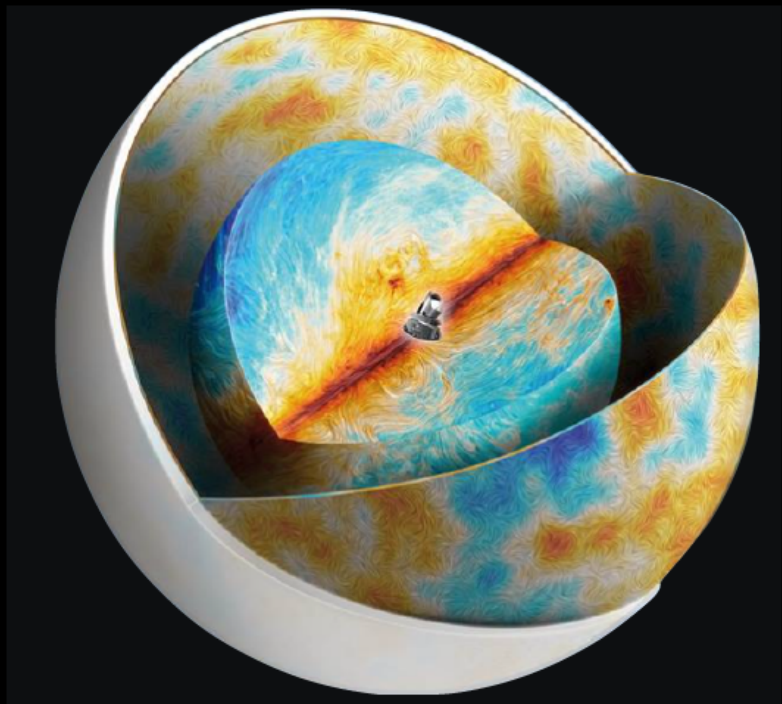
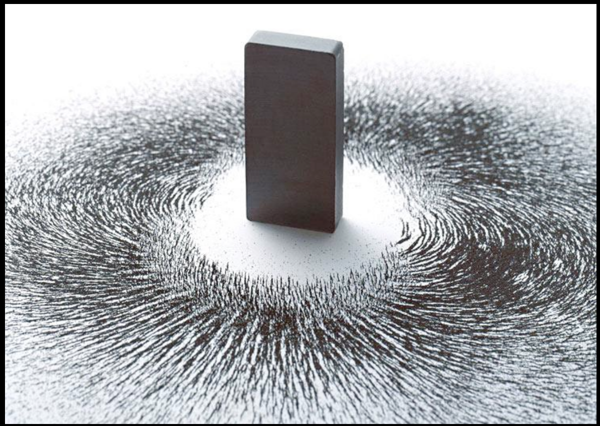
Dust polarized foreground to the CMB

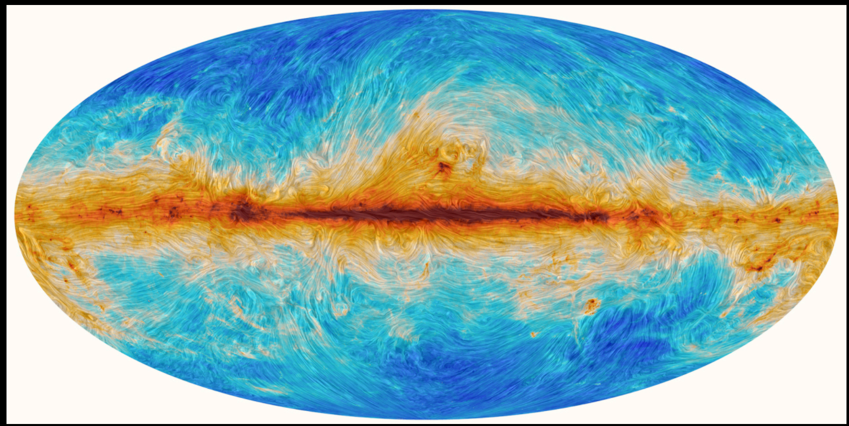


F. Boulanger, J. Aumont, A. Bracco, T. Ghosh, L. Montier, F. Vansyngel

PNCG meeting December 15, 2015

Outline

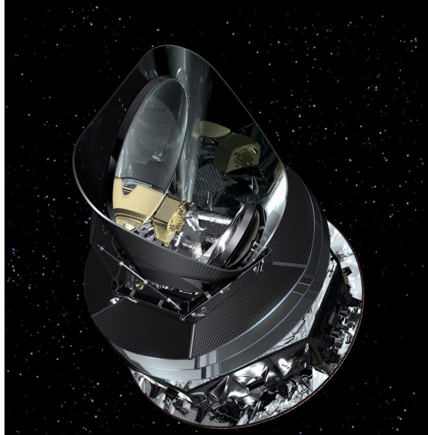




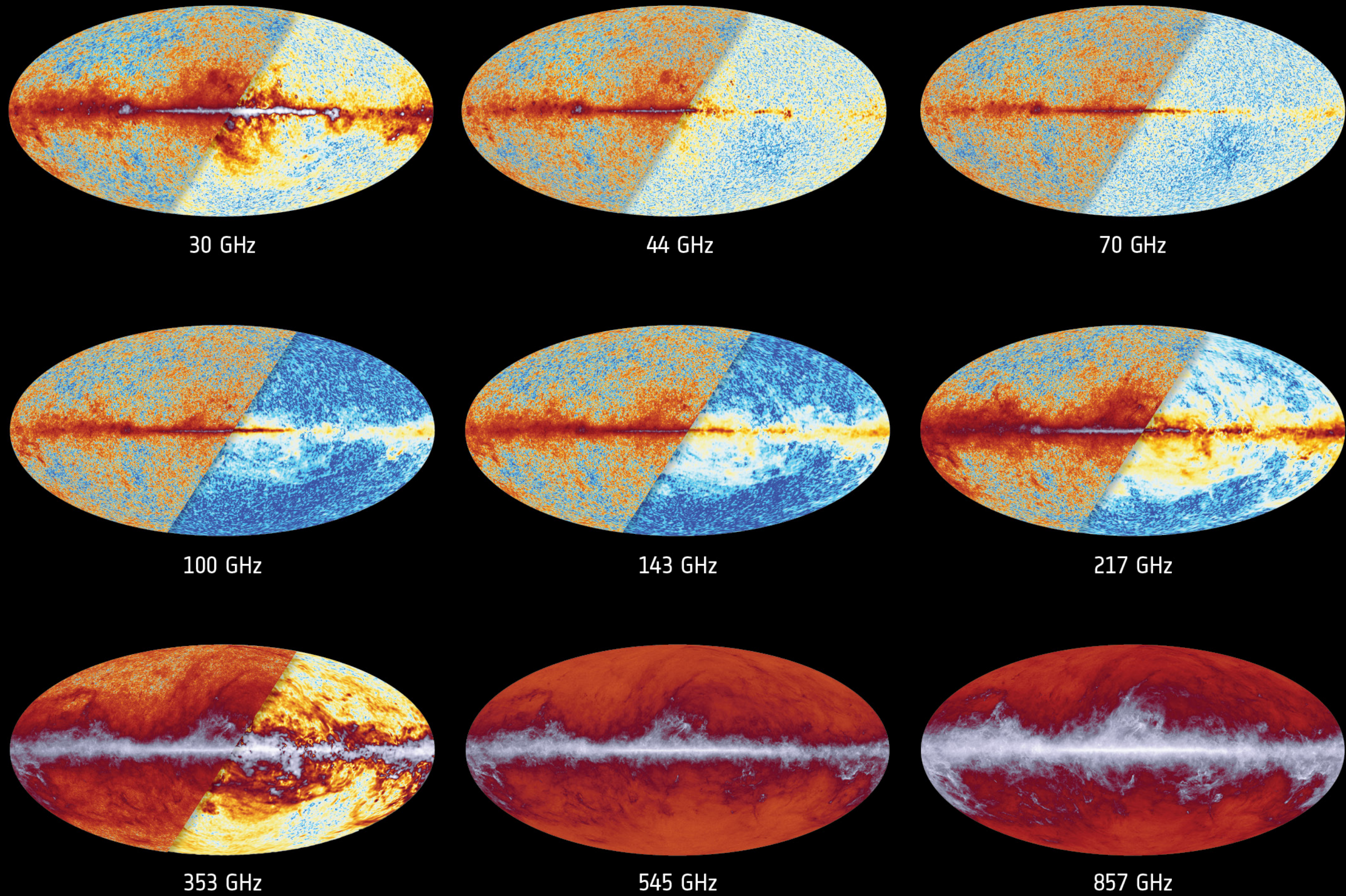
From the physics of the magnetized ISM to the search of CMB B-modes

- ★The search of CMB polarization associated with primordial gravity waves
- ★The signatures of MHD turbulence on dust polarization
- ★Modelling of the dust polarization sky and component separation

