Radio polarization, from 150 MHz to 2.4 GHz

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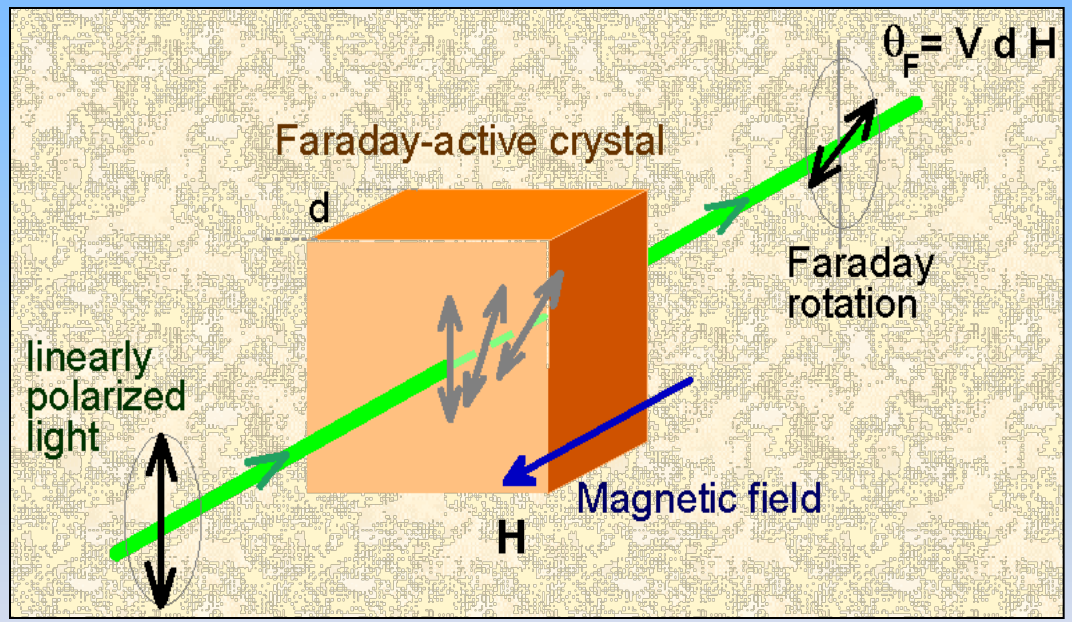
Radio polarization

- Synchrotron emission & polarization give the intensity and the orientation of $B_{\perp}$
- Faraday rotation probes the intensity and direction of $B_{\parallel}$

$$\Theta - \Theta_0 = RM\lambda^2$$

$$RM = K \int_L^0 n_e B_{\parallel} dl$$



- is everywhere in the sky and propagates freely through the Galaxy without absorption;
- is strongly frequency dependent;

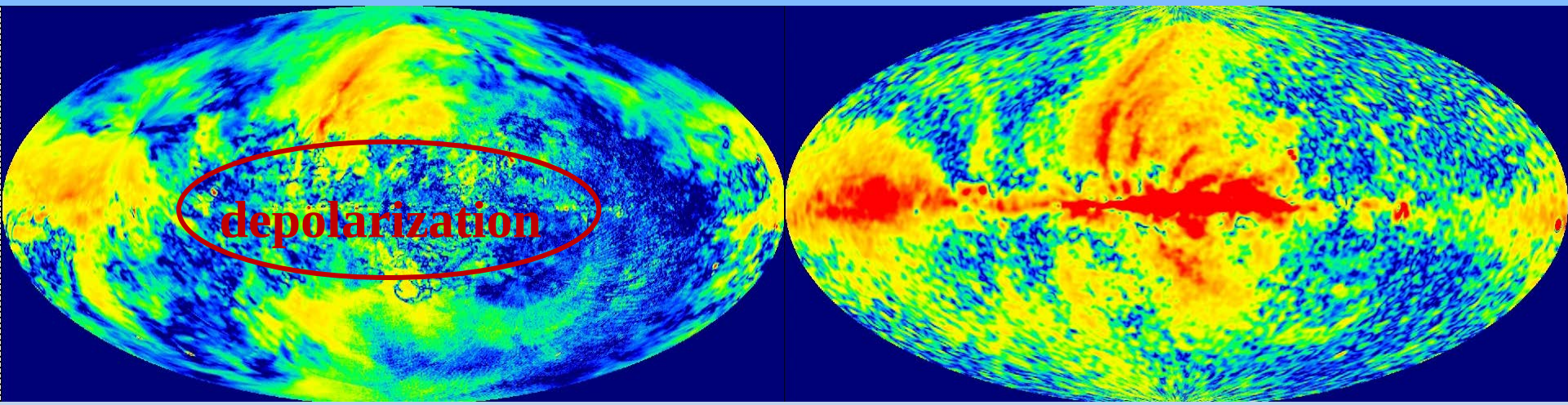
Radio (de)polarization

	Frequency dependent?
• Synchrotron emitting regions and thermal magnetized plasma (i.e. only rotating and not emitting) are co-located → partial or total cancellation when integrated along the line of sight (depolarization by Faraday depth or internal Faraday dispersion);	YES
• Stokes Q&U variations across the source size and smaller than the observing beam → partial or total cancellation when integrated over the beam area (beam depolarization);	NO
• RM variations across the source size and smaller than the observing beam → partial or total cancellation when integrated over the beam area (beam depolarization);	YES
• Stokes Q&U variations across the observed bandwidth (RM) → partial or total cancellation when integrated over the bandwidth (bandwidth depolarization);	YES
• RM Time variations (i.e. ionosphere) → partial or total cancellation when integrated over time;	YES

Radio polarization @ cm wavelengths

1.4 GHz: DRAO (Wolleben et al. 2006) + Villa Elisa (Testori et al. 2008)

22.8 GHz WMAP (Page et al. 2007)



- Synchrotron polarization is a relevant foreground for CMB polarization;
- Measurement of the Galactic magnetic field;
- Measurement of the ISM turbulence;
- Revealing features along the line of sight undetectable otherwise (ISM tomography);

