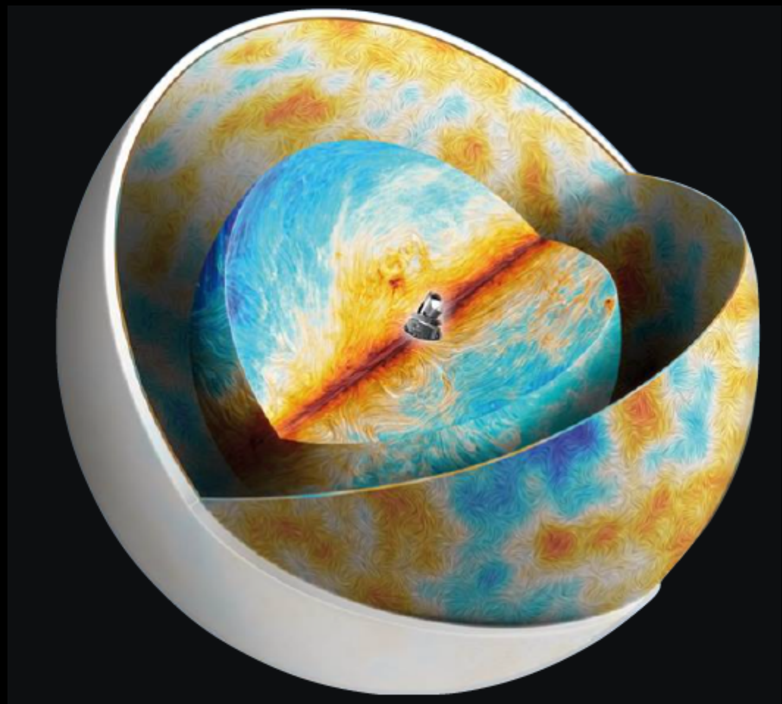
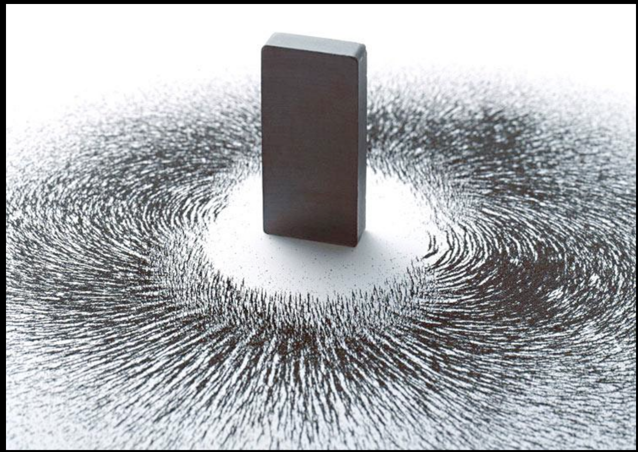
Magnetic fields and dust polarization foreground



F. Boulanger, J. Aumont, A. Bracco, T. Ghosh,
L. Montier, F. Vansyngel

LiteBIRD meeting December 11, 2015

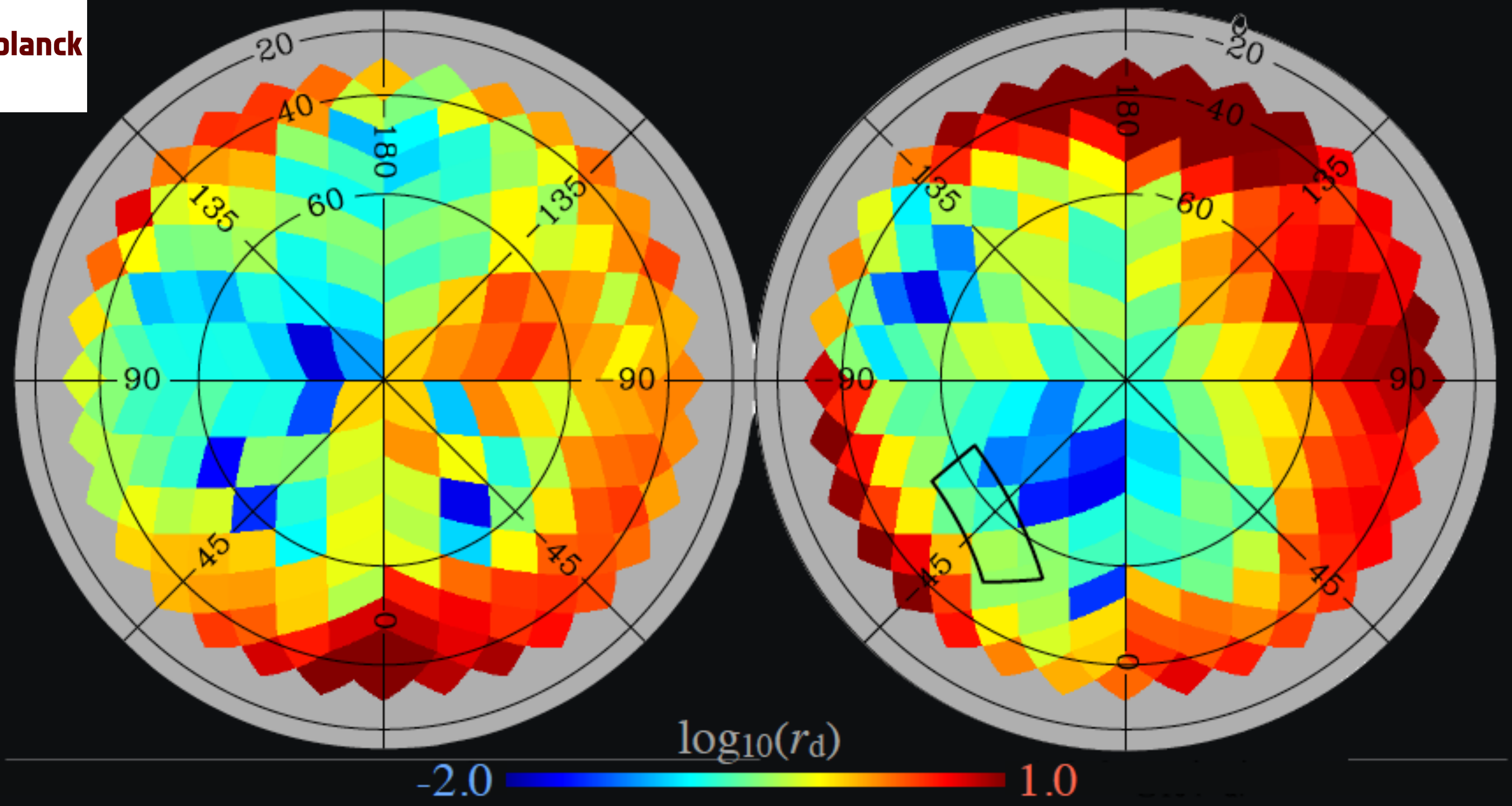
Outline



From ISM physics to sky models of dust polarization for component separation

- Variable polarization from the magnetic field structure
- The correlation between the density structure of matter and that of the interstellar magnetic field
- Decorellation of dust polarization across frequencies

