Forecast for Recovery of r in CMB-Bharat: *foreground complexities and optimum range of frequency*

CMB BHĀRAT: AN INDIAN COSMOLOGY CONSORTIUM

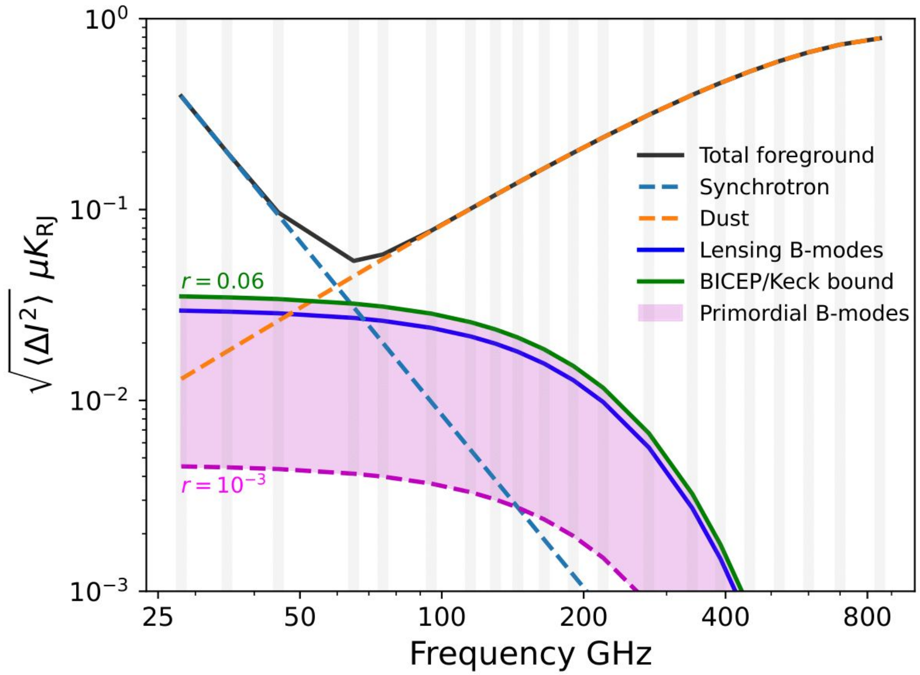
Cosmology From Home 2022

Aparajita Sen
IISER Thiruvananthapuram, India

CMB-Bharat

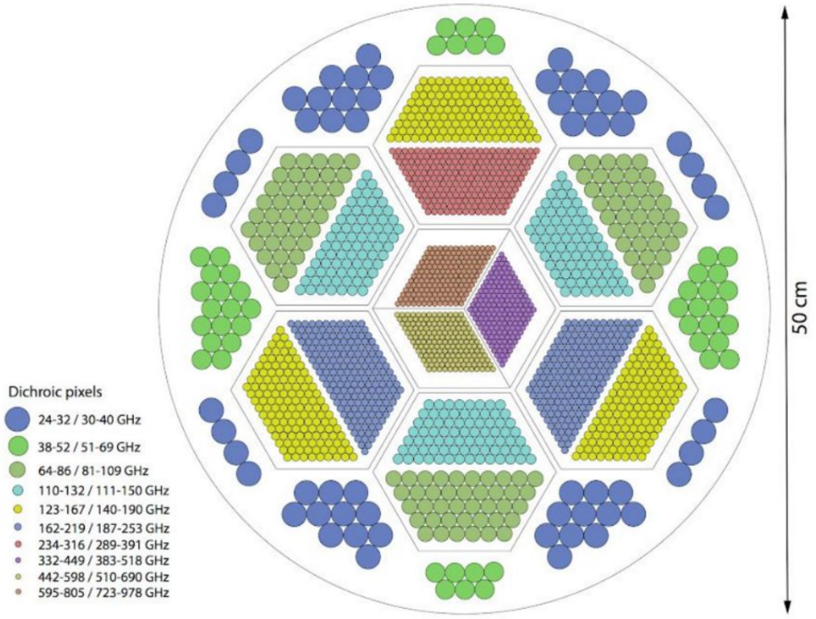
- A next generation satellite which will have a multitude of scientific goals.
- Proposed by Indian Cosmology Consortium as a space mission to ISRO.
- One of the main scientific goals is the detection of B-Mode.
- The inflationary paradigm predicts a primordial B-mode signal sourced by gravitational waves.
- Its power is parameterized by ***tensor-to-scalar ratio,r.***
- r is directly related to energy scale of the universe.
- CMB-Bharat aims to detect r=0.001 at a confidence level of 3σ

The Challenges in Detection of B-mode



- High level of foregrounds.
- Contamination from lensing
- Limited by the noise of detector.

