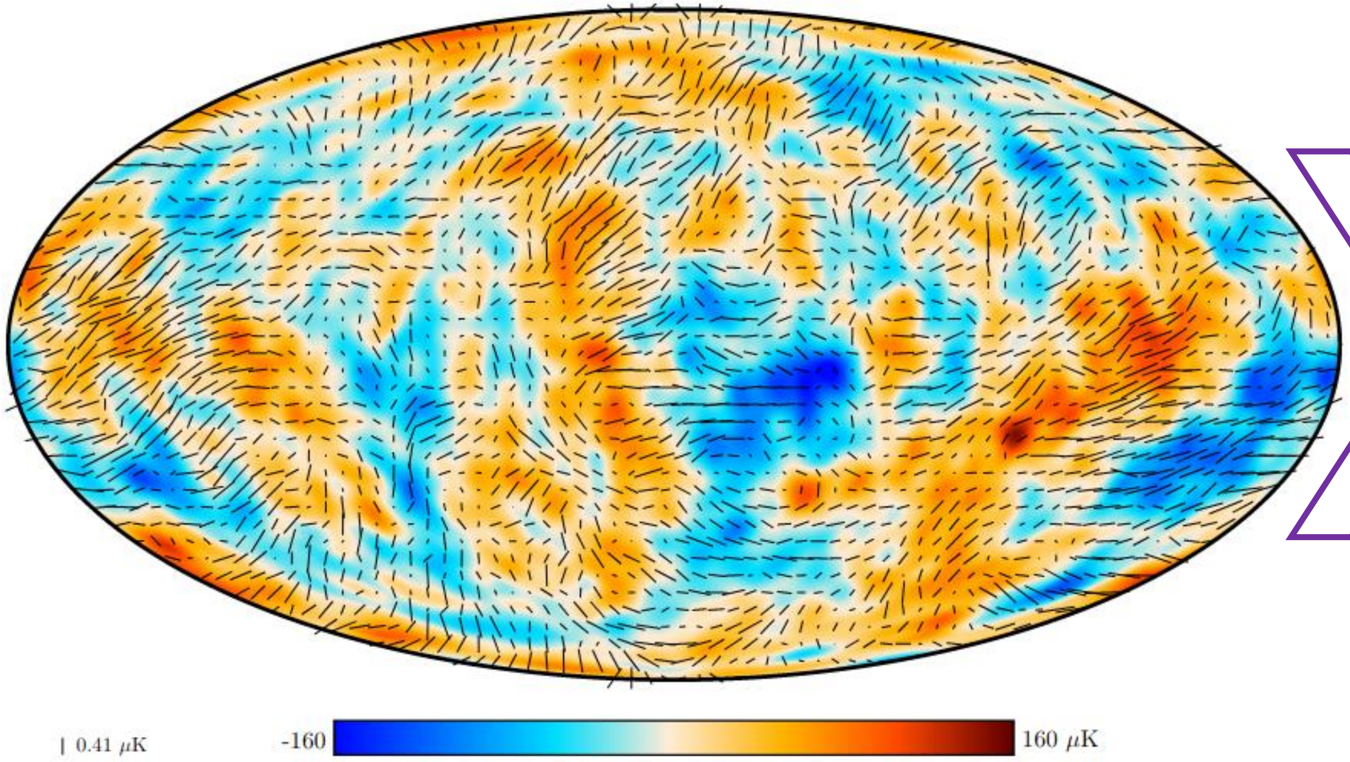
Simultaneous determination of miscalibrated polarization angles and cosmic birefringence from Planck PR4

P. Diego-Palazuelos, J. R. Eskilt, Y. Minami, M. Tristram, R. M. Sullivan, A. J. Banday, R. B. Barreiro, H. K. Eriksen, K. M. Górski, R. Keskitalo, E. Komatsu, E. Martínez-González, D. Scott, P. Vielva, and I. K. Wehus

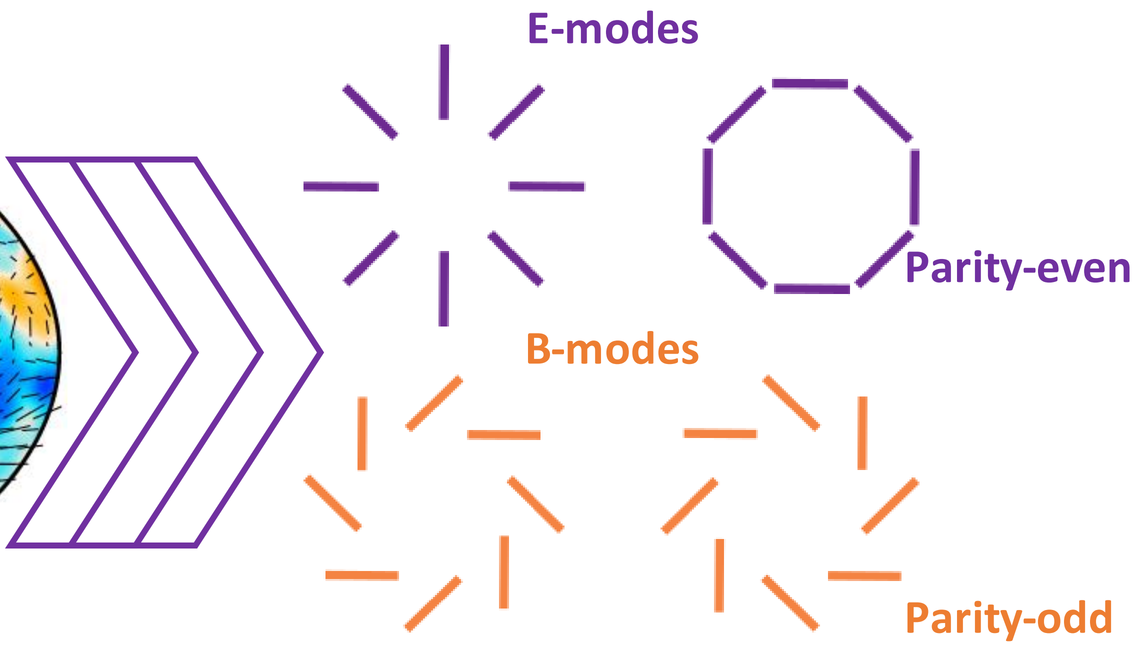
Based on
PDP et al 2022, PRL, 128, 091302
PDP et al 2022 in prep

From Planck to the future of CMB
Ferrara, Italy
May 23-27 2022

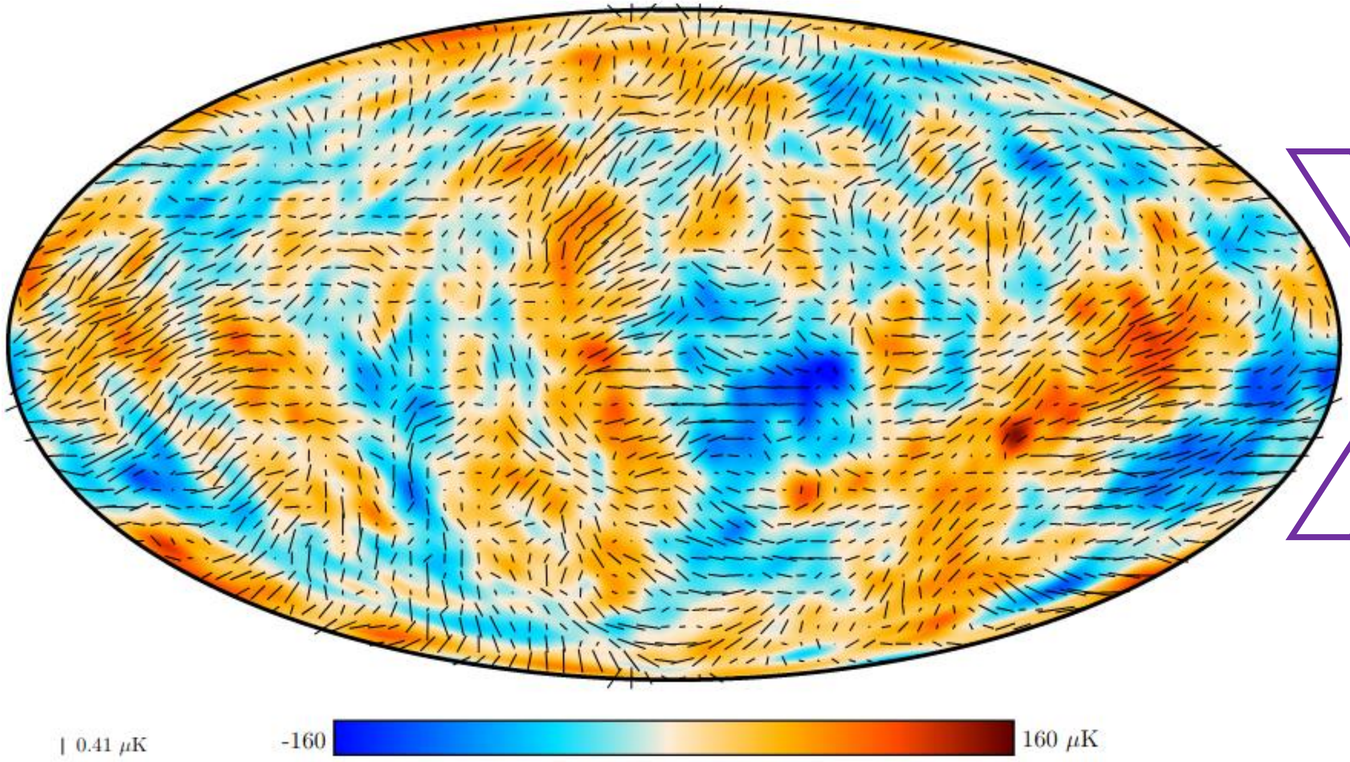
IFCA
EXCELENCIA MARÍA DE MAEZTU
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
UC UNIVERSIDAD DE CANTABRIA



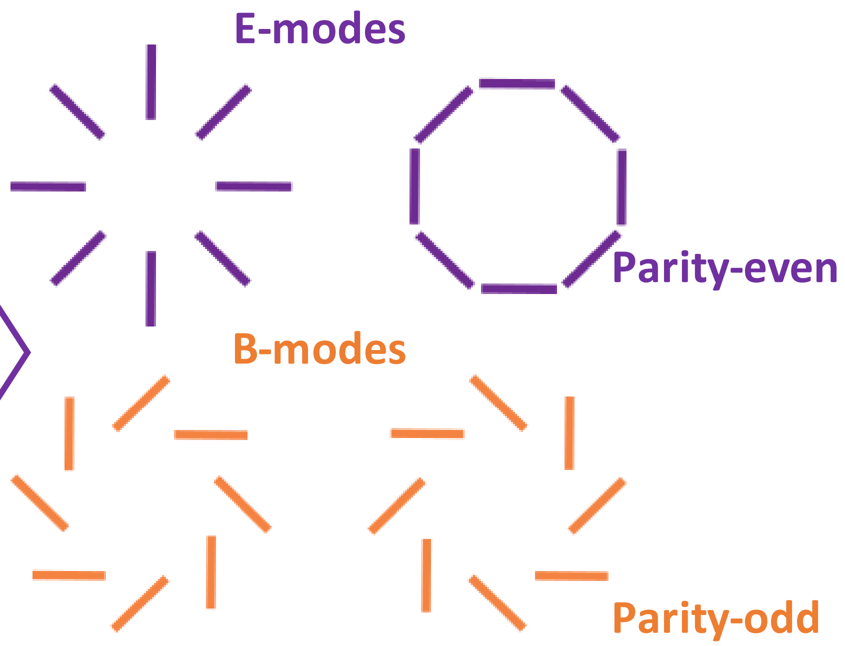
Planck Collaboration I. 2020, A&A, 641, A1



Zaldarriaga & Seljak 1997, PRD, 55, 1830
Kamionkowski et al 1997, PRD, 55, 7368



Planck Collaboration I. 2020, A&A, 641, A1



Zaldarriaga & Seljak 1997, PRD, 55, 1830
Kamionkowski et al 1997, PRD, 55, 7368

Analyzing CMB polarization in terms of spherical harmonics

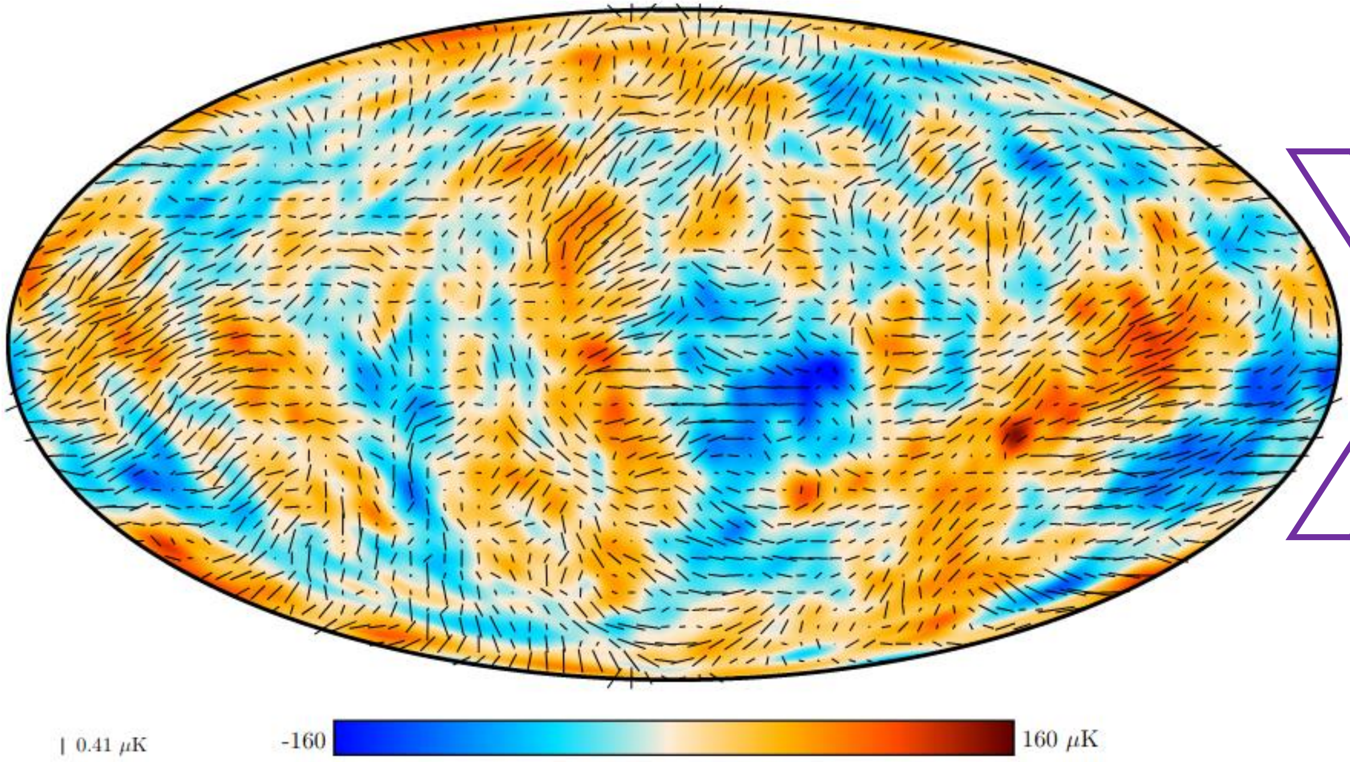
$$\langle E_{\ell m} E^*_{\ell' m'} \rangle = \delta_{mm'} \delta_{\ell\ell'} C_\ell^{EE}$$

$$\langle B_{\ell m} B^*_{\ell' m'} \rangle = \delta_{mm'} \delta_{\ell\ell'} C_\ell^{BB}$$

