The Galactic magnetic field modelled from synchrotron emission and extragalactic sources

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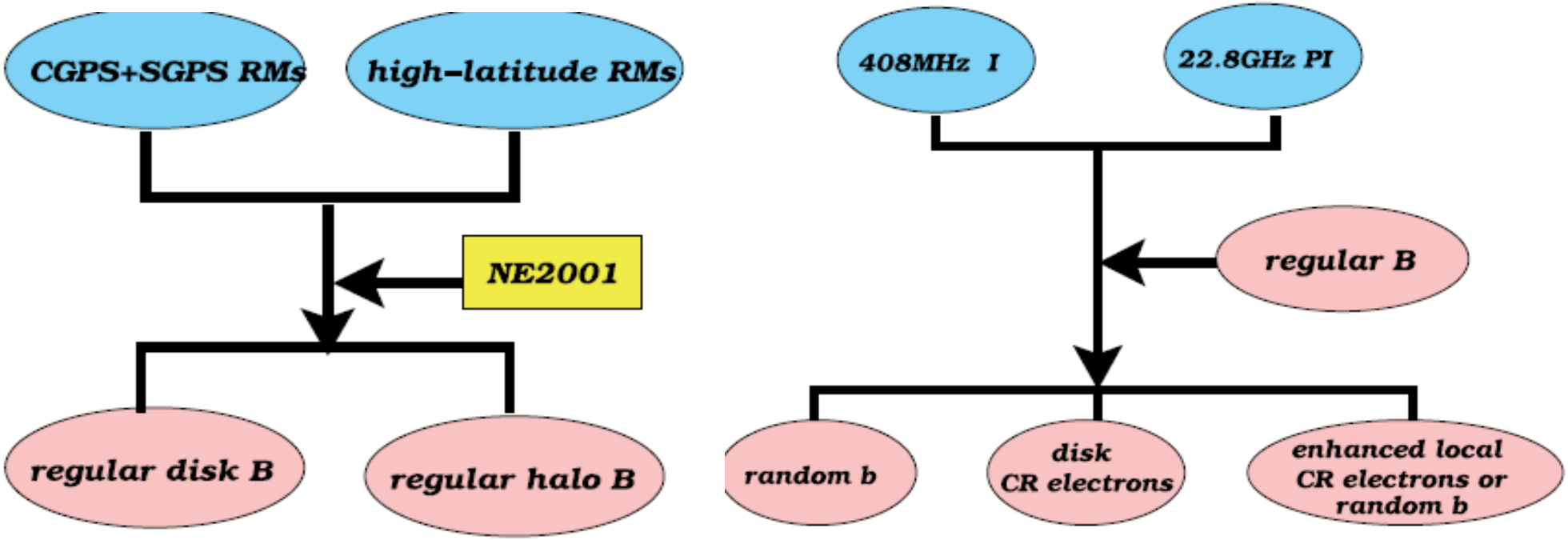
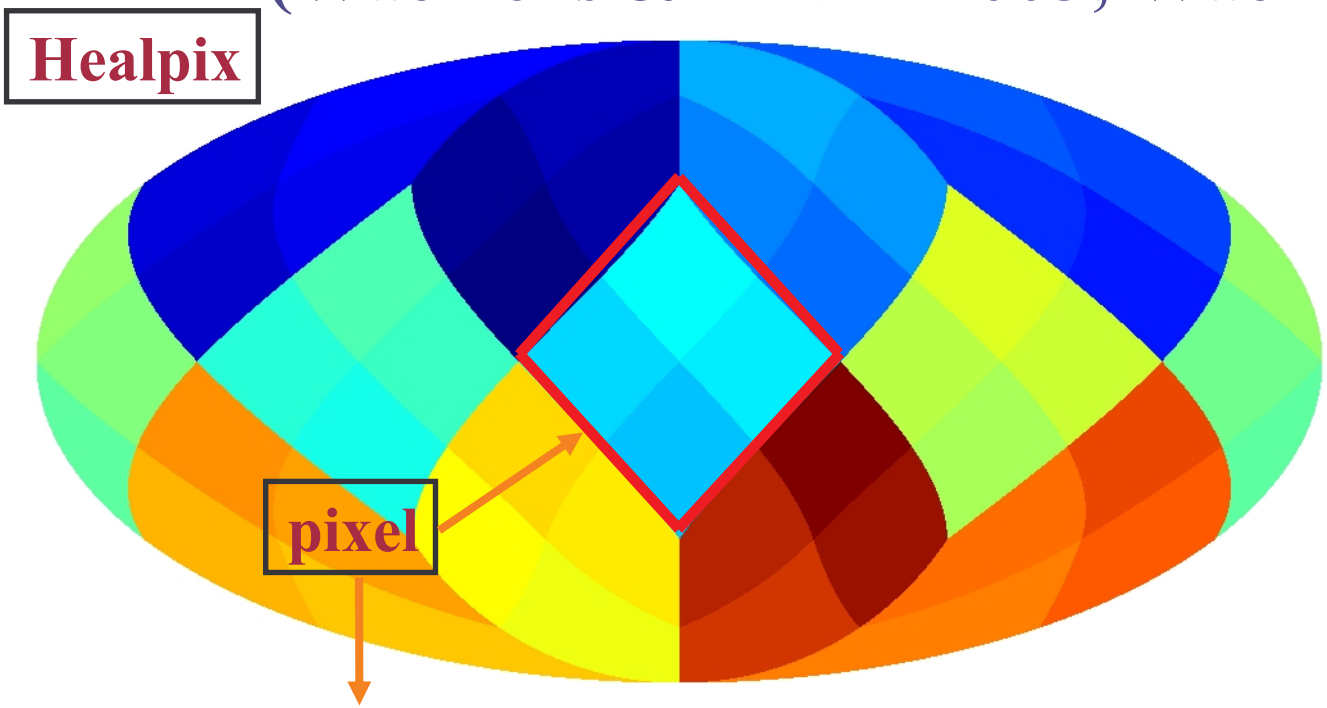
Aim and Method

3D models to account for all relevant radio observations

- **RMs of EGSs**
- **408 MHz total intensity all-sky survey**
- **22.8 GHz polarized intensity all-sky survey**



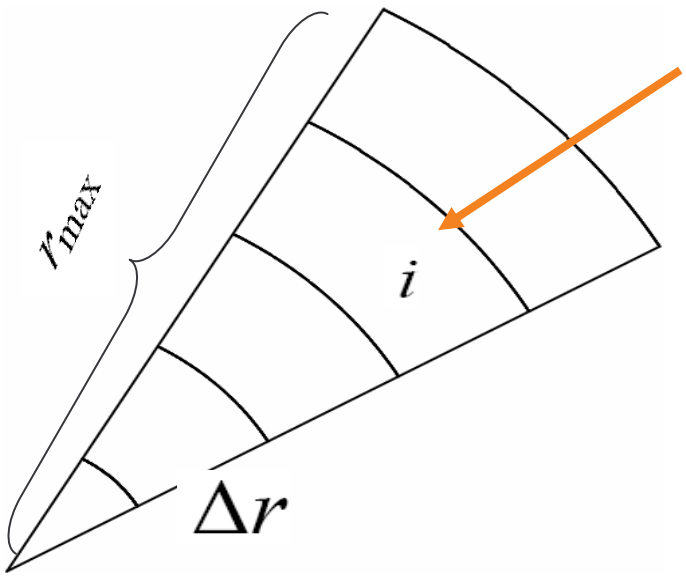
HAMMURABI code
(Waelkens & Enßlin 2005; Waelkens et al. 2009)



