

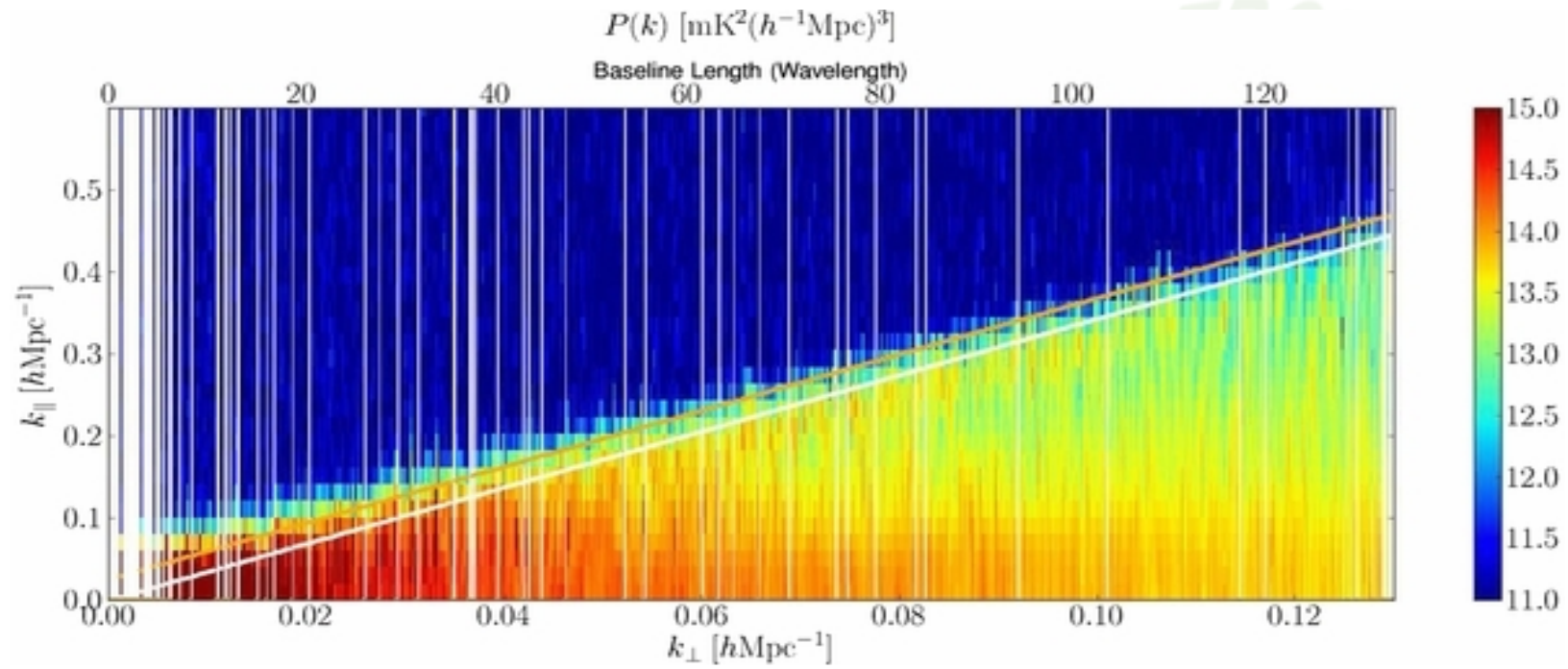
One (wo)man's trash is another (wo)man's treasure...

Galactic foreground science: radio emission, polarization, ISM and magnetic fields

Marijke Haverkorn – Radboud University Nijmegen
Cameron Van Eck, Marco Iacobelli, Jur Remeijn (Radboud)

Gianni Bernardi, Vibor Jelić, Ger de Bruyn

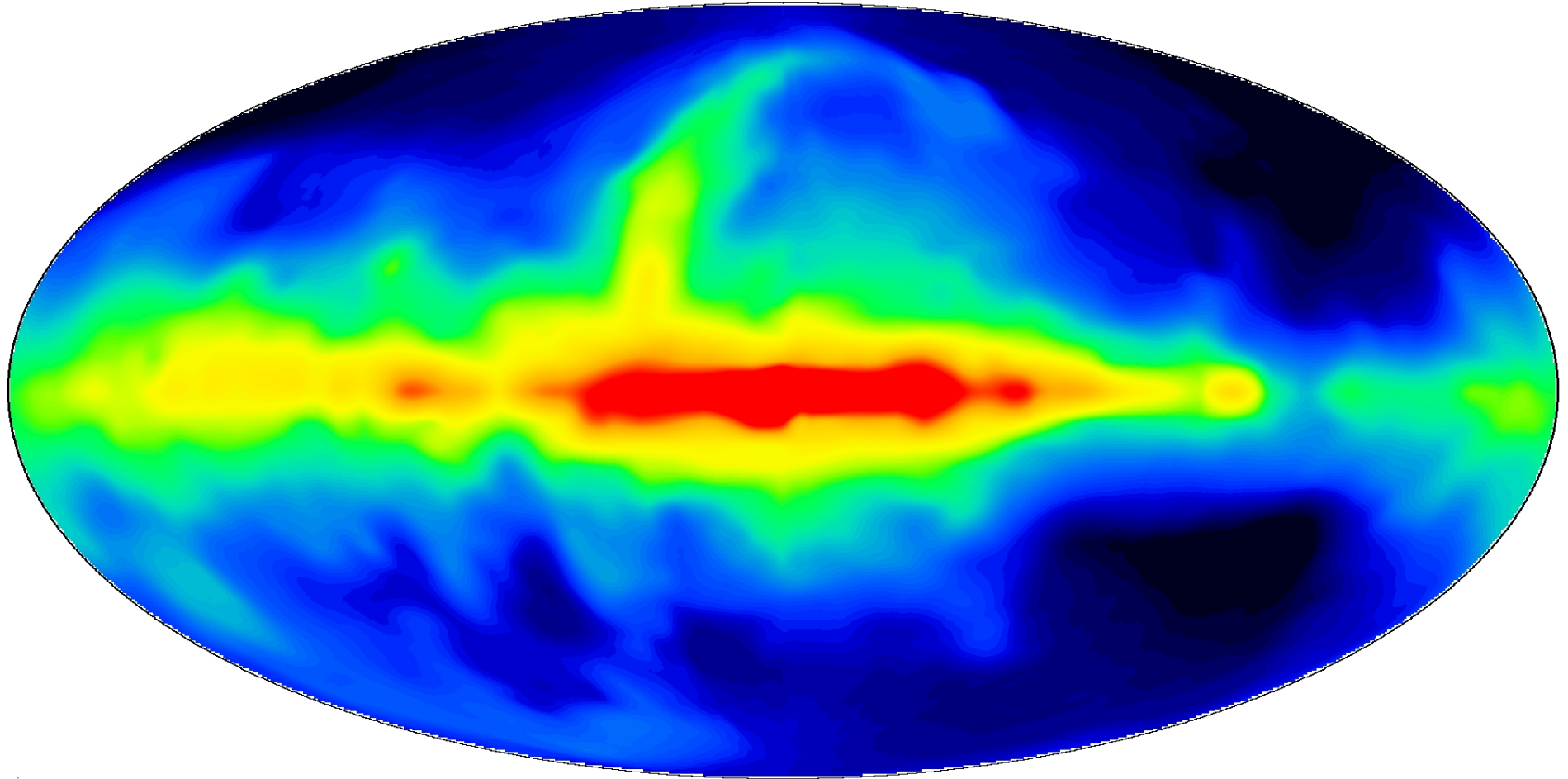




Pober et al (2013)

Synchrotron foreground at 150 MHz

150 MHz

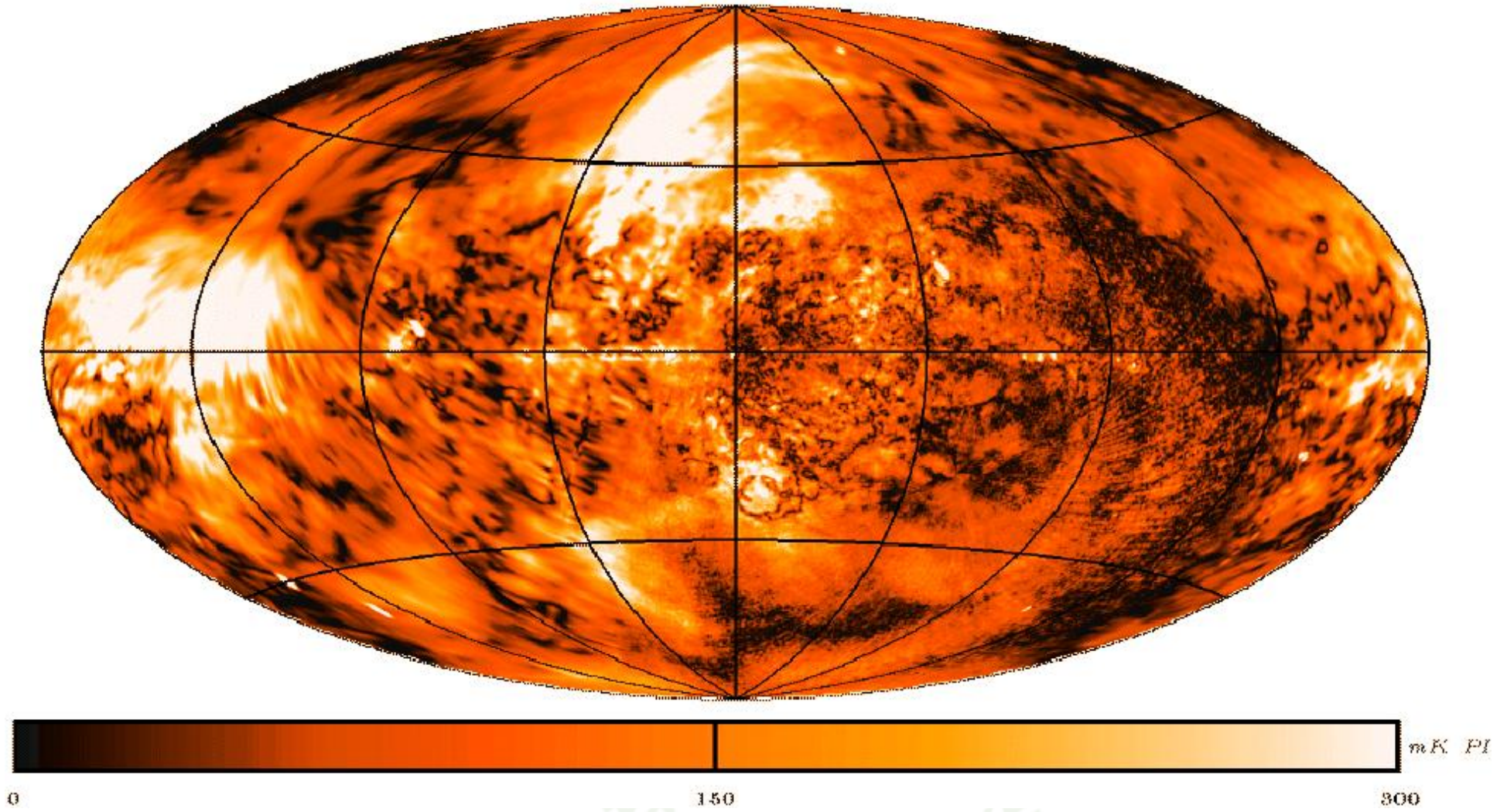


Landecker & Wielebinski (1970)

Parkes 64-m

Polarized synchrotron foreground at **1400** MHz

PI at 1.4 GHz (26m DRAO+30m Villa Elisa)



Polarized foregrounds: the beginning

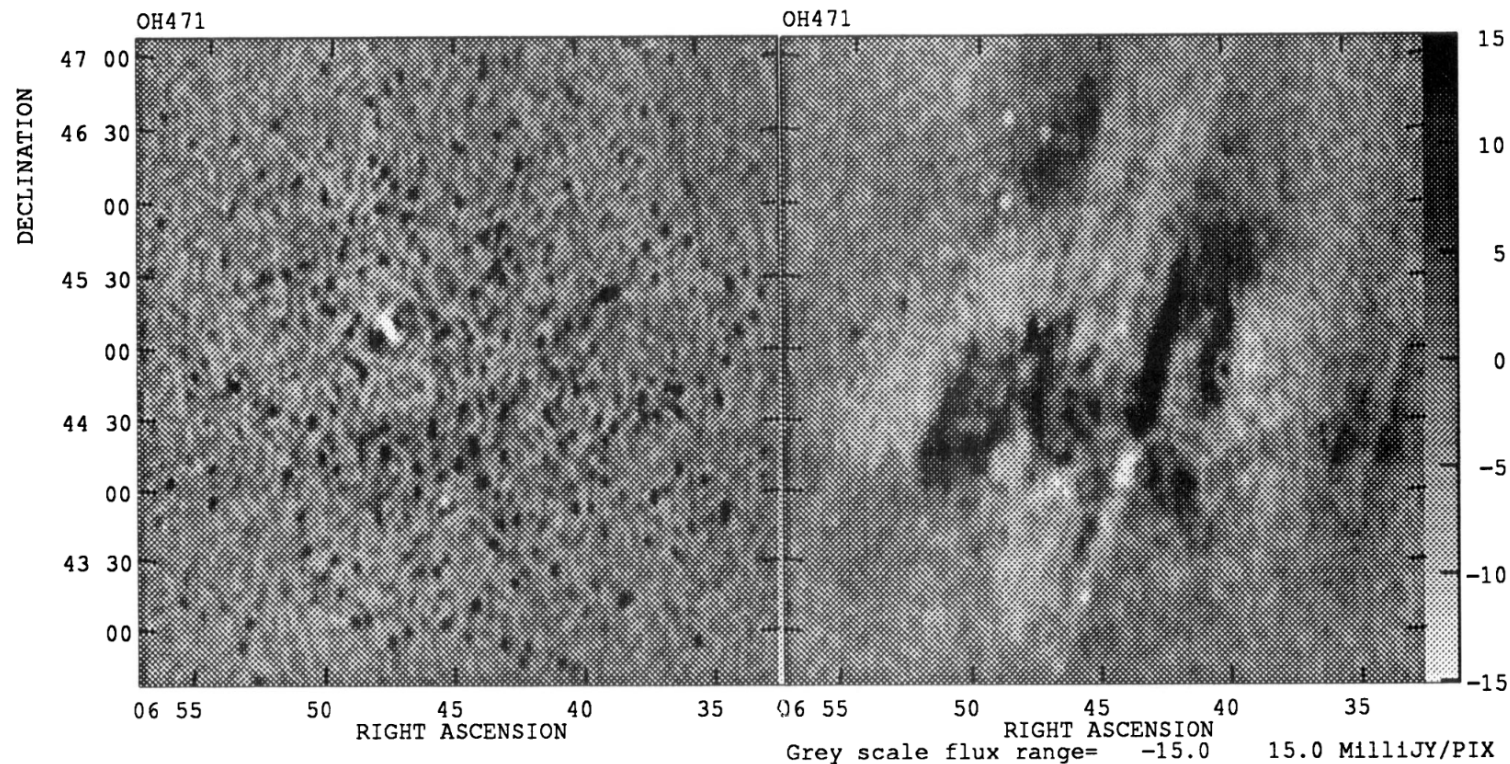
Small scale polarization structure in the diffuse galactic emission at 325 MHz

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Received August 22, 1991; accepted August 28, 1992



Content

Galactic foreground science:

Why?

