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

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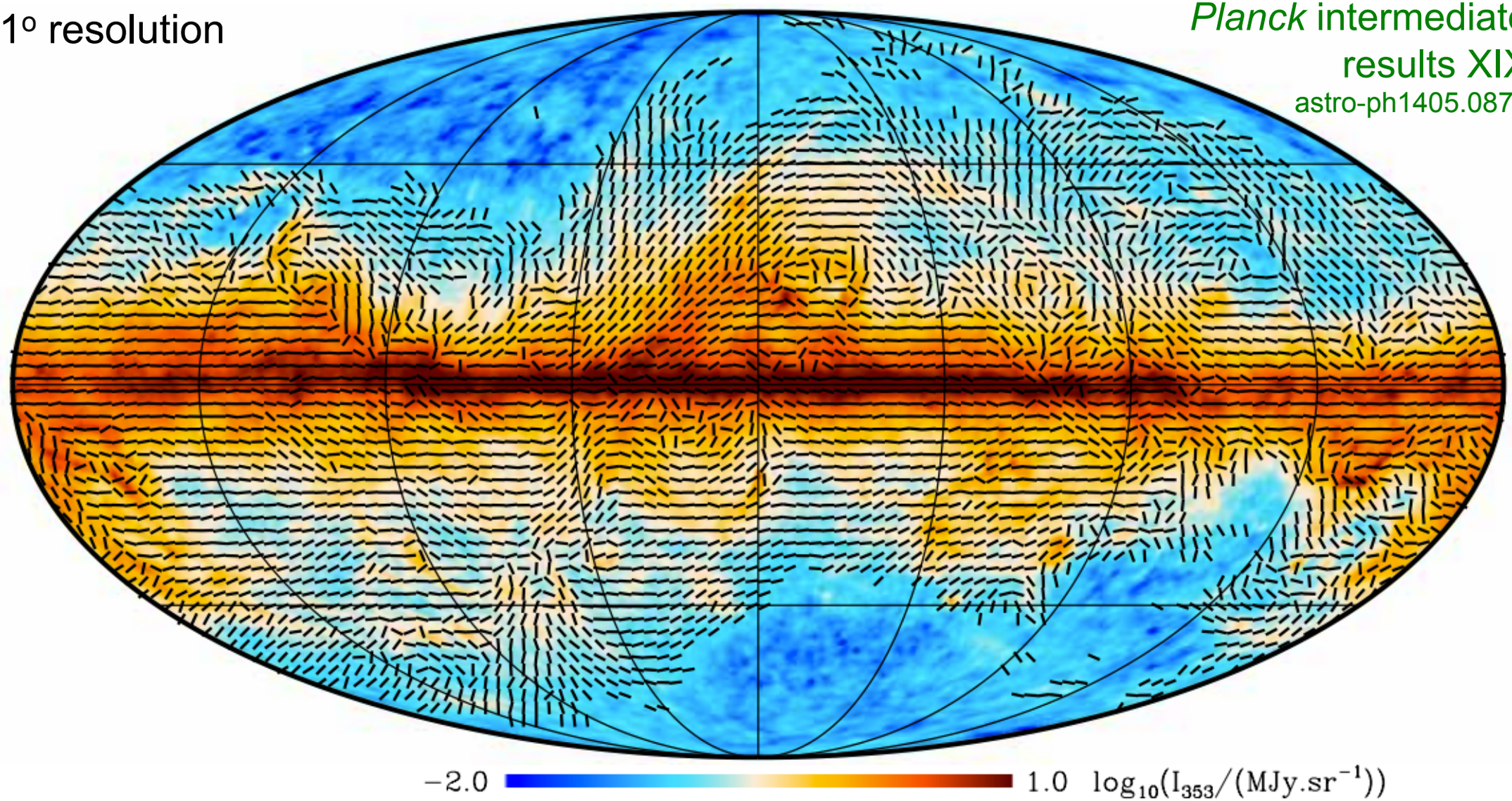
On behalf of the *Planck* Collaboration

GESF2014, From Galactic to Extragalactic Star Formation
Tuesday 9 September

Plane of the sky magnetic field structure of the ISM derived from the dust polarized emission observed by *Planck*

1° resolution

Planck intermediate results XIX
astro-ph1405.0871



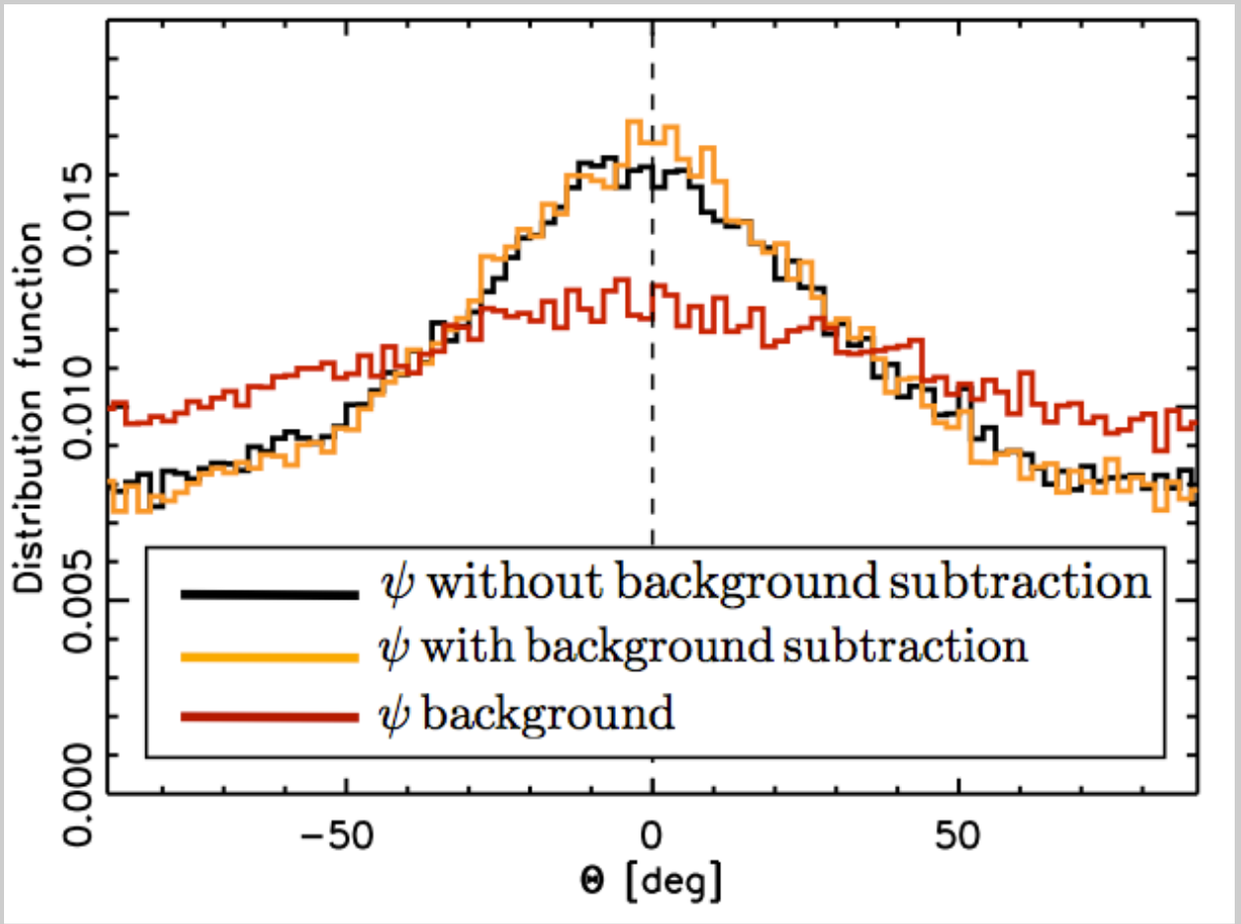
Total intensity at 353 GHz, with plane-of-the-sky magnetic field (B_{POS}) orientation (segments with normalized length)

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

Poster 21 presented by Andrea Bracco

Planck intermediate results XXXII (astro-ph1409.6728)

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



Difference between the orientation of B_{POS} and filamentary structure in the ISM

