Planck constraints on cross-correlations between anisotropic cosmic birefringence and CMB polarization

Marco Bortolami

FLAG meeting, Bologna

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Università degli Studi di Ferrara

Based on
M. Bortolami, M. Billi, A. Gruppuso, P. Natoli, L. Pagano,
JCAP 09 (2022) 075

INFN
Istituto Nazionale di Fisica Nucleare

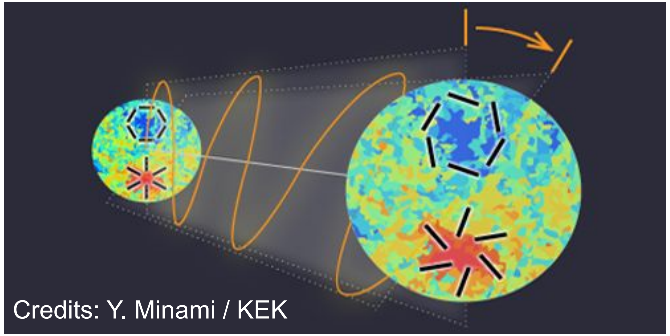
The Cosmic Birefringence effect

- Parity violating extension of standard EM lagrangian: new Physics!
- Models coupling pseudo-scalar (dark) fields to photons: new Physics!

$$\mathcal{L} = -\frac{1}{4}F_{\upsilon\lambda}F^{\upsilon\lambda} - \frac{1}{2}p_{\alpha}A_{\beta}\tilde{F}^{\alpha\beta}$$

Carroll et al., Phys. Rev. D 41, 1231 (1990)

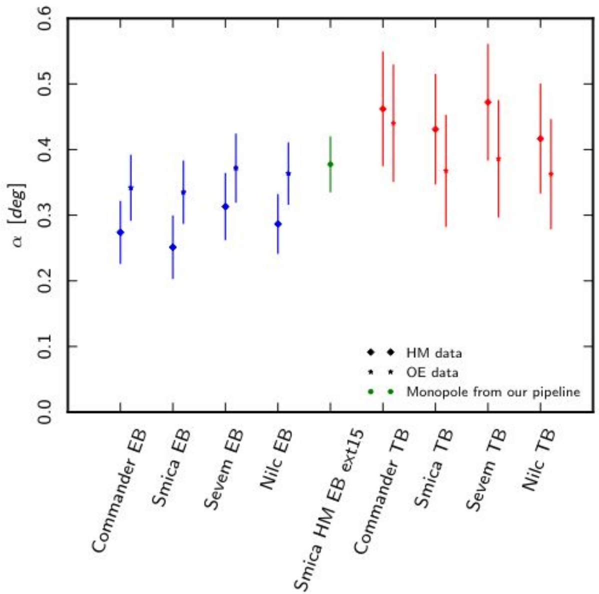
- In vacuo rotation of linear polarization plane by α (CB angle)
- Linearly polarized electromagnetic radiation from distant sources: CMB



The effect can be isotropic or anisotropic.

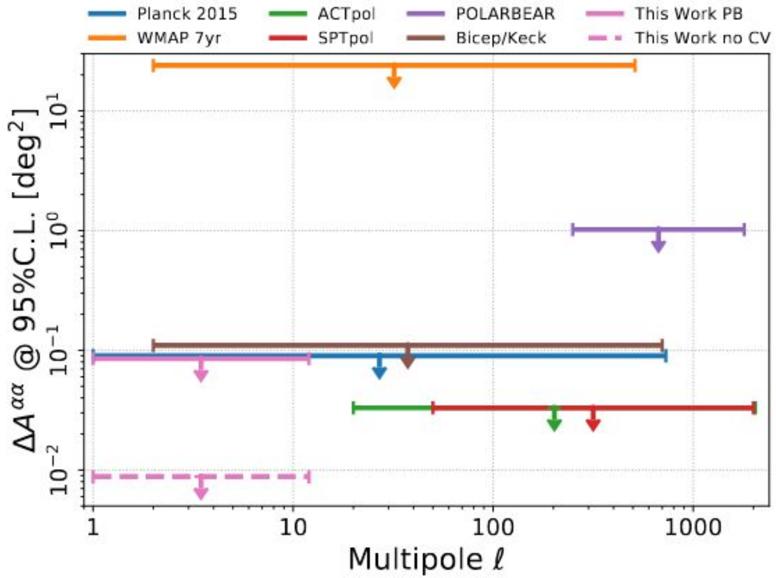
The Cosmic Birefringence effect

Isotropic



Planck 2018	α = 0.35° ± 0.05° (stat) ± 0.28° (syst)
Minami, Komatsu 2020	0.35° ± 0.14°
Diego-Palazueos++ 2022	0.30° ± 0.11°

