Constraining polarized dust spectral energy distribution using multifrequency approach

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On behalf of the Planck Collaboration

CMB Foregrounds Workshop
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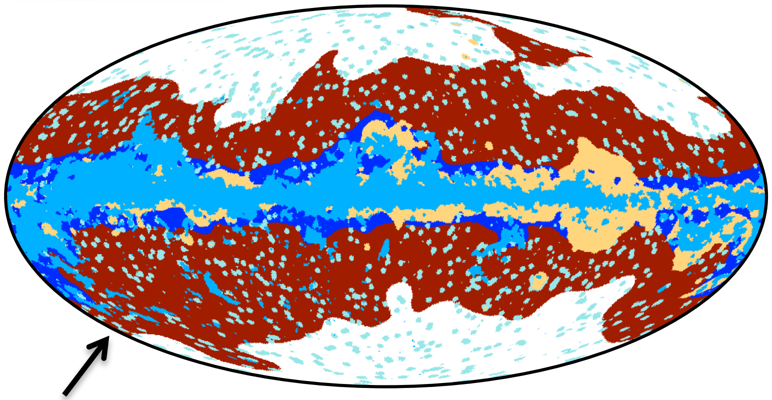
Outline of the talk

- Template-fitting analysis (***Planck intermediate results. XXII 2015***)
- Multicomponent fit in the harmonic space.
- Microwave dust SED for polarization and total intensity.
- Spectral decorrelation of dust B-modes.

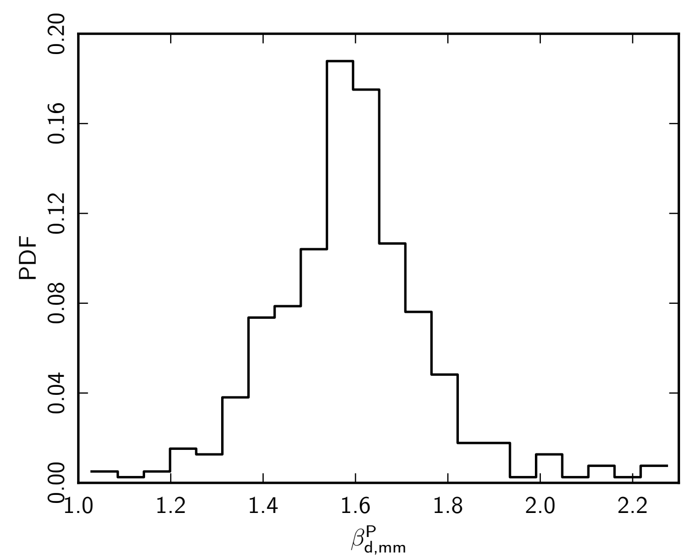
Polarized dust spectral indices at intermediate latitude sky



Only red sky region is considered

To characterize the polarized dust SED, we cross-correlate 353 GHz Q and U maps with the three lowest *Planck* HFI frequency channels (100 – 217 GHz) + LFI (30 – 70 GHz) + *WMAP* (23 – 94 GHz) in the pixel space.

$$\langle \beta^{\rm P}_{\rm d,mm} \rangle = 1.59 \pm 0.17, \;\; T_{\rm d} = 19.6 \text{ K}$$



The cross-correlation coefficients at and above 100 GHz can be decomposed as

$$[\alpha^{\rm P}_{\nu}]^{\rm 1T}_{353} = \alpha^{P}(c_{353}) + \alpha^{\rm P}_{\nu}(d_{353})$$

We work with the colour ratio between two frequencies ν_1 and ν_2 (ν_0 is used as a reference to get rid of the CMB contribution)

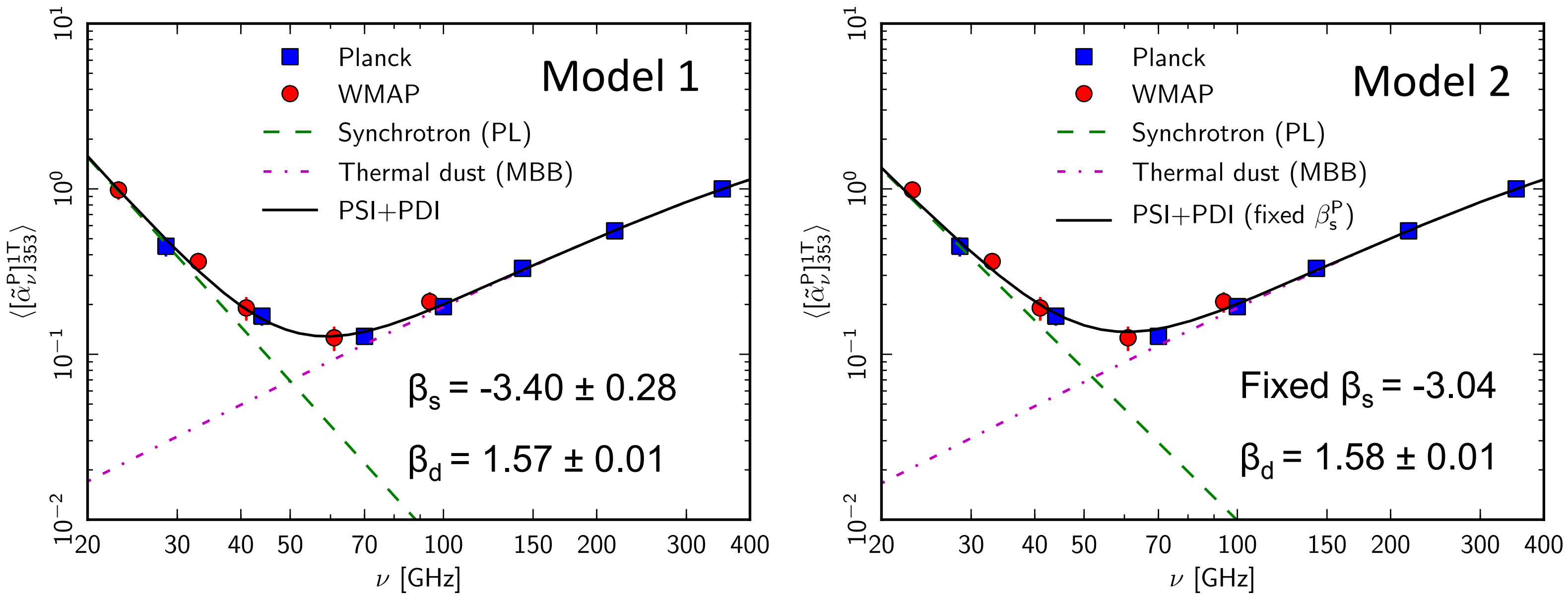
$$R^{\rm P}_{\nu_0}(\nu_2, \nu_1) = \frac{[\alpha^{\rm P}_{\nu_2}]^{1T}_{353} - [\alpha^{\rm P}_{\nu_0}]^{1T}_{353}}{[\alpha^{\rm P}_{\nu_1}]^{1T}_{353} - [\alpha^{\rm P}_{\nu_0}]^{1T}_{353}}$$
$$= \frac{\alpha^{\rm P}_{\nu_2}(d_{353}) - \alpha^{\rm P}_{\nu_0}(d_{353})}{\alpha^{\rm P}_{\nu_1}(d_{353}) - \alpha^{\rm P}_{\nu_0}(d_{353})}$$
$$= f(\beta_{\rm d}, T_{\rm d})$$

Planck intermediate results. XXII 2015

Polarized foregrounds SED

The cross-correlation coefficients are fitted with a simple two-component foreground model (dust + 353 GHz correlated synchrotron):

$$[\alpha_\nu^{\mathrm{P}}]_{353}^{1\mathrm{T}} = A_\mathrm{s}\left(\frac{\nu_1}{23}\right)^{\beta_\mathrm{s}} + \left(\frac{\nu_1}{353}\right)^{\beta_\mathrm{d}-2}\frac{B_{\nu_1}(T_\mathrm{d})}{B_{353}(T_\mathrm{d})} \qquad T_\mathrm{d} = 19.6\,\mathrm{K}$$



Issues:

Planck intermediate results. XXII 2015

- The template polarization maps at 353 GHz have low signal-to-noise ratio at high Galactic latitudes.
- Such correlation analysis picks up only 353-GHz correlated signal. The measured dust SED could be biased due to the spectral decorrelation.

