B-mode forecast for CMB-Bharat proposal

On behalf of the CMB-Bharat collaboration

Debabrata Adak

IUCAA

Kavli IPMU, Japan
Nov 30 - Dec 3

Primordial CMB B-mode polarisation

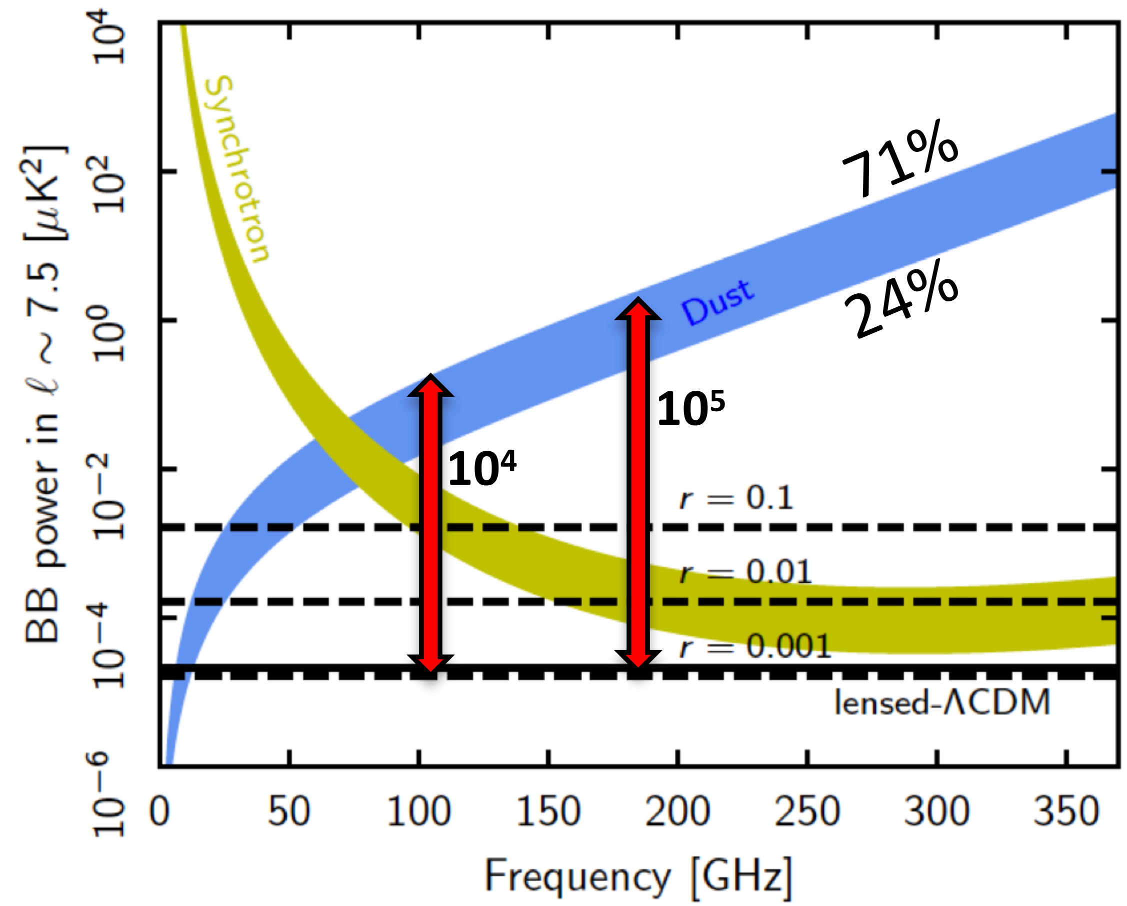
- Large-scale primordial CMB B-mode polarization

Signature of primordial gravitational waves of inflation

- Energy scale of inflation:

$$r = 0.008 \times (E_{\mathrm{inflation}} / 10^{16}\,\mathrm{GeV})^{4}$$

- Best CMB sensitive channels from space is around 200 GHz



Planck collaboration XI (2018)

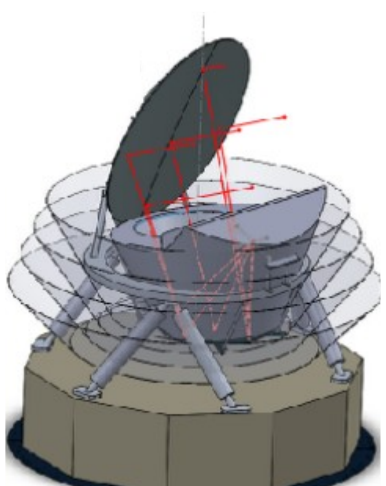
Future CMB satellites aim to detect r ~ 0.001

LiteBIRD (JAXA - Selected)

Matsumura et al, 2013

40 – 402 GHz

2.5 μK.arcmin



PICO (NASA?)

S. Hannany, priv. comm.

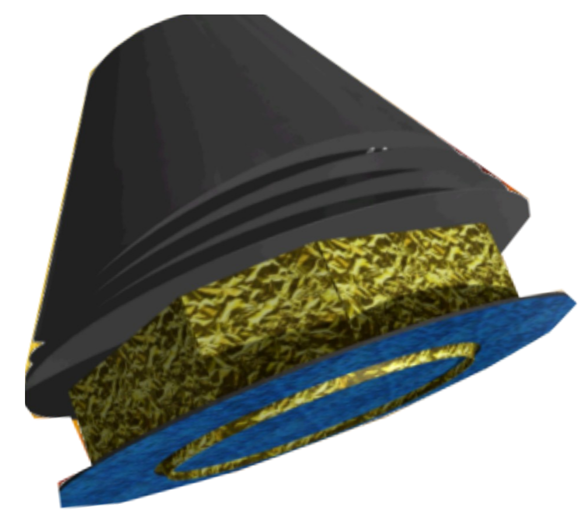
21 – 800 GHz

1 μK.arcmin

CMB -Bharat (ISRO?)

