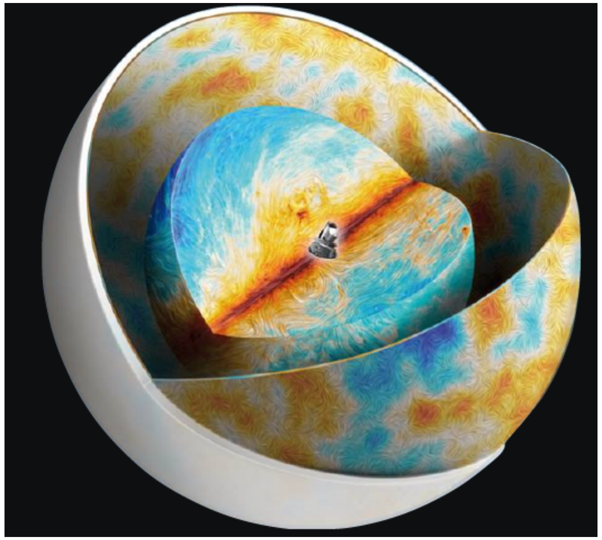
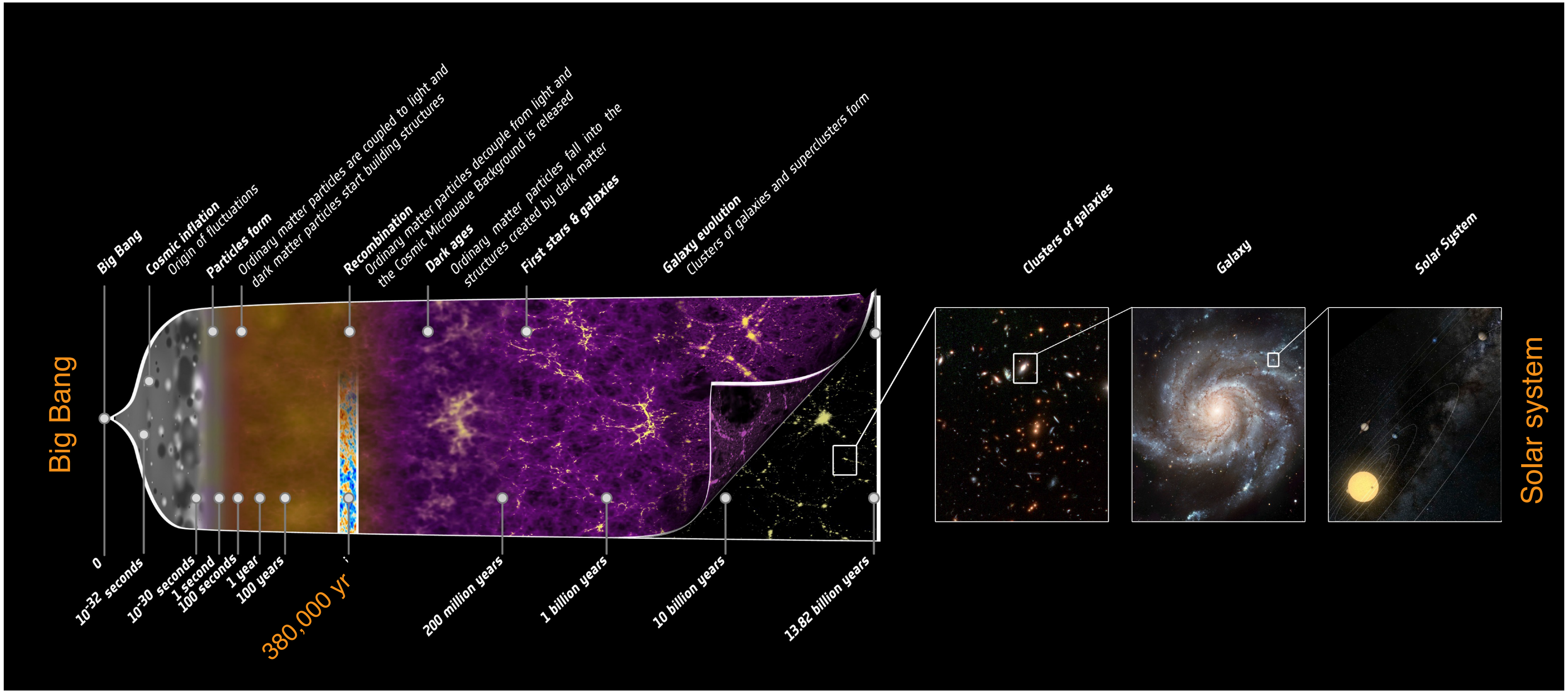
Statistical modelling of dust polarization as a CMB foreground

