Optimization of the next generation of Cosmic Microwave Background (CMB) missions

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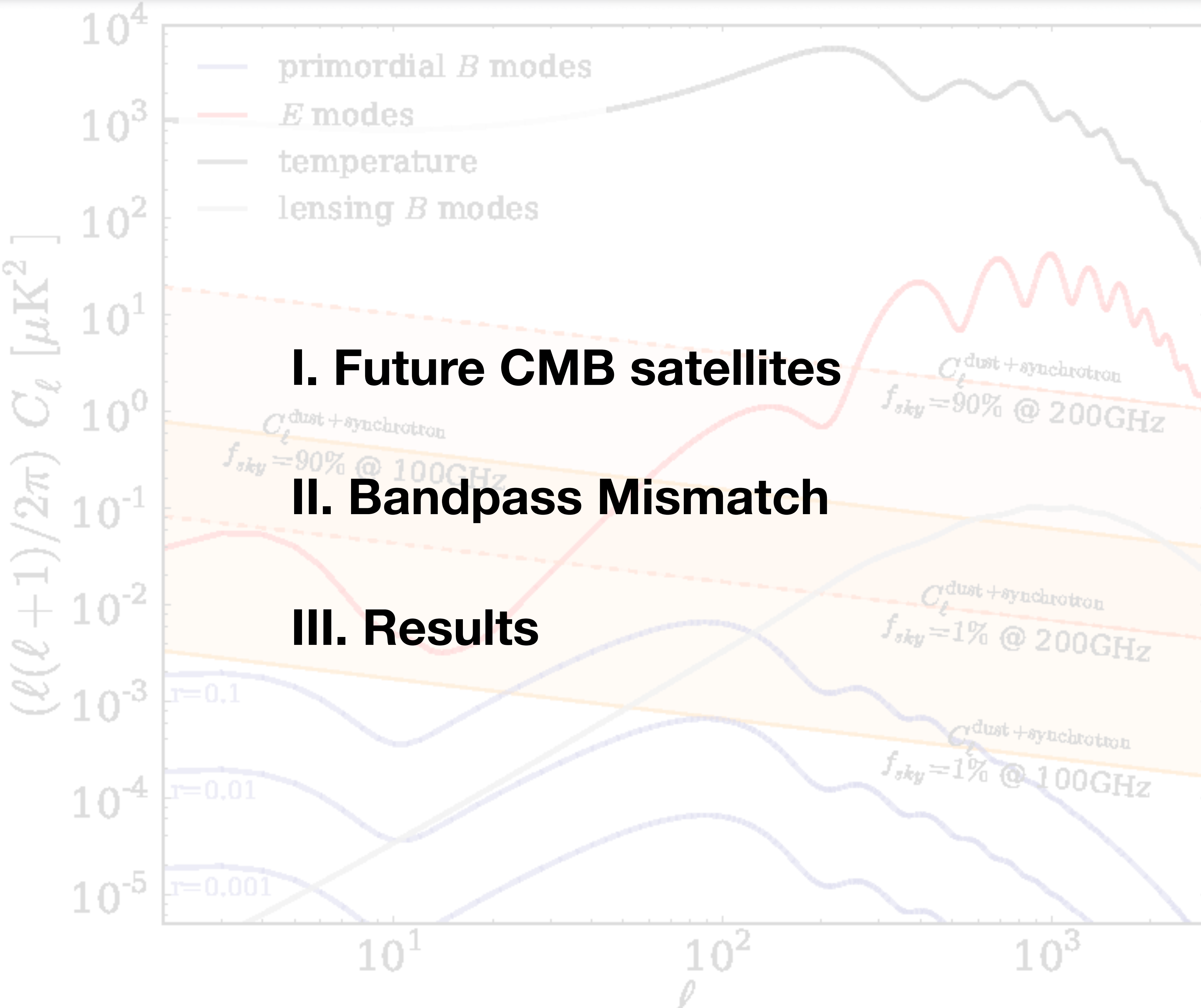
1. Bandpass mismatch error for satellite CMB experiments I: Estimating the spurious signal arXiv:1706.09486 [astro-ph.CO] 28 Jun 2017.

The CMB from A to Z
November 12 - 18, 2017 — IESC, Cargèse, Corsica.

OUTLINE

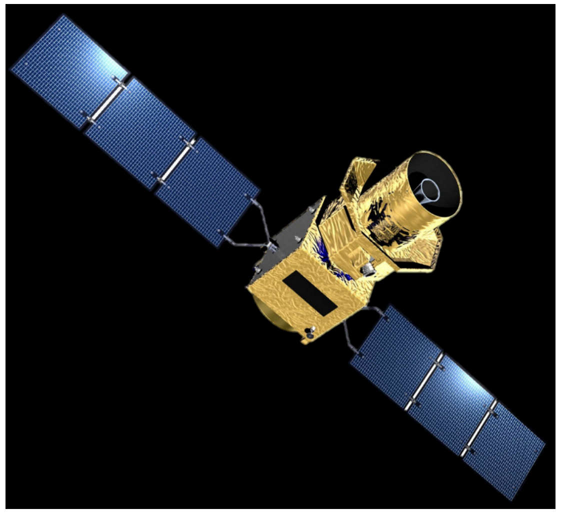


I. Future CMB satellites

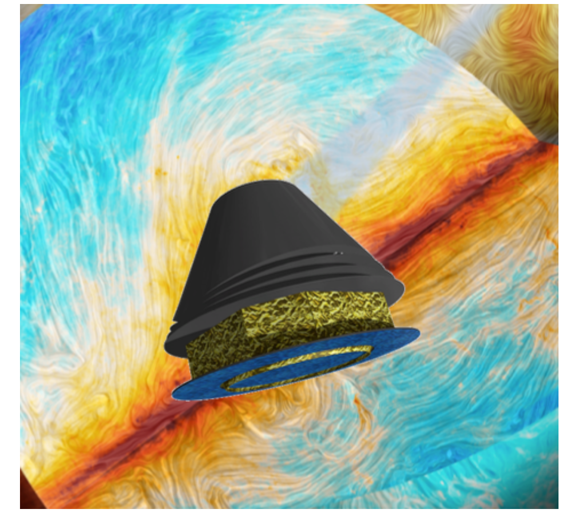
II. Bandpass Mismatch

III. Results

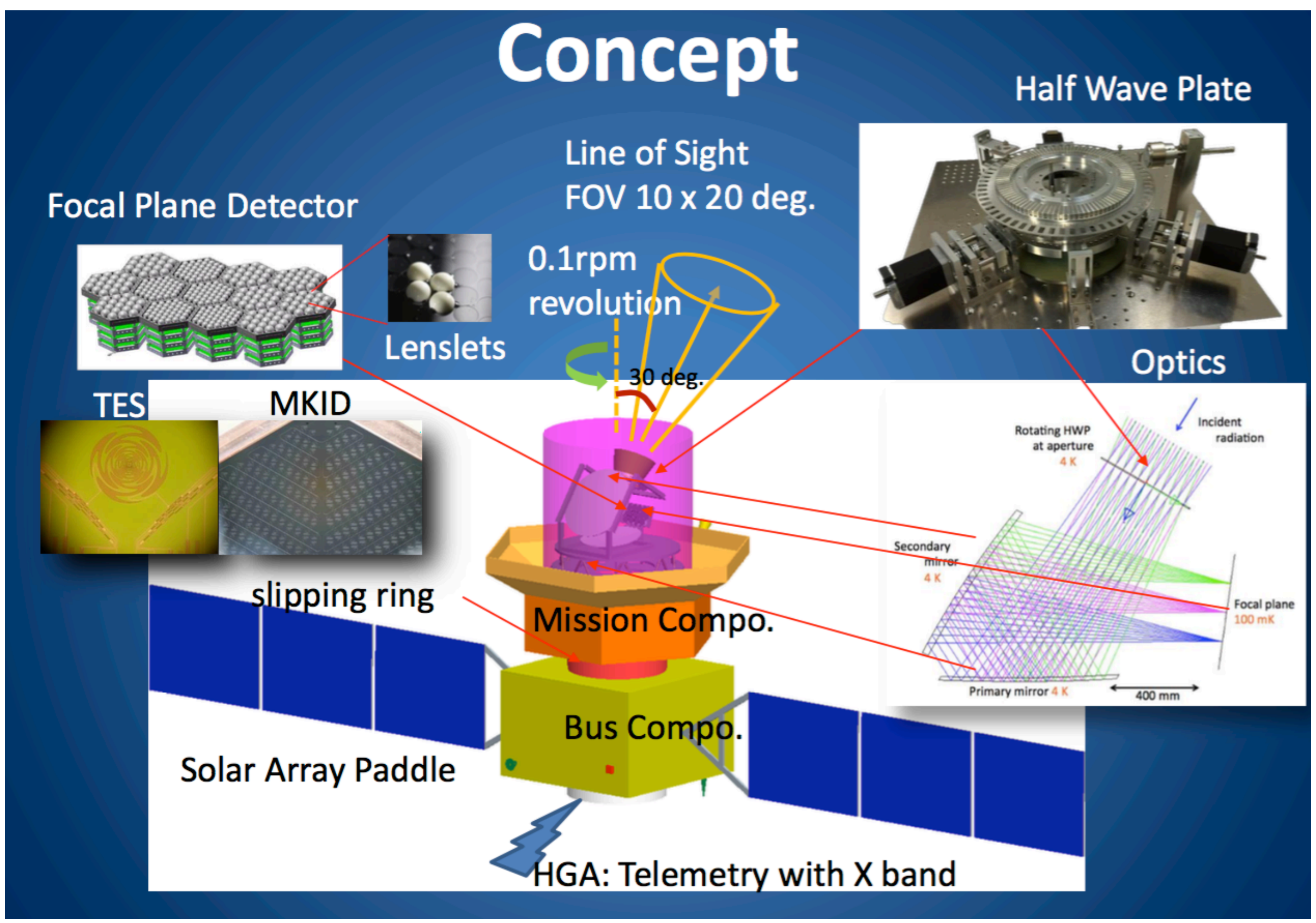
I.1. Future CMB satellites



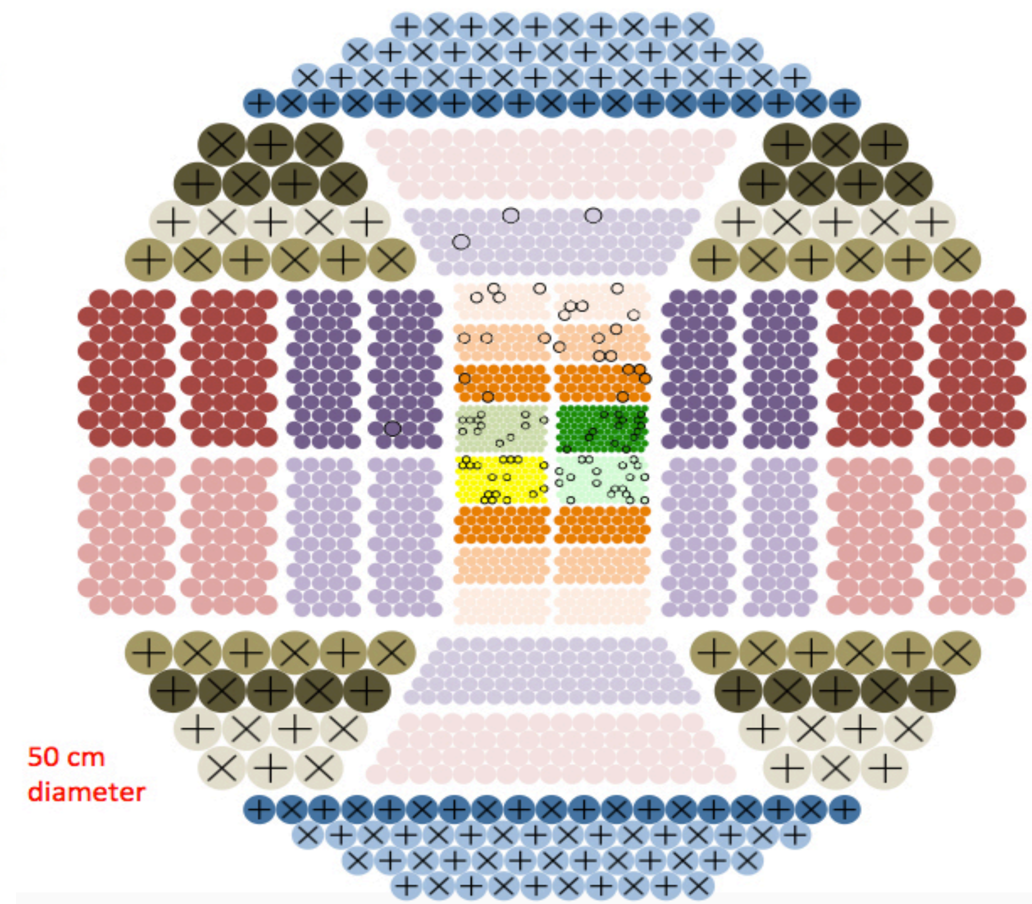
JAXA: LiteBIRD



ESA: CORE like

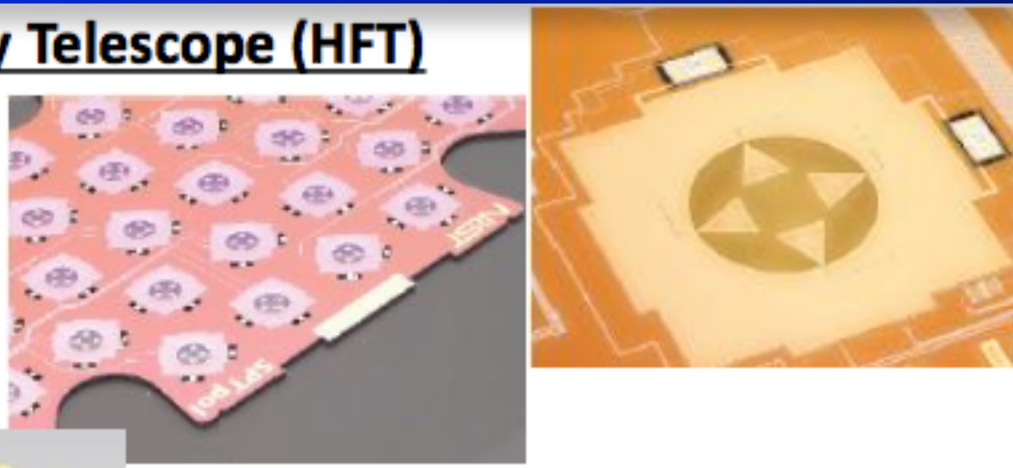


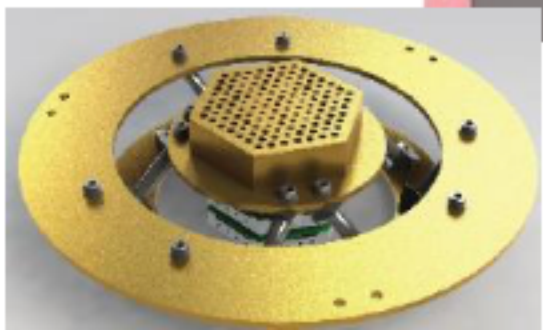
GHz	N_{det} (M5)
60	24×2
70	24×2
80	24×2
90	39×2
100	39×2
115	38×2
130	124
145	144
160	144
175	160
195	192
220	192
255	128
295	128
340	128
390	96
450	96
520	96
600	96
TOTAL	2100