Polarization @ cm wavelengths: bubbles

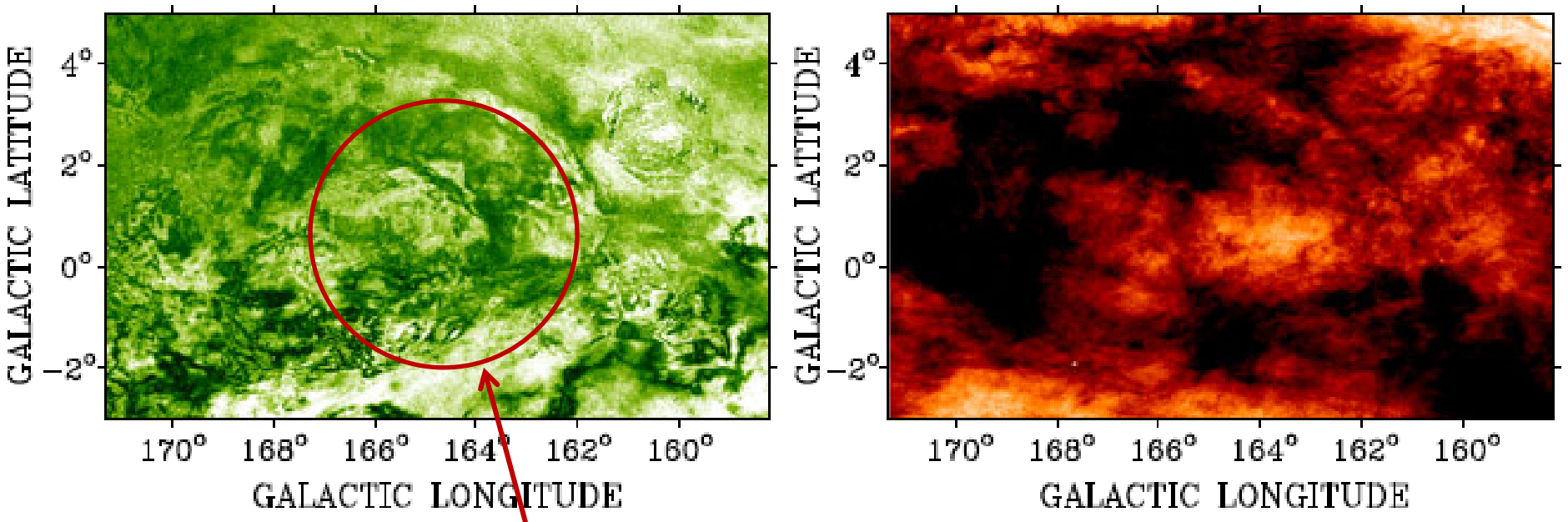


Fig. 2 CGPS data, 1420 MHz, angular resolution $1'$. Polarized intensity (*left*) from 0 (*black*) through *green* to 500 mK (*white*), and H I at $v_{lsr} = -20$ km s^{-1} from 20 (*white*) through *red* to 80 K (*black*)

Giant (350 pc) stellar wind bubble
from a massive star cluster

Landecker 2012

Polarization @ cm wavelength: Faraday screens

4.8 GHz survey, HPBW 9.5´ (Gao et al., 2010)

Foreground screen model: RM -140+/- 20 rad m^{-2}

Negligible depolartion (~3%)

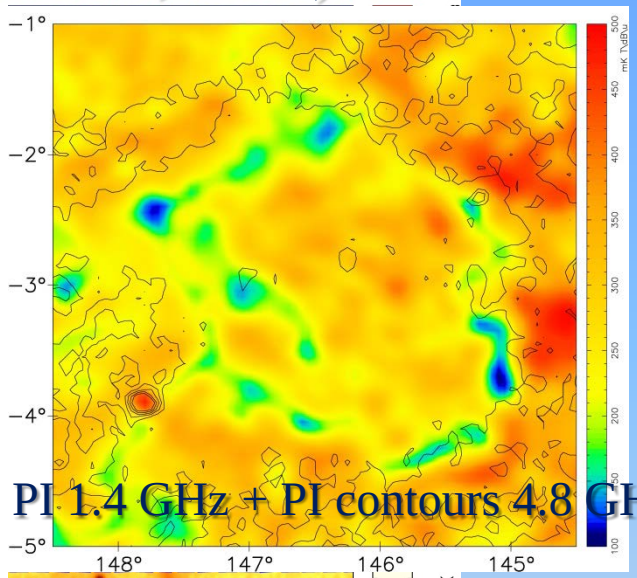
distance ~300 – 700 pc ➔ size ~17 – 40 pc

Foreground screen: *RM ~ n_e $B_{||}$ size*

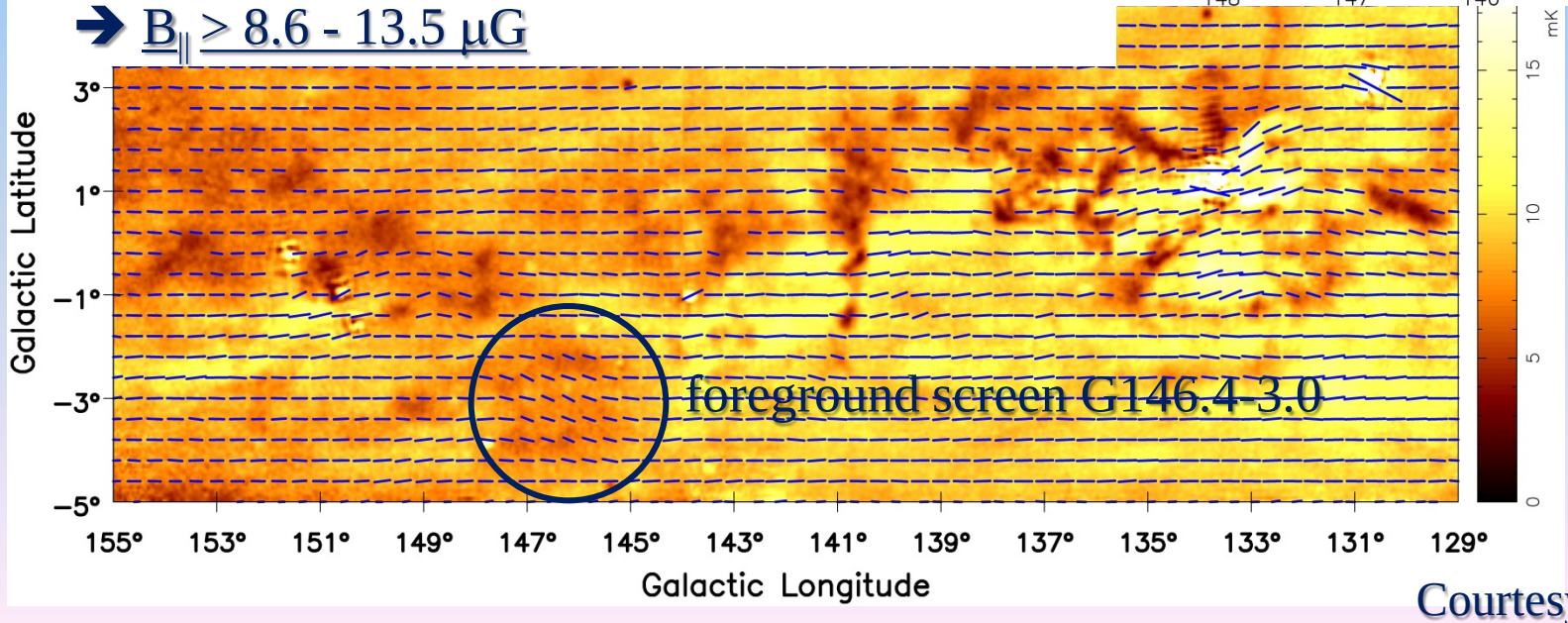
n_e: *no* Hα, upper limit by 4.8 GHz rms-TP

