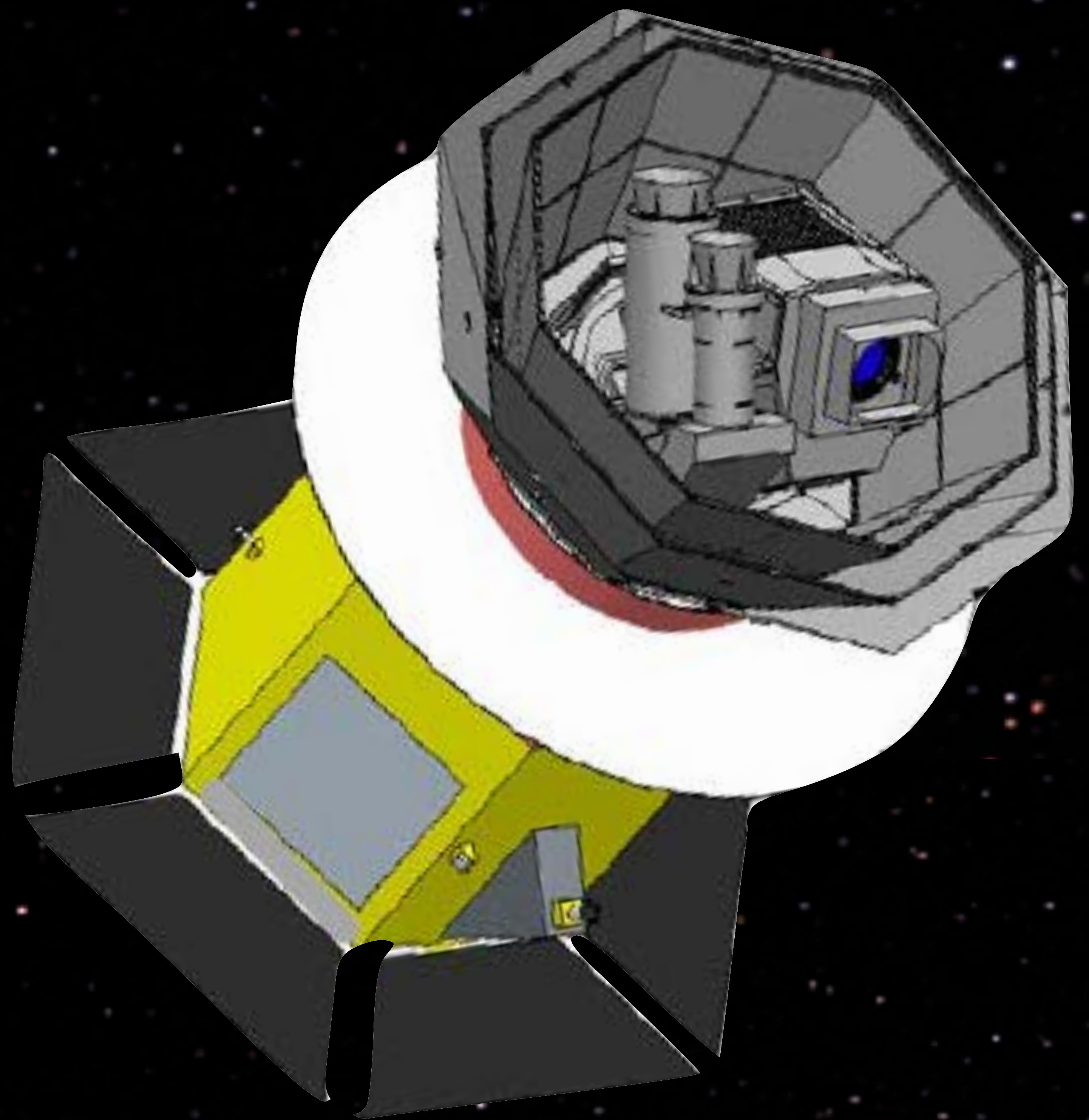
LiteBIRD
Testing cosmic inflation from L2

Cosmological frontiers in fundamental physics
APC - Perimeter - Solvay
26 May 2021