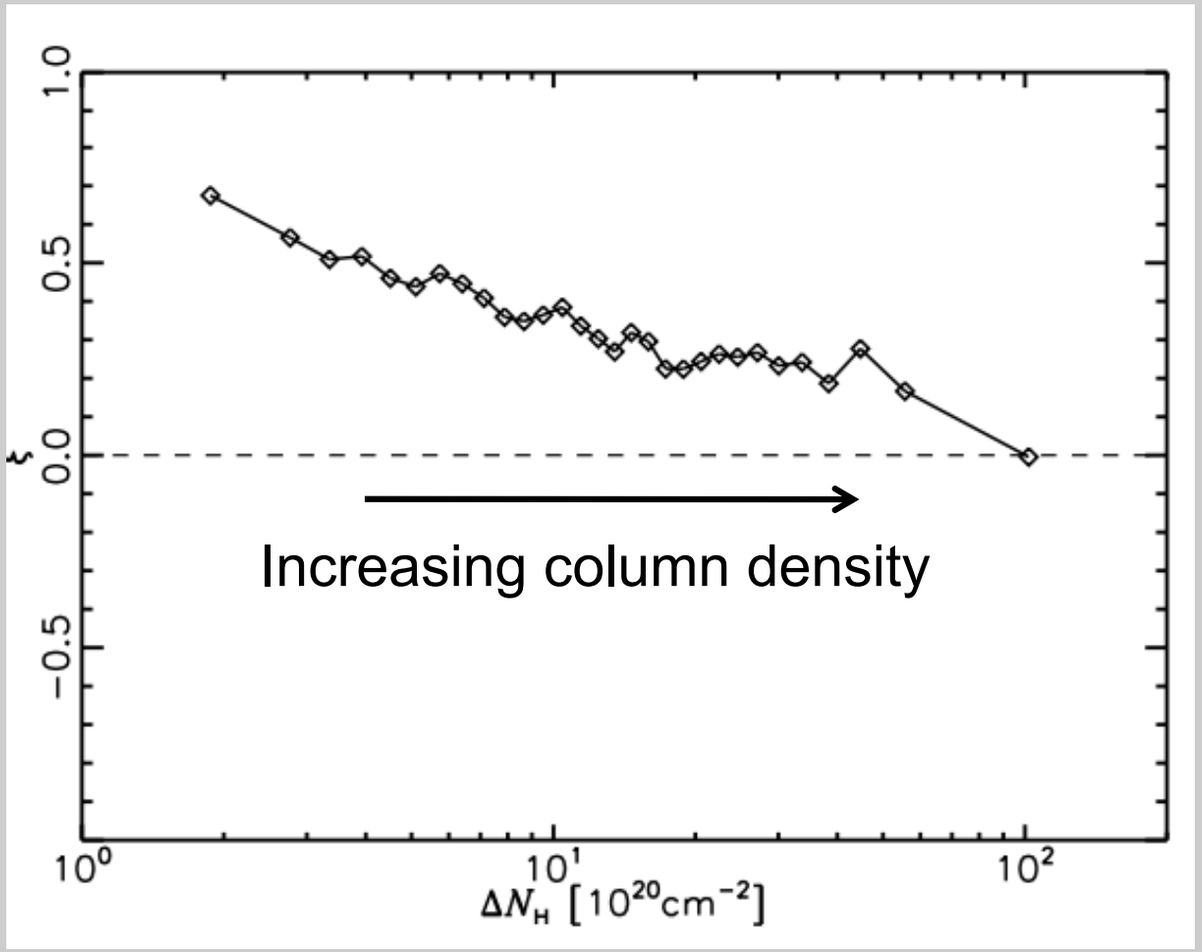
Statistical analysis of the relative orientation between magnetic field and interstellar filaments observed by *Planck*

Poster 21 presented by Andrea Bracco

Planck intermediate results XXXII (astro-ph1409.6728)

- In the diffuse ISM filaments are preferentially aligned with the local B_{POS}
- In molecular clouds filaments are mostly perpendicular to the field

Increasing alignment between the field and the filaments



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

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

- Linear polarization results from aspherical spinning dust grains
- The observed polarized emission depends on the structure of the magnetic field and the polarization efficiency of dust grains

Observed Stokes parameters

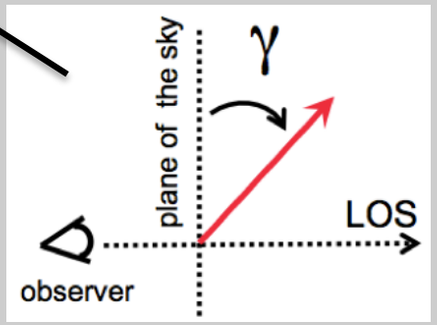
- The imprint of the mean field geometry is present in Q and U, which are integrated quantities along the line of sight (LOS)

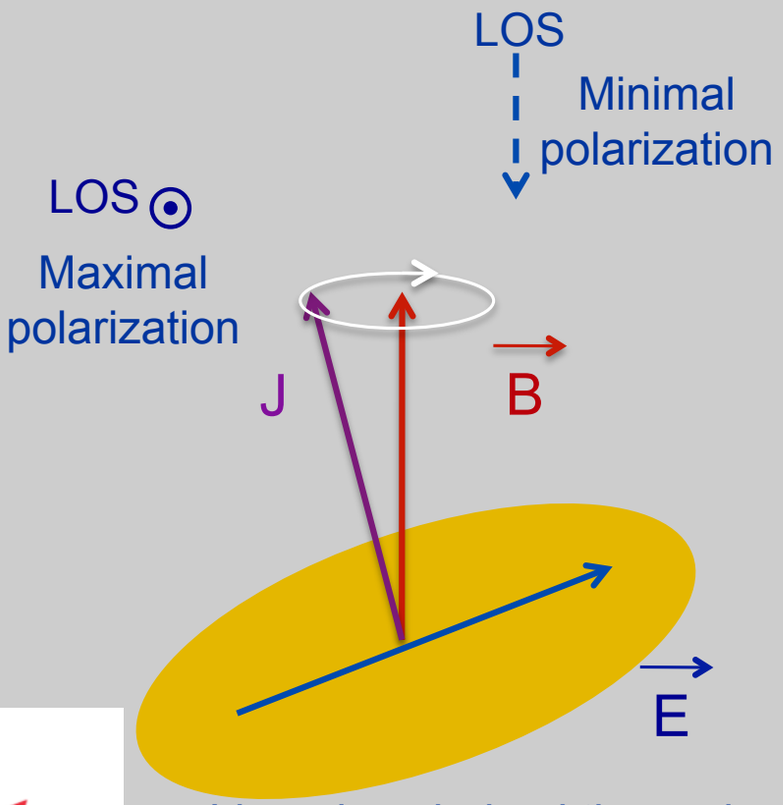
$$Q = \int I\, p_0 \cos(2\psi) \cos^2(\gamma)\, dI$$

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

intrinsic polarization of dust grains

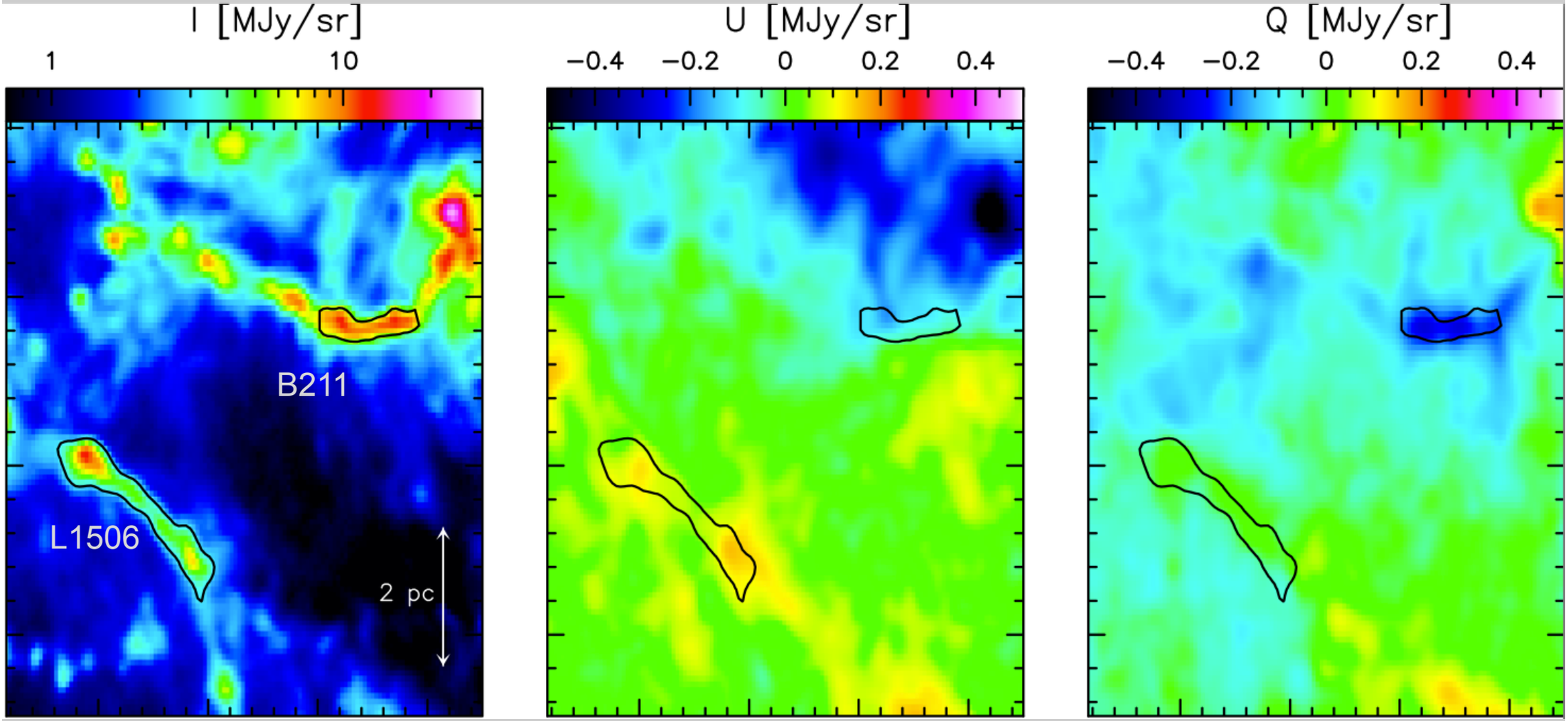
Polarization angle, + 90° orientation of B_{POS}





