Component separation for CMB polarization in the light of the polarized dust angular power spectra measured by Planck-HFI

planck

The Planck collaboration

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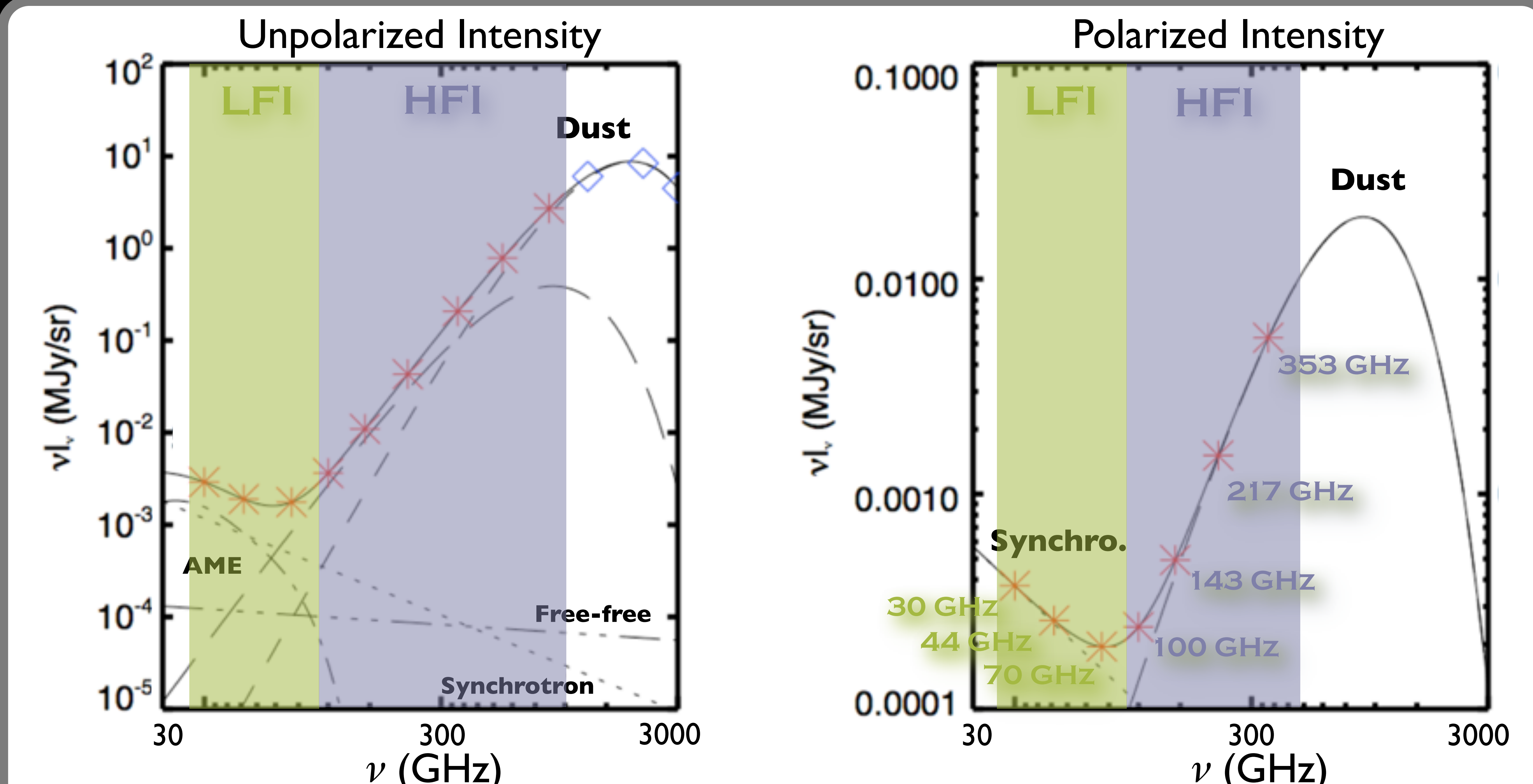
Outline

➡ COMPONENTS OF THE POLARIZED MICROWAVE SKY

II. THE ANGULAR POWER SPECTRA OF THE DUST INTENSITY AND POLARIZATION AS MEASURED BY PLANCK-HFI
   - ★ Are the angular power spectra consistent at low and high Galactic latitudes?
   - ★ What is the shape of the dust polarized angular power spectra?
   - ★ Are the angular power spectra consistent between Planck-HFI frequencies?
   - ★ What is the frequency dependence of the dust polarization?

III. SUMMARY AND CONCLUSIONS

Components of the polarized microwave sky



[Miville-Deschênes 2009]
[PSM, Delabrouille et al. 2012]

- ★The polarized microwave sky is presumably less complex than the intensity one
- ★CMB measurements are mostly contaminated by synchrotron and dust polarization
- ★Precise pre-Planck measurements of the sky of the dust polarization emission on large fractions are lacking
- ★Polarized synchrotron emission should be very weak in HFI channels

pre-Planck properties of the polarized components

	Polarization fraction	Spectral distribution	Spatial distribution	Statistical distribution
CMB	<10%	Black-body, known to instrumental uncertainties	Described by cosmology	Gaussian
Synchrotron	up to 75%	Power-law with β~-3.0, may vary smoothly on the sky	proportional to ℓ^{-3}?	Highly non-Gaussian
Dust	~5% but up to 15-20% in specific regions	Modified blackbody with T~17K and β~1.8, local change of temperature and β, might be different from intensity	proportional to ℓ^{-3}?	Highly non-Gaussian
Radio sources	Very variable, can be time dependent	Very variable, can be time dependent	-	Poisson

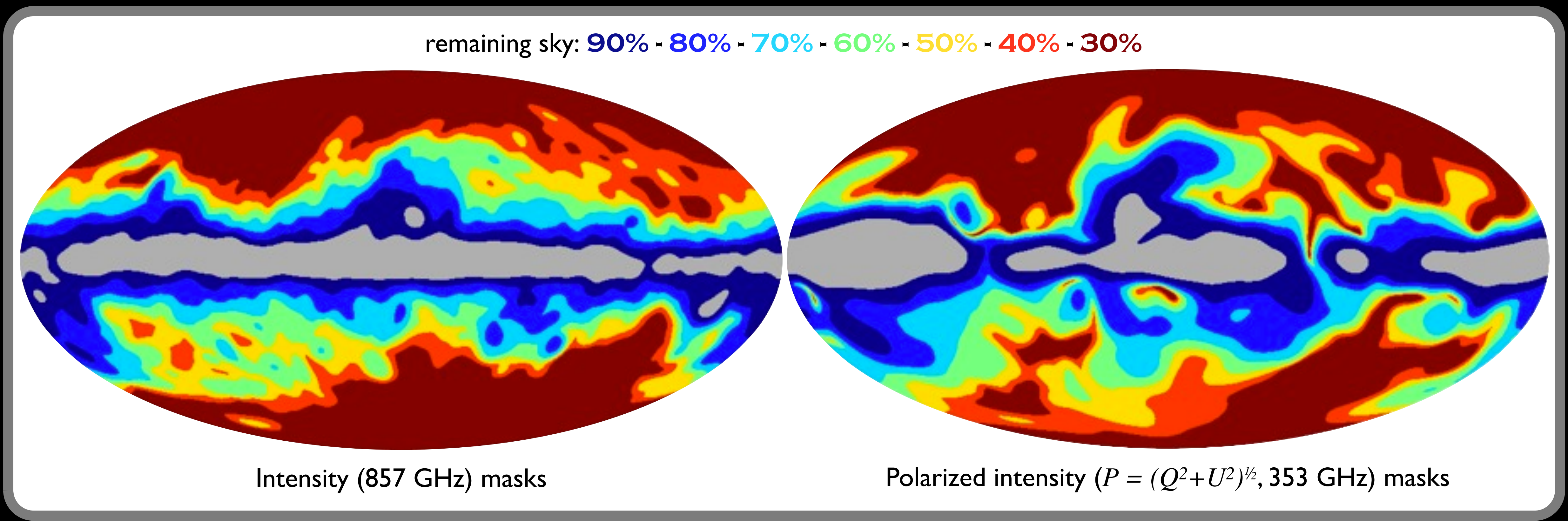
Computation of the power spectra of dust