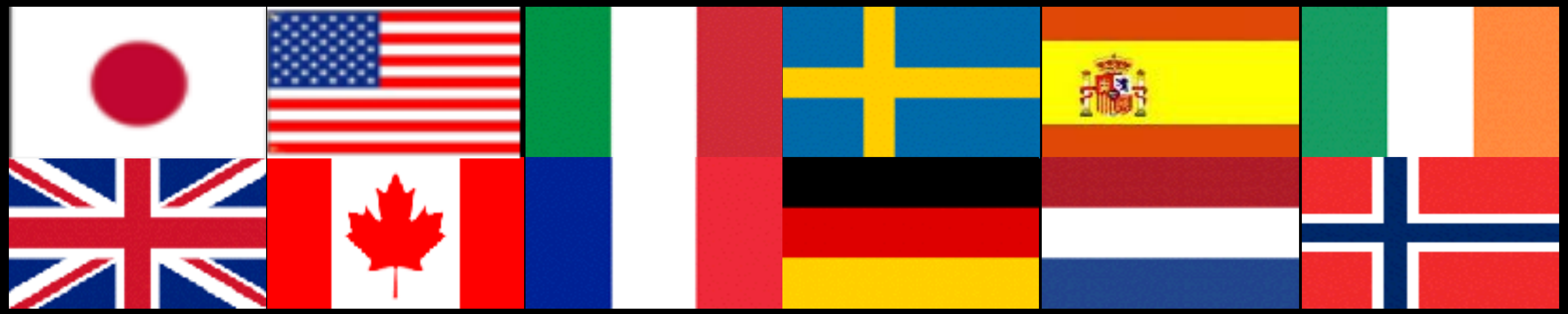


Davide Poletti (SISSA)
On behalf of the LiteBIRD joint study group

SISSA

LiteBIRD

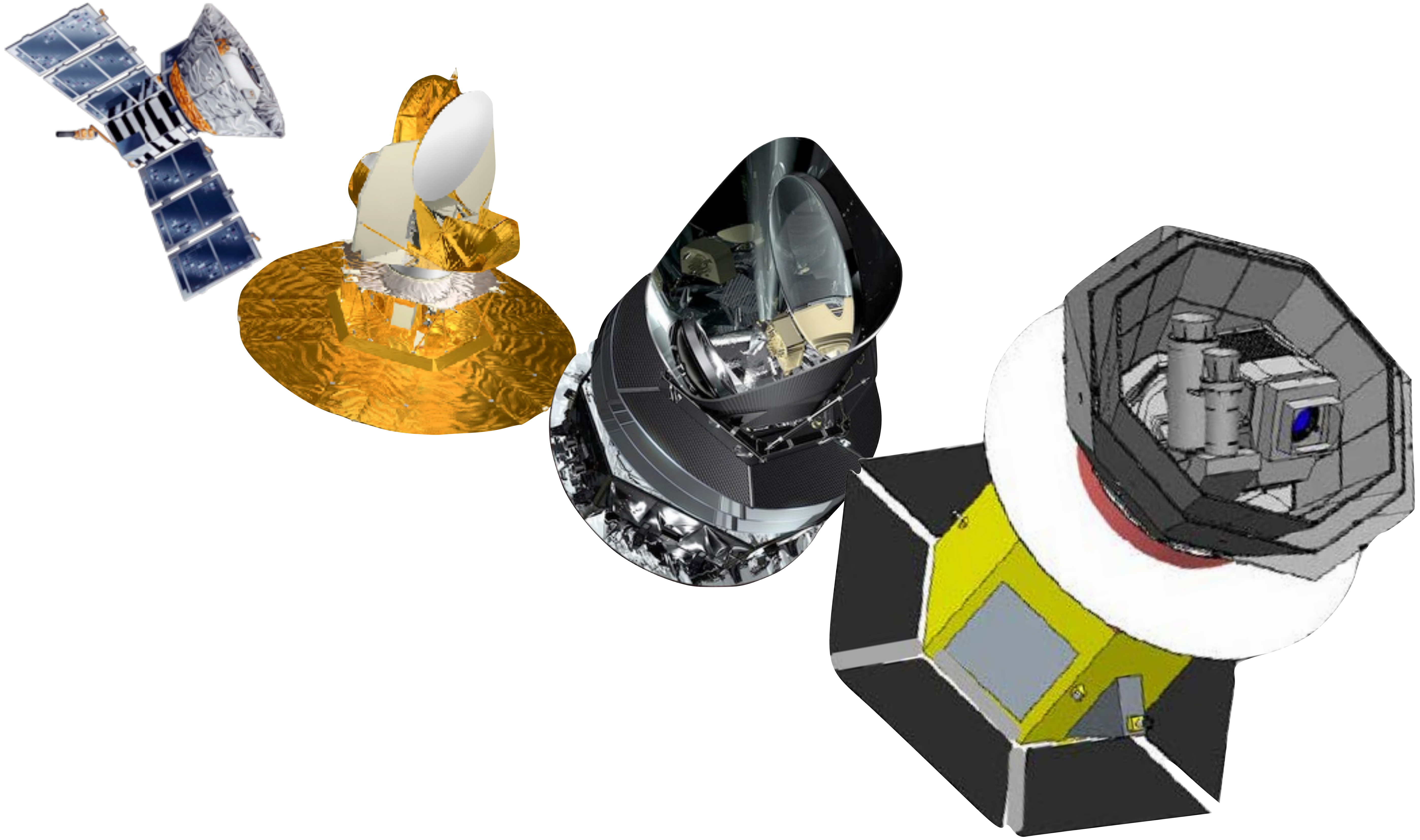
Almost 300 members of the joint study group



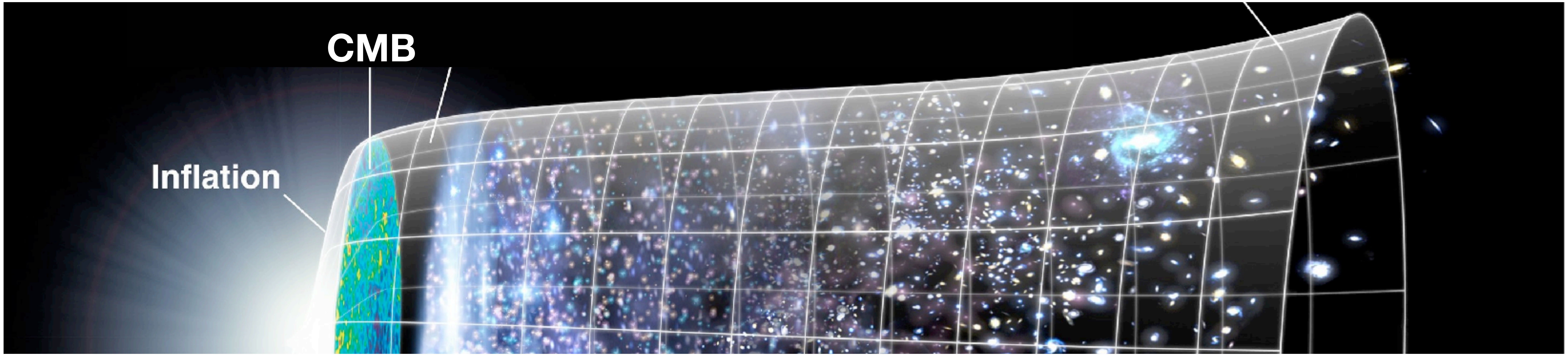
LiteBIRD: the next CMB satellite mission

Satellite for probing cosmic inflation through the cosmic microwave background polarization

May 2019: Selected as JAXA's Strategic large-class mission



Inflation



Big Bang model: problems
- Horizon
- Flatness
- Monopole
- Initial conditions

→ INFLATION

What physics drives it?

Beyond the standard model?
What energy scale?

Did it actually occur?
Can we make falsifiable predictions?
- [x] Near scale-invariant initial conditions
- [ ] **Gravitational wave background**
- [ ] …

