Evolution of Magnetic Fields in Galaxies

Science with POSSUM wide and deep

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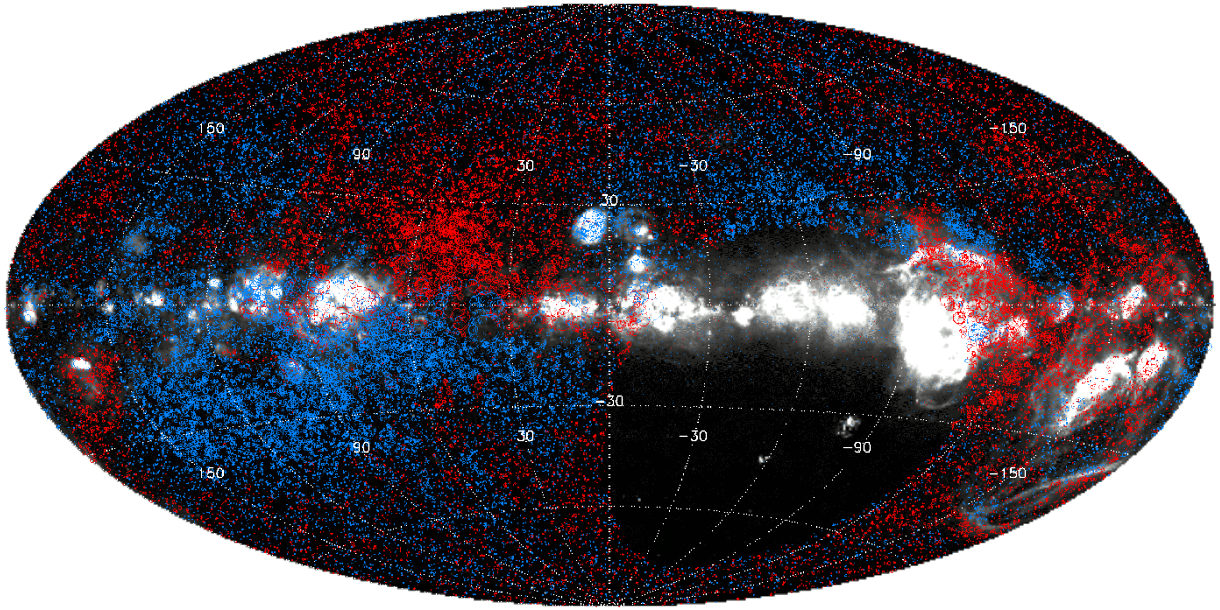
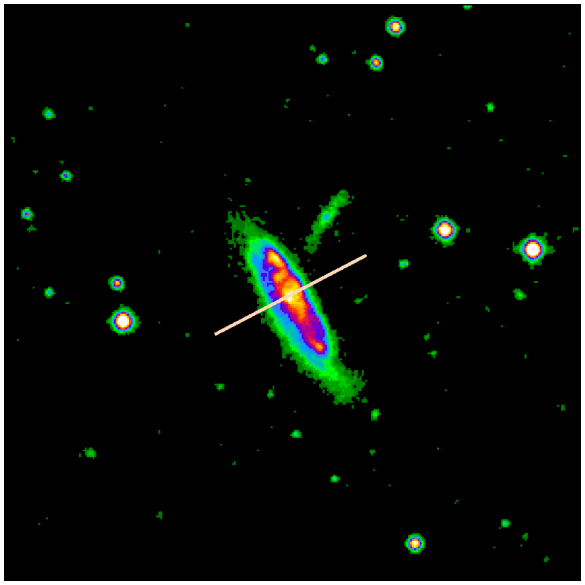




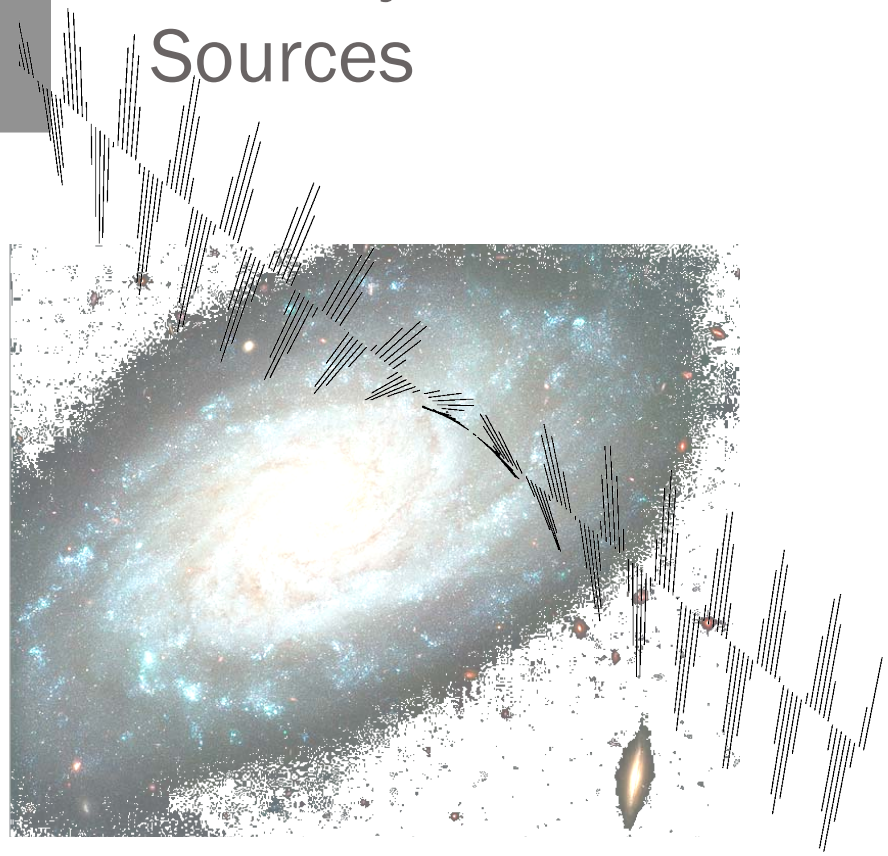
An inconvenient truth …

Magnetic Fields are necessary to understand the physics of the ISM and the evolution of galaxies

- Effect on star formation
- Dynamics, turbulence, heat conduction of ISM and cosmic rays
- Effect on chemical enrichment of ISM and intergalactic medium
- Intergalactic magnetic fields and galaxy evolution
- All phases of the ISM

Faraday Rotation of Polarized Background Sources

Polarised radio source



Observer

Local Group galaxies:
Milky Way: Han et al., Brown et al., Haverkorn et al., …
M31: Han et al. (1998)
LMC: Gaensler et al. (2005)
SMC: Mao et al. (2008)

Occasional single line of sight through high-redshift galaxy (Bernet et al. 2008, Kronberg et al. 2008)