Linearly polarized thermal dust emission

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



Derived quantities from I, Q and U

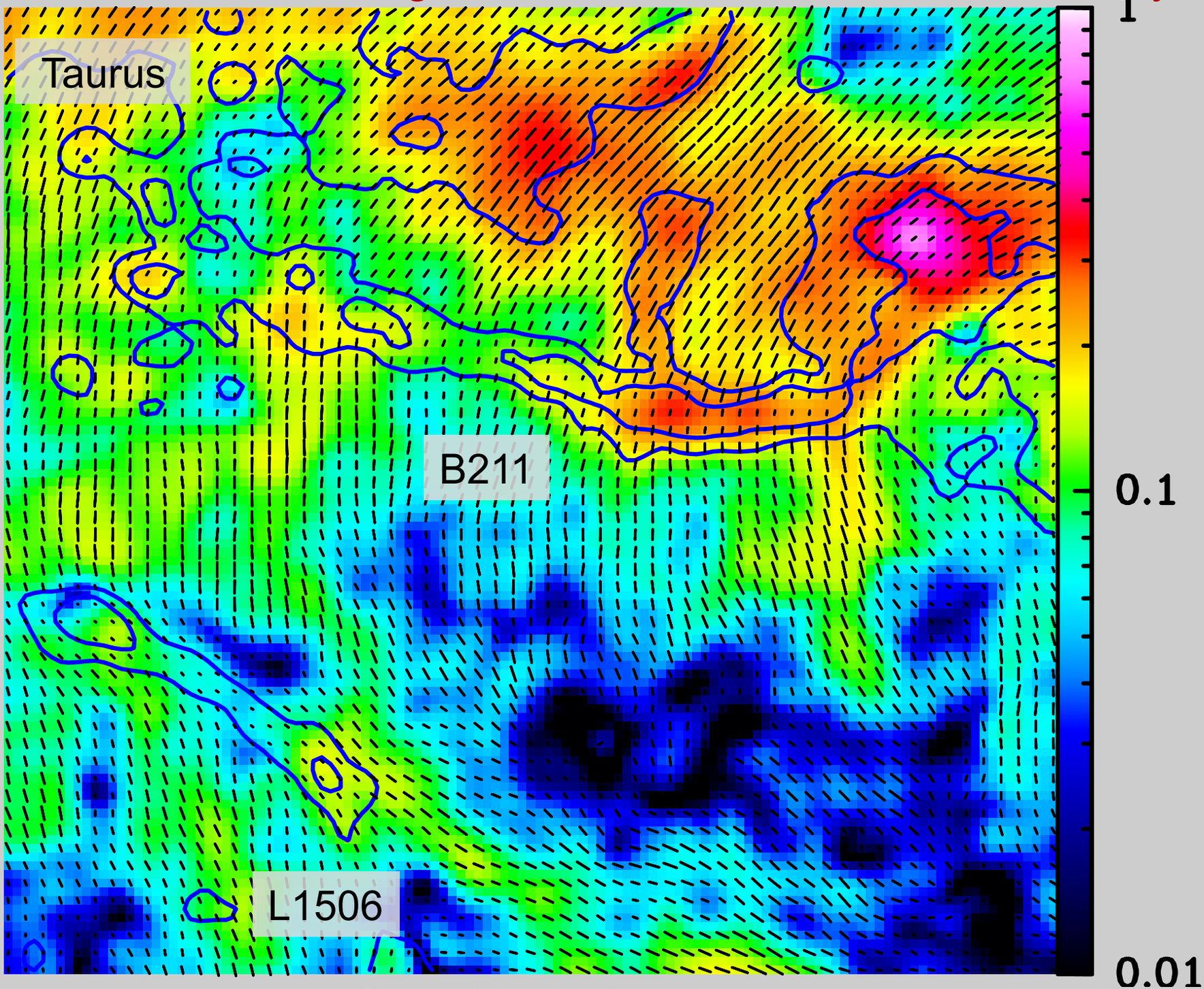
$$P = \sqrt{Q^2 + U^2}$$ Total polarized intensity

$$p = P/I$$ Polarization fraction

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

Resolution: I map 4.8'
Q and U maps: 9.6'

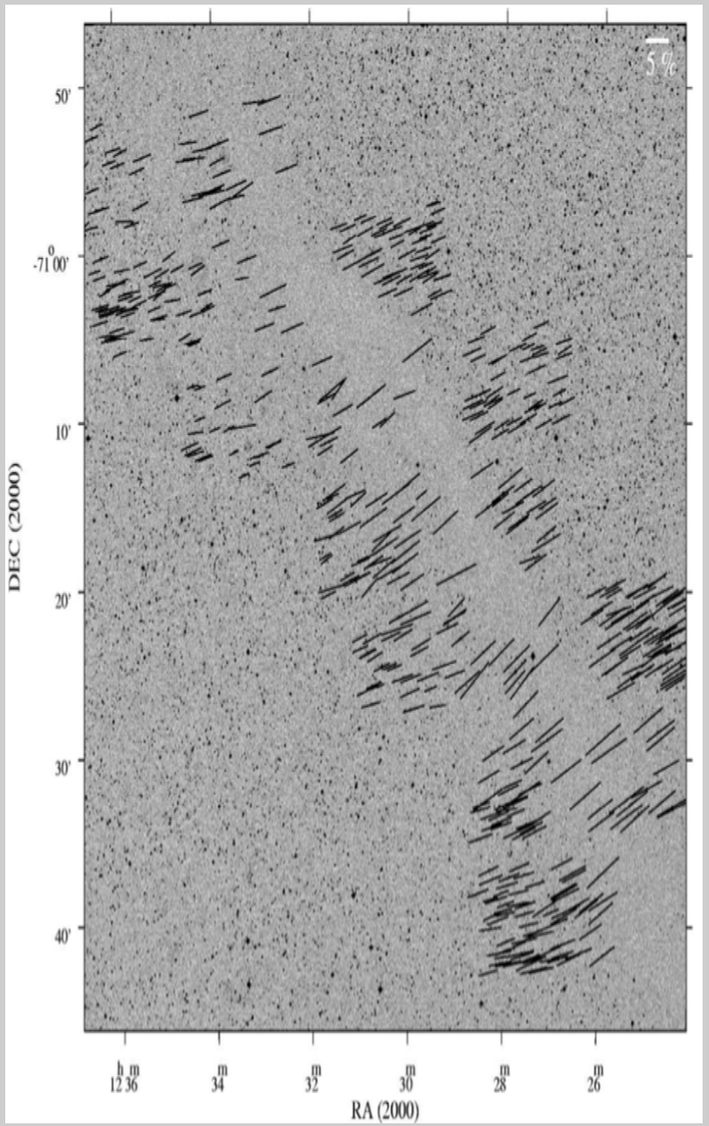
Polarized emission and magnetic field orientation as observed by *Planck*