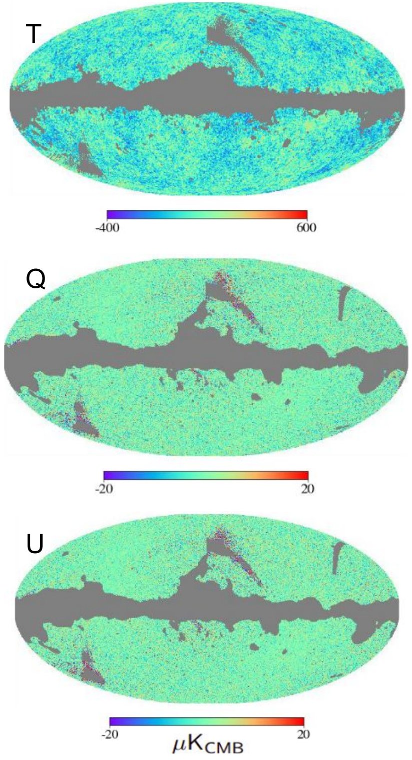
Anisotropic



Planck 2018 (Gruppuso et al. 2020)	$A^{\alpha\alpha} < 0.085$ deg^2
ACTpol (Namikawa et al. 2020)	$A^{\alpha\alpha} < 0.033$ deg^2
SPTpol (Bianchini et al. 2020)	$A^{\alpha\alpha} < 0.033$ deg^2

From CMB to CB maps

Idea: estimate CB isotropic angle in small regions of the sky and study its variation and its correlation with CMB



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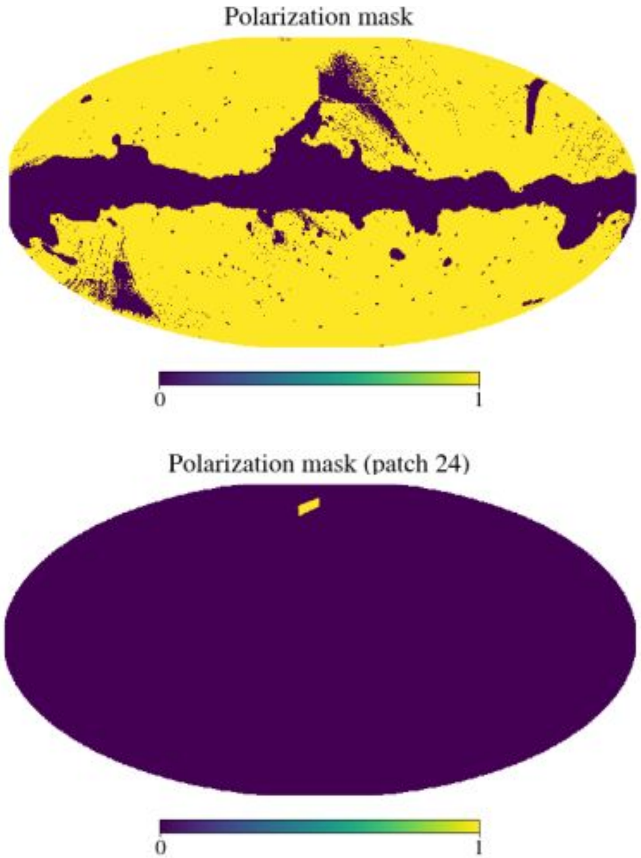
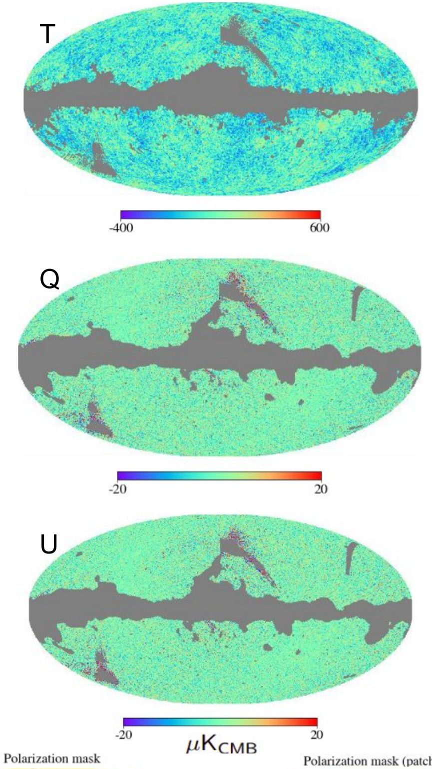
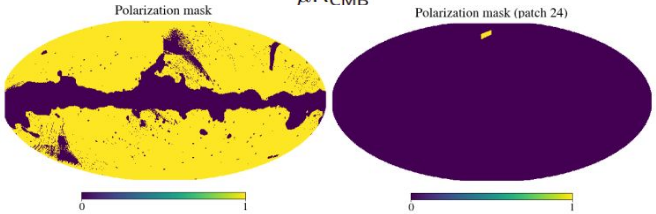
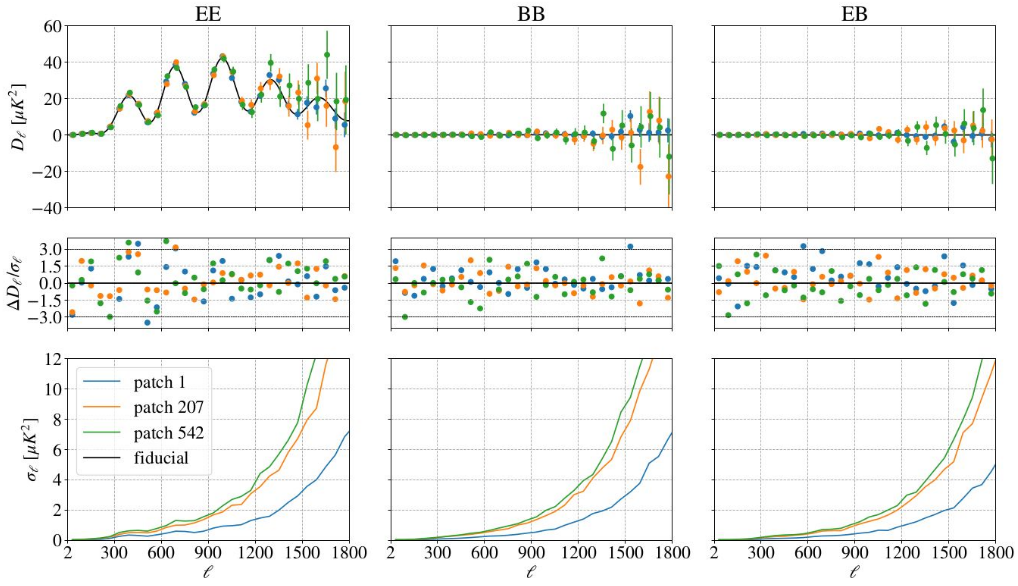