Planck sky Intensity/polarization



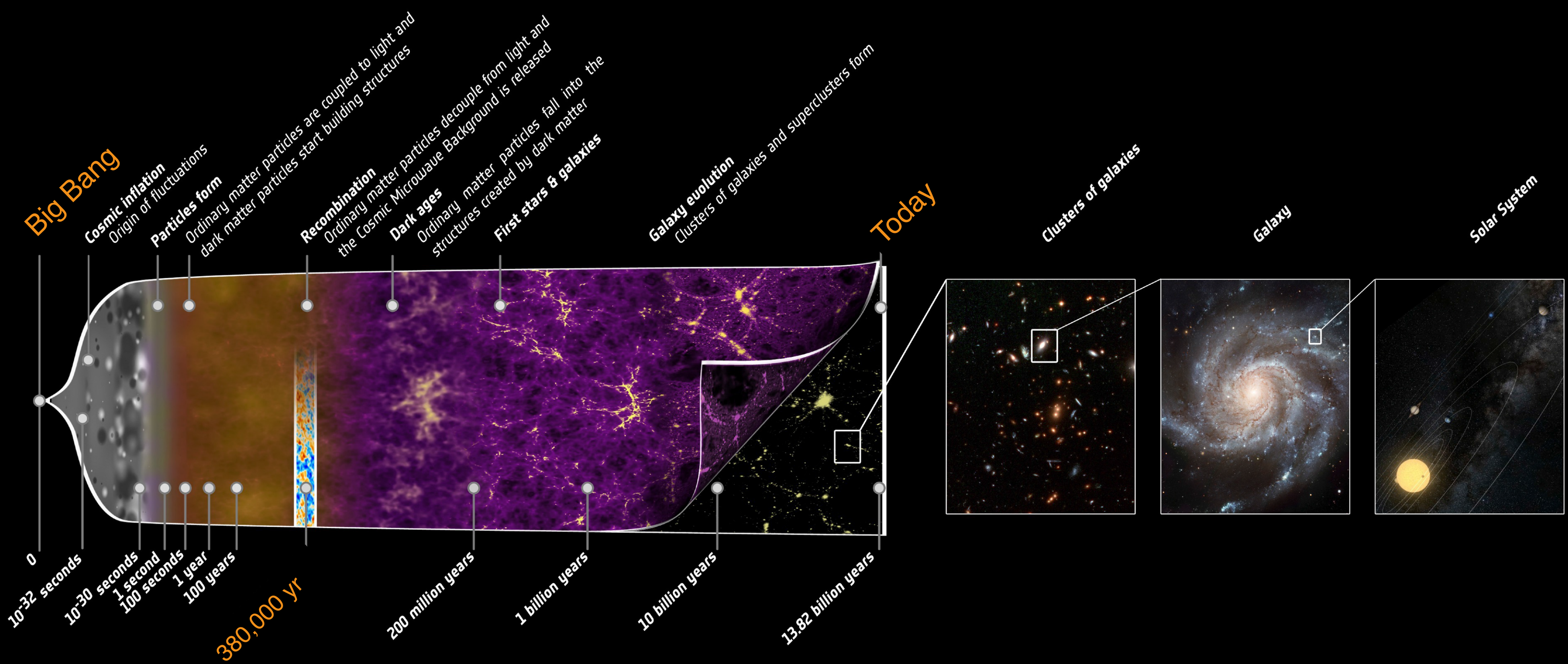
Planck



CMB polarization

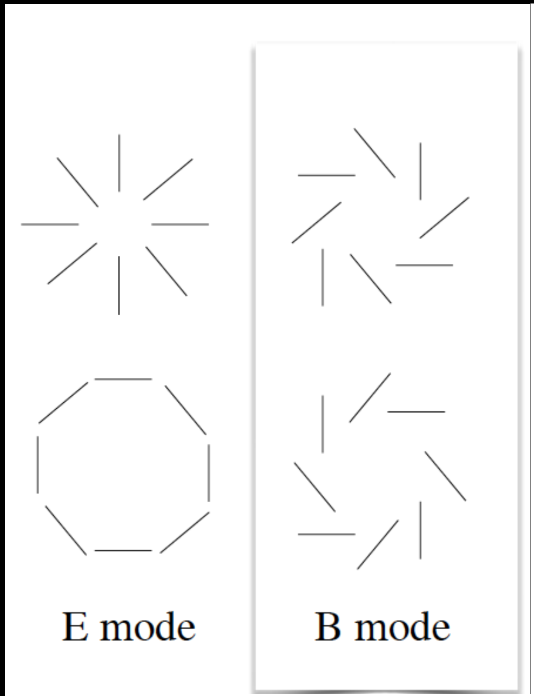
Interstellar magnetic fields

Towards the Big-Bang

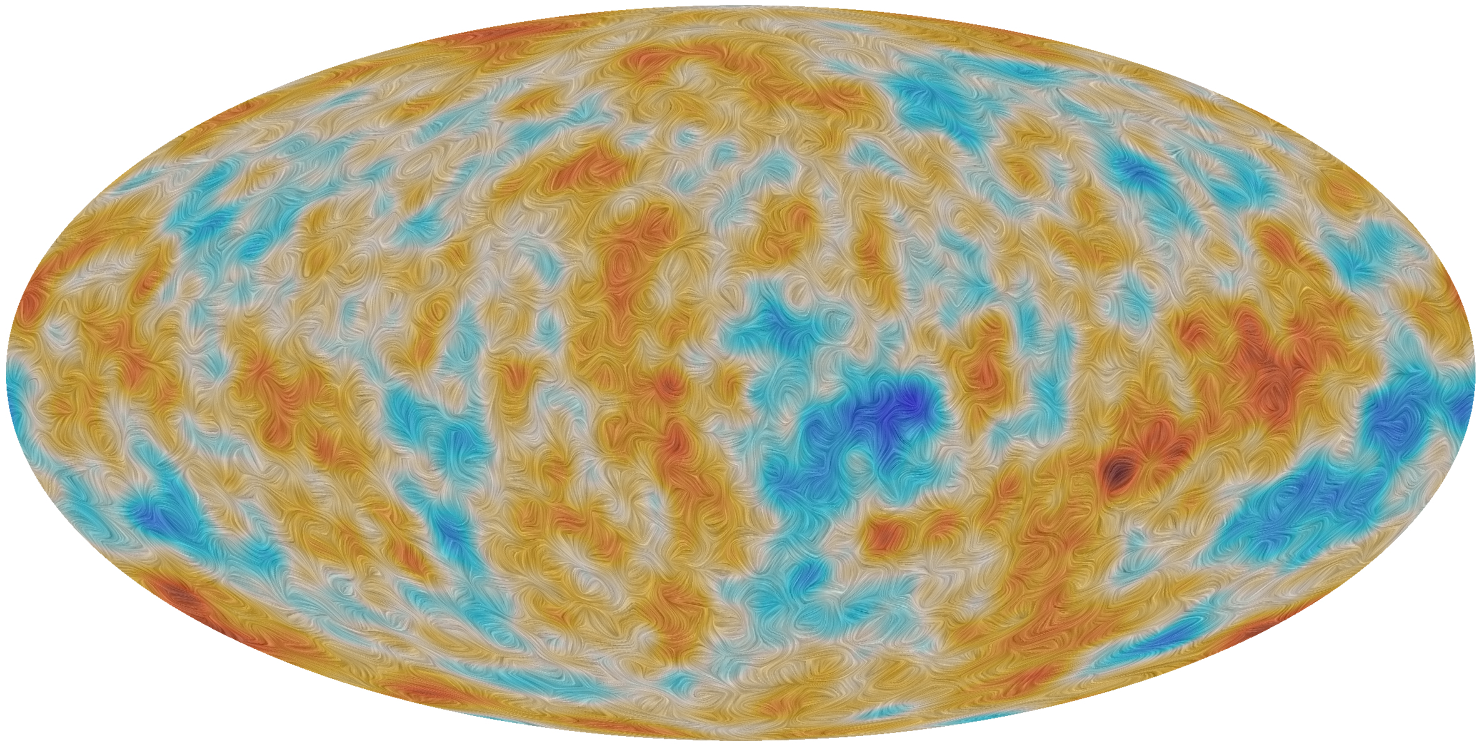


Can we test our understanding of physics back to the earliest moments of the history of the universe?

CMB polarization



To be discovered



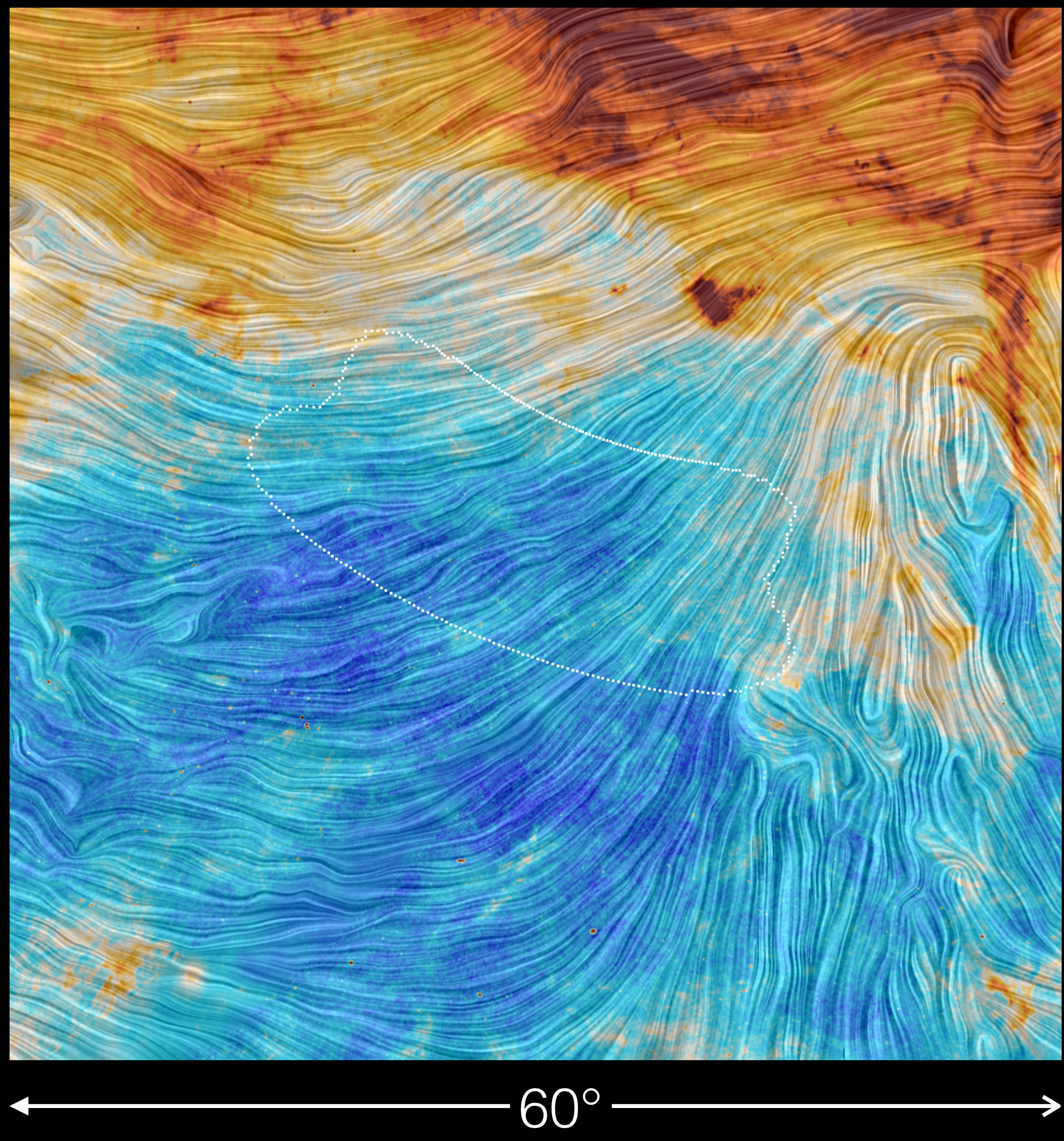
B-modes from primordial gravity waves are not detected in this Planck image

The dust magnetized screen

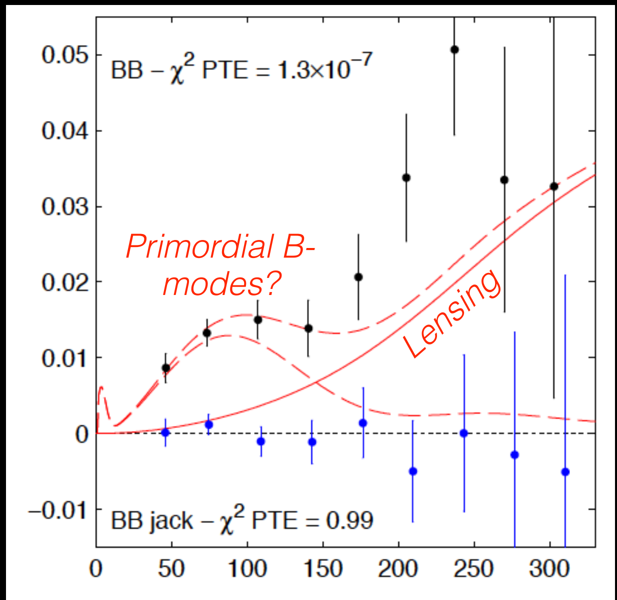
The Planck data has allowed us to characterize the power spectra of dust polarization towards cosmological fields.