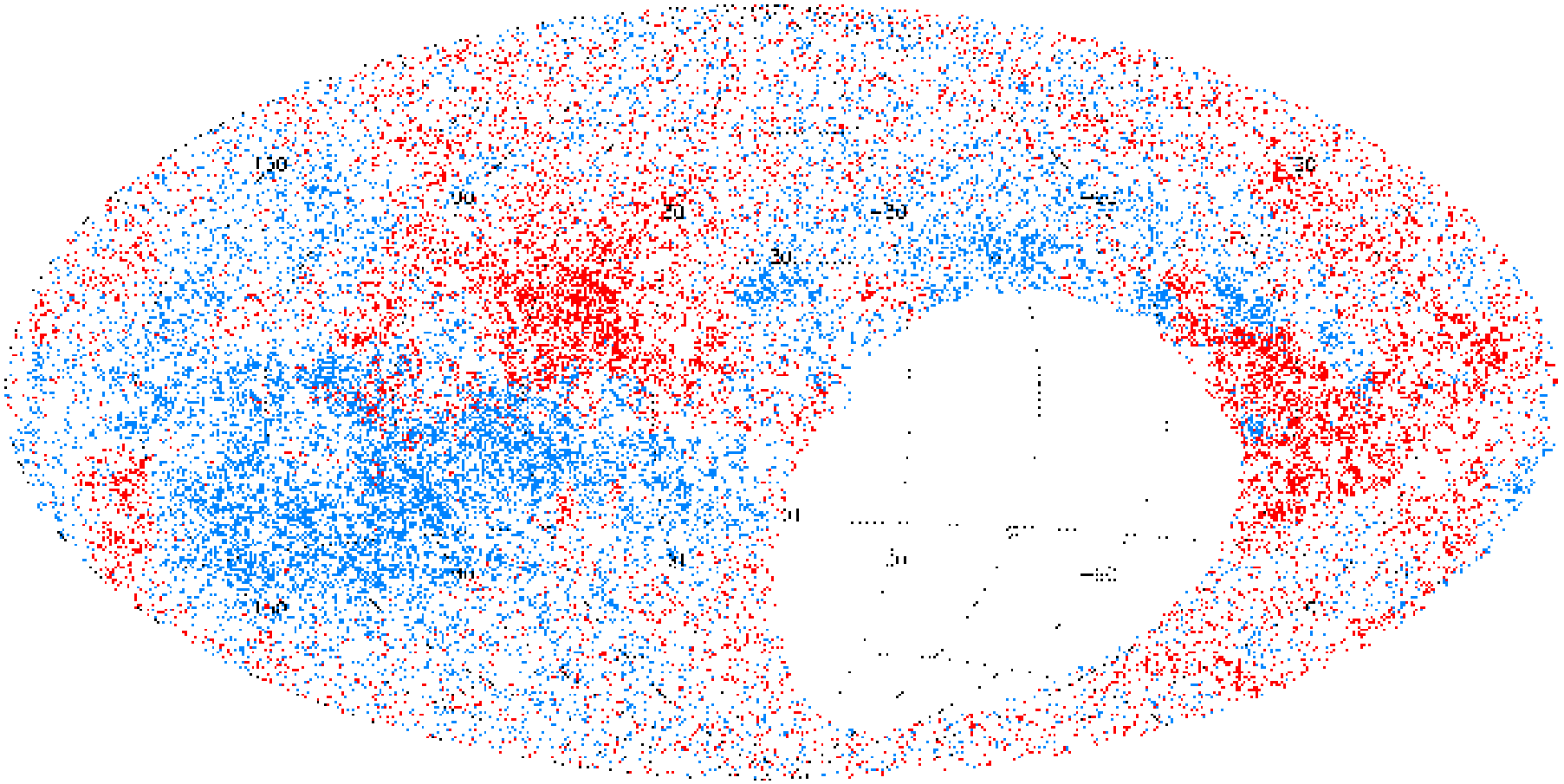
$$\Delta\theta = 0.81\lambda^2 \int n_e \vec{B}\cdot\vec{dl} = \lambda^2 RM$$ radians

Application limited by number of detectable background sources (sensitivity, resolution). SKA: thousands of galaxies with > 20 RMs per galaxy (Stepanov 2008)

Science with all-sky and deep polarisation surveys

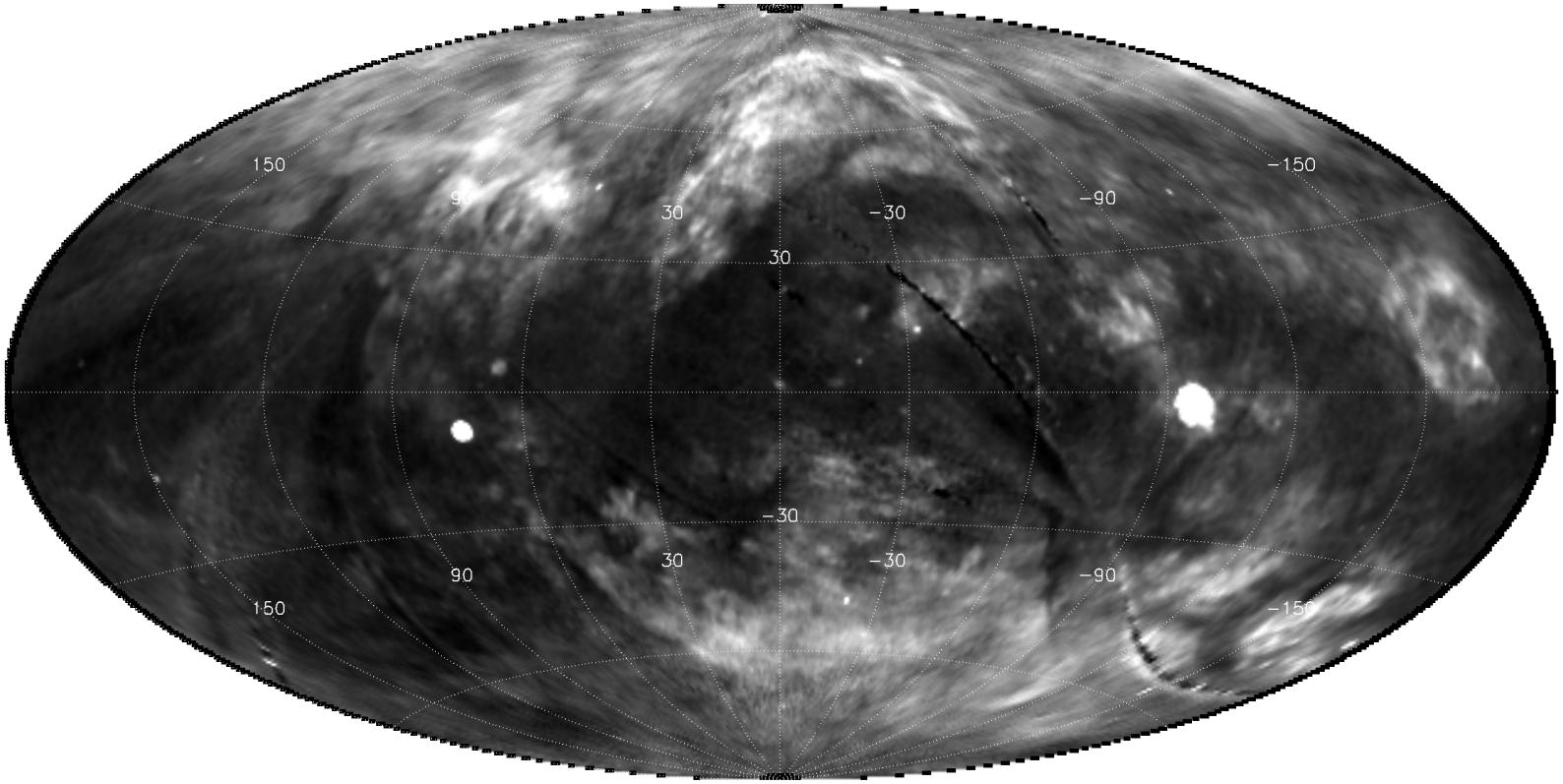
- All-sky rotation measure grid from all sky survey
  - ISM magnetic fields
  - Magnetic fields in clusters and distant galaxies
  - RM as a function of redshift
  - Foreground subtraction for CMB polarisation
  - Test for dynamo models
  - Diffuse polarised emission
- Faint polarised radio sources from deep survey
  - Synchrotron emission from normal galaxies
  - Evolution of magnetic fields in AGN and star forming galaxies
  - Stokes V
  - Polarisation variability