↓

B-modes in the CMB

See talks by A. Malek-Nejad, E. Pajer

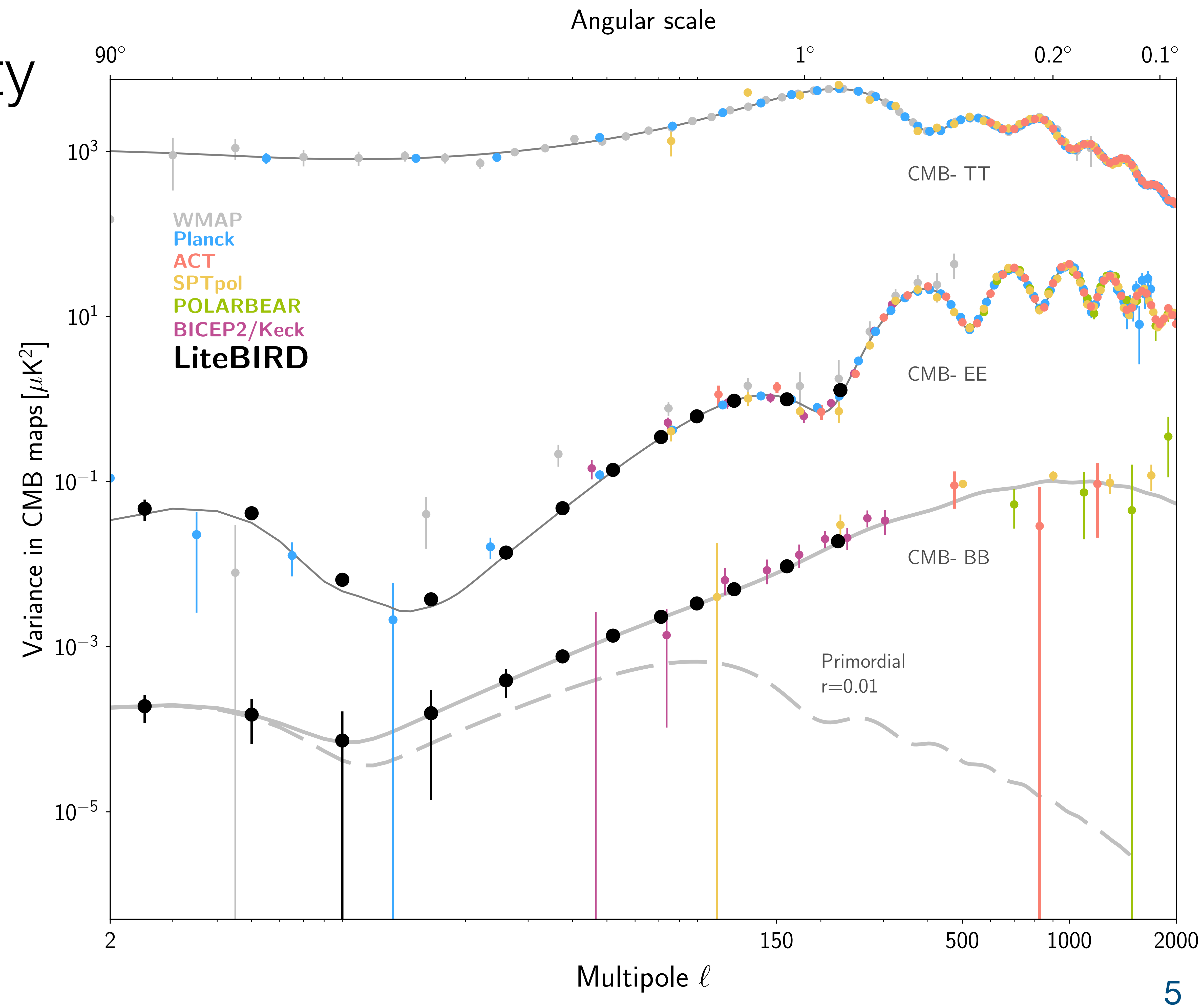
Scientific objectives

Use CMB polarization to search for signal of cosmic inflation

- making a discovery or ruling out well-motivated inflationary models
- insight into the quantum nature of gravity

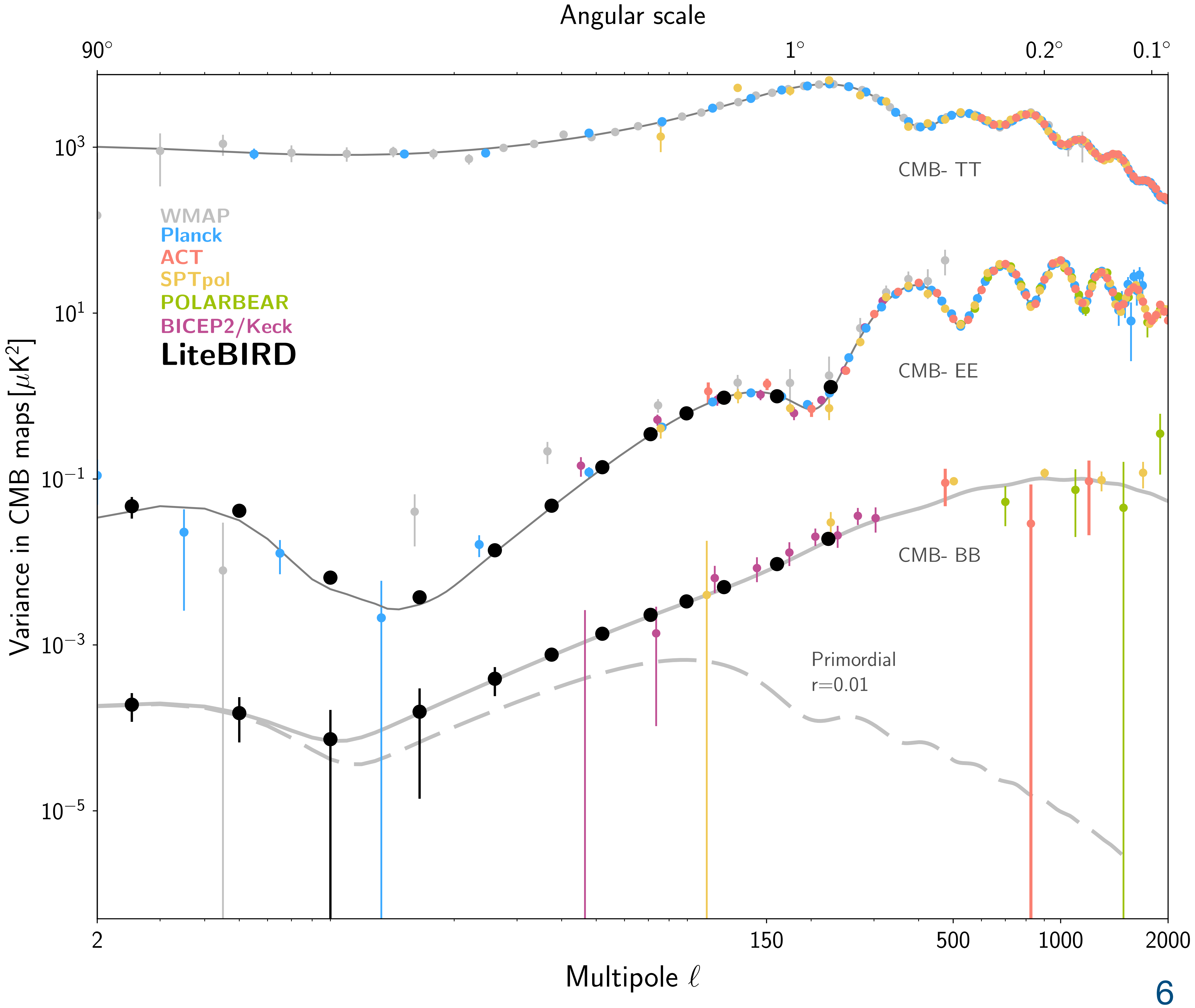
Requirements (no external data)

- For tensor-to-scalar ratio $r = 0$, total uncertainty on $\delta r < 0.001$
- For $r = 0.01$, 5σ-detection of reionisation ($2 \leq \ell \leq 10$) and recombination bump ($11 \leq \ell \leq 200$)



Extra science outcomes

- Further improving sensitivity on r with external data
- Characterization of B-modes and search for source fields (e.g scale-invariance, non-Gaussianity, parity violation)
- Power spectrum features in polarization
- Large-scale E-modes, their implications for reionization history and the neutrino mass
- Cosmic birefringence
- SZ effect (thermal and relativistic correction)
- Elucidating anomalies
- Galactic science
- …