F. Boulanger (IAS), T. Ghosh (NISER), F. Vansyngel (IAC)



Polarized Galactic and CMB skies

Primordial gravitational waves

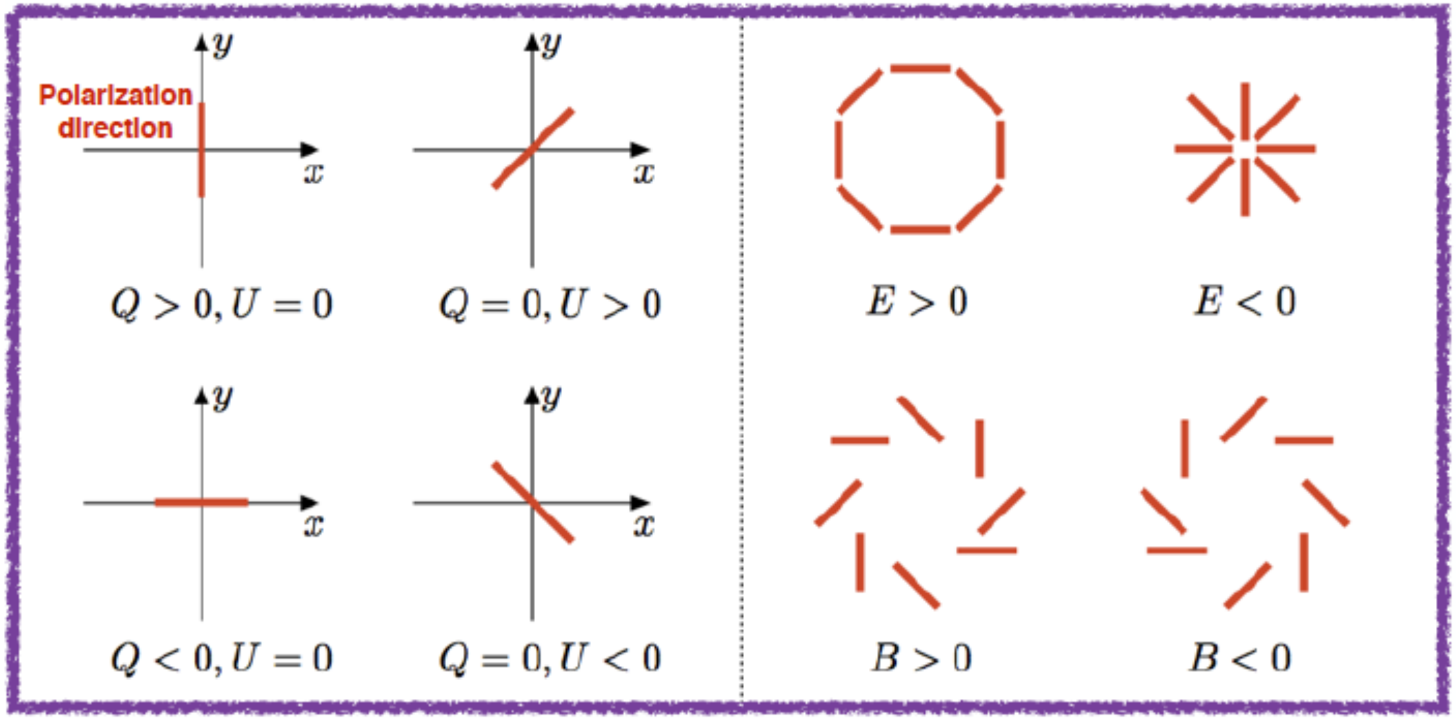


Cosmologists are searching for the imprint on CMB polarization of primordial gravitational waves generated by cosmic inflation

Polarization E- and B-modes

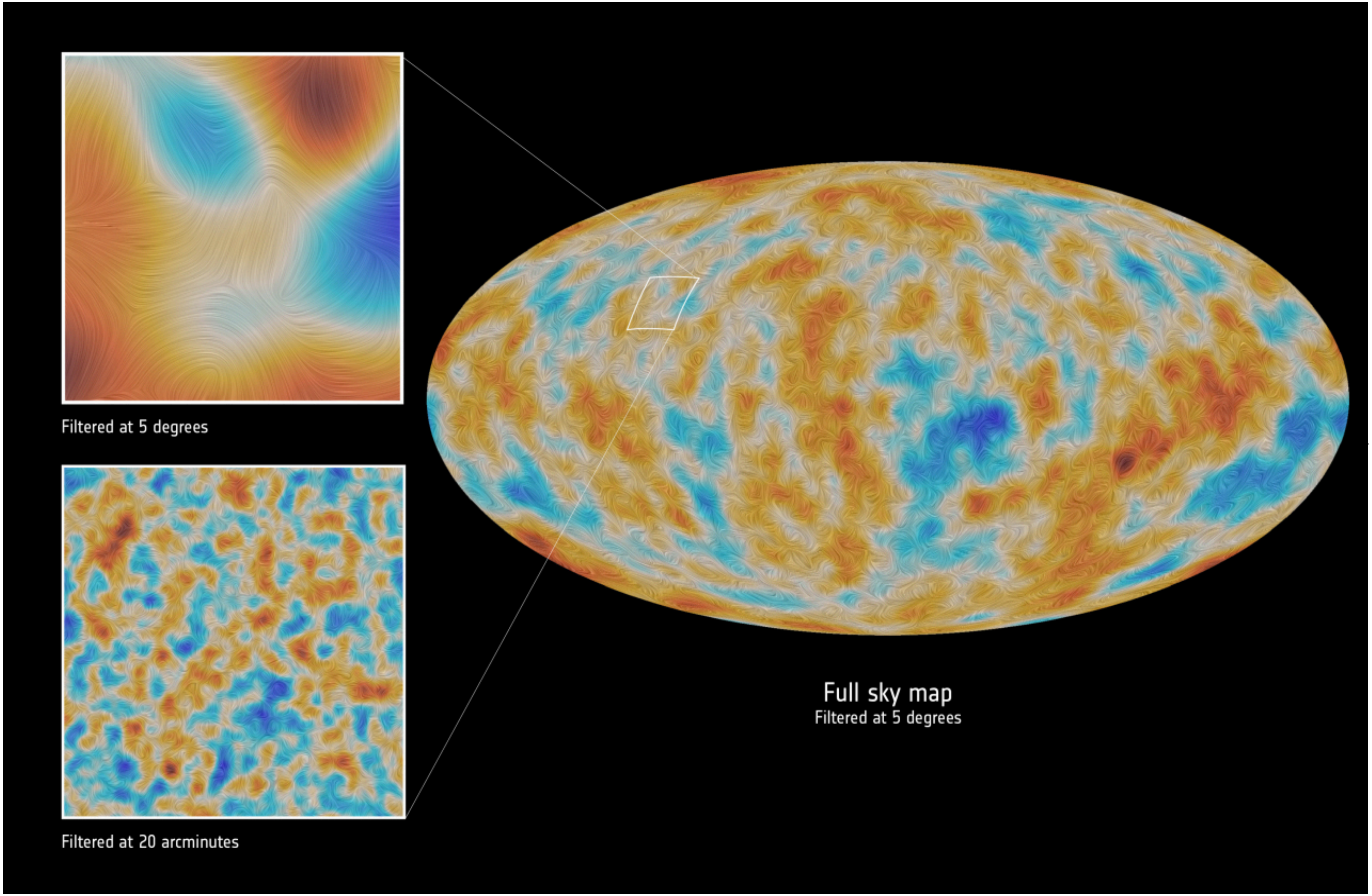
Cosmologist analyze polarization data in terms of E and B-modes, which encode distinct physical information

