Polarization structures to be interpreted as…

# The magnetic Milky Way

## seen through Rotation Measure Synthesis

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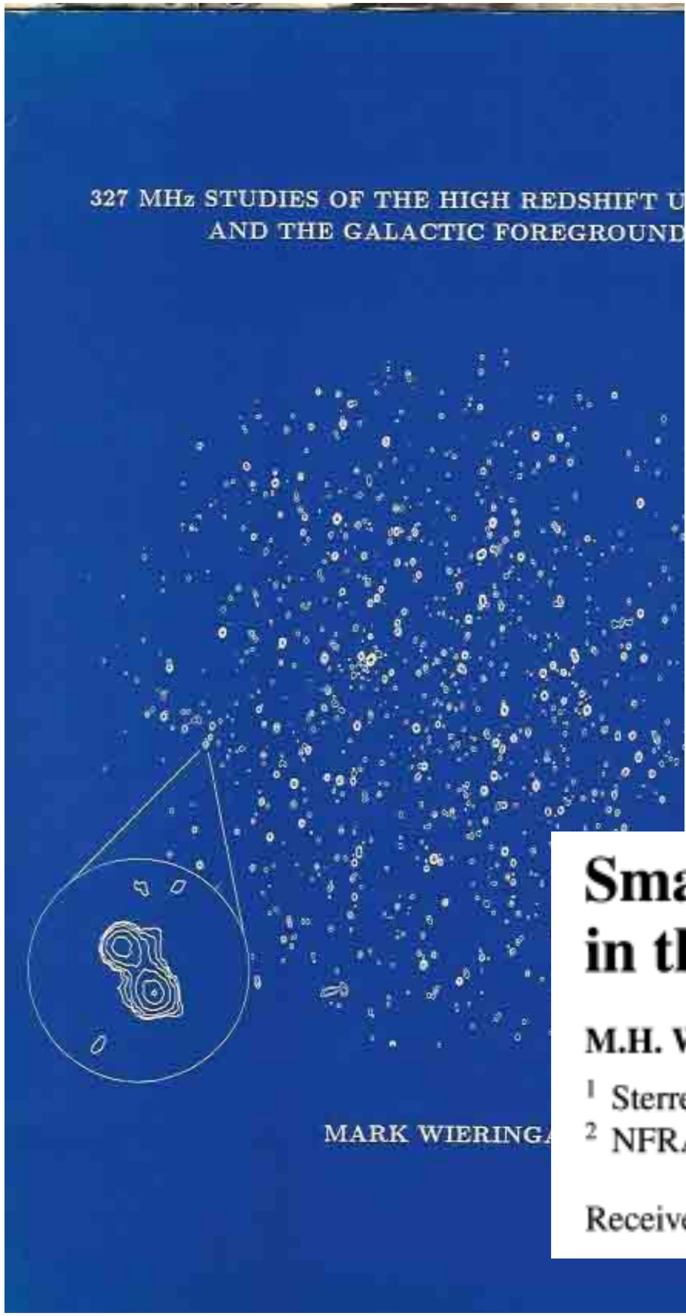


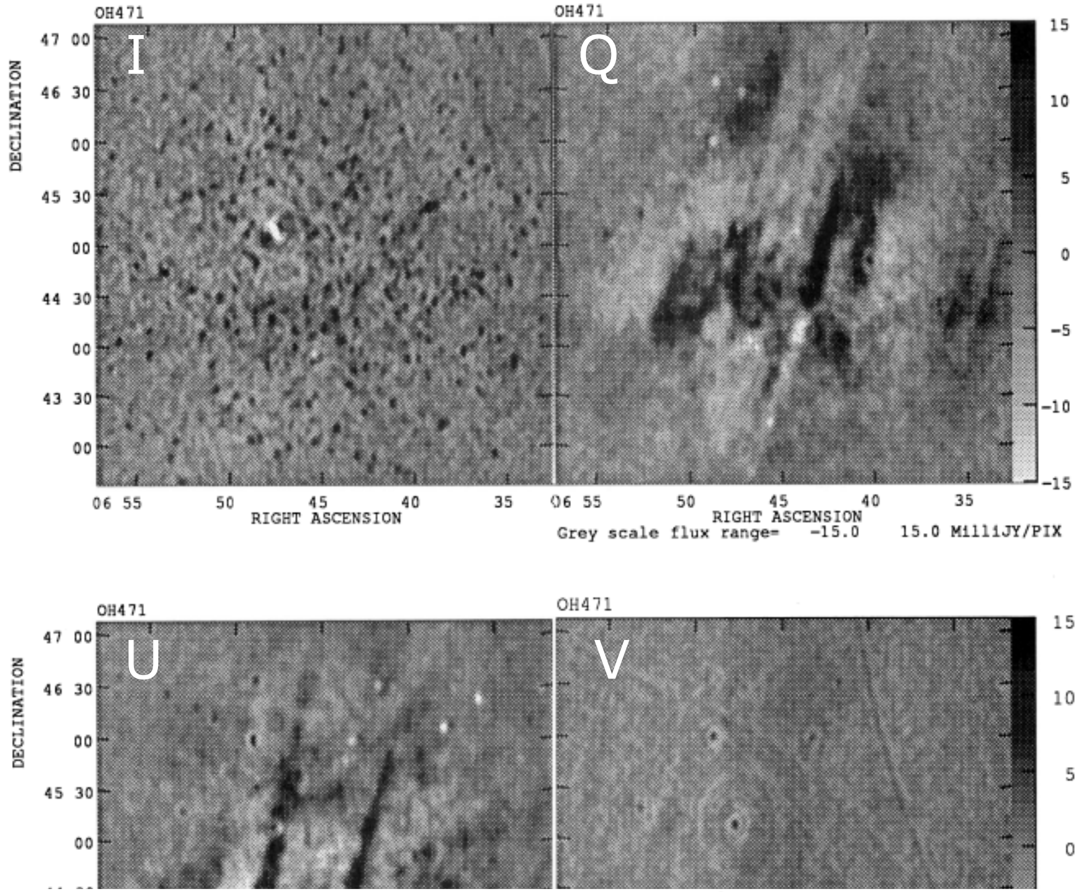


# Small scale polarization structure in the diffuse galactic emission at 325 MHz

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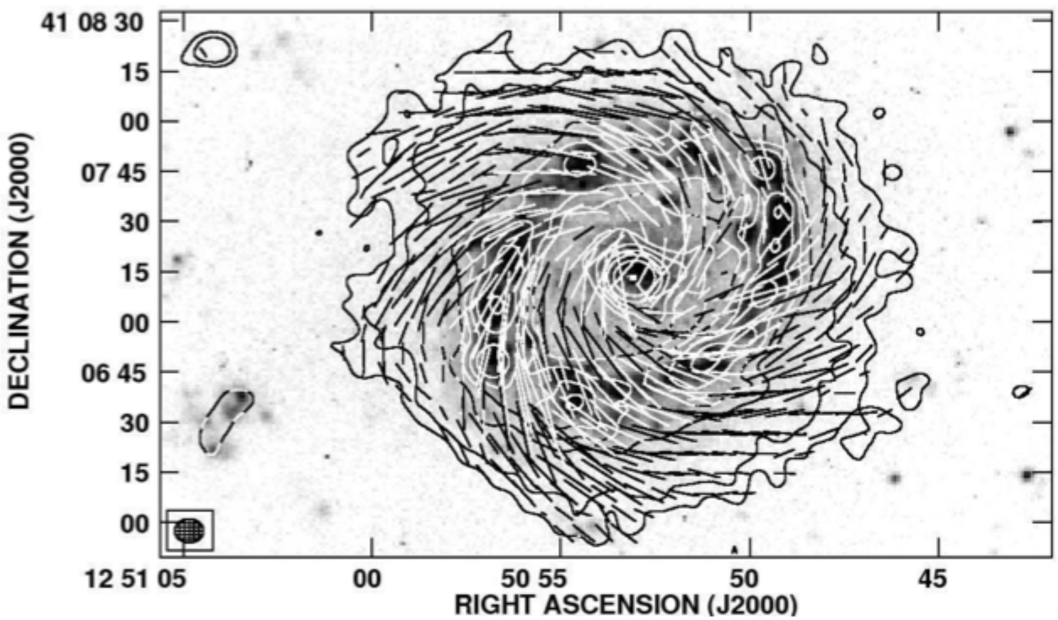
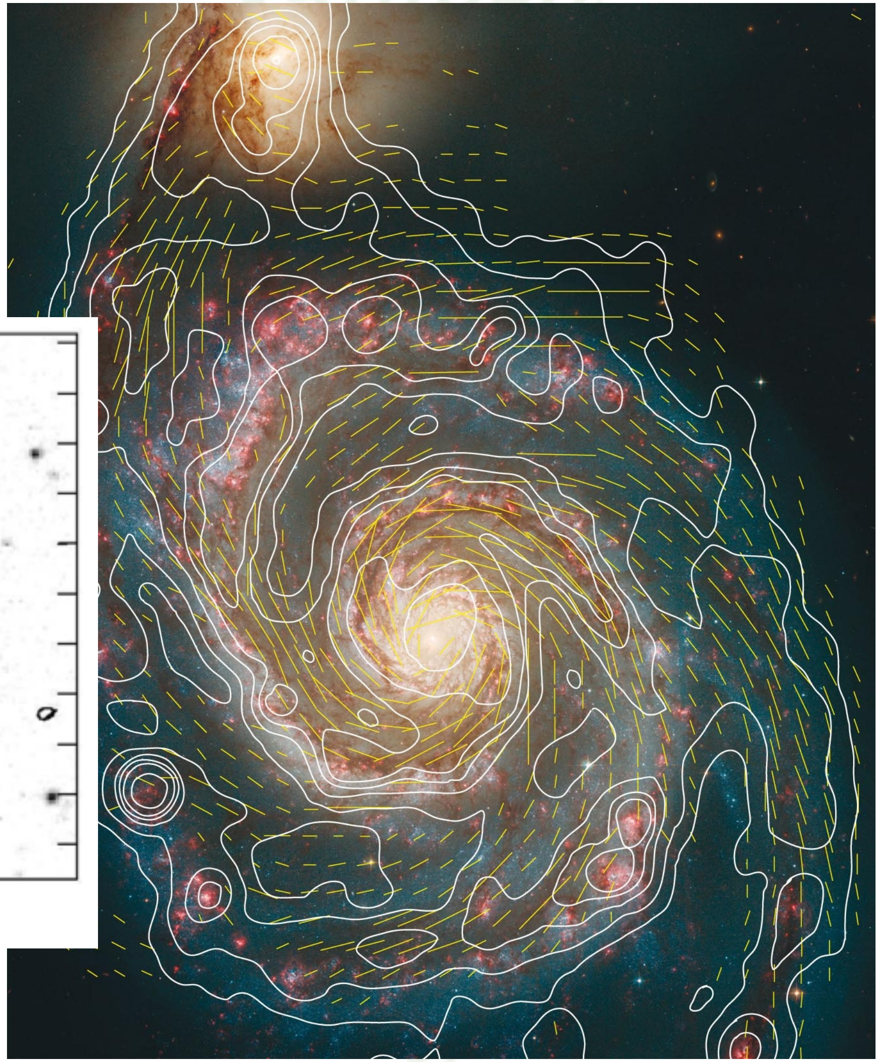
Galactic magnetic fields are everywhere, and they are (almost) always spirals.




