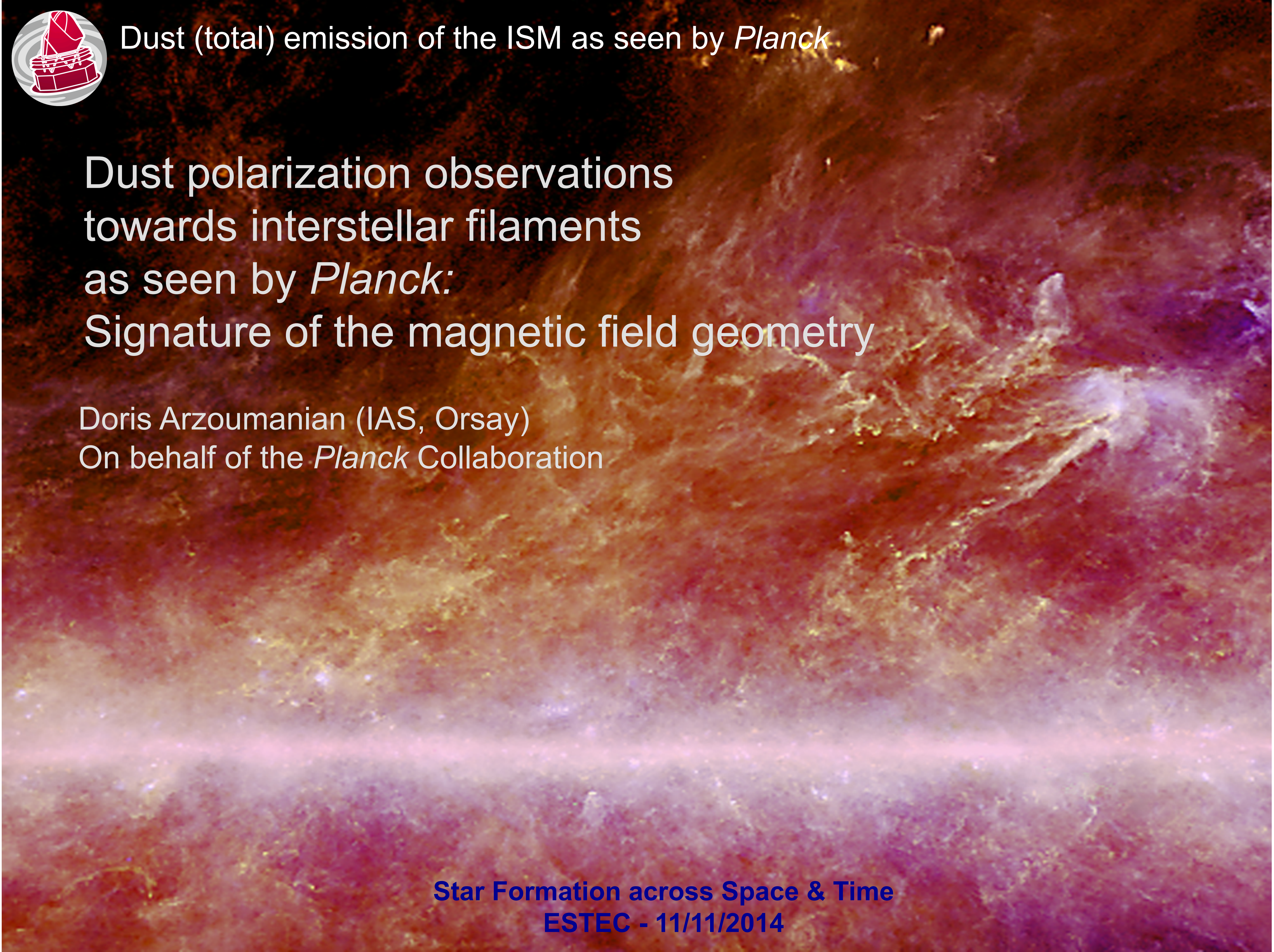
Dust (total) emission of the ISM as seen by *Planck*



Dust polarization observations towards interstellar filaments as seen by *Planck*: Signature of the magnetic field geometry

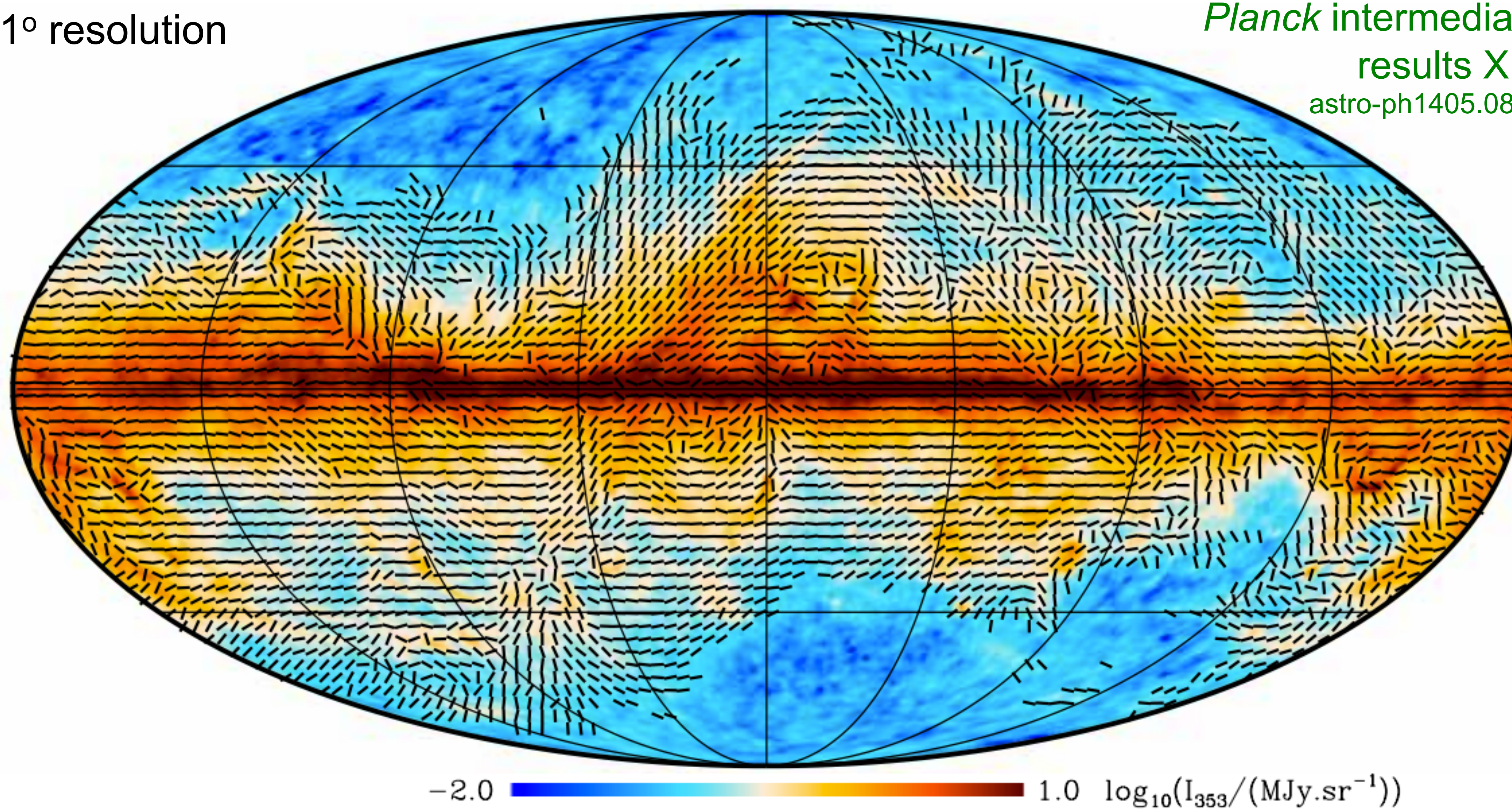
Doris Arzoumanian (IAS, Orsay)
On behalf of the *Planck* Collaboration

Star Formation across Space & Time
ESTEC - 11/11/2014

Large scale magnetic field structure of the ISM derived from the dust polarized emission observed by *Planck*

1° resolution

Planck intermediate results XIX
astro-ph1405.0871

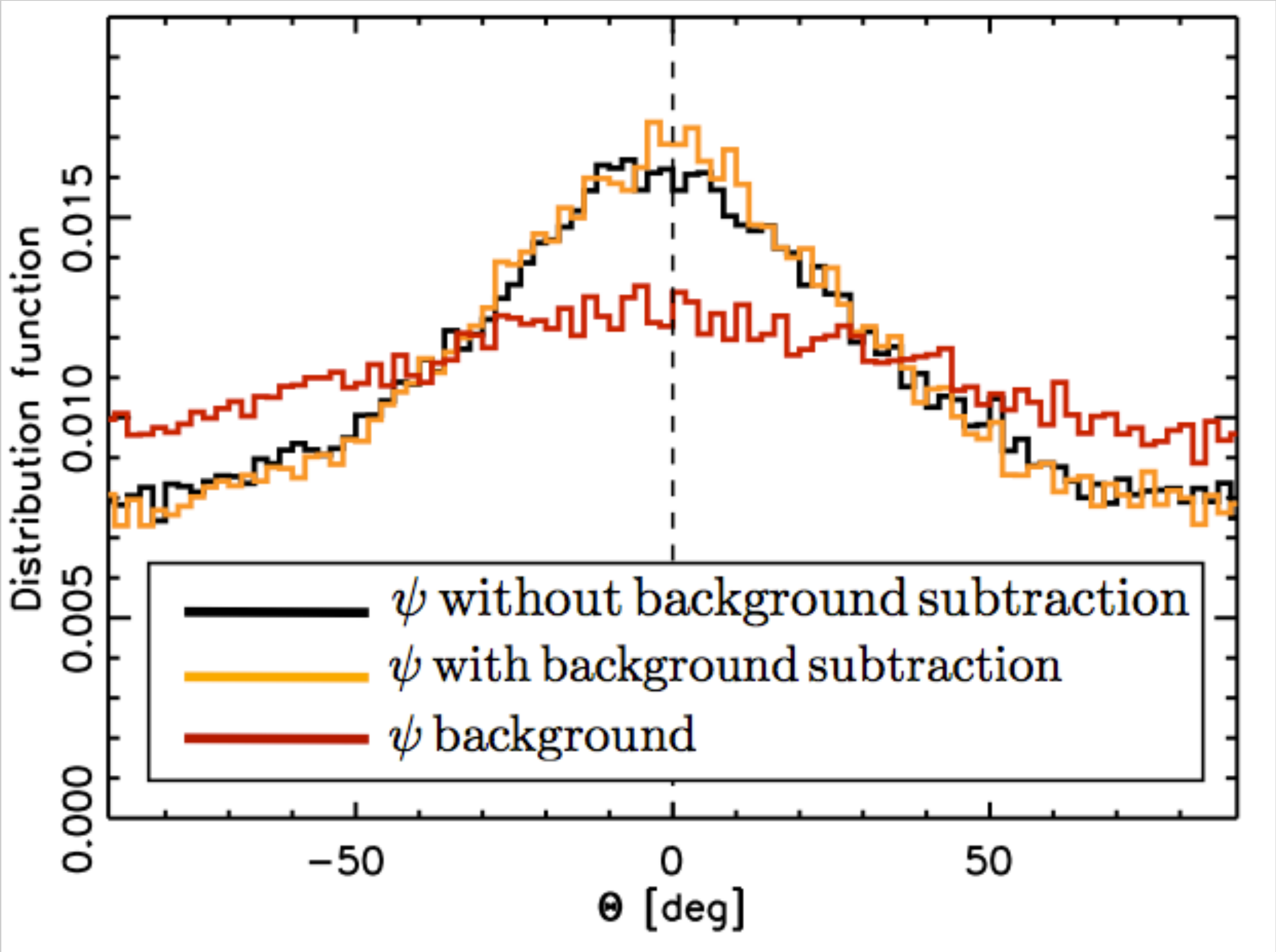


Total intensity at 353 GHz, with plane-of-the-sky magnetic field (B_{POS}) orientation (segments with normalized length)