➡ There is no field where this signal may be neglected

Field observed by the BICEP/Keck Experiment

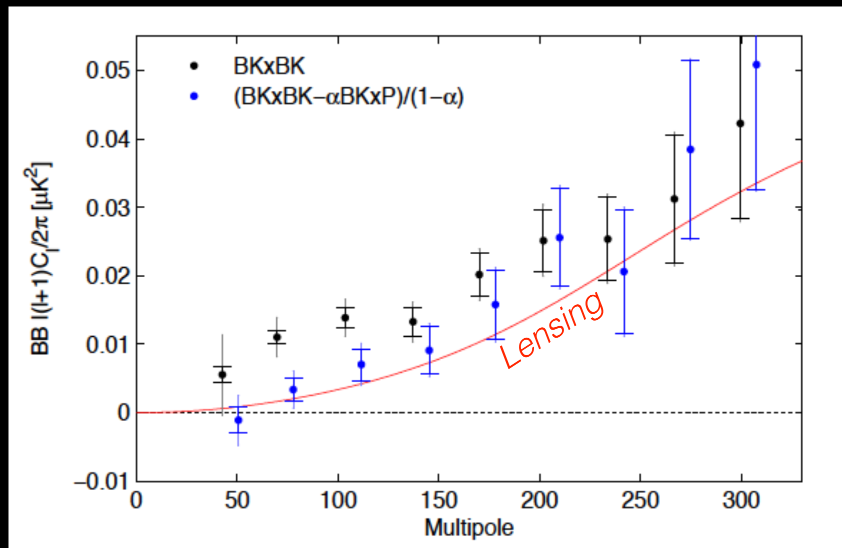


BICEP B-modes



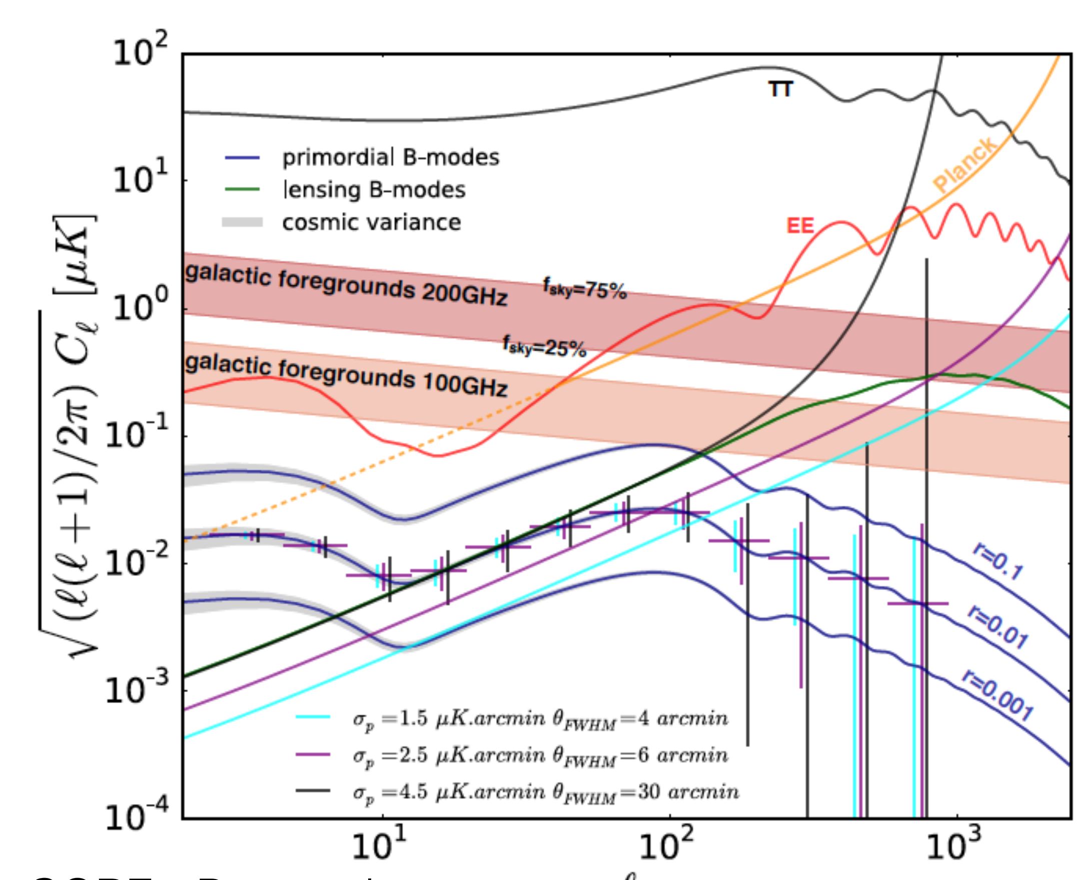
Collaboration BICEP 2014

Residual signal after dust subtraction



Collaborations Planck and BICEP/Keck 2015

A challenging quest



CORE+ Proposal

On-going and future ground-based, balloons and space projects hope to improve the present limit on the amplitude of primordial gravity waves by two orders of magnitude

➡ Separation between CMB and Galactic polarization is a BIG challenge, which relates the search of primordial B-modes to cosmic magnetism

➡ Presentation Marian Douspis: CMB road-map

Magnetic fields are the hidden (*dark*) agent of baryon physics across the universe

Two outstanding questions:

★The origin of cosmic magnetic fields

★Their role in the formation of galaxies, stars and planets

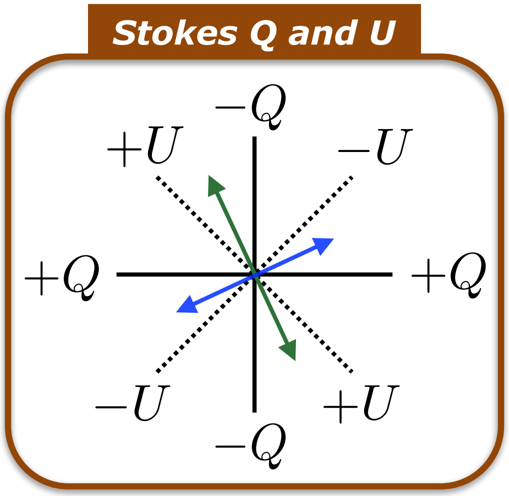
➡ Interstellar MHD turbulence is a main facet of cosmic magnetism

Interstellar MHD Turbulence

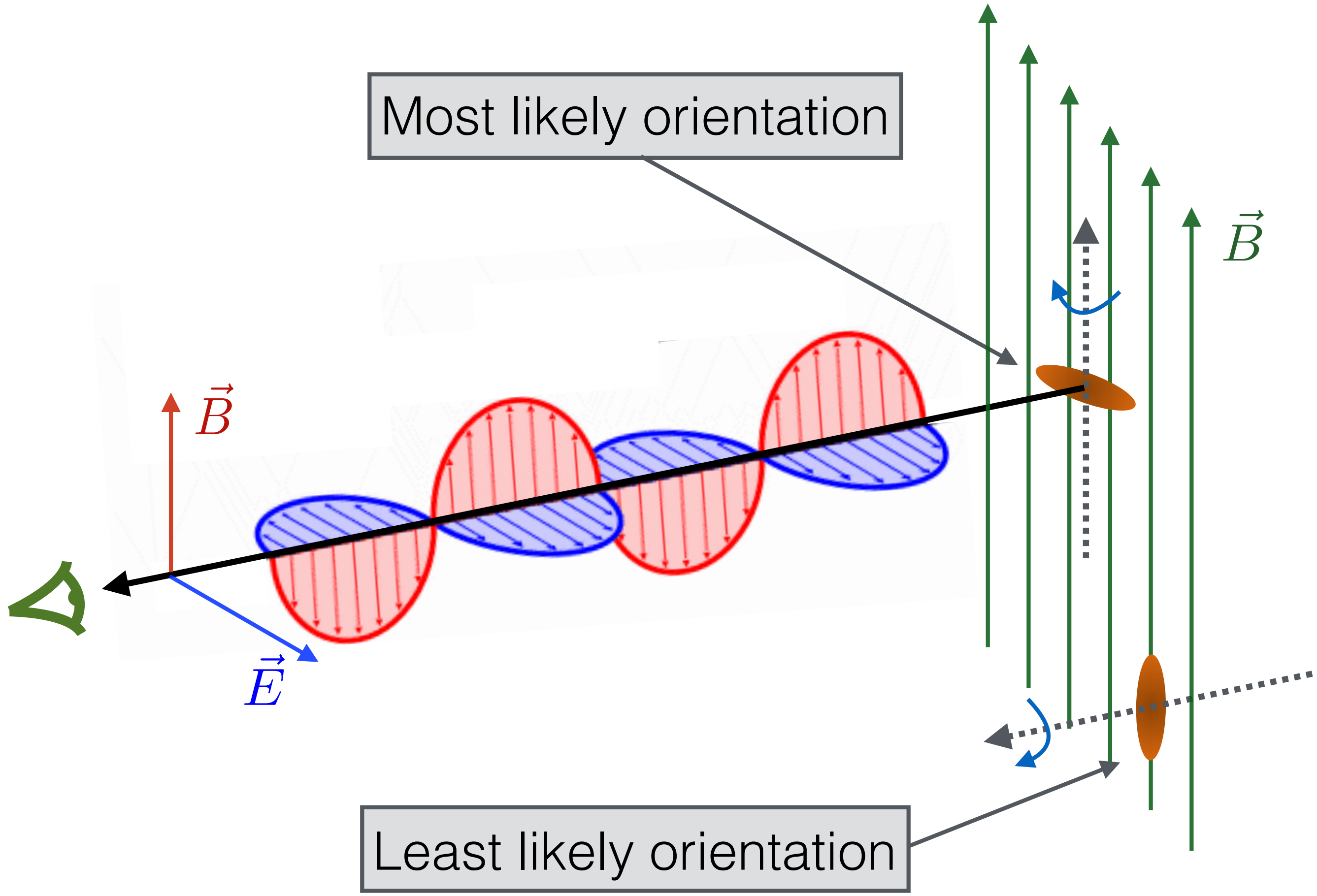
- ★Energy equipartition is observed between kinetic and magnetic energy over a range of scales: in galaxies, the diffuse ISM and star forming molecular clouds
- ★Interstellar MHD turbulence creates a range of density structures in interstellar matter and locally the initial conditions for star formation
- ★It drives the mass, momentum and energy exchange among ISM phases
- ★The structure of the magnetic field is key to the propagation of cosmic rays