Ring galaxy NGC4736 (Chyzy & Buta 2008)

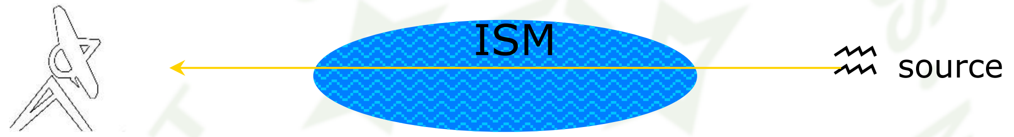


M51 (Fletcher et al 2011, STScI)

# Methods: Faraday rotation

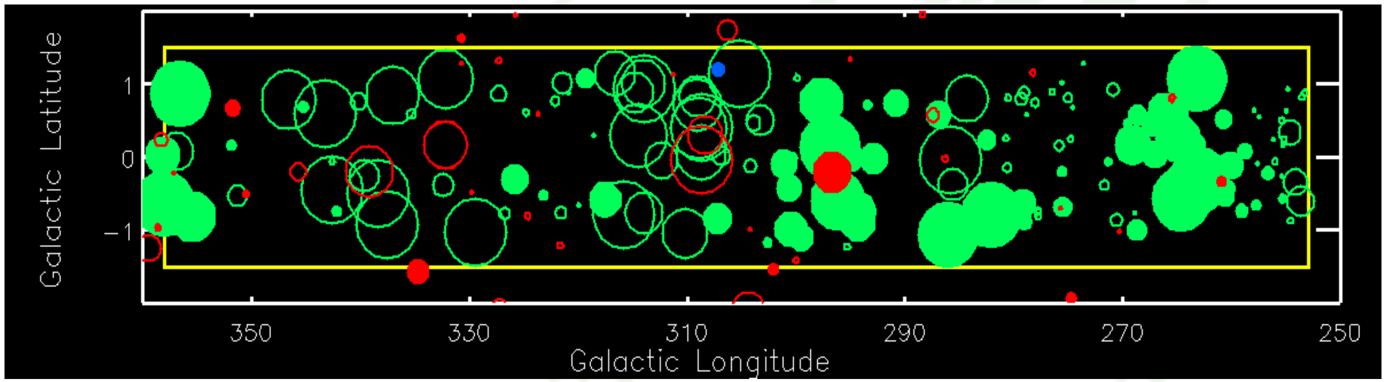
birefringence of magneto-ionized medium for circular polarization causes rotation of linear polarization angle

**'Classically' :**




Polarization angle rotates with observing wavelength λ: $\theta \propto \mathrm{RM}\,\lambda^2$

where rotation measure $$RM \propto \int_0^L n_e \vec{B} \bullet d\vec{l}$$

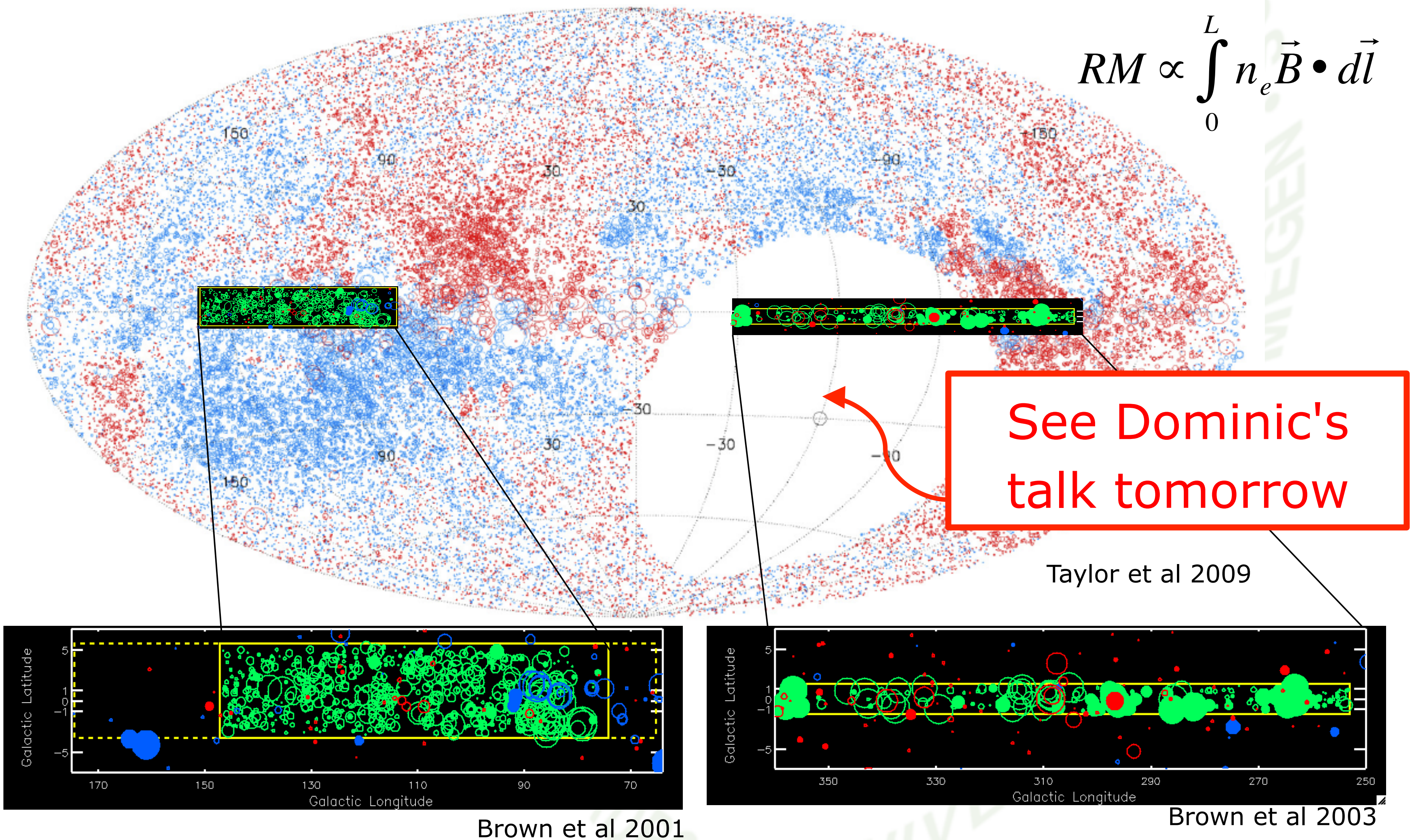



Brown et al 2007

# Methods: “The RM grid”

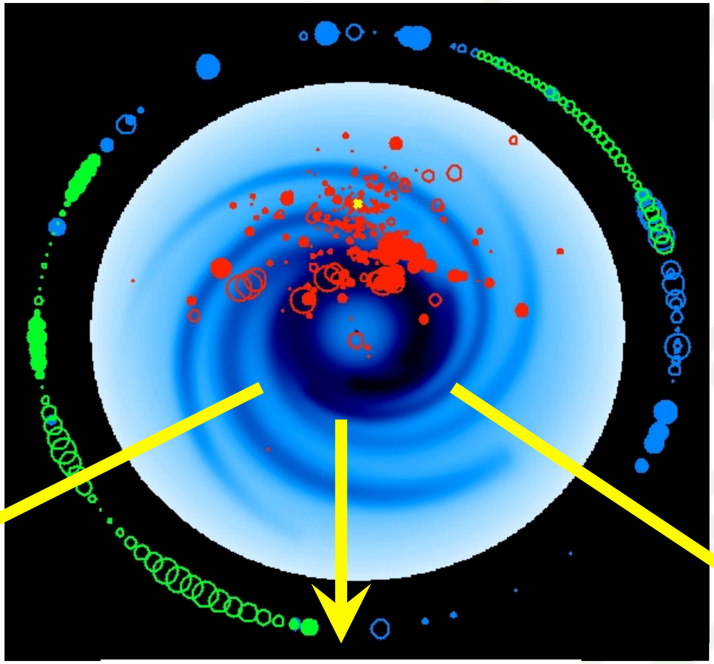
Current RM grid: 37543 NVSS sources = 1 source/sq deg

$$RM \propto \int_0^L n_e \vec{B} \bullet d\vec{l}$$

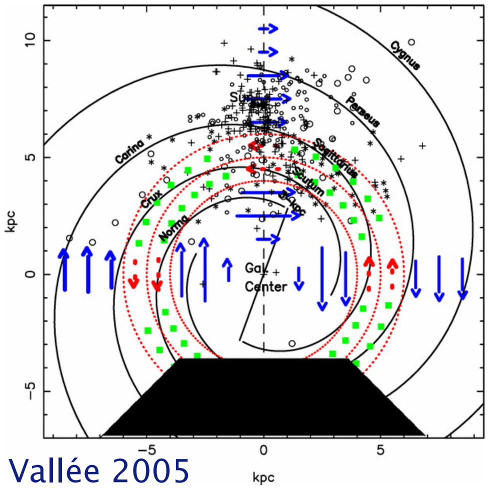


# Use the RM grid for Galactic magnetic field models: much controversy!

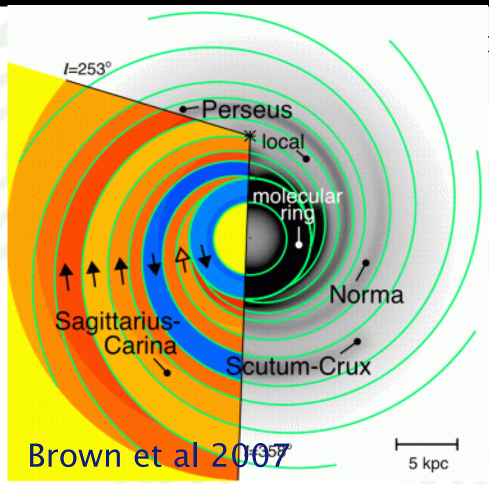
Disk fields are
axisymmetric?
bisymmetric?
mixed modes?
what about reversals?



