# Dust polarization spectral dependence from Planck HFI data as constraint for CMB B-modes detection

Alessia Ritacco (OAC - INAF)

and Francois Boulanger, Vincent Guillet, Jean-Marc Delouis, Jean-Loup Puget, Jonathan Aumont

LPENS
LABORATOIRE DE PHYSIQUE
DE L'ÉCOLE NORMALE SUPÉRIEURE

Work to *be shortly submitted* to A&A

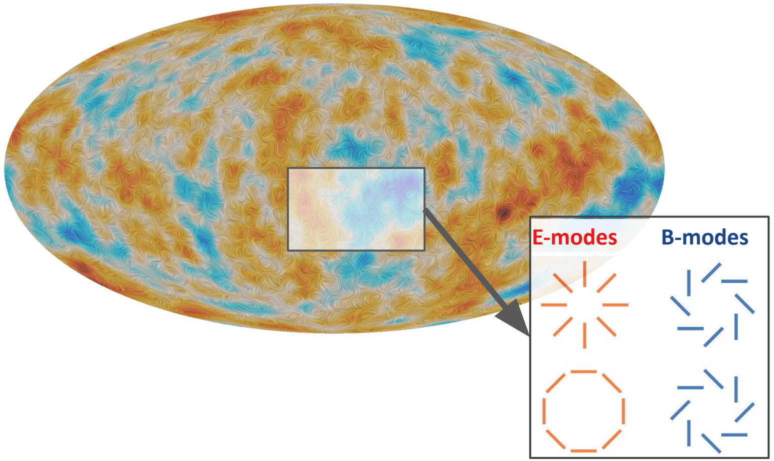
# Outline

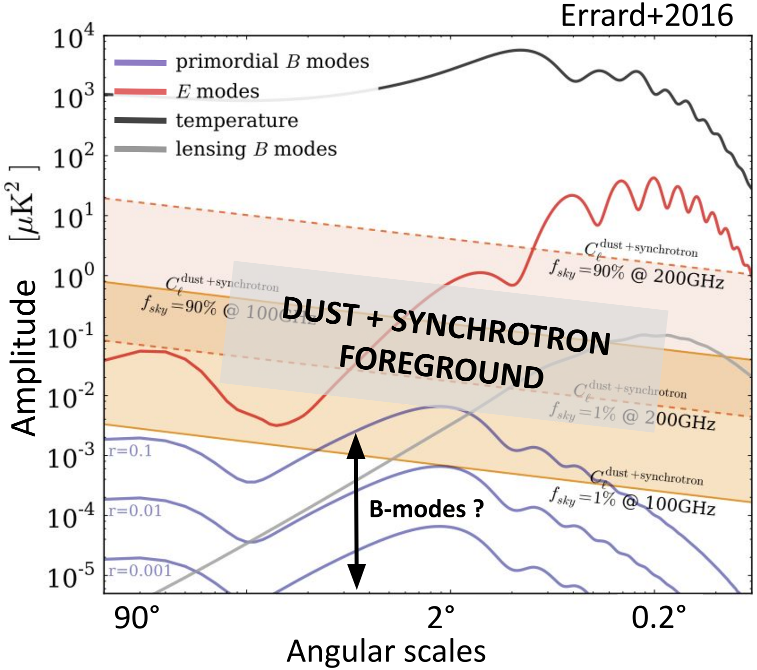
- Scientific context
- Constraints on CMB polarization detection accuracy
- **CMB dust foreground**
  - **A power spectra analysis by using a recent release of Planck HFI data**

# **C**osmic **M**icrowave **B**ackground polarization

## provides a unique insight on the primordial Universe

Credits: ESA and Planck collaboration




**Sensitivity target**
**r parameter ~$10^{-3}$**

LiteBIRD (space)
CMB-S4 (ground)
and others

# **CMB** *B*-modes detection as probe of the inflation

## Technical
## Challenges

★ High sensitivity
(LiteBIRD satellite, CMB-S4 *under development*)

★ Systematic effects control
Half-Wave-Plate devices
( *NIKA2 exemple* ***Ritacco+2017*** *A&A ; Pisano G.,* ***Ritacco A.+2022*** *A&A*)

★ Precise absolute calibration of the polarization angle
**Tau A as primary sky calibrator**
***Ritacco****+Macías-Pérez+Ponthieu et al. A&A, 616, A35* ***2018***
*Aumont+Macías-Pérez+****Ritacco*** *et al. A&A 634, A100* ***2020***