➔ n_e < 0.5 – 0.8 cm^{-3}

➔ $B_{||}$ ≥ 8.6 - 13.5 μG



PI 1.4 GHz + PI contours 4.8 GHz

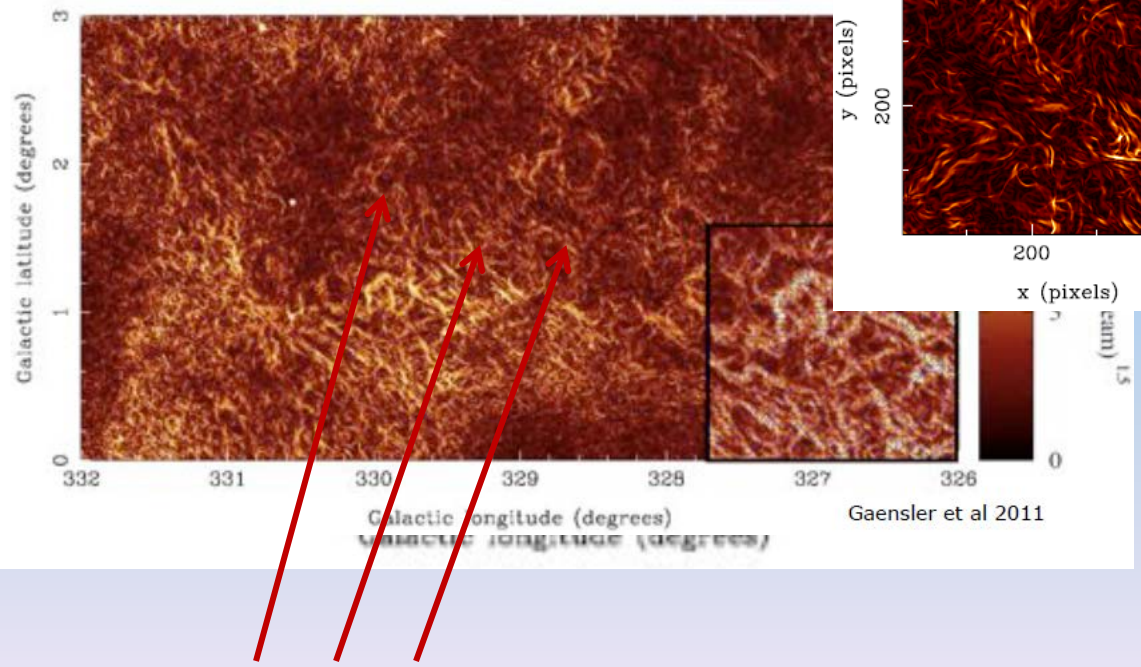


Courtesy W. Reich

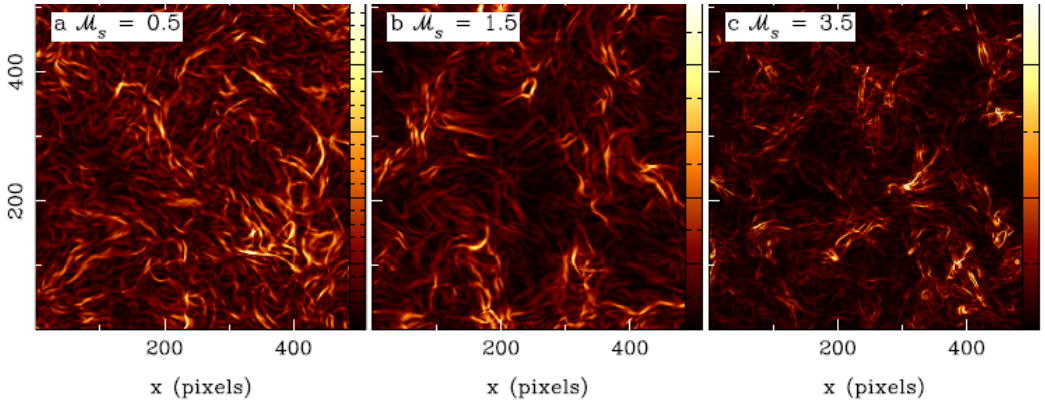
Polarization @ cm wavelengths: imaging the ISM turbulence in the Galactic Plane