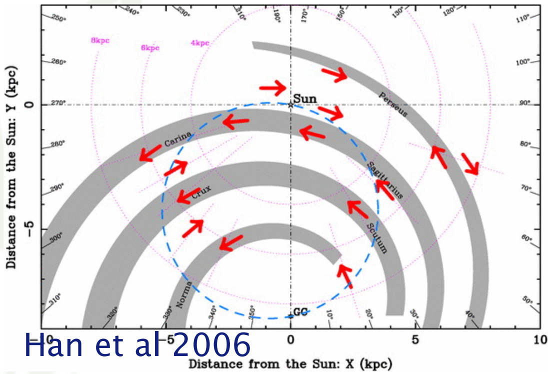
- Extragalactic source RM (blue and green filled/open circles)
- pulsar RM (red filled/open circles)




Vallée 2005




Brown et al 2007




Han et al 2006

# Methods: Faraday rotation

birefringence of magneto-ionized medium for circular polarization causes rotation of linear polarization angle

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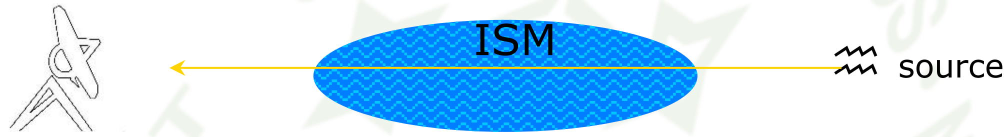



Polarization angle rotates with observing wavelength λ: $\theta \propto RM\,\lambda^2$

where rotation measure $$RM \propto \int_0^L n_e \vec{B} \bullet d\vec{l}$$

**Rotation measure synthesis:** (Burn 1966, Brentjens & de Bruyn 2005)

Faraday depth $$\phi \propto \int_{l_1}^{l_2} n_e \vec{B} \bullet d\vec{l}$$

See Michiel's talk tomorrow

$$P_{obs}(\lambda^2) = W(\lambda^2)P(\lambda^2) = W(\lambda^2)\int_{-\infty}^{\infty} F(\phi)e^{2i\phi\lambda^2}\,d\phi$$

$$R(\phi) = K\int_{-\infty} W(\lambda^2)e \;\; d\lambda$$

$$F_{obs}(\phi) = F(\phi) * R(\phi) = K\int_{-\infty}^{\infty} P_{obs}(\lambda^2)e^{-2i\phi\lambda^2}\,d\lambda^2$$

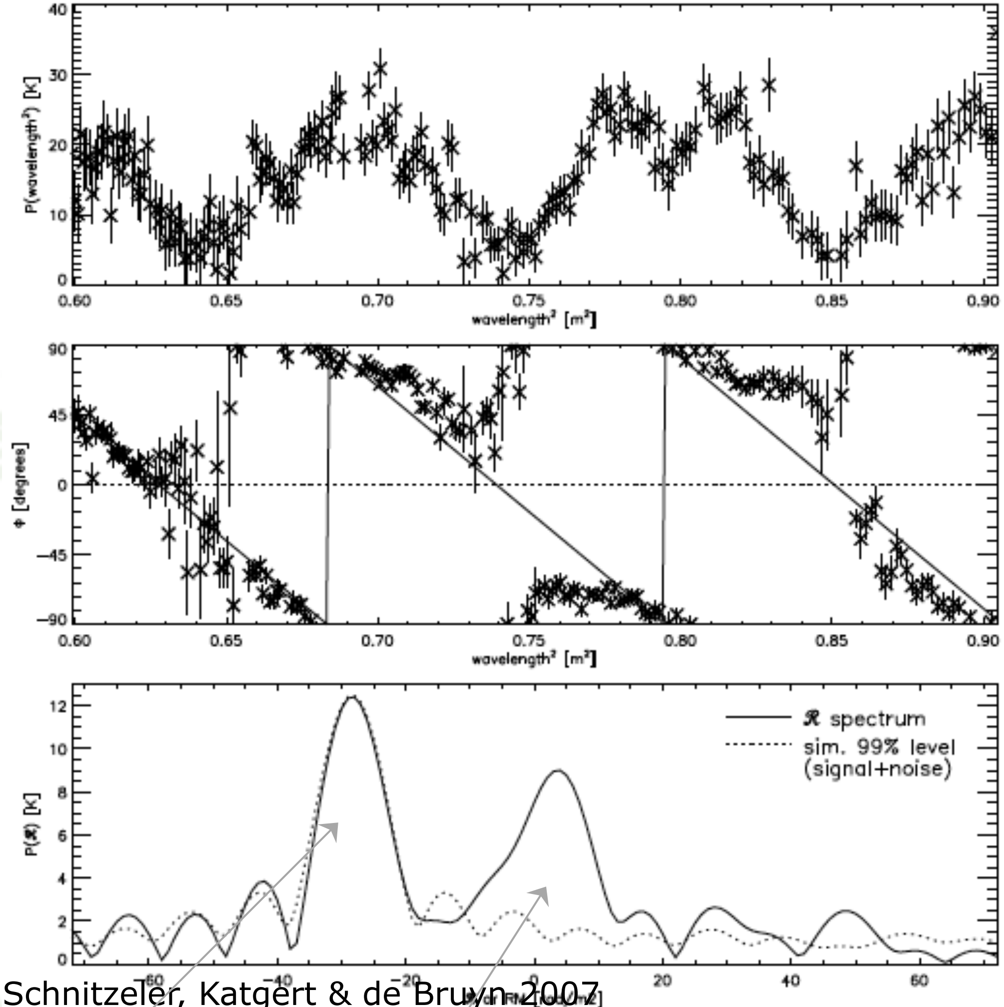
$$K = \left(\int_{-\infty}^{\infty} W(\lambda^2)\,d\lambda^2\right)^{-1}$$

