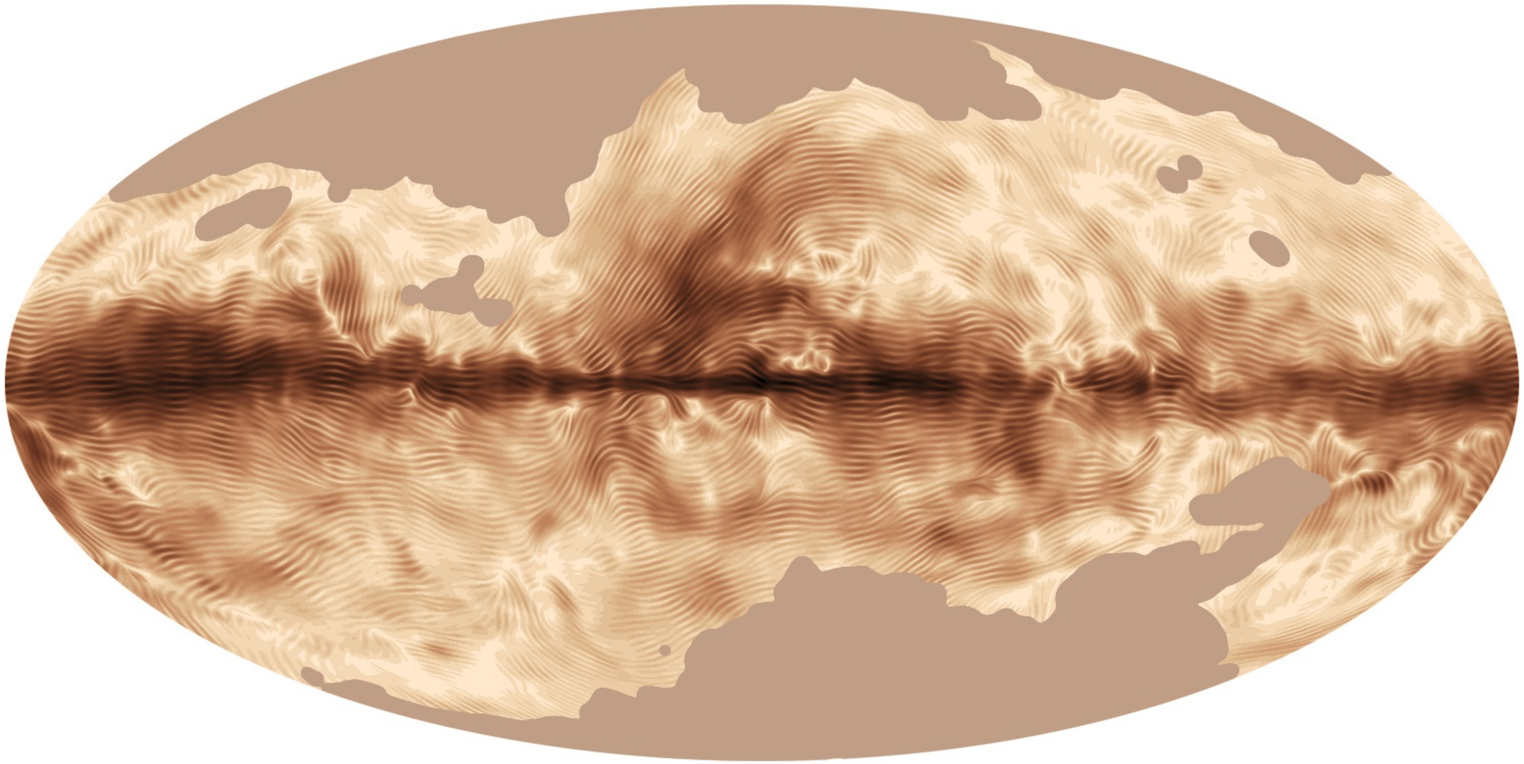
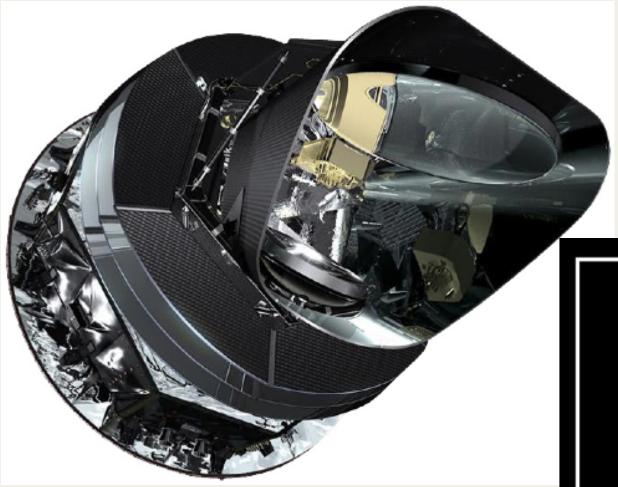
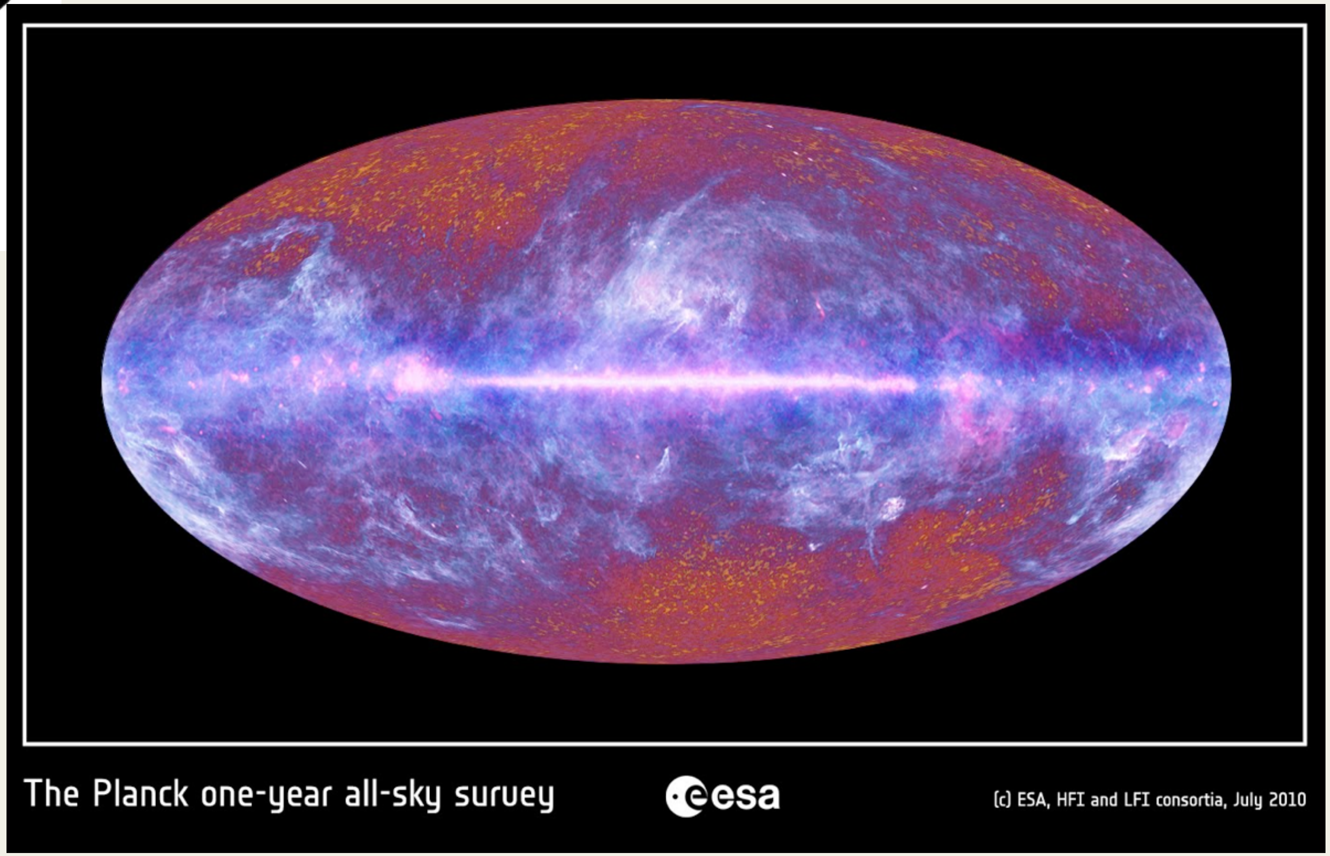
Polarized thermal emission of Galactic dust, as seen by *Planck*



E. Falgarone
(LERMA - ENS Paris et Observatoire de Paris)
on behalf of the *Planck* collaboration

The *Planck* mission





- 2009-2012 space mission
- 9 bands 30 GHz to 857 GHz, 7 bands polarization sensitive
- Measurement of CMB anisotropies
- Mapping of the cold, dusty Milky Way
- Polarization : Galactic dust, primordial gravitational waves

esa

planck

cnes

agenzia spaziale italiana

NASA

CNRS

DTU Space
National Space Institute

Science & Technology Facilities Council

CSIC

National Research Council of Italy

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The first *Planck* papers on polarization

***Planck* intermediate results. XIX.**
An overview of the polarized thermal emission from Galactic dust
Planck Collaboration
arXiv:astro-ph 1405.0871

***Planck* intermediate results. XX.**
Comparison of polarized thermal emission from Galactic dust with simulations of MHD turbulence
Planck Collaboration
arXiv:astro-ph 1405.0872

***Planck* intermediate results. XXI.**
Comparison of polarized thermal emission from Galactic dust at 353 GHz with optical interstellar polarization
Planck Collaboration
arXiv:astro-ph 1405.0873

***Planck* intermediate results. XXII.**
Frequency dependence of thermal emission from Galactic dust in intensity and polarization
Planck Collaboration
arXiv:astro-ph 1405.0874

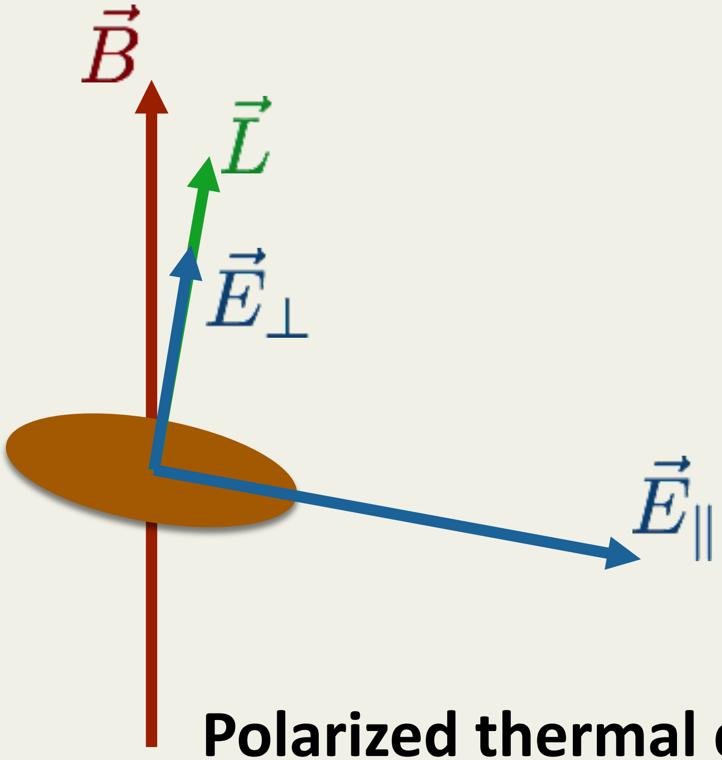
Submitted to A&A April 28
Published on arXiv May 5

Data to be released in the fall

Outline

- Results from Galactic dust polarized emission observed by *Planck*
- Comparison with numerical simulations of compressible MHD turbulence
- Comparison with numerical simulations of incompressible MHD and AD-MHD turbulence

Polarized thermal emission from dust



Aspherical dust grains :

Emissivities larger along long axis

Rotating dust grains :

Angular momentum L aligns with B

Polarized thermal dust emission gives information on :

