Rotation Measure Synthesis of the Local Magnetized ISM

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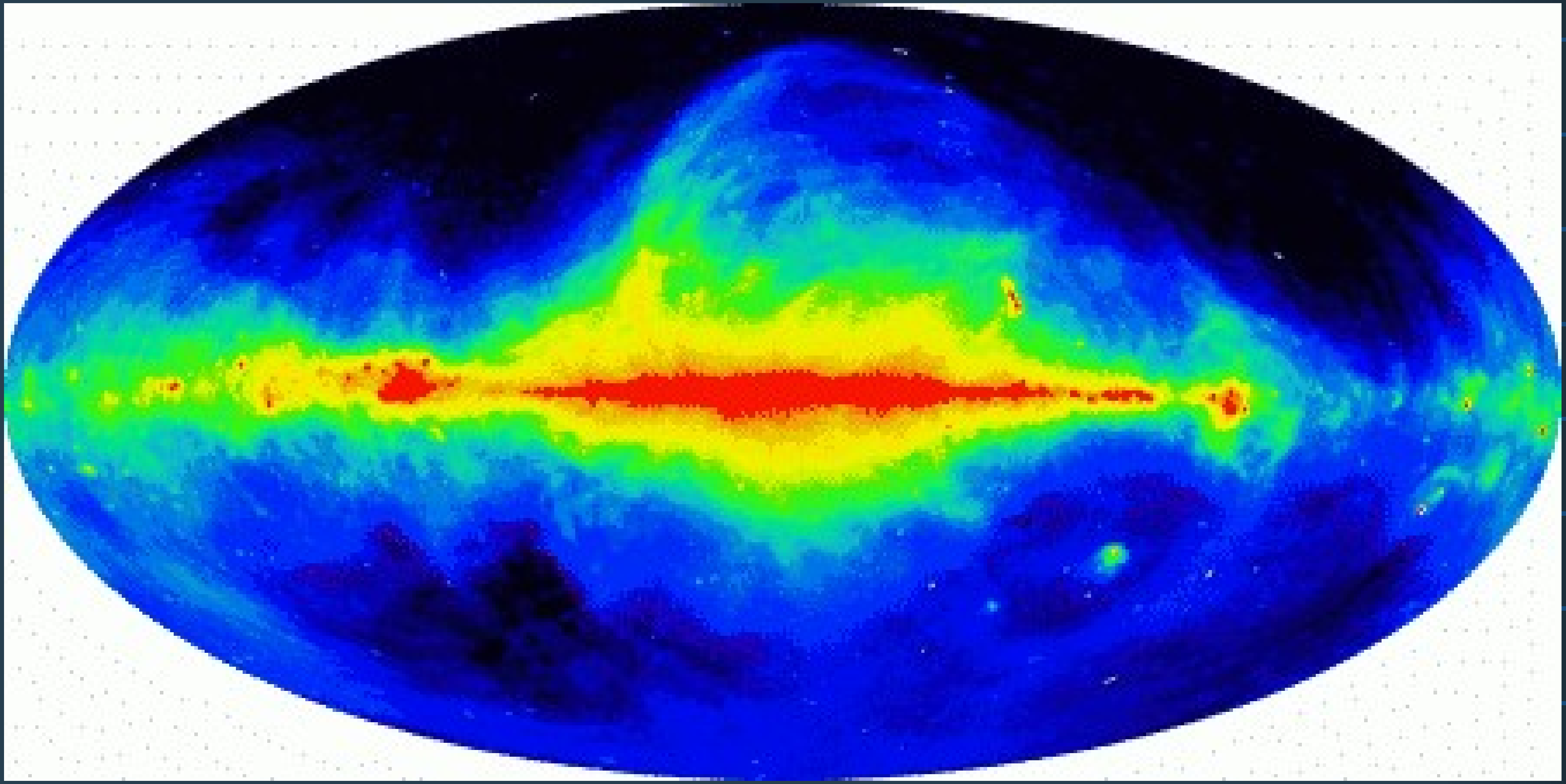
Outline

- Polarization, Faraday Rotation, and Rotation Measure Synthesis
- The Data: GMIMS – The Global Magneto Ionic Medium Survey
- RM-Synthesis of the Northern Sky
- B-Field of a local HI Bubble
- Compact source vs. diffuse emission

The Polarized Sky

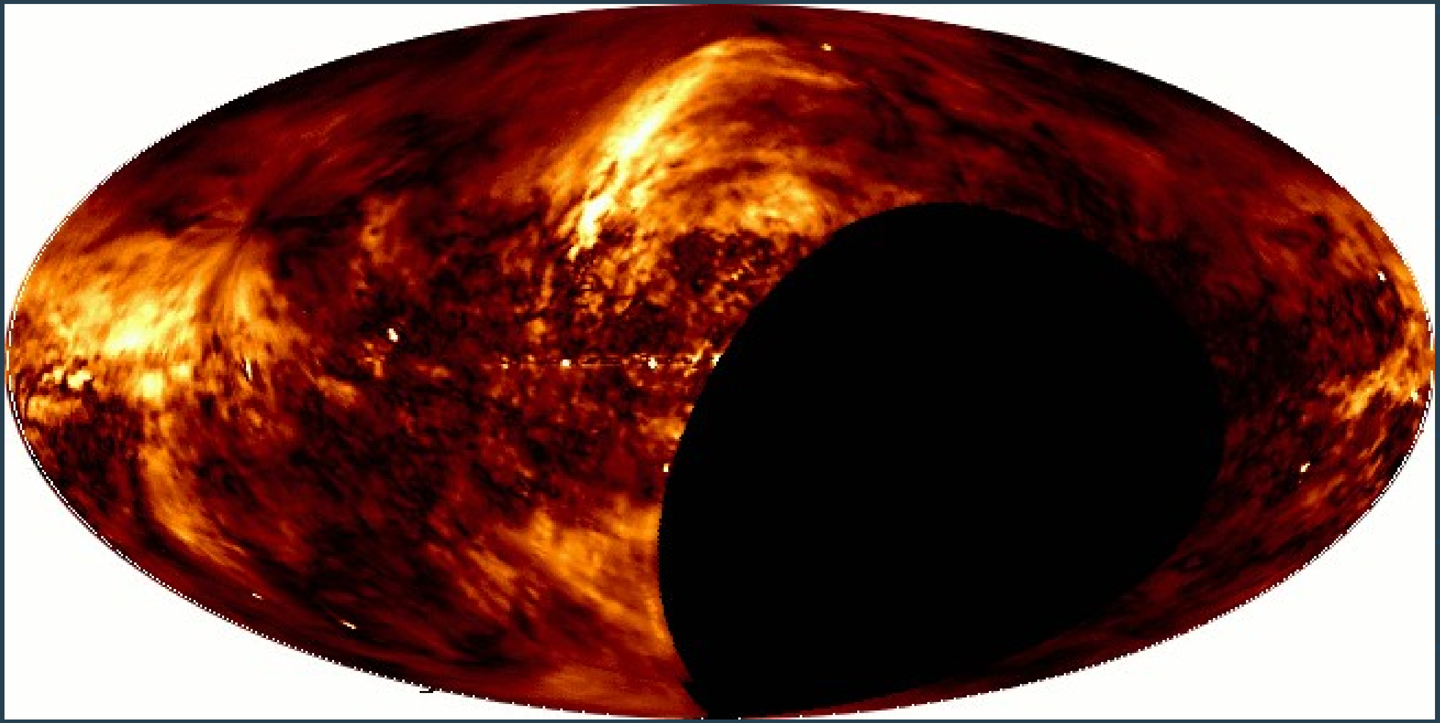
Total Intensity: Haslam et al., 1982



Polarized Intensity: Wolleben et al. 2006

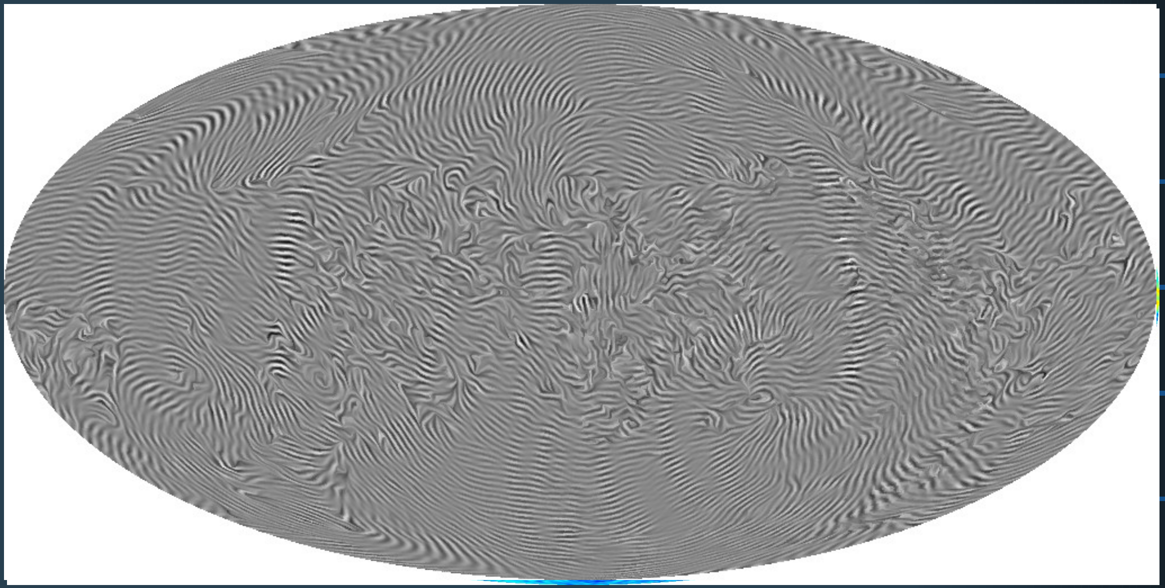
Polarized Emission Surveys

- Polarization surveys at 1.4, 2.8, 5 GHz
- Single frequency surveys (CGPS, EMLS, DRAO, Testori et al.)
- Data suffer from depolarization due to differential Faraday rotation and beam depolarization
- “Depolarization Band” towards the inner Galaxy
- Polarized filament of the North-Polar Spur (local)
- Rotation measures unknown from these observations



Wolleben et al. 2006

Polarization Angle at 1.4 GHz (λ21 cm)



(Testori et al. 2008; Wolleben et al, 2006)

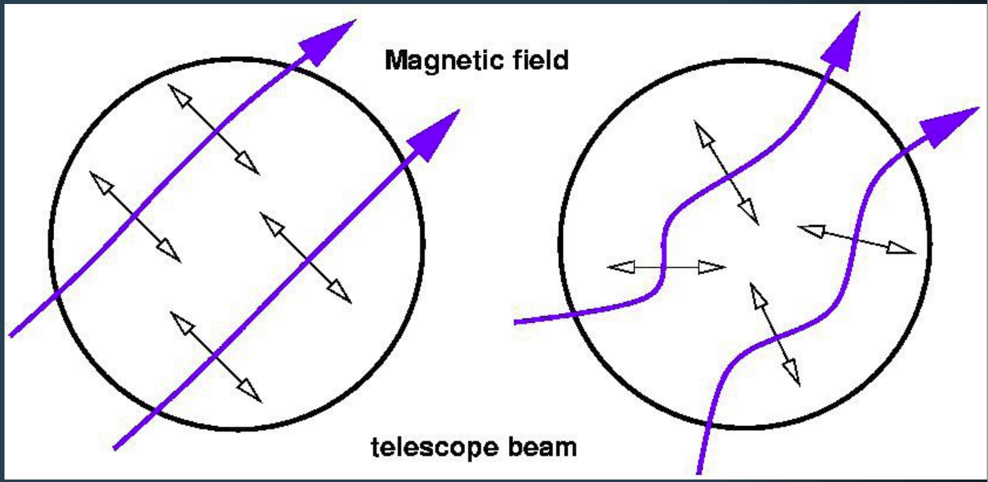
Image produced using the “alice” algorithm developed by David Larson, Johns Hopkins University.