The Rotation Measure Sky



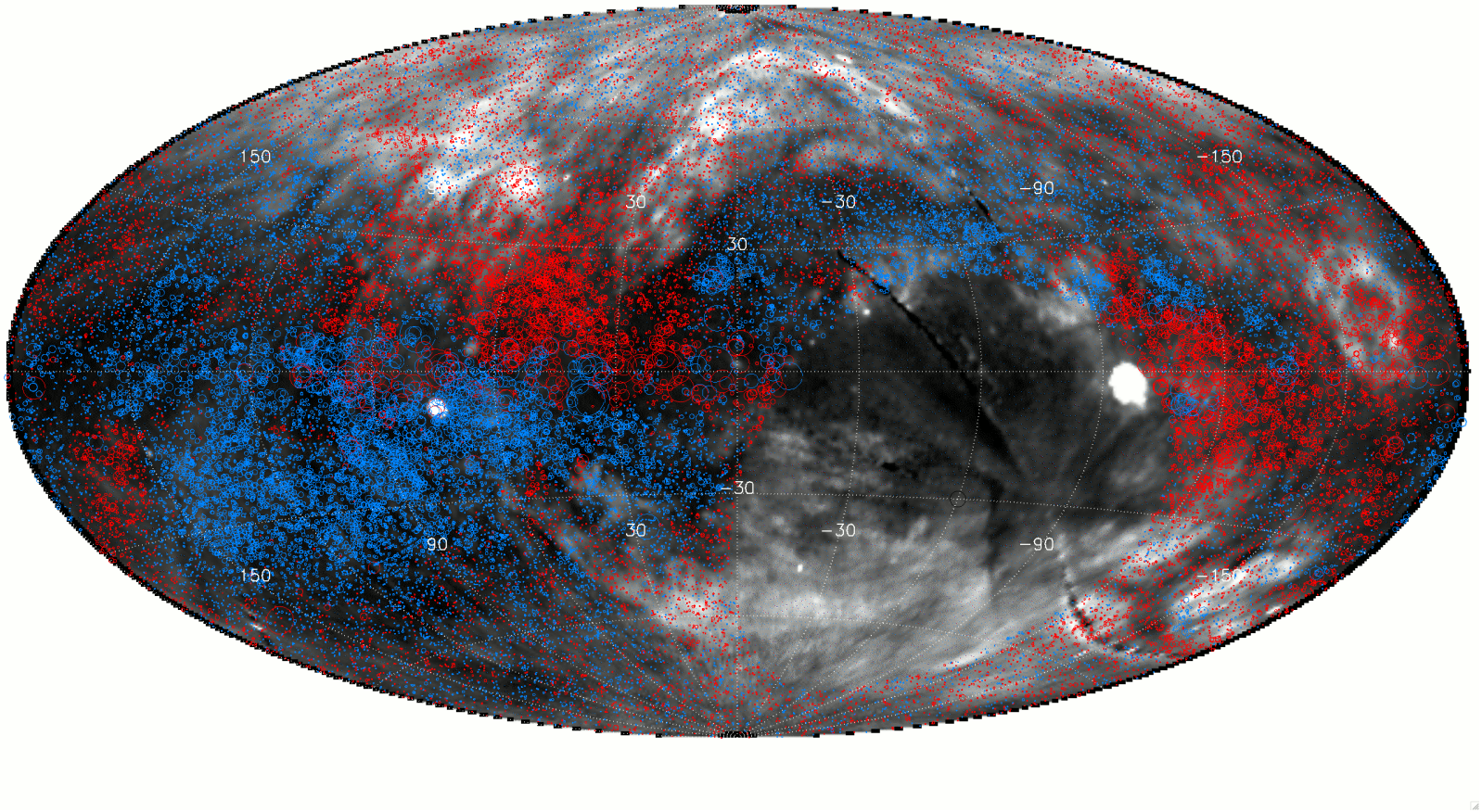
Taylor, Stil & Sunstrum (2009) ApJ submitted 37543 rotation measures derived from NVSS 2-band + bandwidth depolarisation constraint

RM on soft X-ray (ROSAT 0.25 keV)



X-ray image from Snowden et al. (1997)

RM on soft X-ray (ROSAT 0.25 keV)

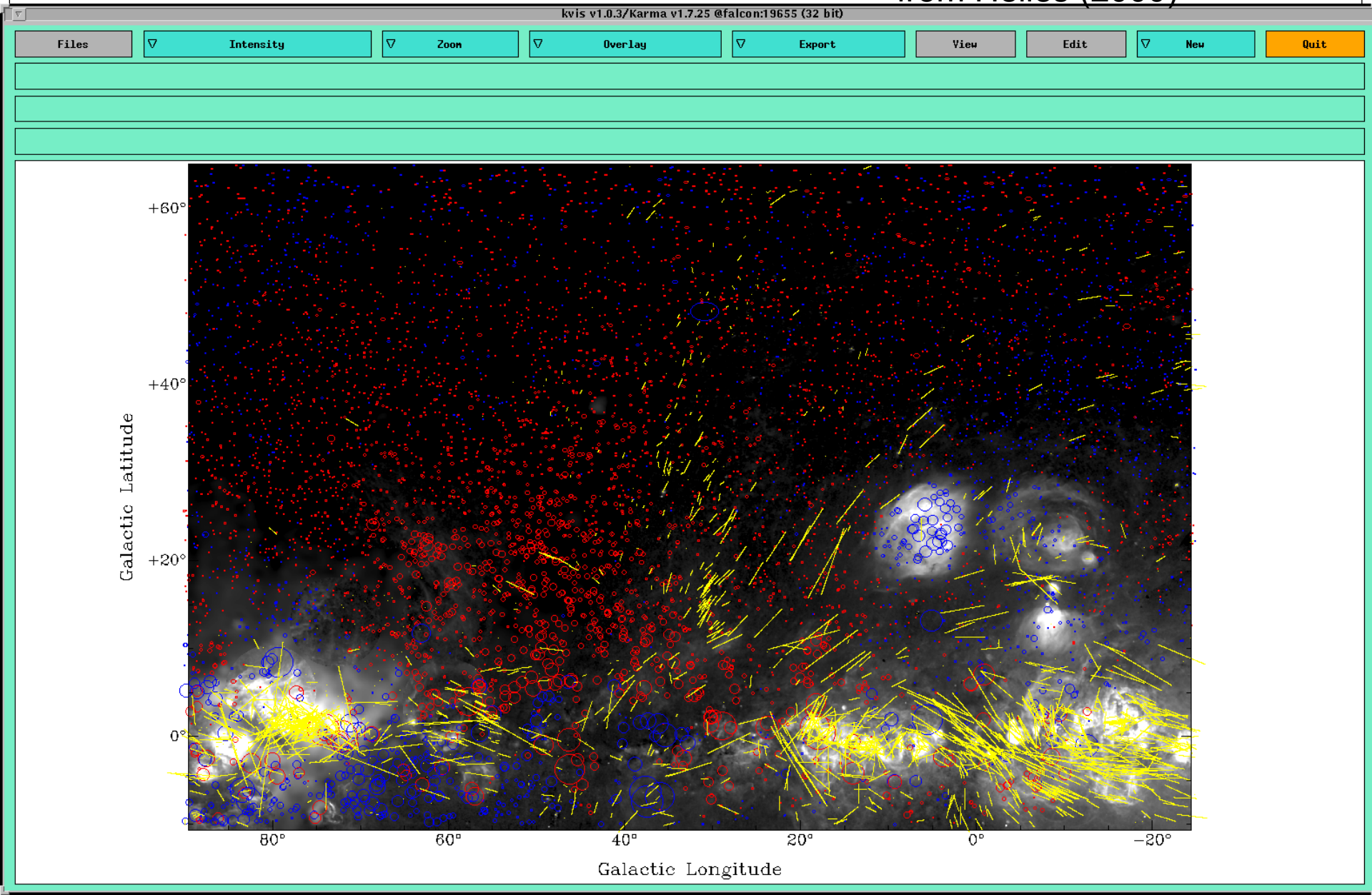


Stil, Taylor & Sunstrum (2009) in prep.

X-ray image from Snowden et al. (1997)

Quadrant 1 (North)

RM on Hα
Stellar polarisation vectors
from Heiles (2000)