Data

- ★ Use of the Planck Sub-millimeter Dust Model at HFI polarized frequencies (100, 143, 217 and 353 GHz) for intensity (I maps) [Planck Collaboration, Planck 2013 results, Explanatory supplement]
- ★ Use of the HFI DX9 data for polarization (Q and U maps)

Method

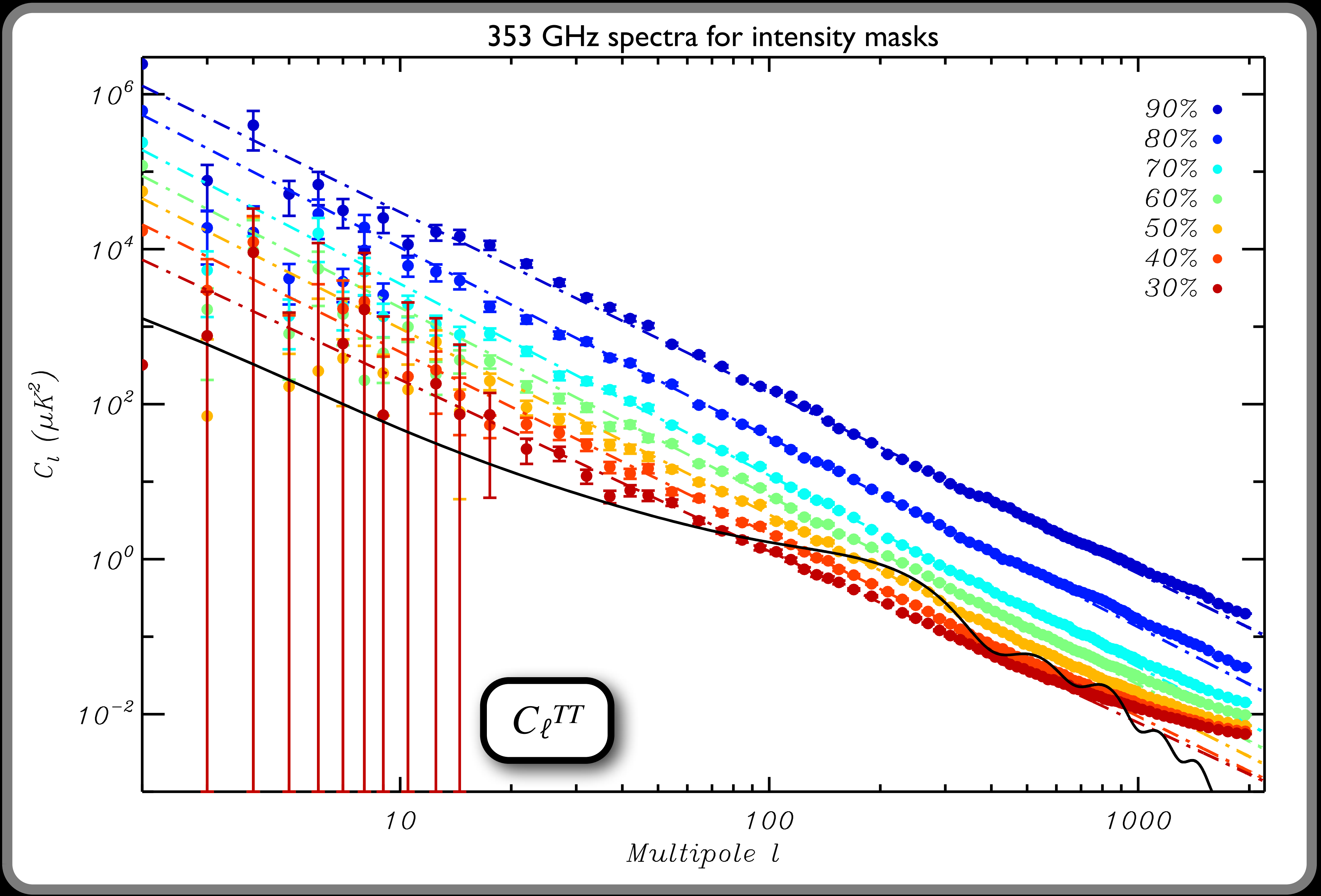
- ★ Computation of the polarized angular power spectra (C_ℓ^{TT}, C_ℓ^{TE}, C_ℓ^{EE}, C_ℓ^{BB}, C_ℓ^{TB} and C_ℓ^{EB})
  - ★ Using XPOL (extension to polarization of XSPECT [Tristram et al. 2005, MNRAS, 358, 833]), pseudo-C_ℓ estimator that corrects for incomplete sky coverage and beam
  - ★ Cross-spectra between detector-sets maps to avoid bias due to correlated noise in auto-spectra.