$$N_{\rm pix} = 12 N_{\rm SIDE}^2$$

$$\Delta\theta \approx \sqrt{\frac{3}{\pi}} \frac{3600'}{N_{\rm SIDE}}$$

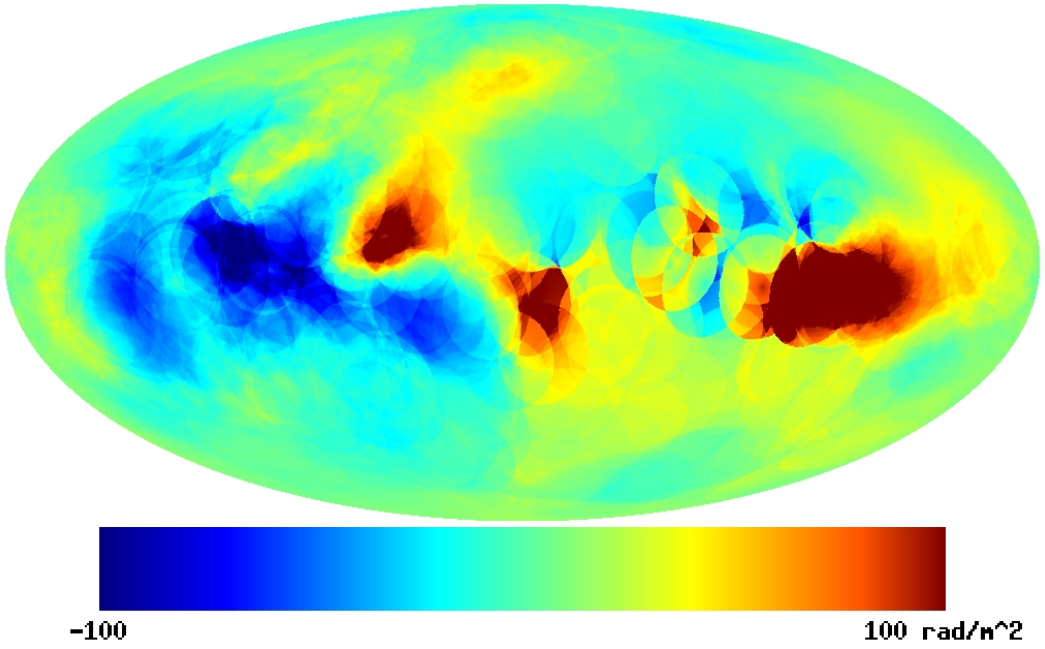
$$N_{\rm SIDE} = 256$$

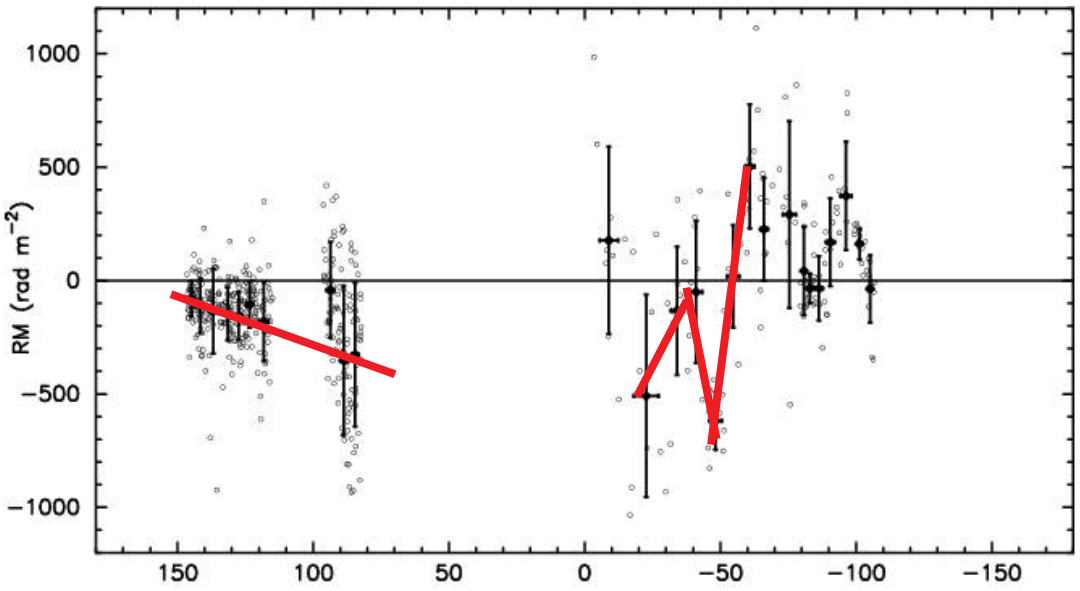


$$\begin{cases} I_i^{\rm syn} = C_I B_{i,\perp}^{(1-p)/2} \nu^{(1+p)/2} \Delta r \\ PI_i = C_{PI} B_{i,\perp}^{(1-p)/2} \nu^{(1+p)/2} \Delta r \\ RM_i = 0.81 n_{ei} B_{i,\parallel} \Delta r \\ \psi_i = \psi_{i,0} + \sum_1^i RM_j \lambda^2 \\ U_i = PI_i \sin(2\psi_i) \\ Q_i = PI_i \cos(2\psi_i) \\ EM_i = n_{ei}^2 \Delta r \\ \tau_i = 8.235 \times 10^{-2} T_i^{-1.35} \nu^{-2.1} EM_i \\ I_i^{\rm ff} = T_i (1 - \exp(-\tau_i)) \end{cases}$$

$$\begin{cases} I^{\rm syn} = \sum_i I_i^{\rm syn} \\ I^{\rm ff} = \sum_i I_i^{\rm ff} \\ Q = \sum_i Q_i \\ U = \sum_i U_i \\ RM = \sum_i RM_i \end{cases}$$

RMs of EGSs (Sun et al. 2008 A&A)





High latitude RMs

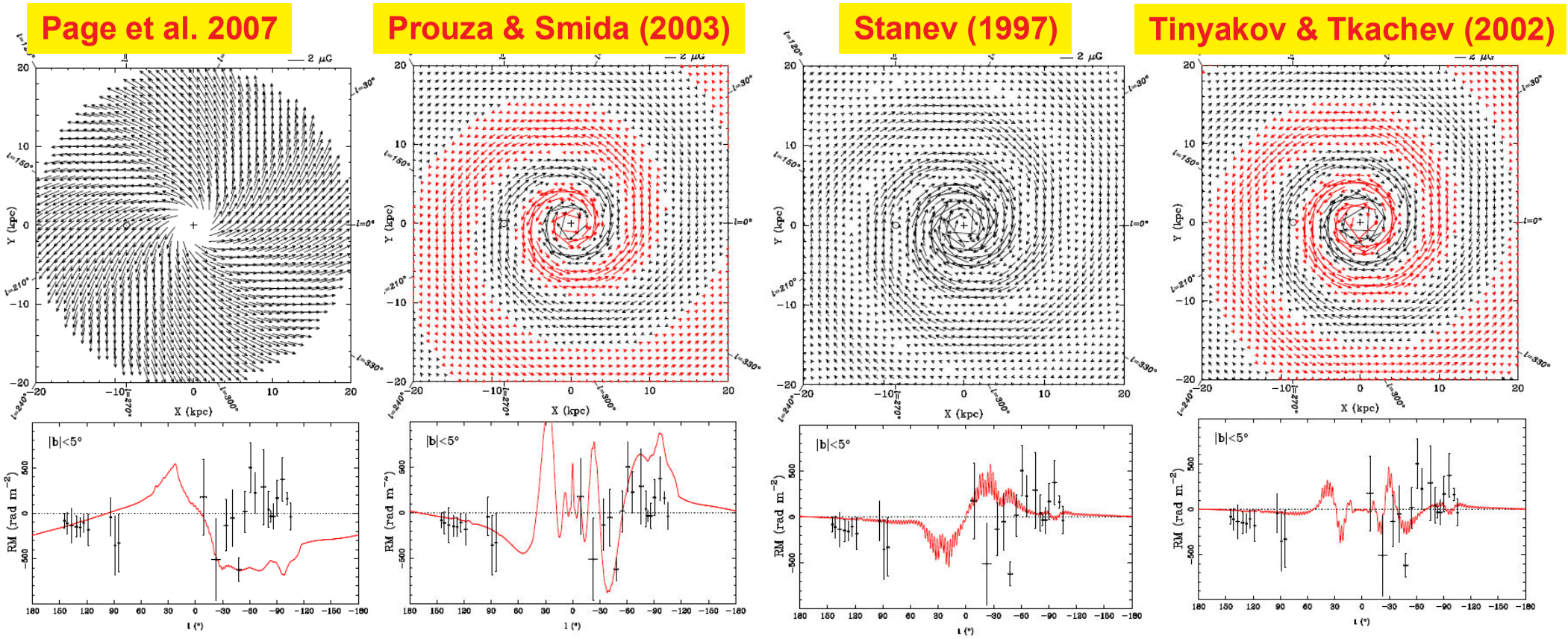
– synthesized map from RMs compiled by Han et al. (1999) and the Effelsberg L-band RM survey (Han et al. in prep.)

– **asymmetric** relative to the plane and the centre towards inner Galaxy

RMs at the Galactic plane

CGPS (Brown et al. 2003)
SGPS (Brown et al. 2007)