Polarized Synchrotron Emission

Depolarization:

- Internal Faraday dispersion (depth depolarization)
- Beam depolarization

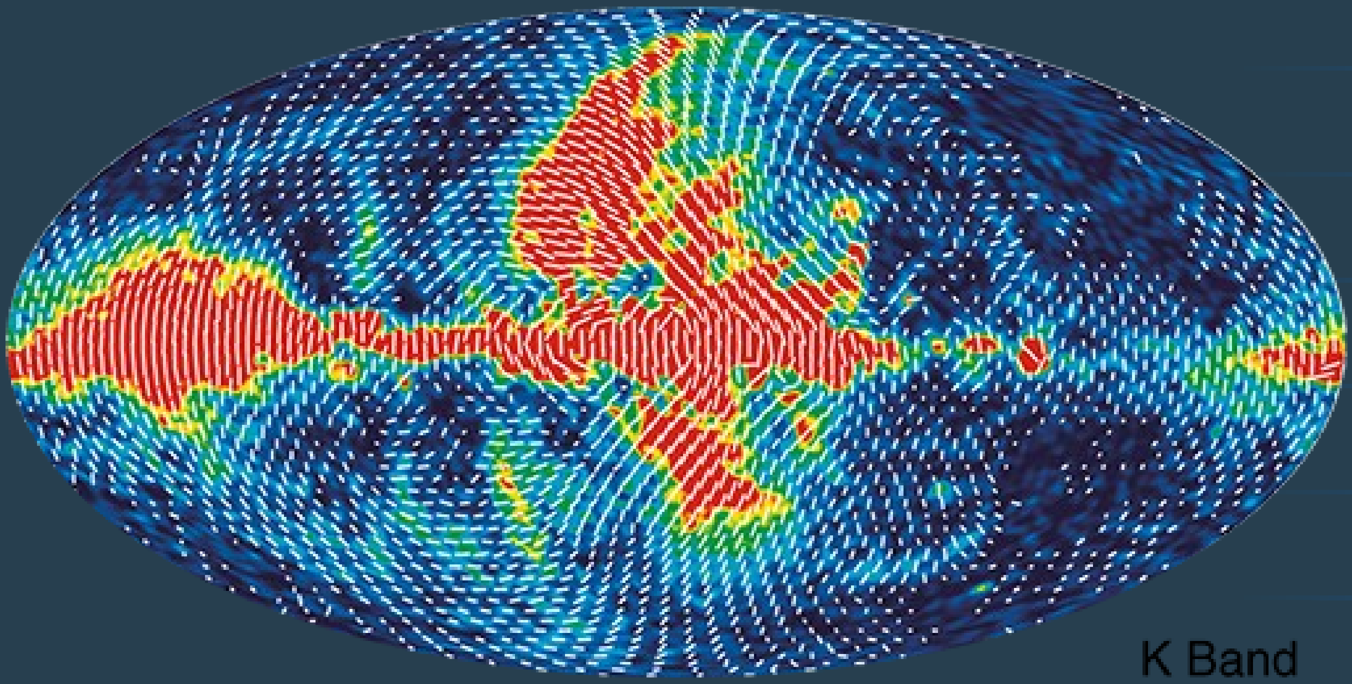
- No Faraday rotation (high enough frequency): PA reveals B_{perp}
- With Faraday rotation:
  - need to measure RM
  - intrinsic PA reveals B_{perp}
  - RM reveals $B_{||}$



(Beck et al. 2003)

Polarized Synchrotron Emission

- Above ~2-10 GHz: very little Faraday rotation

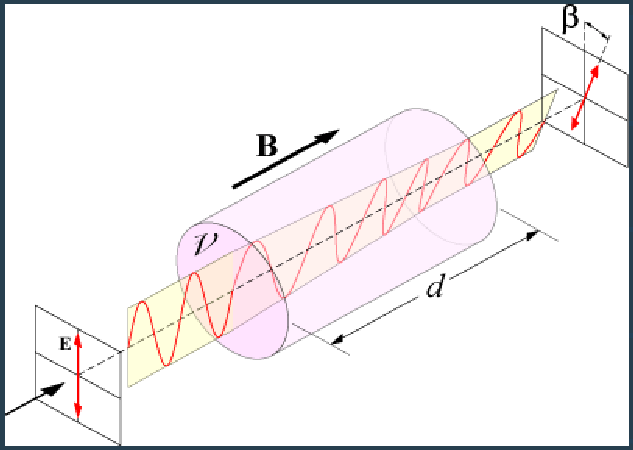


WMAP 23 GHz
(WMAP Science Team)

Faraday Rotation

$$\phi = \phi_0 + RM\,\lambda^2$$

$$RM = \int n_e \boldsymbol{B}\, \boldsymbol{dl}$$



Probes for Faraday rotation measurements:

- **extragalactic point-sources**
  → sightlines through entire Galaxy, have intrinsic RM (noisy probes), sampling
- **pulsars**
  → known distances, no intrinsic RM, usually only a few pulsars in the region of interest
- **diffuse galactic synchrotron emission**
  → high angular resolution, Rotation Measure Synthesis possible

From 2-D to 3-D Polarimetry

Since a few years:

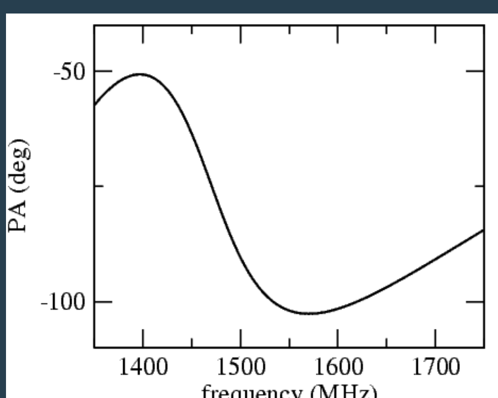
- recent developments in digital signal processing
- design of wide-band antennas, motivated by the SKA
- spectro-polarimetry

=> High resolution, high sensitivity Rotation Measure surveys

Name	Frequency MHz
LOFAR	110 – 250
MWA	80 – 300
SKAMP	700 – 1400
GMIMS	300 – 1800
GALFACTS	1225 – 1525
STAPS	1300 – 1800
SPASS	2300

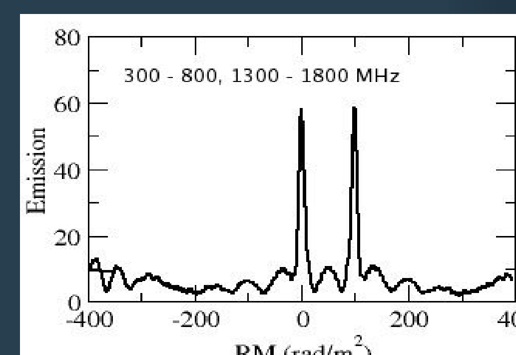
Rotation Measure Synthesis

- Usually polarization angle does not depend linearly on λ^2
- RM-Synthesis is a Fourier Transformation of Stokes U & Q
- Derotation of Faraday-rotated emission using a set of assumed RM values
- Resolution in RM-space (Faraday depth φ) depends on λ^2 coverage



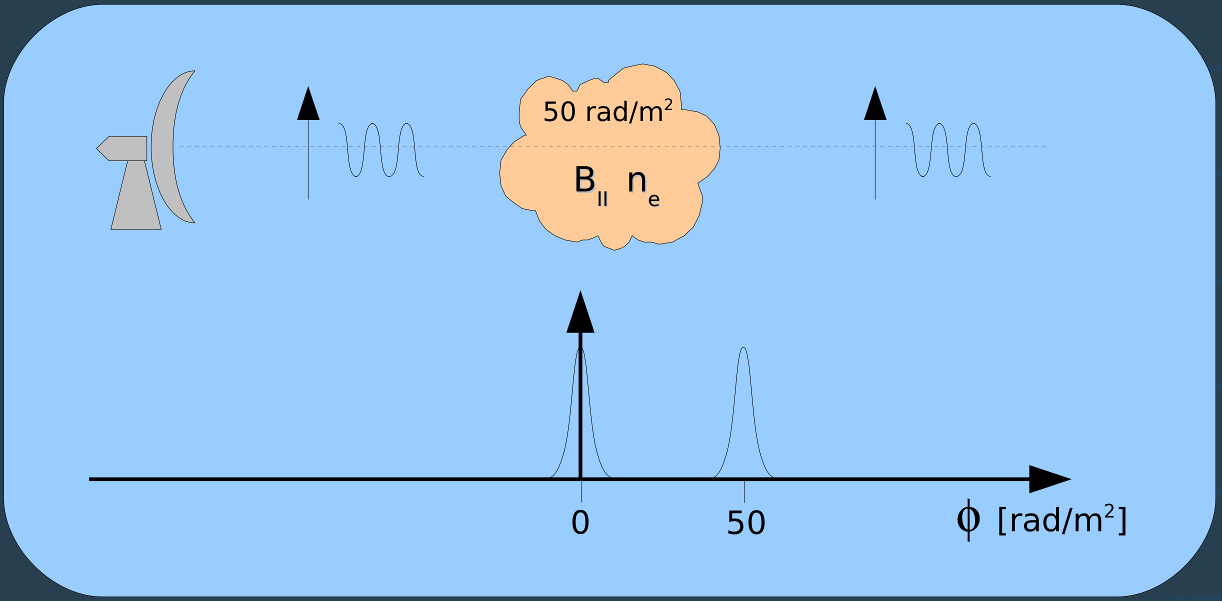
Polarization angle for a simulated line-of-sight