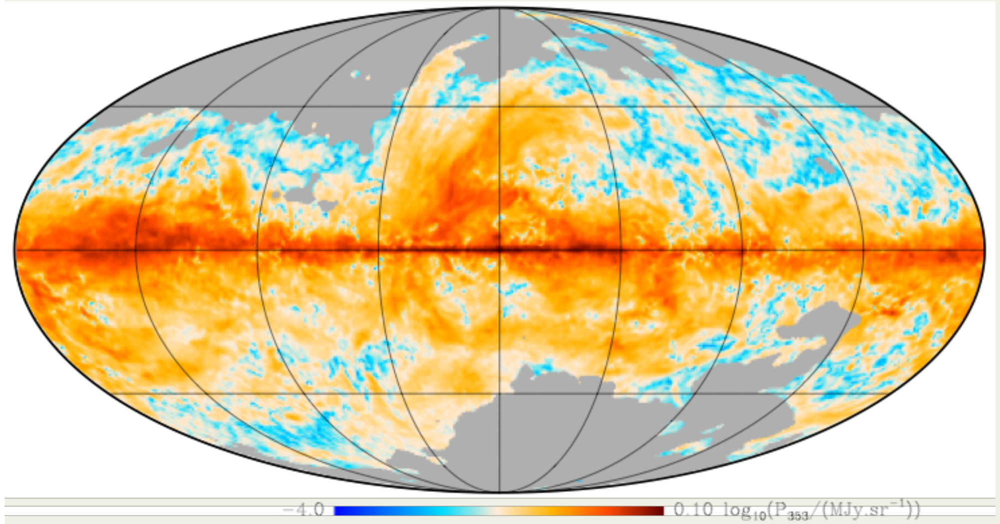
- Dust optical properties and composition
- Magnetic field topology

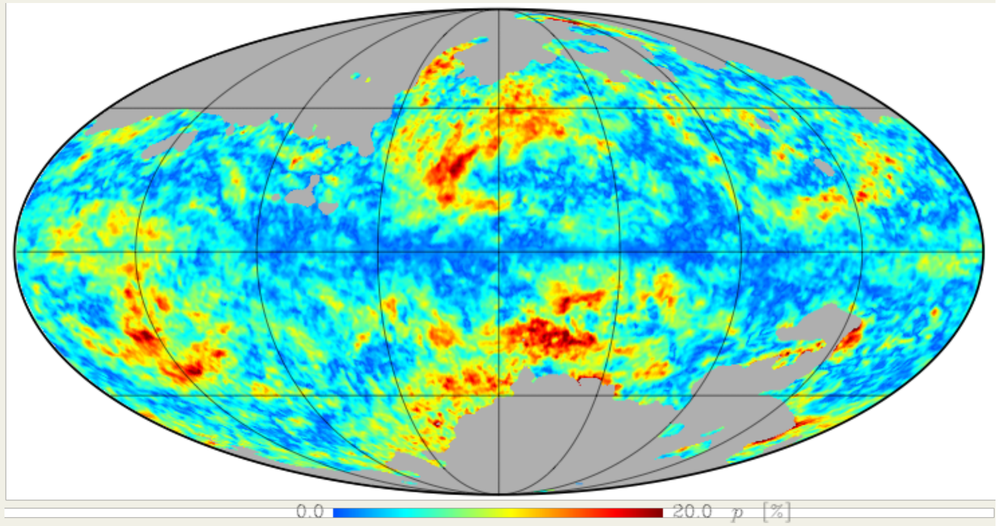
Stein 1966, Andersson 2012, Draine & Fraisse 2009, Hoang & Lazarian 2008, Martin 1975, 2007

Polarized intensity and polarization fraction at 353 GHz

$$P = \sqrt{Q^2 + U^2}$$

$$p = P/I$$

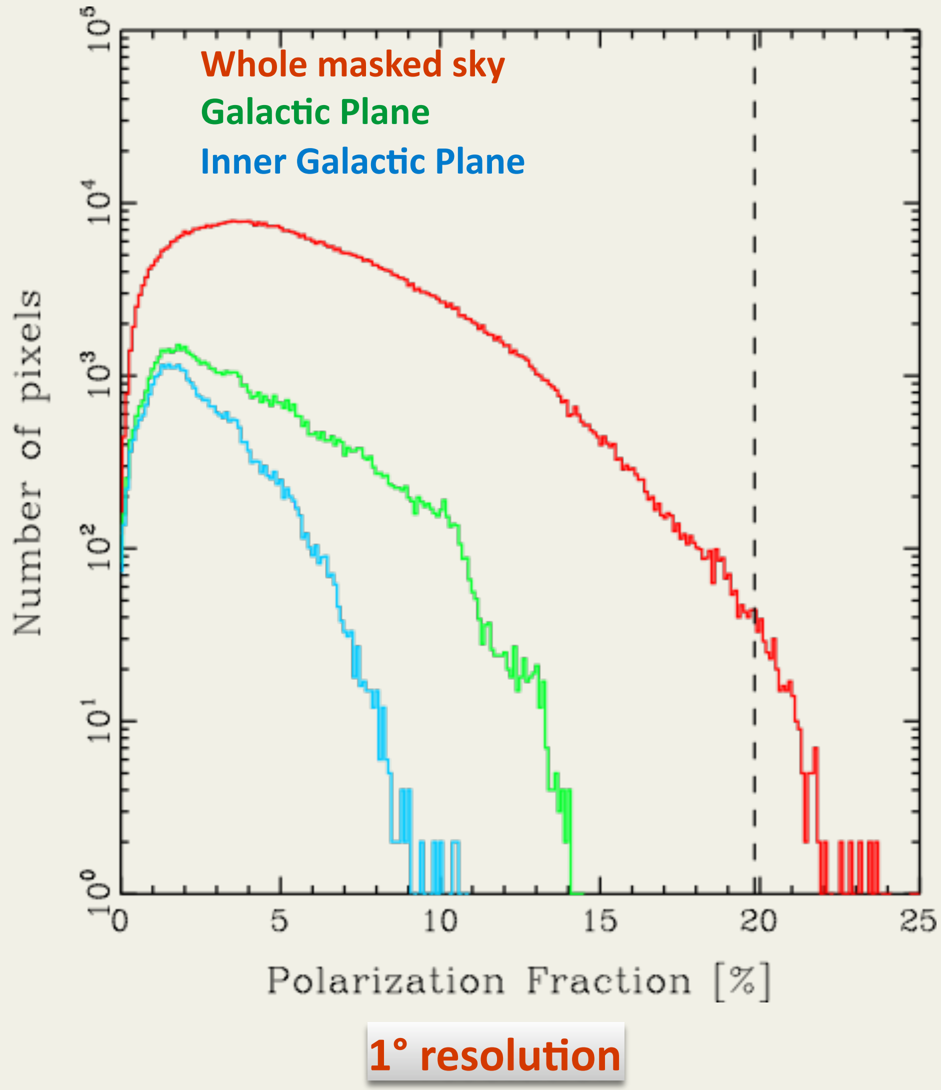


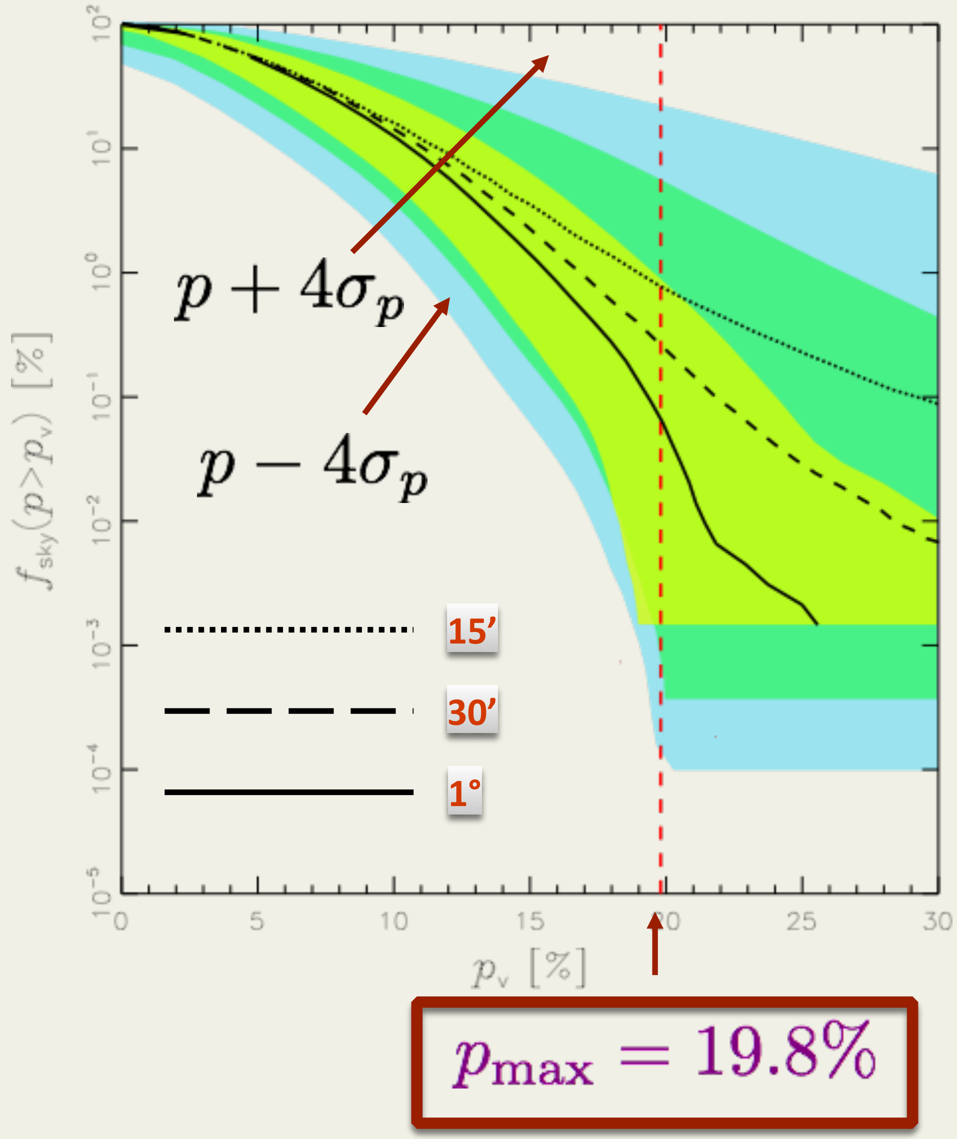


- Low polarization fractions in the Galactic Plane
- Some highly polarized regions (Fan/Auriga, Aquila Rift,...)
- Thin filamentary regions of low polarization

Planck intermediate results. XIX.

