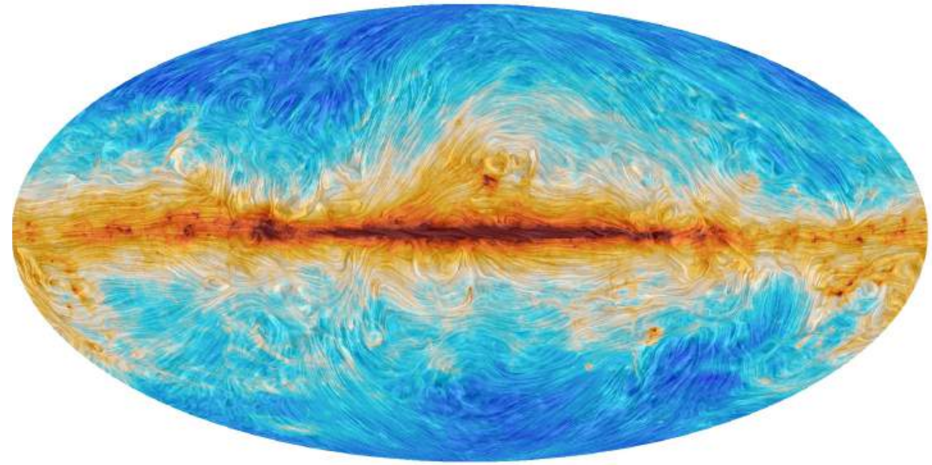


E- and B-modes from the magnetized filamentary structure of the interstellar medium

Planck intermediate results. XXXVIII,
A&A accepted, arXiv 1505.02779

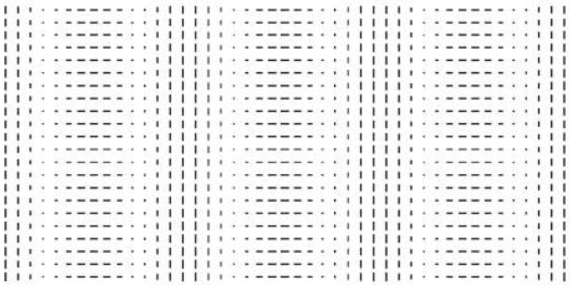
Tuhin Ghosh
IAS, Orsay

ON BEHALF OF THE PLANCK COLLABORATION

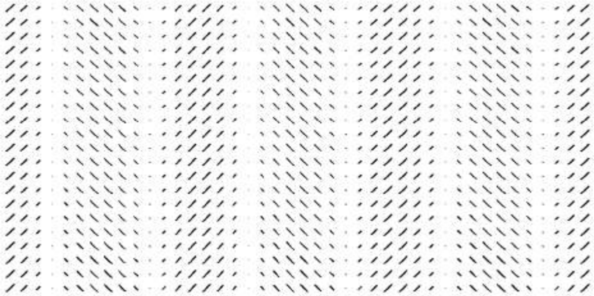
Magnetic fields in the Universe V
From laboratory and Stars to primordial structures
Friday 09 October 2015