★ **Foreground emission subtraction**

# **CMB** *B*-modes detection as probe of the inflation

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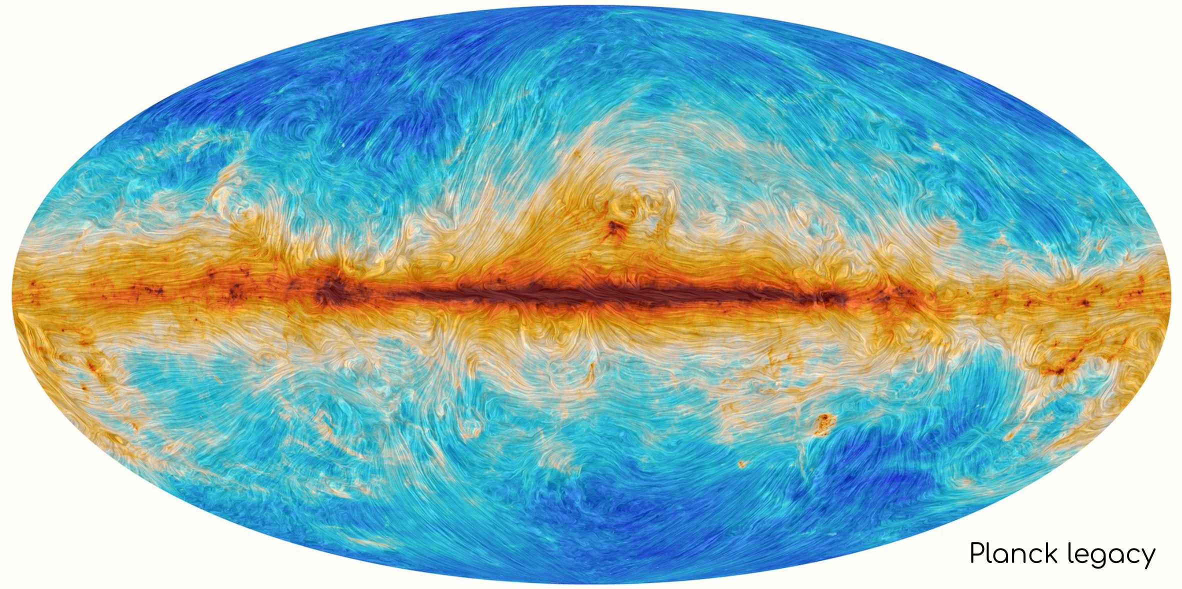
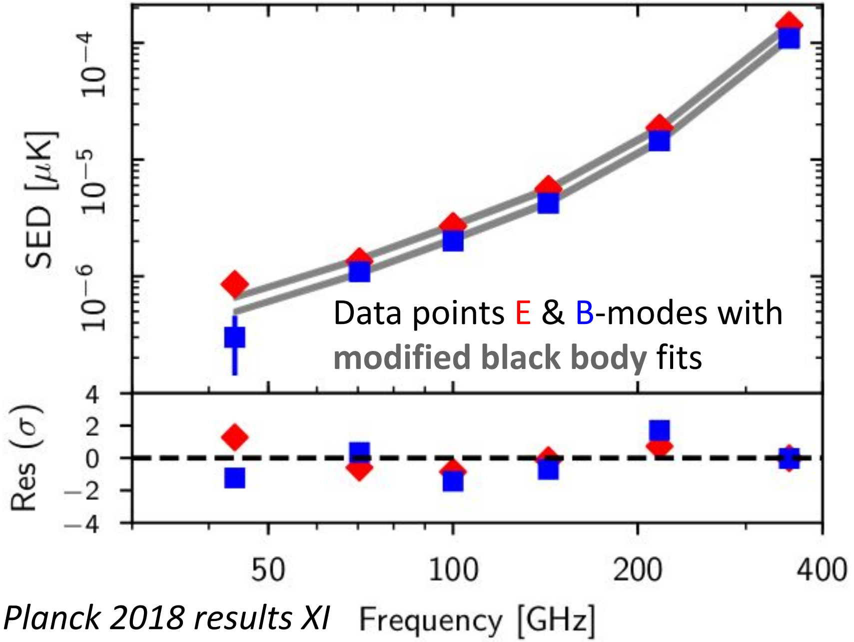
★ **Foreground emission subtraction**

# Polarized **dust** emission




To subtract the sky dust **polarization** we need to have a full-sky modelling
→ So we need to understand how dust polarization behaves

# Dust **mean** Spectral Energy Distribution determined for multipoles $\ell > 40$




*Planck 2018 results XI*

The dust SED in polarization from Planck 2018 results is remarkably well fit by a **single temperature modified black-body emission law** from 353 GHz to 44 GHz.

This brought a significant advance in constraining dust models in astrophysics & for CMB foreground dust component separation methods.

But **low multipoles remain unexplored** because of SNR limitation in polarization data so far

# Dust polarization low-ℓ SED spatial variation

**Ritacco A.**, Boulanger F., Guillet V. et al 2022
*To be submitted shortly to A&A*

# Planck HFI maps

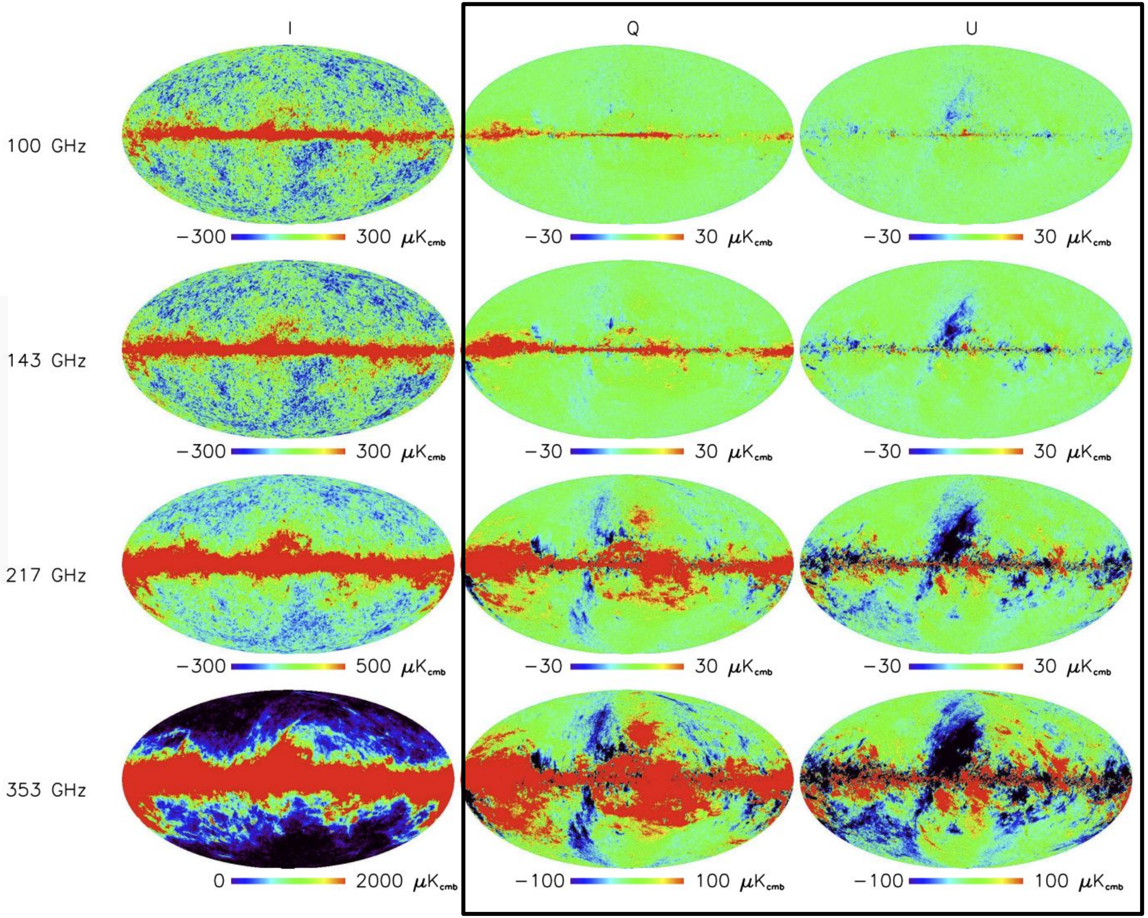
## SRoll2 release

http://sroll20.ias.u-psud.fr/sroll20_data.html

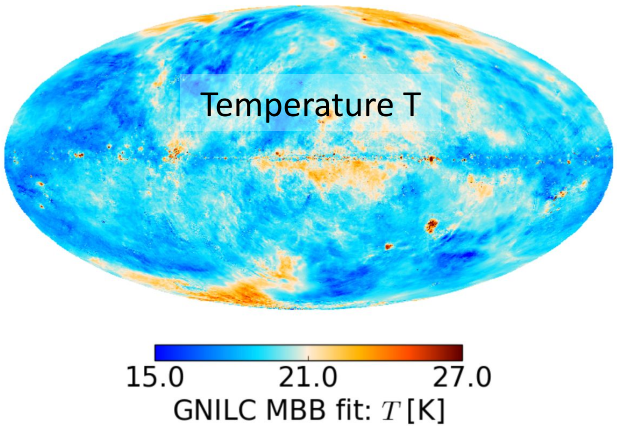
**Improved polarization maps w.r.t PR3**