Maximum polarization fraction

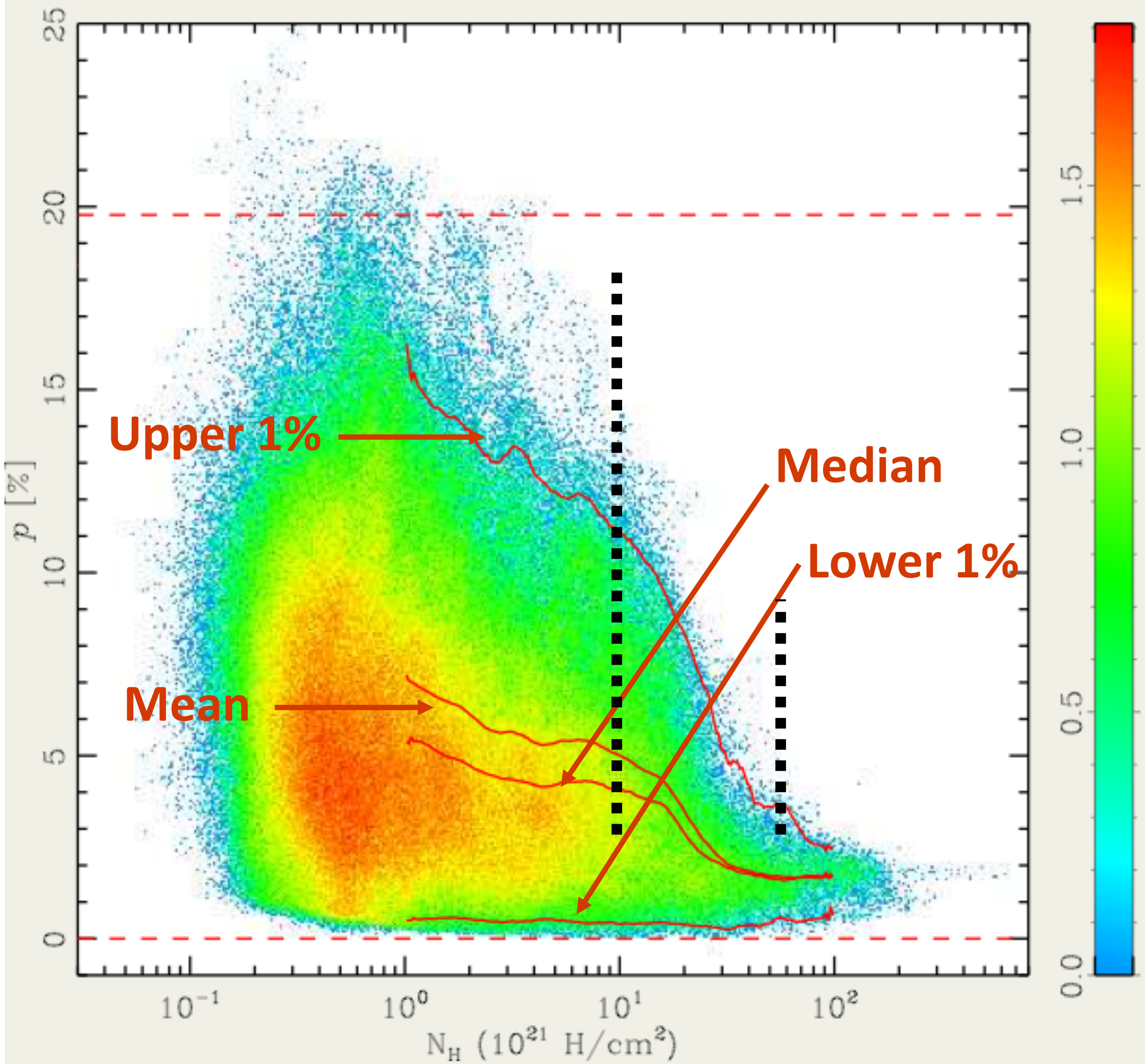




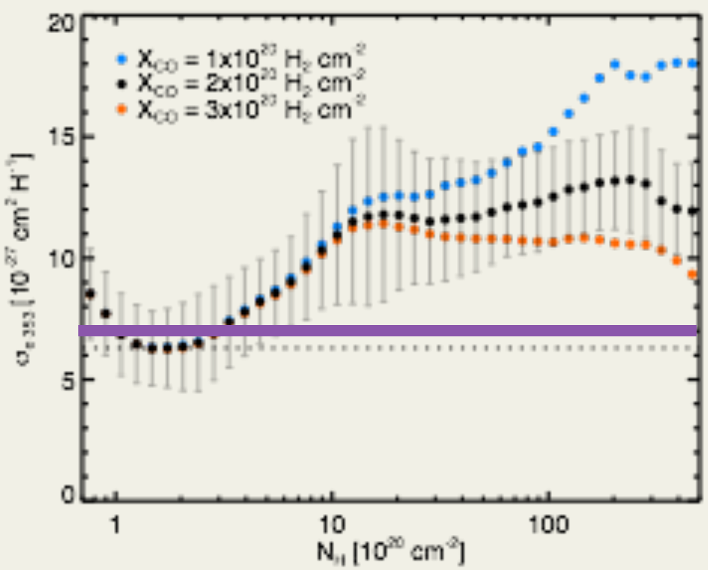
⇨ Intrinsic polarization fraction of dust at least 20%

Planck intermediate results. XIX.

Polarization fraction versus column density



$$N_{\rm H} = 1.42 \times 10^{26} \times \tau_{353}\,{\rm cm}^{-2}$$



Planck 2013 results. XI.

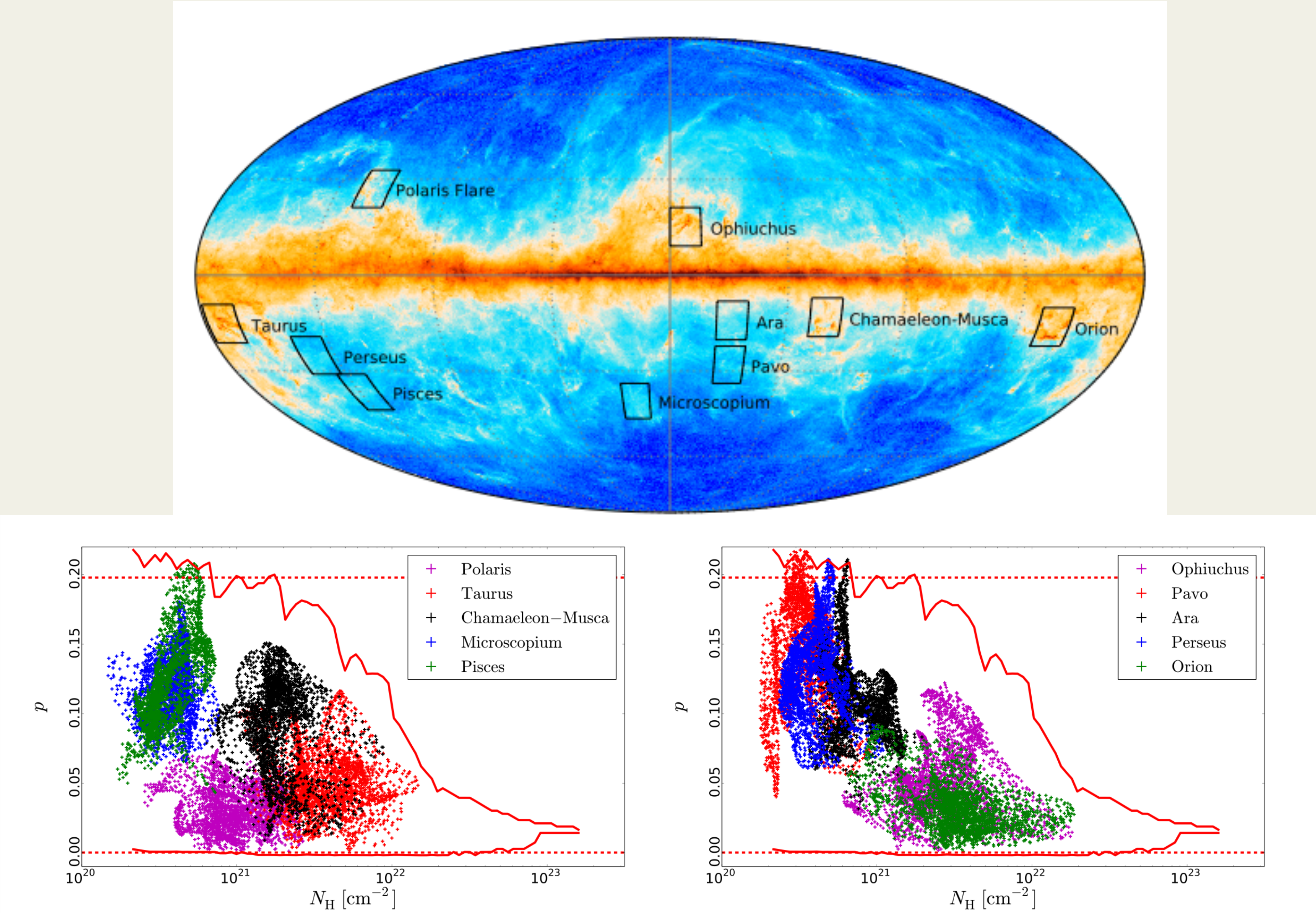
I = 1 MJy sr^{-1} @ 353 GHz

➪ N_H ~ 2×10^{21} cm^{-2}

Two to three regimes of p_{max} decrease with N_H

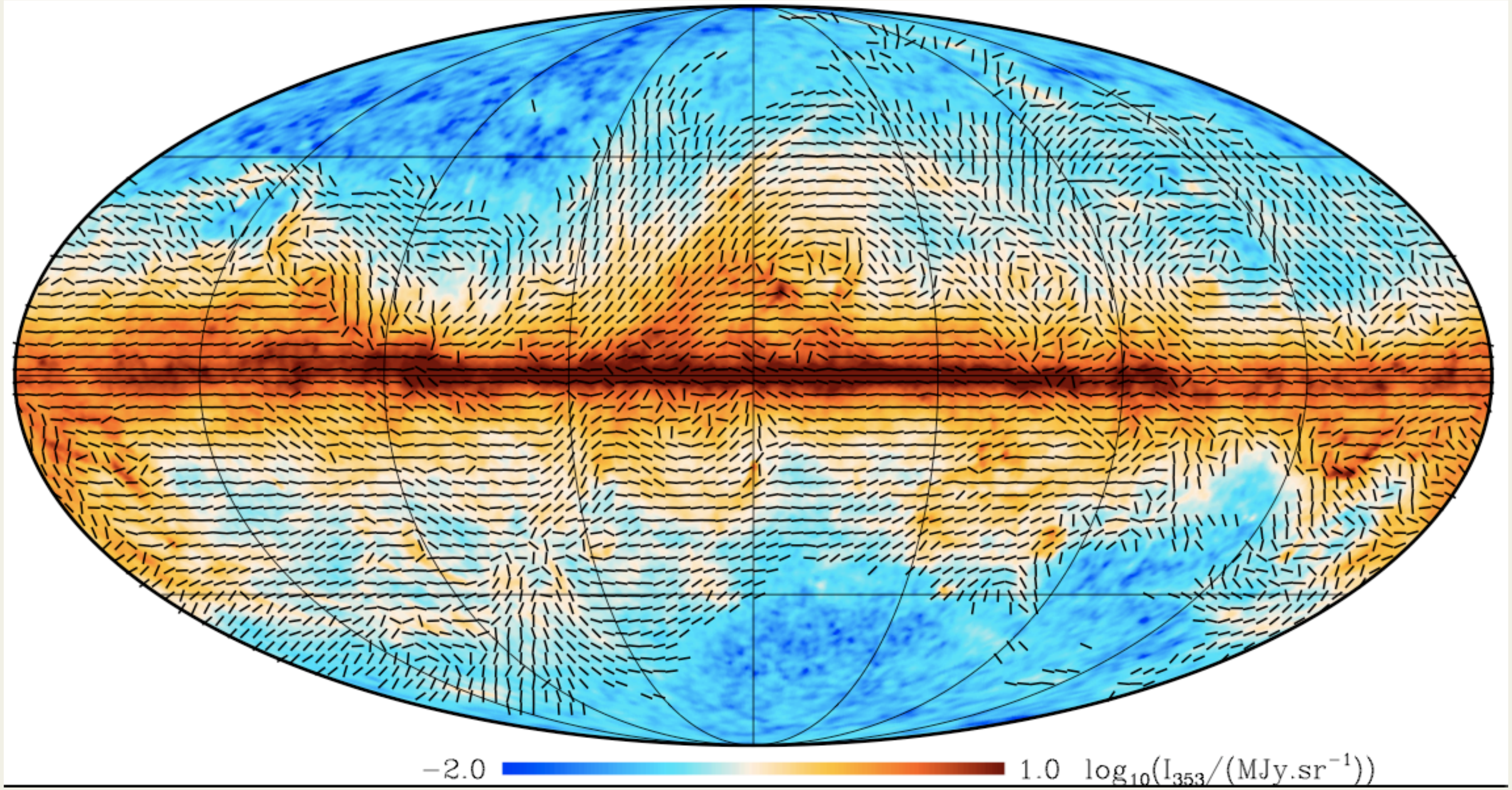
Planck intermediate results. XIX.

