SO with BI study

Elenia Manzan
University of Milan

SO simulation considerations

- Recovering of the **SO forecast**: it's just a proxy.
  - If we consider the polarization white noise level and add a sqrt(2) in the likelihood noise covariance matrix, we find sigma(r) close to forecast
  - However, it's just a proxy. Not even sure we are comparing apples-to-apples since we discard 1/f noise, hit map, FG marginalization, …

- We find that we get some **NaNs in the Dls** computation. They significantly reduce when doing compsep full sky or using nside_fit_parameters = 4. It's some sky coverage related effects, but we don't know precisely why it happens and how to solve it

- About the **Ultra Wide-Band** proposal: Mathias was considering a single UWB from 90 GHz to 250 GHz. However, this means almost 100% bandwidth and from the hardware point of view I think it's too much for feedhorns. If we write this proposal down in a paper, I think that any referee with a bit of familiarity with hardware stuff might argue that's unfeasible.
  In this regard, we might think of doing BI with ***back-to-back Lenslets***: wouldn't bet on this and for sure it requires a more in-depth thought, but if feedhorns can't make it to 100% bandwidth, maybe lenslets can.
  These are my two cents.

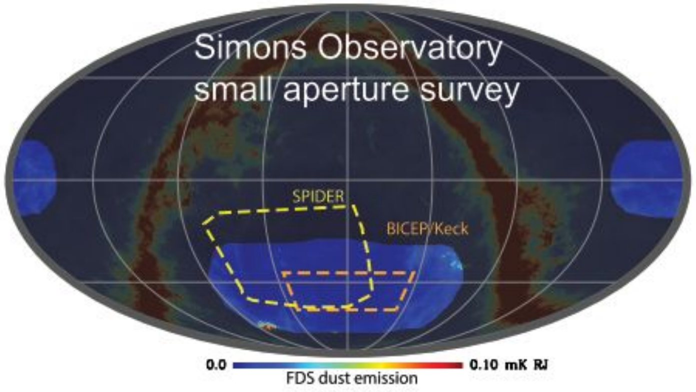
SO SAT baseline

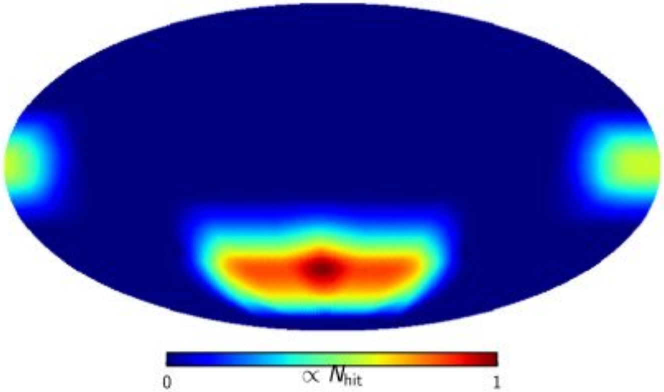
Table 1
Properties of the planned SO surveys[a].

	SATs ($f_{\rm sky} = 0.1$)			LAT ($f_{\rm sky} = 0.4$)		
Freq. [GHz]	FWHM (′)	Noise (baseline) [μK-arcmin]	Noise (goal) [μK-arcmin]	FWHM (′)	Noise (baseline) [μK-arcmin]	Noise (goal) [μK-arcmin]
27	91	35	25	7.4	71	52
39	63	21	17	5.1	36	27
93	30	2.6	1.9	2.2	8.0	5.8
145	17	3.3	2.1	1.4	10	6.3
225	11	6.3	4.2	1.0	22	15
280	9	16	10	0.9	54	37

[a] The detector passbands are being optimized (see Simons Observatory Collaboration in prep.) and are subject to variations in fabrication. For these reasons we expect the SO band centers to differ slightly from the frequencies presented here. 'Noise' columns give anticipated white noise levels for temperature, with polarization noise $\sqrt{2}$ higher as both Q and U Stokes parameters are measured. Noise levels are quoted as appropriate for a homogeneous hits map.

https://arxiv.org/abs/1808.07445





https://arxiv.org/pdf/2302.04276.pdf

Required modifications and additions

Bandwidth taken from digitalized version of this plot, taken from https://arxiv.org/abs/1808.07445

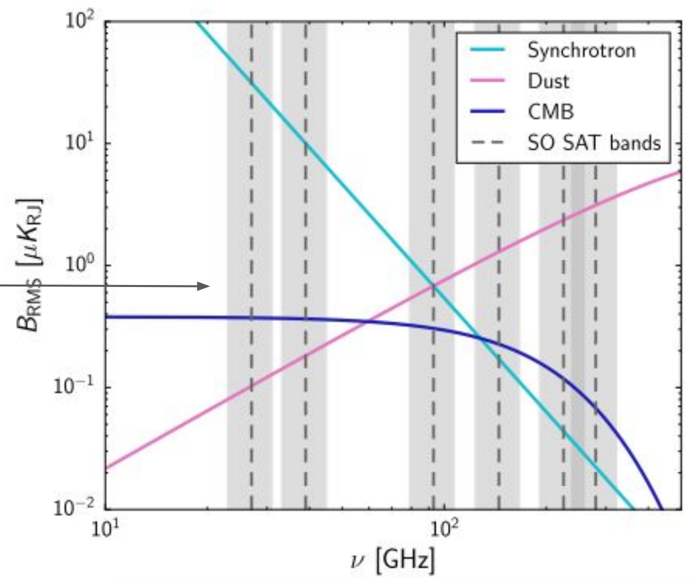
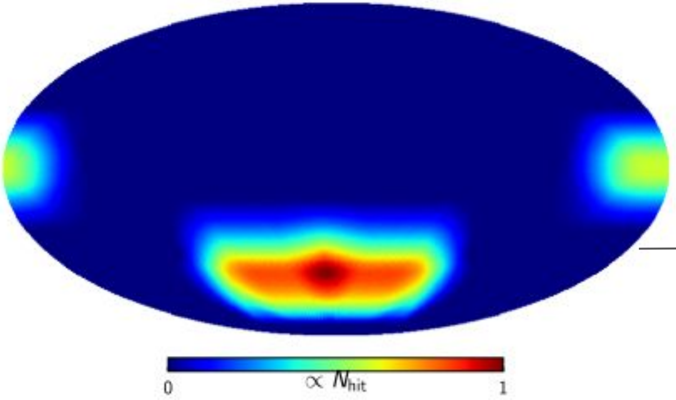


Figure 4. Frequency dependence, in RJ brightness temperature, of the synchrotron and thermal dust emission at degree scales within the proposed footprint for the SATs, compared to the CMB lensing B-mode signal. The turnover of the modified blackbody law for the dust lies above this frequency range.

Sky patch taken from https://github.com/simonsobs/BBPower/tree/main



- From Nside=64 to Nside=256
- From Equatorial (celestial) to Galactic

Noise properties: add 1/f noise in sph. arm. space + 2map

These noise levels are expected to be appropriate for small angular scales, but large angular scales are contaminated by $1/f$ noise at low frequencies in the detector time stream, which arises primarily from the atmosphere and electronic noise. We model the overall expected SO noise spectrum in each telescope and band to have the form

$$N_\ell = N_{\rm red}\left(\frac{\ell}{\ell_{\rm knee}}\right)^{\alpha_{\rm knee}} + N_{\rm white}, \tag{1}$$

where $N_{\rm white}$ is the white noise component and $N_{\rm red}$, $\ell_{\rm knee}$, and $\alpha_{\rm knee}$ describe the contribution from $1/f$ noise. We adopt values for these parameters using data from previous and on-going ground-based CMB experiments. We do not model the $1/f$ noise for the SATs in temperature: we do not anticipate using the SAT temperature measurements for scientific analysis, as the CMB signal is already well measured by *WMAP* and *Planck* on these scales.

SAT polarization: In this case we normalize the model such that $N_{\rm red} = N_{\rm white}$. At a reference frequency of

Table 2
Band-dependent parameters for the large-angular-scale noise model described in Eq. 1. Parameters that do not vary with frequency are in the text.

	SAT Polarization			LAT Temperature
Freq. [GHz]	$\ell_{\rm knee}$ [a]	$\ell_{\rm knee}$ [b]	$\alpha_{\rm knee}$	$N_{\rm red}\,[\mu{\rm K}^2 s]$
27	30	15	-2.4	100
39	30	15	-2.4	39
93	50	25	-2.5	230
145	50	25	-3.0	1,500
225	70	35	-3.0	17,000
280	100	40	-3.0	31,000

[a] Pessimistic case. [b] Optimistic case.

SO SAT Forecast

Table 4
Forecasts for $r = 0$ model using six different cleaning methods, for fiducial foreground model[a]

	Method	SO Baseline pess-$1/f$	SO Baseline opt-$1/f$	SO Goal pess-$1/f$	SO Goal opt-$1/f$
$A_{\rm lens} = 1$	C_ℓ-Fisher	$\sigma = 2.4$	$\sigma = 1.9$	$\sigma = 1.7$	$\sigma = 1.5$
	C_ℓ-MCMC	1.9 ± 2.6	2.3 ± 2.3	2.2 ± 2.1	2.4 ± 2.1
	xForecast	1.3 ± 2.7	1.6 ± 2.1	1.4 ± 1.9	1.6 ± 1.6
	xForecast[b]	0.0 ± 4.0	0.0 ± 3.5	0.0 ± 3.3	0.2 ± 2.8
	BFoRe[b]	-0.5 ± 5.8	-0.5 ± 3.6	-0.6 ± 4.3	-0.5 ± 3.4
	ILC[b]	-0.4 ± 3.9	-0.3 ± 3.1	-0.2 ± 3.9	-0.3 ± 3.0
$A_{\rm lens} = 0.5$	C_ℓ-Fisher	$\sigma = 1.8$	$\boldsymbol{\sigma = 1.4}$	$\sigma = 1.2$	$\sigma = 0.9$
	C_ℓ-MCMC	1.7 ± 2.1	$\mathbf{2.2 \pm 2.0}$	2.0 ± 1.7	2.2 ± 1.7
	xForecast	1.3 ± 2.1	$\mathbf{1.6 \pm 1.5}$	1.3 ± 1.3	1.5 ± 1.0
	xForecast[b]	0.1 ± 3.2	$\mathbf{0.1 \pm 2.6}$	0.0 ± 2.5	0.3 ± 1.8
	BFoRe[b]	-0.2 ± 5.0	$\mathbf{-0.4 \pm 2.6}$	-0.6 ± 3.2	-0.5 ± 2.0
	ILC[b]	-0.3 ± 3.0	$\mathbf{-0.3 \pm 2.4}$	-0.1 ± 2.8	-0.2 ± 2.3

[a] Table gives $(r \pm \sigma(r)) \times 10^3$ for different analysis pipelines (different rows), and different noise configurations (different columns, see Sec. 2.2 for details.). The results for the fiducial lensing and noise combination are highlighted in boldface.
[b] In these cases a foreground residual is additionally marginalized over after map-based cleaning.

Table 5
Forecasts exploring departures from the fiducial case[a]

Method	Fiducial	$r = 0.01$	2-dust +AME	High-res β_s
C_ℓ-Fisher	$\sigma = 1.4$	$\sigma = 1.8$	$\sigma = 1.4$	$\sigma = 1.4$
C_ℓ-MCMC	2.2 ± 2.0	12 ± 2.3	1.5 ± 1.9	5.3 ± 2.0
xForecast[b]	0.1 ± 2.6	9.9 ± 3.3	0.5 ± 3.1	0.0 ± 2.7
BFoRe[b]	-0.4 ± 2.6	9.5 ± 3.2	-0.3 ± 2.4	-0.4 ± 2.7
ILC[b]	-0.3 ± 2.4	9.7 ± 2.8	-0.3 ± 2.5	-0.5 ± 3.5

[a] Table gives $(r \pm \sigma(r)) \times 10^3$ for different analysis pipelines (different rows), and different departures from the fiducial case (an $r = 0.01$ model and two alternative foreground models).
[b] Marginalized over foreground residual after cleaning.

