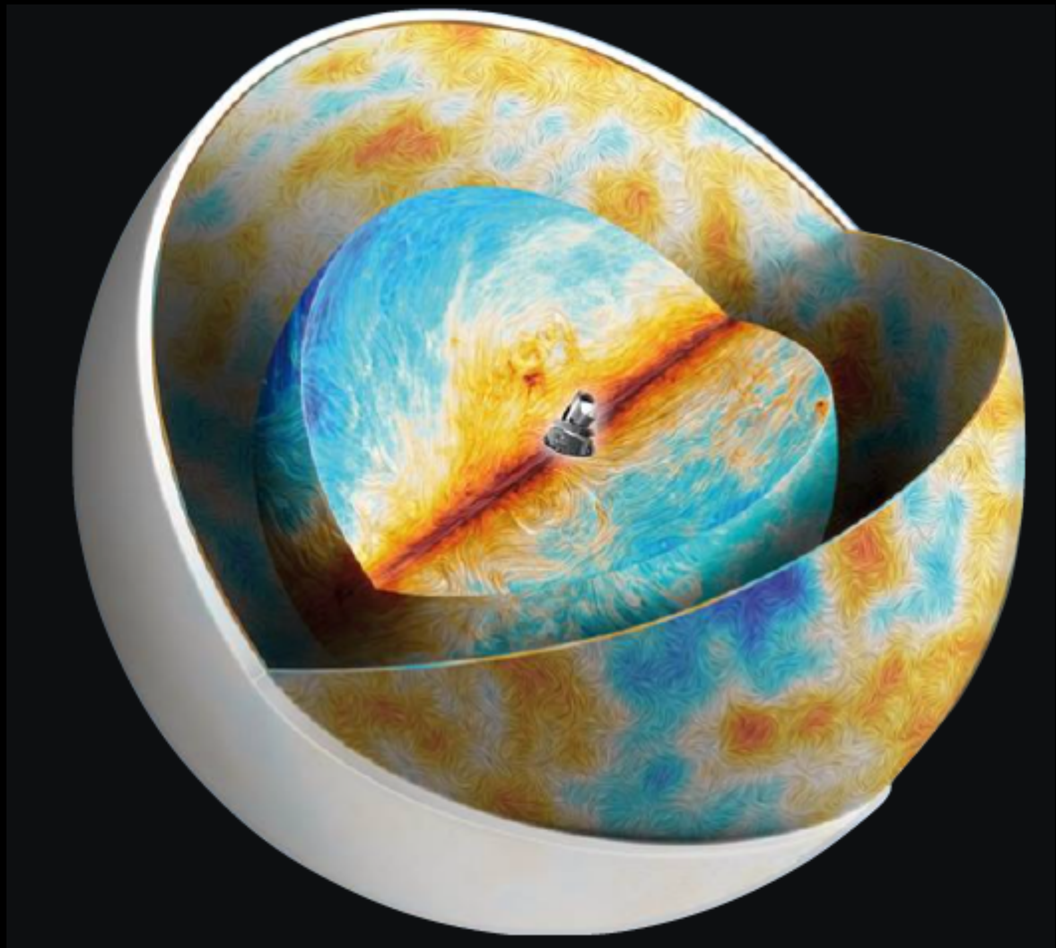
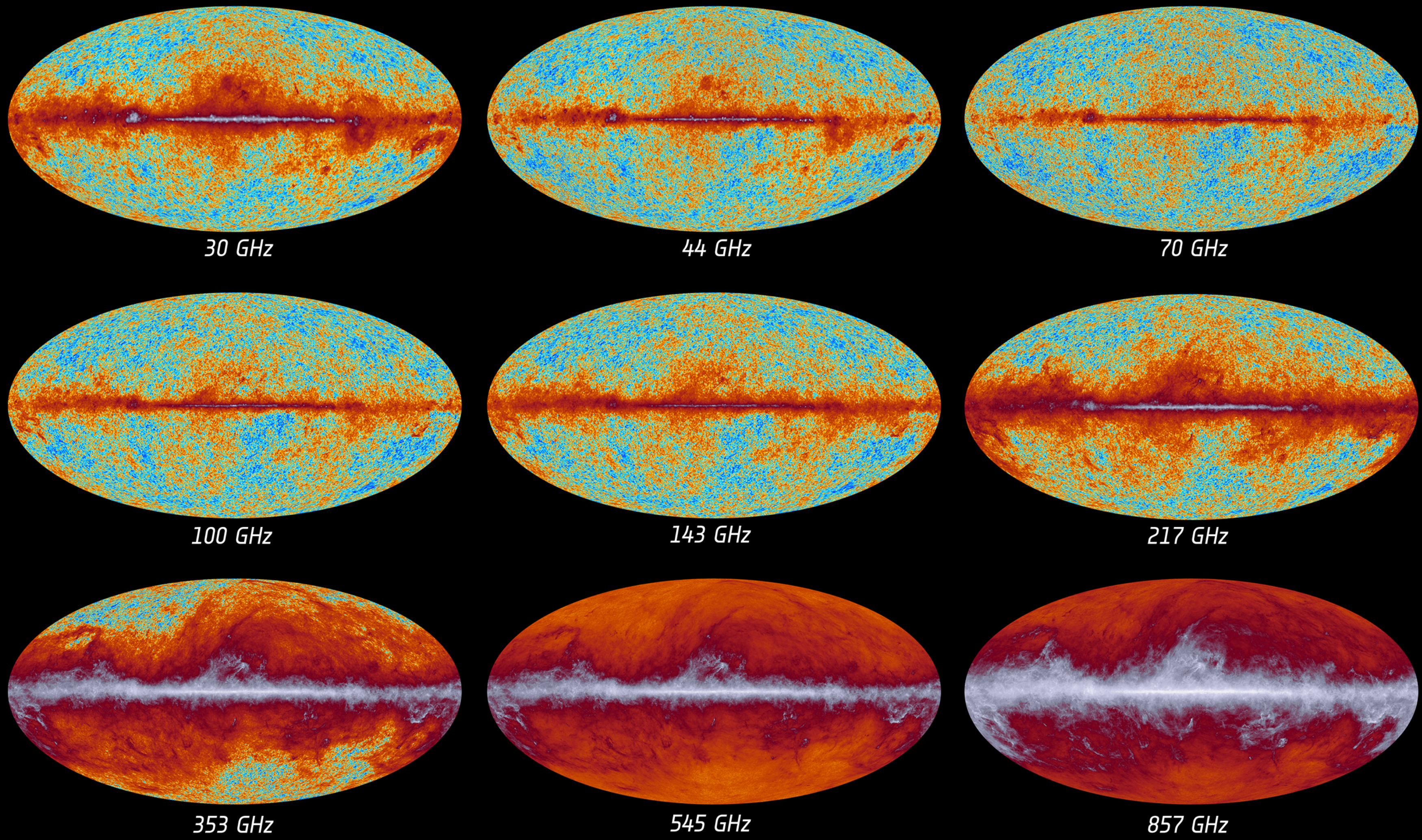
Planck Observations of Galactic polarization



François Boulanger
Institut d'Astrophysique Spatiale

The sky as seen by Planck



Cosmology

- Characterizing and testing the standard Bib-Bang model (ΛCDM)
- Large scale structure of the universe (CMB lensing)
- Hot baryons in clusters and the intergalactic medium (Sunyaev-Zeldovitch effect)
- Cosmic far-infrared background

➡Presentation by Matthieu Tristram

Galactic science

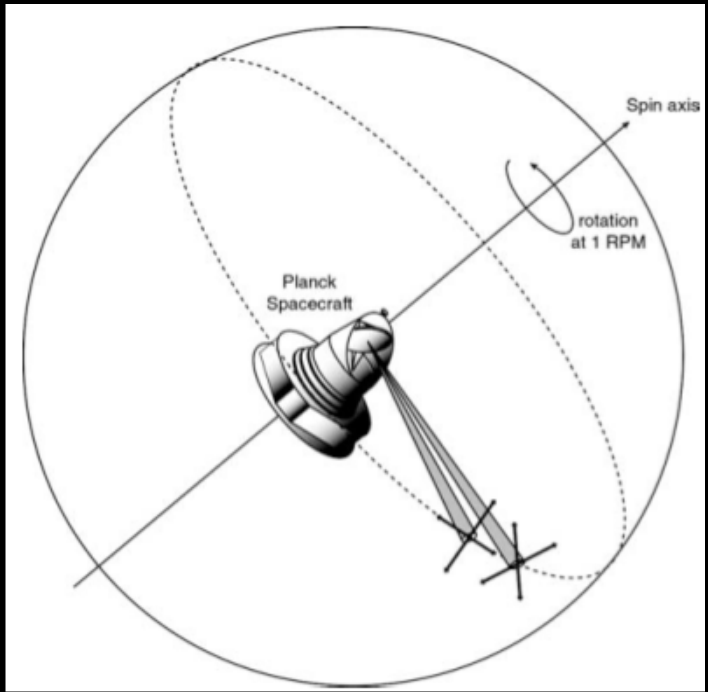
- ISM physics from several emission components: thermal dust, synchrotron, free-free, dipolar emission from small dust particules, CO line emission