Stokes parameters **E and B-modes**



CMB hot and cold spots

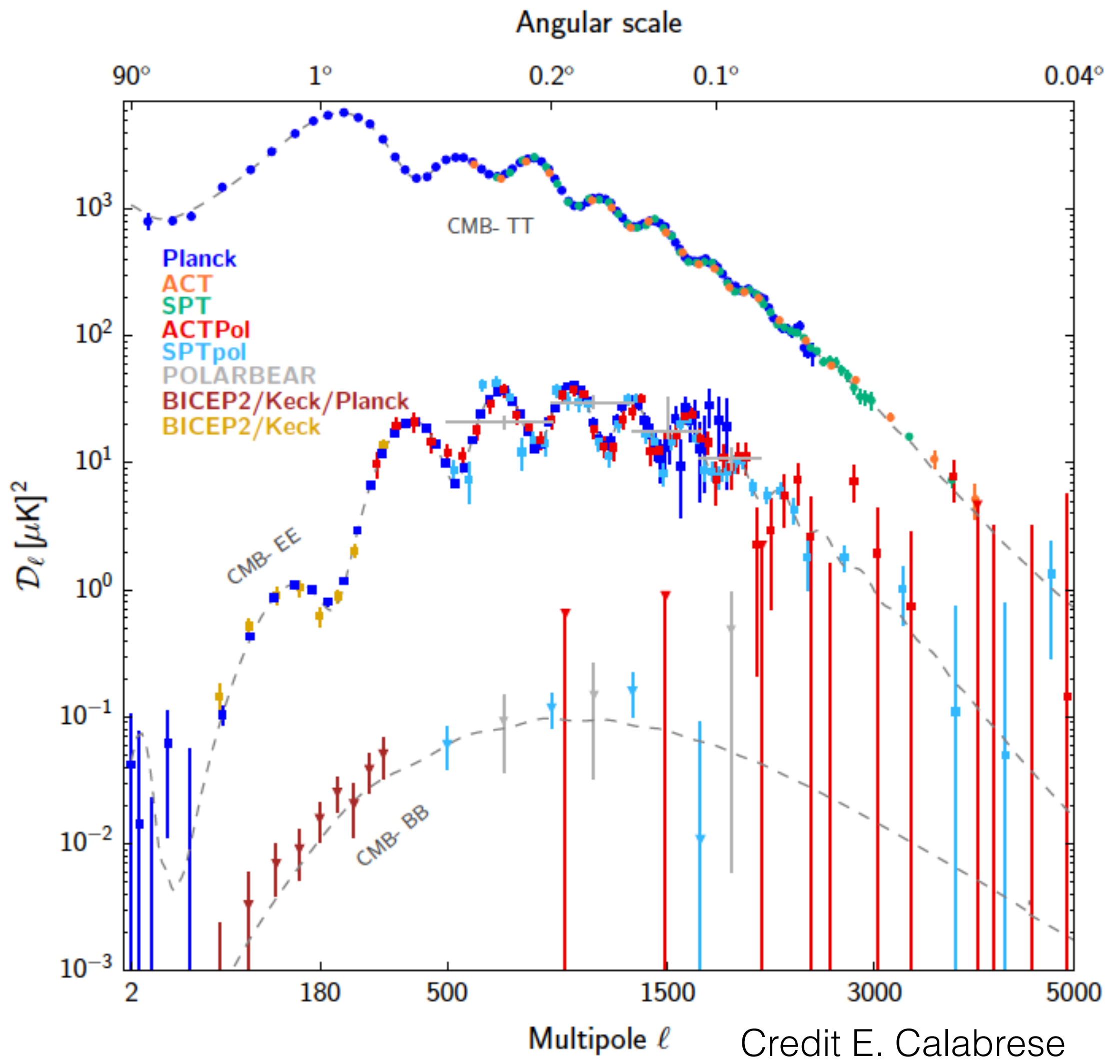
Lensing and **primordial gravitational waves**



Planck CMB polarization map

CMB Power spectra

- E-mode (gradient-like) polarization validates the acoustic interpretation of temperature peaks and enhances the precision of cosmological parameters.
- B-mode (curl-like) polarization from gravitational lensing is also detected
- No detection (yet) of the weaker B-mode signal expected from primordial gravitational waves