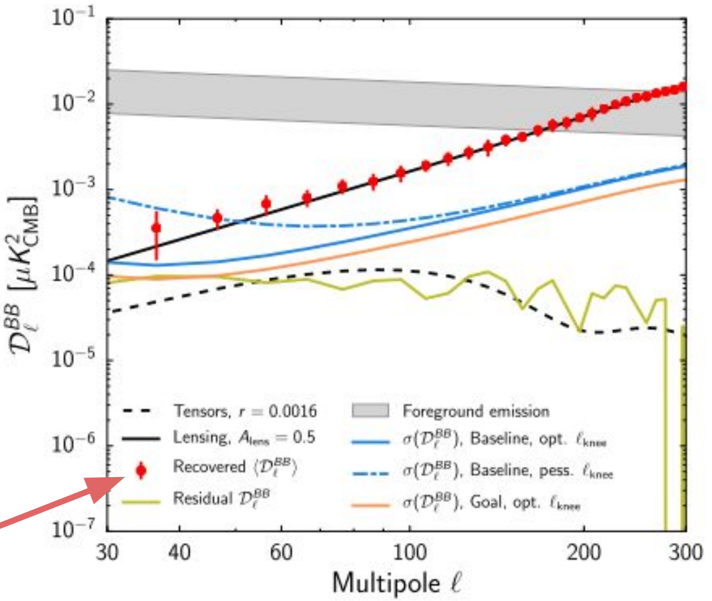
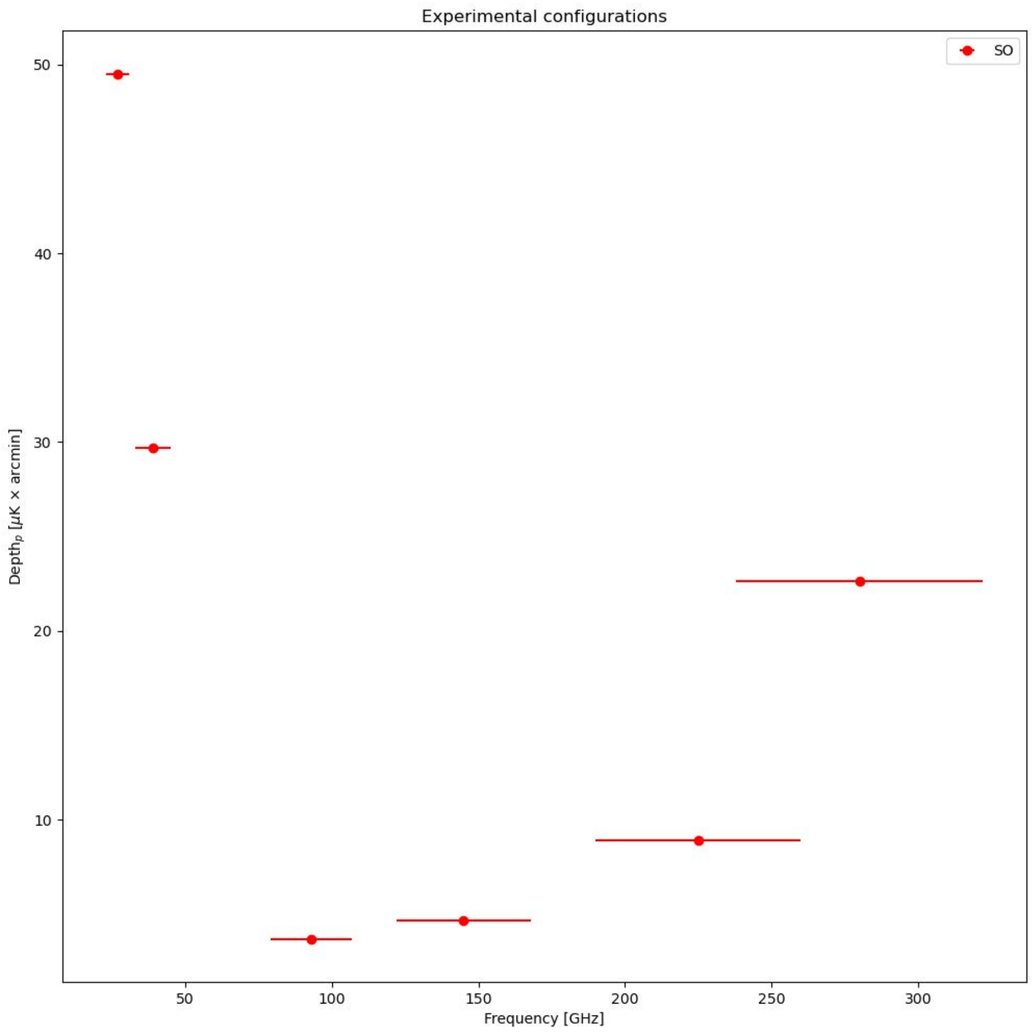


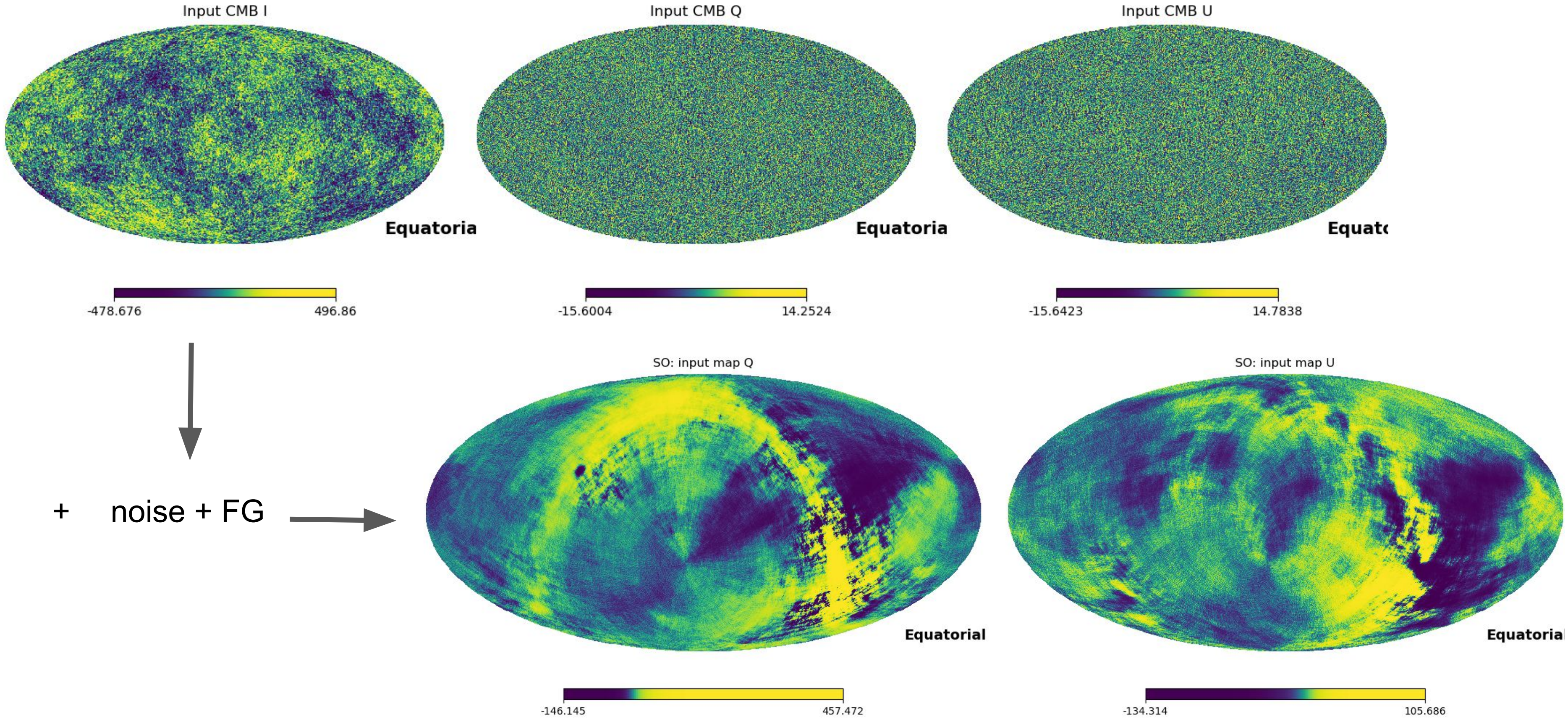
Figure 11. Mean B-mode power spectrum, D_ℓ^{BB}, estimated from simulations using map-level component separation (red) with errors from 100 realizations. The input spectrum (black solid) has $r = 0$ and assumes 50% delensing. The power of the total foreground emission is shown shaded (between 93 GHz, lower, and 145 GHz, upper). Power spectrum uncertainties for $\Delta\ell = 10$ bandpowers are shown (blue, orange) for different SO noise configurations. The contribution of foreground residuals to the recovered D_ℓ^{BB} (yellow) biases the red circles above the input and is comparable to a signal with tensor-to-scalar ratio $r = 0.0016$ (dashed). This bias can be suppressed by marginalizing over the foreground residuals in the likelihood.

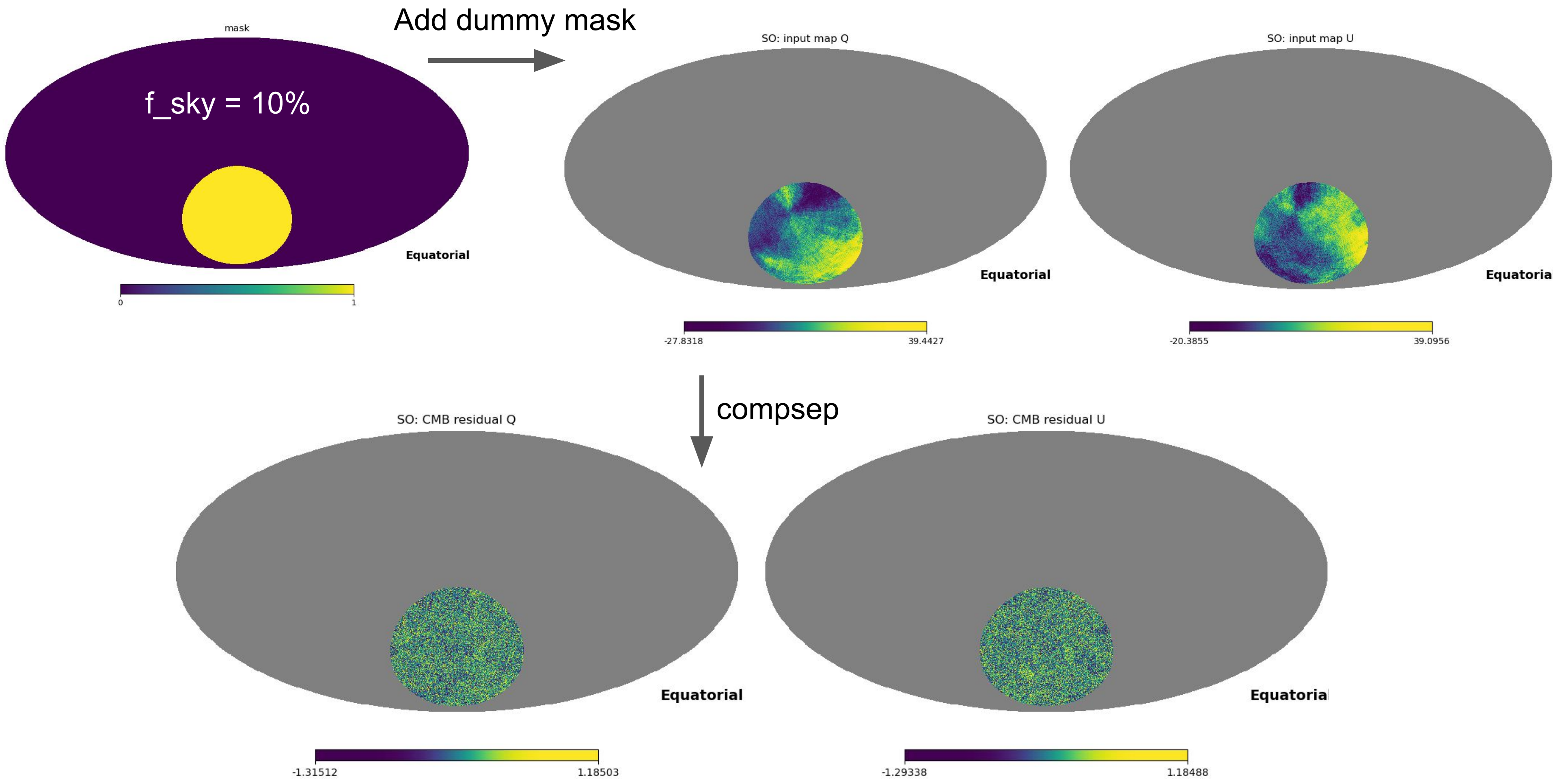
Define instrumental setup



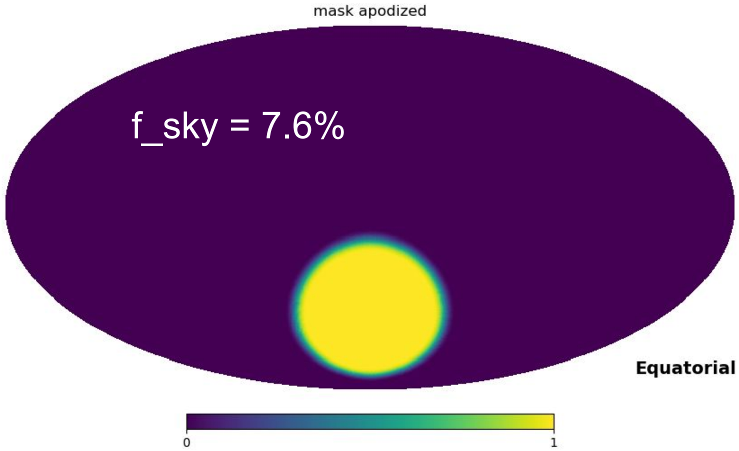
Dummy test on a circular sky patch with just white noise