Main focus on polarization data

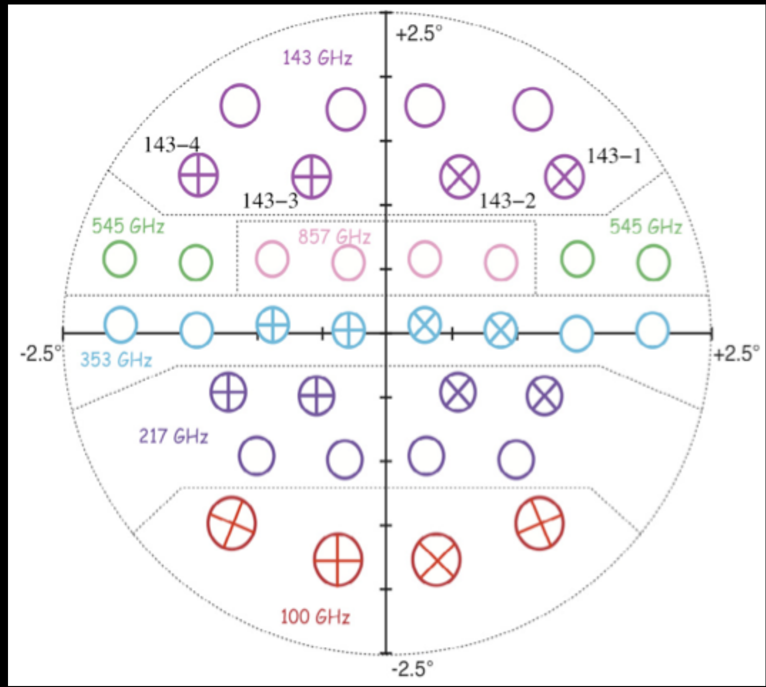
- Galactic magnetic field
- Dust polarization properties

From data to Stokes parameters

Planck scanning the sky



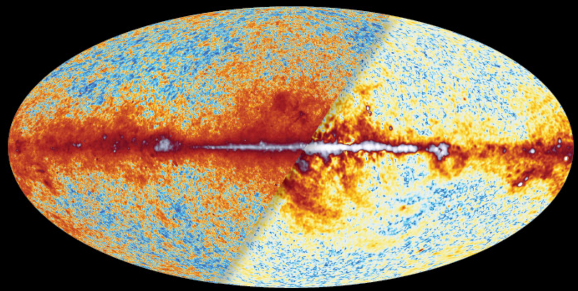
Planck/HFI focal plane



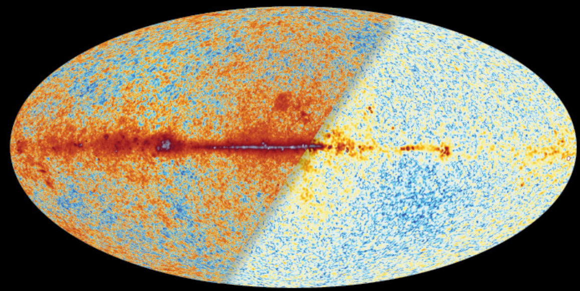
★Multiple scans and multiple surveys provide measurements with different orientations of polarization sensitive bolometers.

★Maps of I, Q and U, and their standard deviations, are inferred from the multiple measurements.