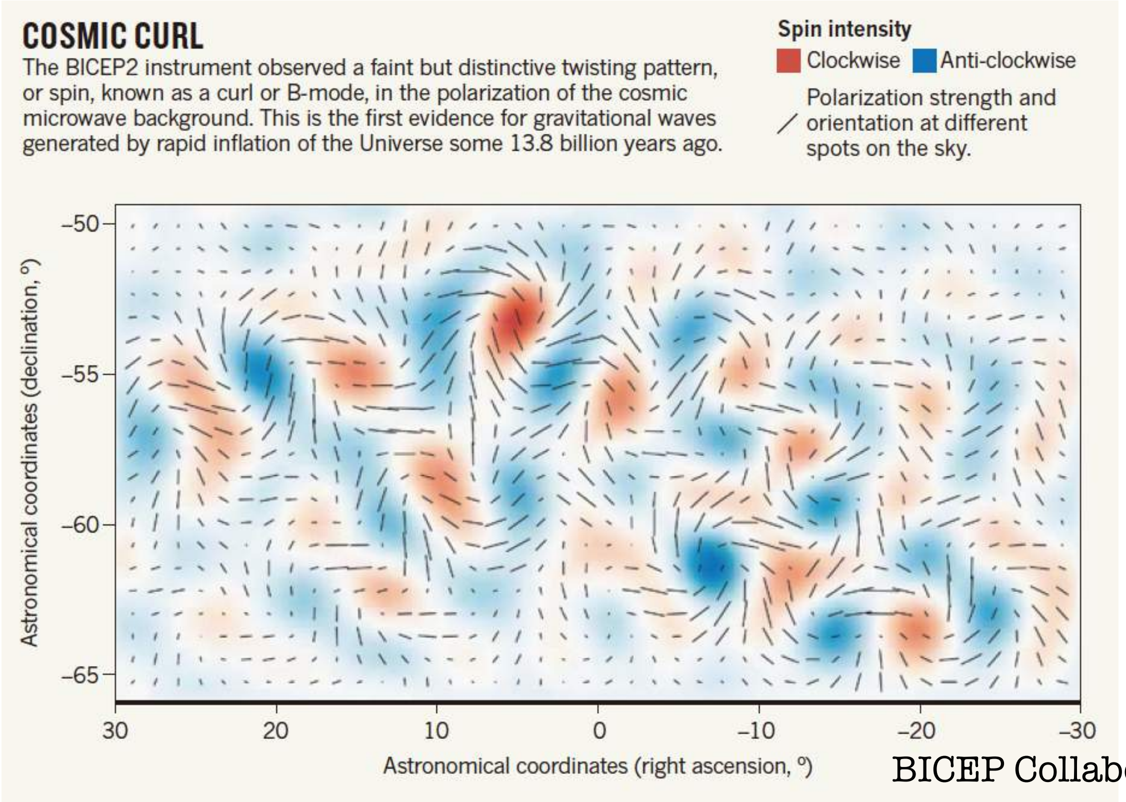
E- and B-modes in a nutshell

E-Mode Polarization Pattern



B-Mode Polarization Pattern

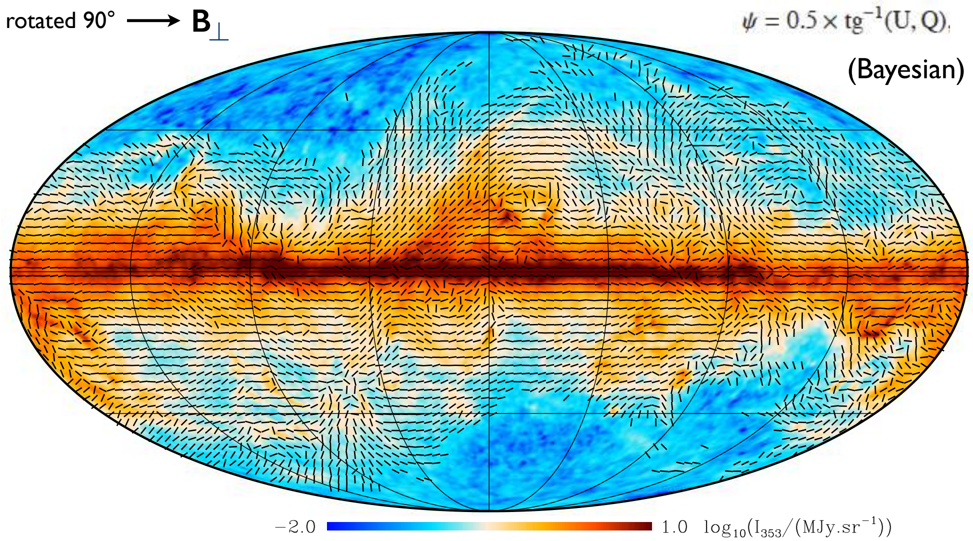




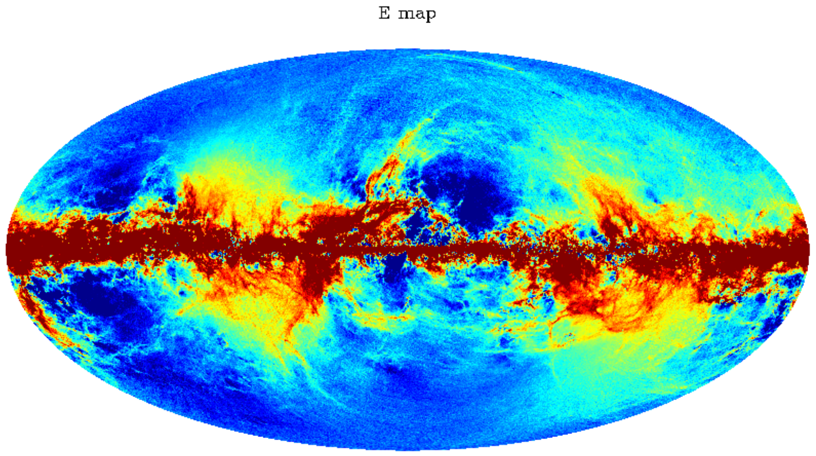
BICEP Collaboration 2014, PRL, 112

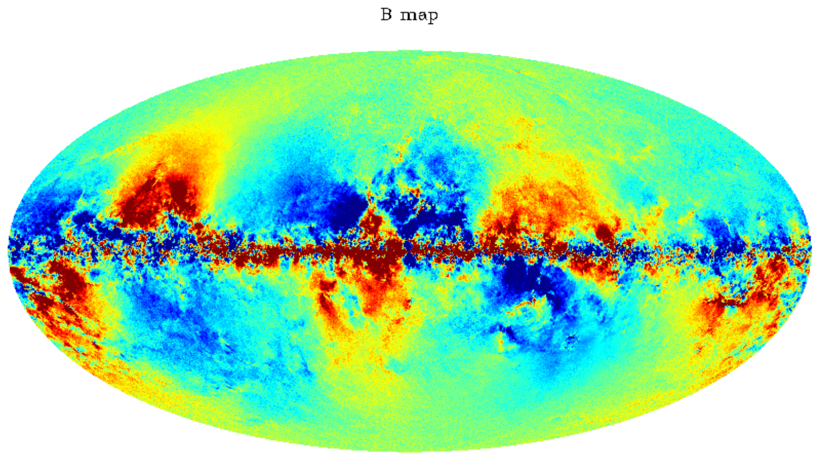
B-mode is nothing to do with the magnetic field

The Planck polarization sky



Color: Intensity at 353 GHz
Lines: Direction of magnetic field as projected on the sky. Normalized length.



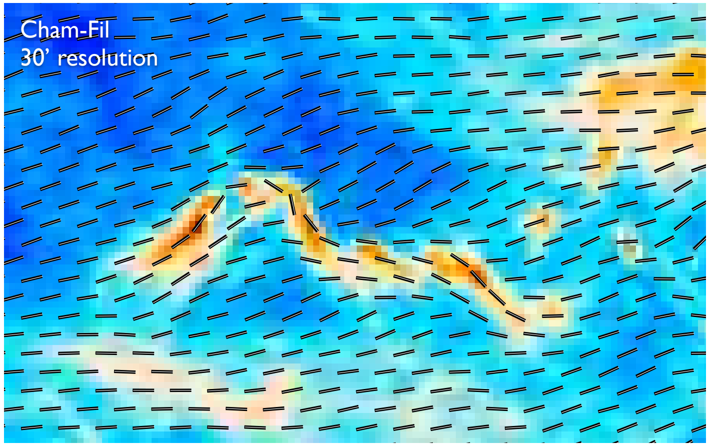


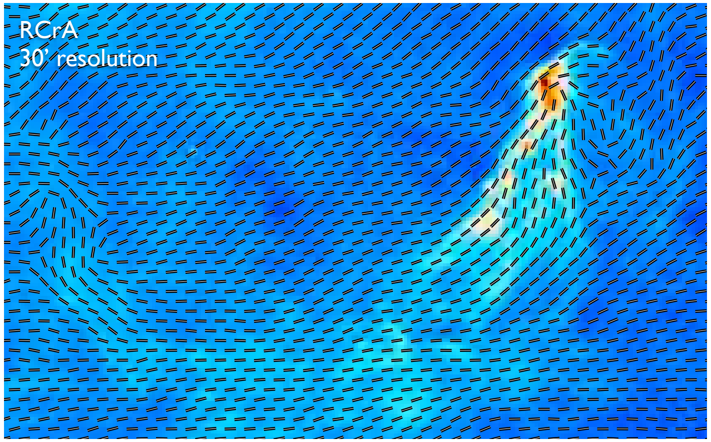
- First all-sky map of dust polarization.
- Complementary to observations of stellar polarization which provide detailed information on smaller angular scales