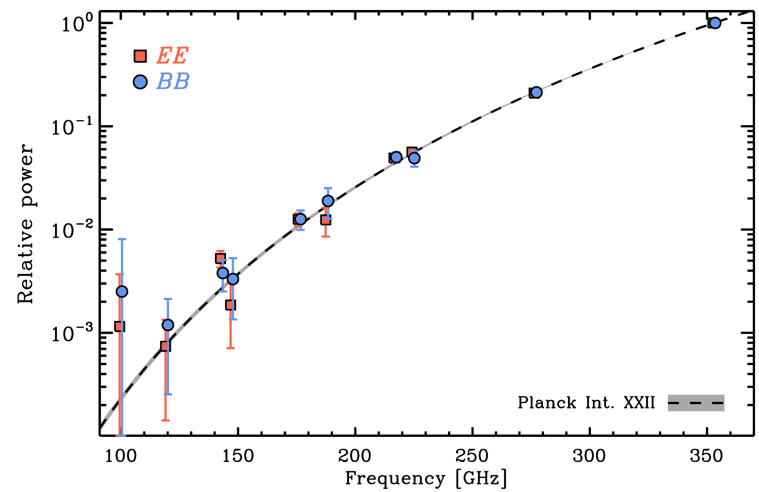
Multicomponent analysis in the harmonic space

- Divide the sky into six large sky regions (f_{sky}= 0.24, 0.33, 0.42, 0.52, 0.62 and 0.71).
- Compute auto- and cross-power spectra over all the sky regions using Xpol.
- CMB is removed from power spectra using the latest Planck best-fit model. CMB variance is included in the error-bars.
- Fit all the spectra simultaneously with five-parameter foreground model as a function of sky regions and multipoles.

foreground model = dust + synchrotron

amplitudes, spectral indices $A_{\rm d}, \beta_{\rm d}$ $A_{\rm s}, \beta_{\rm s}$

Dust-synchrotron correlation parameter = ρ



Planck intermediate results. XXX 2016

Spectral energy distribution of polarized foregrounds

To characterize the SED of polarized foregrounds, we combine the four lowest *Planck* HFI frequency channels (100 – 353 GHz) + LFI (30 GHz) + *WMAP* (23 and 33 GHz).

Amplitude of cross-spectra between frequencies ν_1 and ν_2 :

$$\mathcal{D}_\ell(\nu_1 \times \nu_2) = A_\mathrm{s}\left(\frac{\nu_1\nu_2}{28.4^2}\right)^{\beta_\mathrm{s}} + A_\mathrm{d}\left(\frac{\nu_1\nu_2}{353^2}\right)^{\beta_\mathrm{d}-2}\frac{B_{\nu_1}(T_\mathrm{d})}{B_{353}(T_\mathrm{d})}\frac{B_{\nu_2}(T_\mathrm{d})}{B_{353}(T_\mathrm{d})}$$
$$+ \rho\sqrt{A_\mathrm{s}A_\mathrm{d}}\left[\left(\frac{\nu_1}{28.4}\right)^{\beta_\mathrm{s}}\left(\frac{\nu_2}{353}\right)^{\beta_\mathrm{d}-2}\frac{B_{\nu_2}(T_\mathrm{d})}{B_{353}(T_\mathrm{d})}\right.$$
$$\left.+\left(\frac{\nu_2}{28.4}\right)^{\beta_\mathrm{s}}\left(\frac{\nu_1}{353}\right)^{\beta_\mathrm{d}-2}\frac{B_{\nu_1}(T_\mathrm{d})}{B_{353}(T_\mathrm{d})}\right]$$

$$T_\mathrm{d} = 19.6\,\mathrm{K}$$

This model does not include spectral decorrelation.

Five model parameters:

- The synchrotron and dust amplitudes A_s and A_d .
- The two spectral indices β_s and β_d .
- The dust/synchrotron polarization correlation parameter ρ .

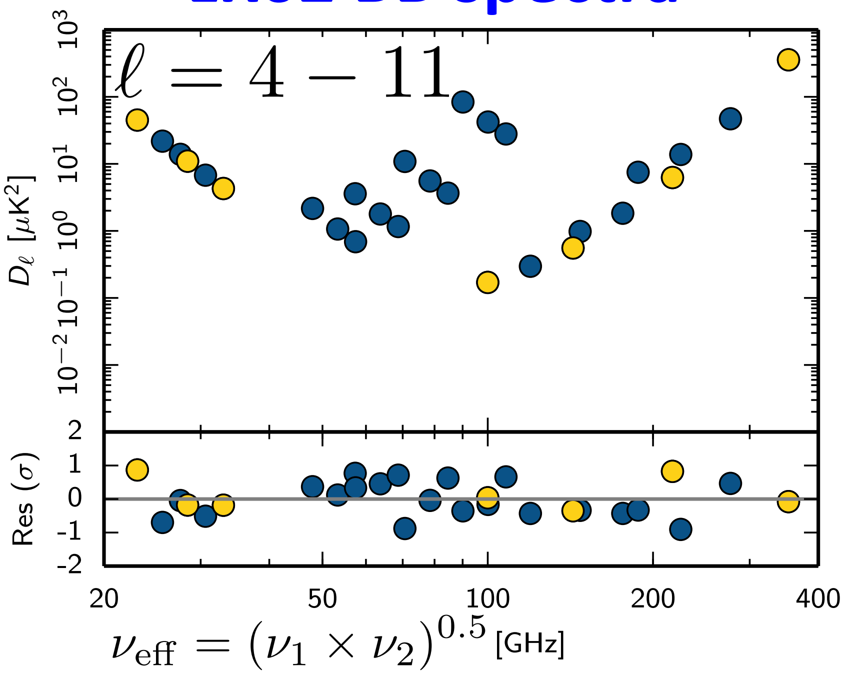
Choi and Page, astro-ph/1509.05934

Data fitting

- Auto- and cross-spectra of seven frequencies provide 28 data points.
- Error-bars on data points are derived from E2E simulations.
- CMB is removed from power spectra using the latest Planck best-fit model. CMB variance is included in the error-bars.
- Fit is done in two steps:
  - first step no prior.
  - second step, a prior, inferred from the results of the first fit, is introduced on the synchrotron spectral index ($\beta_{\rm s} = -3.13 \pm 0.07$).
- Same method repeated on the data, simulations are used to propagate the error-bars and check for a potential bias on foreground parameters.