Dust B-modes predicted contamination at 150 GHz



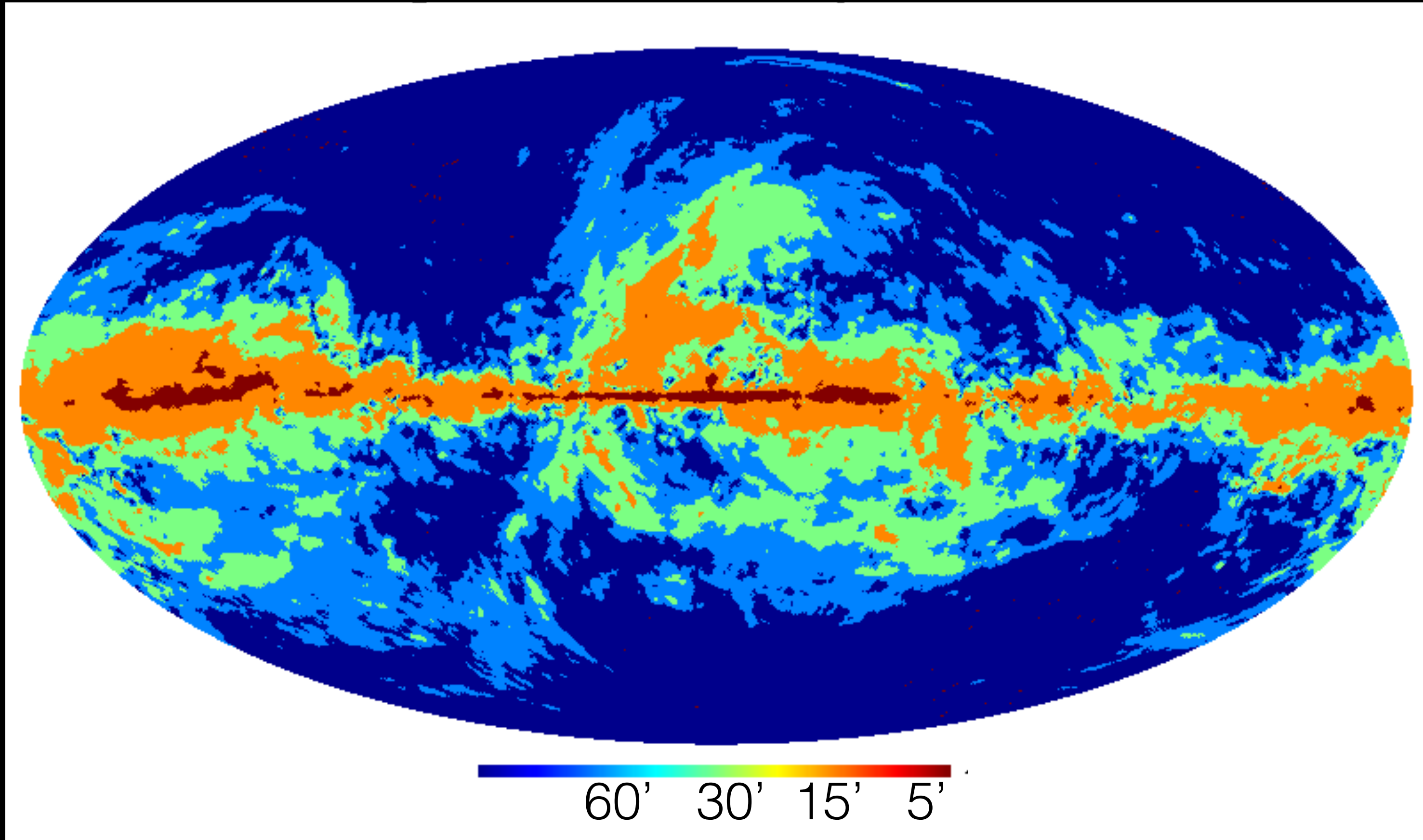
[Planck Intermediate 2014 XXX]

- ★ Extrapolation of the *BB* amplitudes at 150 GHz
- ★ Amplitudes expressed in units of r_d (e.g. r_d = 0.2 means that the dust has the same level as the CMB r = 0.2 at ℓ=100)
- ★ The cleanest regions of the sky have $r_d \sim 0.01 \pm 0.06$
- ★ The dust polarization has to be assessed, everywhere on the sky, to measure the CMB primordial *B*-modes

Overcoming Planck limits

Angular scale where EE dust power = Planck noise

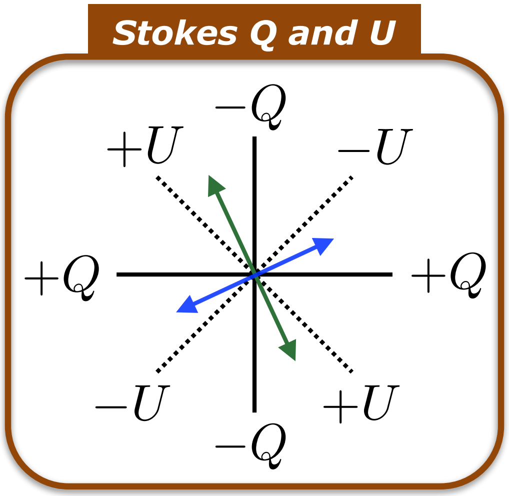
Based on power spectra in Planck intermediate XXX 2014, arXiv 1409.5738

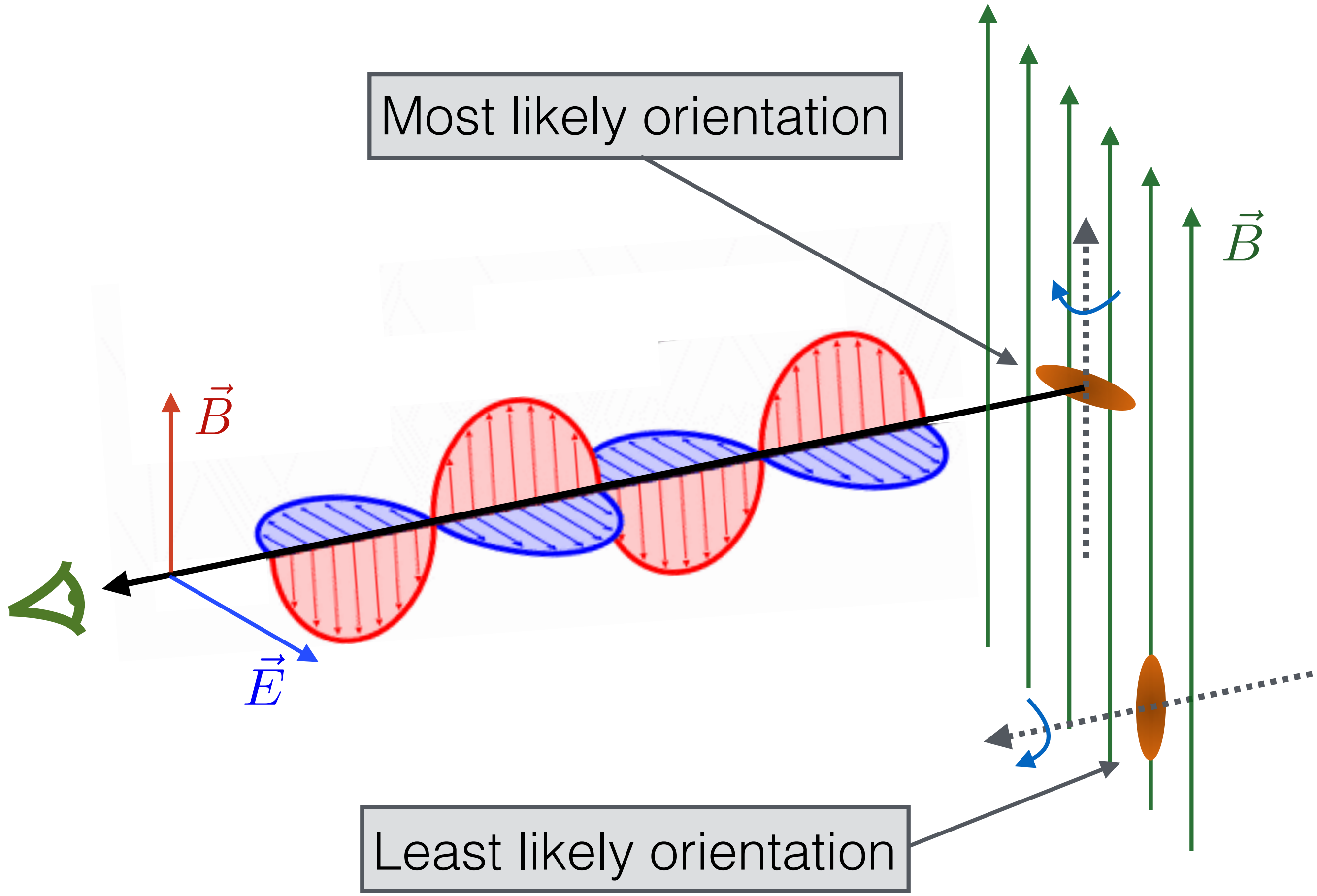


Models of dust polarization built from Planck maps are noise limited

We have to learn from the data to build a phenomenological model of the dust polarization sky that is physically motivated