Planck intermediate results XIX 2015, A&A, 576, A104

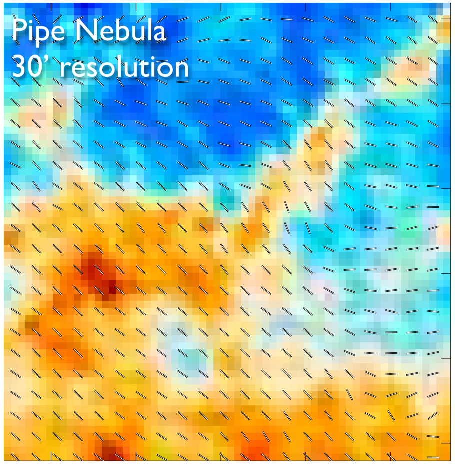
The Planck polarization sky

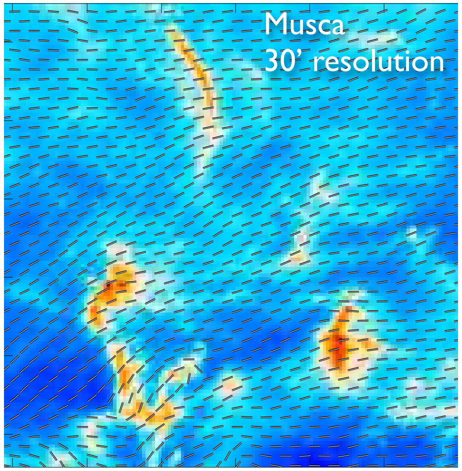
Magnetic field follow filaments





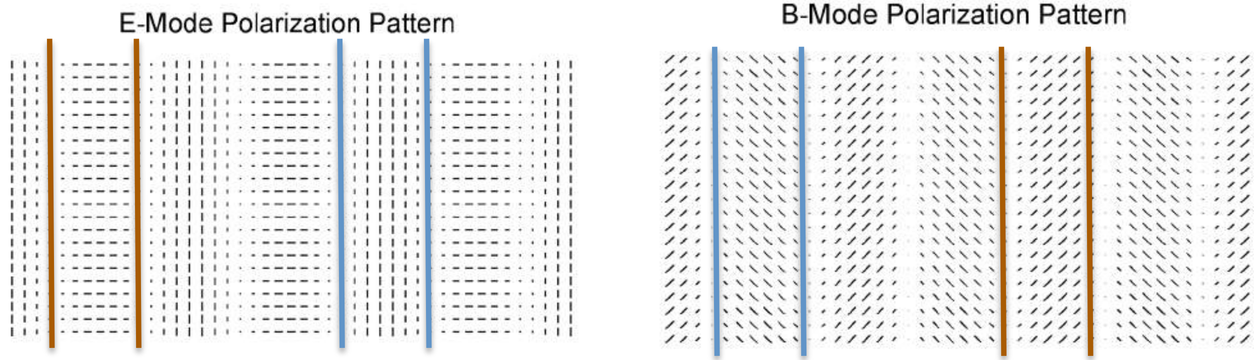
Magnetic field perpendicular to filaments





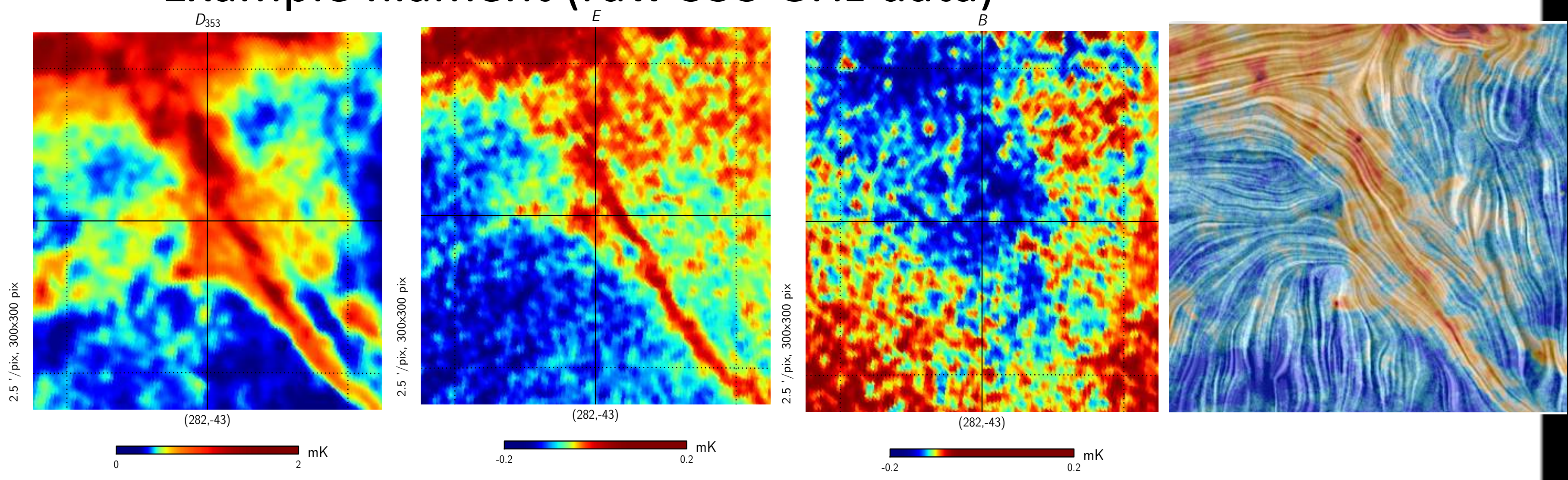
Planck XIX 2015, A&A, 576, A104

E- and B-modes in filaments



Zaldarriaga, PRD 64, 2001

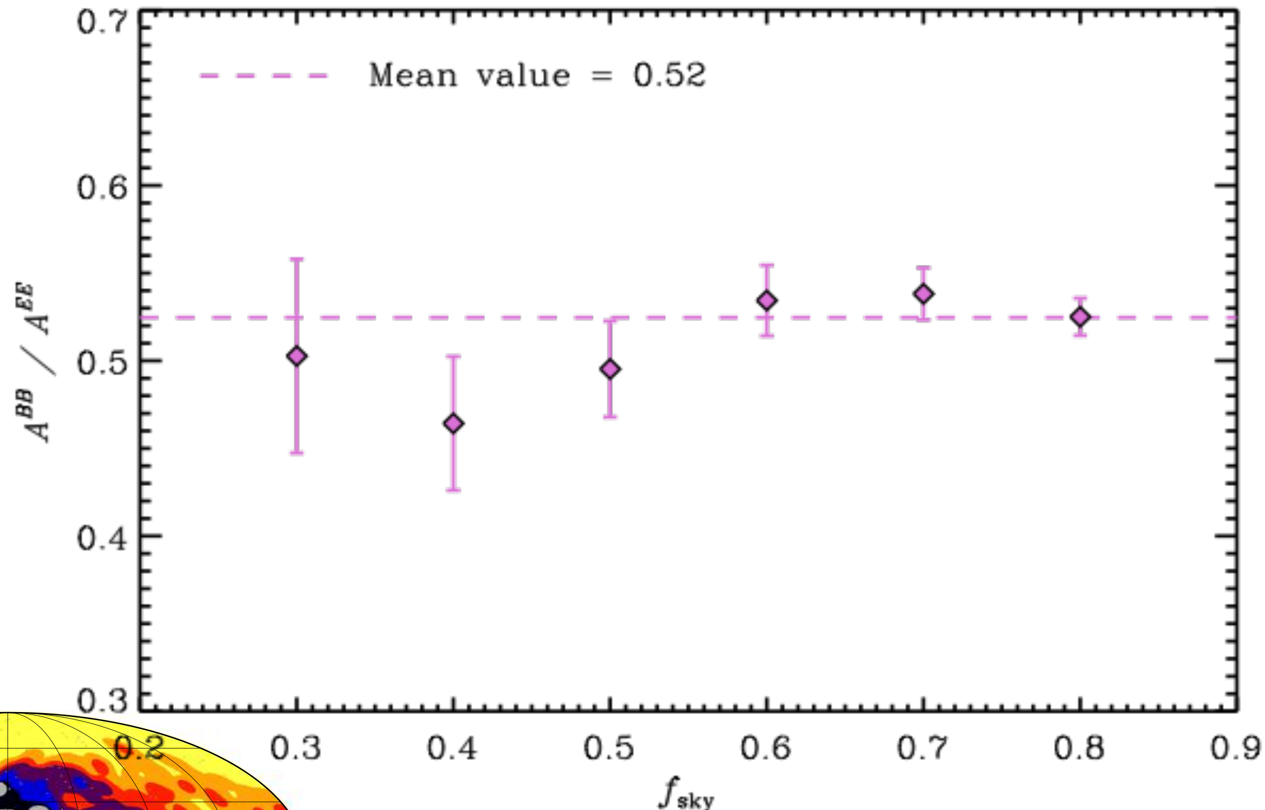
Example filament (raw 353 GHz data)

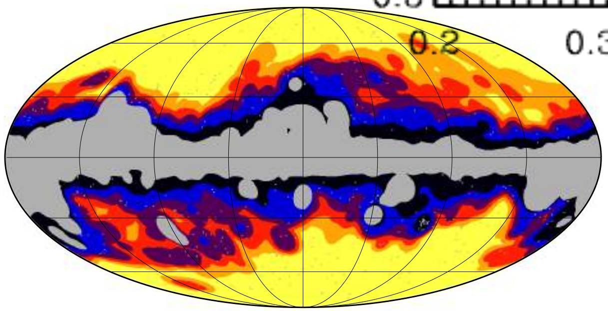


If a filament is preferentially aligned with the local direction of magnetic field, it produces more E-mode than B-mode.