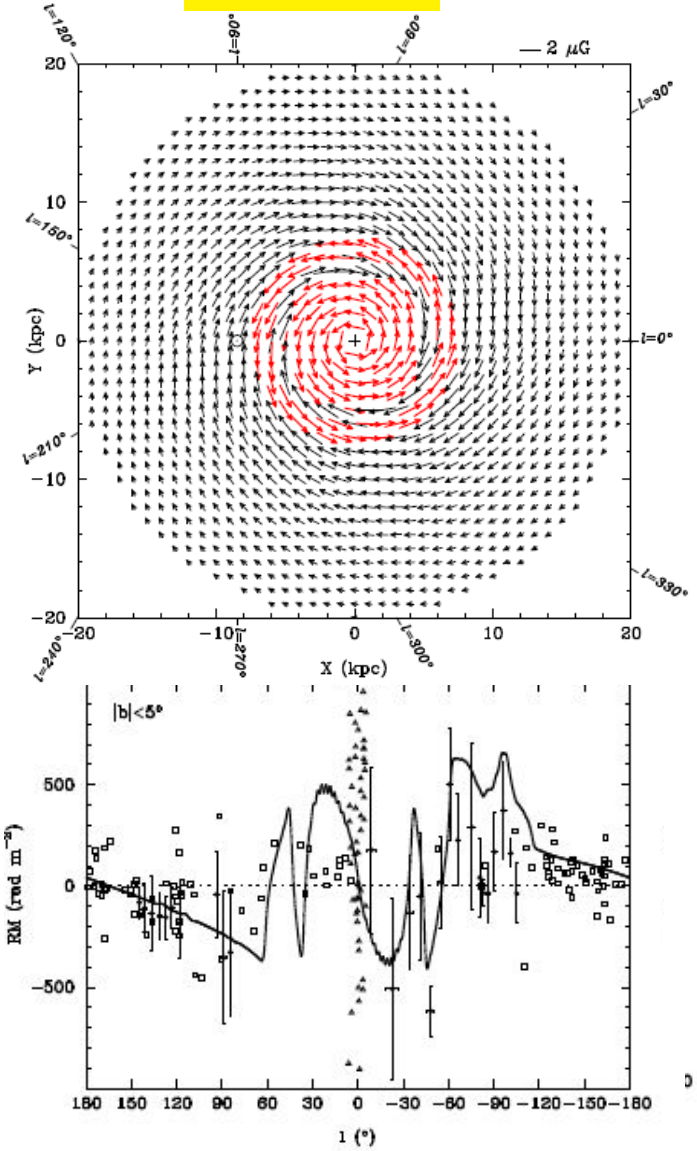
Regular magnetic field in the disk



Early models cannot account for RMs properly

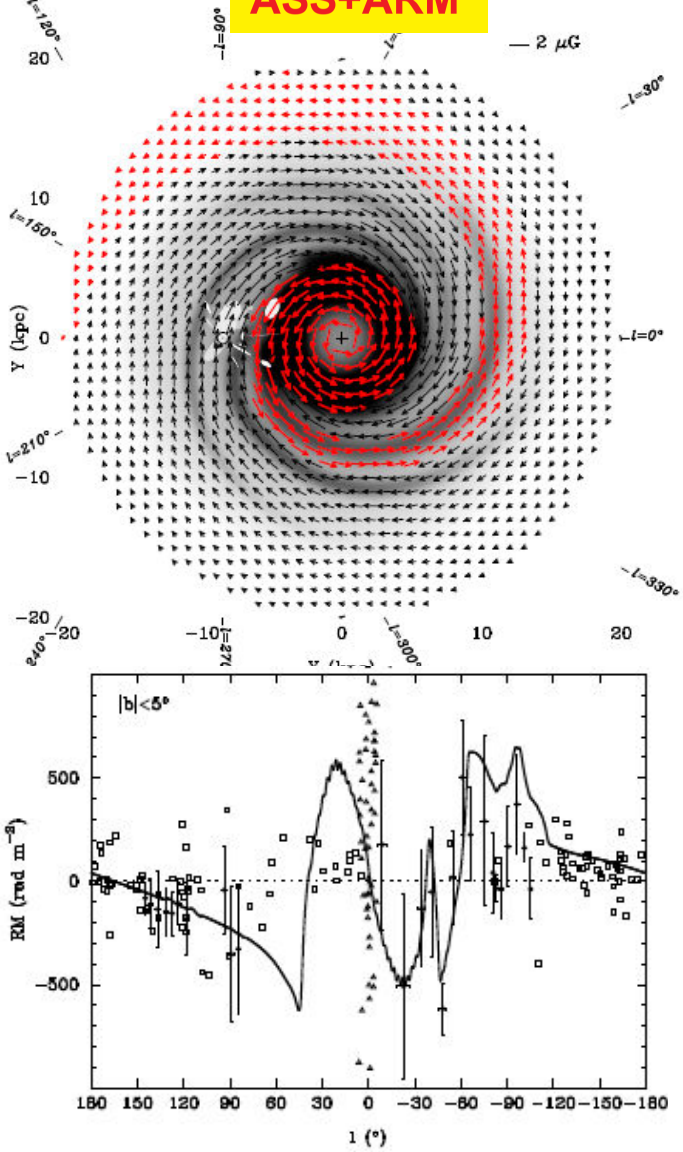
Regular magnetic field in the disk (Sun et al. 2008 A&A)

ASS+RING



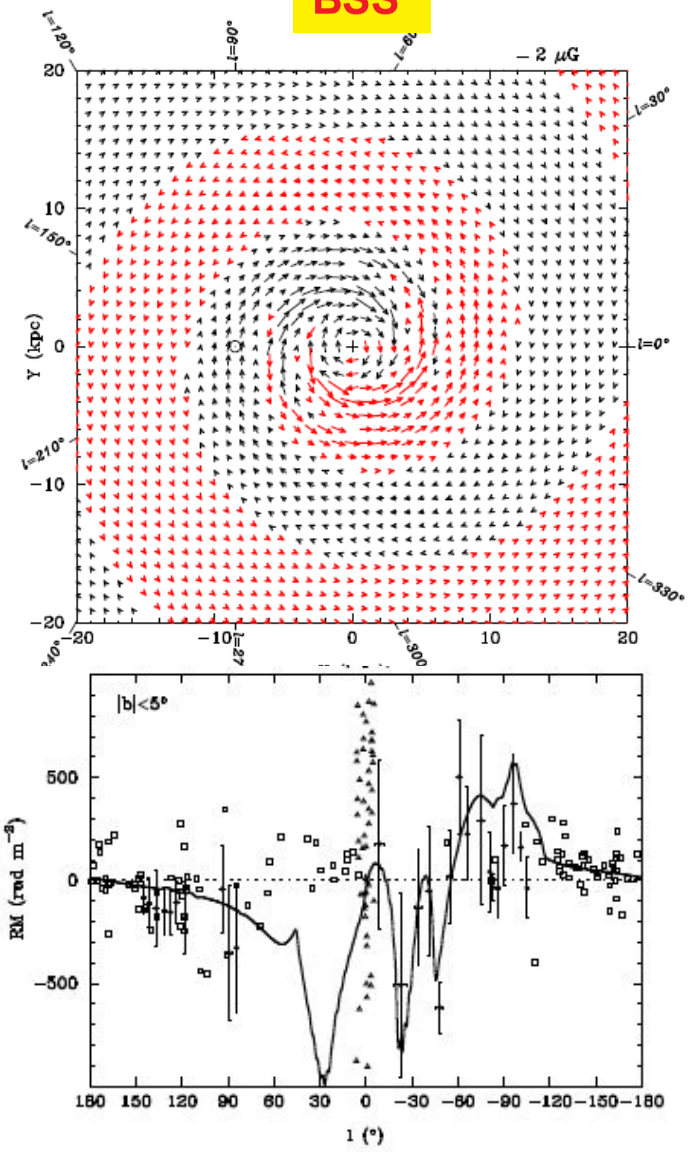
B0=2 microG
R0=10 kpc
z0=1kpc
reversal: 6kpc<R<7.5kpc

ASS+ARM



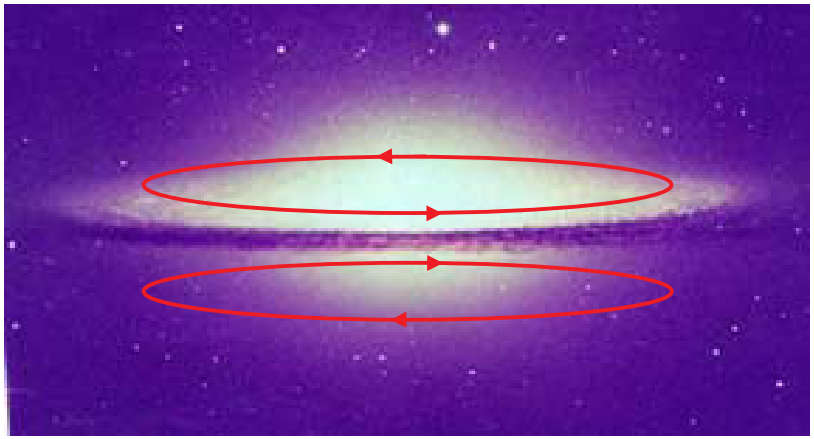
B0=2 microG
R0=8.5 kpc
z0=1kpc
arm models in NE2001