23 - 850 GHz

1.7 μK.arcmin



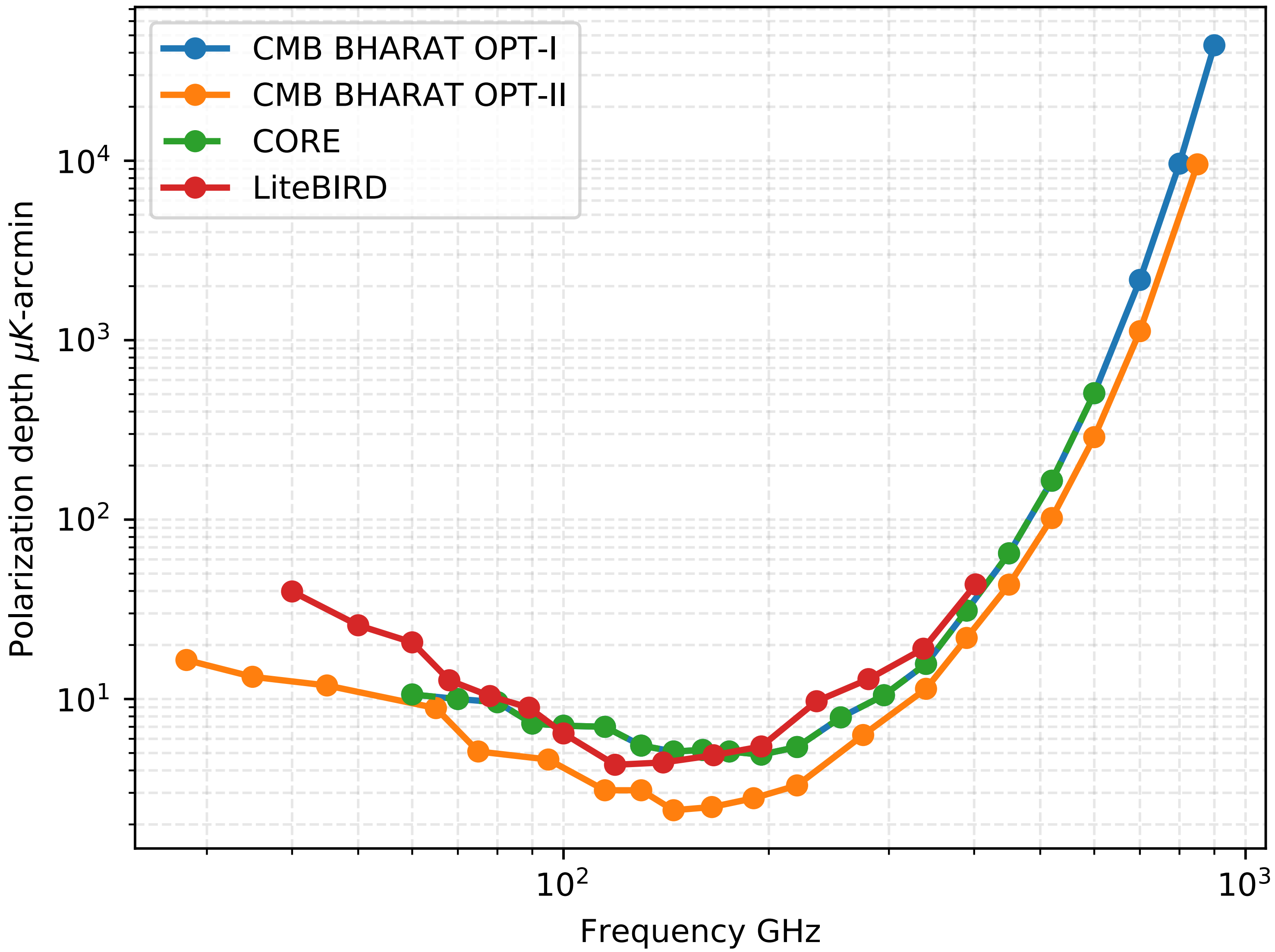
CMB - Bharat in Brief

- *European CMB community proposed CORE, ‘near- ultimate’ CMB polarization mission.*
- *Proposed mission concept did not pass the screening by ESA in January 2017.*
  - *Main issue is cost within ESA M-class envelope.*

ESA encouraged the CORE consortium to consider a joint proposal with a major international partner

Indian CMB community submit the proposal of CMB- Bharat (Exploring Cosmic History and Origins, ECHO) to ISRO on 16th April, 2018

CMB-Bharat Specifications



- **OPT - I:** Same sensitivity as CORE With three more channels in high frequency.
- **OPT-II:** Extension of bands both low and high frequencies with enhanced sensitivity by factor of $\sqrt{2}$.

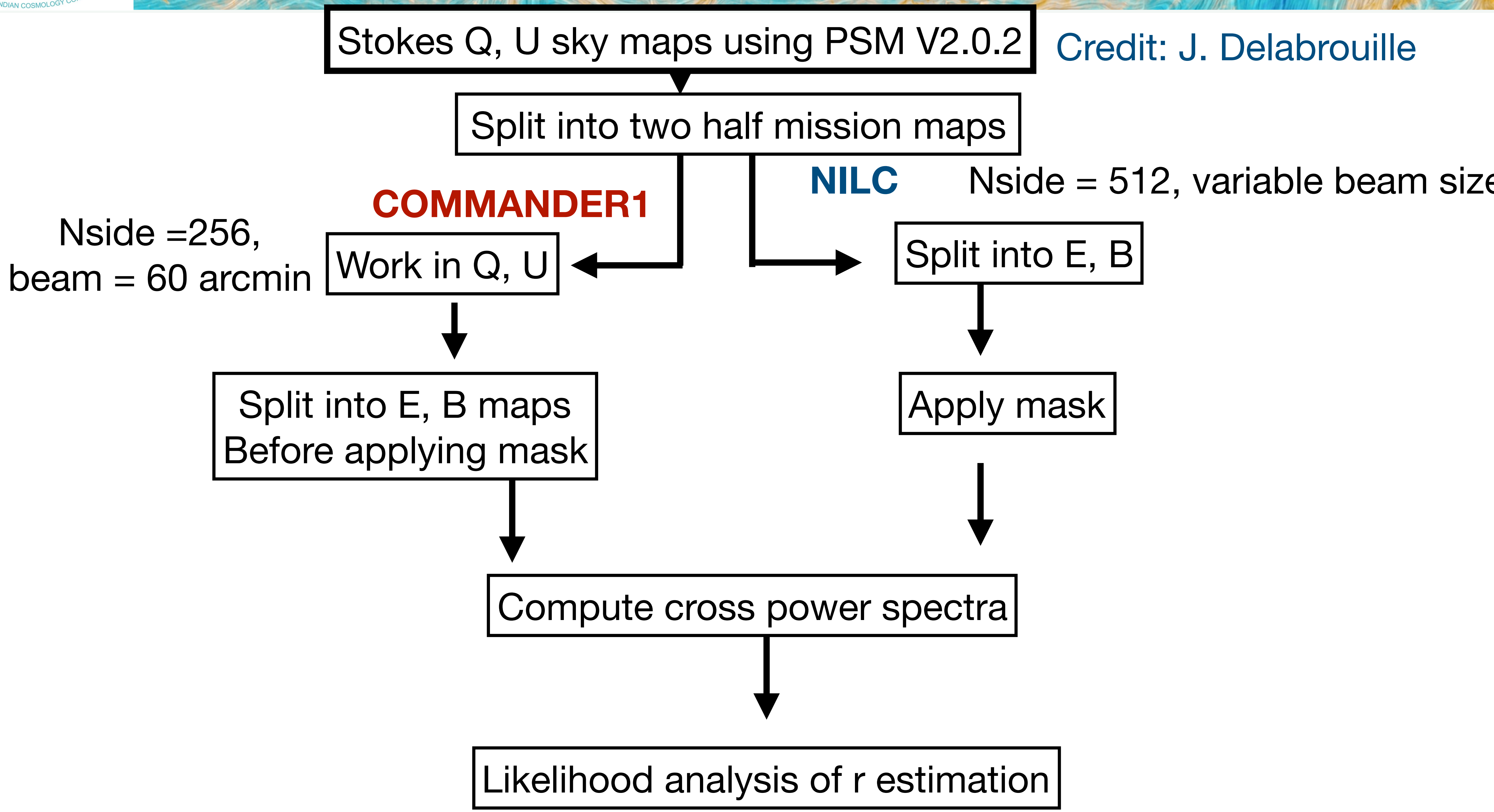
Map Based Analysis

- Working on map based cleaning.