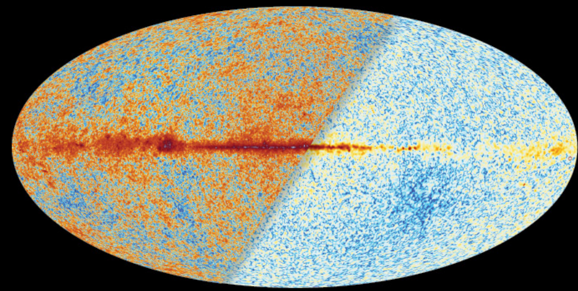
Intensity / Polarization Sky



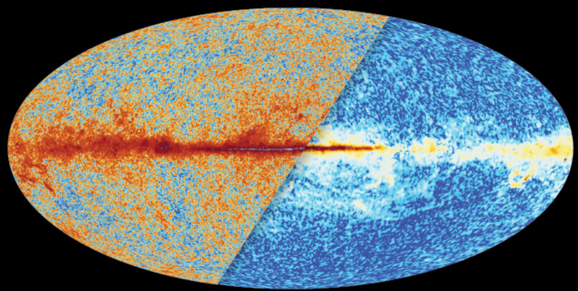
30 GHz



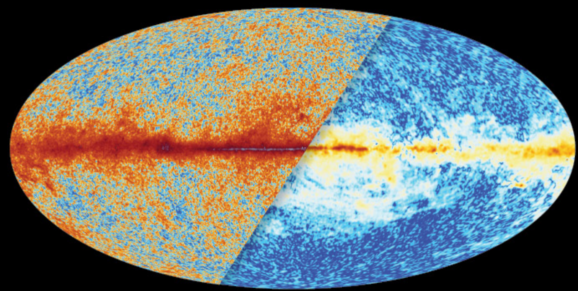
44 GHz



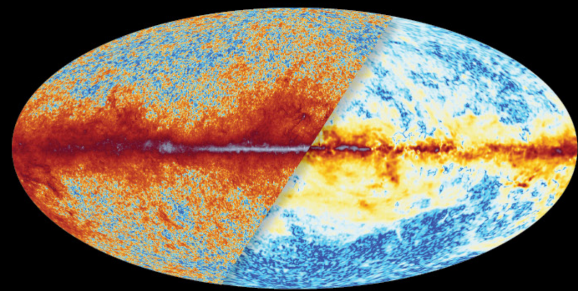
70 GHz



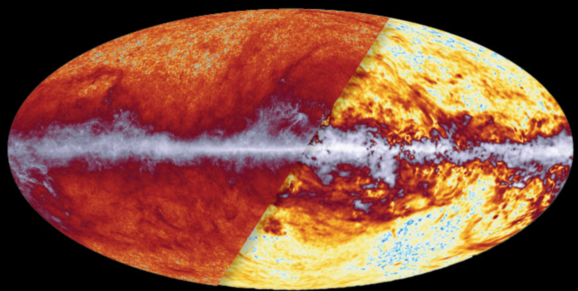
100 GHz



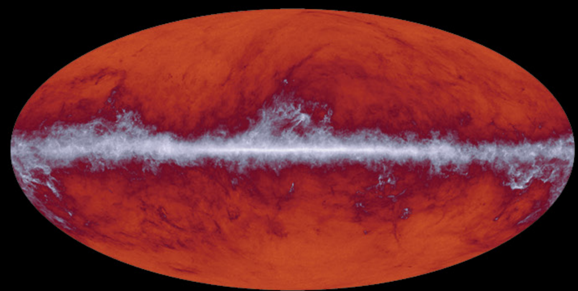
143 GHz



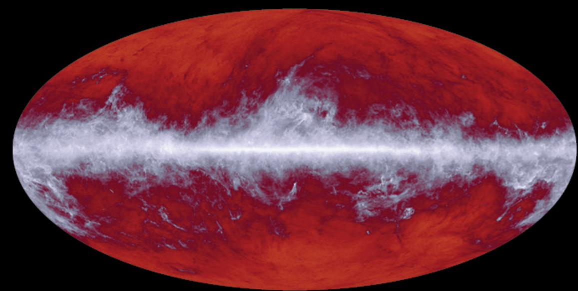
217 GHz



353 GHz

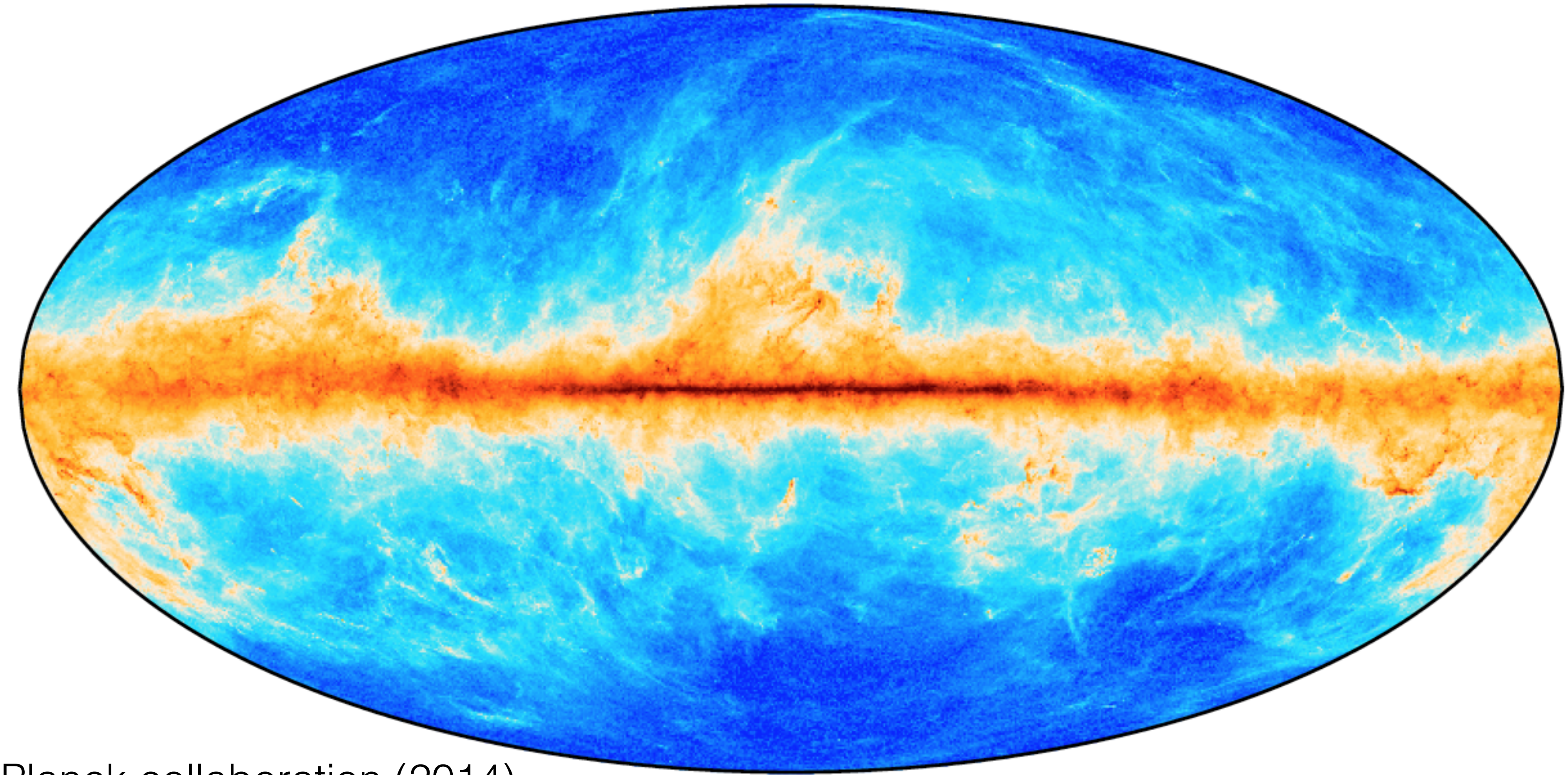


545 GHz



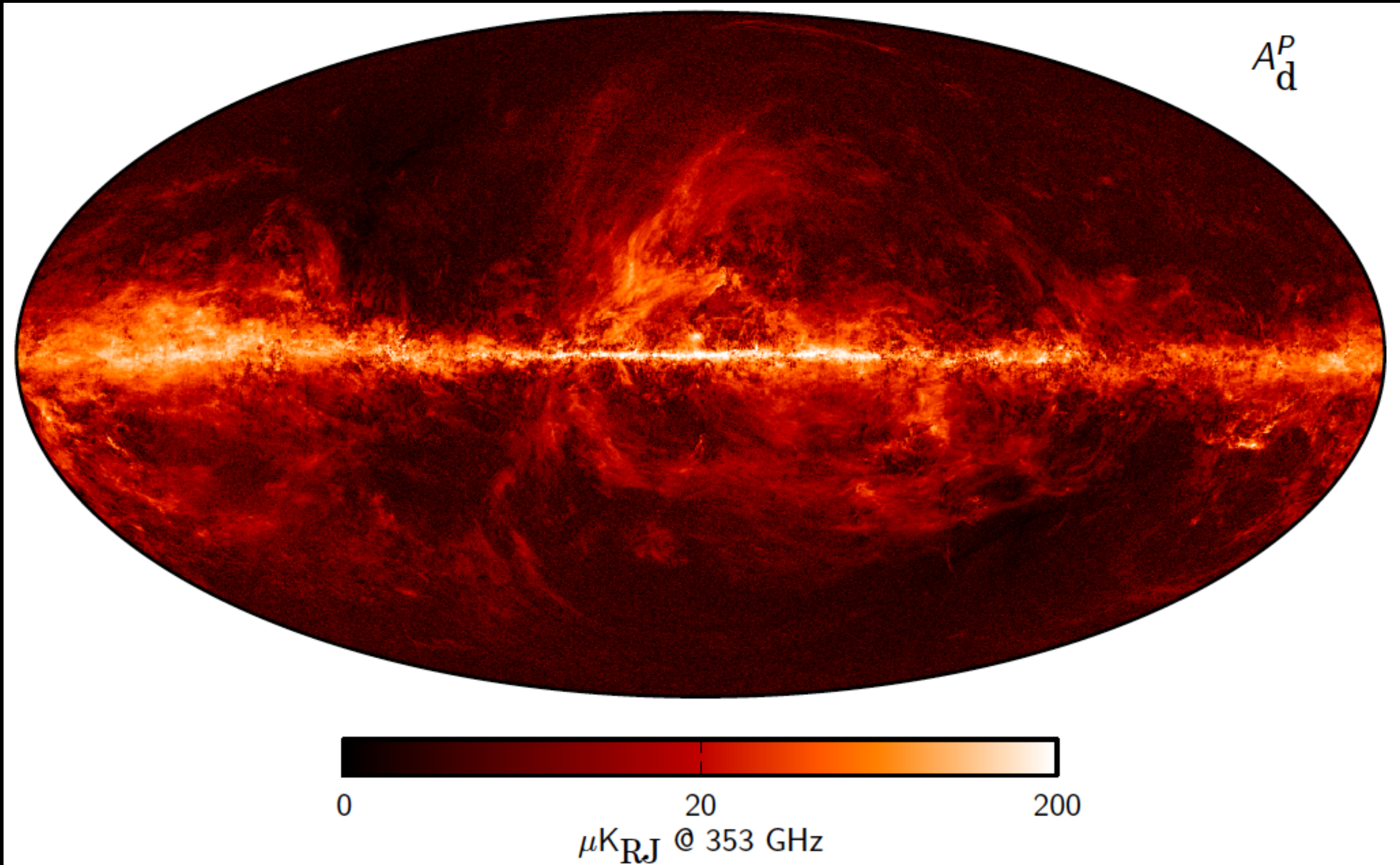
857 GHz

Dust opacity traces dust mass



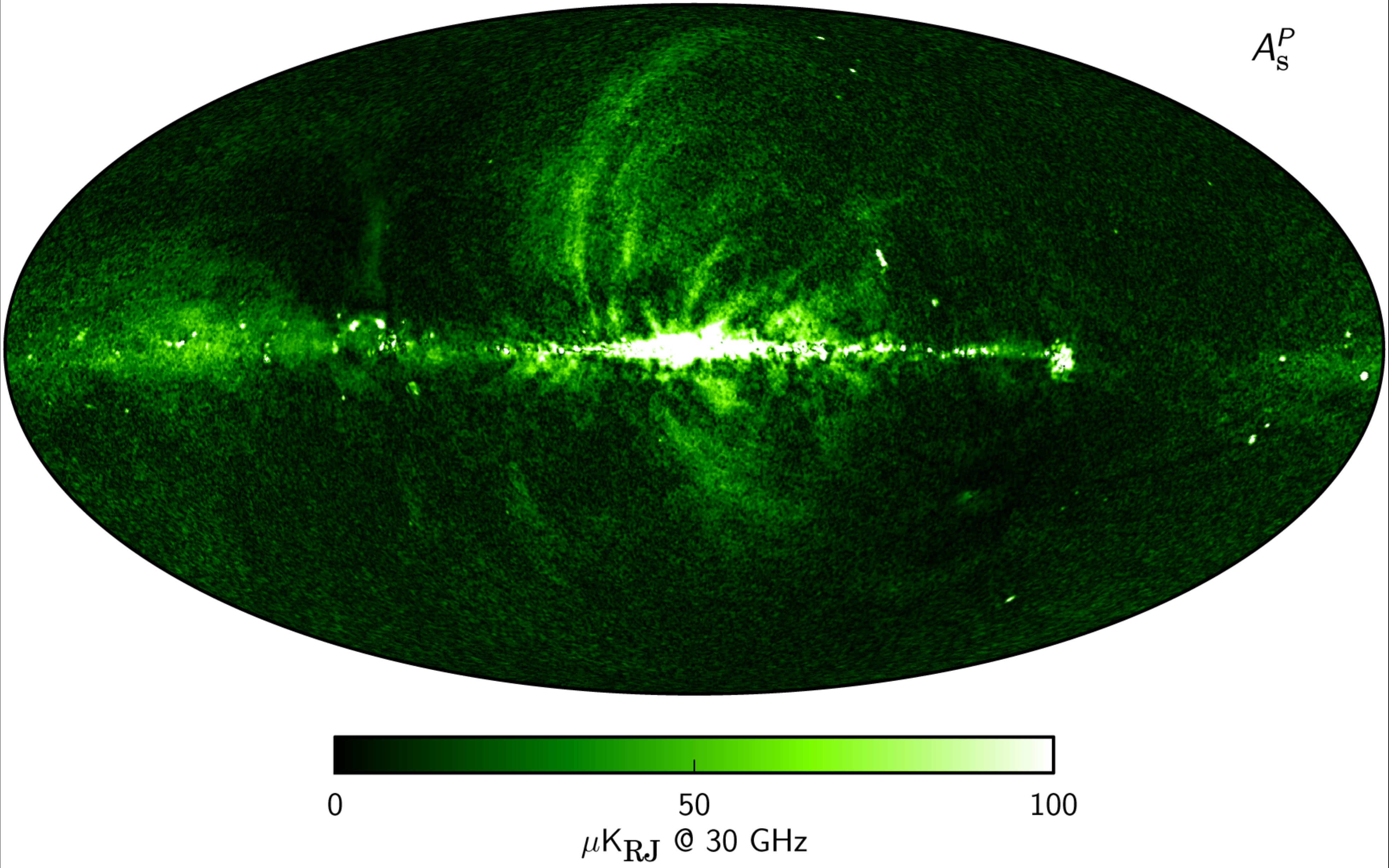
Planck collaboration (2014)