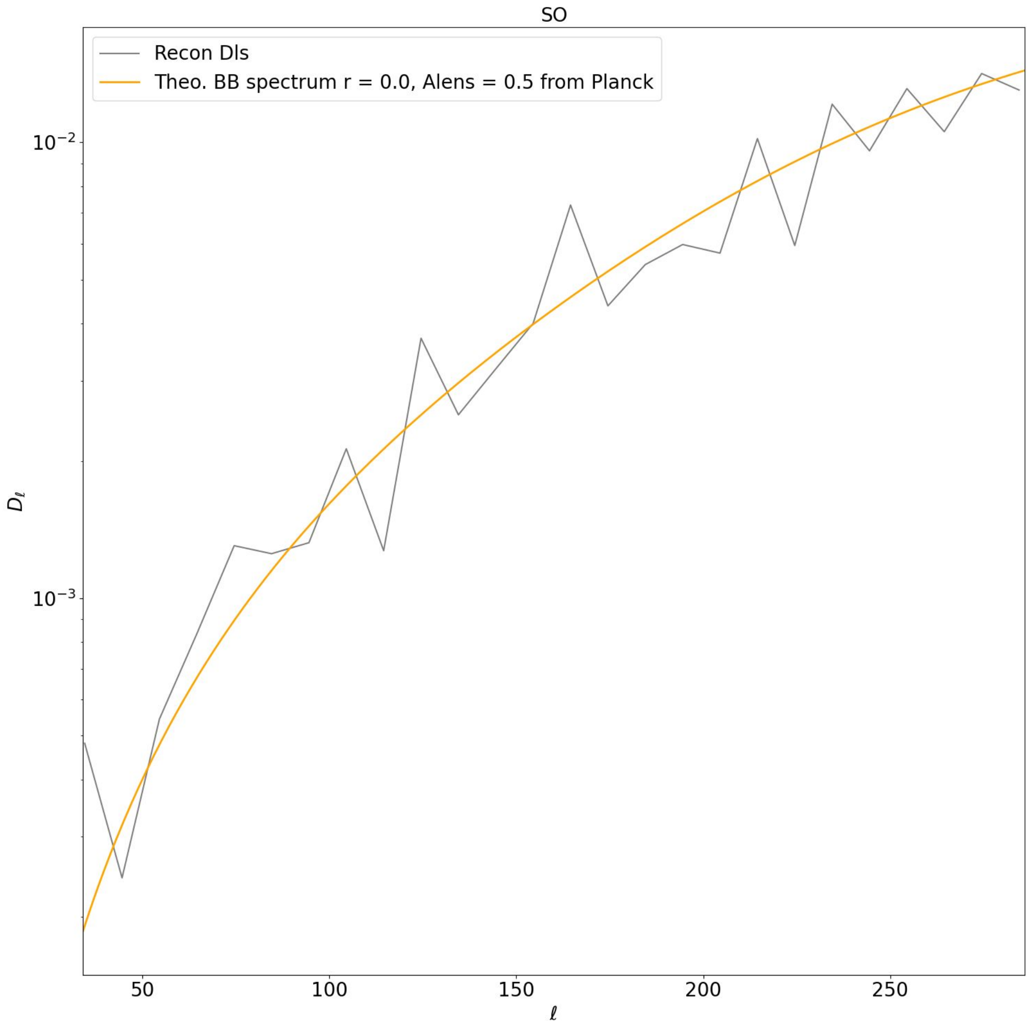
Test the code on a circular patch



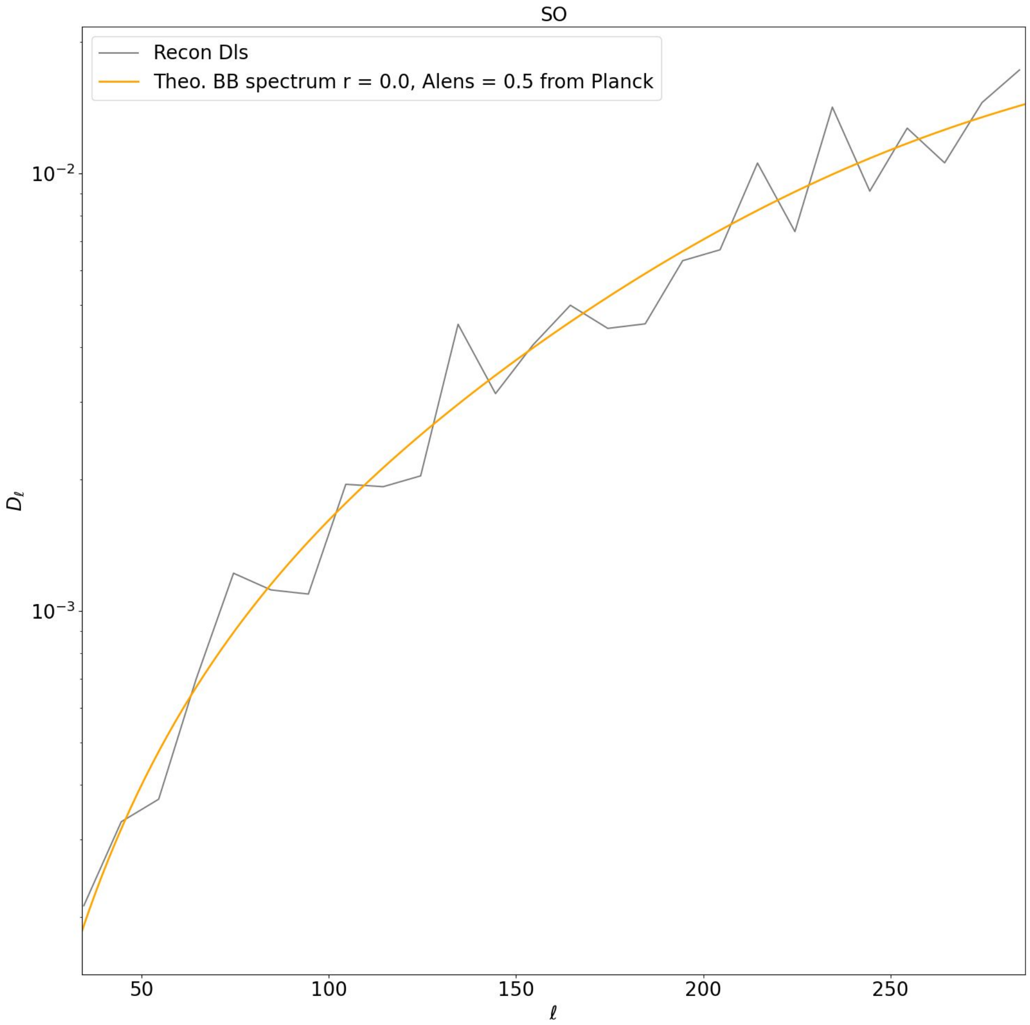

mask
f_sky = 10%
Equatorial
0
1
Add dummy mask
SO: input map Q
Equatorial
-27.8318
39.4427
SO: input map U
Equatoria
-20.3855
39.0956
compsep
SO: CMB residual Q
Equatorial
-1.31512
1.18503
SO: CMB residual U
Equatoria
-1.29338
1.18488

From map to Dls



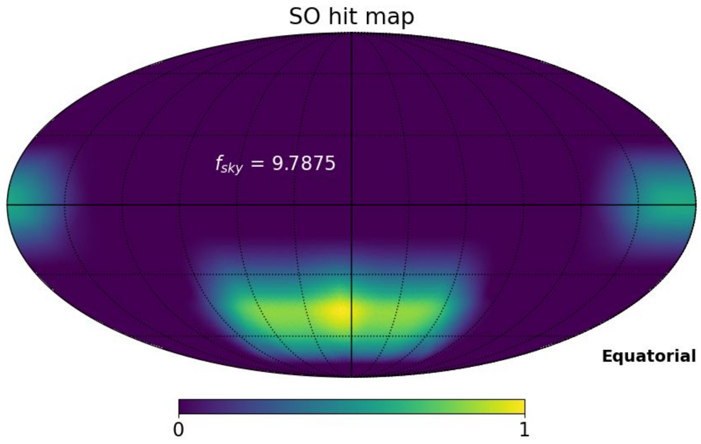


Same result, but from different realization: seems ok



Test with the official sky patch but just white noise

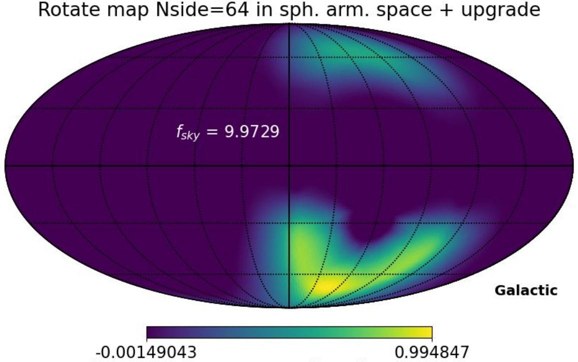
Define coverage



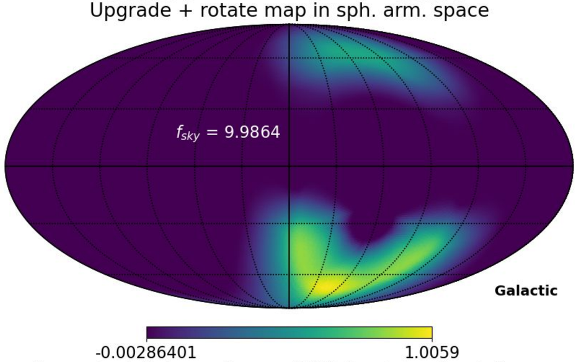
From Nside=64 to Nside=256

From Equatorial (celestial) to Galactic

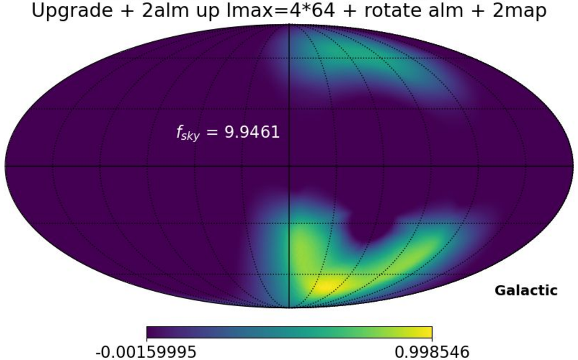
method 1



method 2

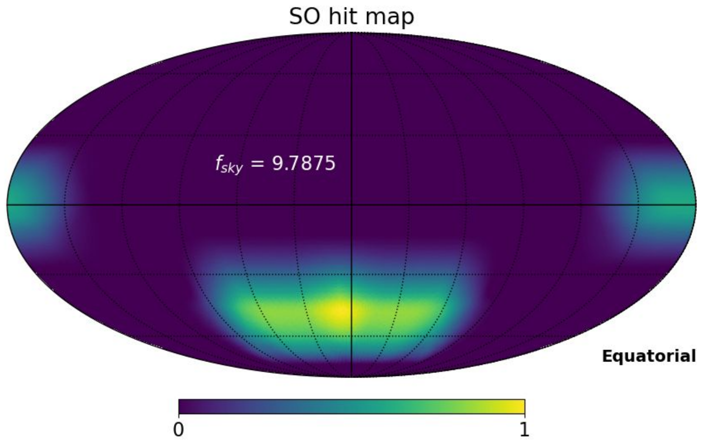


method 3



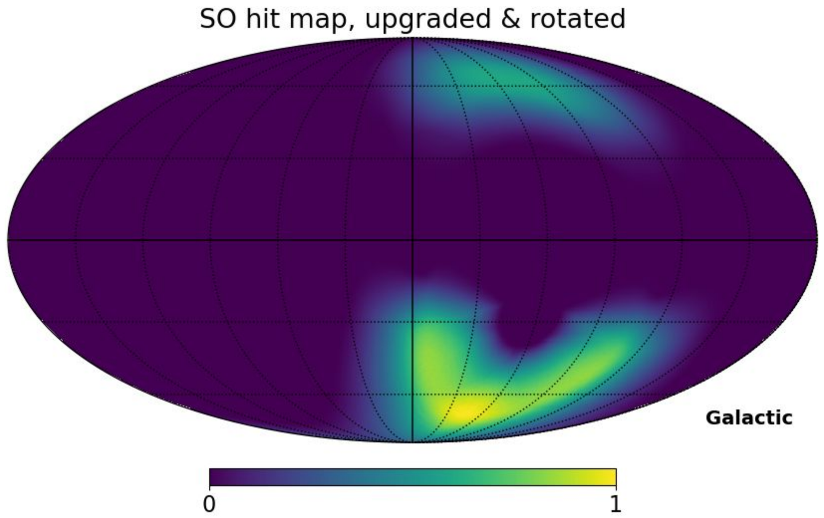
Loris docet: this has less contamination