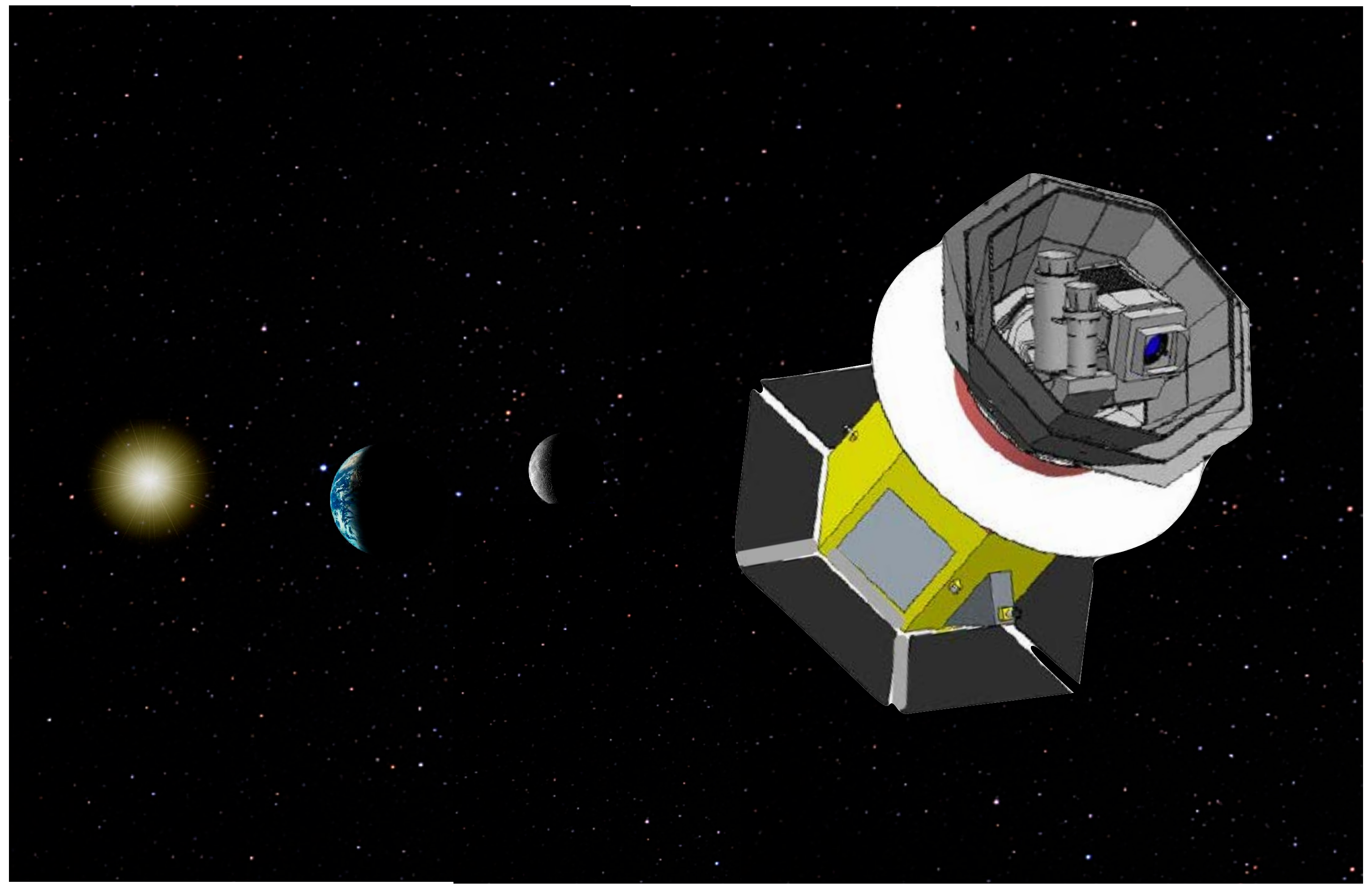


Why space and complementarity with the ground

- Only way to access largest scales
- Ideal environment
(no atmosphere, no ground pickup, no limitations on the choice of the frequency bands)

Small scales

$2 < \ell < 200$



$30 < \ell < \sim 8000$

Large scales
High frequencies

Strategic L-class mission at JAXA

- Flagship science mission with HIIA/H3 vehicle
- 30B yen cost cap (300M USD for 1 USD = 100 yen)