Polarized thermal dust emission essentials

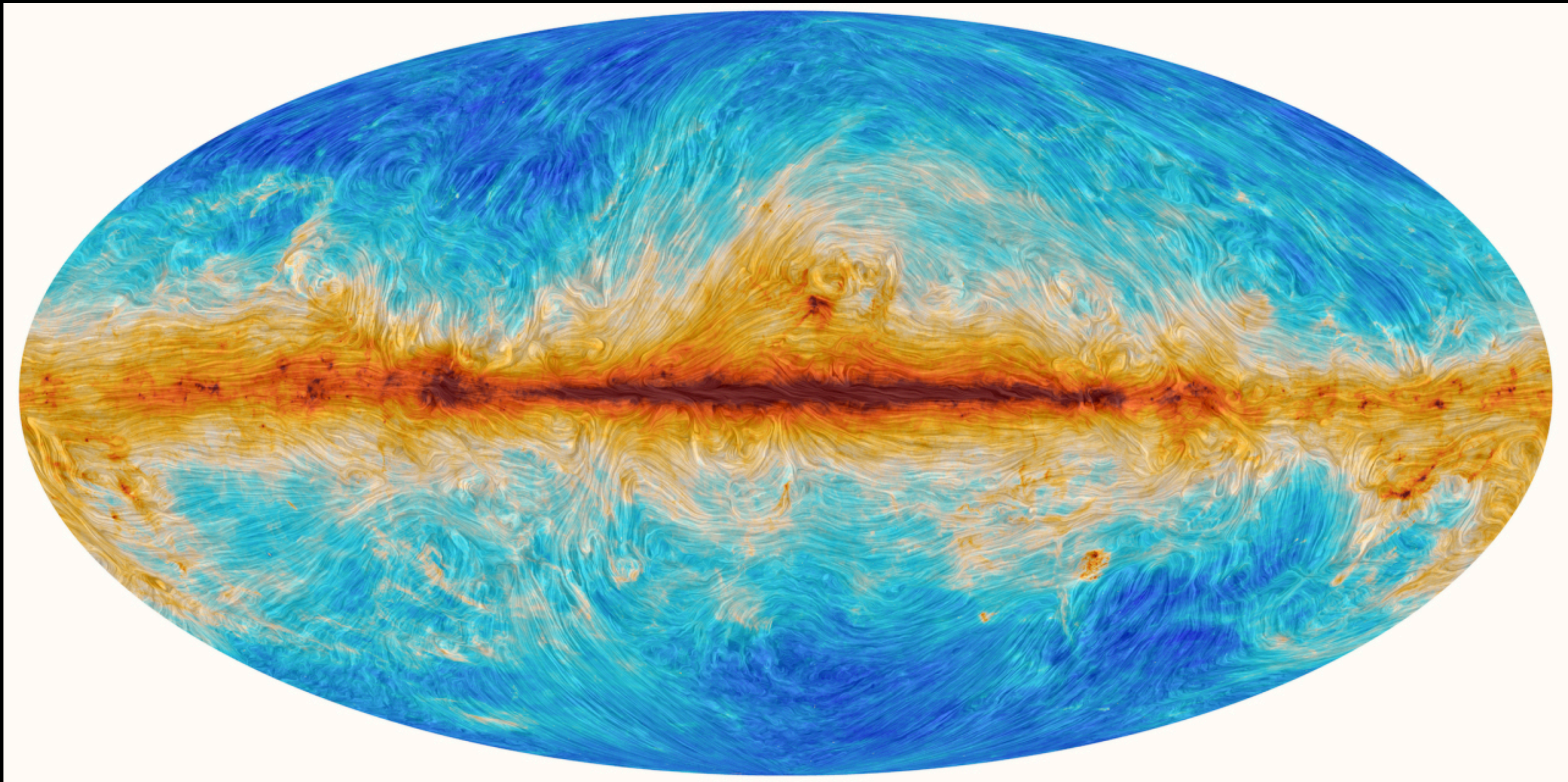




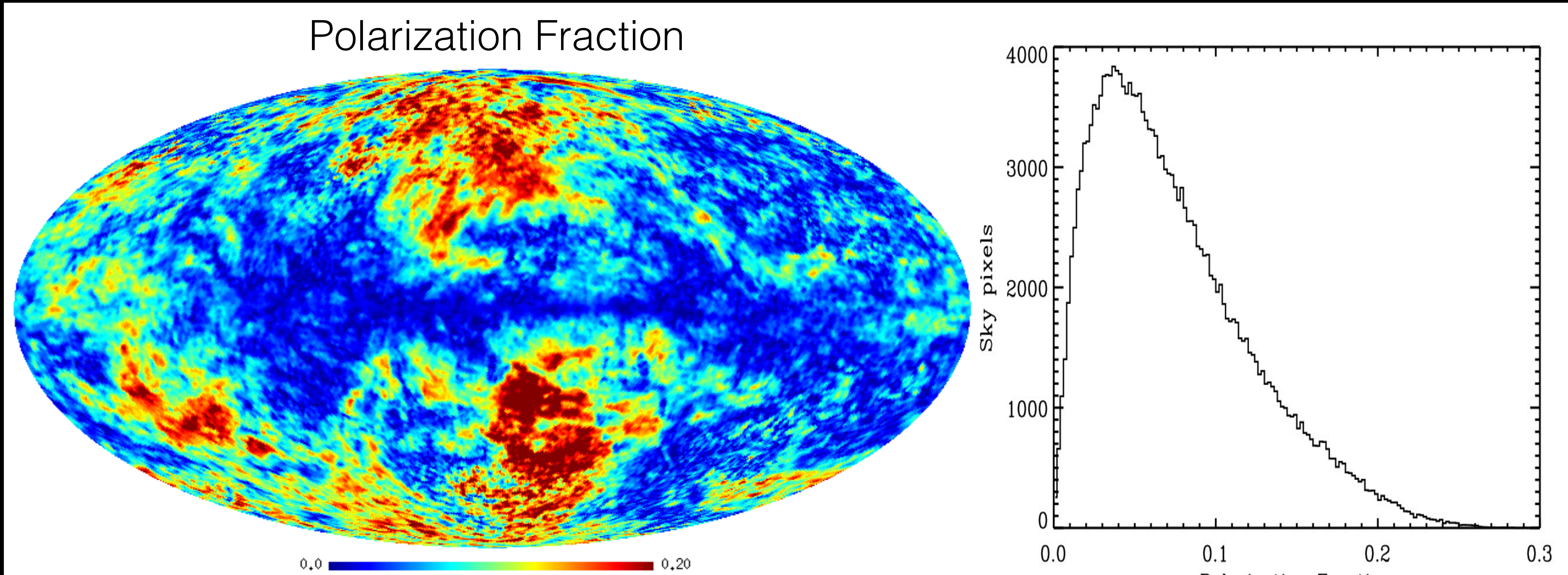
- Grains are aspherical, charged, rotating, and aligned preferentially perpendicularly to the local magnetic field
- Cross sections are proportional to the size, so grains emit more radiation parallel to their long axes
- Polarized thermal emission arises, with an orientation perpendicular to the local magnetic field

Brandon Hensley's Talk

Magnetic field and ISM structure



Polarization Fraction



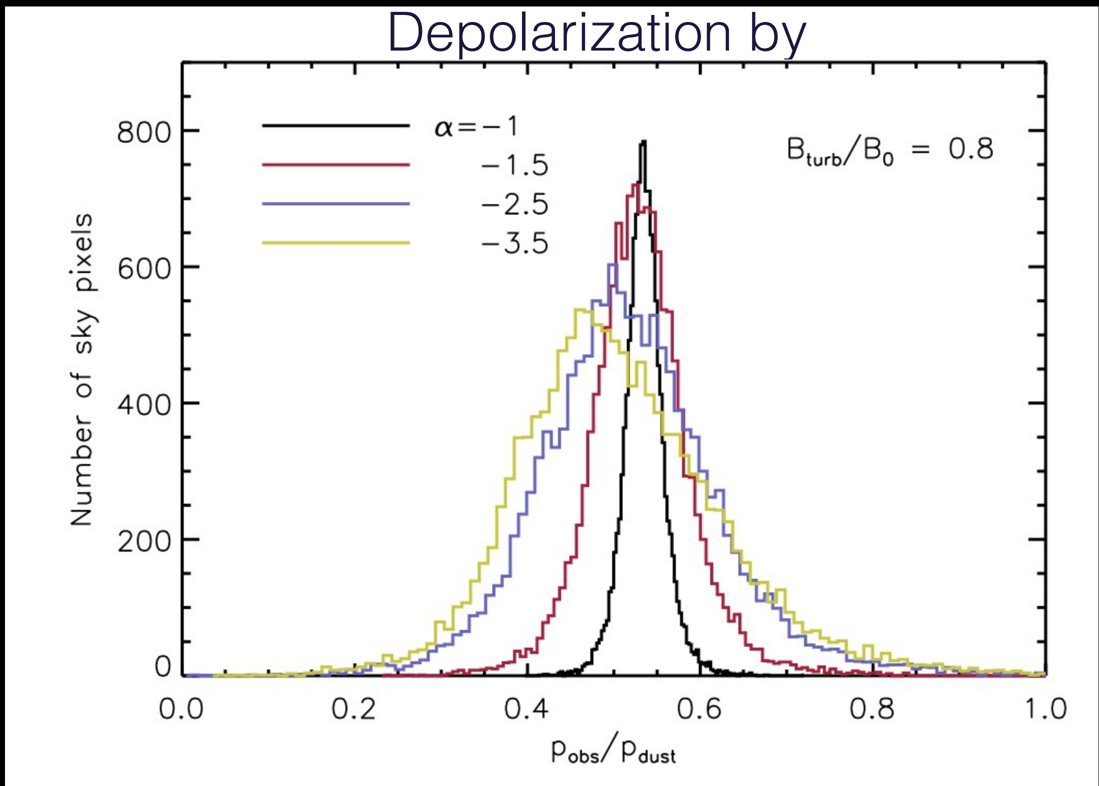
[Planck Intermediate XIX 2014, A&A]

The polarization fraction shows a large scatter, which we interpret as line of sight depolarization associated with interstellar turbulence