Polarized dust emission

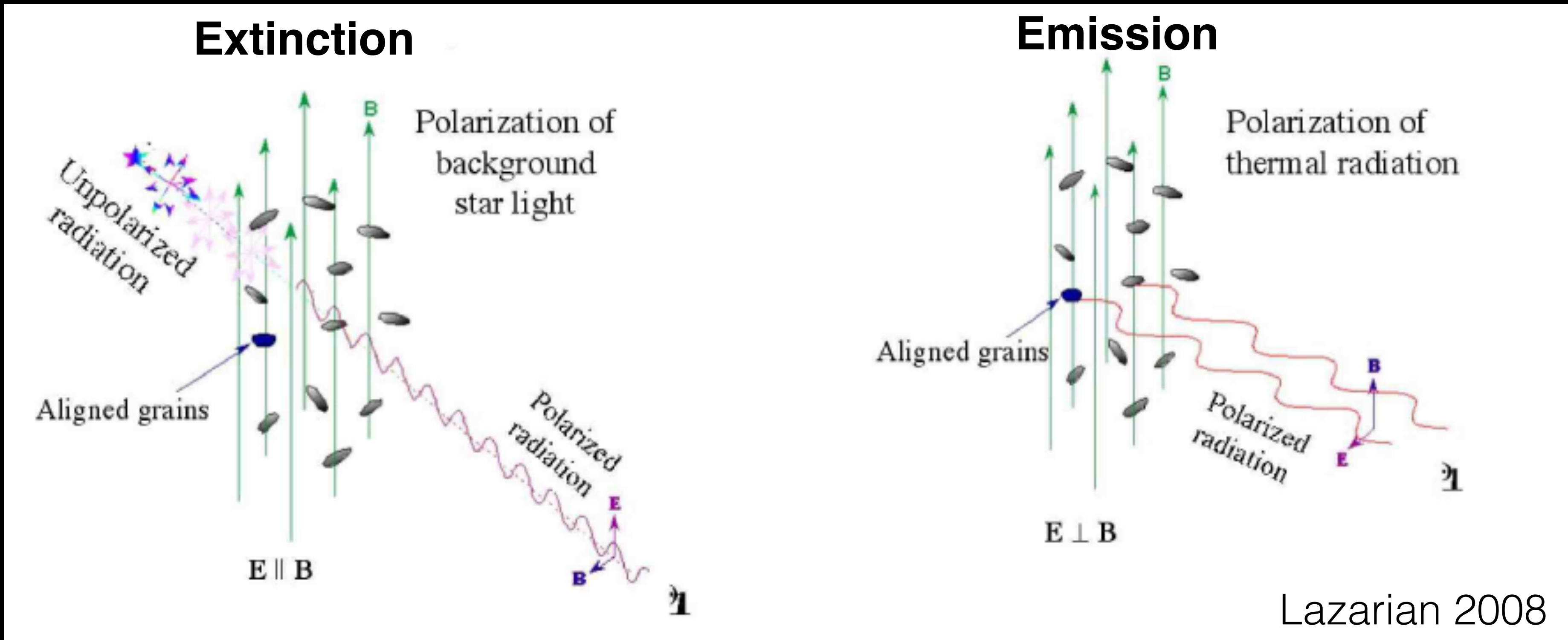


Planck collaboration (2015)

Synchrotron Polarization

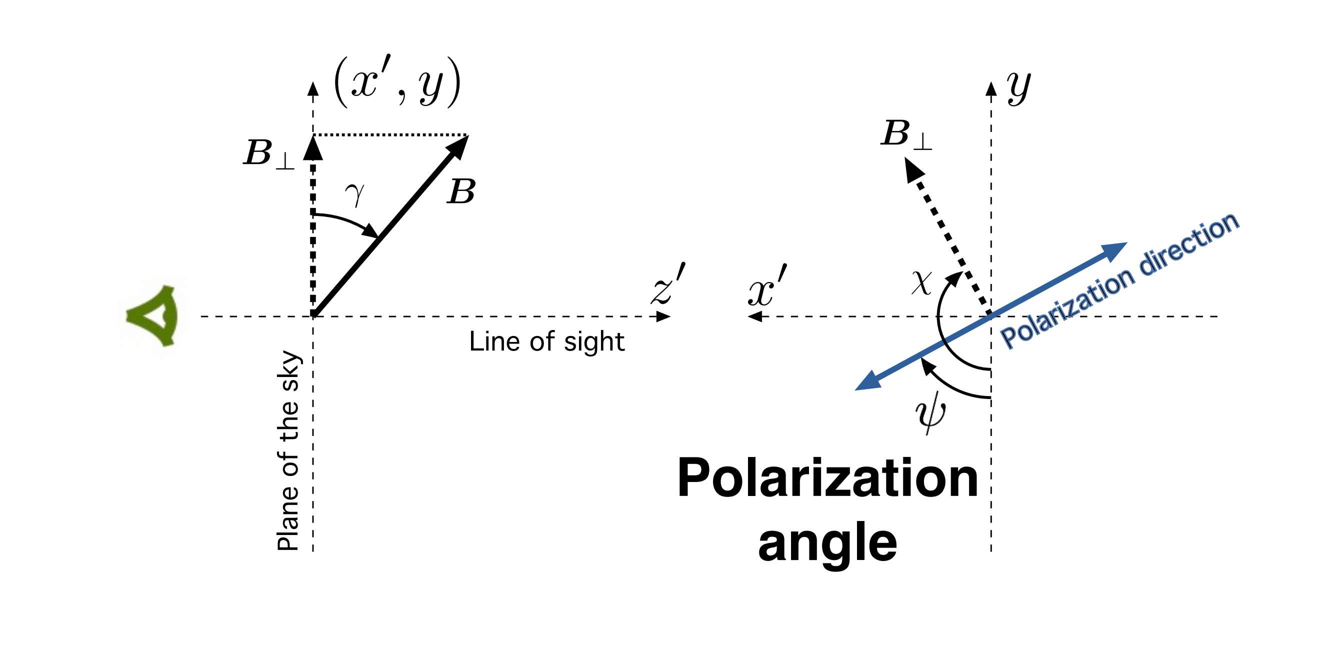


Dust Polarization



- ★Interstellar grains spin around their axis of maximal inertia. Their rotation axis precesses around the magnetic field lines.
- ★Polarization results from grain alignment with the Galactic magnetic field
- ★To the extent that grain polarization properties are homogeneous, dust polarization tracks the magnetic field structure.

What are we measuring?



$$
\begin{aligned}
Q &= \int p_{\max} R \, cos(2\psi) \, cos^2\gamma \, dI \\
U &= -\int p_{\max} R \, sin(2\psi) \, cos^2\gamma \, dI
\end{aligned}
$$

$$
\begin{aligned}
P &= (Q^2 + U^2)^{0.5} \\
p &= P/I \\
\psi &= 0.5 \arctan(-U, Q)
\end{aligned}
$$

Polarization fraction

$$
\begin{aligned}
p &= p_{\max} \, R \, F \, cos^2\gamma \\
R &\quad \text{and} \; F \leq 1
\end{aligned}
$$

R: Rayleigh reduction factor (efficiency of grain alignment)

F: Depolarization factor (change of B orientation within the beam and along the line of sight)

What are we studying?