To learn about the Galactic ecosystem

How?

Rotation measure synthesis/Faraday Tomography

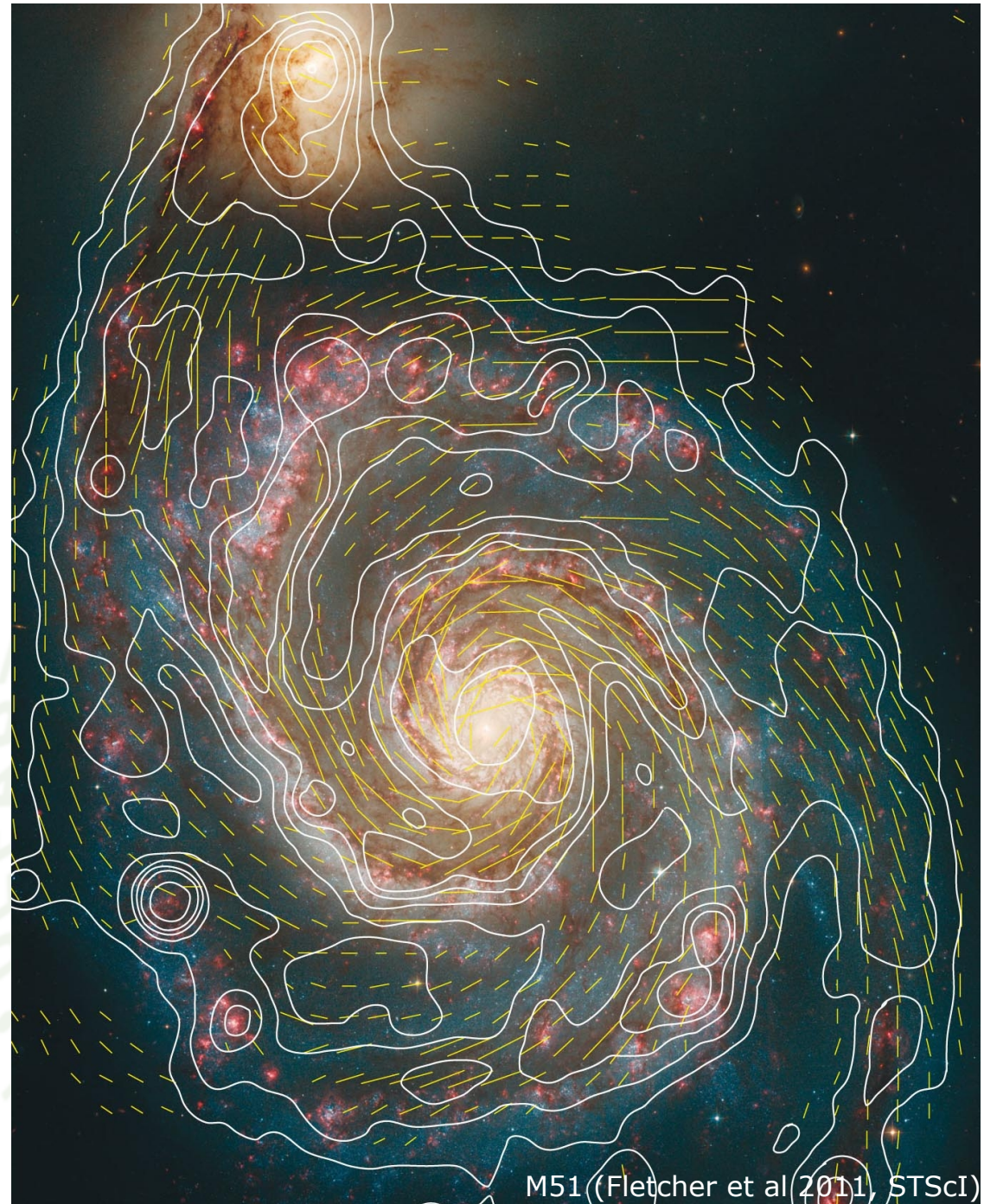
What?

What DO we learn about the Galactic ecosystem?

Magnetic fields are
pervasive in the
interstellar medium

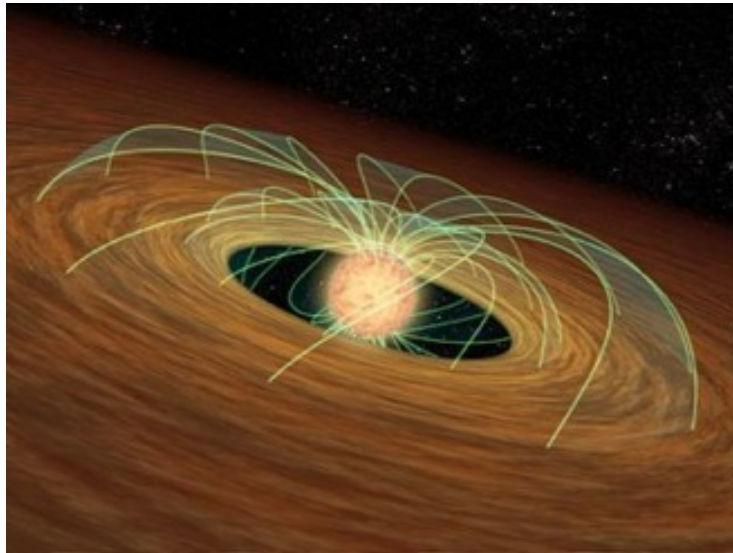
Strength \sim microGauss
 $\approx 10^{-6} B_{\text{Earth}}$

Scale \sim kiloparsec
 $\approx 10^{13} B_{\text{Earth}}$

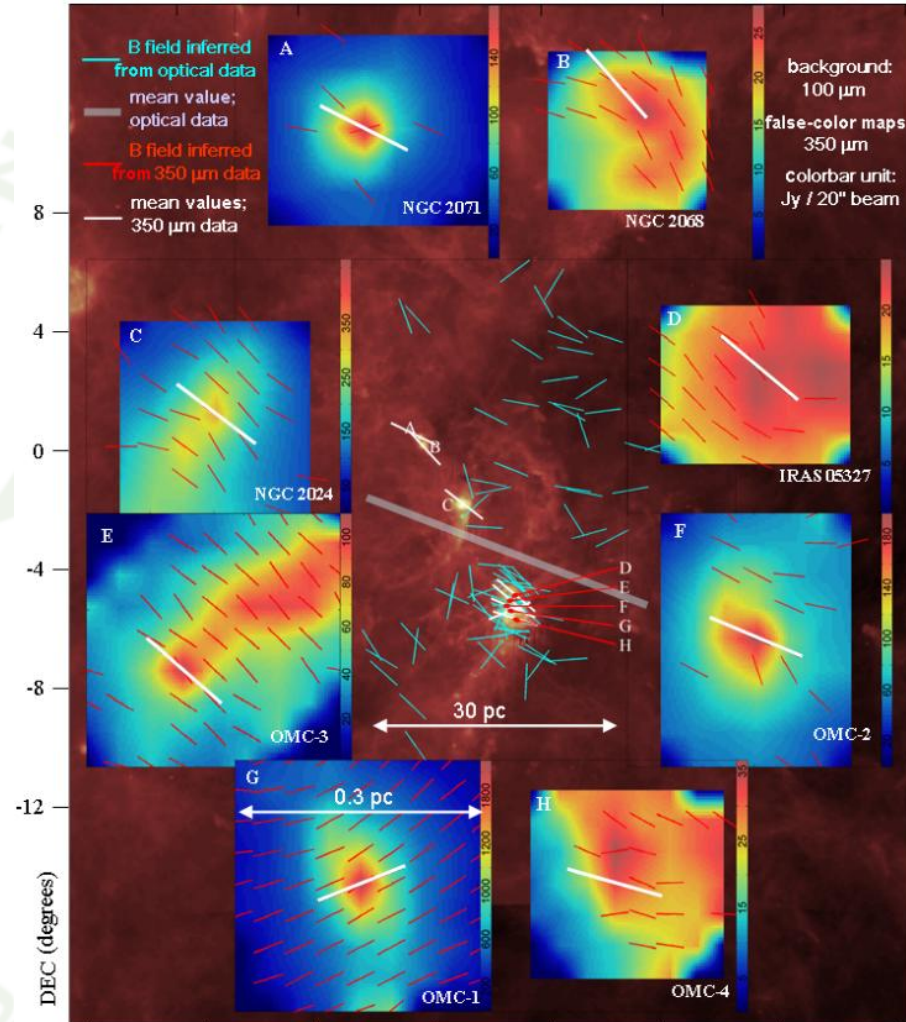


Galactic magnetic fields influence star formation

Magnetic braking stimulates star formation



Magnetic tension delays star formation

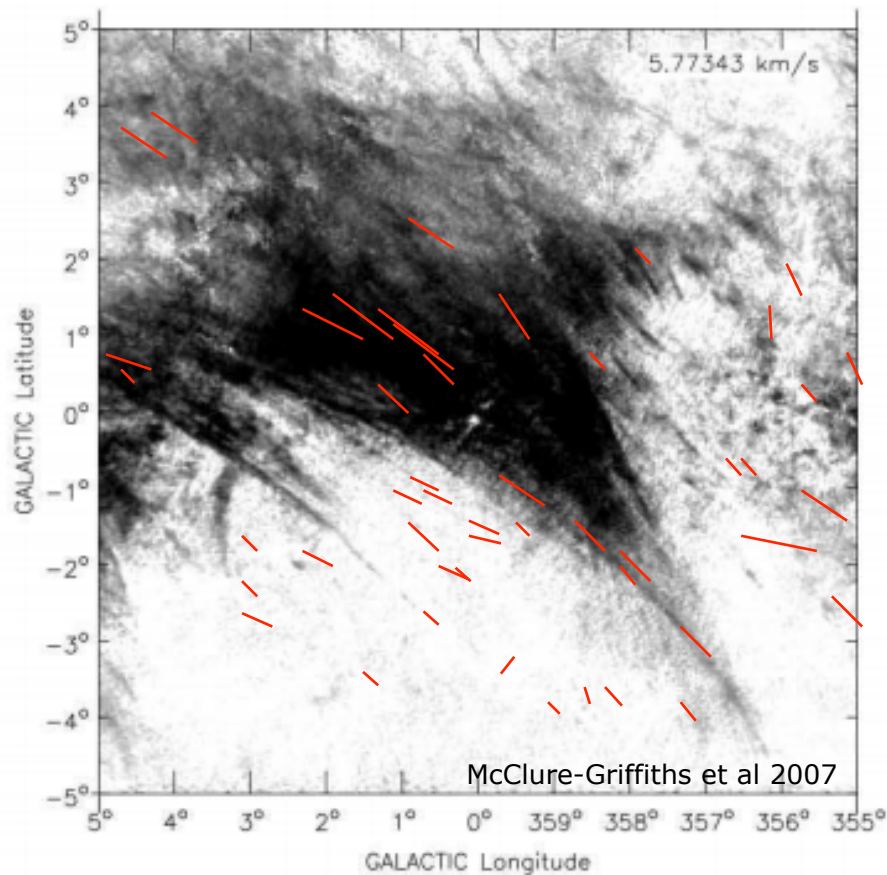


Galactic magnetic fields influence dynamics and evolution of gas clouds

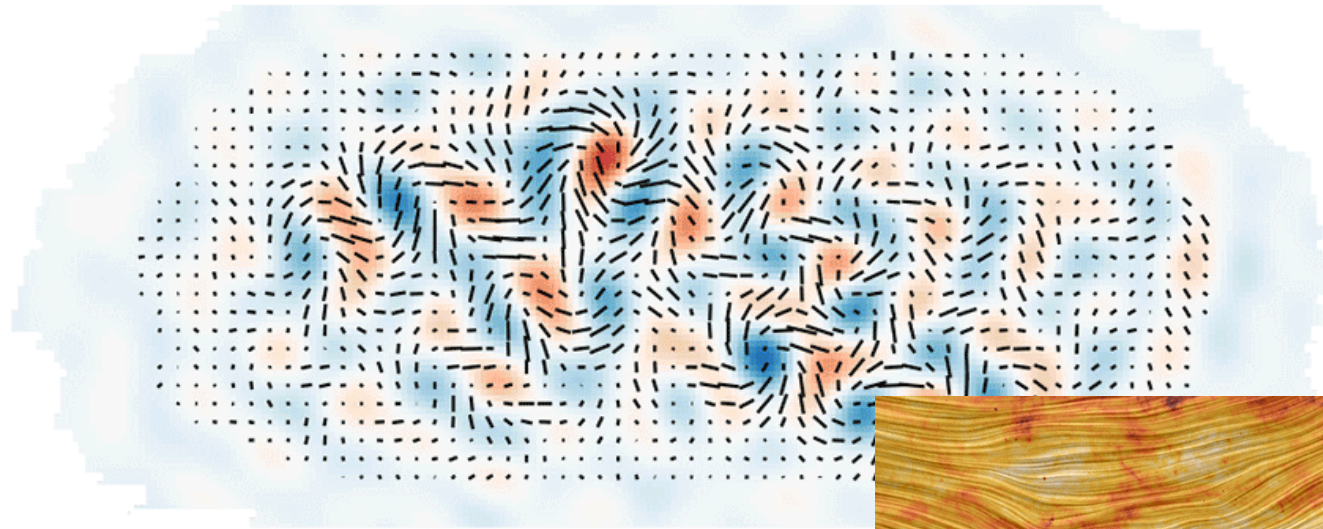
Filaments in clouds of atomic hydrogen...