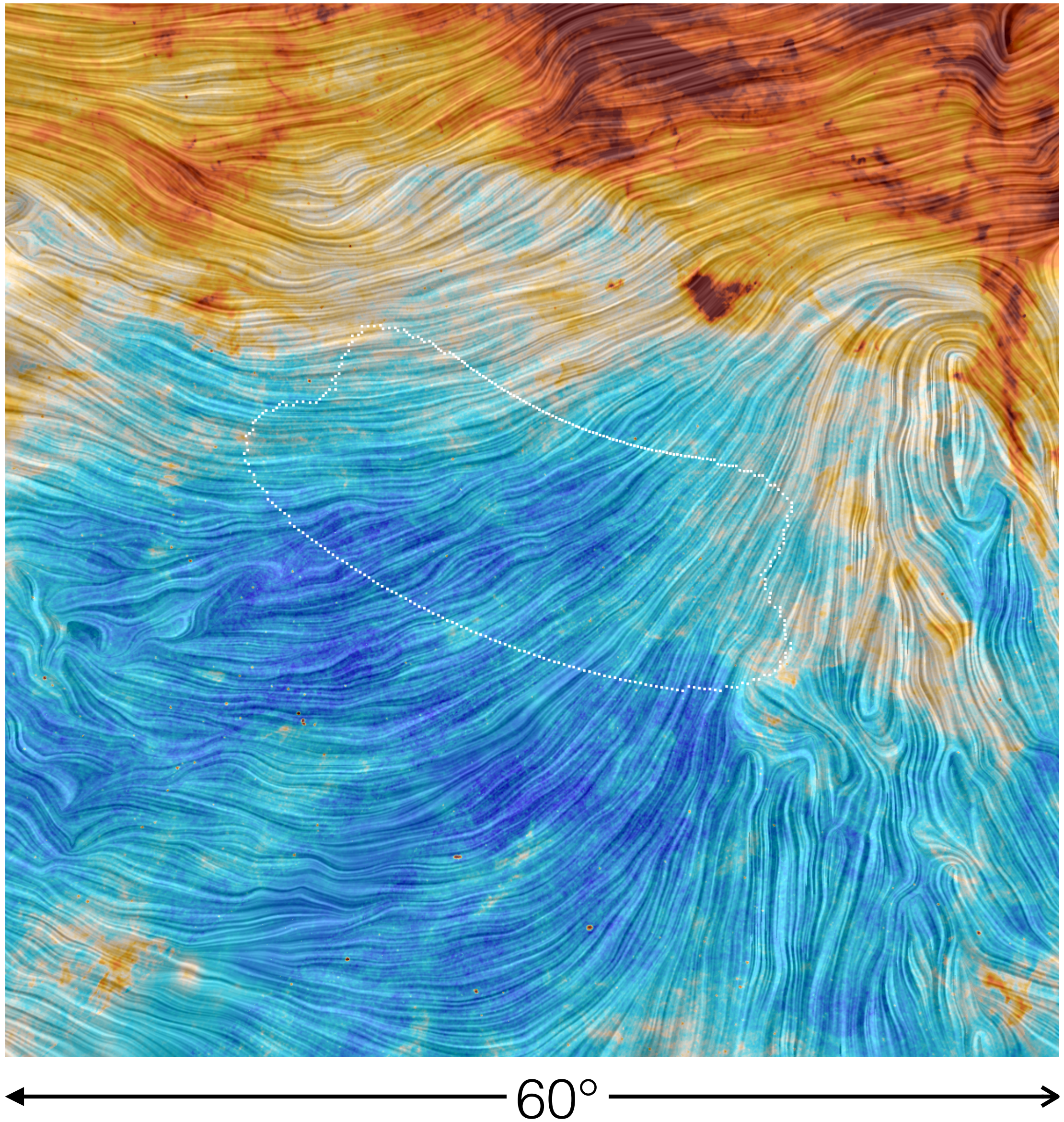


Credit E. Calabrese

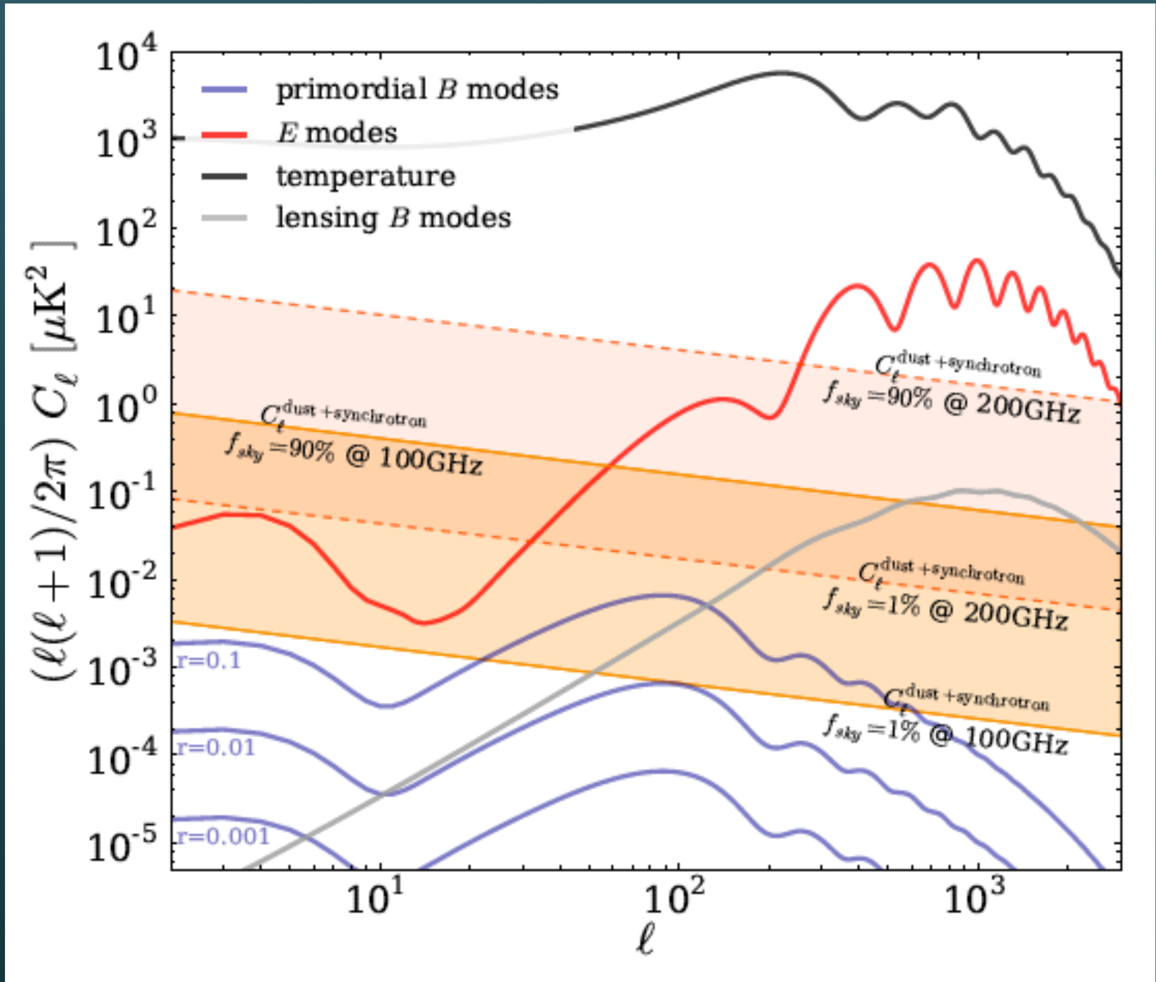
The foreground screen from the magnetized ISM

- The power spectra of dust polarization was characterized over the whole sky using Planck data
- There is no sky area where the Galactic signal may be neglected
- Any claim for a detection will face a critical assessment against alternative interpretations involving foregrounds