Power asymmetry in the dust E- and B-modes

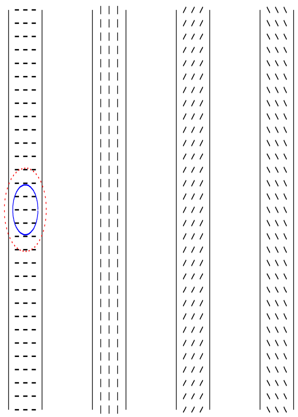
Polarized dust emission produces about half as much as *B*-mode power as *E*-mode power.

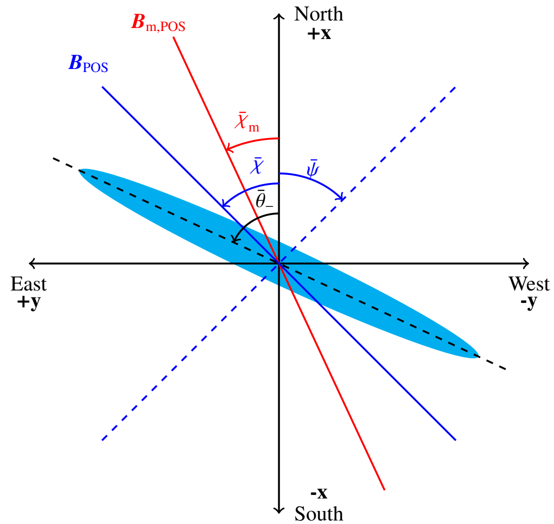


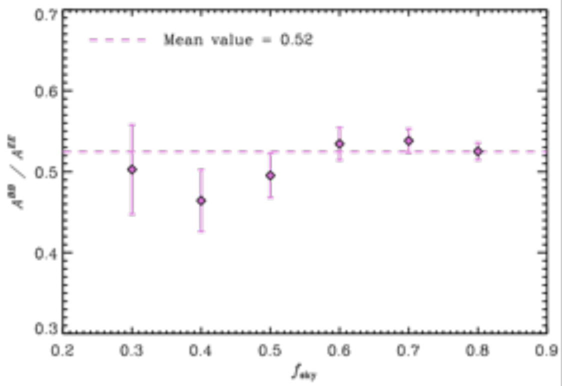


Planck XXX 2014, arXiv:1409.5738

Origin of dust E-B power asymmetry







Identifying elongated straight filaments

Study the relative orientation between the filaments and the magnetic field

BB/EE ~ 1/2

Filament-finding algorithm

Planck XXXVIII 2015, arXiv 1505.02779

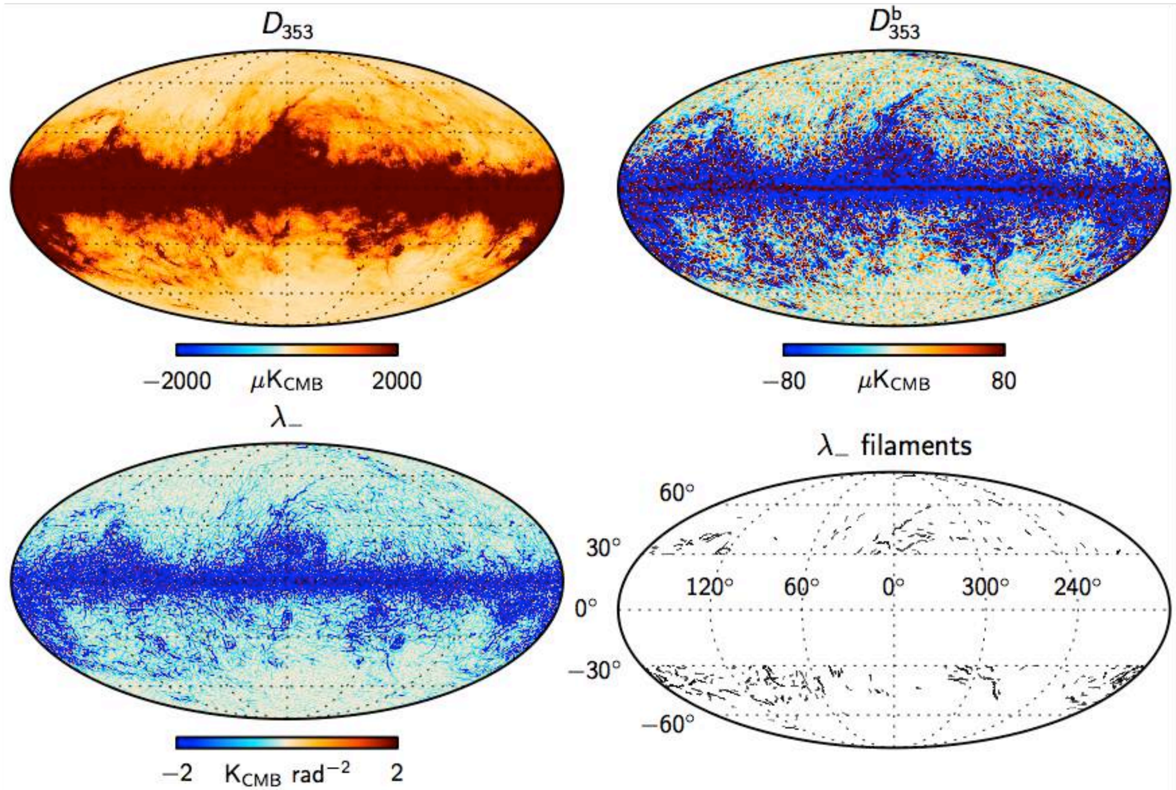
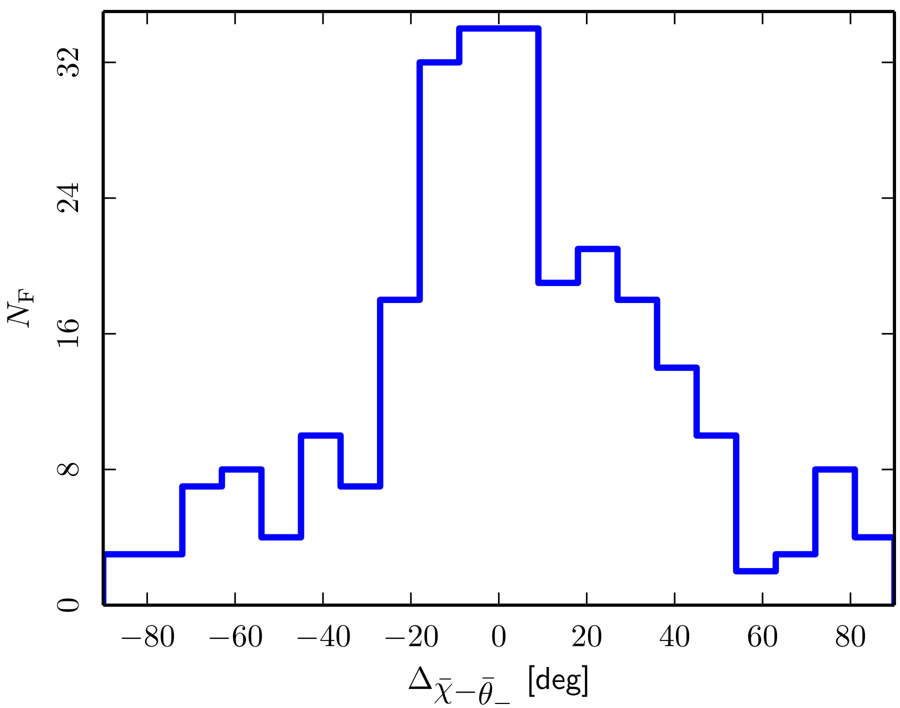