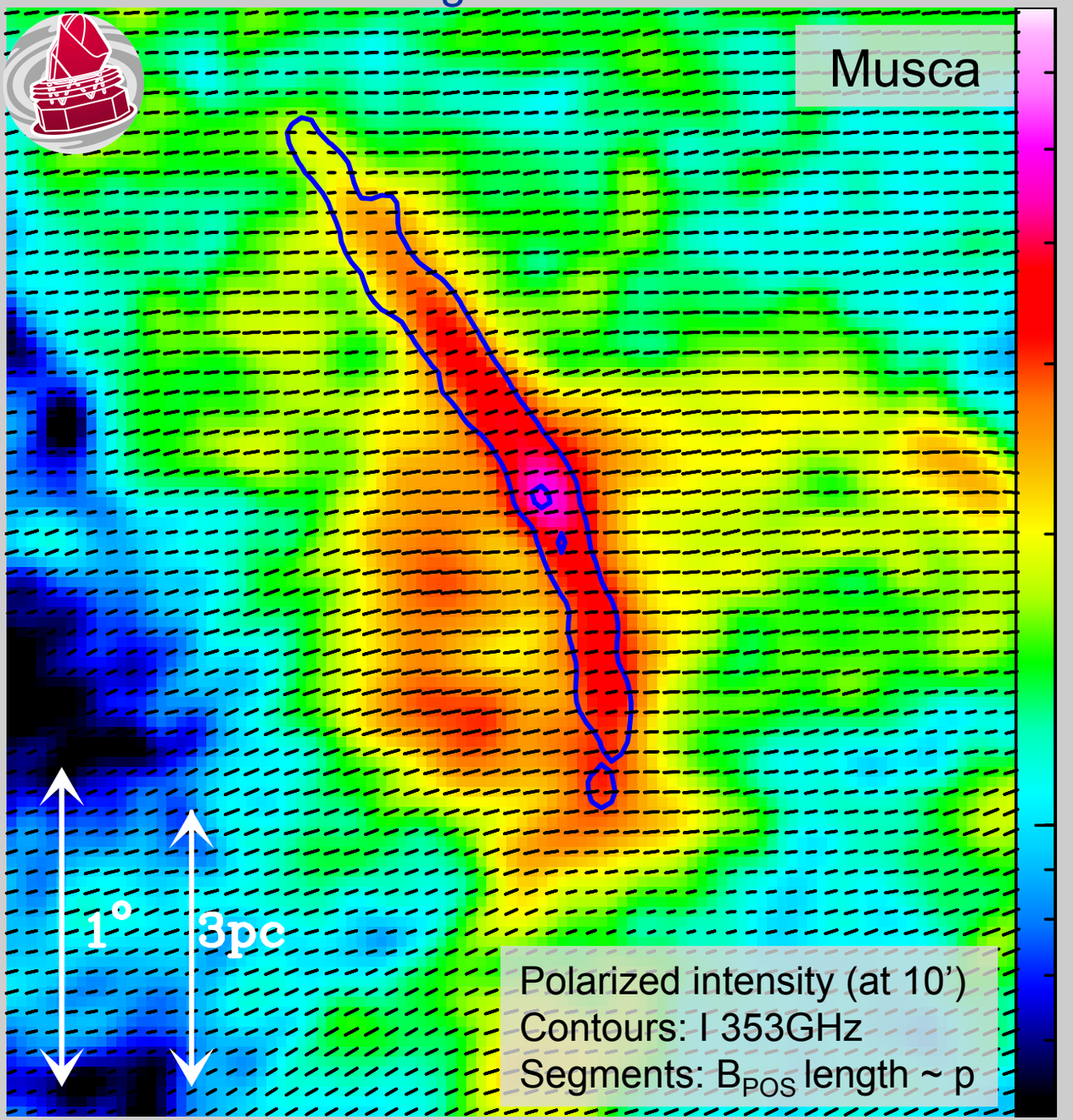
Resolution: 10', blue contours: I 353GHz (3 & 6 MJy/sr), black segments: B_{POS} length ~ polarization fraction

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 optical polarization
Pereyra & Magalhães 2004



Modelling the Stokes parameters observed towards nearby filaments

Planck intermediate results XXXIII (astro-ph1411.2271)

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

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

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

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

Degeneracy

Grain alignment

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

Maximum dust intrinsic polarization

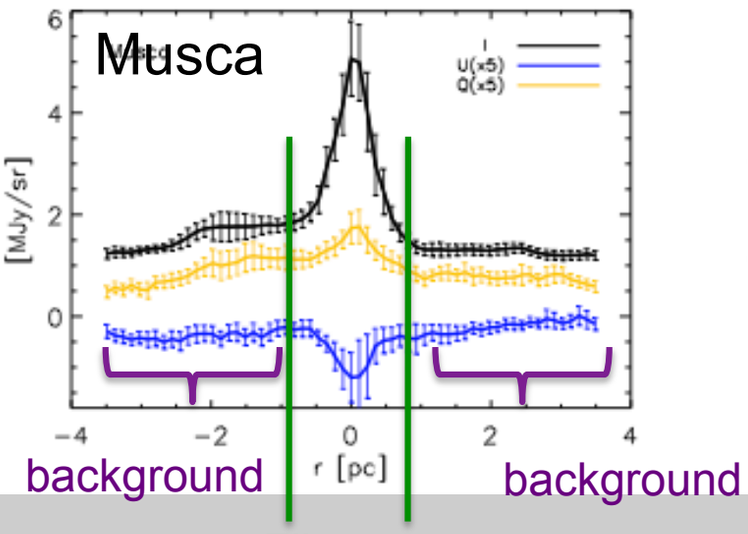
Depolarization due to random B fields along the LOS

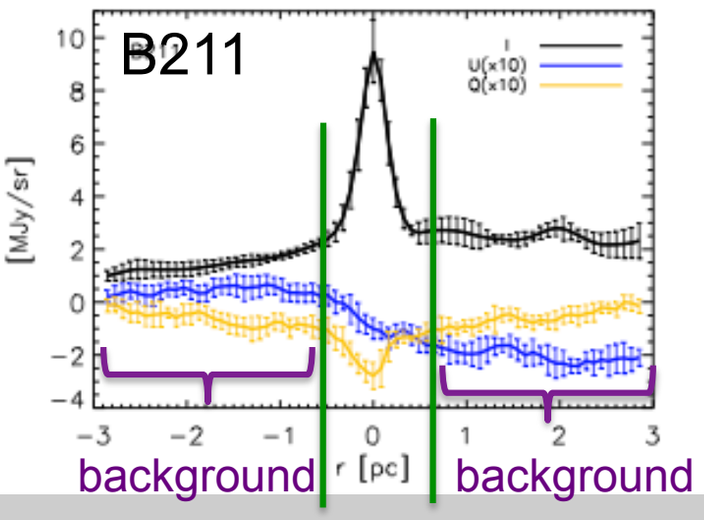
Lee & Draine 1985, Hildebrand 1988

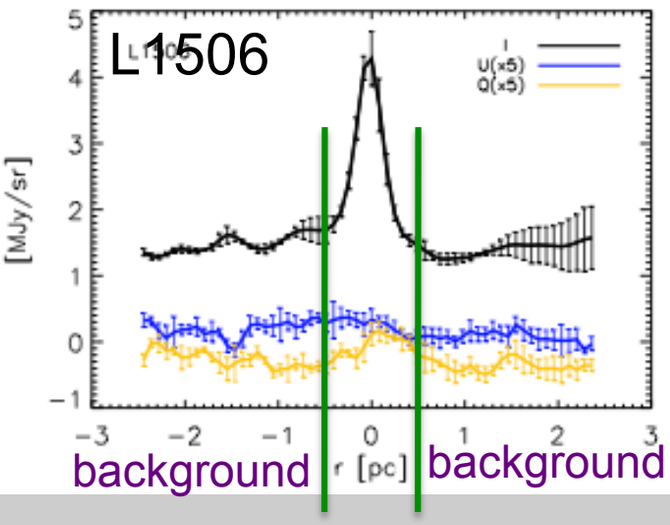
- Fitting the observed Q and U by minimizing the X^2 on all possible pairs of angles