RM Structure Functions

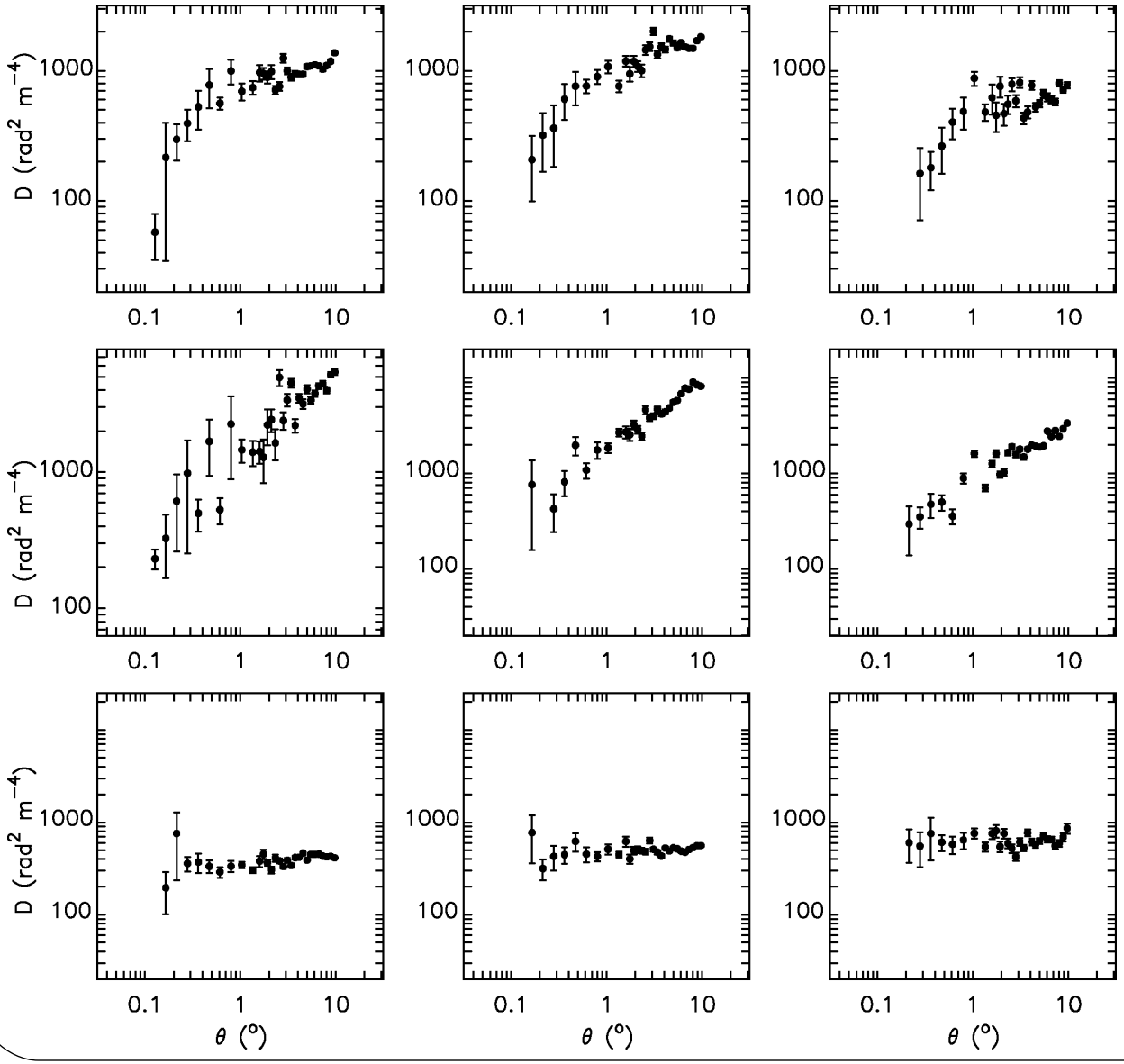
$$D(\delta\theta) = \left\langle \left[RM(\theta) - RM(\theta + \delta\theta) \right]^2 \right\rangle$$

Amplitude of RM fluctuations on angular scale $\delta\theta$
Easier to calculate than powerspectrum for irregularly sampled data
Weight with inverse error of RM

Single-order and higher order structure functions in near future
Mean distance between RM sources ~0.8 degr.
Evaluate for angular scales ~0.1 degr. to 10 degr.

Simonetti et al. (1984, 1986), Leahy (1987), Haverkorn et al. (2008), Roy et al. (2008), ….

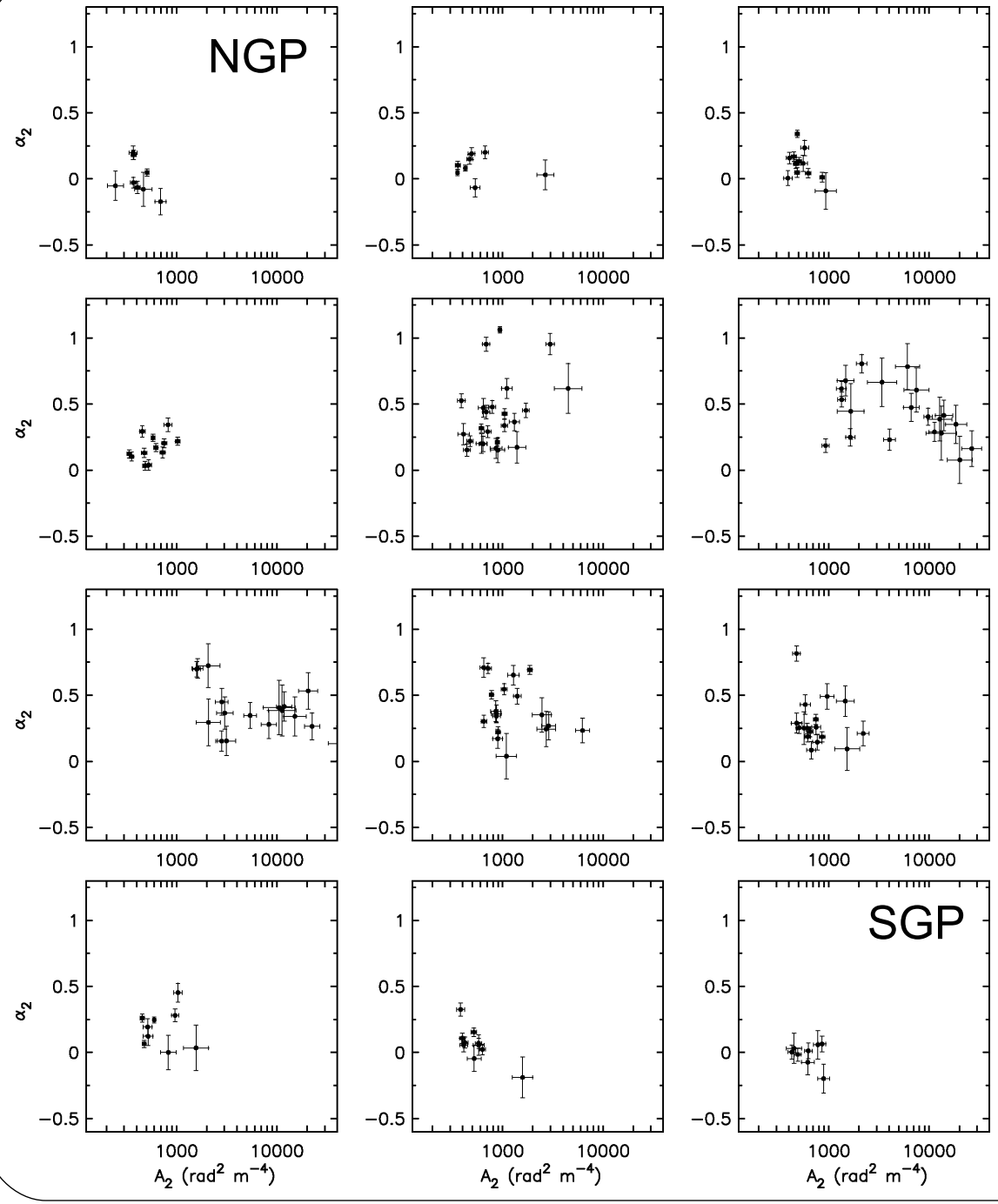
RM Structure Functions
For Different Sections Of The Sky (~ 15° x 15°)



Change in slope near angular scale 1° (e.g. Haverkorn 2008, Roy et al. 2008)