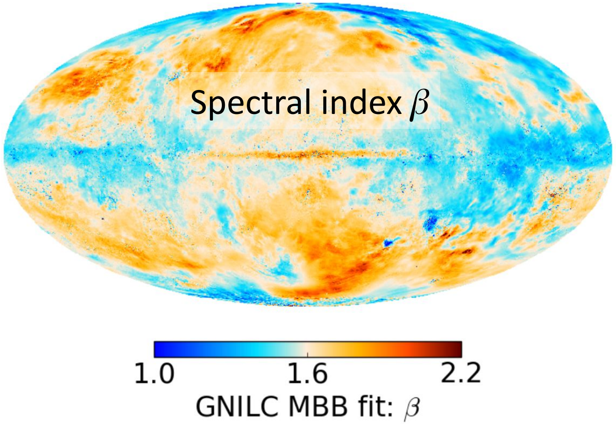
Check out *Delouis et al. A&A 629, A38 (2019)* for technical details

**Polarization maps used**



# A **synthetic model** based on total intensity spatial SED variations




**Modified Black Body function**

$$I_d(\nu) = \tau_{353} \times B(T,\nu) \times \left(\frac{\nu}{353\ \mathrm{GHz}}\right)^{\beta}$$

$\nu_0$

**Extrapolation to polarization**

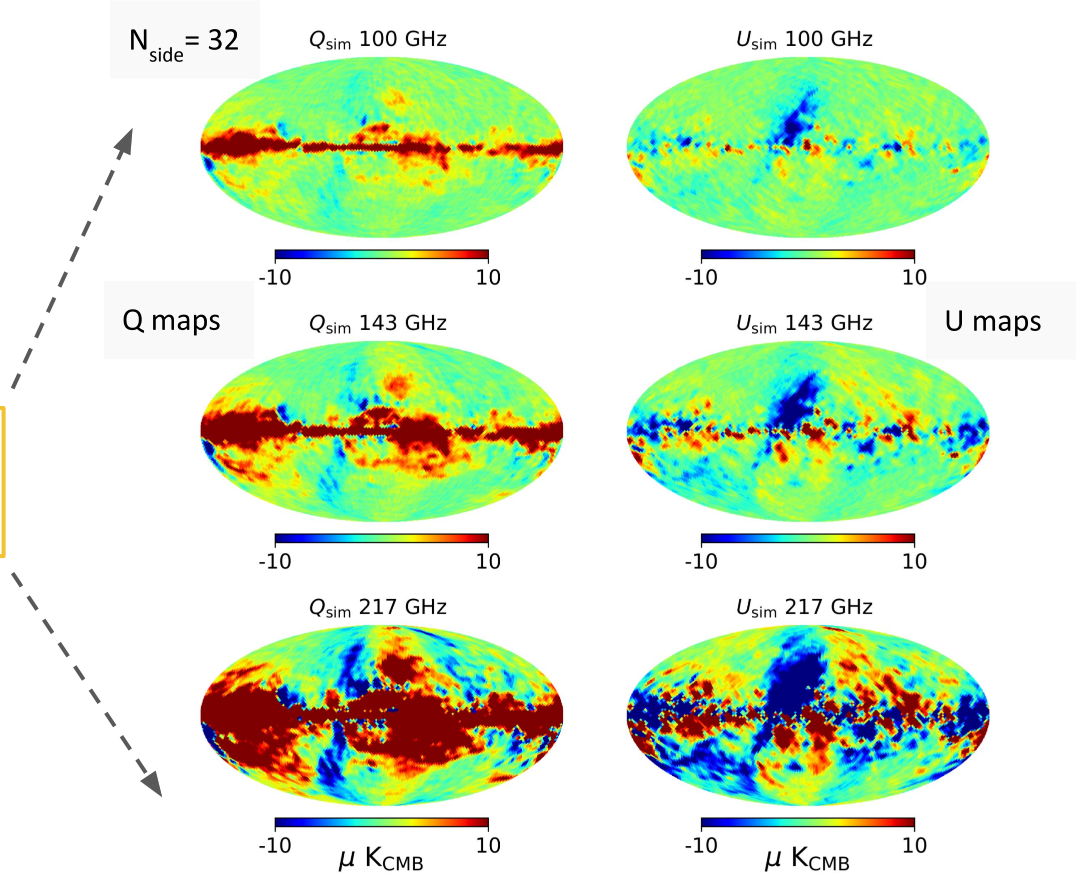
$$Q_{\rm model}(\nu) = \frac{\mathrm{I_d}(\nu)}{\mathrm{I_d}(\nu_0)} \cdot Q_{\rm Planck}(\nu_0)$$

$$U_{\rm model}(\nu) = \frac{\mathrm{I_d}(\nu)}{\mathrm{I_d}(\nu_0)} \cdot U_{\rm Planck}(\nu_0)$$

# A **synthetic model** based on total intensity spatial SED variations

**Including instrumental systematics + noise and CMB**

$$
\begin{aligned}
Q_{\rm sim}(\nu) &= Q_{\rm model}(\nu) + Q_{\rm noise}(\nu) + Q_{\rm CMB} \\
U_{\rm sim}(\nu) &= U_{\rm model}(\nu) + U_{\rm noise}(\nu) + U_{\rm CMB},
\end{aligned}
$$




Two total intensity model considered:

- *Commander* *(Planck Collaboration et al. 2016a)*
- *GNILC* *(Remazeilles+2011)*

# Dust **polarized mean** SED for low multipoles $\ell_{min}, \ell_{max}$=[4,32]

**SED computed** for **100, 143, 217** GHz w.r.t $\nu_0$= 353 GHz

**CROSS POWER SPECTRA ANALYSIS**

$$\gamma_{\rm P}^{XX}(\nu) = \rho \left\langle \frac{{\rm D}(\nu) \times {\rm D}(\nu_0)}{{\rm D}(\nu_0) \times {\rm D}(\nu_0)} \right\rangle_{\ell_{\rm min}, \ell_{\rm max}}$$