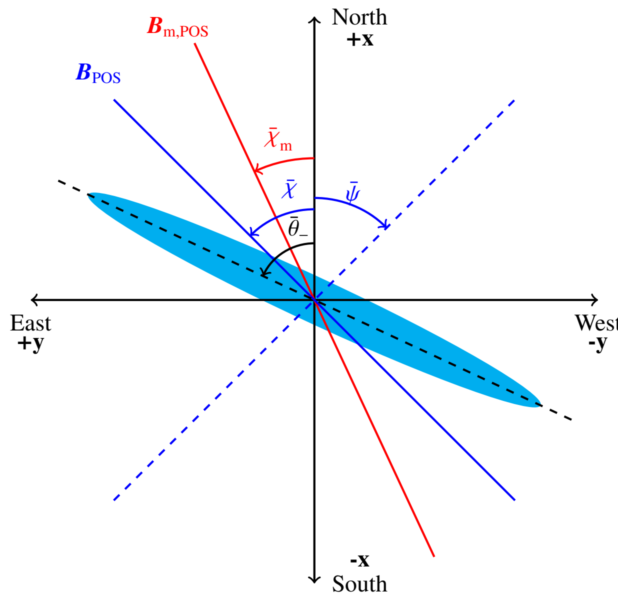
Fig. 2. Data processing steps implemented to identify filaments from the *Planck* data. We start with the *Planck* D_{353} map (upper left panel) smoothed at 15′ resolution. The bandpass-filtered D^{b}_{353} map (upper right panel) is produced using the spline wavelet decomposition, retaining only the scales between $\ell = 30$ and 300. The lower eigenvalue map of the Hessian matrix, λ_{-}, is shown in the lower left panel. Structures identified in the high-latitude sky λ_{-} map are shown in the lower right panel. The superimposed graticule is plotted in each image and labelled only on the lower right panel. It shows lines of constant longitude separated by 60° and lines of constant latitude separated by 30°. The same graticule is used in all plots of the paper.

Bond et al. 2010

- 259 filaments at high Galactic latitude ($|b| > 30^{0}$) with comparable column densities.
- Filaments have typical lengths larger or equal to 2 deg (corresponding to 3.5 pc length for a typical distance of 100 pc).

Histogram of relative orientation (HRO) between the filaments and $\mathcal{B}_{\rm POS}$



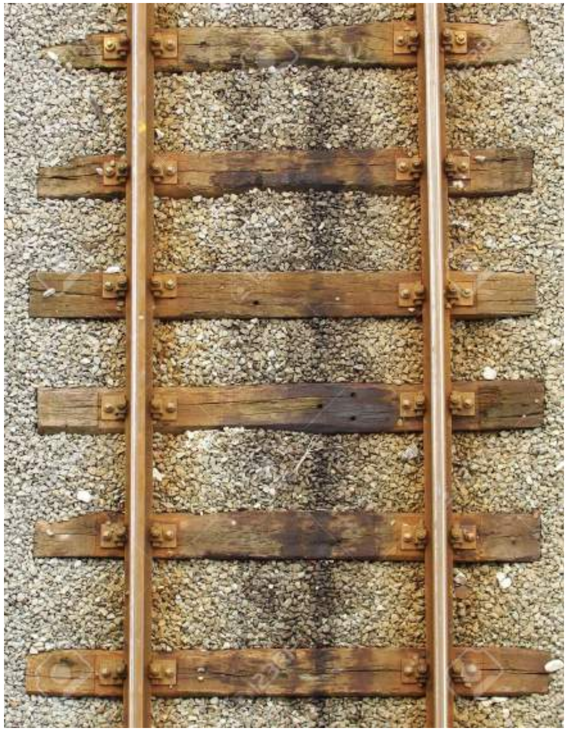


- Filaments are statistically aligned with $\mathcal{B}_{\rm POS}$ in the high-latitude sky .

- The HRO is fitted well with a Gaussian plus a constant. The constant arises from the projection of the magnetic field and filament orientation on the plane of the sky (Planck XXXII 2014, arXiv:1409.6728).