Statistical analysis of the relative orientation between magnetic field and interstellar filaments observed by *Planck*

In the diffuse ISM filaments are preferentially aligned with the local B_{POS}

Planck intermediate results XXXII (astro-ph1409.6728)



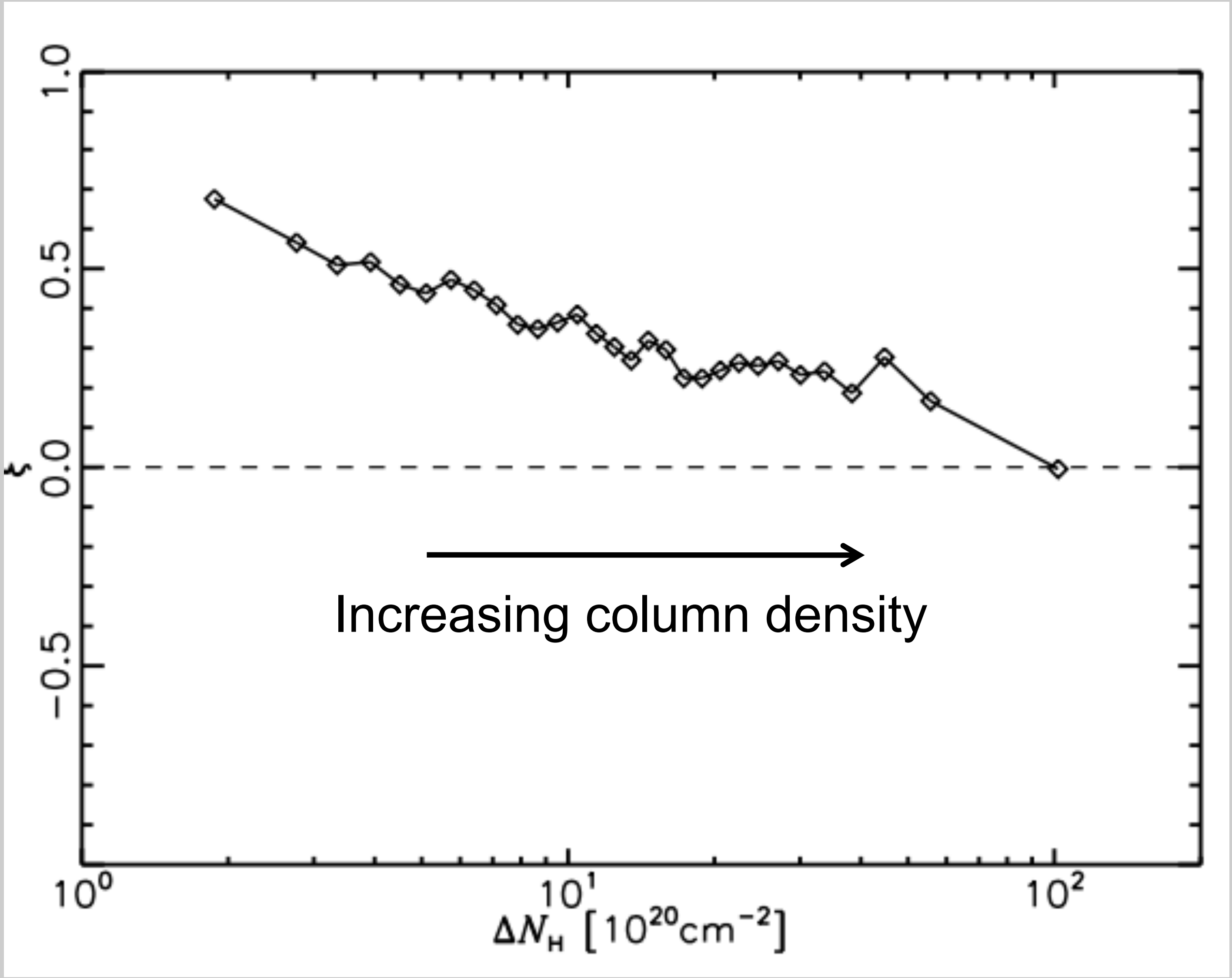
Difference between the orientations of B_{POS} and of interstellar filaments

Statistical analysis of the relative orientation between magnetic field and interstellar filaments observed by *Planck*

In the diffuse ISM, filaments are preferentially aligned with the local B_{POS}
While filaments perpendicular to the field appear in molecular clouds

Planck intermediate results XXXII (astro-ph1409.6728)

Increasing alignment between the field and the filaments



See also
Clark et al. 2014,
McClure-Griffiths 2006,
Chapman et al. 2011,
Pereyra & Magalhães 2004

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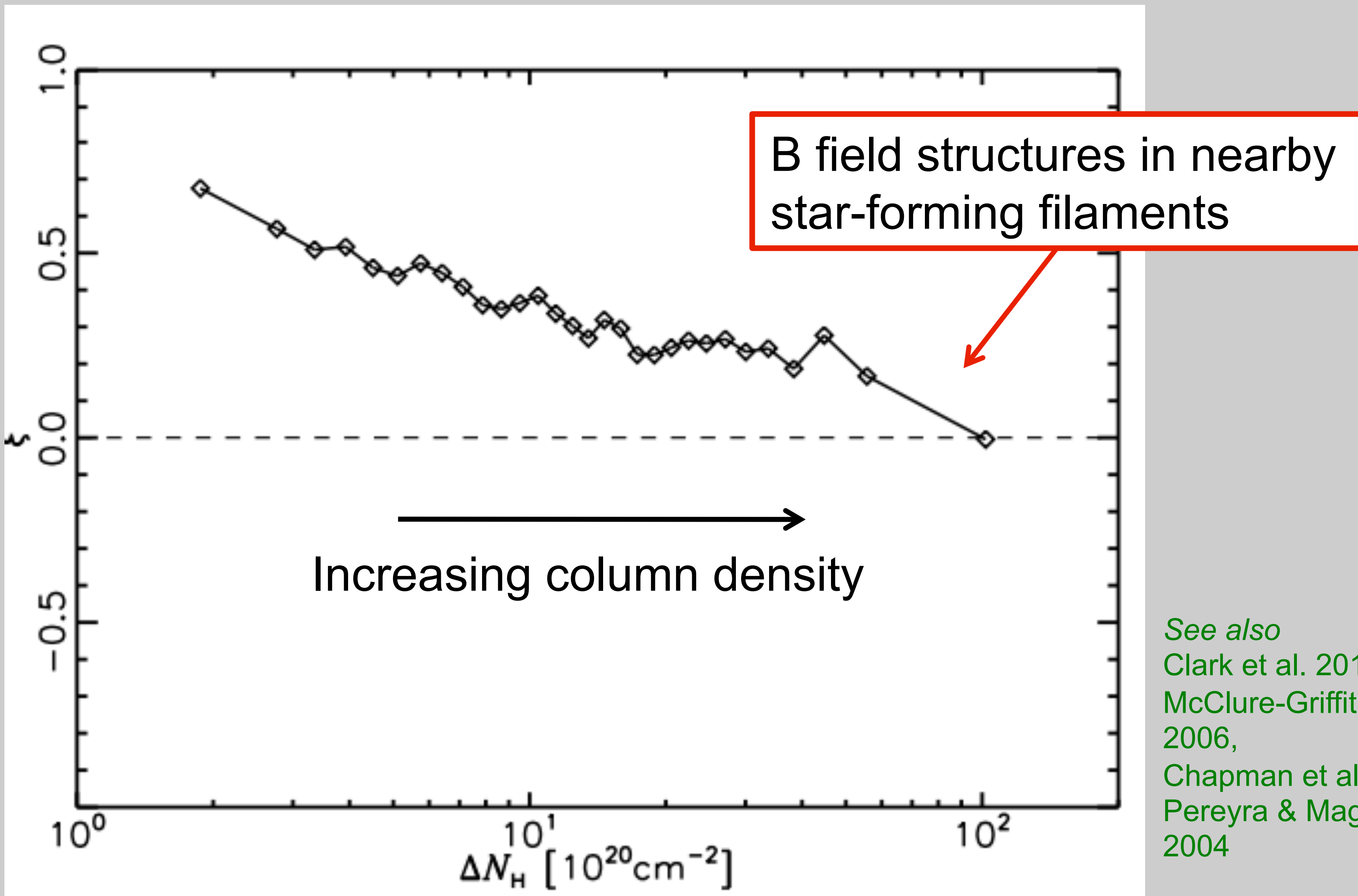