Southern Galactic Plane survey @1.4 GHz

$$|\nabla \boldsymbol{P}| = \sqrt{\left(\frac{\partial Q}{\partial x}\right)^2 + \left(\frac{\partial U}{\partial x}\right)^2 + \left(\frac{\partial Q}{\partial y}\right)^2 + \left(\frac{\partial U}{\partial y}\right)^2}$$



magnetohydrodynamical simulations

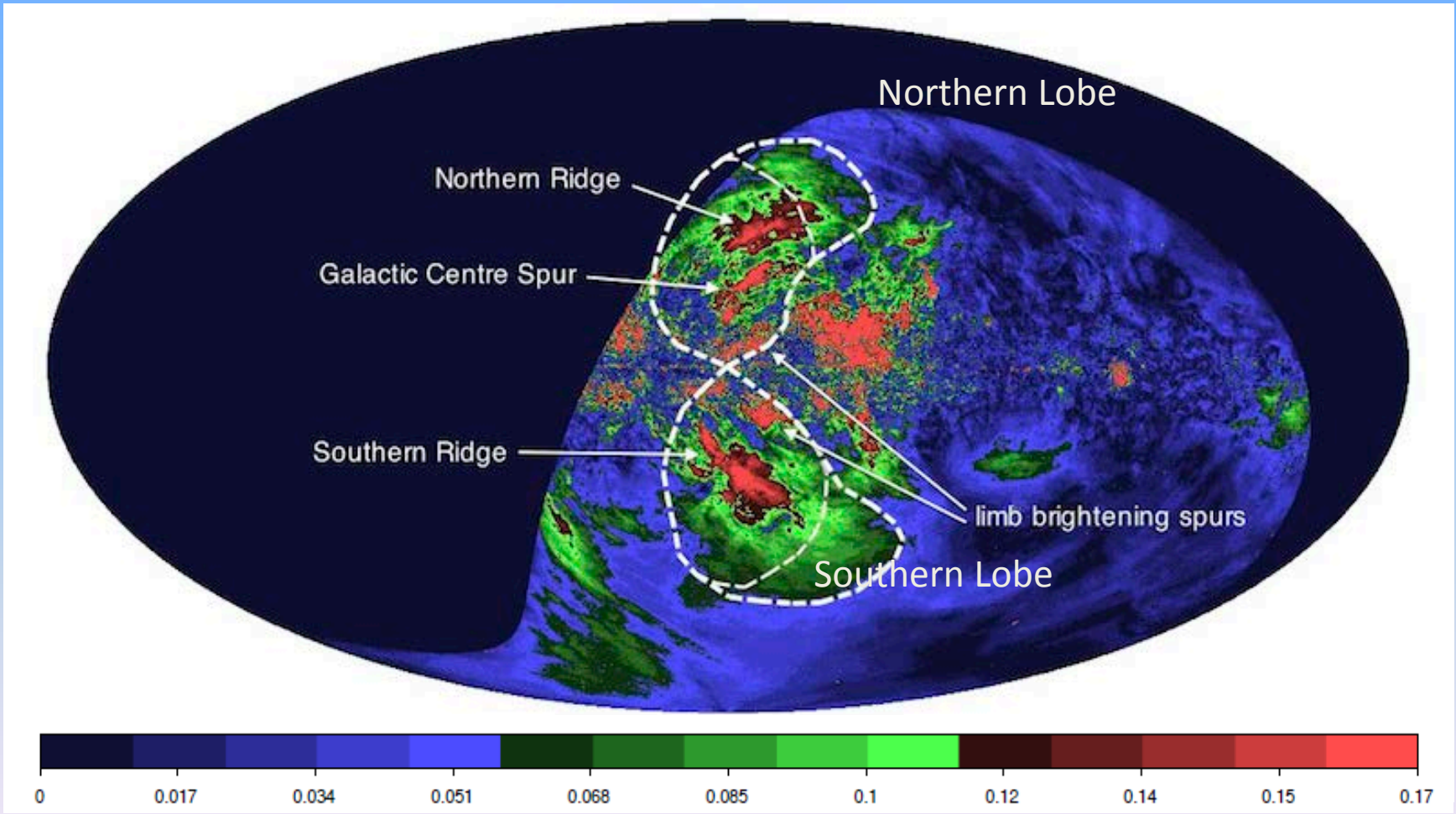


The filamentary web of depolarization canals is the result of magnetic fluctuations generated subsonic turbulence in the ISM

depolarization canals

Gaensler et al. 2011

Polarization @ cm wavelengths: large scale outflows from the Galactic Centre



E. Carretti et al., 2013

Radio polarization @ m wavelengths: RM synthesis

- Generic form of the expression for rotation measure is (Burn 1966):

$$P(\lambda^2) = \int_{-\infty}^{+\infty} F(\phi) e^{2i\phi\lambda^2} d\phi$$

where ϕ (the ***Faraday depth***) has taken the place of RM, and F is the ***Faraday dispersion function***.

- The expression for the (reconstructed) Faraday dispersion function

$$\tilde{F}(\phi) = K \int_{-\infty}^{+\infty} \tilde{P}(\lambda^2) e^{-2i\phi(\lambda^2 - \lambda_0^2)} d\lambda^2$$

can be written as a sum (if channel width is small),

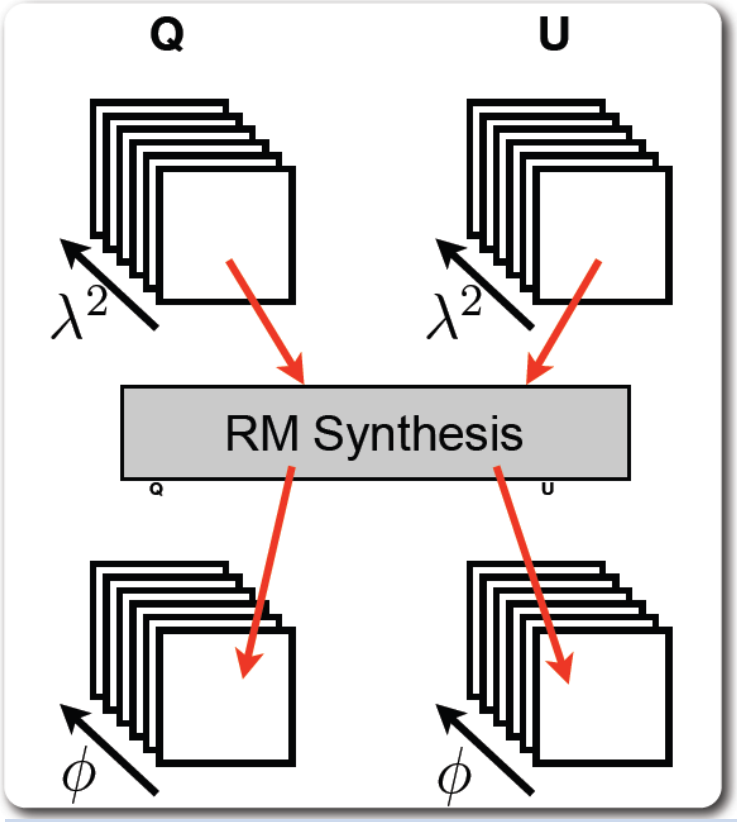
$$\tilde{F}(\phi) = K \sum_{c=1}^{N} \tilde{P}_c e^{-2i\phi(\lambda_c^2 - \lambda_0^2)}$$