Work done by Nicoletta

LR62 BB spectra



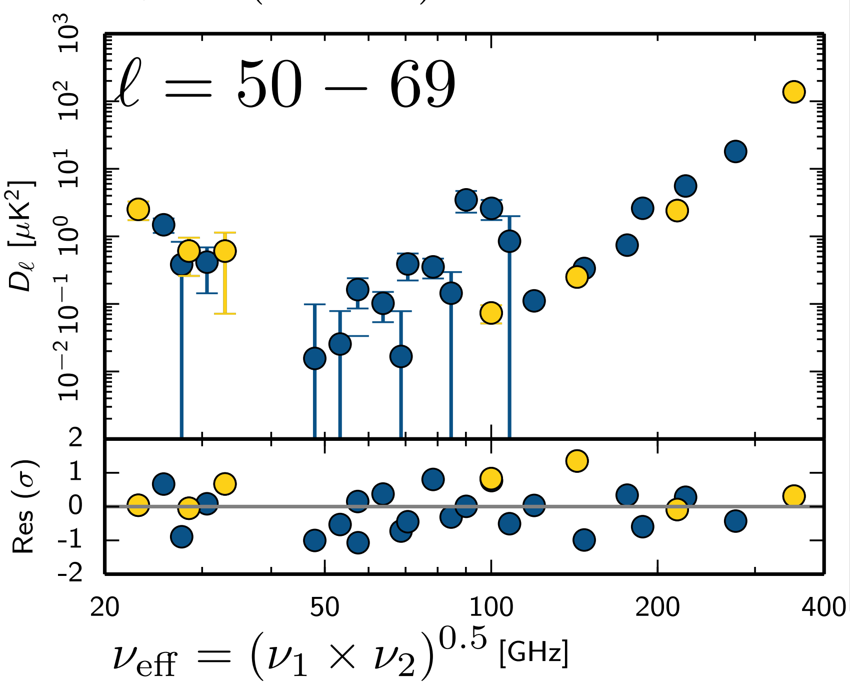
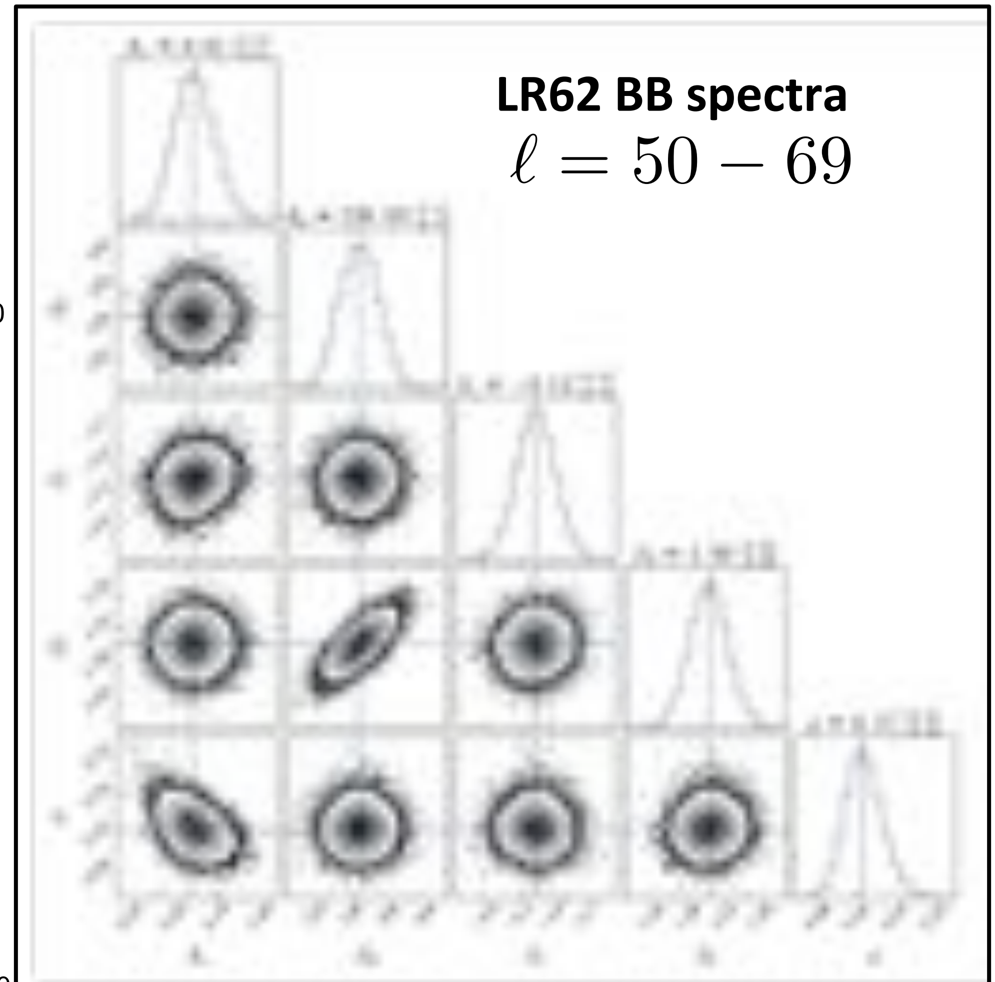
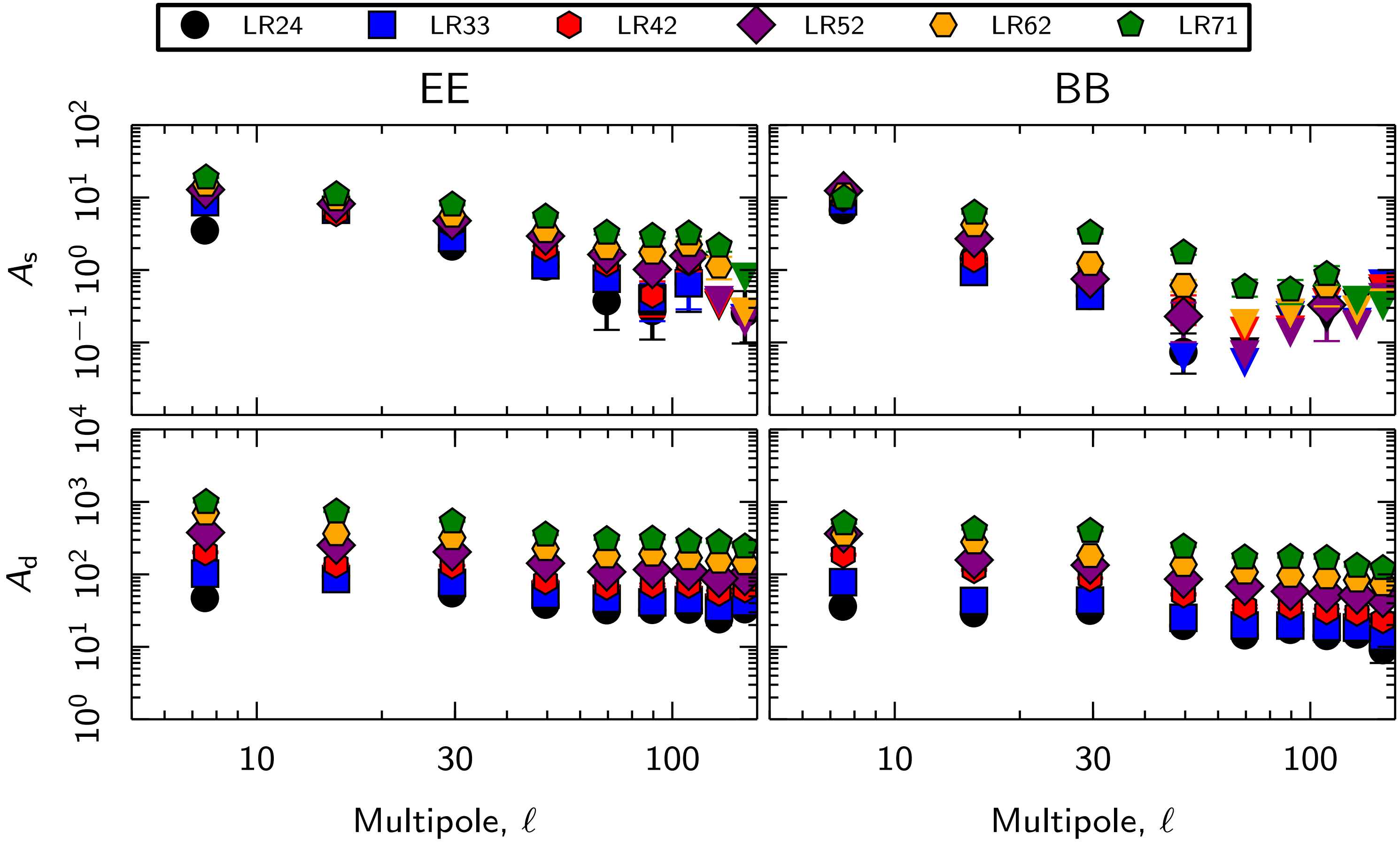