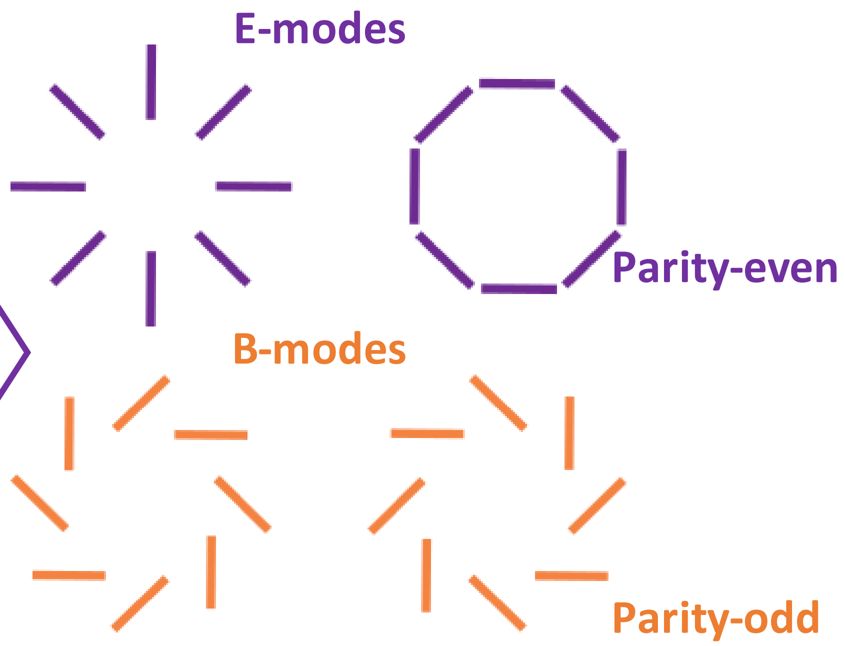
Parity-even

$$\langle E_{\ell m} B^*_{\ell' m'} \rangle = \delta_{mm'} \delta_{\ell\ell'} C_\ell^{EB}$$

Parity-odd



Planck Collaboration I. 2020, A&A, 641, A1



Zaldarriaga & Seljak 1997, PRD, 55, 1830
Kamionkowski et al 1997, PRD, 55, 7368

Analyzing CMB polarization in terms of spherical harmonics

$$\langle E_{\ell m} E^*_{\ell' m'} \rangle = \delta_{mm'} \delta_{\ell\ell'} C_\ell^{EE}$$
$$\langle B_{\ell m} B^*_{\ell' m'} \rangle = \delta_{mm'} \delta_{\ell\ell'} C_\ell^{BB}$$

Parity-even

$$\langle E_{\ell m} B^*_{\ell' m'} \rangle = \delta_{mm'} \delta_{\ell\ell'} C_\ell^{EB}$$

Parity-odd

ΛCDM

The Universe has no preferred direction so the statistics of CMB anisotropies must be invariant under parity transformation

EB≠0 evidence of parity-violating physics

Lue et al 1999, PRL, 83, 1506

DM/DE could be a parity-violating pseudoscalar field $\phi(-\vec{n}) = -\phi(\vec{n})$

Chern-Simons coupling to EM $\frac{1}{4} g_{\phi\gamma} \phi F_{\mu\nu} \tilde{F}_{\mu\nu}$

Carroll at al 1990, PRD, 41, 1231

Carroll & Field 1991, PRD, 43, 3789

Harari & Sikivie 1992, PLB, 289, 67

DM/DE could be a **parity-violating pseudoscalar field** $\phi(-\vec{n}) = -\phi(\vec{n})$

Carroll at al 1990, PRD, 41, 1231

Carroll & Field 1991, PRD, 43, 3789

Harari & Sikivie 1992, PLB, 289, 67

Chern-Simons coupling to EM $\frac{1}{4} g_{\phi\gamma} \phi F_{\mu\nu} \tilde{F}_{\mu\nu}$

rotation of the plane of linear polarization clockwise on the sky by an angle

$$\beta = -\frac{1}{2} g_{\phi\gamma} \int \frac{\partial \phi}{\partial t} dt$$

DM/DE could be a parity-violating pseudoscalar field $\phi(-\vec{n}) = -\phi(\vec{n})$

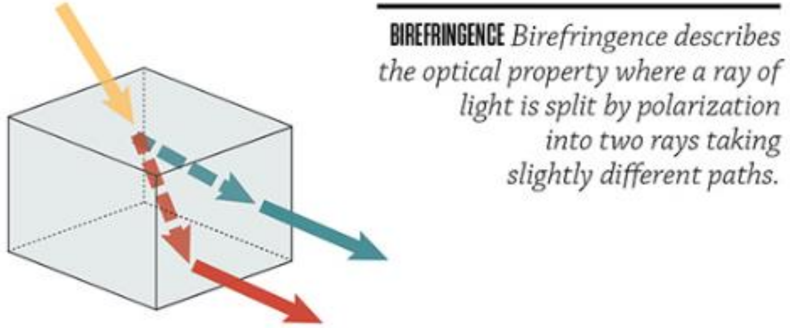
Carroll at al 1990, PRD, 41, 1231
Carroll & Field 1991, PRD, 43, 3789
Harari & Sikivie 1992, PLB, 289, 67

Chern-Simons coupling to EM $\frac{1}{4} g_{\phi\gamma} \phi F_{\mu\nu} \tilde{F}_{\mu\nu}$

rotation of the plane of linear polarization clockwise on the sky by an angle

$$\beta = -\frac{1}{2} g_{\phi\gamma} \int \frac{\partial \phi}{\partial t} dt$$

Cosmic birefringence



DM/DE could be a **parity-violating pseudoscalar field** $\phi(-\vec{n}) = -\phi(\vec{n})$

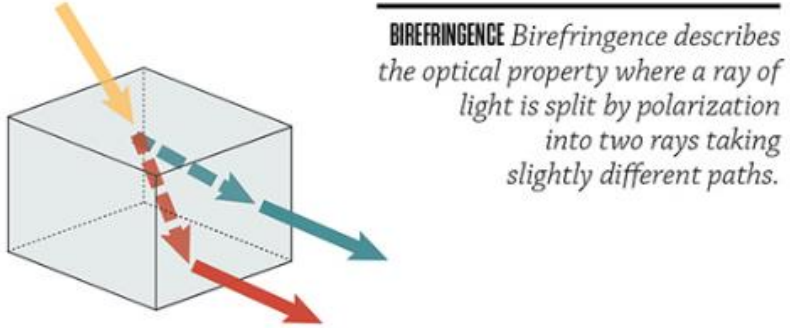
Chern-Simons coupling to EM $\frac{1}{4} g_{\phi\gamma} \phi F_{\mu\nu} \tilde{F}_{\mu\nu}$

Carroll at al 1990, PRD, 41, 1231
Carroll & Field 1991, PRD, 43, 3789
Harari & Sikivie 1992, PLB, 289, 67

rotation of the plane of linear polarization
clockwise on the sky by an angle

$$\beta = -\frac{1}{2} g_{\phi\gamma} \int \frac{\partial \phi}{\partial t} dt$$

Cosmic birefringence



Cosmic birefringence rotates the CMB signal

$$\begin{pmatrix} E^{\mathrm{o}}_{\ell m} \\ B^{\mathrm{o}}_{\ell m} \end{pmatrix} = \begin{pmatrix} \cos(2\beta) & -\sin(2\beta) \\ \sin(2\beta) & \cos(2\beta) \end{pmatrix} \begin{pmatrix} E^{\mathrm{cmb}}_{\ell m} \\ B^{\mathrm{cmb}}_{\ell m} \end{pmatrix}$$

so the observed angular power spectrum becomes

$$C_\ell^{EB,\mathrm{o}} = \frac{1}{2} \sin(4\beta) \left(C_\ell^{EE,\mathrm{cmb}} - C_\ell^{BB,\mathrm{cmb}} \right)$$

Any signal resembling EE found in EB could be attributed to cosmic birefringence

DM/DE could be a parity-violating pseudoscalar field $\phi(-\vec{n}) = -\phi(\vec{n})$

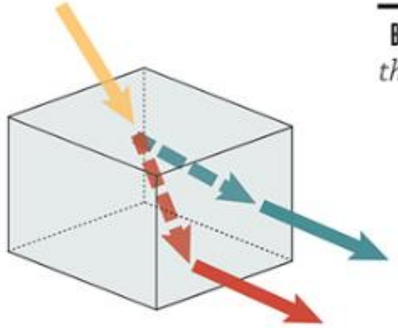
Carroll at al 1990, PRD, 41, 1231
Carroll & Field 1991, PRD, 43, 3789
Harari & Sikivie 1992, PLB, 289, 67

Chern-Simons coupling to EM $\frac{1}{4} g_{\phi\gamma} \phi F_{\mu\nu} \tilde{F}_{\mu\nu}$

rotation of the plane of linear polarization clockwise on the sky by an angle

$$\beta = -\frac{1}{2} g_{\phi\gamma} \int \frac{\partial \phi}{\partial t} dt$$

Cosmic birefringence



Cosmic birefringence rotates the CMB signal

$$\begin{pmatrix} E^{\rm o}_{\ell m} \\ B^{\rm o}_{\ell m} \end{pmatrix} = \begin{pmatrix} \cos(2\beta) & -\sin(2\beta) \\ \sin(2\beta) & \cos(2\beta) \end{pmatrix} \begin{pmatrix} E^{\rm cmb}_{\ell m} \\ B^{\rm cmb}_{\ell m} \end{pmatrix}$$

so the observed angular power spectrum becomes

$$C_\ell^{EB,{\rm o}} = \frac{1}{2} \sin(4\beta) \left(C_\ell^{EE,{\rm cmb}} - C_\ell^{BB,{\rm cmb}} \right)$$

$$C_\ell^{EB,{\rm o}} = \frac{1}{2} \tan(4\beta) \left(C_\ell^{EE,{\rm o}} - C_\ell^{BB,{\rm o}} \right)$$

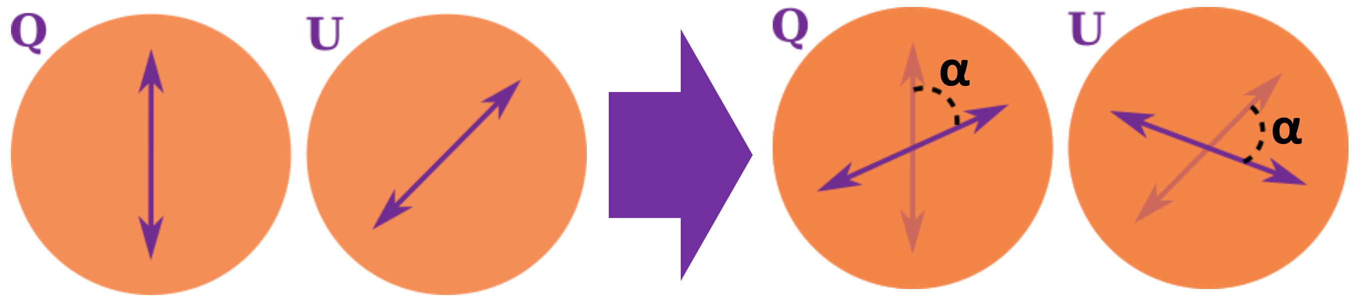
Any signal resembling EE found in EB could be attributed to cosmic birefringence

Base of most of the harmonic-space methodologies applied in the past

Miscalibration of the detector's polarization angle

Krachmalnicoff et al 2022, JCAP, 01, 039

Polarization-sensitive detector



Unknown α miscalibration

Completely degenerate with the birefringence

$$\begin{pmatrix} E^{\mathrm{o}}_{\ell m} \\ B^{\mathrm{o}}_{\ell m} \end{pmatrix} = \begin{pmatrix} \cos(2\alpha+2\beta) & -\sin(2\alpha+2\beta) \\ \sin(2\alpha+2\beta) & \cos(2\alpha+2\beta) \end{pmatrix} \begin{pmatrix} E^{\mathrm{cmb}}_{\ell m} \\ B^{\mathrm{cmb}}_{\ell m} \end{pmatrix}$$