From CMB to CB maps



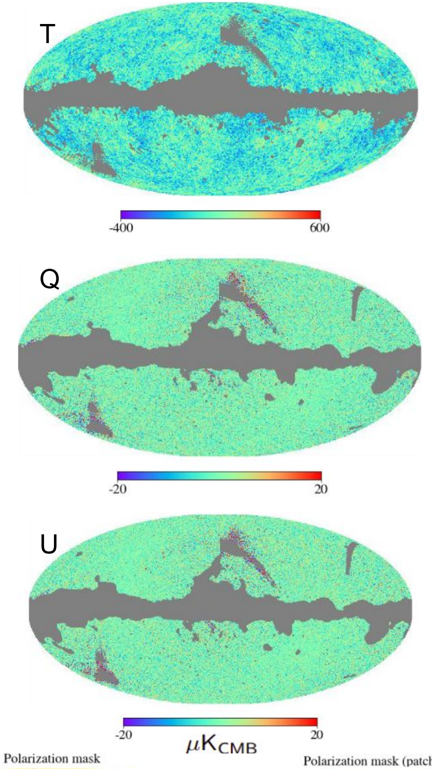


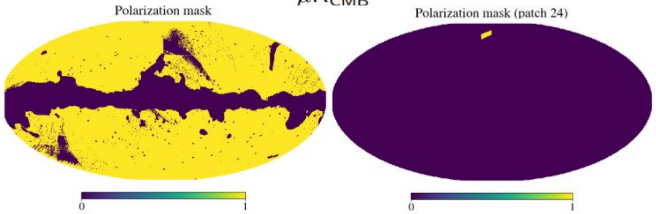
CMB spectra
+
covariance



No apodization
No purification
Binning

From CMB to CB maps





Effect of isotropic CB on CMB spectra

$$C_\ell'^{TT} = C_l^{TT}$$

$$C_\ell'^{EE} = C_\ell^{EE}\cos^2(2\alpha) + C_\ell^{BB}\sin^2(2\alpha)$$

$$C_\ell'^{BB} = C_\ell^{EE}\sin^2(2\alpha) + C_\ell^{BB}\cos^2(2\alpha)$$

$$C_\ell'^{TE} = C_\ell^{TE}\cos(2\alpha)$$

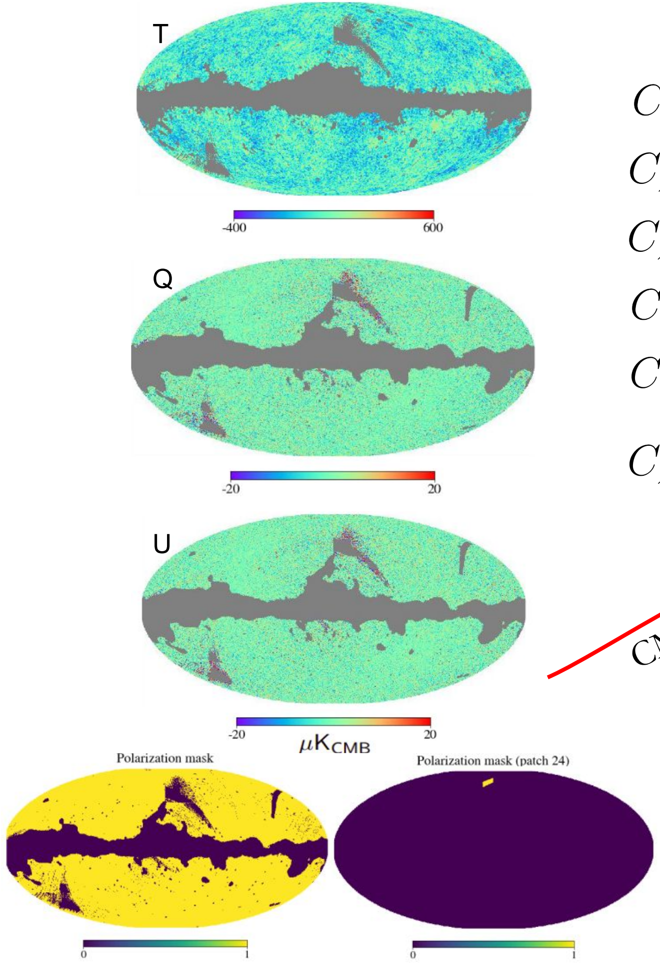
$$C_\ell'^{TB} = C_\ell^{TE}\sin(2\alpha)$$

$$C_\ell'^{EB} = \frac{1}{2}\left(C_l^{EE} - C_\ell^{BB}\right)\sin(4\alpha)$$

Vanishing if P is conserved

CMB spectra

From CMB to CB maps



$$C_\ell^{\prime TT} = C_l^{TT}$$
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CMB spectra