Instrumental Configuration



Courtesy: CMB-BHARAT proposal to ISRO

Frequency Band Centers (GHz)	Beam FWHM (arcmin)	N_{DET}	Sensitivity s (μK.arcmin)
28	39.9	48	16.5
35	31.9	48	13.3
45	24.8	48	11.9
65	17.1	78	8.9
75	14.91	78	5.1
95	11.7	76	4.6
115	9.72	124	3.1
130	8.59	144	3.1
145	7.70	144	2.4
165	6.77	160	2.5
190	5.88	192	2.8
220	5.08	192	3.3
275	4.06	128	6.3
340	3.28	128	11.4
390	2.86	128	21.9
450	2.48	96	43.4
520	2.14	96	102.0
600	1.86	96	288.0
700	1.59	96	1122.0
850	1.31	96	9550.0

Overview

This Talk is based on the following two works:

- **B-mode forecast of CMB-Bhārat,**

  Debabrata Adak, Aparajita Sen, Soumen Basak, Jacques Delabrouille, Tuhin Ghosh, Aditya Rotti, Ginés Martínez-Solaeche, Tarun Souradeep,*Monthly Notices of the Royal Astronomical Society*, Volume 514, Issue 2, August 2022, Pages 3002–3016

- **Optimum Range of Frequency for Thermal Dust Removal in CMB-Bhārat,**

  Aparajita Sen, Debabrata Adak, Soumen Basak, Tuhin Ghosh. (Manuscript under preparation)

Overview:

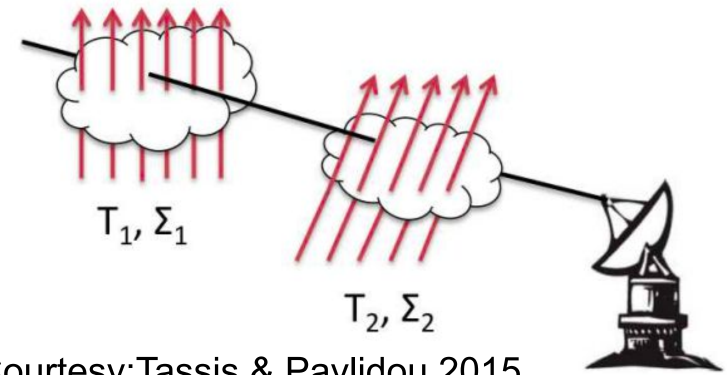
- Test the ability of CMB-Bharat to detect CMB-B-mode
- We consider a range of foreground components.
- We also account for complexities in dust and synchrotron modelling.
- Frequency bands higher than 100GHz are dominated by thermal dust.
- How to improve the performance of component separation techniques?
- Increase the frequency range for dust observations.
- Is this true for CMB-Bharat frequency configuration?

Thermal Dust Models

The thermal dust emission is empirically modelled Modified Black Body Spectra at a single temperature

$$I_\nu = A_D^I \left(\frac{\nu}{\nu_0} \right)^{\beta_d} B_\nu(T_d).$$

This modelling does not account for line-of-sight effects, variation in dust composition and size and the galactic magnetic field



Courtesy:Tassis & Pavlidou,2015

Complex Thermal Dust Models

- **The MKD-Dust model**: 3-dimensional modelling of dust which accounts for variation in dust properties along line-of-sight. *Martınez-Solaeche et.al, 2018*, Karakci & Delabrouille (2018)

$$I_\nu = \int_0^\infty dr \frac{d\tau(r,\nu_0)}{dr} \left(\frac{\nu}{\nu_0}\right)^{\beta(r)} B_\nu(T(r))$$