**SED**

**Polarization efficiency**

*Planck Coll. et al.* *2020b*

**SPECTRA**

***XX*=EE, BB**

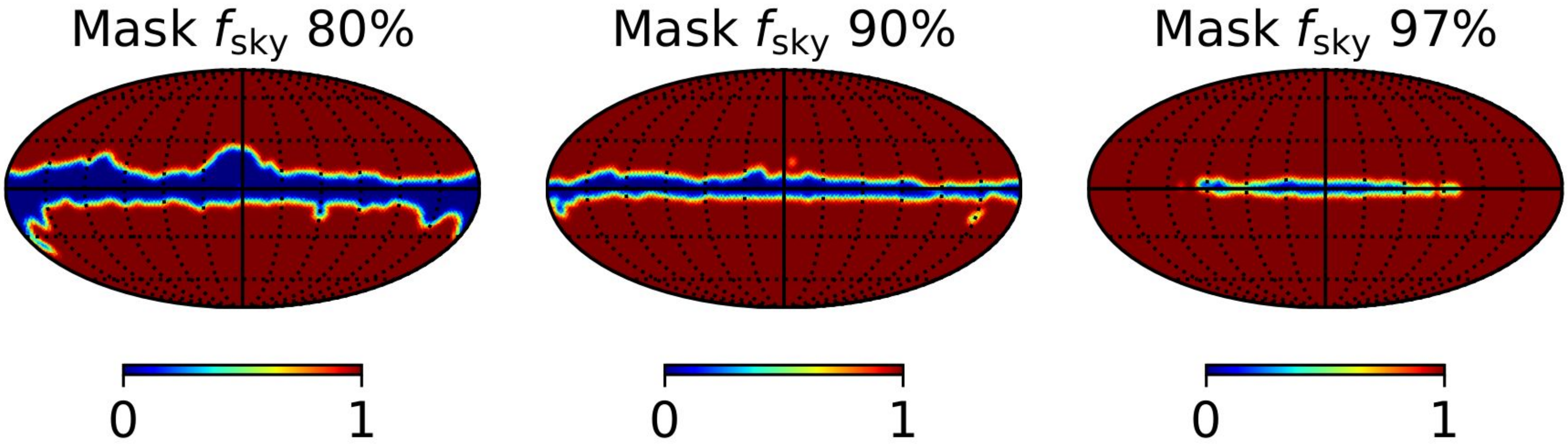
**D($\nu$)** is either:

- ***Planck SRoll2* polarization Q,U maps** corrected for synchrotron (100, 143 GHz)