See also
Clark et al. 2014,
McClure-Griffiths 2006,
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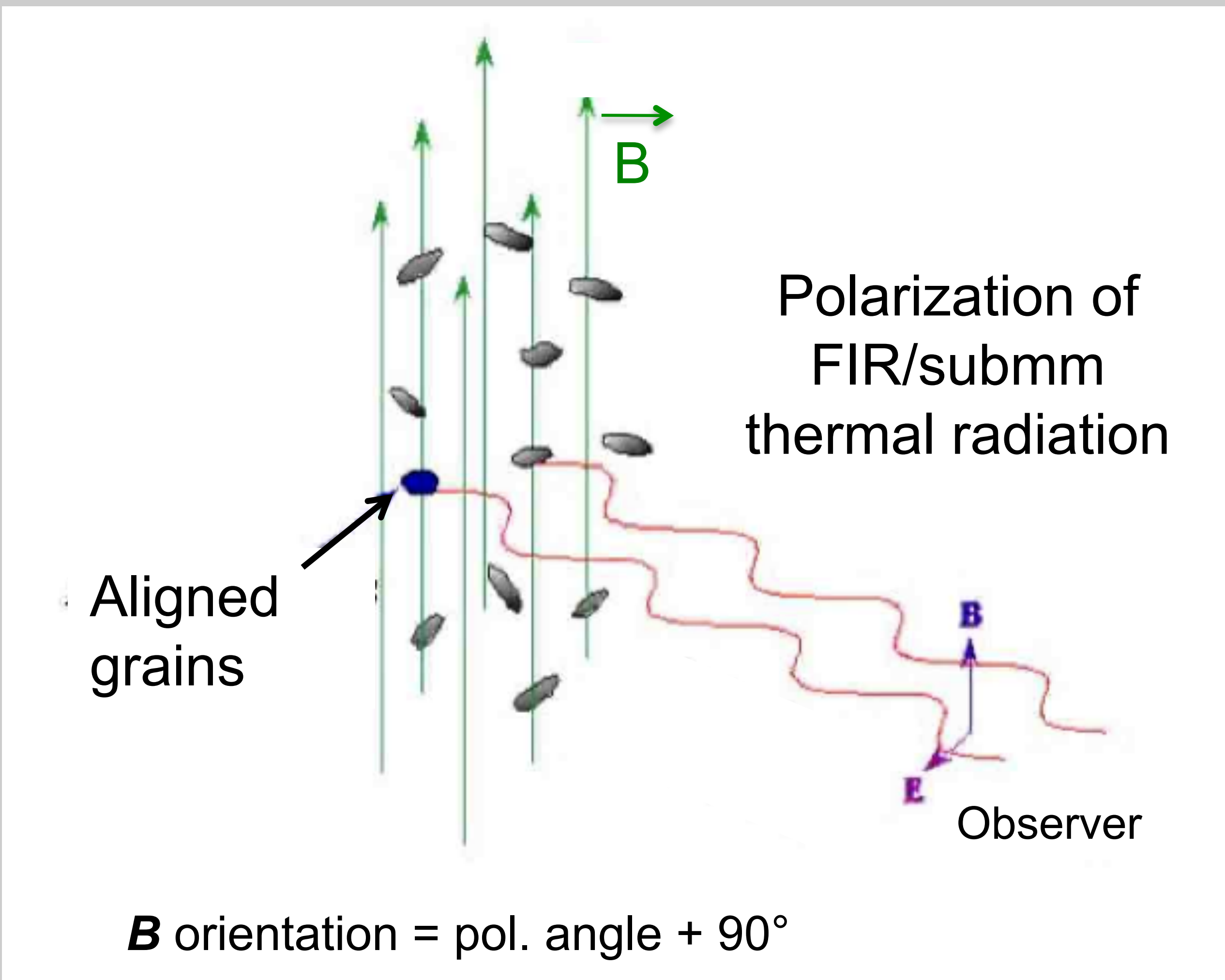
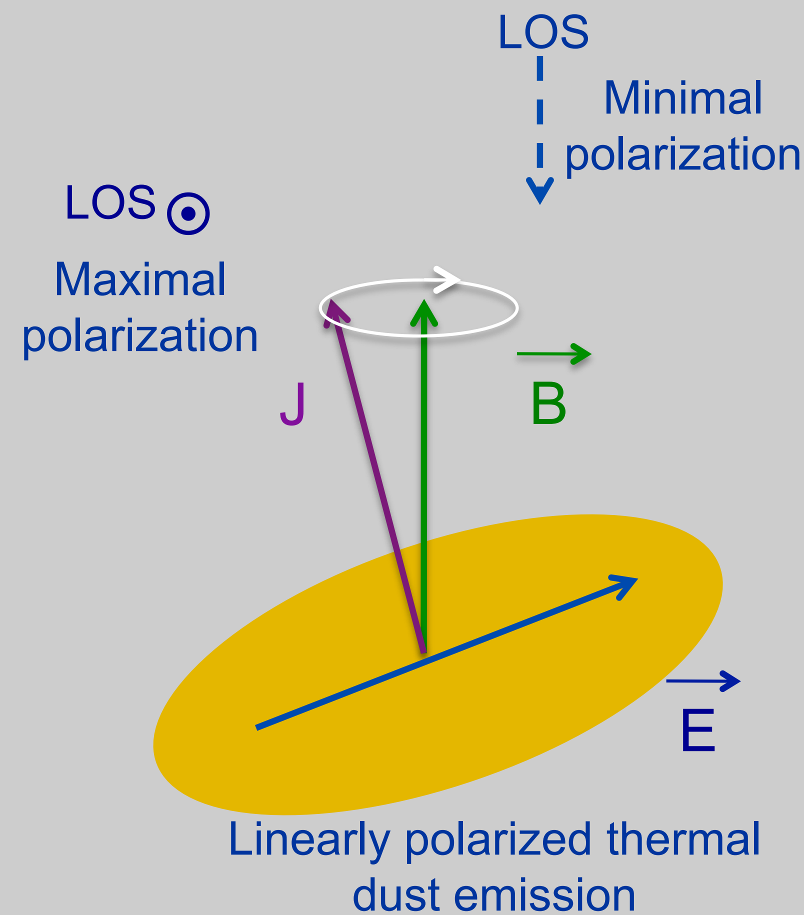
Pereyra & Magalhães 2004

Planck probes the polarized thermal emission from the cold dust in the ISM

- Linear polarization results from non-spherical spinning dust grains, which precess around the ambient magnetic field (Davis & Greenstein 1951, Vaillancourt 2007)
- The polarization angle is perpendicular to the magnetic field projected on the plane of the sky (Hildebrand 1983)





Planck probes the polarized thermal emission from the cold dust in the ISM

• Linear polarization results from non-spherical spinning dust grains, which precess around the ambient magnetic field (Davis & Greenstein 1951, Vaillancourt 2007)

• The observed polarized emission depends on the structure of the magnetic field and the polarization efficiency of dust grains

Observed Stokes parameters

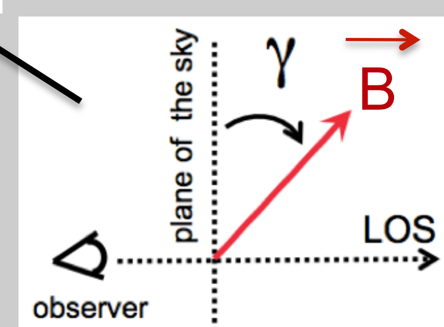
• The imprint of the mean field geometry is present in *Q* and *U*, which are integrated quantities along the line of sight (LOS)

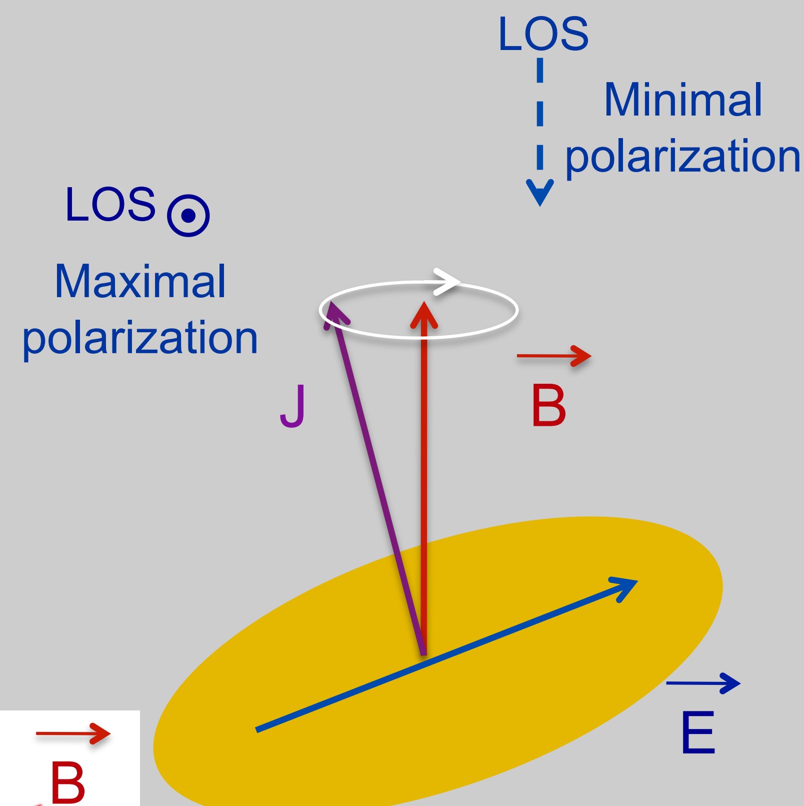
$$Q = \int I\, p_0 \cos(2\psi) \cos^2(\gamma)\, dl$$

$$U = \int I\, p_0 \sin(2\psi) \cos^2(\gamma)\, dl,$$

Polarization fraction of dust grains

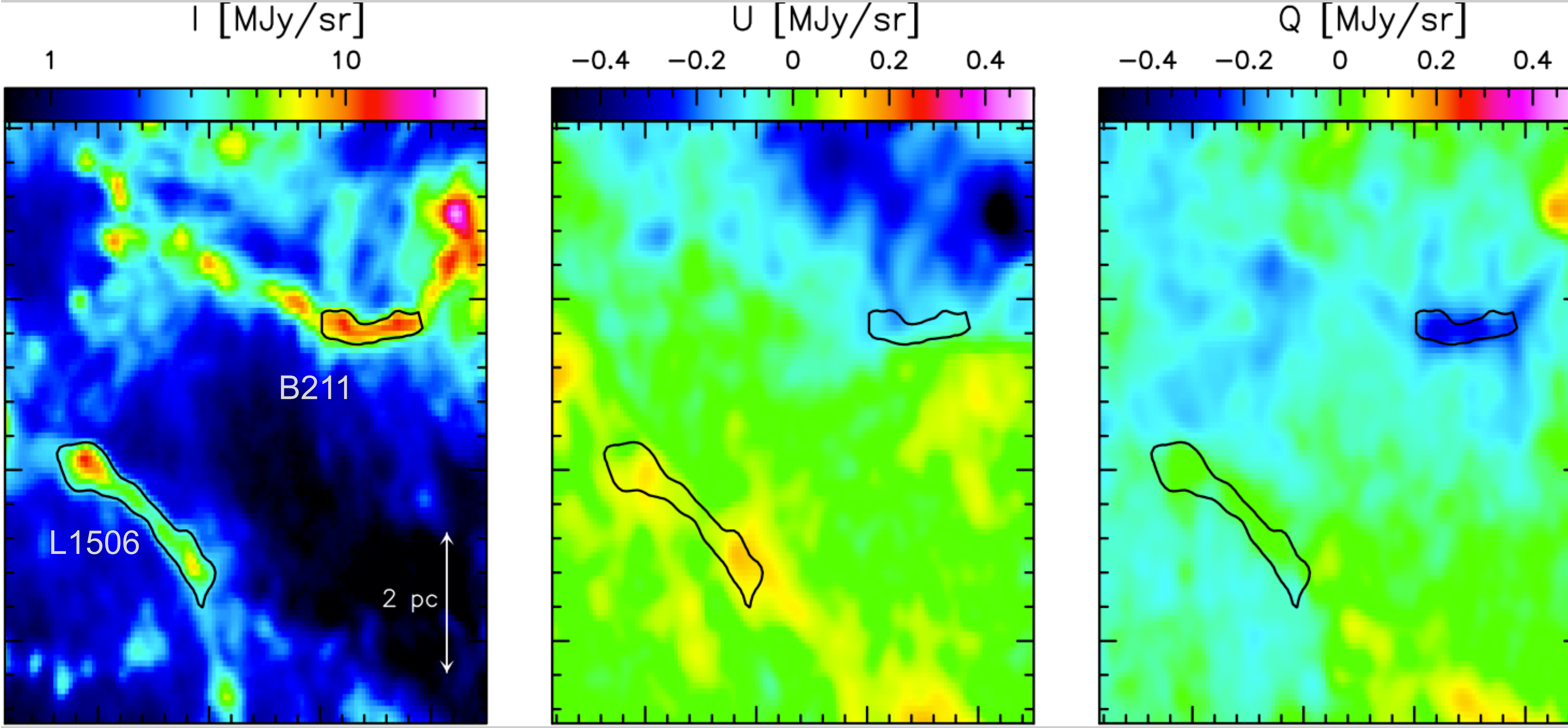
Polarization angle, + 90° orientation of B_{POS}