- **TD-dust model**: Generated from 3 phases of HI cloud. (*Ghosh et.al.2017 & Adak et.al. 2017*)
- **Physical dust model**: Accounts for physical properties of the dust grains (*Hensley&Draine 2017*)

Synchrotron model

- The Synchrotron is modelled by a power law.
- Realistically, we average of different populations of electron.
- Sum of power law is not a power law.
- Synchrotron Complexity is modelled by a curve power law.

$$Q^s_\nu = u_\nu Q^s_{\nu_0} \left(\frac{\nu}{\nu_0} \right)^{\beta_s + 2}$$

$$U^s_\nu = u_\nu U^s_{\nu_0} \left(\frac{\nu}{\nu_0} \right)^{\beta_s + 2},$$

$$\beta_s = -3.11 + C \log \left(\frac{\nu}{23} \right).$$

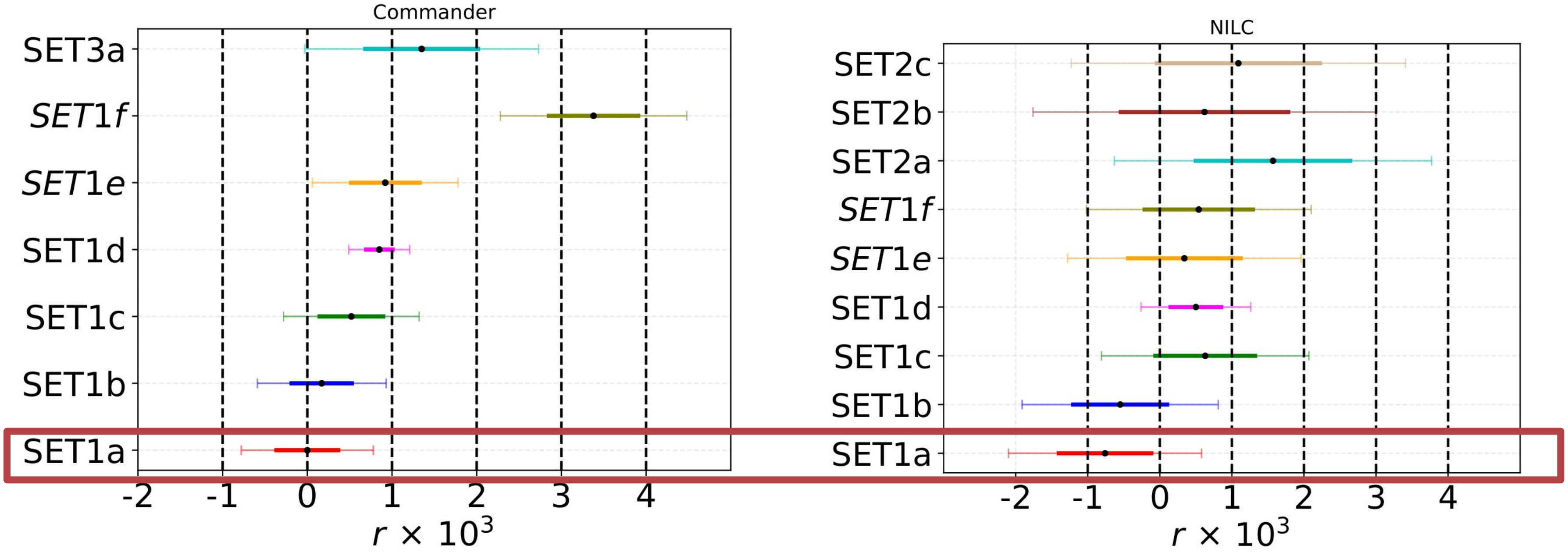
Methodology

1. Generate Sky simulations at CMB-BHARAT frequency bands.
2. Apply two Component Separation Methods: ***NILC and Commander*** separately.
3. Recover the angular power spectrum
4. Use Maximum likelihood method to recover r and its uncertainty.