Illustration of data input and fit results



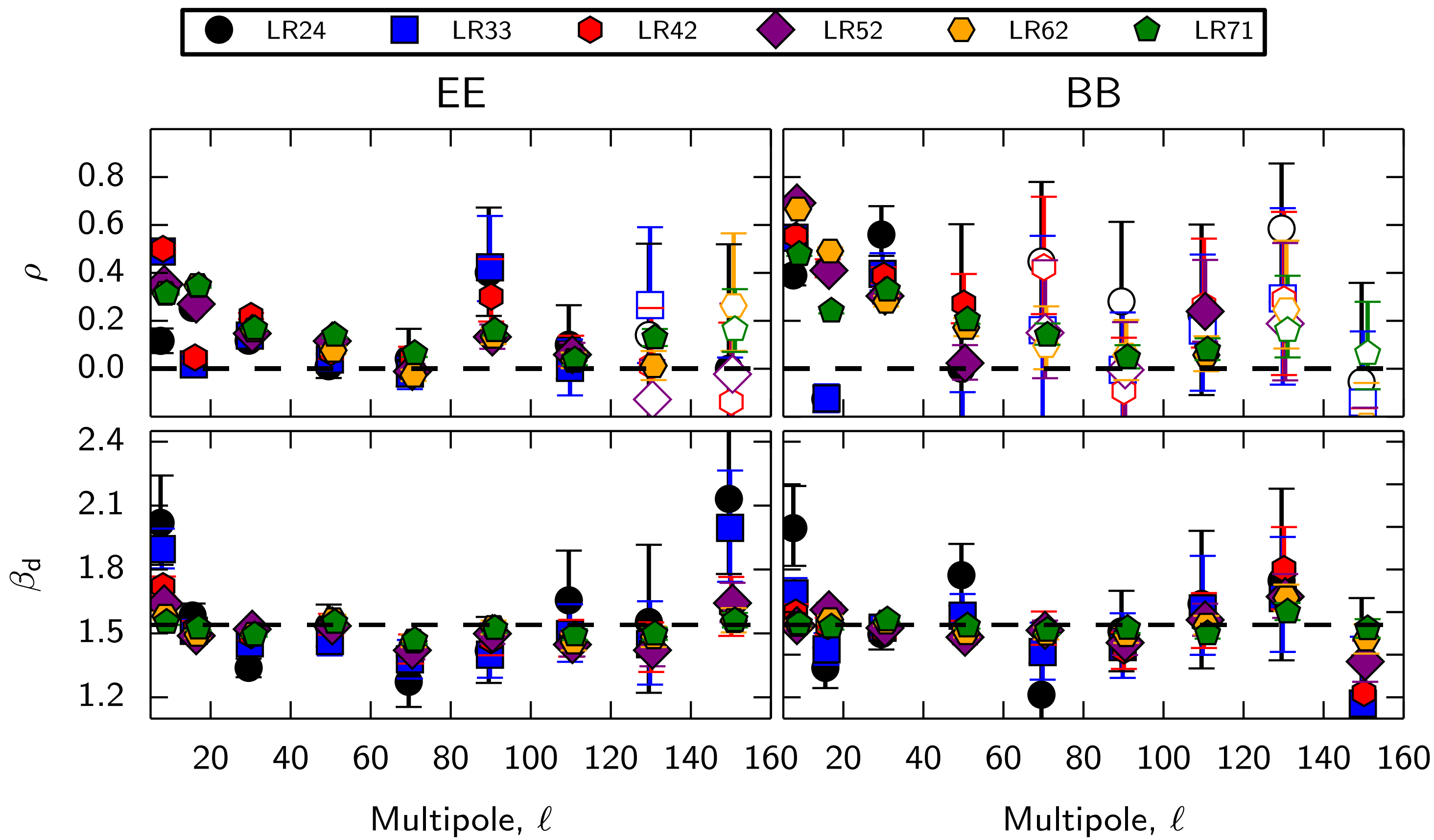
Dust and synchrotron amplitudes



Inverted triangles = one sigma upper limit

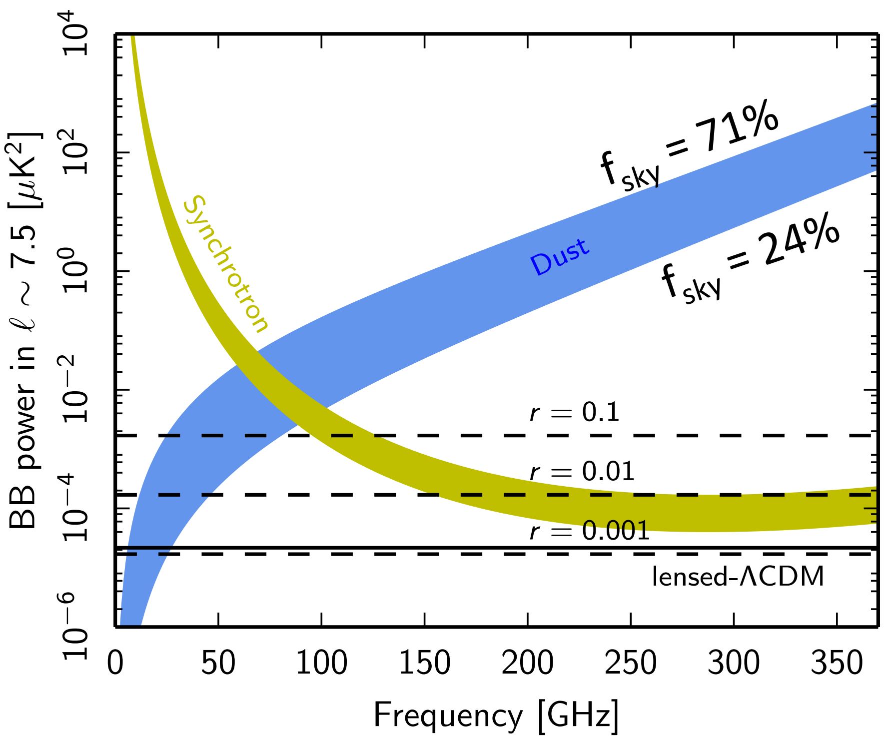
BB A_s/A_d ratio is maximum at low multipoles and for the smallest sky region (LR24)