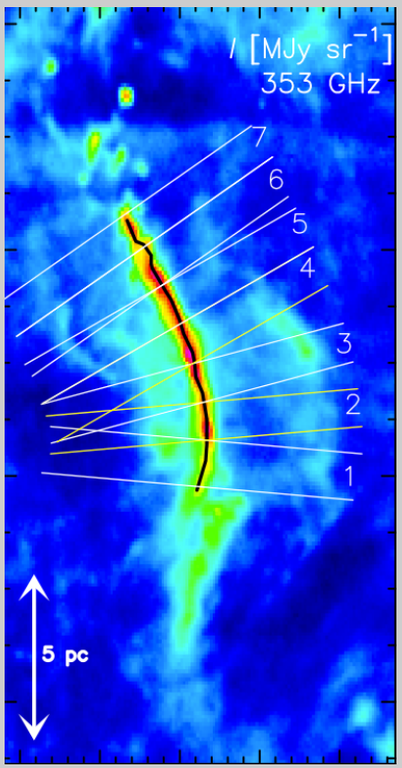
- Free parameters: two pairs of angles (filament and background) defining the 3D structure of the field

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





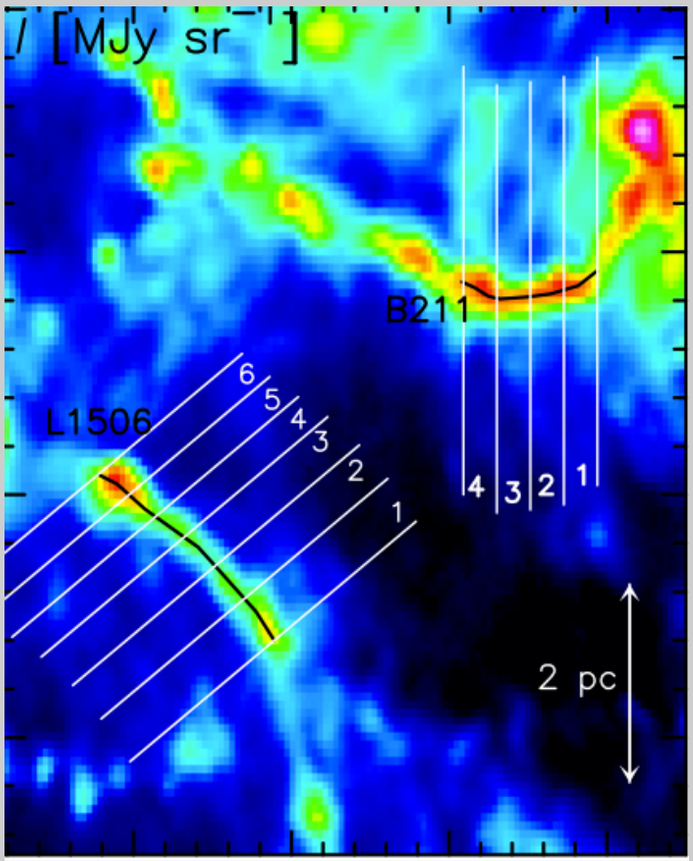




Two layer model to estimate the contribution of the filament to the total observed emission

$$I_{\rm mod} = I_{\rm bg} + I_{\rm fil}$$
$$U_{\rm mod} = U_{\rm bg} + U_{\rm fil}$$
$$Q_{\rm mod} = Q_{\rm bg} + Q_{\rm fil}$$

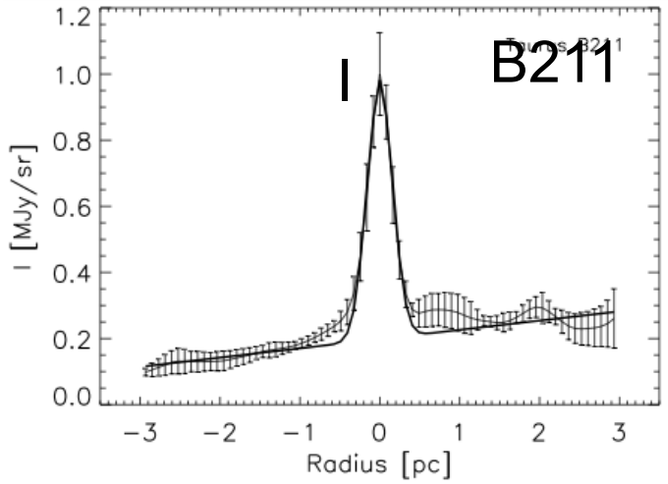
Fitting the observed Q and U profiles to derive the 3D field geometry with constant p_0

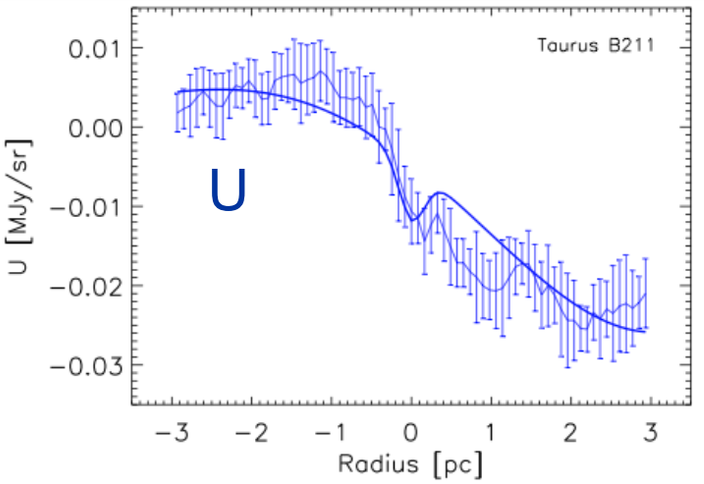


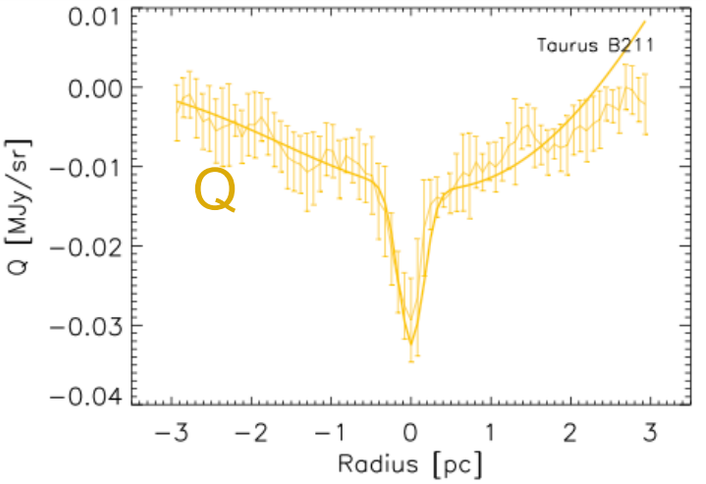
Results of the modelling (Ia)

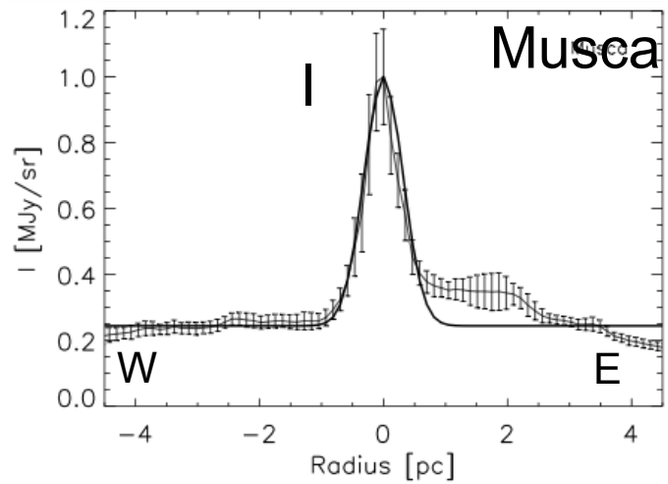
Polarization properties, at the resolution of *Planck* observations, are well modelled with a uniform field in the filament, which differs from that of its parent cloud, assuming constant dust polarization efficiency

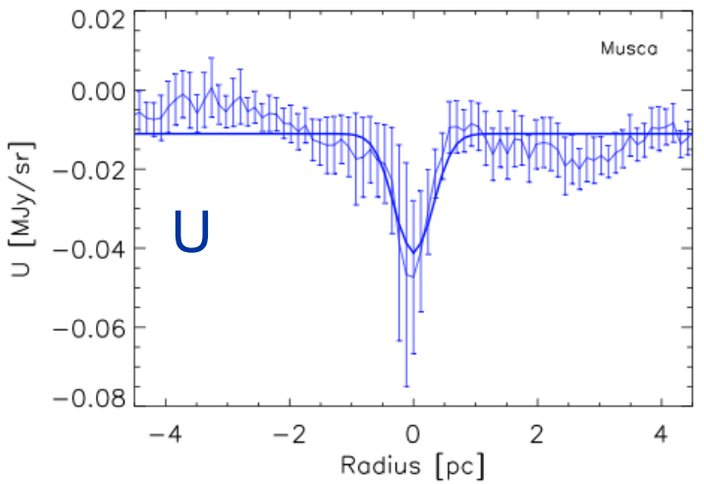
Examples of observed and model Stokes parameters profiles