Coherence length of B field

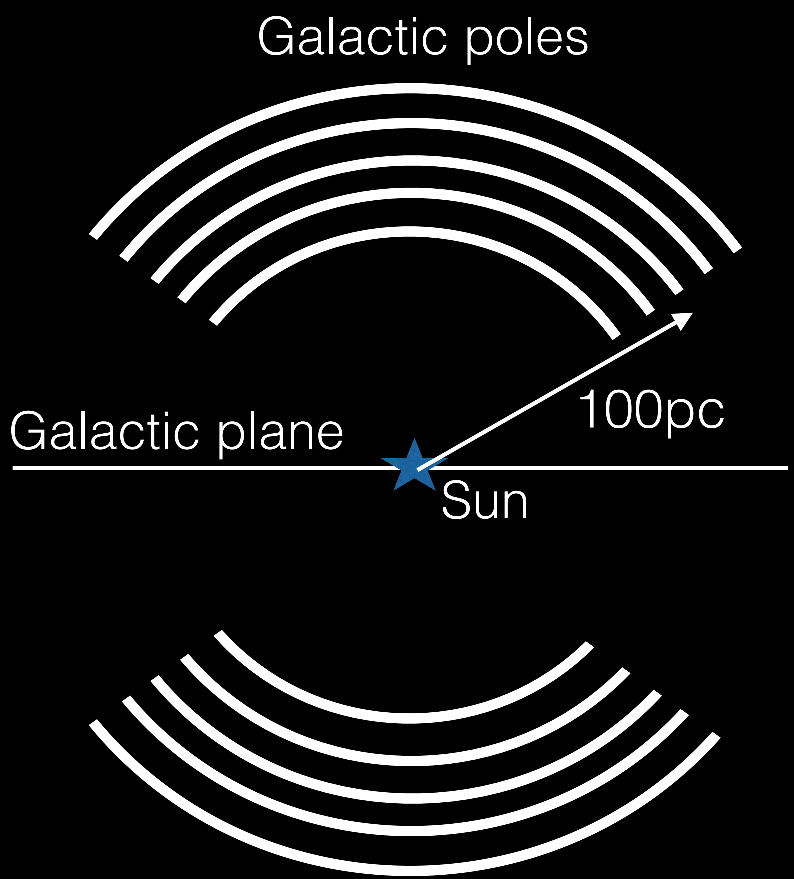
Magnetic field: $\vec{B} = \vec{B}_0 + \vec{B}_{turb}$ $(<\vec{B}_{\rm turb}> = 0)$

Depolarization due to turbulence is quantified for power spectra realizations of B_{turb} components along each line of sight



- ★The correlation length of turbulence λ increases with the spectral index α of magnetic turbulence.
- ★ The large variance of p shows that fluctuations of B_{turb} arise from a small number N= L/λ of *turbulent cells* along the line of sight of length L.
- ★The density structure of the ISM also matters.

Dust polarization model (I)



$$\vec{B} = \vec{B}_0 + \vec{B}_{turb} \qquad (<\vec{B}_{\rm turb}>=0)$$

★The mean field is characterized by a fixed orientation (l_0 and b_0)

★The turbulent component is characterized by the ratio B_{turb}/B_0 and the spectral index of the power spectrum (α)

★We model the line of sight depolarization summing the emission over a small number of layers with independent realizations of turbulence. This simplification allows us to compute the model on the sphere.

Dust polarization model (II)

$$I_\nu = \sum_{i=1}^{N_l} \left[1 - p_0 \left(\cos^2 \gamma_i - \frac{2}{3} \right) \right] \epsilon_i(\nu);$$

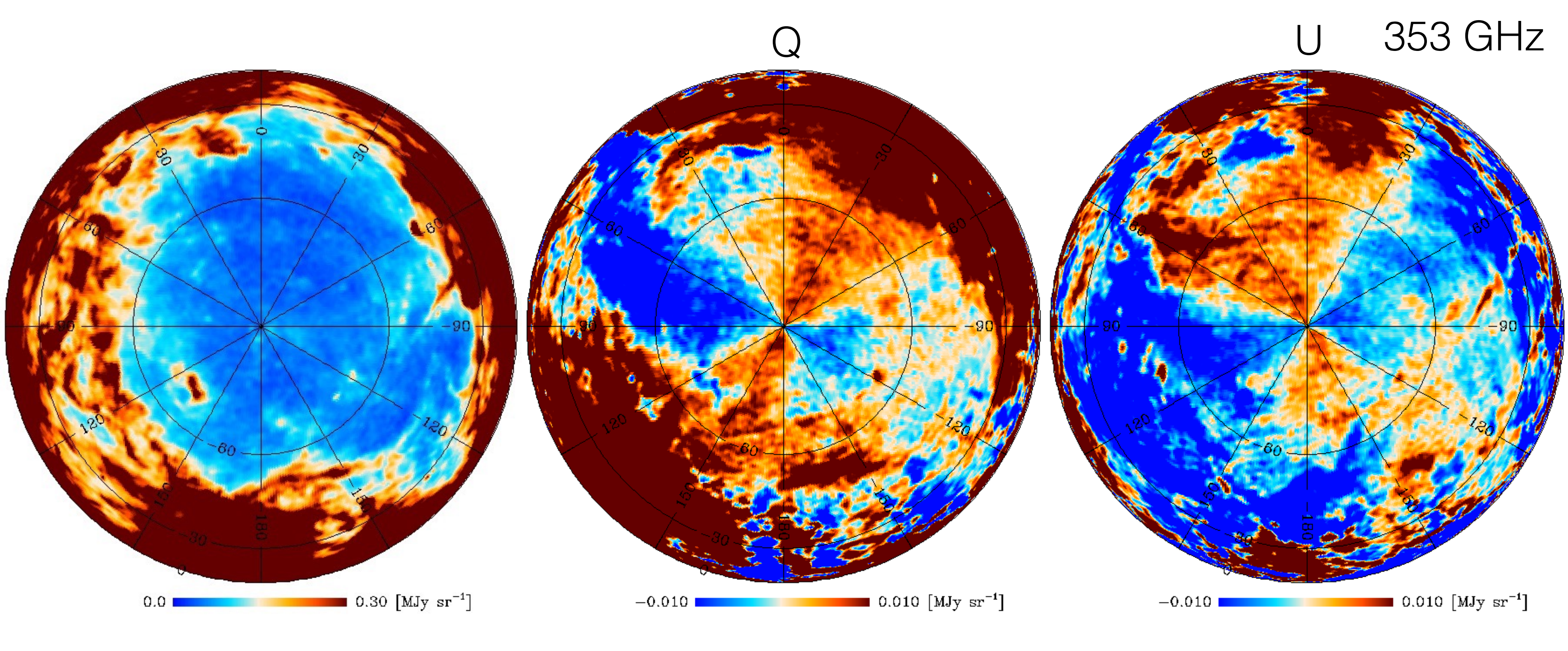
$$Q_\nu = \sum_{i=1}^{N_l} p_0 \, cos^2(\gamma_i) \, cos(2\psi_i) \, \epsilon_i(\nu);$$

$$U_\nu = \sum_{i=1}^{N_l} p_0 \, cos^2(\gamma_i) \, sin(2\psi_i) \, \epsilon_i(\nu),$$

where the sum is over the layers, $\epsilon_i(\nu)$ is the integral of the source function over each layer, and γ_i and ψ_i define the magnetic field orientation within the layer i.

- ➡The model provides maps of Q/I and U/I that are combined with the observed I map from dust to produce simulated Q and U maps.
- ➡The magnetic field angles are assumed to be uncorrelated between layers
- ➡To account for large scatter of the polarization fraction, N_l must be small

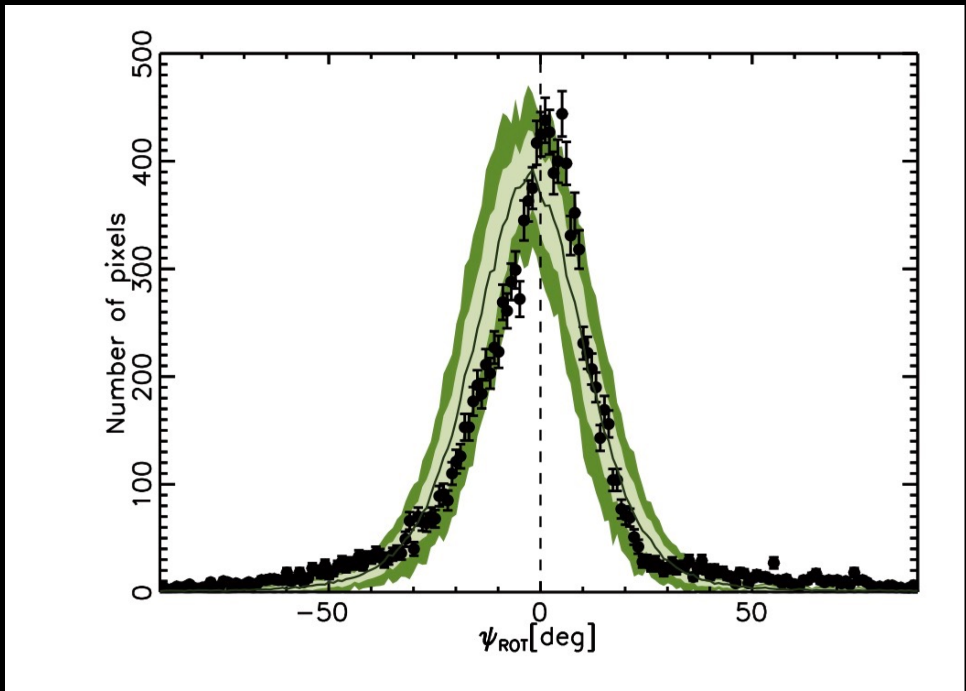
Planck data towards southern Galactic cap