BICEP/Keck field on Planck image

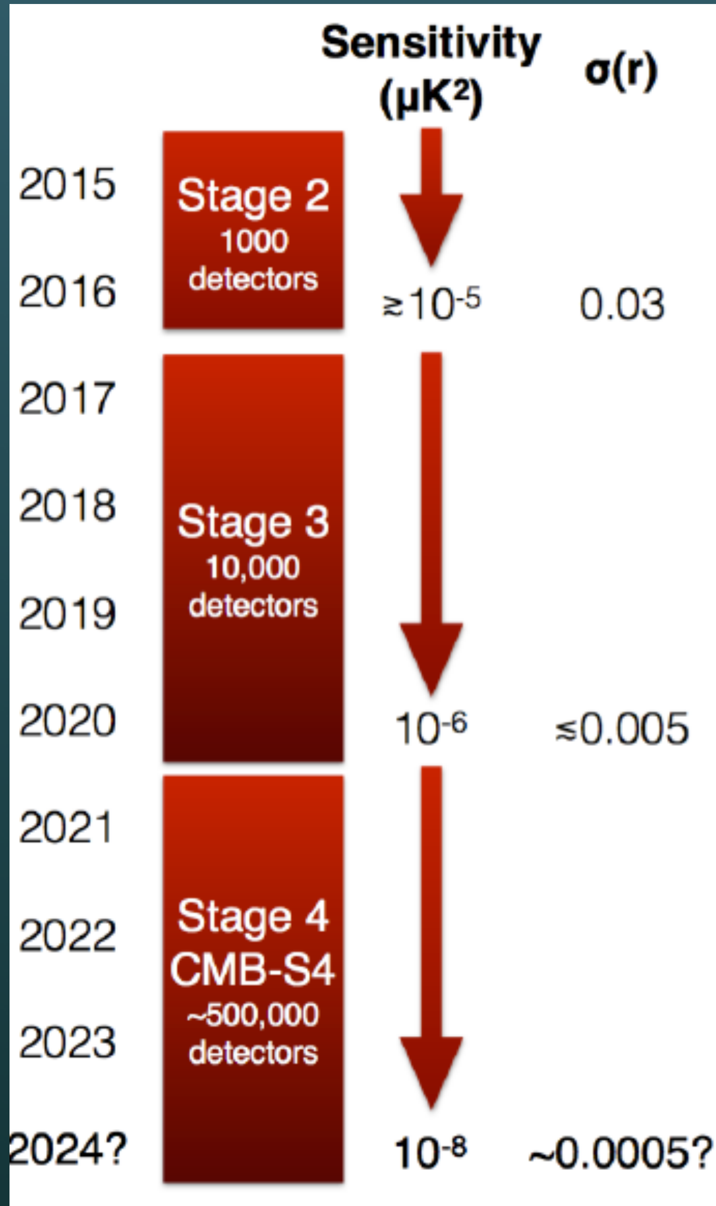


Primordial B-mode signal



Errard+ 2016

Ground-based observations



Carlstrom+ 2016

Modelling motivations

- Statistical modeling of foregrounds is required to confidently identify primordial CMB B-modes (or set upper limits)

- Propagate instrumental effects in end-to-end simulations of data pipeline

- Optimize component separation for CMB polarization and assess statistically uncertainties

- Astrophysical interpretation of data

Modelling approach

- Stokes I from 353 GHz dust-only sky map (CMB and cosmic infrared background subtracted)
- Magnetic field model required to compute noise-free Stokes Q and U maps
- Ordered magnetic field + statistical model of turbulent component
- Model parameters fitted on Planck dust power spectra EE, BB and TE and one-point statistics of polarization fraction and angle

Statistical model

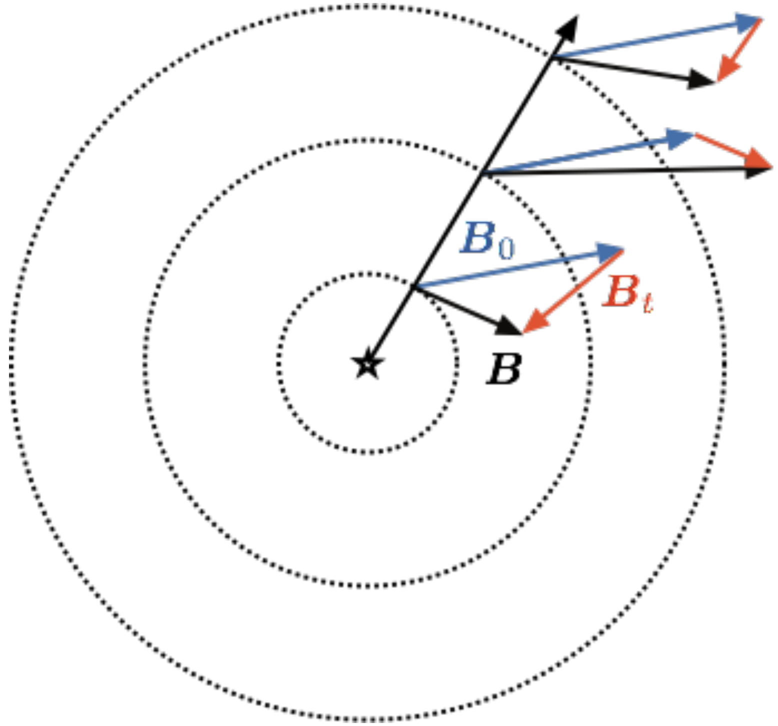
- Magnetic field
  - Uniform + random

$$\boldsymbol{B} = |\boldsymbol{B}_0| \, (\hat{\boldsymbol{B}}_0 + f_{\mathrm{M}} \, \hat{\boldsymbol{B}}_{\mathrm{t}})$$

  - Power-law spectrum

$$C_\ell \propto \ell^{\alpha_{\mathrm{M}}} \text{ for } \ell \geq 2$$

- Distribution of matter from total intensity Planck map
- Correlation between magnetic field and matter
- Summing emission over N emitting layers (ISM structure along the line of sight)