... are shaped by magnetic fields

See talk by
Susan Clark

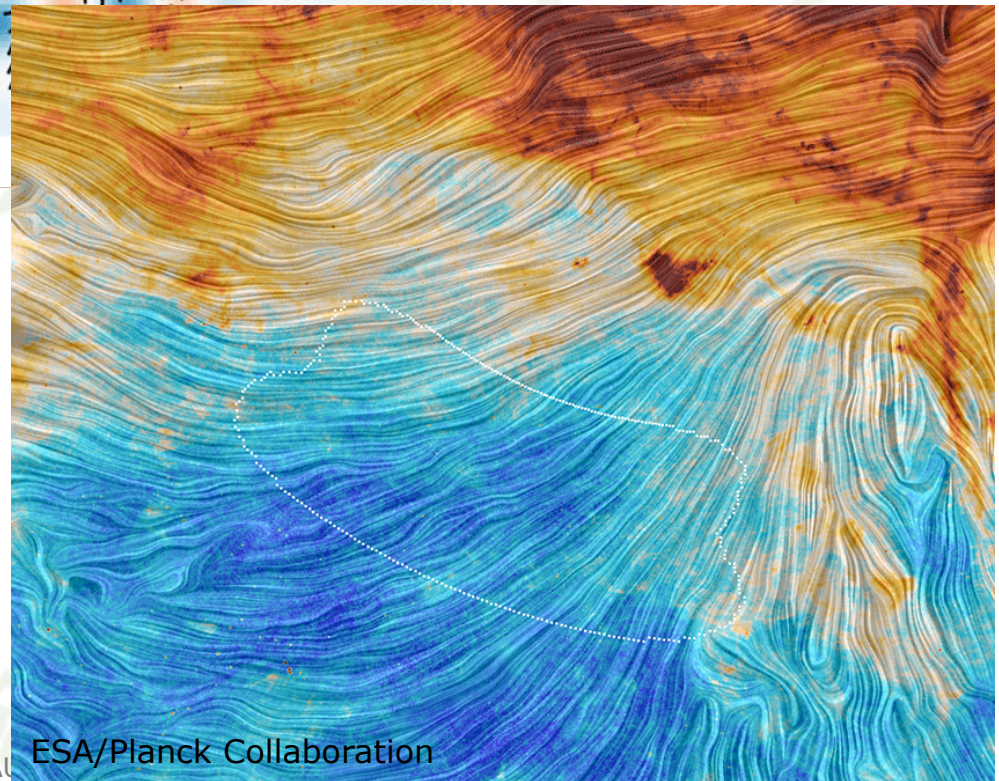


Galactic magnetic fields and dust provide foregrounds for CMB B-modes



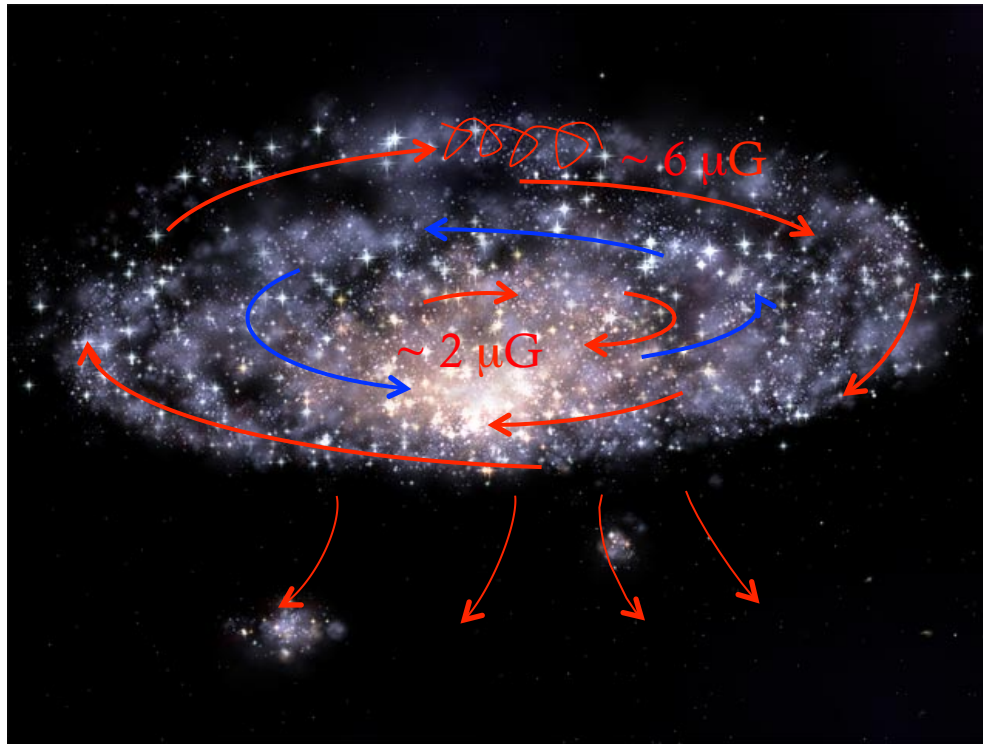
Ade et al (2014)

See talk by
François Boulanger



ESA/Planck Collaboration

The Magnetic Milky Way: what do we know?



Orientation of field:

- along spiral arms
- mostly in the Galactic plane
- one large reversal in direction
- a turbulent component
- component perpendicular to plane

Strength magnetic field:

- $B_{\text{reg}} \approx 2 \mu\text{G}$ at Solar radius
- $B_{\text{tot}} \approx 6 \mu\text{G}$ at Solar radius
- $B_{\text{tot}} \approx 10 \mu\text{G}$ towards inner Galaxy

See talk by
Charlotte Sobey

Faraday rotation

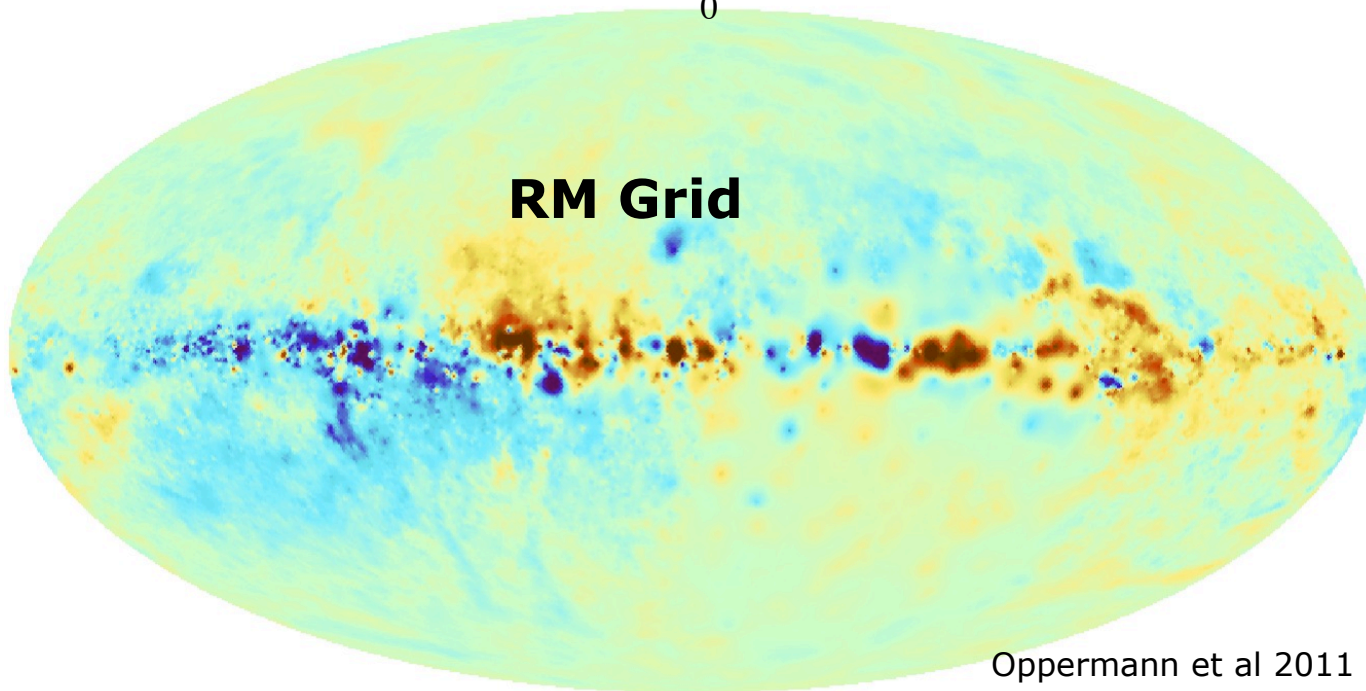
1 'Classical':



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

where **rotation measure**

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



Faraday rotation

1 'Classical':

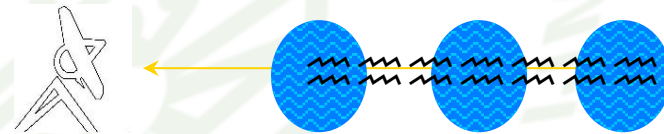


Polarization angle rotates with observing wavelength λ : $\theta \propto RM \lambda^2$

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

2 Rotation measure synthesis: (Burn 1966, Brentjens & de Bruyn 2005; Heald 2009)

Faraday depth $\phi \propto \int_0^l n_e \vec{B} \cdot d\vec{l}$

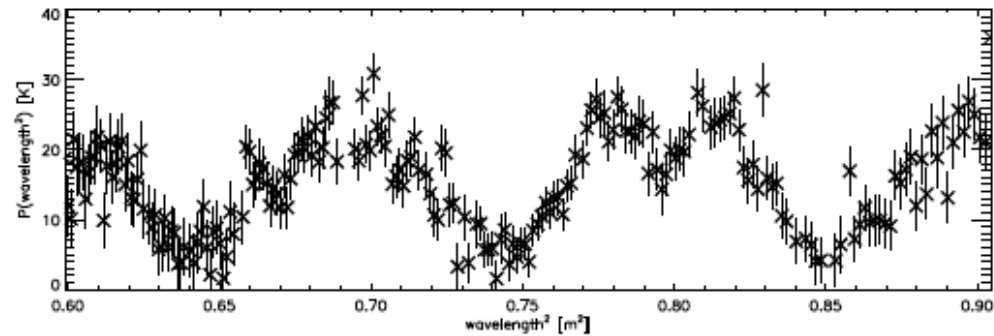


$$P_{obs}(\lambda^2) = W(\lambda^2) \int_{-\infty}^{\infty} F(\phi) e^{2i\phi\lambda^2} d\phi$$

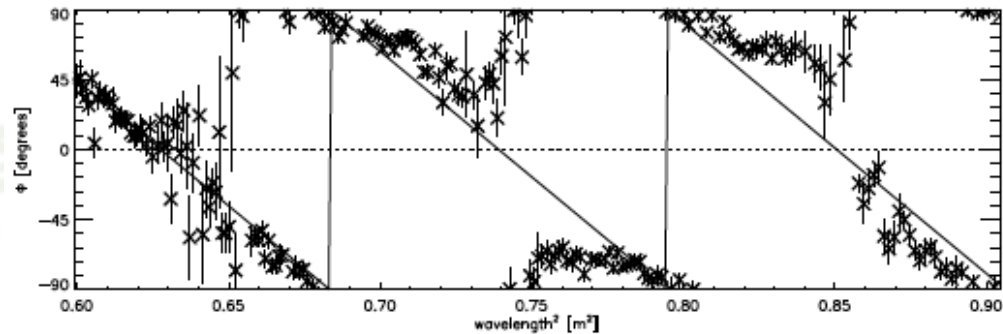
$$F_{obs}(\phi) = K \int_{-\infty}^{\infty} P_{obs}(\lambda^2) e^{-2i\phi\lambda^2} d\lambda^2 \quad K = \left(\int_{-\infty}^{\infty} W(\lambda^2) d\lambda^2 \right)^{-1}$$