("trial RM" interpretation)

- The RMSF is then

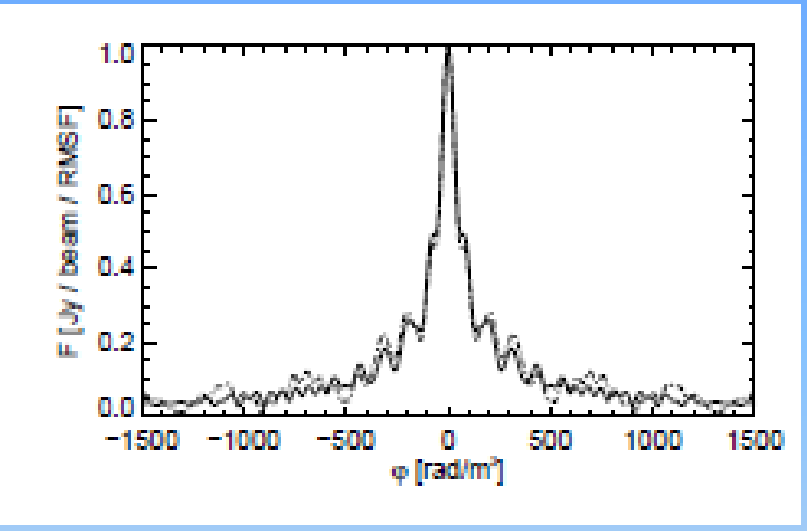
$$R(\phi) = K \sum_{c=1}^{N} w_c e^{-2i\phi(\lambda_c^2 - \lambda_0^2)}$$

$$K = \left(\sum_{c=1}^{N} w_c \right)^{-1}$$

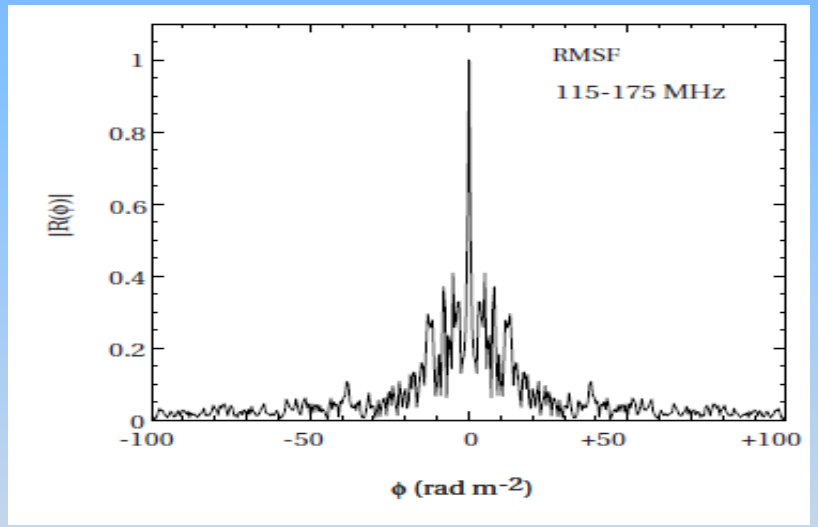


Brentjens & de Bruyn 2005

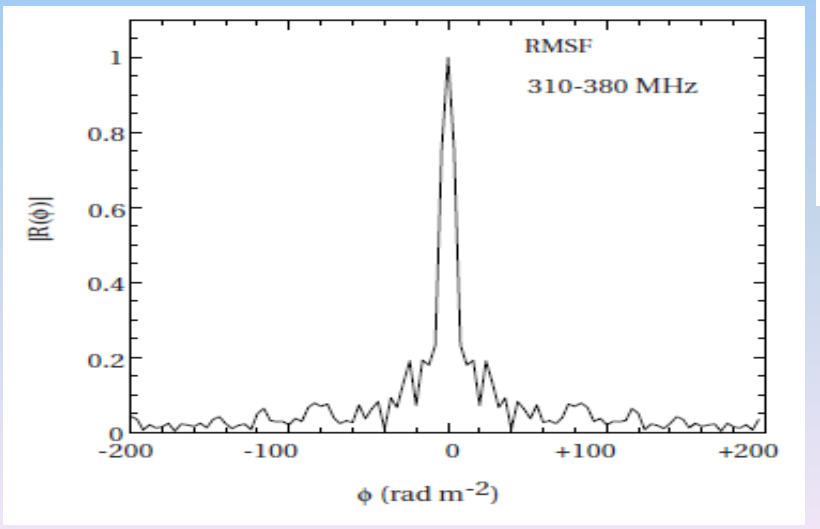
Resolution to extended polarized structures in RM space