- 11 different full sky model, consistent with Planck results, with r ranging from 0 to 0.001, delensing level (84%).

- Two component separation approaches
- Commander1(Debabrata)
- NILC (Aparajita Sen)

Analysis Pipeline



Map based models

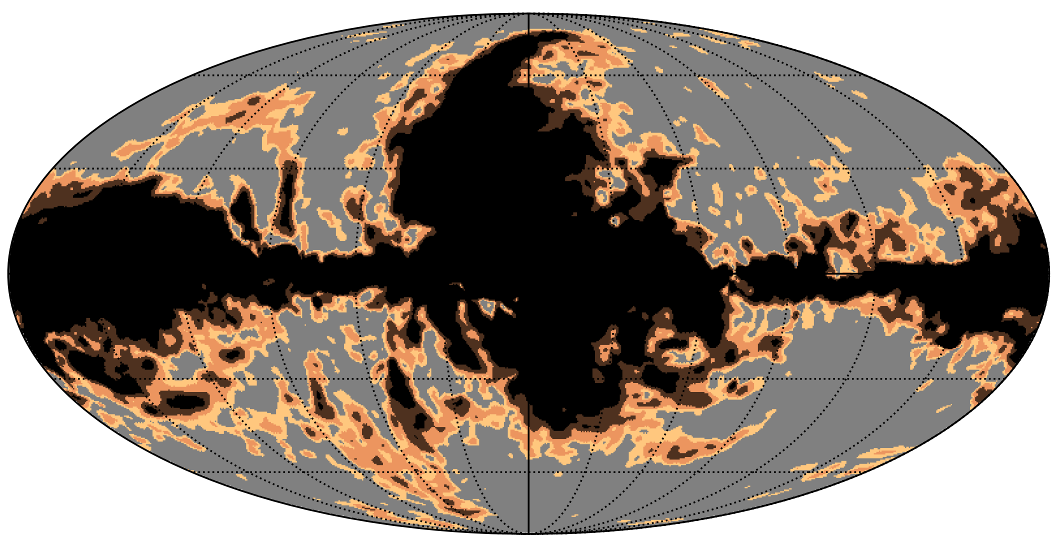
Component	Emission law	Nomenclature	Additional information/Templates
CMB	Blackbody with scaling, $a_\nu = \frac{dB_\nu(T)}{dT}\|_{T_{CMB}}$; $T_{CMB} = 2.725$K	-	r = 0
Thermal dust	MBB	`GNILC − dust`	*Planck* `GNILC` maps at 353 GHz from Planck Collaboration XLVIII (2016)
		`TD − dust`	HI based dust polarization model at high galactic latitude developed in Ghosh et al. (2017) and Adak et al. (2020)
		`Gines − dust`	Multi-layer dust model from dust extinction maps developed in Martínez-Solaeche et al. (2018)
Synchrotron	Power-law, spatially varying spectral index with $\langle\beta_s\rangle$ = -3.00	`Power − law`	`SMICA` Q, U synchrotron maps from Planck Collaboration IV (2018) at 30 GHz
	frequency dependent spectral index; $\beta_s = -3.11 + Clog(\frac{\nu}{23})$ with curvature, C = -0.3 at 23 GHz	`Curved − power − law`	Template maps are same as for `Power − law`
	`GALPROP` scaling; $(\frac{\nu}{30})^2 \frac{f_s(\frac{\nu}{\alpha})}{f_s(\frac{30}{\alpha})}$ with constant $\alpha > 0$ and $f_s(\nu)$ is taken from external template generated from `GALPROP` code	`GALPROP`	Template maps are same as for `Power − law`
Spinning dust	CNM emission law with 1% polarization fraction and dust polarization angle		*Planck* thermal dust intensity at 353 GHz (Planck Collaboration XLVIII 2016) scaled at 23 GHz with correlation coefficient of 0.91 K/ K
Point-sources	Sources from radio surveys extrapolated with power laws;	-	Radio sources have median polarization fraction of 2.7% and 4.8% for two class of power-laws;
	IRAS survey modelled with modified blackbody emission laws.		IR sources are taken from IRIS data and having mean polarization fraction of 1.5%