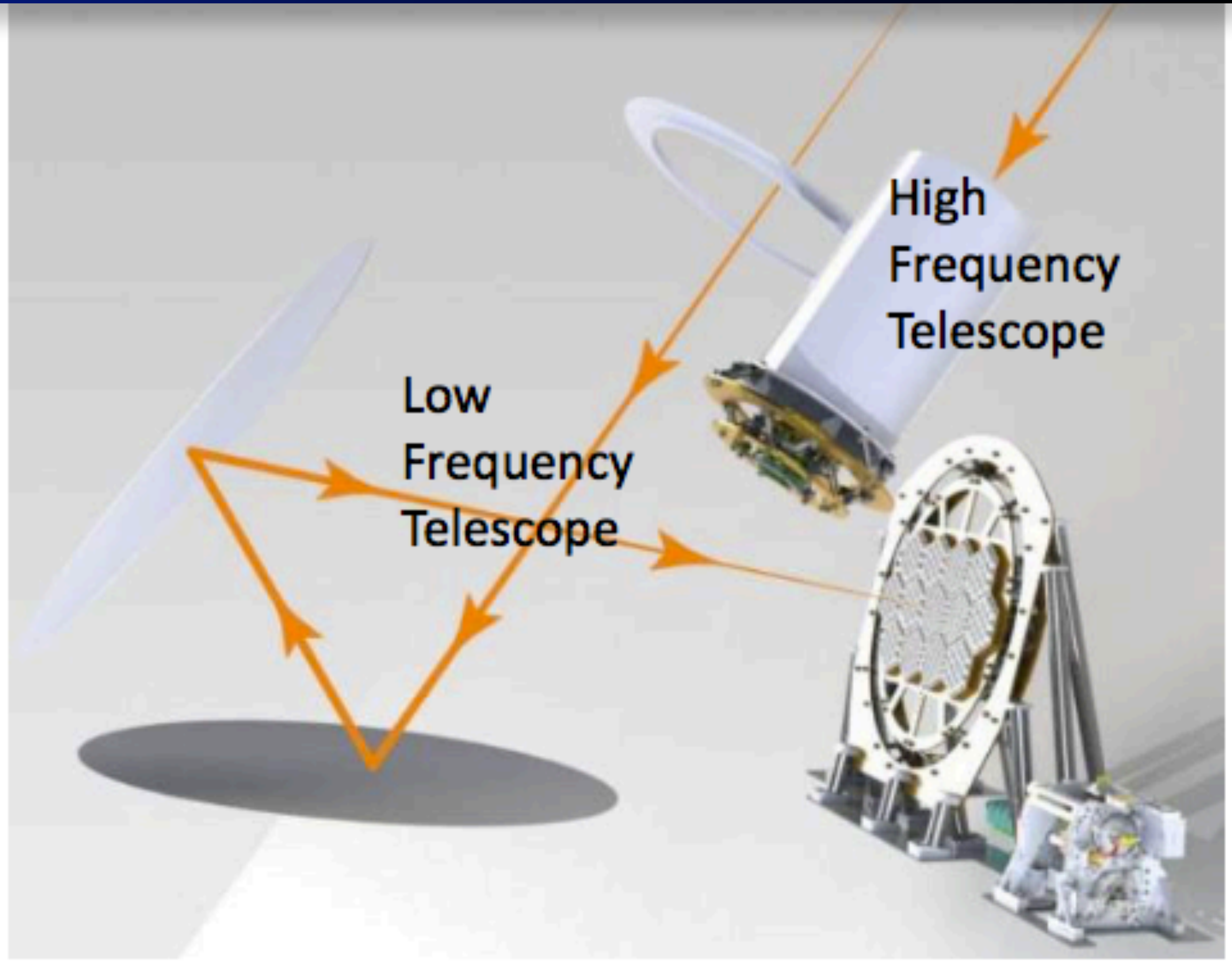
I.1. LiteBIRD Focal plane

High Frequency Telescope (HFT)

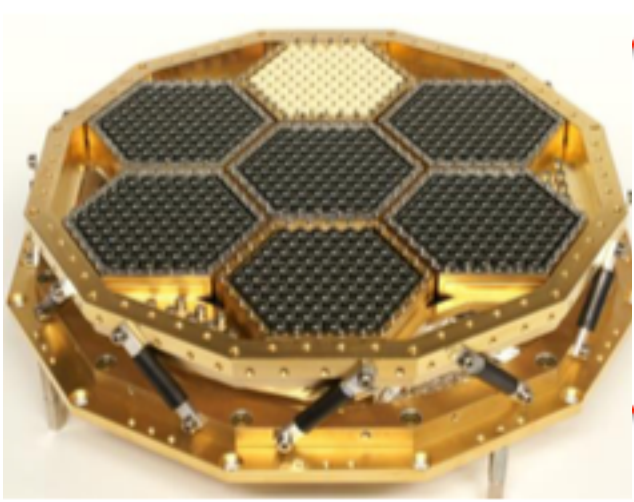


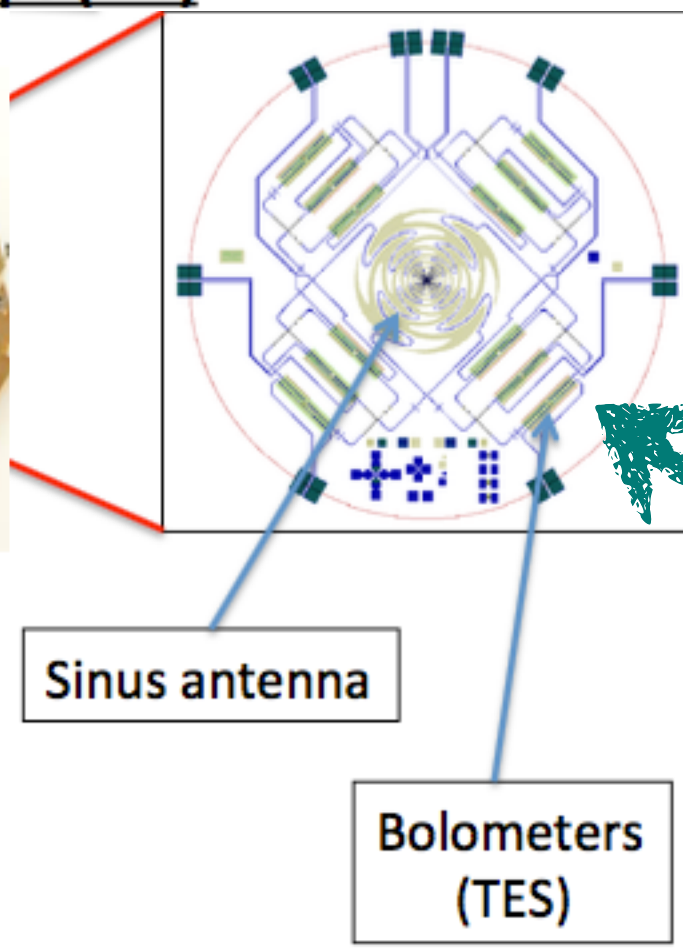


The TES array with corrugated feedhorn developed for ABS, ACTpol, SPTpol by UC Boulder, NIST, and Stanford.



Low Frequency Telescope (LFT)





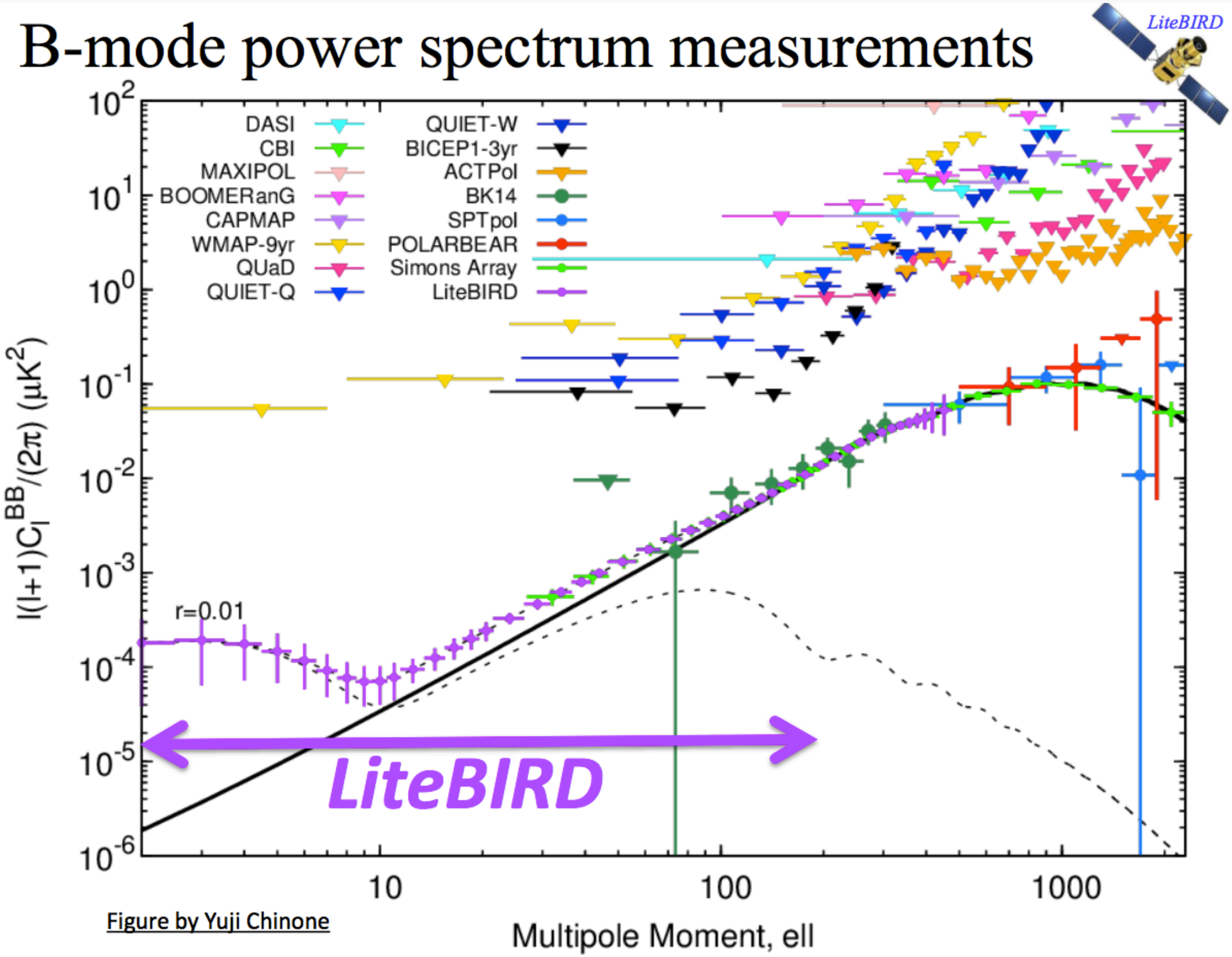
The TES array with a lenslet developed for POLARBEAR by UC Berkeley and UCSD.

- Low Frequency Telescope → 40 GHz ~ 235 GHz
- High Frequency Telescope → 280 GHz ~ 402 GHz