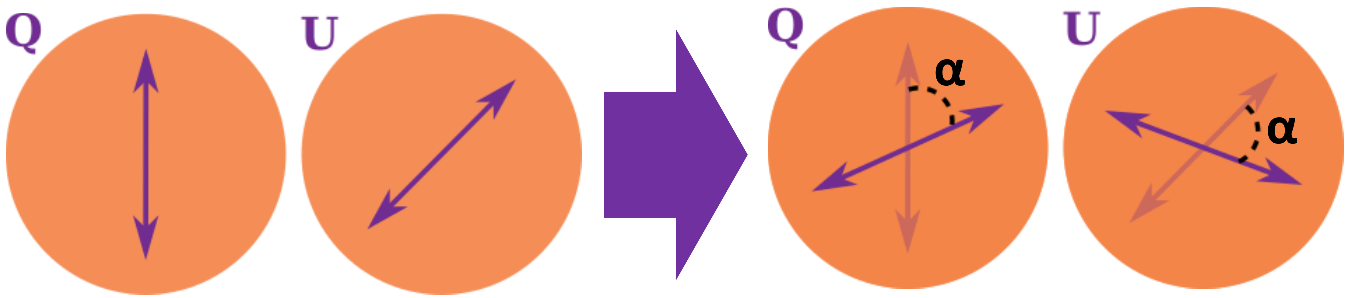
$$C_\ell^{EB,\mathrm{o}} = \frac{1}{2}\tan(4\alpha+4\beta)\left(C_\ell^{EE,\mathrm{o}} - C_\ell^{BB,\mathrm{o}}\right)$$

EB yields α+β

Miscalibration of the detector's polarization angle

Krachmalnicoff et al 2022, JCAP, 01, 039

Polarization-sensitive detector



Unknown α miscalibration

Completely degenerate with the birefringence

$$\begin{pmatrix} E^{\mathrm{o}}_{\ell m} \\ B^{\mathrm{o}}_{\ell m} \end{pmatrix} = \begin{pmatrix} \cos(2\alpha + 2\beta) & -\sin(2\alpha + 2\beta) \\ \sin(2\alpha + 2\beta) & \cos(2\alpha + 2\beta) \end{pmatrix} \begin{pmatrix} E^{\mathrm{cmb}}_{\ell m} \\ B^{\mathrm{cmb}}_{\ell m} \end{pmatrix}$$

$$C_\ell^{EB,\mathrm{o}} = \frac{1}{2} \tan(4\alpha + 4\beta) \left(C_\ell^{EE,\mathrm{o}} - C_\ell^{BB,\mathrm{o}} \right)$$

EB yields α+β

Spurious TB and EB correlations can also be produced by

- **intensity-to-polarization leakage**
- **beam leakage**
- **cross-polarization effects**

Miller et al 2009, PRD, 79, 103002

Past measurements

early WMAP & BOOMERANG	$\beta = -6.0° \pm 4.0°$ (stat) $\pm$?? (sys)	Feng et al 2006, PRL, 96, 221302
QUaD	$\beta = 0.55° \pm 0.82°$ (stat) $\pm 0.5°$ (sys)	Wu et al 2009, PRL, 102, 161302
WMAP 9-year	$\beta = -0.36° \pm 1.24°$ (stat) $\pm 1.5°$ (sys)	Hinshaw et al 2013, ApJS, 208, 19
Planck 2015	$\beta = 0.31° \pm 0.05°$ (stat) $\pm 0.28°$ (sys)	*Planck* Collaboration XLIX. 2016, A&A, 596, A110

⋮

Often dominated by systematic uncertainties

Calibration strategies set a ≈ 0.5° - 1° limit

Past measurements

early WMAP & BOOMERANG	β = - 6.0°	± 4.0° (stat) ± ?? (sys)	Feng et al 2006, PRL, 96, 221302
QUaD	β = 0.55°	± 0.82° (stat) ± 0.5° (sys)	Wu et al 2009, PRL, 102, 161302
WMAP 9-year	β = - 0.36°	± 1.24° (stat) ± 1.5° (sys)	Hinshaw et al 2013, ApJS, 208, 19
Planck 2015	β = 0.31°	± 0.05° (stat) ± 0.28° (sys)	*Planck* Collaboration XLIX. 2016, A&A, 596, A110

⋮

Often dominated by systematic uncertainties

Calibration strategies set a ≈ 0.5° - 1° limit

Birefringence depends on the propagation length of photons

Use Galactic foreground emission as our calibrator

Minami et al 2019, PTEP, 083E02

Minami et al 2019, PTEP, 083E02
Minami 2020, PTEP, 063E01
Minami & Komatsu 2020, PTEP, 103E02

Observed signal is a rotation of the CMB and Galactic foreground emissions

$$\begin{pmatrix} E^{\rm o}_{\ell m} \\ B^{\rm o}_{\ell m} \end{pmatrix} = \begin{pmatrix} \cos(2\alpha) & -\sin(2\alpha) \\ \sin(2\alpha) & \cos(2\alpha) \end{pmatrix} \begin{pmatrix} E^{\rm fg}_{\ell m} \\ B^{\rm fg}_{\ell m} \end{pmatrix} + \begin{pmatrix} \cos(2\alpha+2\beta) & -\sin(2\alpha+2\beta) \\ \sin(2\alpha+2\beta) & \cos(2\alpha+2\beta) \end{pmatrix} \begin{pmatrix} E^{\rm cmb}_{\ell m} \\ B^{\rm cmb}_{\ell m} \end{pmatrix}$$

so the observed EB is

$$C_\ell^{EB,{\rm o}} = \frac{\tan(4\alpha)}{2}\left(C_\ell^{EE,{\rm o}} - C_\ell^{BB,{\rm o}}\right) + \frac{1}{\cos(4\alpha)} C_\ell^{EB,{\rm fg}} + \frac{\sin(4\beta)}{2\cos(4\alpha)}\left(C_\ell^{EE,{\rm cmb}} - C_\ell^{BB,{\rm cmb}}\right)$$

Minami et al 2019, PTEP, 083E02
Minami 2020, PTEP, 063E01
Minami & Komatsu 2020, PTEP, 103E02

Observed signal is a rotation of the CMB and Galactic foreground emissions

$$\begin{pmatrix} E^{\mathrm{o}}_{\ell m} \\ B^{\mathrm{o}}_{\ell m} \end{pmatrix} = \begin{pmatrix} \cos(2\alpha) & -\sin(2\alpha) \\ \sin(2\alpha) & \cos(2\alpha) \end{pmatrix} \begin{pmatrix} E^{\mathrm{fg}}_{\ell m} \\ B^{\mathrm{fg}}_{\ell m} \end{pmatrix} + \begin{pmatrix} \cos(2\alpha+2\beta) & -\sin(2\alpha+2\beta) \\ \sin(2\alpha+2\beta) & \cos(2\alpha+2\beta) \end{pmatrix} \begin{pmatrix} E^{\mathrm{cmb}}_{\ell m} \\ B^{\mathrm{cmb}}_{\ell m} \end{pmatrix}$$

so the observed EB is

Experimental constraints

Planck Collaboration XI. 2020, A&A, 641, A11
Martire et al 2022, JCAP, 04, 003

$$C_\ell^{EB,\mathrm{o}} = \frac{\tan(4\alpha)}{2}\left(C_\ell^{EE,\mathrm{o}} - C_\ell^{BB,\mathrm{o}}\right) + \frac{1}{\cos(4\alpha)} C_\ell^{EB,\mathrm{fg}} + \frac{\sin(4\beta)}{2\cos(4\alpha)}\left(C_\ell^{EE,\mathrm{cmb}} - C_\ell^{BB,\mathrm{cmb}}\right)$$

0

Minami et al 2019, PTEP, 083E02
Minami 2020, PTEP, 063E01
Minami & Komatsu 2020, PTEP, 103E02

Observed signal is a rotation of the CMB and Galactic foreground emissions

$$\begin{pmatrix} E^{\rm o}_{\ell m} \\ B^{\rm o}_{\ell m} \end{pmatrix} = \begin{pmatrix} \cos(2\alpha) & -\sin(2\alpha) \\ \sin(2\alpha) & \cos(2\alpha) \end{pmatrix} \begin{pmatrix} E^{\rm fg}_{\ell m} \\ B^{\rm fg}_{\ell m} \end{pmatrix} + \begin{pmatrix} \cos(2\alpha+2\beta) & -\sin(2\alpha+2\beta) \\ \sin(2\alpha+2\beta) & \cos(2\alpha+2\beta) \end{pmatrix} \begin{pmatrix} E^{\rm cmb}_{\ell m} \\ B^{\rm cmb}_{\ell m} \end{pmatrix}$$

so the observed EB is

Experimental constraints

Planck Collaboration XI. 2020, A&A, 641, A11
Martire et al 2022, JCAP, 04, 003

$$C_\ell^{EB,{\rm o}} = \frac{\tan(4\alpha)}{2}\left(C_\ell^{EE,{\rm o}} - C_\ell^{BB,{\rm o}}\right) + \frac{1}{\cos(4\alpha)} C_\ell^{EB,{\rm fg}} + \frac{\sin(4\beta)}{2\cos(4\alpha)}\left(C_\ell^{EE,{\rm cmb}} - C_\ell^{BB,{\rm cmb}}\right)$$

0

Build a Gaussian likelihood to simultaneously determine both angles

$$-2\ln\mathcal{L} = \sum_{b=1}^{N_{\rm bins}} \left(\mathbf{A}\bar{C}^{\rm o}_b - \mathbf{B}\bar{C}^{\rm cmb}_b\right)^T \mathbf{M}_b^{-1} \left(\mathbf{A}\bar{C}^{\rm o}_b - \mathbf{B}\bar{C}^{\rm cmb}_b\right) + \sum_{b=1}^{N_{\rm bins}} \ln|\mathbf{M}_b|$$

Cross-correlation of frequency bands of any CMB experiment

$$\bar{C}^{\rm o}_b = \left(C_b^{E_iE_j,{\rm o}} \; C_b^{B_iB_j,{\rm o}} \; C_b^{E_iB_j,{\rm o}}\right)^T$$

Theoretical prediction for CMB angular power spectra

$$\bar{C}^{\rm cmb}_b = \left(C_b^{EE,{\rm cmb}} b_b^i b_b^j \omega^2_{b,{\rm pix}} \; C_b^{BB,{\rm cmb}} b_b^i b_b^j \omega^2_{b,{\rm pix}}\right)^T$$

Covariance matrix

$$\mathbf{M}_\ell = \mathbf{A}{\rm Cov}\left(\bar{C}^{\rm o}_\ell, \bar{C}^{{\rm o}T}_\ell\right)\mathbf{A}^T$$

Rotation matrices

$$\mathbf{A}(\alpha_i,\alpha_j) = \begin{pmatrix} \frac{-\sin(4\alpha_j)}{\cos(4\alpha_i)+\cos(4\alpha_j)} & \frac{\sin(4\alpha_i)}{\cos(4\alpha_i)+\cos(4\alpha_j)} & 1 \end{pmatrix}$$

$$\mathbf{B}(\alpha_i,\alpha_j,\beta) = \frac{\sin(4\beta)}{2\cos(2\alpha_i+2\alpha_j)}\begin{pmatrix} 1 & -1 \end{pmatrix}$$

Planck PR4 (NPIPE reprocessing)

Reprocessing of raw LFI and HFI *Planck* data
Scale-dependent reduction of total uncertainty due to
- Addition of data acquired during repointing maneuvers
- Improved modeling of instrumental noise and systematics

Planck Collaboration 2020, A&A, 643, A42

- NPIPE 100, 143, 217, 353 GHz data
- Focus on high-ℓ data to target the birefringence angle from recombination → bin C_ℓ/M_ℓ from ℓ_{min}=51 to ℓ_{max}=1490 with $\Delta\ell$ = 20 spacing
- A/B detector splits → β, α_i (i=1,…,8)
- Start by considering a null foreground EB

Planck PR4 (NPIPE reprocessing)

Reprocessing of raw LFI and HFI *Planck* data

Scale-dependent reduction of total uncertainty due to

- Addition of data acquired during repointing maneuvers
- Improved modeling of instrumental noise and systematics