Constant slope

(Nearly) Flat but non-negligible foregound

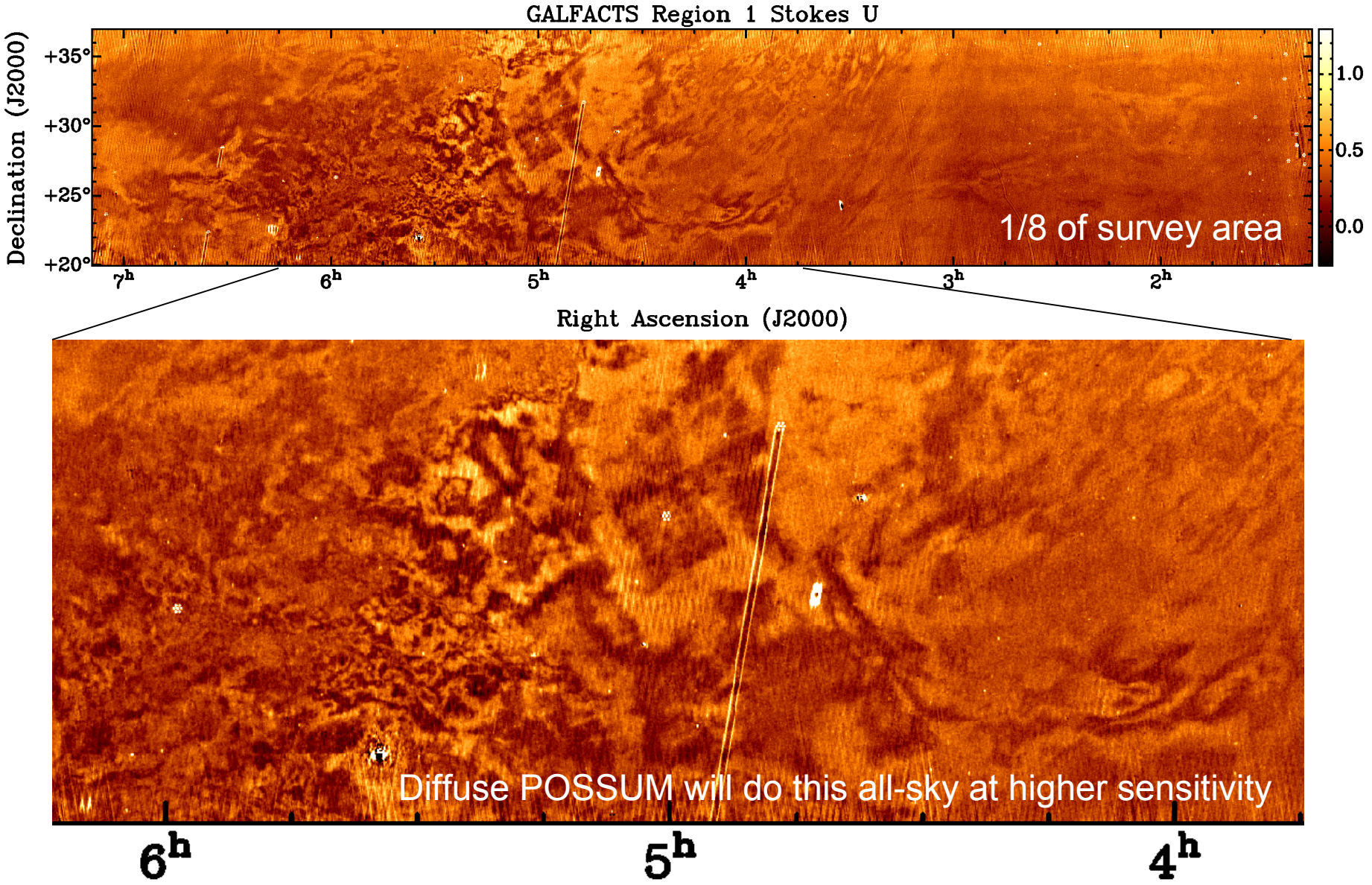


Slope > 1° vs. Amplitude as a function of Galactic Latitude

Flat structure function at high latitude consistent with previous results (Simonetti et al. 1984)

But: <u>significant foreground at Galactic Poles</u>

GALFACTS 8000 channels / 300 MHz, 3' beam



Rotation Measure Grid

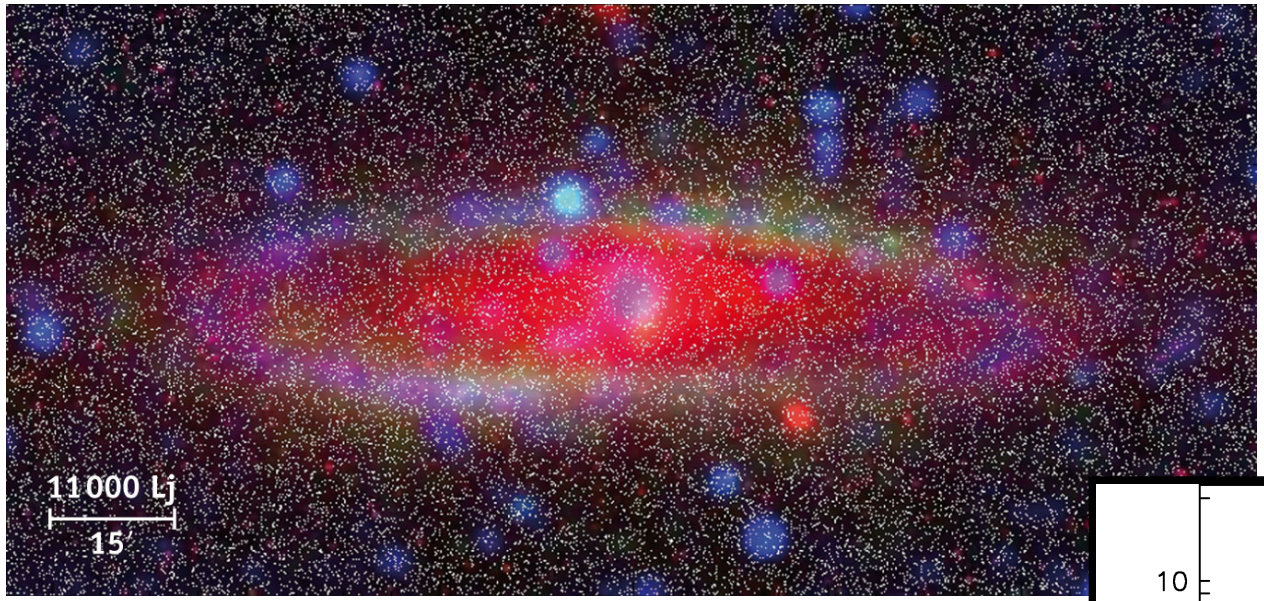
The radio polarisation sky is 100% filled with structure on angular scales << 1' to > 90°

All-sky RM grid probes magnetic fields in ISM from pc to kpc scale and magnetic fields in external galaxies and (super)clusters

POSSUM will be a factor 30 more sensitive than the NVSS with a factor 3 higher resolution, and an order of magnitude higher resolution than GALFACTS

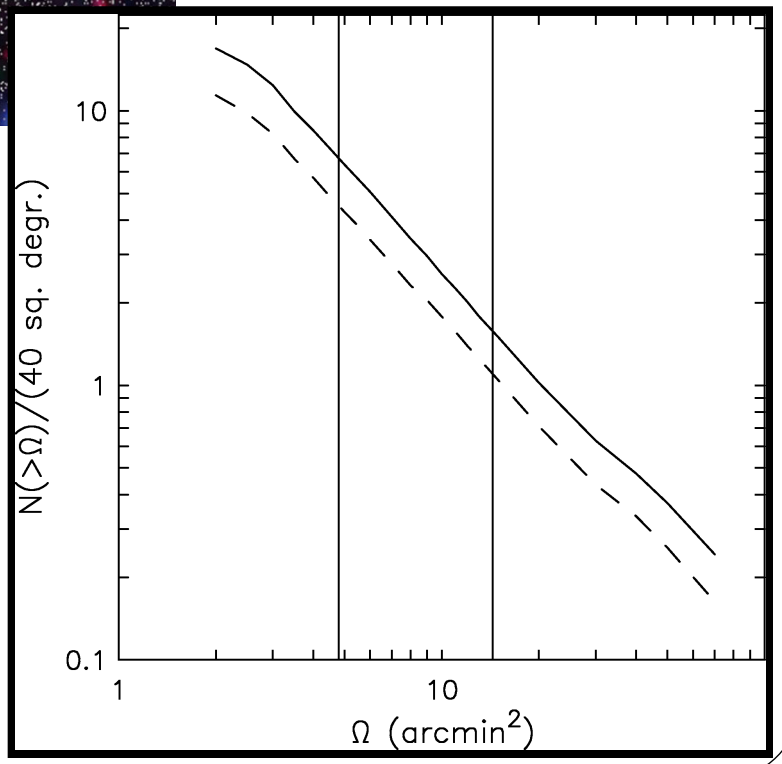
Source density on the sky defines RM sensitivity and angular resolution for ISM work