15 frequency bands
> 2000 detectors

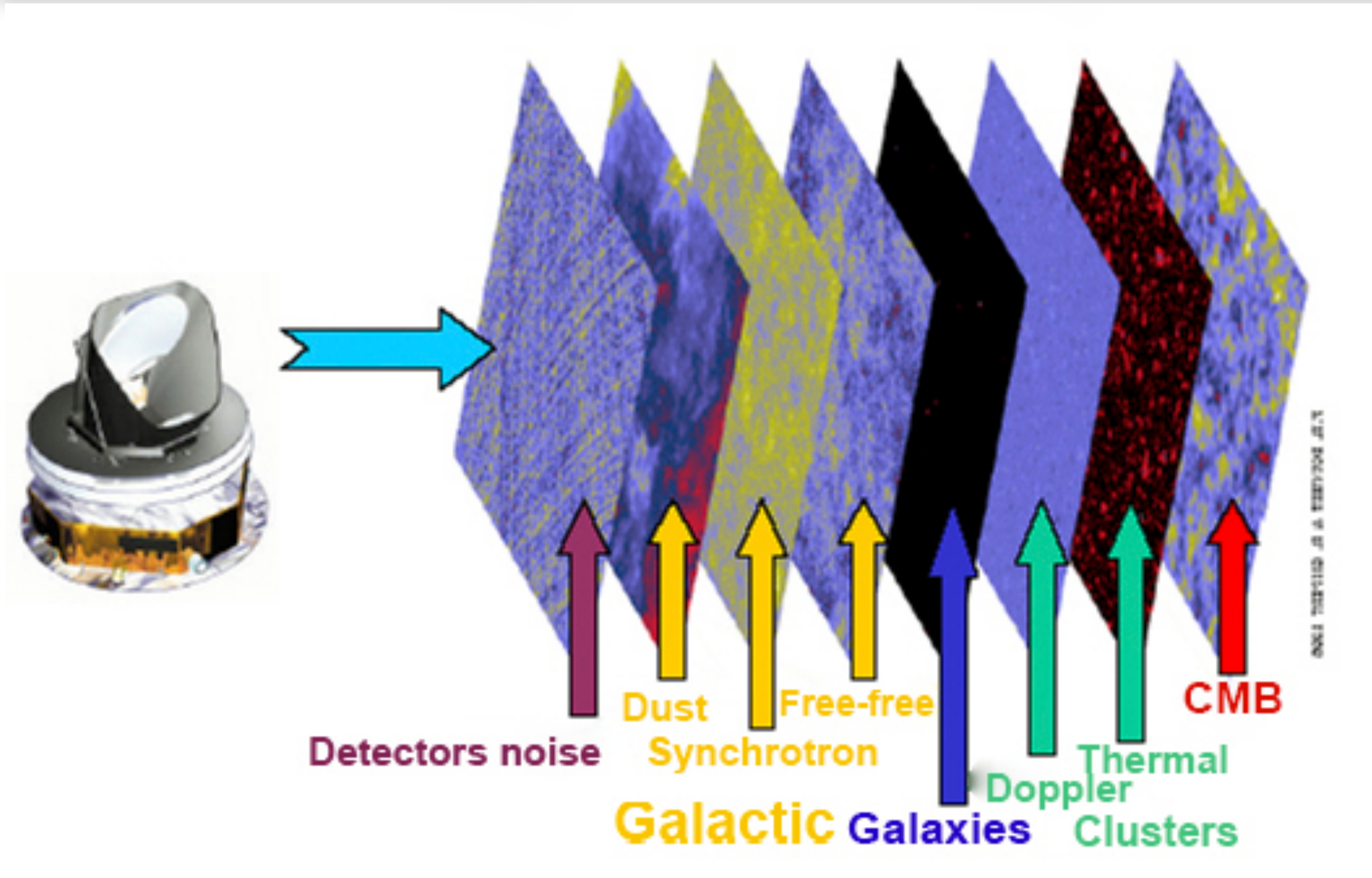
Bandpass filters

I.1. LiteBIRD confident level

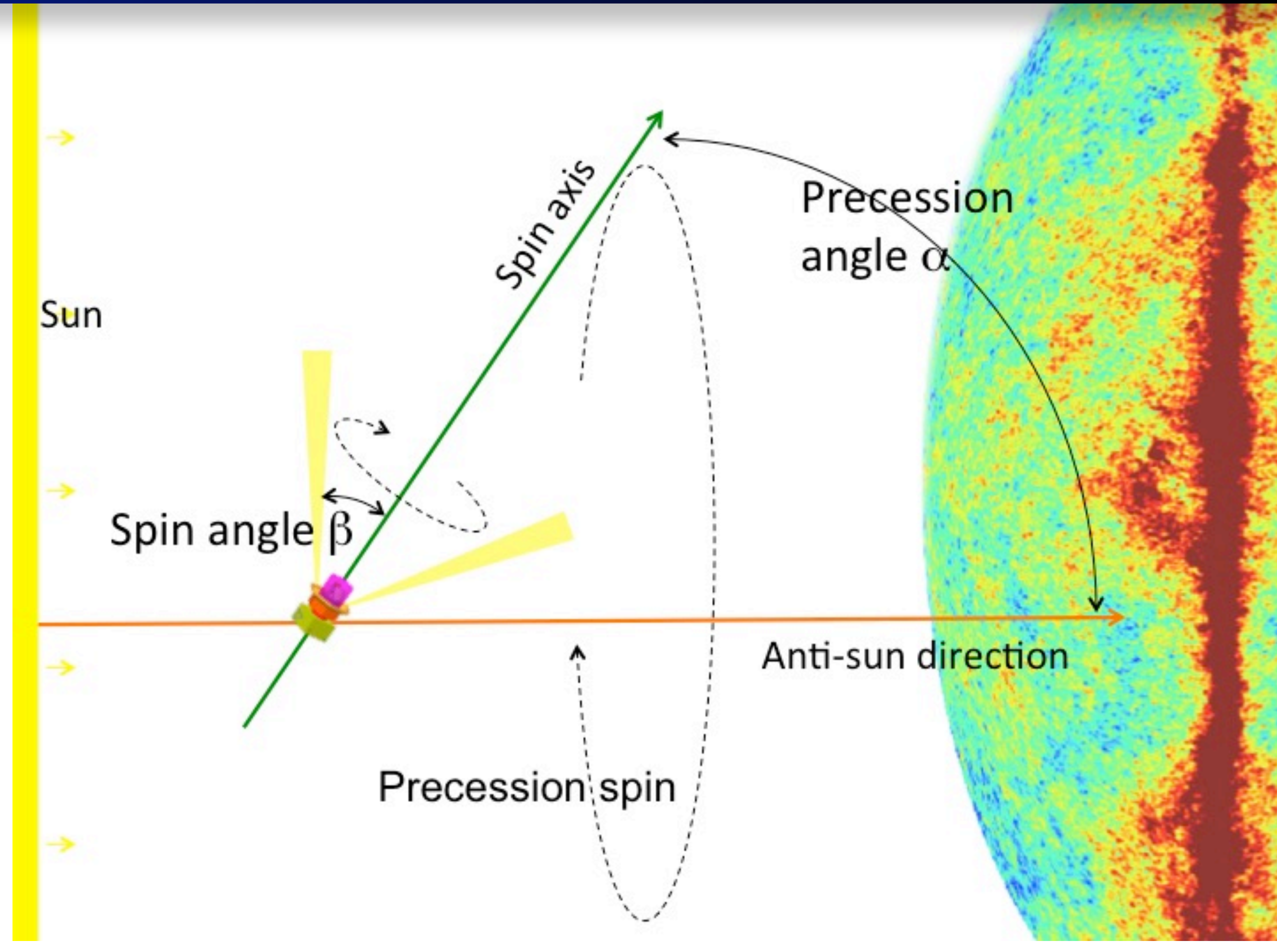


Measurements with $r < 0.002$ (95% C.L.) for $2 \leq l \leq 200$ are important

I.1. LiteBIRD scanning strategy



@François Bouchet



$$S = I + Q\cos 2\psi + U \sin 2\psi + n$$

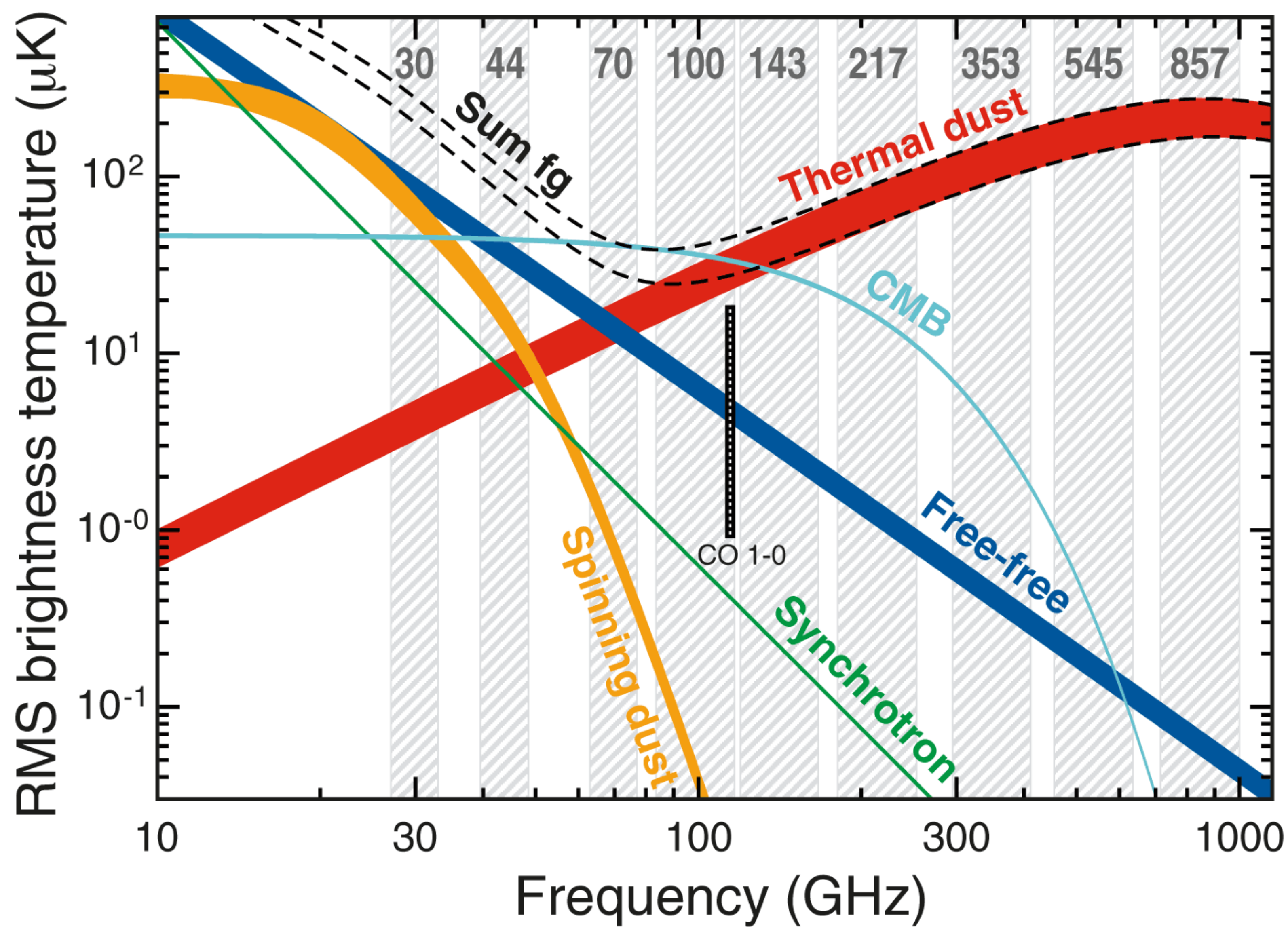
$$I = I_{CMB} + I_{dust} + I_{components}$$

\psi: polarizer angle

Similar for Q and U

I.1. Potential systematic effects

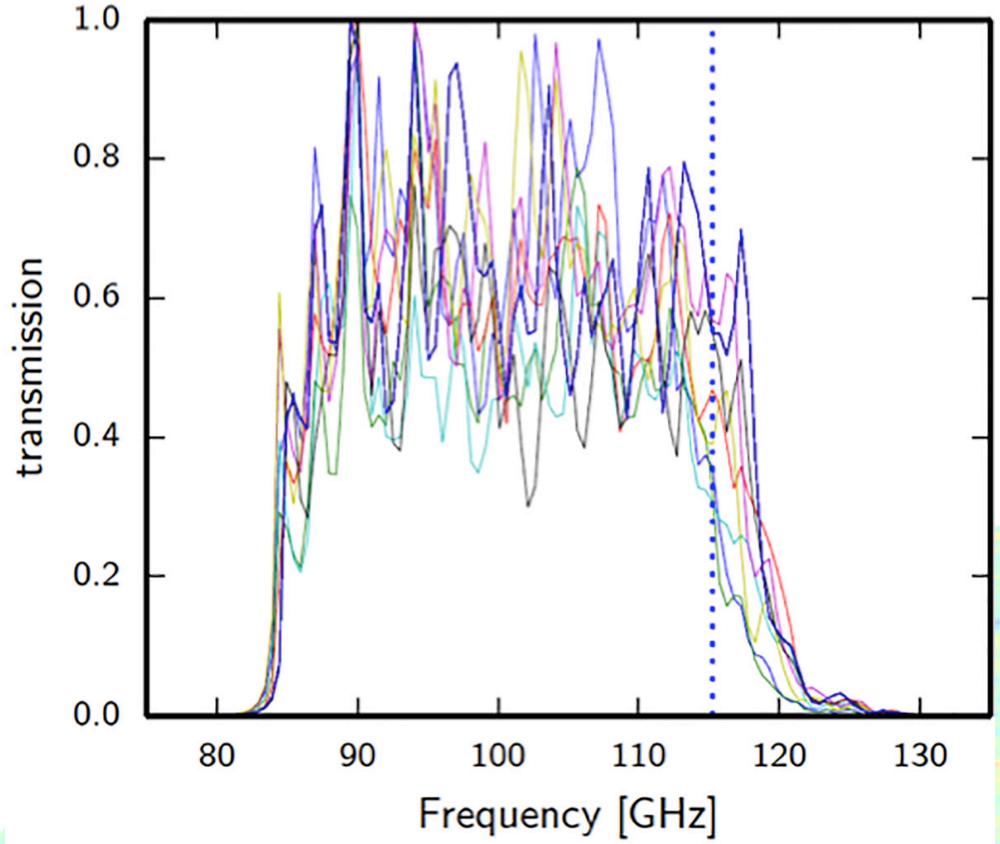
- Beam mismatch
- HWP imperfections
- Cosmic rays
- 1/f noise
- ***Bandpass mismatch***
- Thermal fluctuations
- …