Polarized dust emission in nearby clouds



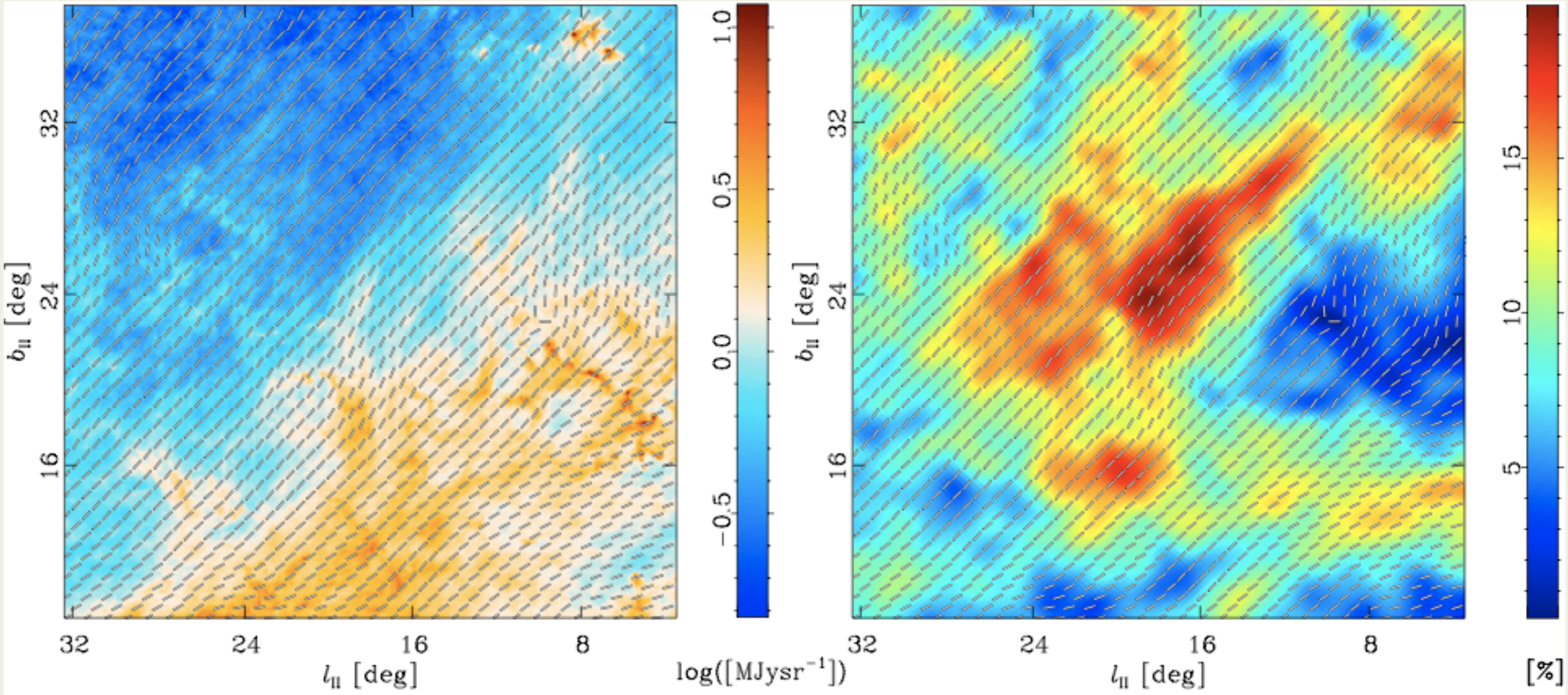
Planck intermediate results. XX.

Orientation of the POS magnetic field



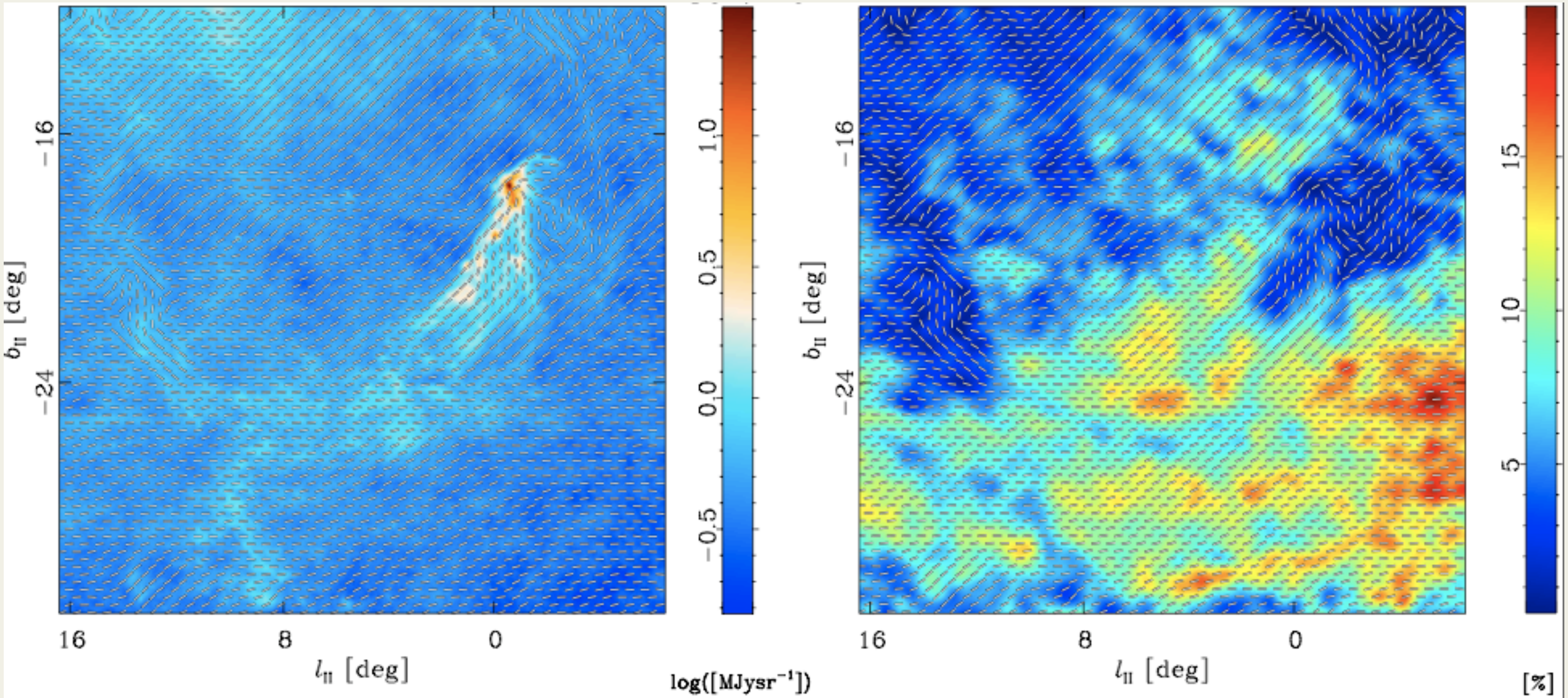
- Polarization angle ordered over large areas
- Sharp variations along filamentary structures not associated with filaments of matter

Aquila Rift



353 GHz intensity (left) and polarization fraction (right)
+ orientation of B in the plane-of-the-sky

R Corona Australis

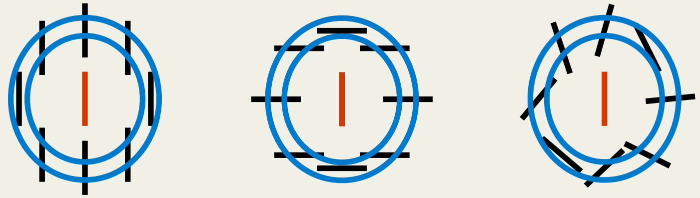


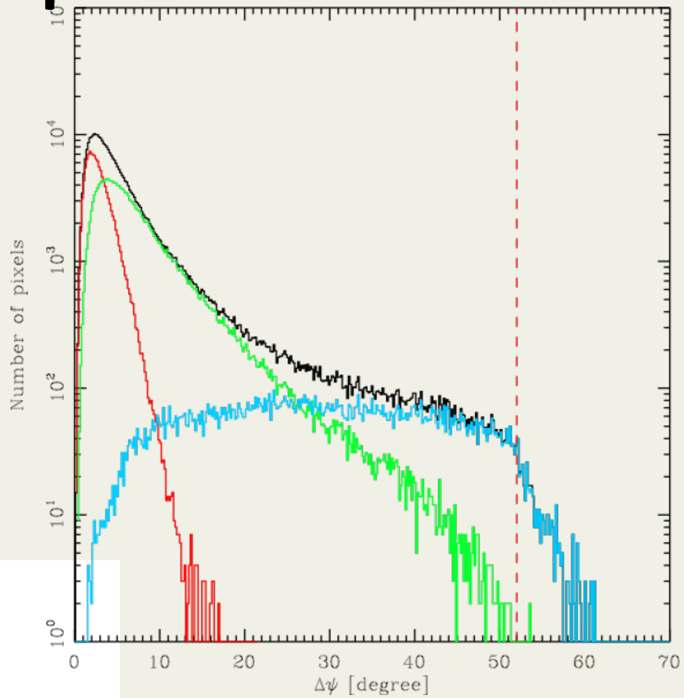
353 GHz intensity (left) and polarization fraction (right)
+ orientation of B in the plane-of-the-sky

Polarization angle dispersion

$$\Delta\psi^2(l) = \frac{1}{N}\sum_{i=1}^{N}\left[\psi\left(\mathbf{r}\right) - \psi\left(\mathbf{r}+\mathbf{l}_i\right)\right]^2$$

$\Delta\psi = 0$ $\quad$ $\Delta\psi = \pi/2$ $\quad$ $\Delta\psi = \pi/\sqrt{12}$