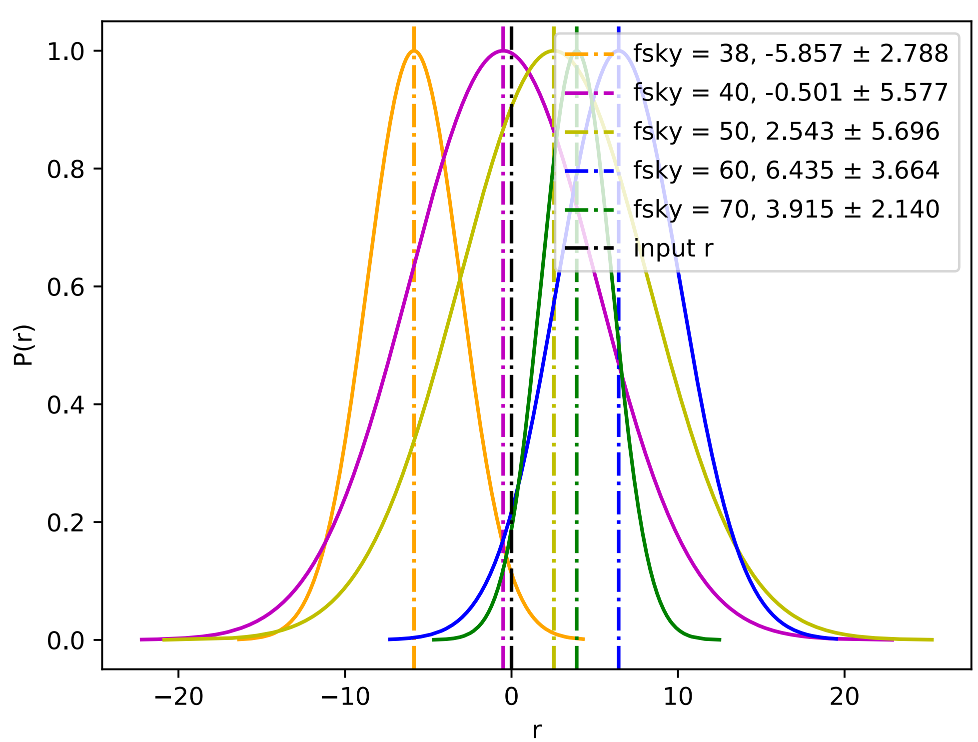
Set of the simulations

Sim.ID	Pipeline	Dust	Synchrotron	Spinning dust	point-sources	delensing
SET1a	NILC, COMMANDER	GNILC − dust	GALPROP	✗	✗	✗
SET1b	NILC, COMMANDER	GNILC − dust	GALPROP	✓	✗	✗
SET1c	NILC, COMMANDER	GNILC − dust	GALPROP	✓	✓	✗
SET1d	NILC, COMMANDER	GNILC − dust	GALPROP	✓	✓	✓(84 %)
SET2a	NILC	Gines − dust	GALPROP	✓	✓	✗
SET2b	NILC	Gines − dust	Power − law	✓	✓	✗
SET2c	NILC	Gines − dust	Curved − power − law	✓	✓	✗
SET3a	COMMANDER	TD − dust	GALPROP	✓	✓	✗
SET3a$'$	COMMANDER	TD − dust	GALPROP	✓	✓	✗
SET1d$'$	NILC,COMMANDER	GNILC − dust	Power − law	✓	✓	✗
SET1d$''$	NILC,COMMANDER	GNILC − dust	Curved − power − law	✓	✓	✗

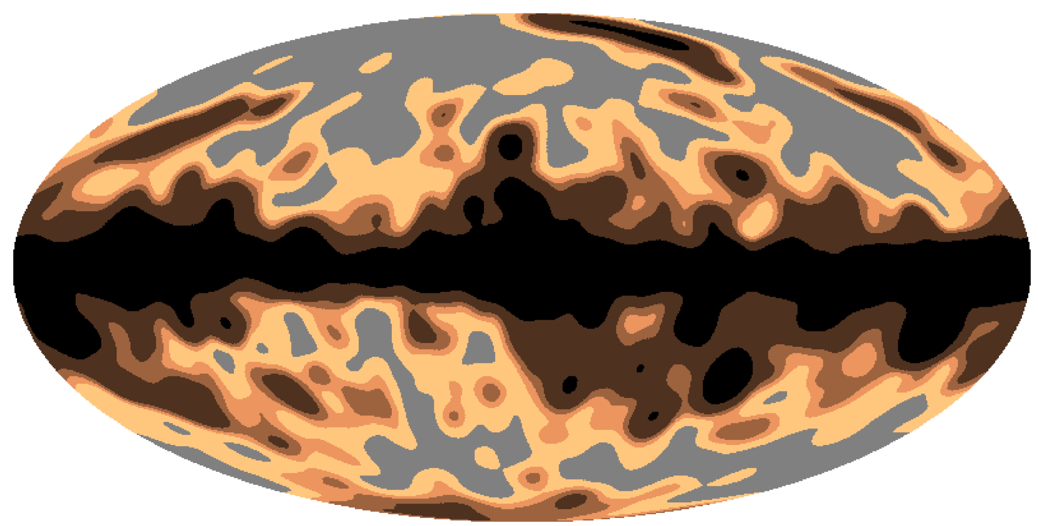
Results (Analysis on different masks)