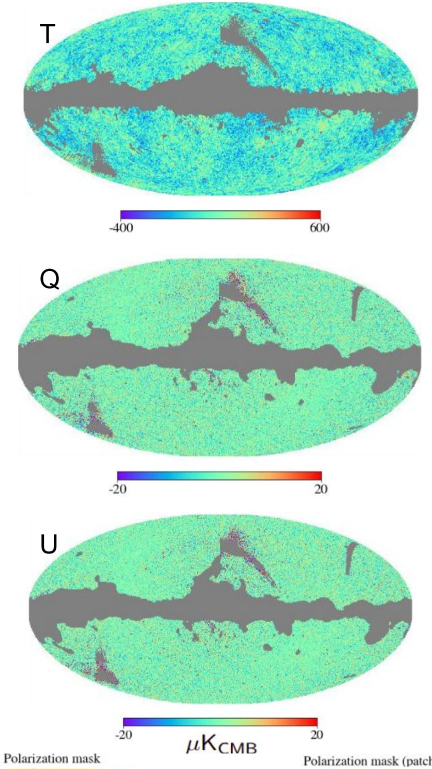
D-estimators

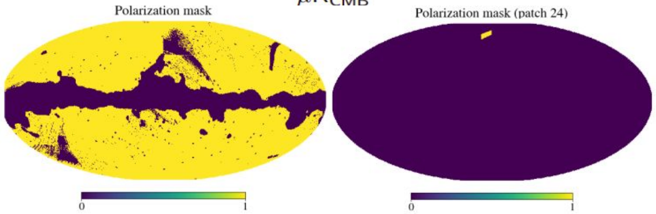
$$D_\ell^{EB}(\alpha) = \hat{C}_\ell{}^{EB}\cos(4\alpha) - \frac{1}{2}\left(\hat{C}_\ell^{EE} - \hat{C}_\ell^{BB}\right)\sin(4\alpha)$$
$$\chi^2_Y(\alpha) = \sum_{\ell\ell'} D_\ell^Y \, {M_{\ell\ell'}^{YY}}^{-1} D_{\ell'}^Y$$

Gruppuso et al., A note on the birefringence angle estimation in CMB data analysis (2016)

From CMB to CB maps

Repeat for all the patches, data and simulation maps, different component separation methods, PR3 and PR4





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CMB spectra

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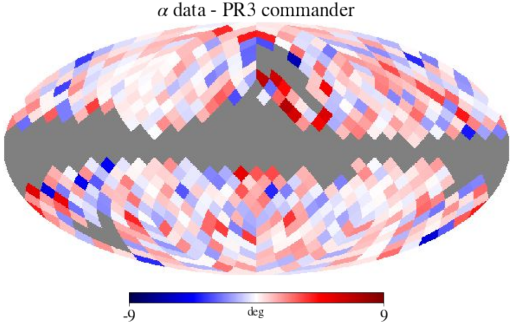
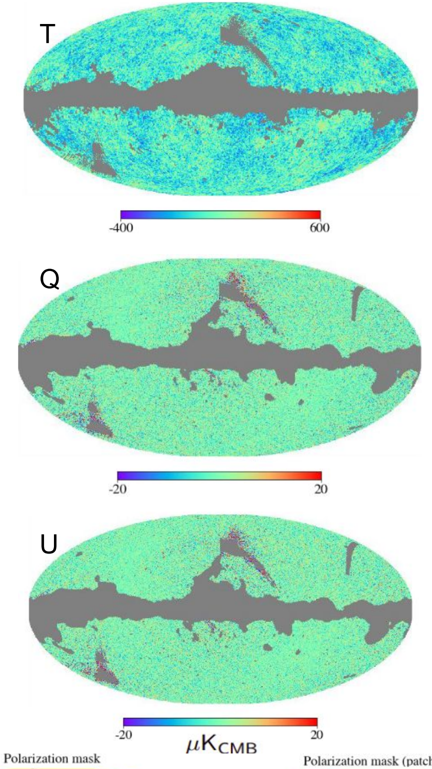
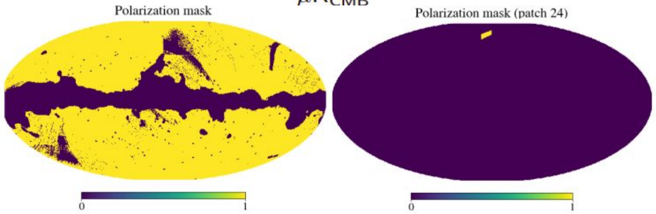
$$\chi^2_Y(\alpha) = \sum_{\ell\ell'} D_\ell^Y \, M_{\ell\ell'}^{YY^{-1}} \, D_{\ell'}^Y$$