Turbulent field

$$\boldsymbol{B} = \boldsymbol{B}_0 + \boldsymbol{B}_t$$

Ordered field

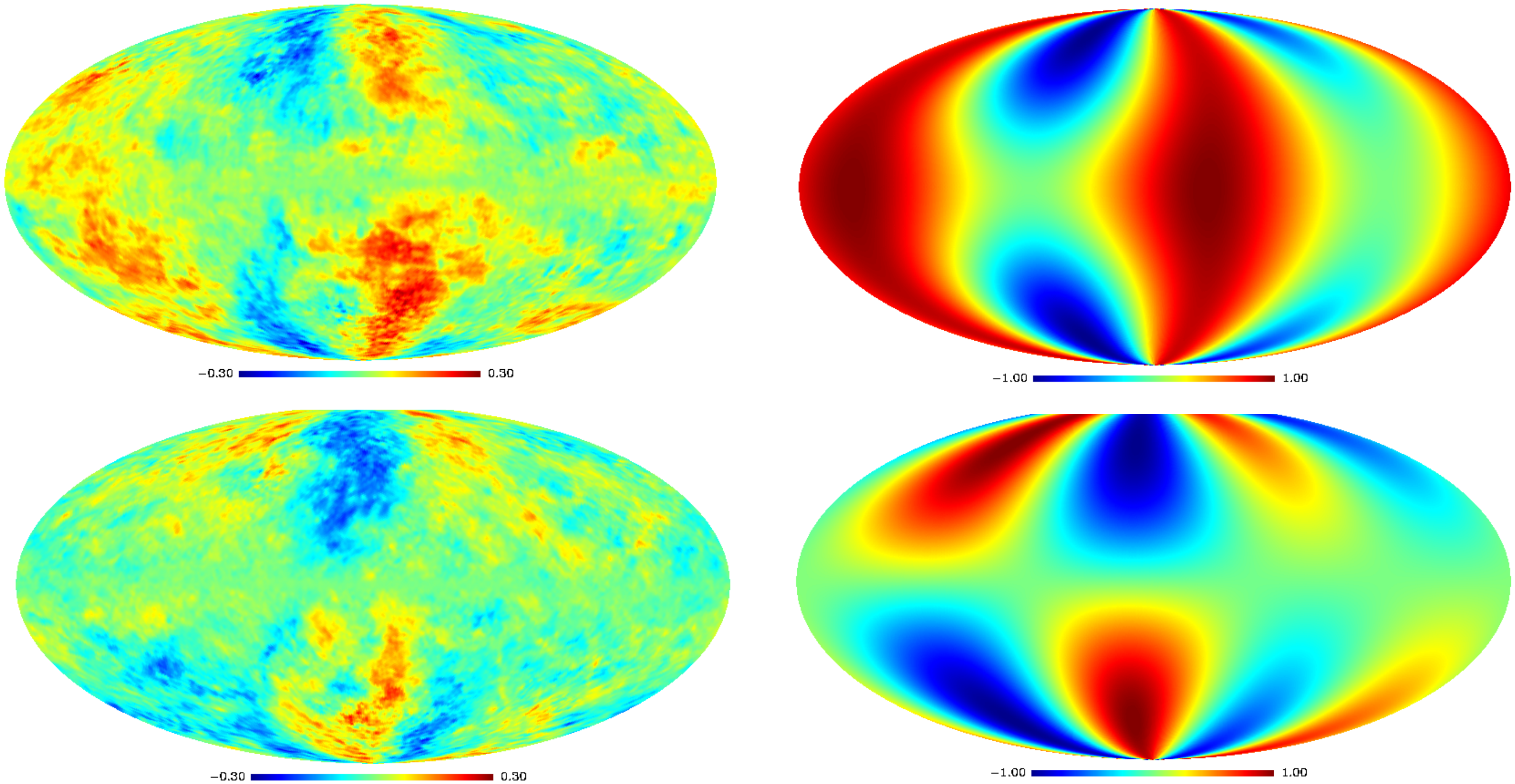
Planck collaboration XLIV (2016), Ghosh+ 2017, Vansyngel+ 2017

Ordered magnetic field

Planck maps smoothed (80' beam) | Model with no turbulence

Stokes Q/I

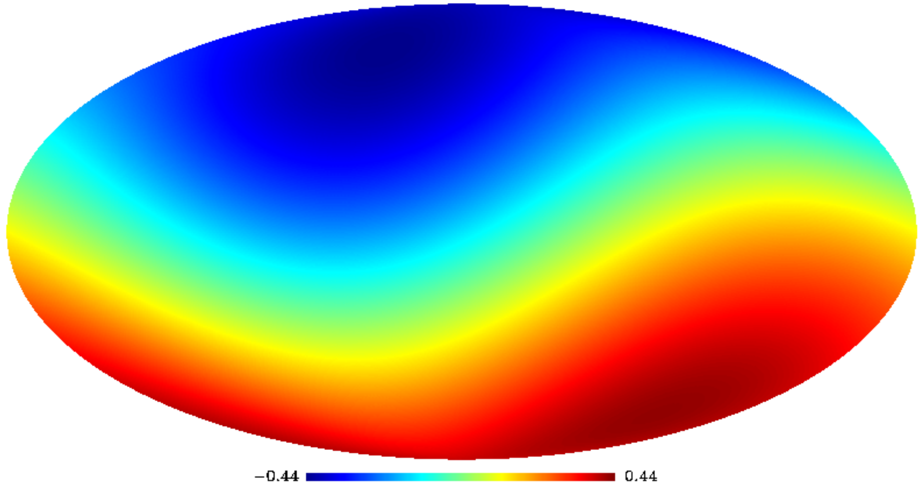
Stokes U/I



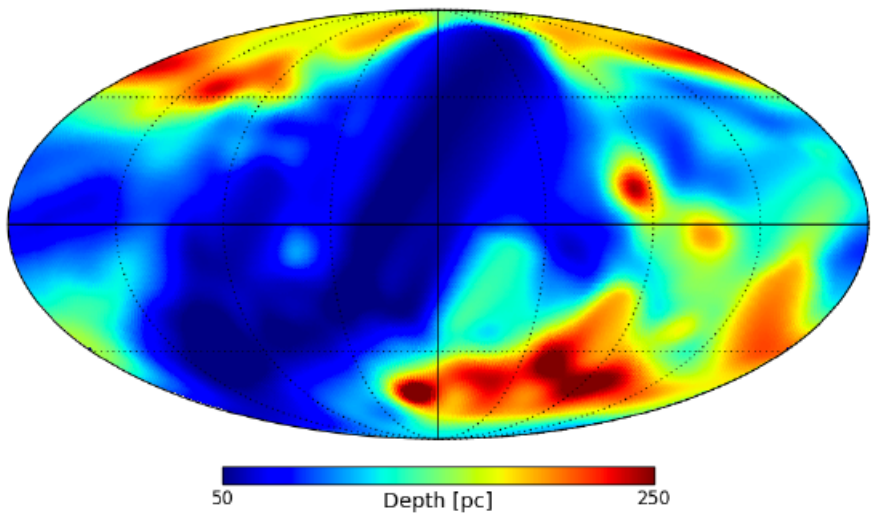
Ordered magnetic field

- Ordered magnetic field inferred from data fitting includes a significant component pointing towards the Galactic disk at both poles
- We may be seeing a local deformation of the Galactic magnetic field associated with the Local Bubble
- The extension of the Bubble towards the pole is comparable to the dust scale-height