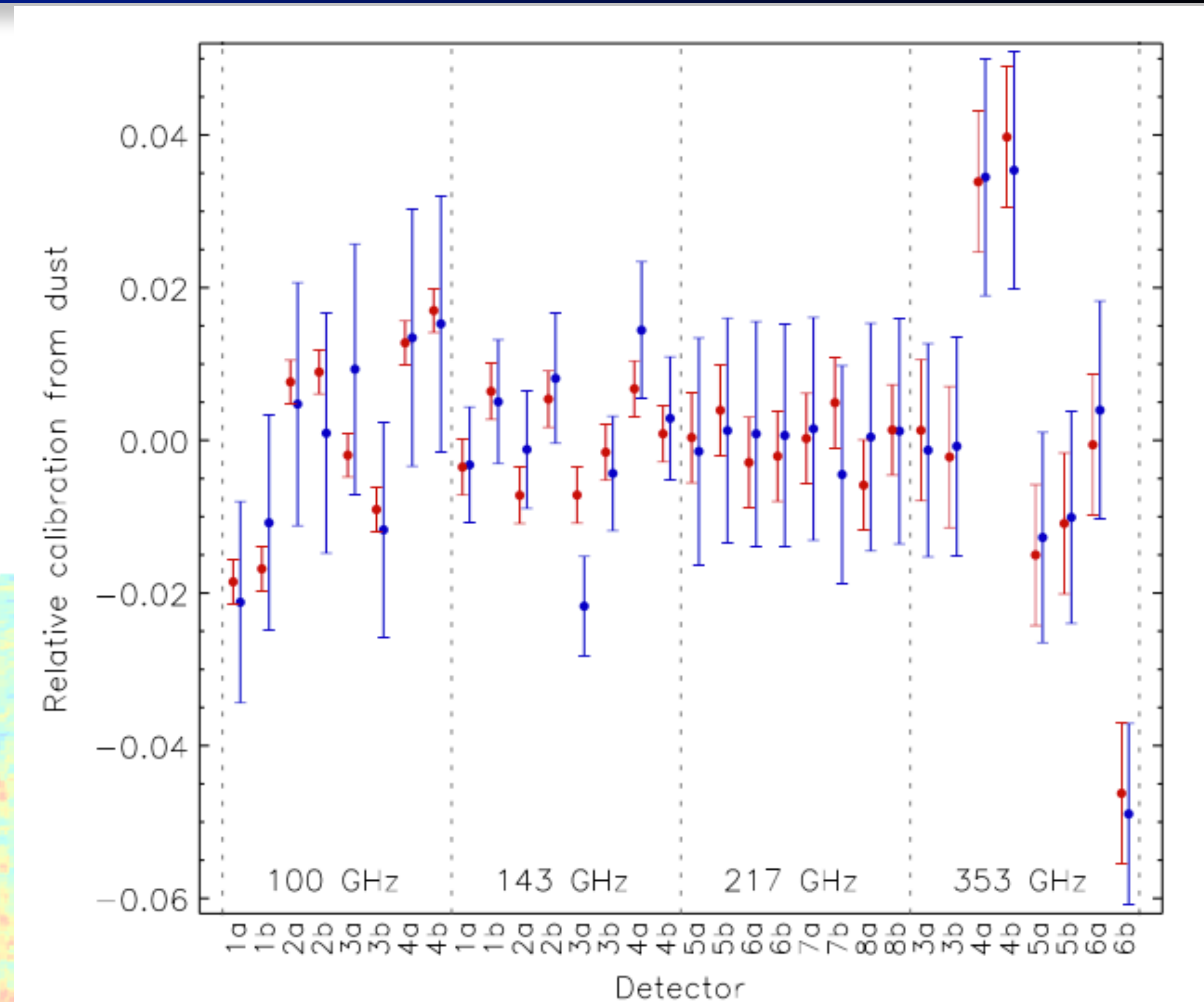


Foregrounds affect the measurement accuracy of CMB

II.1. Bandpass mismatch

Planck: Bandpass shape of several detectors





Relative calibration of dust different from detector to detector after calibrating CMB

γ_d **- 1 ~ 1%**

Blue: ground, red: flight

(Planck: A&A 596, A107 (2016))

$$S = I_{CMB} + \gamma_d I_{dust} + \gamma_s I_{dust} + \ldots$$

Leakage from intensity I to polarization Q, U

II. 1. Bandpass mismatch

Filters **Dust: Grey body**

$$\gamma_d = \left(\frac{\int d\nu \; g_i(\nu) \left(\frac{\nu}{\nu_0}\right)^{\beta} \frac{B(\nu;T_d)}{B(\nu_0;T_d)}}{\int d\nu g_i(\nu) \left(\frac{\partial B(\nu;T)}{\partial T}\right)\Big|_{T_0}} \right) \left(\frac{\partial B(\nu_0;T)}{\partial T}\right)\Big|_{T_0}$$

CMB: Black body **Normalization CMB**

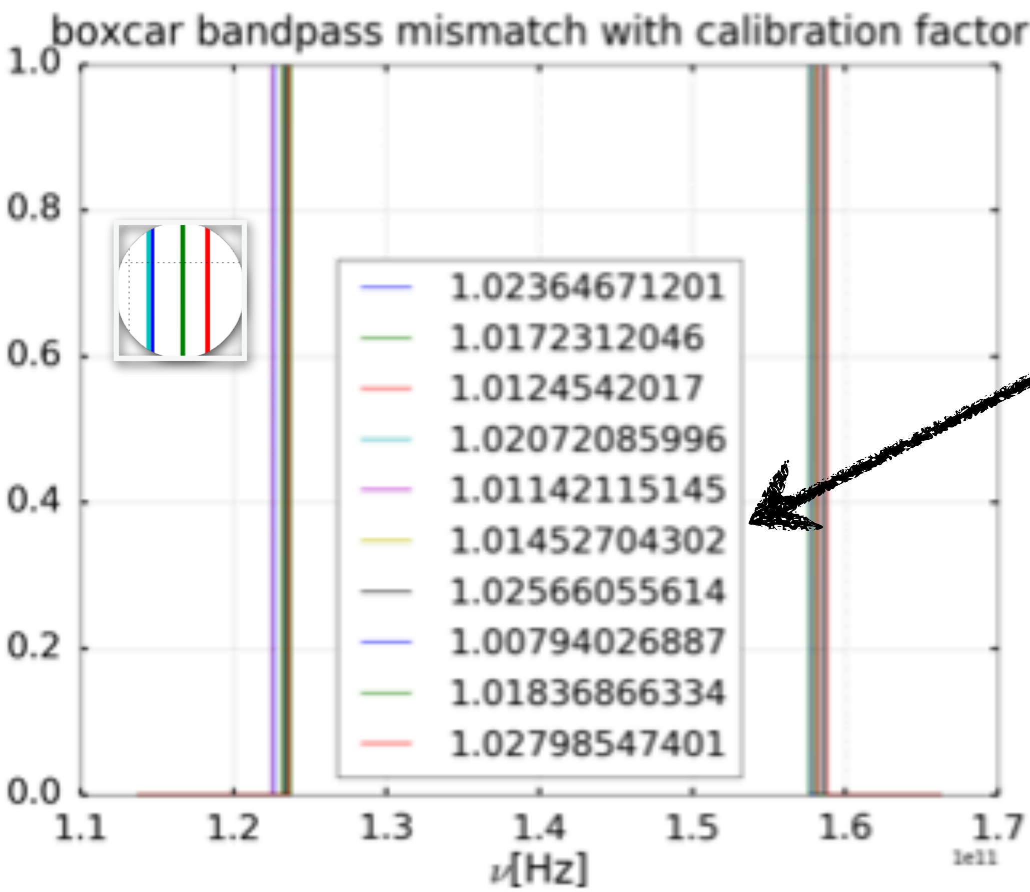
$T_0 = T_{CMB} = 2.725$
$T_d = 19\text{K}$
$\beta = 1.62$
$\nu_0 = 140\ \text{GHz}$

$$B(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{k_B T}} - 1}$$ **Planck's law**

$\gamma_s,\ \gamma_f,\ \gamma_{spin}$

II.1. Bandpass mismatch -> filters

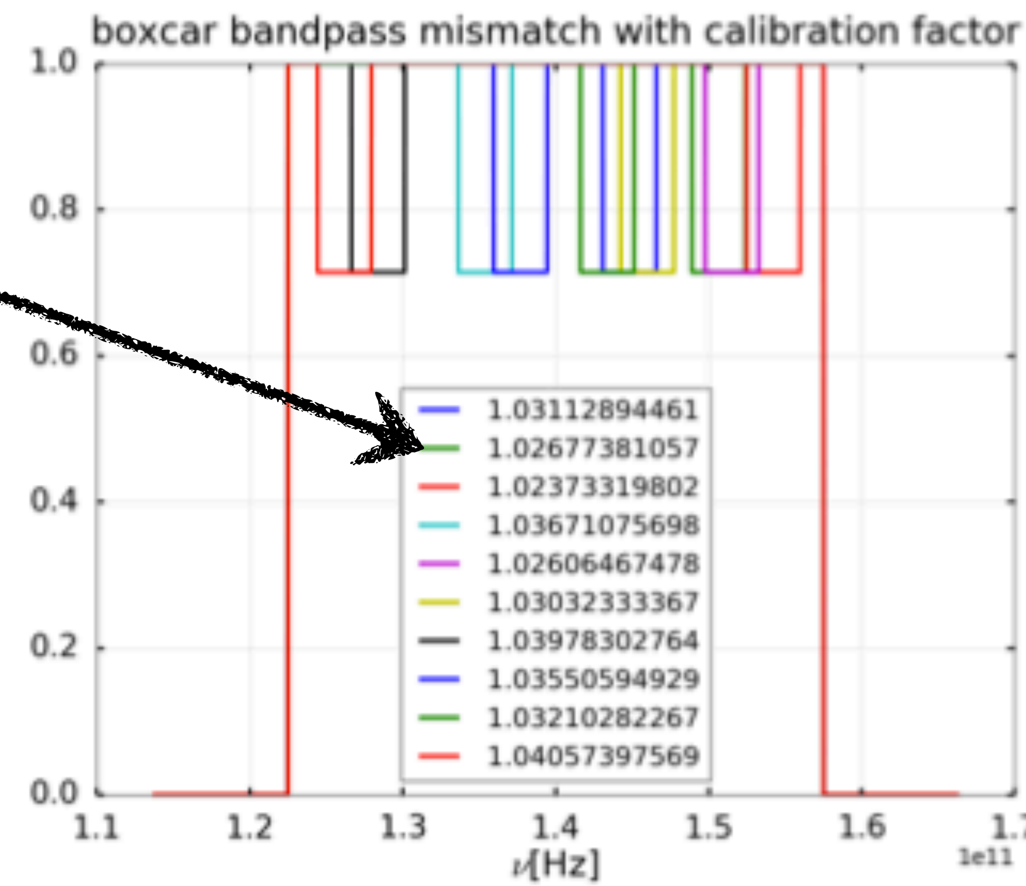
Planck-like errors 1% variation



standard deviation $\sigma = 0.00626$

γ_d

Top-hat filters



standard deviation $\sigma = 0.005975$

Half of a percent from detector to detector

II.2. Bandpass mismatch -> Simulation

- **In order to estimate leakage:** The effect of intensity to polarization
- Data simulation: $S = I_{CMB} + \gamma_d I_{dust} + \gamma_s I_{dust} + \ldots$
- No polarization
- No noise or white noise
- Same pixellisation between input and output maps
- Simulations at 140 GHz **using** different configutations

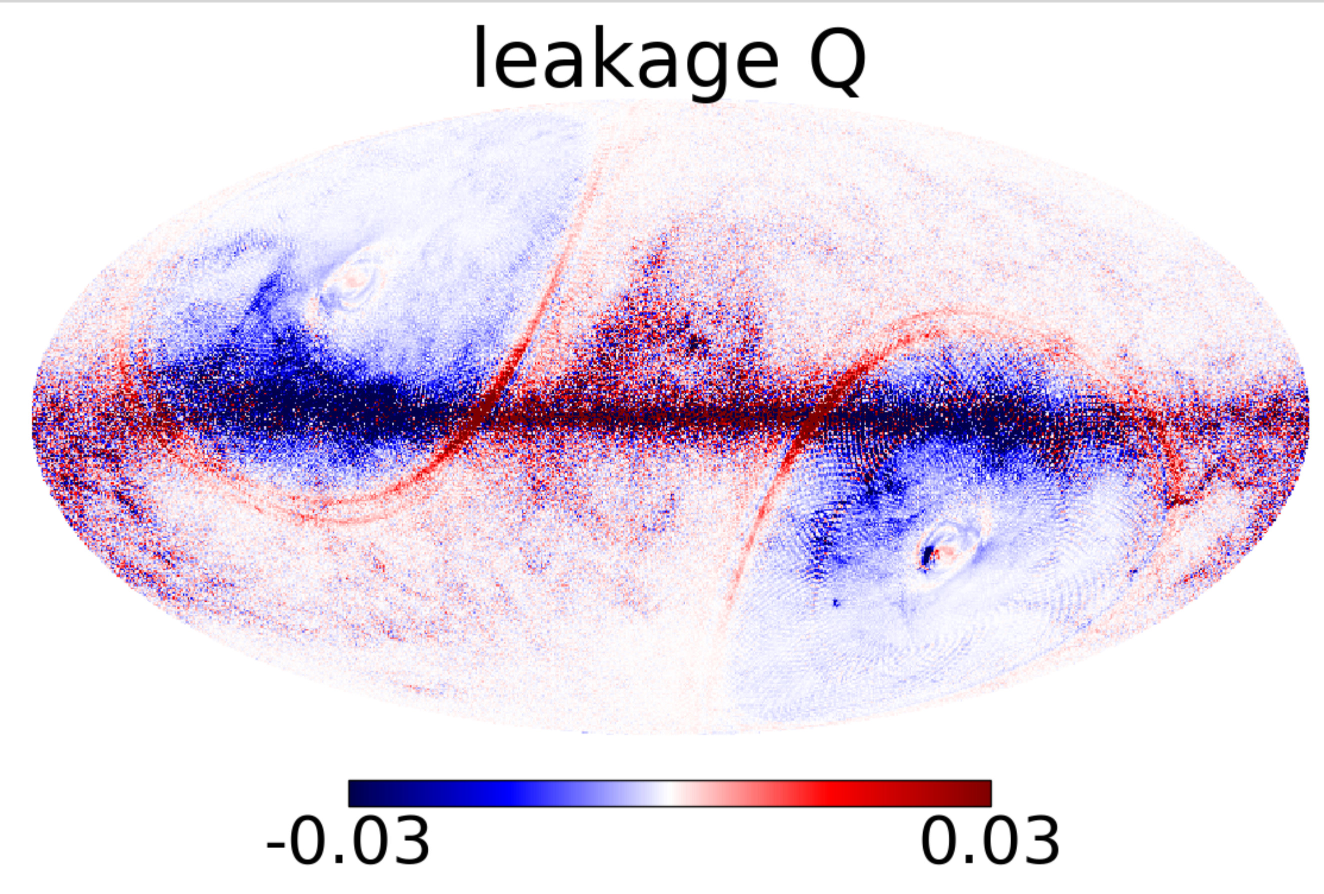
The map of intensity I and polarization Q *and* U is $\mathrm{m} = \begin{pmatrix} I \\ Q \\ U \end{pmatrix}$,