RMS



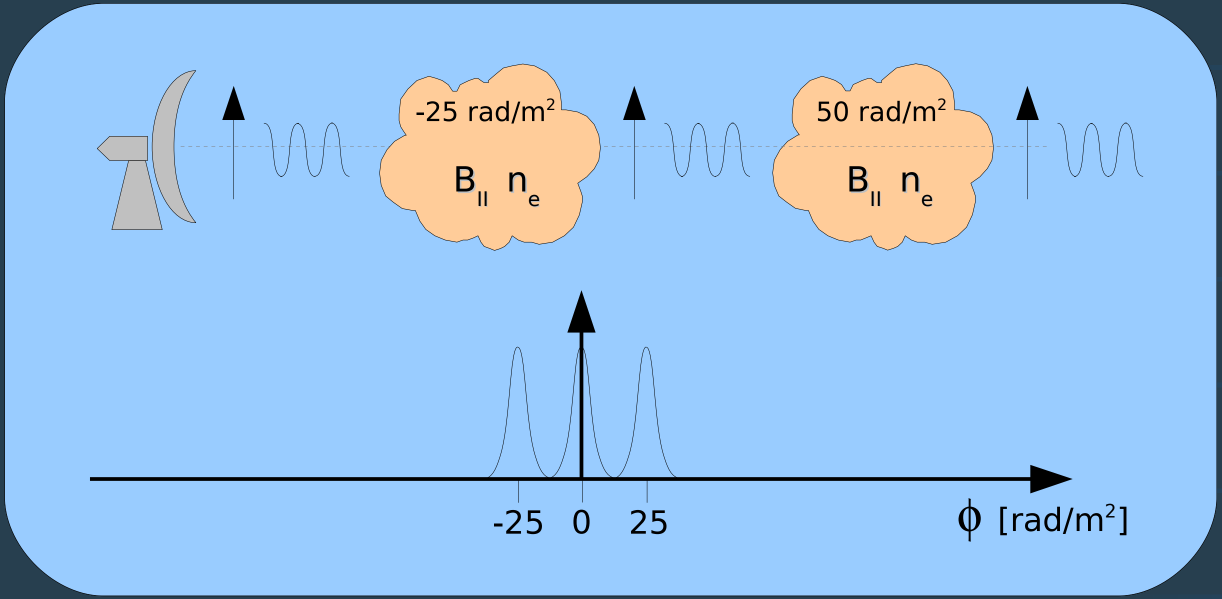
the RM-Spectrum for this line-of-sight

Rotation Measure Synthesis

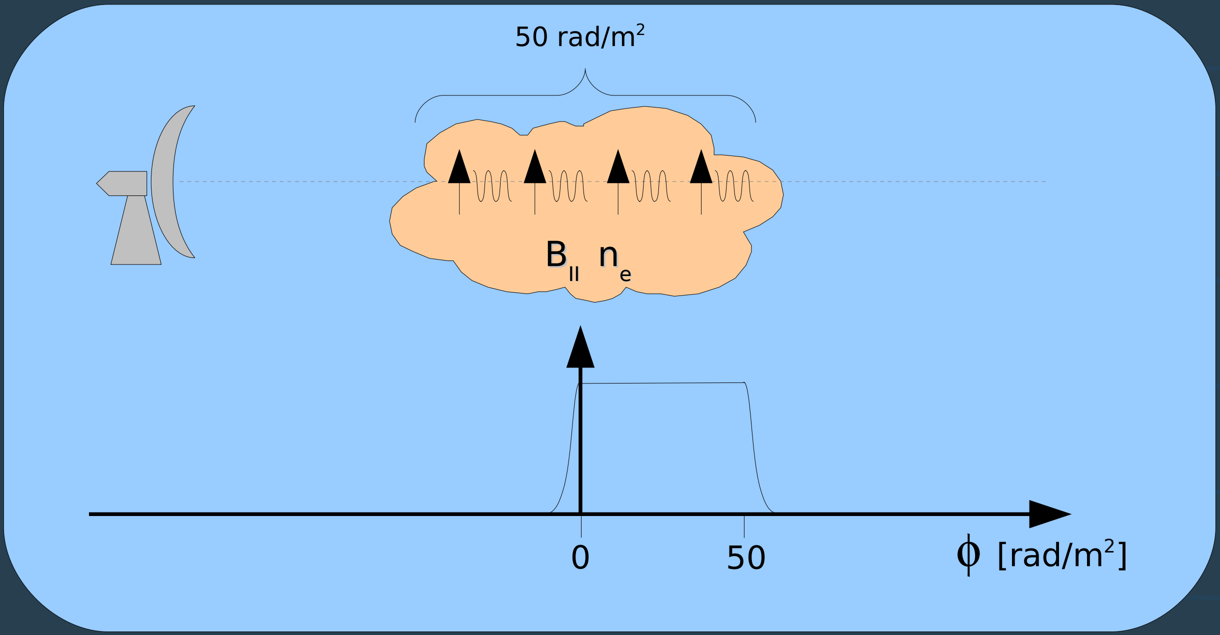


RM-Synthesis can disentangle emission and rotation layers.

Rotation Measure Synthesis

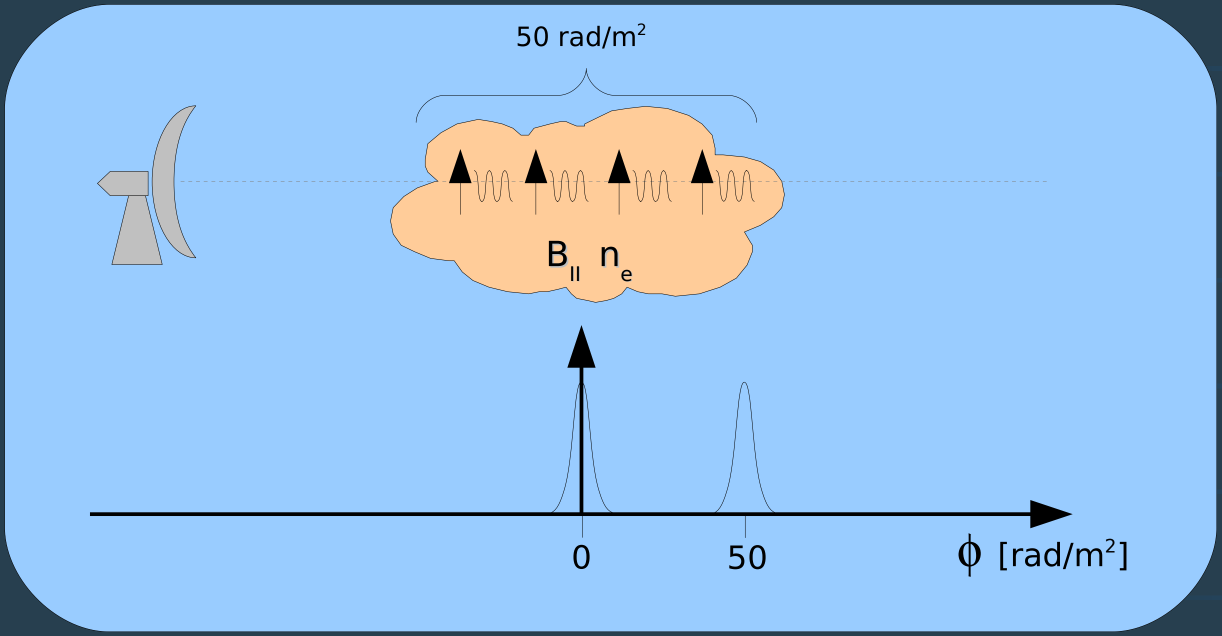


Rotation Measure Synthesis



Mixed emitting and Faraday-rotating region

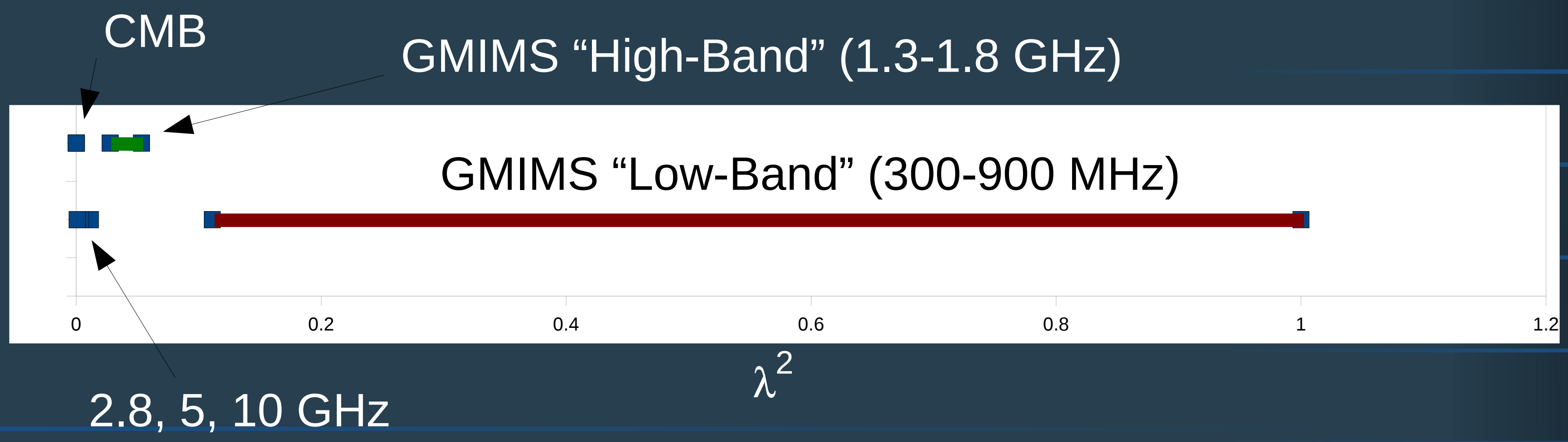
Rotation Measure Synthesis



Incomplete frequency coverage results in loss of information.

Rotation Measure Synthesis

- Requires wide-band spectro-polarimetry
- For the diffuse emission: requires absolute calibration of data
- 3 parameters important for RM-Synthesis observations:
  - resolution in Faraday depth
  - sensitivity to extended RM structures
  - the highest RM
- determined by frequency coverage (actually λ^2 coverage) and frequency resolution



GMIMS: The Global Magneto Ionic Medium Survey




ANTF, Australia	E. Carretti
Univ. of Tasmania	J. Dickey
Univ. of Newcastle, UK	A. Fletcher
Univ. of Sydney, Australia	B. Gaensler
CAS, China	J.L. Han
ASTRON, Netherlands	M. Haverkorn
DRAO, Canada	T. Landecker
Univ. of Manchester, UK	P. Leahy
CSIRO ATNF, Australia	N. McClure-Griffith
CSIRO ATNF, Australia	D. McConnell
MPIfR, Germany	W. Reich
Univ. of Calgary, Canada	R. Taylor
DRAO, Canada	M. Wolleben (PI)

300 -800 MHz	Effelsberg 100-m	Rx under constr.
800 -1300 MHz	Kunming 40-m	feas. study
1300-1800 MHz	DRAO 26-m	55% complete
300 -900 MHz	Parkes 64-m	30% complete
800 -1300 MHz	?	
1300-1800 MHz	STAPS,Parkes 64-m	100% complete, PI: M. Haverkorn

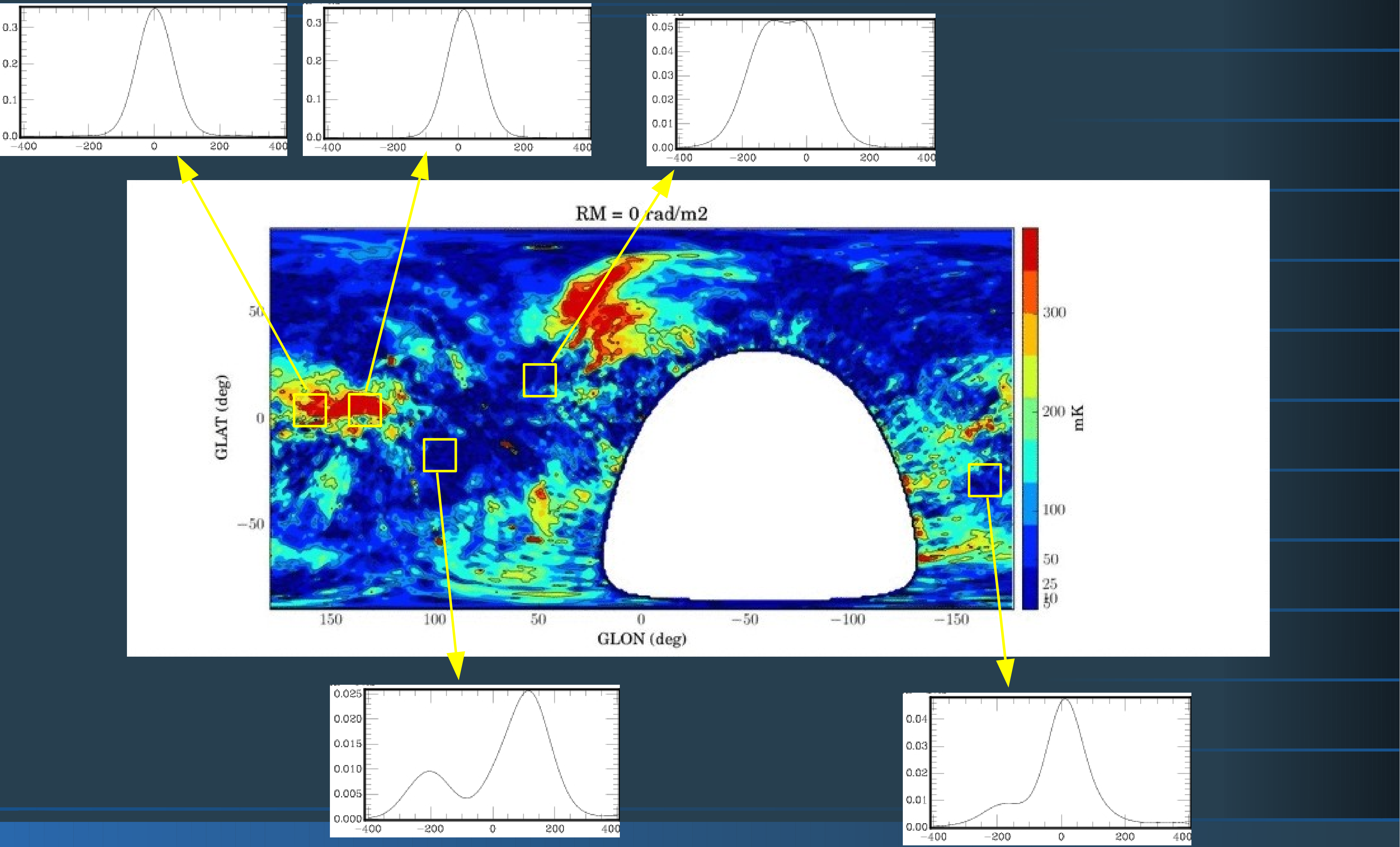
The Global Magneto-Ionic Medium Survey: GMIMS