Linearly polarized thermal dust emission

The Taurus molecular cloud as observed by *Planck* at 353 GHz



Derived quantities from *I, Q* and *U*

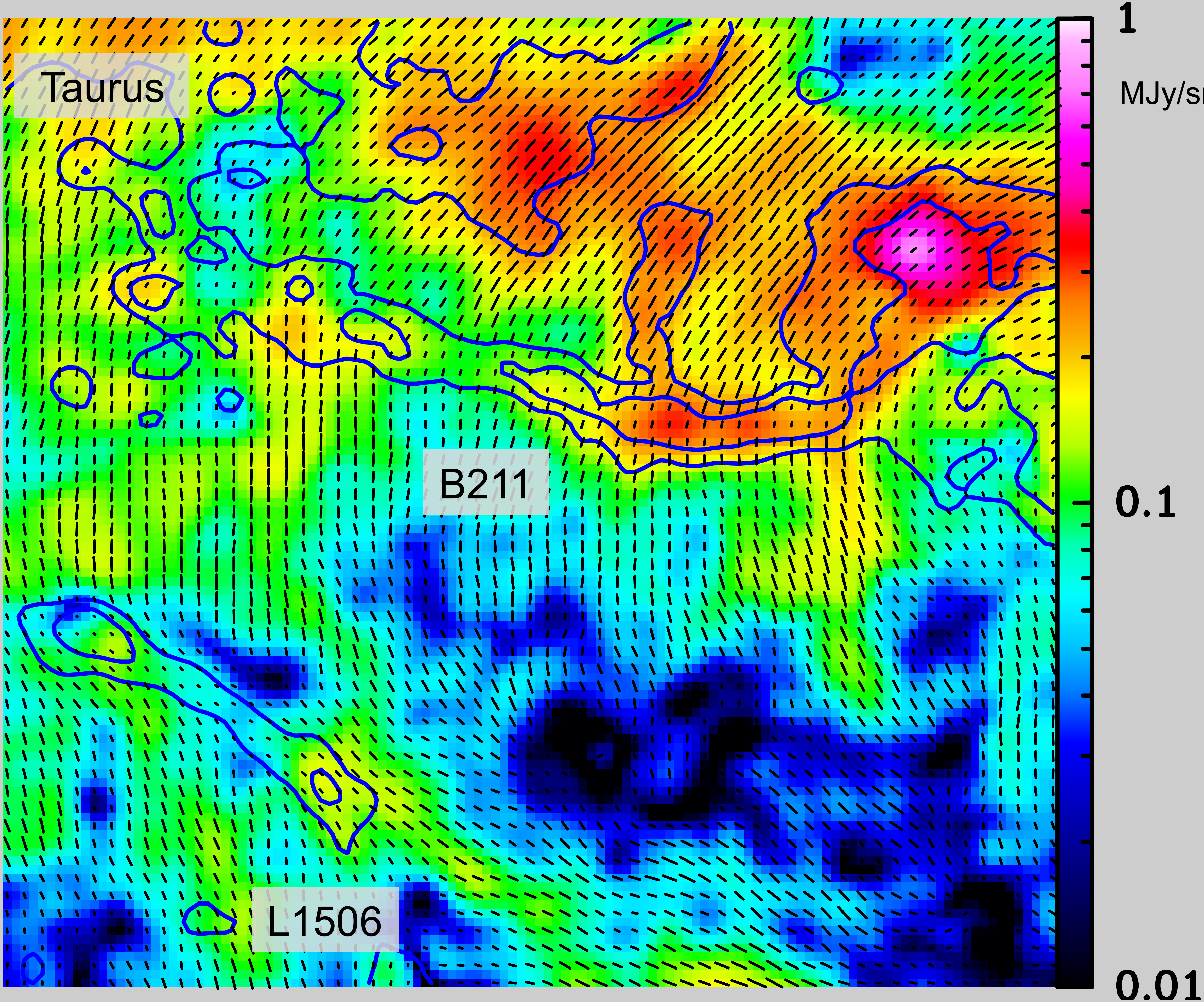
Resolution: *I* map 5'
Q and *U* maps: 10'

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

$$p = P/I$$ Polarization fraction

$$\psi = 0.5 \times \arctan(-U, Q).$$ Polarization angle, + 90° orientation of ***B*** field projected on the plane of the sky

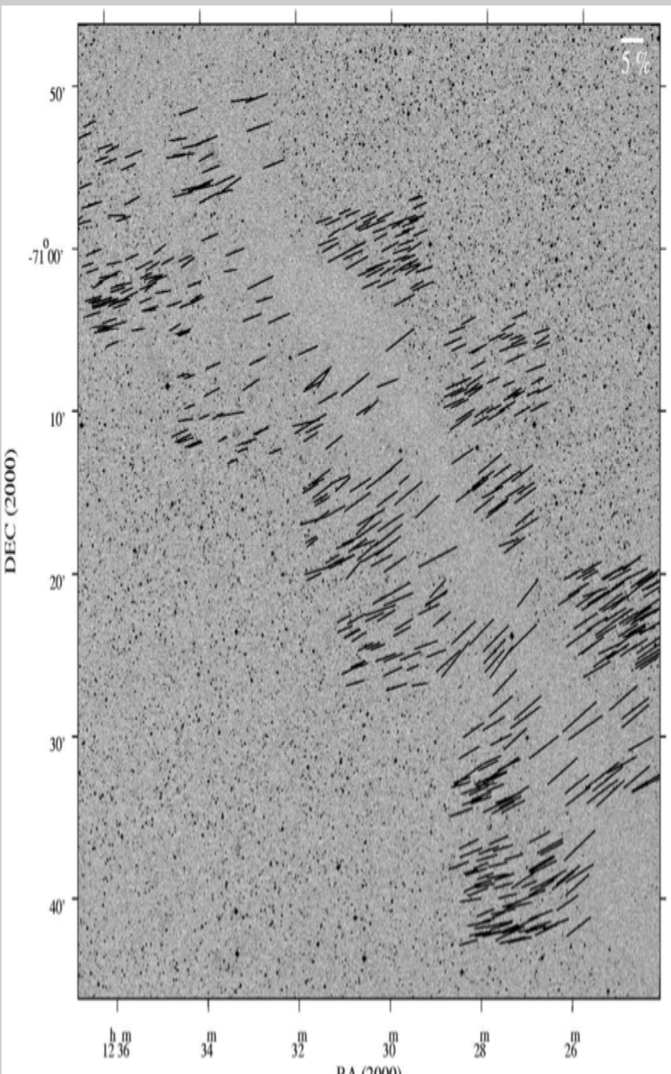
Polarized emission and magnetic field orientation as observed by *Planck*



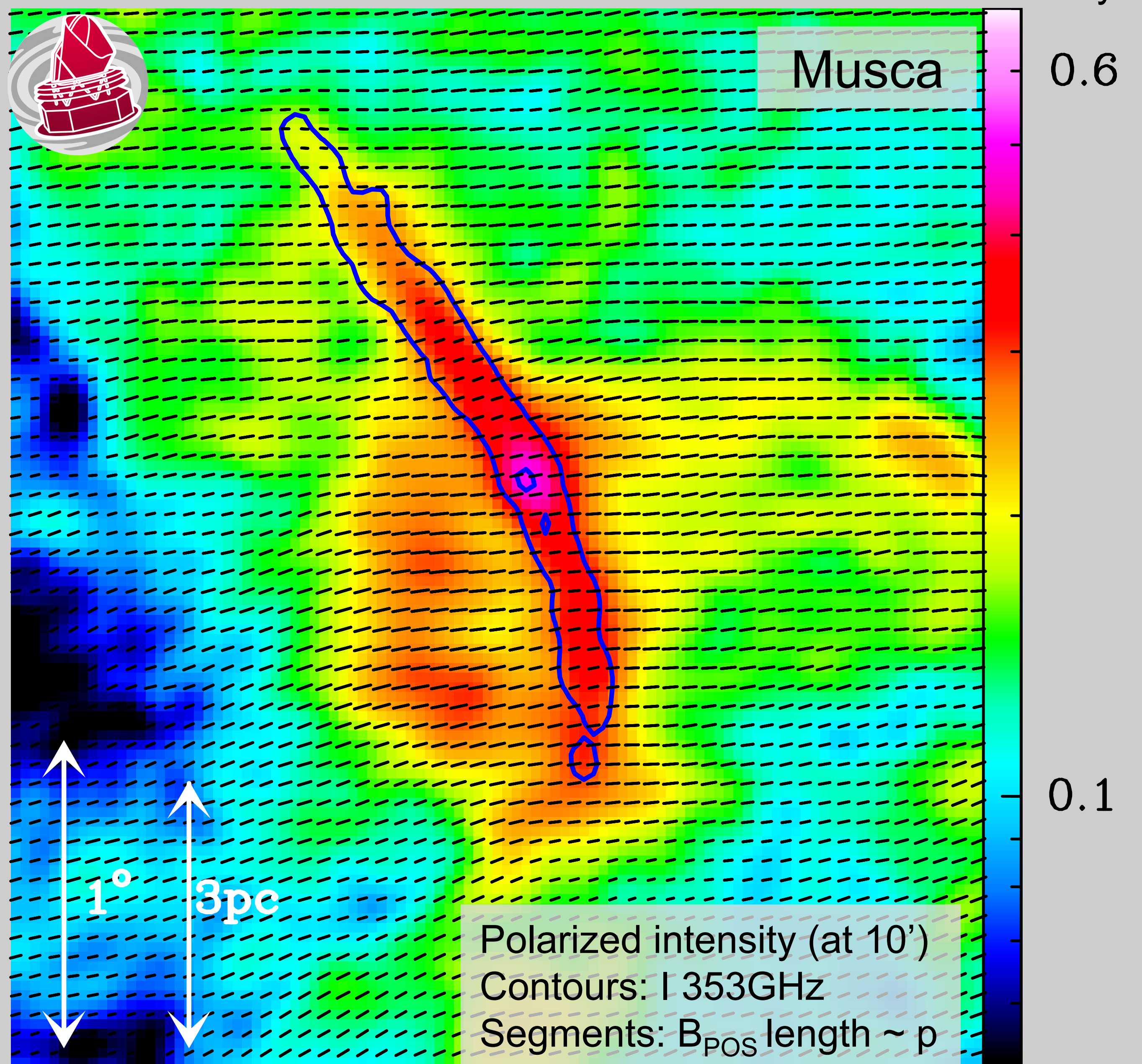
Resolution: 10’, blue contours: I 353GHz (3 & 6 MJy/sr), black segments: B_{POS} length ~ polarization fraction

Dust emission observed towards interstellar filaments is polarized, the field structure is ordered

- What is the 3D magnetic field structure of a star forming filament?
- Is it the same as that of the surrounding cloud?