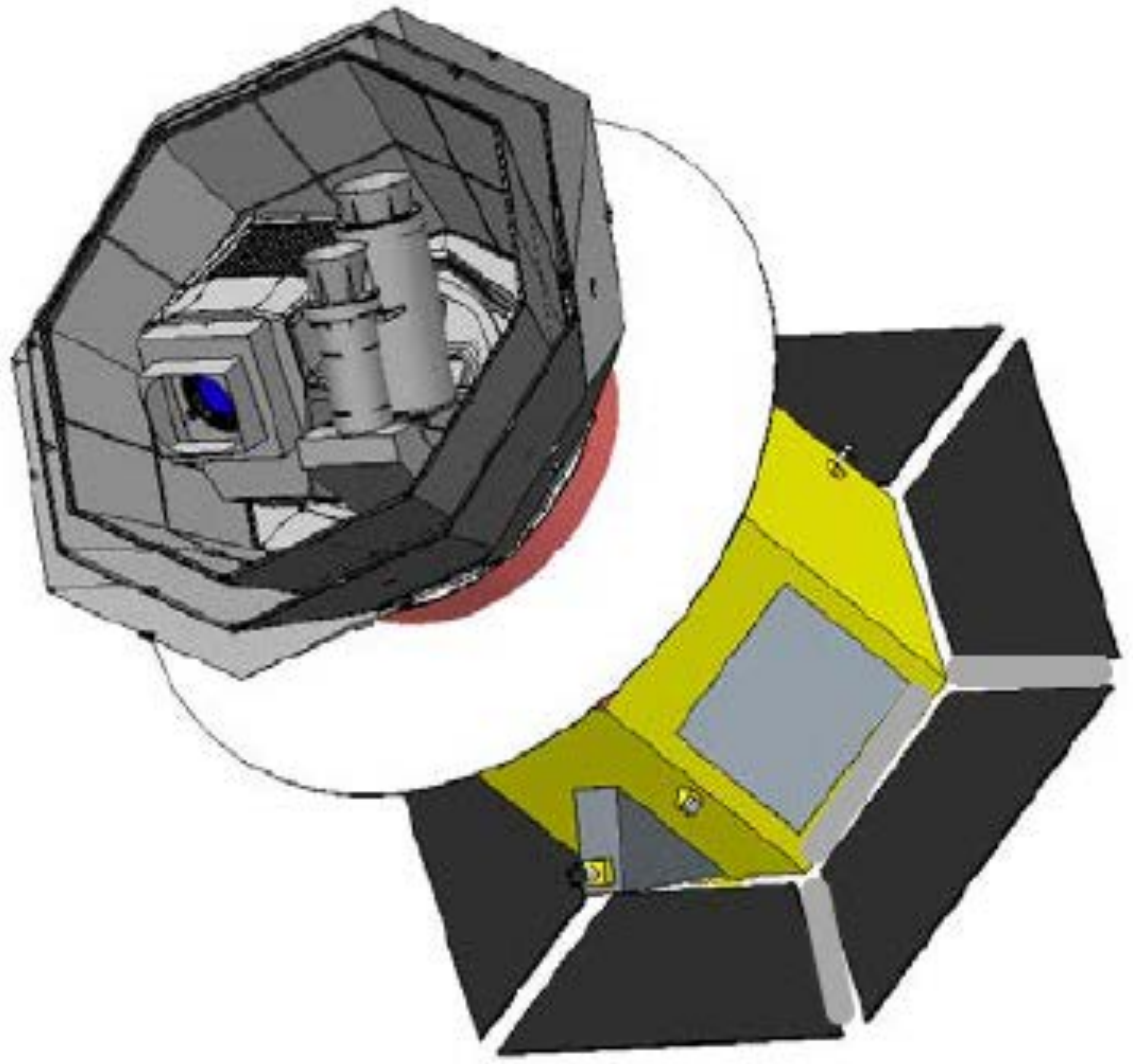
L-class #3
to be planned

Japanese Fiscal Year	20	21	22	23	24	25	26	27	28	29	30	31	32

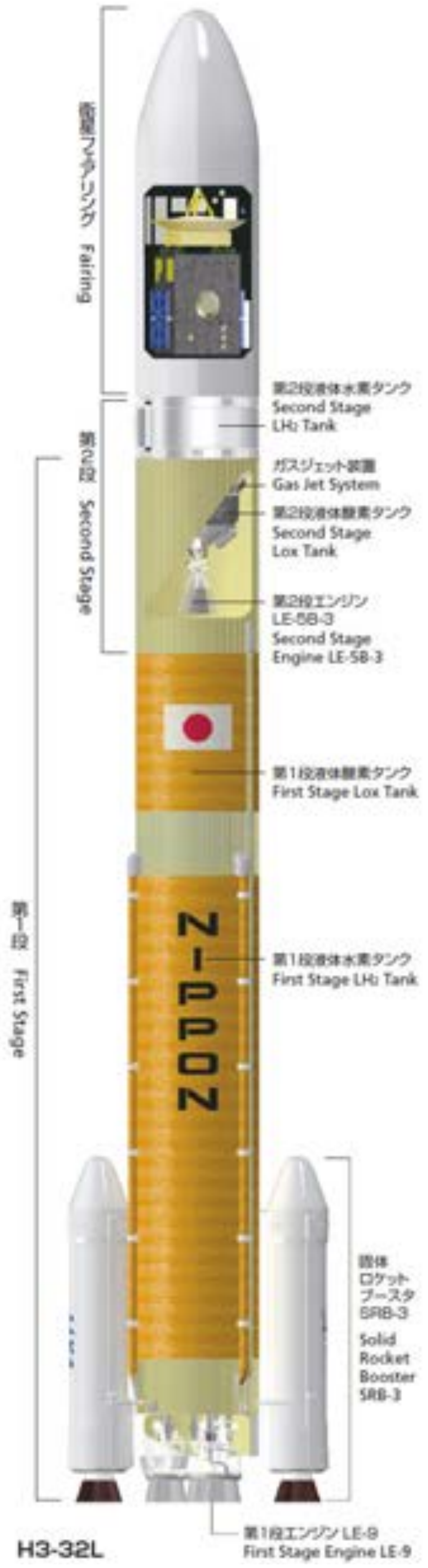
HIIA

XRISM
(recovery of Hitomi)

L-class #1
Martian
Moons
eXploration
(MMX)

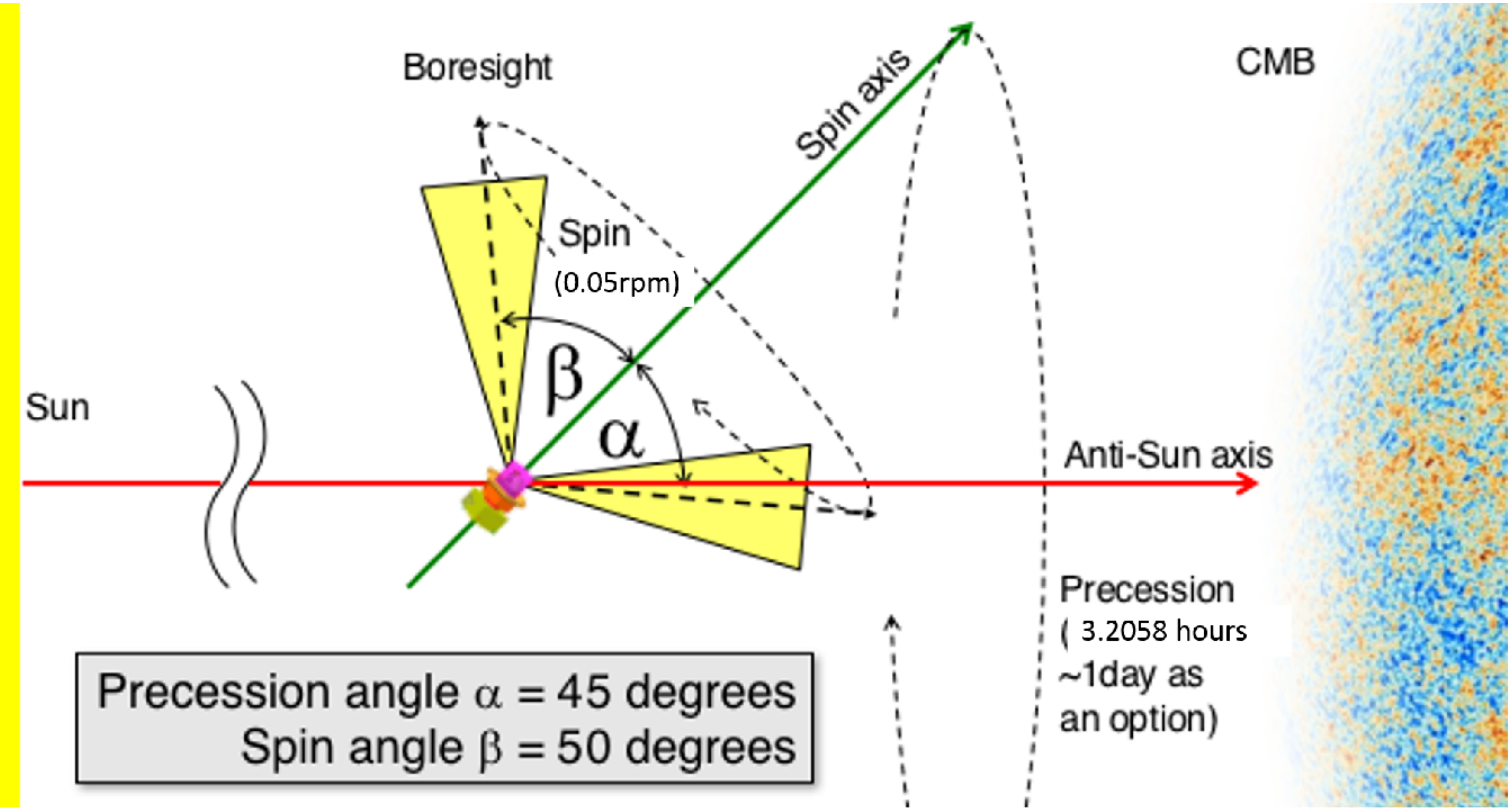


L-class #2
LiteBIRD
(selected in
May 2019)