Sky simulations

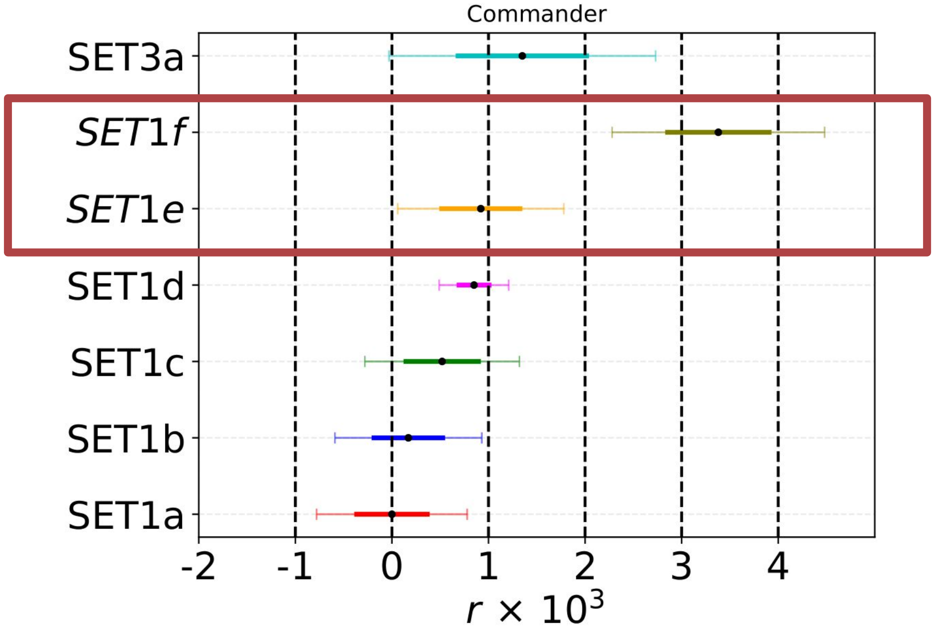
Sim.ID	Pipeline		Dust	Synchrotron	AME	point-sources	delensing	Decorrelation
	Commander	NILC						
SET1a	✓	✓	GNILC – dust	GALPROP	✗	✗	✗	✗
SET1b	✓	✓	GNILC – dust	GALPROP	✓	✗	✗	✗
SET1c	✓	✓	GNILC – dust	GALPROP	✓	✓	✗	✗
SET1d	✓	✓	GNILC – dust	GALPROP	✗	✗	✓	✗
SET1e	✓	✓	GNILC – dust	Power – law	✓	✓	✗	✗
SET1f	✓	✓	GNILC – dust	Curved–power–law	✓	✓	✗	✗
SET2a	✓	✓	MKD – dust	GALPROP	✓	✓	✗	✓
SET2b	✓	✓	MKD – dust	Power – law	✓	✓	✗	✓
SET2c	✓	✓	MKD – dust	Curved–power–law	✓	✓	✗	✓
SET3a	✓	✗	TD – dust	GALPROP	✓	✓	✗	✗
SET3b	✓	✗	TD – dust	GALPROP	✓	✓	✗	✓