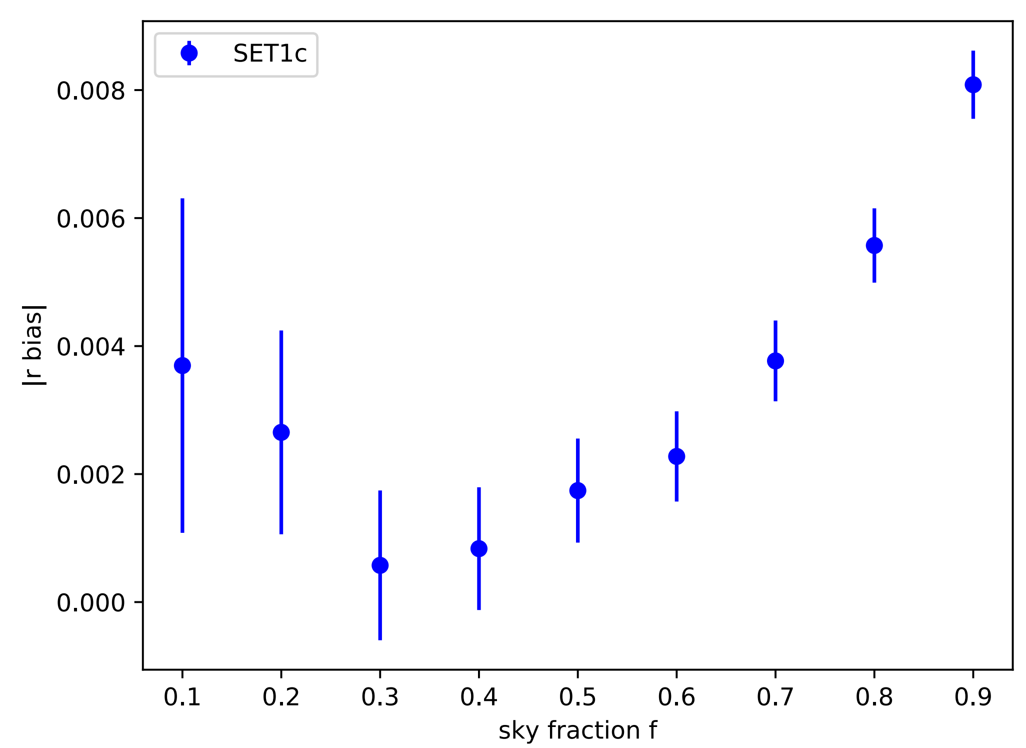
Commander





NILC



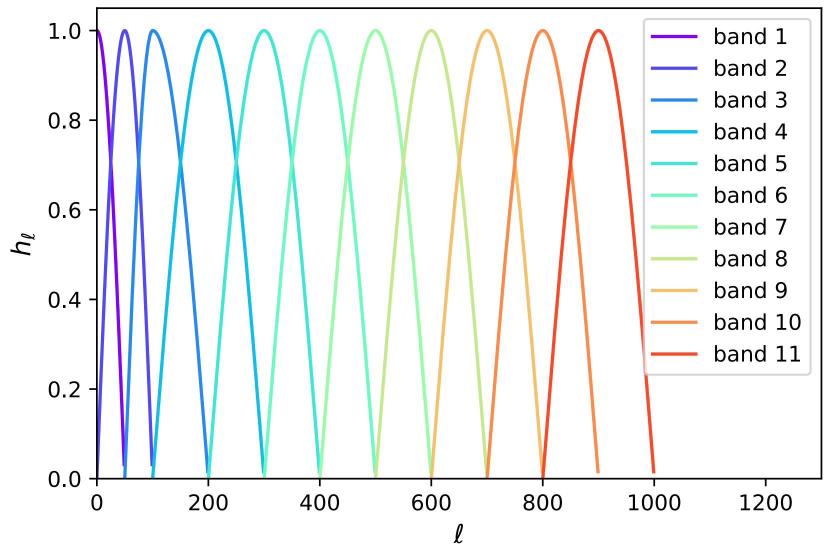


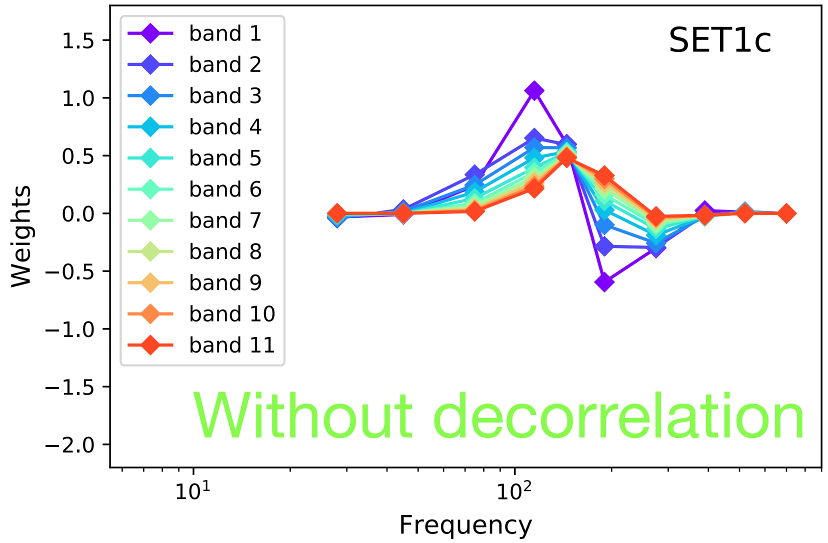
Results

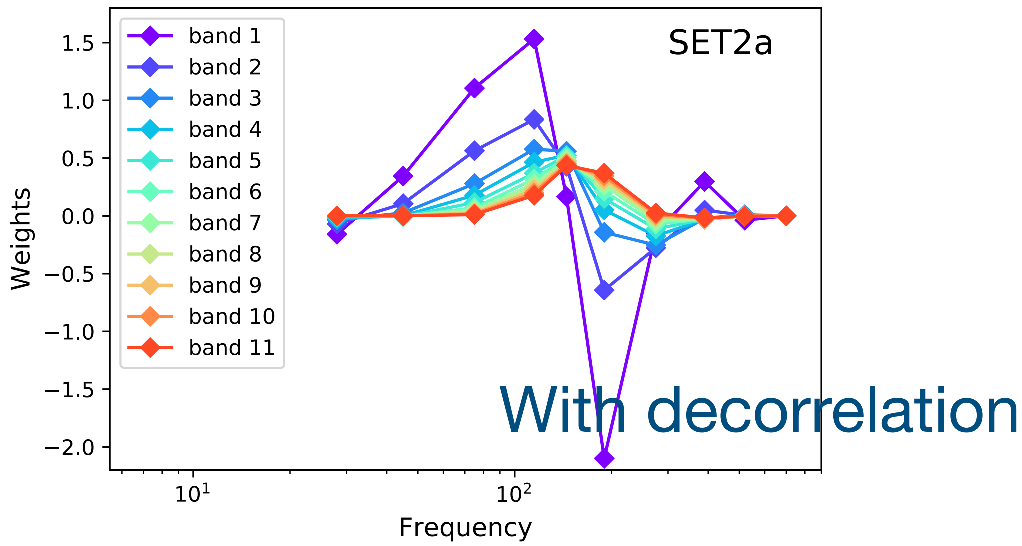
Experiment	inpur r		Sim.ID	COMMANDER			NILC		
				r_{mp}	$\sigma(r_{mp})$	r_{95}	r_{mp}	$\sigma(r_{mp})$	r_{95}
			SET1a	1.80	5.74	12.71	-1.34	0.94	0.50
			SET1b	2.33	6.02	13.77	-0.81	0.91	0.98
			SET1c	2.55	5.73	13.44	0.79	0.95	2.66
			SET1d	4.61	1.77	4.64	2.04	0.96	3.92
		Decorrelation	SET1d$'$	0.96	5.55	11.50	1.33	1.21	3.71
			SET1d$''$	4.78	4.02	12.41	1.17	1.13	3.38
OPTION-II	r = 0.0		$\boxed{\text{SET2a}}$	$\boxed{81.73}$	$\boxed{2.70}$	$\boxed{86.86}$	$\boxed{1.62}$	$\boxed{1.33}$	$\boxed{4.22}$
			SET2b	-	-	-	1.98	1.41	4.74
			SET2c	-	-	-	2.18	1.36	4.85
		✔	SET3a	1.35	0.69	2.66	-	-	-