- GMIMS is a wide-band, spectro-polarimetric survey
- GMIMS is bringing together three technologies:
  - wideband feeds and receivers
  - wideband, digital polarimeters
  - rotation measure synthesis
- Frequency coverage from 300 MHz to 1.8 GHz
- All-sky, single-dish telescopes (absolutely calibrated)
- 6 component surveys (low-band, mid-band, and high-band)

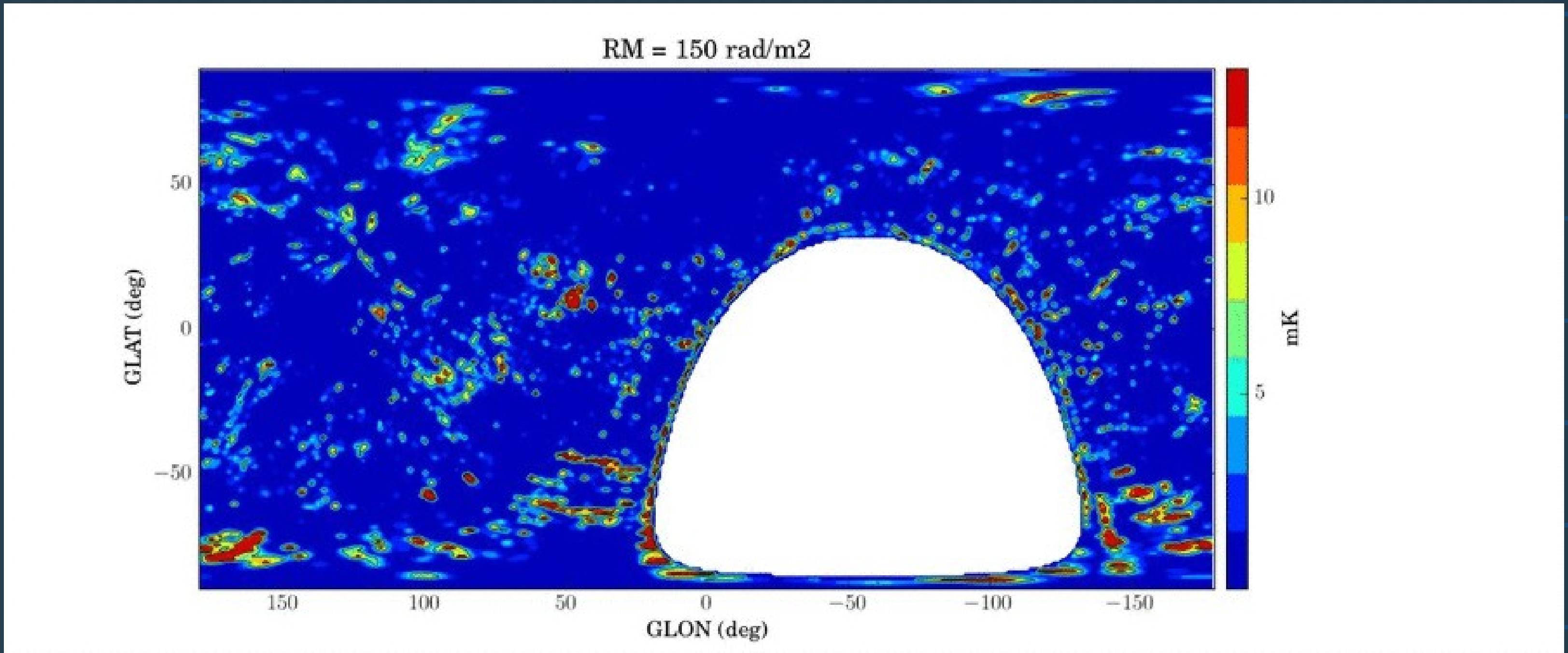
GMIMS Science Goals

- Major science goals:
  - The morphology of the local MIM
  - The disk-halo transition
  - Interstellar turbulence
  - The large-scale Galactic magnetic field
  - The origin of objects only seen in polarization
  - Total intensity mapping of the sky
- Secondary science goals:
  - Zero-spacings for ASKAP, GALFACTS
  - CMB foregrounds
  - EoR foregrounds
  - Piggy-back transient surveys

RM-Synthesis of the Northern Sky
1.4 – 1.7 GHz

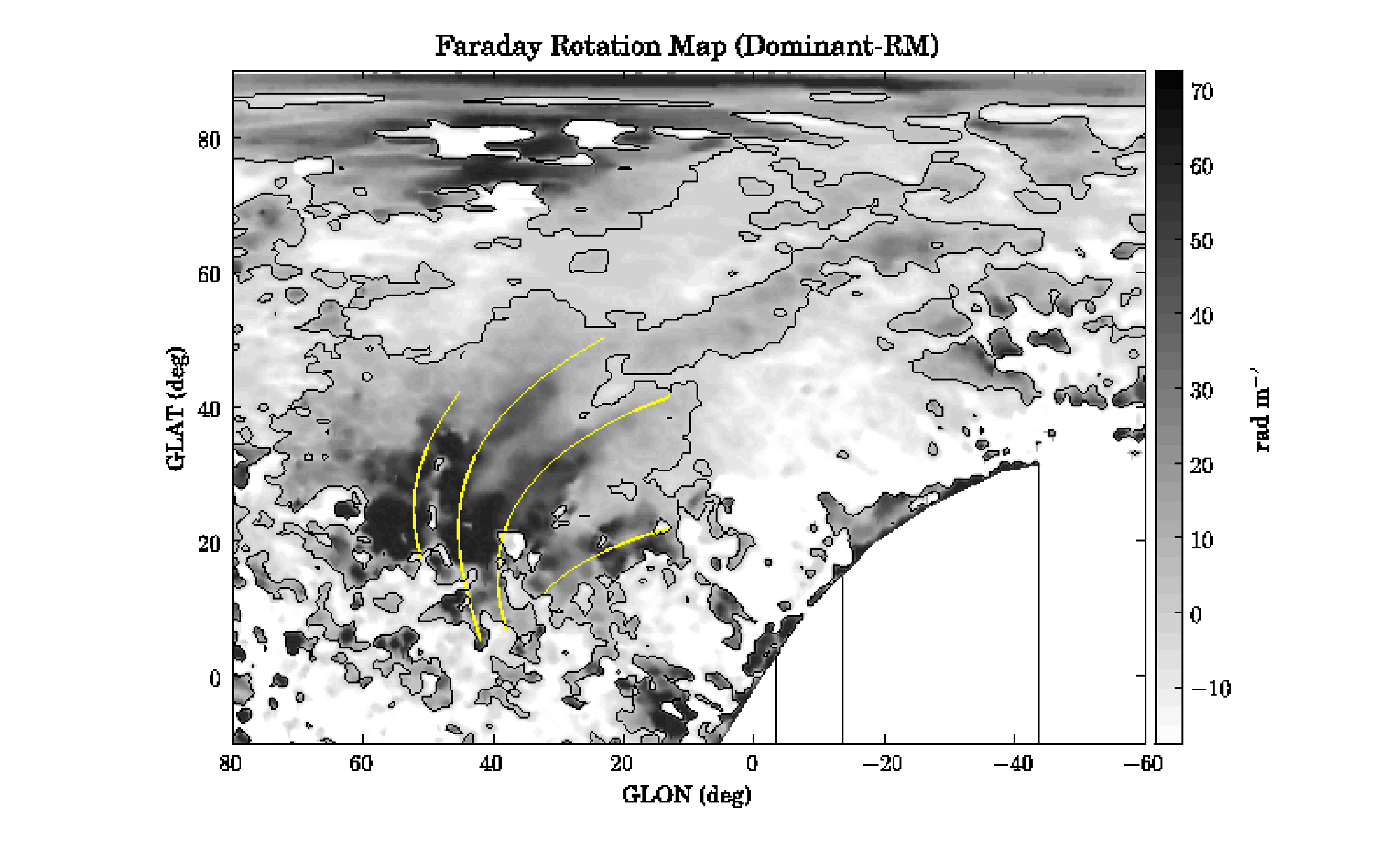


GMIMS: The Global Magneto Ionic Medium Survey



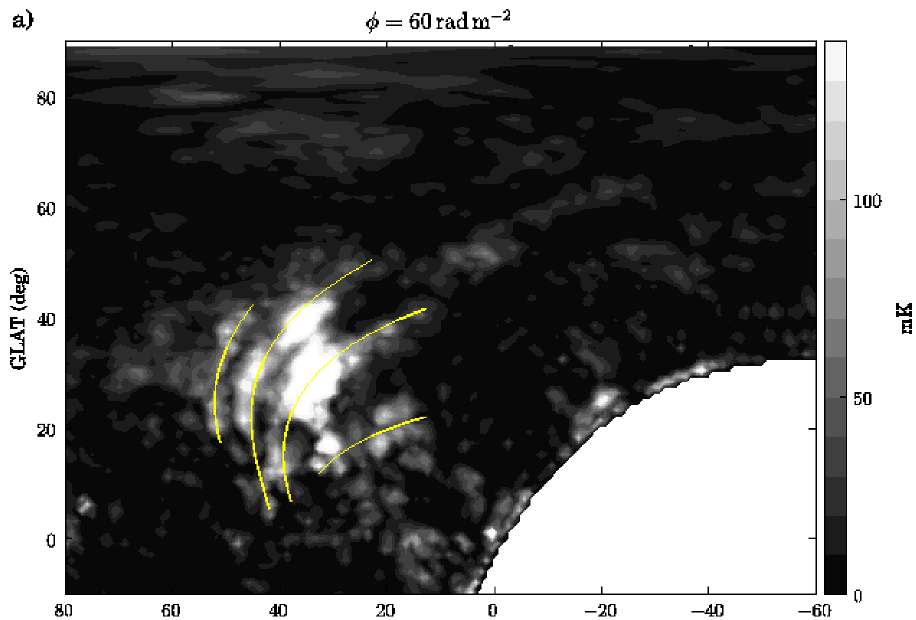
- RM-Synthesis Cube, Galactic coordinates, third dimension: Faraday depth φ
- First data from GMIMS North (1.3 – 1.8 GHz), 2048 frequency channels
- rms noise: 25 mK in a single channel, 1 mK in an RM-Synthesis frame
- RM cleaning performed
- Resolution in Faraday depth: 132 rad/m^2
- Largest scale in Faraday depth: 106 rad/m^2