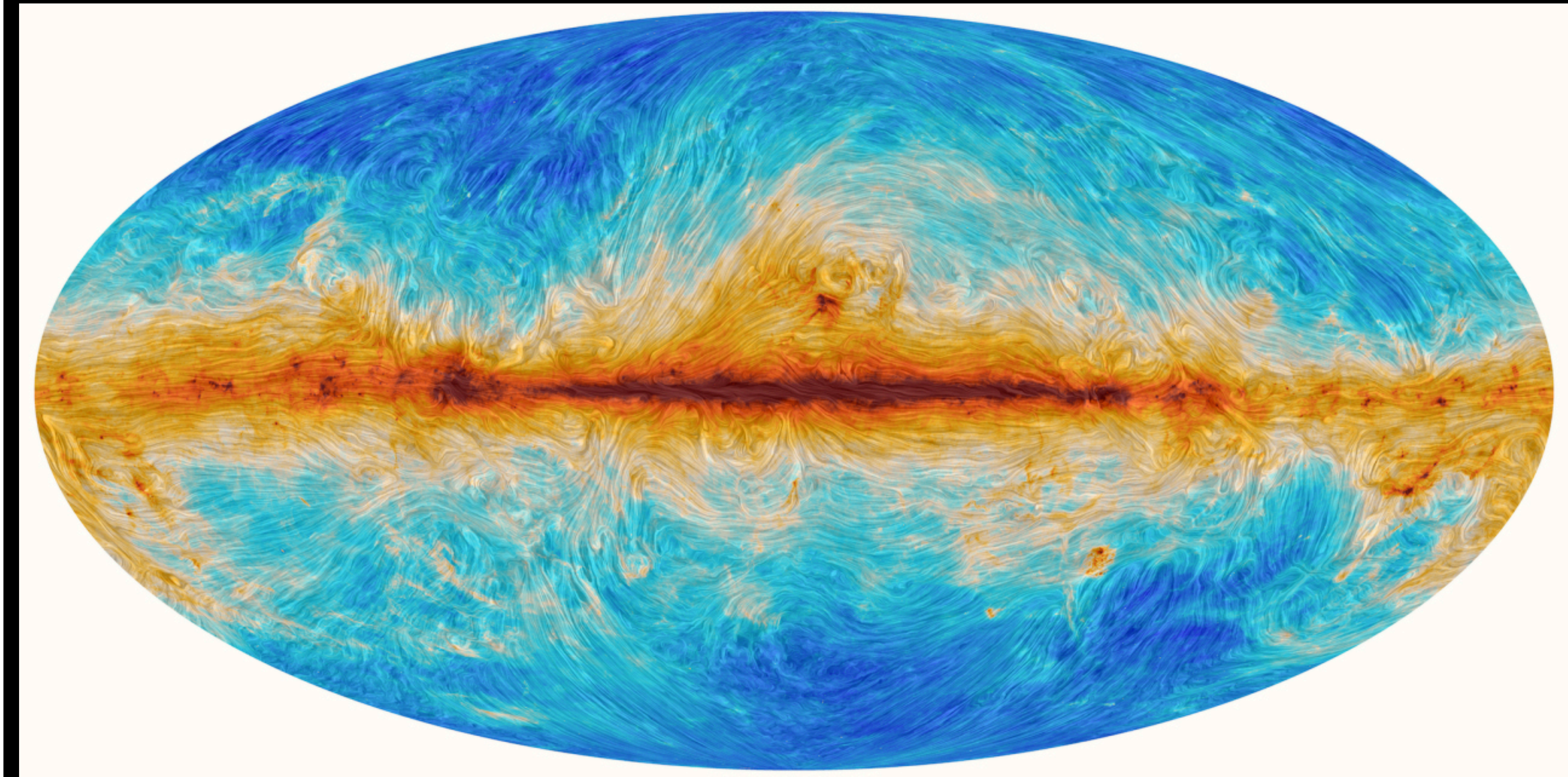
★Magnetic field structure

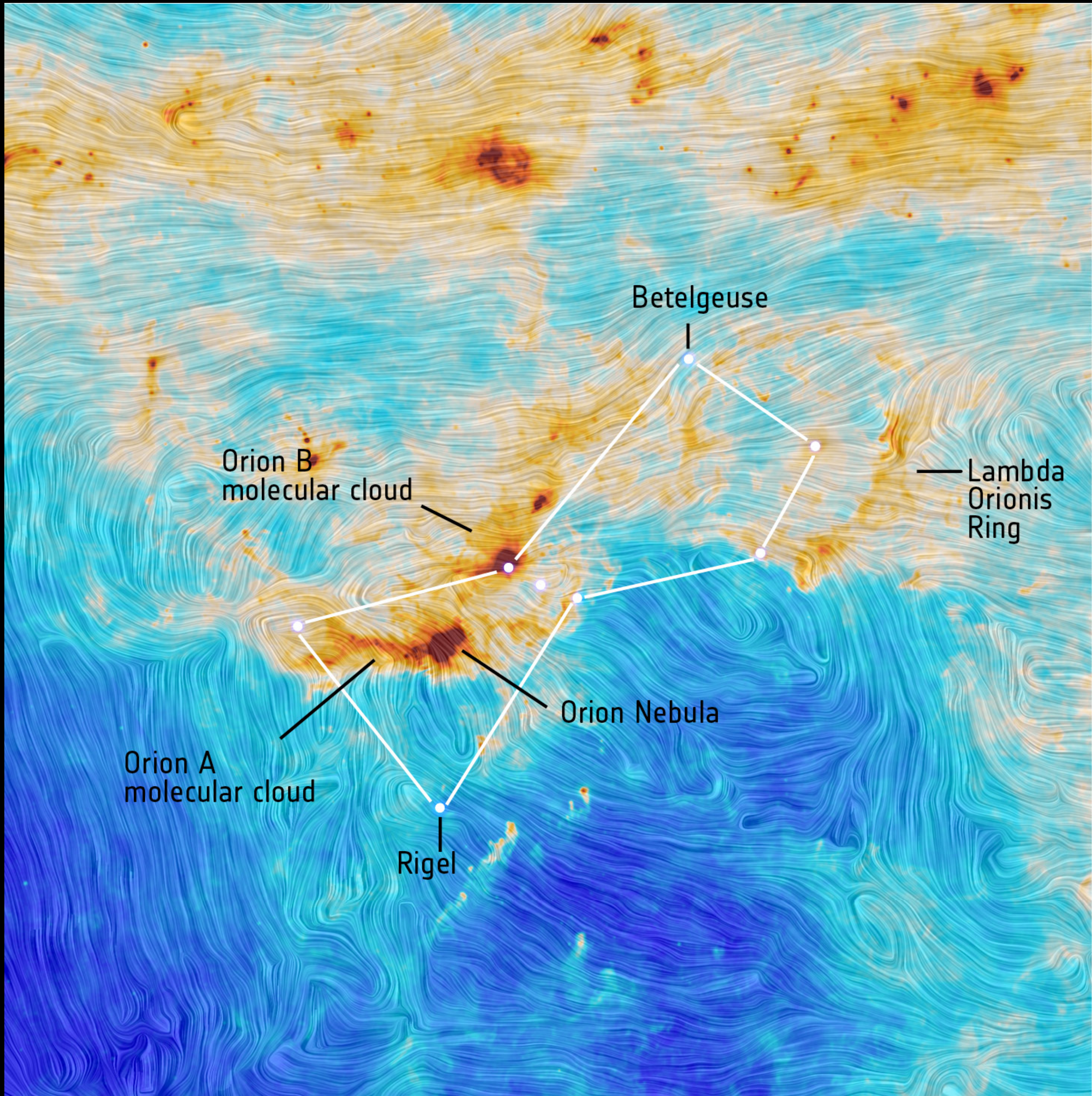
- The magnetic facet of interstellar turbulence
- The role the magnetic field plays in the formation of the filamentary structure of the ISM

★Interstellar Dust

- Dust includes grain with different composition and a range of sizes with distinct polarization properties
- We are working towards a dust model that matches polarization and intensity data in emission and extinction
- Evolution of dust polarization properties in the ISM

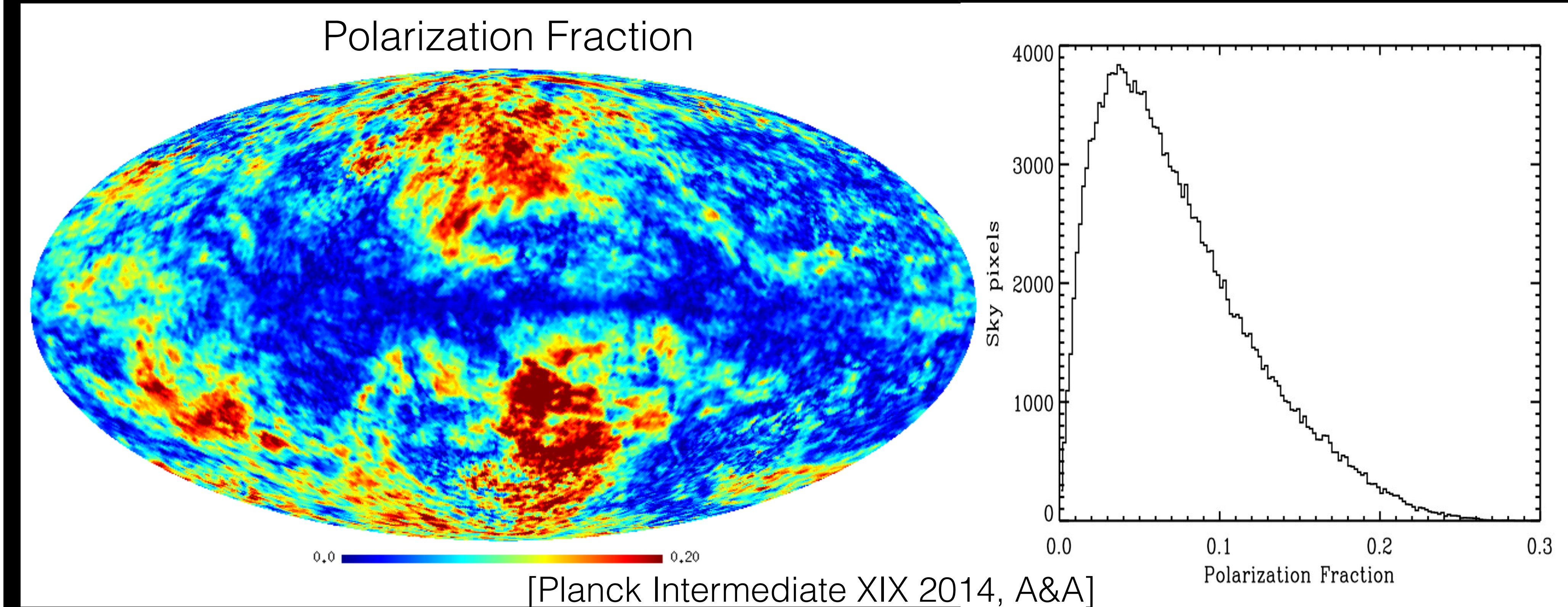
Magnetic field and ISM structure





Betelgeuse
Orion B
molecular cloud
Lambda
Orionis
Ring
Orion Nebula
Orion A
molecular cloud
Rigel