# Methods: Rotation Measure Synthesis along a single line of sight

Linearly polarized intensity

Polarization angle

Faraday depth spectrum

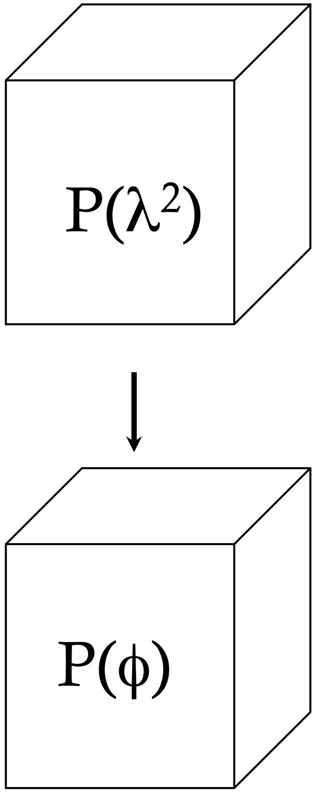



Schnitzeler, Katgert & de Bruyn 2007

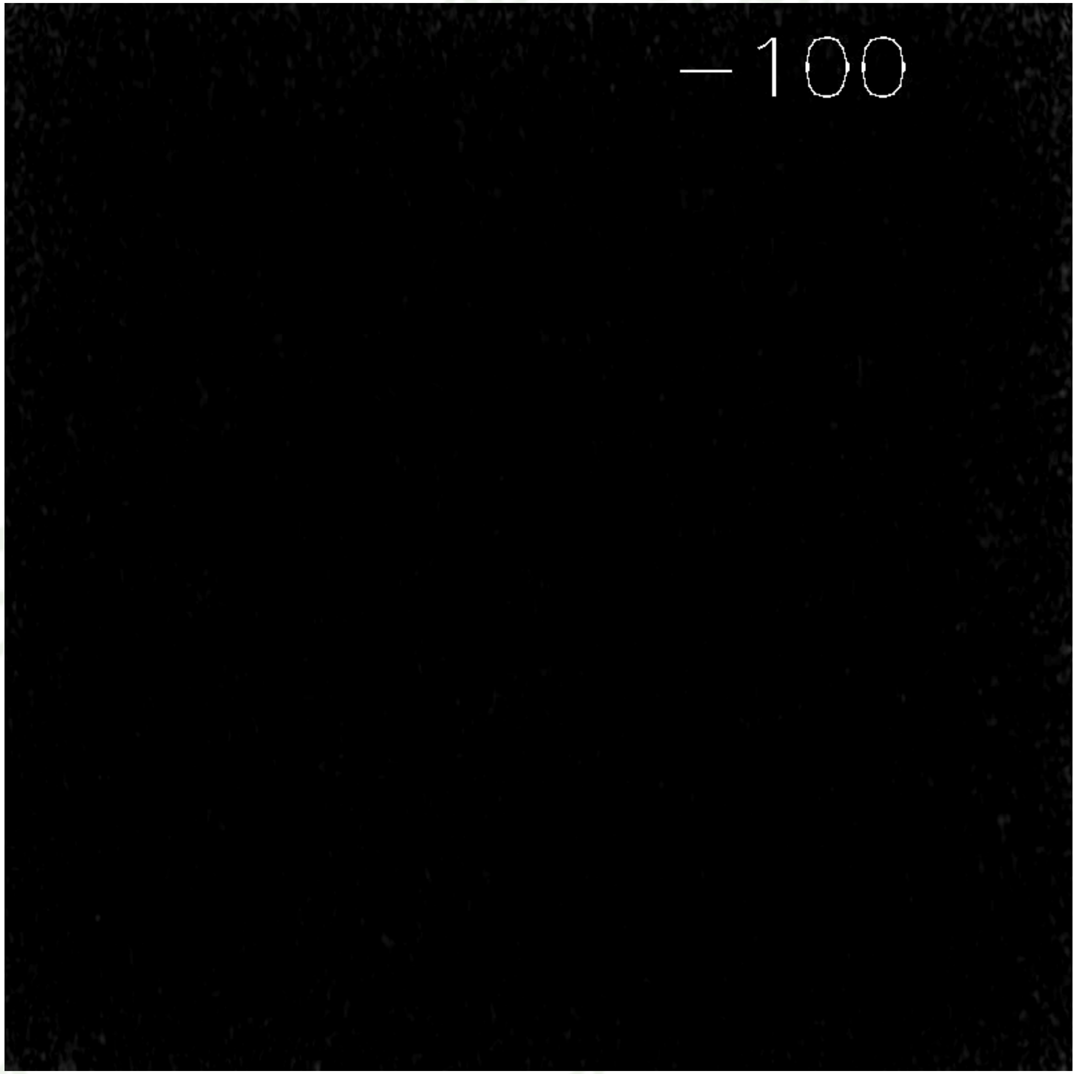
e.g. extragalactic point source

e.g. Galactic interstellar medium

# Methods: Rotation Measure Synthesis across an entire field




φ = Faraday depth
$= 0.81 \int n_e \, \mathbf{B \cdot dl}$

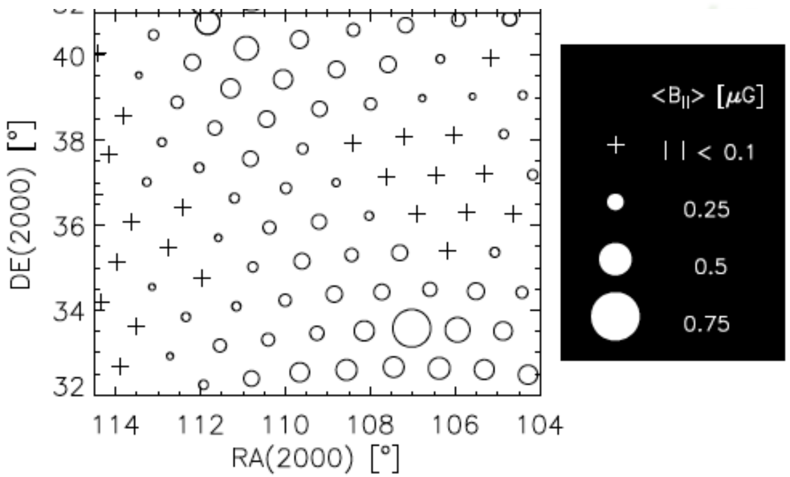


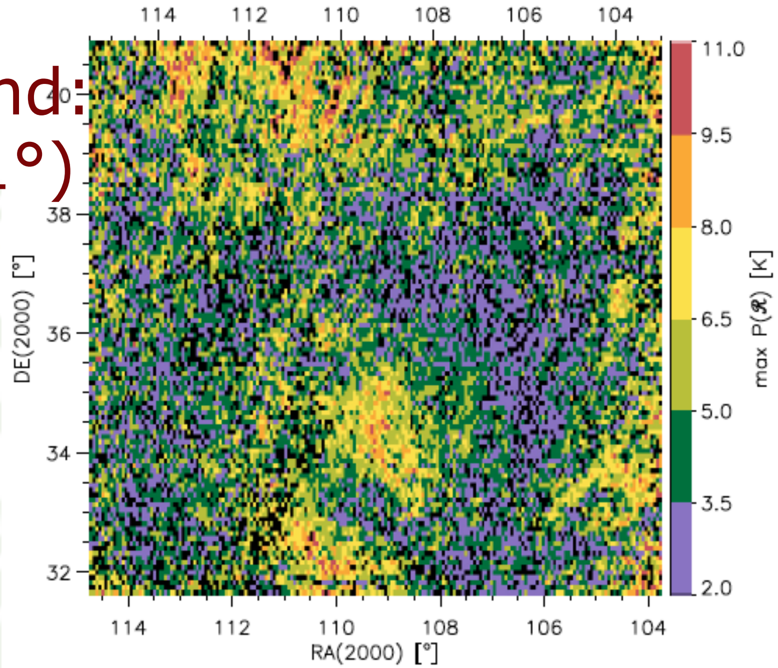

7°x7° field around (l,b) = (181°,20°)
Schnitzeler, Katgert & de Bruyn 2007

# RM Synthesis of Galactic foreground: GEMINI field at (l,b) = (181°, +21°)

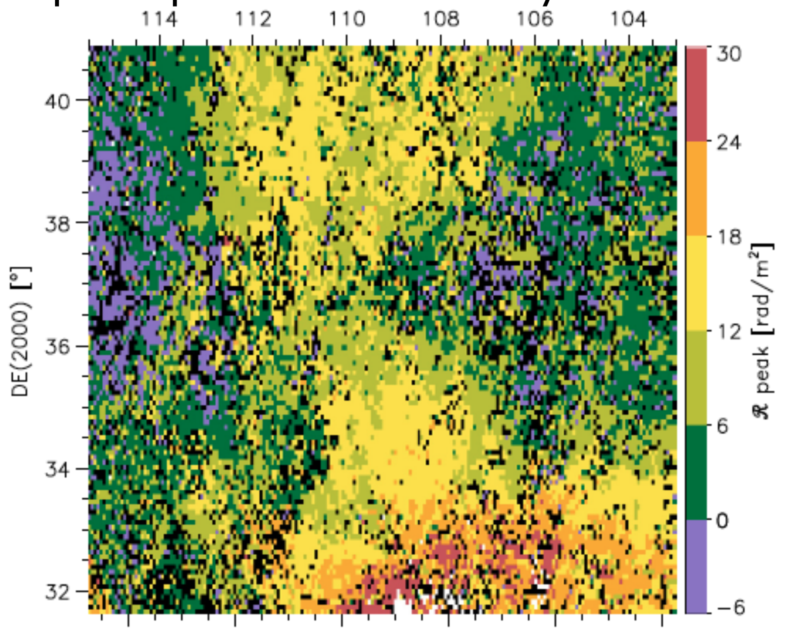
~10% of sightlines Faraday thin
(Faraday screens)

Magnetic field strength $B_{//}$:



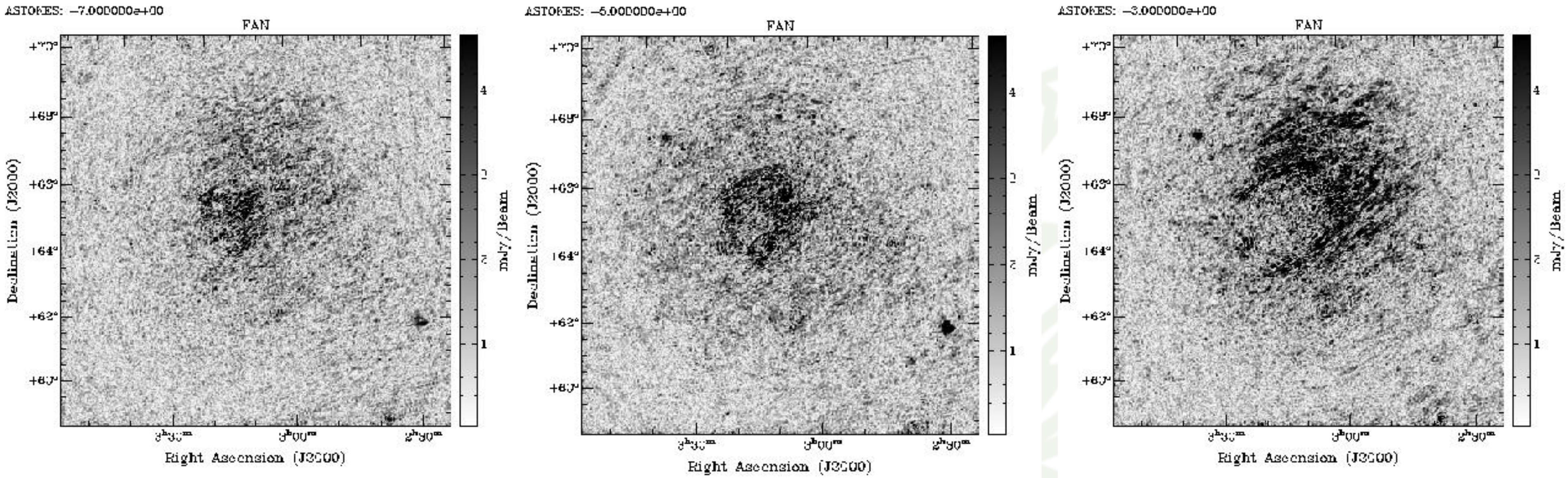

peak polarized intensity



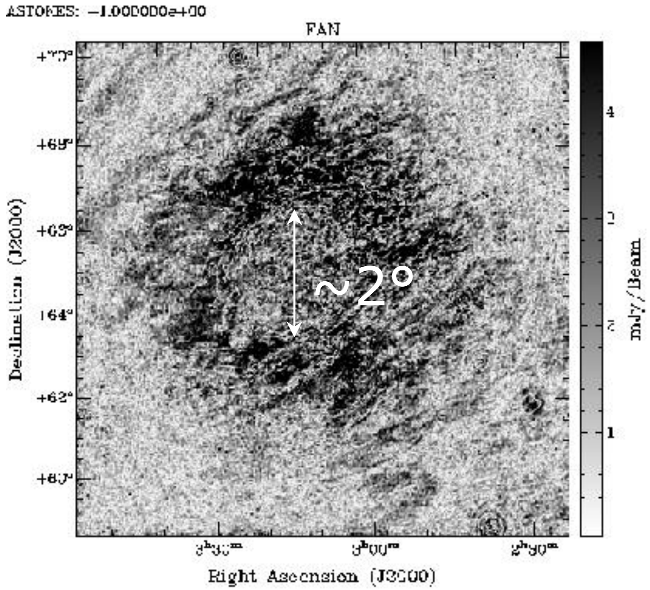

Faraday depth at that peak

| | |
|---|---|
| FWHM | 2.8 x 4.7 arcmin |
| Freq | 324 – 387 MHz ( $\lambda^2$: 0.86 - 0.6 $m^2$) |
| FWHM RMSF | 12 rad $m^{-2}$ |