CMB subtraction and systematics assessment

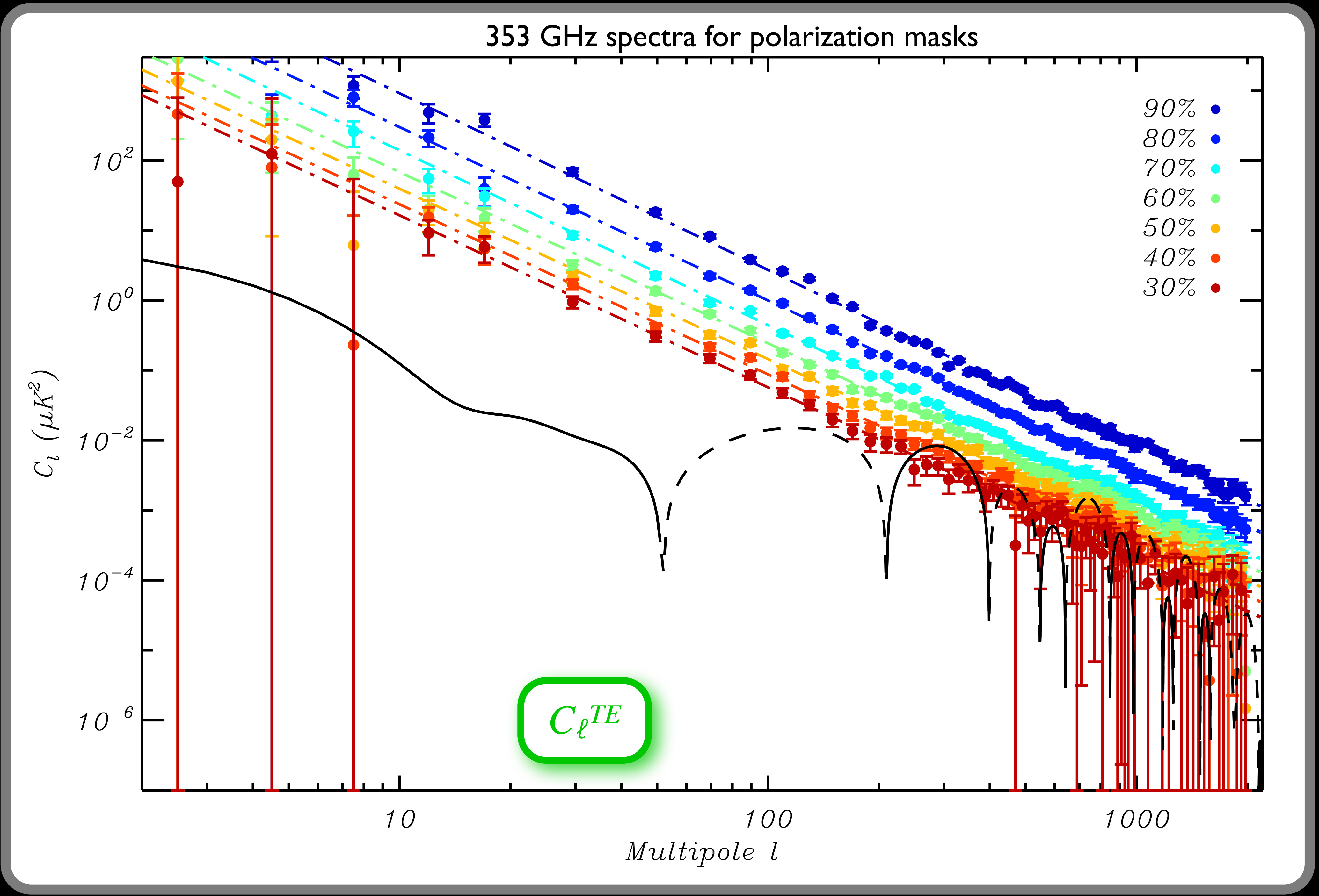
- ★ Subtraction of the CMB component in C_ℓ for TT, EE, BB and TE (but which model is still a secret...)
- ★ Assessment of spectral and calibration mismatch intensity to polarization leakage ([Matthieu Tristram's talk @ ESLAB])

Angular power spectra of the dust at 353 GHz



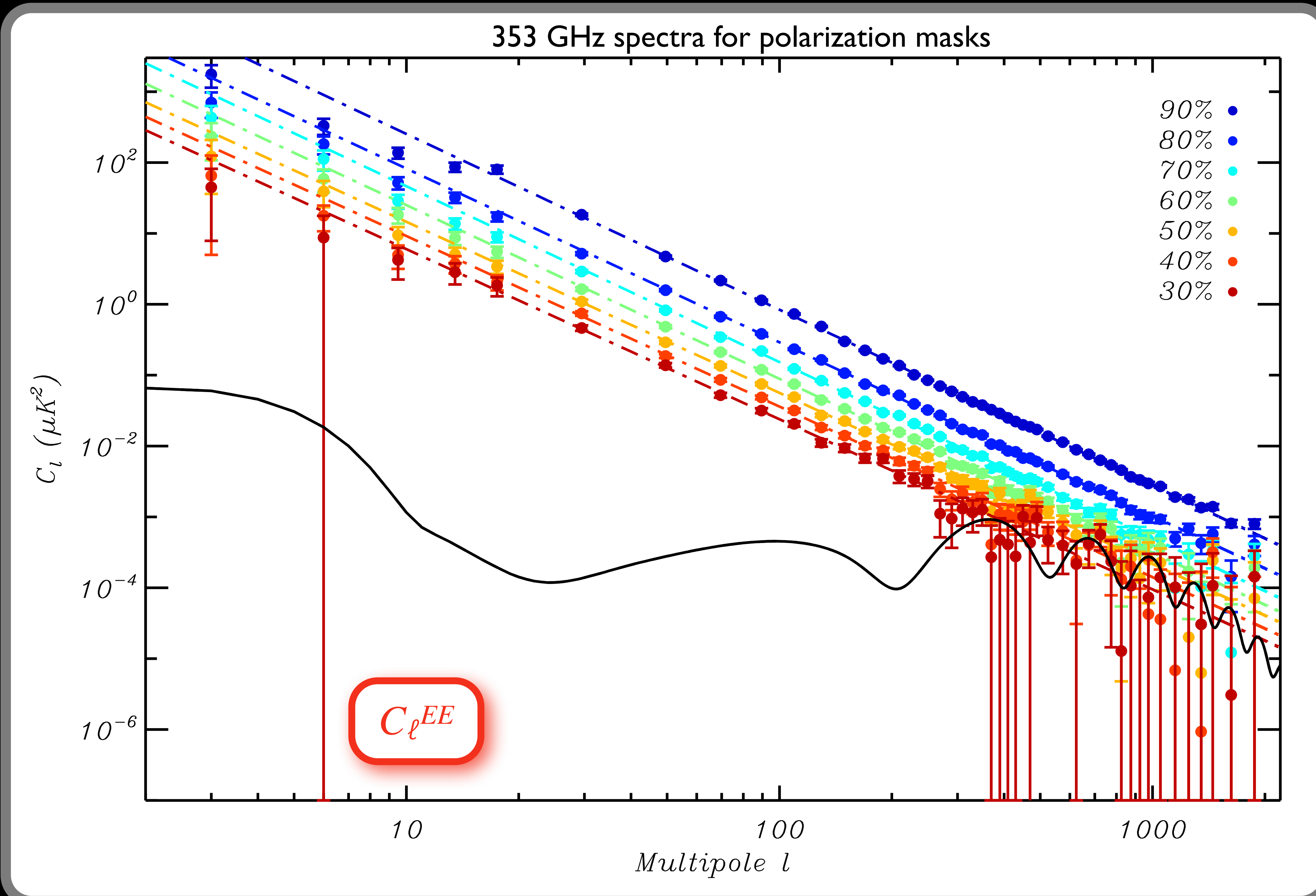
- ⋆Point sources flatten the spectra at high-ℓ
- ⋆High-Galactic latitude masks are dominated by CIB at high-ℓ
- ⋆Apart from that the spectra show a power-law in ℓ behaviour