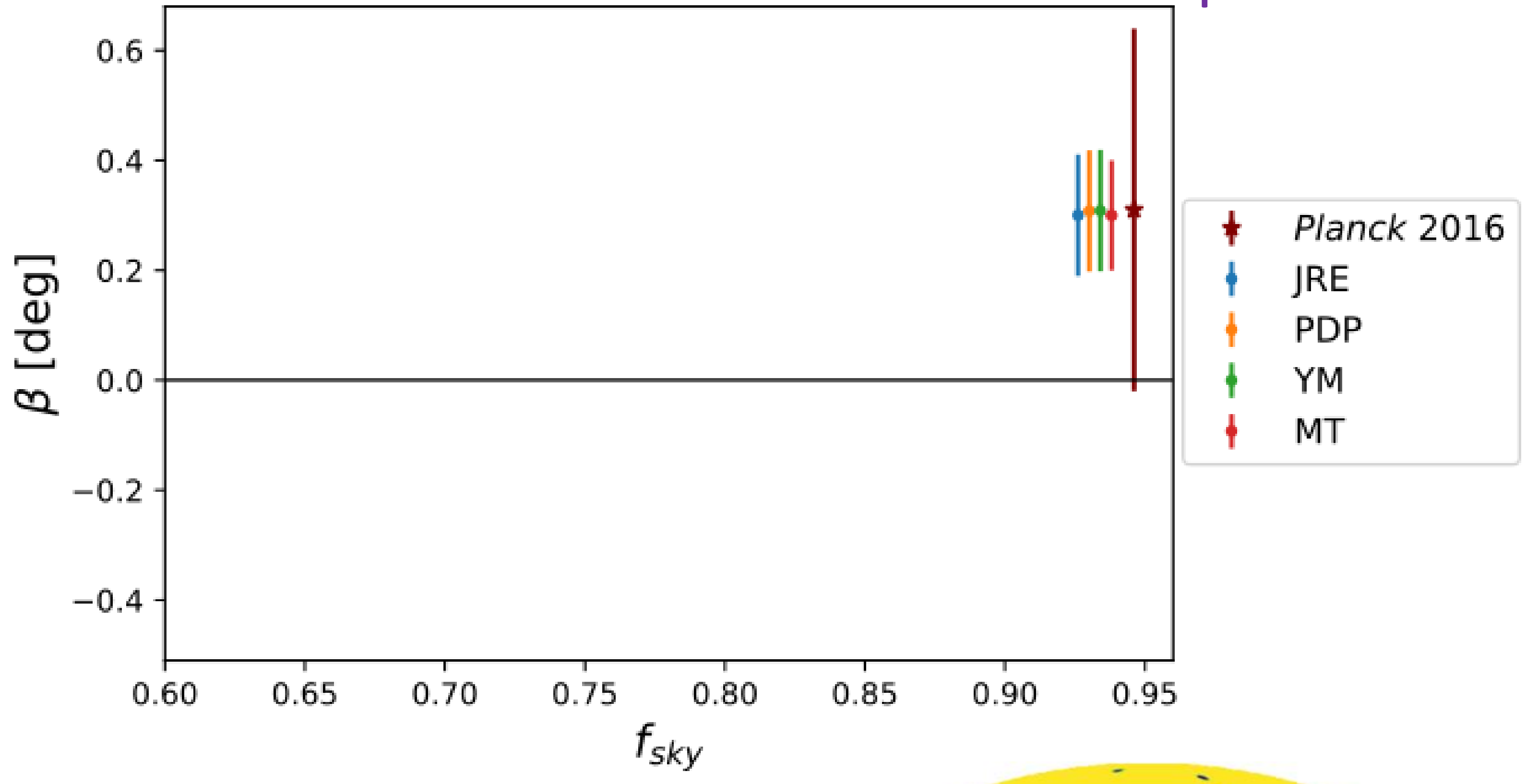
Planck Collaboration 2020, A&A, 643, A42

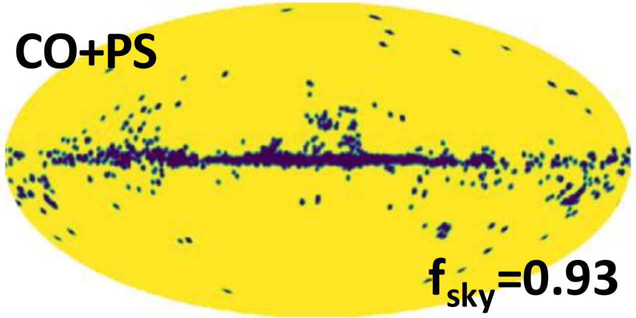
- NPIPE 100, 143, 217, 353 GHz data
- Focus on high-ℓ data to target the birefringence angle from recombination → bin C_ℓ/M_ℓ from ℓ_{min}=51 to ℓ_{max}=1490 with $\Delta\ell$ = 20 spacing
- A/B detector splits → β, α_i (i=1,…,8)
- Start by considering a null foreground EB

Consistent results across 4 independent pipelines

Pipeline	Implementation	Pseudo-C_ℓ
JRE	Posterior distribution via MCMC	PolSpice
MT	Posterior distribution via MCMC	Xpol
YM	Posterior distribution via MCMC	NaMaster
PDP	Analytical minimization	NaMaster

For nearly full-sky: β = 0.30° ± 0.11° (2.7σ) → Consistent with and more precise than previous measurements!

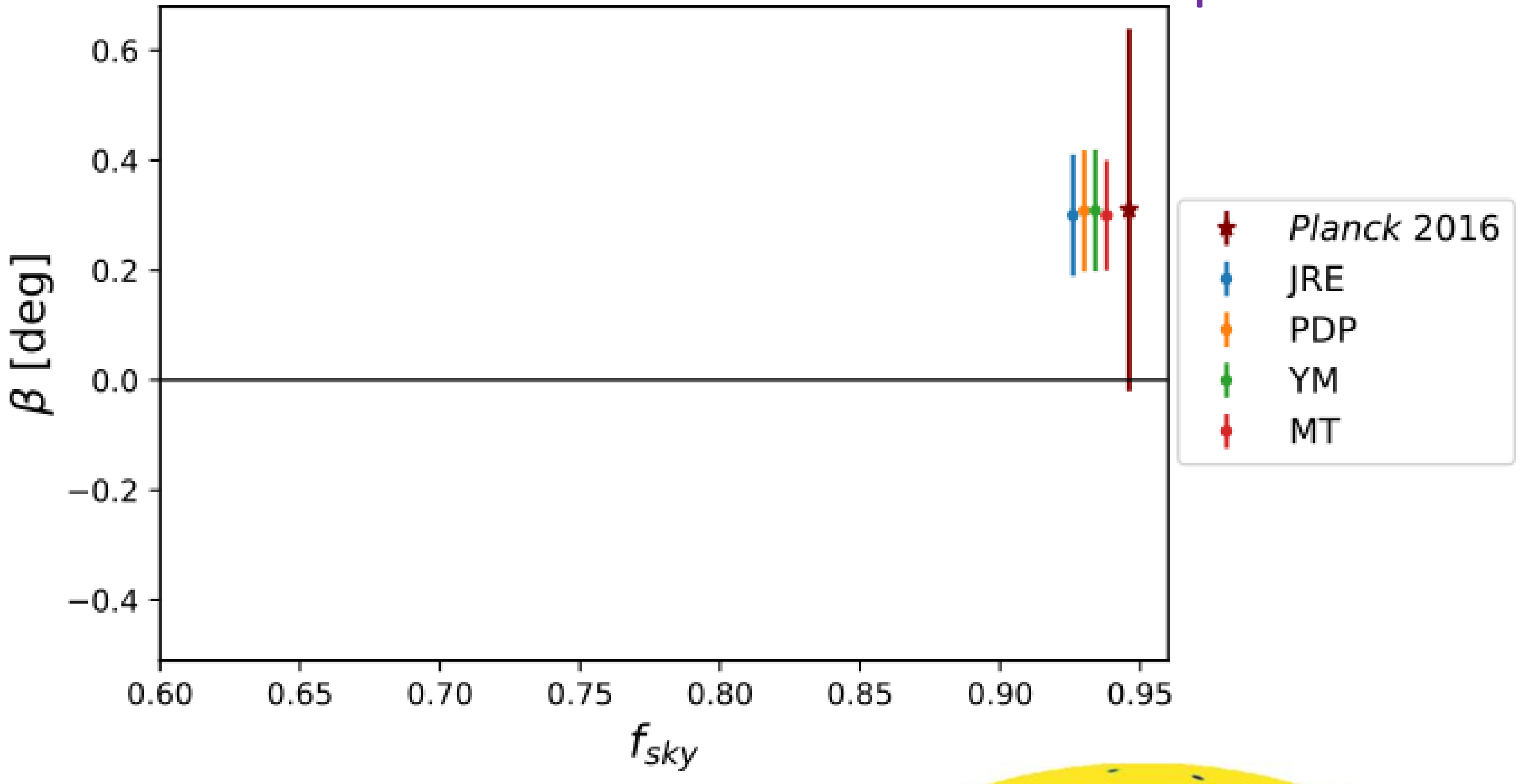


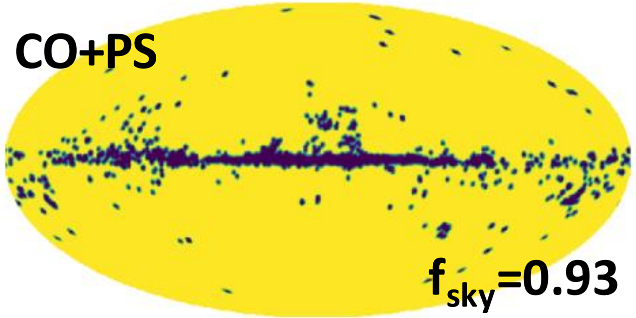


For nearly full-sky: β = 0.30° ± 0.11° (2.7σ) → Consistent with and more precise than previous measurements!

α & β are an isotropic rotation of the whole sky

We expect compatible angles from different regions of the sky

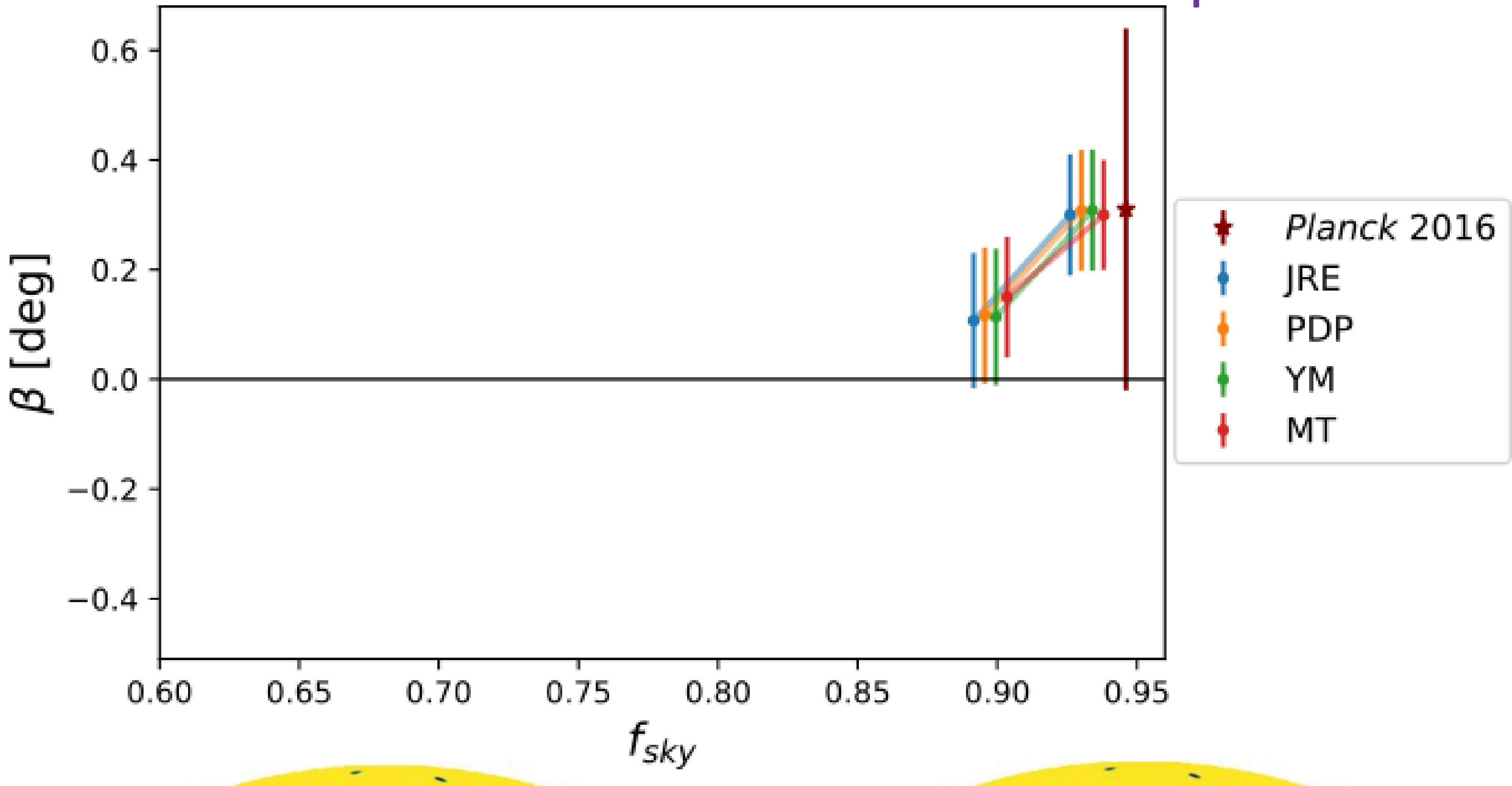


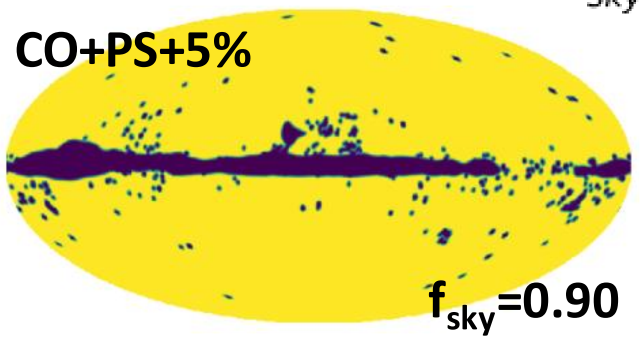


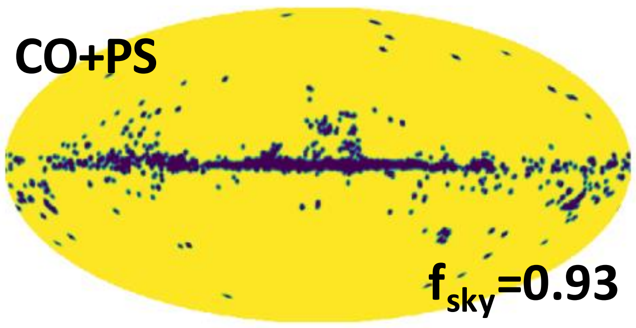
For nearly full-sky: β = 0.30° ± 0.11° (2.7σ) → Consistent with and more precise than previous measurements!