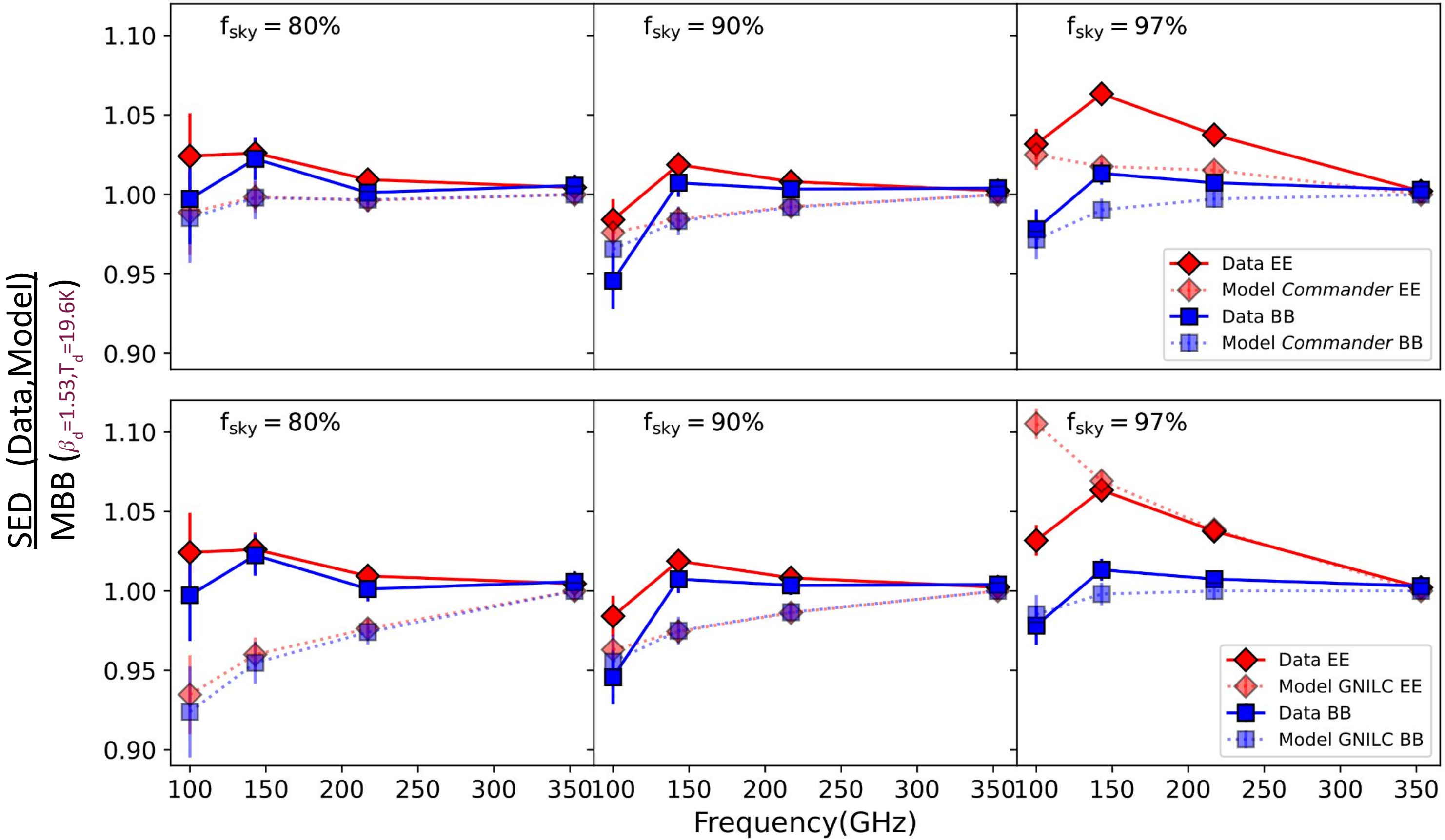
or

- ***Commander,* GNILC Q,U model maps**

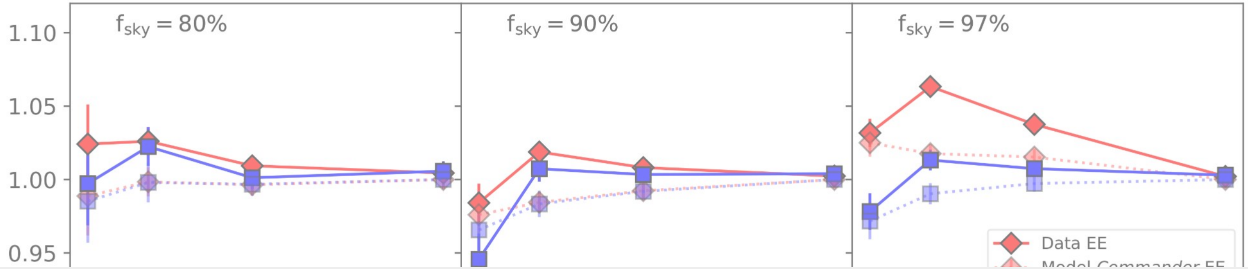
# Galactic masks used for the power spectra data analysis



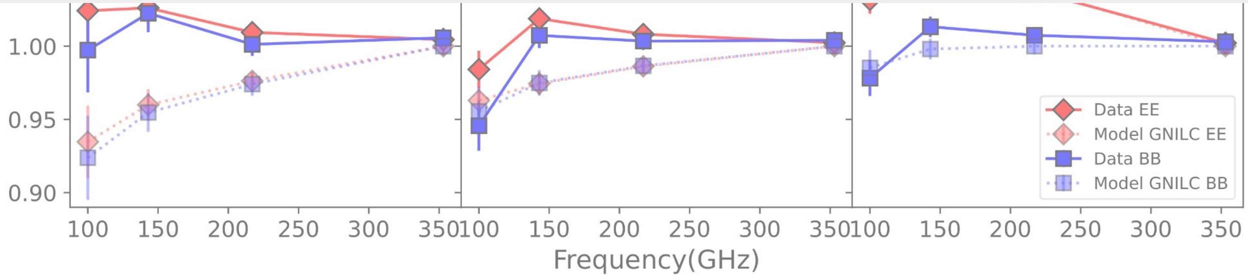
# Dust **polarized mean** SED for low multipoles $\ell_{min,}\ell_{max}$=[4,32]



# Dust **polarized mean** SED for low multipoles $\ell_{min,} \ell_{max}$=[4,32]




- **Mean polarization SED** confirmed **remarkably close** to total intensity (*confirming previous results*)
- Also consistent within 5% with a **M**odified **B**lack **B**ody function with $T_d$=19.6 K and $\beta_d$=1.53
- However, models based on total intensity cannot **completely** reproduce the signal observed in polarization



# Spatial SED variation of the dust polarization

## Residual maps

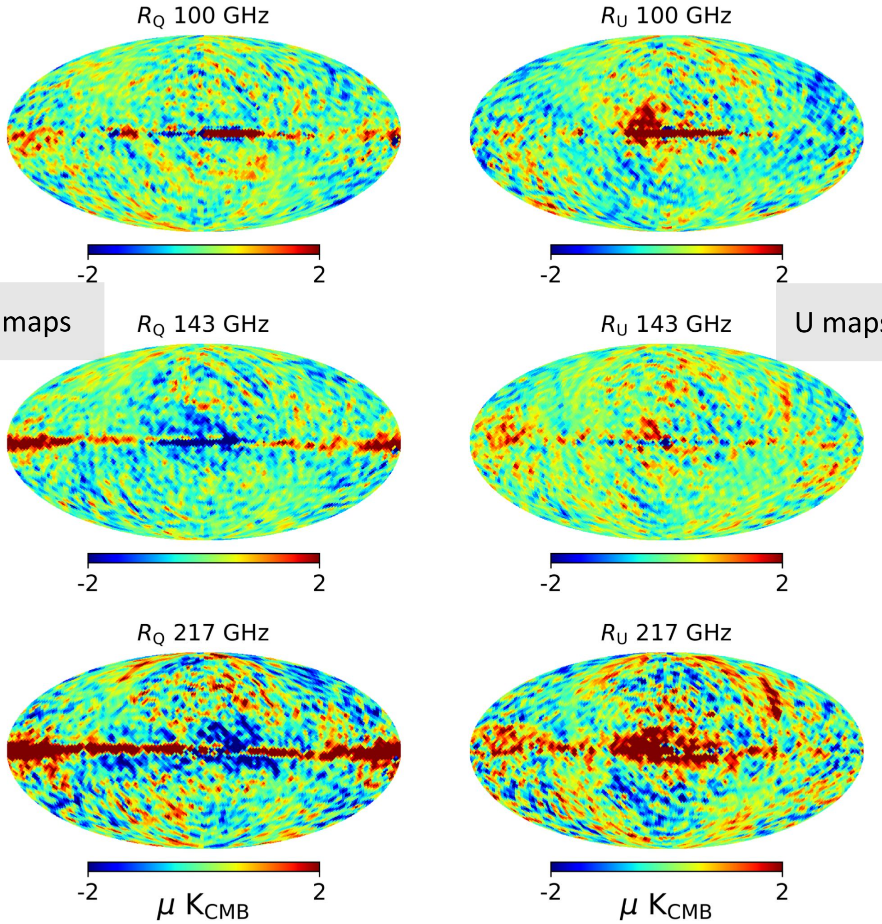
$$R_Q(\nu) = Q_{\mathrm{d}}(\nu) - \gamma_{\mathrm{P}}(\nu) \cdot Q_{\mathrm{Planck}}(\nu_0)$$
$$R_U(\nu) = U_{\mathrm{d}}(\nu) - \gamma_{\mathrm{P}}(\nu) \cdot U_{\mathrm{Planck}}(\nu_0).$$