Angular power spectra of the dust at 353 GHz



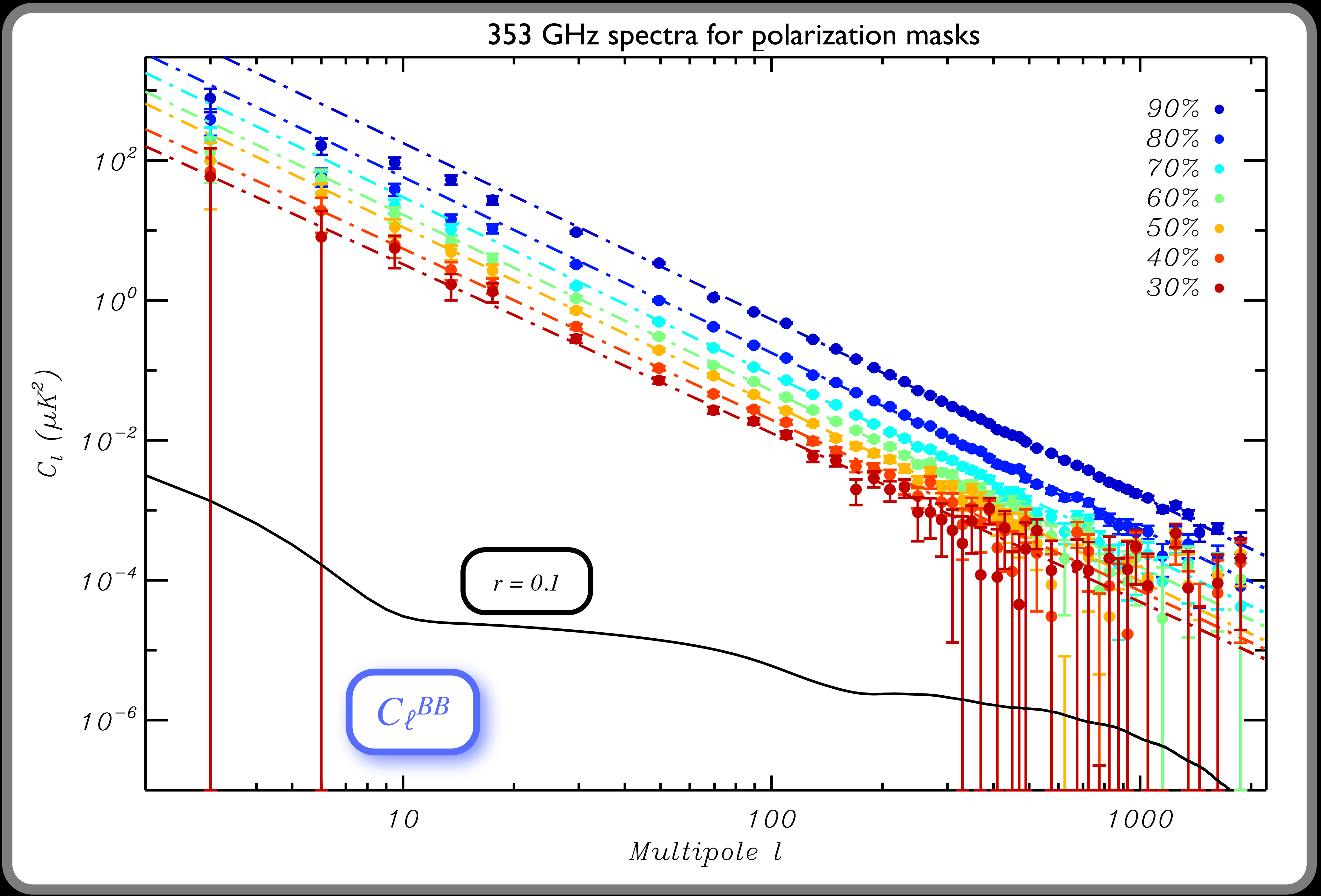
★ Spectra are very parallel and well fitted by a power low in ℓ

Angular power spectra of the dust at 353 GHz



- ★ Spectra are very parallel and well fitted by a power low in ℓ

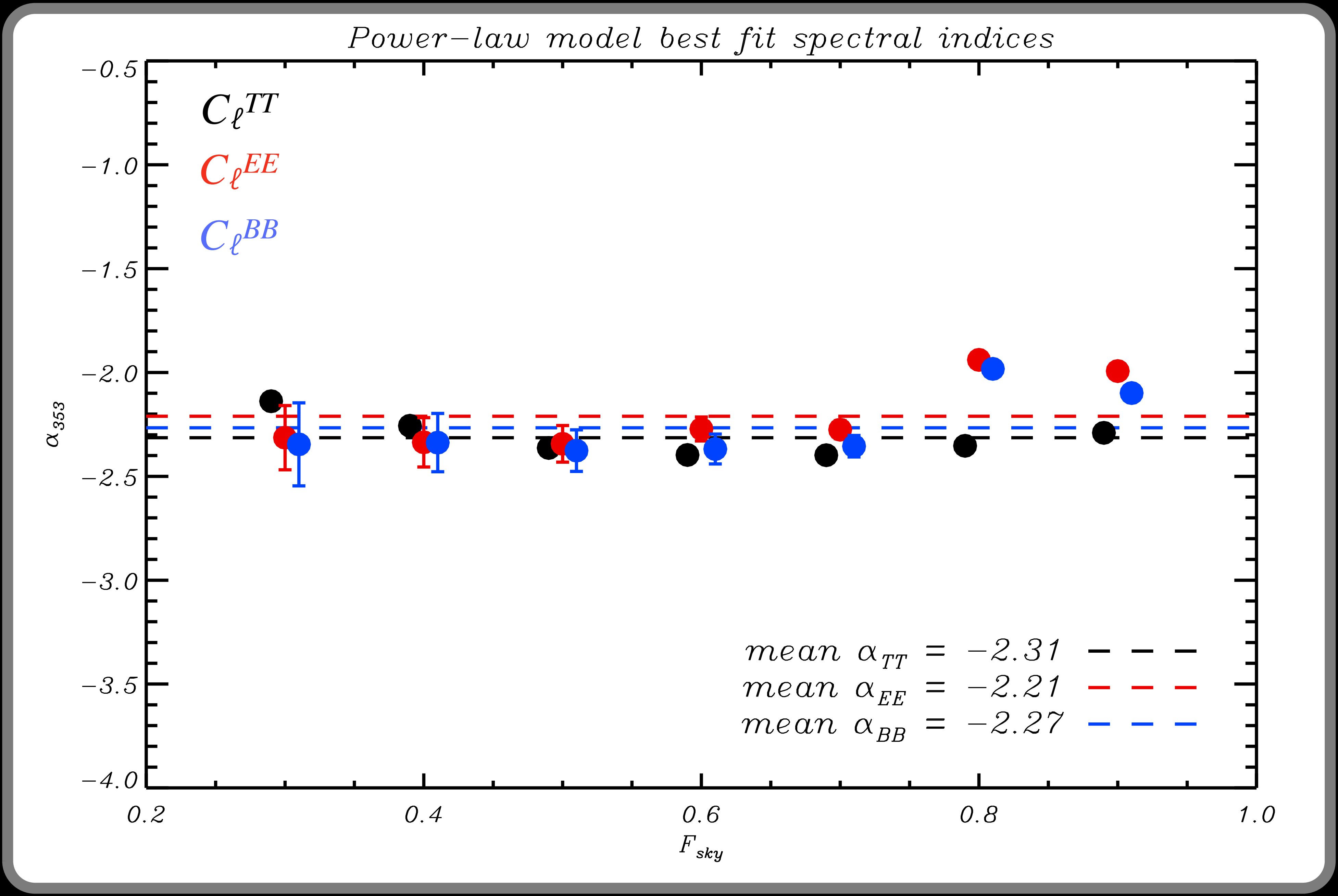
Angular power spectra of the dust at 353 GHz