Component of B_0 perpendicular to Galactic disk



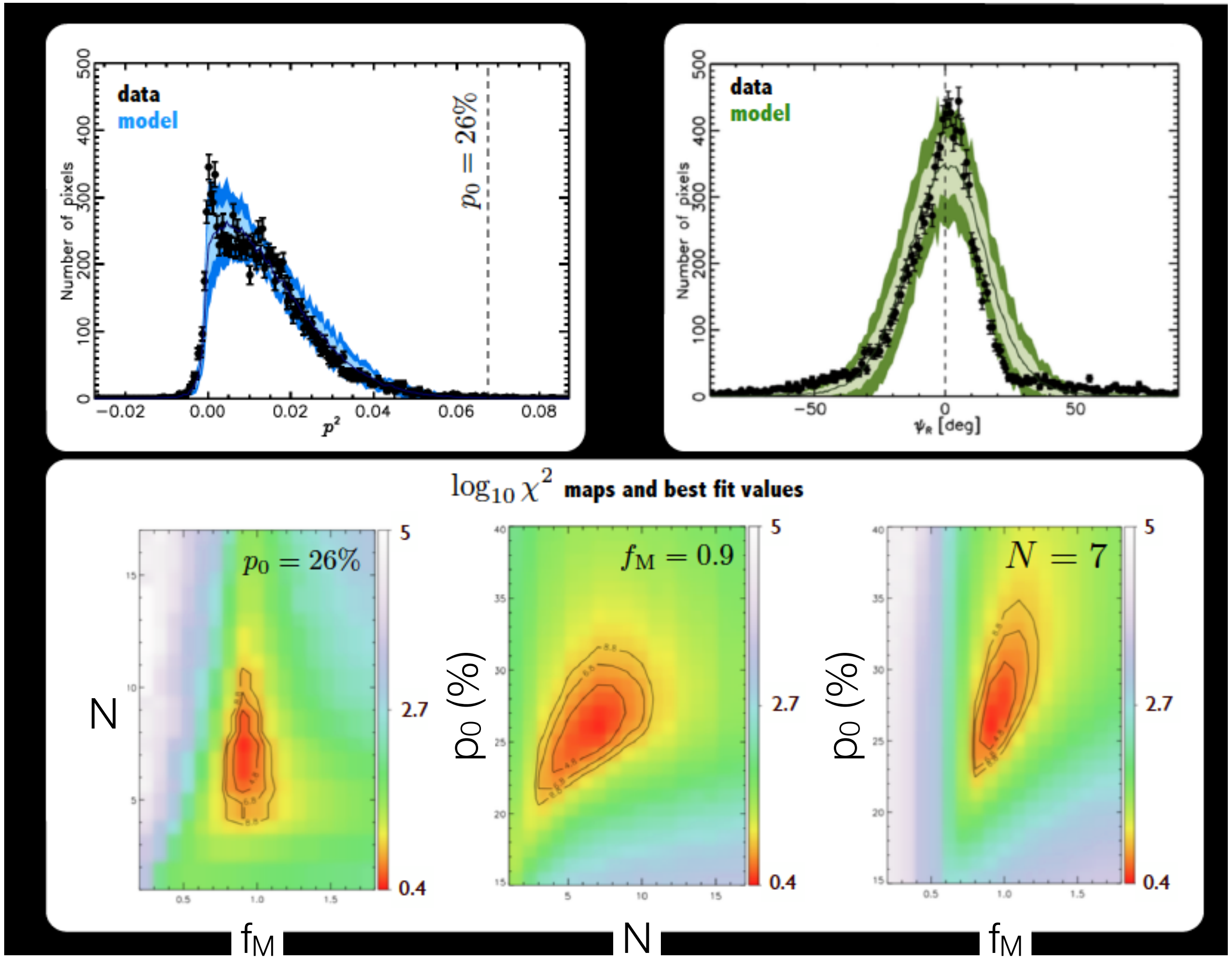
3D structure of the local bubble of hot plasma