**Mean SED**

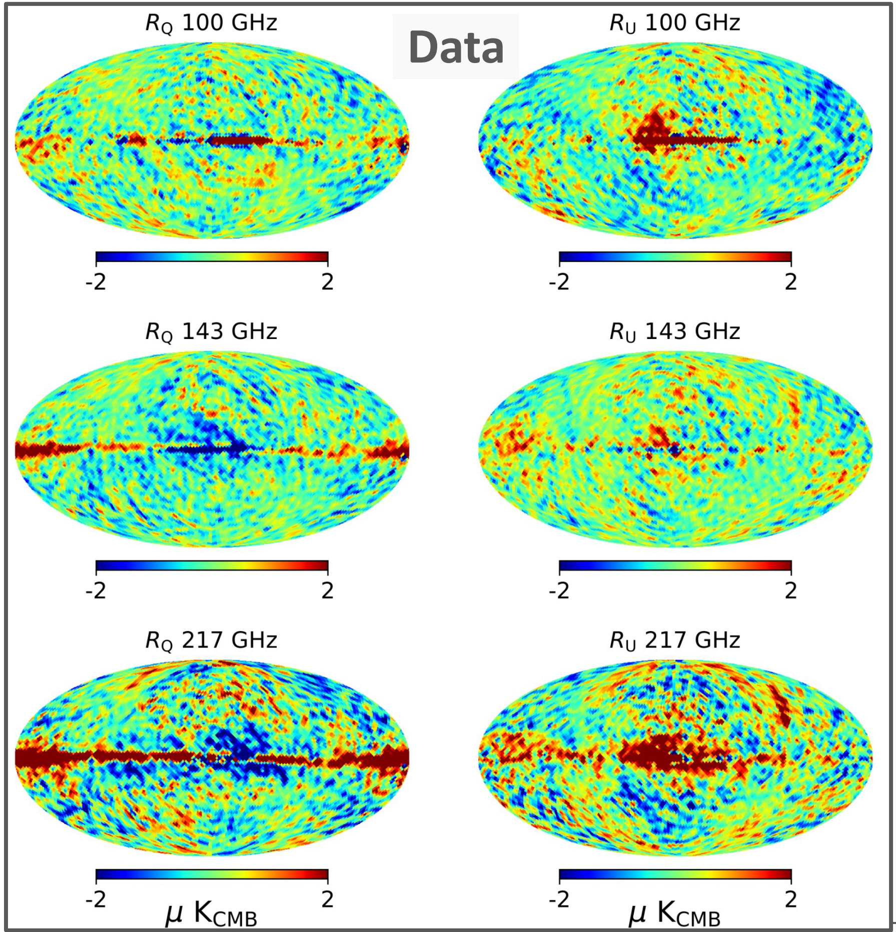
Corrected for synchrotron at 100,143 GHz