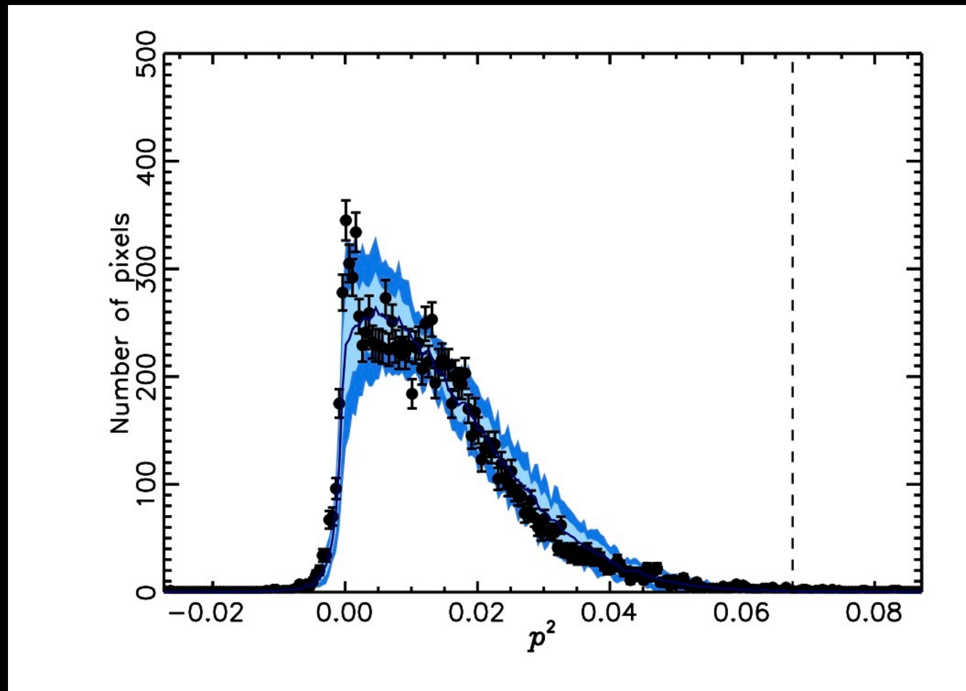


- Polarization patterns towards Galactic caps allow us to measure the direction of the mean magnetic field in the Solar Neighborhood

Bracco - PhD 2014, Université Paris-Sud, Orsay

Histograms of polarization angle and fraction

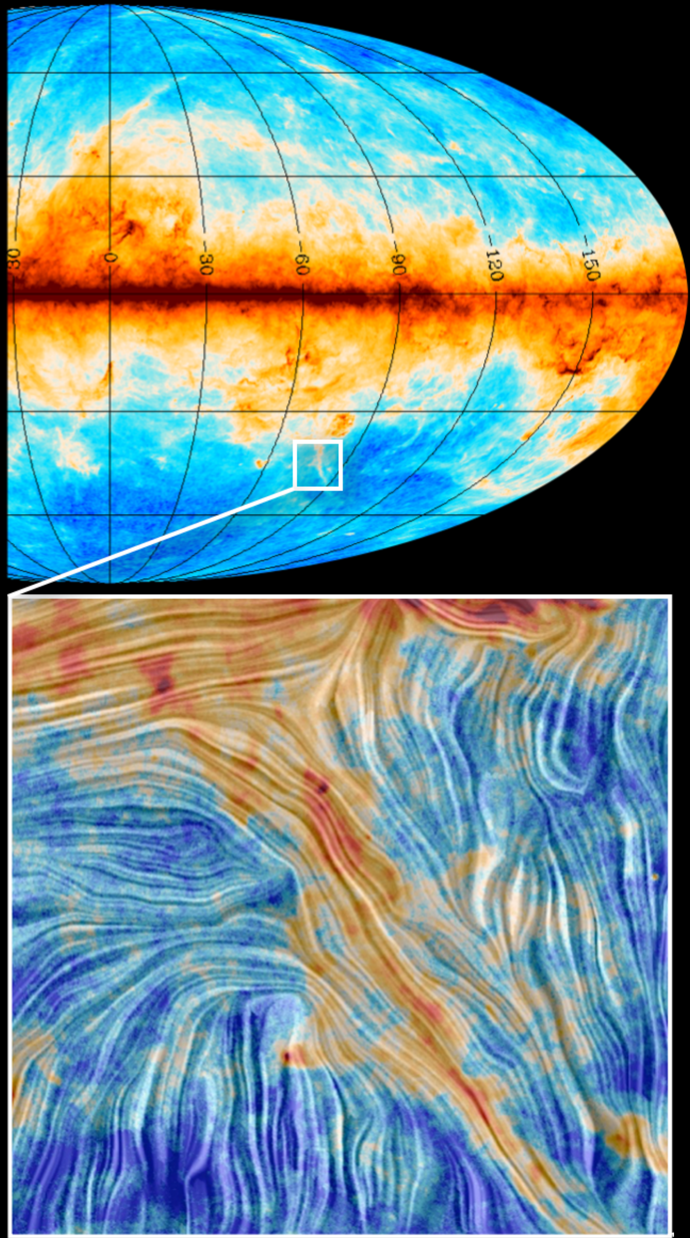




- Model fit of the histograms (polarization angle and fraction) for $B_{turb}/B_0 = 0.8/0.9$ with $N_{Layers} = 4/7$ (Bracco PhD Thesis 2014).
- The same model fits polarization power spectra within constrains on the magnetic energy spectrum (Presentation Vansyngel today)

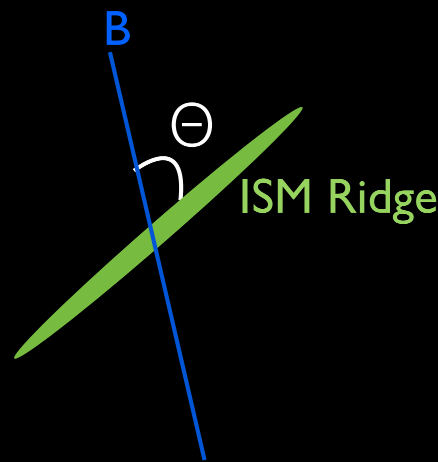
The filamentary structure of matter

[Planck Intermediate XXXII 2014, arXiv:1409.6728]



(*Planck* intensity 353GHz, B-field lines)