# RM Synthesis of Galactic foreground: FAN region at (l,b) = (137°, +8°)




Bernardi et al (2009)




- “expanding” polarized structure
- ONLY detectable in radio polarization
- maximum Faraday depth in center, decreasing towards the edge

| | |
|---|---|
| FWHM | 2.8 x 4.7 arcmin |
| Freq | 324 – 387 MHz ( $\lambda^2$: 0.86 - 0.6 $m^2$) |
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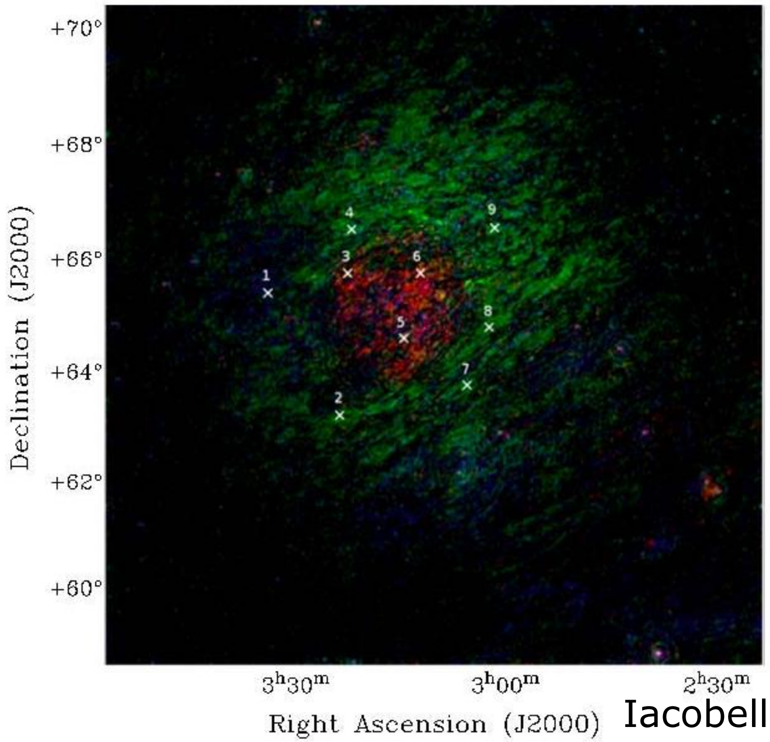
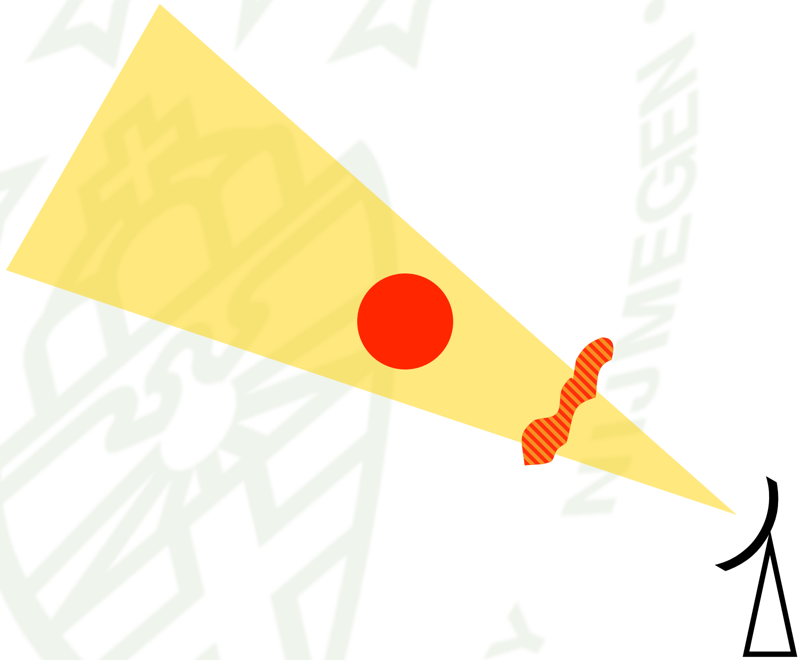


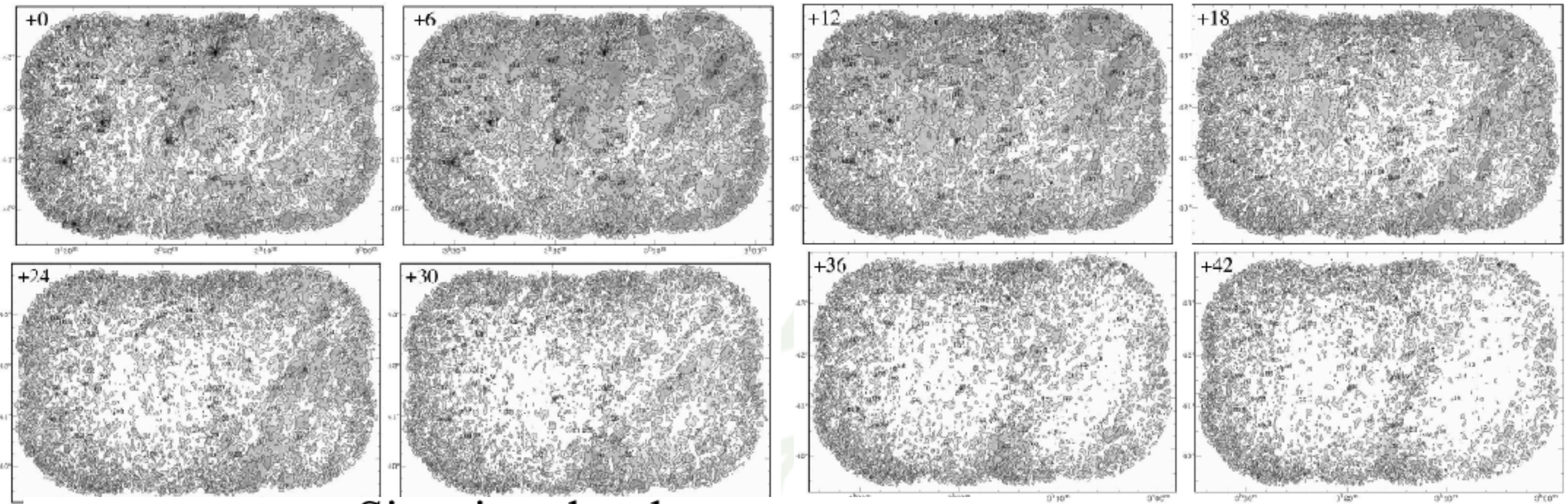

Iacobelli et al 2012



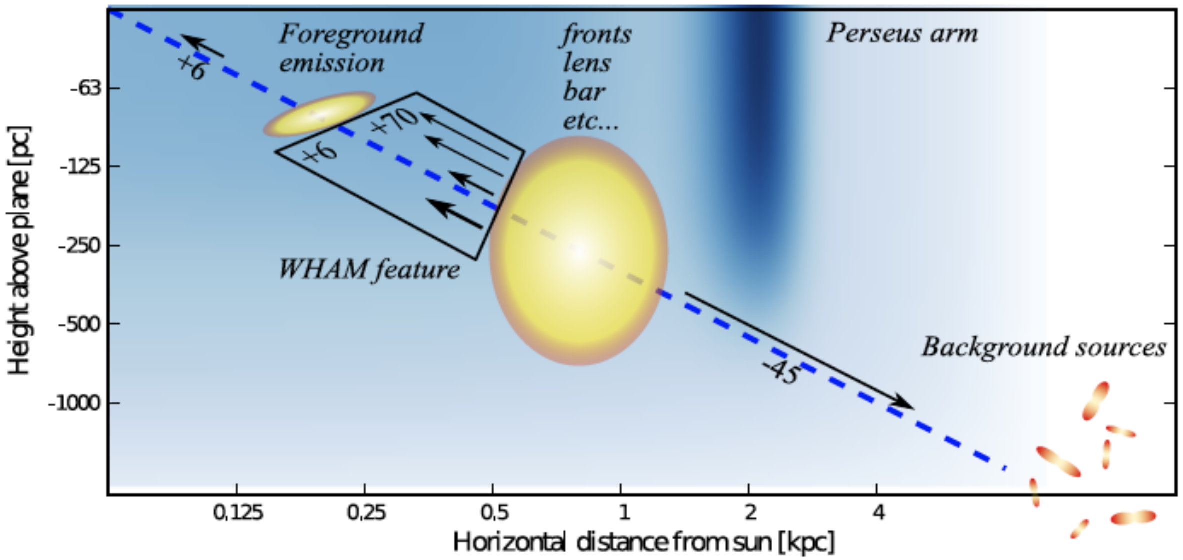
Proposed model:

- foreground component: Local Bubble wall
- circular feature: HII region expanding in low-density plasma
- discrete, small-scale, synchrotron emitting structures