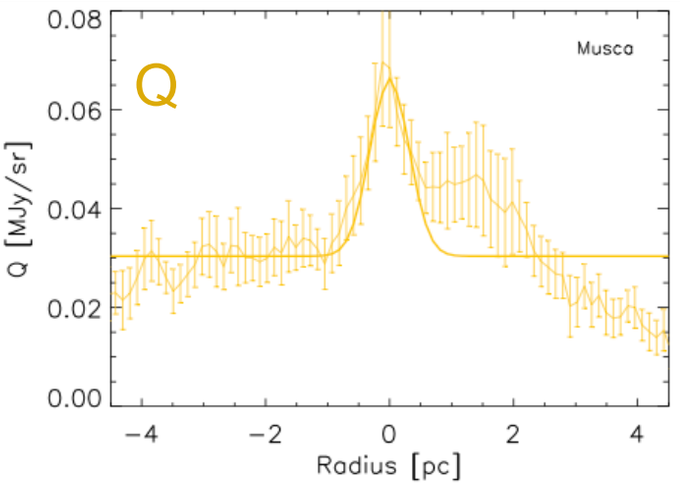








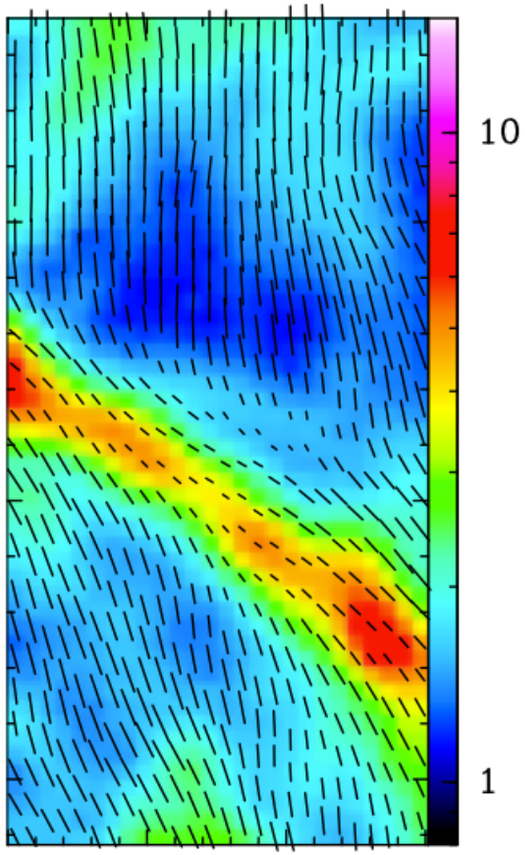




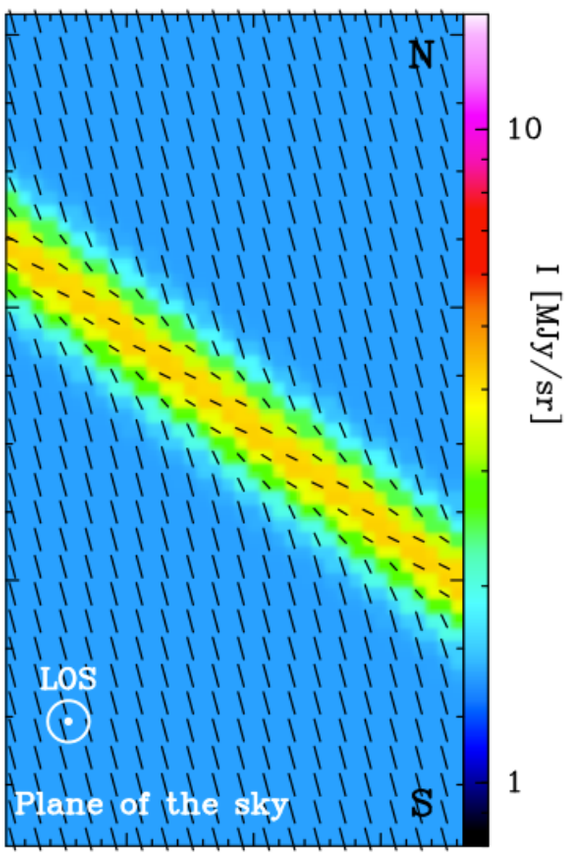
Results of the modelling (Ib)

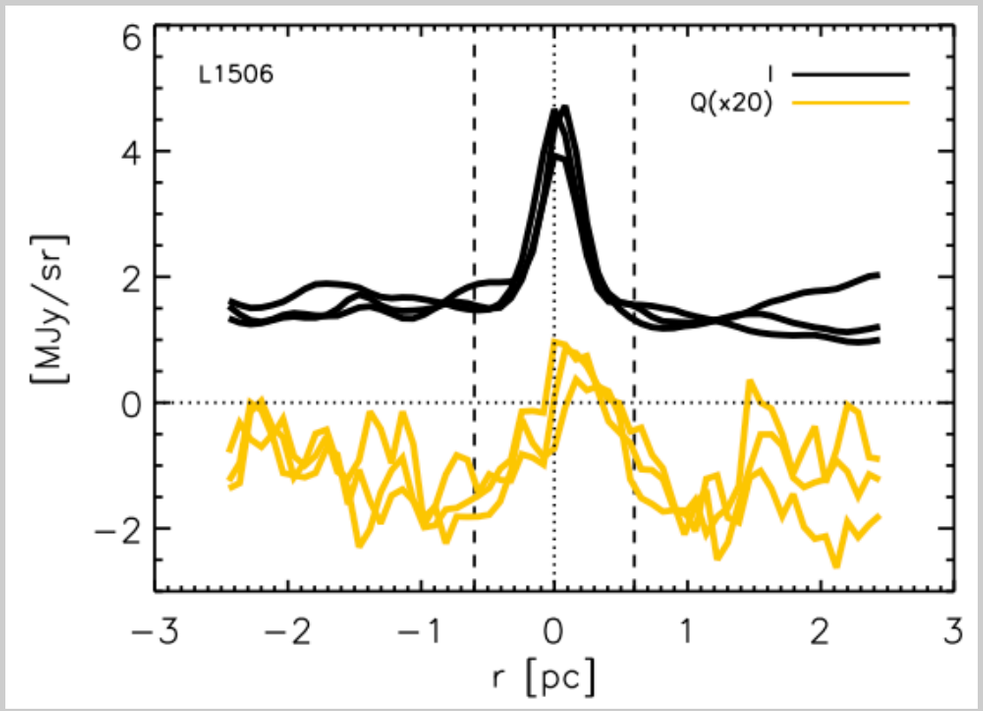
- The polarized emission observed towards L1506 does not coincide spatially with that of the total emission
- A uniform field in the filament does not reproduce well the observed emission
- The L1506 filament is aligned with its local field, while the field in its surrounding is perpendicular to its main axis