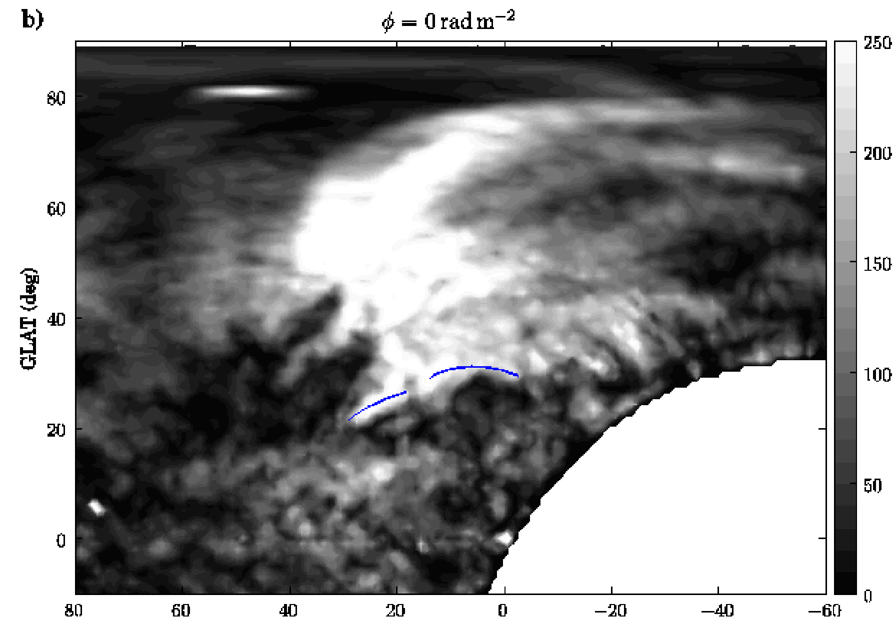
Faraday Rotation Map



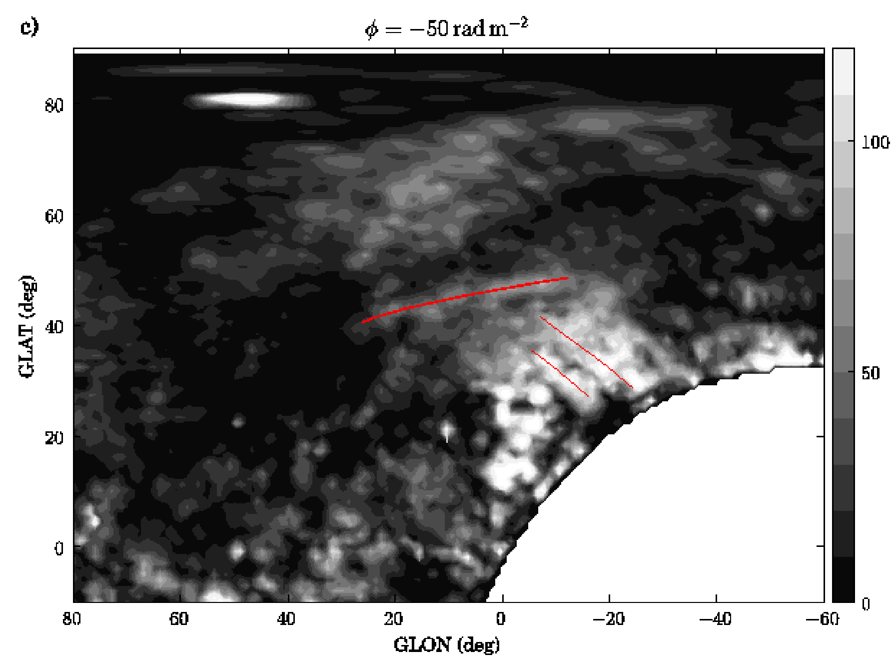
- Map shows φ of the dominant emission in each pixel
- (the position of the peak in the RM-Synthesis spectrum for each pixel)
- Grey scales chosen to make structures with positive φ more visible
- Contour line corresponds to φ = 0 rad/m^2
- Four yellow lines, fitted by eye, indicate location of four filaments identified in the Faraday rotation map

RM-Synthesis Frames



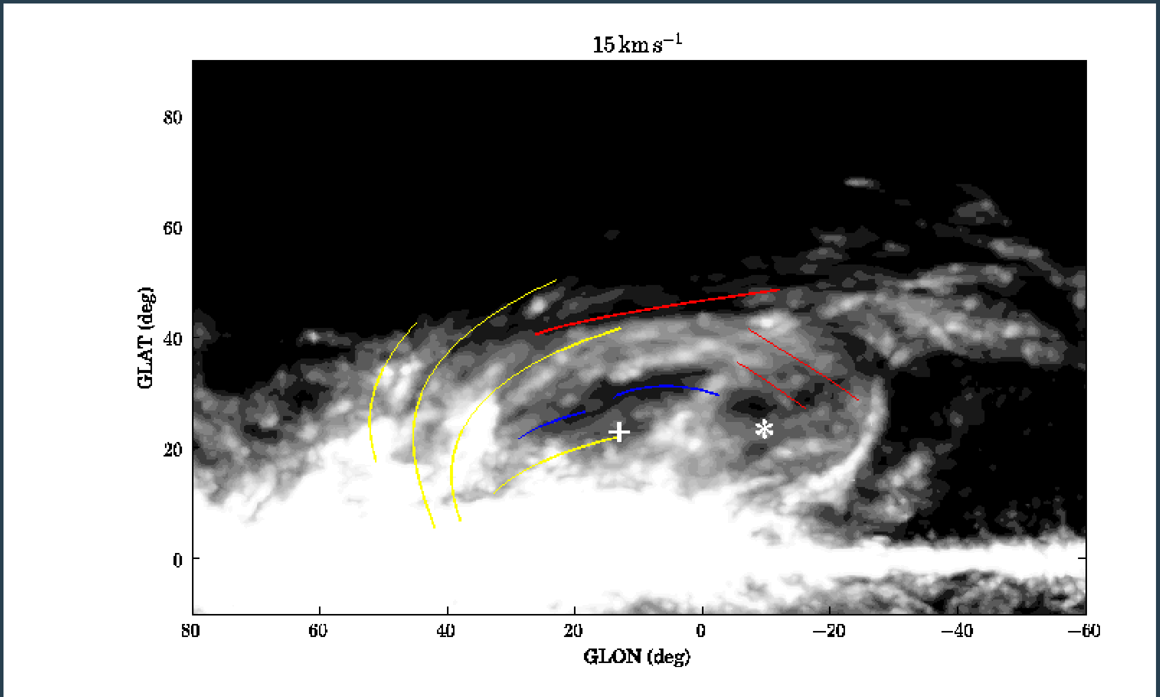


- RM-Synthesis frames showing polarized intensity at various Faraday depths
- Four yellow lines are repeated at 60 rad/m^2
- Blue and red lines indicate polarized filaments identified in the RM-Synthesis cube



HI Bubble

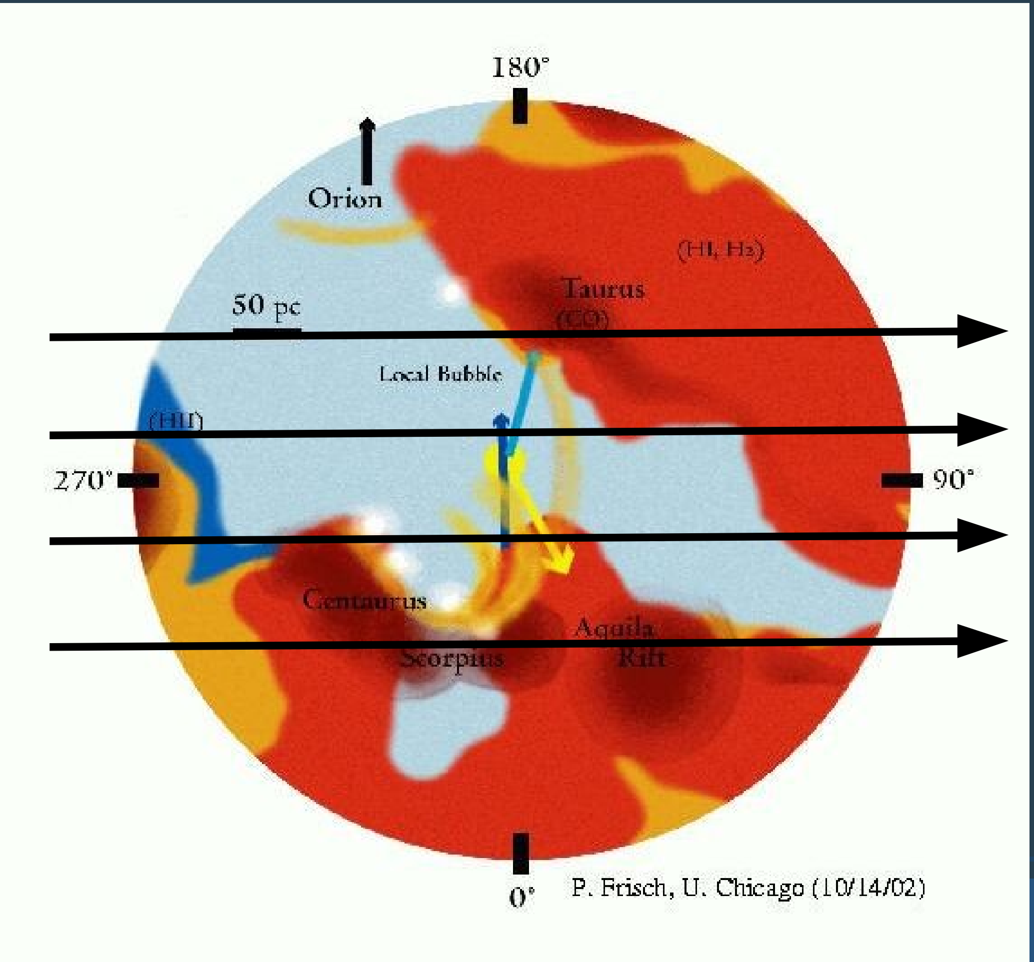
(LAB HI Survey, Kalberla 2005)

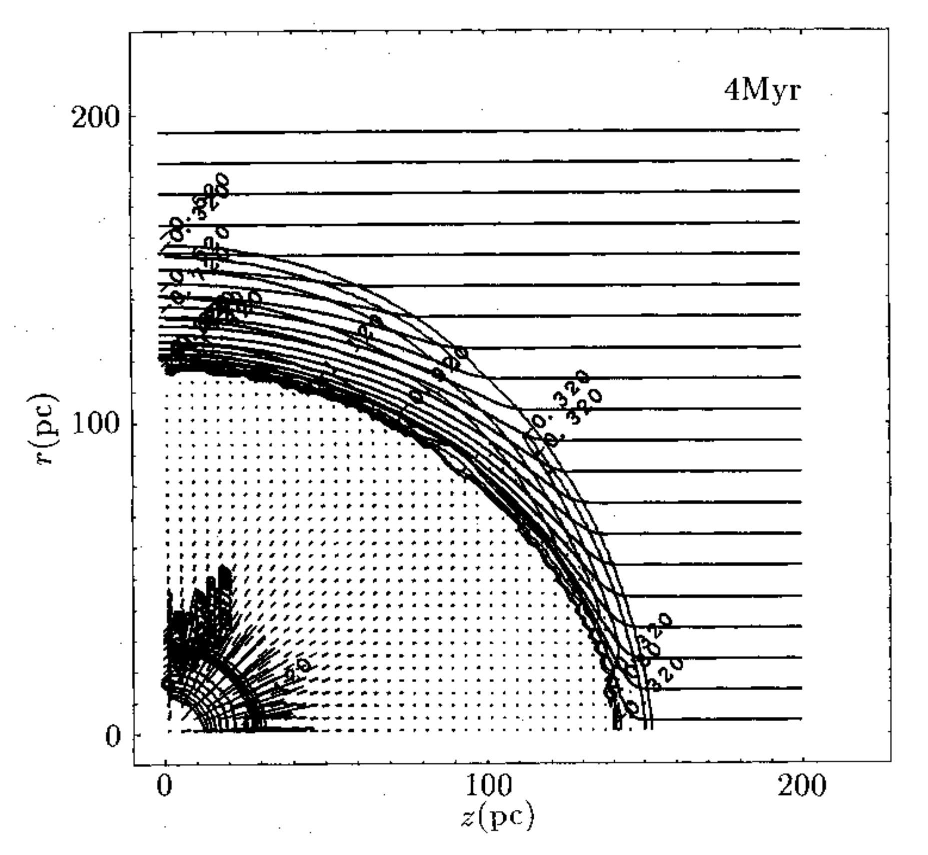


- Map of HI temperature at 15 kms^{-1}
- Polarized filaments associated with HI bubble
- correlations and anti-correlations between polarized intensity and HI
- Position of the Upper-Scorpius OB association today and 5 Myr ago

The Local ISM

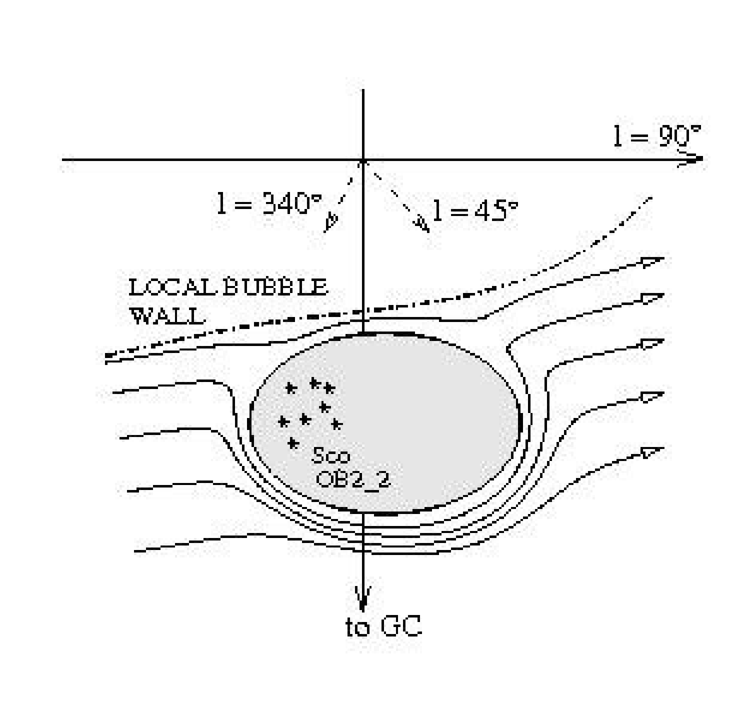
- Local Bubble, mean local B-field pointed towards l=90°
- Expanding shells sweep up and compress the ambient B-field
- Scorpius Centaurus association ~100pc away towards the Galactic centre