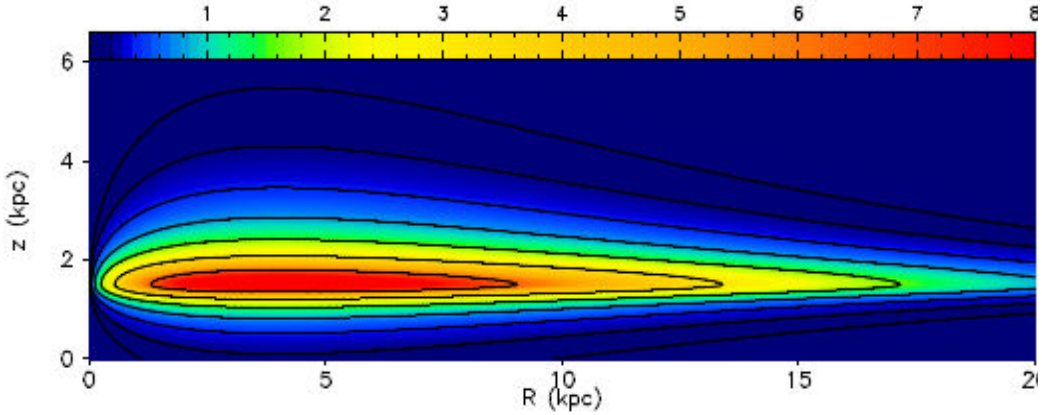
BSS

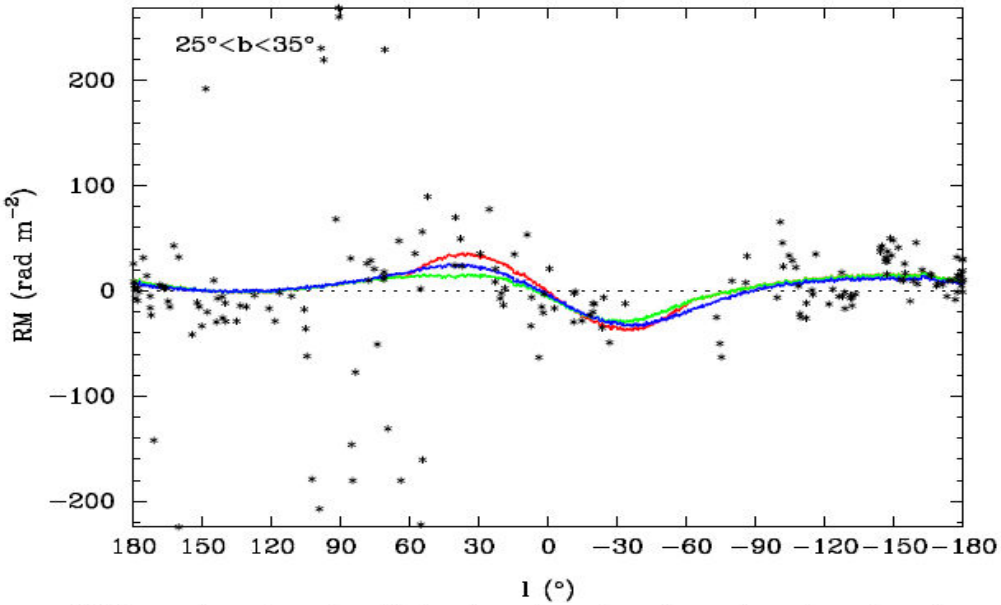


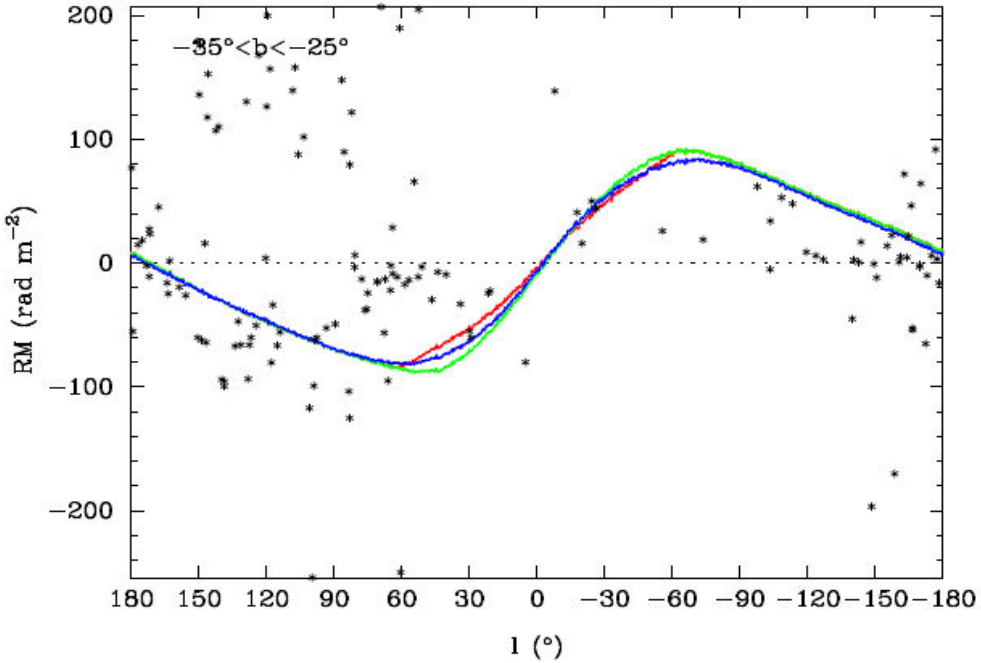
B0=2 microG
R0=6 kpc
z0=1kpc

Regular magnetic fields in the halo (Sun et al. 2008 A&A)



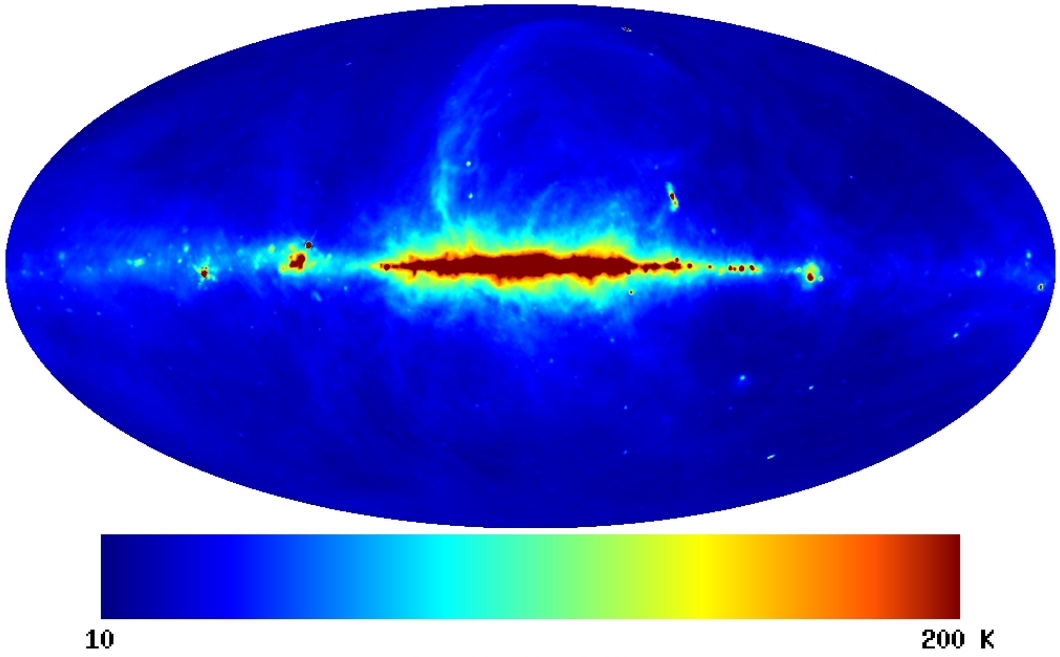




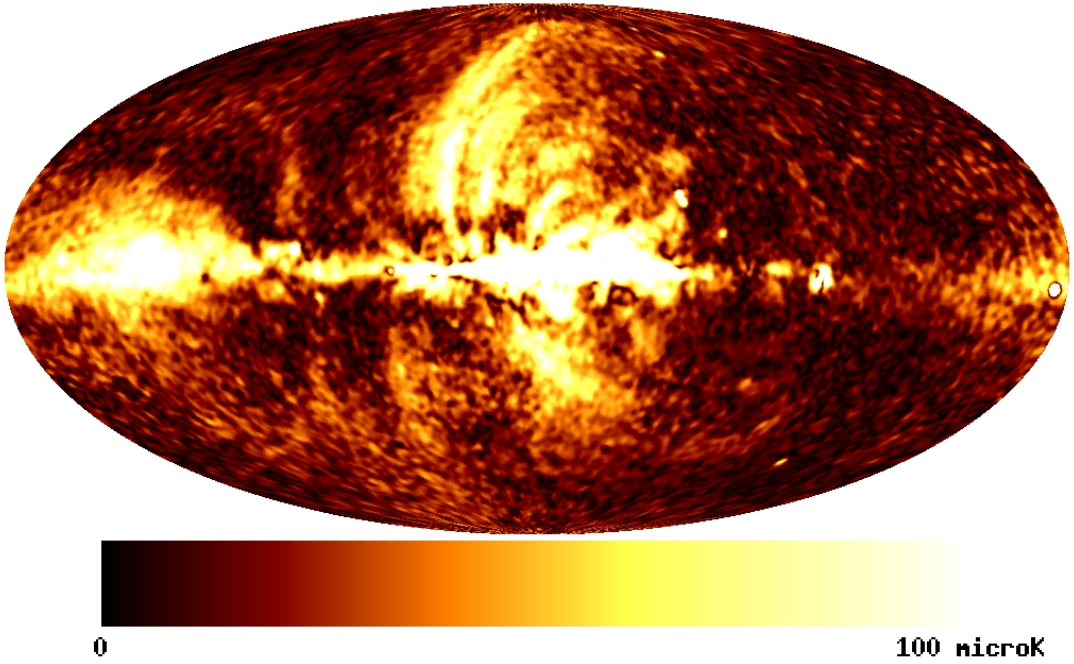


– toroidal field
– opposite direction below and above the plane
– maximum about 10 microG