★Spectra are roughly parallel and well-fitted by a power-law in ℓ

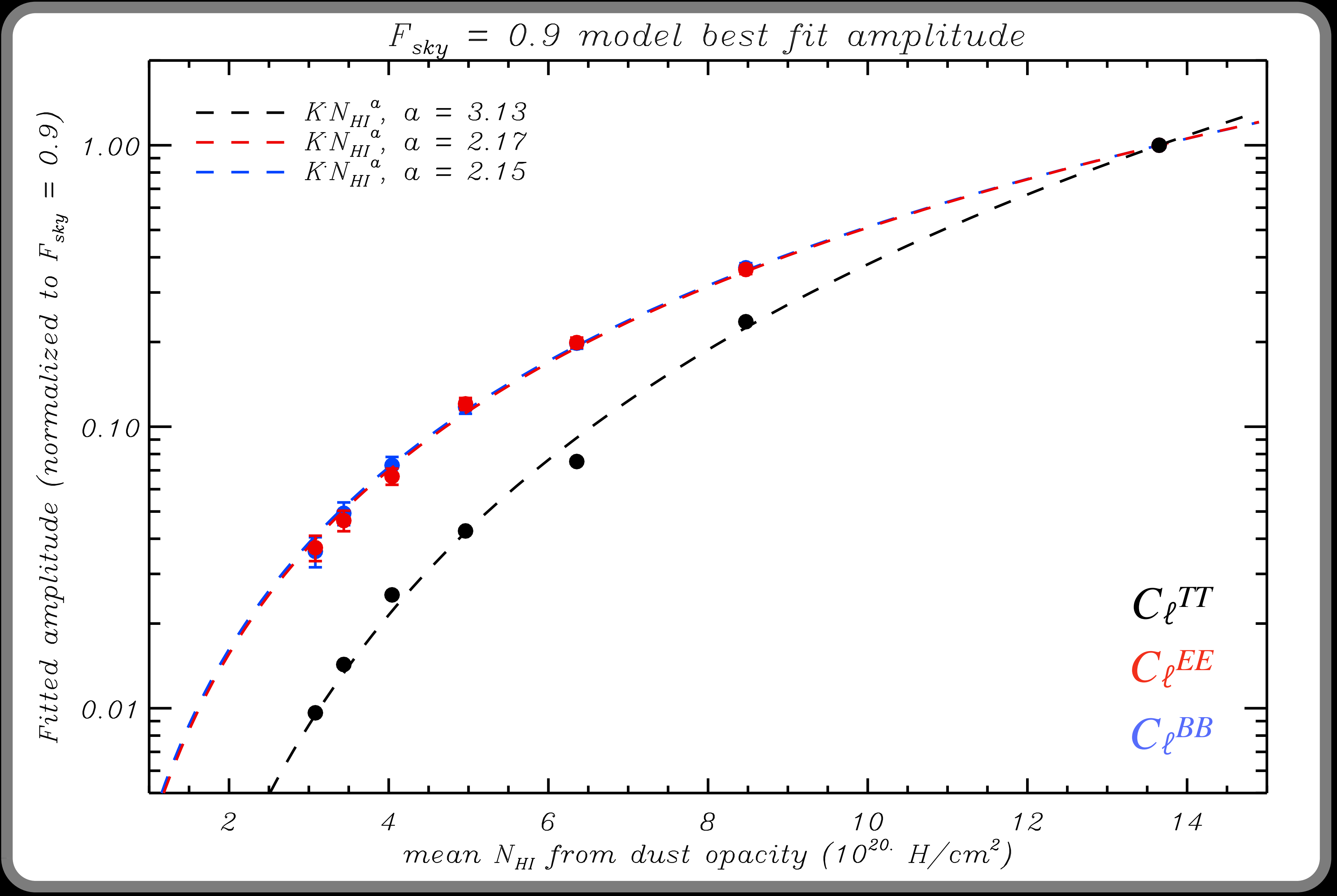
★Dust *BB* spectra are slightly lower than for *EE*

Shape of the polarized C_ℓ of the dust



- ★A power-law model is fitted to the *TT*, *EE* and *BB* spectra for each mask ($C_\ell \equiv A{\cdot}\ell^{-\alpha}$)
- ★Fitted spectral indices are stable from 10 to 90% of the sky
- ★They have similar *EE* and *BB*
- ★*TT* is flatter than expected (not in -2.6) because we do not mask point sources

Proposition for a mask dependence law



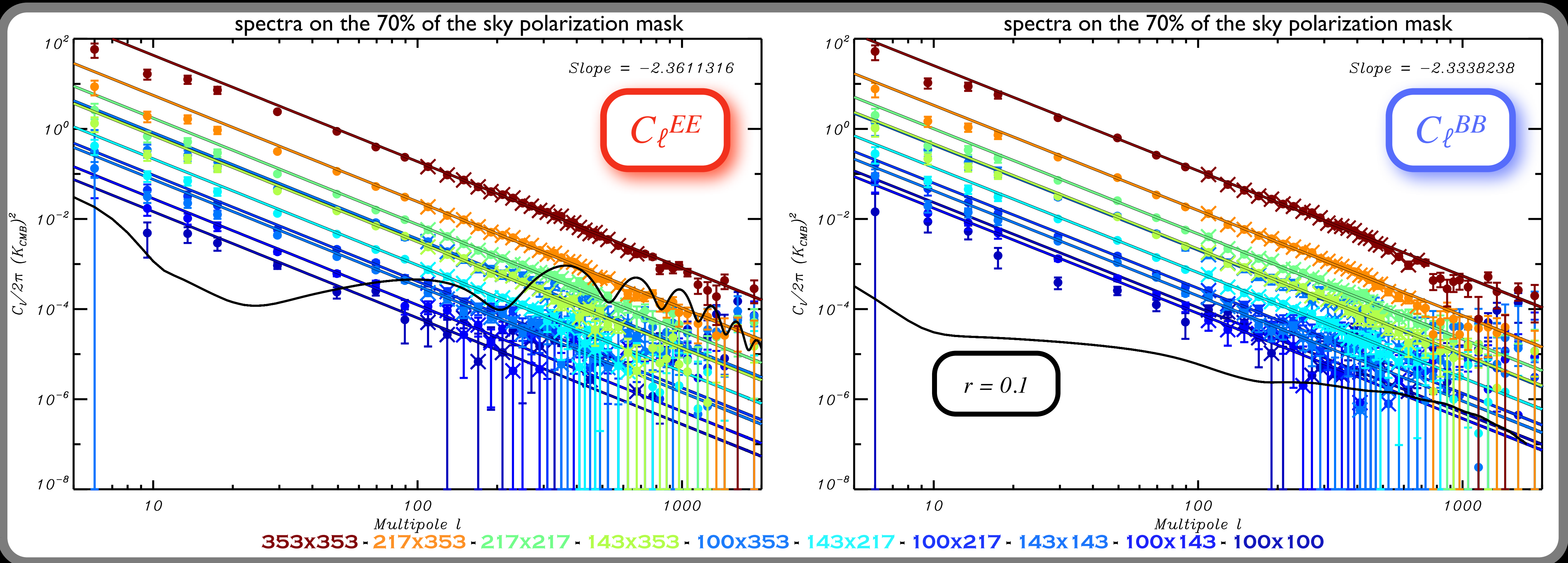
★We fit the amplitudes of the spectra on the intensity and polarization masks with respect to the amplitude of the spectra on 90% of the sky