α & β are an isotropic rotation of the whole sky

We expect compatible angles from different regions of the sky



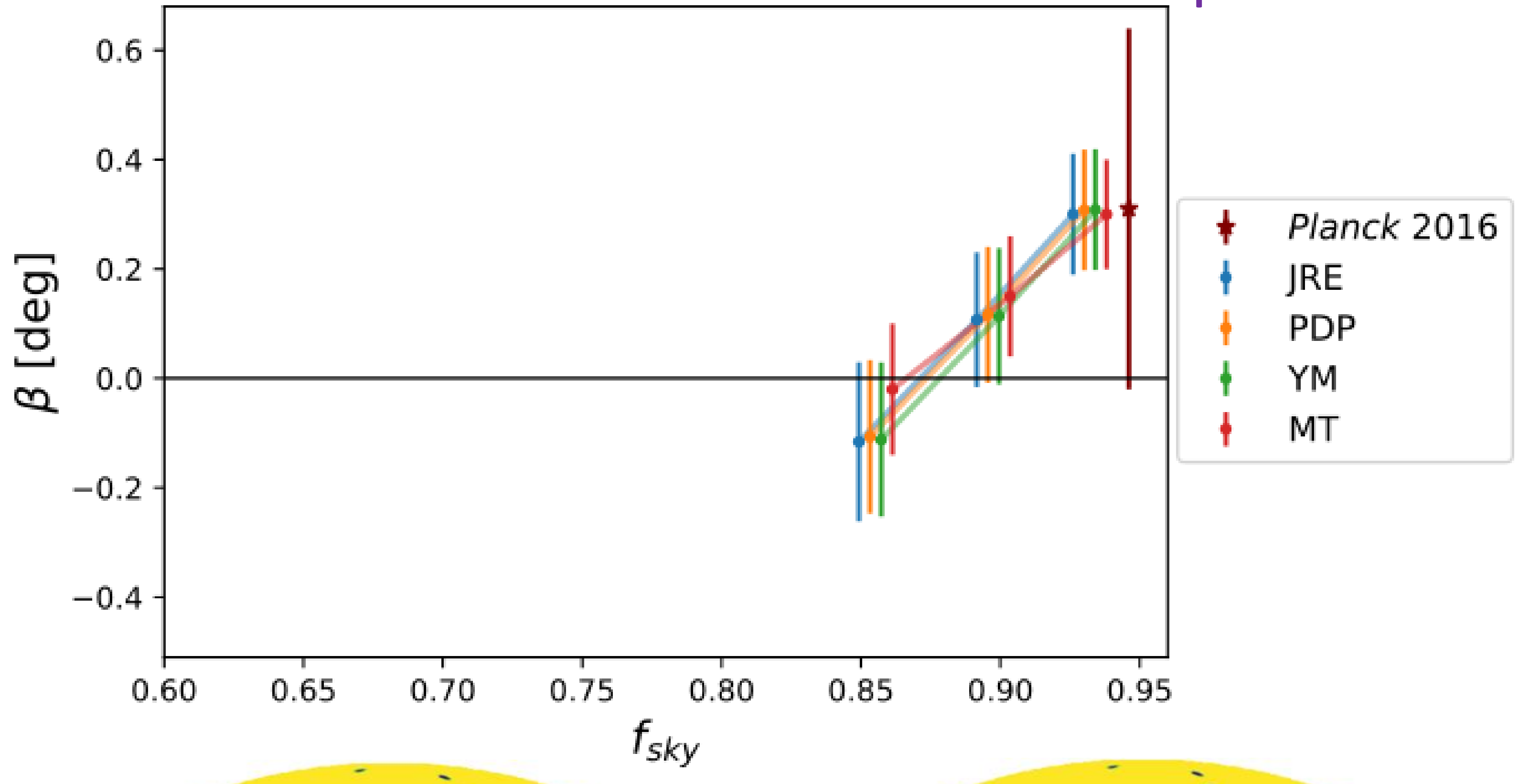


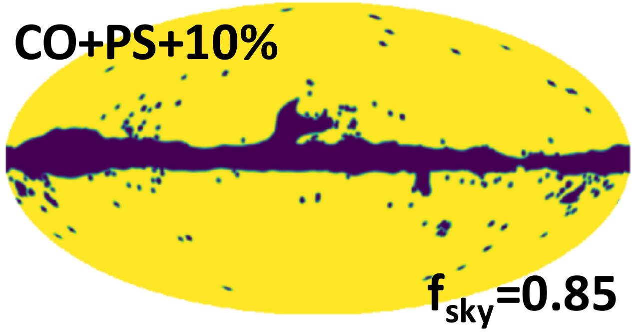


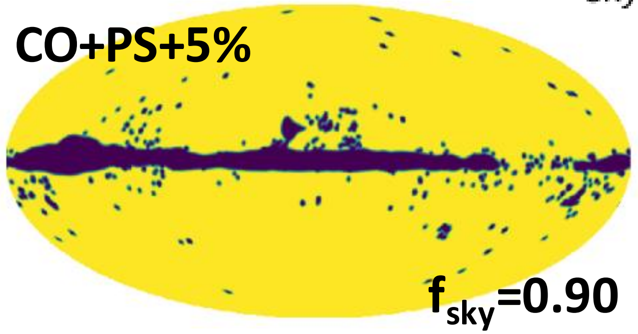
For nearly full-sky: β = 0.30° ± 0.11° (2.7σ) → Consistent with and more precise than previous measurements!

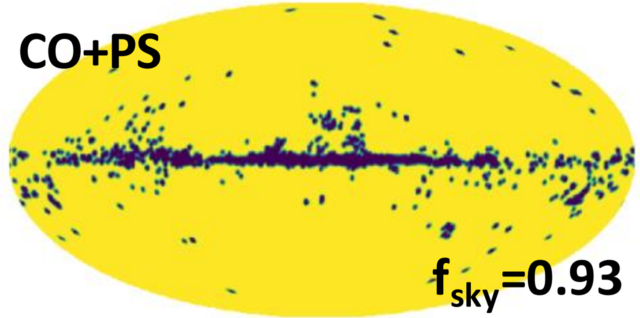
α & β are an isotropic rotation of the whole sky

We expect compatible angles from different regions of the sky





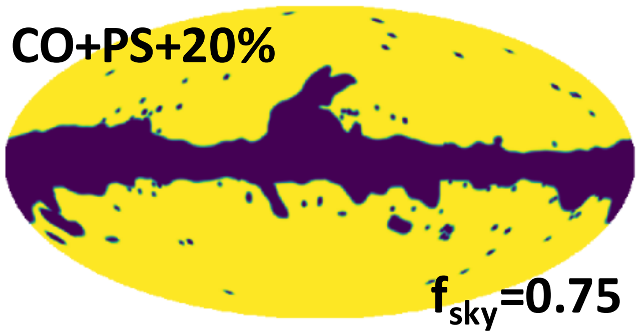


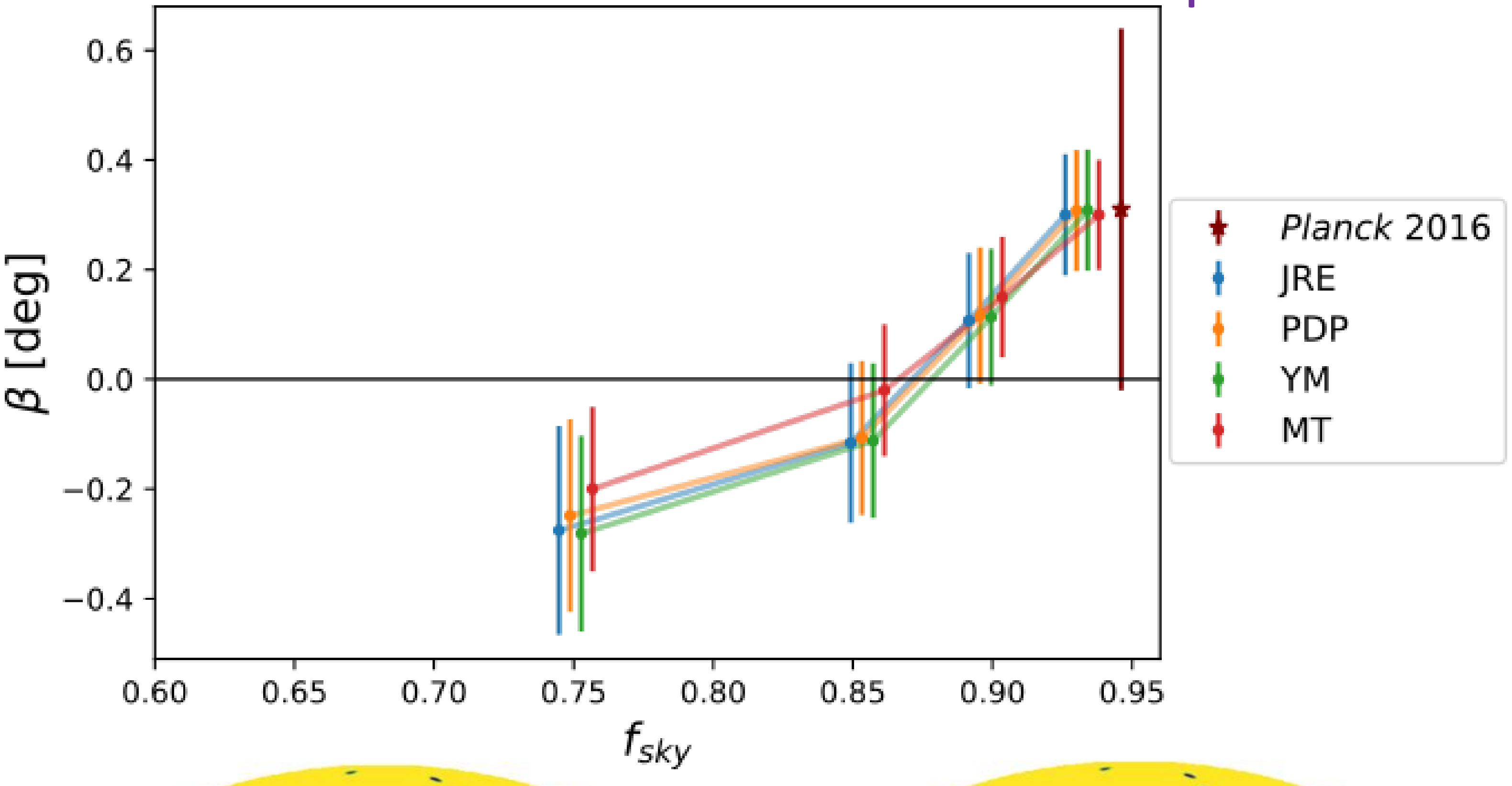


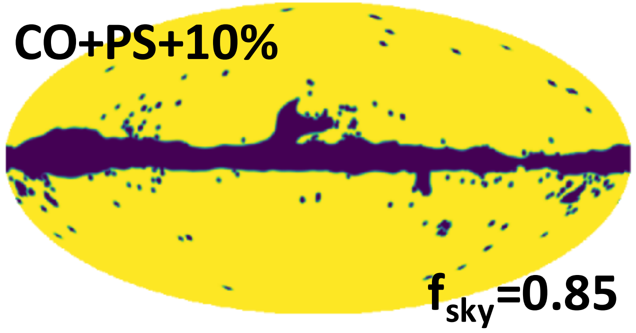
For nearly full-sky: β = 0.30° ± 0.11° (2.7σ) → Consistent with and more precise than previous measurements!

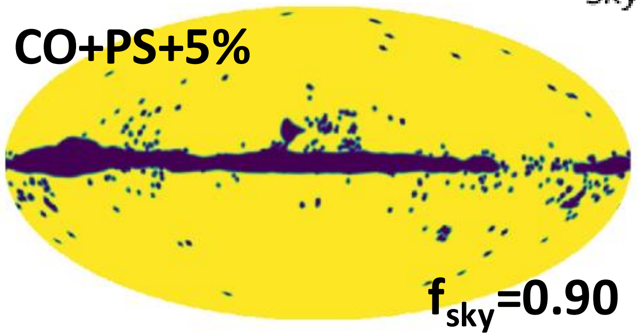
α & β are an isotropic rotation of the whole sky

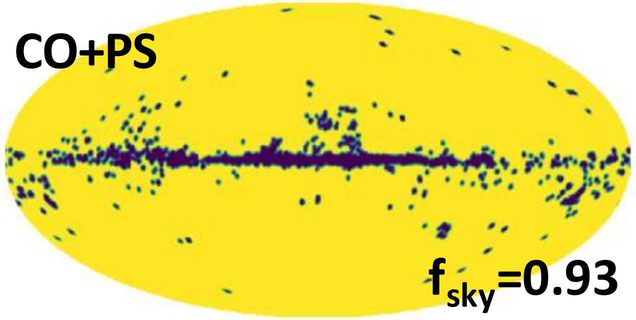
We expect compatible angles from different regions of the sky