All-sky survey: total + polarization intensity



– 408MHz I (Haslam et al. 1982)
– synchrotron template



– 22.8 GHz PI (Page et al. 2007)
(local: fan region and Loop I)
– PI asymmetric to the centre

Random fields, CR electrons and local excess of synchrotron emission (Sun et al. 2008 A&A)

CR electrons:

spectral index of –3

normalization factor:

$$C(R,z) = C_0 \exp\left(-\frac{R - R_\odot}{8\ \mathrm{kpc}} - \frac{|z|}{1\ \mathrm{kpc}}\right)$$

truncation at 1 kpc

local flux density at 10 GeV

0.4 $(\mathrm{Gev\ m^2\ sr\ s})^{-1}$

Random fields:

Gaussian, homogeneous

strength: 3 microG

Local excess

Observational evidence

-- emissivity:

>2 kpc at 74 MHz:

0.35 -- 1.0 K/pc (Nord et al. 2006)

<1 kpc at 22 MHz:

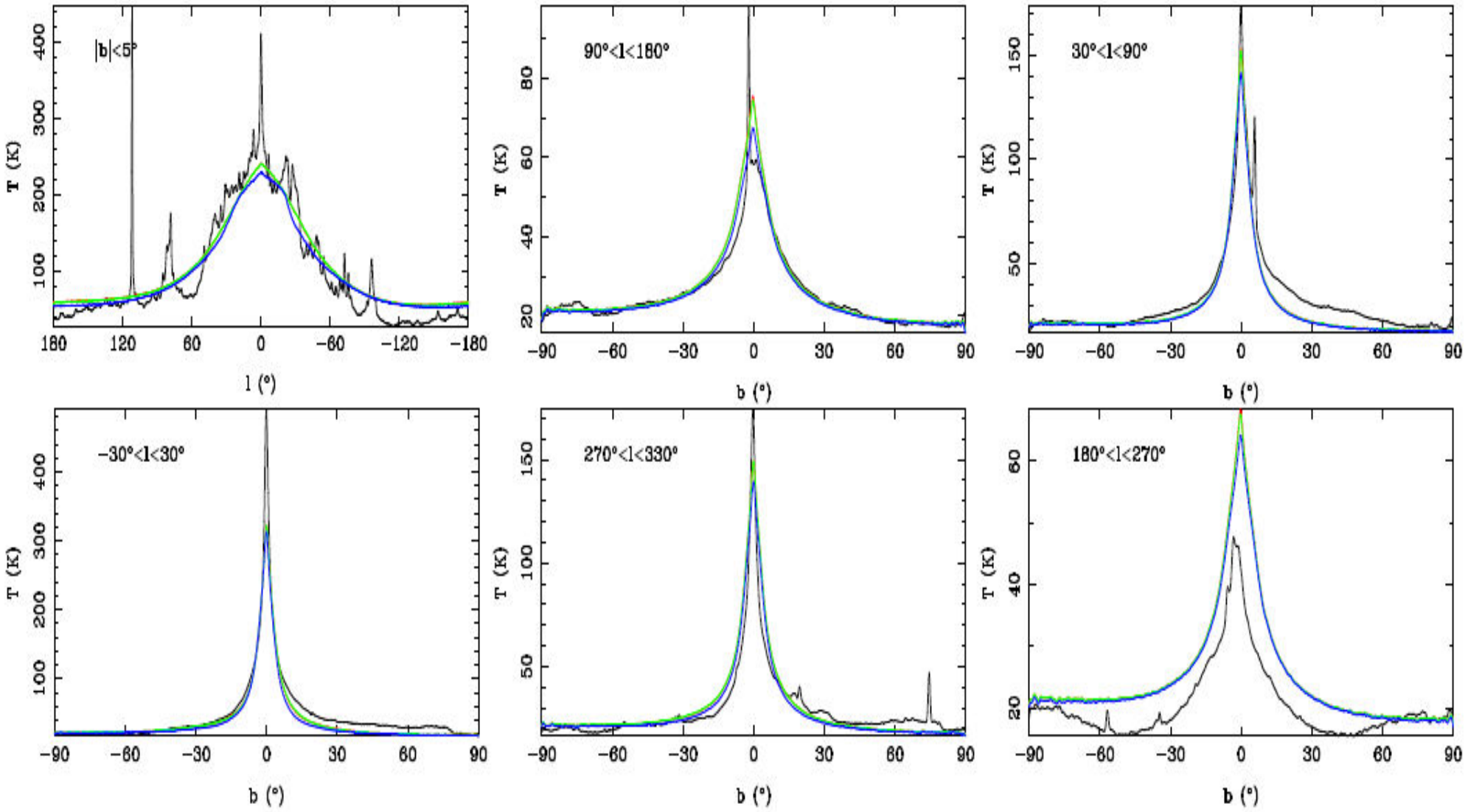
30 K/pc (Roger et al. 1999)

1.5K/pc at 74 MHz

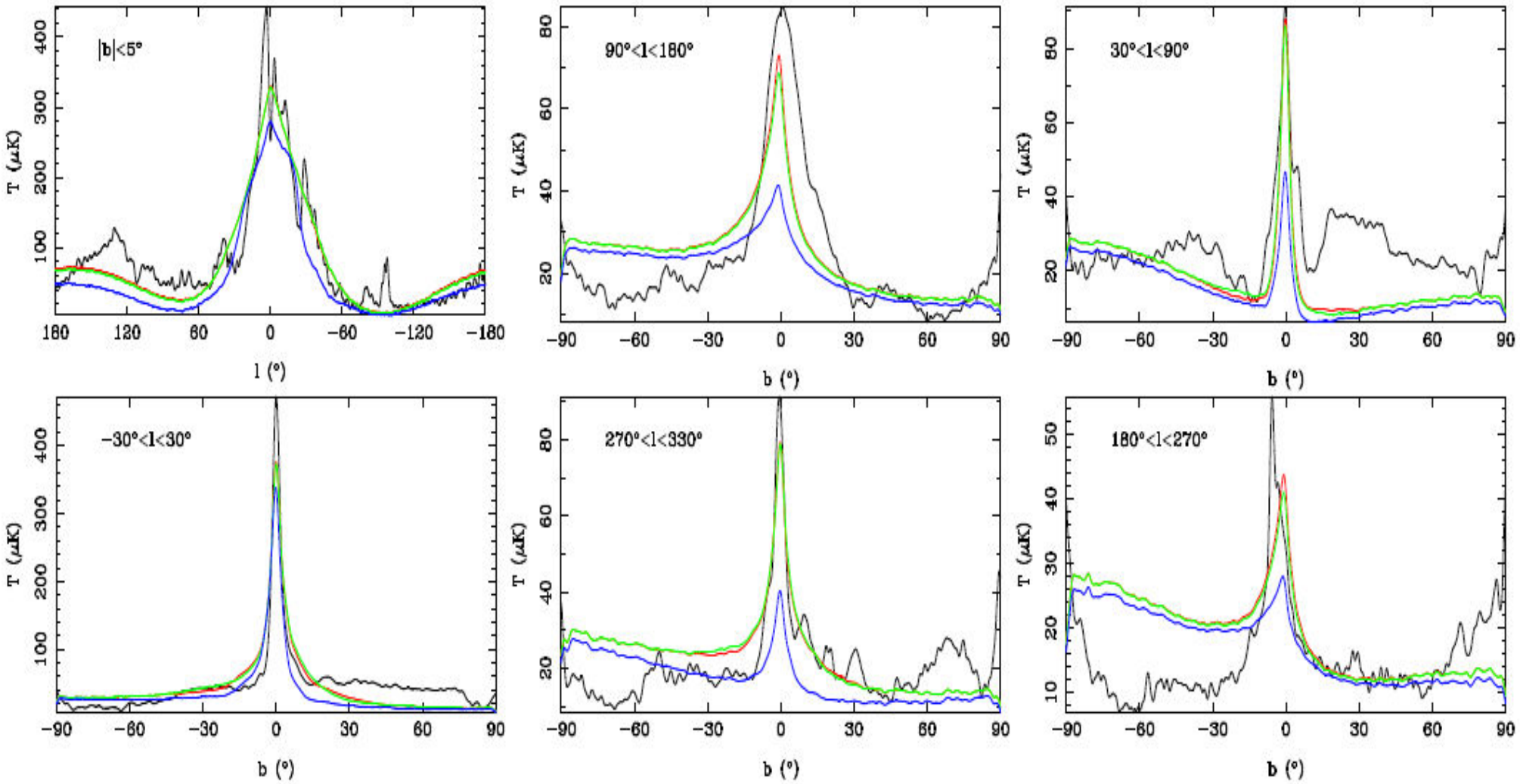
-- excessive: towards Taurus clouds at 150 pc (Wolleben & Reich 2004)