Planck Observations



Our model

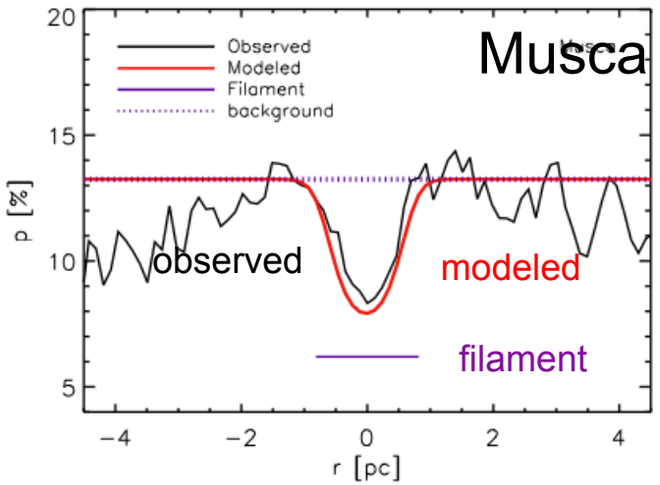


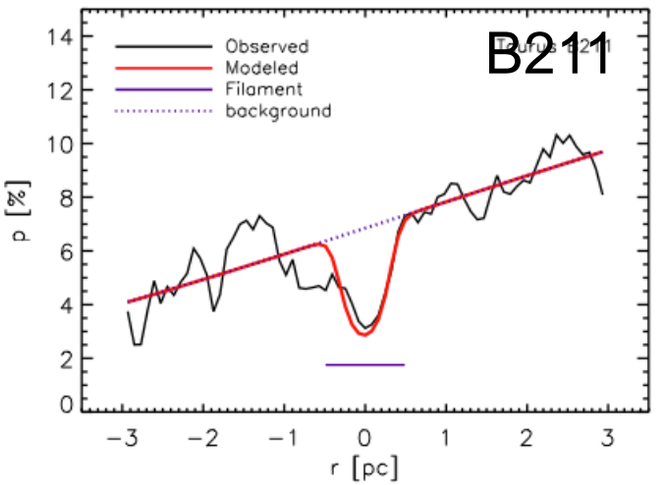


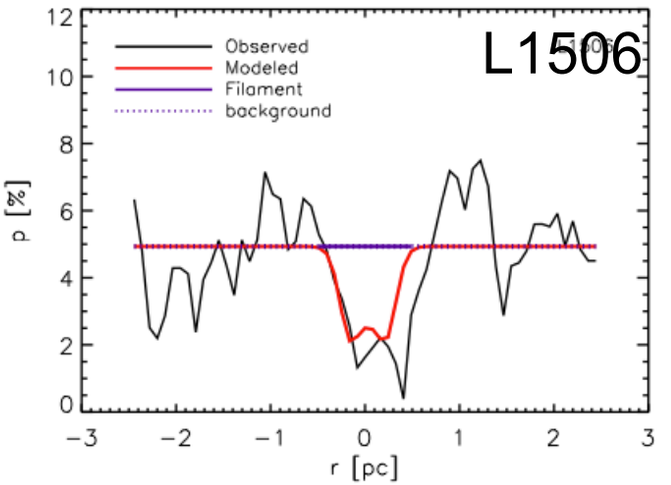
Results of the modelling (II)

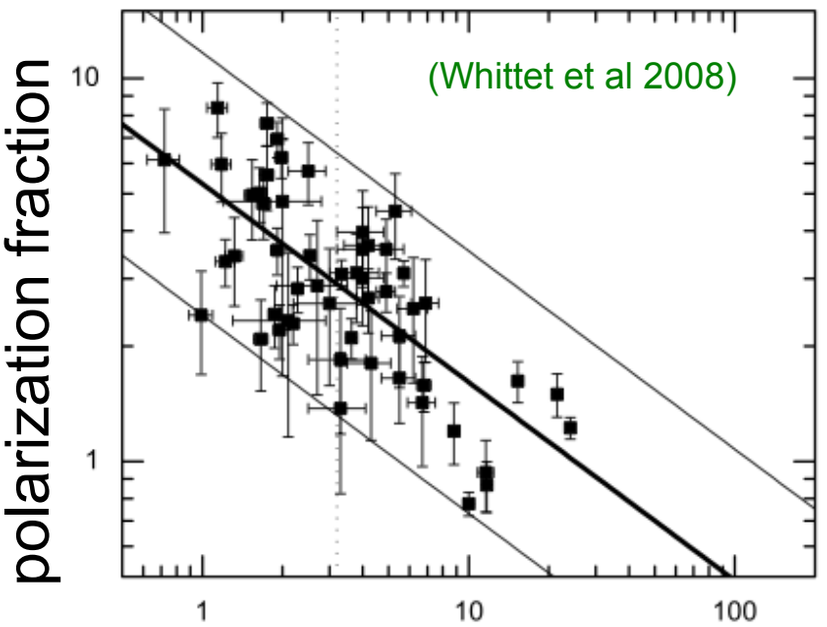
In our model the drop in the observed polarization fraction is explained by the B field geometry

Observed and model profiles of the polarization fraction (*p*)









Decrease of *p* due to loss of dust alignment in dense shielded regions

(Goodman 1992, Whittet et al 2008, Chapman et al. 2011, 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)

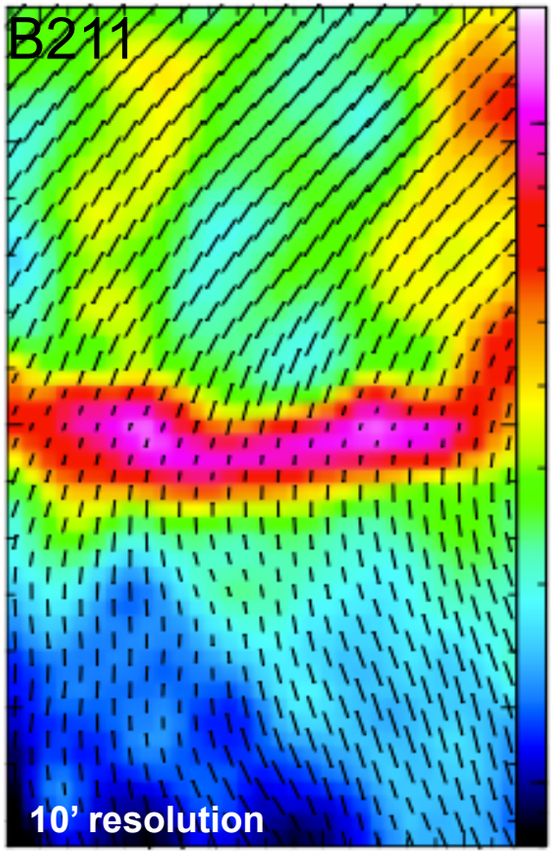
Results (III)

Magnetic field geometry observed towards filaments and their surroundings

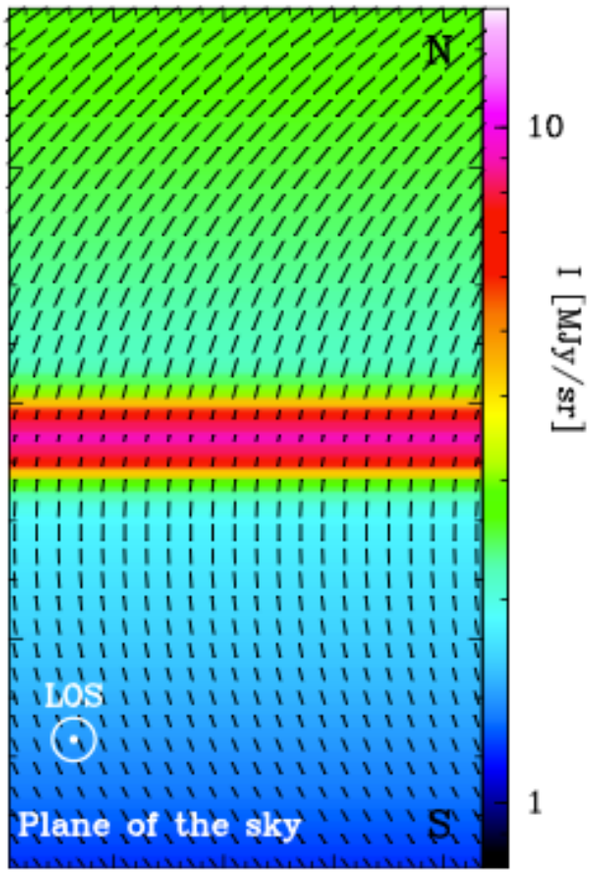
- The magnetic field geometry surrounding the filaments has an ordered component with a non-zero mean orientation
- Compatible with a regime dynamically dominated by magnetic fields?