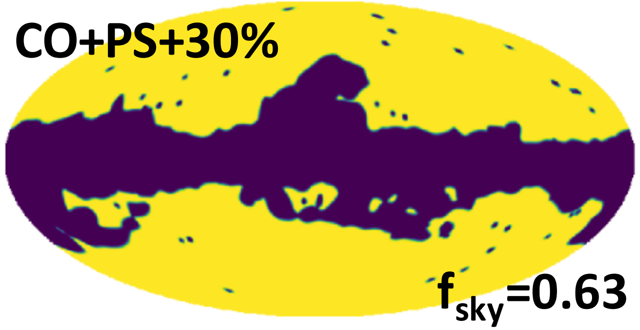


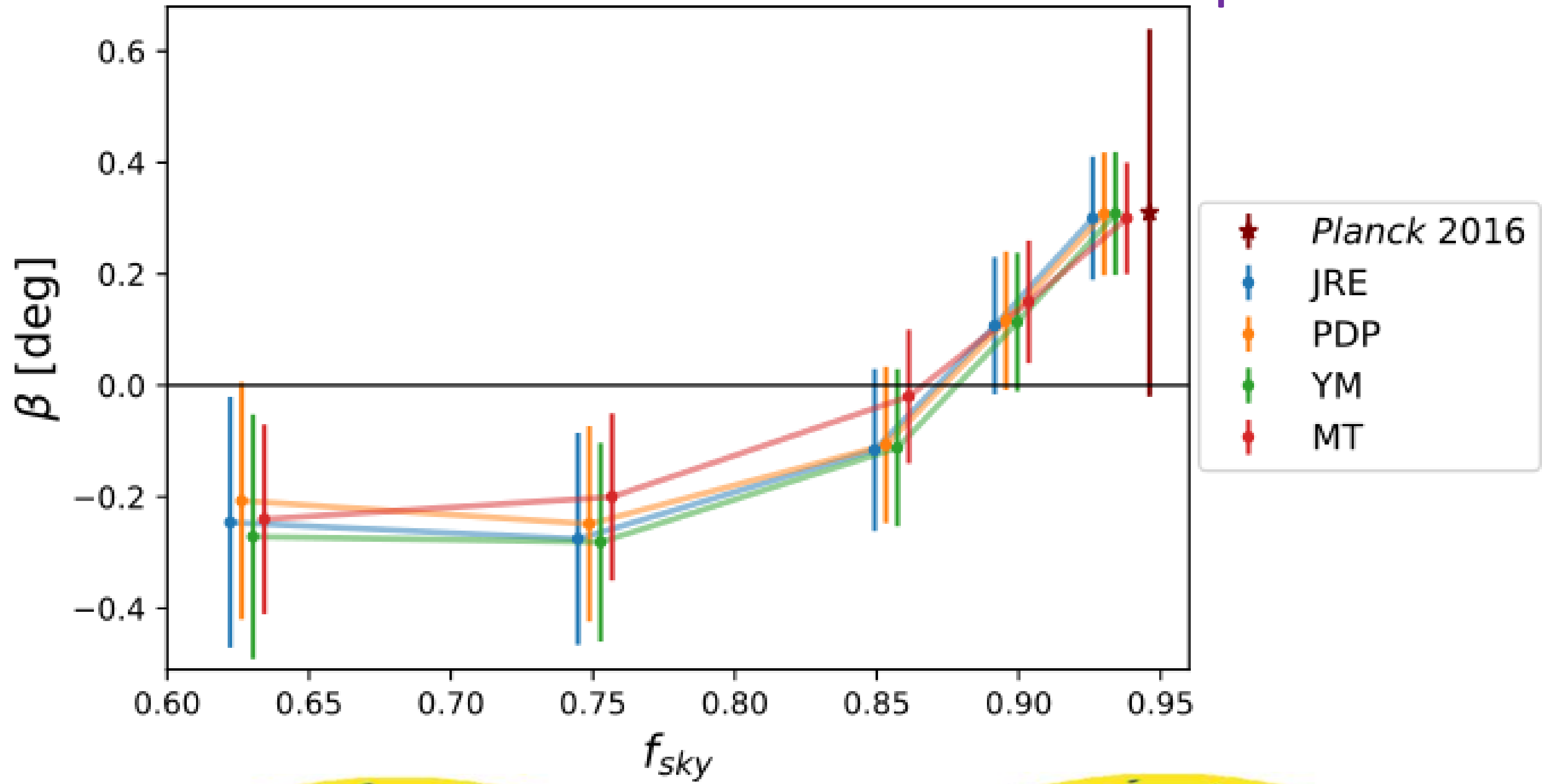


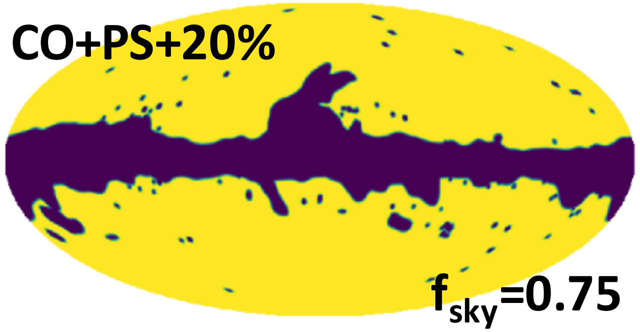


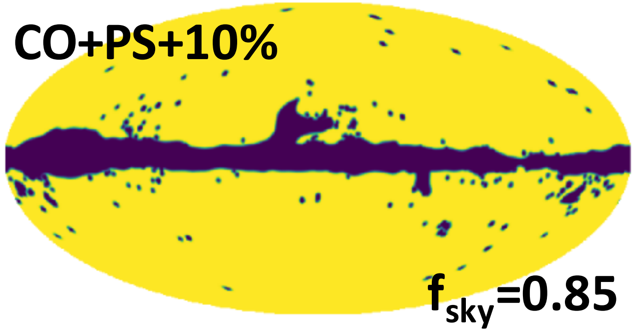


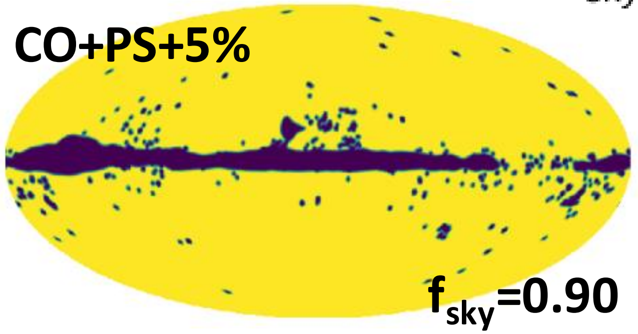
For nearly full-sky: β = 0.30° ± 0.11° (2.7σ) → Consistent with and more precise than previous measurements!

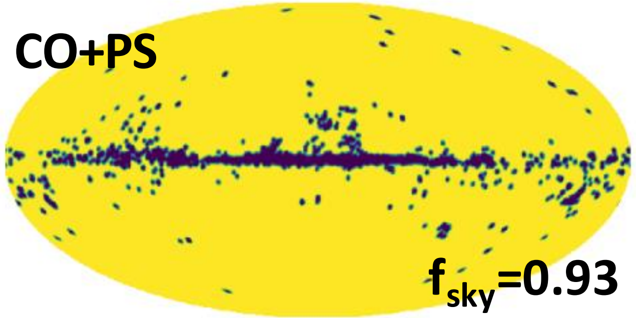




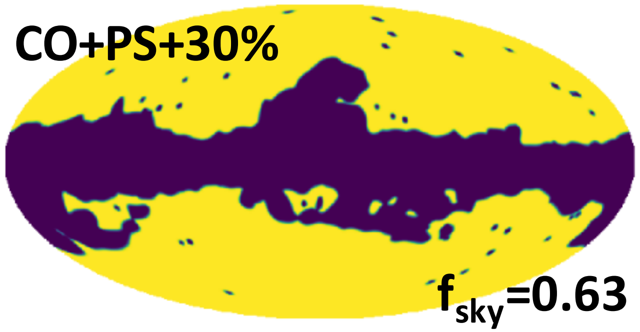


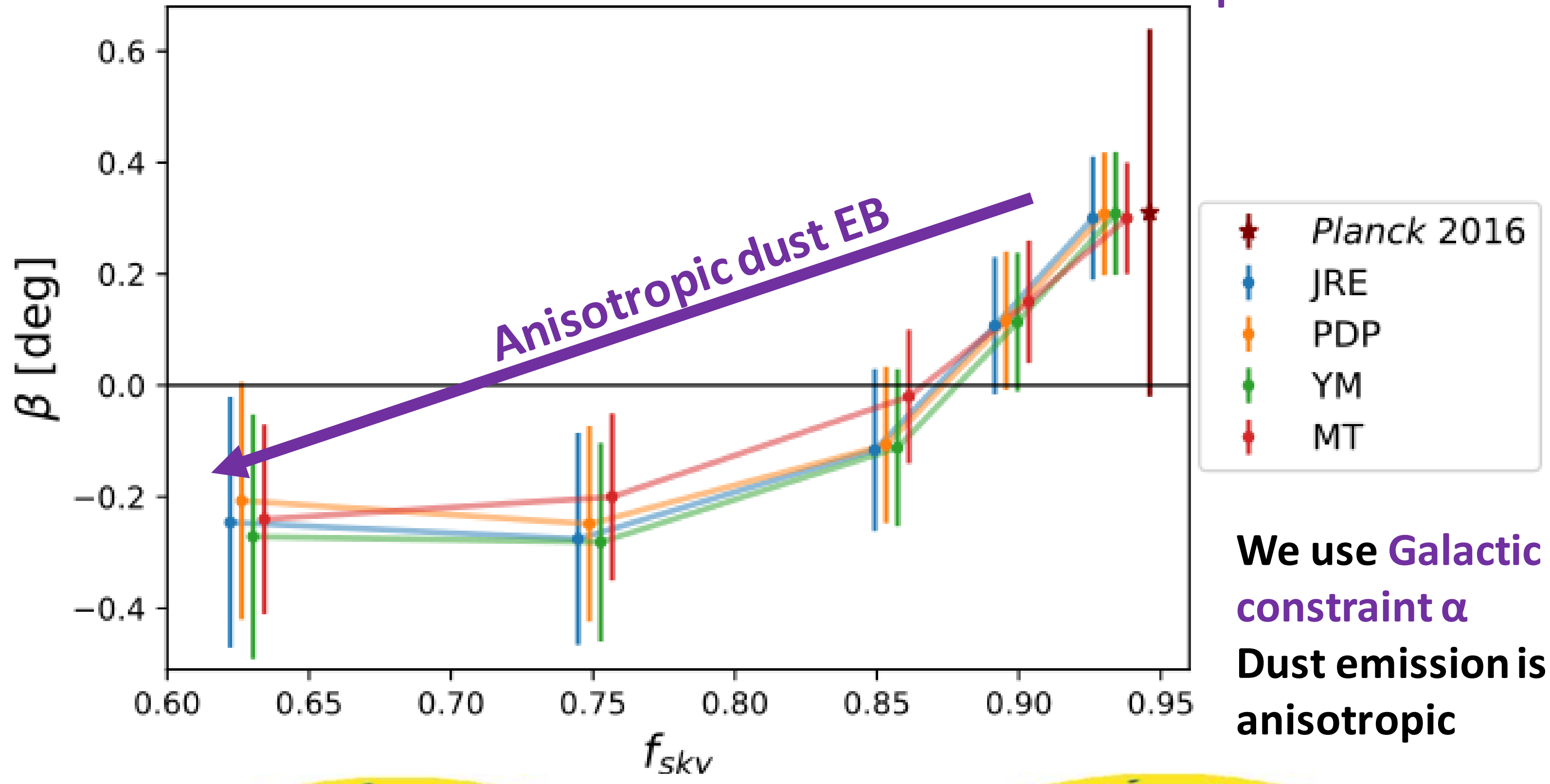






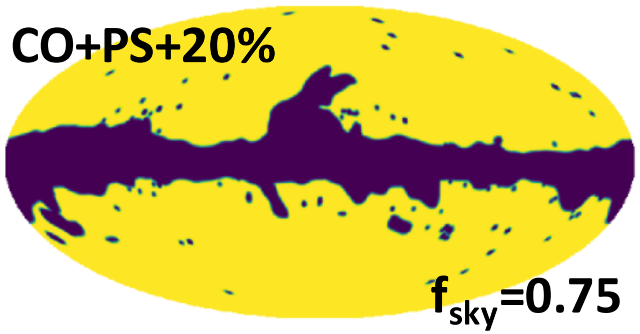
For nearly full-sky: β = 0.30° ± 0.11° (2.7σ) → Consistent with and more precise than previous measurements!

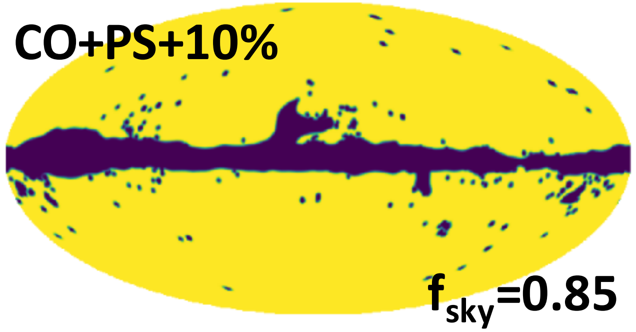


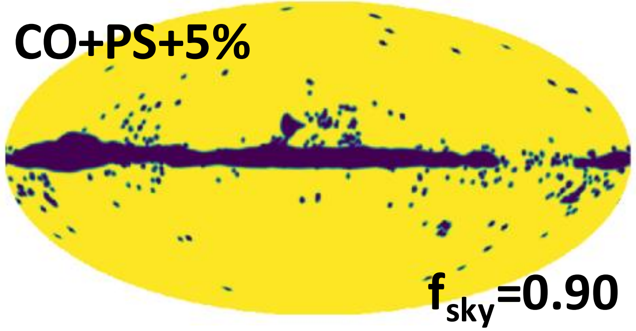


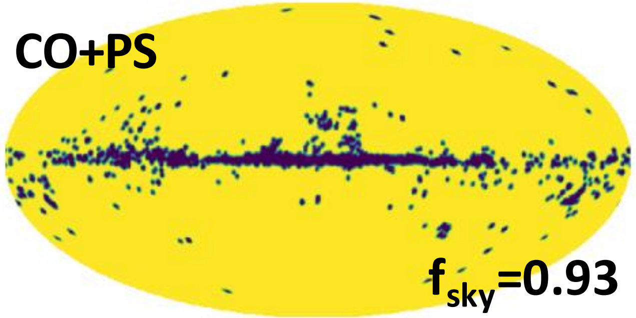
We use Galactic dust to constraint α

Dust emission is highly anisotropic



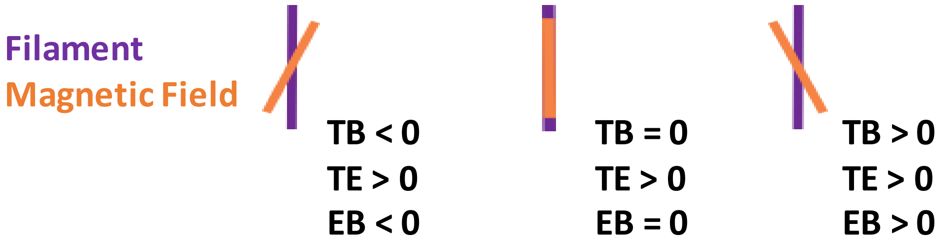






Clark et al 2021, ApJ, 919, 53

Misalignment between the filamentary dust structures of the ISM and the plane-of-sky orientation of the Galactic magnetic field