Define coverage



From Nside=64 to Nside=256

From Equatorial (celestial) to Galactic

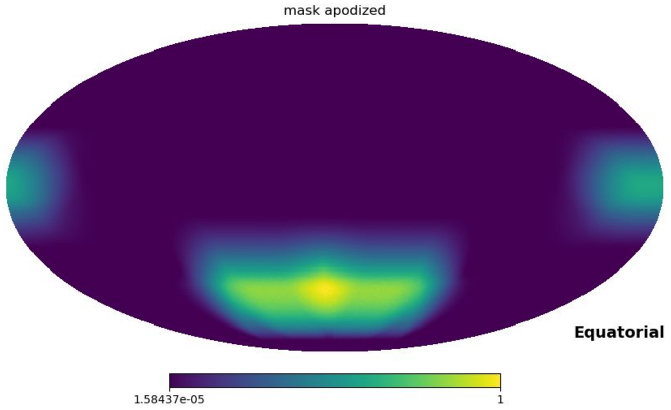


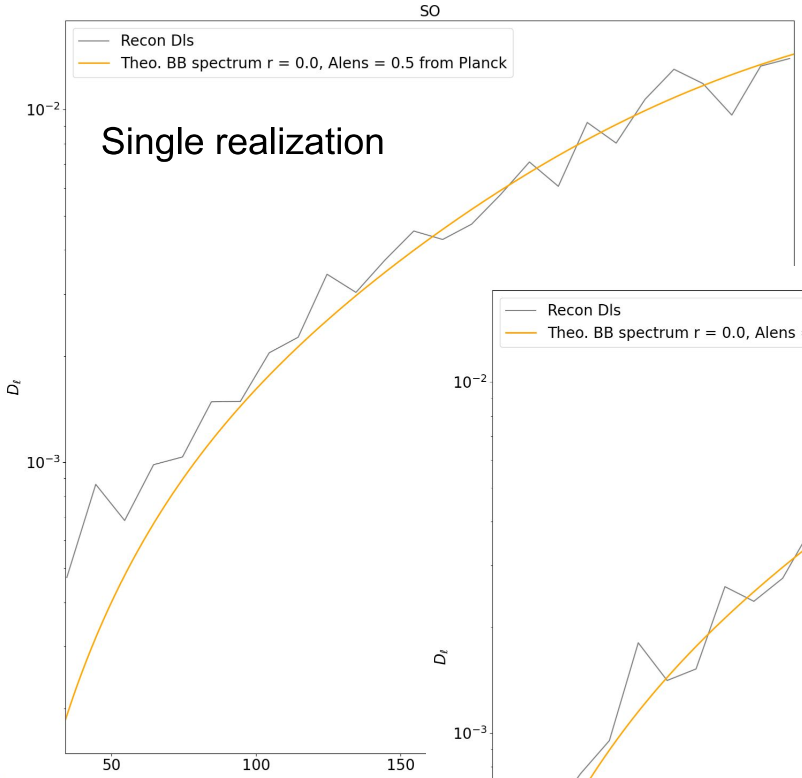
Obtained with method 3 and then normalized

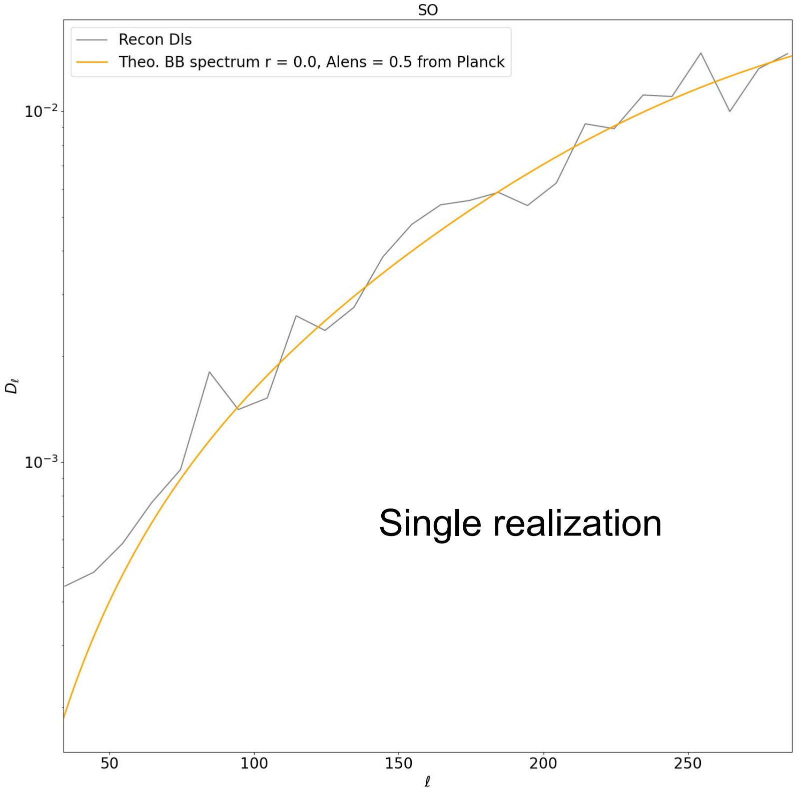
Test 1

Sky patch for compsep defined
by taking pixels with coverage > 0.05

Then I pass to Namaster the hit map itself with apo_size=1 (so that it doesn't modify the hit map significantly. If I use apo_size=0 I get all NaNs and I don't know why)

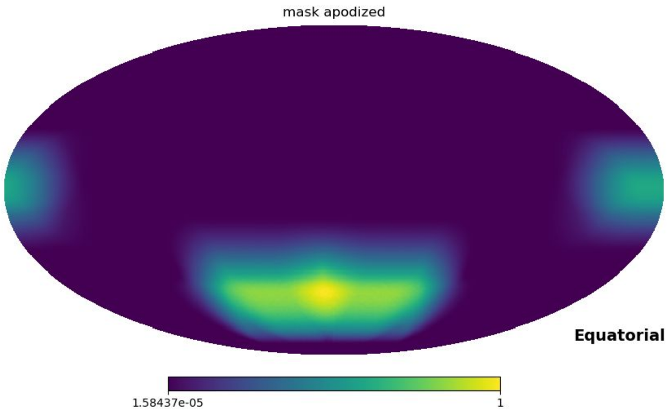


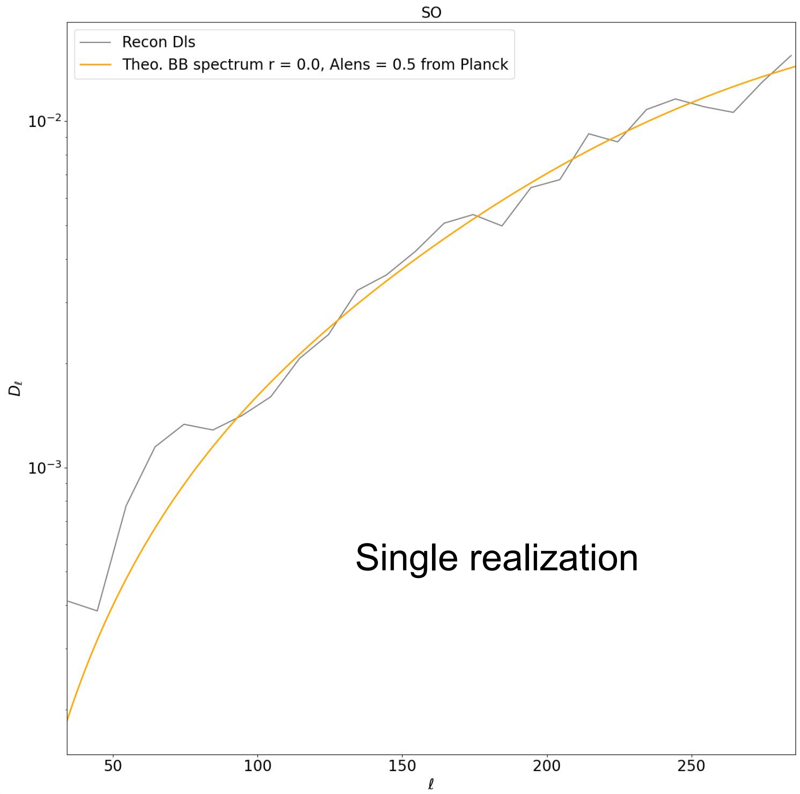




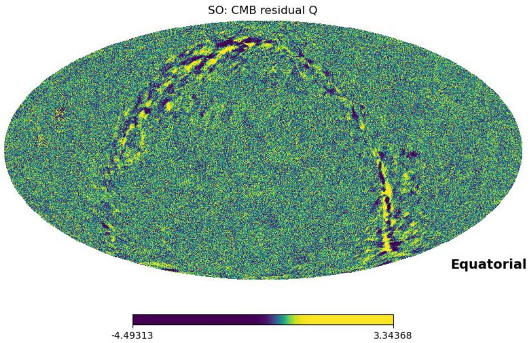
There's too much mismatch between skypatch used in compsep and the one in Namaster

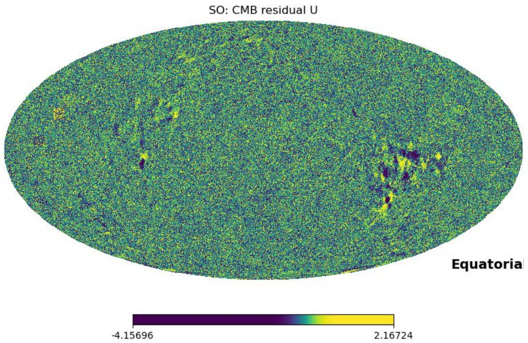
Test 2





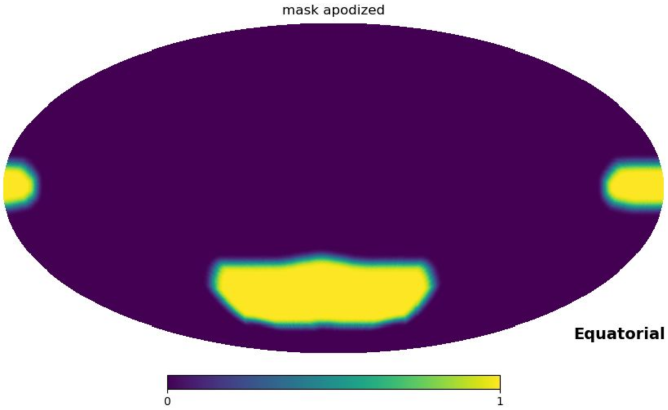
compsep almost full sky (pixel seen if cov > 0)
+ mask in Namaster is the official SO hit mask with additional 1 deg apo to make Namaster work



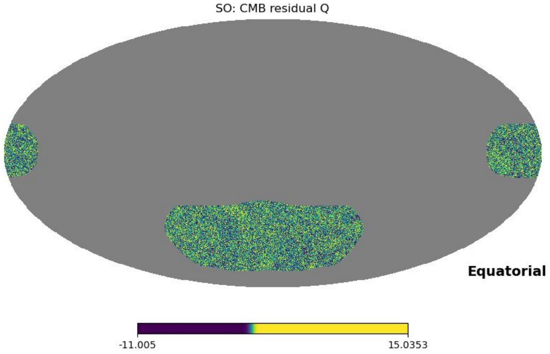


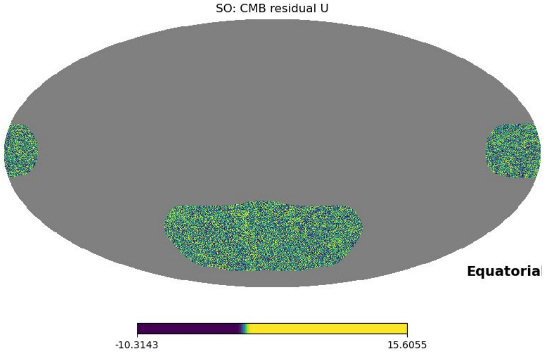
This method is self-consistent but the compsep is almost full sky. But FGB doesn't take hit maps, just zeros or hp.UNSEEN

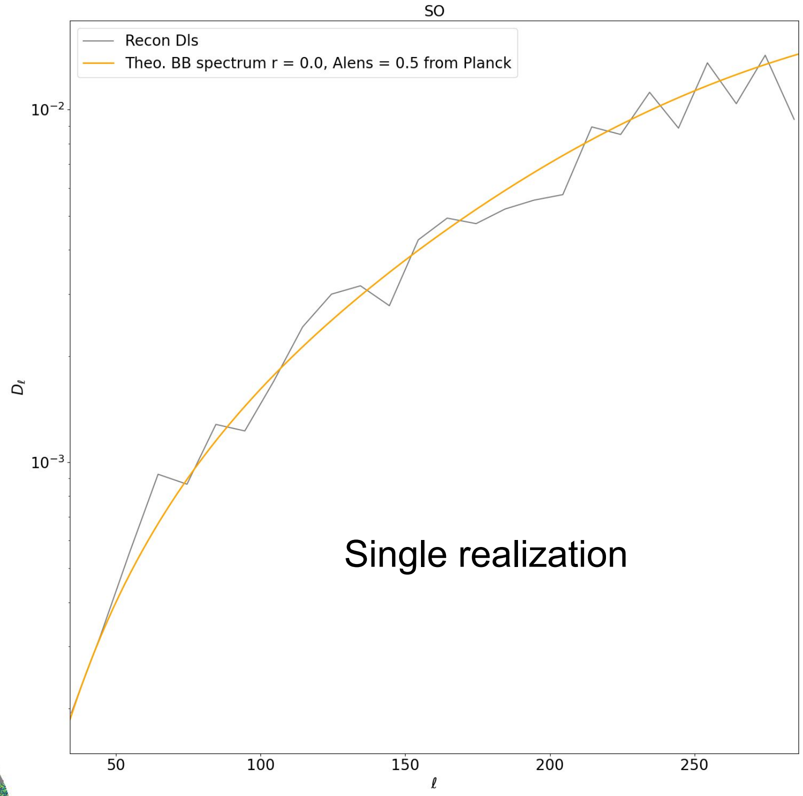
Test 3



Def pixel as seen if coverage > 0.3
Pass this coverage to Namaster + apo = 10 deg