★We plot the amplitudes as a function of the mean column density of the masks inferred from the opacity of the Planck Sub-millimeter Dust Model [Planck Collab., Planck 2013 results, Explanatory supplement]

★We find that the amplitudes of the spectra follow nicely a power-law of the mean column density

★The dependence law is steeper for intensity than for polarization

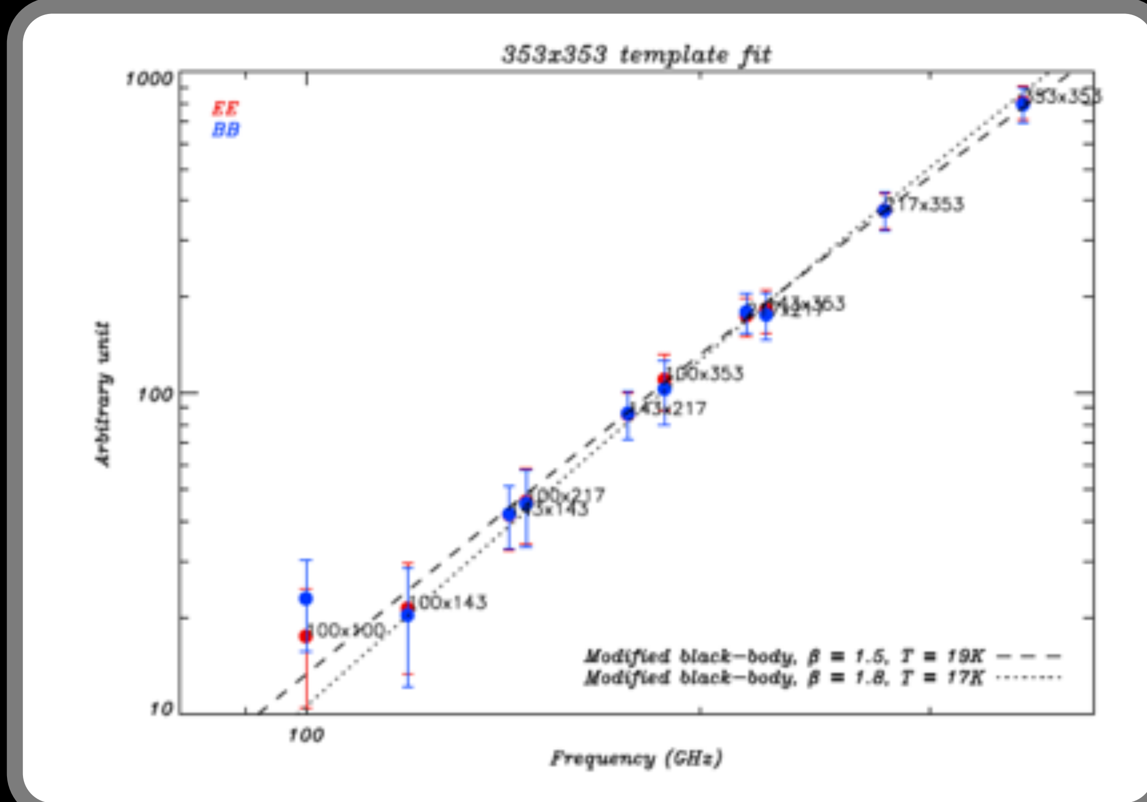
Consistency across HFI frequency bands



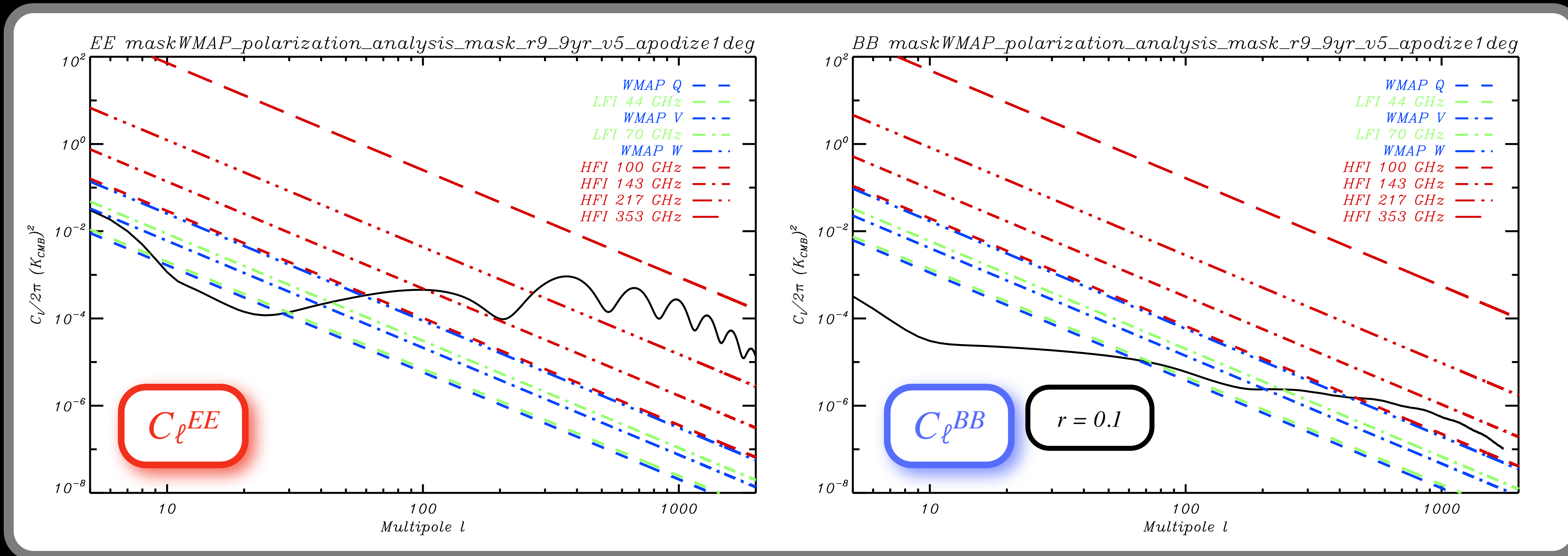
★Spectra among the HFI frequencies are very coherent in *EE* and *BB*

★The SED computed from the effective frequencies are compatible with the other Planck polarization results, i.e. dust polarization is well modeled by a modified blackbody with β = 1.6 and T = 19.6 K

[see Ghosh's poster @ ESLAB, Planck Intermediate Paper 87, to be published]



Prediction for dust contamination on WMAP polarization mask



★The spectra are computed on the WMAP polarization analysis mask

★A power-law in ℓ is fitted at 353 GHz and then extrapolated to WMAP, LFI and HFI frequencies using a modified blackbody SED with β = 1.6 and T = 19.6 K

★We find that dust polarization is a significant contaminant for CMB polarization analysis, even down to the WMAP Q or LFI 44 GHz bands

★On such a mask, low-ℓ *BB* primordial signal for r = 0.1 will need a very accurate dust subtraction, even for the low-frequency experiments

★Planck polarized measurements of the dust emission will be primordial for CMB component separation!