80 rad m^2



1 rad m^2



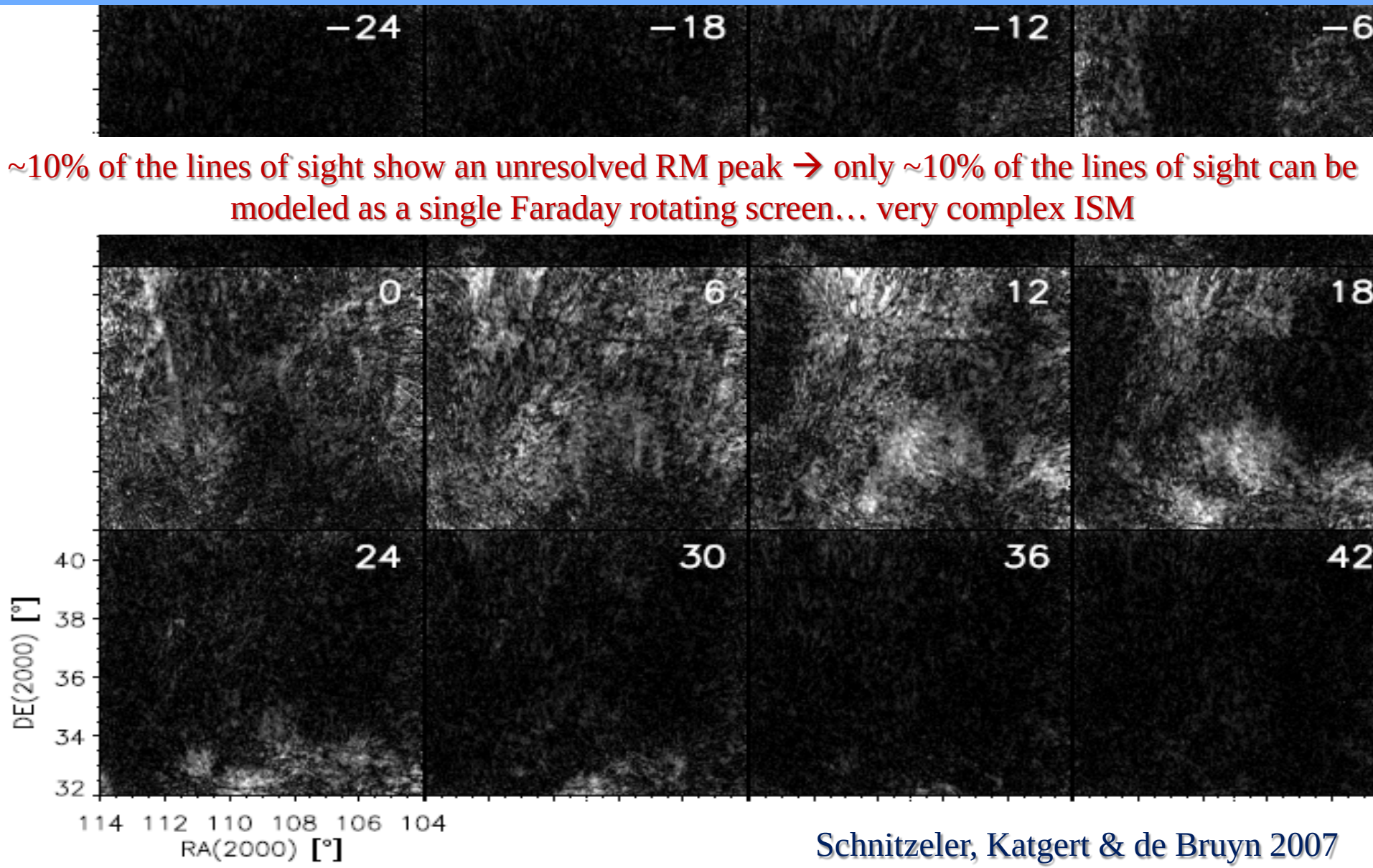
10 rad m^2

Low frequency radio polarimetry is great for ISM tomography!

Radio polarization @ m wavelengths

- Is a contamination for observations of the redshifted 21cm line (EoR and BAO);
- Faraday rotation is exacerbated;
- Sensitive to weak magnetic fields a/o small n_e fluctuations;
- Depolarization is exacerbated;
- Probes essentially local features (distant emission is easily depolarized);
- RM synthesis has very high RM resolution → separate tiny contributes along the line of sight (unique of m wavelength polarimetry);
- cm + m wavelength radio polarimetry → more complete picture of the ISM (and Galactic foreground);

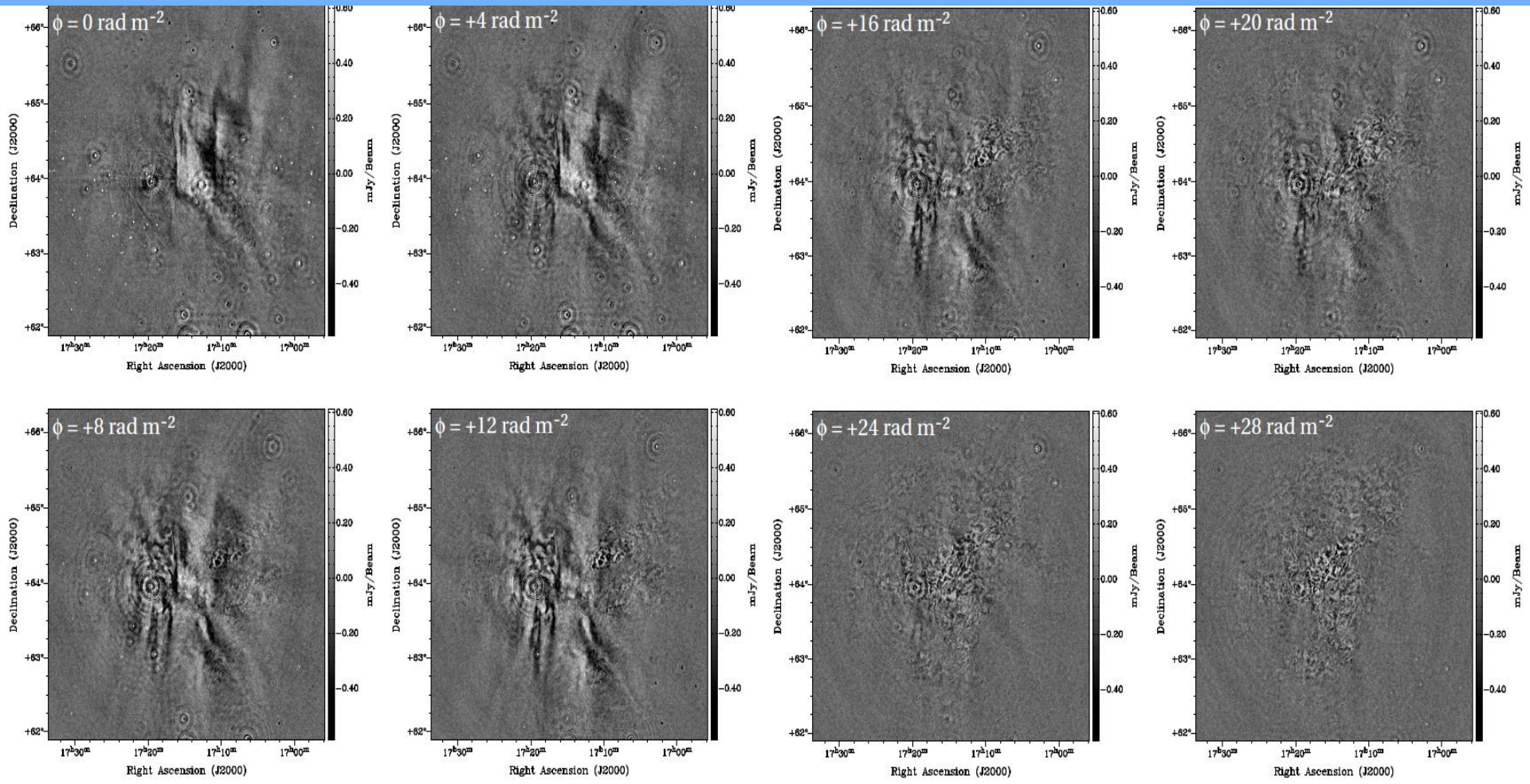
Radio polarization @ 90 cm: the Galactic anticentre, (l,b) ~ (180°,20°)