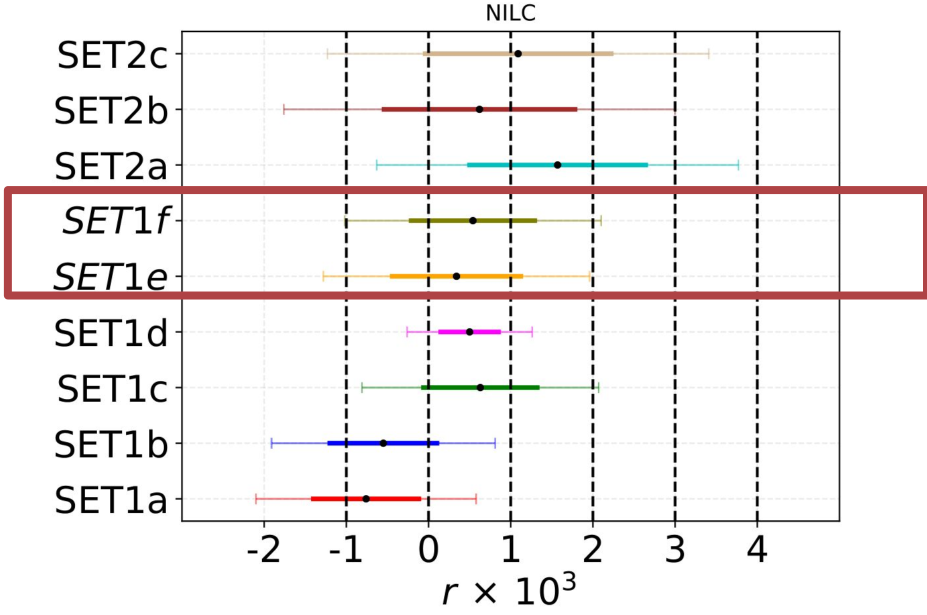
r forecast : Baseline model



uncertainty= 0.0004-0.0007

r forecast : Synchrotron Complexity





r forecast : Dust Complexity

Sim.ID	NILC			Commander		
	$r_{mp} \times 10^3$	$\sigma(r_{mp})\times 10^3$	χ^2/dof	$r_{mp} \times 10^3$	$\sigma(r_{mp})\times 10^3$	χ^2/dof
SET1a	-0.76	0.67	0.60	-0.08	0.39	0.95
SET2a	1.57	1.10	1.11	47.45	1.48	33.72
SET2b	0.62	1.19	1.91	51.06	1.56	33.92
SET2c	1.09	1.16	1.90	34.82	1.43	25.57
SET3a	-	-	-	1.35	0.69	4.02
SET3b		-	-	188.41	5.93	123.0

MKD DUST

TD-DUST

Optimum range frequency channels

What is the frequency range at for which will ensure optimal removal of thermal dust component?

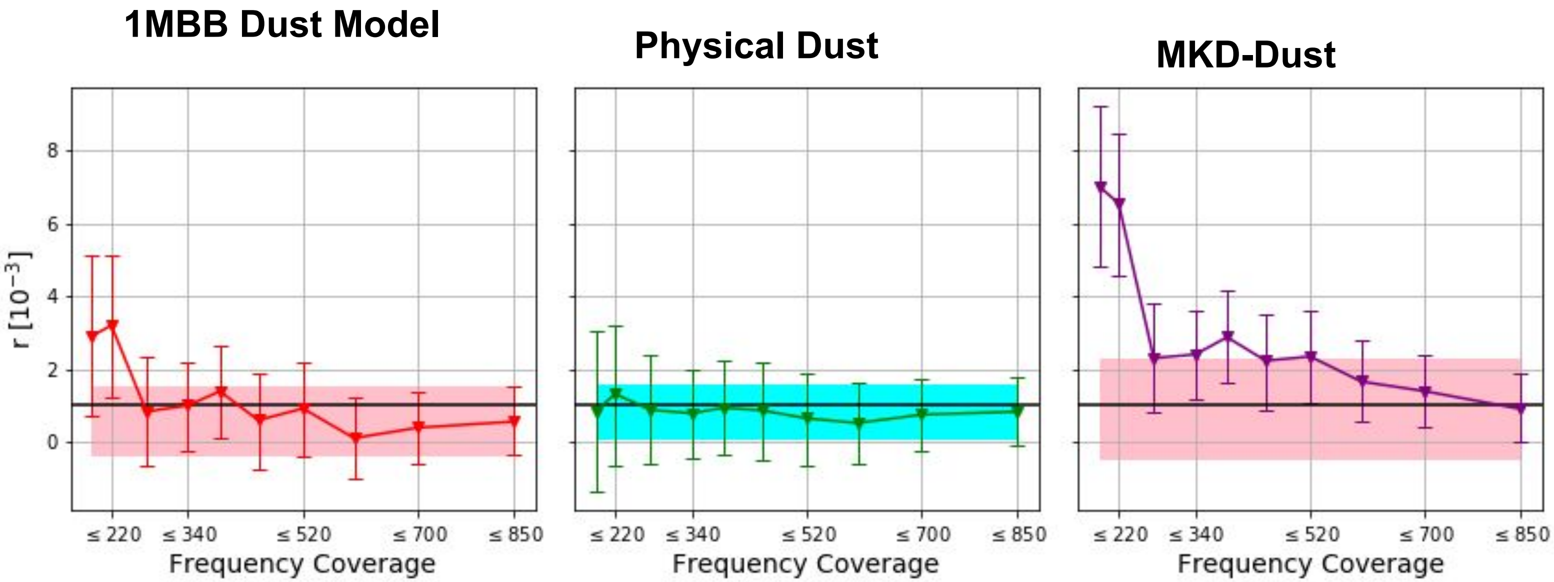
Henseley & Bull 2018 has shown that in some cases it is more beneficial to limit the observations at lower frequencies ~200-500 GHz.

