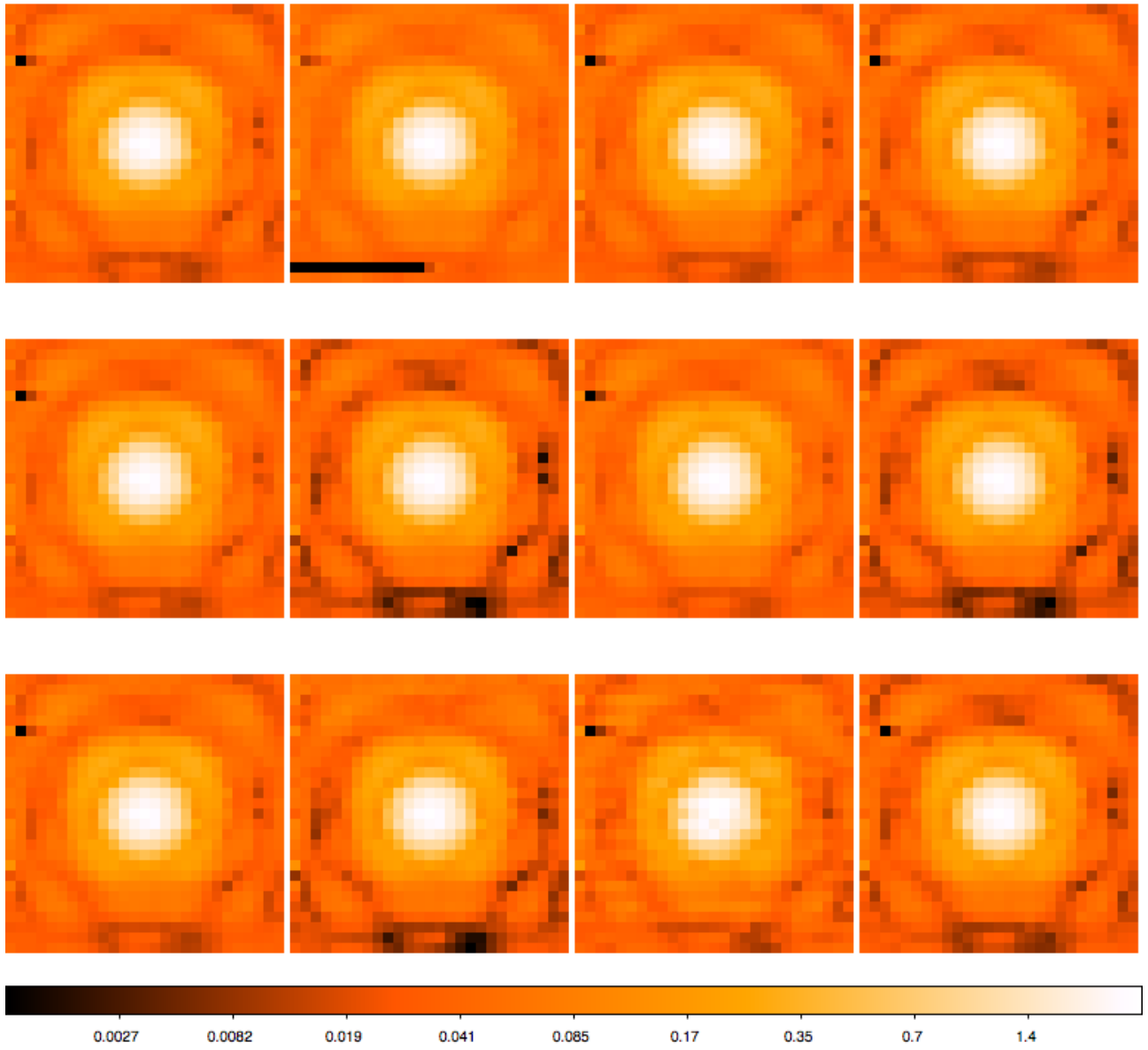
ultra-deep wide-band (sub-microJy) polarization surveys…