➡ Observations provide access to the structure of magnetic field, and its correlation with the density and velocity structure of the gas

Polarized thermal dust emission essentials



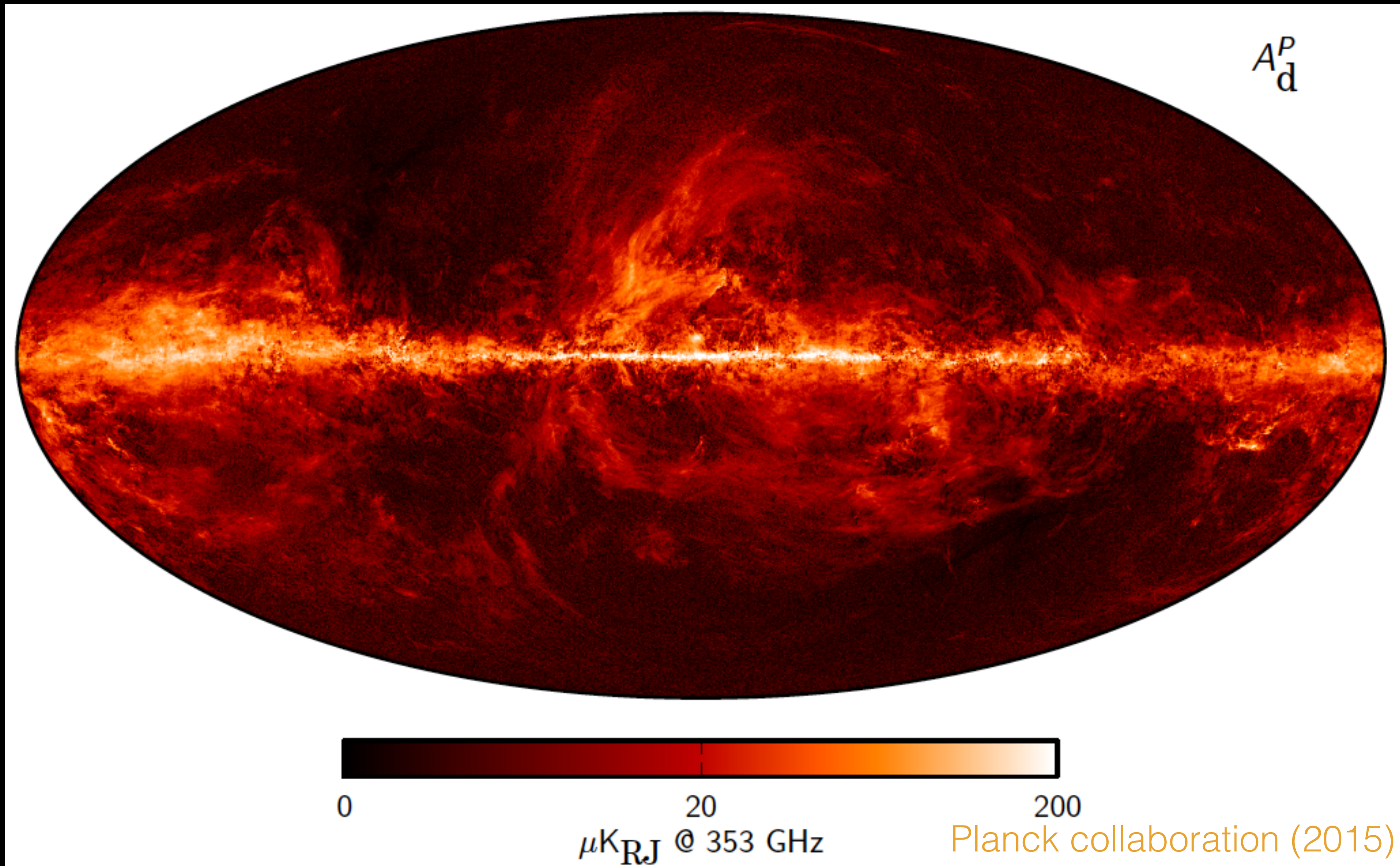
Polarization orientation
Magnetic field orientation



- 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

Credit F. Levrier

Polarized dust emission

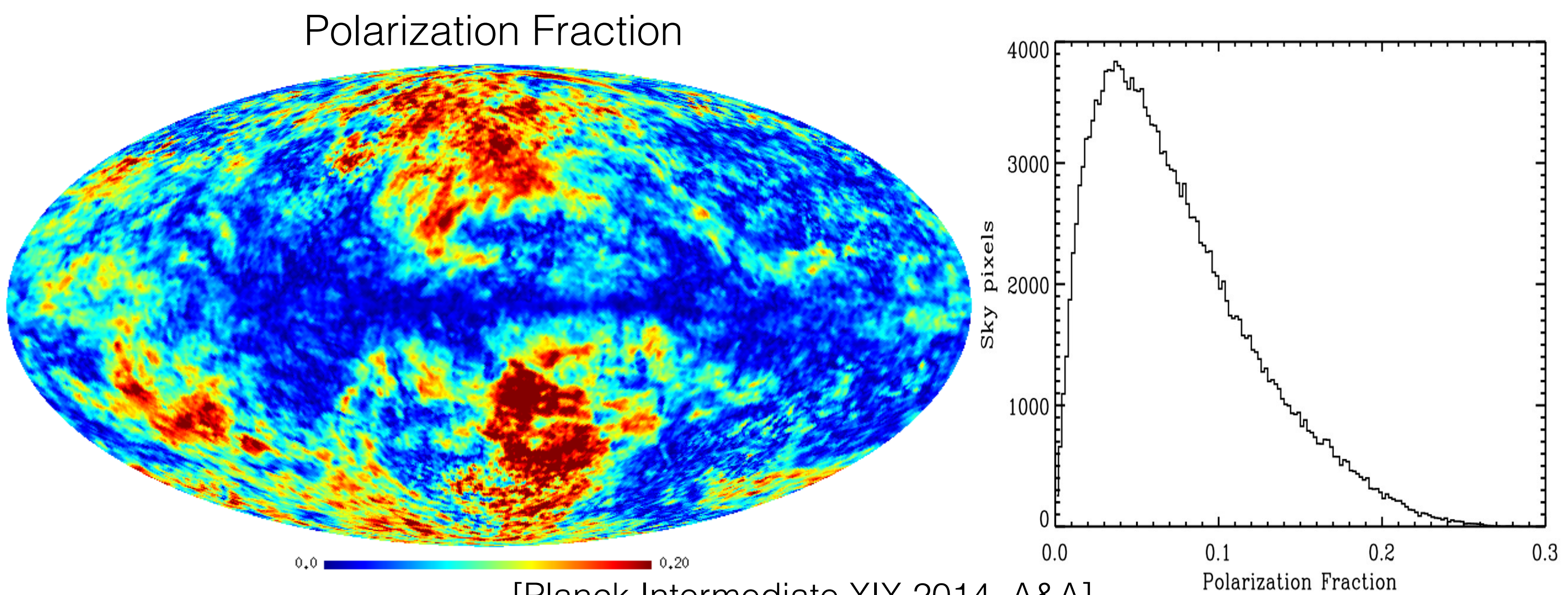


Planck collaboration (2015)

First all-sky image of dust polarization

➡ Structure of the Galactic magnetic field

Polarization Fraction



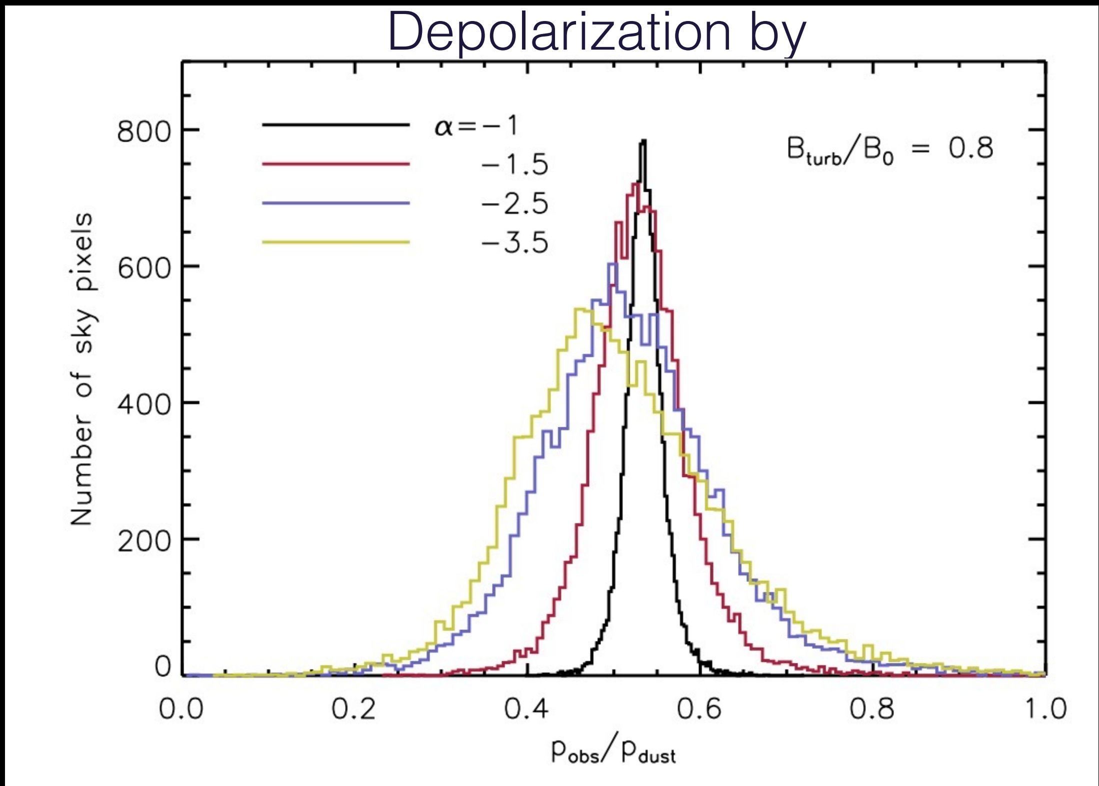
[Planck Intermediate XIX 2014, A&A]