Faraday rotation

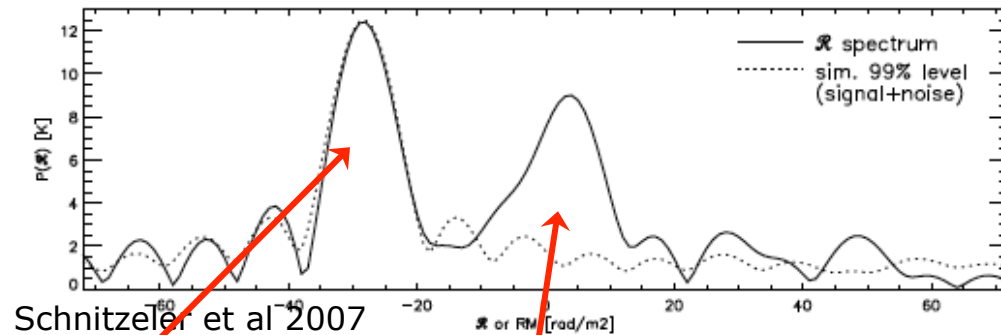
Linearly polarized intensity



Polarization angle



Faraday depth spectrum

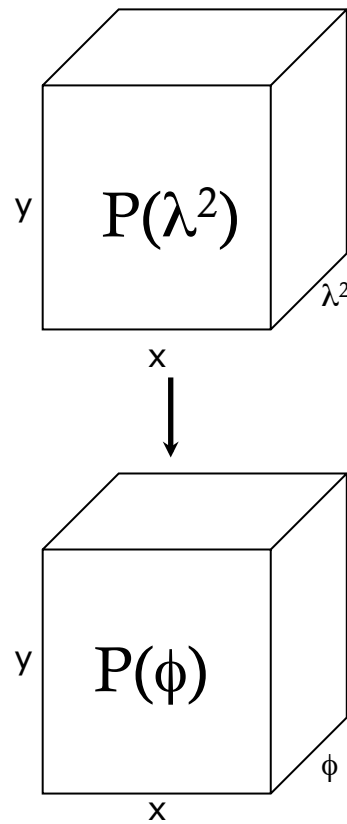


extragalactic point source

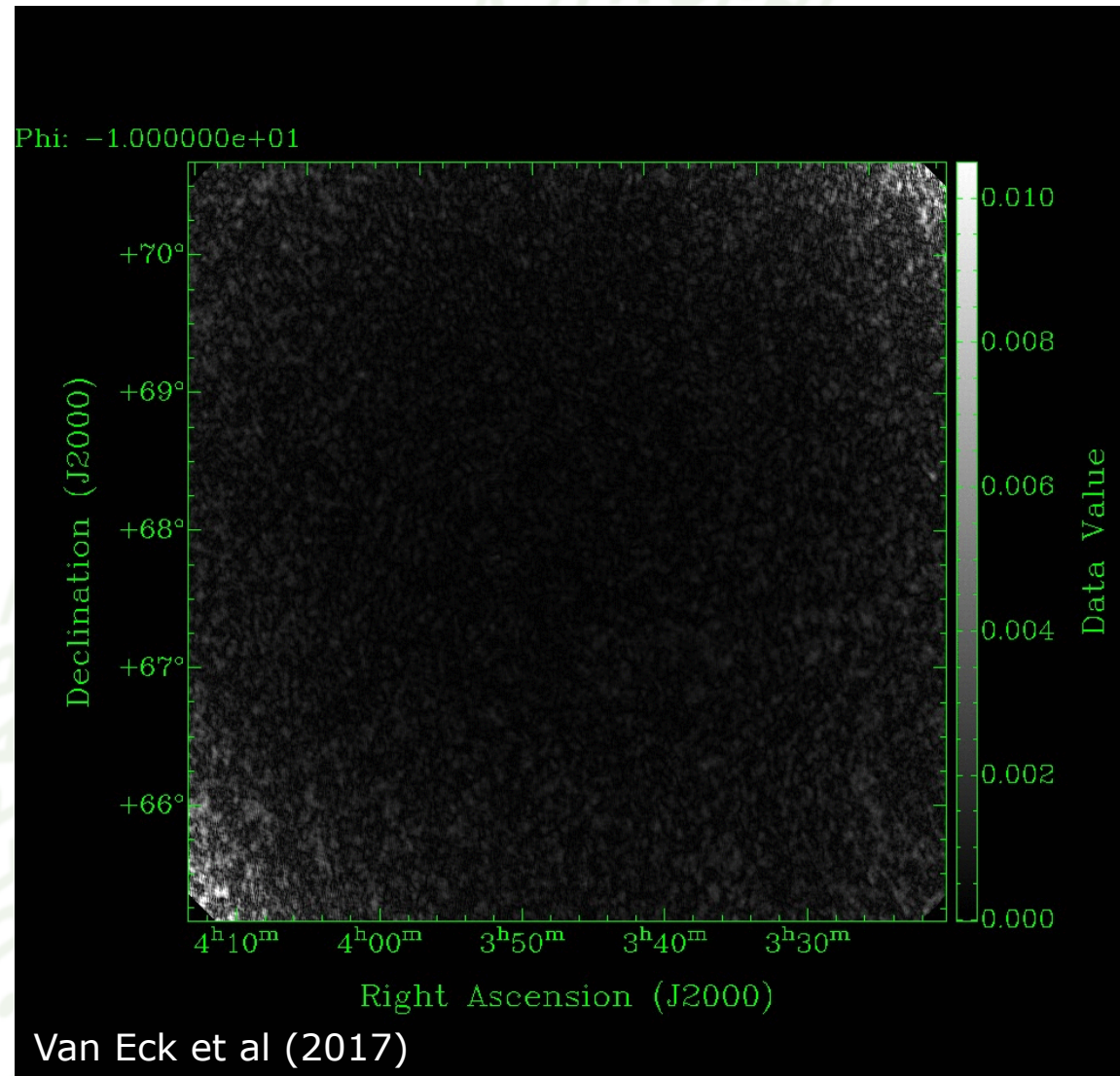
Galactic interstellar medium

... or the other way around!

Example Rotation measure synthesis:



Faraday depth
 $\phi = 0.81 \int n_e \mathbf{B} \cdot d\mathbf{l}$



RM synthesis at low frequencies



LOFAR

WSRT

MWA

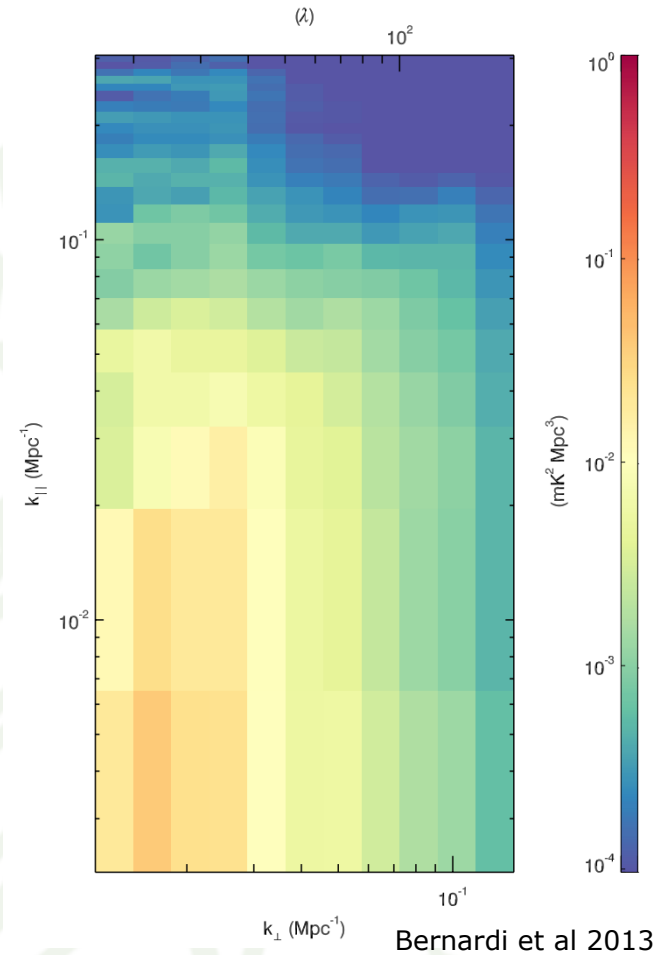
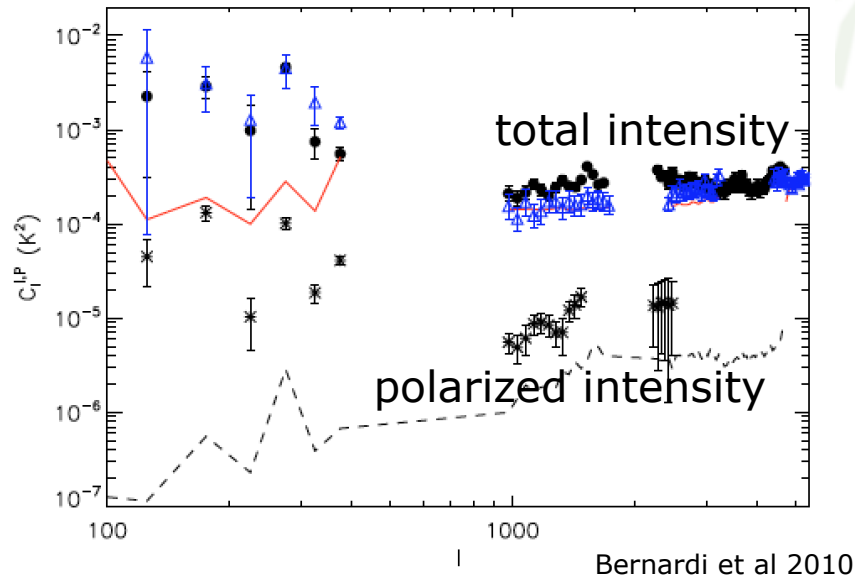
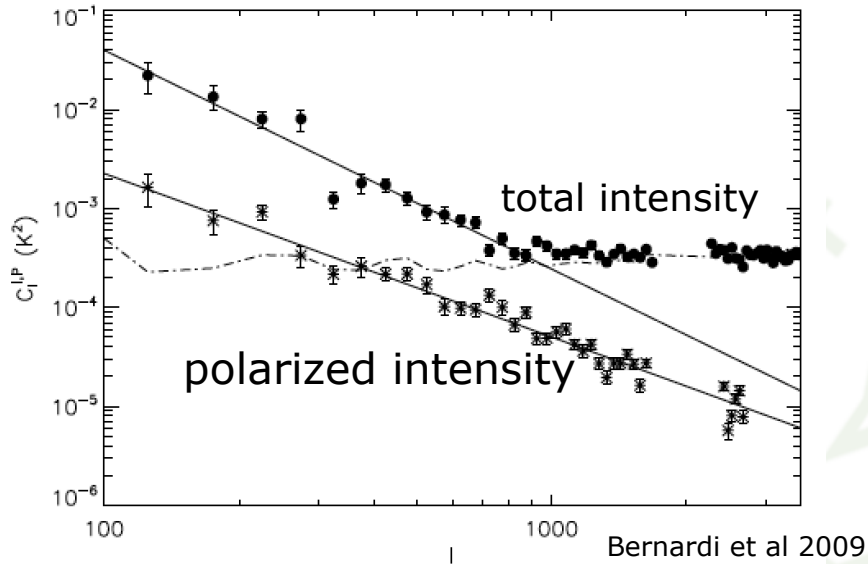


low frequency = excellent Faraday depth resolution



"missing short spacings" in wavelength: no Faraday thick structures

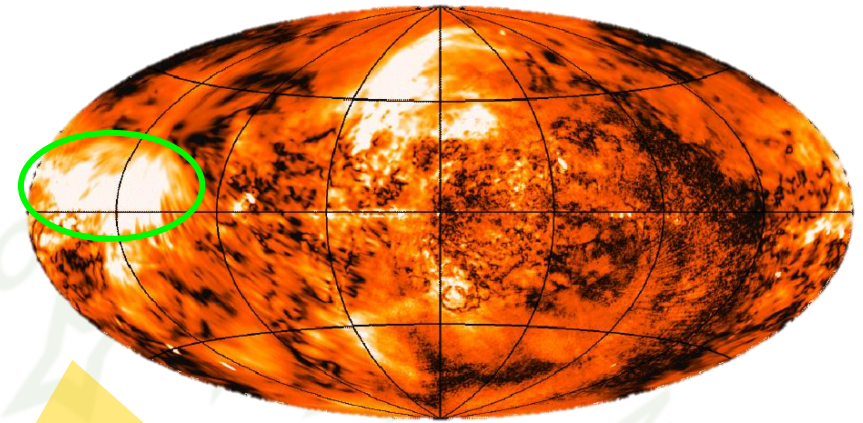
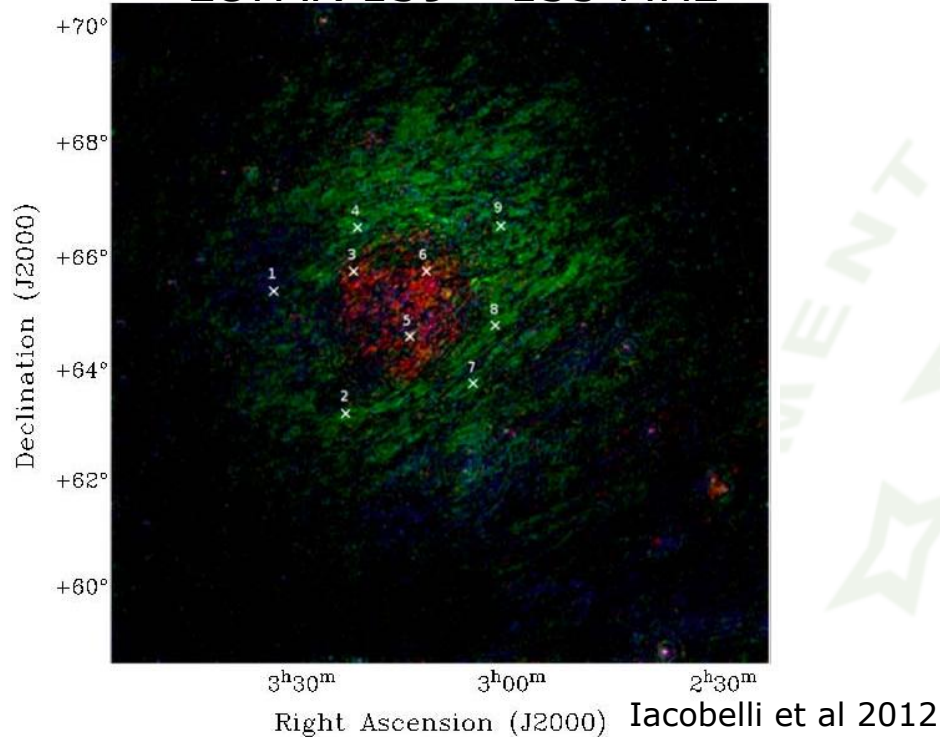
Galactic foregrounds for EoR