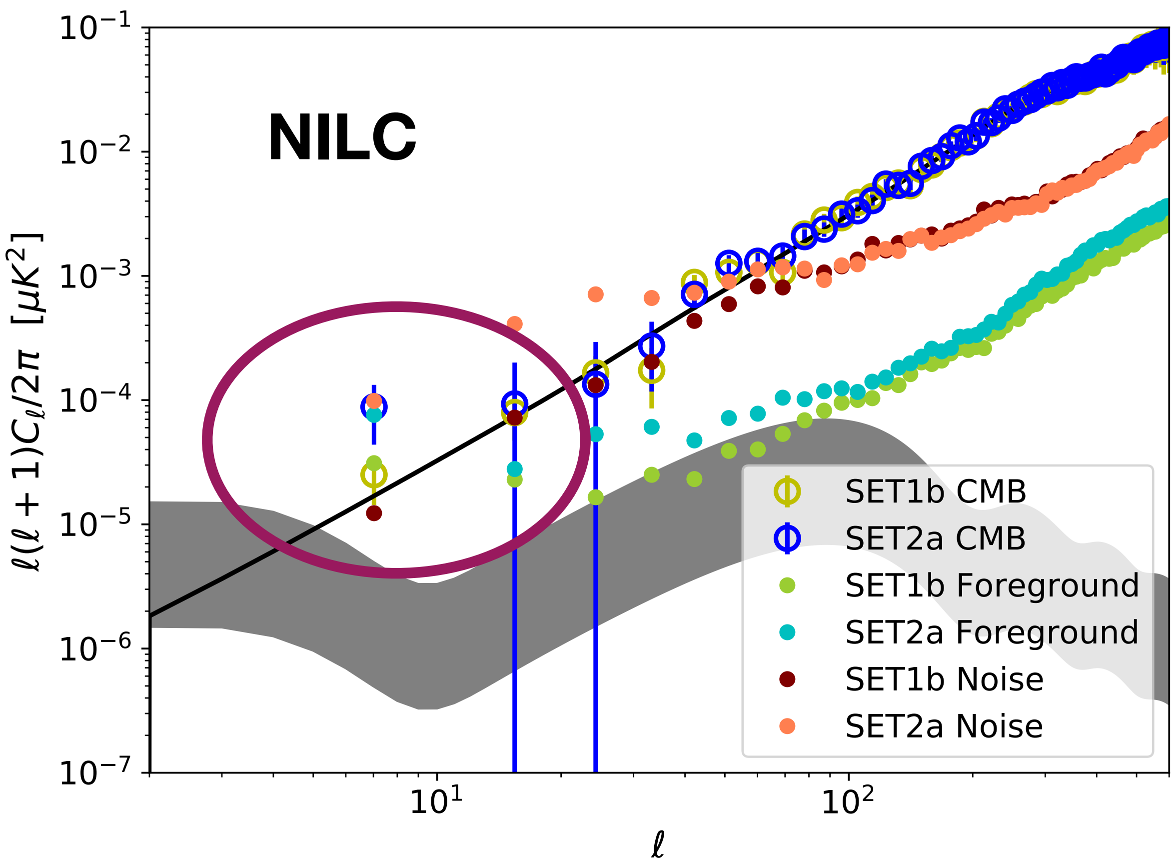
Comment : σ_r **= 0.005 - 0.006**

Results (decorrelation)









Results (decorrelation)

Experiment	inpur r	Sim.ID	COMMANDER			NILC		
			r_{mp}	$\sigma(r_{mp})$	r_{95}	r_{mp}	$\sigma(r_{mp})$	r_{95}
		SET1a	1.80	5.74	12.71	-1.34	0.94	0.50
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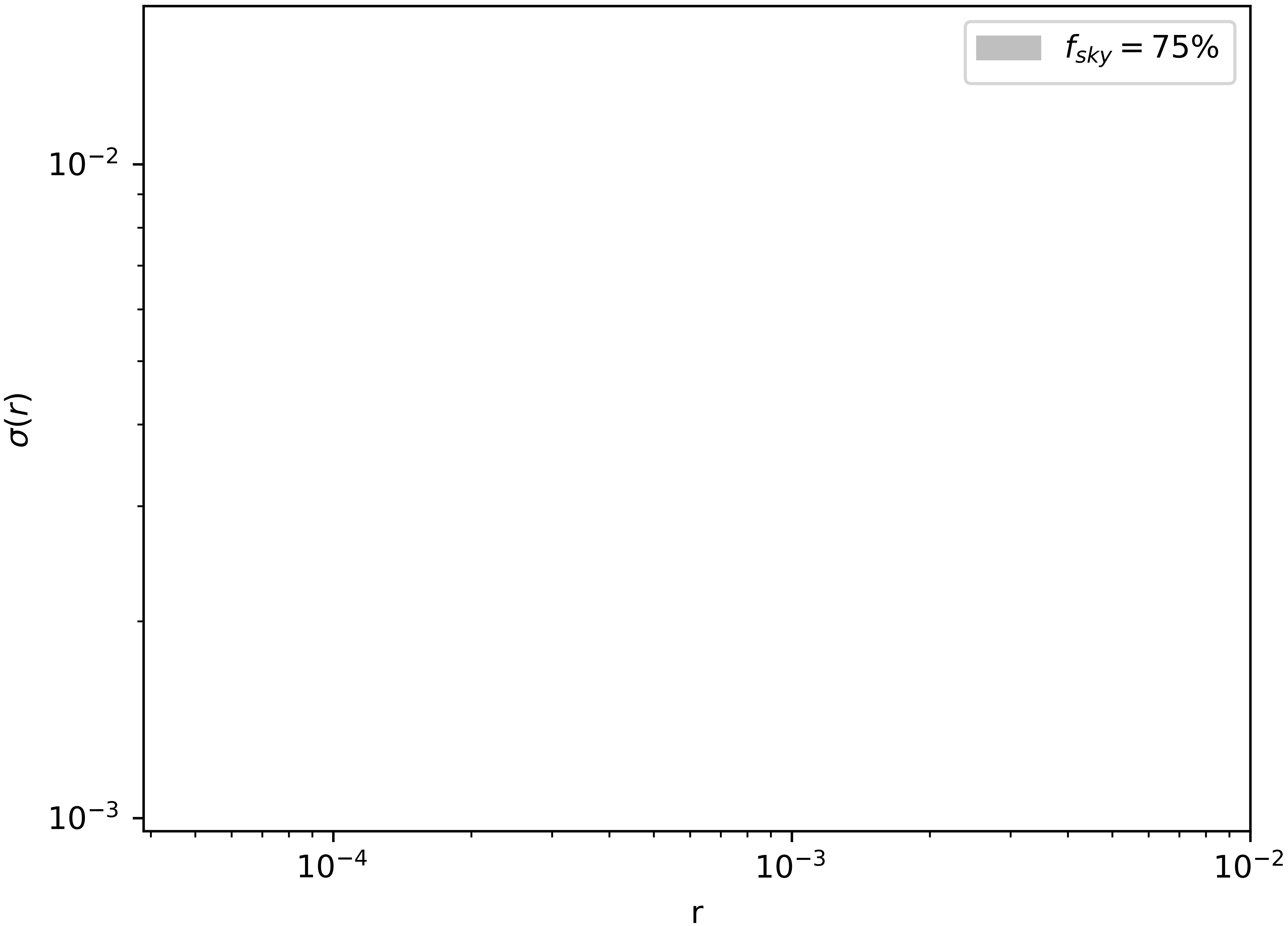
		SET1c	2.55	5.73	13.44	0.79	0.95	2.66
		SET1d	4.61	1.77	4.64	2.04	0.96	3.92
		SET1d$'$	0.96	5.55	11.50	1.33	1.21	3.71
		SET1d$''$	4.78	4.02	12.41	1.17	1.13	3.38
OPTION-II	r = 0.0	SET2a	81.73	2.70	86.86	1.62	1.33	4.22
		SET2b	-	-	-	1.98	1.41	4.74
		SET2c	-	-	-	2.18	1.36	4.85
TD-dust		SET3a	1.35	0.69	2.66	-	-	-

MBB components	inpur r	Sim.ID	$A_{lens} = 1$		
			r_{mp}	$\sigma(r_{mp})$	r_{95}
one MBB	r = 0	SET3a'	188.41	5.93	-
three MBB			33.47	1.88	-

Results (delensing)

Experiment	inpur r	Sim.ID	COMMANDER			NILC		
			r_{mp}	$\sigma(r_{mp})$	r_{95}	r_{mp}	$\sigma(r_{mp})$	r_{95}
		SET1a	1.80	5.74	12.71	-1.34	0.94	0.50
		SET1b	2.33	6.02	13.77	-0.81	0.91	0.98
		SET1c	2.55	5.73	13.44	0.79	0.95	2.66
84% delensing		SET1d	4.61	1.77	4.64	2.04	0.96	3.92
		SET1d$'$	0.96	5.55	11.50	1.33	1.21	3.71
		SET1d$''$	4.78	4.02	12.41	1.17	1.13	3.38
OPTION-II	r = 0.0	SET2a	81.73	2.70	86.86	1.62	1.33	4.22
		SET2b	-	-	-	1.98	1.41	4.74
		SET2c	-	-	-	2.18	1.36	4.85
		SET3a	1.35	0.69	2.66	-	-	-