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

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

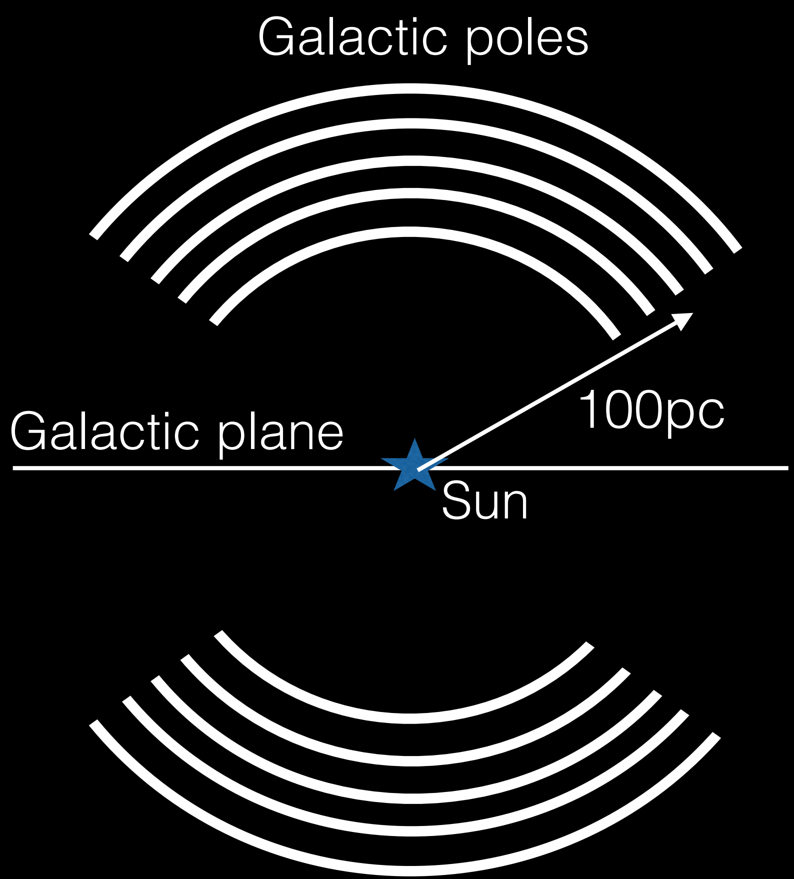


★The correlation length of turbulence λ increases with the spectral index α of magnetic turbulence.

★ 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



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

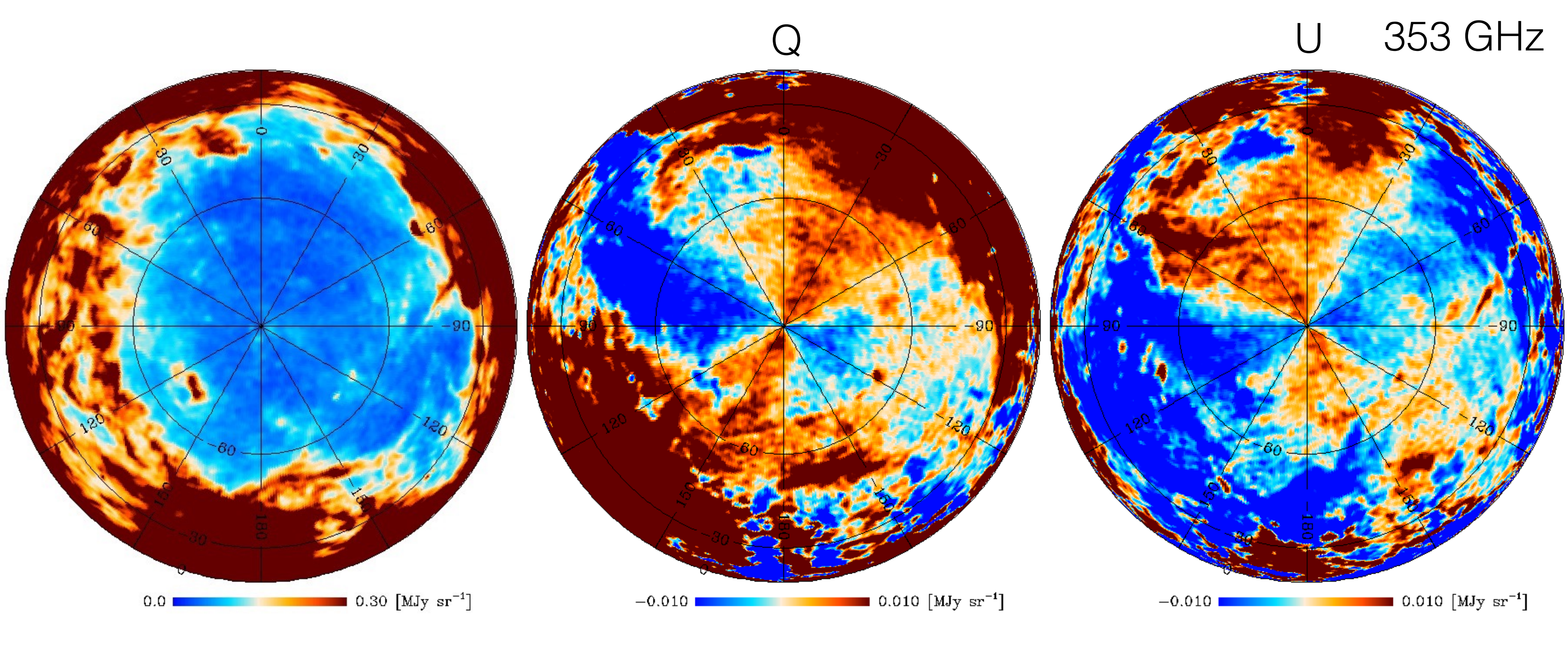
★The mean field is characterized by a fixed orientation (l_0 and b_0)

★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.

Mean Magnetic Field

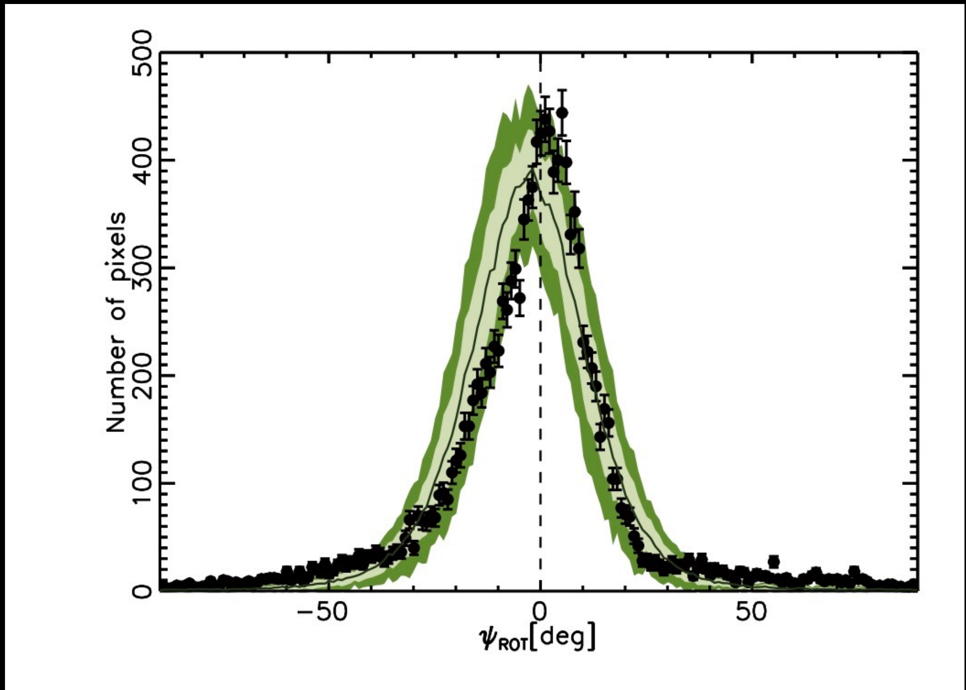
Planck data towards southern Galactic cap