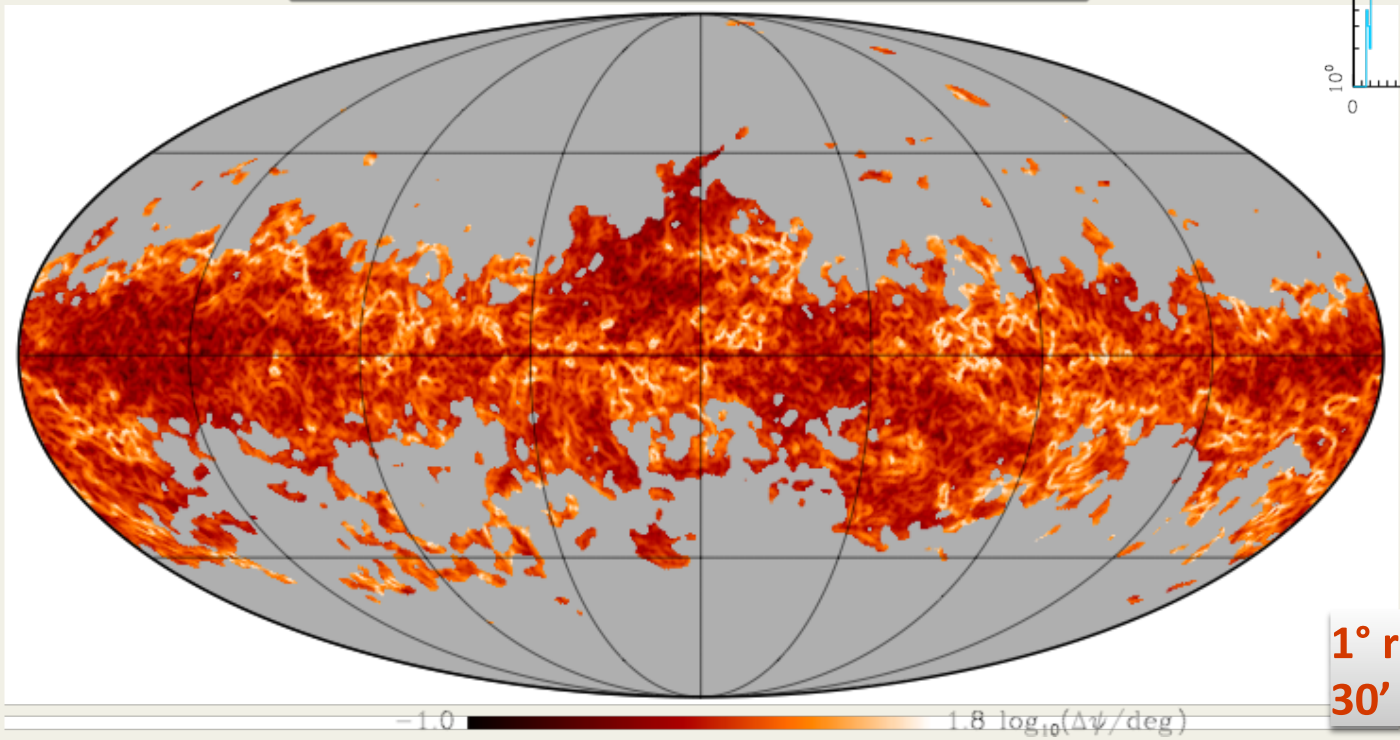


Whole masked sky

$p > 5\%$

$5\% > p > 1\%$

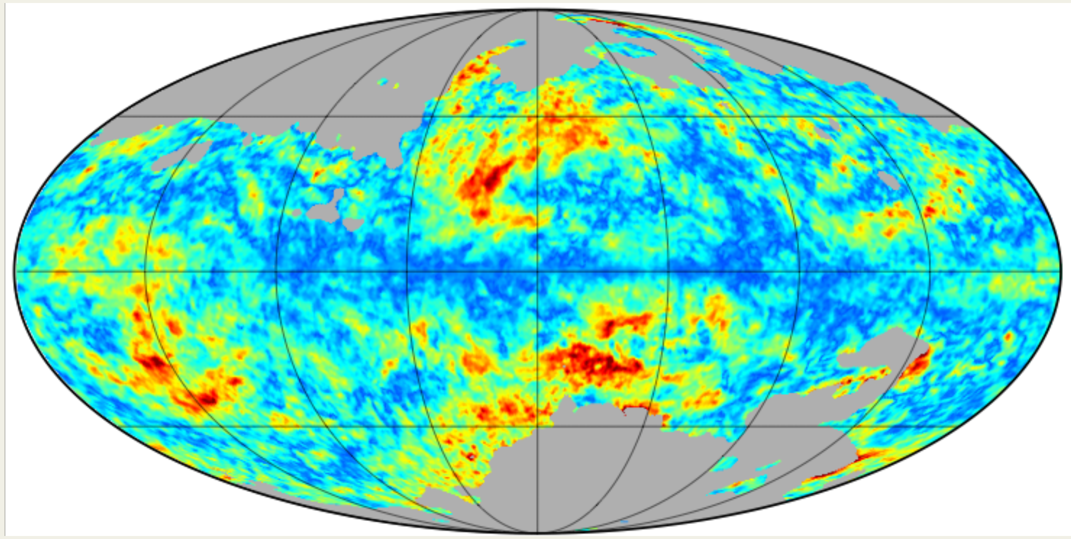
$p < 1\%$

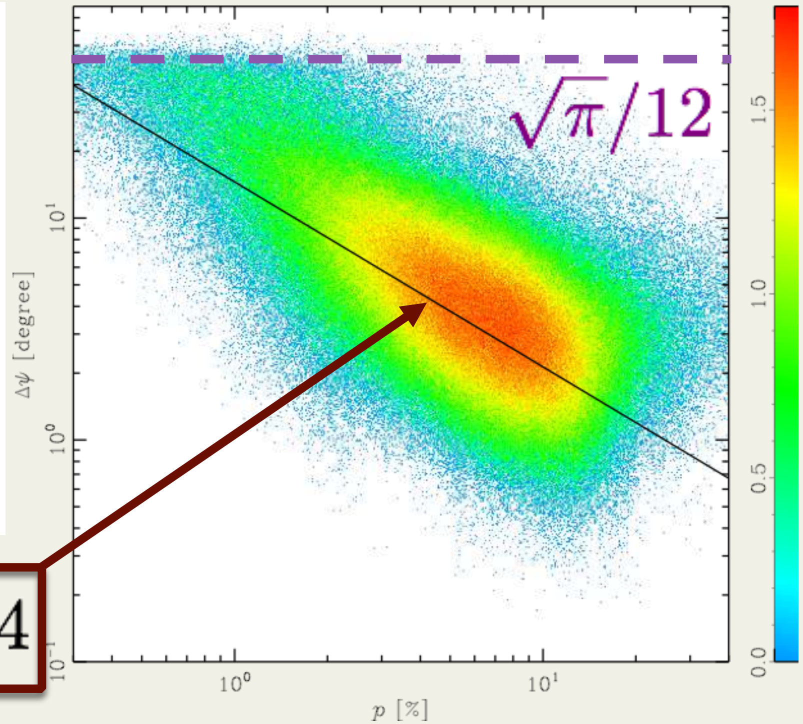


1° resolution
30' lag

Planck intermediate results. XIX.

Anticorrelation with polarization fraction



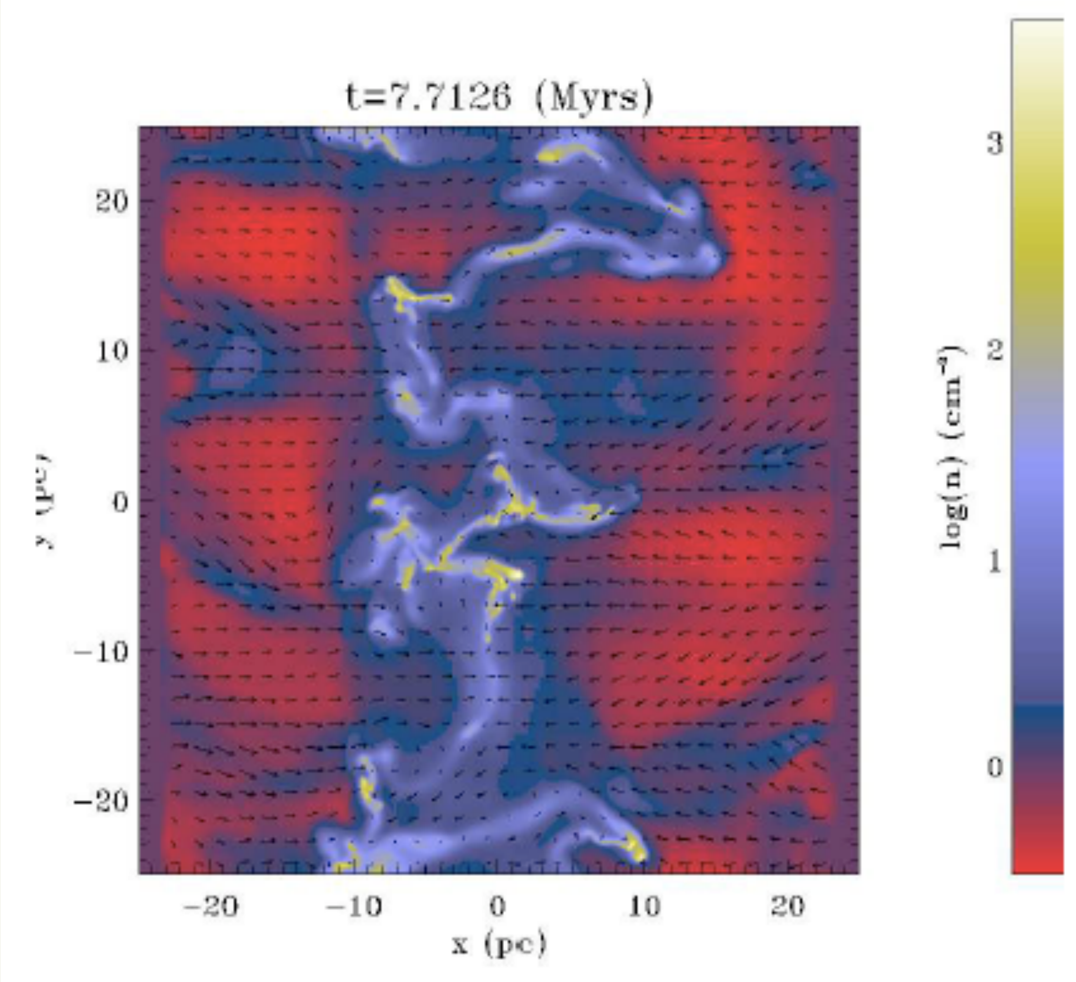


$$\log(\Delta\psi/\,\mathrm{deg}) = -0.834\log p - 0.504$$

- Strong anti-correlation between p and $\Delta\psi$
- Low p where the polarization angle changes abruptly
- Increased lag flattens the anti-correlation

Planck intermediate results. XIX.

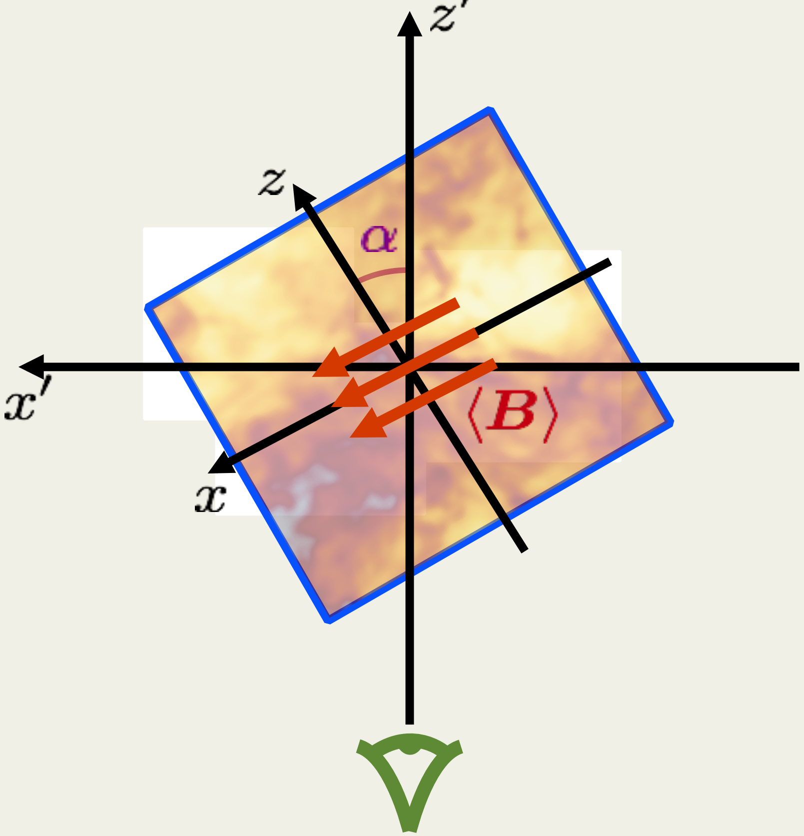
Numerical Simulations :
(I) Compressible bi-phasic MHD turbulence



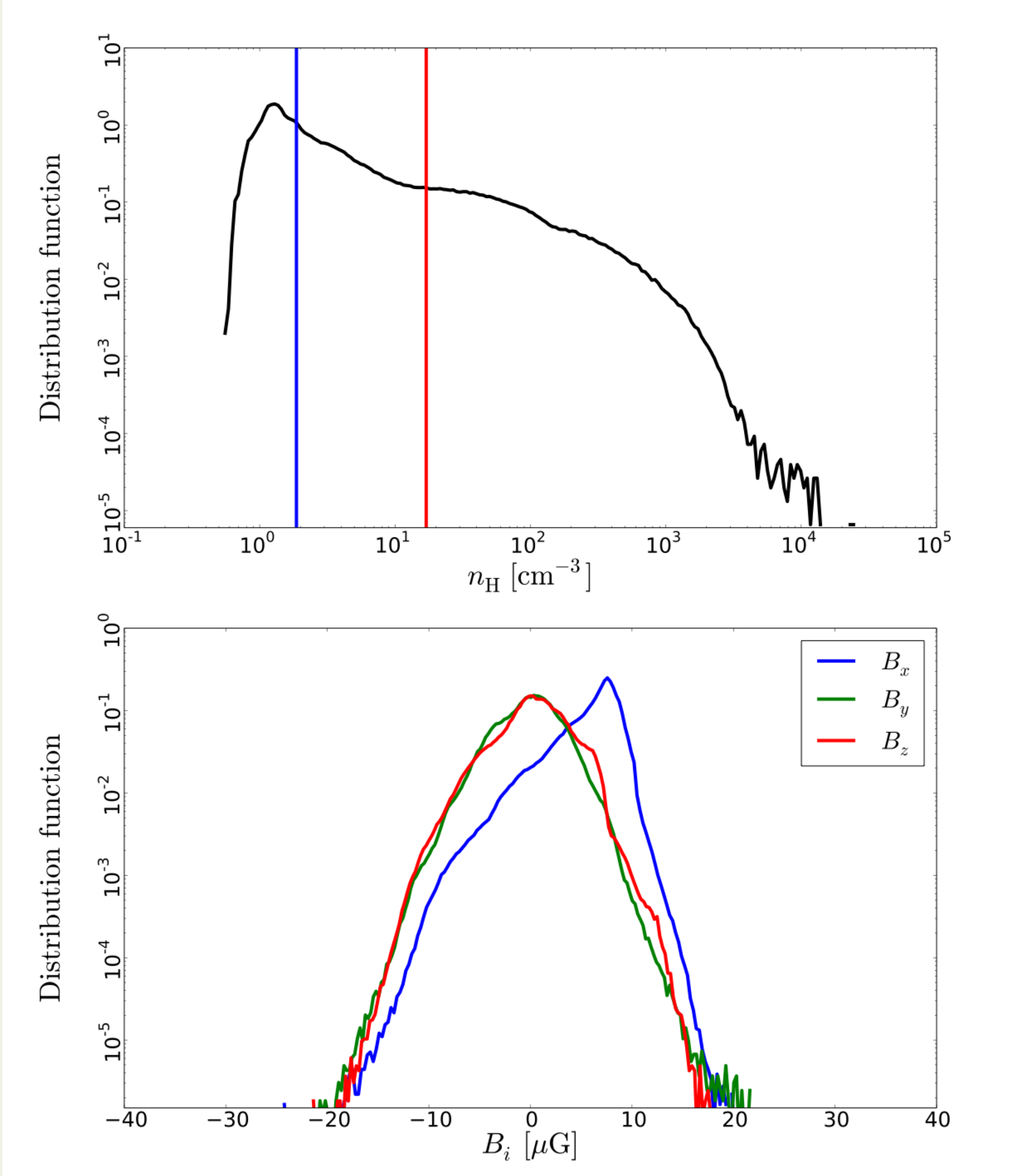
Hennebelle + 2008

- Converging flows of warm neutral medium
- Anisotropy of B
- Adaptive Mesh Refinement