Liu+ 2016

Polarization fraction and angles

Polarization fraction | Polarization angle

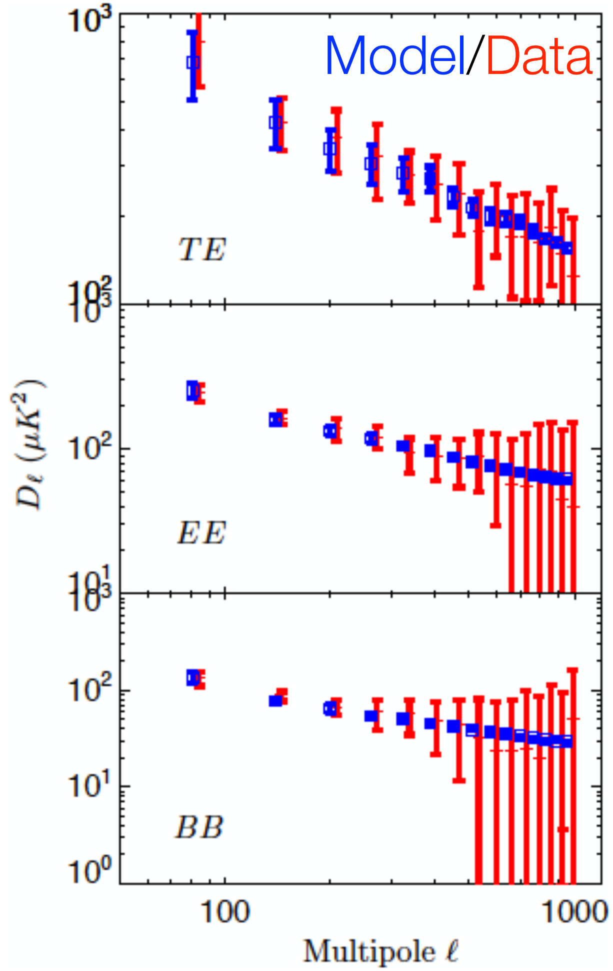


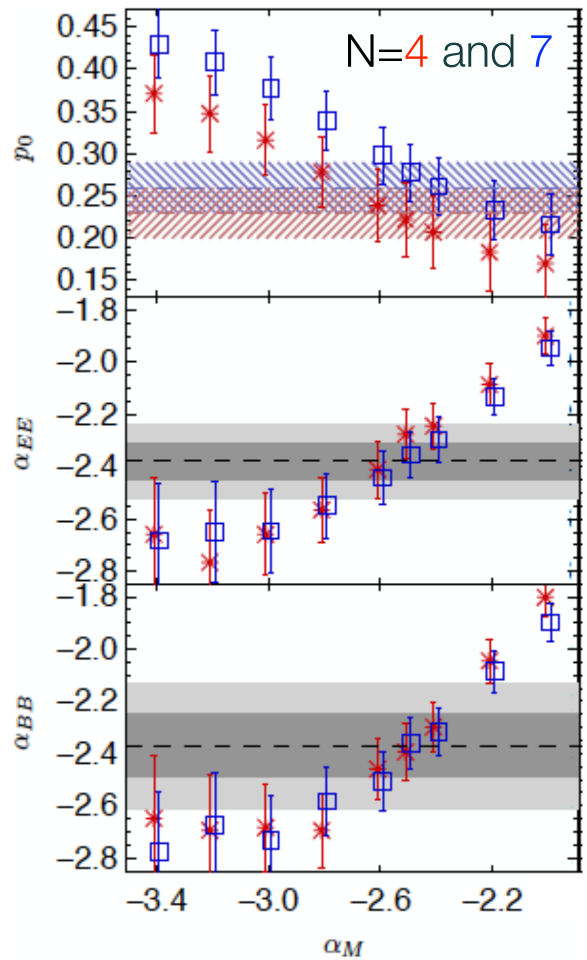
- High dust polarization fraction (p_0=0.26)
- Turbulence is sub/ trans-Alvenic (f_M = 0.9)
- Small number of structures/turbulent cells along the line of sight (N~5-7)

Magnetic Field power spectrum

The slopes of power-spectra are matched for a magnetic field power spectrum index α_M = -2.5

Vansyngel+ 2017

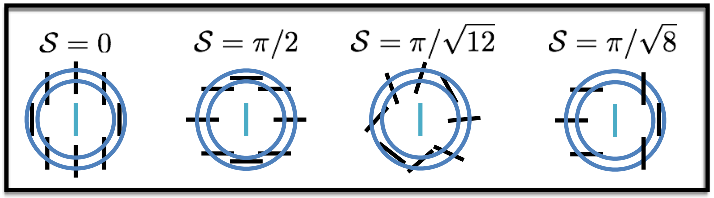




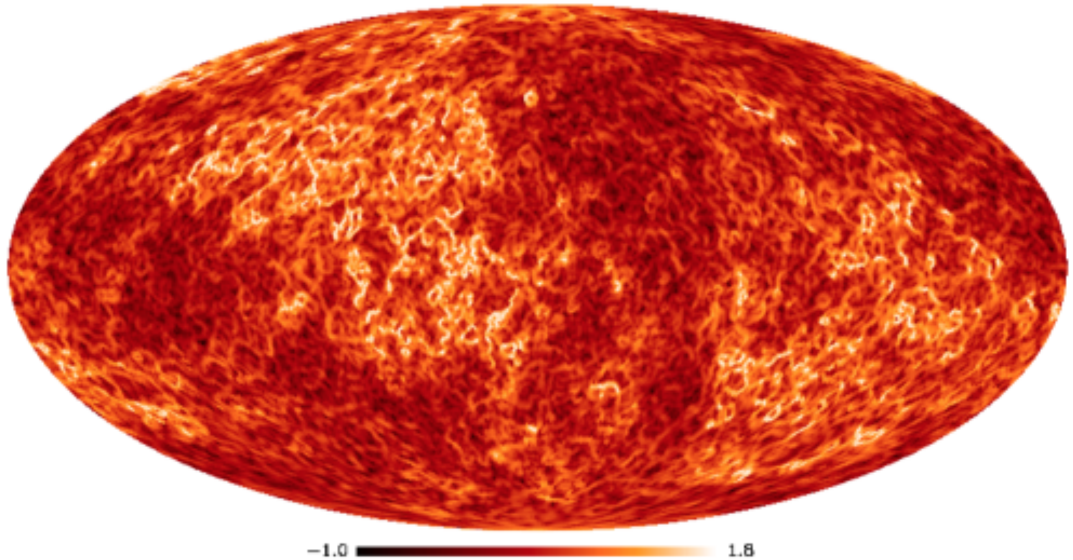
Filamentary structure of sky polarization

Dispersion function of polarization angles

$$\mathcal{S}(\boldsymbol{r},\delta) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[\psi(\boldsymbol{r}+\boldsymbol{\delta}_i)-\psi(\boldsymbol{r})\right]^2}$$



Dispersion function for model maps



- Gaussian model of the magnetic field accounts for the observed filamentary structure of the S map.
- In this model, filaments are present where the ordered field orientation is close to the line of sight

Next steps

- Multi-frequency modelling required to account for correlations between dust polarization/emission properties and the structure of the magnetized ISM
- 3D model of the ordered magnetic field
- Non-Gaussian (non-parametric) model of the turbulent component of the magnetic field
- Extend modelling to synchrotron polarization and account for its correlation with dust polarization on large angular scales

Summary

- Dust polarization dominates CMB primordial B-modes over the whole sky
- Statistical modelling required to analyze CMB data and confidently claim detection
- Modeling also provides a framework to relate data to the structure of the magnetized ISM characterizing interstellar turbulence
- More insights on dust polarization in upcoming talks by Susan Clark and Marc-Antoine Miville Deschênes