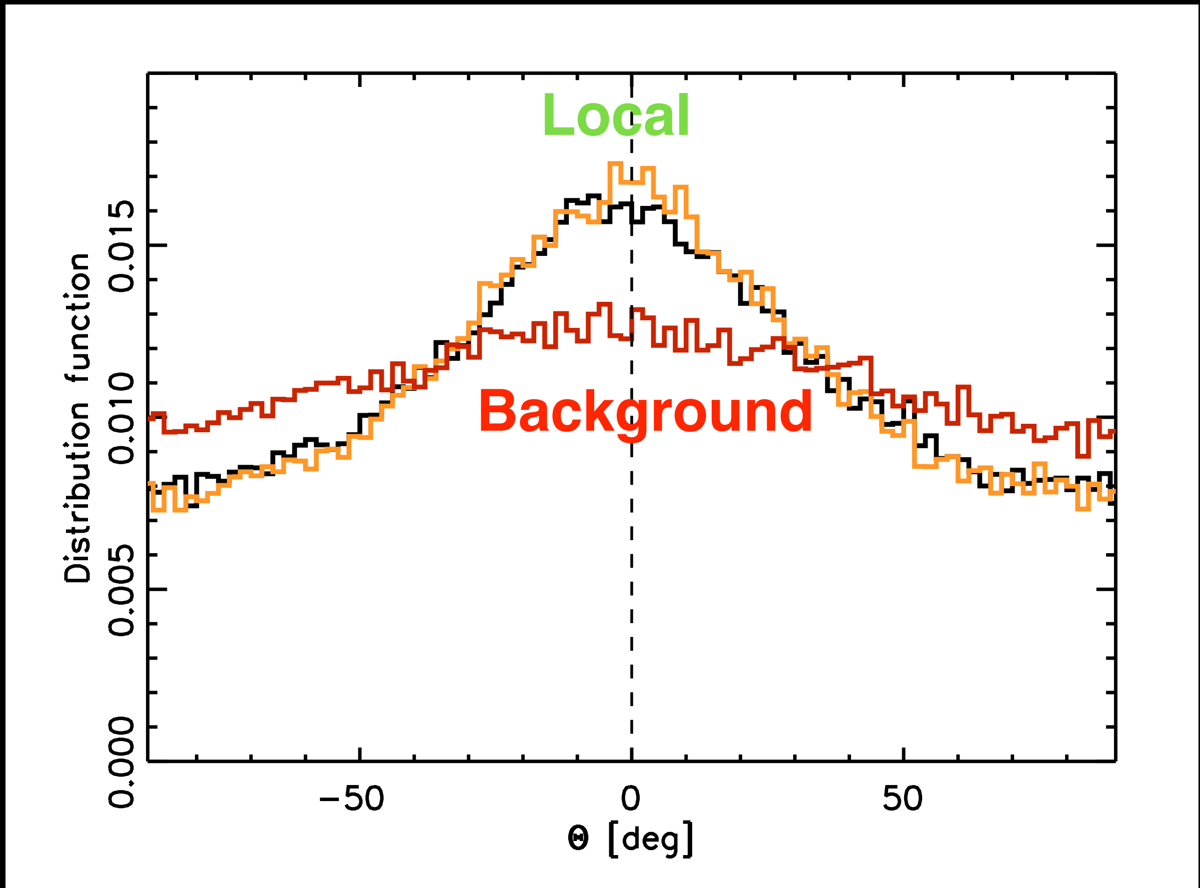
The filamentary structure of the interstellar medium

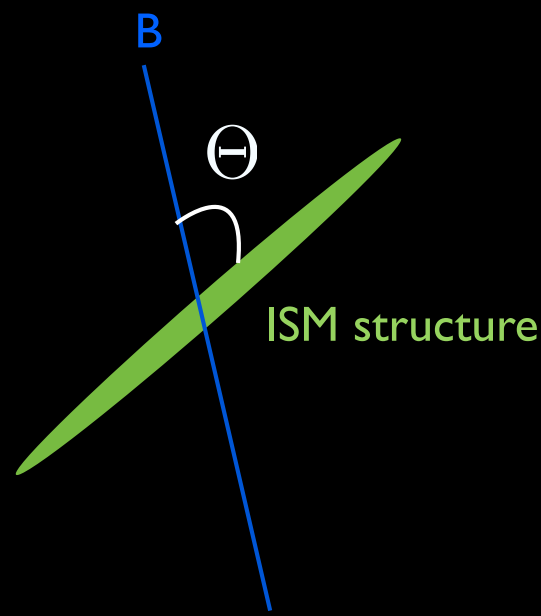


In the diffuse ISM we observe an alignment of the filamentary structures with the magnetic field orientation

Alignment with magnetic Field

[Planck Intermediate XXXII 2014, arXiv:1409.6728]
Bracco - PhD 2014, Université Paris-Sud, Orsay

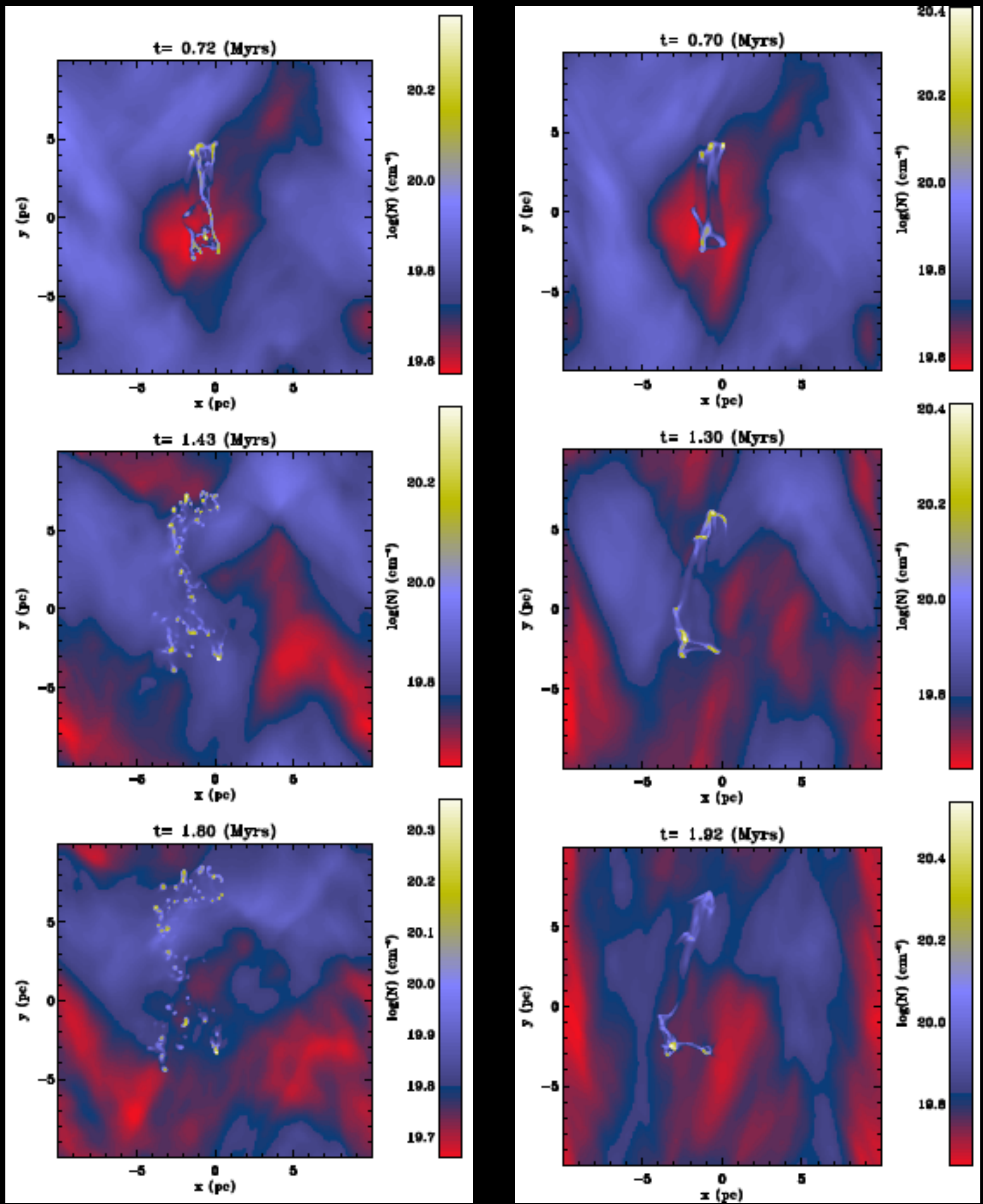




The structures tend to be aligned with the local magnetic field

Projection effects (3D to 2D) are crucial for the interpretation of the shape of the distribution