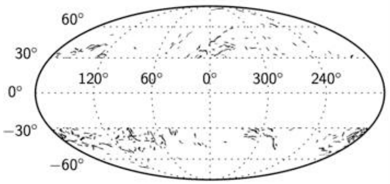
Planck XXXVIII 2015, arXiv 1505.02779

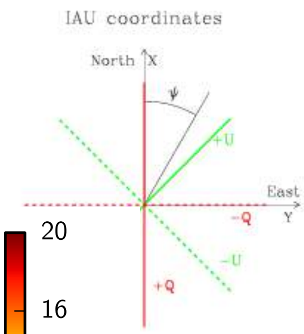
Projection effects

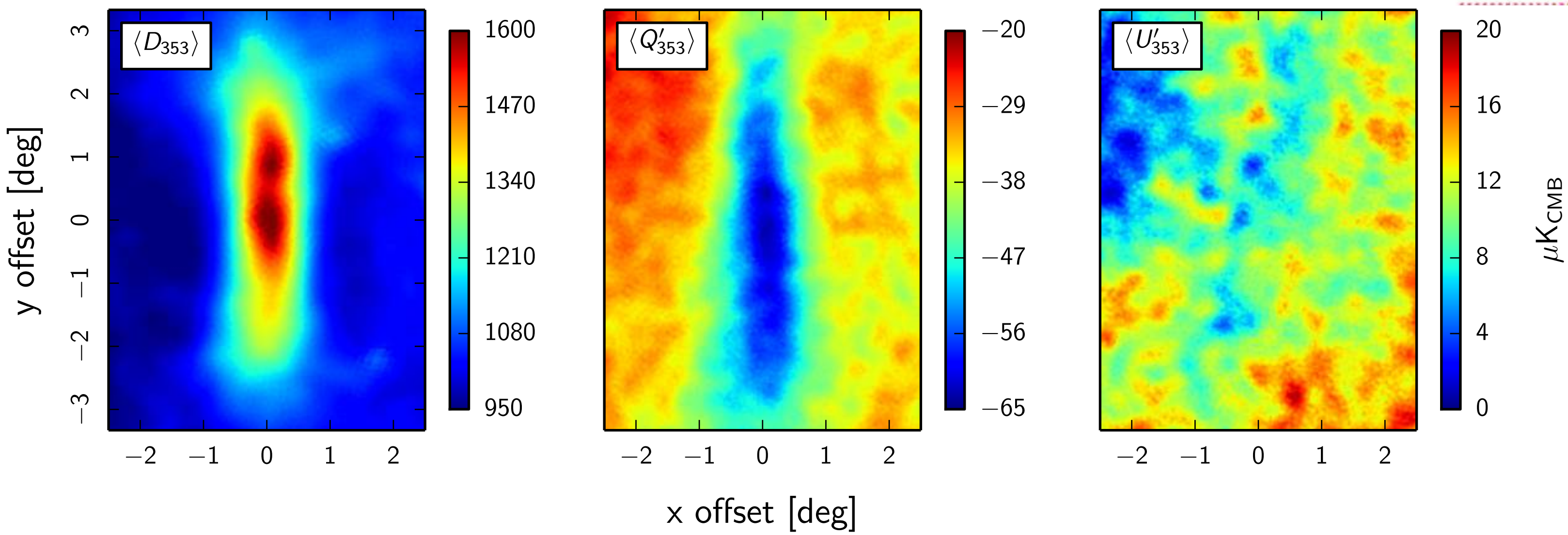


Projection effects (3D to 2D) are crucial for the interpretation of the shape of the distribution.

Stacking of filaments in our sample





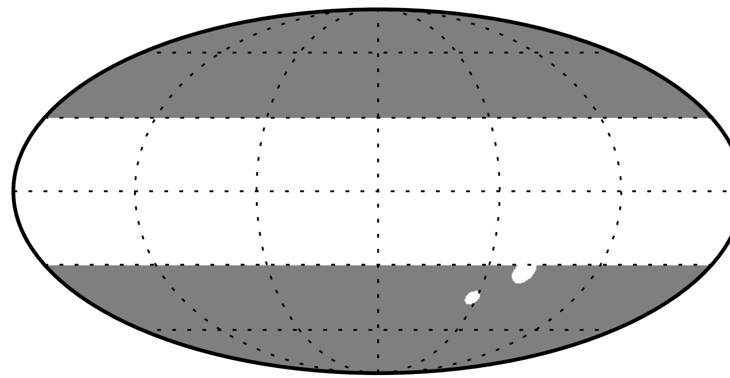


- Q' and U' are the Stokes Q and U maps computed with respect to the axis of the filament.
- The average filament appears as a negative feature with respect to the background in <Q'> image and is not seen in <U'> image.
- The 1 sigma uncertainty on the <Q'> and <U'> images is 1.3 uK_{CMB}.
- The homogeneous background in the <Q'> and <U'> images reflects the smoothness of B_{POS} over the patch size of 7x5 square degrees.
- The mean polarization fraction of the dust emission in these intensity filaments is 11%.

Planck XXXVIII 2015, arXiv 1505.02779

BB/EE variance ratio using filtered data

High-latitude sky



$$V^{EE}(\mathrm{HL}) = \frac{1}{N_{\mathrm{HL}}}\sum_{i=1}^{N_{\mathrm{HL}}} E^{\mathrm{b}}_{353,\mathrm{HM1}} E^{\mathrm{b}}_{353,\mathrm{HM2}} = (46.6 \pm 1.1)\,\mu\mathrm{K}^2_{\mathrm{CMB}}\ ,$$

$$V^{BB}(\mathrm{HL}) = \frac{1}{N_{\mathrm{HL}}}\sum_{i=1}^{N_{\mathrm{HL}}} B^{\mathrm{b}}_{353,\mathrm{HM1}} B^{\mathrm{b}}_{353,\mathrm{HM2}} = (29.1 \pm 1.0)\,\mu\mathrm{K}^2_{\mathrm{CMB}}\ ,$$

$$\boxed{\frac{V^{BB}(\mathrm{HL})}{V^{EE}(\mathrm{HL})} = 0.62 \pm 0.03}$$

This ratio is computed over the angular scales $30 < l < 300$.

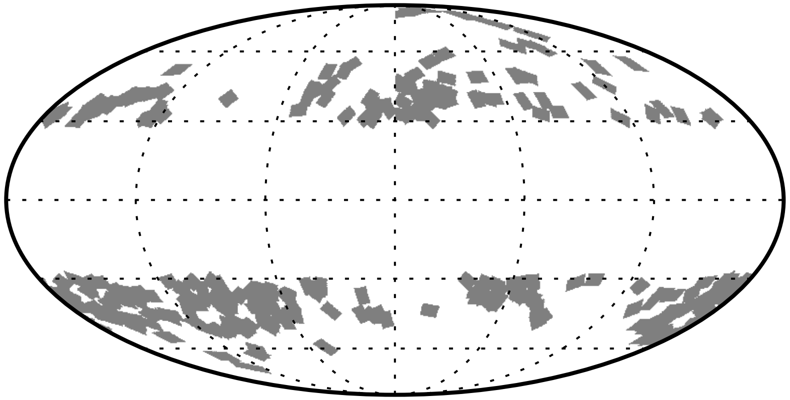
The 1 sigma errorbar on the variance estimate is computed using the cross-product of the independent subsets of the Planck data.

Planck XXXVIII 2015, arXiv 1505.02779

BB/EE variance ratio using filtered data

Filaments and their surroundings

(f_1=f_{sky}=0.28)



$$V^{EE}\,(\mathrm{SP}) = \frac{1}{N_{\mathrm{SP}}}\sum_{i=1}^{N_{\mathrm{SP}}} E^{\mathrm{b}}_{353,\mathrm{HM1}}\,E^{\mathrm{b}}_{353,\mathrm{HM2}} = (137.5 \pm 1.4)\,\mu\mathrm{K}^2_{\mathrm{CMB}}\ ,$$

$$V^{BB}\,(\mathrm{SP}) = \frac{1}{N_{\mathrm{SP}}}\sum_{i=1}^{N_{\mathrm{SP}}} B^{\mathrm{b}}_{353,\mathrm{HM1}}\,B^{\mathrm{b}}_{353,\mathrm{HM2}} = (91.2 \pm 1.3)\,\mu\mathrm{K}^2_{\mathrm{CMB}}\ ,$$

$$\frac{V^{BB}\,(\mathrm{SP})}{V^{EE}\,(\mathrm{SP})} = 0.66 \pm 0.01$$

This ratio is computed over the angular scales $30 < l < 300$.

The 1 sigma errorbar on the variance estimate is computed using the cross-product of the independent subsets of the Planck data.