Musca in absorption with starlight polarization
Pereyra & Magalhães 2004



Modelling the Stokes parameters observed towards nearby filaments

Reconstructing the 3D magnetic field of the filament and its parent cloud, with a uniform dust polarization fraction (p_0)

The model assumes that all of the observed polarized emission is accounted for by the field geometry

$$Q = \int I\, p_0 \cos(2\psi) \cos^2(\gamma)\, dI$$

$$U = \int I\, p_0 \sin(2\psi) \cos^2(\gamma)\, dI,$$

Degeneracy

Grain alignment

$$p_0 = p_{\max} R\, F$$

Maximum dust intrinsic polarization

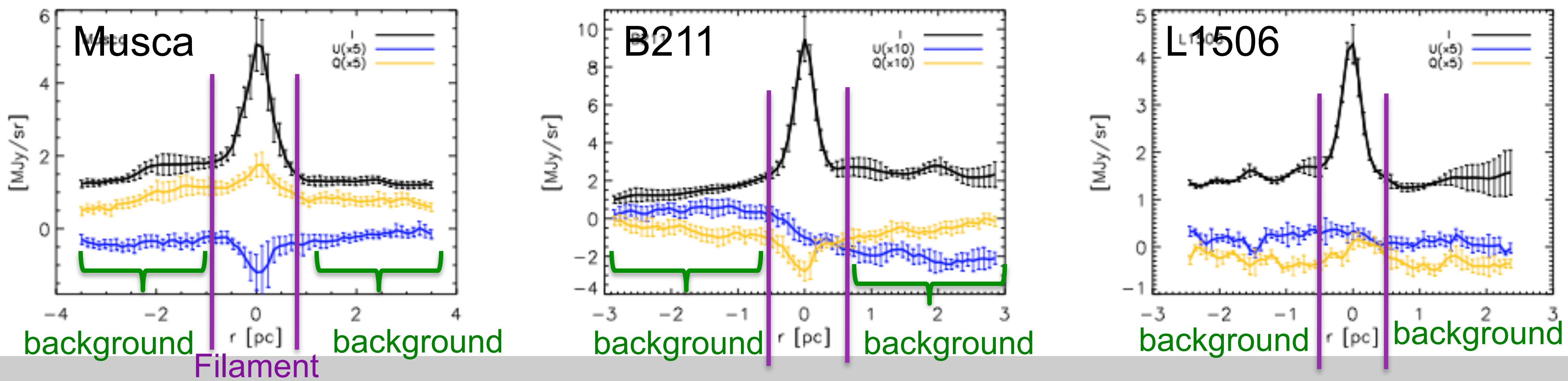
Depolarization due to random B fields along the LOS

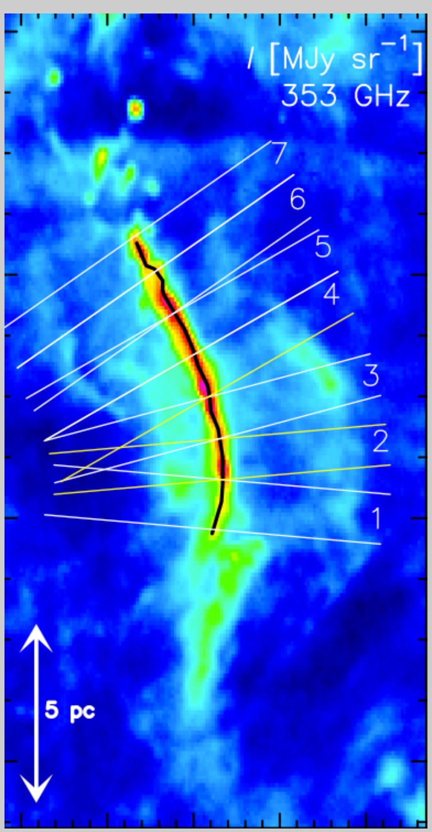
Lee & Draine 1985, Hildebrand 1988

- Fitting the observed Q and U by minimizing the X^2 on all possible pairs of angles

- Free parameters: two pairs of angles (filament and background) defining the 3D structure of the field

Modelling the mean radial profiles of the Stokes parameters perpendicular to the filament's main axis

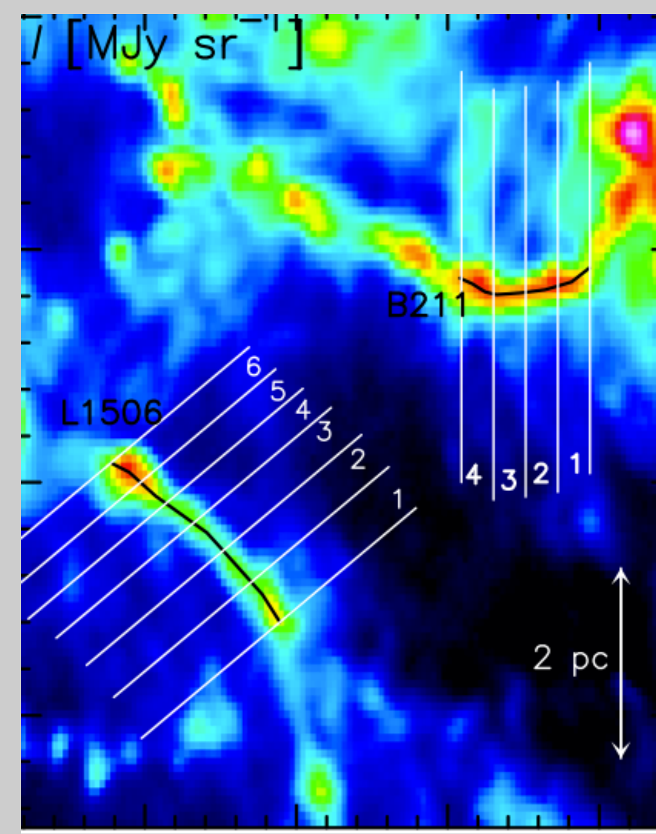




Two layer model to estimate the contribution of the filament to the total observed emission

$$
\begin{aligned}
I_{\mathrm{mod}} &= I_{\mathrm{cl}} + I_{\mathrm{fil}} \\
U_{\mathrm{mod}} &= U_{\mathrm{cl}} + U_{\mathrm{fil}} \\
Q_{\mathrm{mod}} &= Q_{\mathrm{cl}} + Q_{\mathrm{fil}}
\end{aligned}
$$

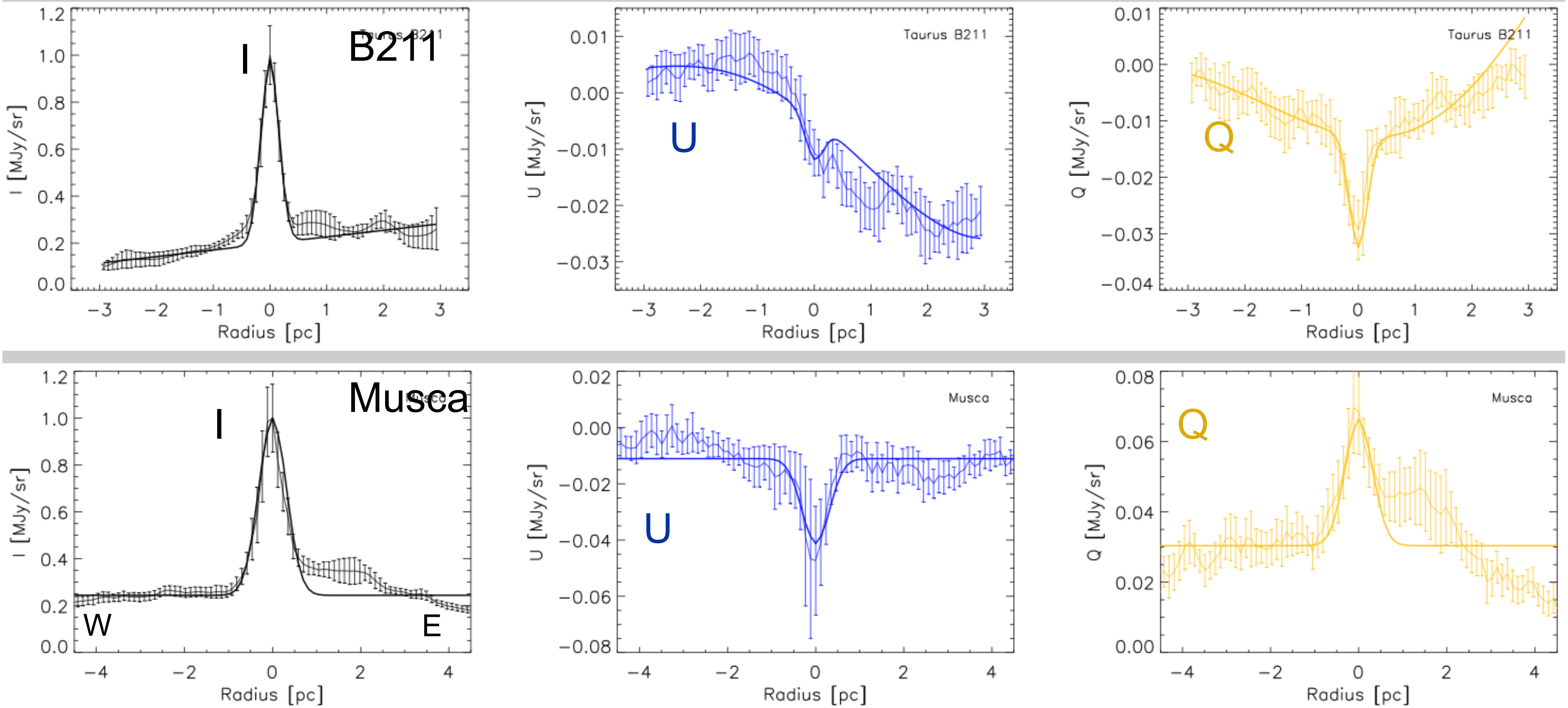
Fitting the observed *Q* and *U* profiles to derive the 3D field geometry with constant p_0



Results of the modelling (Ia)

Polarization properties, at the resolution of *Planck* observations, are well modelled with a uniform field in the filament, which differs from that of its parent cloud, assuming constant dust polarization efficiency

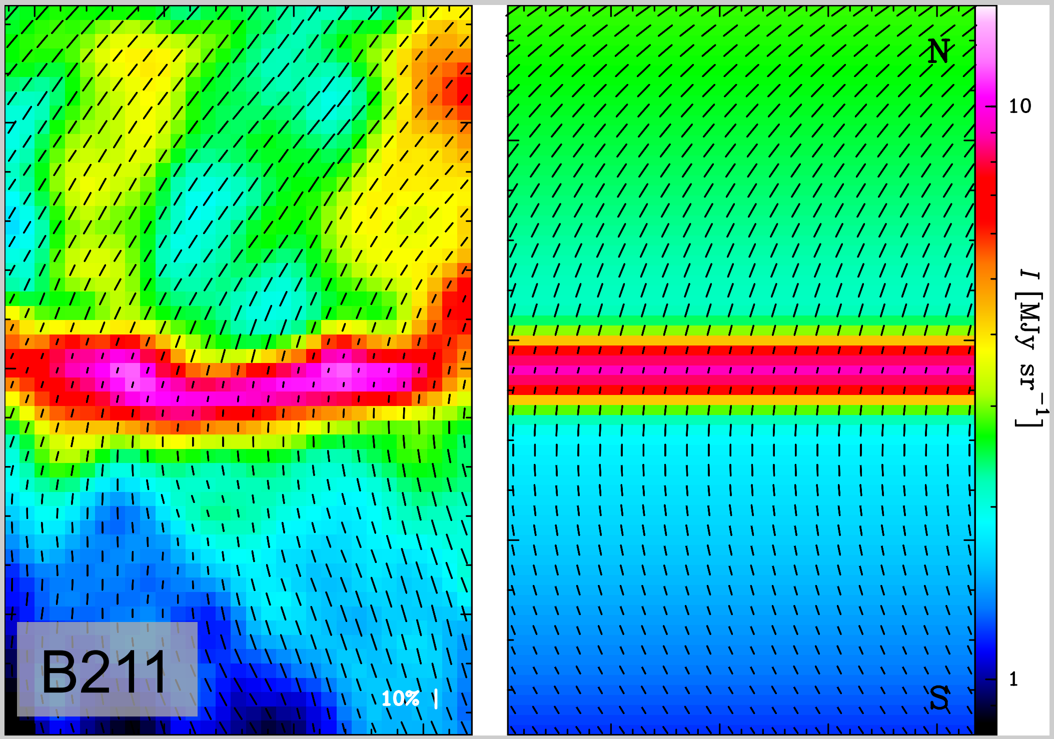
Examples of observed and modelled Stokes parameters profiles