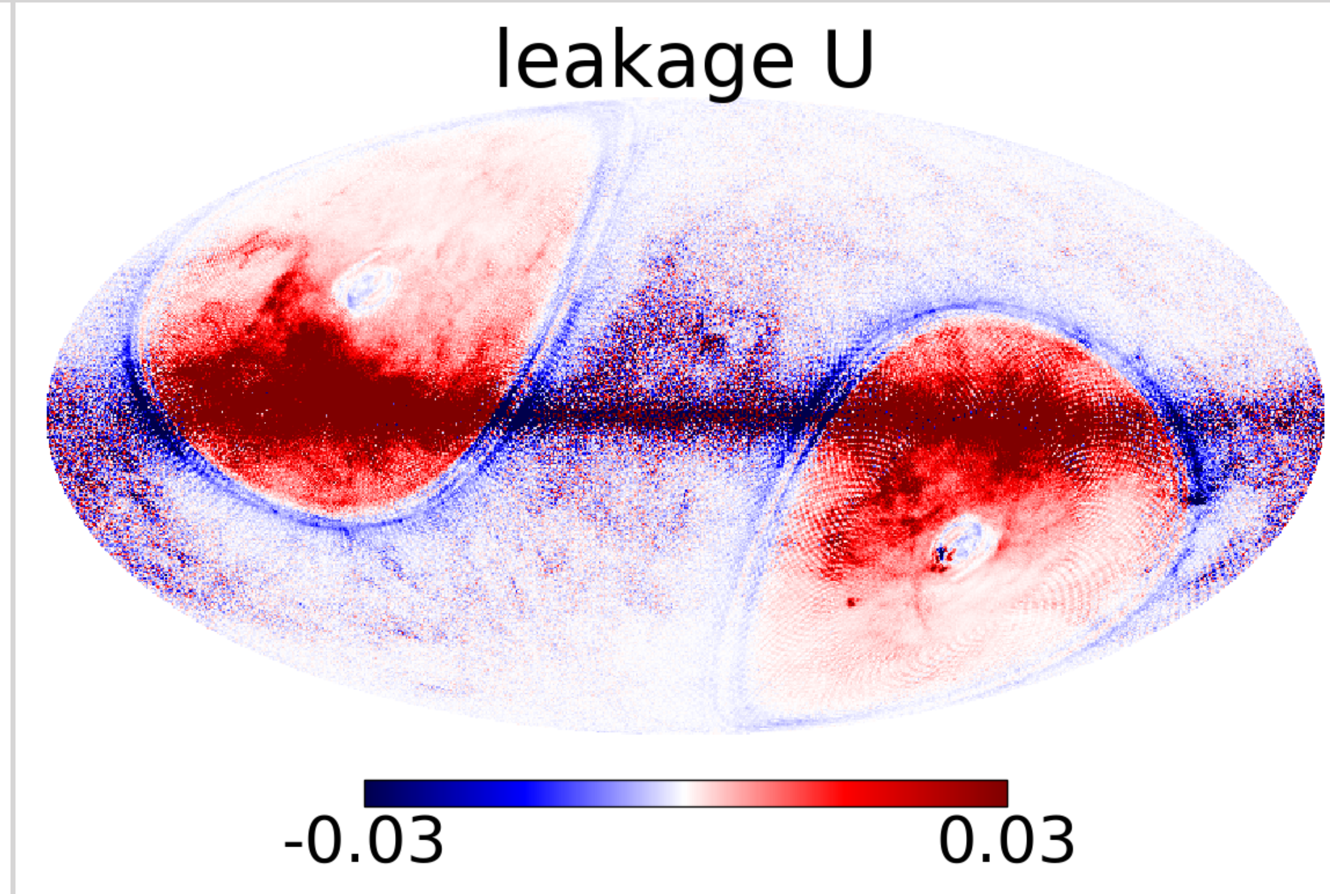
the map-making solution:

$$m = [A^T N^{-1} A]^{-1} A^T N^{-1} S_{sky} \qquad (1)$$

The pointing matrix for pixel p: $\mathrm{A} = \left(1 \ \cos(2\psi) \ \sin(2\psi)\right)_p$

III. Results (1) -> Leakage maps

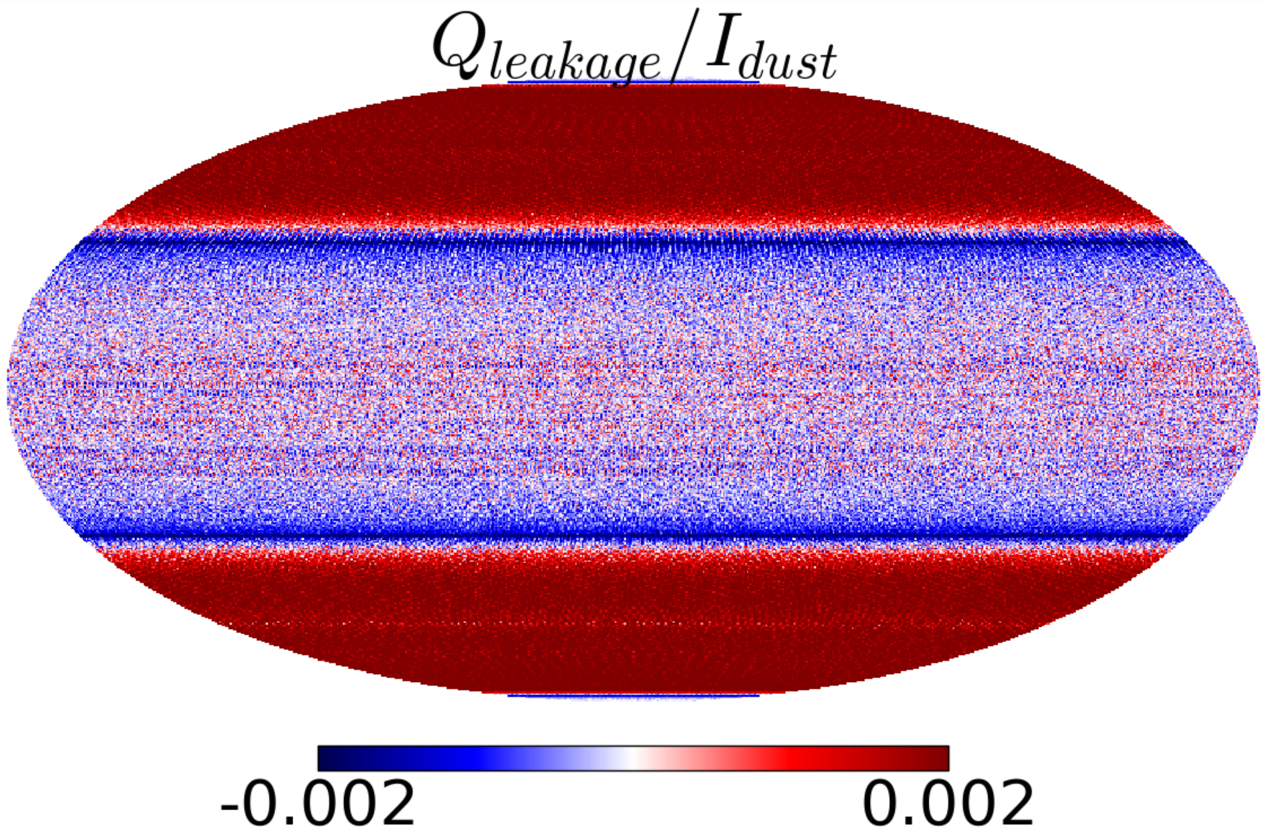


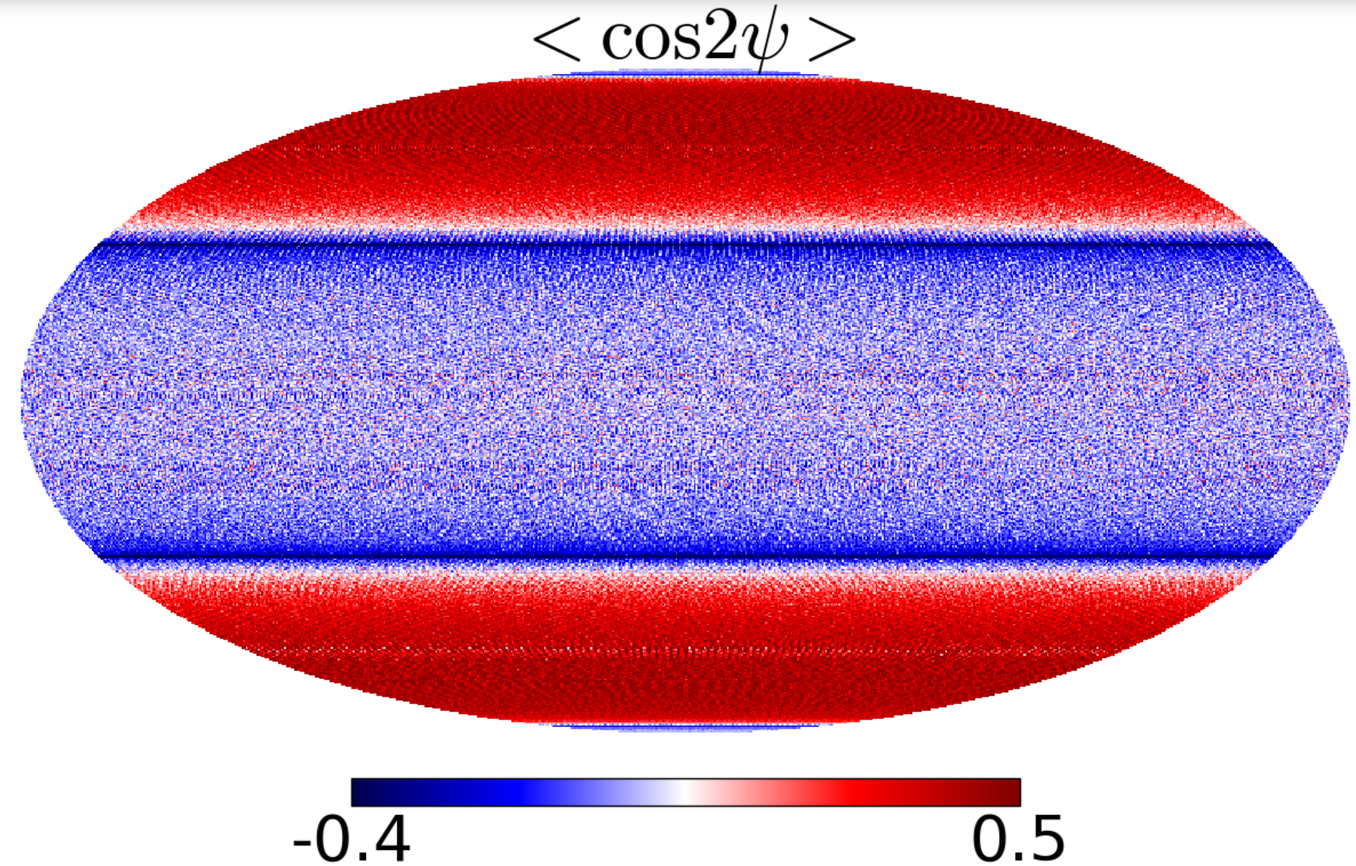


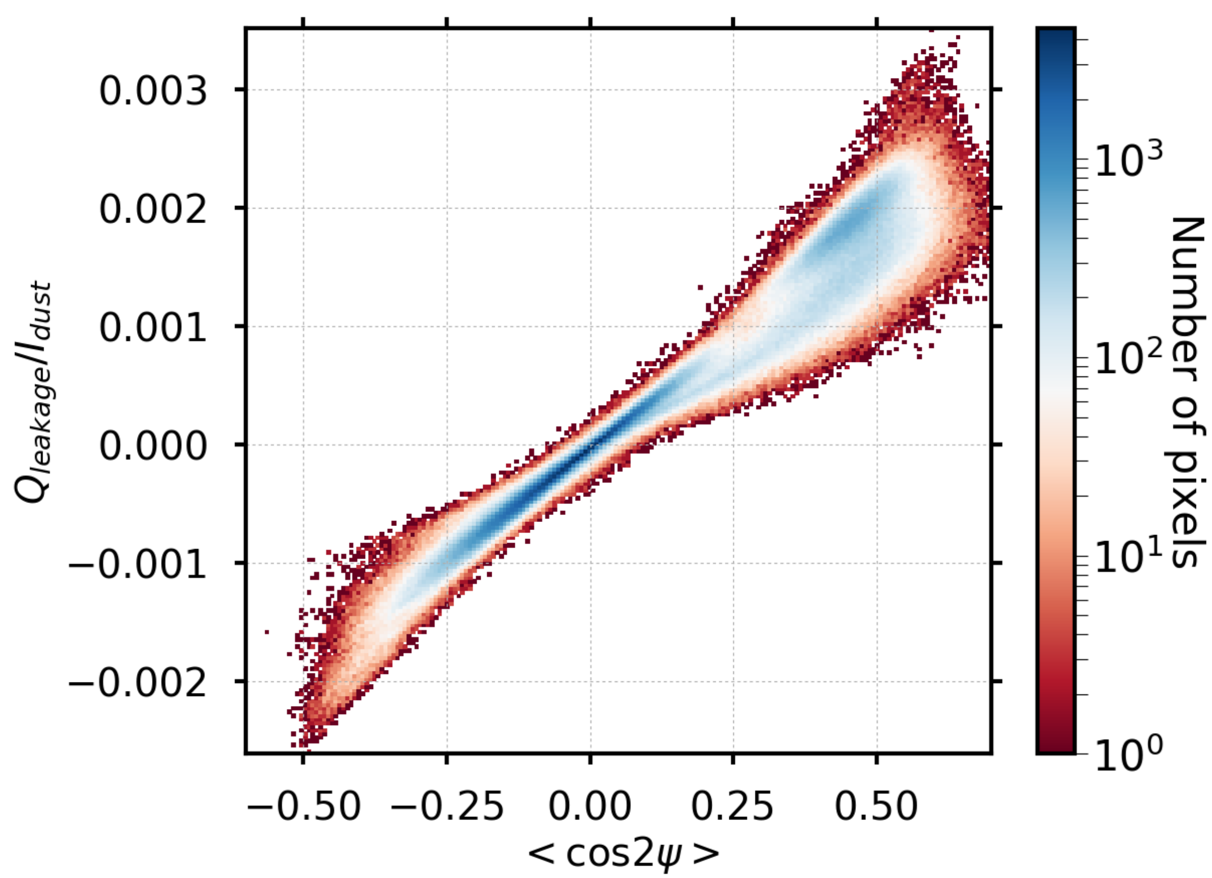
$$\alpha = 65^\circ, \beta = 30^\circ, t_{prec} = 96.2minus, \omega_{spin} = 0.1rpm$$