Summary and conclusions

- ★ We measure for the first time the polarized angular power spectra of the dust on the whole sky
  - ★ Are the angular power spectra consistent at low and high Galactic latitudes?
  - ➡ They show very consistent shapes and their amplitude can be expressed as a function of the mean column density of the mask
  - ★ What is the shape of the dust polarized angular power spectra?
  - ➡ Spectra are very well fitted by power-law in ℓ with a spectral index of -2.3 in polarization
  - ★ Are the angular power spectra consistent between Planck-HFI frequencies?
  - ➡ They show very consistent shapes from 353 GHz down to 100 GHz
  - ★ What is the frequency dependence of the dust polarization?
  - ➡ Dust polarization frequency dependence follows accurately a modified blackbody with β = 1.6 and T = 19.6 K

- ★ Planck will be able to give a benchmark of the dust contamination for CMB polarization experiments, for every sky-coverage and every frequency band

- ★ Given the expected levels of dust polarization, dust cleaning has to be very efficient for BB modes analysis, even for the "low-frequency" experiments

- ★ This statistical measurements of the polarized dust properties need now to be confronted to models (dust grain properties, alignment, Galactic magnetic field structure)

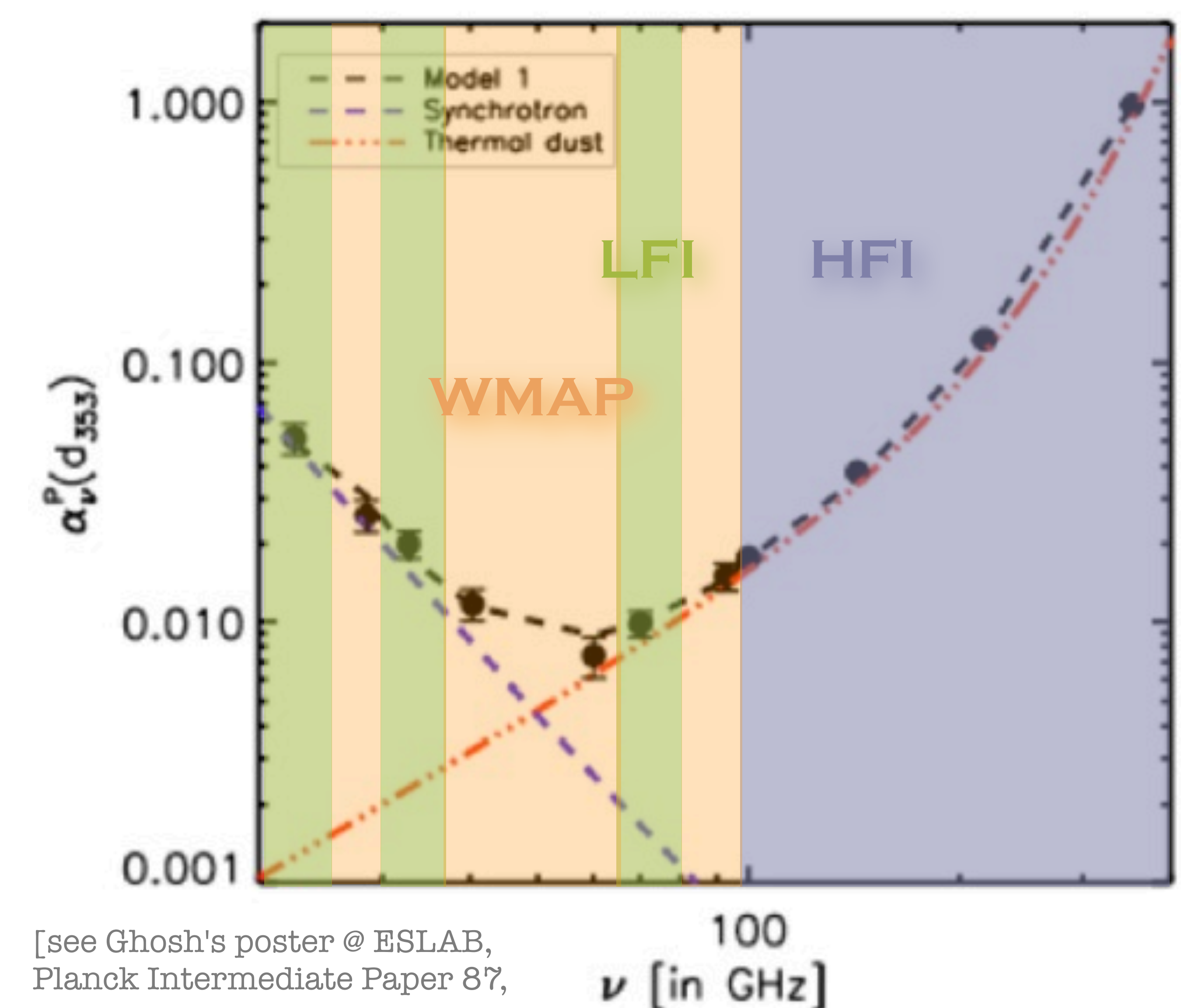
The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

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.