See talk by
Samir Choudhuri

Galactic science

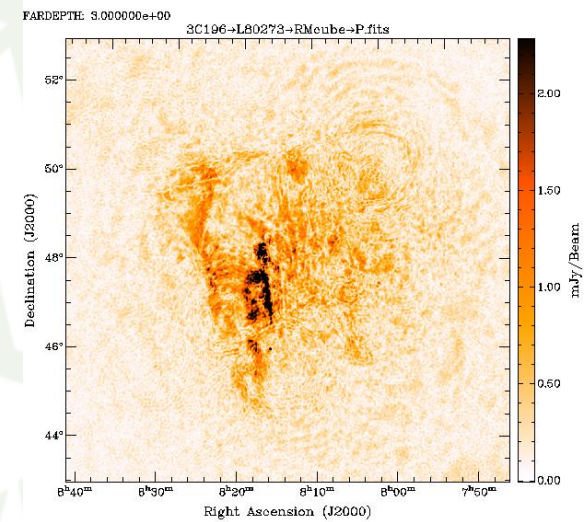
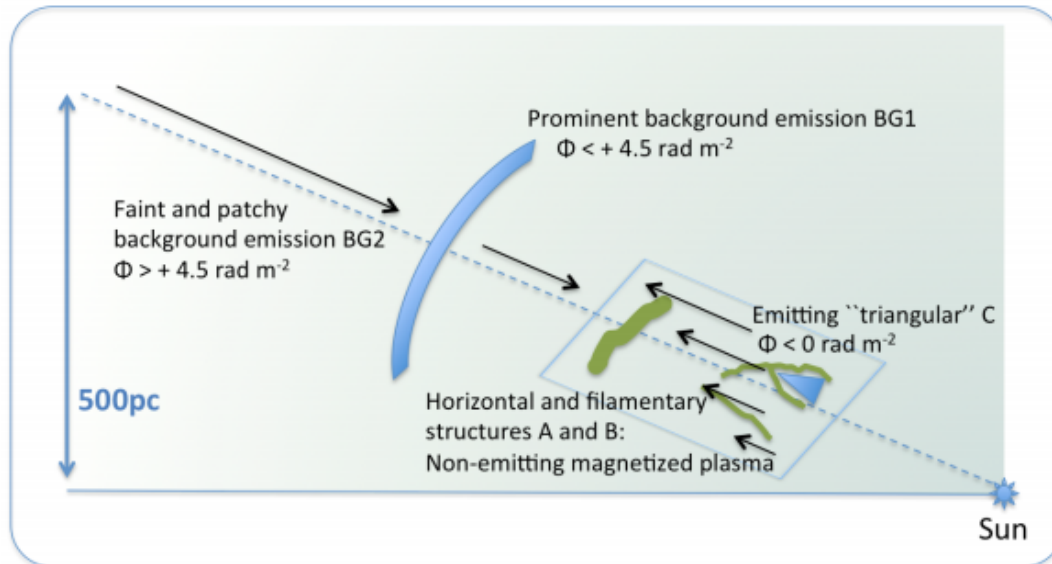
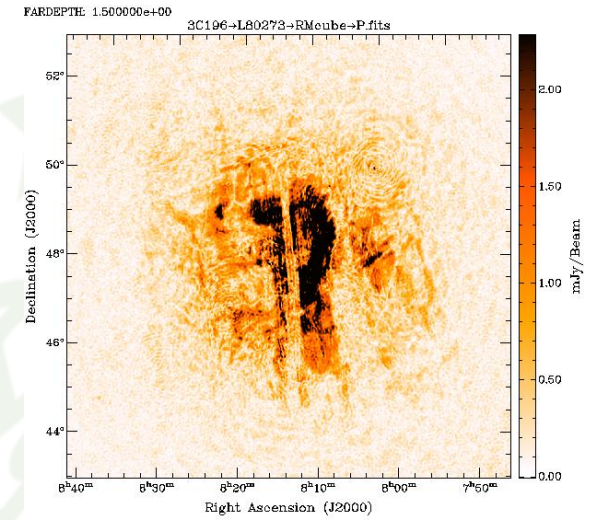
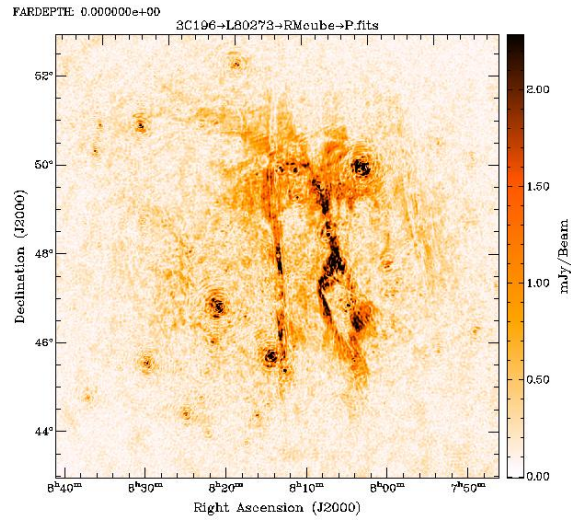
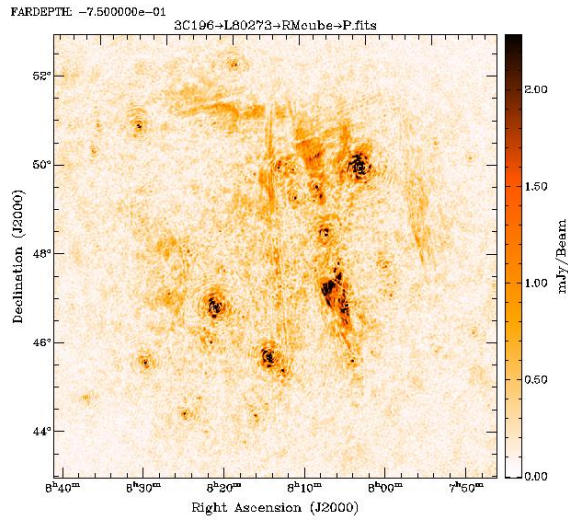
LOFAR 139 – 155 MHz



Proposed model:

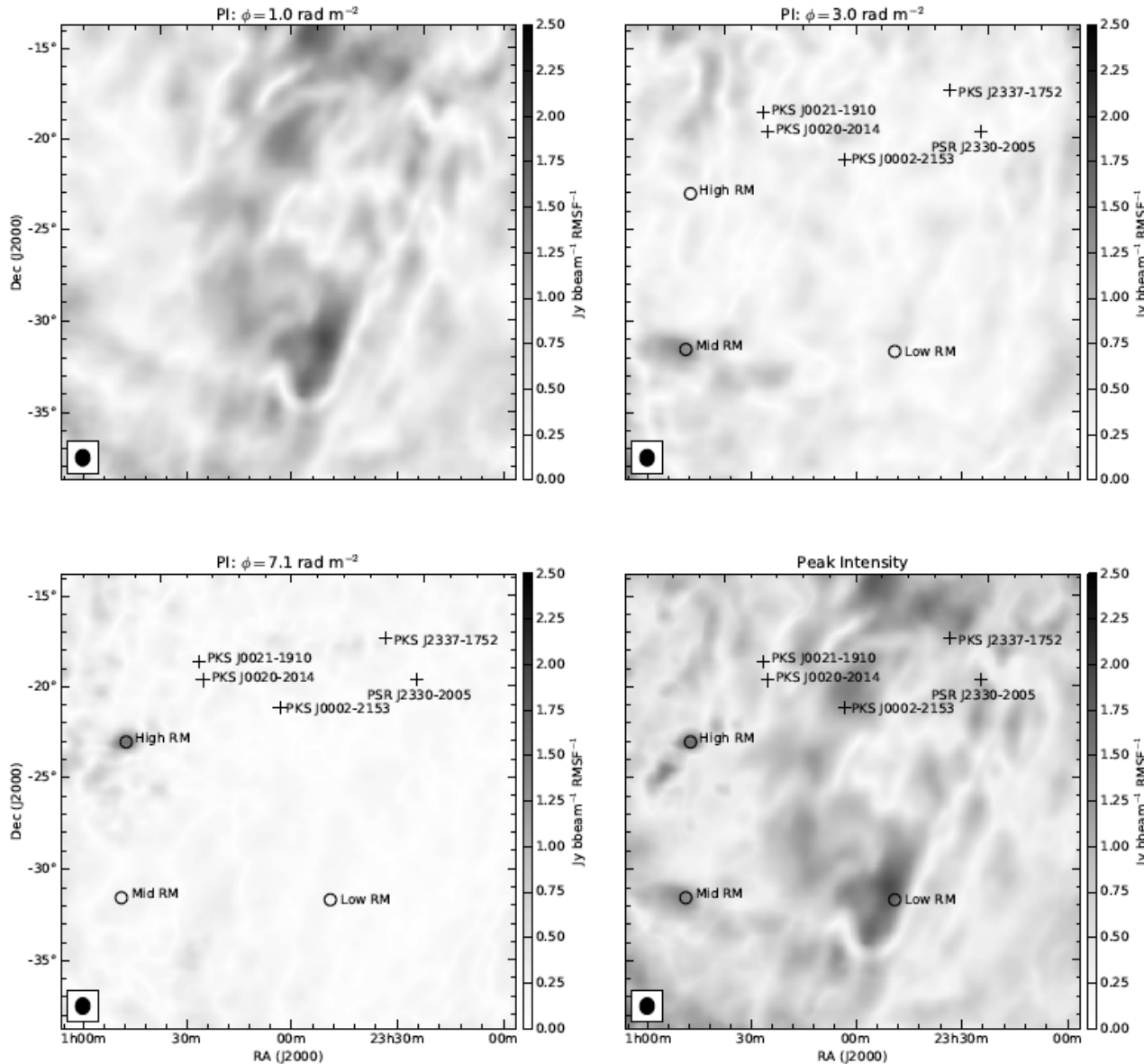
- foreground component: Local Bubble wall
- circular feature: HII region expanding in low-density plasma
- discrete, small-scale, synchrotron emitting structures

Galactic science in the LOFAR 3C196 field



Jelic et al 2015

Galactic foregrounds with MWA



Structure mostly intrinsic emission, not a Faraday screen.

Dist \sim 50-100 pc

Lenc et al (2016)

How to interpret these structures?

Challenges:

- No direct distance information: order in distance of structures is unclear
- Observational bias: e.g. insensitivity to Faraday-thickness, depolarization of distant structures

Solutions/first tries:

1. Understand biases through simulations
2. Find associations with other tracers
3. Get global picture: connect individual fields
4. Broader frequency coverage = more sensitivity

How to interpret these structures?

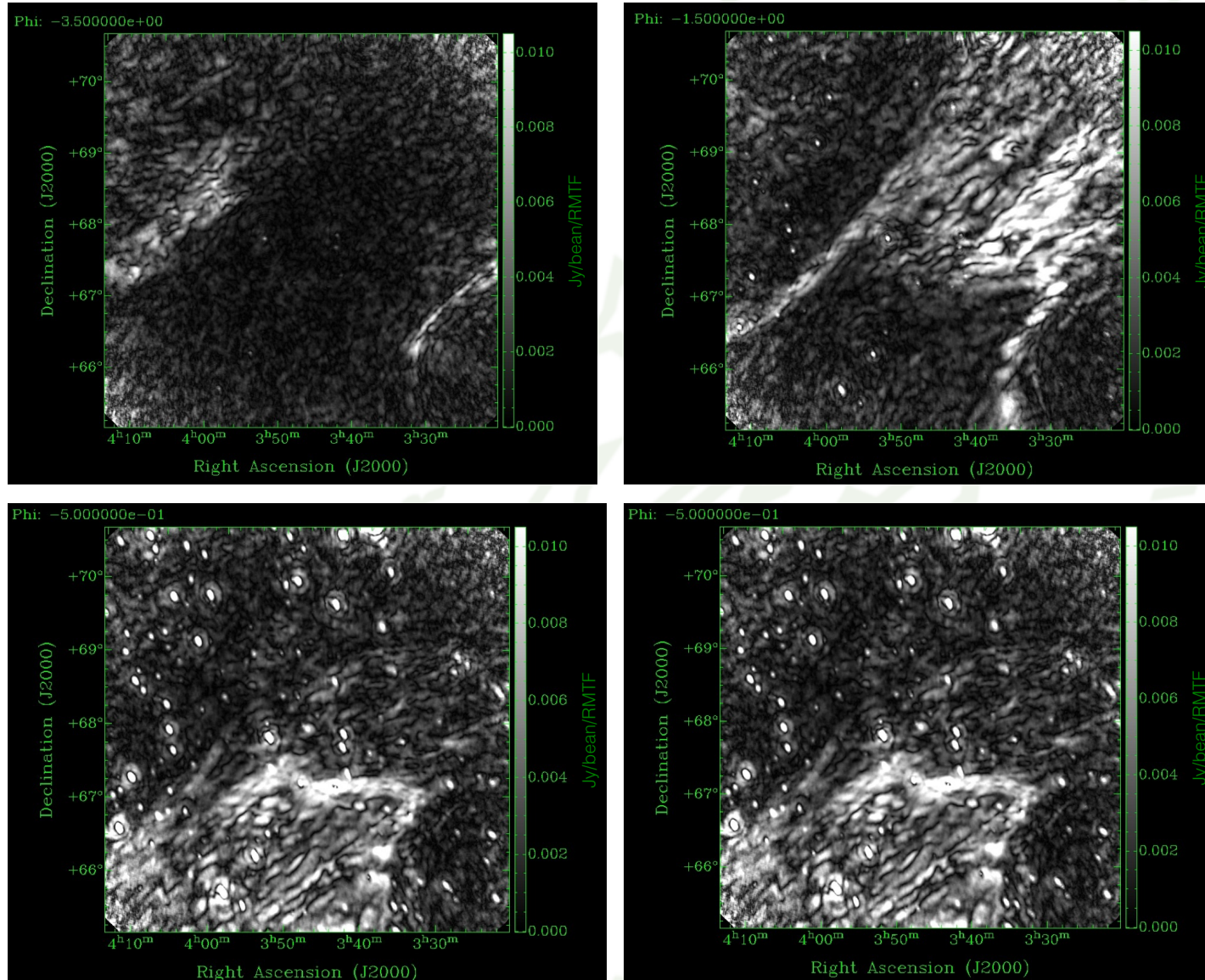
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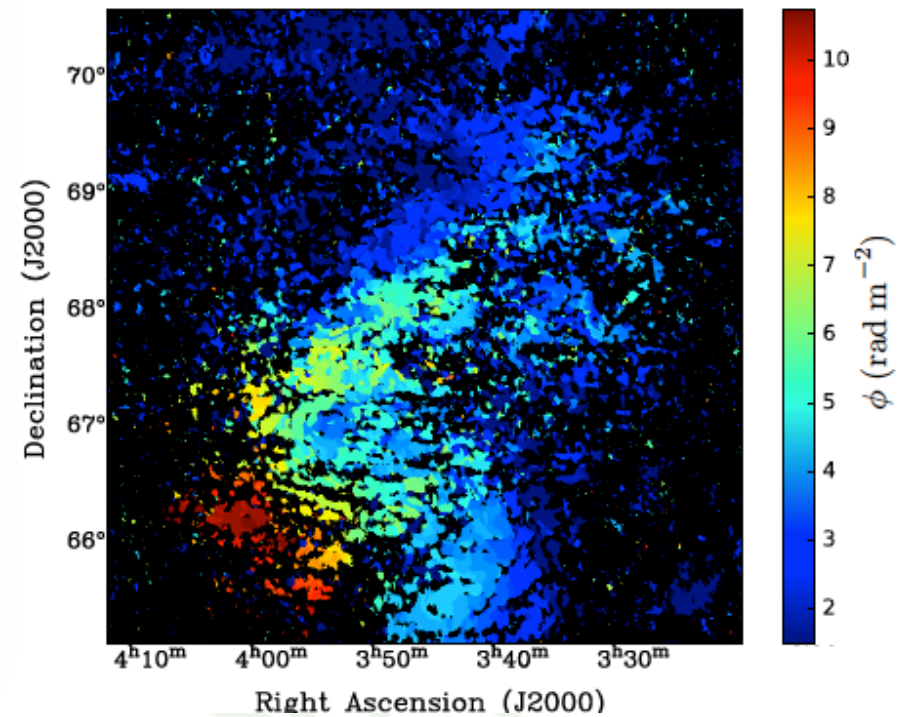
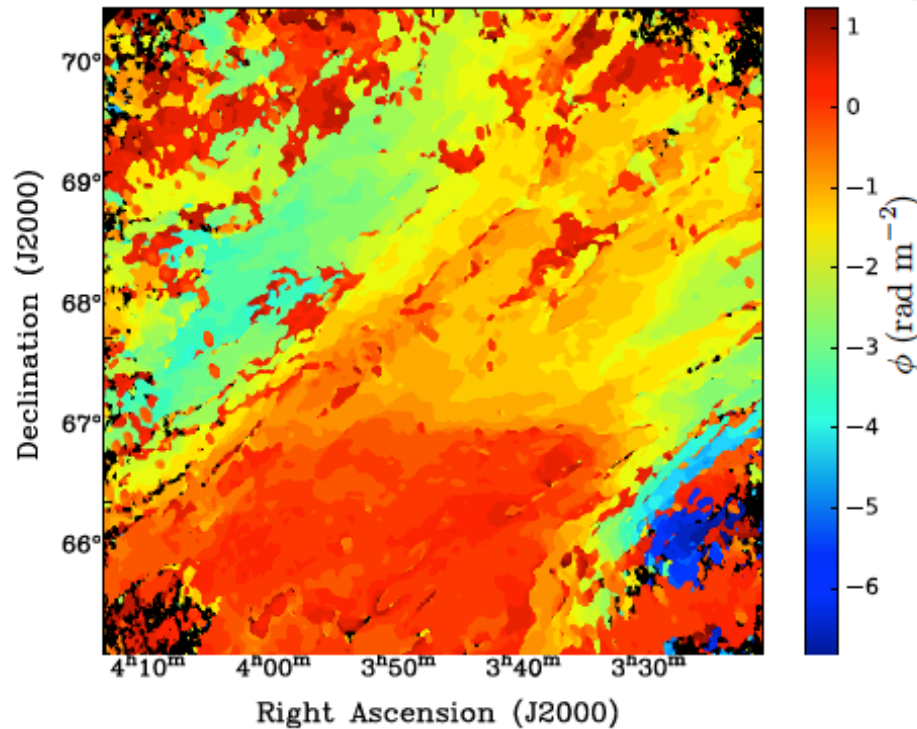
Solutions/first tries:

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2. Find associations with other tracers: synchrotron emission components \leftrightarrow neutral clouds

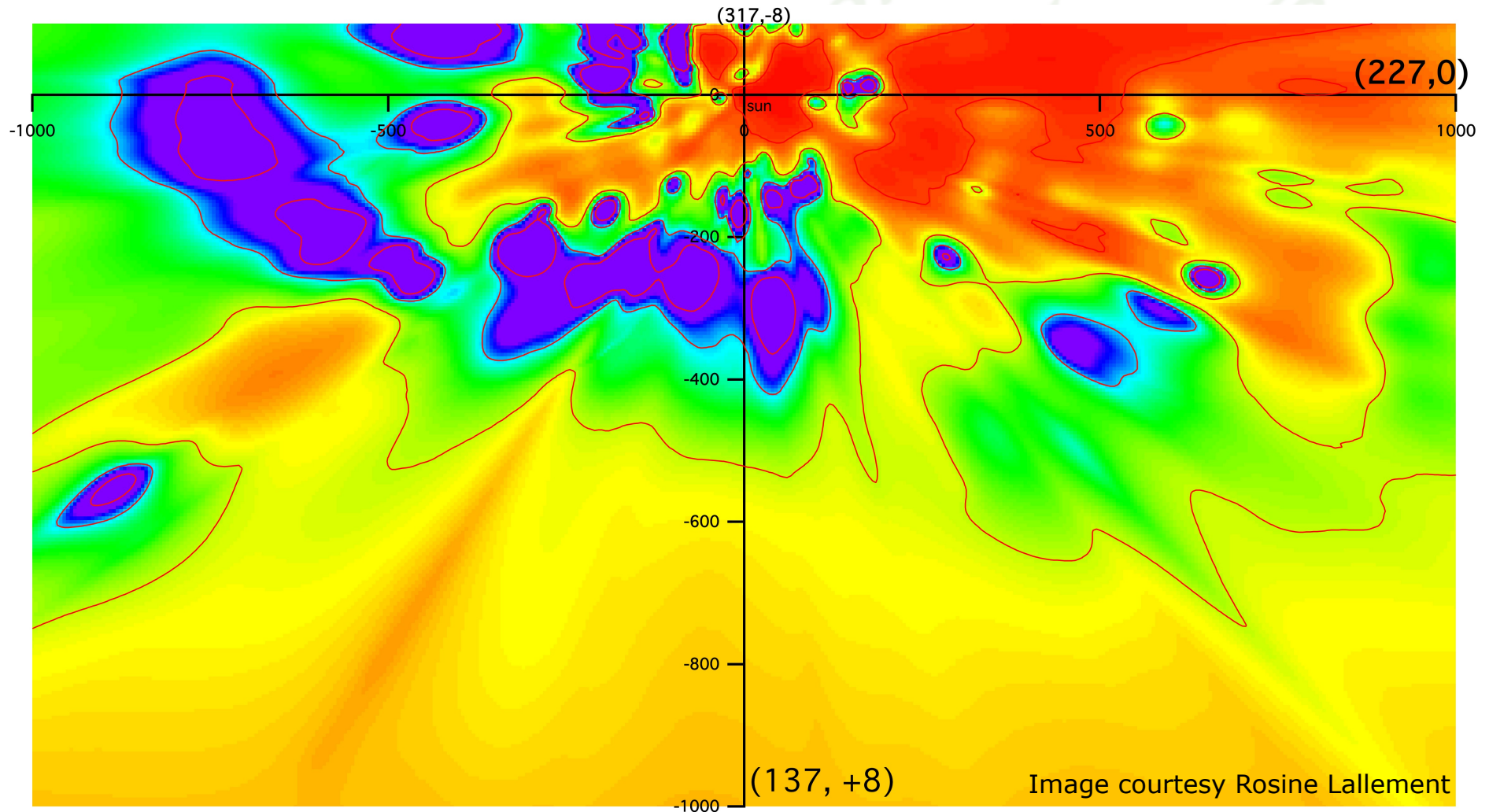


2. Find associations with other tracers: synchrotron emission components \leftrightarrow neutral clouds



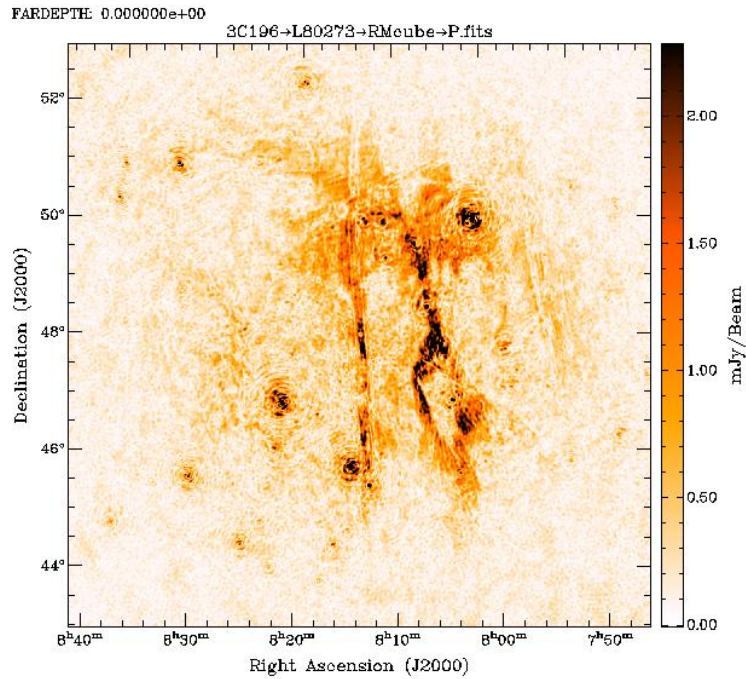
Van Eck et al, 2017

2. Find associations with other tracers: synchrotron emission components \leftrightarrow neutral clouds

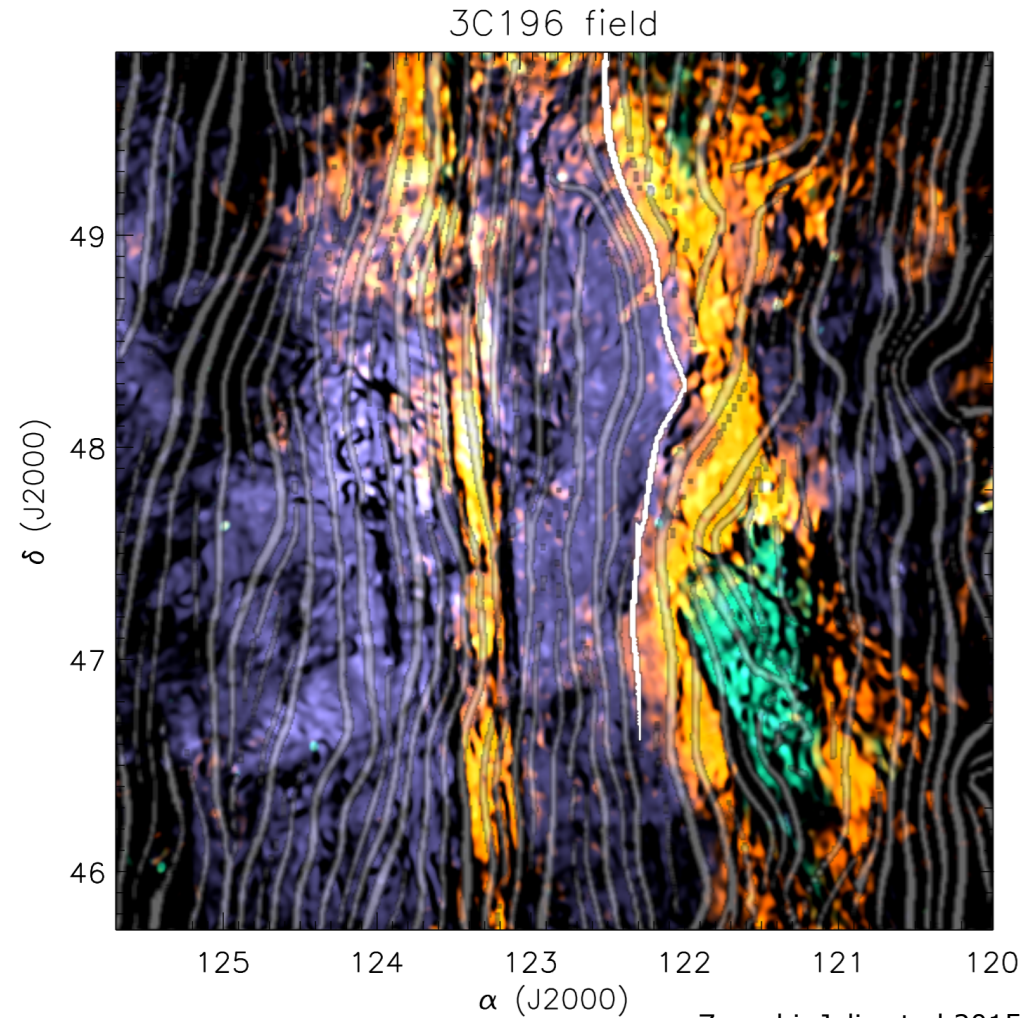


Emitting components correspond to neutral clouds

2. Find associations with other tracers: Faraday depth \leftrightarrow Planck polarization

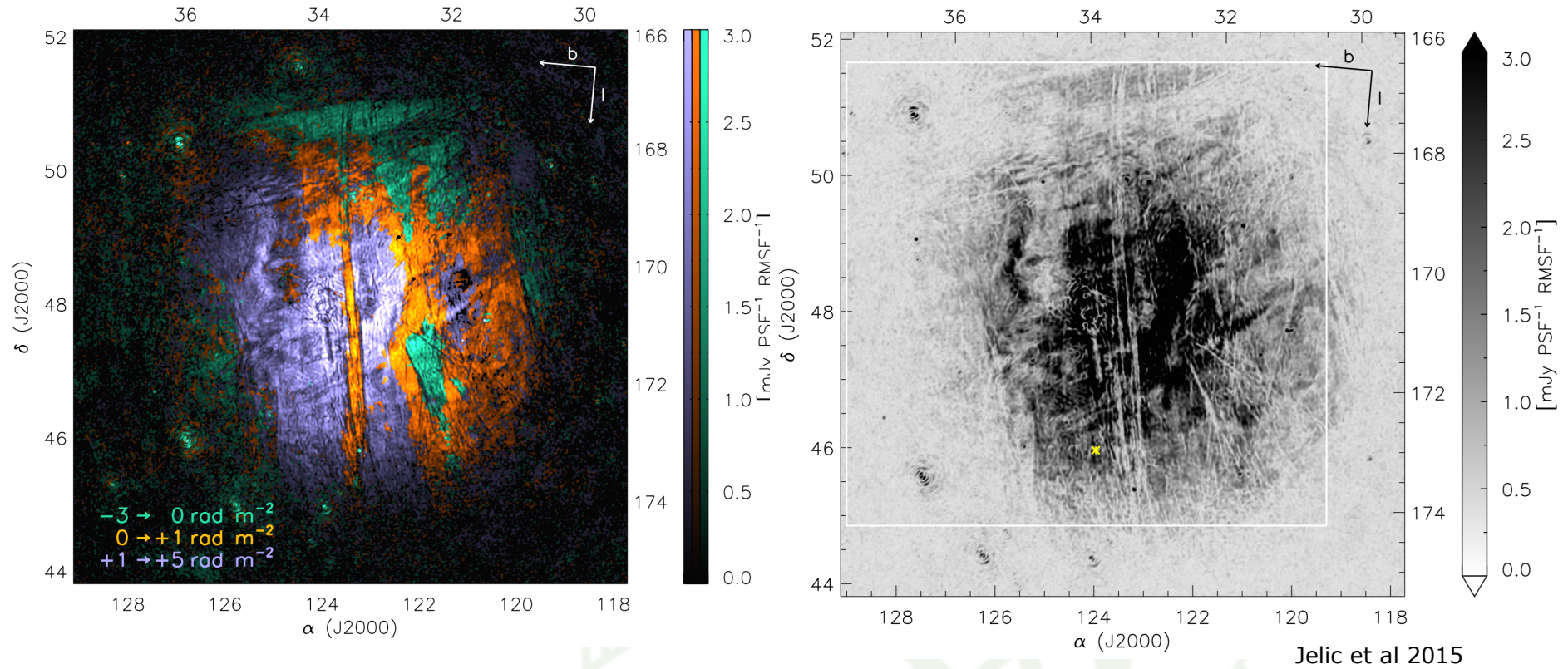


See talk by
Marc-Antoine
Miville-Deschênes

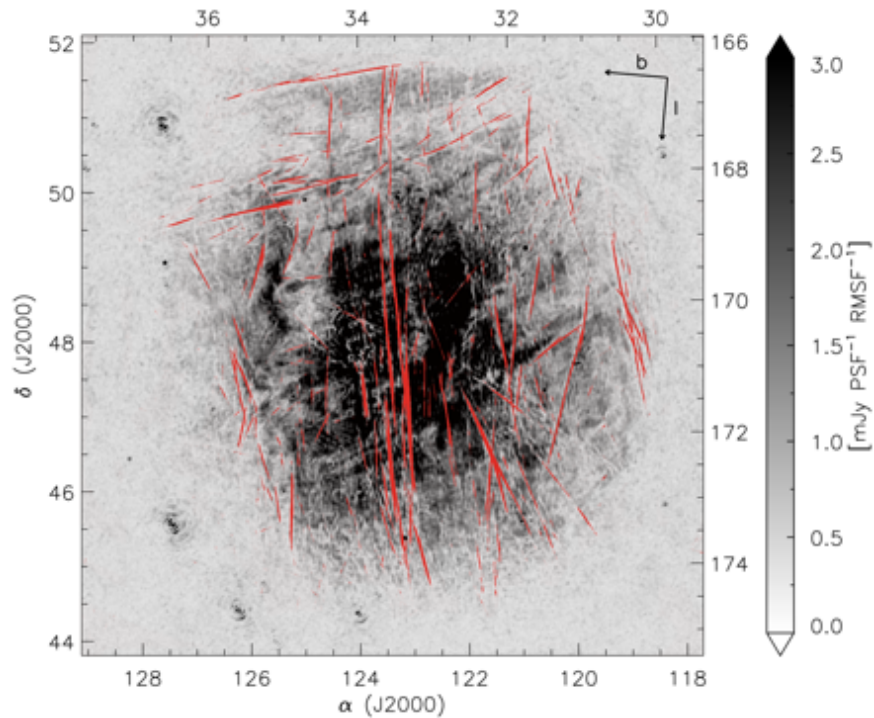


Zaroubi, Jelic et al 2015

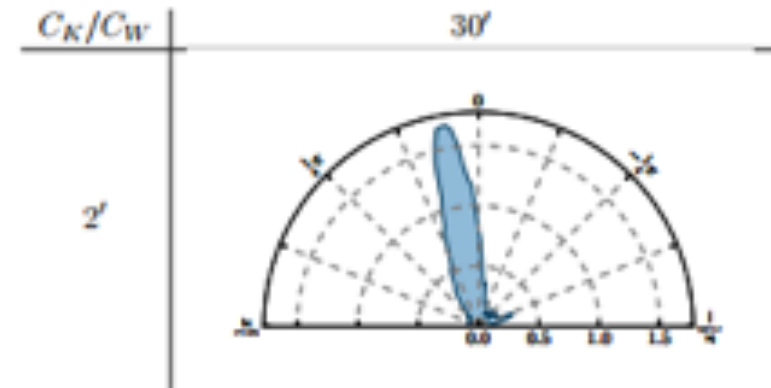
2. Find associations with other tracers: "depolarization canals"?