HD MHD



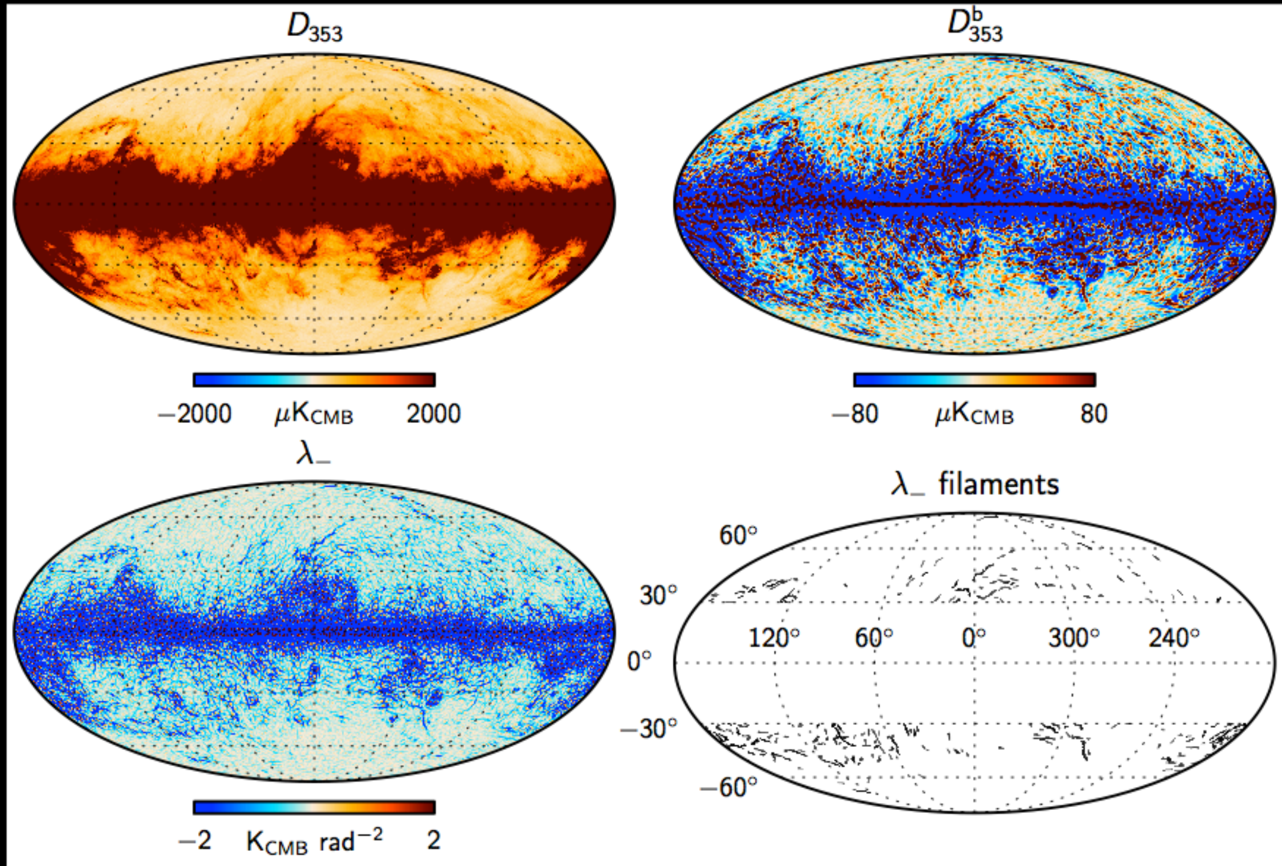
Formation of a filament through shear

★In both experiments, the gas condensation is stretched into a filamentary structure by the velocity shear, but in the HD case the structure is broken up by instabilities, while in the MHD case it remains coherent.

★Filamentary structures may result from turbulent shear (rather than shocks) that stretches gas condensations and the magnetic field.

Hennebelle 2013

E/B asymmetry



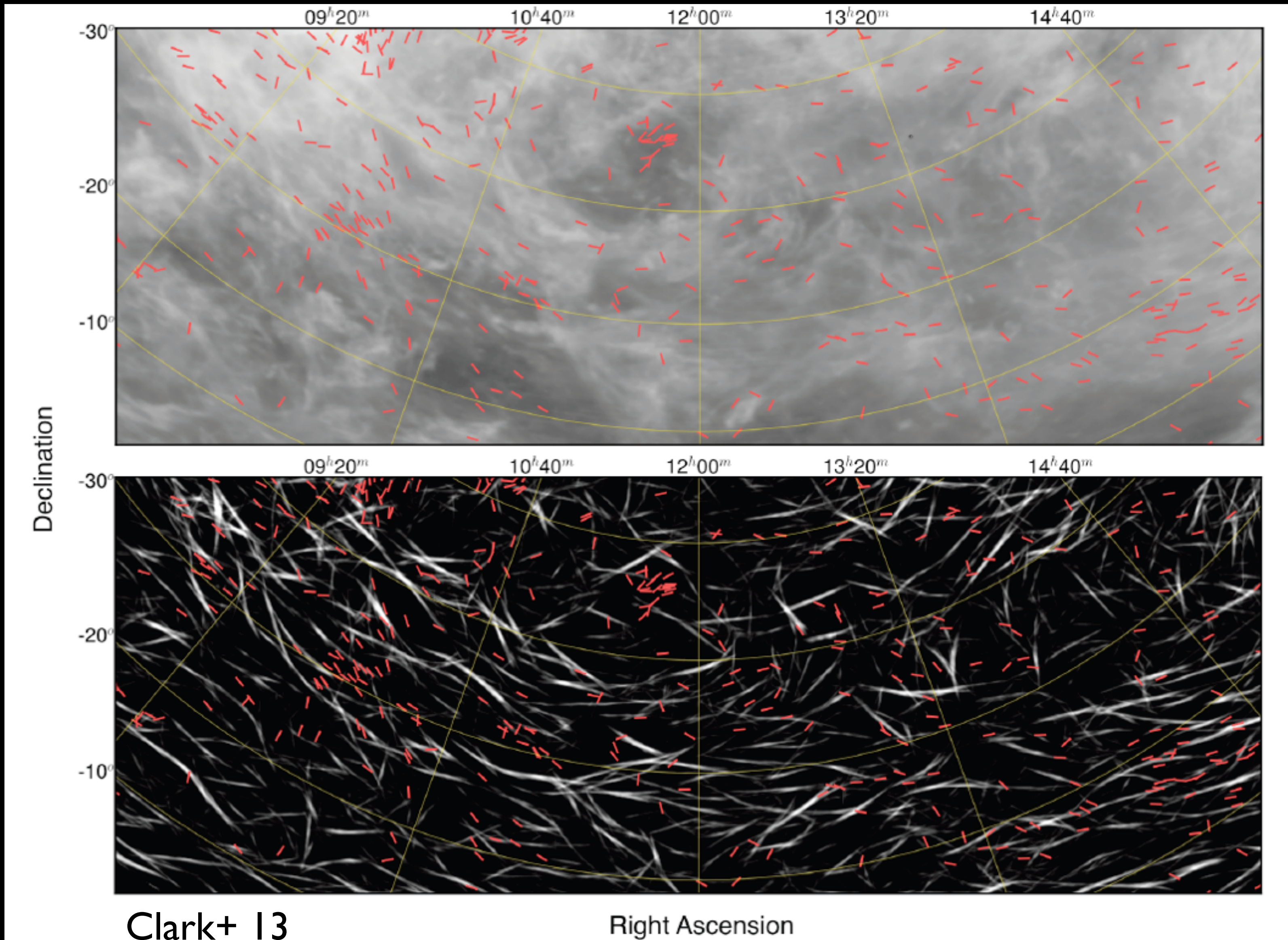
Planck XXXVIII 2015, arXiv 1505.02779

★We identified 259 filaments at high Galactic latitude (|b| > 30^0) with lengths larger or equal to 2 deg

★These filaments dominate the variance of dust polarization at |b| > 30^0

★Alignment between the orientation of the filaments and the magnetic field accounts for the TE correlation and the E/B asymmetry