Required by fitting isotropy high latitude (>30 deg) emission

Total intensity at 408 MHz



PI at 22.8 GHz



ASS field can properly reproduce PI asymmetry in the plane

Model revisited (Sun & Reich 2010, RAA)

Problem

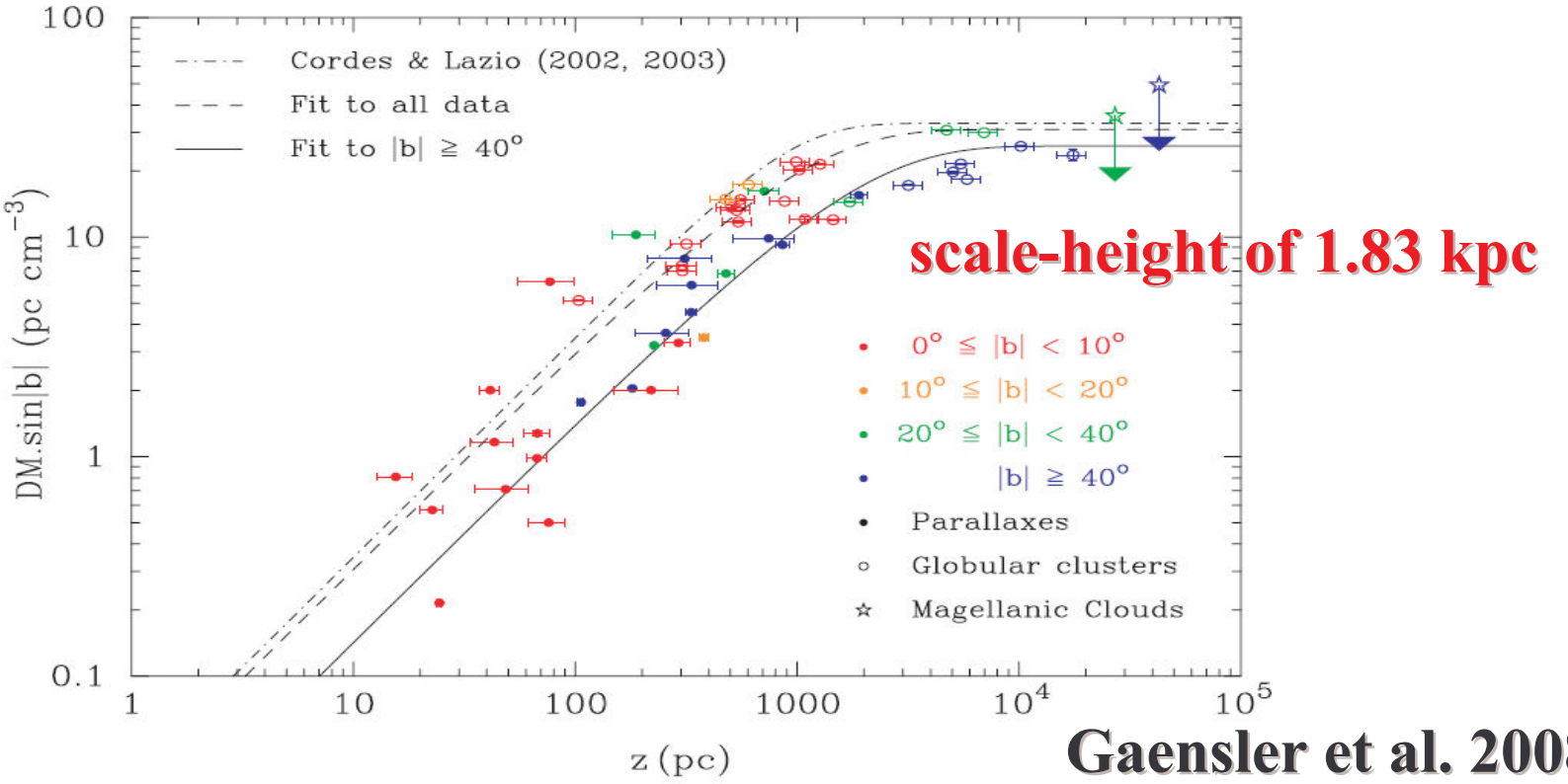
– the halo field of about 10 micorG **too large**

– **truncation** of electron density

Reason and solution

– the scale-height of NE2001 **too small**

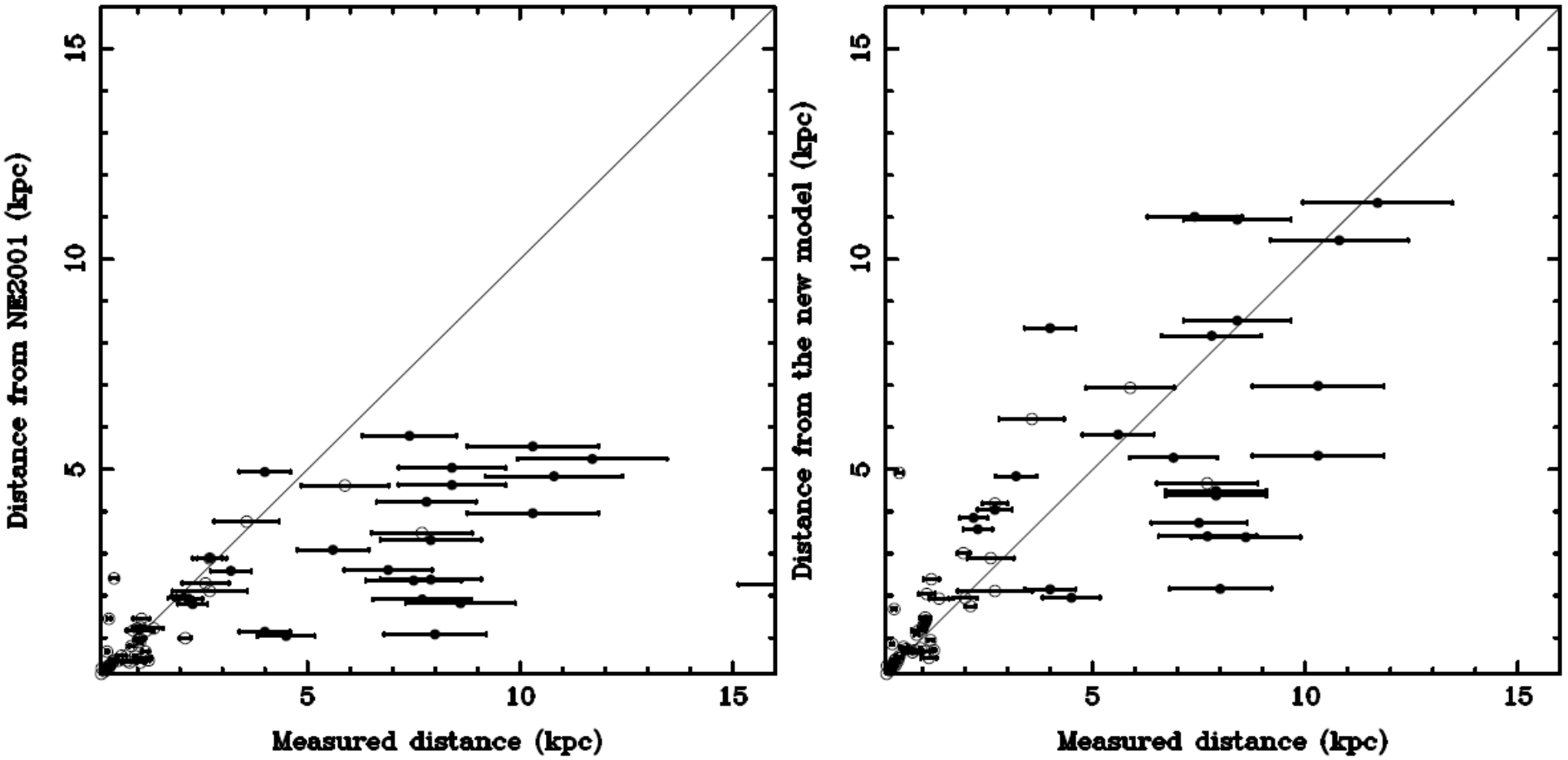
– increase the scale-height by a factor of **2**



scale-height of 1.83 kpc

Gaensler et al. 2008

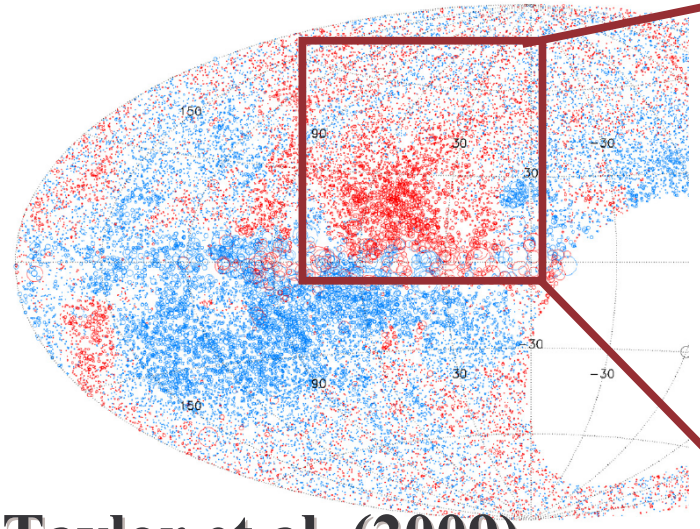
Model revised: replace the thick disk component