Polarization Fraction

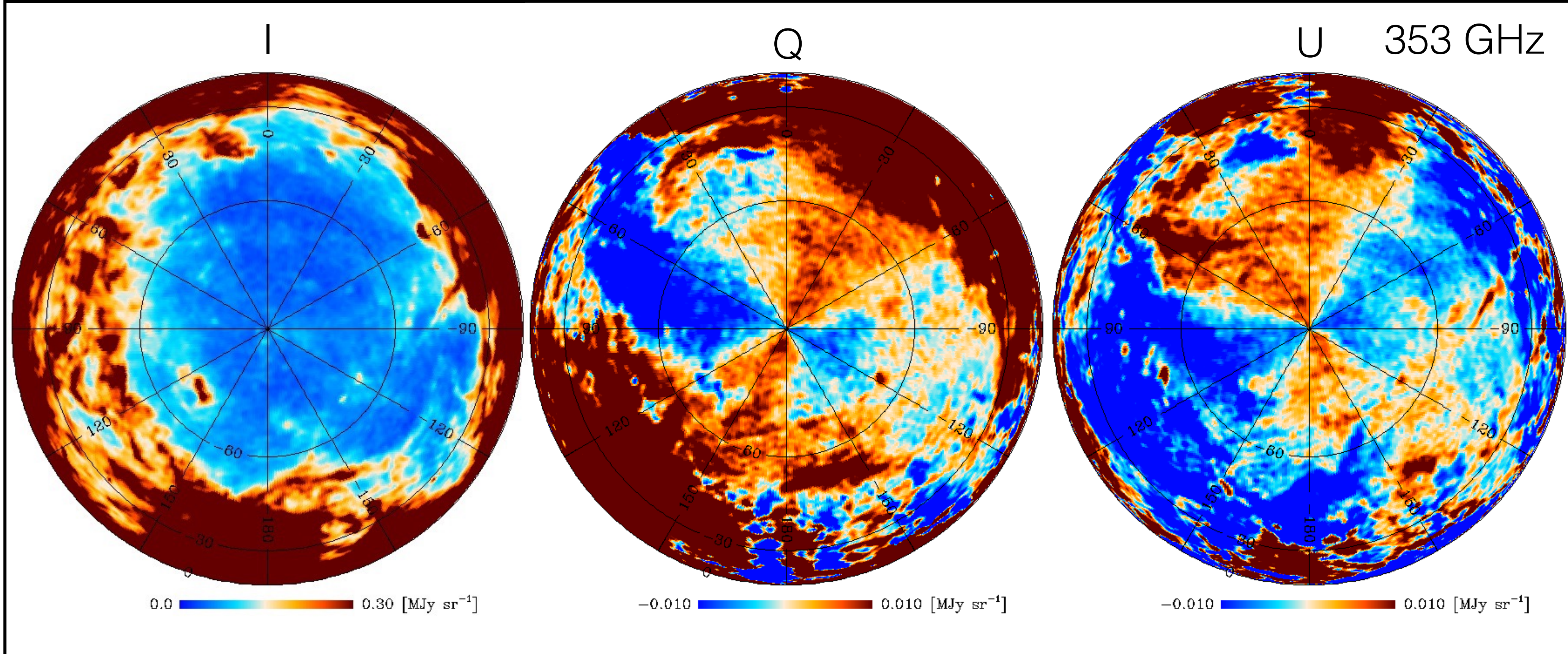


[Planck Intermediate XIX 2014, A&A]

- The polarization fraction shows a large scatter, which we interpret as line of sight depolarization associated with interstellar turbulence
- The maximal polarization fraction is higher than expected. It is a challenge for dust models to explain such high values

Mean Magnetic Field

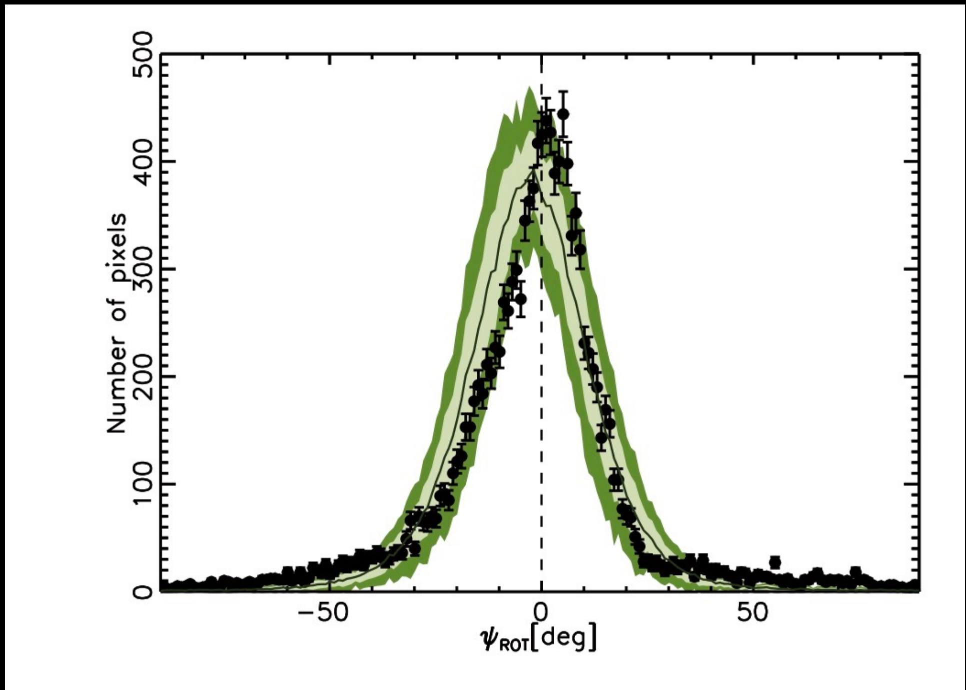
Planck data towards southern Galactic cap

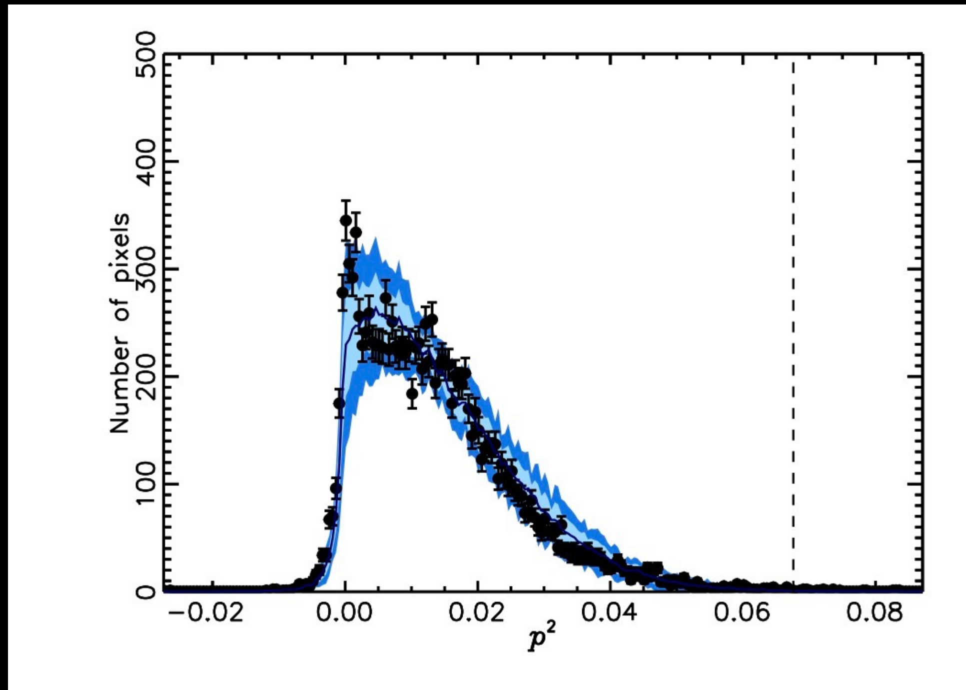


- Polarization patterns towards Galactic caps allow us to measure the direction of the mean magnetic field in the Solar Neighborhood