Planck XXXVIII 2015, arXiv 1505.02779

Sky variance from the bright filaments

High-latitude sky:

$$V^{EE}(\mathrm{HL}) = 46.6\,\mu\mathrm{K}^2_{\mathrm{CMB}}$$

Filaments and their surroundings (f_1=0.28):

$$V^{EE}(\mathrm{SP}) = 137.5\,\mu\mathrm{K}^2_{\mathrm{CMB}}$$

The ratio of the sky variance is

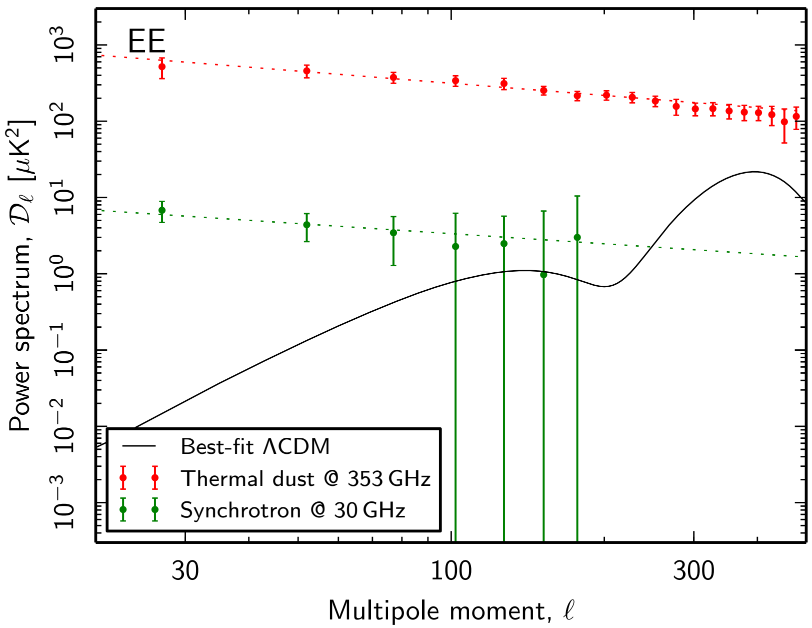
$$R_{\mathrm{SP}} = \frac{f_1 \times V^{EE}\,(\mathrm{SP})}{V^{EE}\,(\mathrm{HL})} = 0.83\ .$$

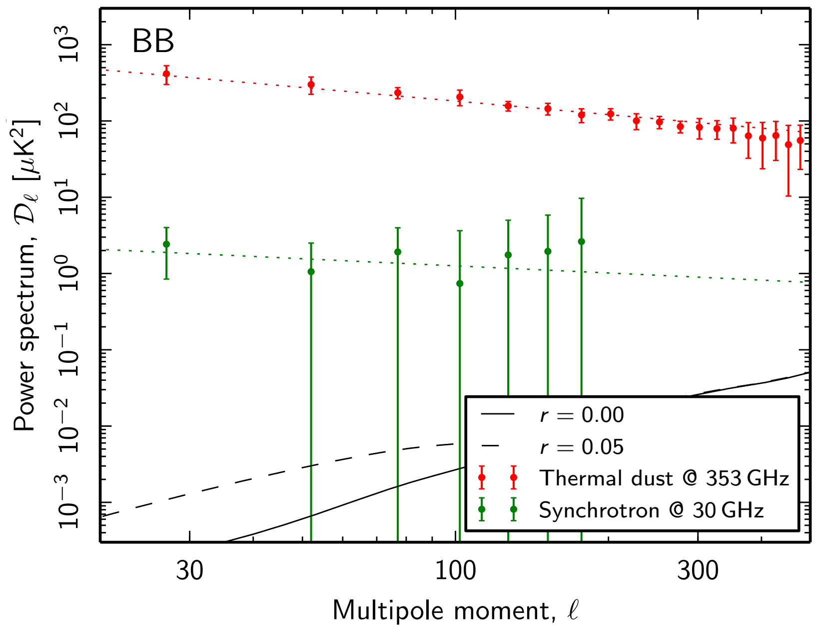
83 % of the total variance in EE polarization is in the bright dust intensity filaments.

- Rest of the high-latitude latitude sky (1-f_1=0.72) does not contribute much to the sky variance. It includes structures like local dispersion of the polarization angle.