CB maps



From CMB to CB maps





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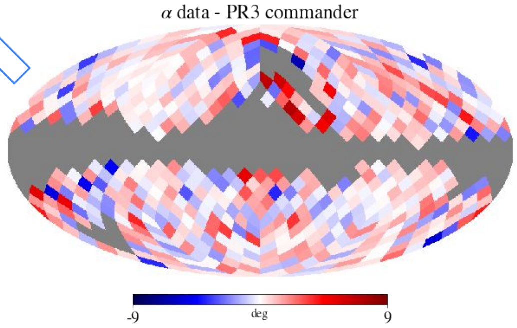
CMB spectra

QML estimator:
CB spectra
Cross-correlation between CB and CMB



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$$\chi^2_Y(\alpha) = \sum_{\ell\ell'} D_\ell^Y \, M_{\ell\ell'}^{YY^{-1}} D_{\ell'}^Y$$

Monopole

case	α [deg]
PR3 `Commander`	0.27 ± 0.05 (stat) ± 0.28 (syst)
PR3 `NILC`	0.26 ± 0.05 (stat) ± 0.28 (syst)
PR3 `SEVEM`	0.27 ± 0.05 (stat) ± 0.28 (syst)
PR3 `SMICA`	0.24 ± 0.05 (stat) ± 0.28 (syst)
NPIPE `Commander`	0.33 ± 0.04 (stat) ± 0.28 (syst)
NPIPE `SEVEM`	0.33 ± 0.04 (stat) ± 0.28 (syst)
[23] (PR3)	0.35 ± 0.14 (stat)
[24] (NPIPE)	0.30 ± 0.11 (stat)
[26] (NPIPE + WMAP)	$0.30^{+0.094}_{-0.091}$ (stat)
Planck 2018	0.35° ± 0.05° (stat.) ± 0.28° (syst.)

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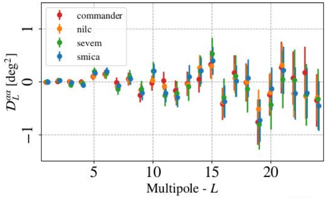
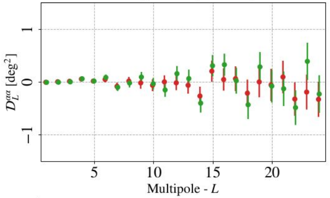
Spectra

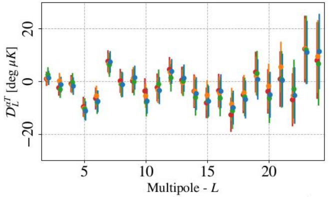
$\alpha\alpha$ data spectra (PR3)



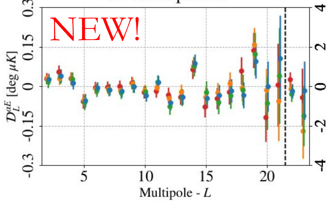
$\alpha\alpha$ data spectra (NPIPE)



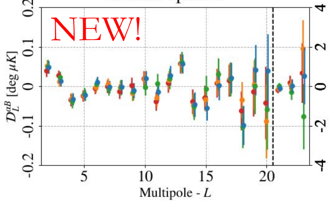
αT data spectra



αE data spectra



αB data spectra



Monopole

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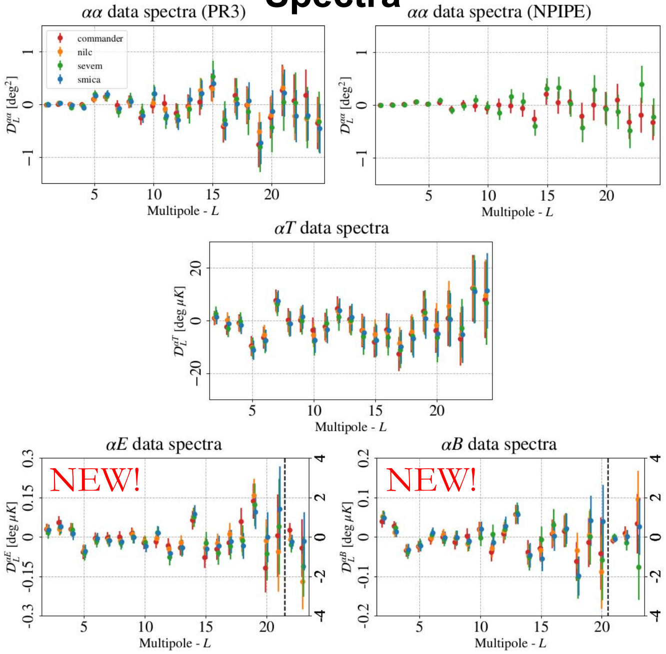
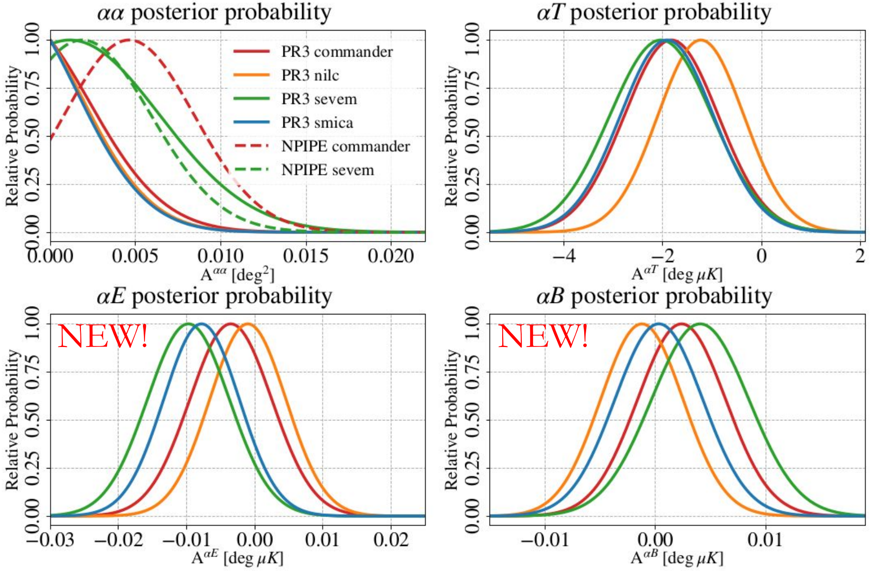
Spectra