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

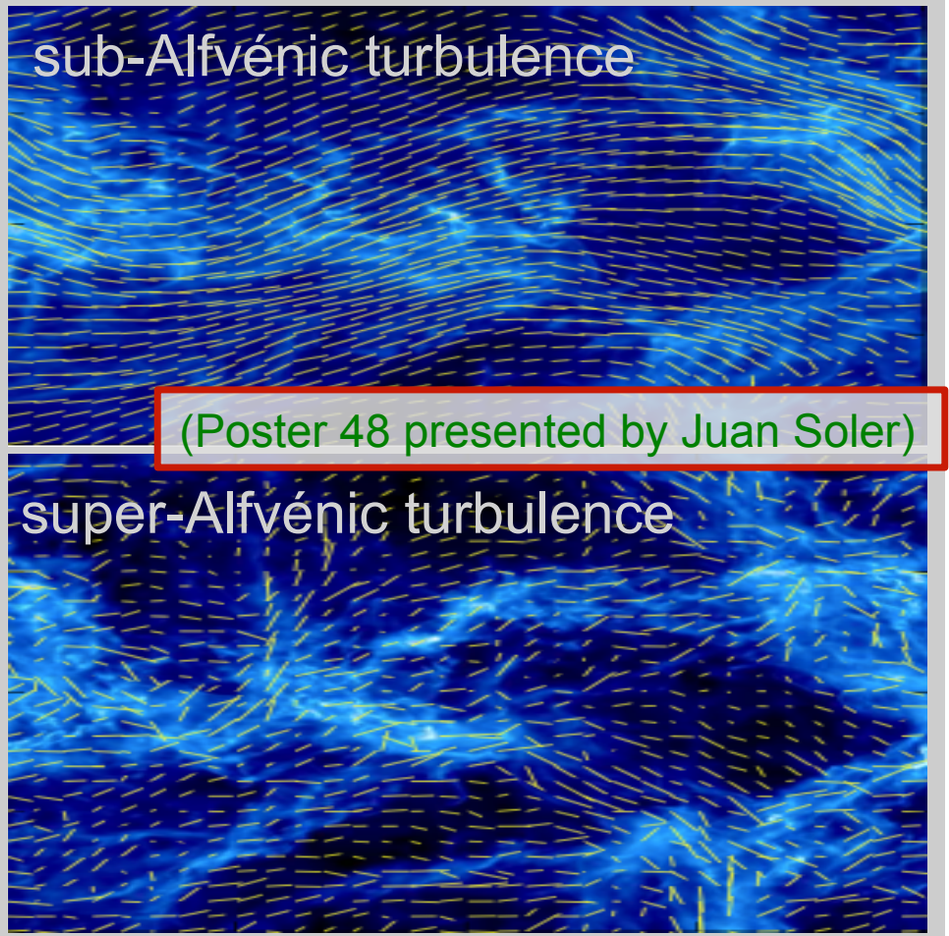


Our model



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

MHD numerical simulations



(Poster 48 presented by Juan Soler)

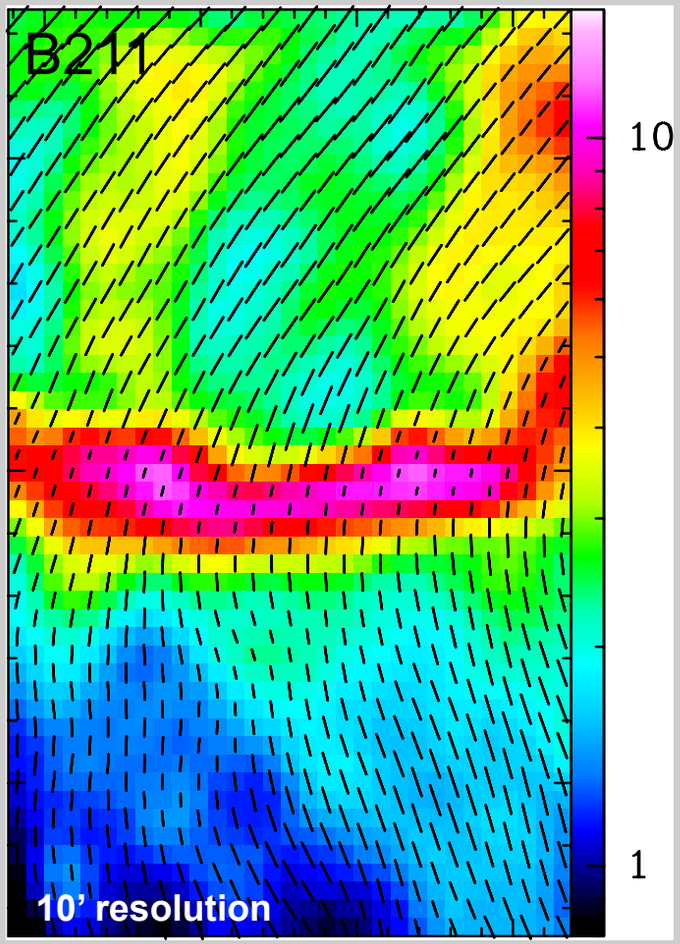
simulations from StarFormat (P. Hennebelle)

Results (IV)

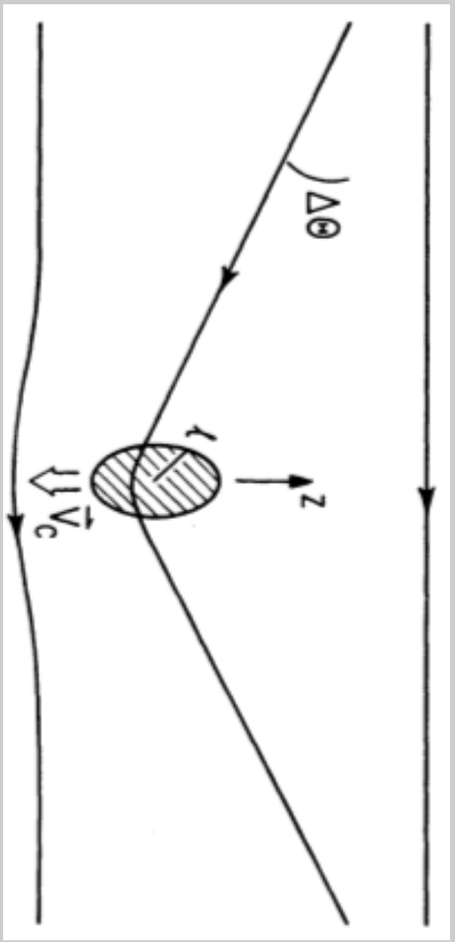
The magnetic field geometry changes during the formation and evolution of filaments?

- Different orientation of the field in the filament and its surrounding cloud

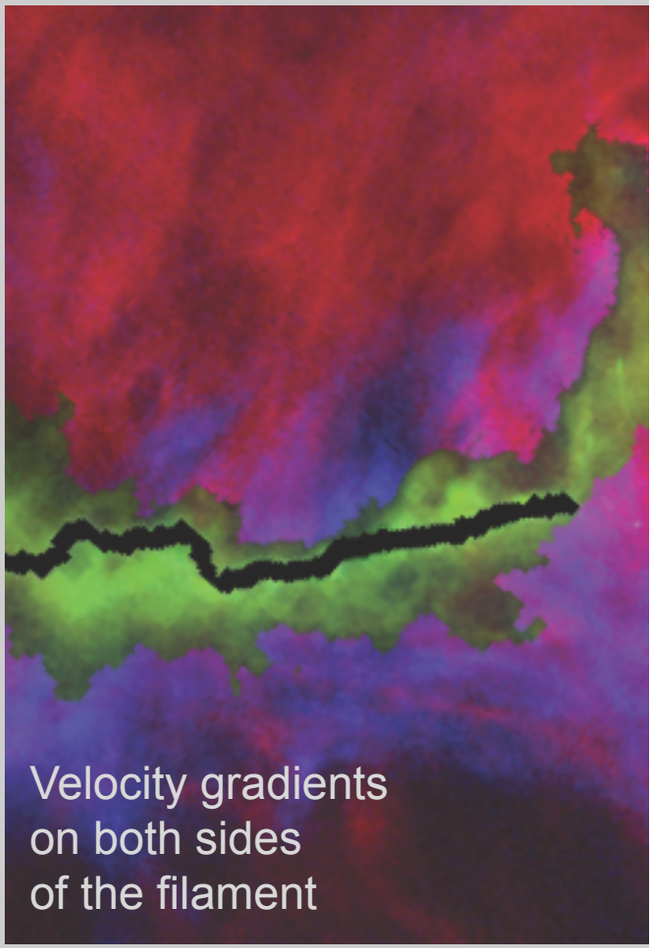
Planck Observations



Sketch from Zweibel 1990
distortion of field lines by differentiated motions



CO observations from Goldsmith et al. 2008
Figure adapted from Palmeirim et al. 2013



Conclusions and perspectives

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

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

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

• The B field surrounding the filaments has an ordered mean component which may be compatible with sub-Alfvénic turbulence

• The model 3D B field of the filaments is different from that of their surrounding clouds, this may suggest an evolution of the B field topology during the formation of filamentary structures in molecular clouds

→ Comparison with numerical simulations are needed

→ Increasing the statistics

References: *Planck* intermediate results XXXII & XXXIII (astro-ph1409.6728 & 1411.2271)