~10% of the lines of sight show an unresolved RM peak → only ~10% of the lines of sight can be modeled as a single Faraday rotating screen… very complex ISM

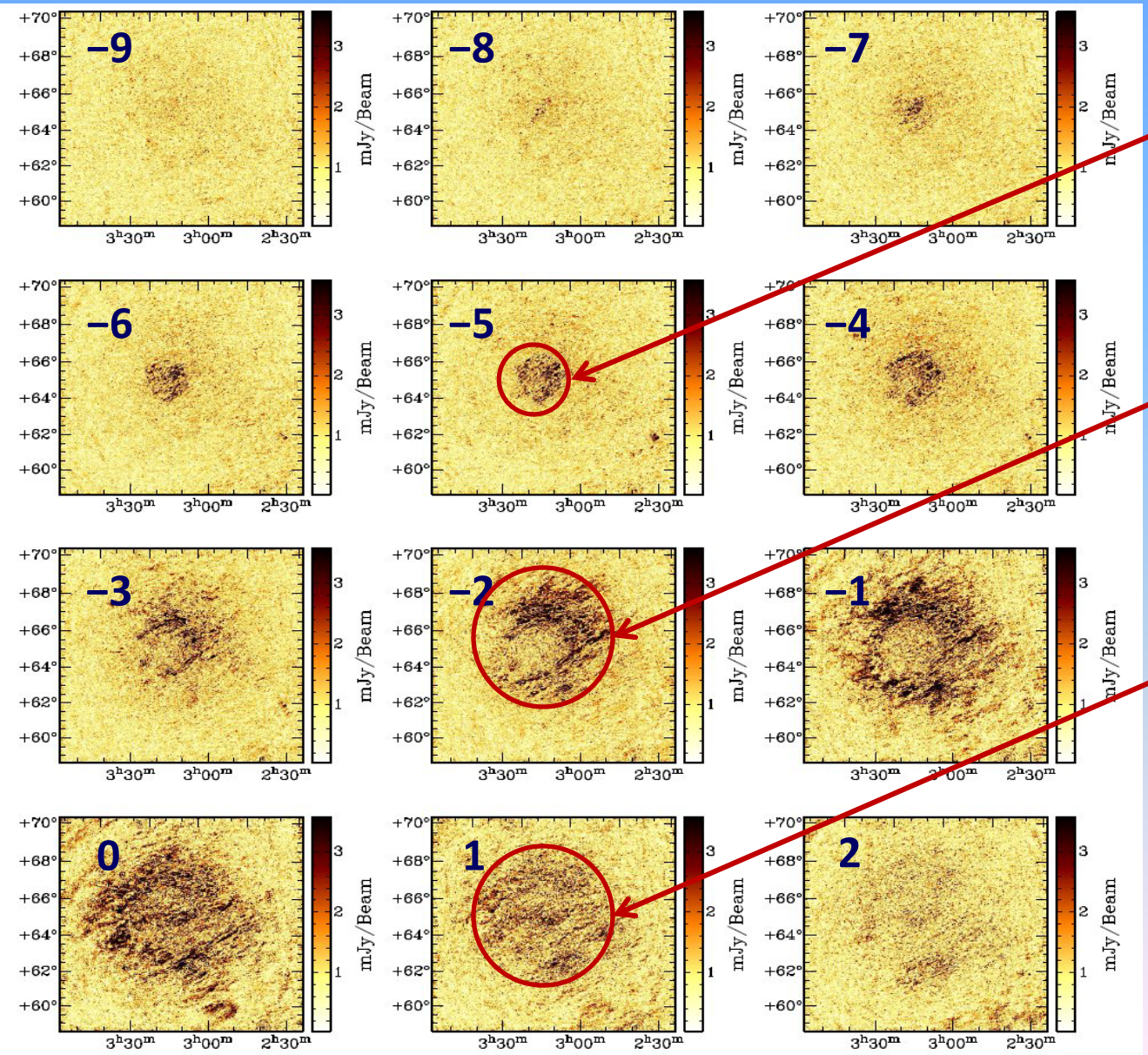
Schnitzeler, Katgert & de Bruyn 2007

Radio polarization @ 90 cm: towards the Abell 2255, (l,b) ~ (94°,35°)



Pizzo 2009

Radio polarization @ 2m: the Fan region, (l,b) ~ (140°,6°)



"Bubble" component: a nearby (200 pc) relic Stromgren sphere

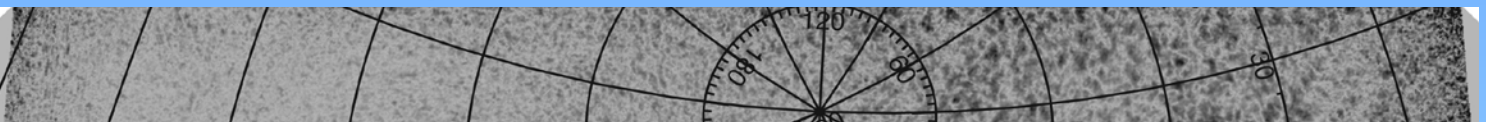
"Ring" component: background Local Bubble (100 pc),

"Curtain" component: magnetic field reversal and compression in front of the Local Bubble (?)