Spectral parameters

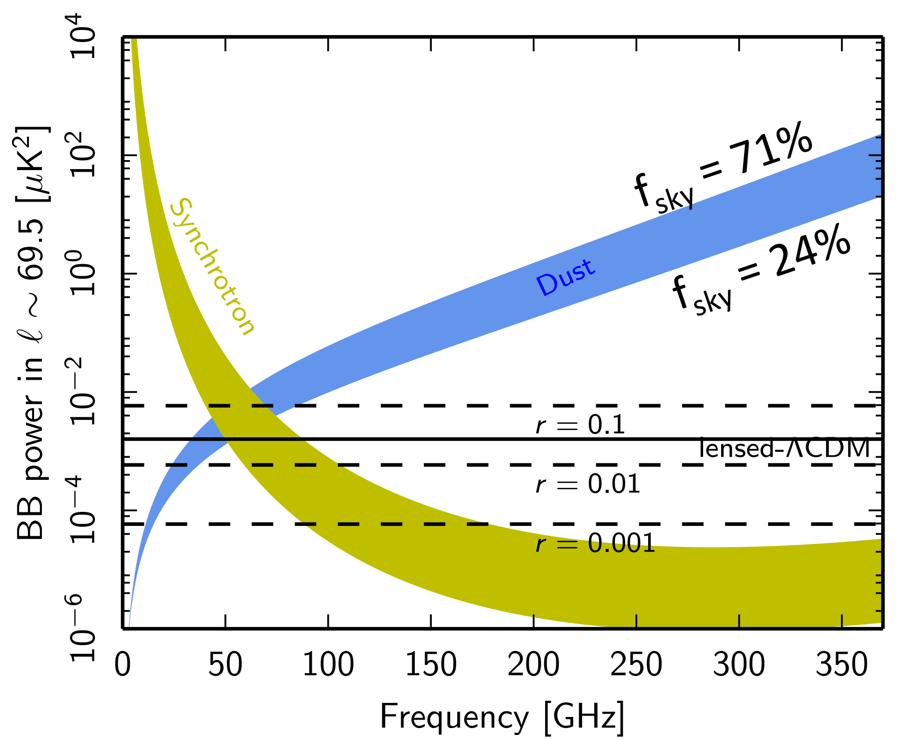


- Only ρ depends systematically on ℓ .
- No systematic variations of β_d with sky region, except for the lowest ℓ bin.

Reionization B-modes ℓ range



Recombination B-modes ℓ range



- The frequency at which dust and synchrotron *B*-modes power are equal depends on multipole and sky region.
- Dust quickly dominates synchrotron at higher frequencies.

Dust SED for polarization and total intensity

- For this comparison, we only use 217 and 353 GHz maps, which are dust dominated (+ CIB for total intensity).

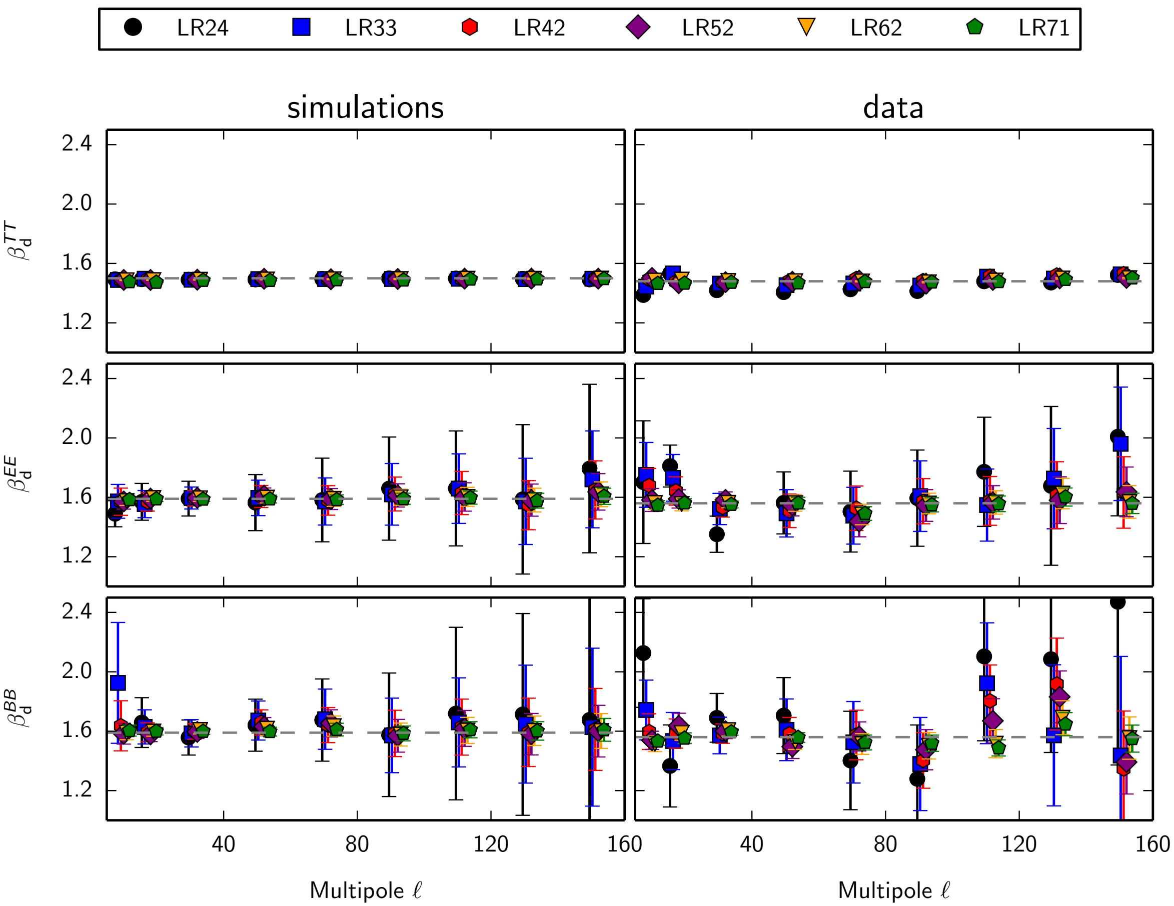
- Spectral indices for polarization and total intensity are derived from the 217x353 correlation. We compute

$$\alpha_\ell^{XX}(217,353) = \frac{C_\ell^{XX}(217 \times 353)}{C_\ell^{XX}(353 \times 353)}$$

for *XX* = *TT*, *EE* and *BB*

- The same data analysis is repeated on simulated skies (300 realizations) to check for systematics and compute error-bars.

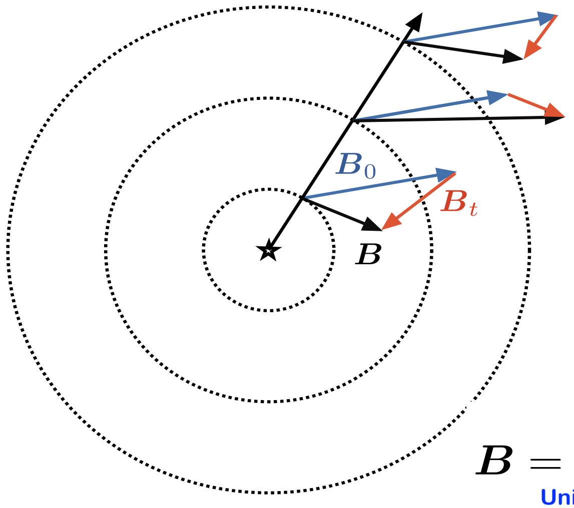
Spectral indices for dust polarization



- The mean spectral index for dust polarization is β(P) = 1.56 ± 0.01 (for T_d=19.6K), a value slightly smaller than that (1.59) reported in PIP XXII.
- We find a small difference between spectra indices for polarization and total intensity: β(P) - β(I) = 0.08 ± 0.02 as in PIP XXII.
- Some evidence that the dust spectral index may vary more for polarized emission than total intensity.
- Good match between indices derived from colour ratios and multifrequency SED fitting.