Tomisaka, 1992

Magnetic Field



- Positive φ in the east changes to negative φ in the west, suggesting that the B-field is wrapped around the bubble
- Polarized emission at φ=0 rad/m^2 along the centre of the bubble links these two regions
- Shape and implied B-field configuration of this HI bubble suggest that is has expanded asymmetrically
- Expansion constrained to only one direction along the line-of-sight

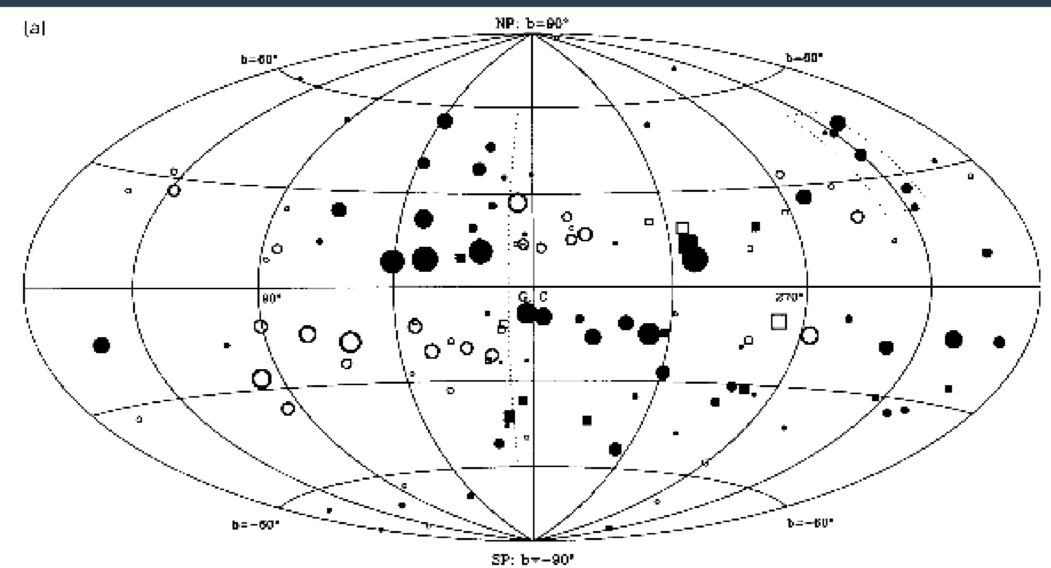
Distance and Origin

- Expanding HI shells associated with stellar winds and supernovae explosions originating in the stars of the Scorpius-Centaurus OB association
- Upper Scorpius sub-group is the furthest away (145 pc), in the centre of the western side of the HI shells.
- Linear size of bubble of the order of 200pc x 100pc
- Nearside is 95pc away, far side 195pc away
- Wall of Local Bubble about 80pc away in this direction
- The shells act as a Faraday-rotating screen to the strong background emission and also as a weaker mixed emitting and rotating slab
- These structures are not associated with the North Polar Spur as they do not resemble the shape of the spur

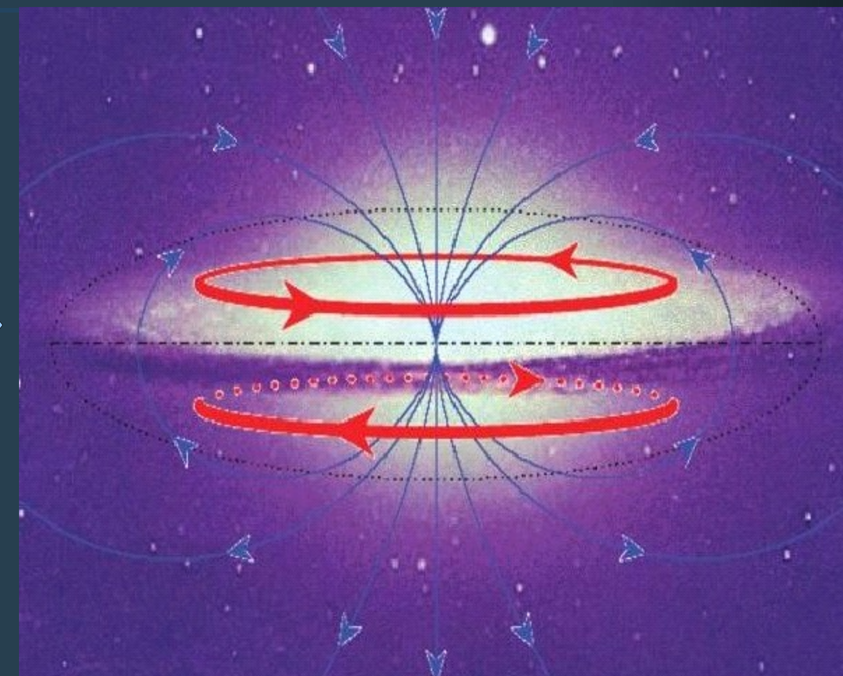
Magnetic Field

- No Hα emission found (VTSS/WHAM)
- RM must be due to enhanced B-field
- average n_e approx 0.02 cm^{-3}
- shell thickness ~13pc, path length ~100pc
- 50-60 rad/m^2 corresponds to $B_{||}$ approx 20-34 μG

Antisymmetries in the FR Sky

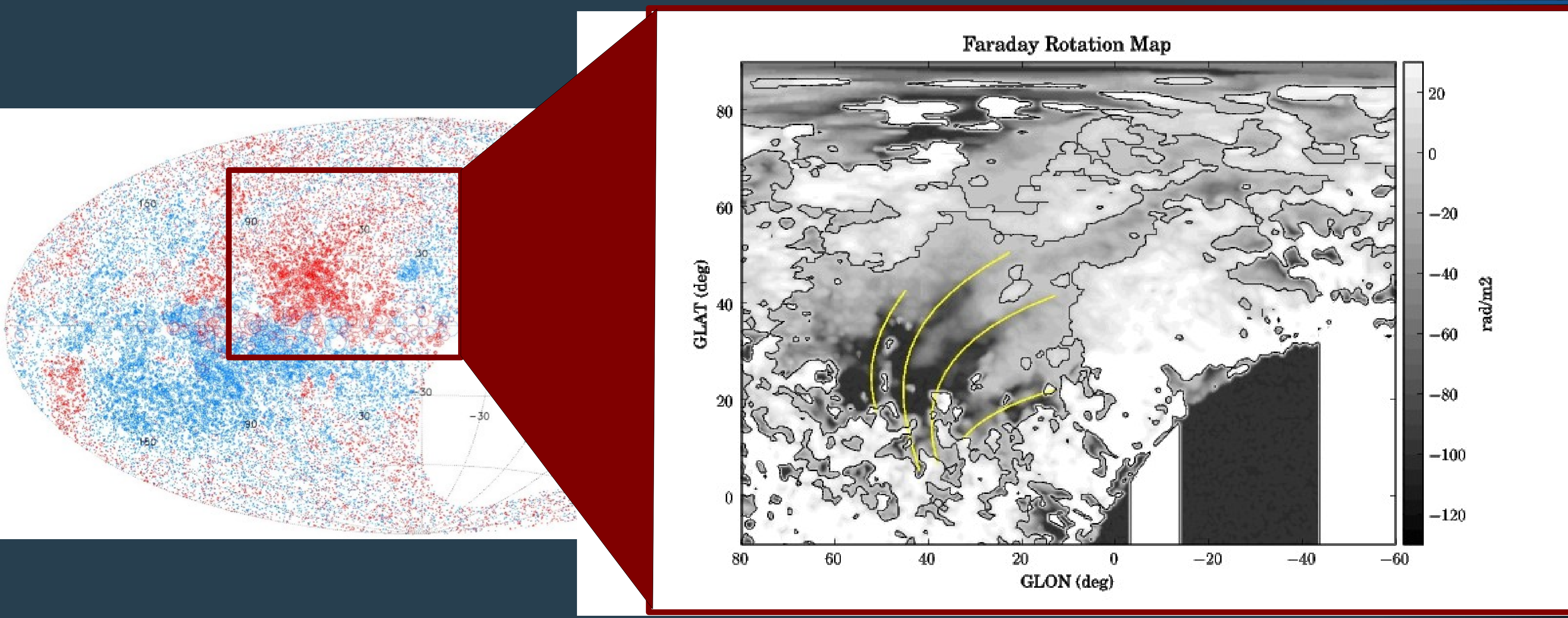


(Han et al, 1999)



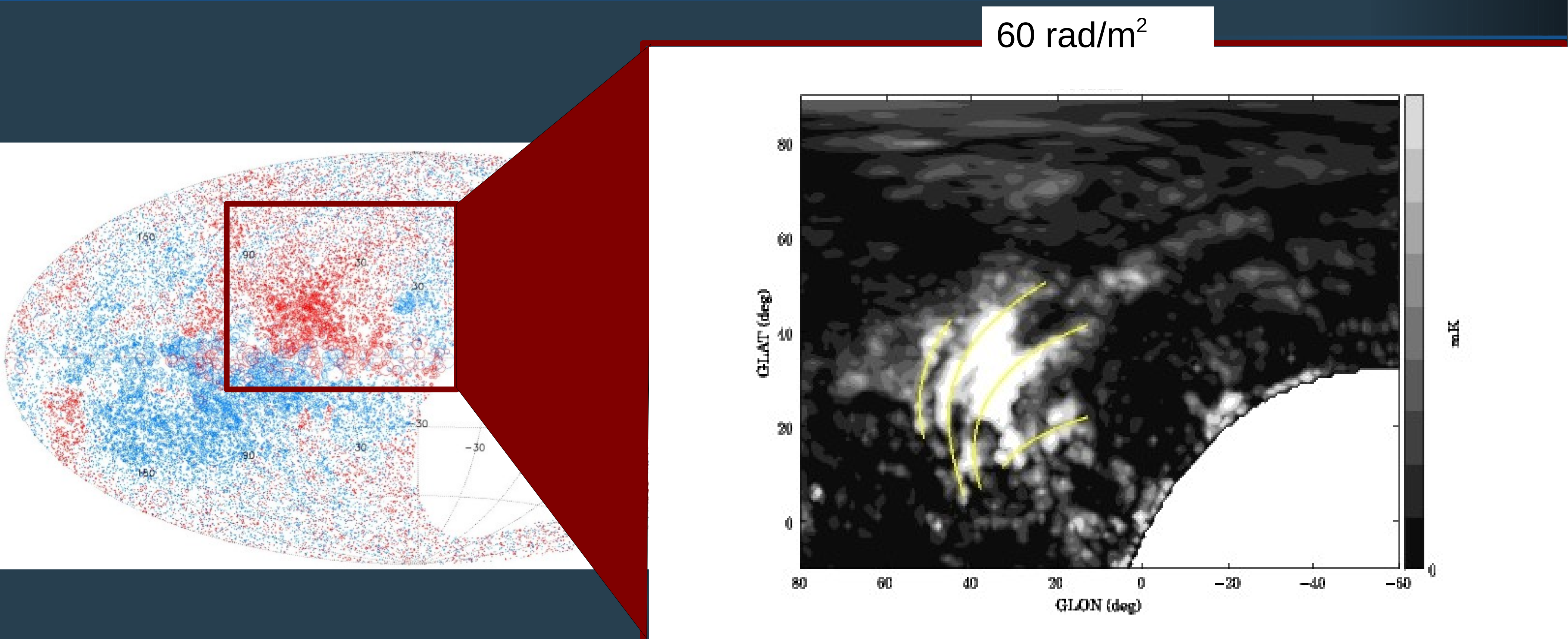
- Observed antisymmetry of RMs in the inner Galaxy.
- Indicates azimuthal B-field with reversed field directions.
- This seems to suggest an A0 dynamo acting in the halo.

Antisymmetries in the FR Sky



This HI bubble produces a large-scale pattern in rotation measures on the sky that <u>mimics the effect that the regular magnetic field of the Milky Way would have</u> on the Faraday rotation of compact sources, both in magnitude and sign.