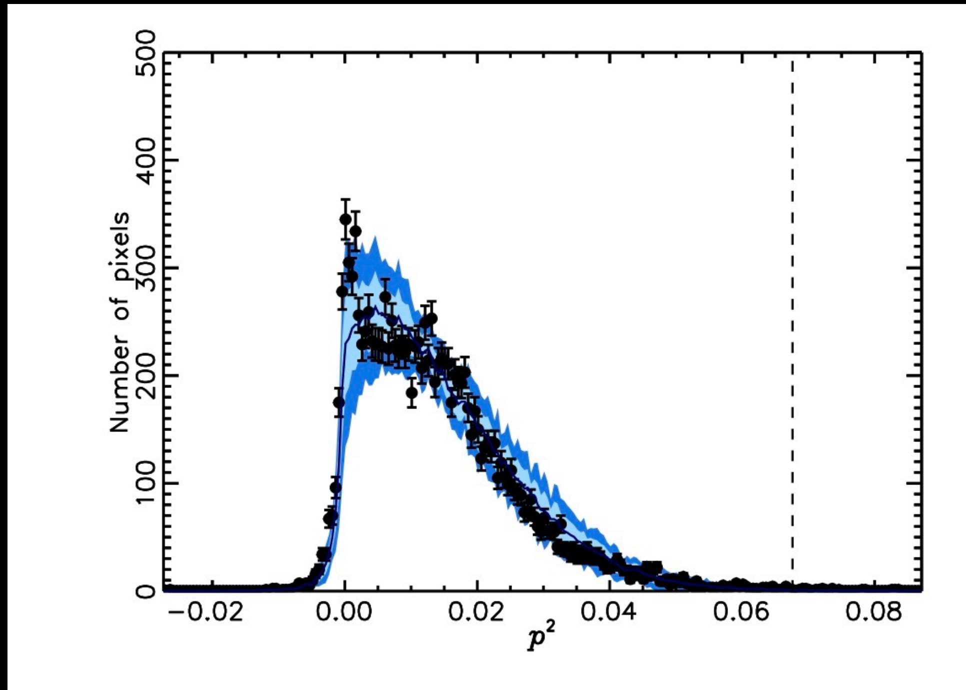


- Polarization patterns towards Galactic caps allow us to measure the direction of the mean magnetic field in the Solar Neighborhood

Bracco - PhD 2014, Université Paris-Sud, Orsay

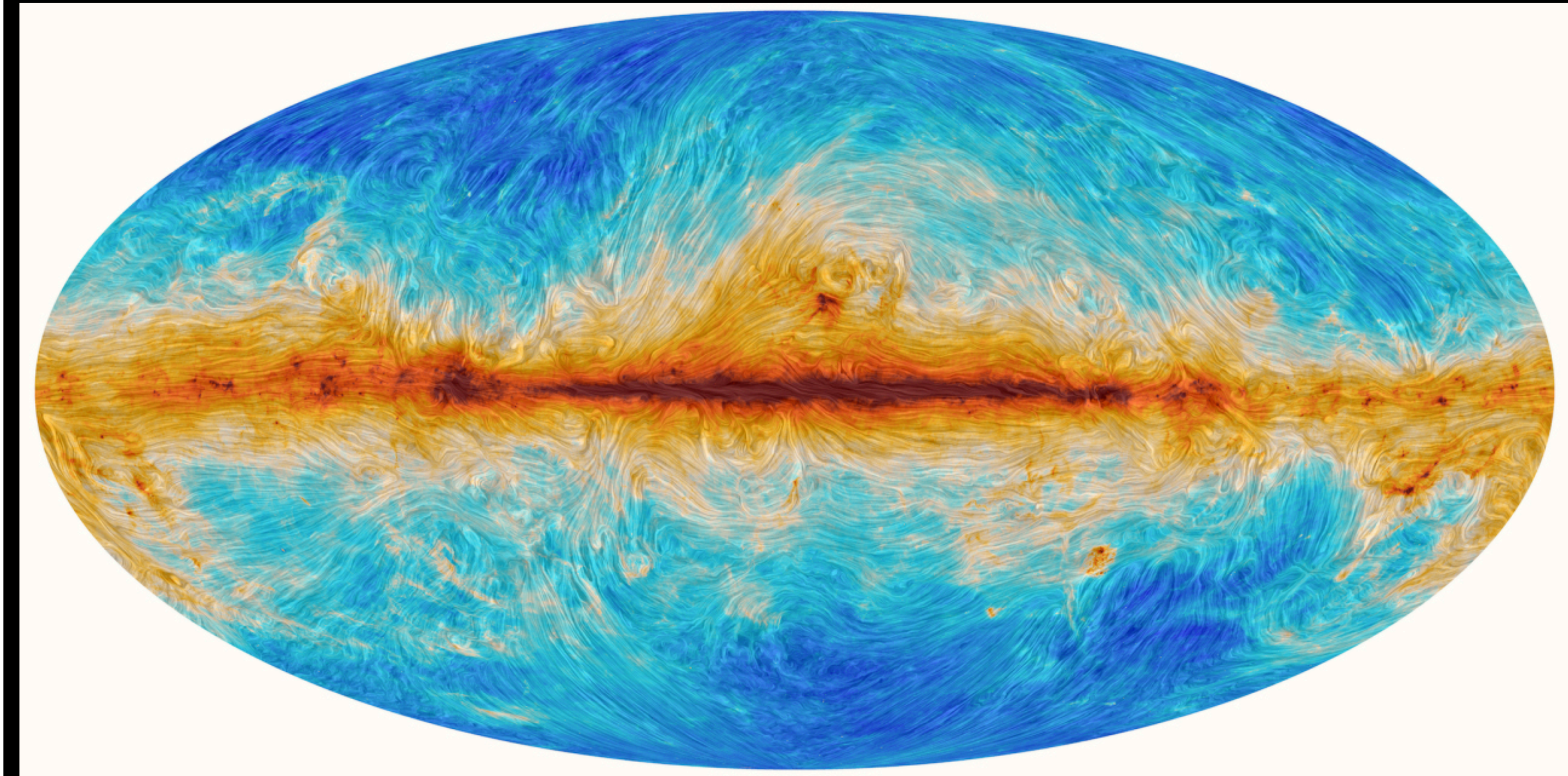
Histograms of polarization angle and fraction





- 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

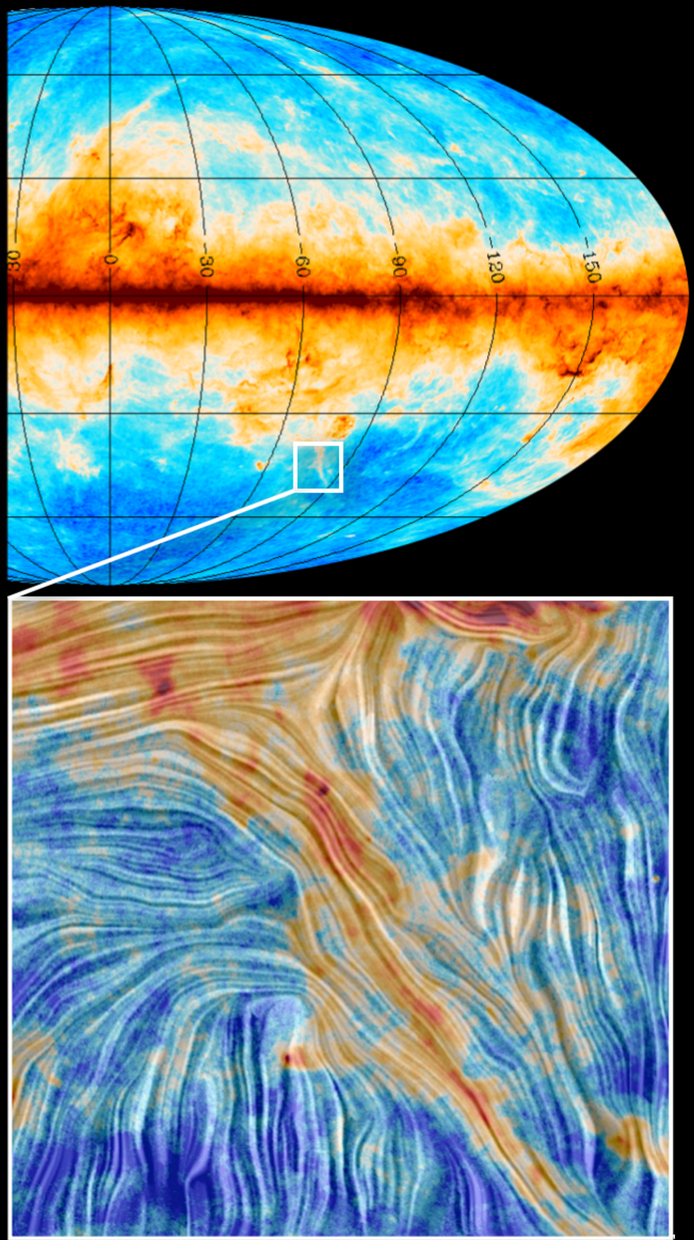
Magnetic field and ISM structure



Planck intensity map with B-field lines inferred from dust polarization overlaid

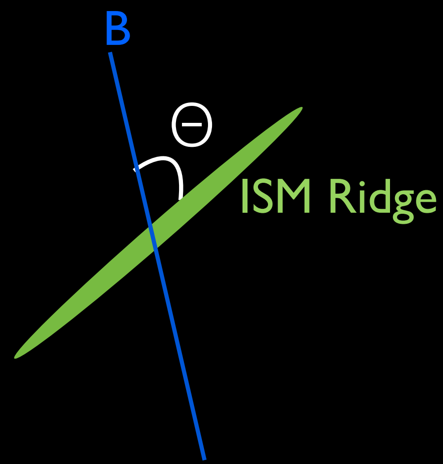
The filamentary structure of matter

[Planck Intermediate XXXII 2014, arXiv:1409.6728]