Density and magnetic field distributions

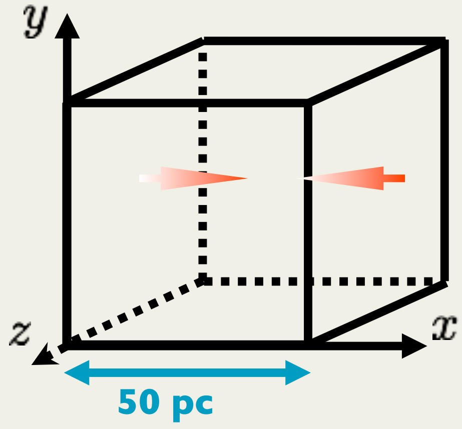


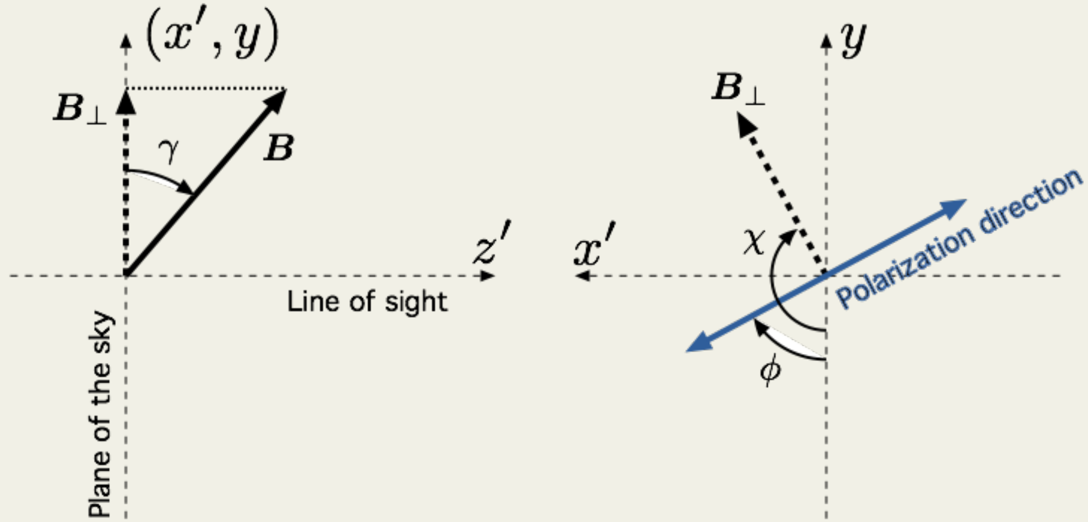
Rotation of the anisotropic cube



Planck intermediate results. XX.

Simulating polarized dust emission





- 18 pc subset of a 50 pc cube
- Converging flows of magnetized warm gas (WNM)

- Mean magnetic field along the flows
- Rotation of the cube, placed at 200 pc
- Simulated Stokes maps smoothed at 5'

$$I = \int S_\nu e^{-\tau_\nu} \left[1 - p_0 \left(\cos^2\gamma - \frac{2}{3}\right)\right] \mathrm{d}\tau_\nu$$

$$Q = \int p_0 S_\nu e^{-\tau_\nu} \cos(2\phi) \cos^2\gamma \mathrm{d}\tau_\nu$$

$$U = \int p_0 S_\nu e^{-\tau_\nu} \sin(2\phi) \cos^2\gamma \mathrm{d}\tau_\nu$$

« Intrinsic dust polarization parameter »

$$p_0 = 0.2$$

Opacity at 353 GHz (Planck Collaboration XXXI, 2014)

$$\tau_{353}/N_{\mathrm{H}} = 1.2 \times 10^{-26}\,\mathrm{cm}^{-2}$$

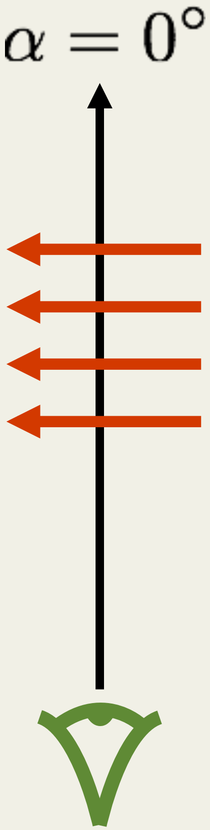
Dust temperature

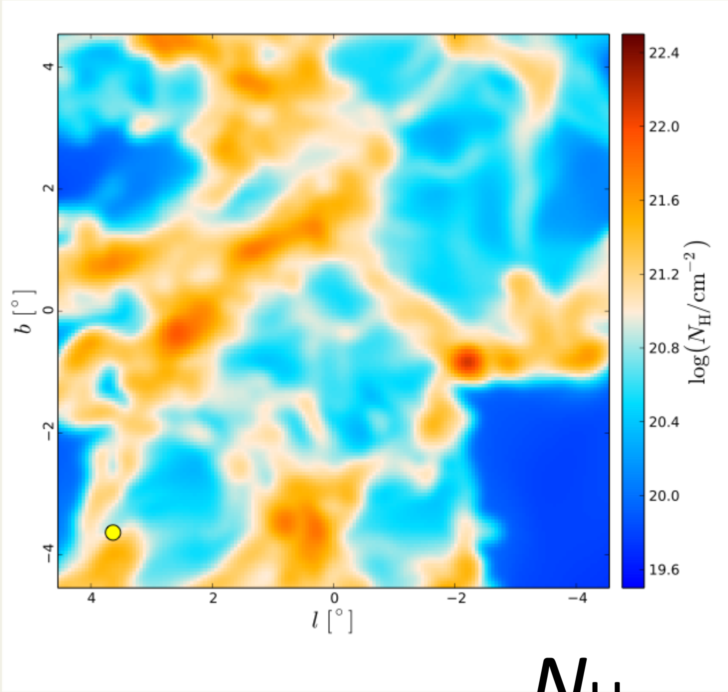
$$T_d = 18\,\mathrm{K}$$

Planck intermediate results. XX.