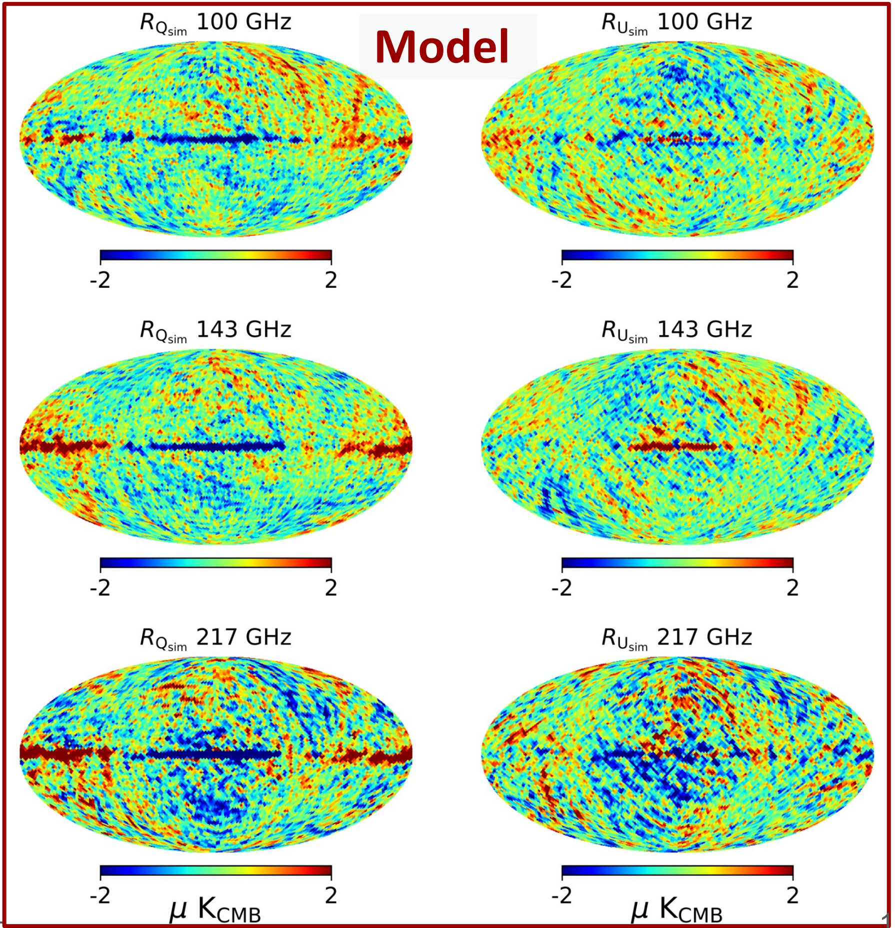
Q maps

U maps

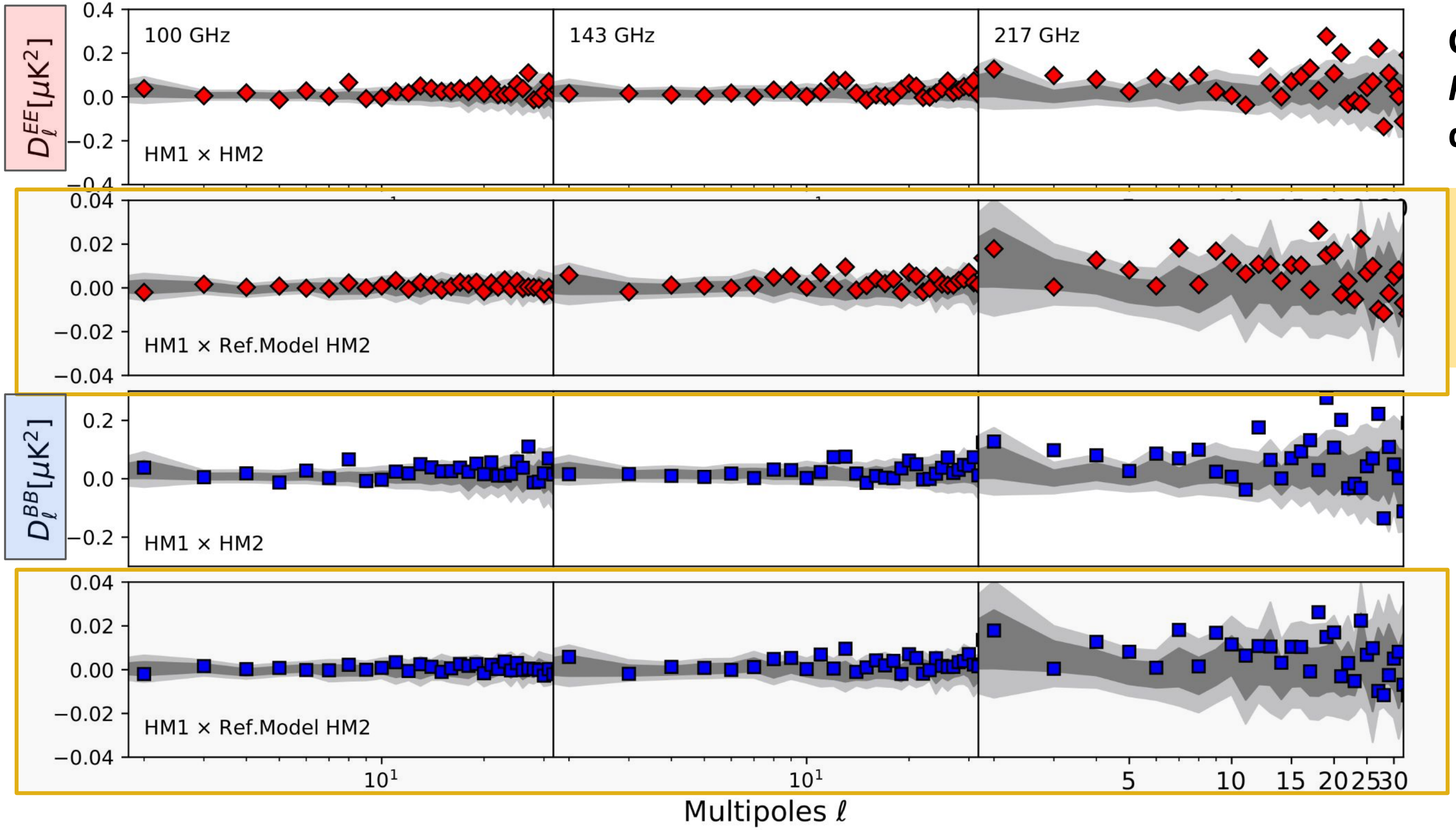


# Residual polarization maps



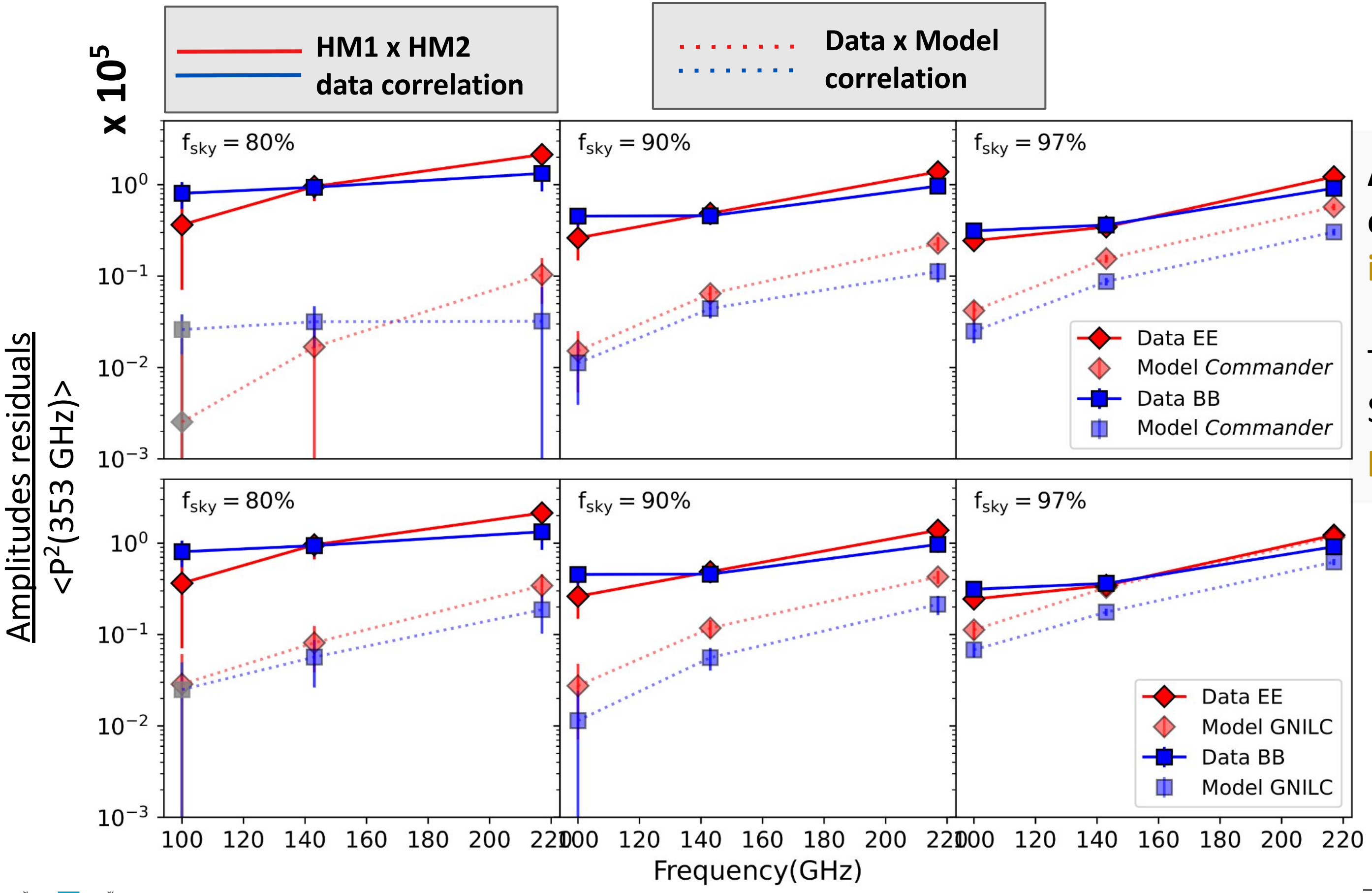
# Cross power spectra analysis of residual maps