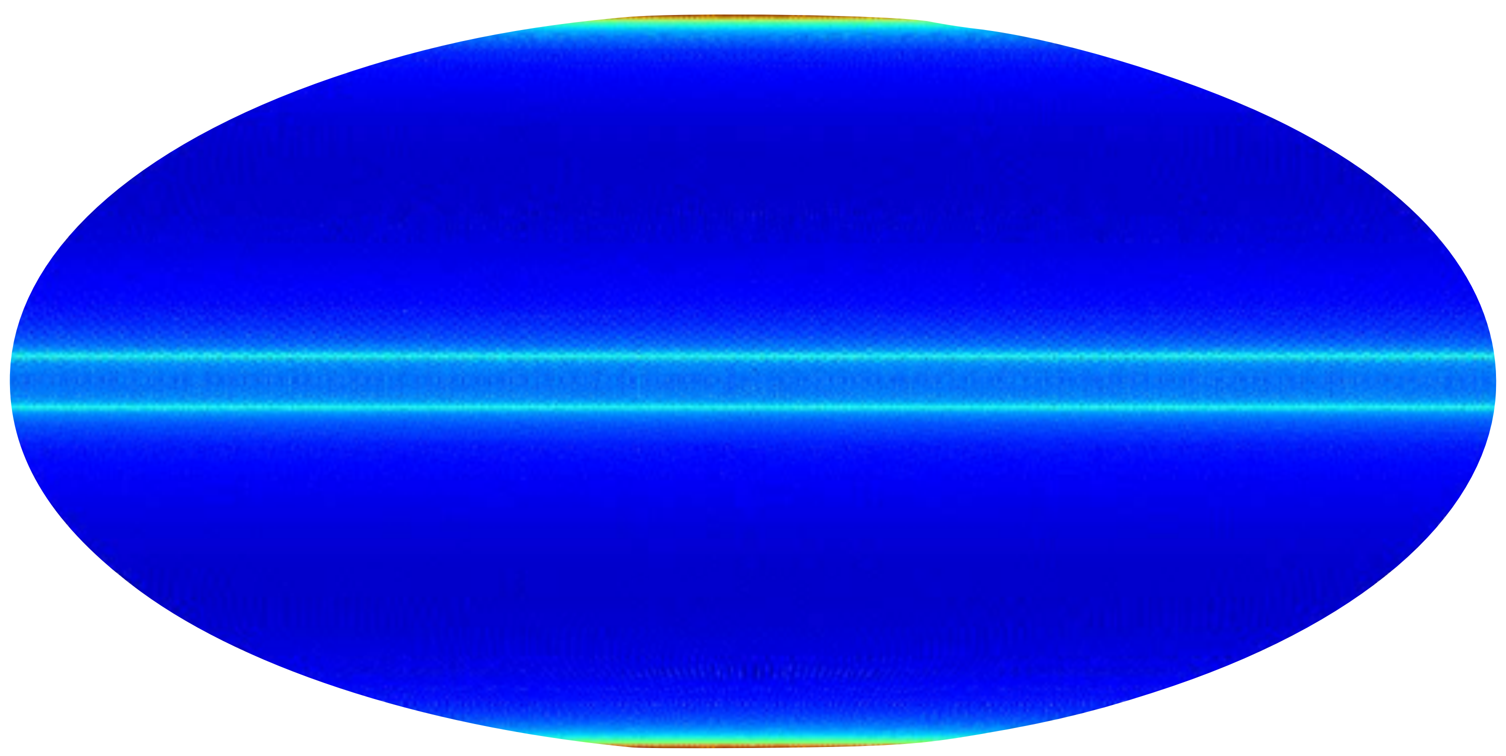


H3

Observation



Coverage after one year



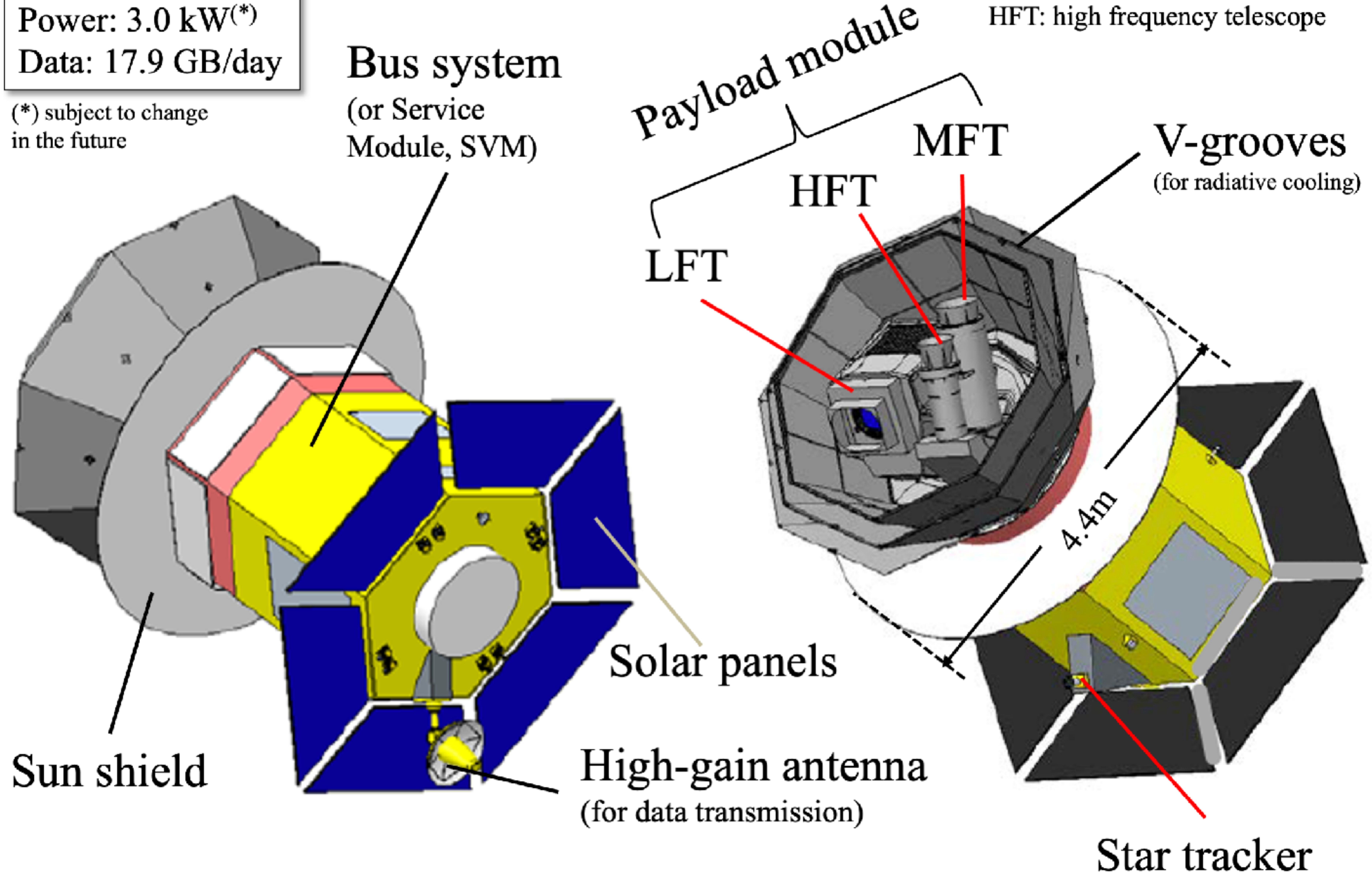
Orbit: L2 Lissajous orbit
Observation time: 3 years
Frequency range: 34 to 448 GHz
N bands: 15
Resolution: 70-18 arcmin