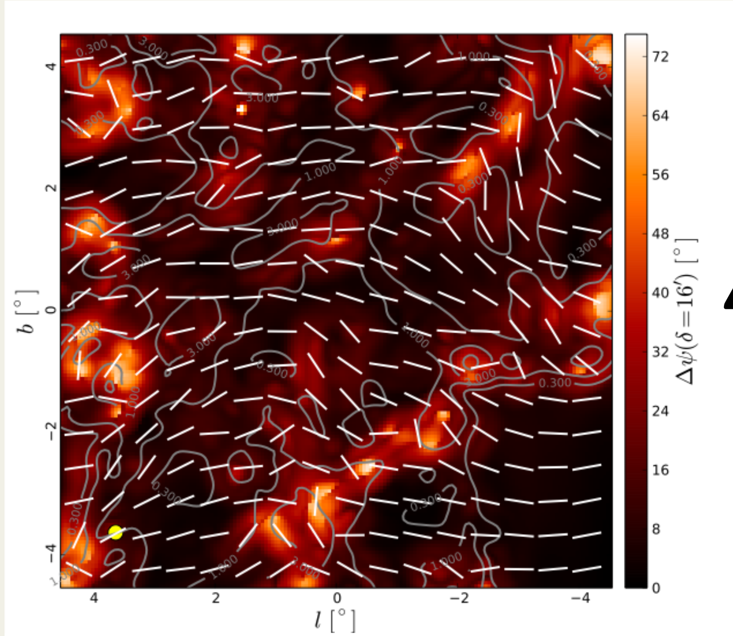
Following Lee & Draine 85 and others…

Simulated polarization maps

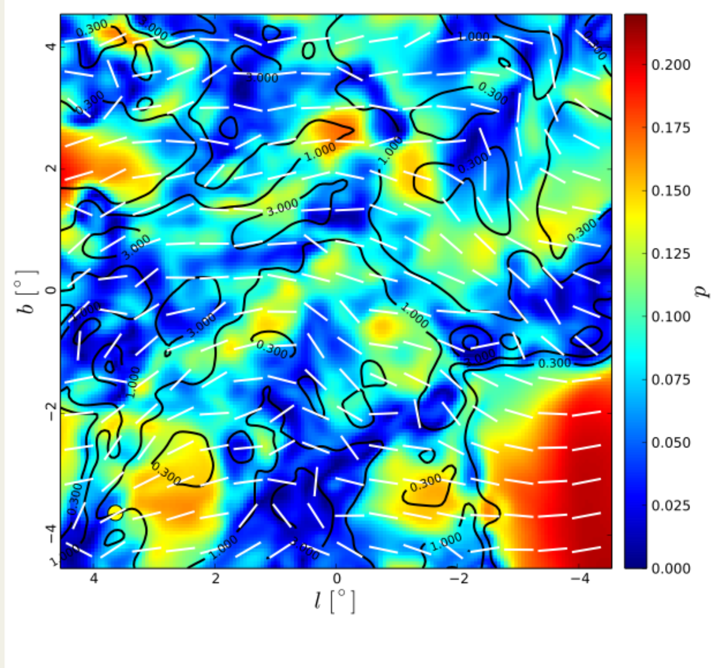




N_H



$\Delta\psi$



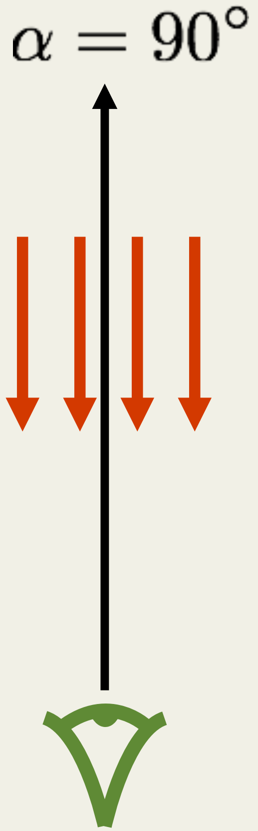
p

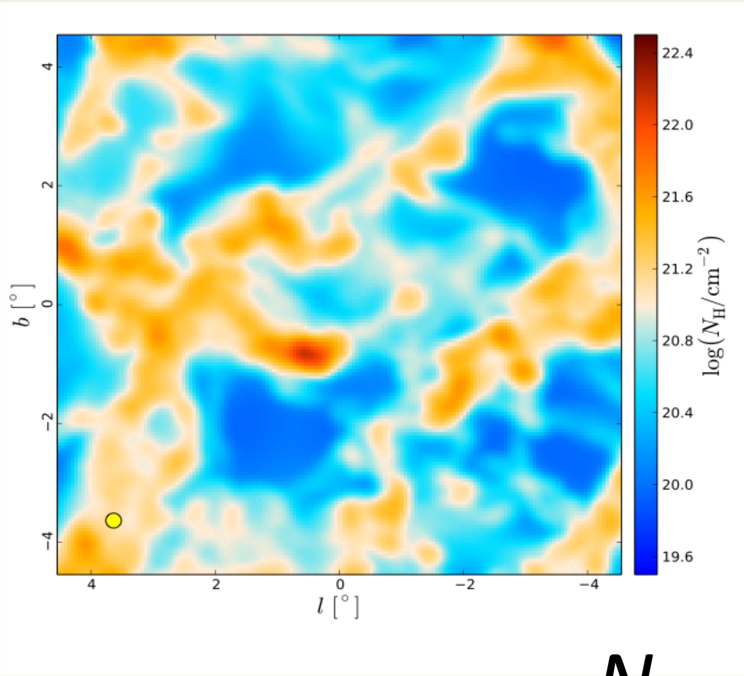
Anti-correlation p_{max} and N_H

Anti-correlation p_{max} and $\Delta\psi$

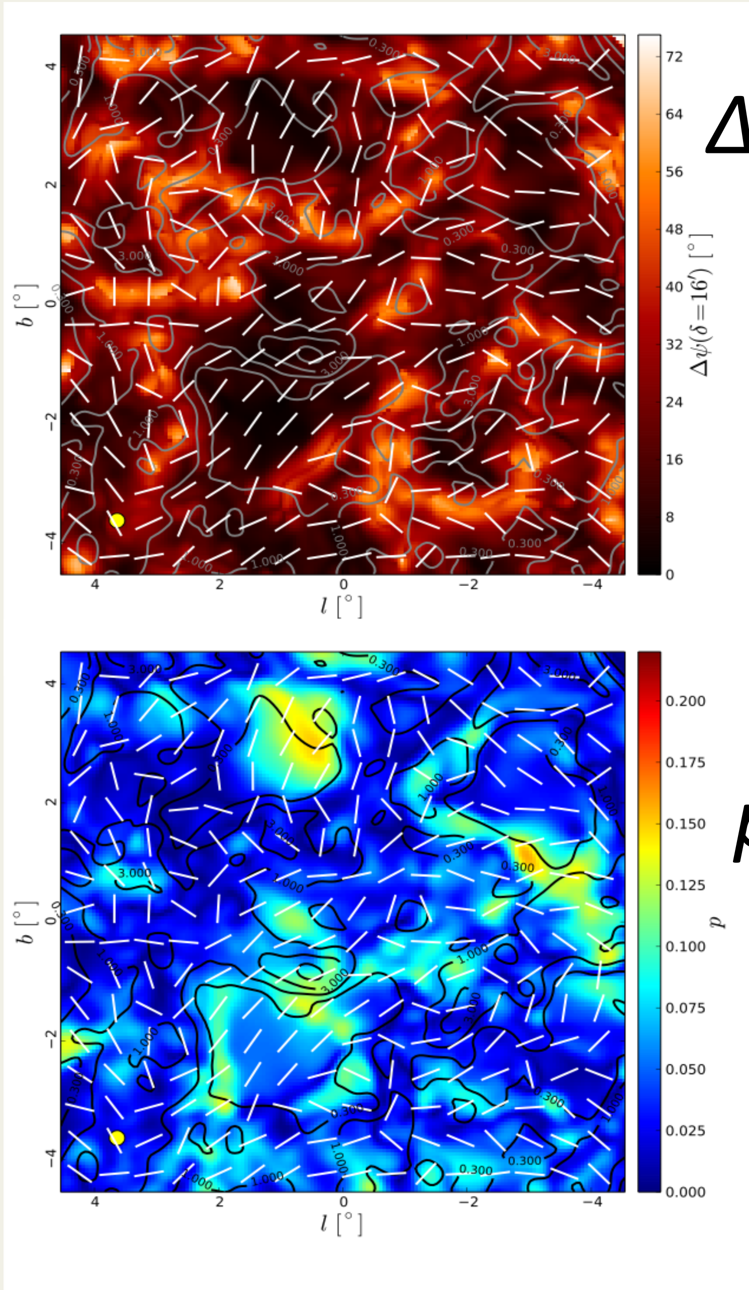
Planck intermediate results. XX.

Simulated polarization maps





N_H



$\Delta\psi$

p

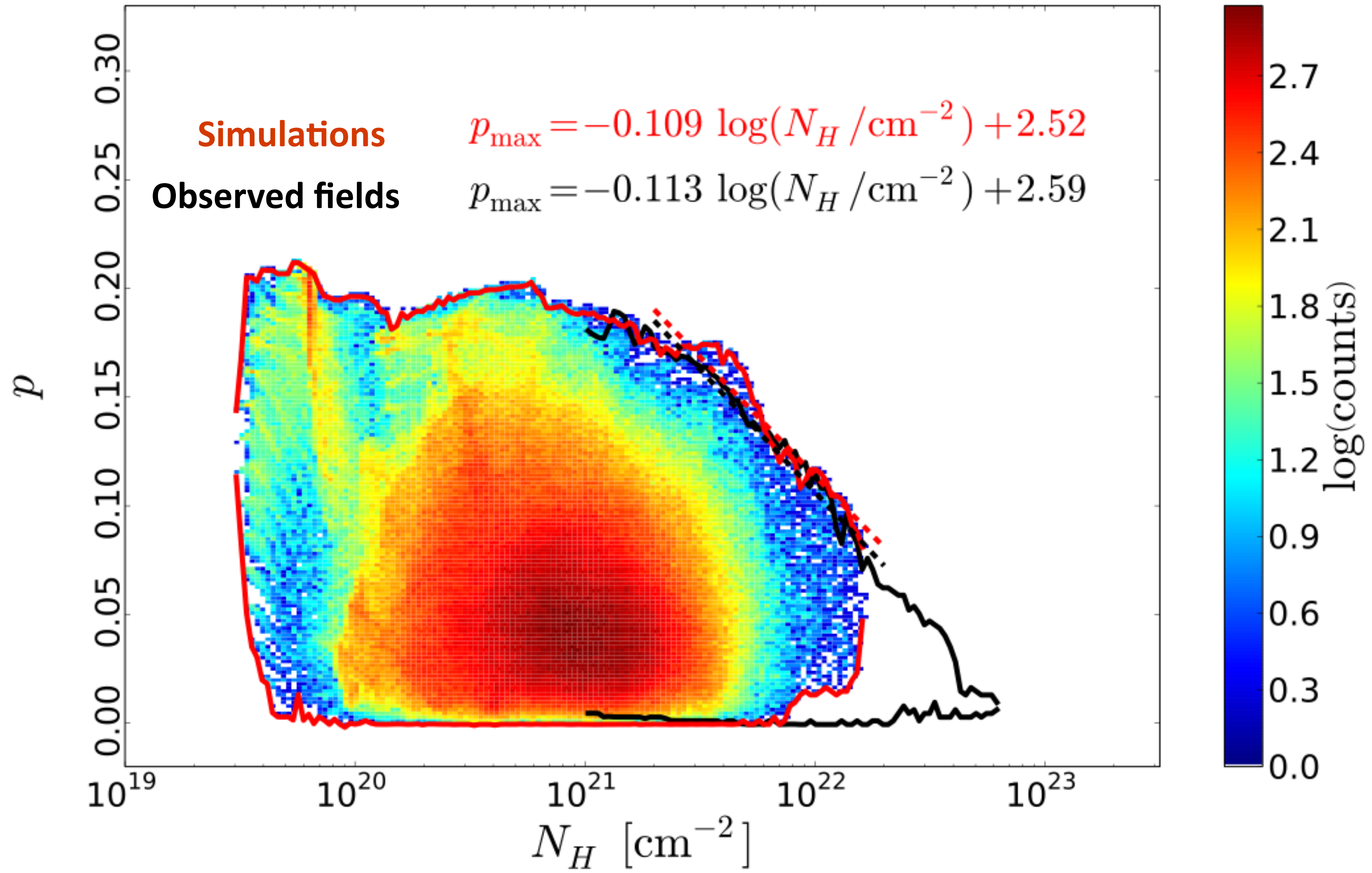
Anti-correlation p_{max} and N_H

Anti-correlation p_{max} and $\Delta\psi$

Overall lower polarization fractions

Planck intermediate results. XX.

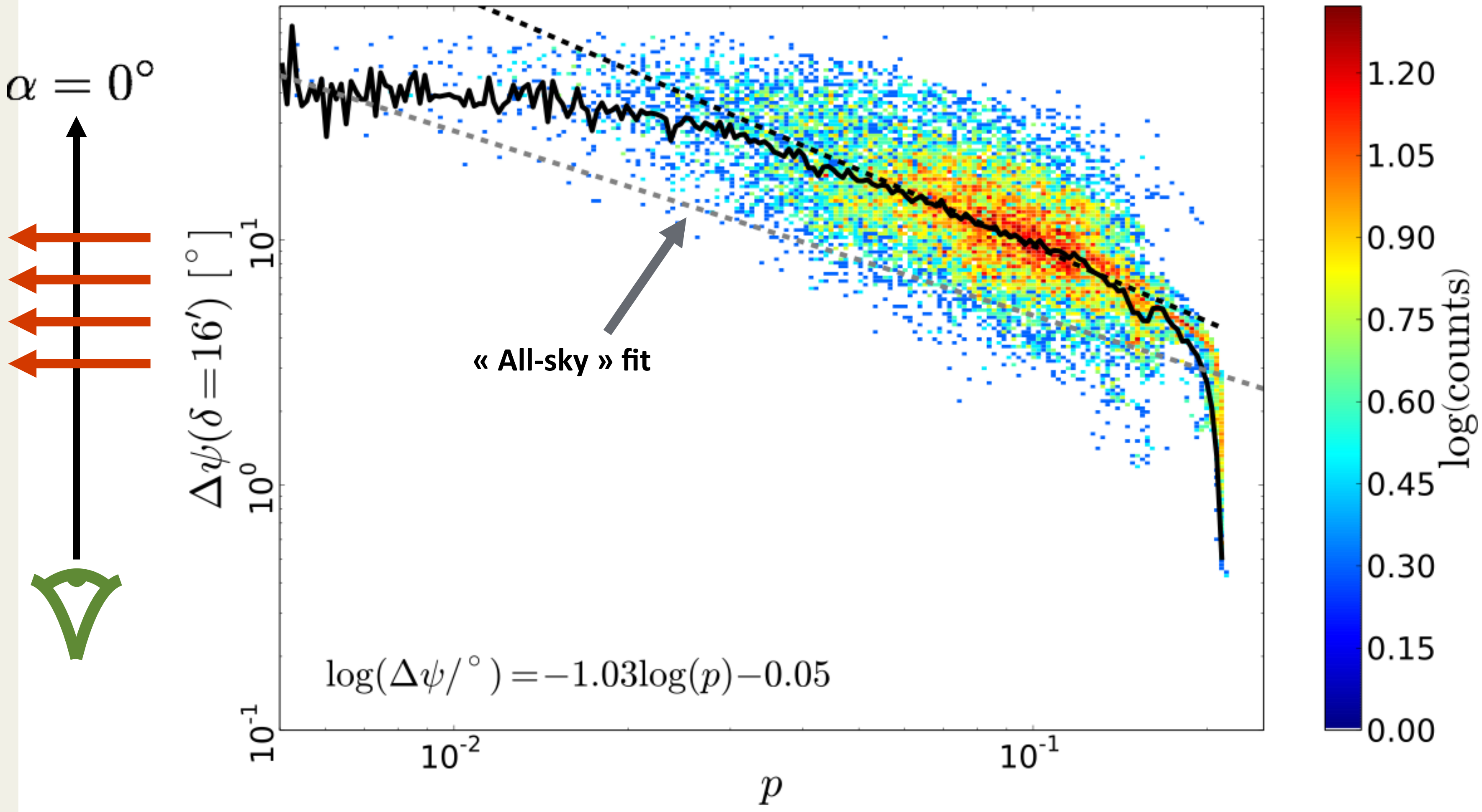
Polarization fraction versus column density



Simulations reproduce very well the decrease of p_{max} with N_H in the range 10^{21} to a few 10^{22} cm^{-2}

Planck intermediate results. XX.