Antisymmetries in the FR Sky



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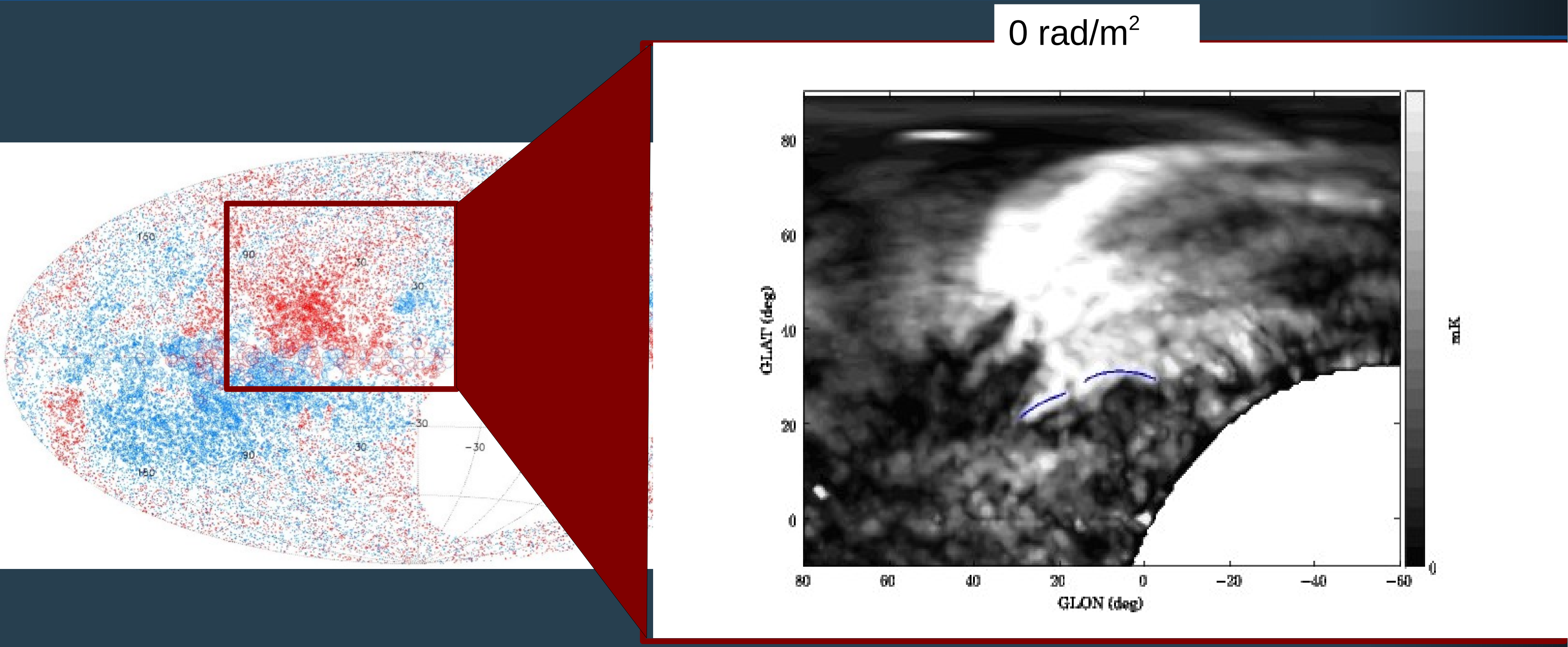

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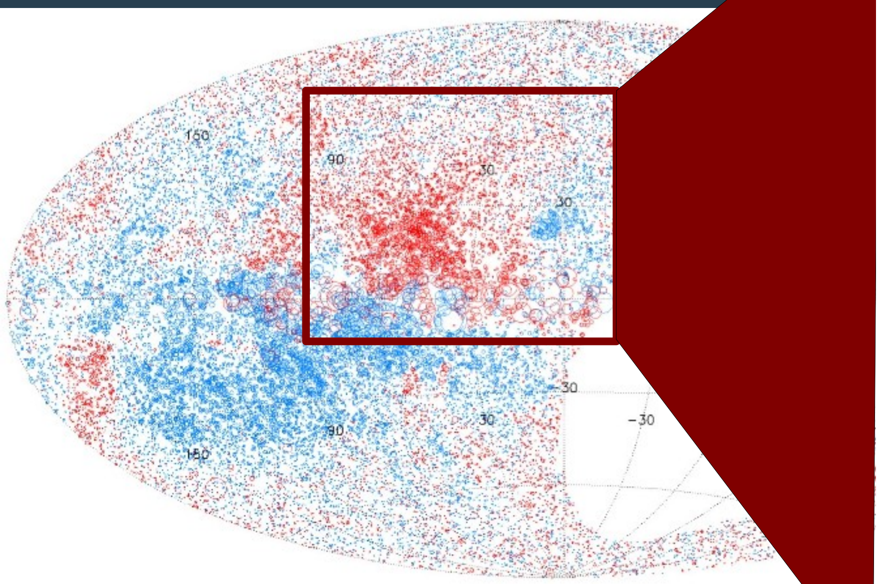

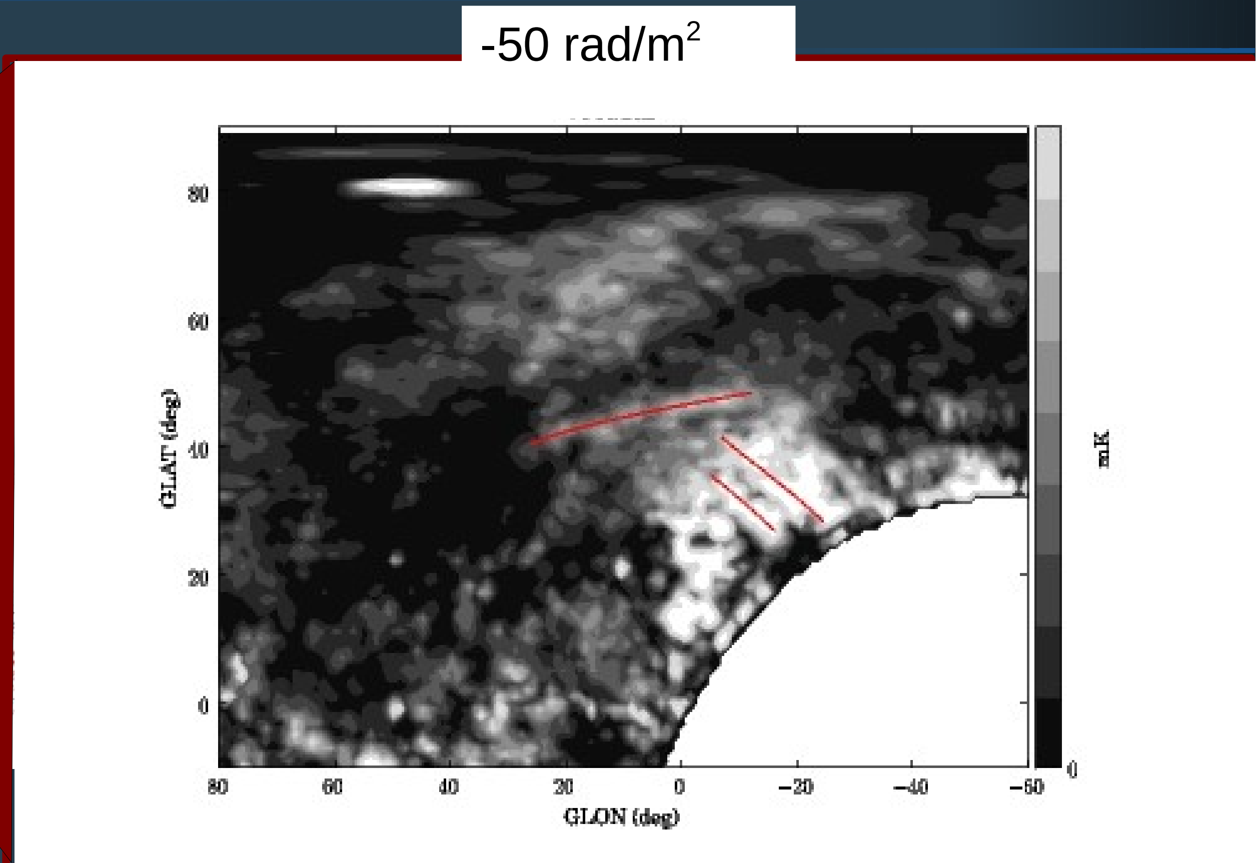

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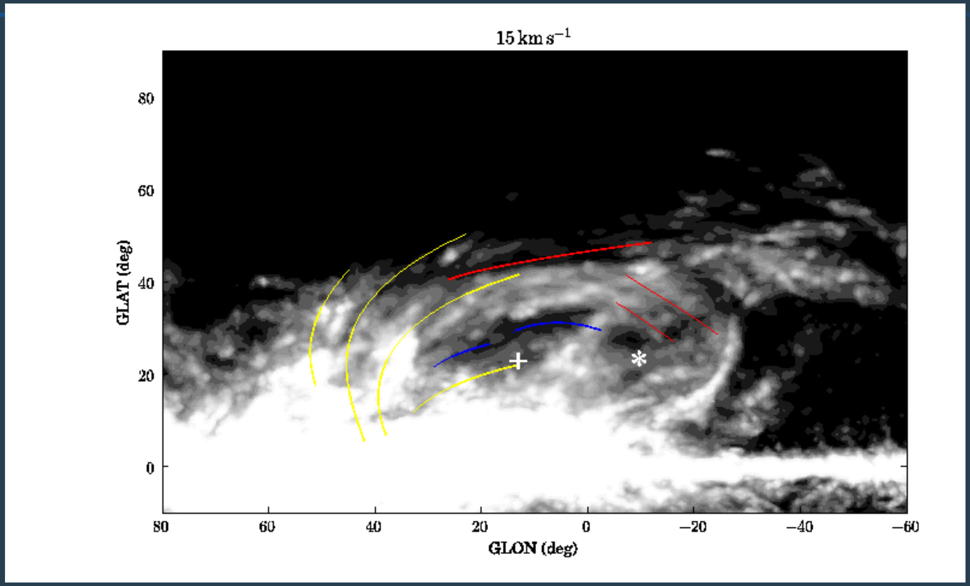
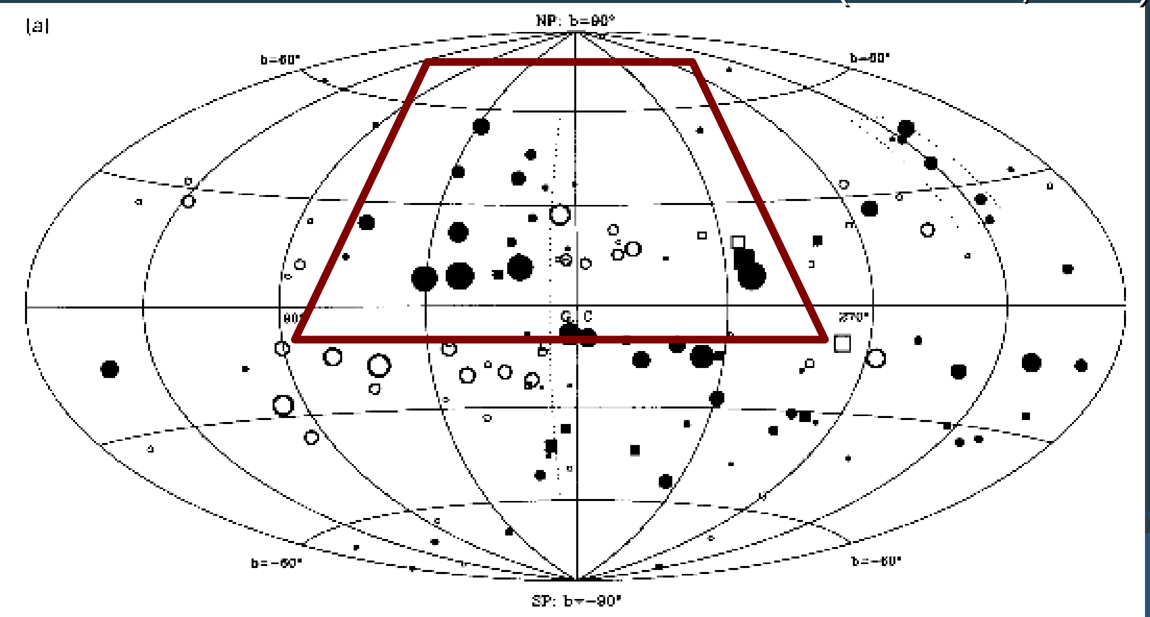
Antisymmetries in the FR Sky