The Rotation Measure Grid: Extragalactic



5000 RMs
per square deg.
20 RMs/galaxy

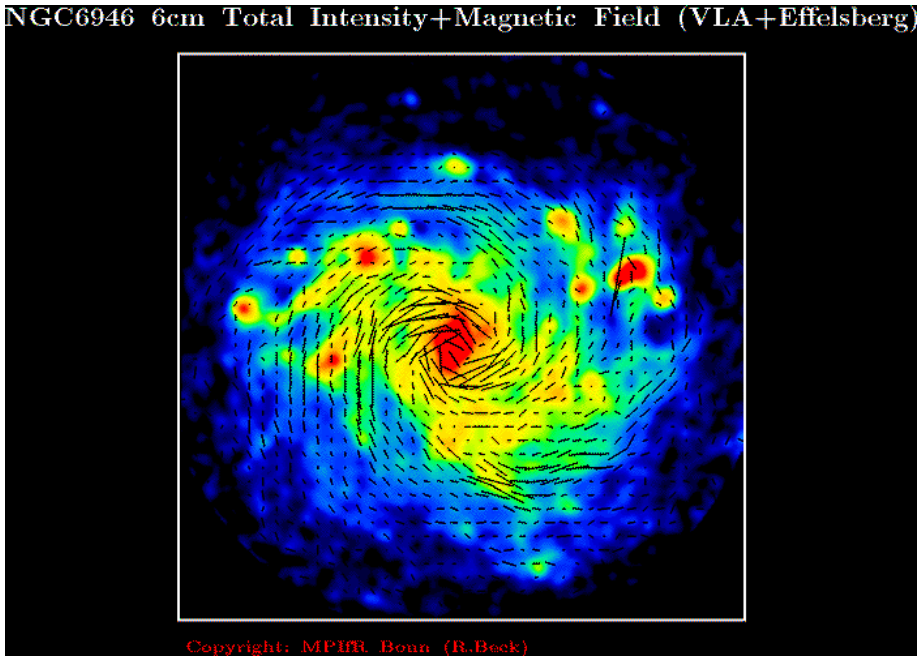
15000 RMs
per square deg.
20 RMs/galaxy



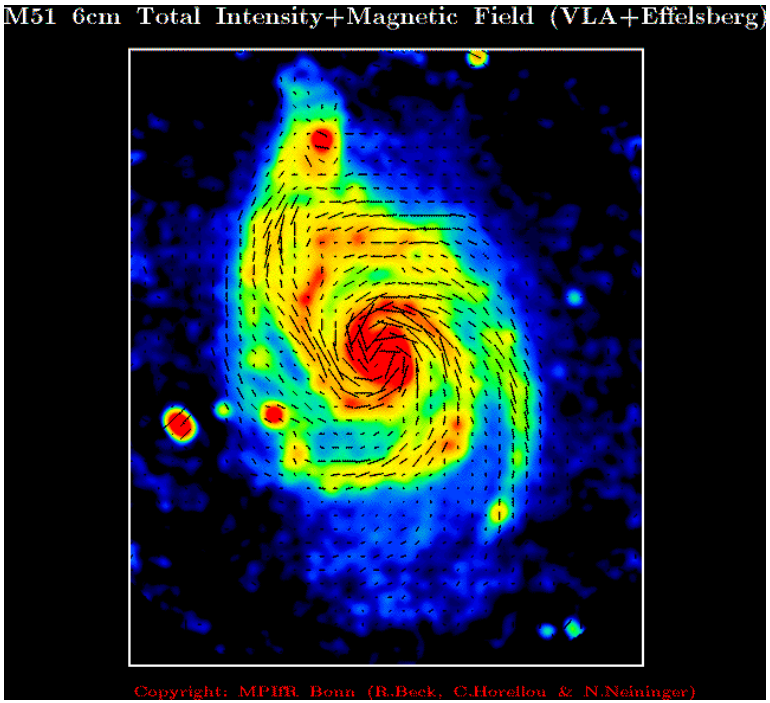
Number of galaxies in the UGC with solid angle > Ω (out to twice the optical radius)
Dashed: UGC spirals
Solid: all UGC galaxies

Somewhat lower numbers than Stepanov et al. (2008)

Polarized Synchrotron Emission from Spiral Galaxies



NGC 6946 (Beck et al. 2007)

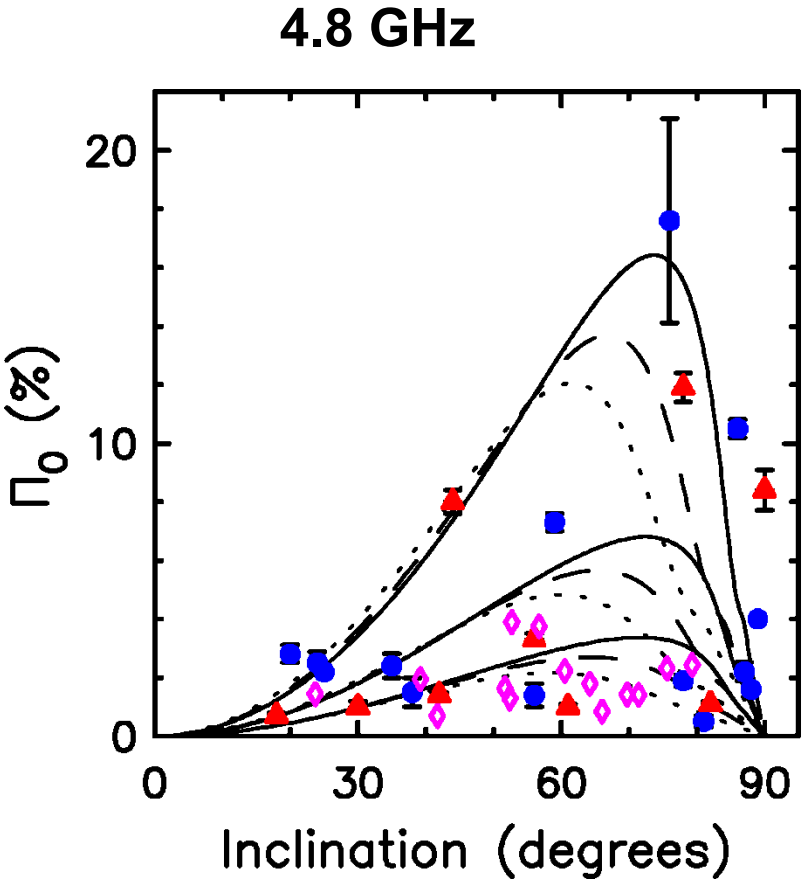


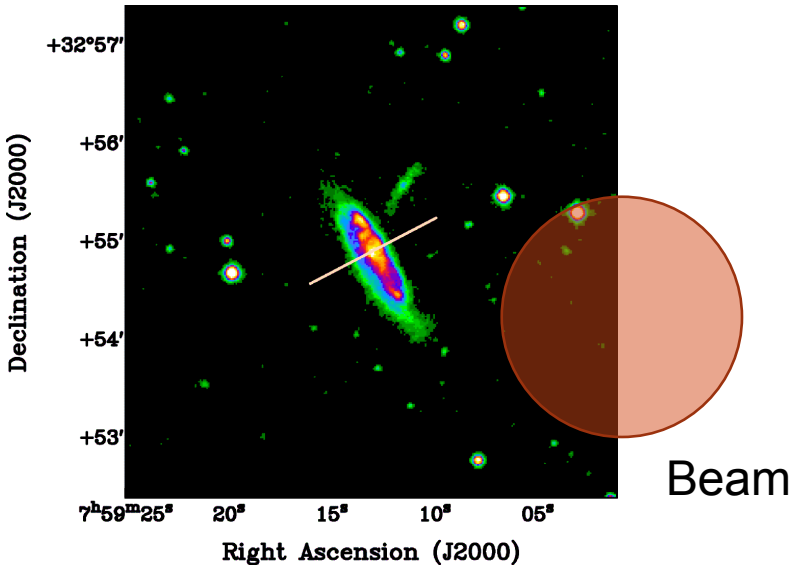
M51 (Fletcher et al. 2004)

Typical resolution 10” or 200 pc

To do this at z=0.5 ($S_{1.4}$ = 0.01 mJy) with <u>2 kpc resolution</u> requires sensitivity ~2 nJy/beam at 0.3” resolution!