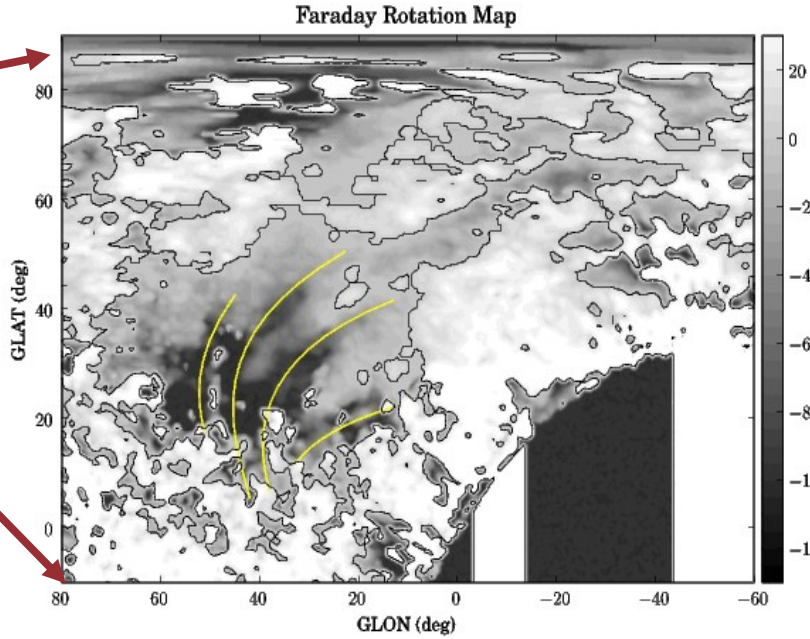


Measured distances from parallaxes (Verbiest et al. 2009) and globular clusters (web by Paulo Freire)

NE2001 deficit: Kramer et al. (2003), Lorimer et al. (2006)

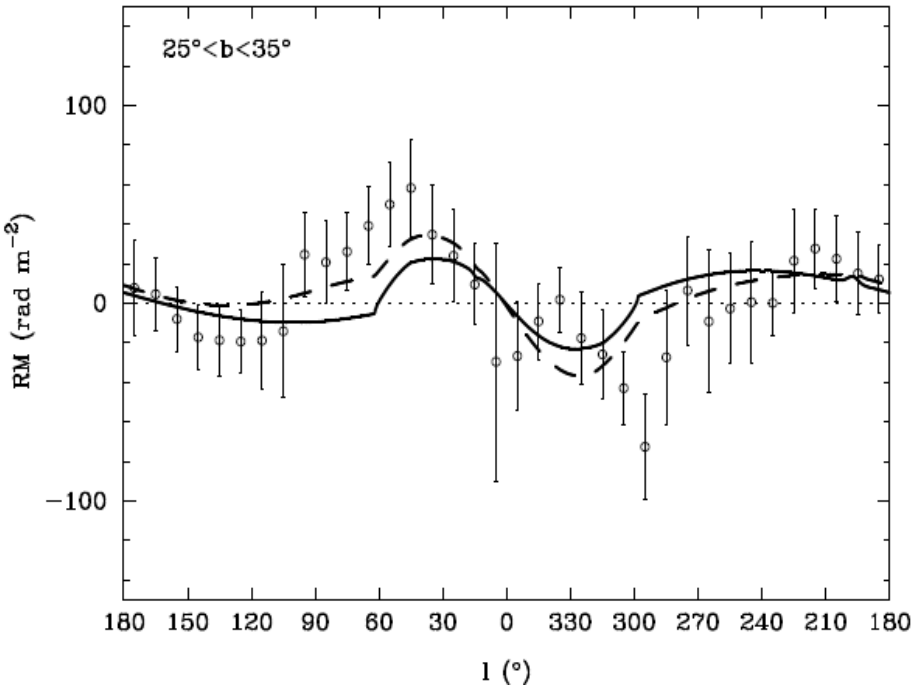
Model revised: small halo field

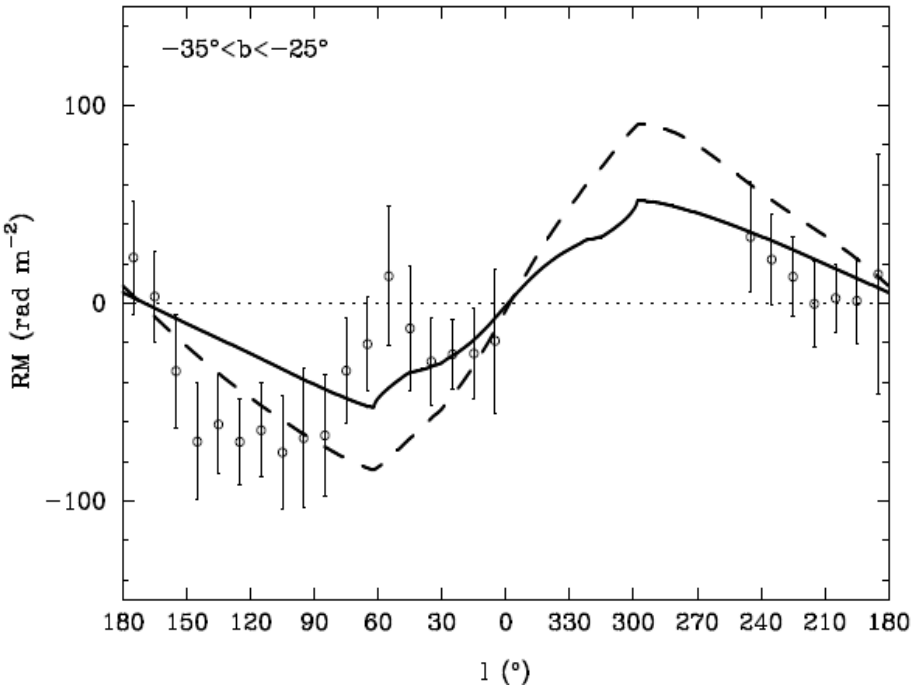




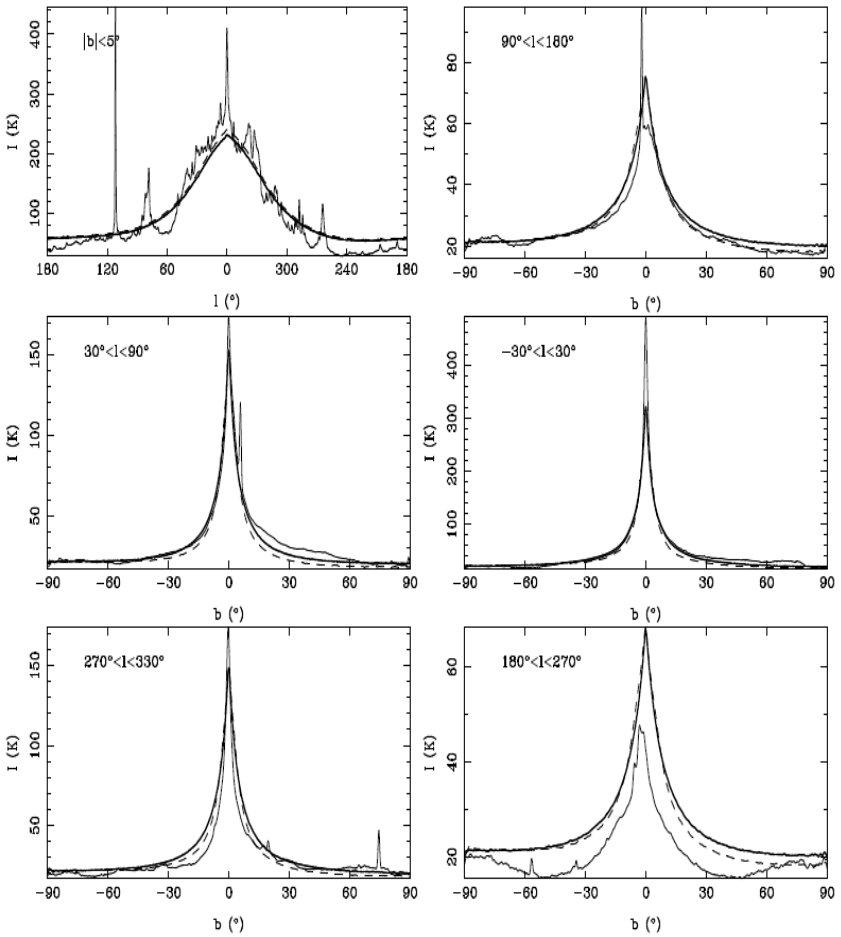
Wolleben et al. 2010, ApJL, in press
GMIMS
1.3 – 1.8 GHz
local filaments