Filaments in the diffuse ISM

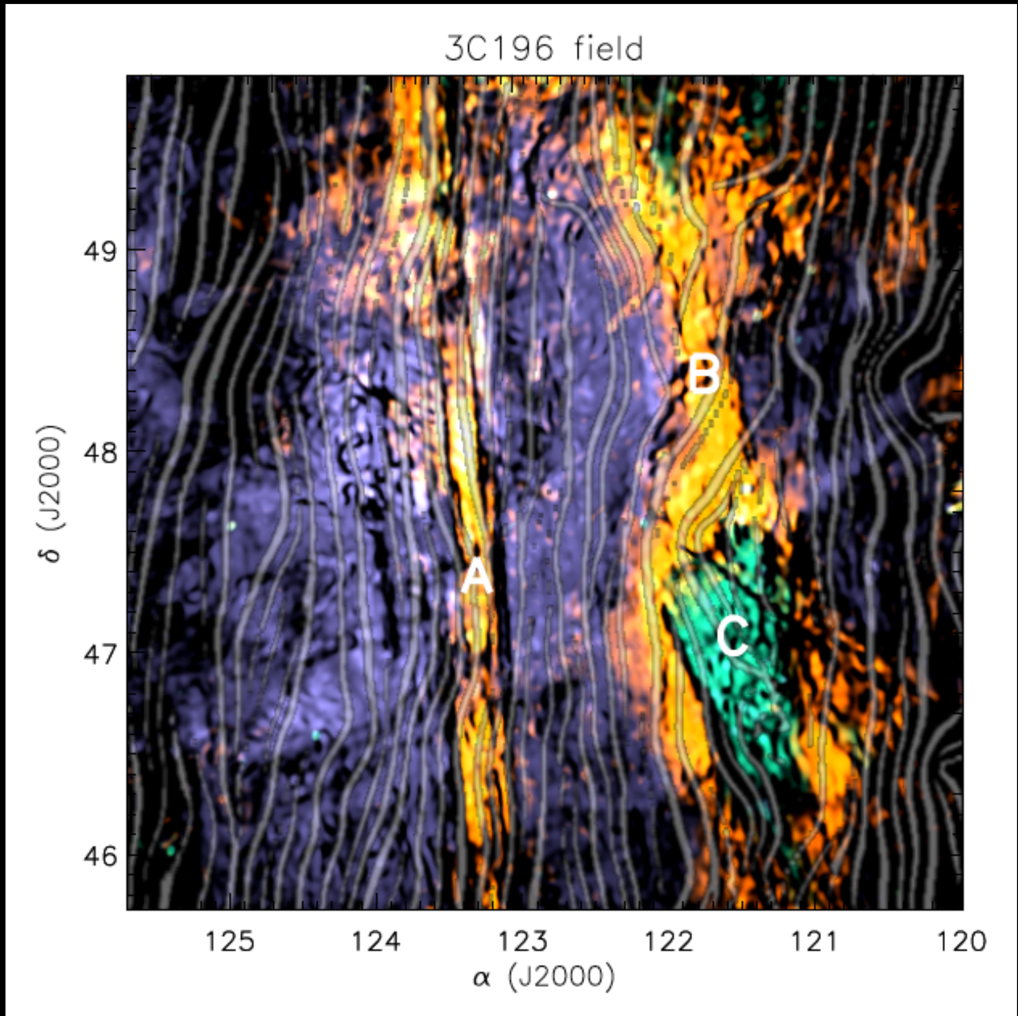


HI GASS map
16' resolution

Filaments
extracted from
the data

Magnetic fields across ISM phases

Colors code Faraday depth
Field lines from dust polarization



LOFAR Faraday synthesis, Zaroubi+ 2015

- ★Faraday rotation traces B field in the warm ionized medium
- ★Dust emission comes mainly from the neutral medium.
- ★We observe a correlation between spatial features in the LOFAR Faraday synthesis map with the field lines from dust polarization
- ★This correlation is not observed in all the fields we have looked at.

From ISM physics to component separation

★ The magnetic field has a big imprint on the variance of dust polarization for three reasons:

(1) Its strength is comparable to that of the mean field

(2) The ratio between its correlation length and the line of sight length is small

(3) It is observed to be correlated with the filamentary structure of matter

★ The filamentary structure is known from HI (21cm) observations to arise mainly from the cold neutral medium

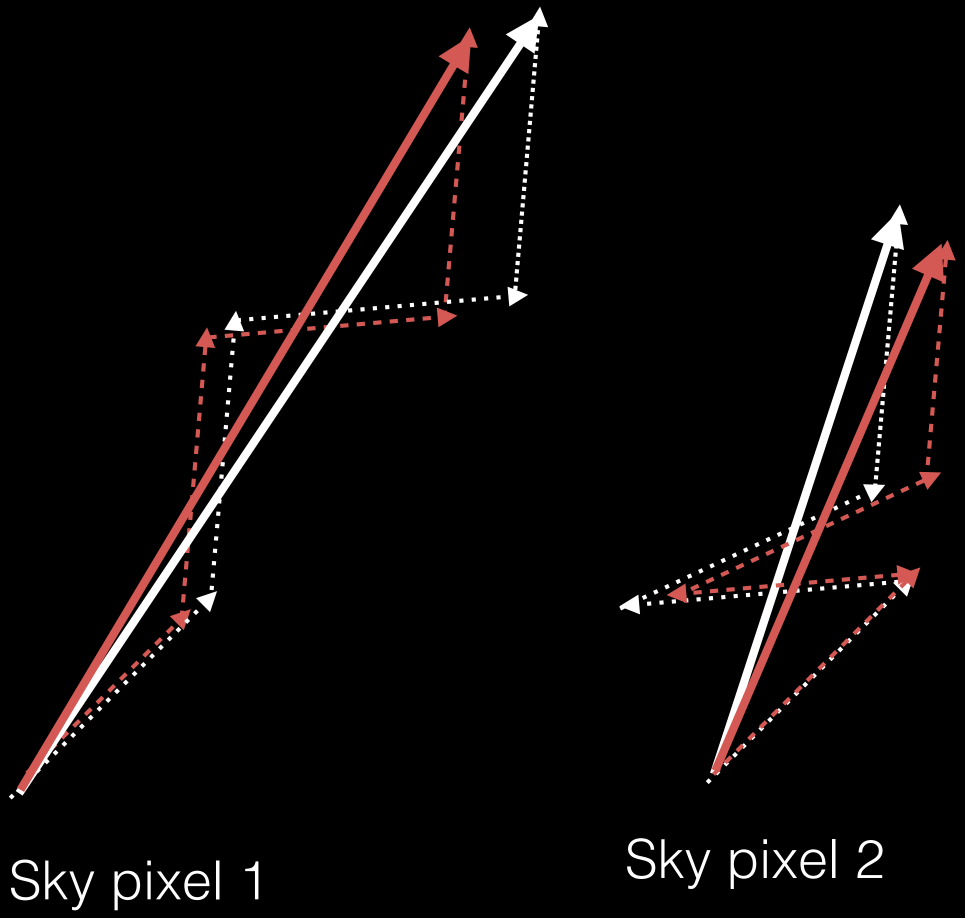
★ Dust polarization properties are likely to differ between the cold (dense) and warm (teneous) gas phases

➡ The variance of dust polarization reflects the physical coupling between dust, magnetic field and the ISM density structure

➡ This coupling generates decorrelation across frequencies larger for polarization than temperature data

Schematic explanation

Same I but different polarized intensity and polarization angle



Frequencies ν_1 and ν_2

Dust polarization may be viewed as a random walk in the Q,U plane with a small number of steps

- The magnetic field orientation sets the direction of the step
- Dust polarized intensity sets the length
- Decorrelation of the dust polarization signal between frequencies results from the correlation between the magnetic field, ISM structure and dust polarization properties.

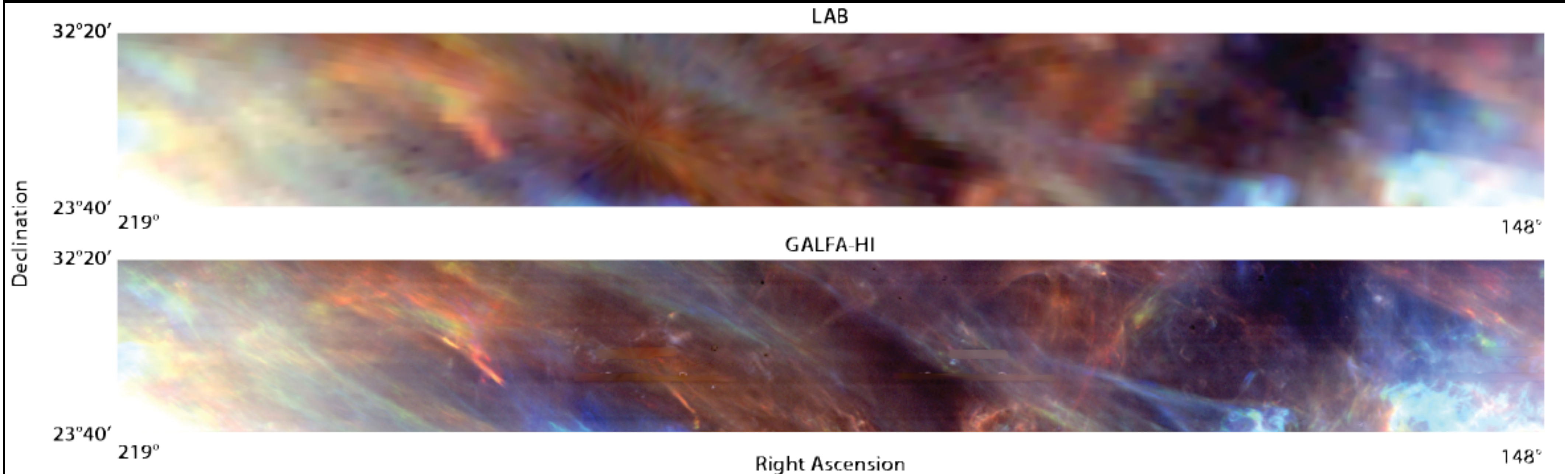
Both the polarized intensity and polarization angle change with frequency.

Decorrelation is a non-linear effect that modifies the frequency dependence of dust polarization.

Angular resolution matters

Both the field structure along the line of sight and within the beam matters

HI channels maps (colors) at 30' (LAB) and 5' (GALFA) angular resolutions



Clark+ 13

➡ Imaging of the magnetic field structure at high frequencies would permit to model beam depolarization in low angular resolution microwave CMB data

Summary and perspectives

- ★The required accuracy on dust/CMB separation to detect primordial B-modes at $r=10^{-3}$ is high (a few 10^{-3} at the recombination bump). This is a BIG challenge.
- ★We are working towards this building a physical understanding of the dust polarization sky from the Planck data.
- ★The variance of dust polarization reflects the coupling between the structure of matter, the magnetic field and dust polarization properties.
- ★This is non linear effect that generates decorrelation across frequencies, which is expected to be larger for polarization than for intensity (Presentation by Jonathan Aumont today)
- ★We are preparing sky models of dust polarization to test the ability of current methods of component separation to face this difficulty and to formulate new methods in this new context (Presentation by Flavien Vansyngel today)