# RM Synthesis of Galactic foreground: towards Perseus cluster at (l,b) = (150°, +-13°)



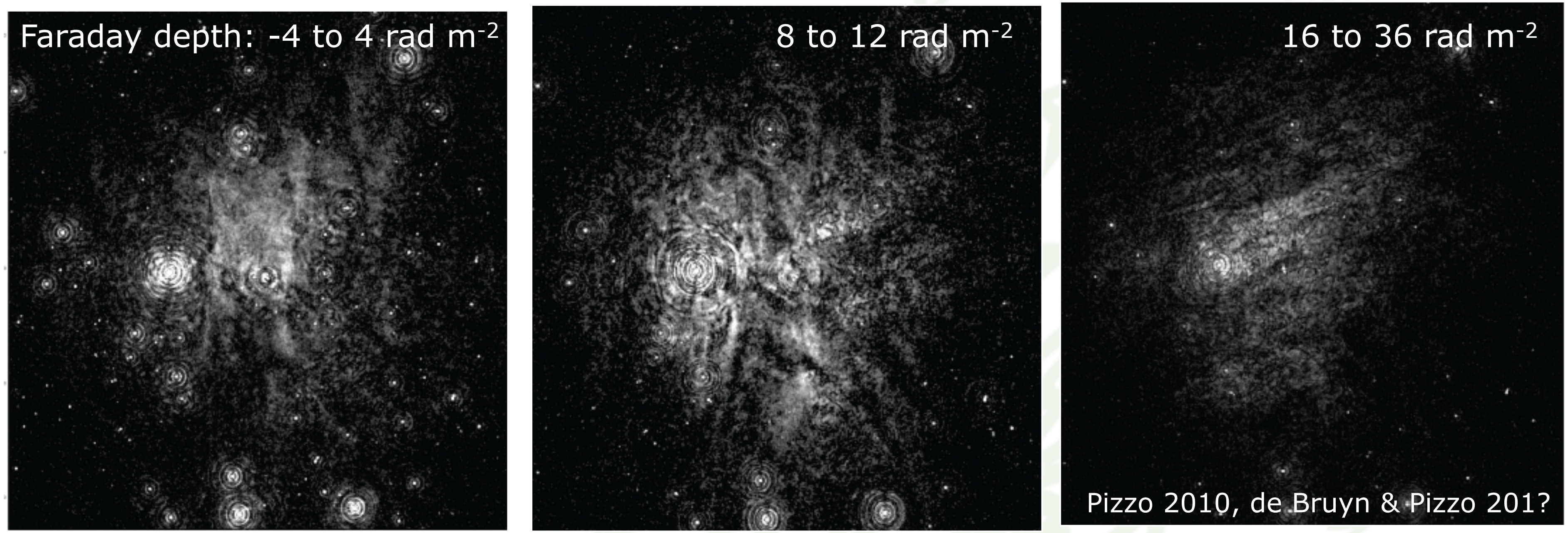

Situation sketch

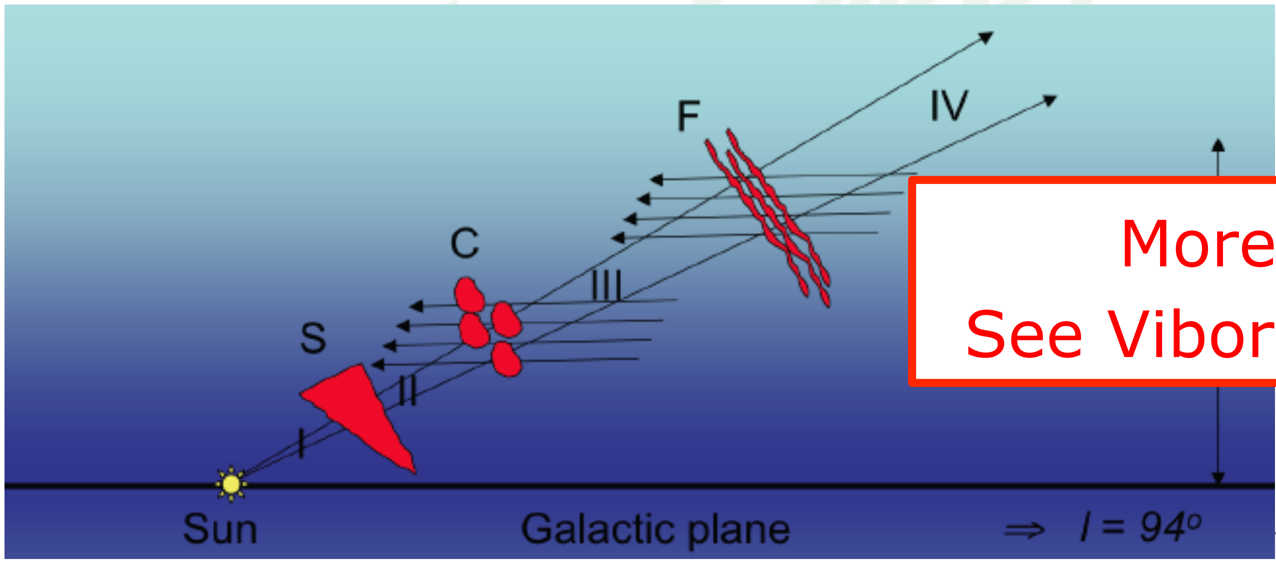



Brentjens 2011

| | |
|---|---|
| FWHM | 2 x 3 arcmin |
| Freq | 324 – 378 MHz |
| FWHM RMSF | 12 rad m$^{-2}$ |

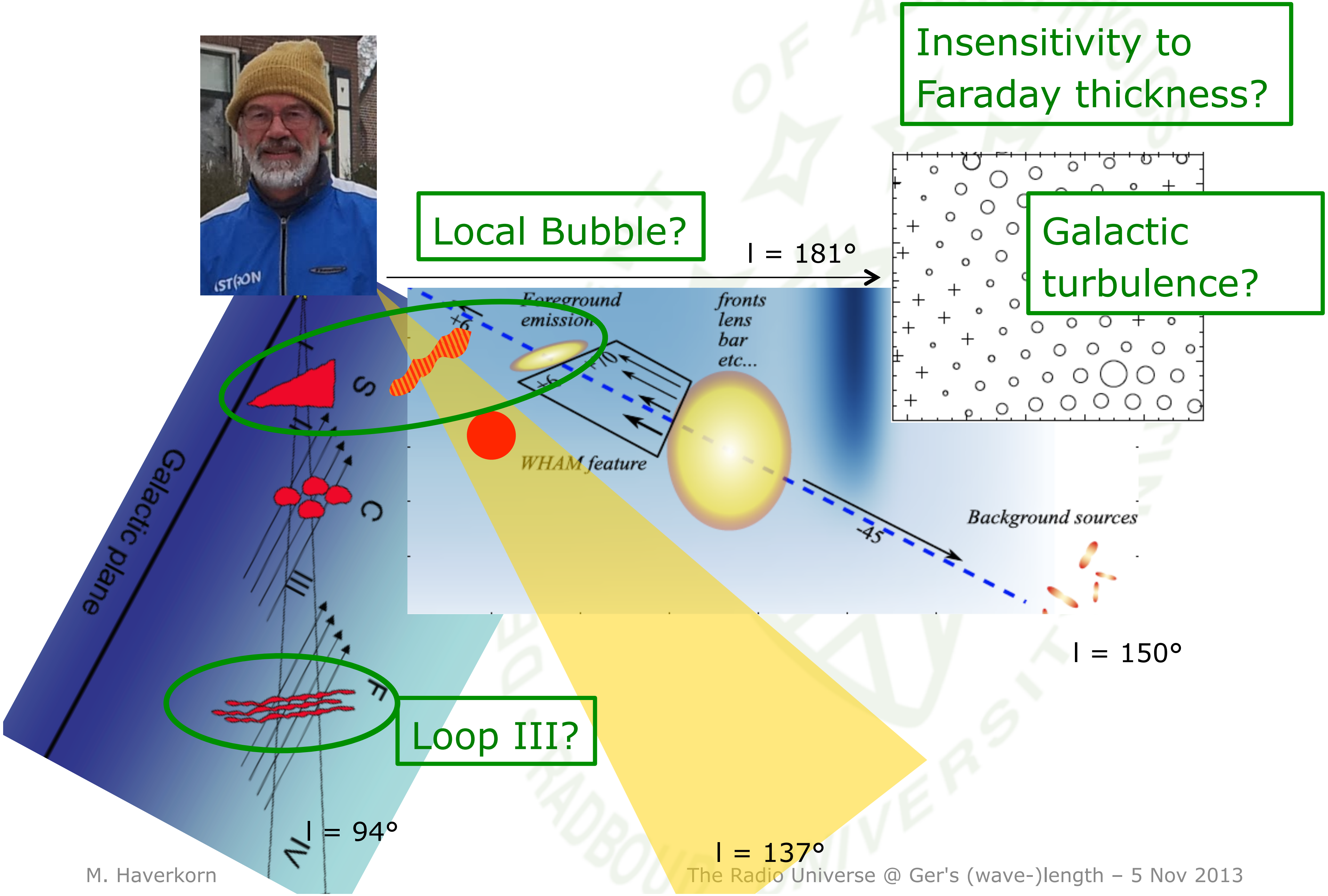
# RM Synthesis of Galactic foreground: towards the A2255 cluster at (l,b) = (94°, +35°)