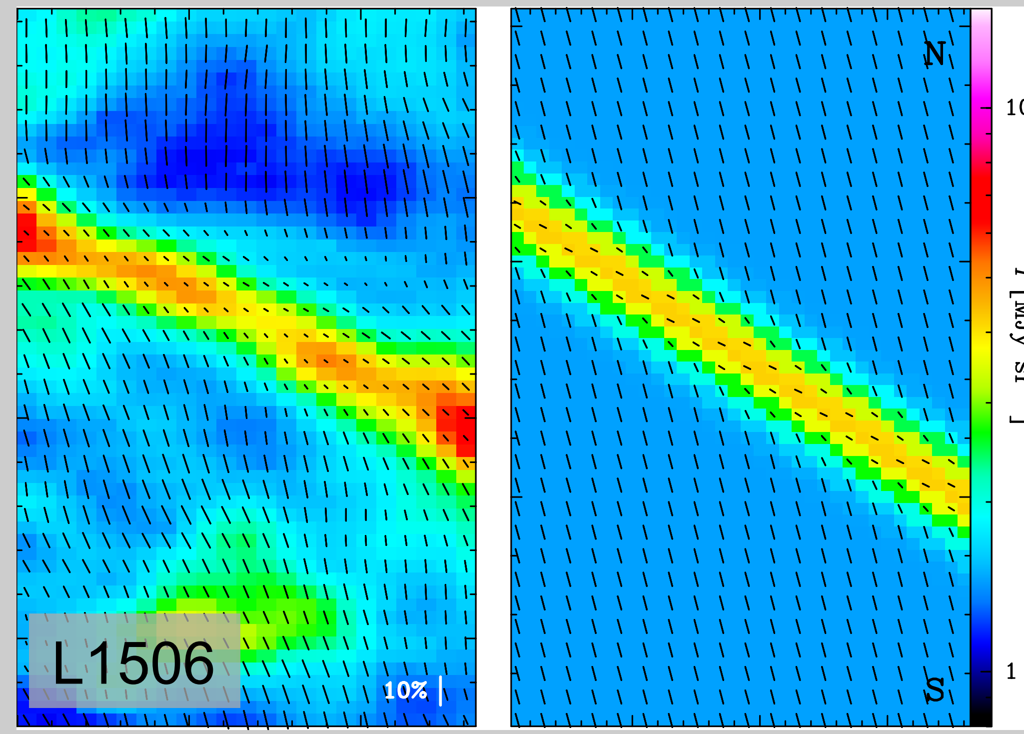
Results of the modelling (Ib)

The observed polarization fraction and B field orientation are well reproduced

Planck Observations — Our model



Planck Observations — Our model

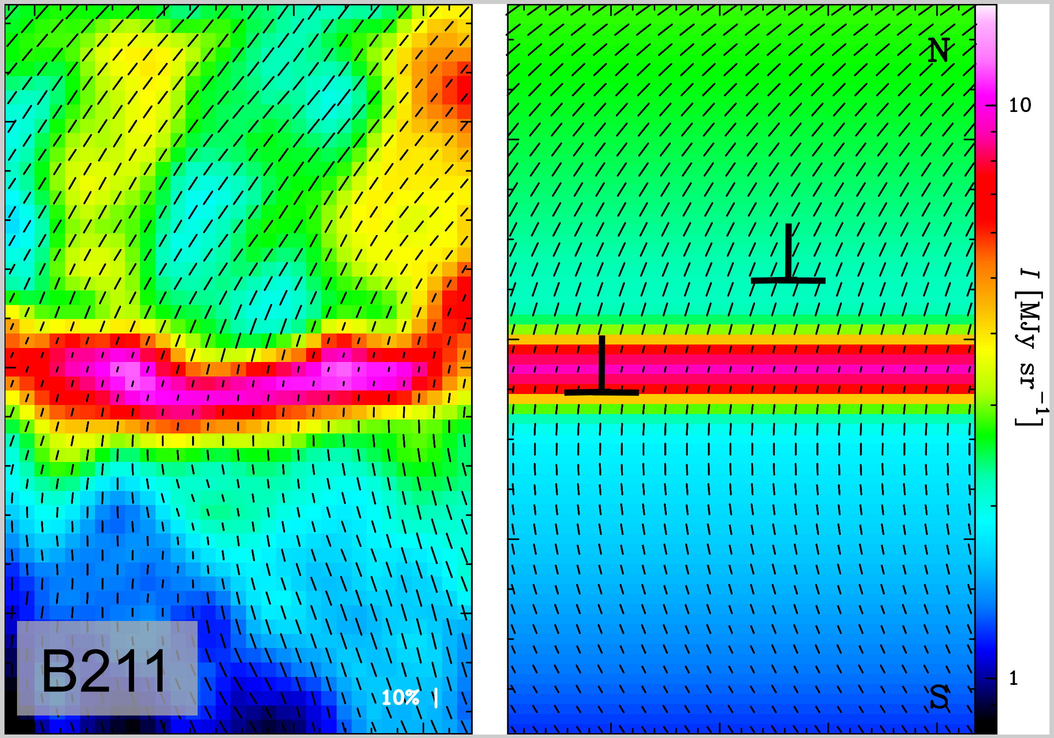


I map at 353GHz,
black segments: orientation of B_{POS},
Length of the segments ~ polarization fraction

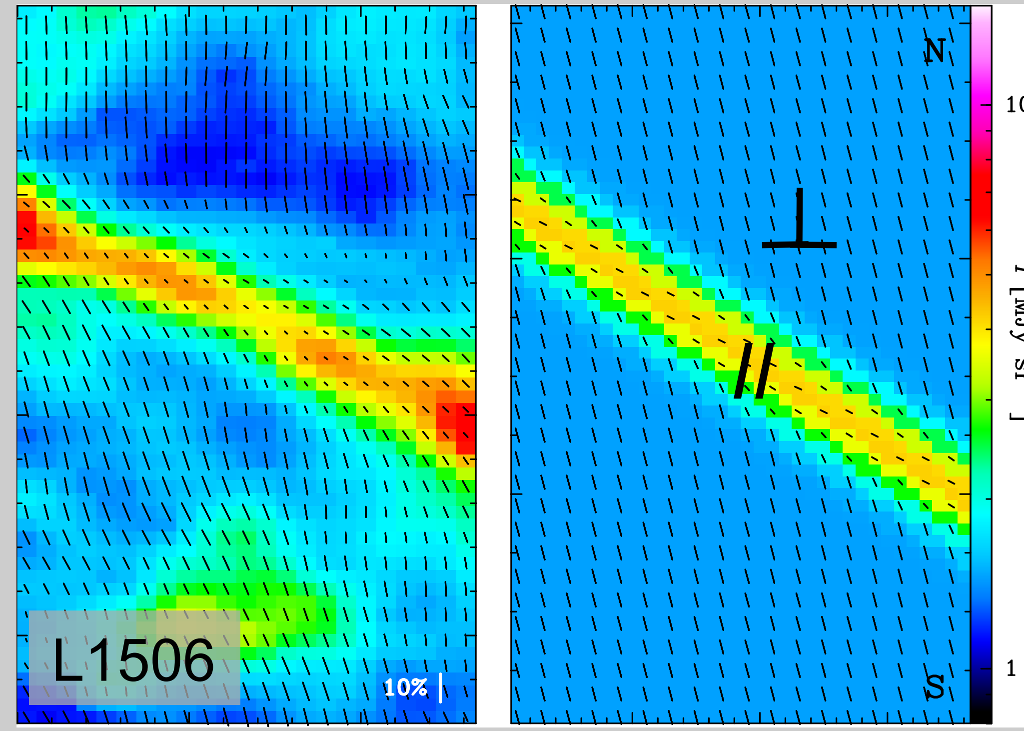
Results of the modelling (II)

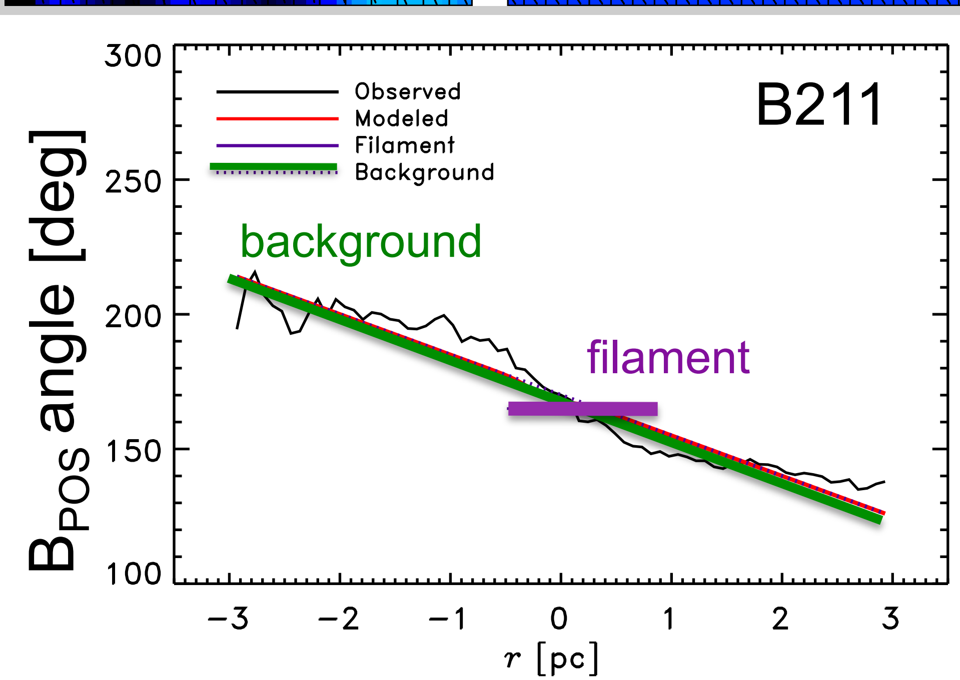
Variation of the POS B field in the filament and the background