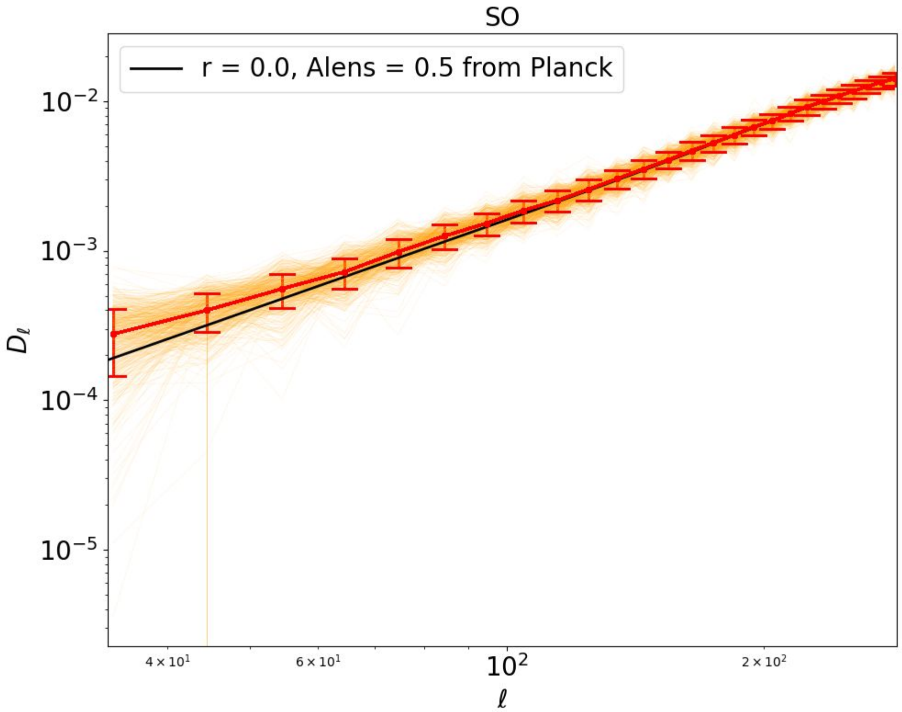


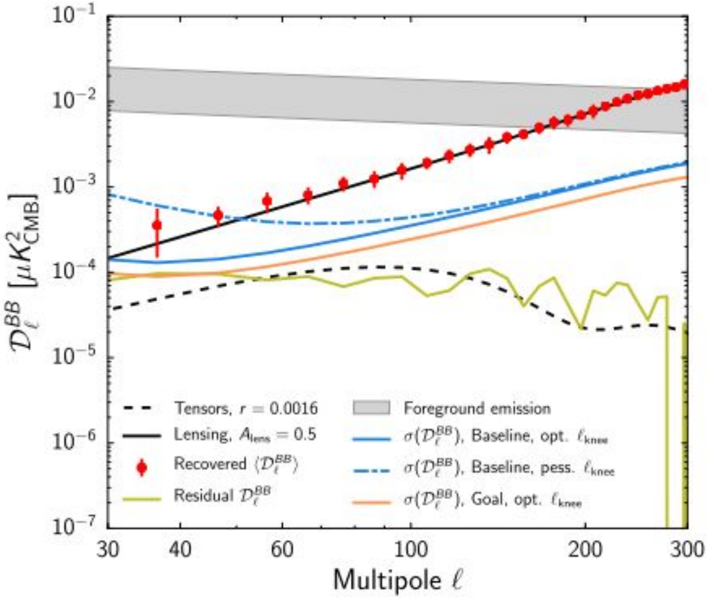


This method is also self-consistent but the sky patch deviates from the official one

Test 2 with full pipeline (500 reals)

compsep almost full sky (pixel seen if cov > 0)
+ mask in Namaster is the official SO hit mask with additional 1 deg apo to make Namaster work





Test 2 with full pipeline (500 reals)

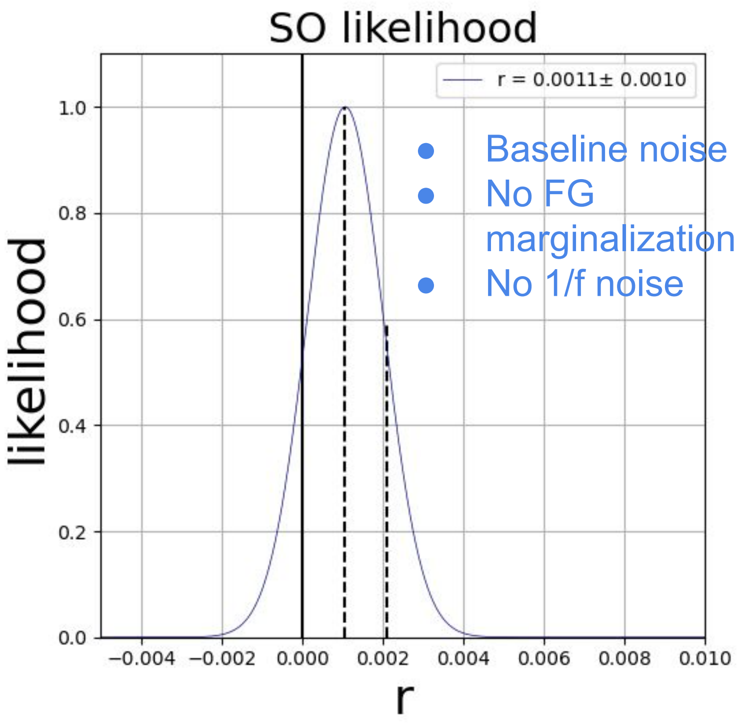


Table 4
Forecasts for $r = 0$ model using six different cleaning methods, for fiducial foreground model[a]

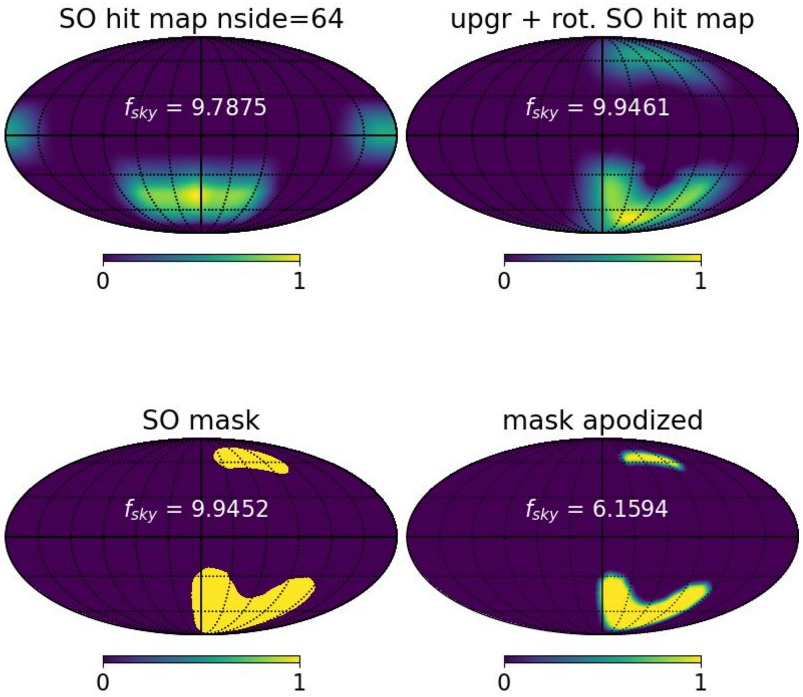
	Method	SO Baseline pess-$1/f$	SO Baseline opt-$1/f$	SO Goal pess-$1/f$	SO Goal opt-$1/f$
$A_{\rm lens} = 1$	C_ℓ-Fisher	$\sigma = 2.4$	$\sigma = 1.9$	$\sigma = 1.7$	$\sigma = 1.5$
	C_ℓ-MCMC	1.9 ± 2.6	2.3 ± 2.3	2.2 ± 2.1	2.4 ± 2.1
	xForecast	1.3 ± 2.7	1.6 ± 2.1	1.4 ± 1.9	1.6 ± 1.6
	xForecast[b]	0.0 ± 4.0	0.0 ± 3.5	0.0 ± 3.3	0.2 ± 2.8
	BFoRe[b]	-0.5 ± 5.8	-0.5 ± 3.6	-0.6 ± 4.3	-0.5 ± 3.4
	ILC[b]	-0.4 ± 3.9	-0.3 ± 3.1	-0.2 ± 3.9	-0.3 ± 3.0
$A_{\rm lens} = 0.5$	C_ℓ-Fisher	$\sigma = 1.8$	$\boldsymbol{\sigma = 1.4}$	$\sigma = 1.2$	$\sigma = 0.9$
	C_ℓ-MCMC	1.7 ± 2.1	$\mathbf{2.2 \pm 2.0}$	2.0 ± 1.7	2.2 ± 1.7
	xForecast	1.3 ± 2.1	$\boxed{\mathbf{1.6 \pm 1.5}}$	1.3 ± 1.3	1.5 ± 1.0
	xForecast[b]	0.1 ± 3.2	$\mathbf{0.1 \pm 2.6}$	0.0 ± 2.5	0.3 ± 1.8
	BFoRe[b]	-0.2 ± 5.0	$\mathbf{-0.4 \pm 2.6}$	-0.6 ± 3.2	-0.5 ± 2.0
	ILC[b]	-0.3 ± 3.0	$\mathbf{-0.3 \pm 2.4}$	-0.1 ± 2.8	-0.2 ± 2.3

- Baseline noise
- No FG marginalization
- opt-1/f noise

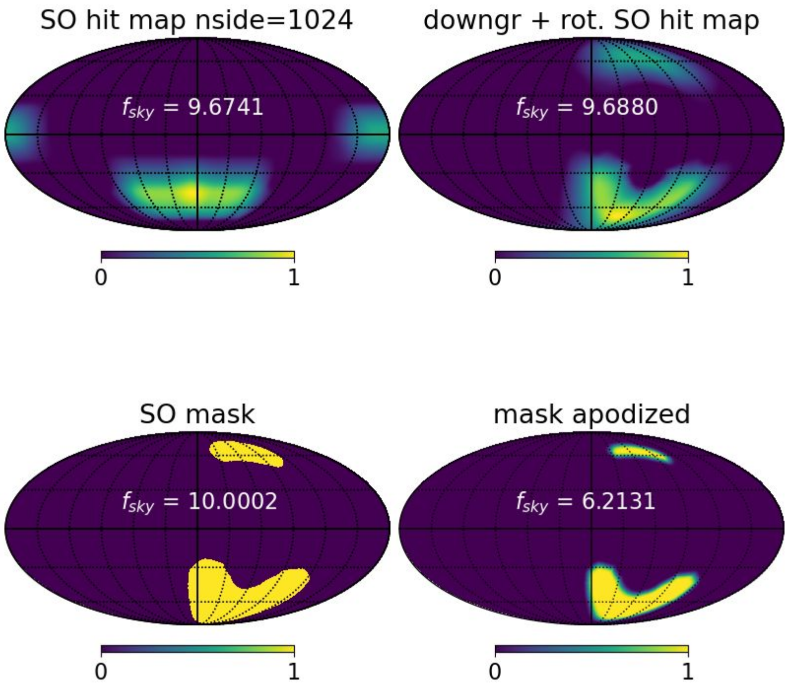
[a] Table gives $(r \pm \sigma(r)) \times 10^3$ for different analysis pipelines (different rows), and different noise configurations (different columns, see Sec. 2.2 for details.). The results for the fiducial lensing and noise combination are highlighted in boldface.
[b] In these cases a foreground residual is additionally marginalized over after map-based cleaning.