The satellite

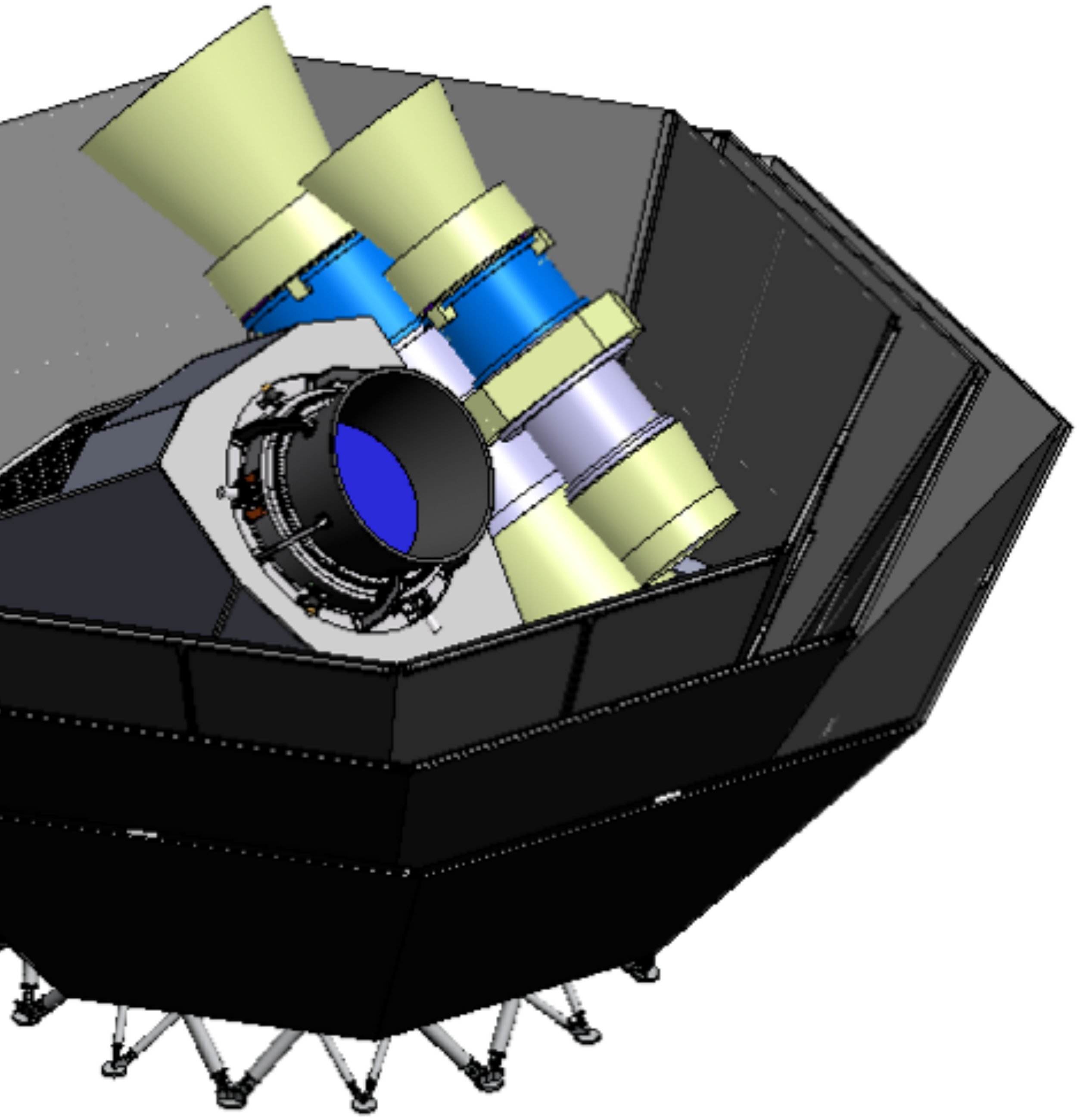
Mass: 2.6 t(*)
Power: 3.0 kW(*)
Data: 17.9 GB/day

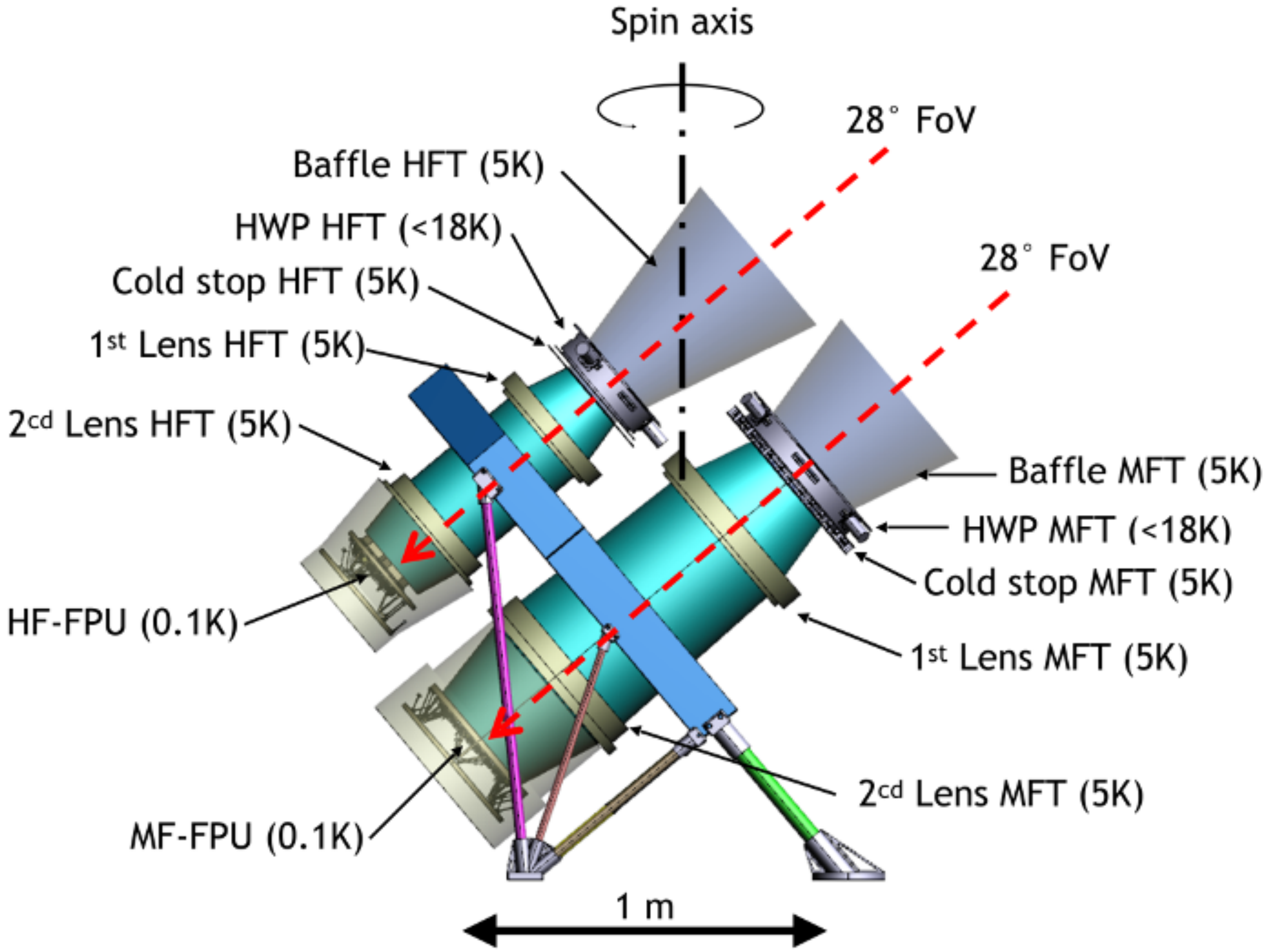
(*) subject to change in the future

LFT: low frequency telescope
MFT: medium frequency telescope
HFT: high frequency telescope