Spiral Galaxies as Unresolved Polarized Radio sources

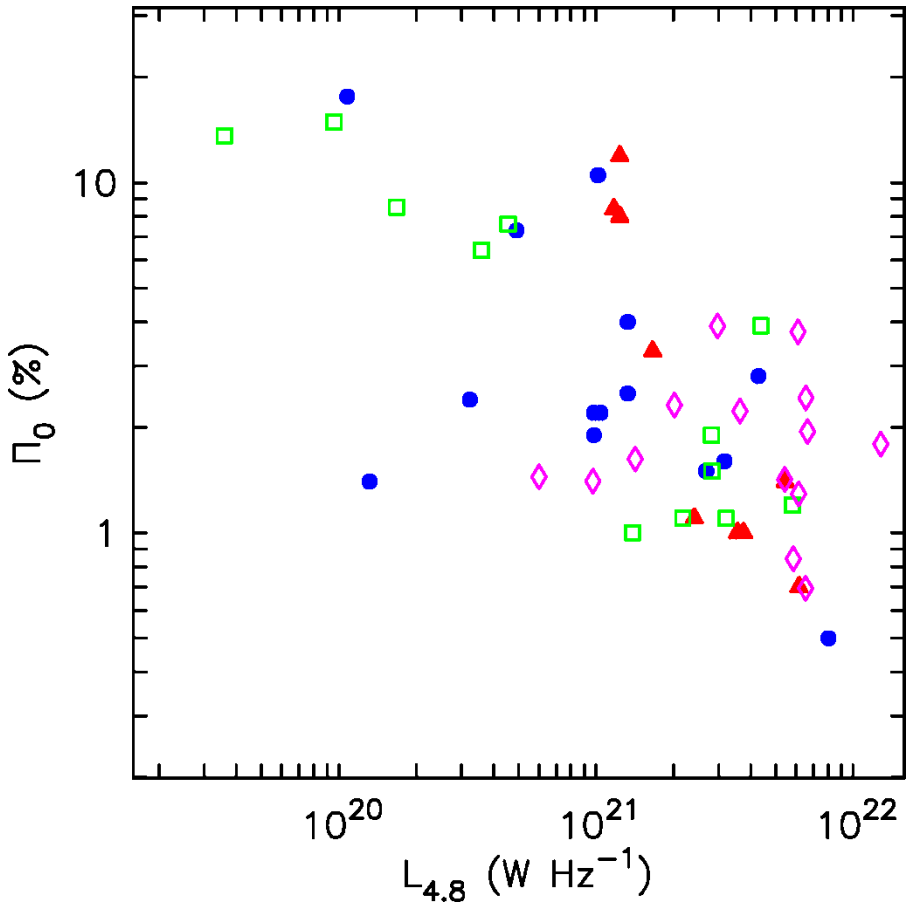




UGC 4132 at **74 Mpc**
Effelsberg 4.8 GHz

Stil, Krause, Beck & Taylor 2009 ApJ arXiv:0810.2303
Integrated polarization of nearby spiral galaxies at 4.8 GHz
New Effelsberg observations of galaxies in Local Super Cluster

Correlate With Other Integrated Quantities



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

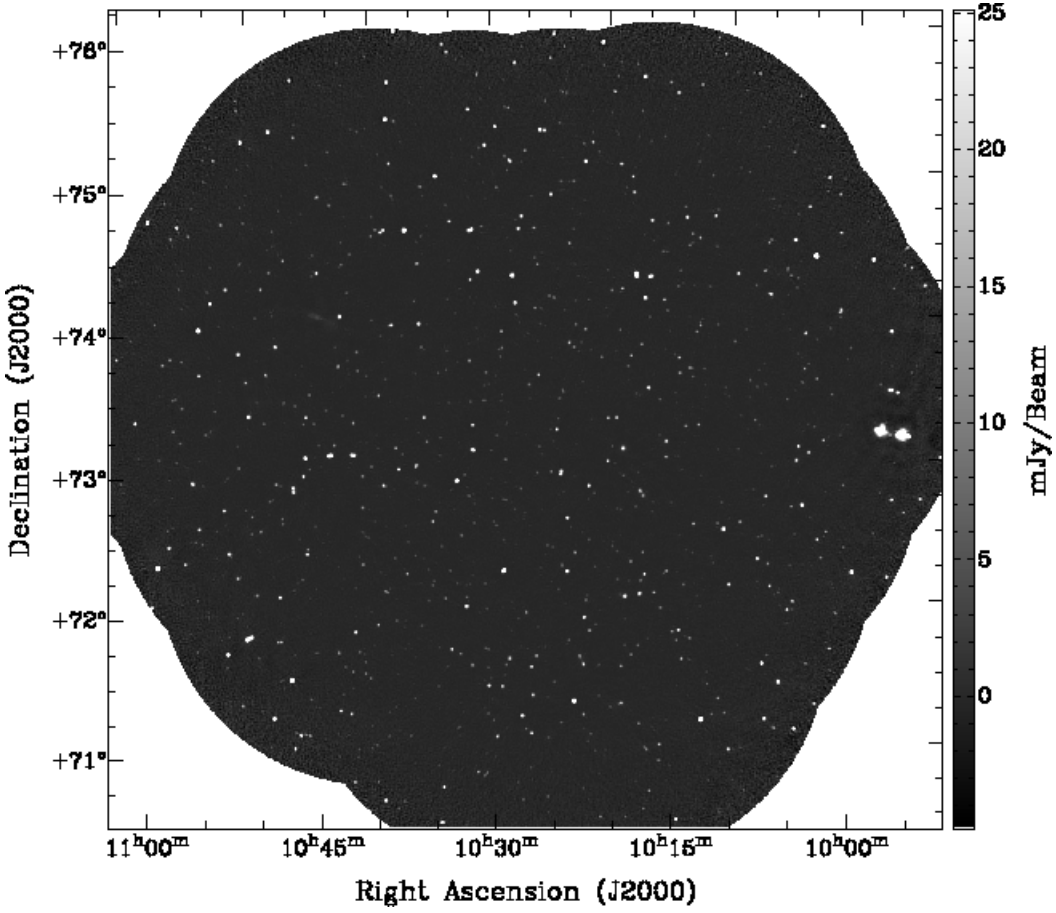
Highly ordered large-scale magnetic fields restricted to galaxies with a low radio luminosity ($L < L^*$).

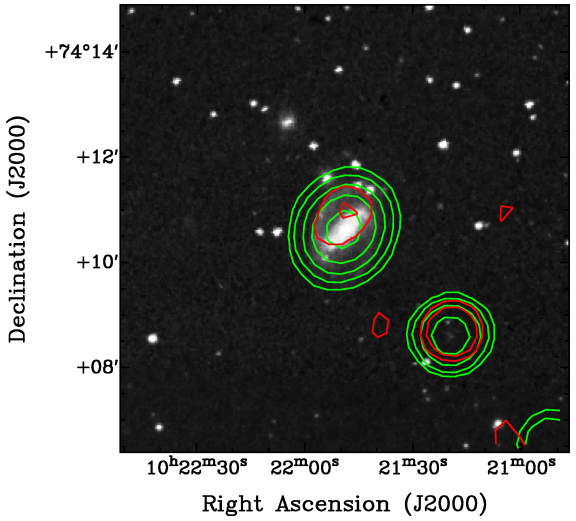
No correlation with optical luminosity

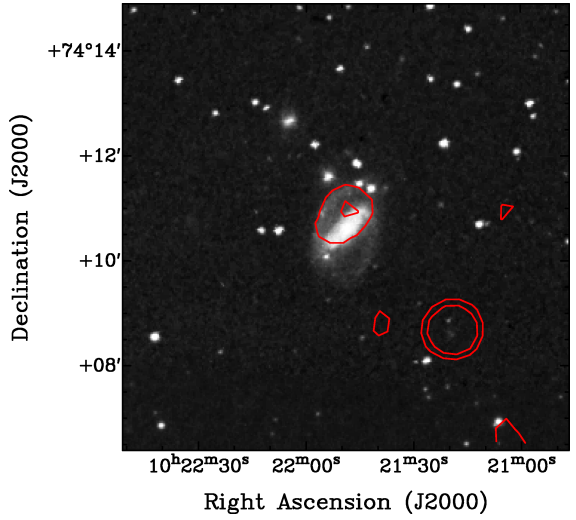
<u>Relation to star formation rate</u>

Future: larger samples at 4.8 GHz and 1.4 GHz (GALFACTS) POSSUM wide & deep

UGC 5582 in DRAO Planck (Spider) Deep Field (2.7 % pol. at 1.4 GHz) Many more from GALFACTS