On the discrepancy between my and Mathias' results

Coverage map from SO hit map nside=64



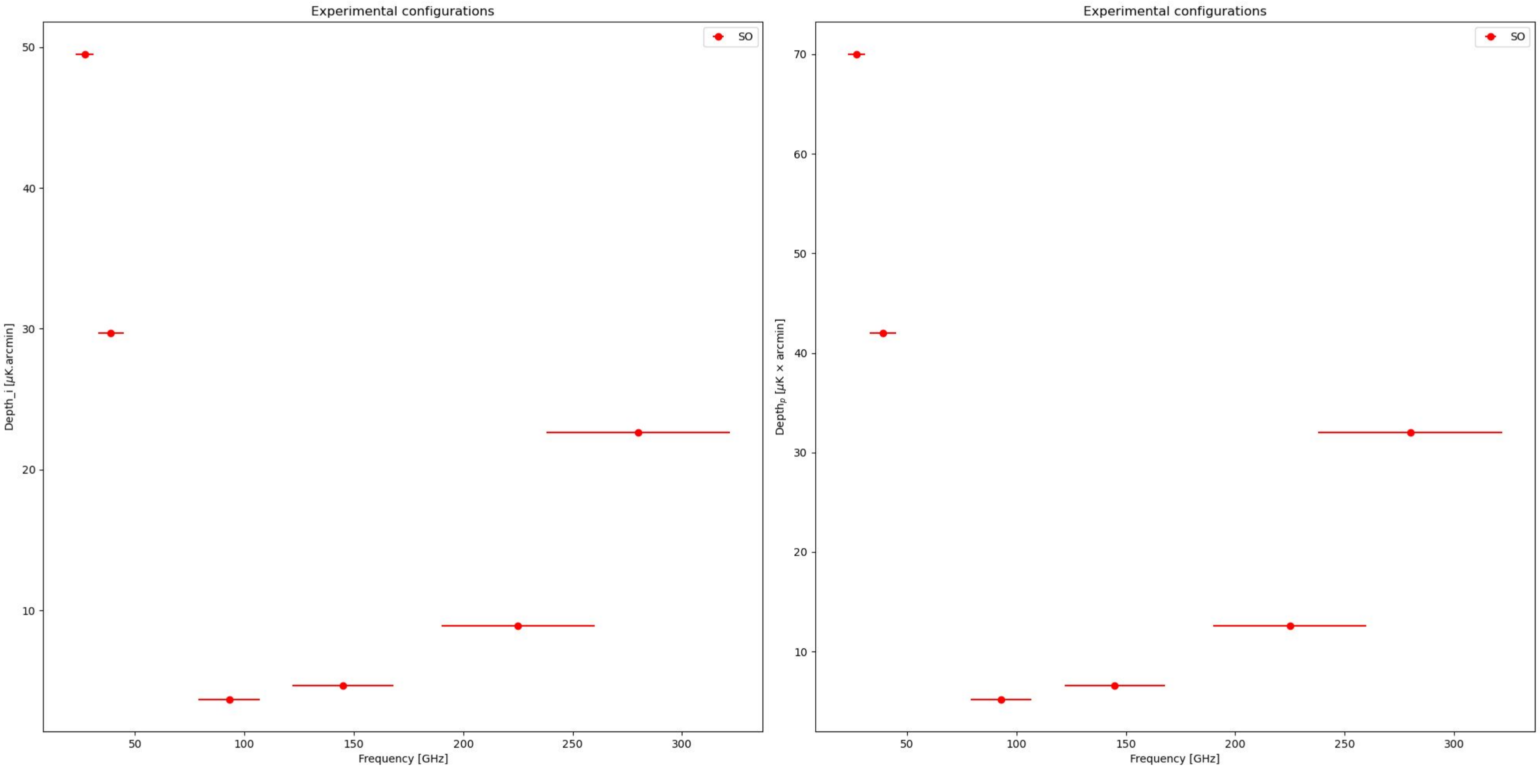
Coverage map from SO hit map nside=1024



no major difference

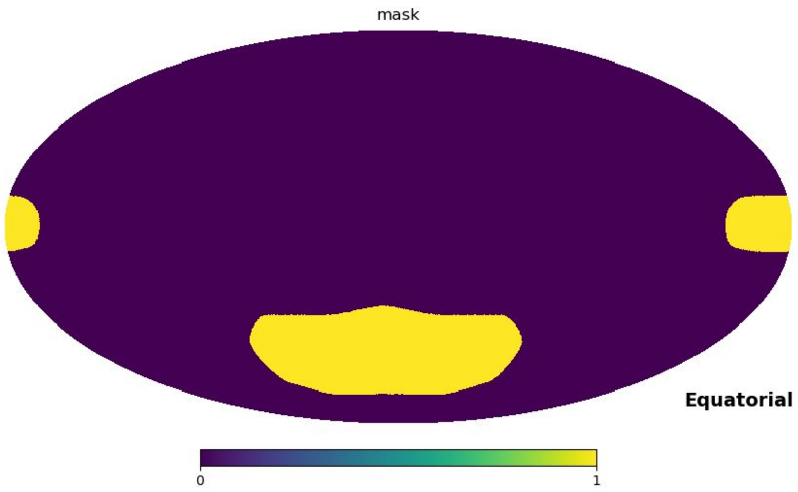
Test single realization using:

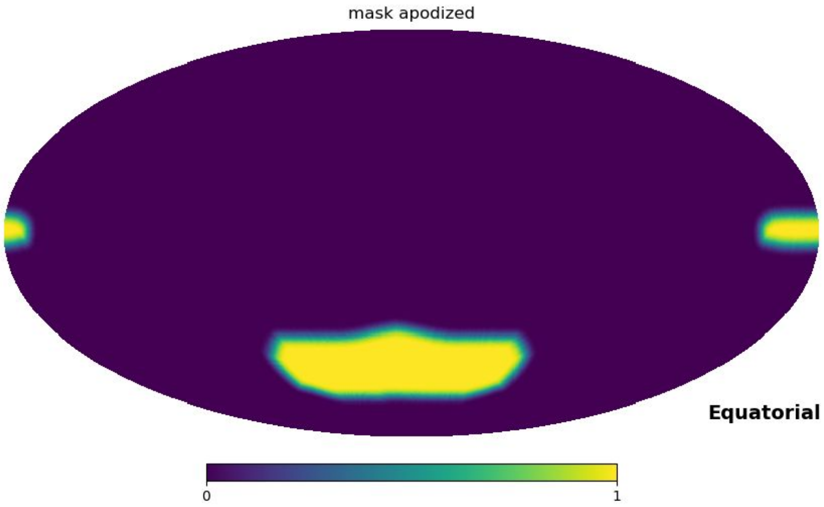
- pol wh noise*sqrt(2) for cross-spectra
- binary coverage from hit map at nside=1024



Test single realization using:

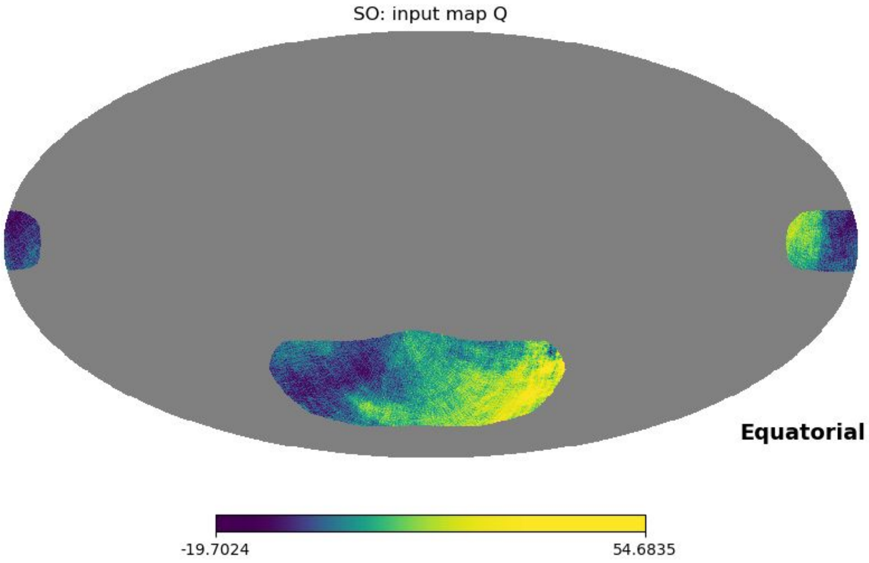
- pol wh noise*sqrt(2) for cross-spectra
- binary coverage from hit map at nside=1024

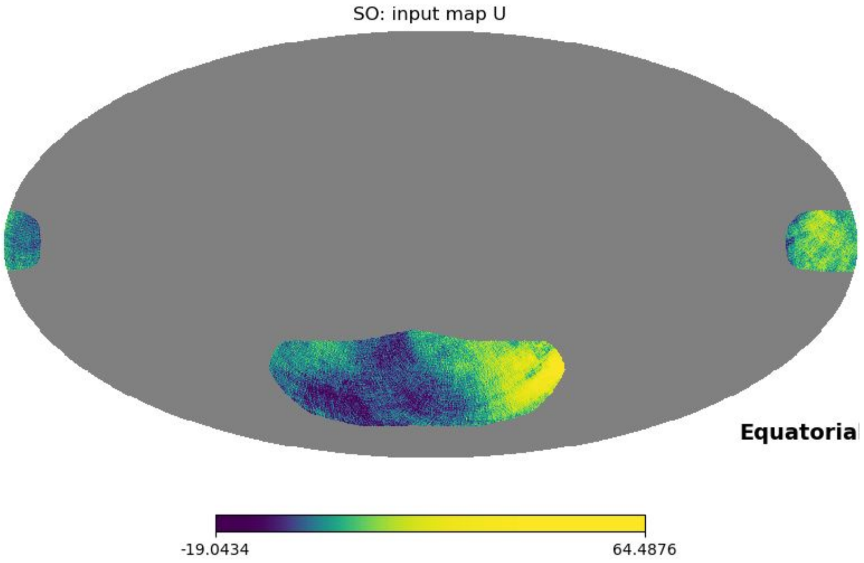




Test single realization using:

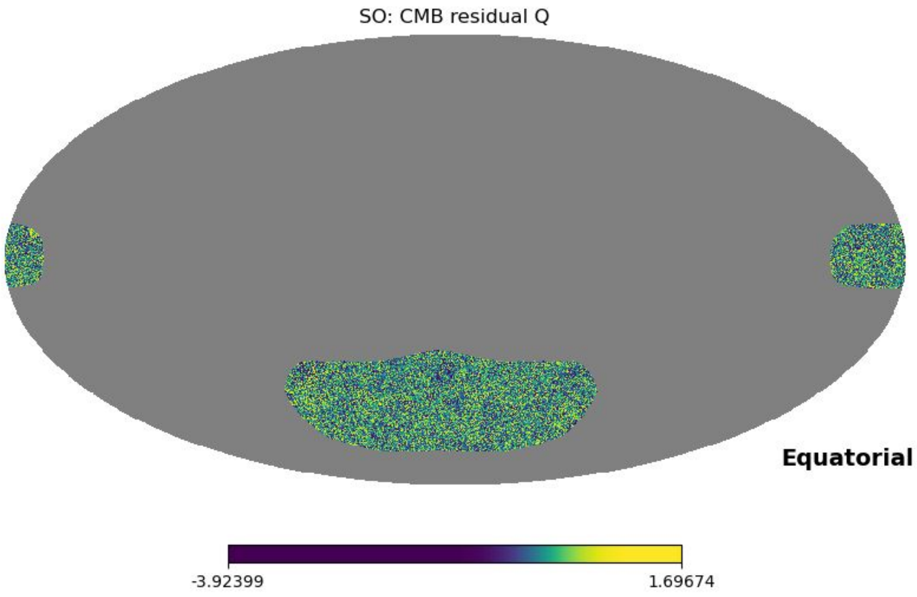
- pol wh noise*sqrt(2) for cross-spectra
- binary coverage from hit map at nside=1024

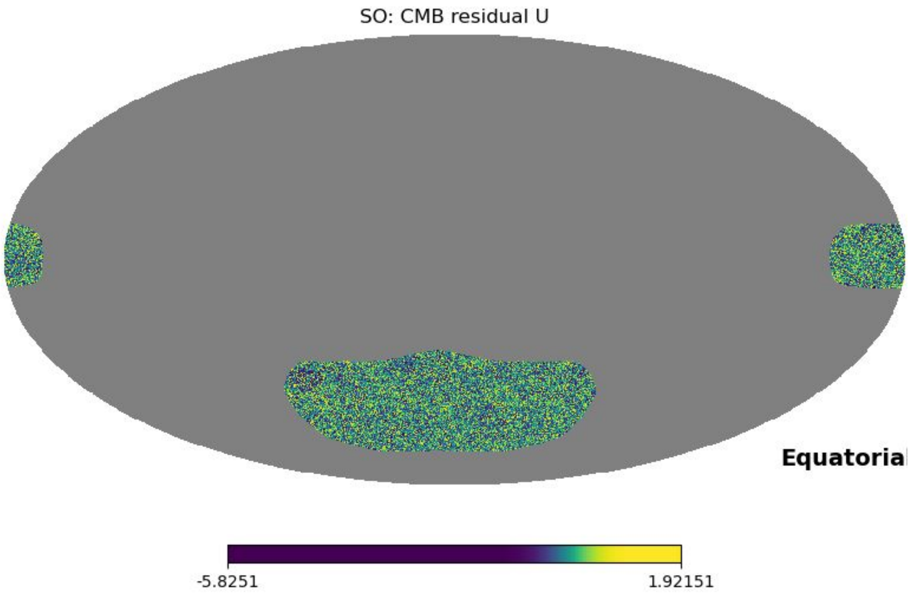




Test single realization using:

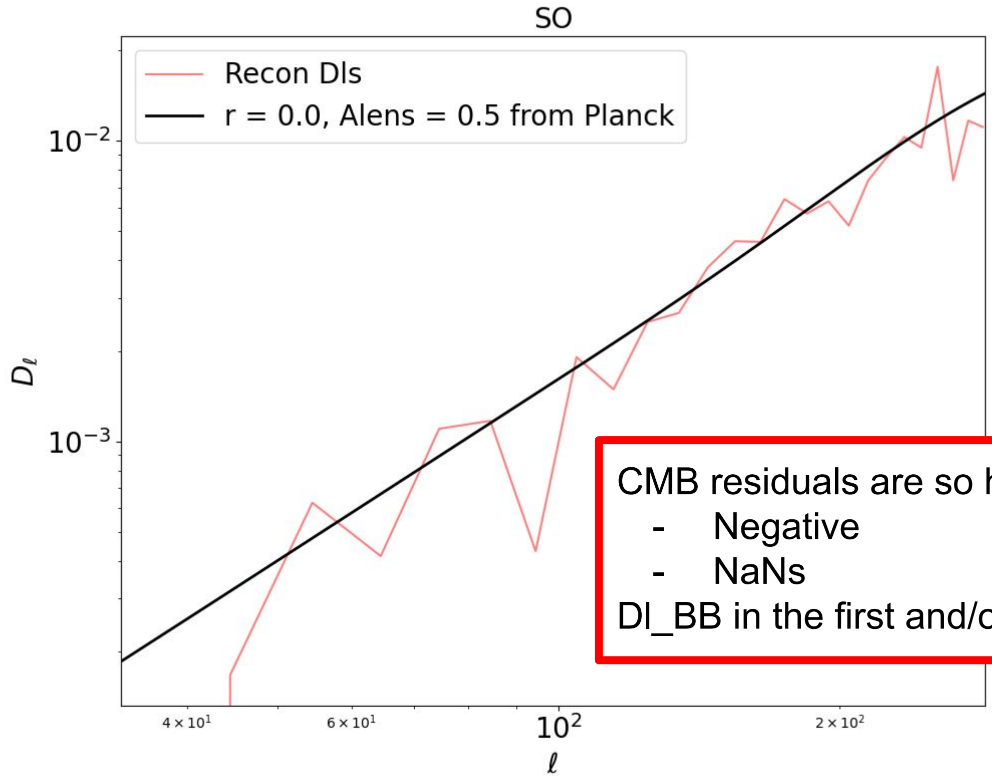
- pol wh noise*sqrt(2) for cross-spectra
- binary coverage from hit map at nside=1024





Test single realization using:

- pol wh noise*sqrt(2) for cross-spectra
- binary coverage from hit map at nside=1024



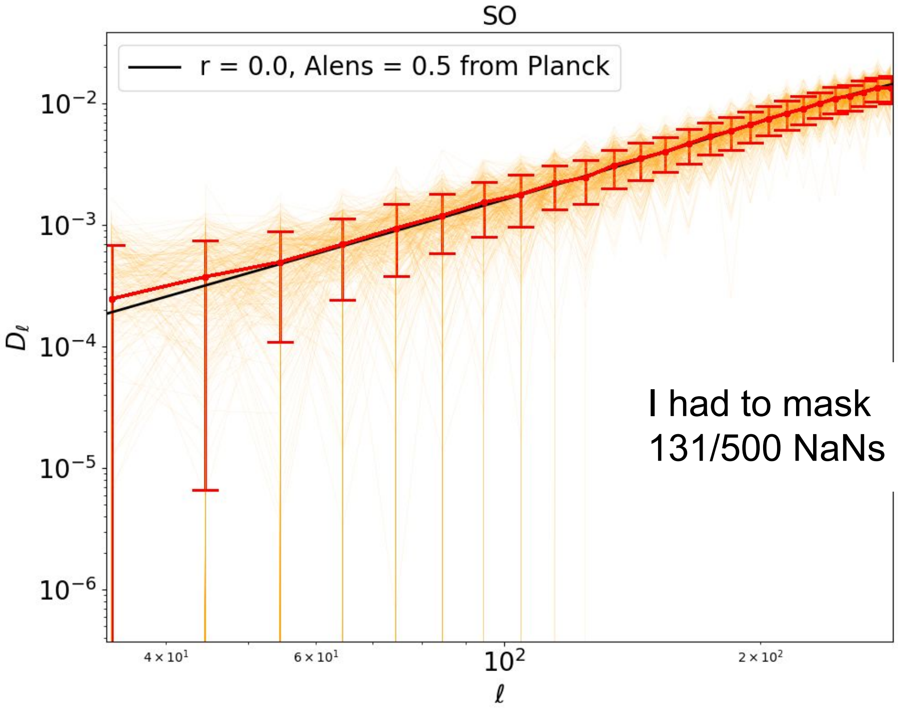
CMB residuals are so high that I get

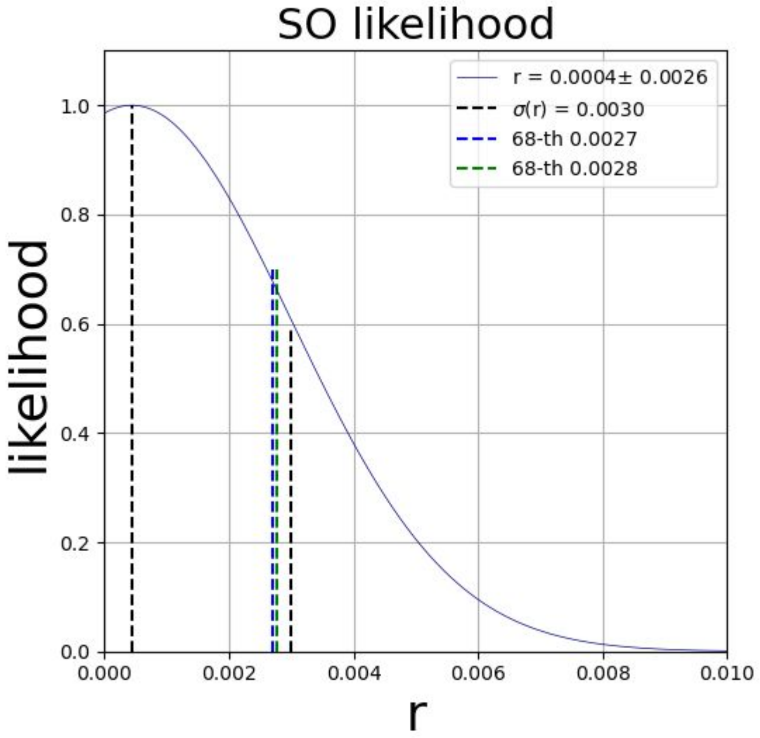
- Negative
- NaNs

Dl_BB in the first and/or second bin!

Full pipeline using:

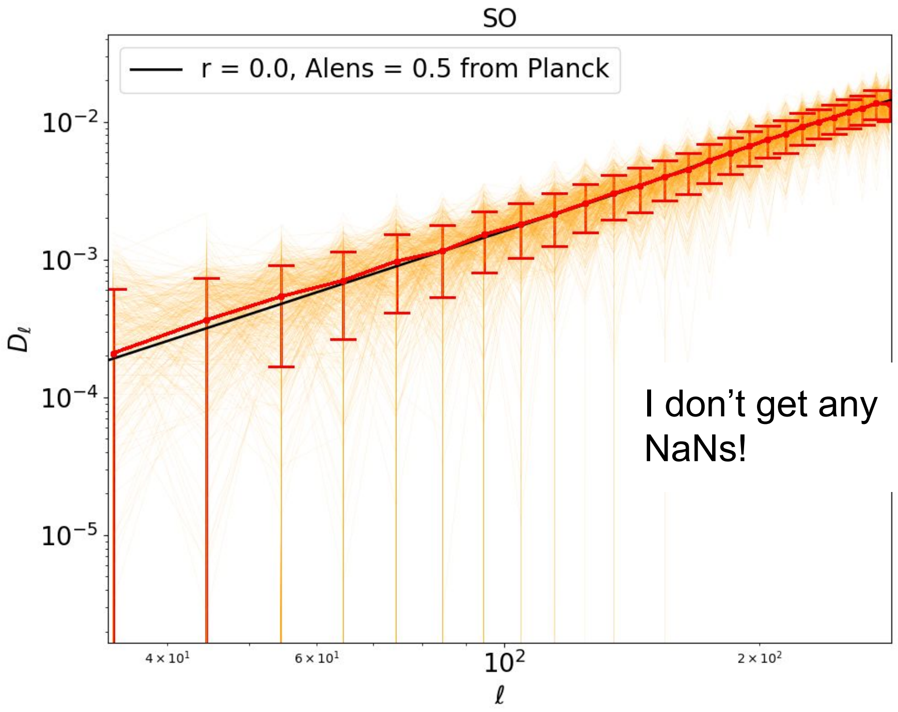
- pol wh noise*sqrt(2) for cross-spectra
- binary coverage from hit map at nside=1024



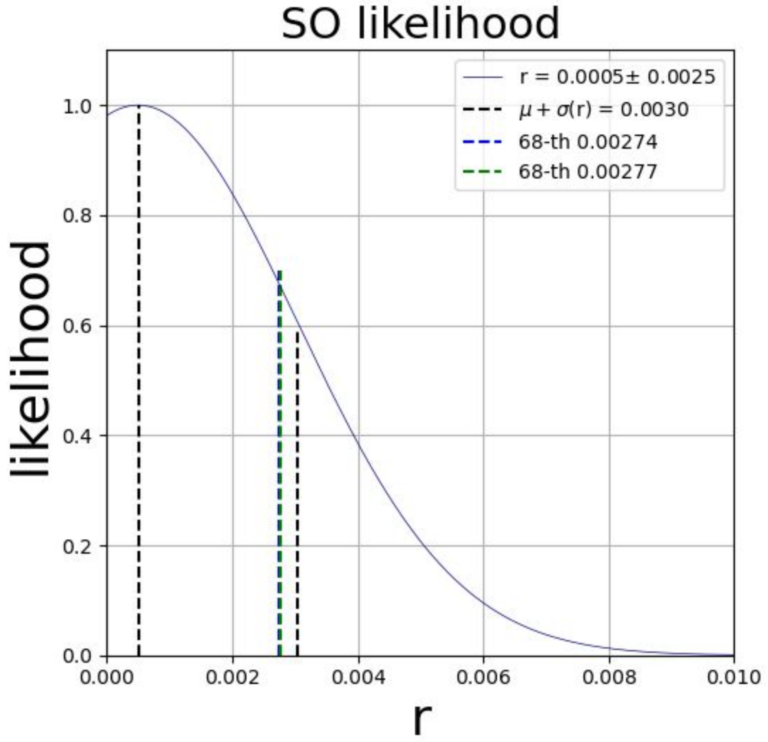


Full pipeline **FULL-SKY** using:

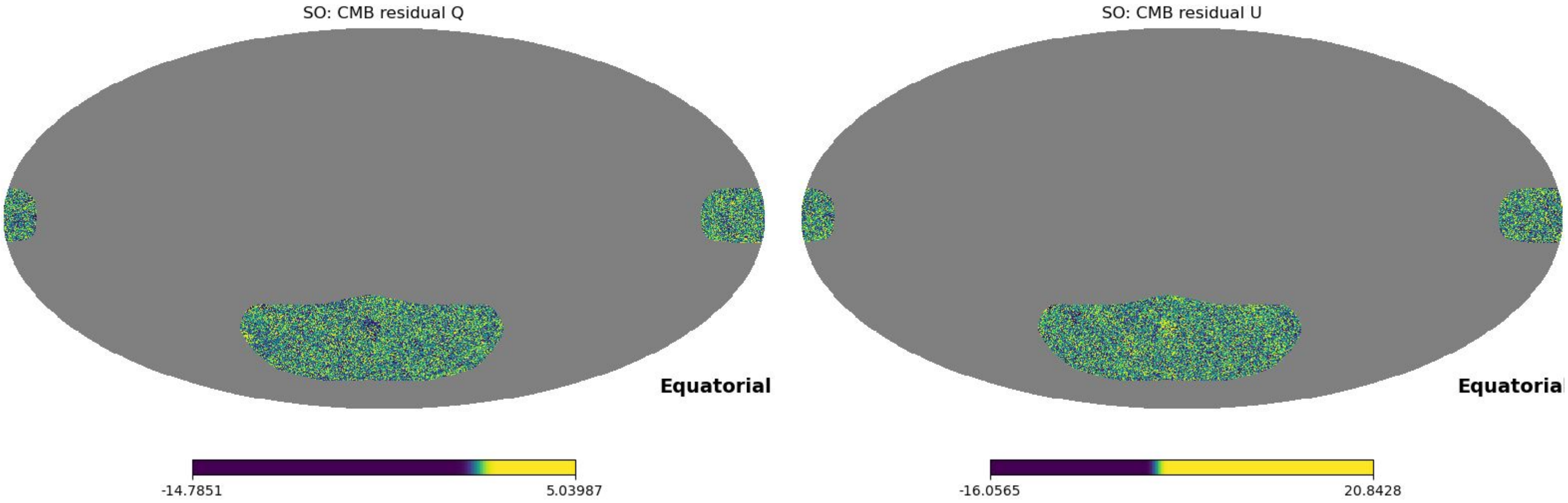
- pol wh noise*sqrt(2) for cross-spectra
- binary coverage from hit map at nside=1024



I don't get any NaNs!