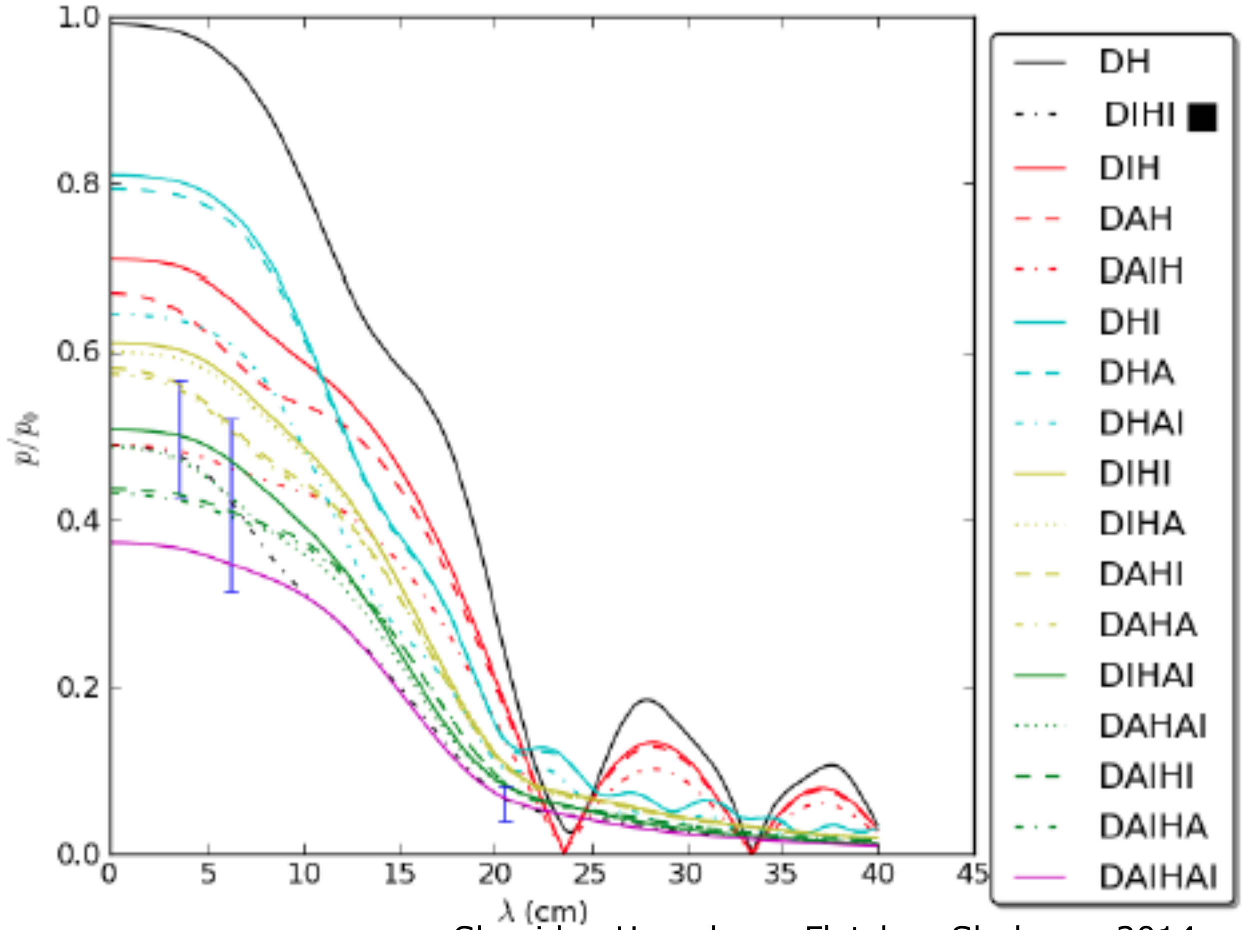




More?
See Vibor's talk

# RM Synthesis of Galactic foreground: Big Picture?

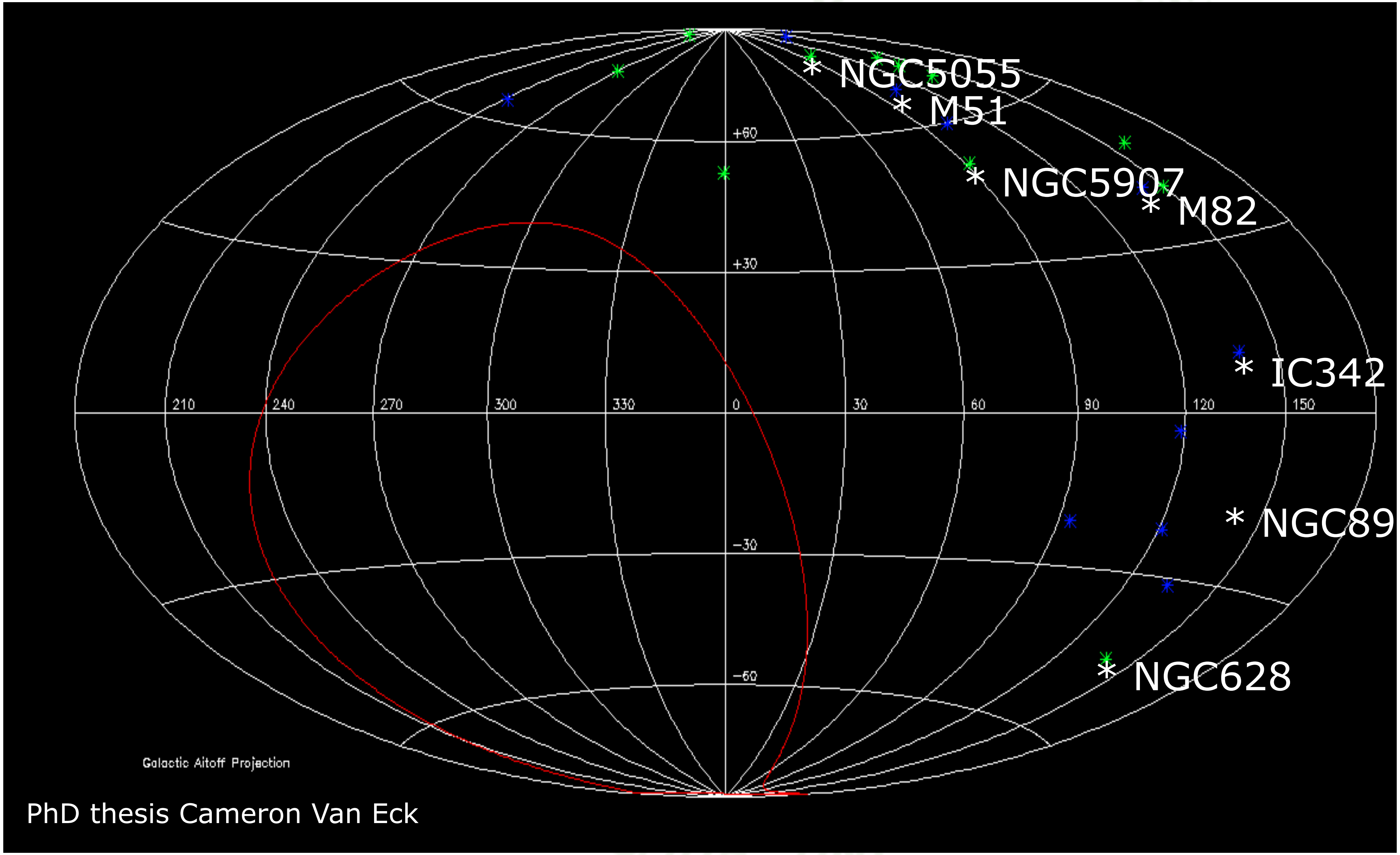


# RM Synthesis of Galactic foreground: Big Picture?

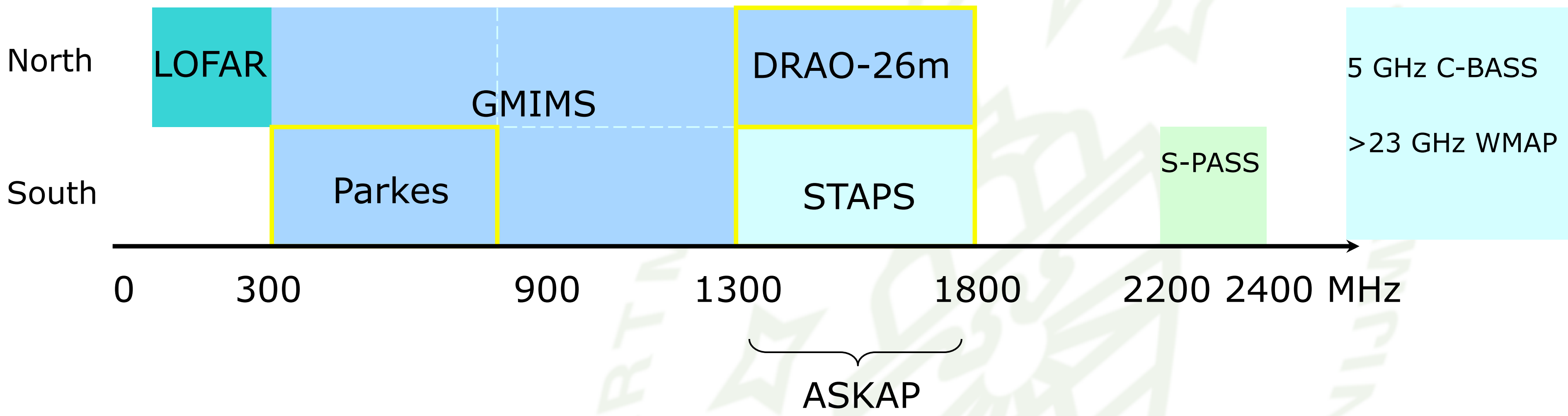



Shneider, Haverkorn, Fletcher, Shukurov 2014

# LOFAR RM Synthesis fields: Galactic foreground around nearby galaxies



# GMIMS: Global Magneto-Ionic Medium Survey (PI Landecker; Wolleben et al 2009)

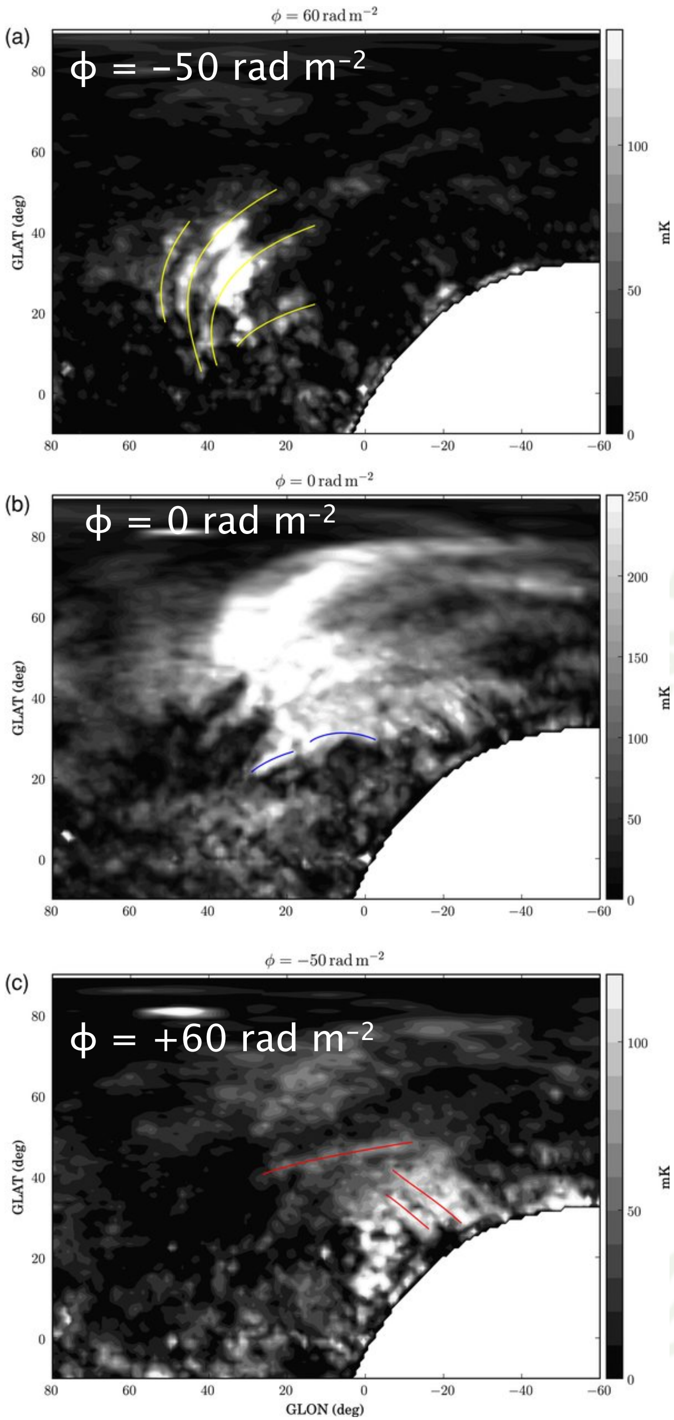



Angular resolution 30 – 60 arcmin

Faraday depth resolution of 3.5 rad $m^{-2}$

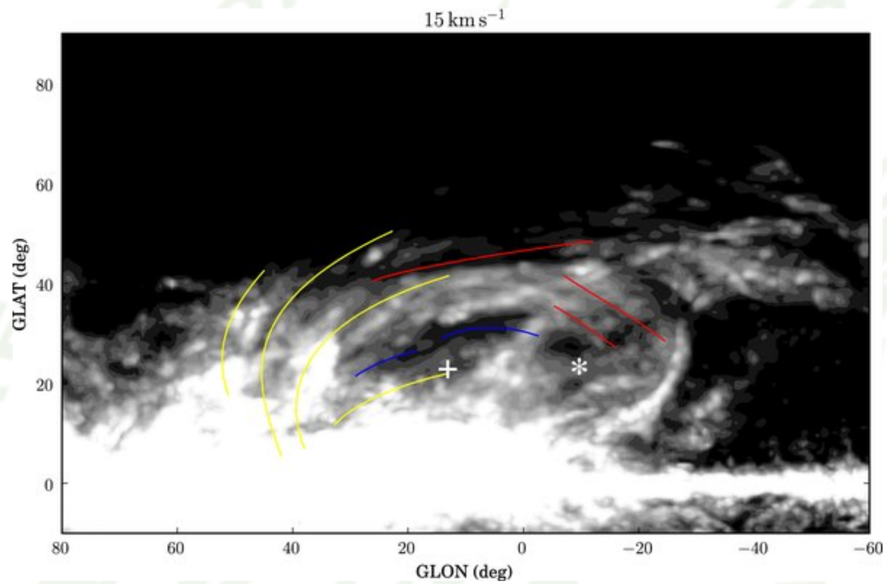
Maximum detectable Faraday depth ~ 115 rad $m^{-2}$

GMIMS + LOFAR: Faraday depth resolution of < 0.5 rad $m^{-2}$




# First results DRAO-26m survey:

Wolleben et al 2010

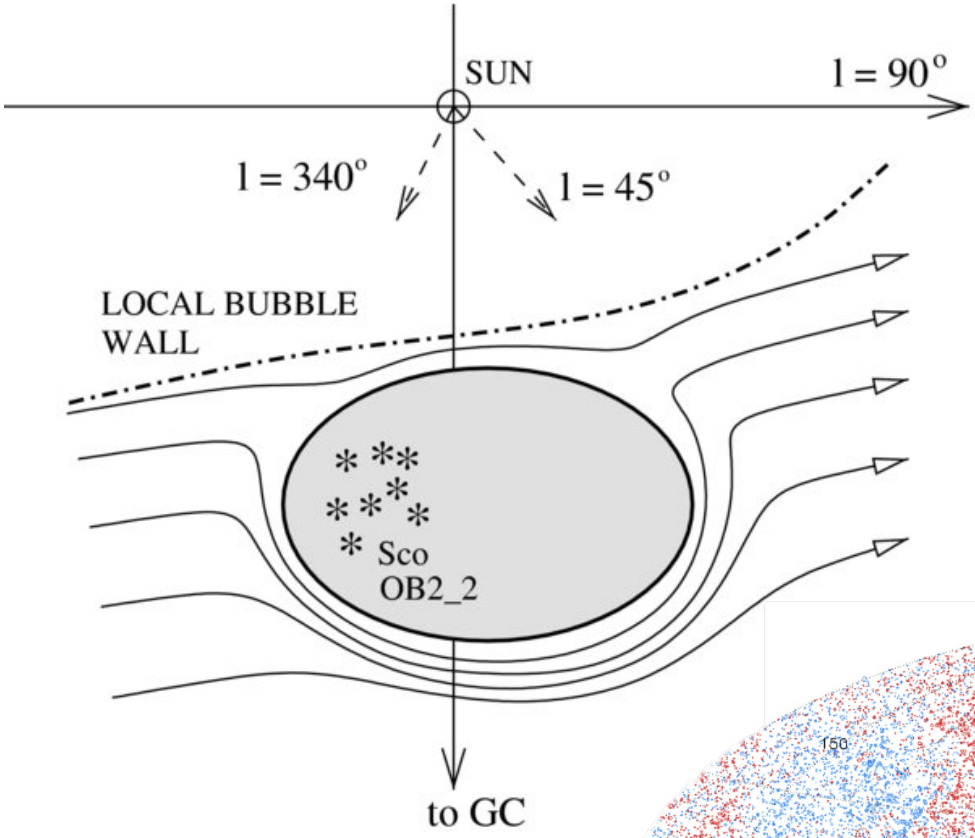