Constraints (scale invariant spectra)



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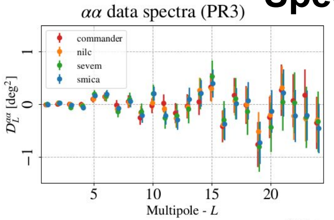

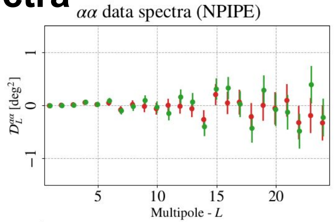

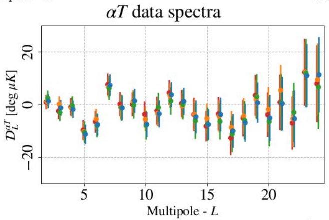

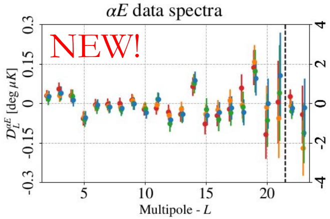

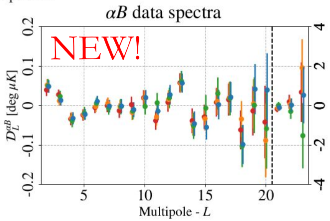

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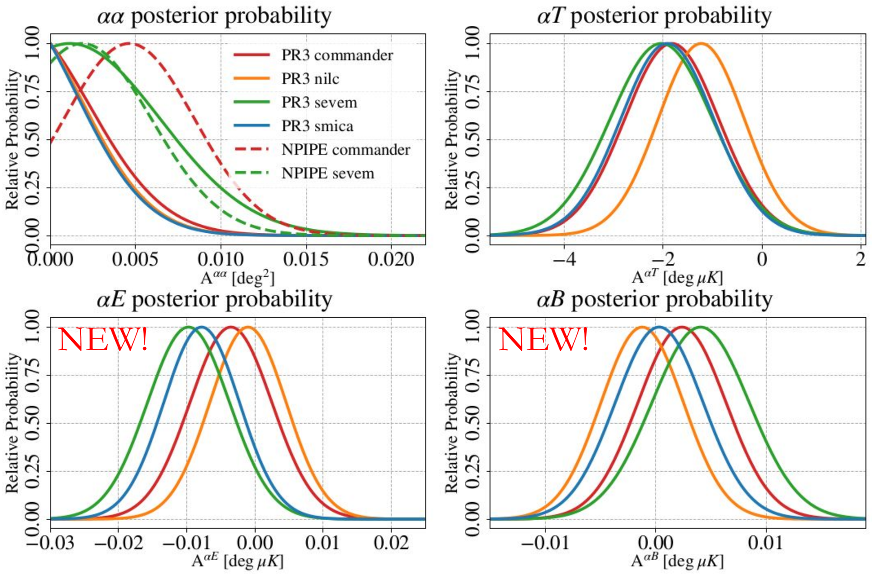


parameter	Commander	NILC	SEVEM	SMICA
$A^{\alpha\alpha}$ [deg^2] PR3	< 0.007	< 0.007	< 0.010	< 0.007
$A^{\alpha\alpha}$ [deg^2] NPIPE	< 0.010	-	< 0.009	-
$A^{\alpha T}$ [μK deg] PR3	-1.827 ± 0.953	-1.229 ± 0.873	-2.037 ± 1.038	-1.916 ± 0.945
$A^{\alpha E}$ [nK deg] PR3	-3.5 ± 6.0	-1.0 ± 5.6	-9.7 ± 6.0	-7.8 ± 5.6
$A^{\alpha B}$ [nK deg] PR3	2.4 ± 4.0	-1.2 ± 3.7	4.0 ± 4.4	0.3 ± 4.0

$$A^{\alpha T} = 0.899 \pm 1.089\,[\mathrm{deg}\cdot\mu K]\ \text{for SMICA},$$
$$A^{\alpha T} = 0.897 \pm 1.026\,[\mathrm{deg}\cdot\mu K]\ \text{for NILC},$$
$$A^{\alpha T} = 1.394 \pm 1.223\,[\mathrm{deg}\cdot\mu K]\ \text{for SEVEM},$$
$$A^{\alpha T} = 0.918 \pm 1.119\,[\mathrm{deg}\cdot\mu K]\ \text{for Commander},$$