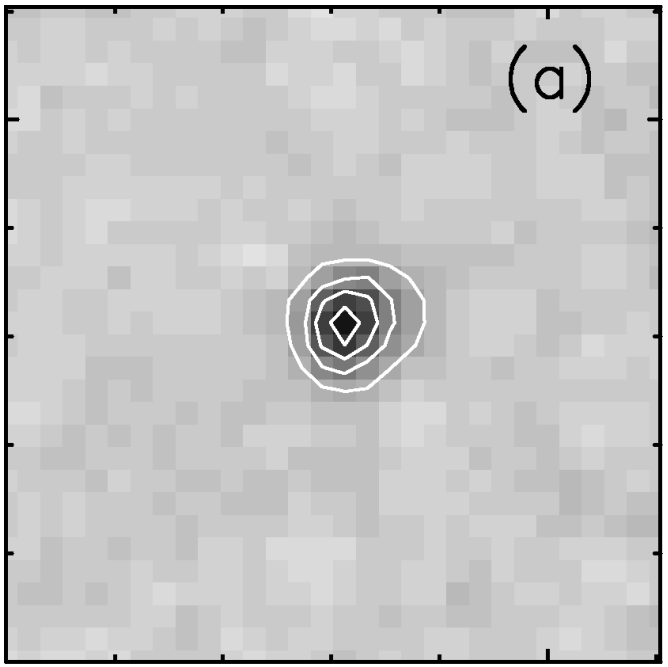




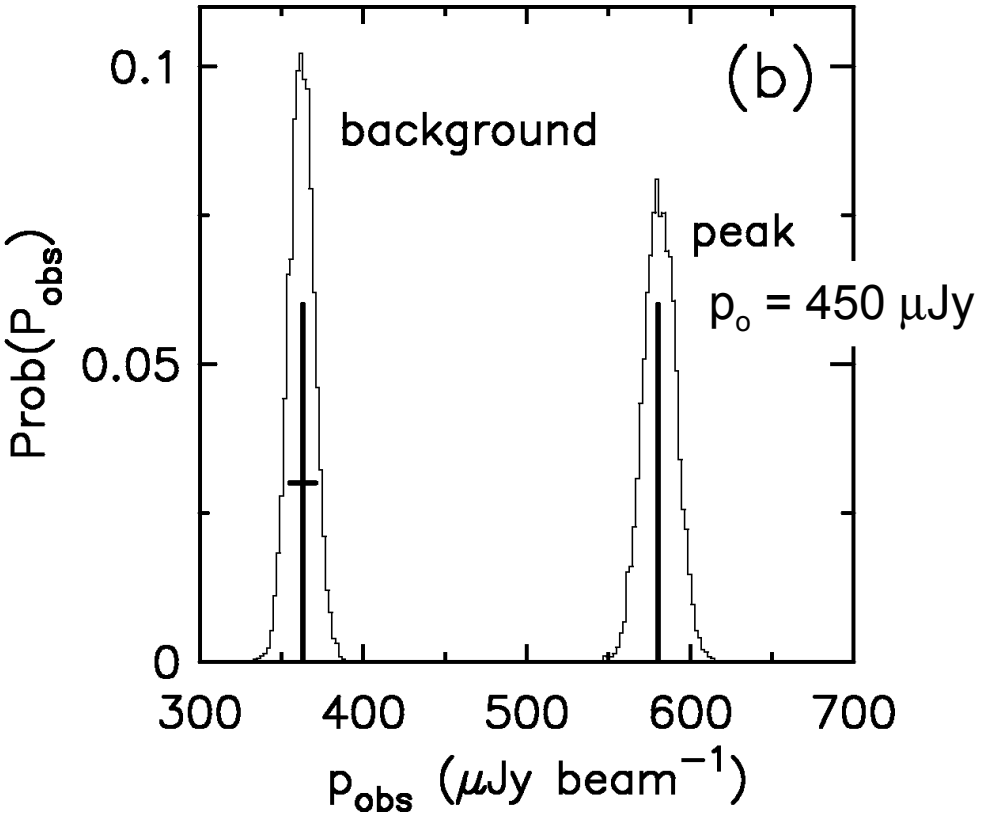
Polarized intensity contours (red) on Stokes I

Deep polarised source counts from stacking

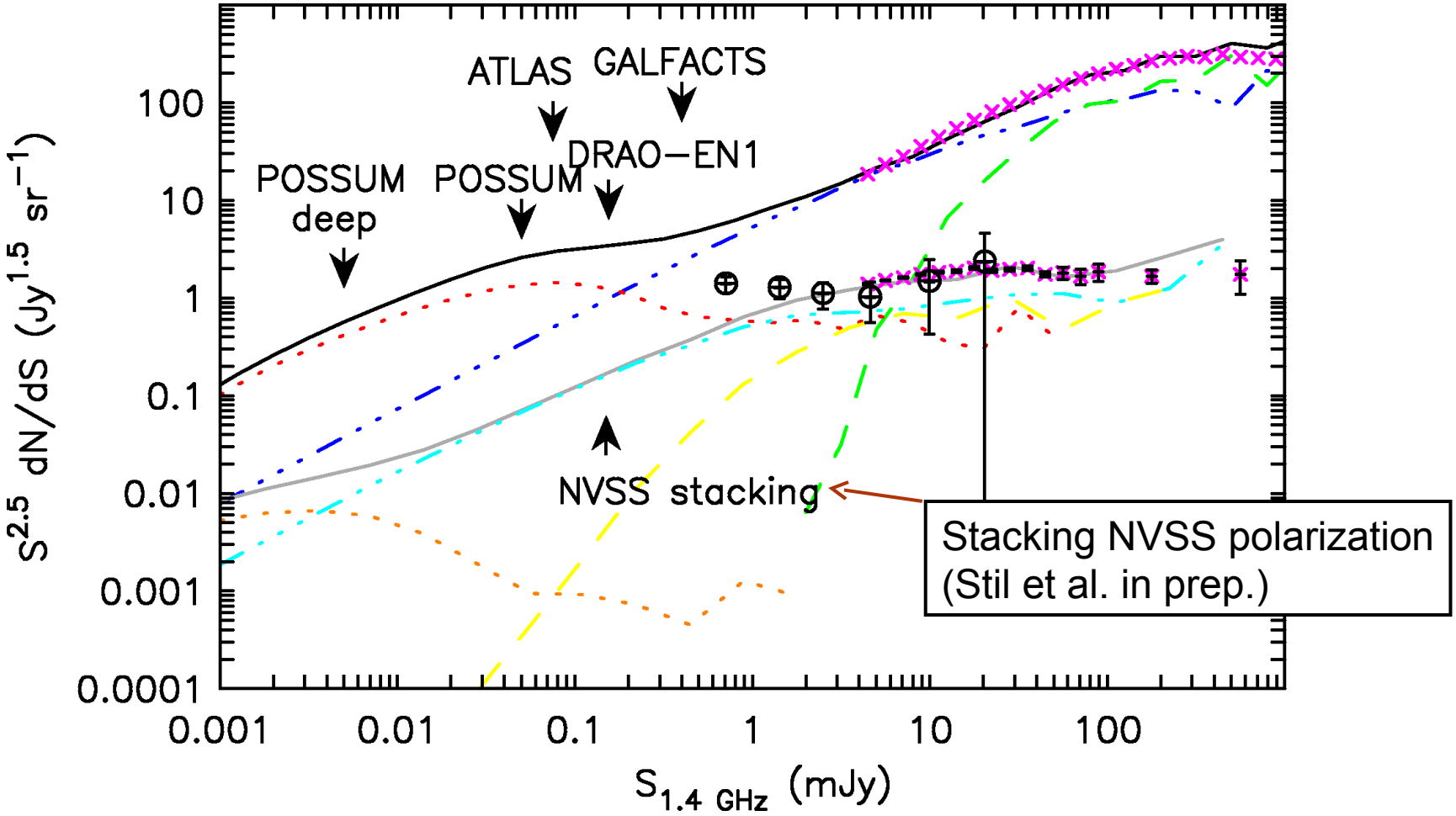
Stacking of NVSS sources in polarised intensity as a function of total flux density
Obtain median fractional polarisation as function of total flux density
Derive deep polarised source counts



~ 2000 sources



Fitting both Stokes I and polarised source counts



Models based on Stokes I SKADS S-cubed simulation (Wilman et al. 2008)
Details of polarisation model in O'Sullivan et al. (2009), Stil et al. (2009)

Conclusions

- **POSSUM wide** will provide a dense all-sky RM grid probing
  - Galactic magnetic field structure from pc to kpc scale
  - Turbulent properties of magnetised ISM
  - Extragalactic magnetic fields in galaxies, (super)clusters
  - Evolution of magnetic fields through RM-redshift dependence
- **POSSUM deep** will provide the densest RM sampling to date (~ 1 RM / 10 square arcmin)
  - Small-scale ISM turbulence at high latitude
  - Deep polarised source counts (evolution)
  - RM vs redshift