Taylor et al. (2009)

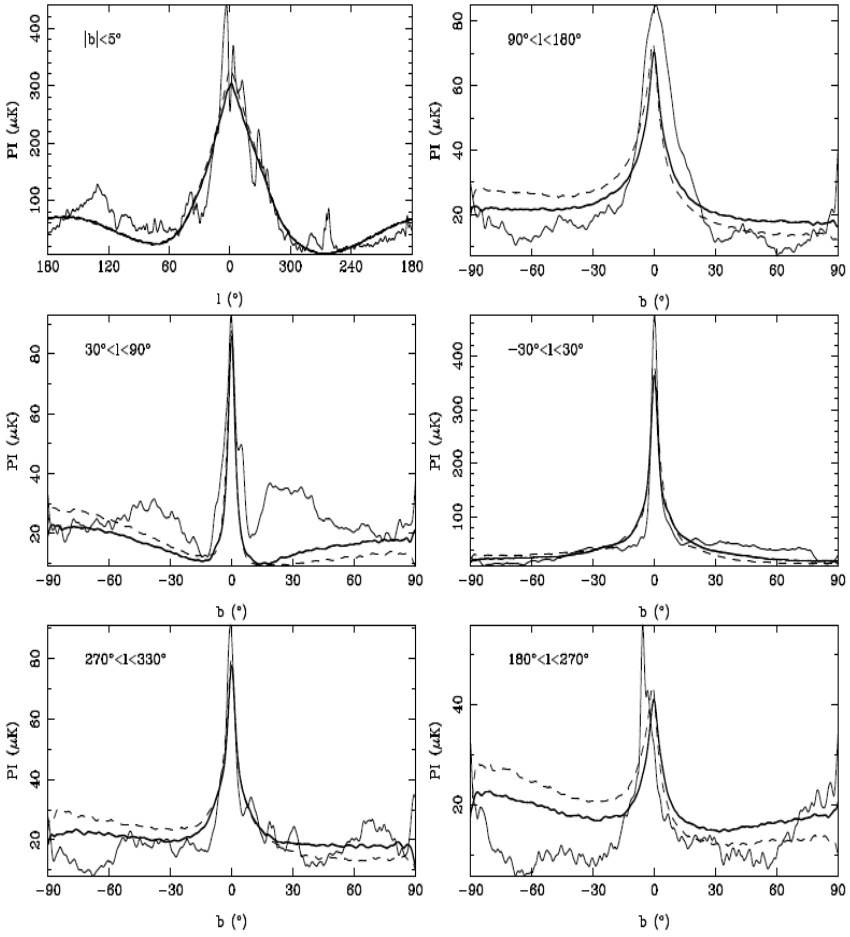




Model revised: no CRE truncation

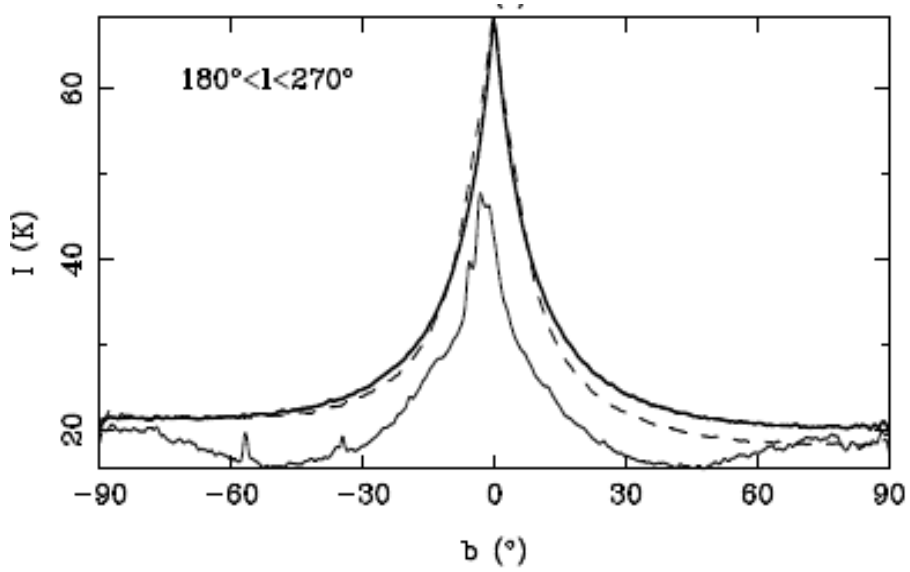


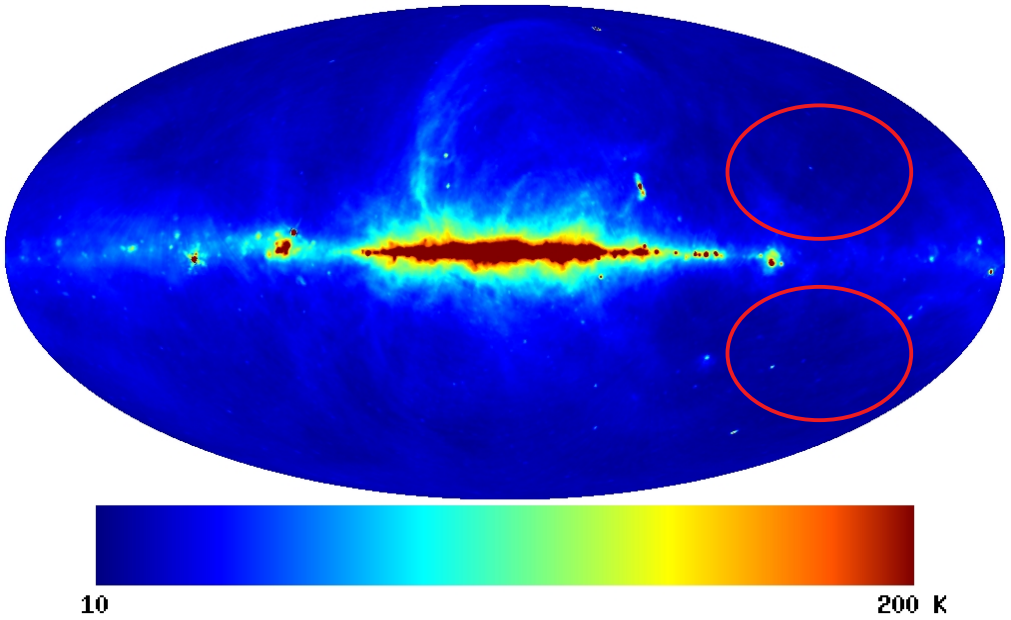
I at 408 MHz

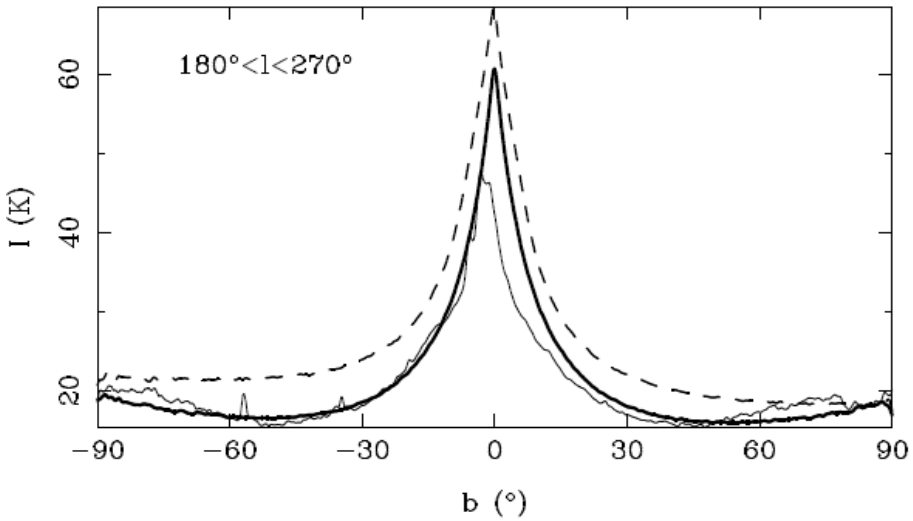


PI at 22.8 GHz

Model revised: shift of the local enhancement?







shift to l=45 deg by about 560 pc

Summary

Regular field

- **disk: ASS+RING, ASS+ARM, BSS**
  - **local field strength: 2 microG**
  - **scale-length: 10 kpc**
  - **scale-height: 1 kpc**
- **halo: toroidal, opposite below and above the plane**
  - **maximum of about 2 microG**

Random field

- **3 microG, homogeneous and isotropic**

CRE

- **scale-length: 8 kpc scale-height 0.8 kpc**

TE

- **scale-height for thick disk ~ 2 kpc (~ 1 kpc for NE2001)**

Local enhancement

- **not centred at the Sun**
- **account for the high latitude emission**