Sign and magnitude of EB can be predicted from EE, TE, and TB

$$C_\ell^{EB,\mathrm{dust}} \approx 2A_\ell C_\ell^{EE,\mathrm{dust}} \frac{C_\ell^{TB,\mathrm{dust}}}{C_\ell^{TE,\mathrm{dust}}}$$

Take dust C_ℓ to be that of NPIPE @ 353GHz

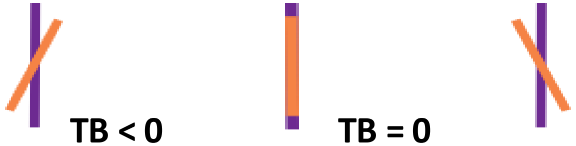
A_ℓ **free amplitude parameter**

$$0 \leq A_\ell \ll 1$$

Clark et al 2021, ApJ, 919, 53

Misalignment between the filamentary dust structures of the ISM and the plane-of-sky orientation of the Galactic magnetic field

Filament
Magnetic Field



TB < 0	TB = 0	TB > 0
TE > 0	TE > 0	TE > 0
EB < 0	EB = 0	EB > 0

Sign and magnitude of EB can be predicted from EE, TE, and TB

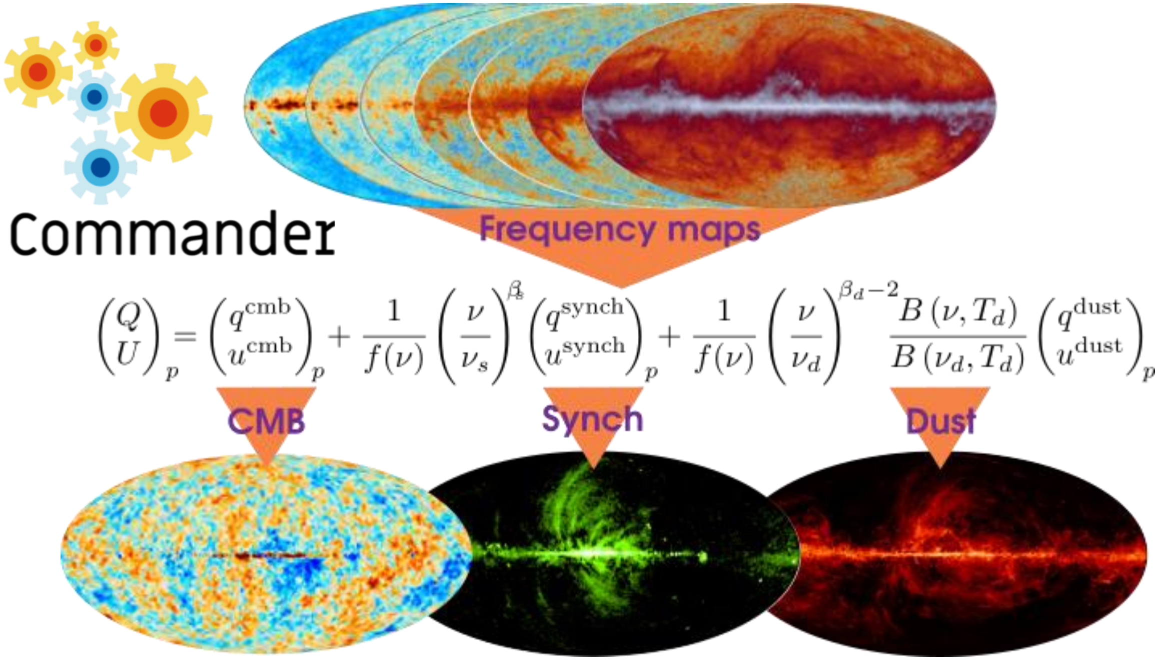
$$C_\ell^{EB,\mathrm{dust}} \approx 2A_\ell C_\ell^{EE,\mathrm{dust}} \frac{C_\ell^{TB,\mathrm{dust}}}{C_\ell^{TE,\mathrm{dust}}}$$

Take dust C_ℓ to be that of NPIPE @ 353GHz

A_ℓ **free amplitude parameter**

$$0 \leq A_\ell \ll 1$$

Take the Commander sky model as our foreground model

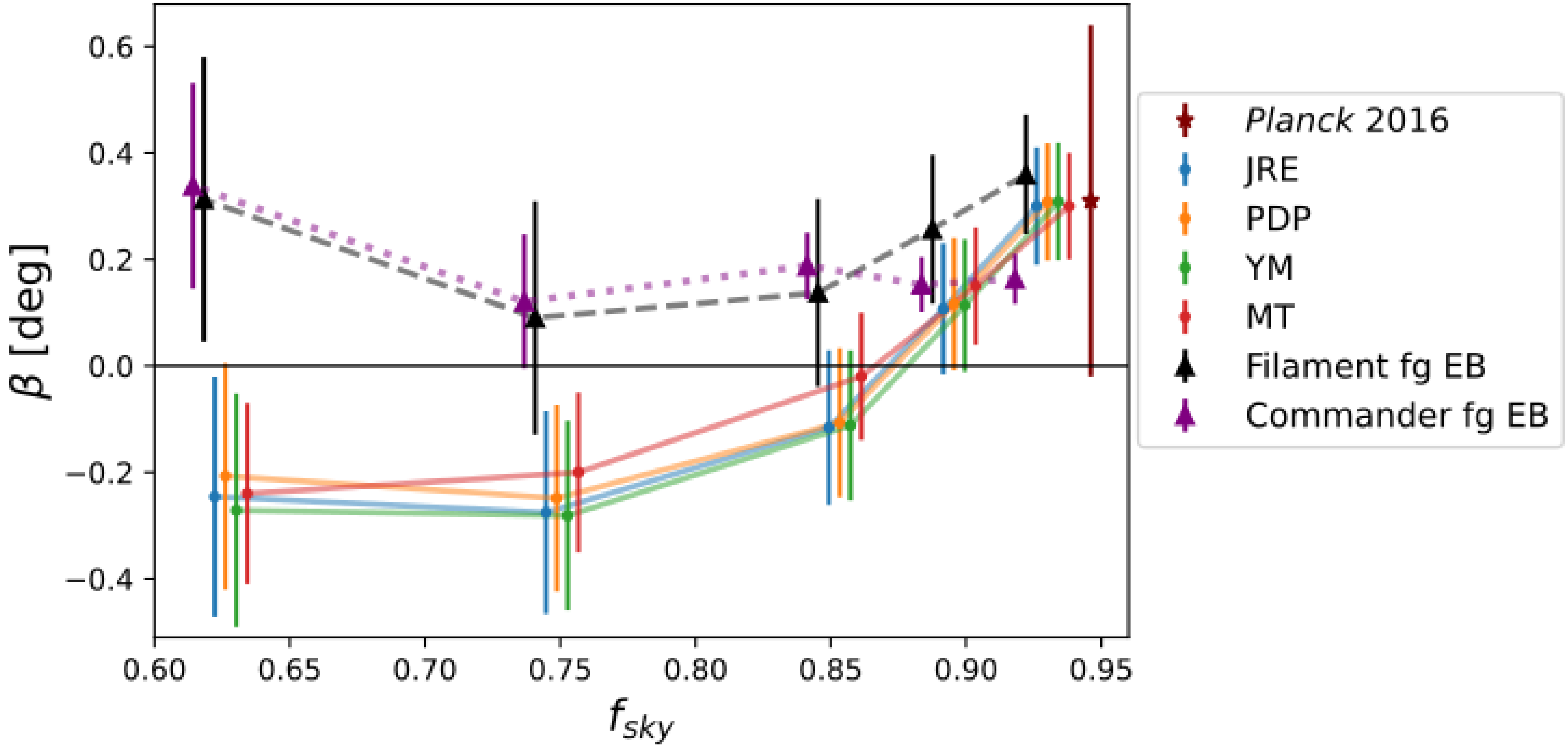


Planck Collaboration IV. 2020, A&A, 641, A4

$$C_\ell^{EB,\mathrm{dust}} \approx \mathcal{D} C_\ell^{EB,\mathtt{Commander}}$$

$\mathcal{D}$ **free amplitude parameter**

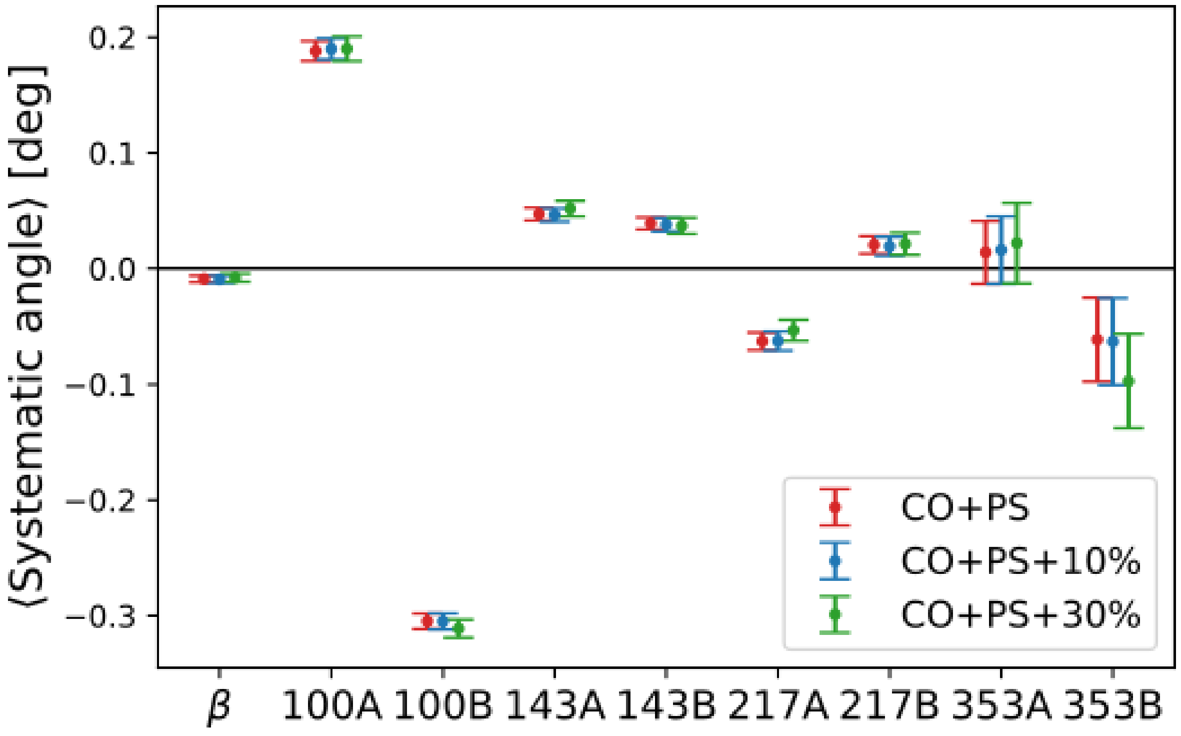
$\beta>0$ for all f_{sky}, confirming that the decline was caused by dust EB



Good agreement except at f_{sky}=0.93 → complexity of dust emission near the Galactic plane not fully captured by Commander sky model

Quantifying systematics using NPIPE end-to-end simulations

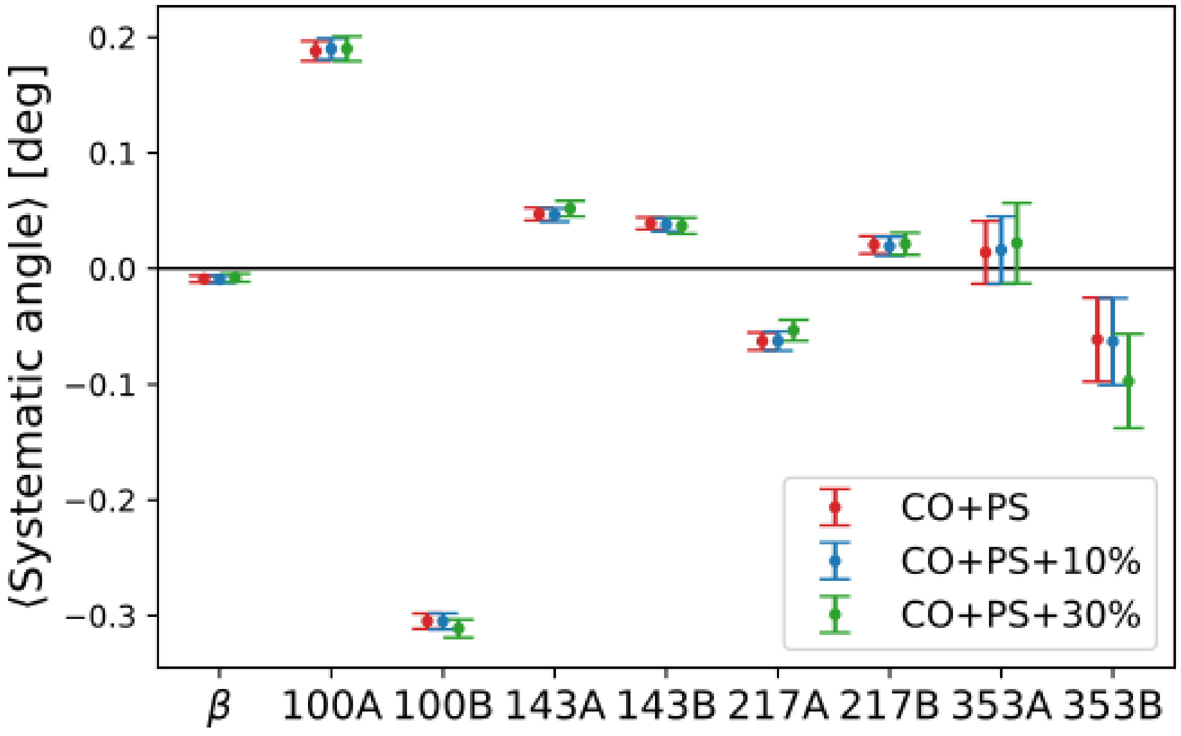
Simulations of CMB + Noise + Systematics