- 3rd Generation calibration algorithms need to be implemented and pipelined

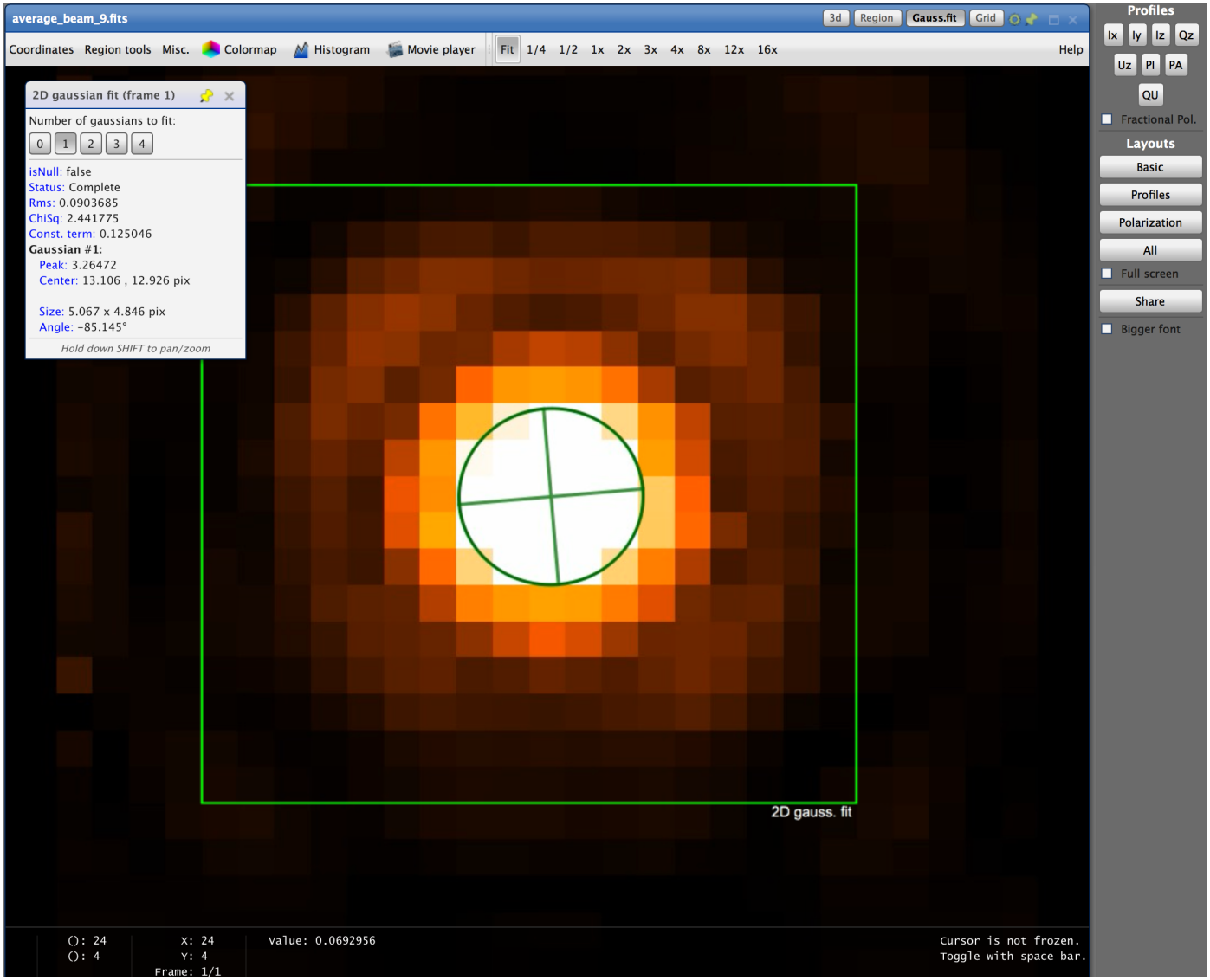
  - Pointing self-calibration
  - Direction dependent corrections (A-term)
  - Wide-band polarization imaging (multi-frequency synthesis and RM synthesis)
  - Simultaneous w-term, A-term and mosaicing



GMRT Primary Beams



GMRT main lobe ellipticity typically a few %



Next steps:

- Spectroscopic and photometric redshifts from to identify AGN vs galaxies, and measured distances and luminosities
- Deeper noise-limited radio imaging to probe polarization to sub-μJy flux densities (+A configuration)
- Statistical approaches to exploration of polarization counts at low signal-to-noise
- Measure full-Stokes off axis beams and corrected for instrumental polarization residual over wide field and wide band.