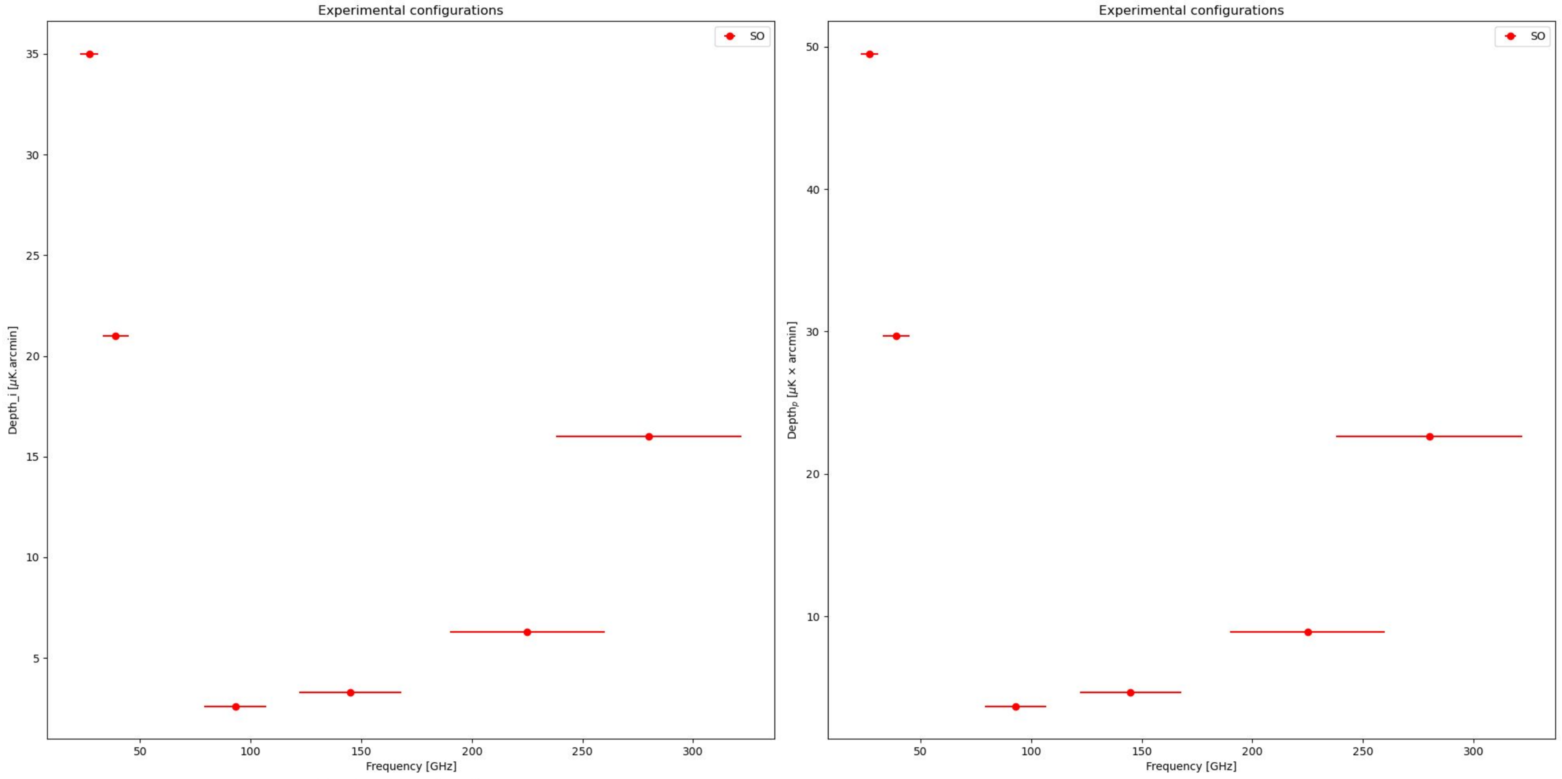


Example of reconstructed CMB map that leads to NaN



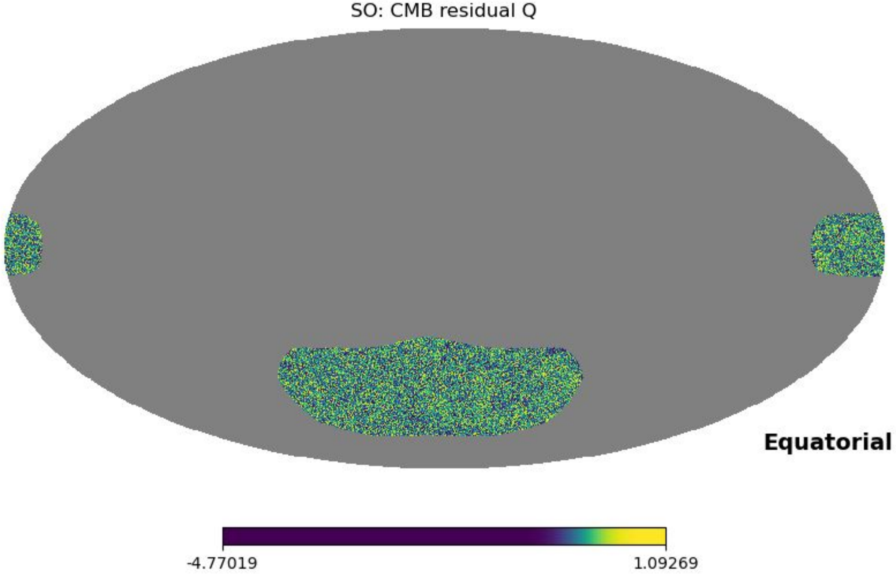
Test single realization using:

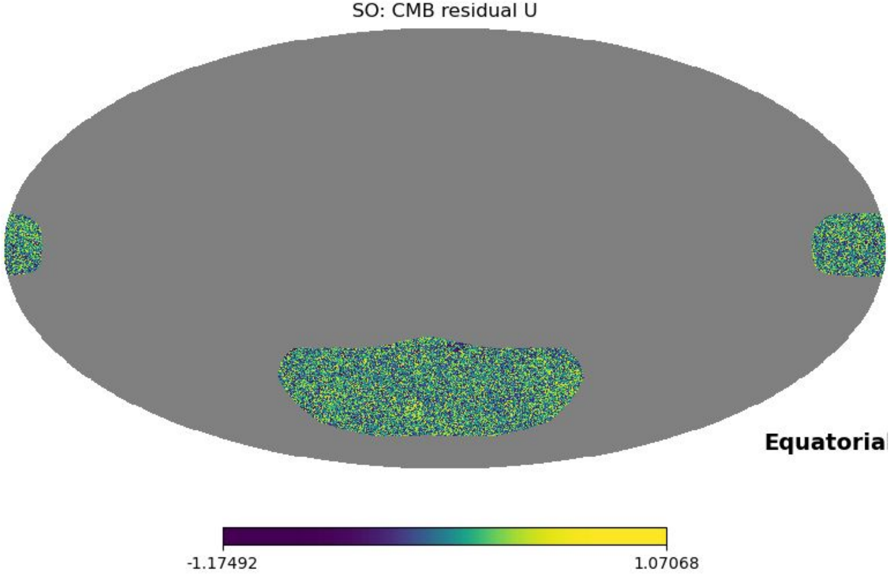
- pol wh noise
- binary coverage from hit map at nside=1024



Test single realization using:

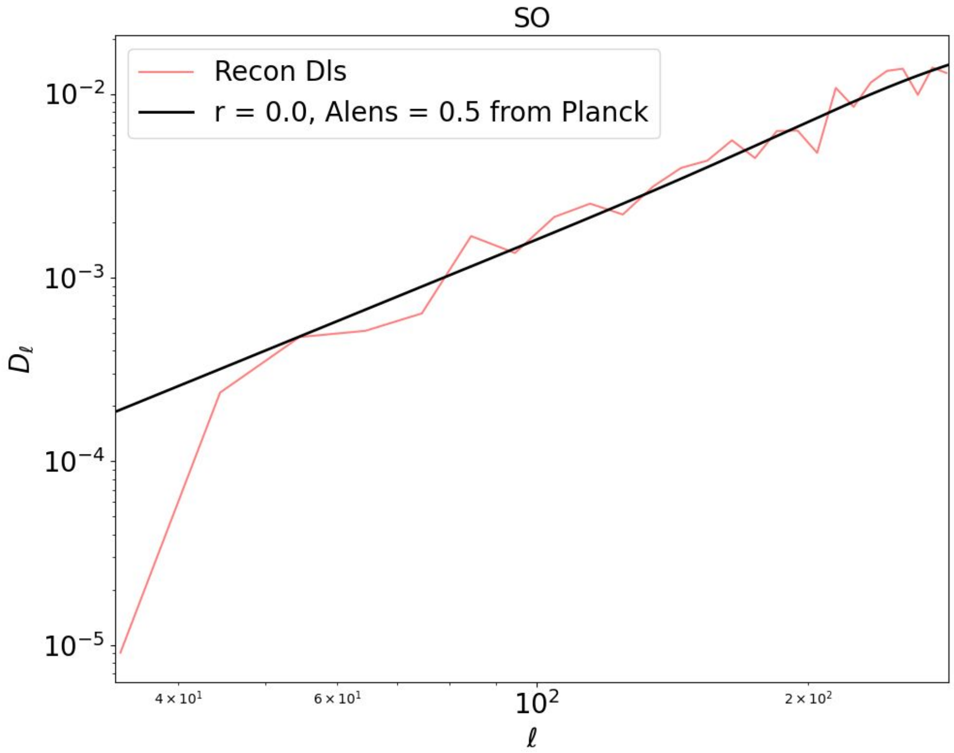
- pol wh noise
- binary coverage from hit map at nside=1024





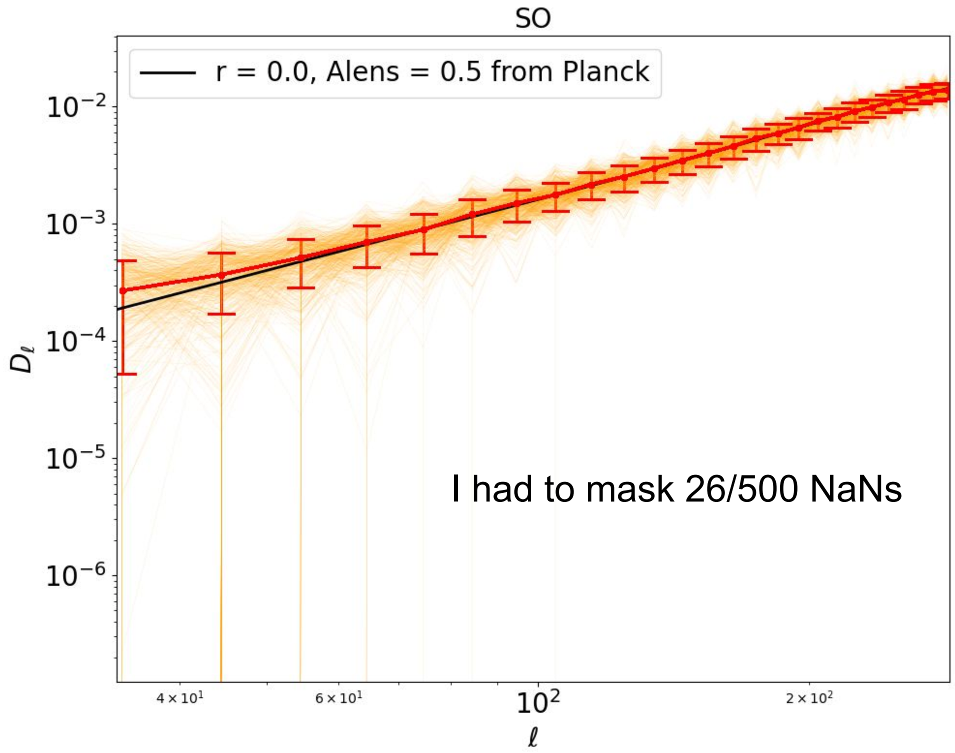
Test single realization using:

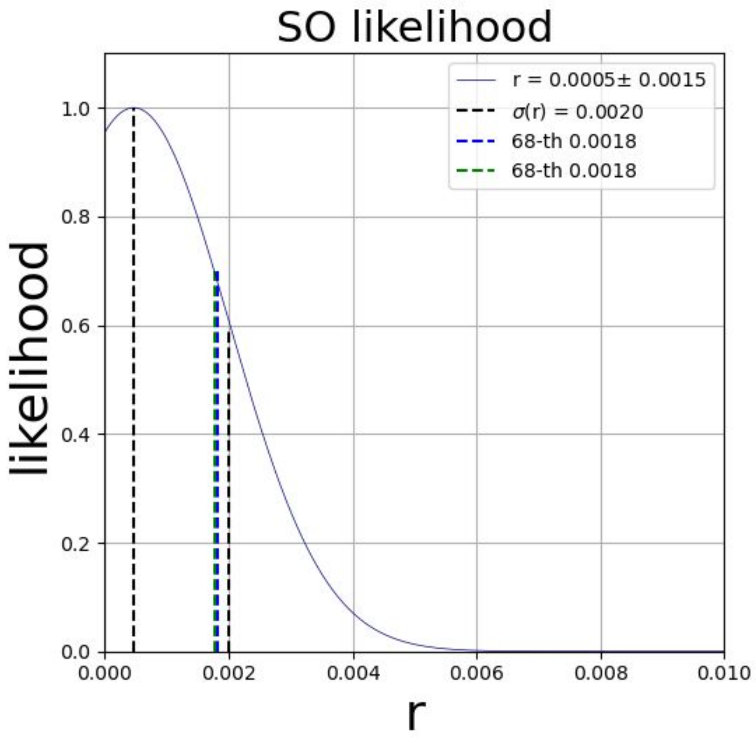
- pol wh noise
- binary coverage from hit map at nside=1024



Test **full pipeline** using:

- pol wh noise
- binary coverage from hit map at nside=1024





Test **full pipeline** using:
- pol wh noise
- binary coverage from hit map at nside=1024
- add sqrt(2) in the noise cov matrix N

This is the only way I could recover something close to Mathias'