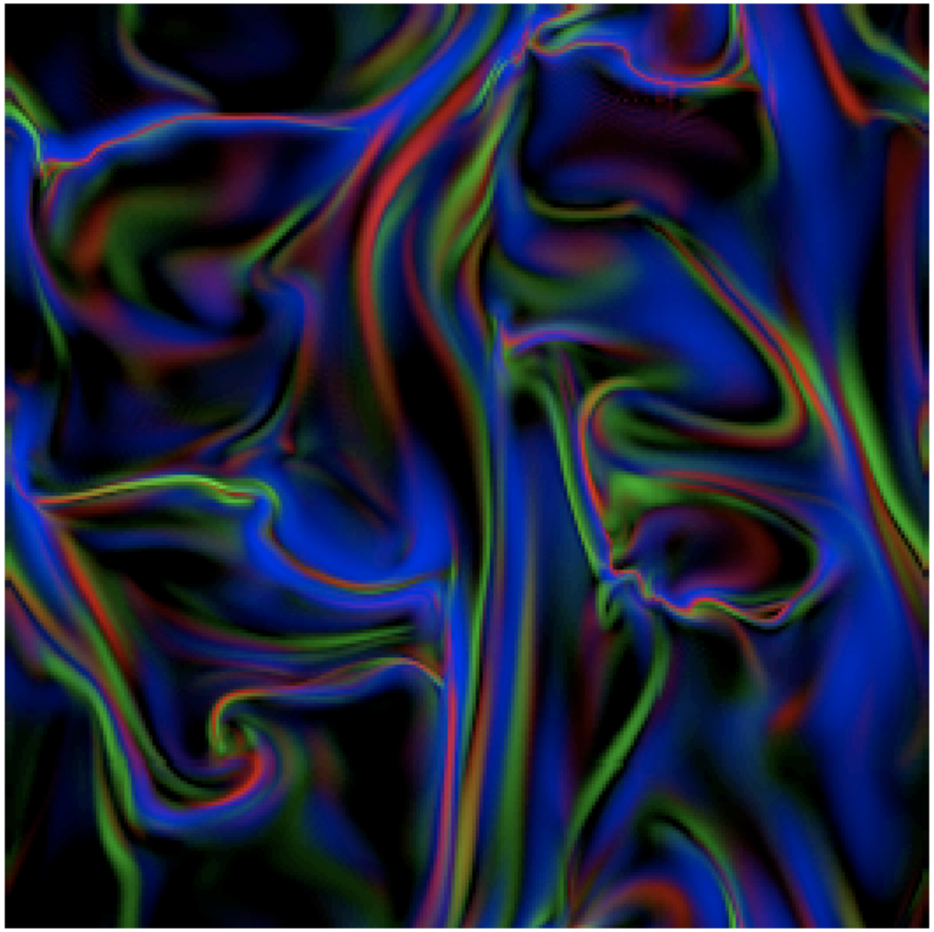
Polarization fraction and angle dispersion



Global trend is reproduced, but simulations tend to have too high an angular dispersion

Planck intermediate results. XX.

Numerical simulations: (II) Non-ideal incompressible turbulence



Ohmic dissipation:

$D_{ohm} = \eta\, j^2$

Viscous dissipation:

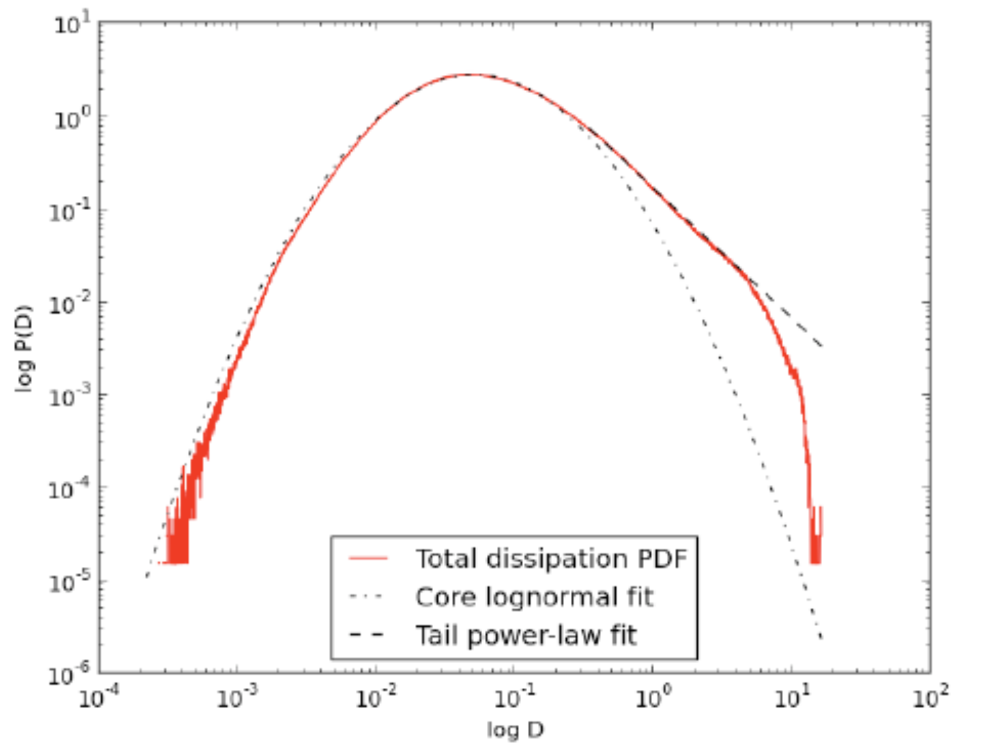
$D_{visc} = \nu\omega^2$

Dissipation by ion-neutral drift (ambipolar diffusion):

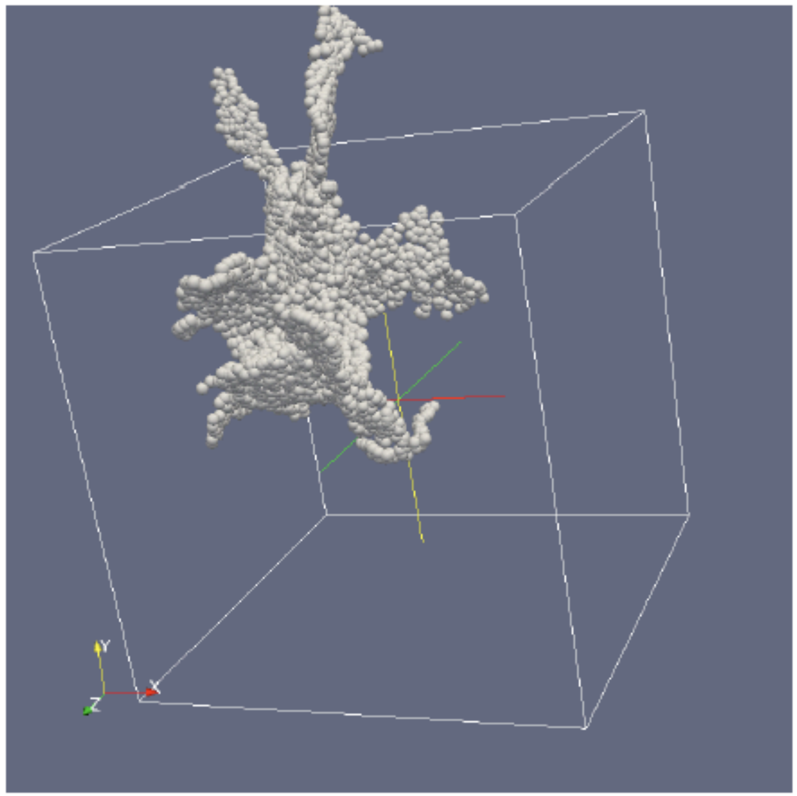
$D_{AD} = \alpha(j\times B)^2$

Slice in 512^3 spectral NS, Momferratos et al 2014 MNRAS

Intermittency of dissipation : ohmic, viscous and ambipolar diffusion



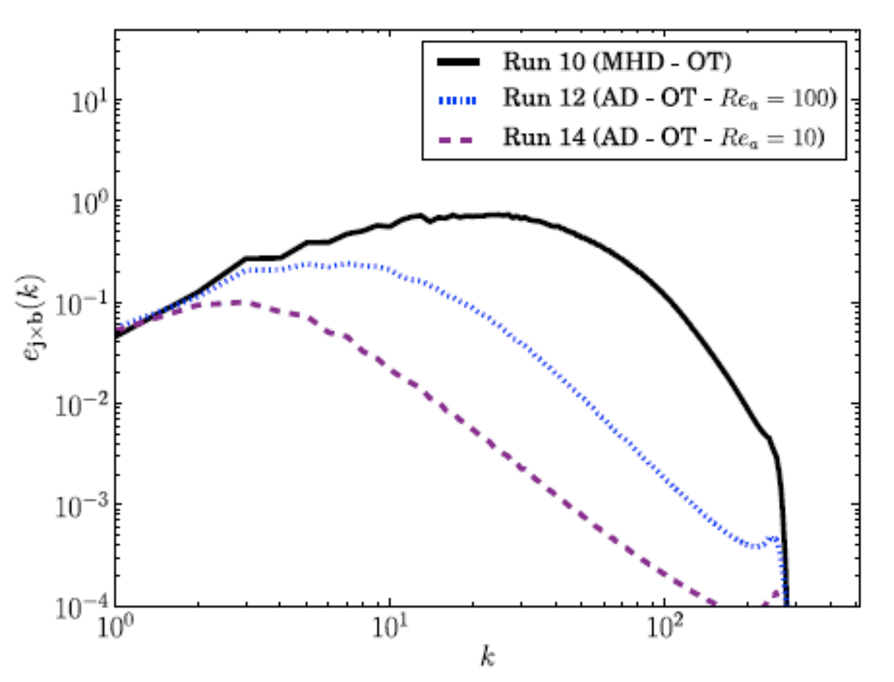
The 10% most dissipative events contribute to 30% of total dissipation



Structure of dissipation rate extremum

Momferratos et al. 2014

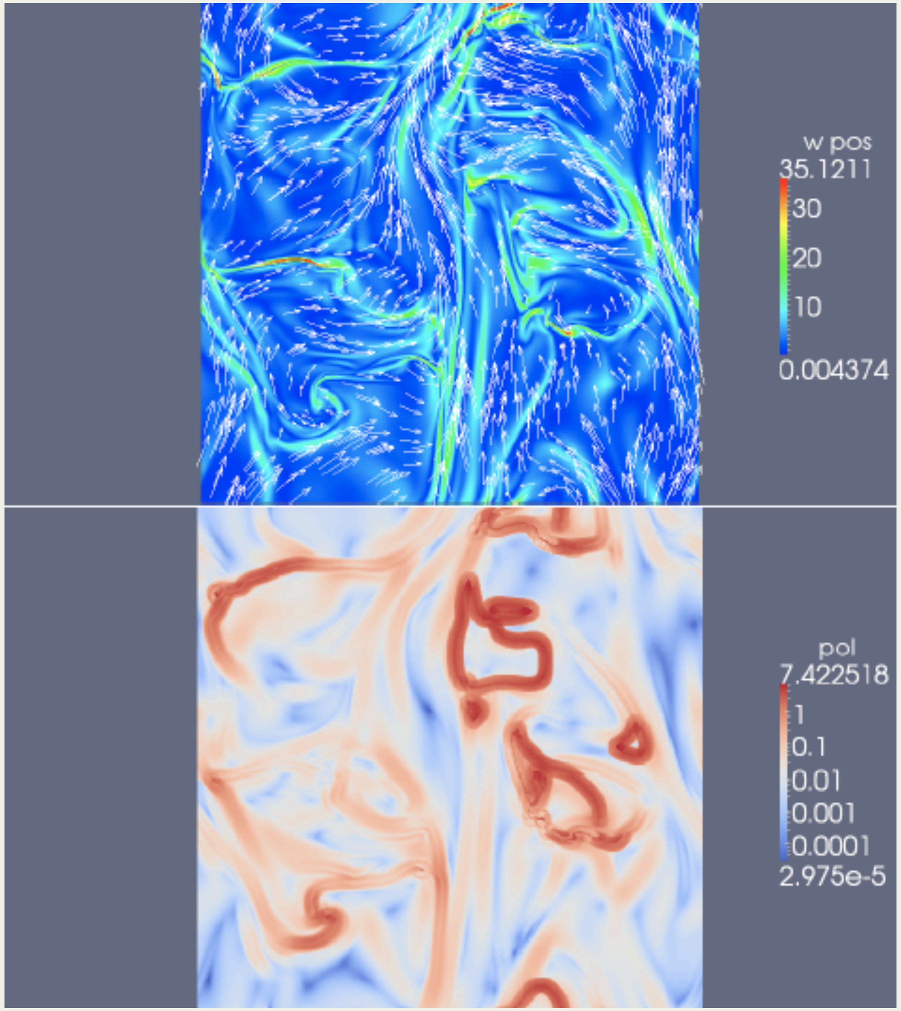
Energy spectra of j x B



➪ ambipolar diffusion generates force-free field at small scales

Comparison with observables

➪ Vorticity POS projection and B_{POS}



➪ Increments of polarization orientation

In summary

- Large fluctuations of the dust polarization fraction p for $N_H <$ a few 10^{22} cm^{-2}
- High p_{max} ➩ high intrinsic polarization of dust > 20%
- Systematic decrease of p_{max} with N_H
  ➩ fluctuations of the magnetic field orientation
  ➩ loss of radiative grain alignment $N_H >$ a few 10^{22} cm^{-2}
- Polarization angle ψ ordered over large areas
- Sharp variations of ψ ➩ filamentary structures, not filaments of matter
- Anti-correlation of ψ dispersion and p
- Anisotropic simulations of MHD compressible turbulence : reproduce major trends, stress role of large scale field
- AD-MHD incompressible turbulence : largest variations of ψ on most intense shears and currents