Results(Detection significance)



Discovery space of CMB-Bharat

- Design driver: Details CMB polarization study
    - lensing map with S/N > 15 at all scale.
    - Constrain the ΛCDM or extension more precisely

- *Comes ‘for free’ but having rich scientific interest*
- *map of SZ effect.*
- *Extragalactic sources/CIB*
- *Galactic foregrounds*
- *Magnetic field*
- *Reionization*
- *Neutrino mass*
- *Statistical anisotropy and non- Gaussianity*

One-minute Summary

- ECHO is the instrument with combination of full sky coverage, high resolution and sensitivity, large frequency coverage in a single platform.
- Huge discovery space: Inflation, particle physics, galactic and extragalactic astronomy
  - particularly designed to detect : r ~ 0.001.
- We consider 11 set of simulations, 84% delensing, decorrelation effect.
- In this forecast study, we do not consider non-white noise, systematics.
- We are hopeful to see ISRO to support CMB Bharat (ECHO).

Thank you

Extra slides

Capabilities achieved within India

- Service module
  - Design, fabrication, assembly, testing
- Launch to L2
- Tracking & control
- Orbit maintenance
- Science data downlink
- Data products and analysis
- Mission planning and operation

Indian contribution

Capabilities achieved with modest planned investments

- Telescope and Optics
  - Design, fabrication, assembly, testing
  - Reflectors, baffling
  - Reimaging optics, filters
- Science Payload
  - Design, assembly, testing

Indian contribution

Capabilities achieved with long-term planned investments

- Broadband photon-noise-limited sensors & readout for CMB frequency bands
- Cryogenic coolers at 100mK in space

Working Group

Cluster Physics from CMB:
Lead: Subhabrata Majumdar (TIFR)
Members: Suvodip Mukherjee, Dhiraj Hazra, K.P. Singh, Siddharth Savyasachi Malu, Abhirup Datta, Priyanka Singh

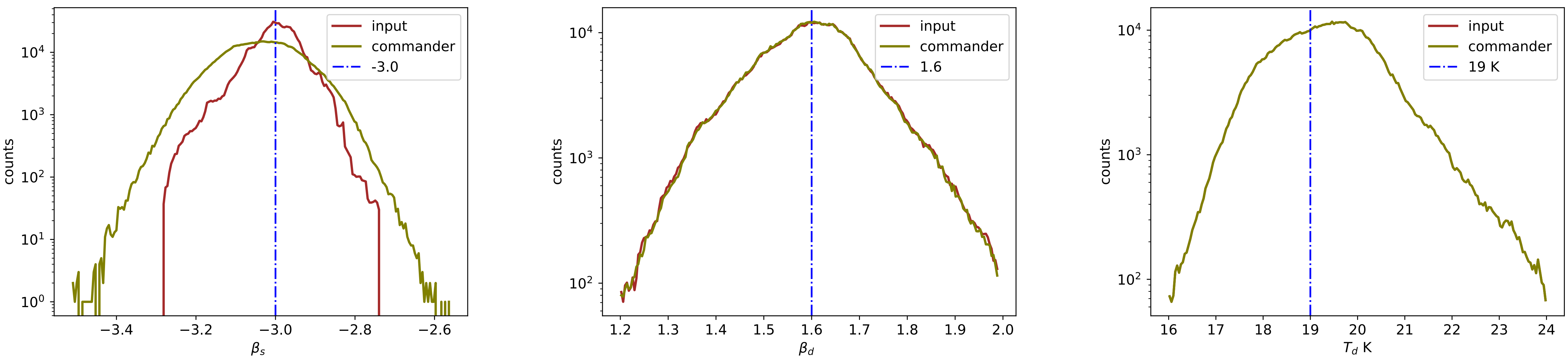
Foregrounds and CIB:
Lead: Tuhin Ghosh (NISER)
Members: Rajib Saha, Soumen Basak, Pavan K. Aluri, Moumita Aich, Ranajoy Banerji, Aditya Rotti, Abhirup Datta, Pravabati Chingangbam, Sandeep Rana (List Here)

Instrument science:
Lead: Zeeshan Ahmed (Stanford Univ)
Members: Aafaque R Khan, Rahul Datta, Mayuri S.Rao, Ritoban Thakur

Inflation:
Lead: L. Sriramkumar (IIT Madras)
Members: Dhiraj Hazra, Anshuman Maharana, Urjit Yajnik, Raghu Rangarajan, Supratik Pal, Anjan Ananda Sen, Subodh Patil, Rajeev Kumar Jain, Gaurav Goswami, V. Sreenath, Debika Chowdhury, Pravabati Chingangbam, Moumita Aich (List here)