Gruppuso et al., 2020, Planck 2018 constraints on anisotropic birefringence and its cross-correlation with CMB anisotropy

Conclusions

- New analysis pipeline
- Low resolution maps of CB
- Auto- and cross-correlation CB spectra
- Updated constraints for monopole, $\alpha\alpha$ and αT
- New constraints for αE and αB

Maps and spectra publicly available at https://github.com/marcobortolami/AnisotropicBirefringence_patches

Future perspectives

- Forecasts for new experiments (LiteBIRD, CMB-S4, …)
- ~~Increase patch resolution~~

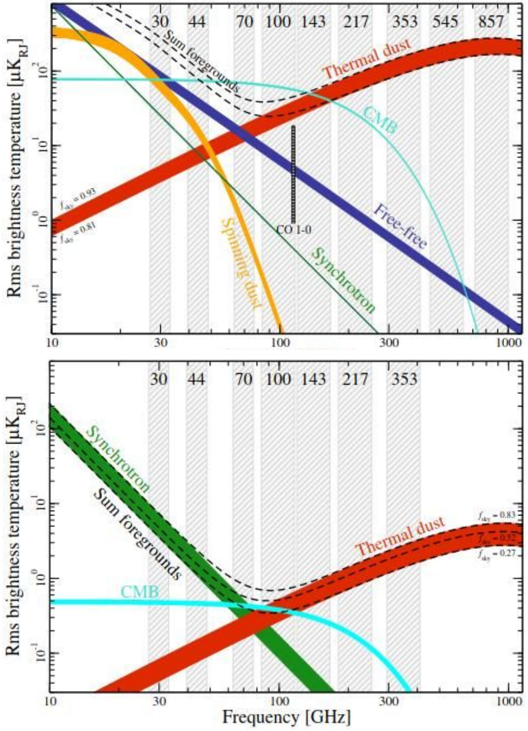
THANK YOU

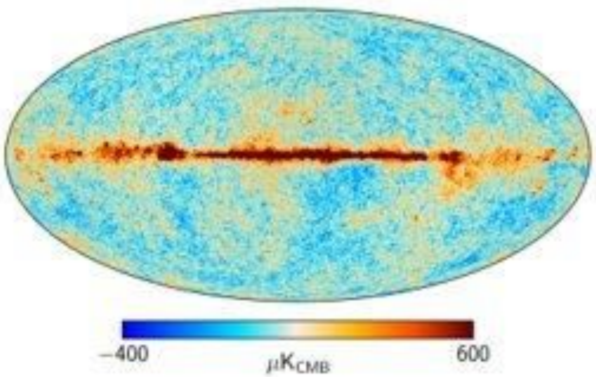
BACK UP

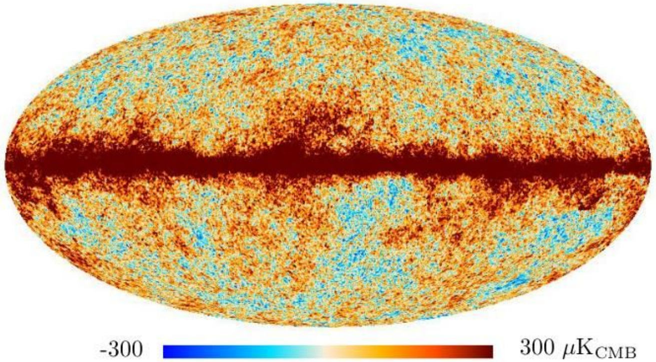
Planck Collaboration 2020, A&A, 641, A1-A3

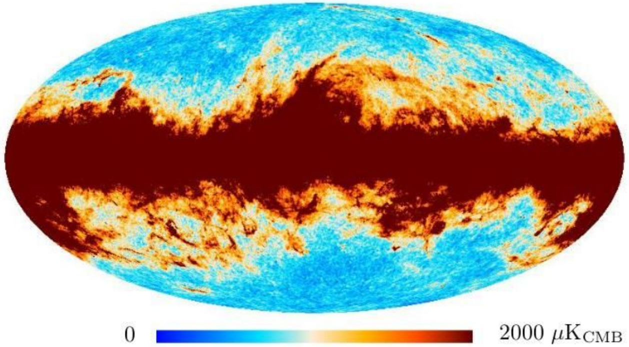
CMB analysis: foregrounds and masks

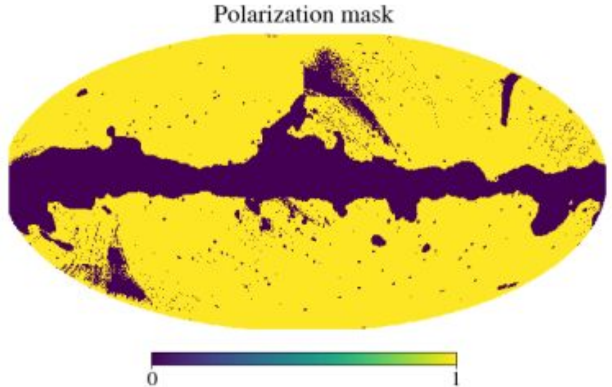
- Planck satellite detected the CMB at 30, 44, 70 ,100, 143, 217, 353 GHz
- Foregrounds (dust, synchrotron, …) removed by component separation methods
- Mask to exclude non reliable pixels