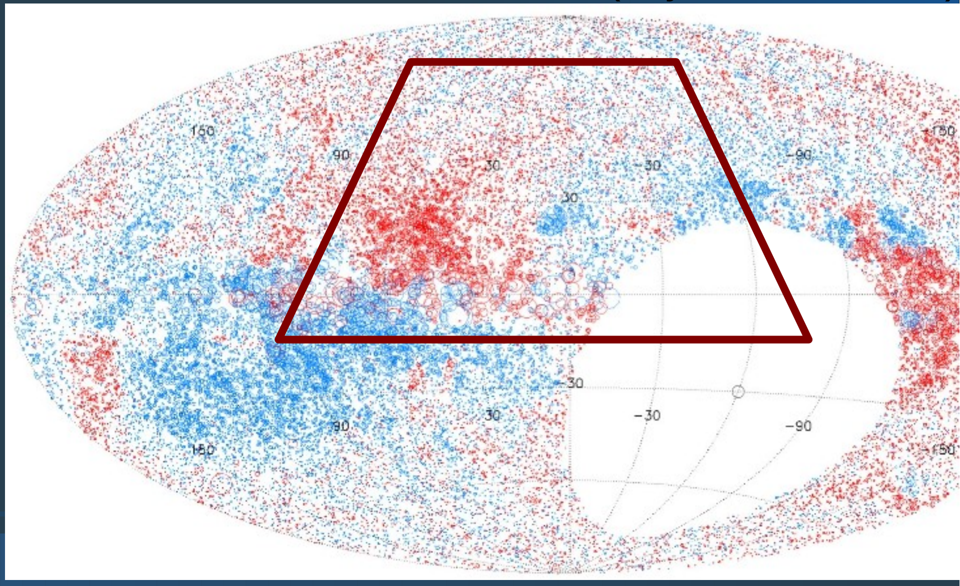


- Several authors have pointed out that the antisymmetry may be due to Loop I
- Our data show that another local object (not the NPS) mimics the antisymmetric pattern of a large scale B-field
- Detection made possible by high angular resolution RM-maps of the diffuse Galactic emission

Pulsars (Han et al, 1999)

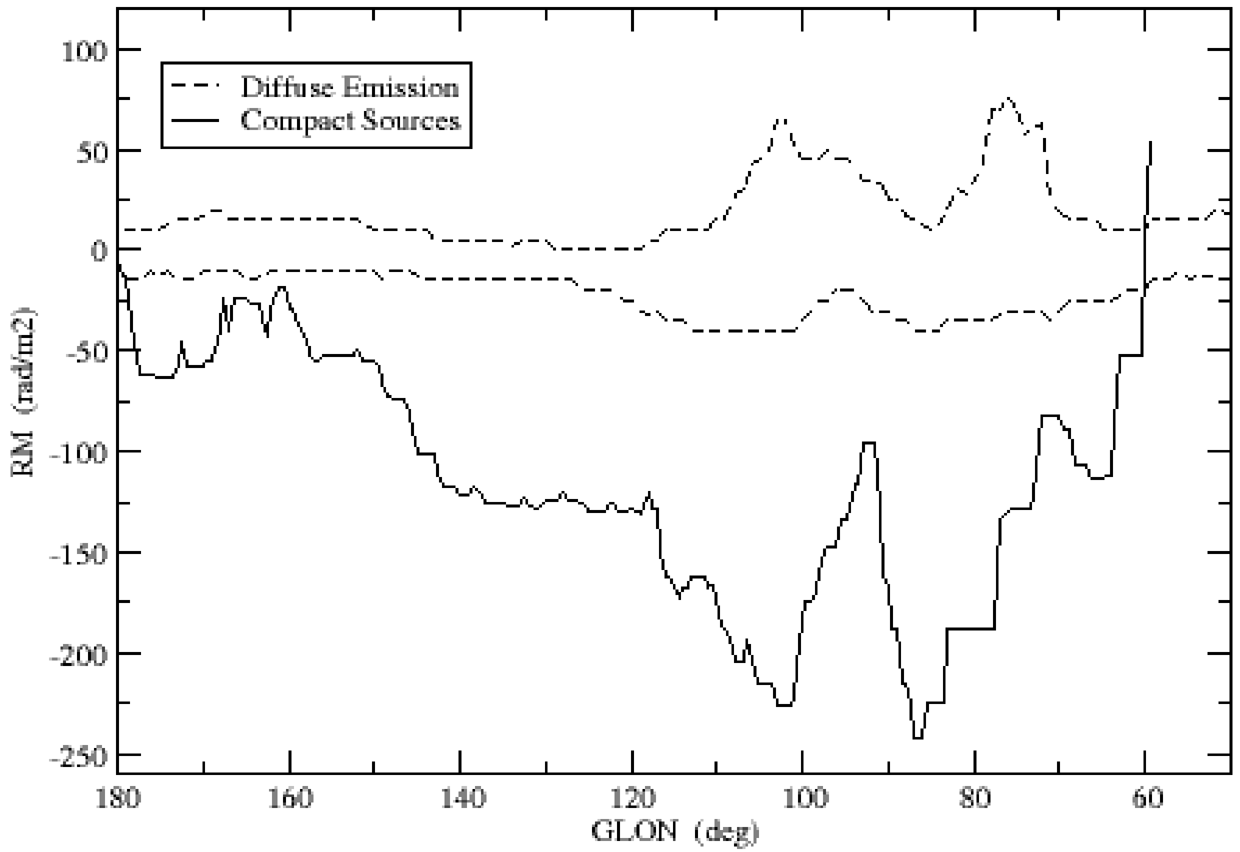


EG sources (Taylor et al, 2009)

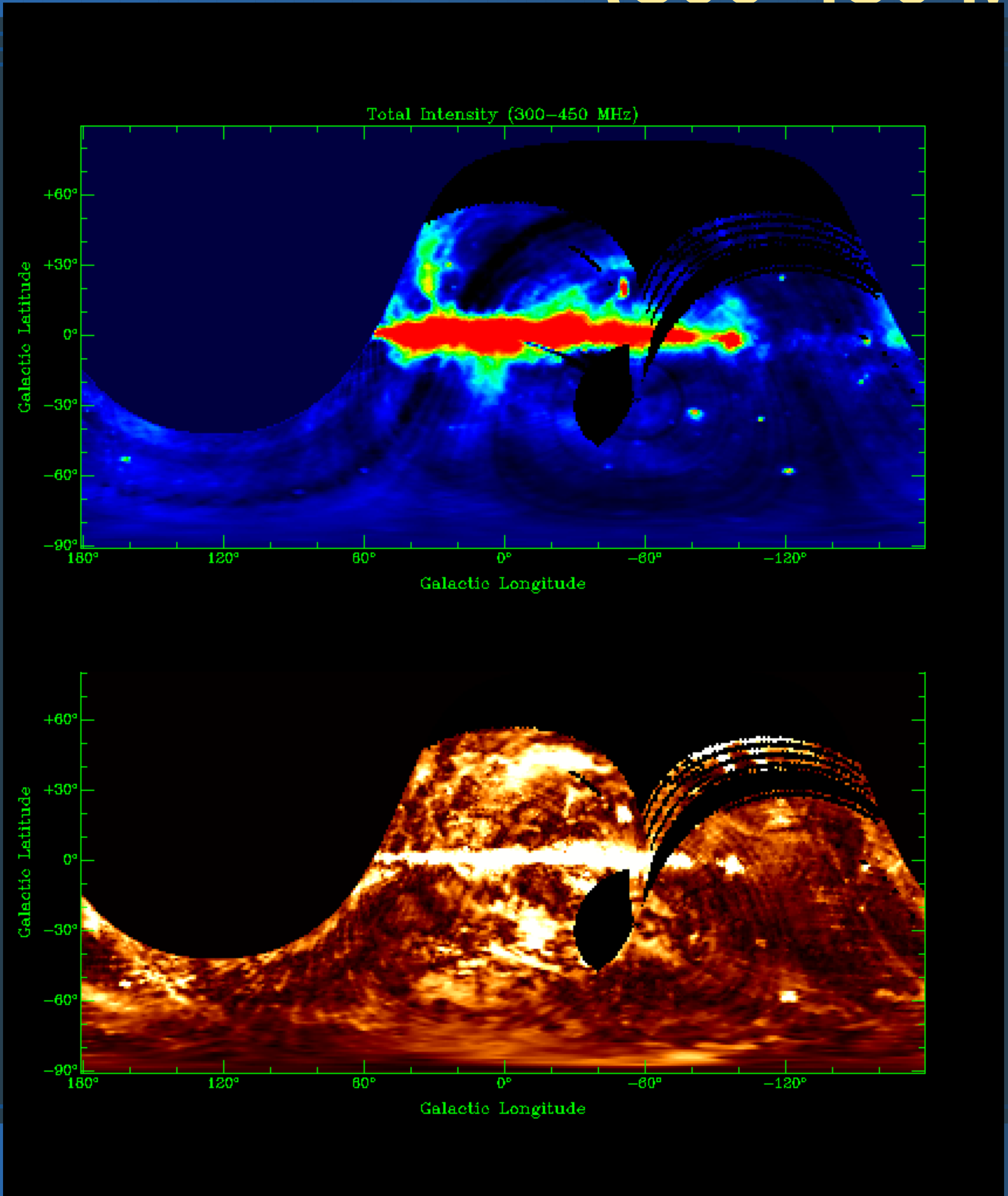


Diffuse Emission vs. Compact Source RMs

- RMs of compact sources from Canadian Galactic Plane Survey (Jo-Anne Brown, CGPS)
- RMs of diffuse emission from GMIMS High-Band North (DRAO 26-m Telescope)



First Data from Parkes 64-m (300-480 MHz)



Total Intensity

Polarized Intensity

Summary

- GMIMS is a wide-band, spectro-polarimetric survey from 300 MHz to 1.8 GHz, using single-dish telescopes
- First RM-Synthesis of the Galactic diffuse emission with a single-dish telescope over the whole Northern sky
- High angular resolution Faraday-rotation map reveals filamentary structures associated with a local HI bubble (not the North Polar Spur)
- These structures can be explained by a B-field wrapped around this bubble
- The resulting signature in the Faraday rotation sky mimics that of a large-scale Galactic B-field
- (Wolleben et al. 2010, in prep.)


GMIMS
The Global Magneto-Ionic Medium Survey

| Introduction | Science | News & Status | Technical | People | Pictures | Internal   Site updated March 6, 2010

Parkes 64-m Telescope

The Parkes 64-m Telescope in Australia is used for two GMIMS surveys: Low-Band South (300-900 MHz) and STAPS (1.2-1.8 GHz).

DRAO 26-m Telescope

Introduction

GMIMS is a survey of the polarized emission over the entire sky, covering the wavelength range from 16 cm up to 1 metre (300 MHz to 1.8 GHz). 10 institutions around the world are participating to study the magneto-ionic medium of our Galaxy - the medium composed of magnetic fields and electrons.

The prime tracers of magnetic fields are polarized radio waves: synchrotron emission bears the imprint of the field direction at origin, and Faraday rotation along the propagation path permits quantitative measurement of the line-of-sight field. Current data (e.g. picture on the right shows polarized intensity at 1.4 GHz in Galactic coordinates) suggest that the appearance of the polarized sky is dominated by Faraday rotation but are inadequate for deriving physical quantities except for a few objects. Recent advances in digital signal processing have made wide-band spectro-polarimetric back-ends available for astronomy, and a powerful new signal processing technique, RM-Synthesis, has been developed (Brentjens & de Bruyn, 2005). GMIMS brings these two techniques together. This will allow important physical parameters to be measured that are otherwise hard to quantify

Of particular importance are some questions that can be studied in the Milky Way. Are the magnetic fields in the disk and halo related, and if so, on what scales? What are

https://www.astrosci.ca/users/drao/gmims