222 detectors and 365 days observation

III. Results (2) -> Analytic estimation







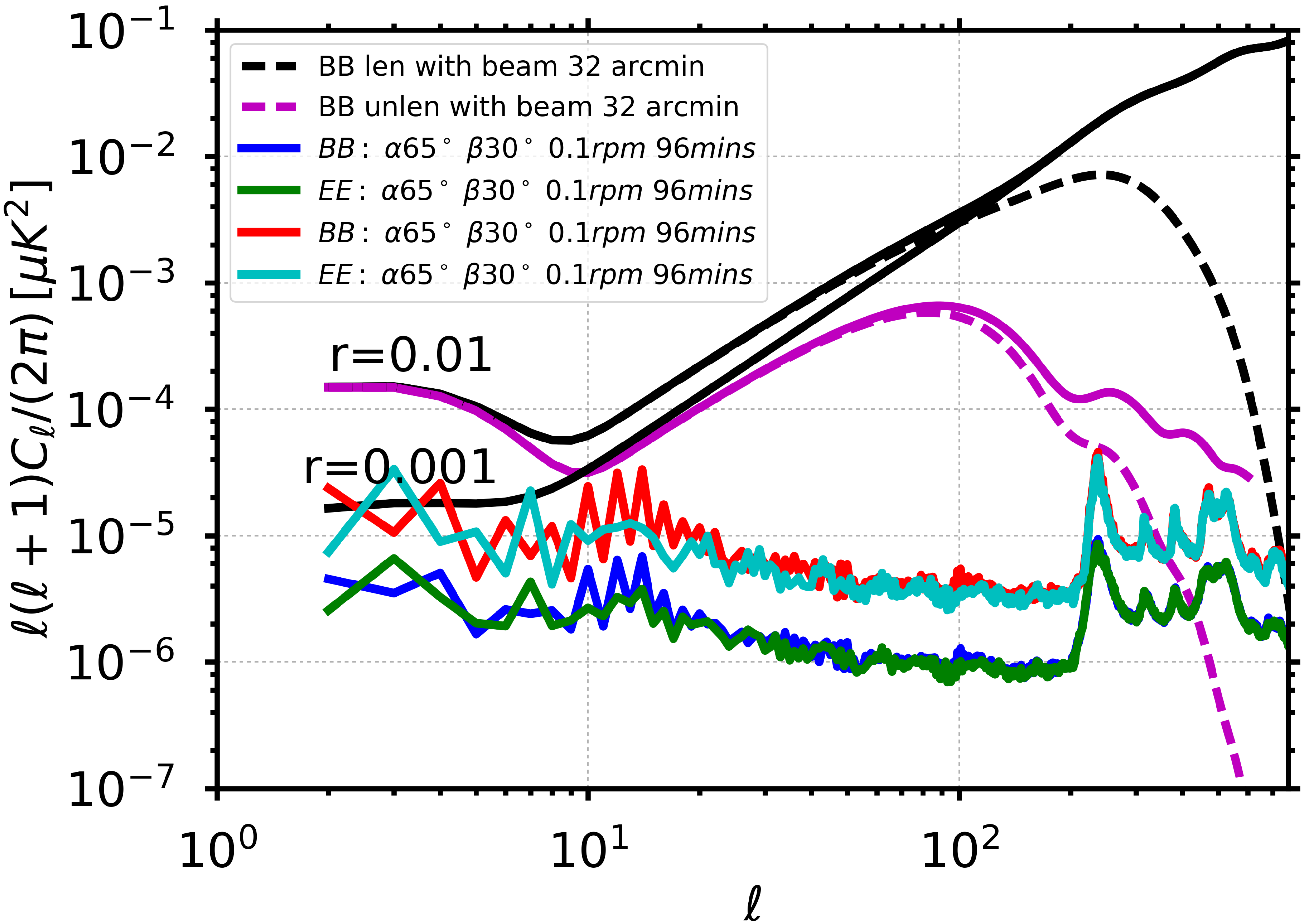
a pair detector

$$\begin{pmatrix} \frac{\delta Q_p}{I_{\mathrm{Gal};p}} \\ \frac{\delta U_p}{I_{\mathrm{Gal};p}} \end{pmatrix} = \left(\gamma^a_{\mathrm{Gal}} - \gamma^b_{\mathrm{Gal}}\right) \begin{pmatrix} \langle \cos 2\psi \rangle \\ \langle \sin 2\psi \rangle \end{pmatrix}$$

leakage **cross moment**

III. Results (3) -> 1 / N_det

$$\frac{1}{N_{det}}$$



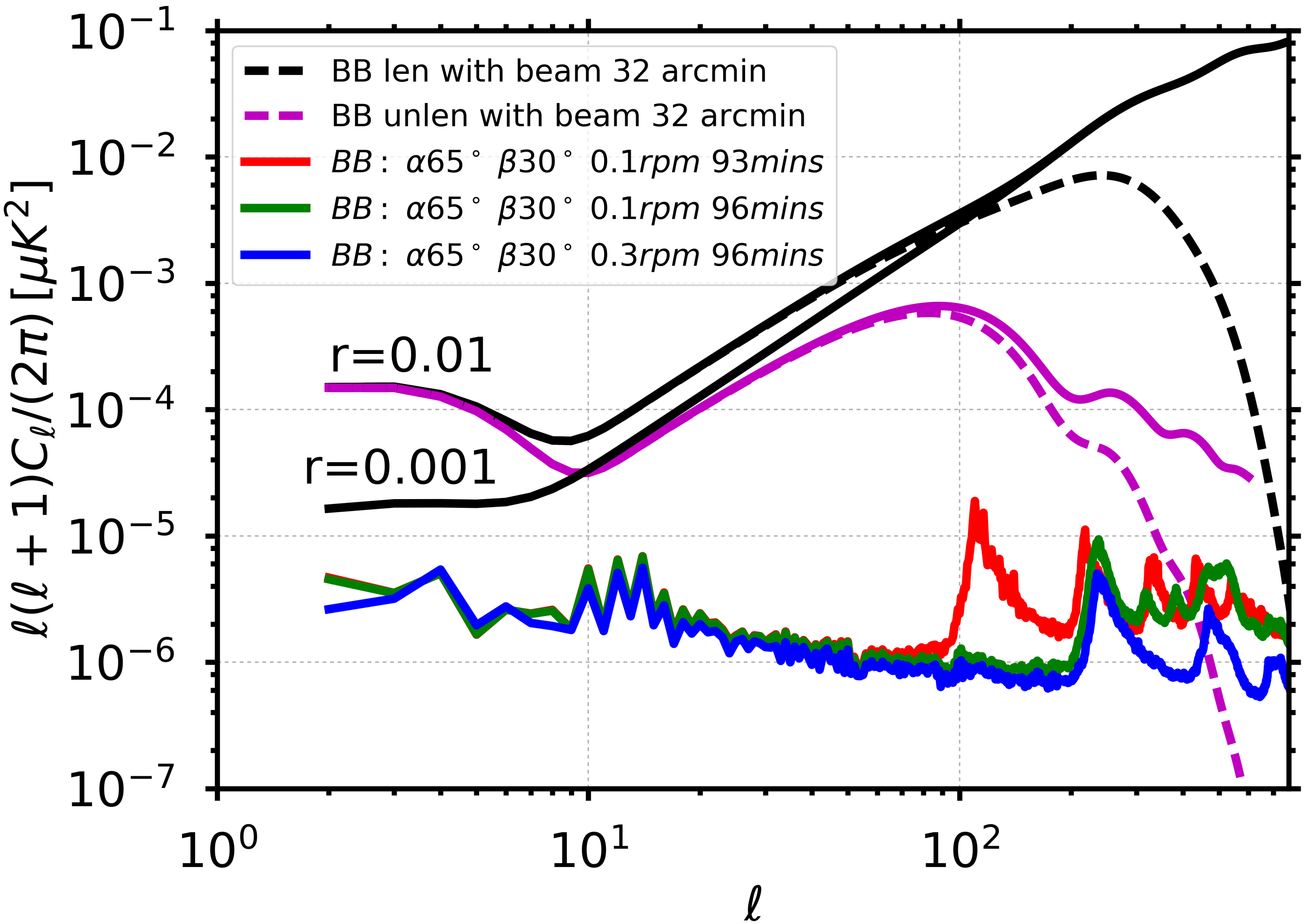
$$\alpha = 65^\circ, \beta = 30^\circ, t_{prec} = 96.2minus, \omega_{spin} = 0.1rpm$$