Bernardi et al. 2009, Iacobelli et al. 2013

Radio polarization @ 2 m: imaging the ISM turbulence outside the Galactic lane

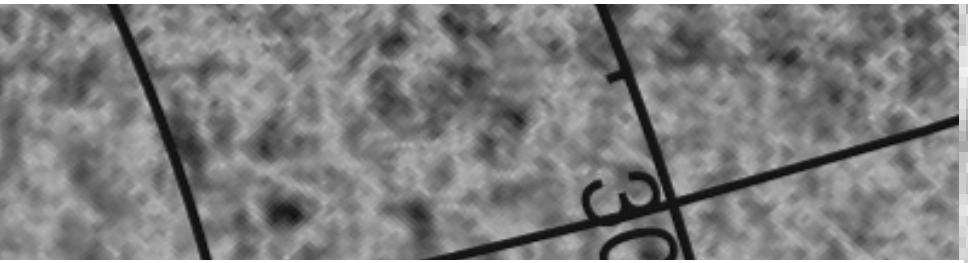
δ=-27° survey @ 189 MHz with the Murchison Widefield Array



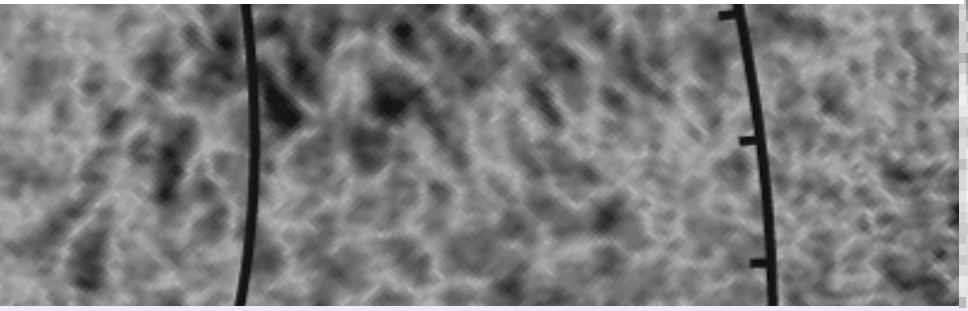
$\phi = 0$ rad m^2

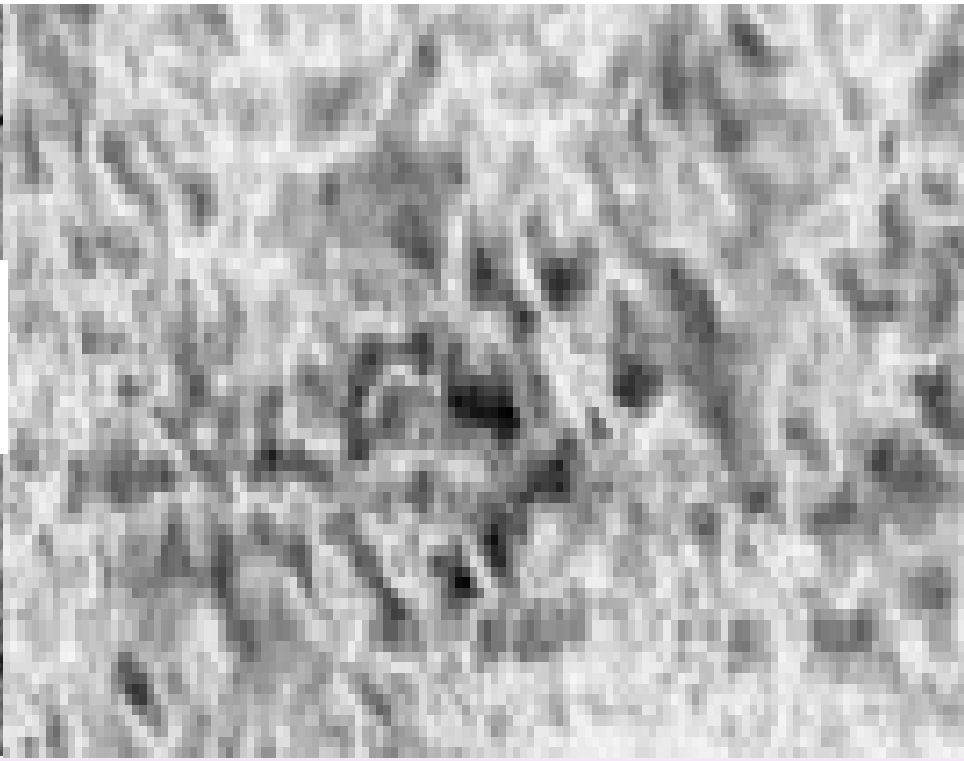
filamentary polarized emission @ 189 MHz

filamentary polarized emission at 1.4 GHz



Local (< 150 pc) ISM turbulence outside the Galactic Plane detectable only at very low frequencies





Bernardi et al. 2013 (submitted)

Conclusions and future

- Radio polarization is a foreground for cosmology (for both the CMB and the redshifted 21cm line);
- The ISM is very rich of structures (bubbles, filaments, arcs) that can only be revelead through polarimetry
  - cm/mm wavelength polarimetry is a powerful tracer of the Galactic Magnetic field
- Low frequency polarimetry is unique to local structures and weak magnetic fields;
- Low frequency polarimetry is affected by complex ISM, with multiple emission along the line of sight;
- Only full frequency coverage from m to mm wavelengths can give a complete picture of the ISM;
- Planck + cm wavelength + low frequency radio surveys (GMIM,, LOFAR, MWA) promise to fill the gap;
  - SKA will offer continuous coverage in the 60 MHz – 3 GHz frequency range;

THANK YOU