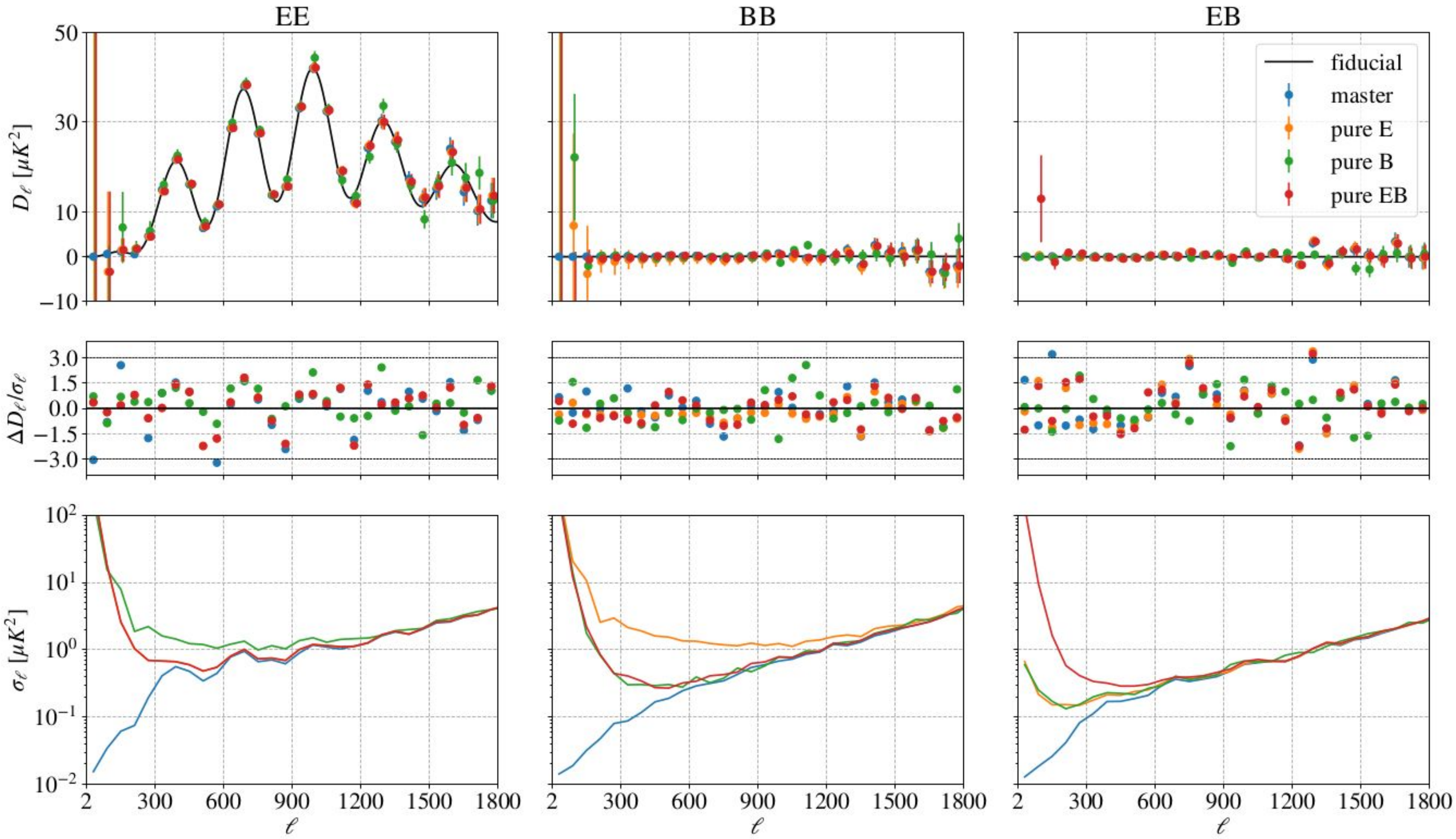








Purification study



$$\chi^2\left(A^{\alpha X}\right) = \sum_{L,L'} \left(\frac{L(L+1)}{2\pi} C_L^{\alpha X} - A^{\alpha X}\right) M_{LL'}^{-1} \left(\frac{L'(L'+1)}{2\pi} C_{L'}^{\alpha X} - A^{\alpha X}\right)$$

$$M_{LL'} = \left\langle \frac{L(L+1)}{2\pi} C_L^{\alpha X} \frac{L'(L'+1)}{2\pi} C_{L'}^{\alpha X} \right\rangle$$