20% masked galactic, 74 and 222 detectors and 365 days observation, 10 sims

III. Results (4) -> precession and spin

20% masked galactic, 222 detectors and 365 days observation, 10 sims

$\alpha = 65^\circ, \beta = 30^\circ$

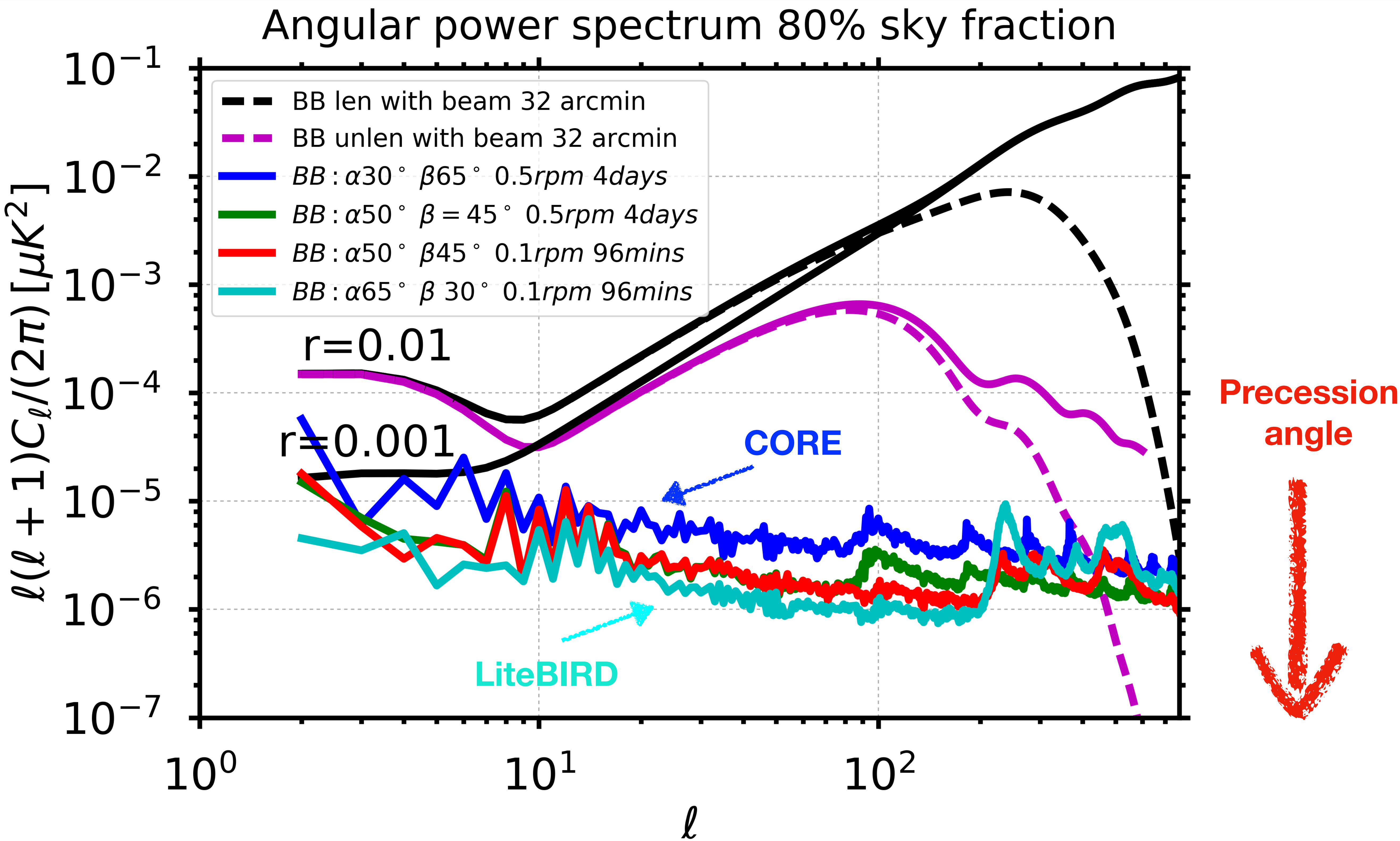


precession 93 minutes 0.1 rpm

precession 96 minutes 0.1 rpm

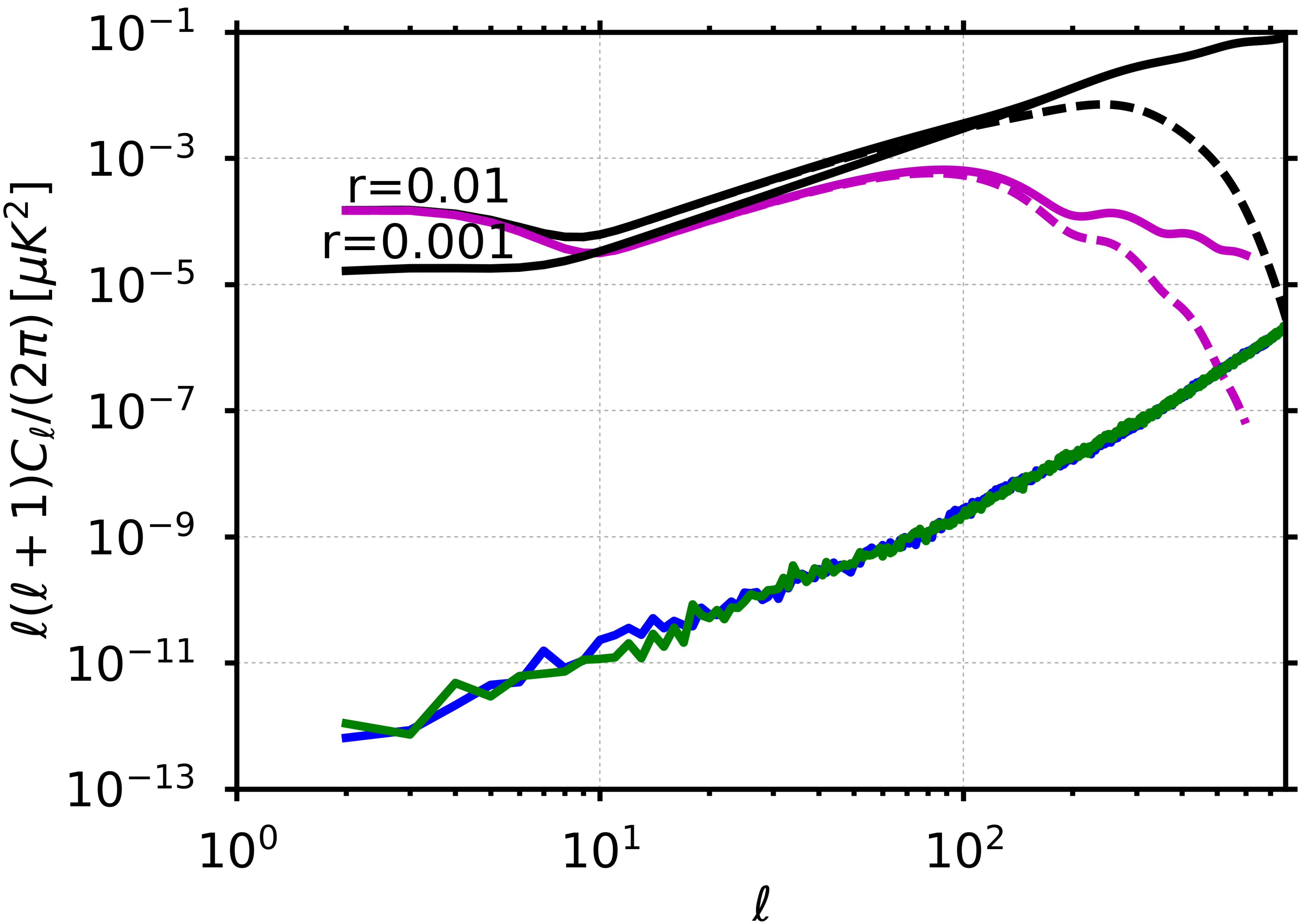
precession 96 minutes 0.3 rpm

III. Results (5) -> scanning strategies



20% masked galactic, 222 detectors and 365 days observation, 10 sims

III. Results (6) -> An ideal Half-Wave Plate



20% masked galactic, 50 detectors and 180 days observation

III. Results (Conclusions)

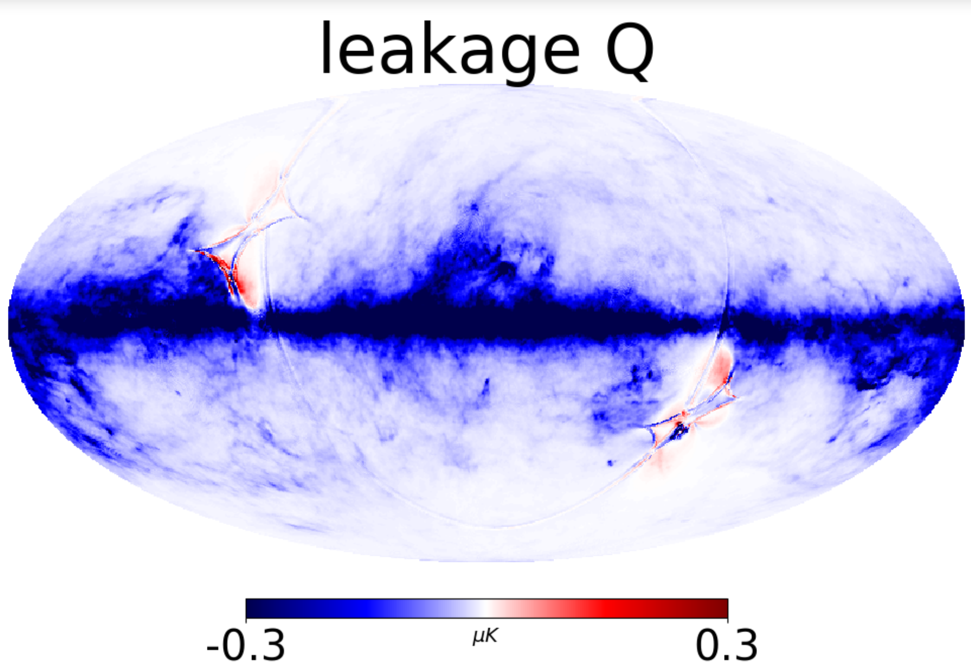
222 detectors and 365 days observation, \tau=0.055 +- 0.009

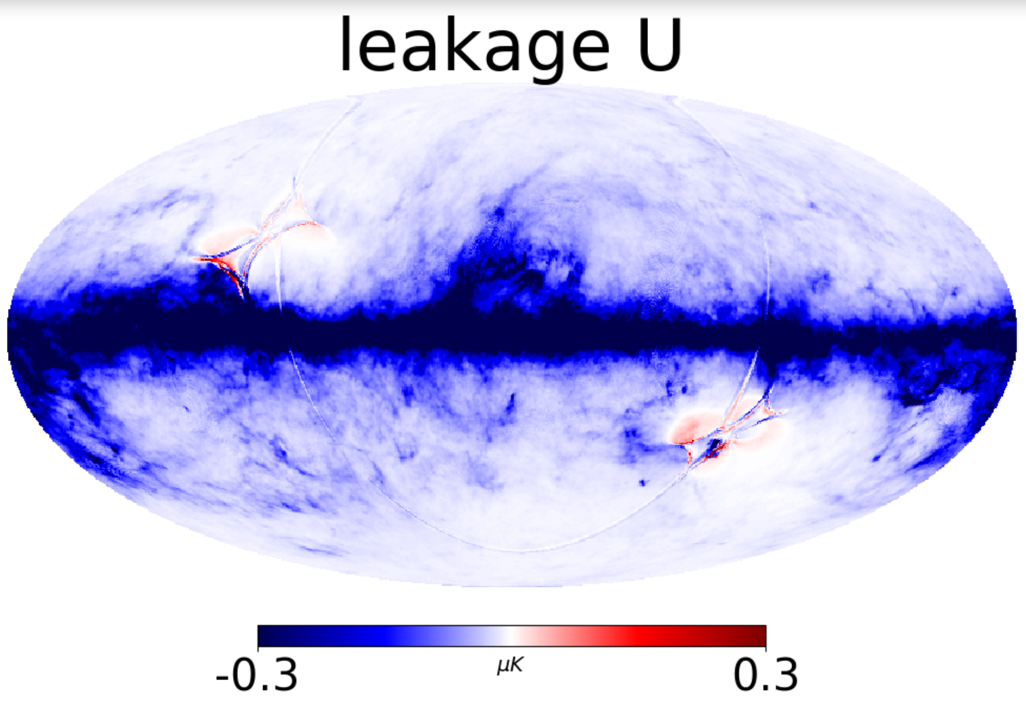
	$2 \leq \ell \leq 10$	$10 \leq \ell \leq 200$
$\alpha = 30°;\ \beta = 65°;\ \tau_{\rm prec} = 4\,{\rm days};\ \omega_{\rm spin} = 0.5\,{\rm rpm}$	$1.83\ \times 10^{-3}$	$9.32\ \times 10^{-5}$
$\alpha = 50°;\ \beta = 45°;\ \tau_{\rm prec} = 4\,{\rm days};\ \omega_{\rm spin} = 0.5\,{\rm rpm}$	$6.49\ \times 10^{-4}$	$4.66\ \times 10^{-5}$
$\alpha = 50°;\ \beta = 45°;\ \tau_{\rm prec} = 96\,{\rm min};\ \omega_{\rm spin} = 0.1\,{\rm rpm}$	$6.32\ \times 10^{-4}$	$3.08\ \times 10^{-5}$
$\alpha = 65°;\ \beta = 30°;\ \tau_{\rm prec} = 93\,{\rm min};\ \omega_{\rm spin} = 0.1\,{\rm rpm}$	$3.29\ \times 10^{-4}$	$7.61\ \times 10^{-5}$
$\alpha = 65°;\ \beta = 30°;\ \tau_{\rm prec} = 96\,{\rm min};\ \omega_{\rm spin} = 0.1\,{\rm rpm}$	$3.27\ \times 10^{-4}$	$2.11\ \times 10^{-5}$
$\alpha = 65°;\ \beta = 30°;\ \tau_{\rm prec} = 96\,{\rm min};\ \omega_{\rm spin} = 0.3\,{\rm rpm}$	$3.03\ \times 10^{-4}$	$1.77\ \times 10^{-5}$

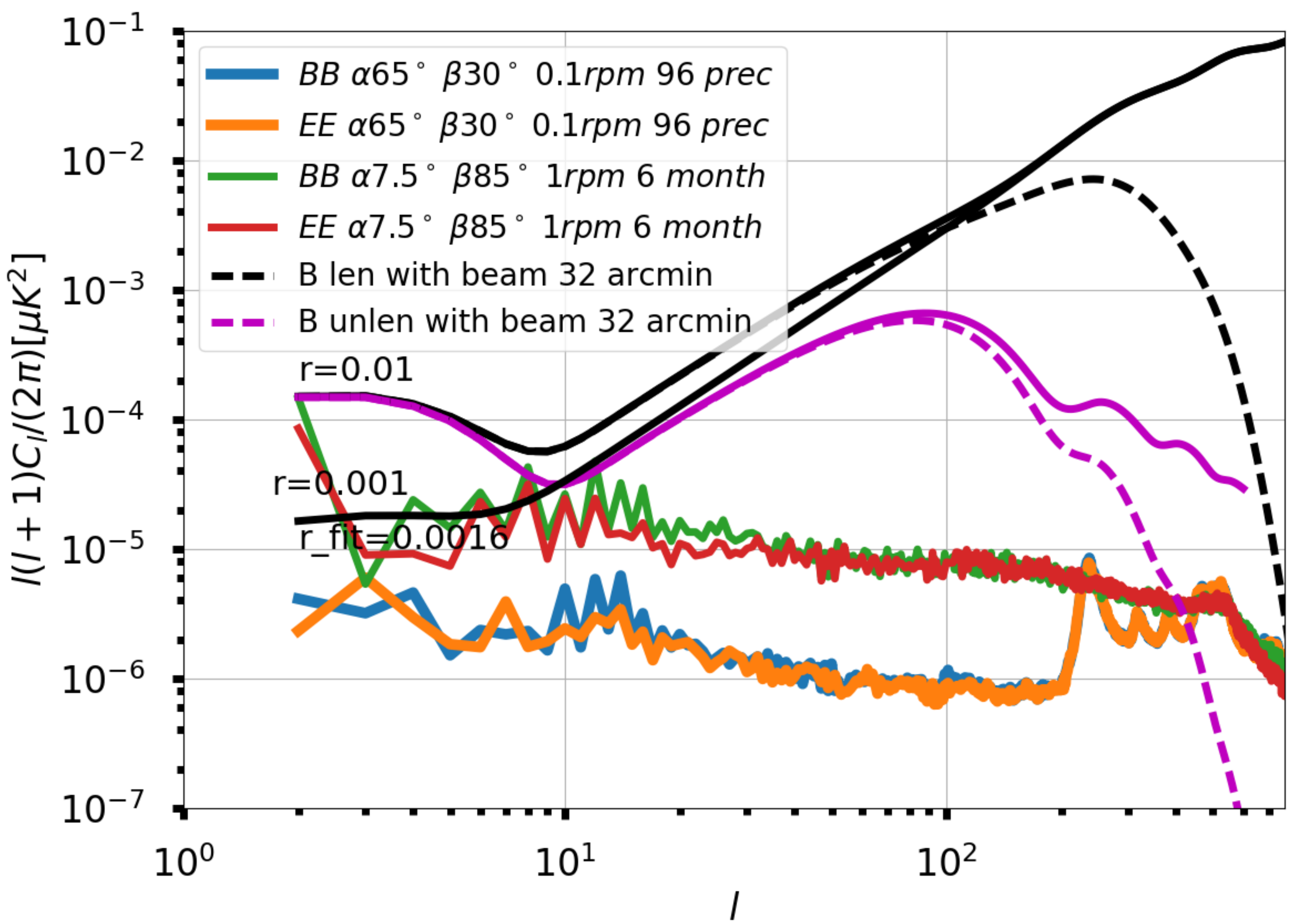
- Tensor-to-scalar r is order of 10^-3 in reionization bump, bandpass mismatch is not negligible effect.
- Correlation between leakage maps and cross moment.
- 1/N_det relationship => increase number of detectors.
- Bandpass mismatch error for satellite CMB experiments II: Correction effect (R. Banerji et al) *in preparation.*
- An ideal half wave plate mitigates the effect.

Merci beaucoup!