Multiple dust components along different line of sights

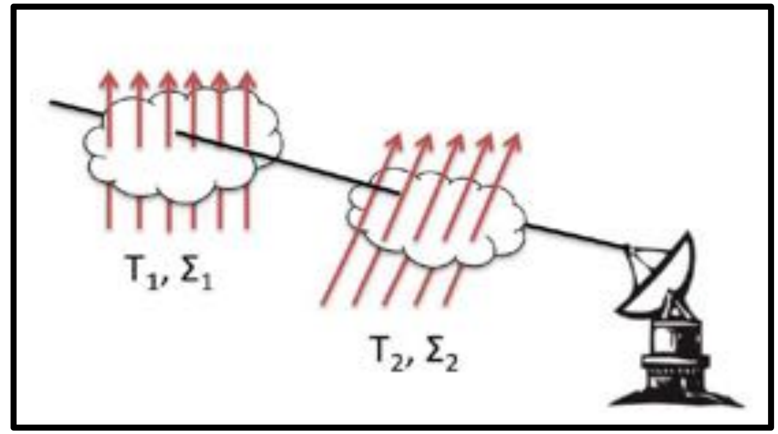
Stacking of small number of polarized emission layers, with plane-of-sky spatial correlations



Turbulent field

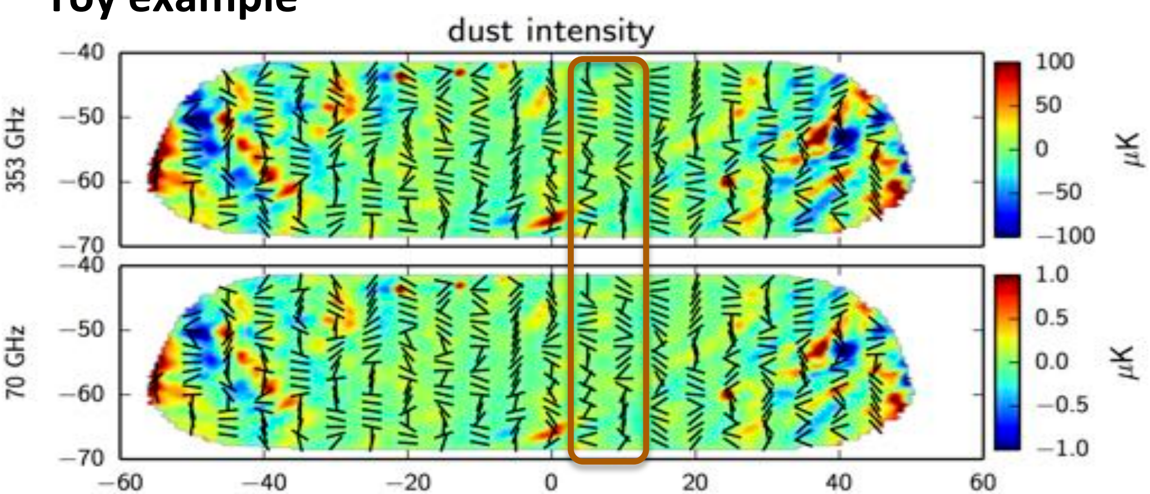
$$B = B_0 + B_t$$

Uniform field



Tassis and Pavlidou, 2015, MNRAS

Toy example



Correlation ratio of dust B-modes between two different frequencies is measured as

$$R_\ell^{BB} = \frac{\mathcal{D}_\ell^{BB}(\nu_1 \times \nu_2)}{\sqrt{\mathcal{D}_\ell^{BB}(\nu_1 \times \nu_1) \times \mathcal{D}_\ell^{BB}(\nu_2 \times \nu_2)}}$$

Planck intermediate results XLIV, 2016, A&A
Vansyngel et al. 2017, A&A
Ghosh et al. 2017, A&A

Spectral energy distribution of dust emission

To characterize the spectral decorrelation of dust B-modes over the multipole bin 50-160, we only consider the four lowest *Planck* HFI frequency channels (100 – 353 GHz)

Amplitude of cross-spectra between HFI frequencies ν_1 and ν_2 :

$$\mathcal{D}_\ell(\nu_1 \times \nu_2) = A_\mathrm{d} \left(\frac{\nu_1 \nu_2}{353^2}\right)^{\beta_\mathrm{d}-2} \frac{B_{\nu_1}(T_\mathrm{d})}{B_{353}(T_\mathrm{d})} \frac{B_{\nu_2}(T_\mathrm{d})}{B_{353}(T_\mathrm{d})} R_\ell(\delta_\mathrm{d}, \nu_1, \nu_2)$$

where

$$T_\mathrm{d} = 19.6\,\mathrm{K}$$

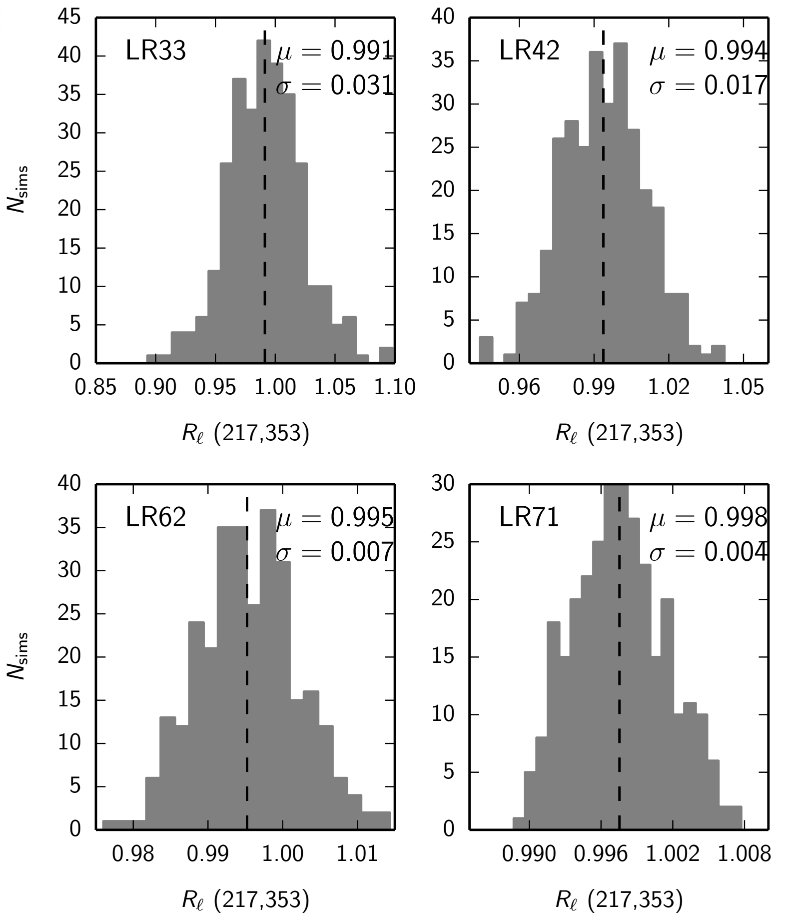
$$R_\ell(\delta_\mathrm{d}, \nu_1, \nu_2) = \exp\left[-\delta_\mathrm{d} \ln\left(\frac{\nu_1}{\nu_2}\right)^2\right]$$

Assumes a frequency dependence model of spectral decorrelation based on ***Vansyngel et al. 2017***.