**Correlation between *Planck half-mission* data sets**

**Correlation between data and the *Commander* model**

# Averaged cross-correlation between multipoles ℓ=[4,32]

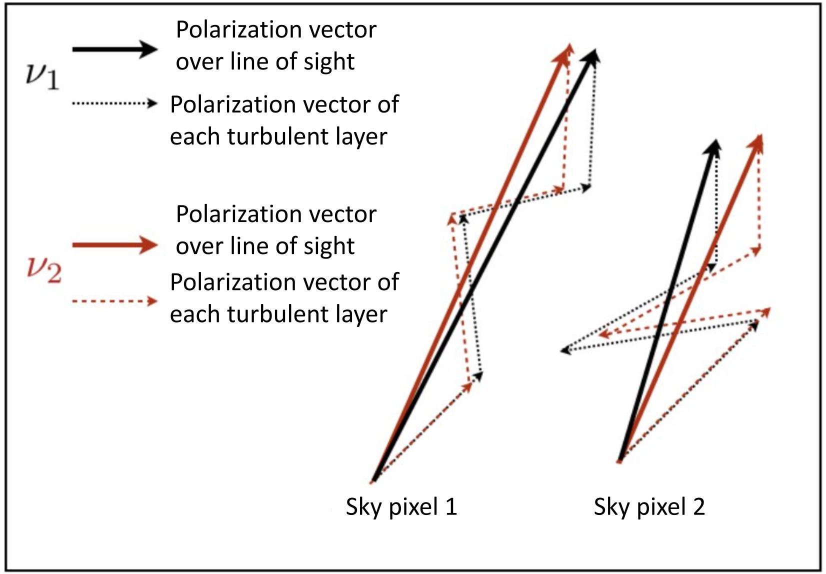



**At high latitudes→less $f_{sky}$ correlation with total intensity models is lost**

They **cannot reproduce** spatial SED variations detected in **polarization data**

# Contribution from **polarization angles**

*Planck* intermediate results L. 2017




Decomposition of the LOS complex **polarization vector** into a random walk process through different turbulent layers for two pixels at two frequencies, $\mathbf{v_1}$ and $\mathbf{v_2}$.

→ **Decorrelation of the polarization pattern from 350 GHz to 100 GHz maps**

# Isolating polarization angle variation effect

We build **synthetic Stokes Q and U** parameters which depend on the polarization angle

**SED**

**Synthetic maps Q & U**

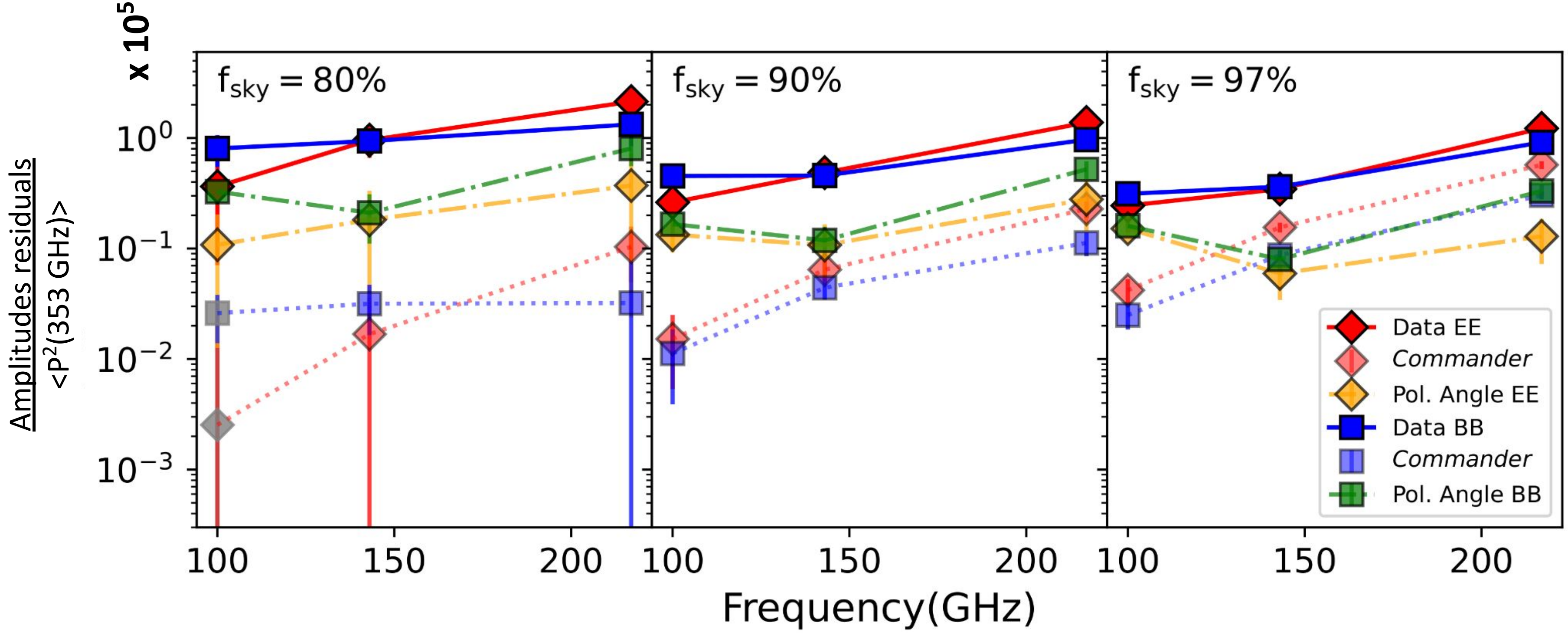
$$\tilde{Q}(\nu) = \gamma_P(\nu) \cdot P(\nu_0) \times \cos 2\psi(\nu)$$
$$\tilde{U}(\nu) = \gamma_P(\nu) \cdot P(\nu_0) \times \sin 2\psi(\nu)$$

polarization angle maps:
$\psi_\nu$ = 0.5 x atan(U/Q)

**Residual maps**

$$R_{\tilde{Q}}(\nu) = \tilde{Q}(\nu) - \gamma_P(\nu) \cdot \tilde{Q}(\nu_0)$$
$$R_{\tilde{U}}(\nu) = \tilde{U}(\nu) - \gamma_P(\nu) \cdot \tilde{U}(\nu_0)$$

# Isolating polarization angle variation effect




Amplitudes of cross spectra residuals
due to polarization angle effect

# Conclusions

## Power spectra to characterise spatial variations of polarized dust SED for $\ell$=[4,32]

– **Mean polarization SED** confirmed **remarkably close** to total intensity and a MBB with T=19.6K and $\beta$=1.53.

– **Residual maps** at **100, 143 and 217 GHz quantifies spatial variations** of the **dust polarization**.

– Residual maps correlated with ***Commander* and GNILC ref. models** account for a **fraction** of the **total polarization SED variation.**

– We quantify **variations in the polarization angle**.
**Dominant effect with decreasing $f_{sky}$, towards high Galactic latitudes.**

*Ritacco, Boulanger, Guillet, Delouis, Puget, Aumont A&A 2022 (shortly submitted)*

**New requirements for CMB dust polarized foreground modelling**