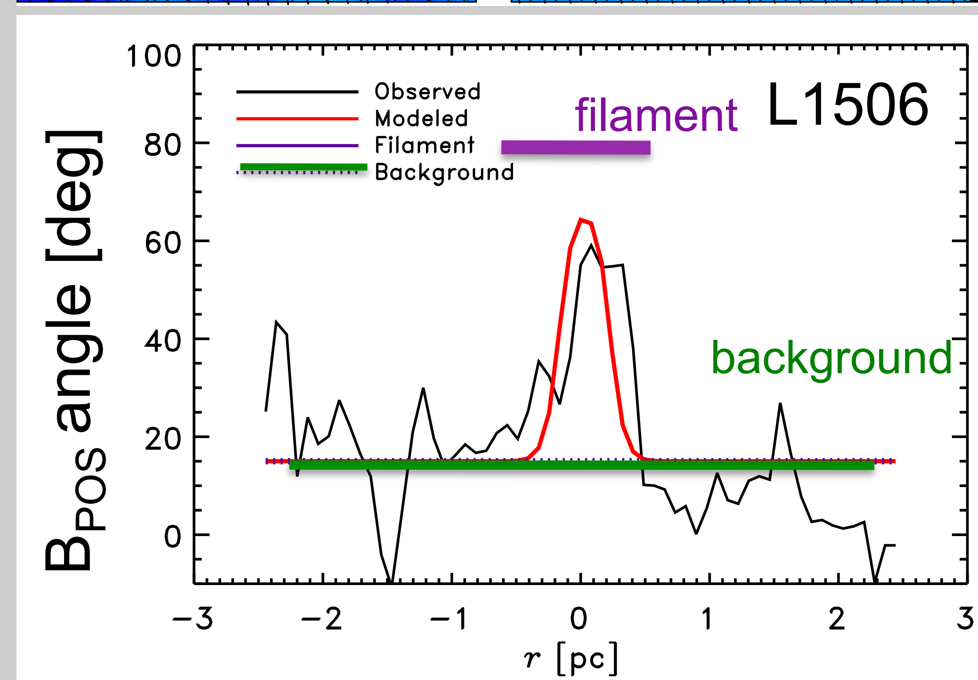
Planck Observations | Our model



Planck Observations | Our model



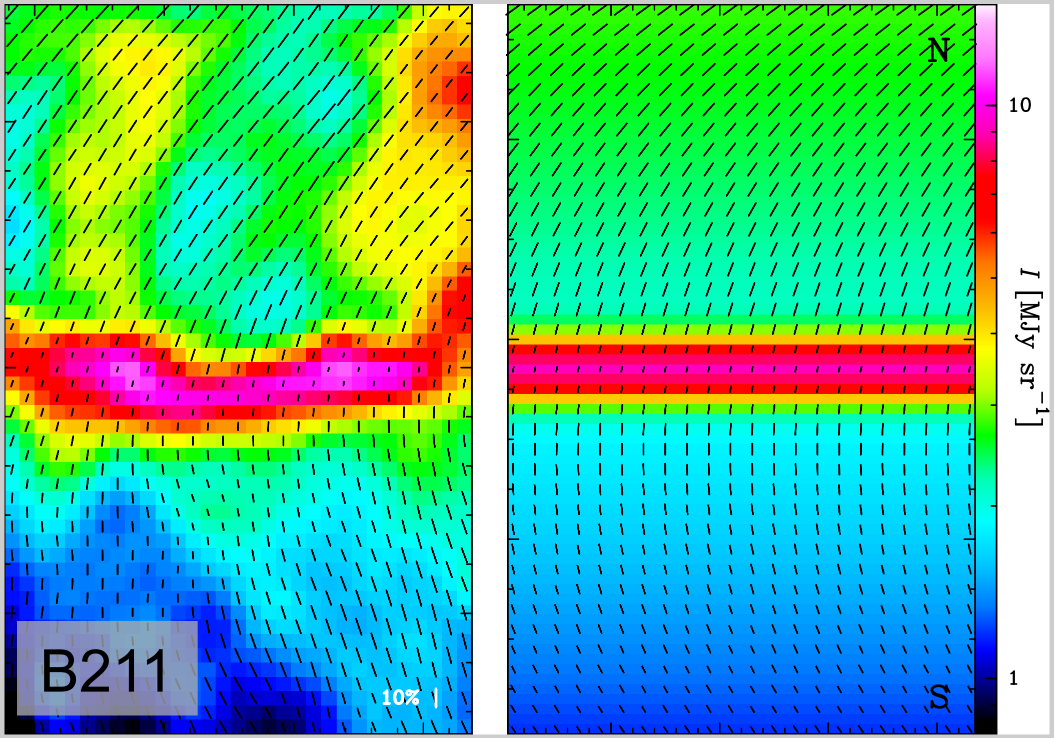




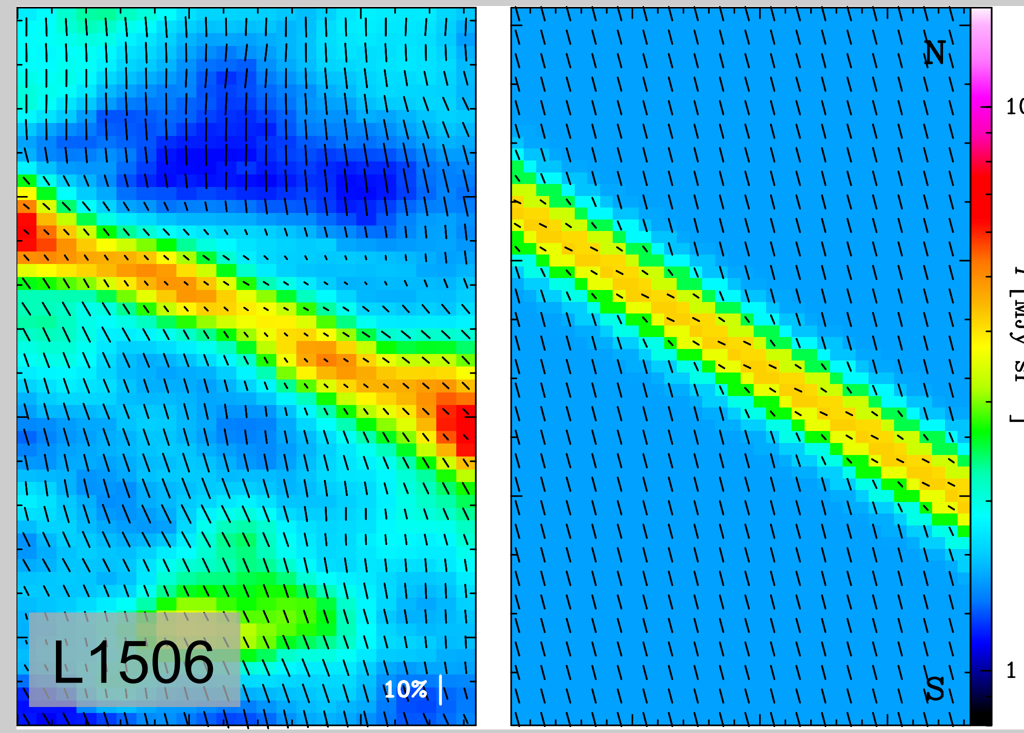
Results of the modelling (III)

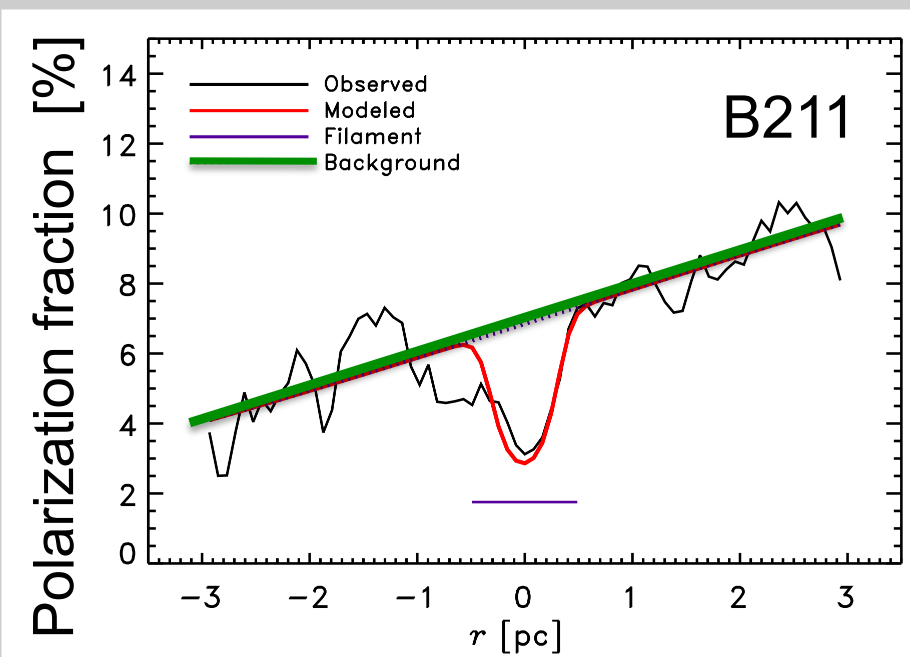
Dececrease of the polarization fraction in the filament