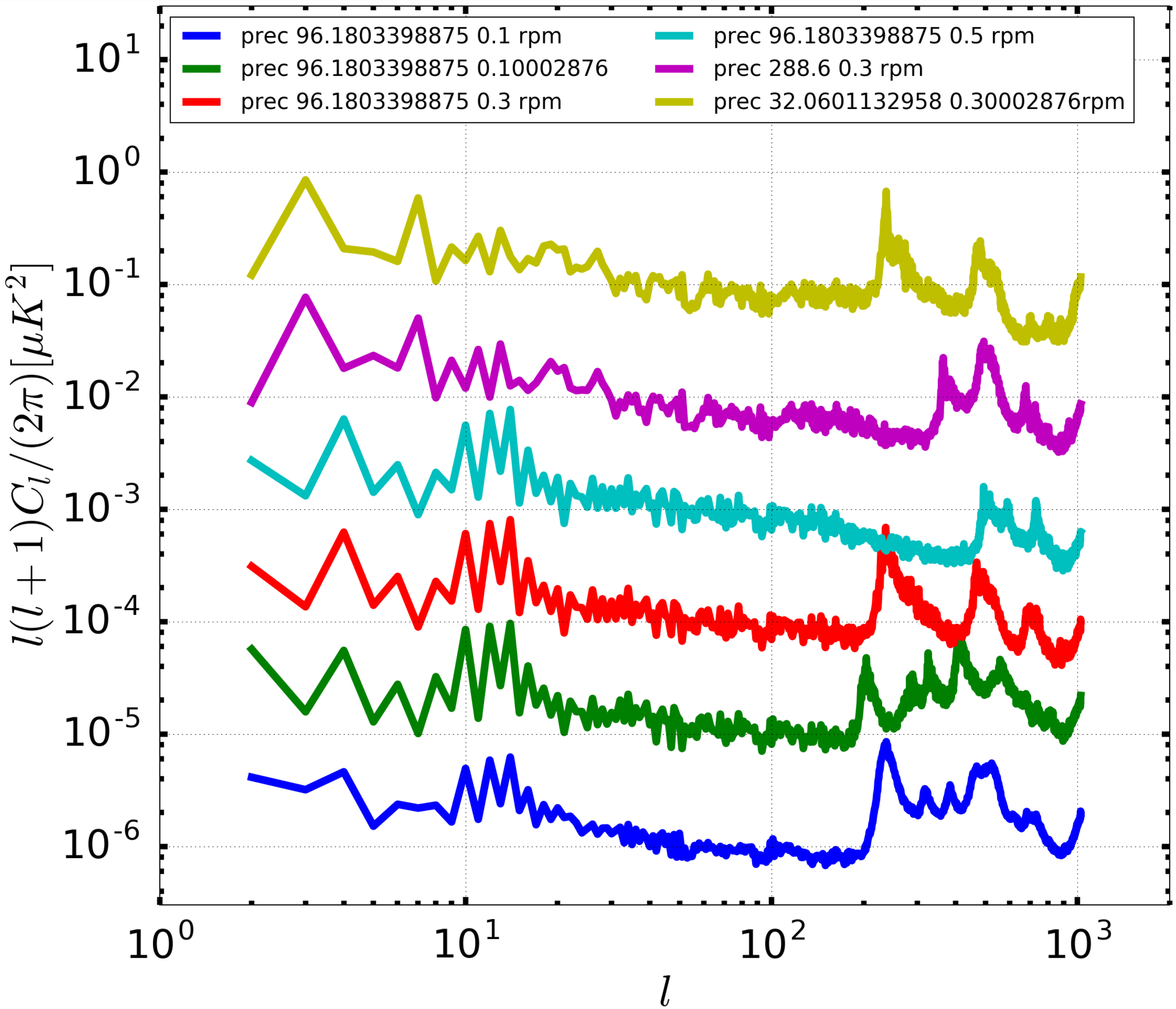
Backup (1) -> Planck leakage





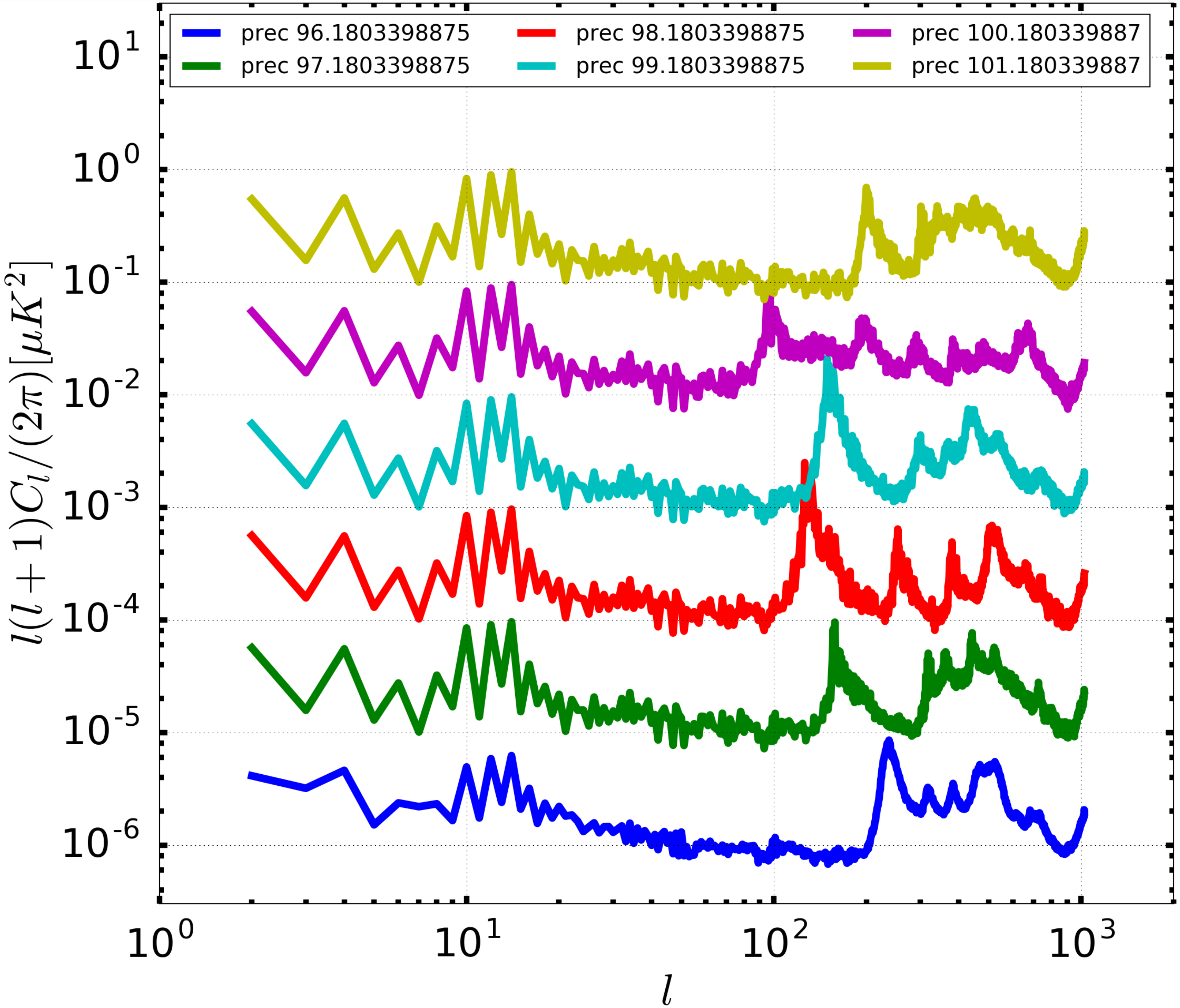


Backup (2) -> Vary scanning strategy params



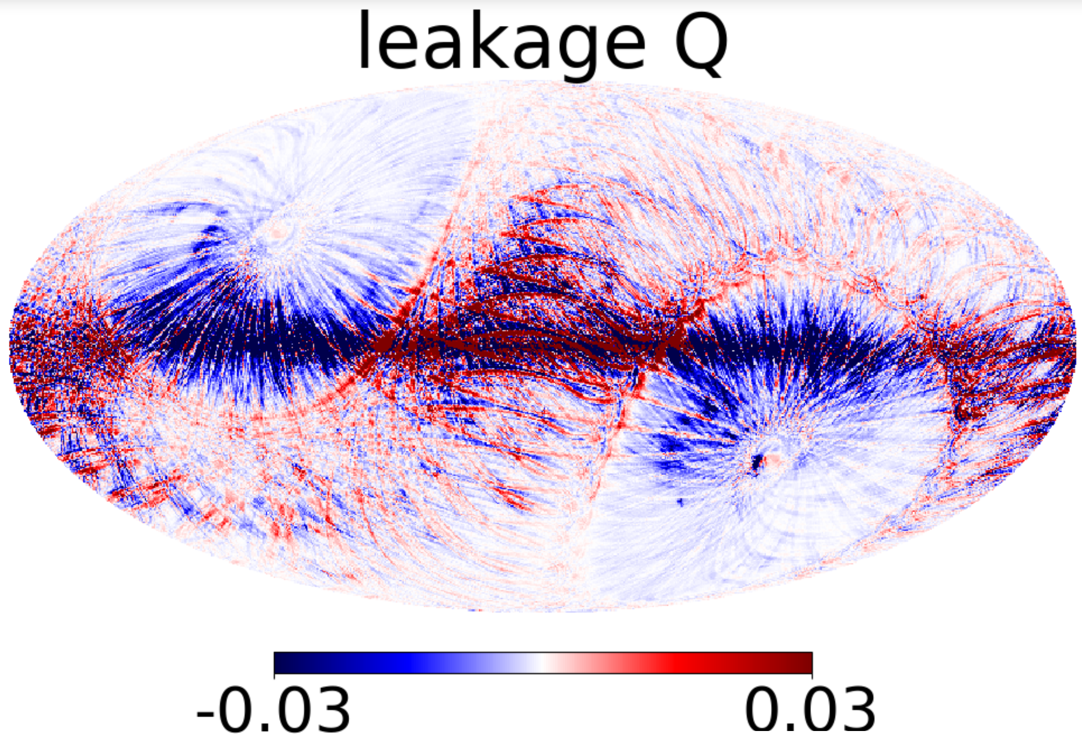
20% masked galactic, 222 detectors and 365 days observation

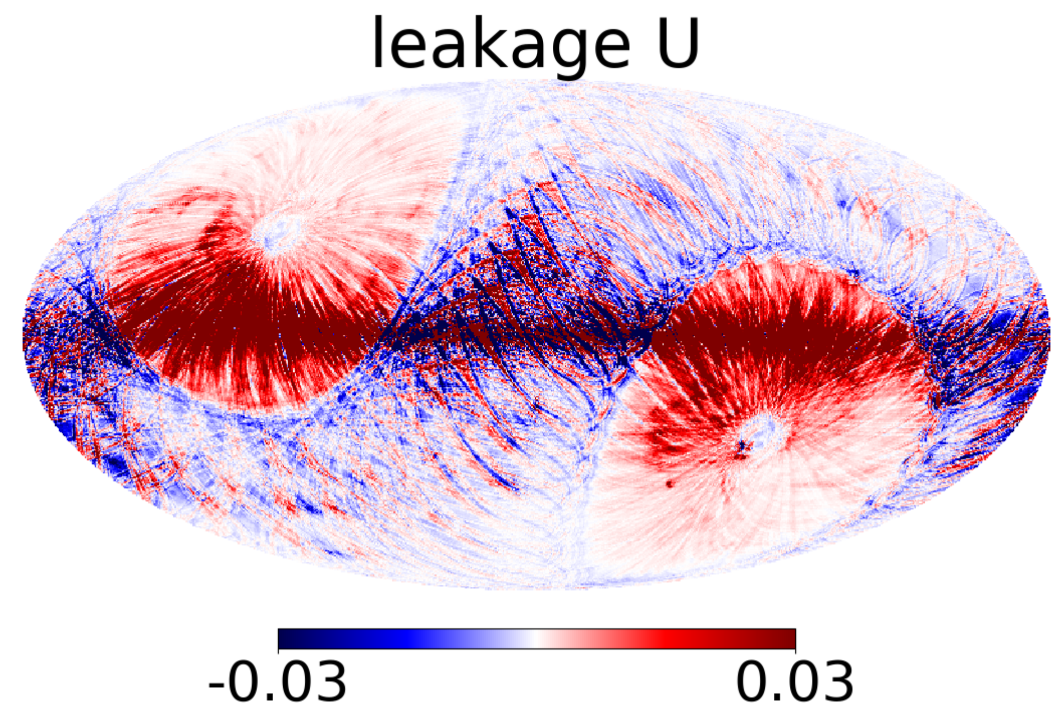
Backup (3) -> Vary scanning strategy: Precession

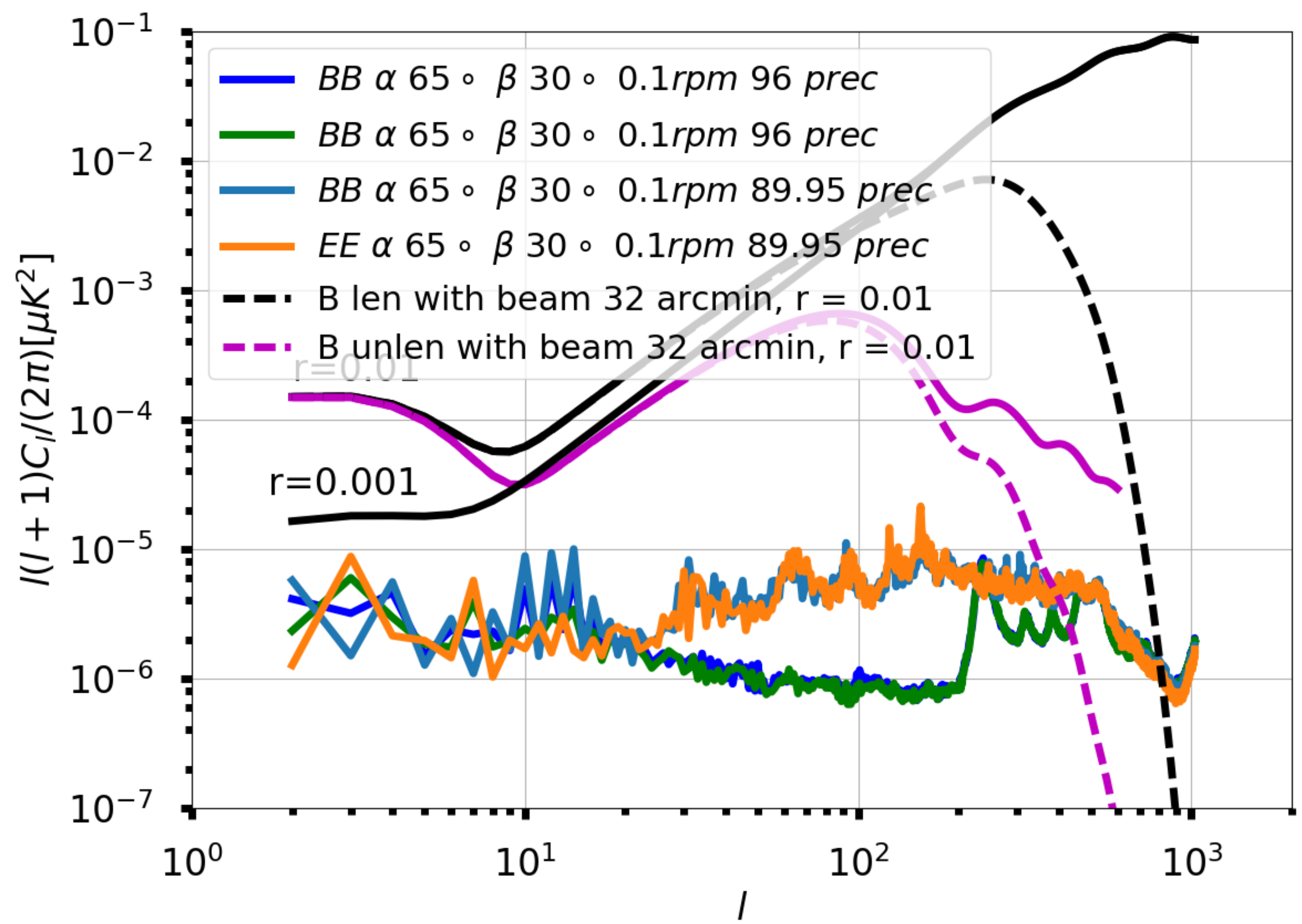


20% masked galactic, 222 detectors and 365 days observation

Backup -> bad scanning strategy params







20% masked galactic, 222 detectors and 365 days observation