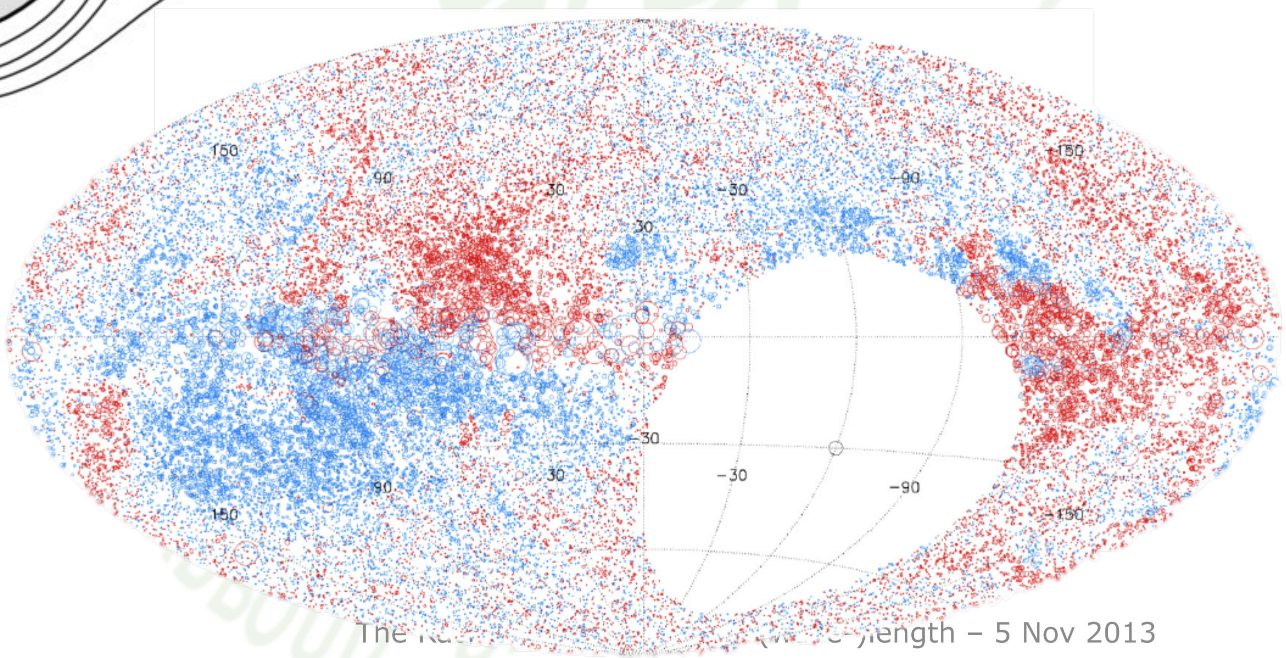

- filaments coincide with one side of an HI bubble
- no synchrotron emission
- magnetic field wrapped around
- strength about 20 – 34 μG

| | |
|---|---|
| FWHM | 30 - 40 arcmin |
| Freq | 1277 – 1762 MHz |
| FWHM RMSF | 132 rad $m^{-2}$ |

# First results DRAO-26m survey:

Wolleben et al 2010



# Summarizing:

RM Synthesis gives us the 3D (2.5D?) information needed for disentangling the magnetic field in the Milky Way

Early RM Synthesis results of Galactic diffuse polarization give multiple discrete Faraday depth components, due to:

- directivity of magnetic field?
- discrete synchrotron emission regions?
- discrete Faraday rotation regions?
- RM Synthesis artefacts?
- all of the above?

Projects addressing these issues:

LOFAR Galactic Science; GMIMS; see next talk!