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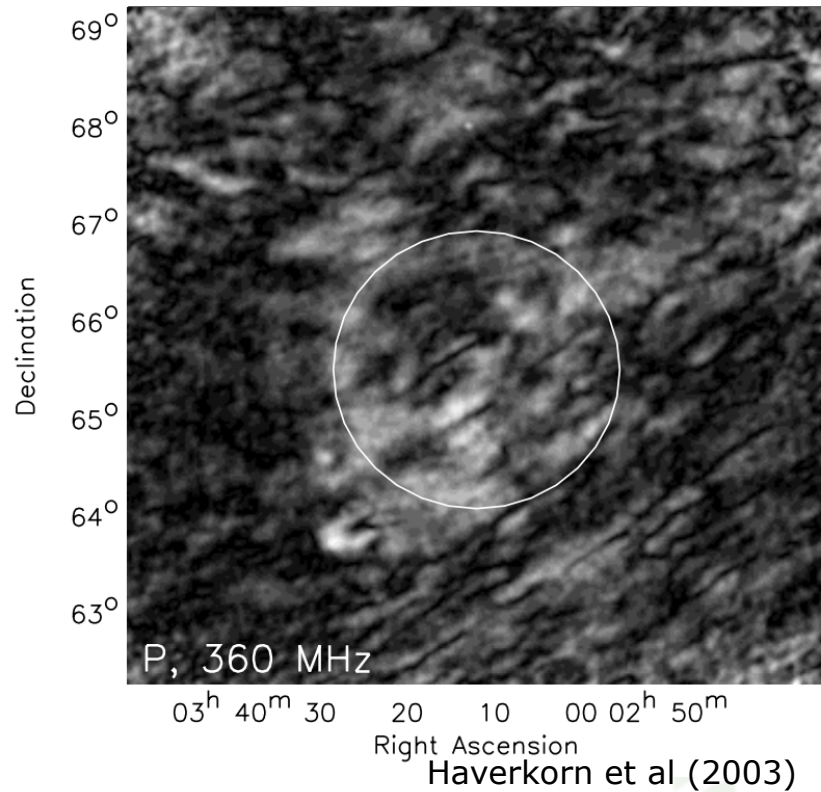
Rolling Hough Transform (Clark et al. 2013)



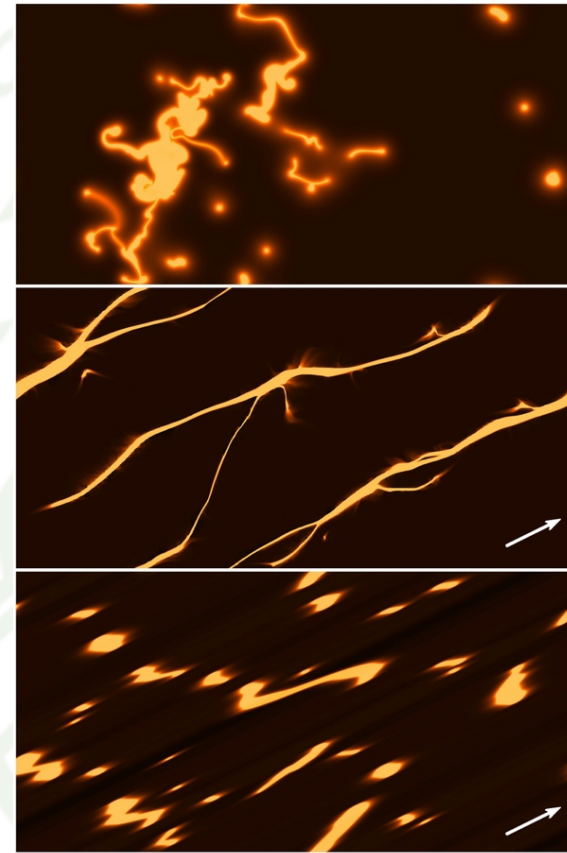
David Klindžić, Dora Prelogović (PMF, Croatia)

orientation seems to be the same as orientation of **HI fibres** (EBHIS data) and magnetic field component as probed by **Planck** in the same field

2. Find associations with other tracers: "depolarization canals"?



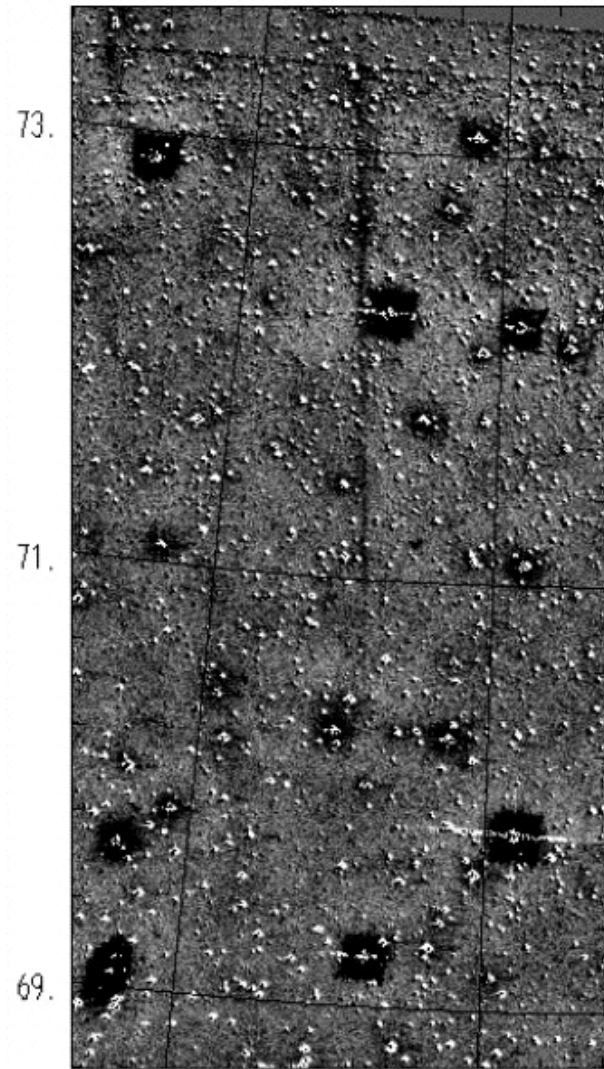
WSRT: straight depolarization
canals follow Galactic plane



Choi & Stone (2012)

Simulations: thermal instability
can heat/ionize along field lines

2. Find associations with other tracers: "depolarization canals"?



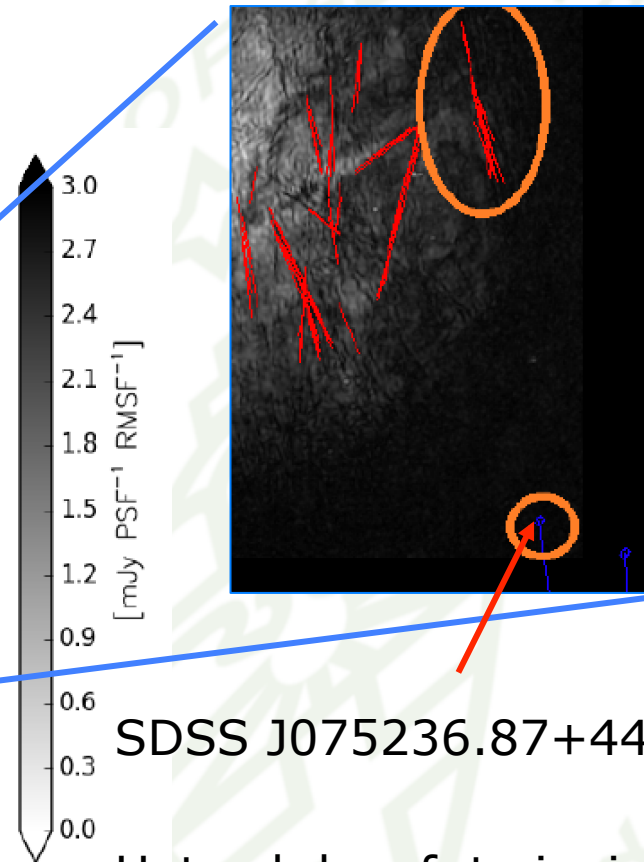
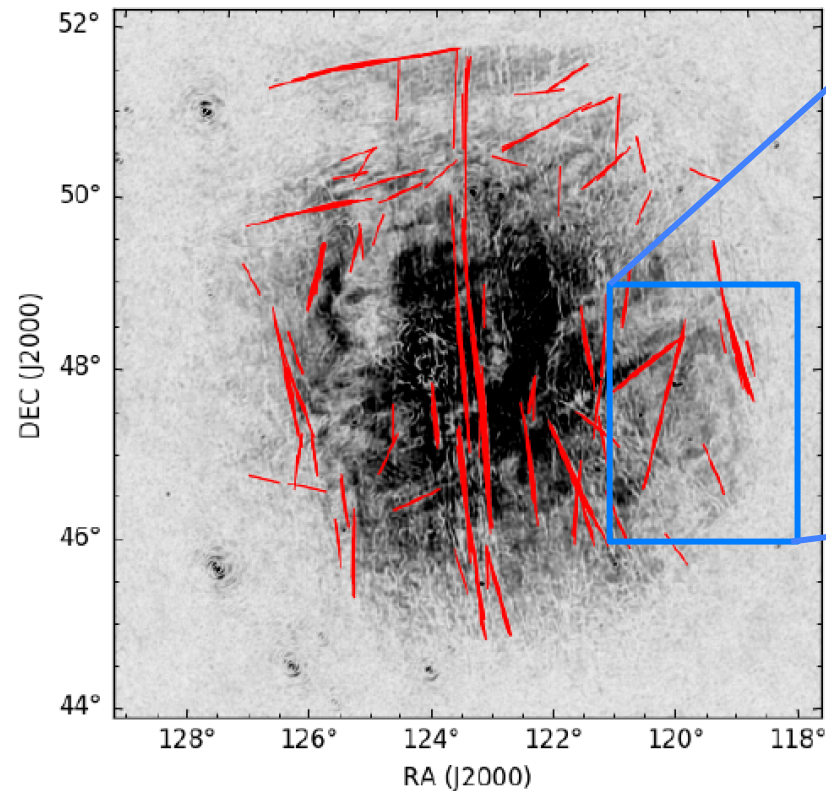
Mysterious, narrow ionized H α filament

Could be an ionized trail left by photoionization from a star or compact object

148.