Planck XXXVIII 2015, arXiv 1505.02779

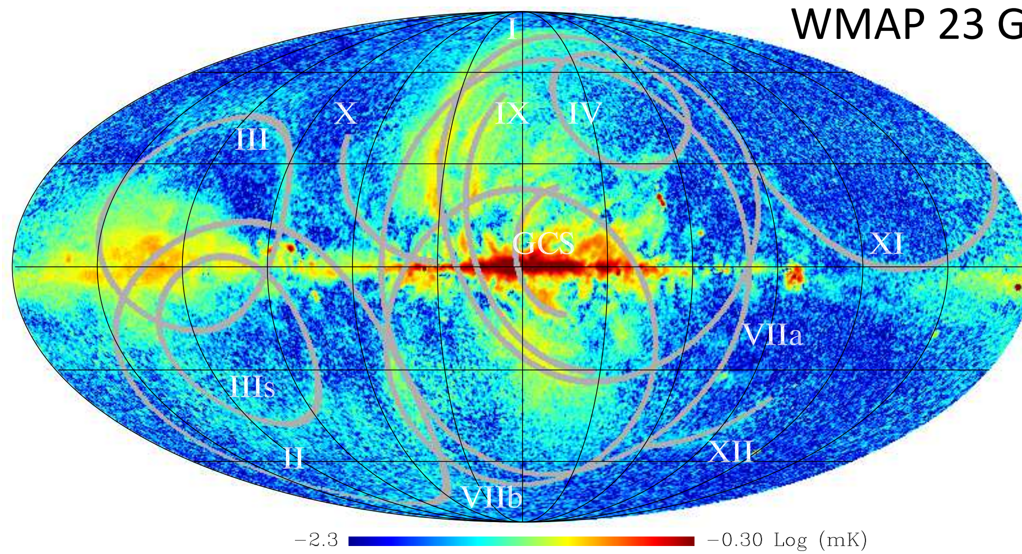
Synchrotron polarization





BB/EE ~ 0.36

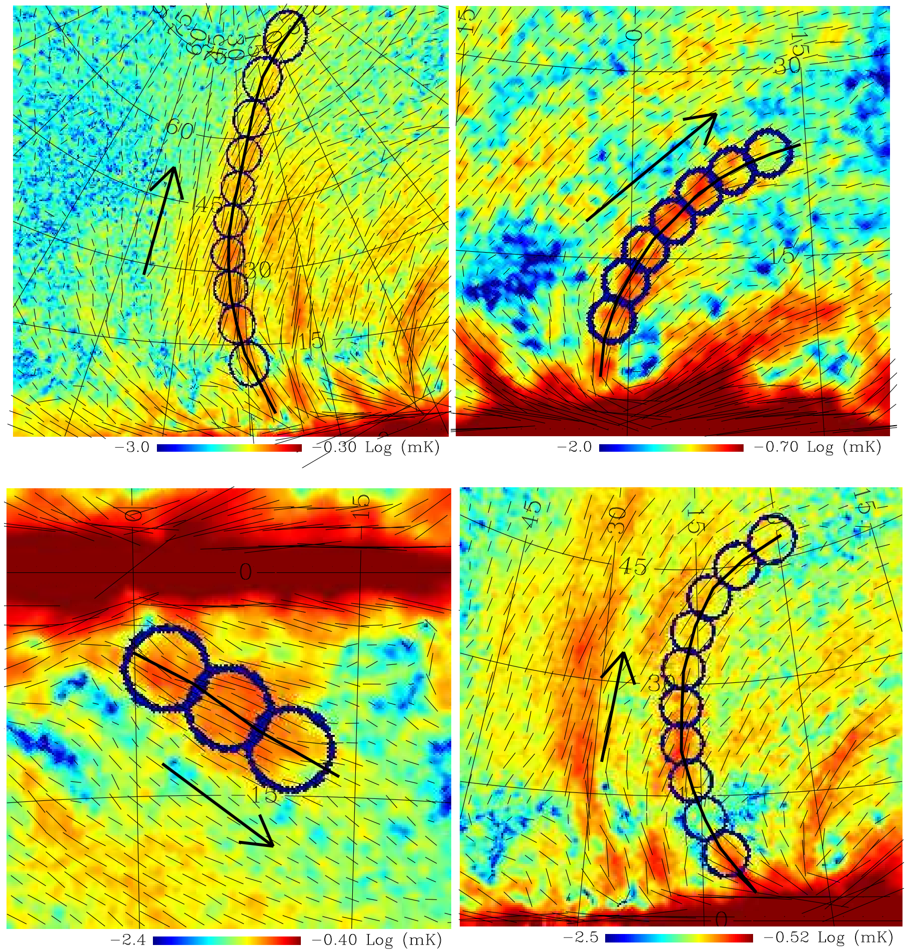
WMAP 23 GHz



Planck 2015 results. X. arXiv 1502.0158

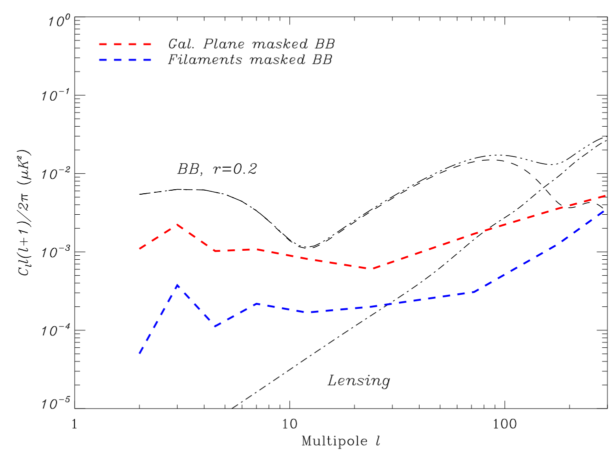
Synchrotron polarization

Filaments/part of loops



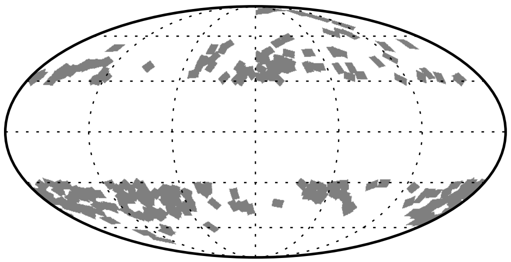
Vidal et. al. 2015, MNRAS, 452

Strong alignment between the filaments in the synchrotron emission and the magnetic field



B-mode power spectrum

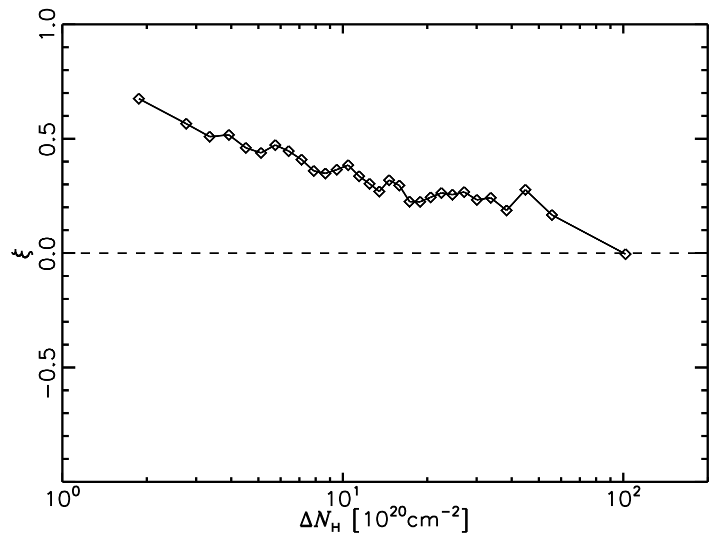
Overall picture



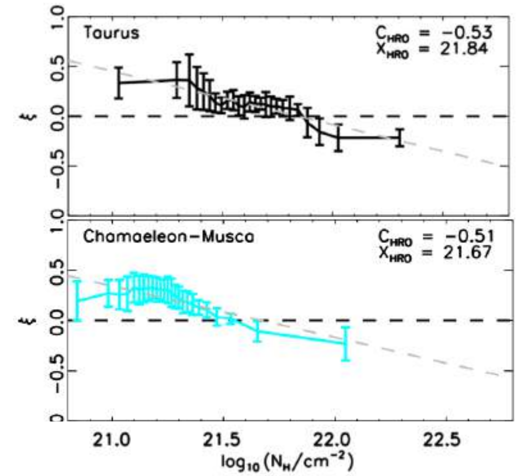
Diffuse ISM

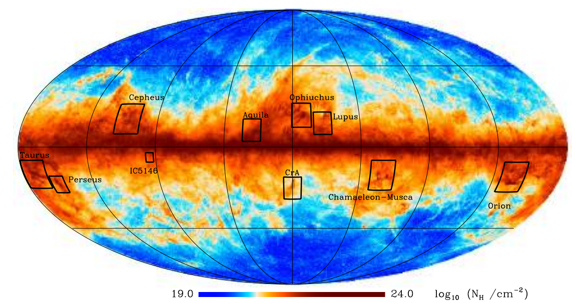
Planck XXXVIII 2015,
arXiv 1505.02779

degree of alignment vs column density



Planck XXXII 2015,
arXiv 1409.0678



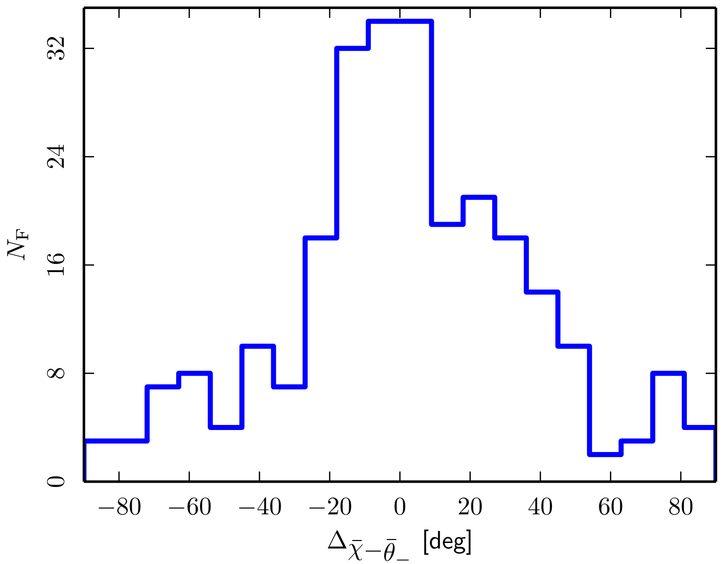


Molecular clouds

Planck XXXV 2015,
arXiv 1502.04123

Degree of alignment is:
equal to 1 in case of perfect alignment
equal to -1 in case of perfect perpendicularity

Conclusions



- Filaments in the diffuse medium are **statistically aligned** with the local magnetic field.

- The mean polarization fraction of the dust emission in the filaments of diffuse interstellar medium is **11%**.

- The histogram of relative orientation between the bright filaments and the local magnetic field can explain the **observed E-B power asymmetry**.

- Future models of dust polarization need to take into account the **alignment between the filaments and the magnetic field.**

  (See poster by Flavien Vansyngel)

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.