Bracco - PhD 2014, Université Paris-Sud, Orsay

Histograms of polarization angle and fraction



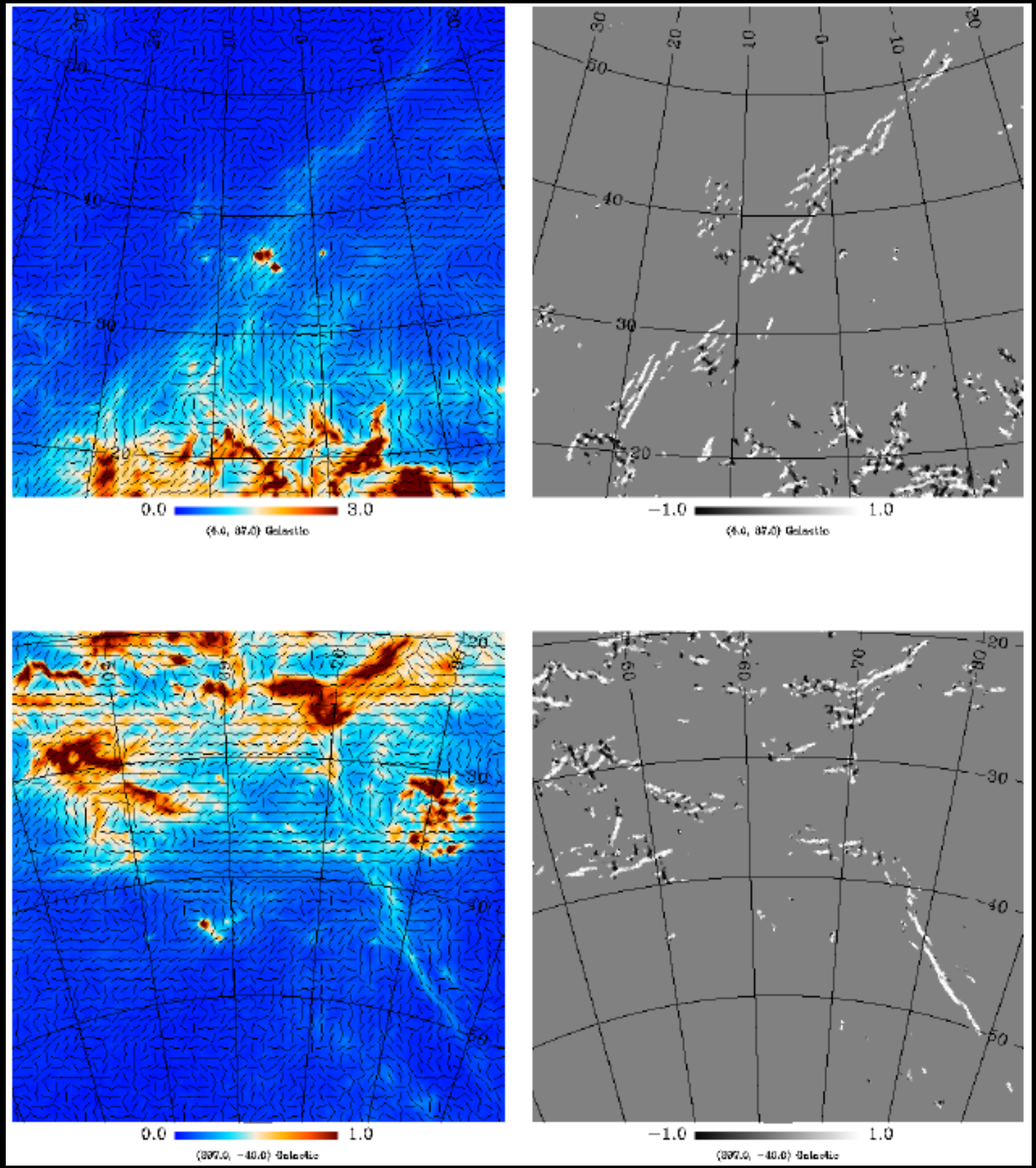


- Model fit of the histograms (polarization angle and fraction) indicates that interstellar turbulence is sub-Alfevnic.
- The same model fits polarization power spectra within constrains on the magnetic energy spectrum (steeper than $k^{-2.5}$)

Bracco - PhD 2014, Université Paris-Sud, Orsay

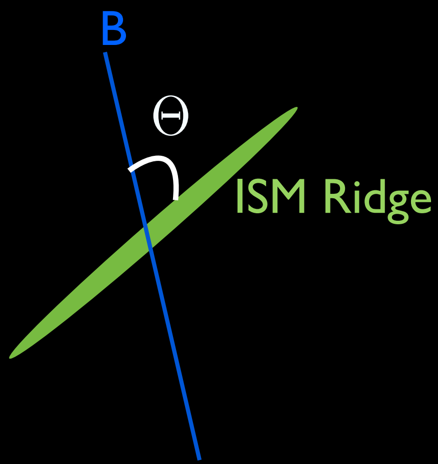
Magnetic fields and structure formation

I map Cos 2Θ



[Planck Intermediate XXXII 2014, arXiv:1409.6728]

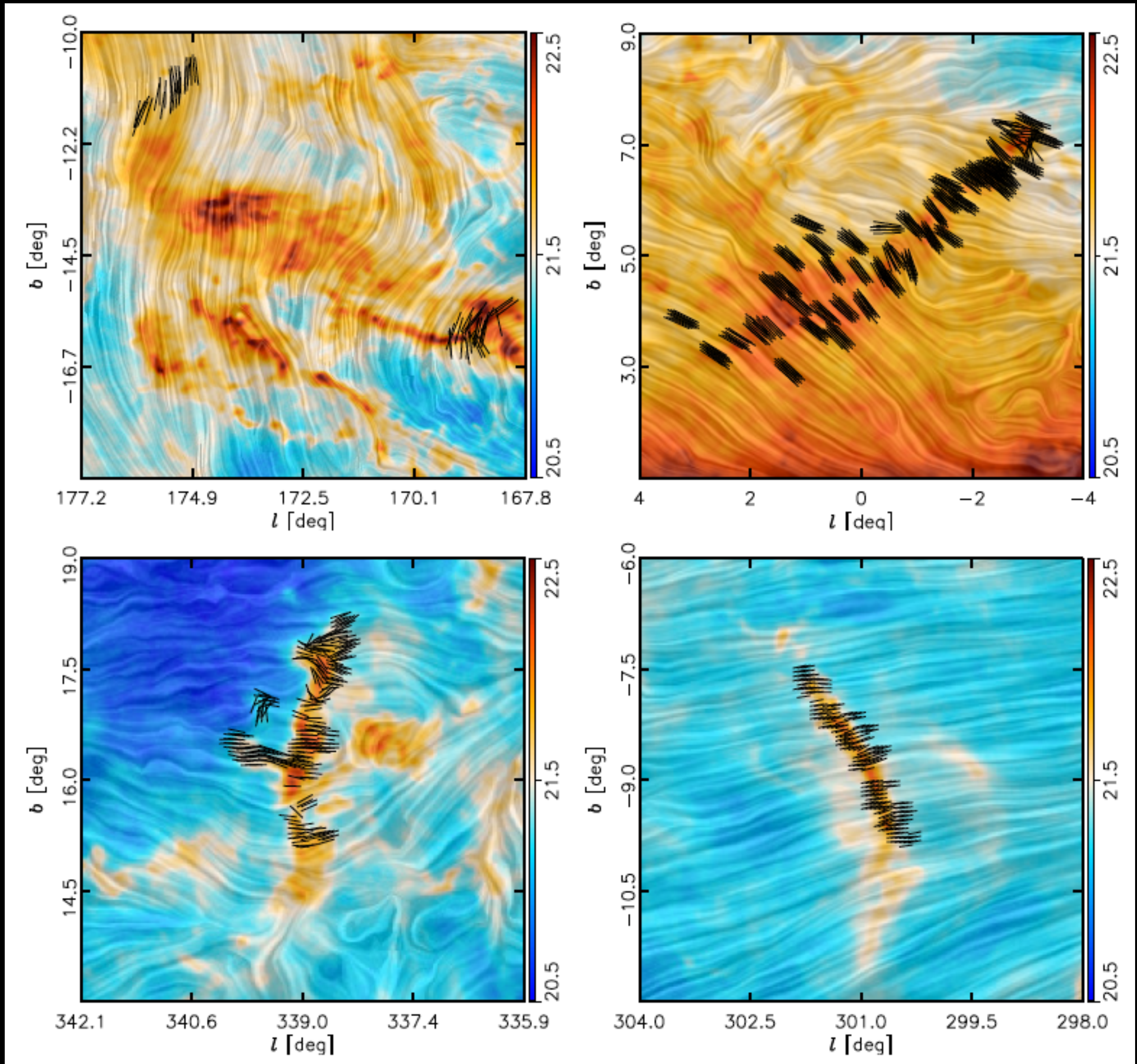
The filamentary structure of the interstellar medium