Three model parameters:

- The dust amplitude A_d .
- The dust spectral index β_d .
- The dust decorrelation parameter δ_d .

Spectral decorrelation

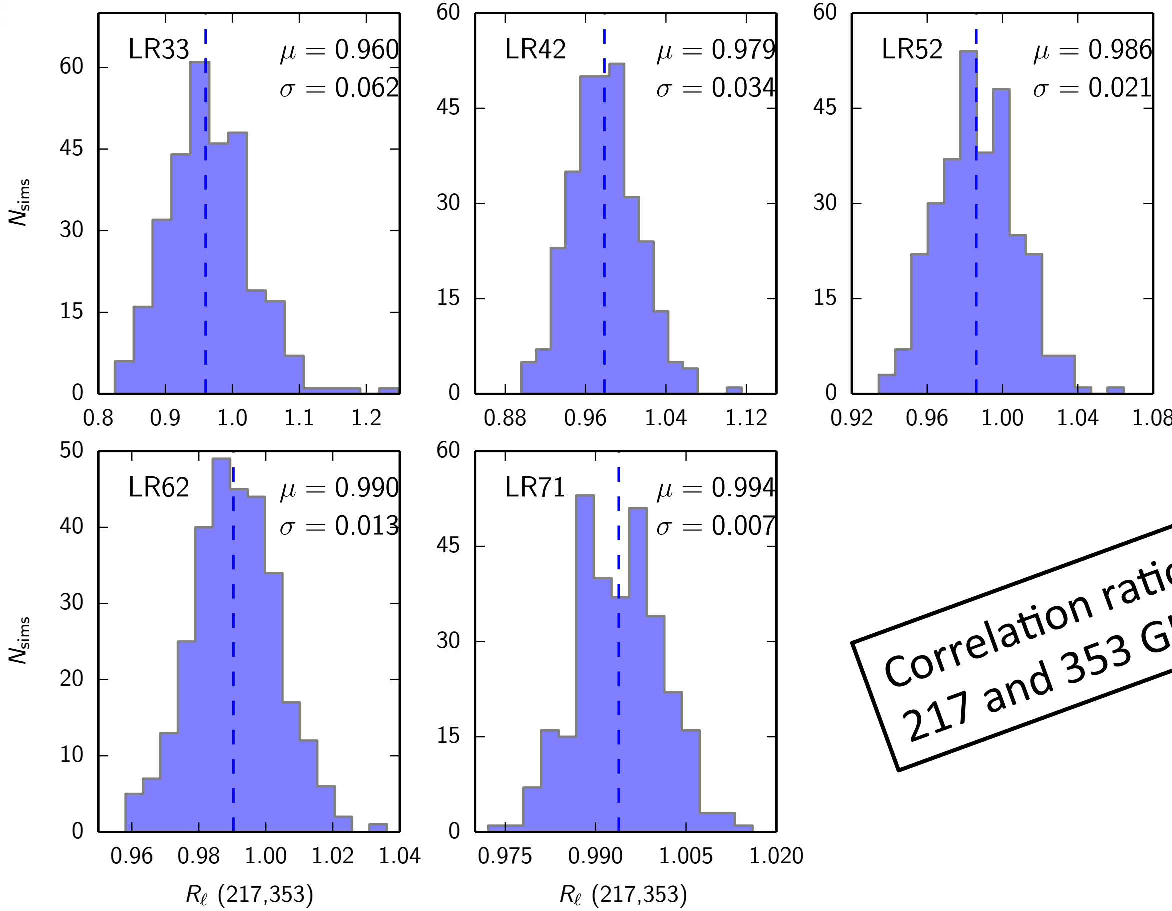


SED fit to HFI-only auto- and cross-spectra.

<u>300 E2E simulations</u> :

- results of HFI-only (100 – 353 GHz) multi-frequency fit over the multipole range 50 – 160.
- The mean of spectral correlation ratio is consistent with one within 1 sigma error-bars.

Spectral decorrelation

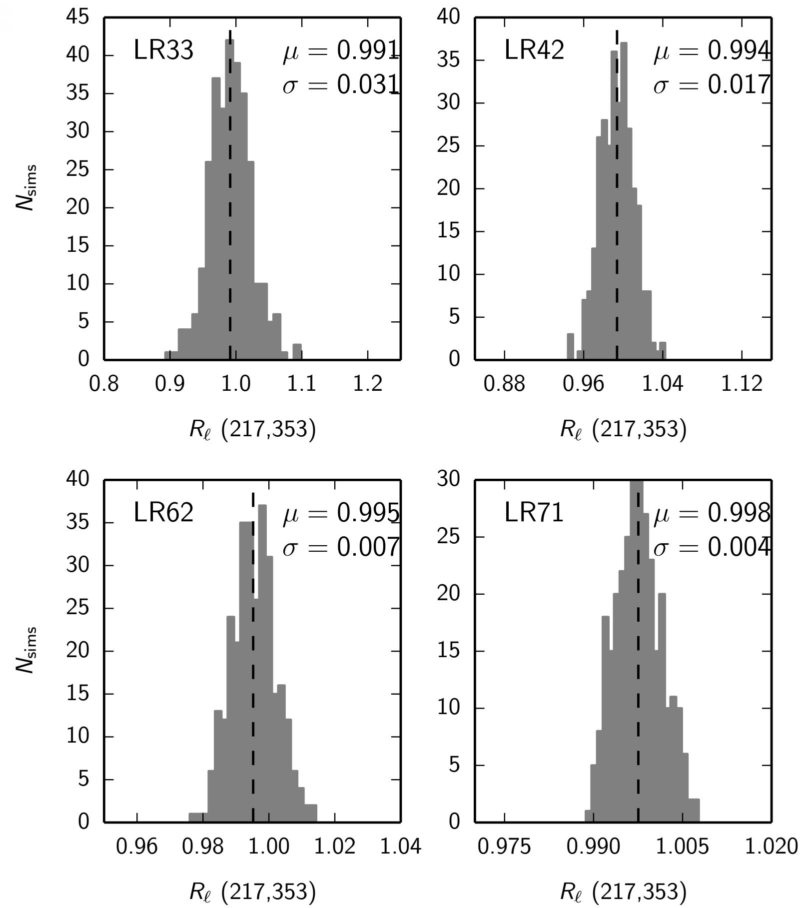


Correlation ratio between 217 and 353 GHz.

300 E2E simulations :

- results of dust correlation ratio derived from 217 and 353 GHz bands over the multipole range 50 - 160.
- The mean of dust spectral correlation ratio is less than one (instrumental systematics, CMB lensing B-mode signal).

Spectral decorrelation



SED fit to HFI-only auto- and cross-spectra.