Backups

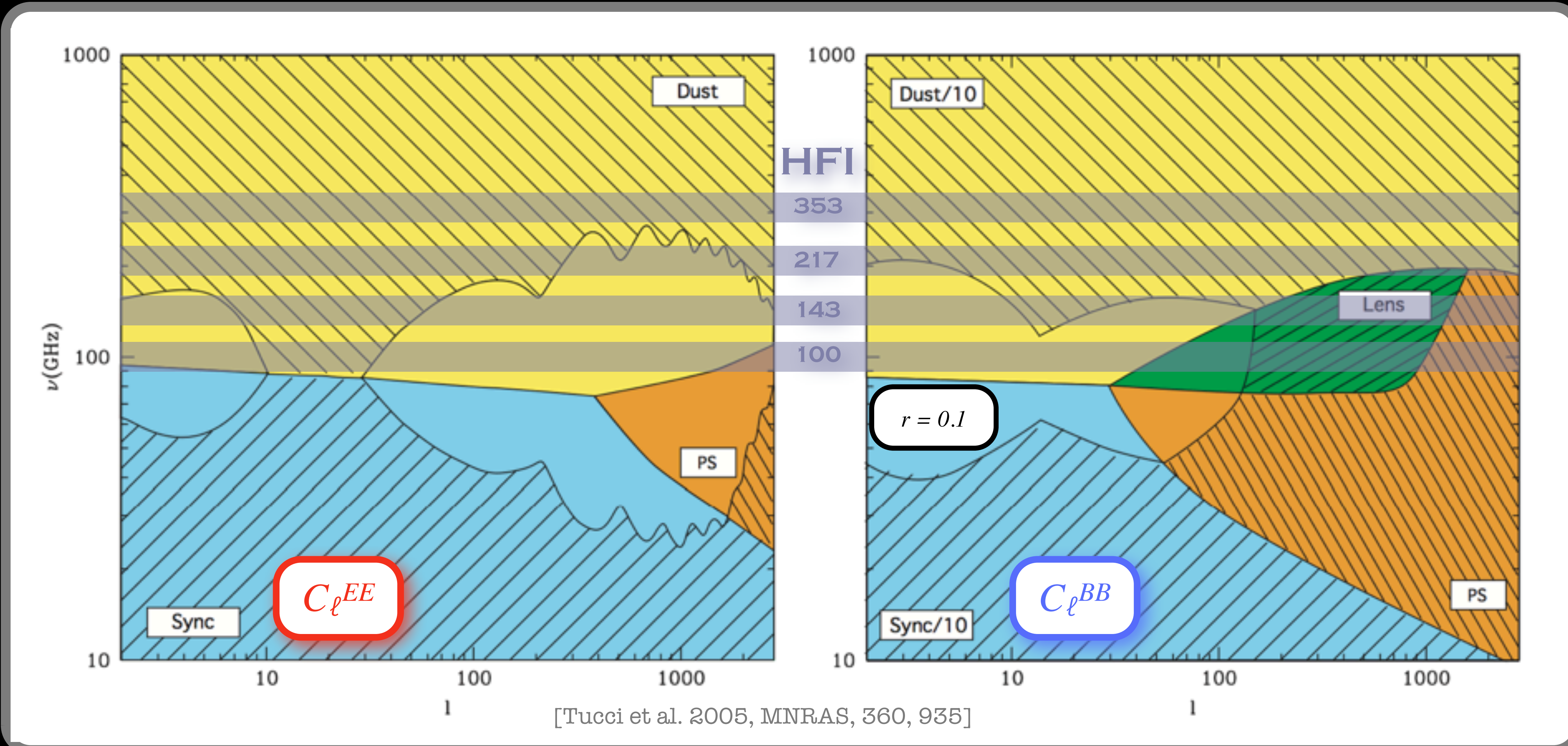
Measured spectra of synchrotron and dust

★Cross-correlation of Q_ν and U_ν maps (WMAP, LFI and HFI) with $Q_{353\mathrm{GHz}}$ and $U_{353\mathrm{GHz}}$
★Turn-over of SED of polarized emission around 60 GHz, like for intensity
★Polarized synchrotron emission is measured to be very weak in HFI channels



[see Ghosh's poster @ ESLAB, Planck Intermediate Paper 87, to be published]

Power spectra of the polarized components



★Predictions of the polarized dominant components for $|b| > 20°$ as a function of the angular scale and of the frequency

★Dust polarized intensity might be underestimated in this model

★The CMB *EE* spectrum dominates at both large and intermediate angular scales from 70 to 150 GHz

★For $T/S \equiv r = 0.1$, the CMB *BB* spectrum dominates at large scales from 70 to 150 GHz if synchrotron and dust polarization are reduced by 10!

Computation of the power spectra of dust

Data

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Method

★ Computation of the polarized angular power spectra (C_ℓ^{TT}, C_ℓ^{TE}, C_ℓ^{EE}, C_ℓ^{BB}, C_ℓ^{TB} and C_ℓ^{EB})

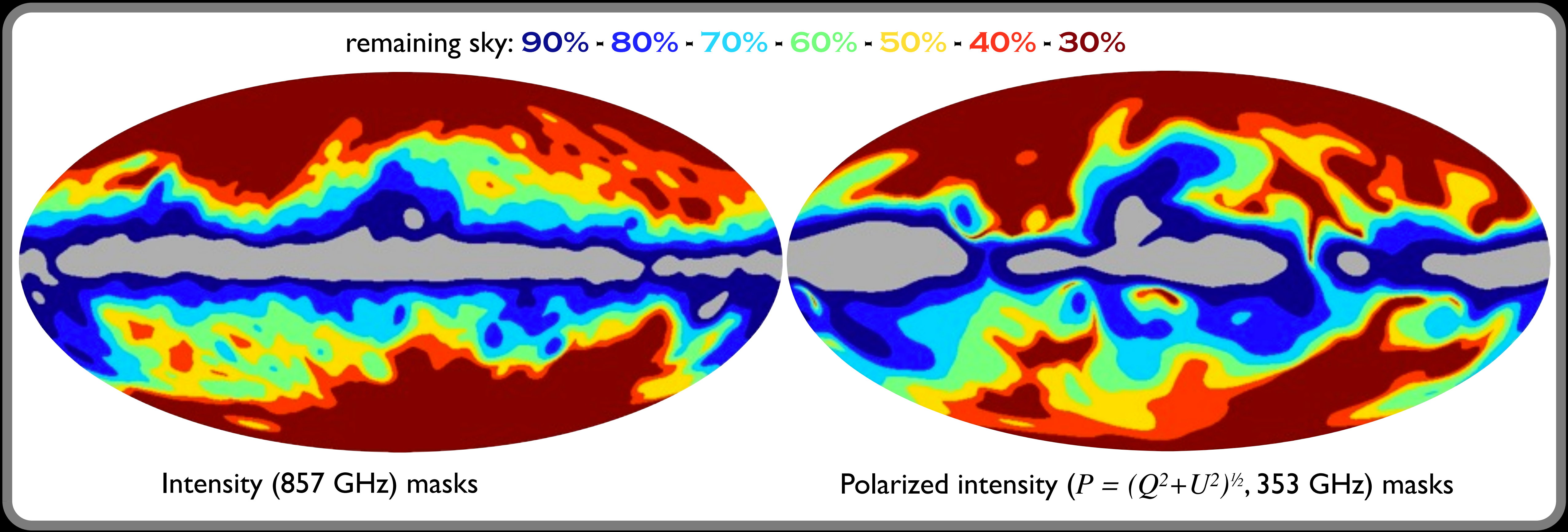
- ★ Masking and apodization (described in the next slide)
- ★ Computation of the angular power spectra done with XPOL (extension to polarization of XSPECT [Tristram et al. 2005, MNRAS, 358, 833]), pseudo-C_ℓ estimator that corrects for incomplete sky coverage and beam
- ★ Use XPOL on detector-sets maps to avoid bias due to correlated noise in auto-spectra.
  ex: spectrum at 353 GHz = 353_{DS1}x353_{DS2},
  for 100x353 GHz = (100_{DS1}x353_{DS1}+100_{DS1}x353_{DS2}+100_{DS2}x353_{DS1}+100_{DS2}x353_{DS2})/4

CMB subtraction and systematics assessment

★ Subtraction of the CMB component in C_ℓ for TT, EE, BB and TE (but which model is still a secret...)

★ Assessment of spectral and calibration mismatch intensity to polarization leakage ([Matthieu Tristram's talk @ ESLAB])

Masks of the sky used in the analysis



- ★We define different masks for intensity and polarization
- ★Intensity masks are constructed from the 857 GHz I map smoothed to 10°
- ★Polarization masks are constructed from the 353 GHz P map smoothed to 10°
- ★In each case, we define masks masking 10, 20, 30, 40, 50, 60 and 70 % of the sky
- ★Each mask is apodized with a 1° Gaussian
- ★We do not mask point sources