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

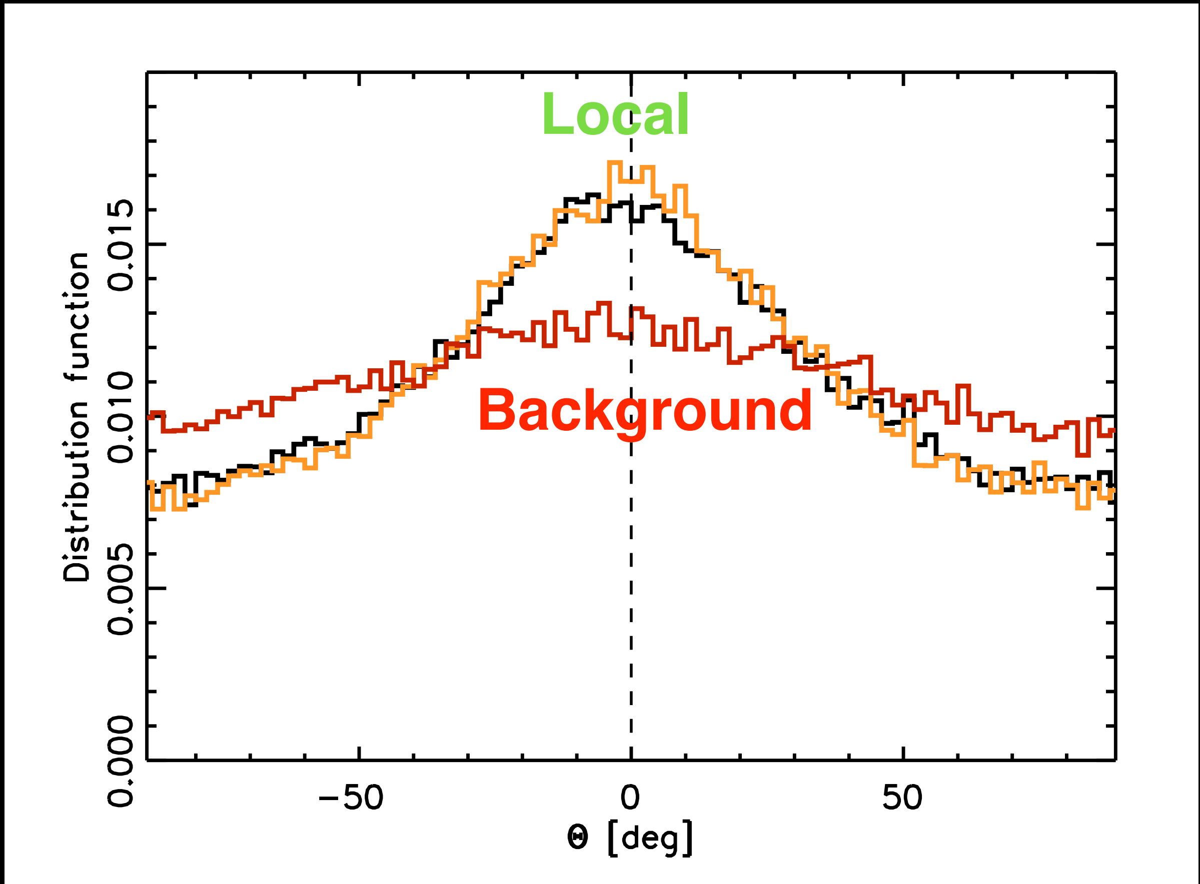
The filamentary structure of the interstellar medium

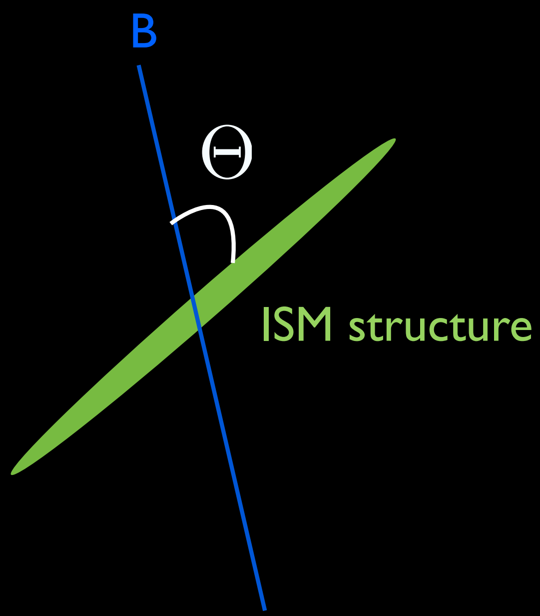


In the diffuse ISM we observe an alignment of the filamentary structures with the magnetic field orientation

Alignment with magnetic Field

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

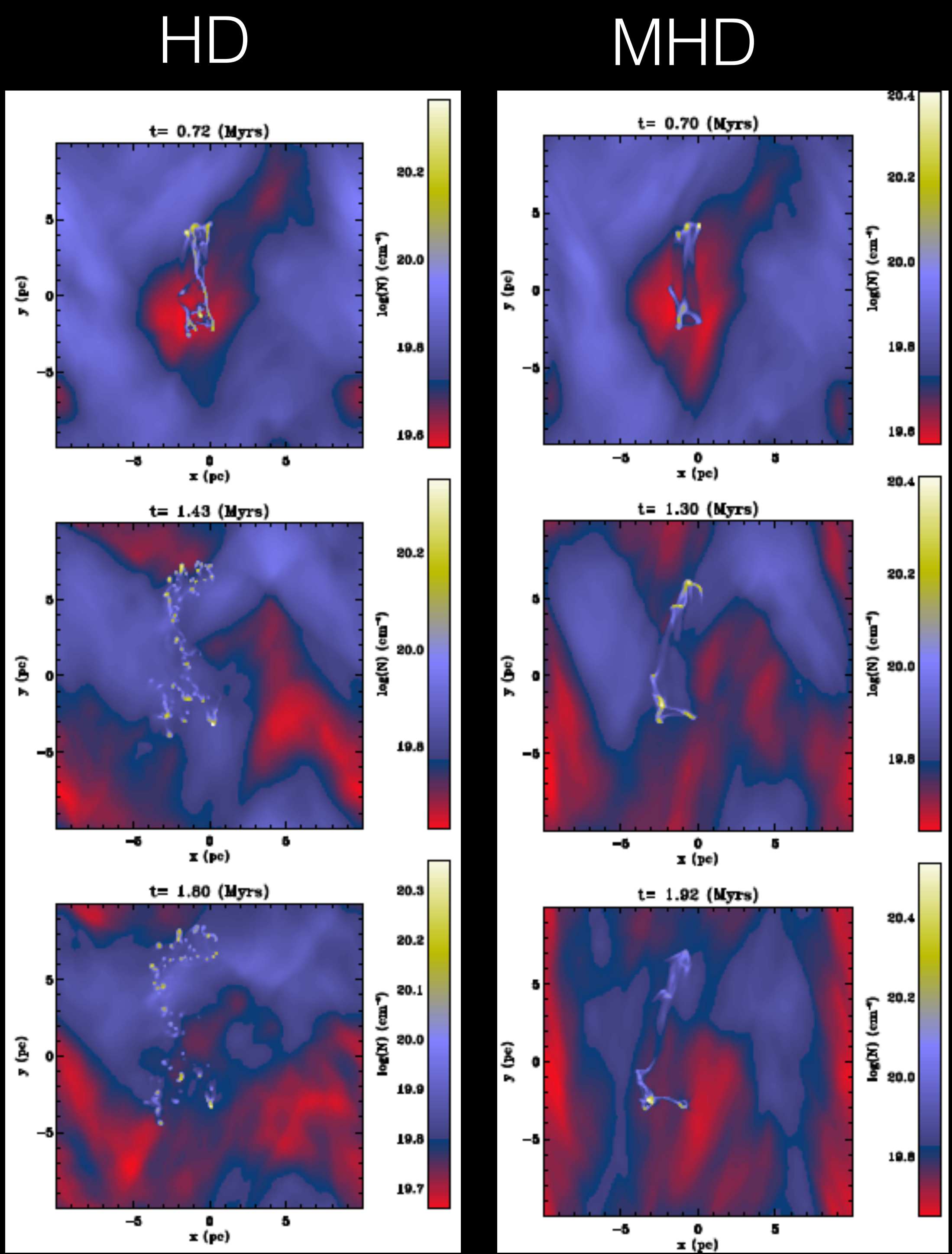




The structures tend to be aligned with the local magnetic field

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

Formation of a filament through shear

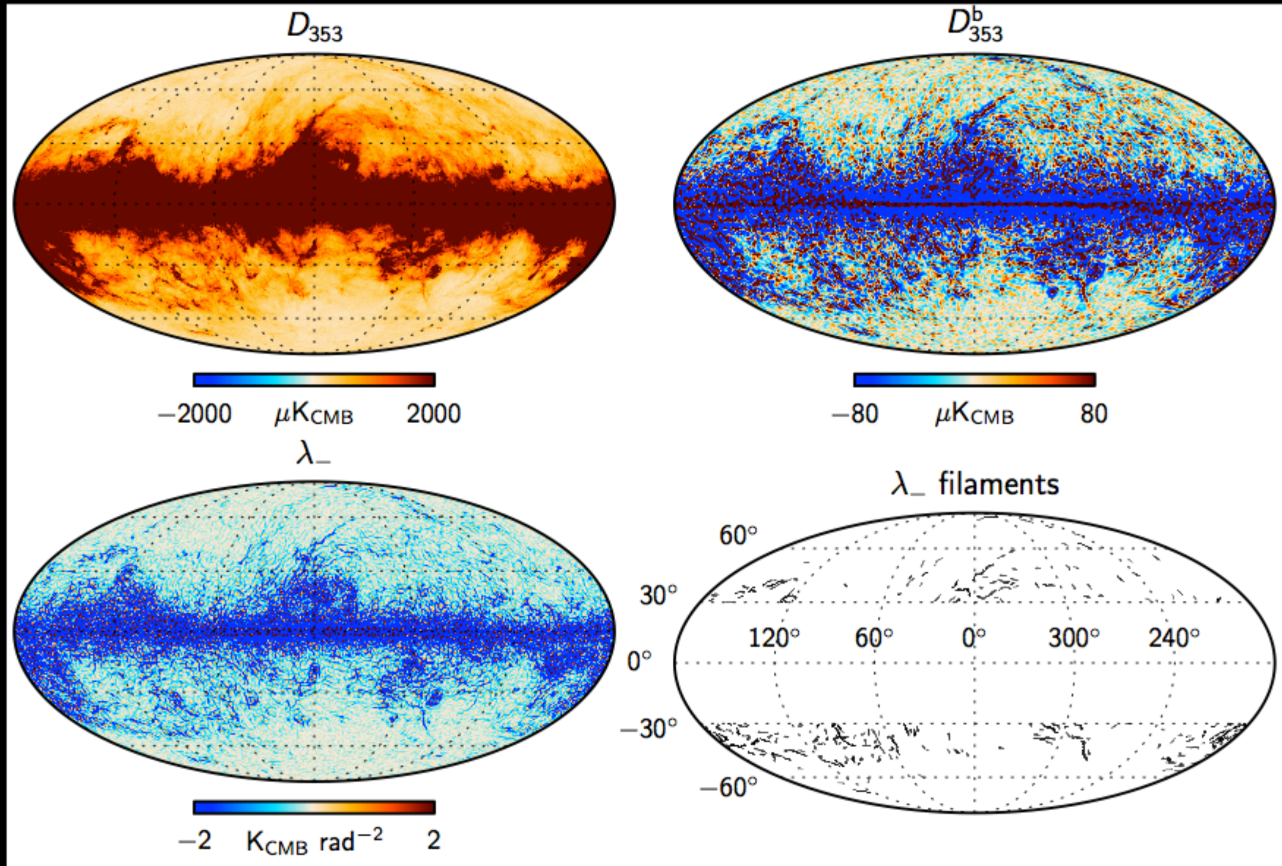


Hennebelle 2013

★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.