Analysis done on single pixel of sky, parametric component separation

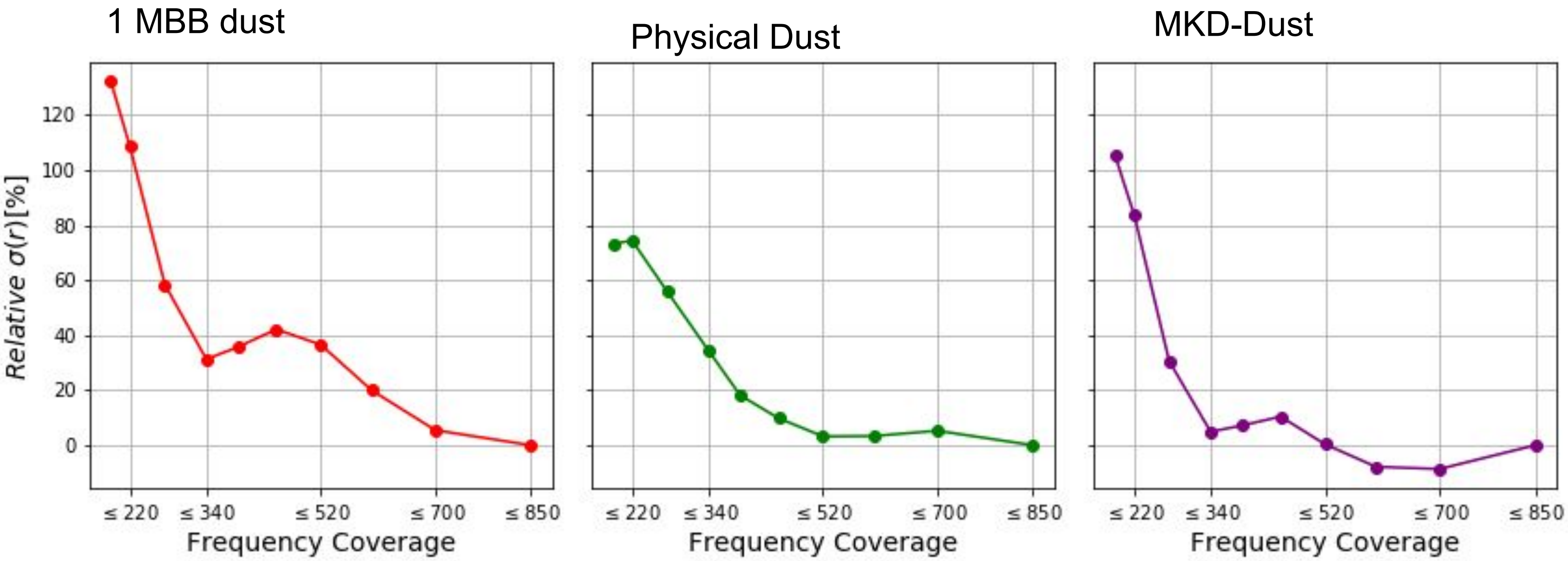
We analyse for CMB-Bharat frequency channels for the given noise budget

Analysis done on full sky, Blind component separation method used.

Results: Change in bias on r



Results: Change in sensitivity of the instrument



Conclusions

- The configuration of CMB-Bharat can recover r~0.001.
- The bias in r increases in case of complex dust models such as the MKD-dust.
- In the Commander1 method we see that bias is also introduced when the curve in the spectral index is not accounted for.
- Also not suitable for frequency decorrelated dust models.
- Thermal dust observations upto 500 GHz is adequate for minimizing its contamination.