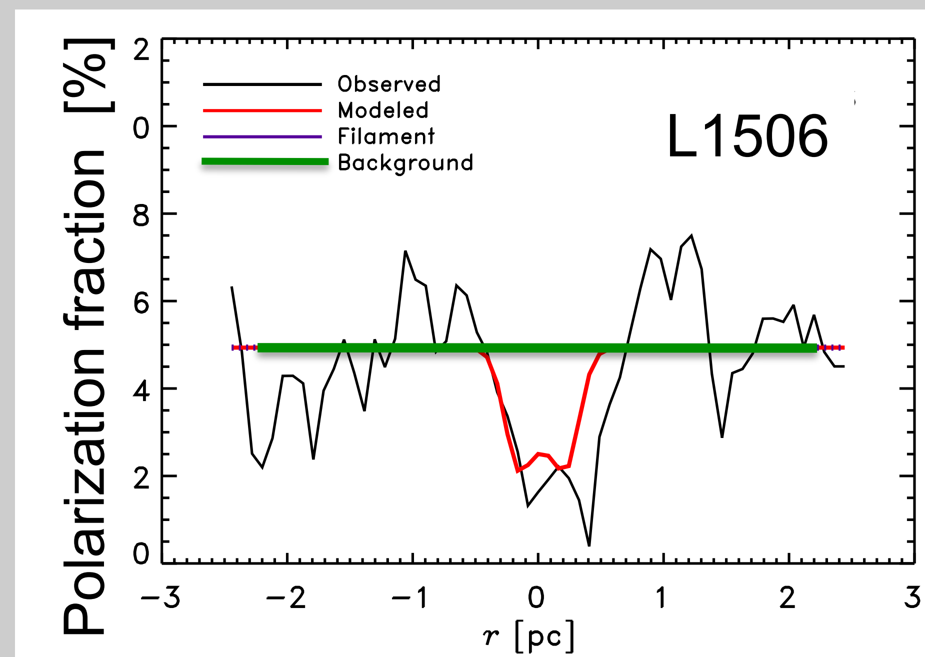
Planck Observations | Our model



Planck Observations | Our model

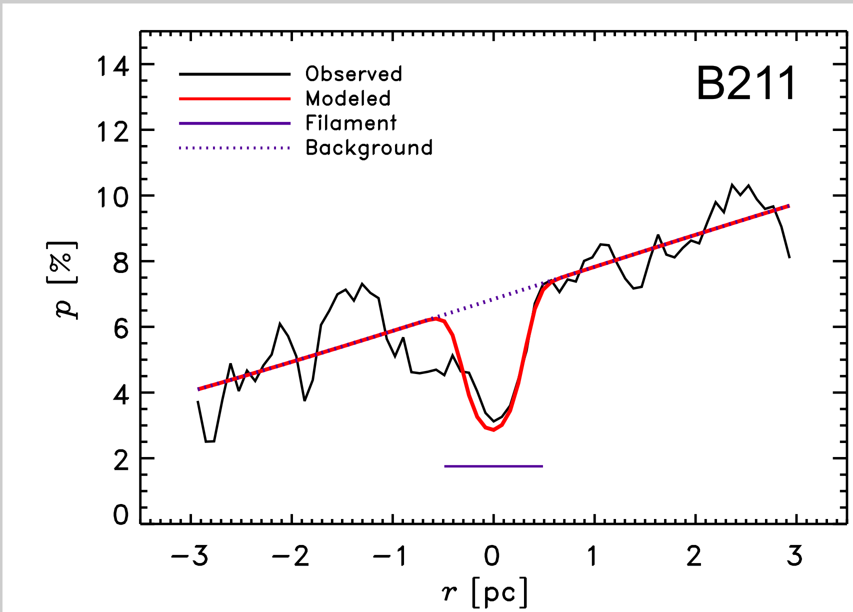


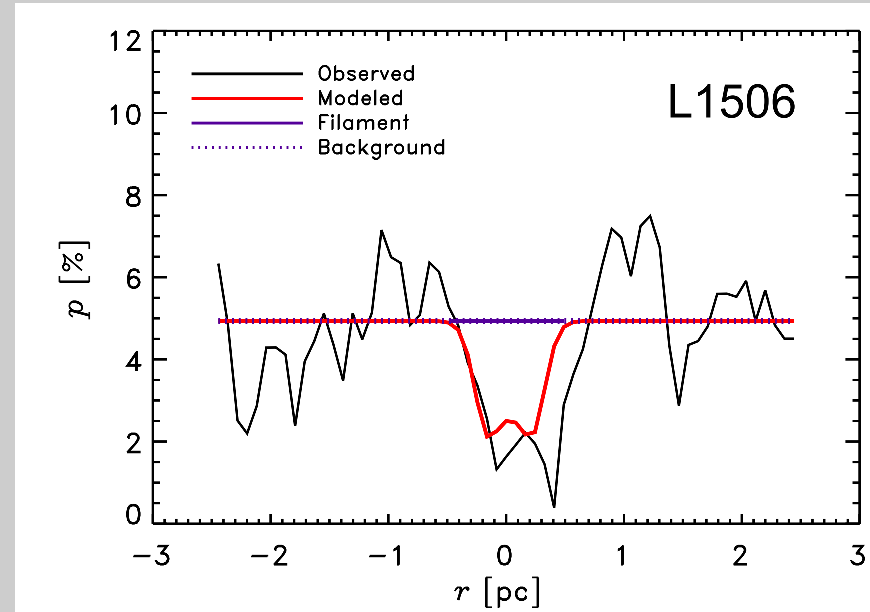


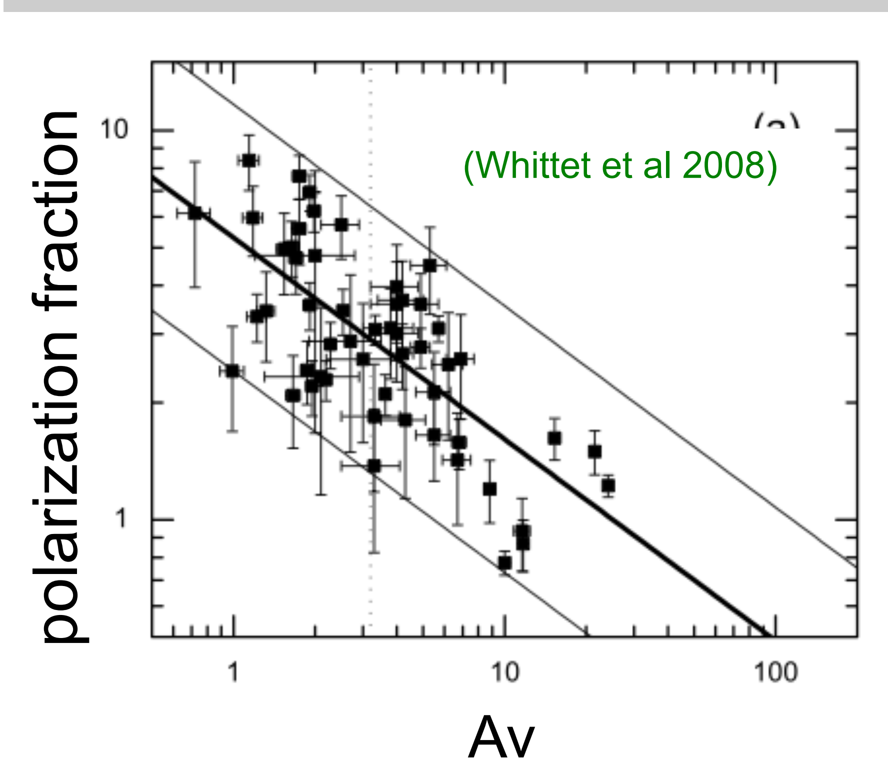


Results of the modelling (III)

In our two layer model, the drop in the observed *p* is explained by the geometry of B







Other interpretations

Decrease of *p* due to loss of dust alignment in dense shielded regions
(Goodman 1992, Whittet et al 2008, Chapman et al. 2011, Alves et al. 2014, Ward-Thomson et al. 2000, Matthews & Wilson 2000)

Decrease of *p* due to depolarization from turbulent field along the LOS and orientation of the field
(Planck Collaboration Int. XX 2014, Falceta-Gonçalves et al. 2008, 2009)

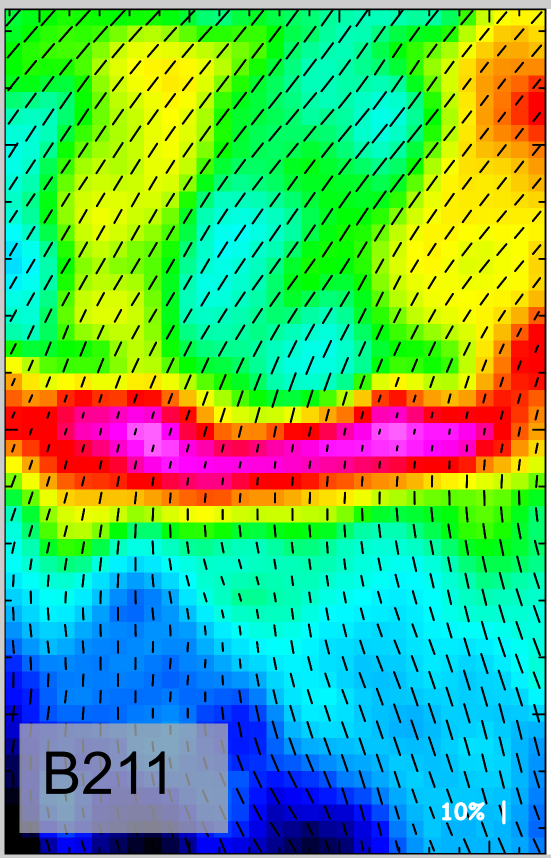
Results (IV)

Magnetic field geometry observed towards filaments and their surroundings

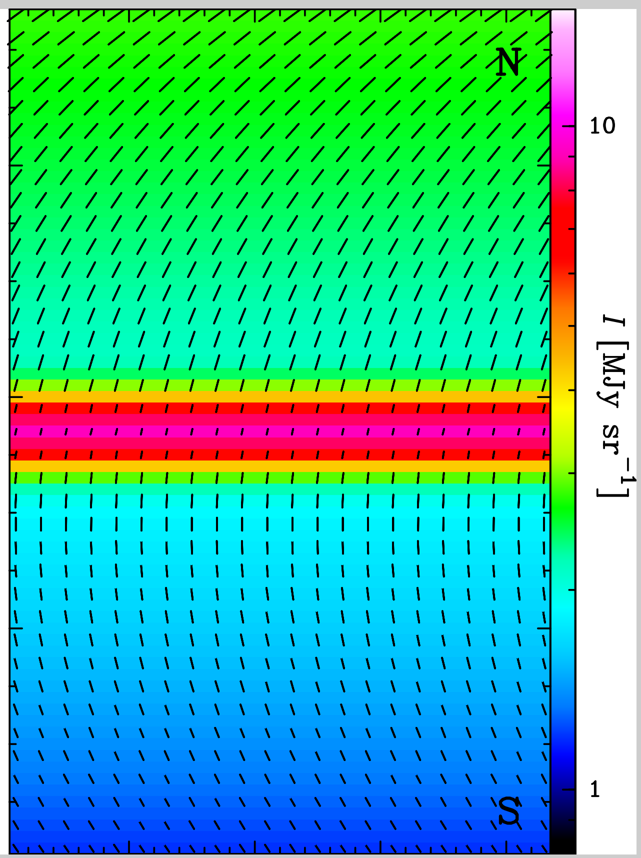
- The magnetic field geometry surrounding the filaments has an ordered component that can be inferred from *Planck* maps
- Compatible with a regime dynamically dominated by magnetic fields?

Comparison with MHD numerical simulations (e.g., Falceta-Gonçalves et al. 2008, Soler et al. 2013) and with estimation of field strength from Chandrasekhar-Fermi method (e.g., Chapman et al. 2011)

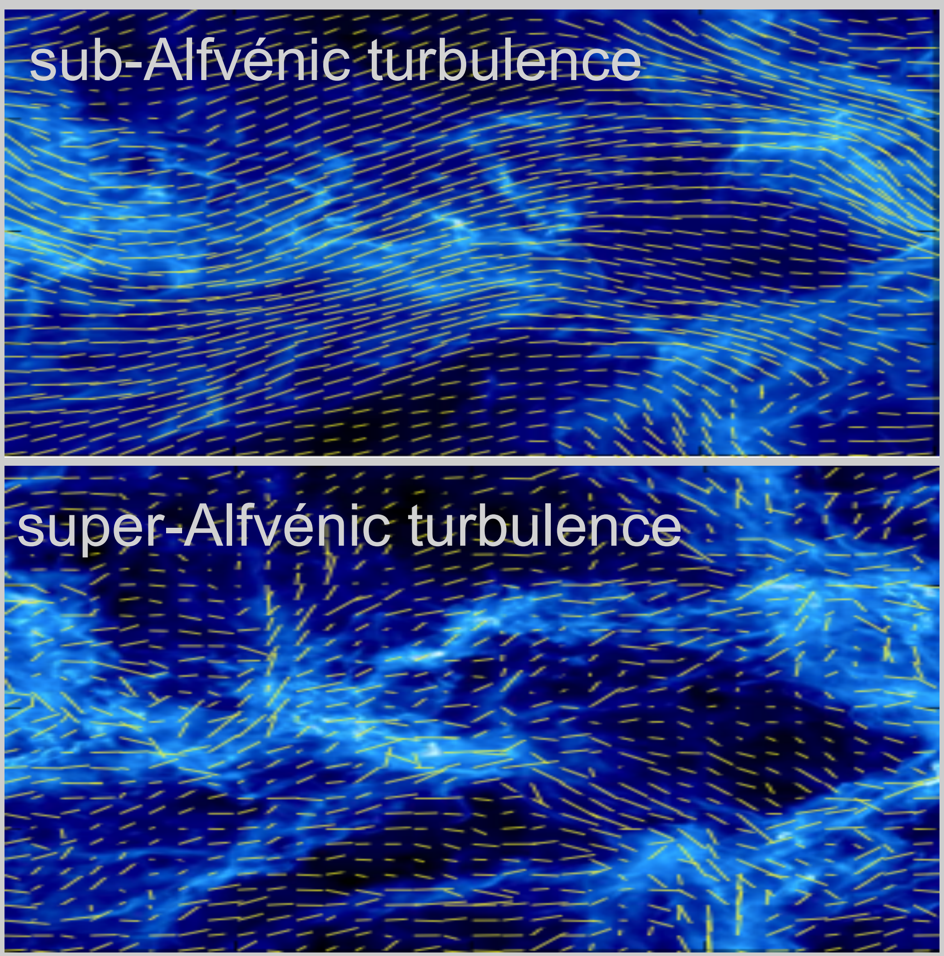
Planck Observations



Our model



MHD numerical simulations Soler et al. 2013



I map and orientation of B_{POS} (length ~ polarization fraction)

Conclusions and perspectives

• Interstellar filaments are seen in dust polarized emission, which carries the signature of the magnetic field geometry

• *Planck* dust polarization observations of (3) nearby filaments are well fitted with a uniform field assuming constant dust polarization fraction

→ Combining with higher angular resolution observations to resolve the central parts of the filaments, where other configurations of the field and/or tangling of the field lines could also contribute to the observed polarized emission

• The modelled 3D magnetic fields of the filaments are different from that of their surrounding clouds

→ Increasing the statistics

→ Studying the link between velocity and magnetic fields

• The B field surrounding the filaments has an ordered mean component: Compatible with sub-Alfvénic/Alfvénic turbulence?

Planck intermediate results XXXIII (astro-ph1411.2271)