E/B asymmetry



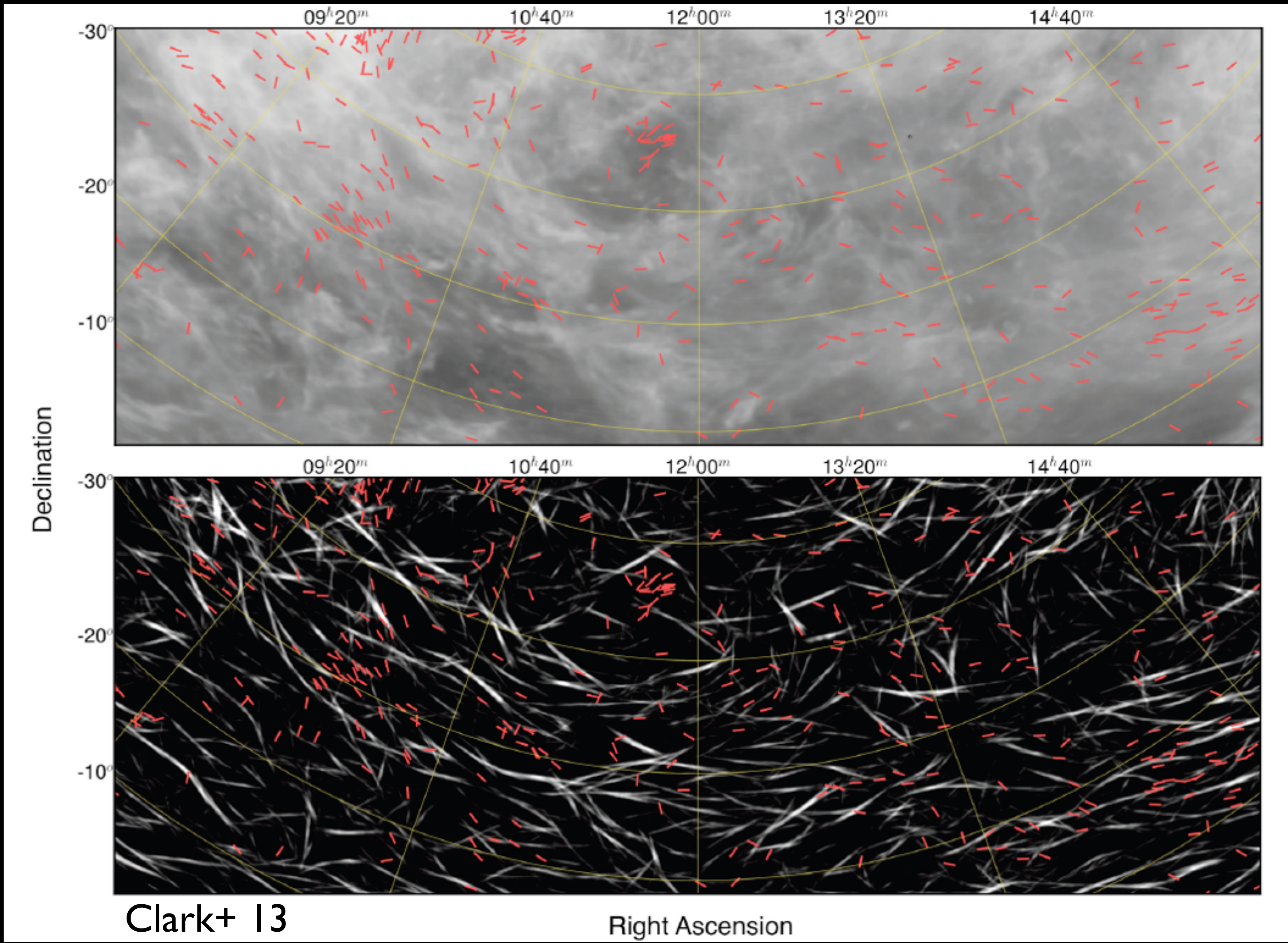
Planck XXXVIII 2015, arXiv 1505.02779

★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

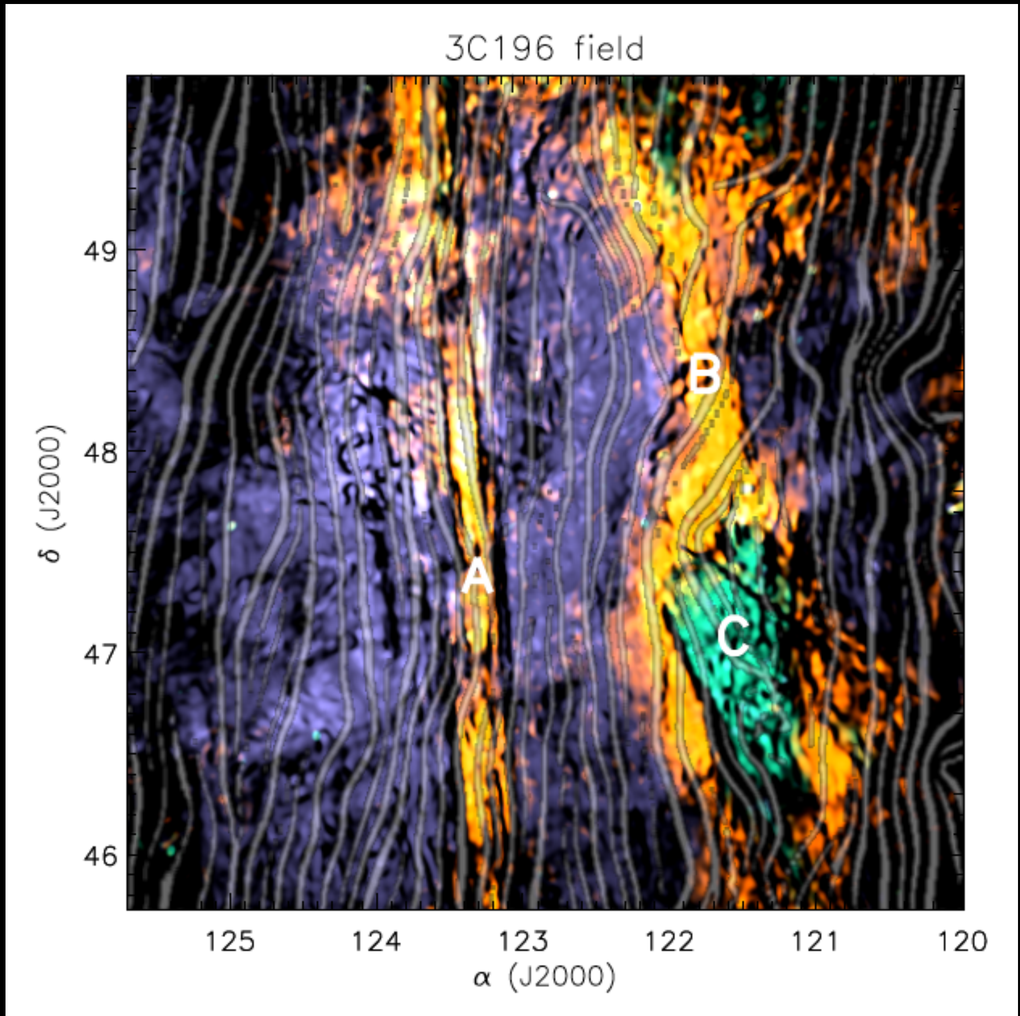


HI GASS map
16' resolution

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 major imprint on the variance of dust polarized emission 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

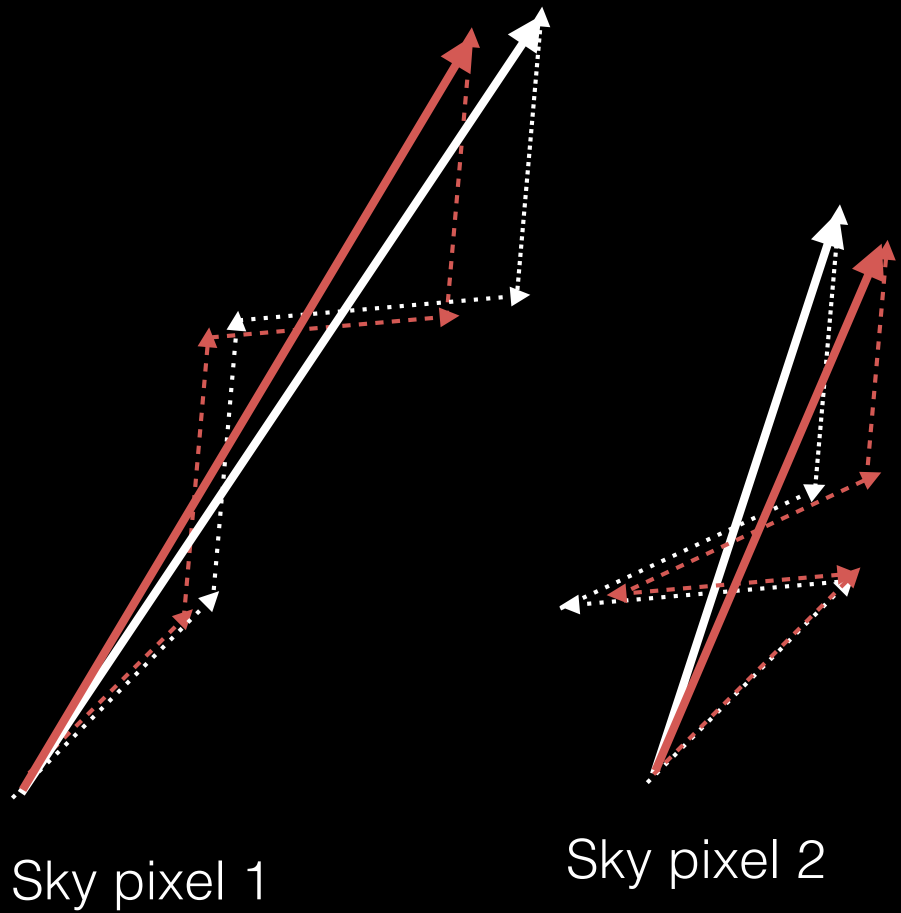
★ Dust polarization properties are likely to differ between the cold (dense) and warm (teneous) gas phases

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

➡ This coupling generates de-correlation 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.

➡How and to what accuracy can component separation algorithms can correct this?

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 goal 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

★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