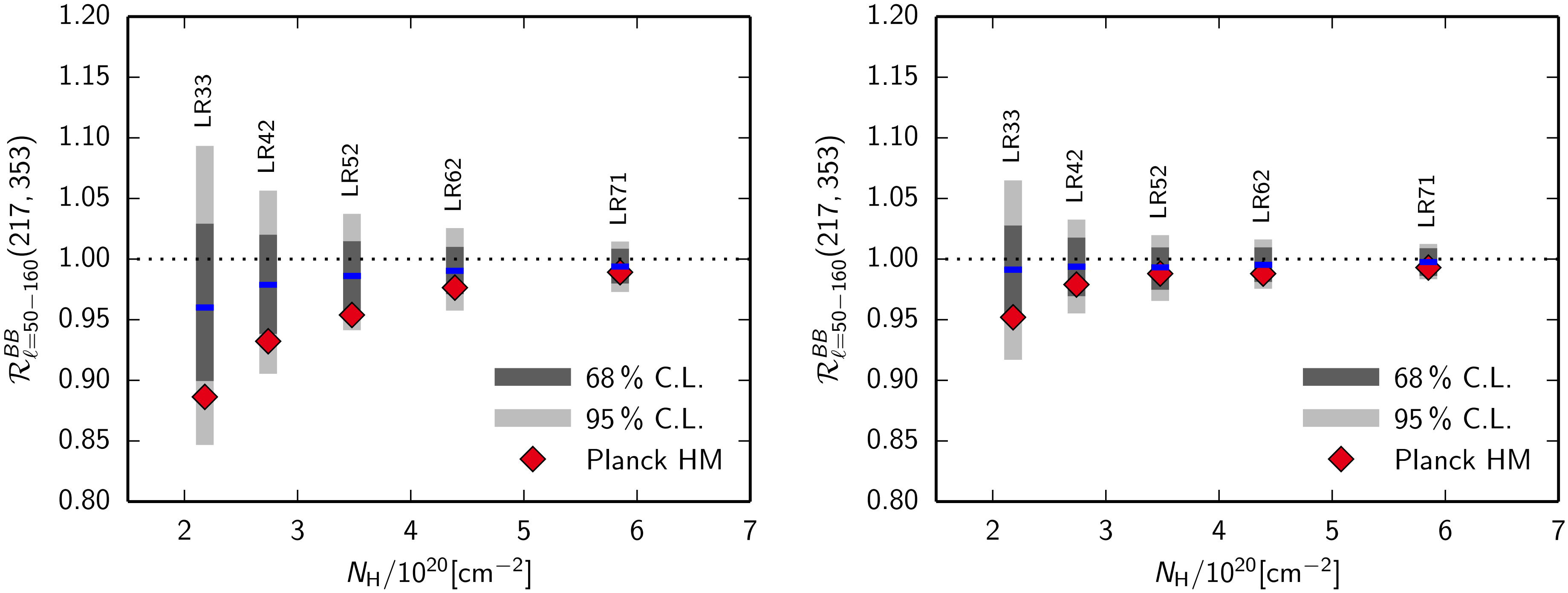
<u>300 E2E simulations</u> :

- results of HFI-only (100 – 353 GHz) multi-frequency fit over the multipole range 50 – 160.
- The mean of spectral correlation ratio is consistent with one within 1 sigma error-bars.

Spectral decorrelation

Using 217/353 correlation ratio

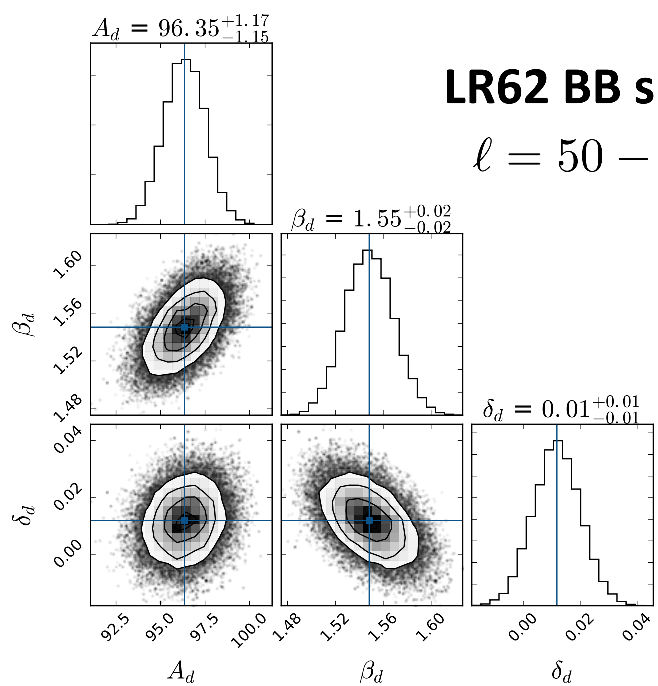
Multi-frequency fit to all HFI spectra



- Multifrequency approach provides a tighter constraint on spectral decorrelation of dust B-modes.

	LR33	LR42	LR52	LR62	LR71
Lower limits (95% C.L)	0.927	0.963	0.974	0.983	0.992
E2E simulations	0.991 ± 0.031	0.994 ± 0.017	0.993 ± 0.010	0.995 ±0.007	0.998 ± 0.004
FFP10 model	0.992	0.994	0.996	0.997	0.998

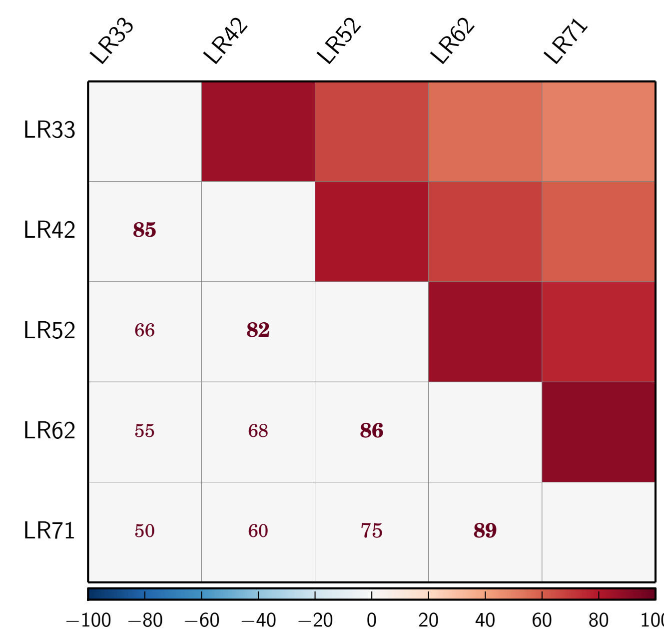
Illustration of fit results for the Planck data



LR62 BB spectra

$\ell = 50 - 160$

Correlation plot



Conclusions

- We use multicomponent analysis to measure polarized foregrounds SED as a function of sky regions and multipoles.
- From the SED fitting analysis, we find $\beta_{\rm d}^{EE} = 1.517 \pm 0.004({\rm stat.}) \pm 0.01({\rm syst.})$ and $\beta_{\rm d}^{BB} = 1.538 \pm 0.004({\rm stat.}) \pm 0.01({\rm syst.})$
- From the colour ratio of 217x353 and 353x353 spectra, we find the mean polarized dust spectral index $\beta_{\rm d}^{EE,BB} = 1.56 \pm 0.01({\rm stat.}) \pm 0.02({\rm syst.})$.
- The dust-synchrotron correlation dominates at low ells.
- There is a small difference between spectral index of polarization and total intensity $\Delta\beta_{\rm d} = 0.08 \pm 0.01$ as in PIPXXII.
- We find no evidence for a loss of correlation in the Planck data.
- We provide lower limits to the correlation ratio that are tighter than values derived from the correlation ratio of 217 and 353 GHz alone.

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

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