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

Magnetic fields and star formation

Planck and stellar polarization

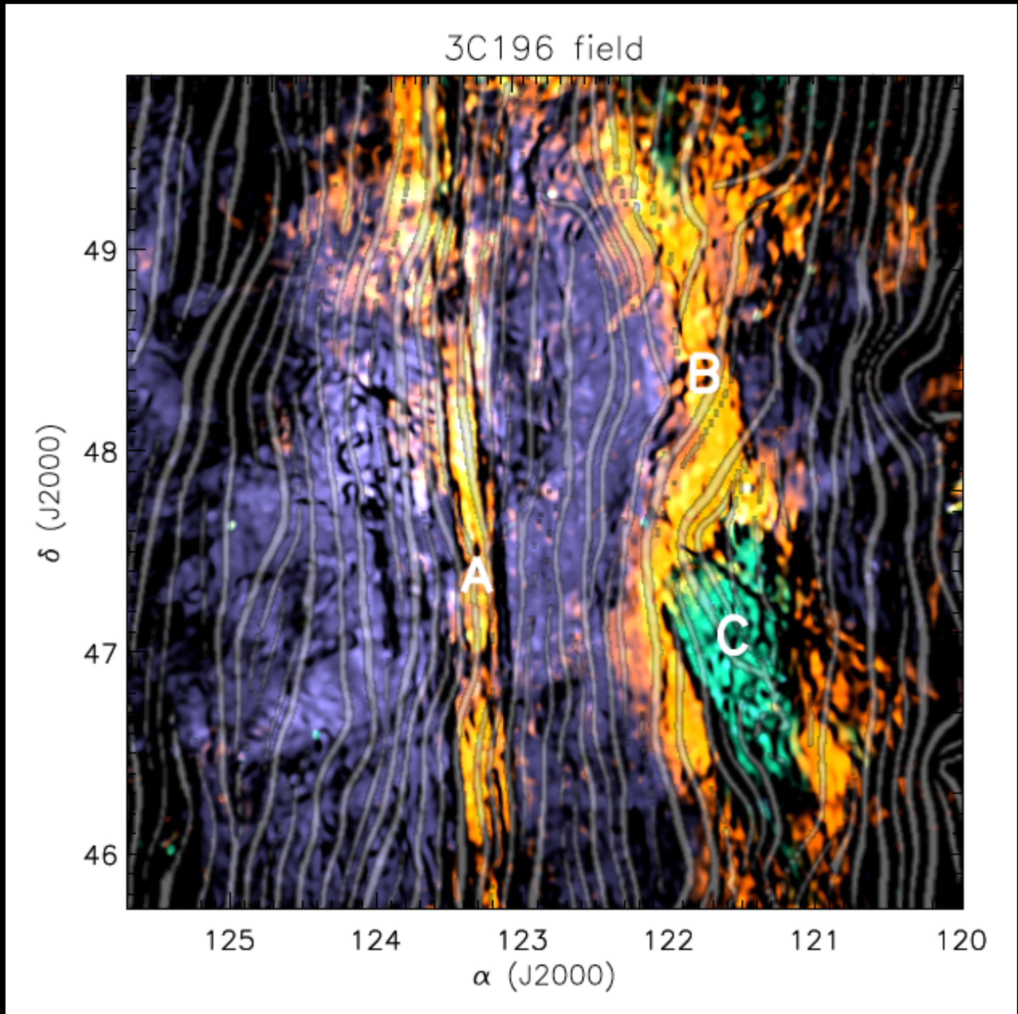


[Planck Intermediate XXXV 2014, arXiv:1502.04123]

Magnetic field in molecular clouds

- Magnetic field tends to be perpendicular to star forming filaments
- This is might be a signature of the formation of gravitationally bound structures for a dynamically important magnetic field.

Magnetic fields across ISM phases



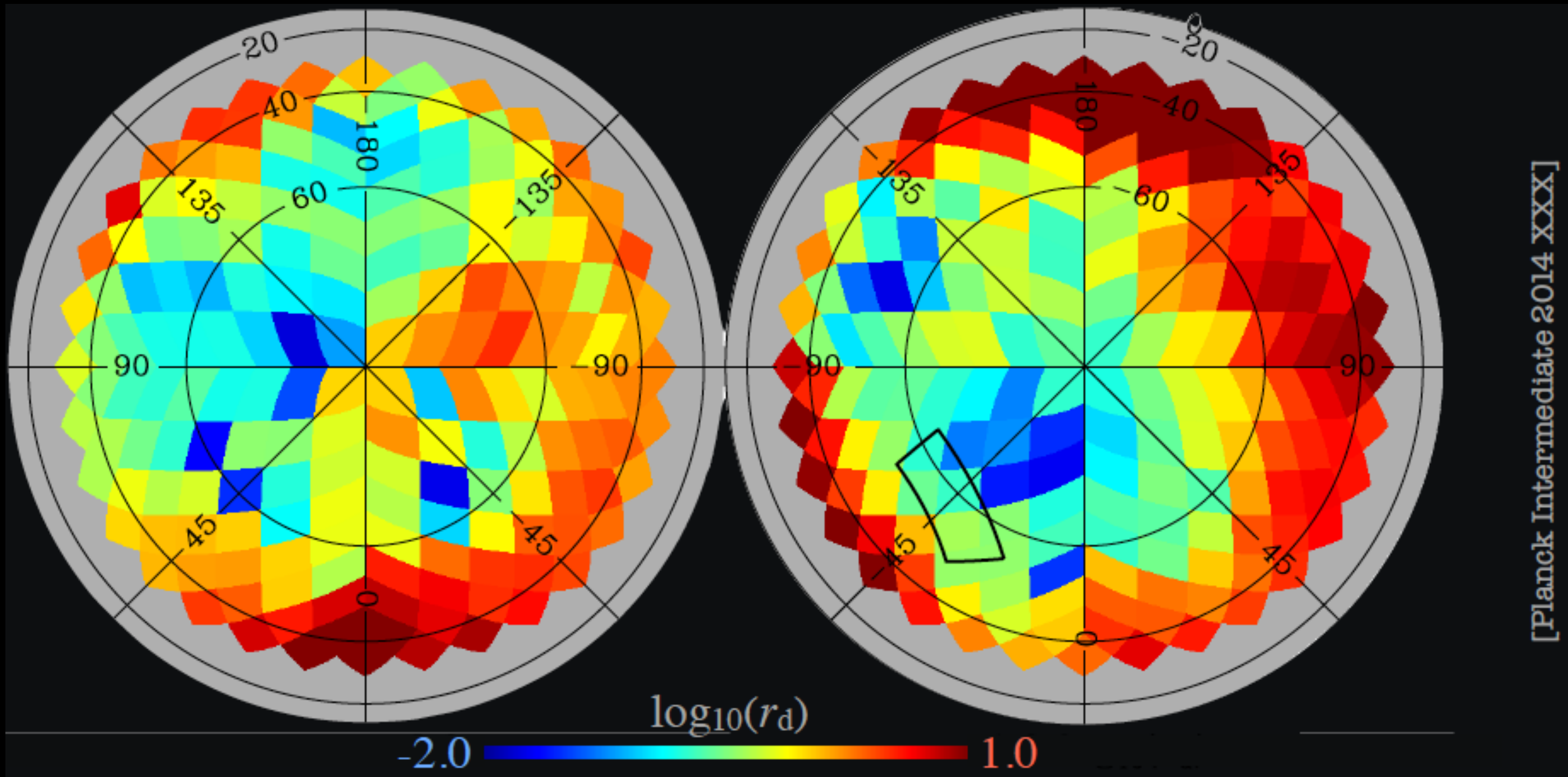
LOFAR Faraday synthesis + field lines from dust polarization, Zaroubi+ 2015

★Faraday rotation traces B field in the warm ionized medium

★We observe a surprising 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.

Dust foreground to CMB B-modes



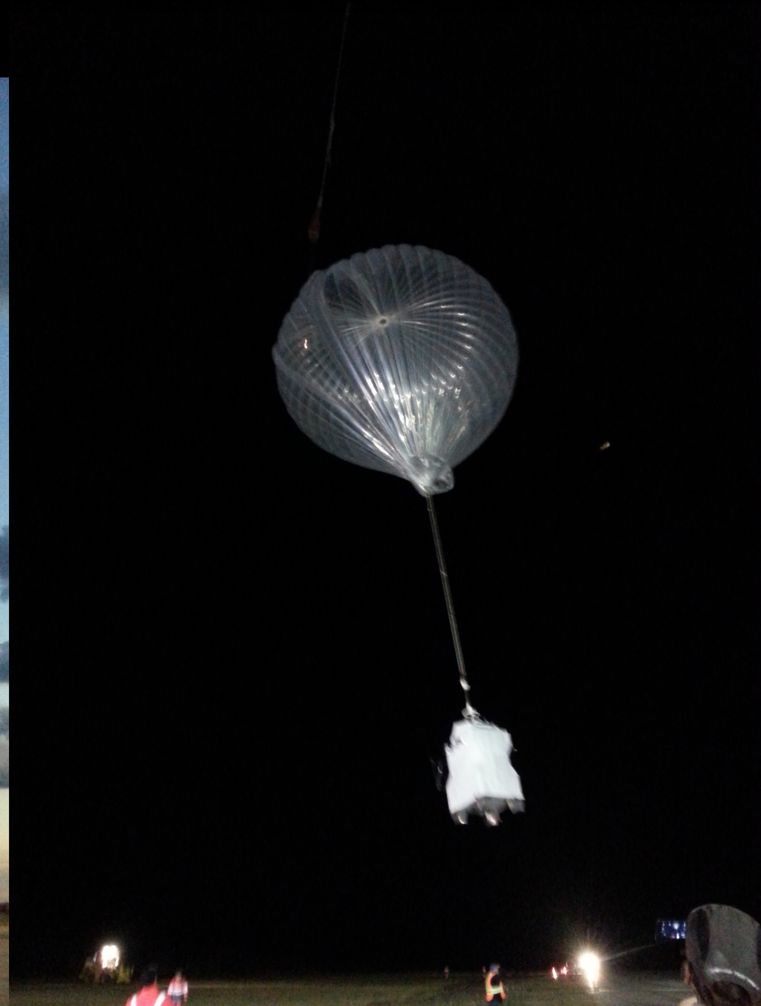
★Dust BB amplitude extrapolated from 353 to 150 GHz

★Expressed in units of the tensor-to-scalar CMB parameter r

★The cleanest regions of the sky have r ~ 0.01±0.06

★There is no region of the sky where the primordial B-mode signal may be measured without subtracting dust polarization

The future of polarimetry



- PILOT french far-IR balloon polarization experiment launched sunday night from Timmins (Ontario)
- We are preparing a new instrument with larger bolometer arrays for subsequent flights

Conclusions

- ★Planck observations of light emitted by interstellar dust are revealing a new sky for Galactic astrophysics.
- ★These maps provide astrophysicists with the most detailed view yet at the Galactic magnetic field, which we use to study interstellar turbulence and the formation of the filamentary structure of interstellar matter.
- ★The spectral dependence of the polarized signal from dust furthers our understanding of the nature of interstellar dust
- ★Dust polarization is a dominant foreground to CMB B-mode polarization.
- ★The Planck survey is followed-up by ground-based and balloon experiments that benefit from the advent of large bolometer arrays. A new polarization space project (CORE+) will be submitted to the M5 call of ESA.

➡ www.planckandthemagneticfield.info