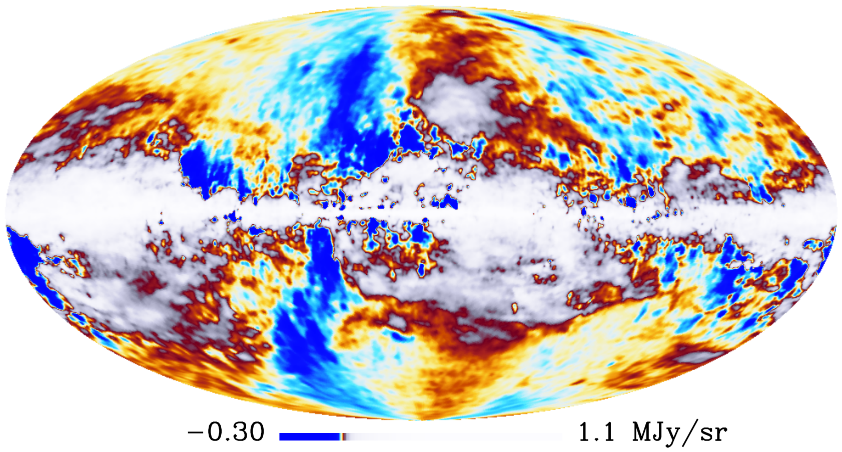
And 8 more

Spectral parameters

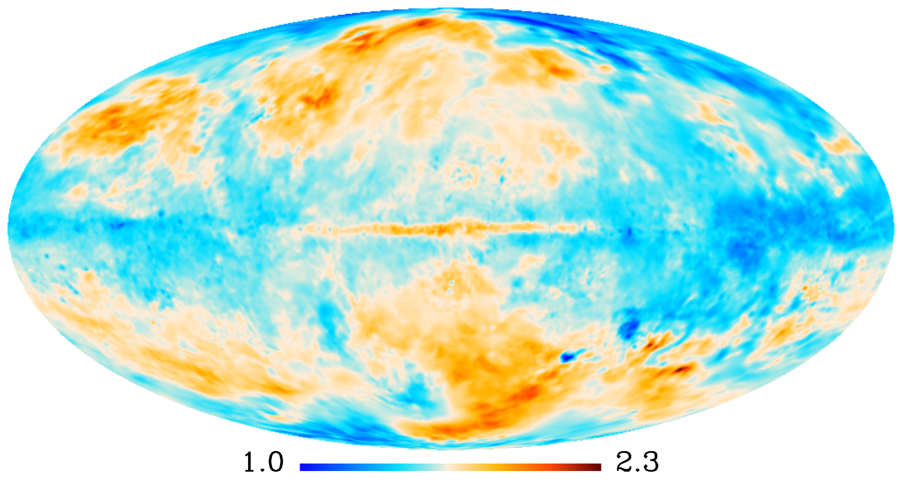


Maps

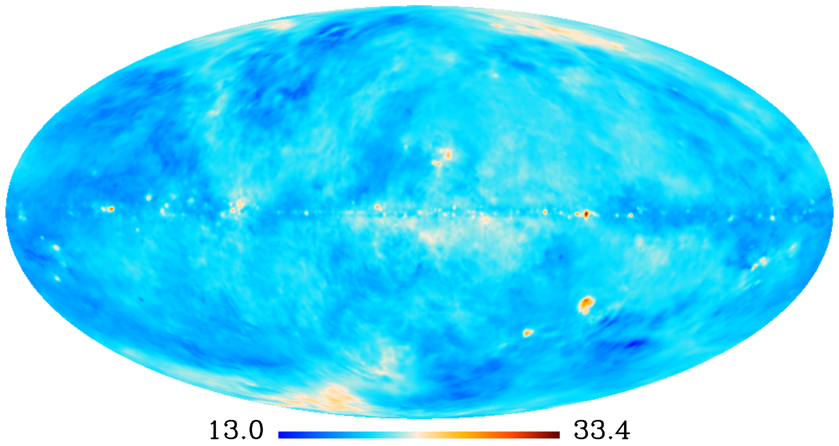
thermaldust_ampl1 Q_POLARISATION



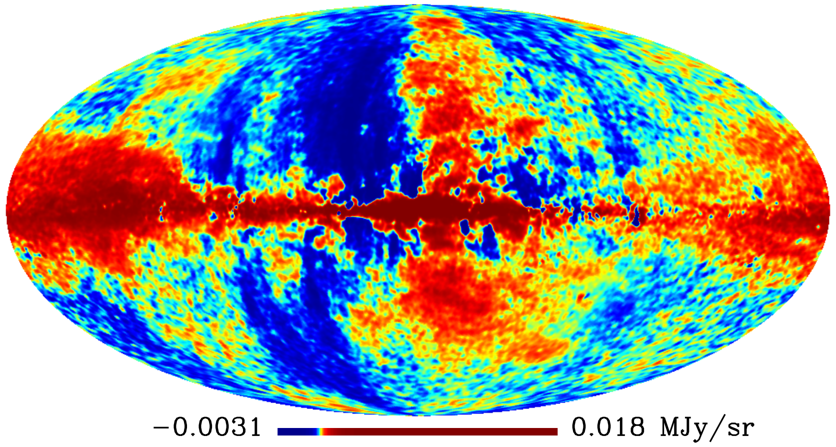
thermaldust_spec_1 Q_POLARISATION



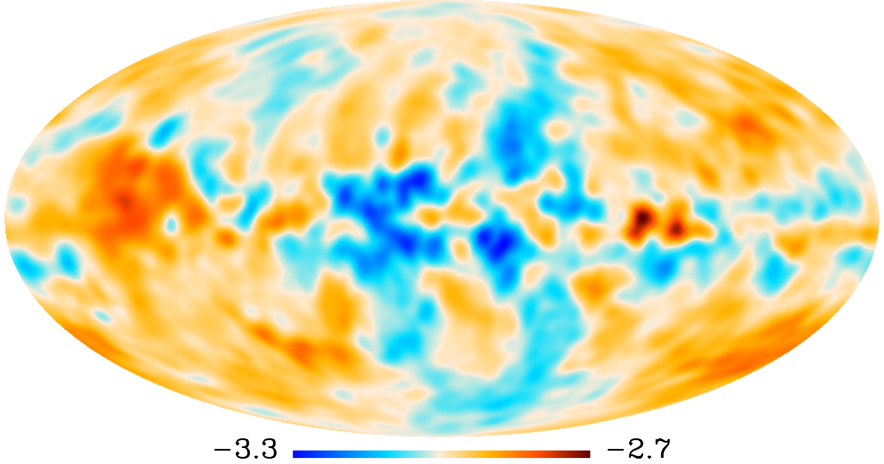
thermaldust_temp_1 Q_POLARISATION



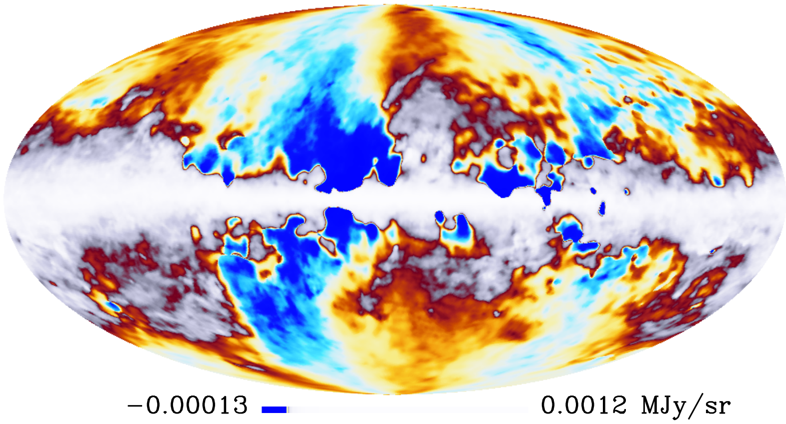
Synchrotron amplitude, Stokes Q



Synchrotron spectral index (for K_{RJ} units)



spindust_ampl Q_POLARISATION



Experiment	A_{lens}	r_{mp}	σ_r	r_{95}	SNR
CORE	0.0	1.998	0.470	-	4.251
	0.5	1.317	0.713	2.715	1.848
	1.0	1.237	0.905	3.013	1.367
CMB BHARAT OPT-I	0.0	0.976	0.359	-	2.719
	0.5	0.774	0.562	1.877	1.375
	1.0	0.788	0.744	2.246	1.060
CMB BHARAT OPT-II	0.0	0.312	0.147	-	2.129
	0.5	0.208	0.344	0.883	0.603
	1.0	0.211	0.518	1.226	0.407
LiteBIRD	0.0	2.278	0.592	-	3.847
	0.5	2.231	0.874	-	2.553
	1.0	2.353	1.109	-	2.122