Average over 100 simulations
Error bar = simulations' dispersion / sqrt(100)

Quantifying systematics using NPIPE end-to-end simulations

Simulations of CMB + Noise + Systematics

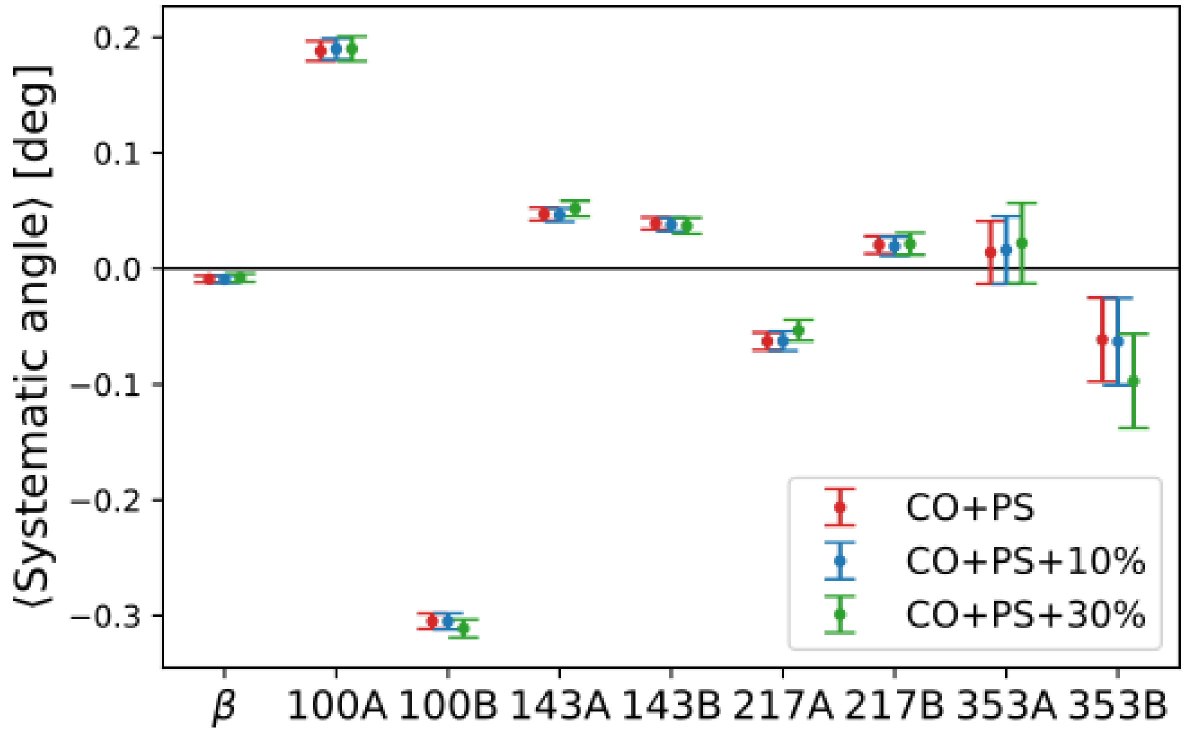


None of the known systematics produce the decrease on β seen as we enlarge the Galactic mask

Average over 100 simulations
Error bar = simulations' dispersion / sqrt(100)

Quantifying systematics using NPIPE end-to-end simulations

Simulations of CMB + Noise + Systematics



Average over 100 simulations
Error bar = simulations' dispersion / sqrt(100)

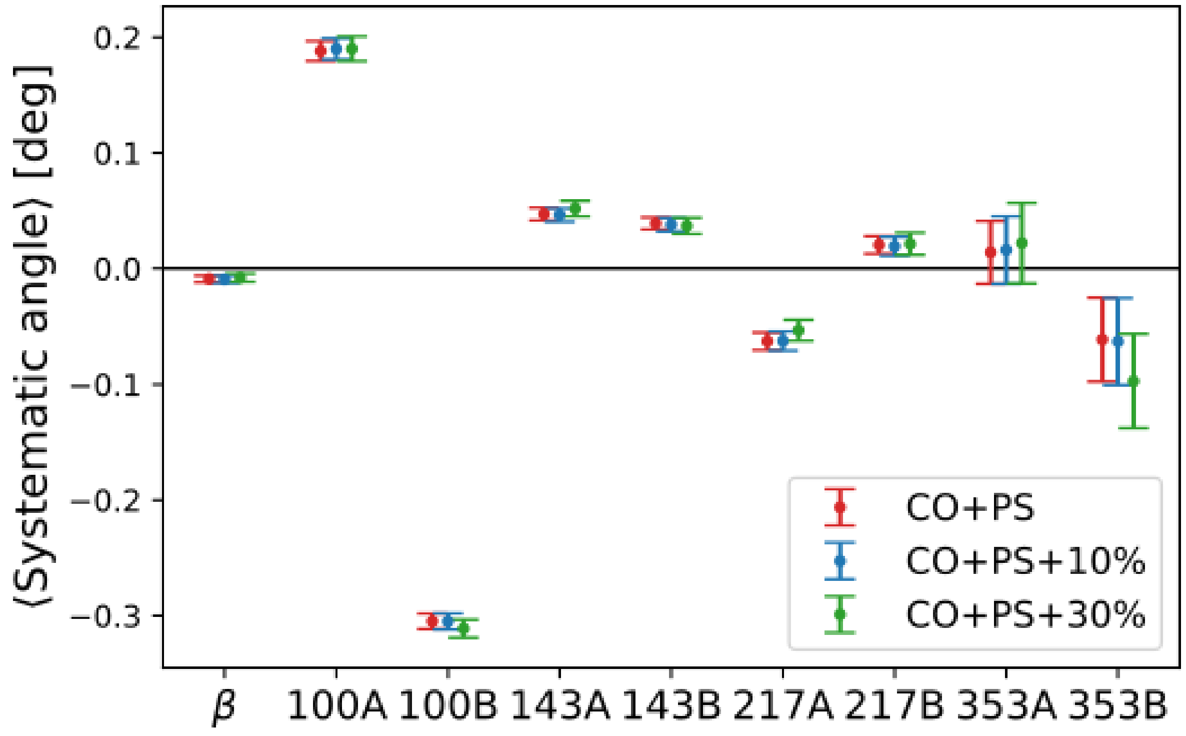
None of the known systematics produce the decrease on β seen as we enlarge the Galactic mask

	From simulations	σ_{stat} in fit to data
$\langle\alpha_{100A}\rangle$ =	0.188° ± 0.009°	0.13°
$\langle\alpha_{100B}\rangle$ =	- 0.305° ± 0.007°	0.12°

→ cross-polarization effect

Quantifying systematics using NPIPE end-to-end simulations

Simulations of CMB + Noise + Systematics



Average over 100 simulations
Error bar = simulations' dispersion / sqrt(100)

None of the known systematics produce the decrease on β seen as we enlarge the Galactic mask

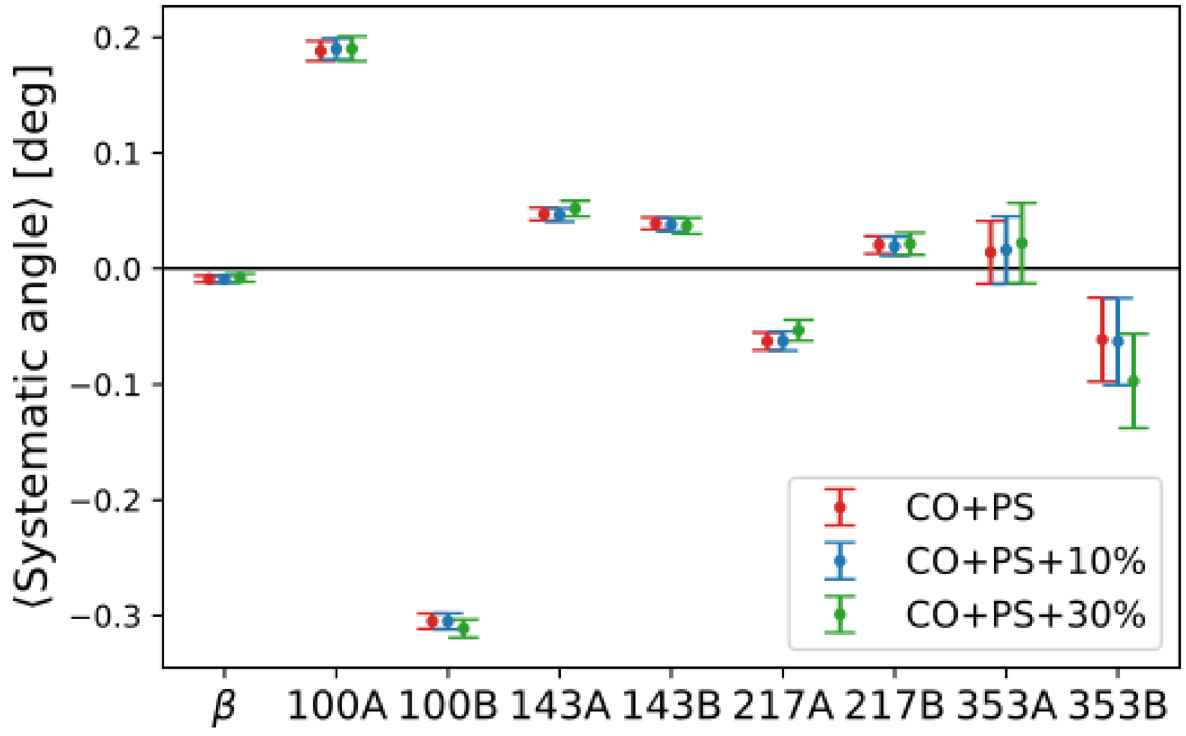
	From simulations	σ_{stat} in fit to data
$\langle\alpha_{100A}\rangle$ =	0.188° ± 0.009°	0.13°
$\langle\alpha_{100B}\rangle$ =	- 0.305° ± 0.007°	0.12°

→ cross-polarization effect

α_{sys} don't need to agree with data
→ simulations can't include the actual α_i present in the data

Quantifying systematics using NPIPE end-to-end simulations

Simulations of CMB + Noise + Systematics



Average over 100 simulations
Error bar = simulations' dispersion / sqrt(100)

None of the known systematics produce the decrease on β seen as we enlarge the Galactic mask

	From simulations	σ_{stat} in fit to data
$\langle\alpha_{100A}\rangle =$	$0.188° \pm 0.009°$	0.13°
$\langle\alpha_{100B}\rangle =$	$-0.305° \pm 0.007°$	0.12°

→ cross-polarization effect

α_{sys} don't need to agree with data

→ simulations can't include the actual α_i present in the data

Negligible impact on β

$\langle\beta_{sys}\rangle =$	$-0.009° \pm 0.003°$	0.11°

Conclusions

Our methodology provides a systematic-free measurement of birefringence...

$\beta = 0.30° \pm 0.11°$ (stat) $\pm 0.009°$ (sys) for nearly full-sky data (2.7σ)

vs previous harmonic-space methods $\beta = 0.31° \pm 0.05°$ (stat) $\pm 0.28°$ (sys)

***Planck* Collaboration XLIX. 2016, A&A, 596, A110**

Conclusions

Our methodology provides a systematic-free measurement of birefringence...

β = 0.30° ± 0.11° (stat) ± 0.009° (sys) for nearly full-sky data (2.7σ)

vs previous harmonic-space methods β = 0.31° ± 0.05° (stat) ± 0.28° (sys)

***Planck* Collaboration XLIX. 2016, A&A, 596, A110**

... but it's quite sensitive to the EB correlation of Galactic foreground emission

Dust EB produces a decrease of β as we enlarge the Galactic mask

Conclusions

Our methodology provides a systematic-free measurement of birefringence...

$\beta = 0.30° \pm 0.11°$ (stat) $\pm 0.009°$ (sys) for nearly full-sky data (2.7σ)

vs previous harmonic-space methods $\beta = 0.31° \pm 0.05°$ (stat) $\pm 0.28°$ (sys)

Planck Collaboration XLIX. 2016, A&A, 596, A110

... but it's quite sensitive to the EB correlation of Galactic foreground emission

Dust EB produces a decrease of β as we enlarge the Galactic mask

Results are promising, but we do not assign cosmological significance to the measured value of β until we improve our knowledge of the foreground polarization

Conclusions

Our methodology provides a systematic-free measurement of birefringence...

$\beta = 0.30° \pm 0.11°$ (stat) $\pm 0.009°$ (sys) for nearly full-sky data (2.7σ)

vs previous harmonic-space methods $\beta = 0.31° \pm 0.05°$ (stat) $\pm 0.28°$ (sys)

Planck Collaboration XLIX. 2016, A&A, 596, A110

... but it's quite sensitive to the EB correlation of Galactic foreground emission

Dust EB produces a decrease of β as we enlarge the Galactic mask

Results are promising, but we do not assign cosmological significance to the measured value of β until we improve our knowledge of the foreground polarization

To be confirmed as a cosmological signal ...

- Search for β in independent datasets, especially full-sky missions such as LiteBIRD
- Impulse on EB science for current/future CMB experiments

Importance of high-fidelity end-to-end simulations