144. McCullough & Benjamin (2001)

2. Find associations with other tracers: "depolarization canals"?

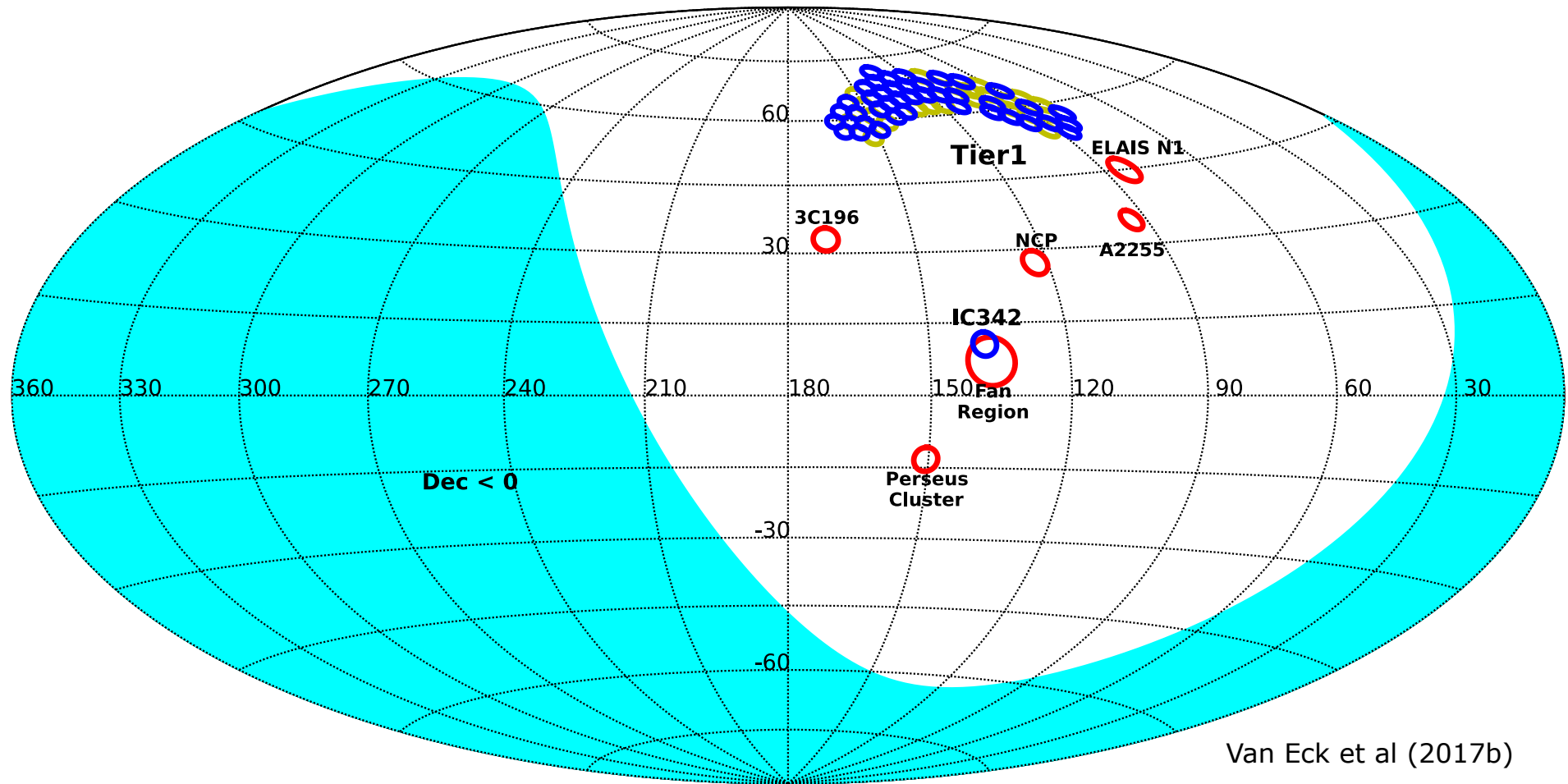


SDSS J075236.87+441642.4

Hot subdwarf to ionize this trail?

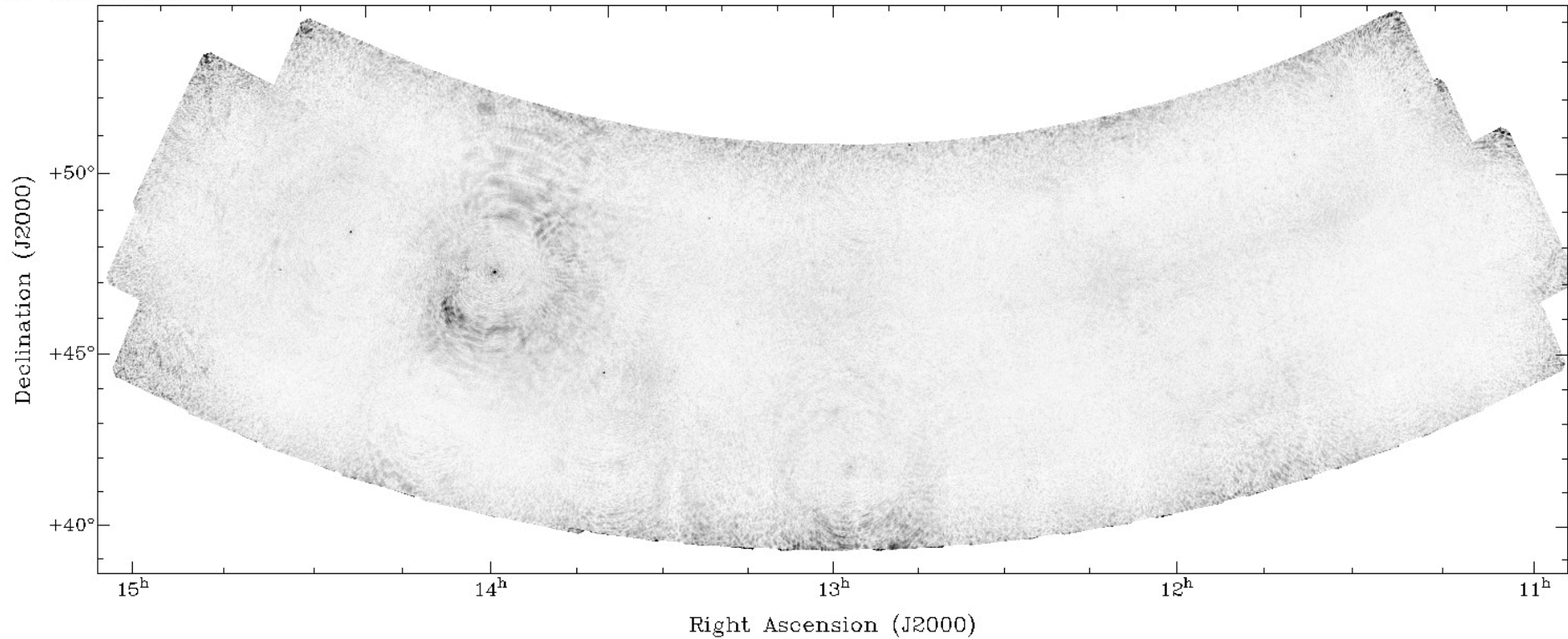
Jur Remeijn
bachelor thesis Radboud University

3. Get global picture: spectro-polarimetry of the LOFAR Tier1 survey



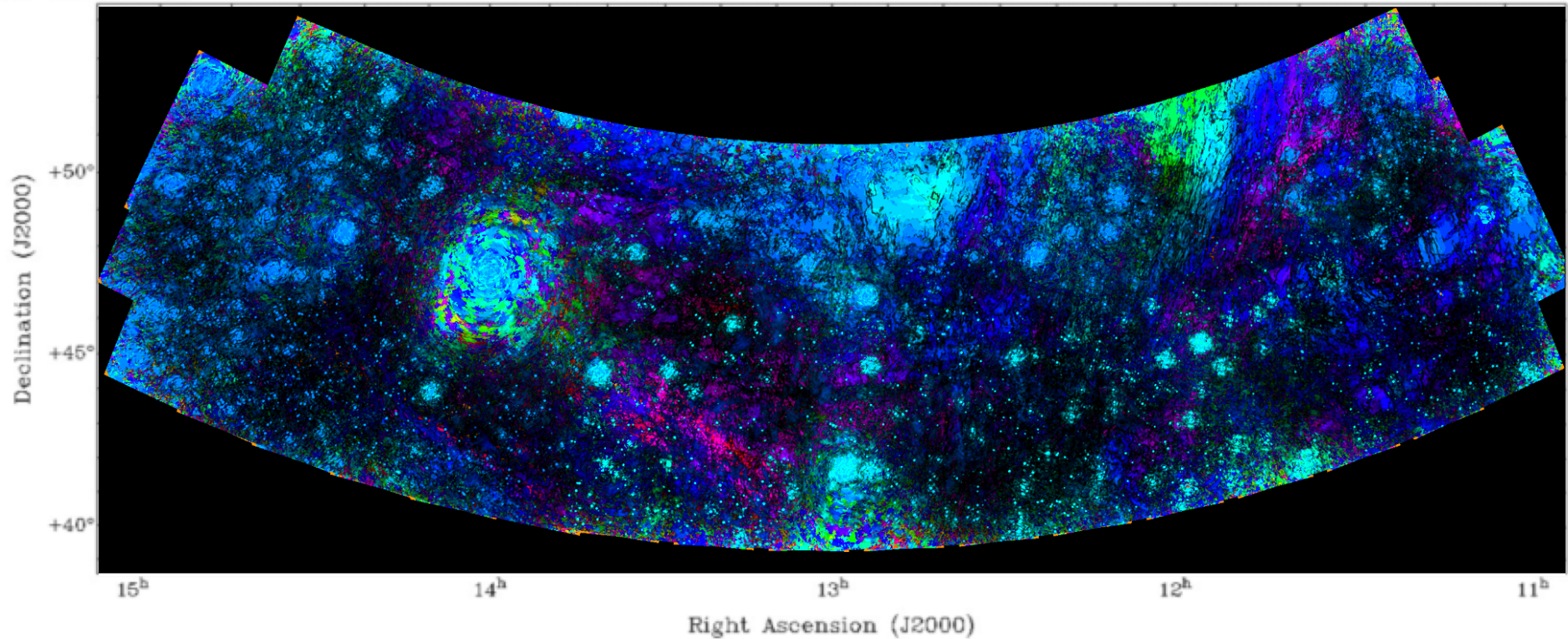
3. Get global picture: spectro-polarimetry of the LOFAR Tier1 survey

Phi: $-1.000000e+01$



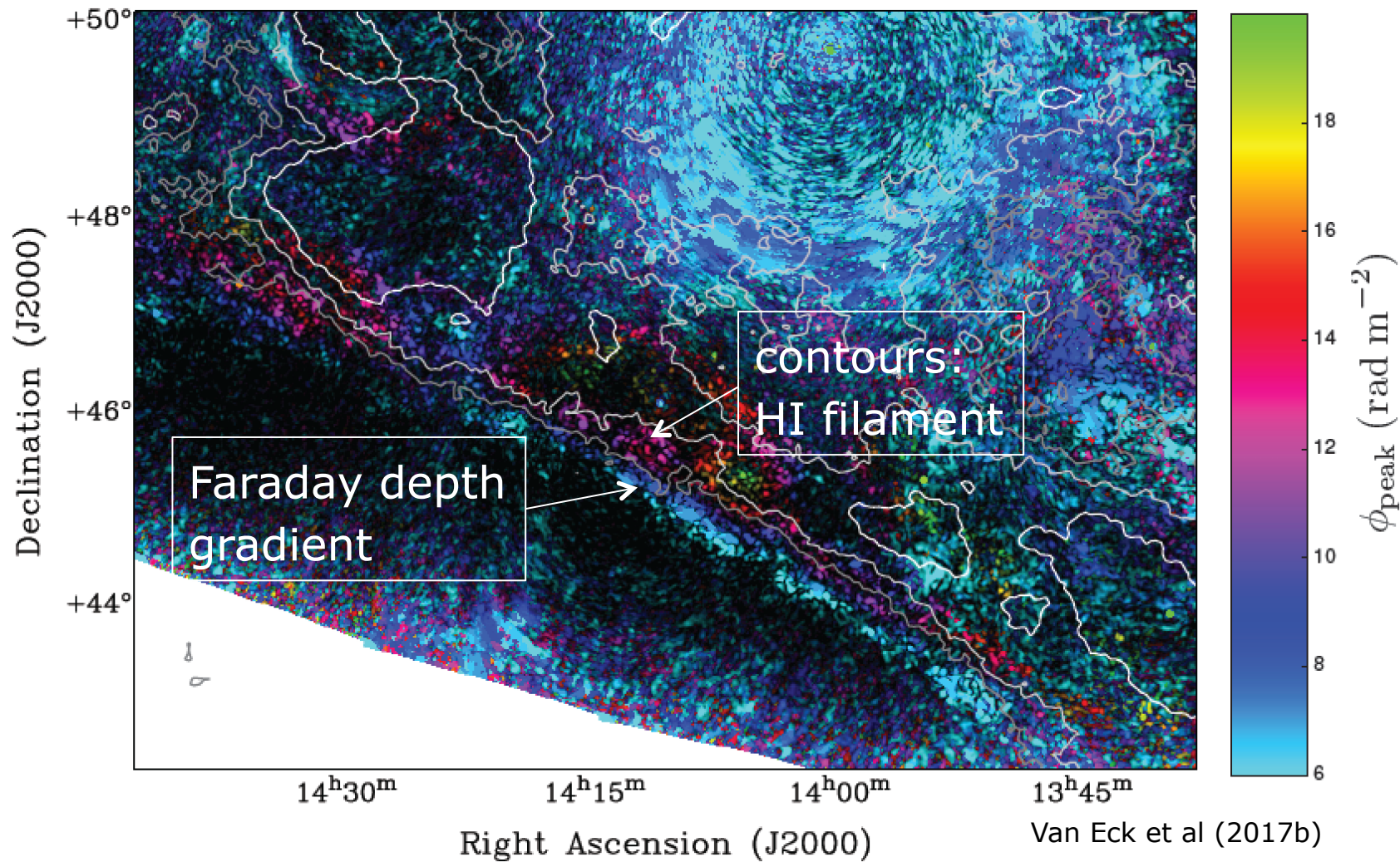
Van Eck et al (2017b)

3. Get global picture: spectro-polarimetry of the LOFAR Tier1 survey



Van Eck et al (2017b)

Neutral hydrogen filament with ionized edge?



Summary

- * Epoch of Reionization observations are EXCELLENT for studying the Milky Way
- * Faraday Tomography probes the local Galactic magnetic field
- * Interstellar medium components seem intricately connected in detail: ionized medium, neutral medium and magnetic fields