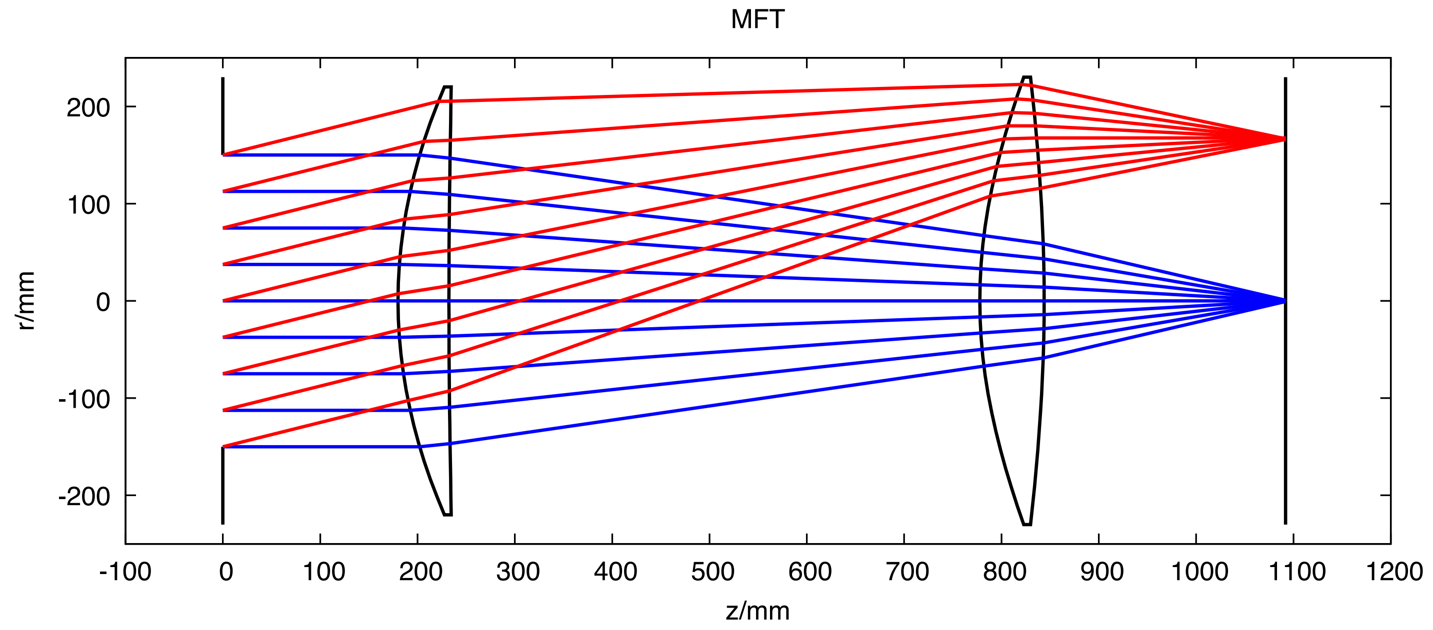


Payload

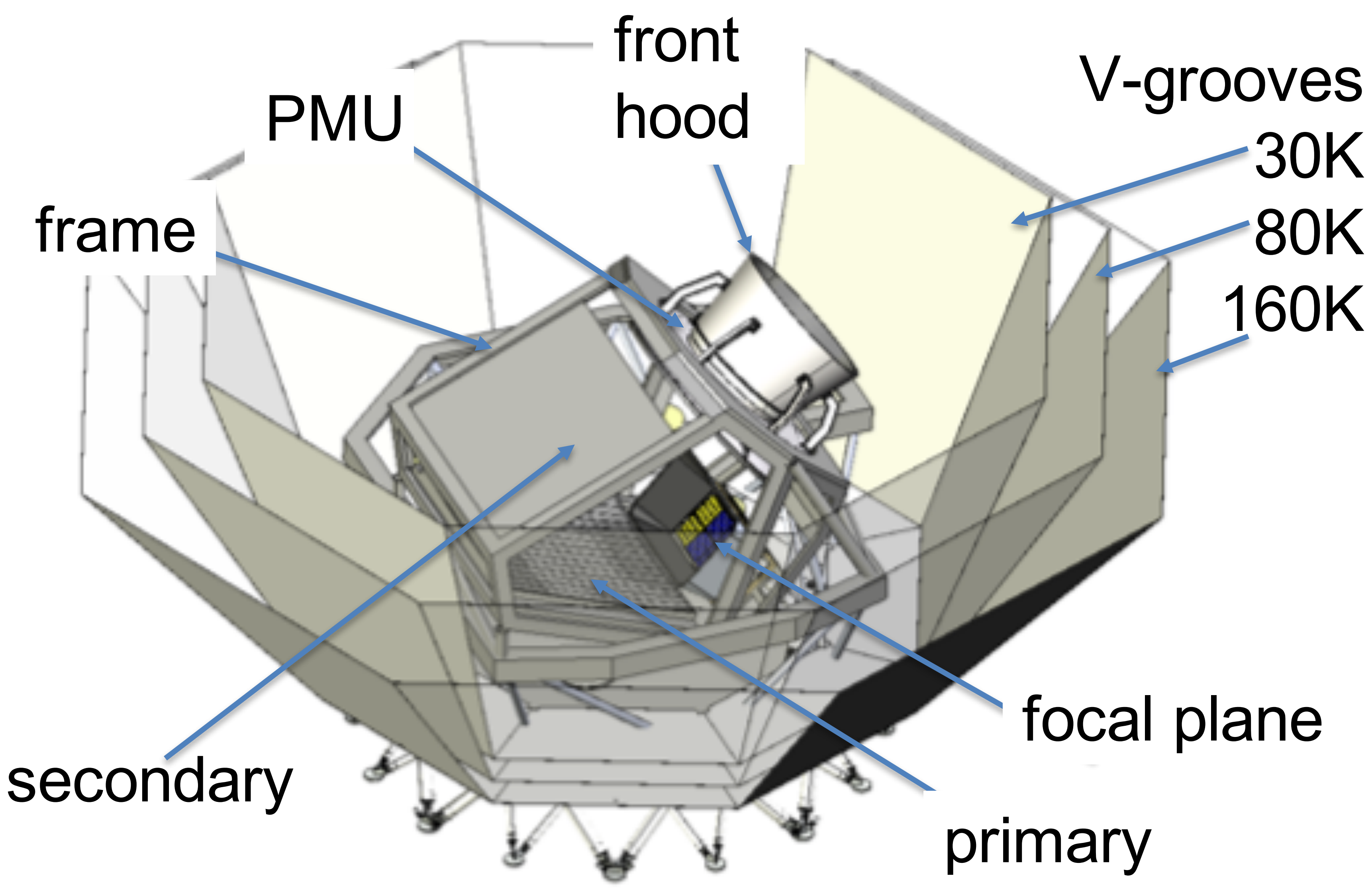




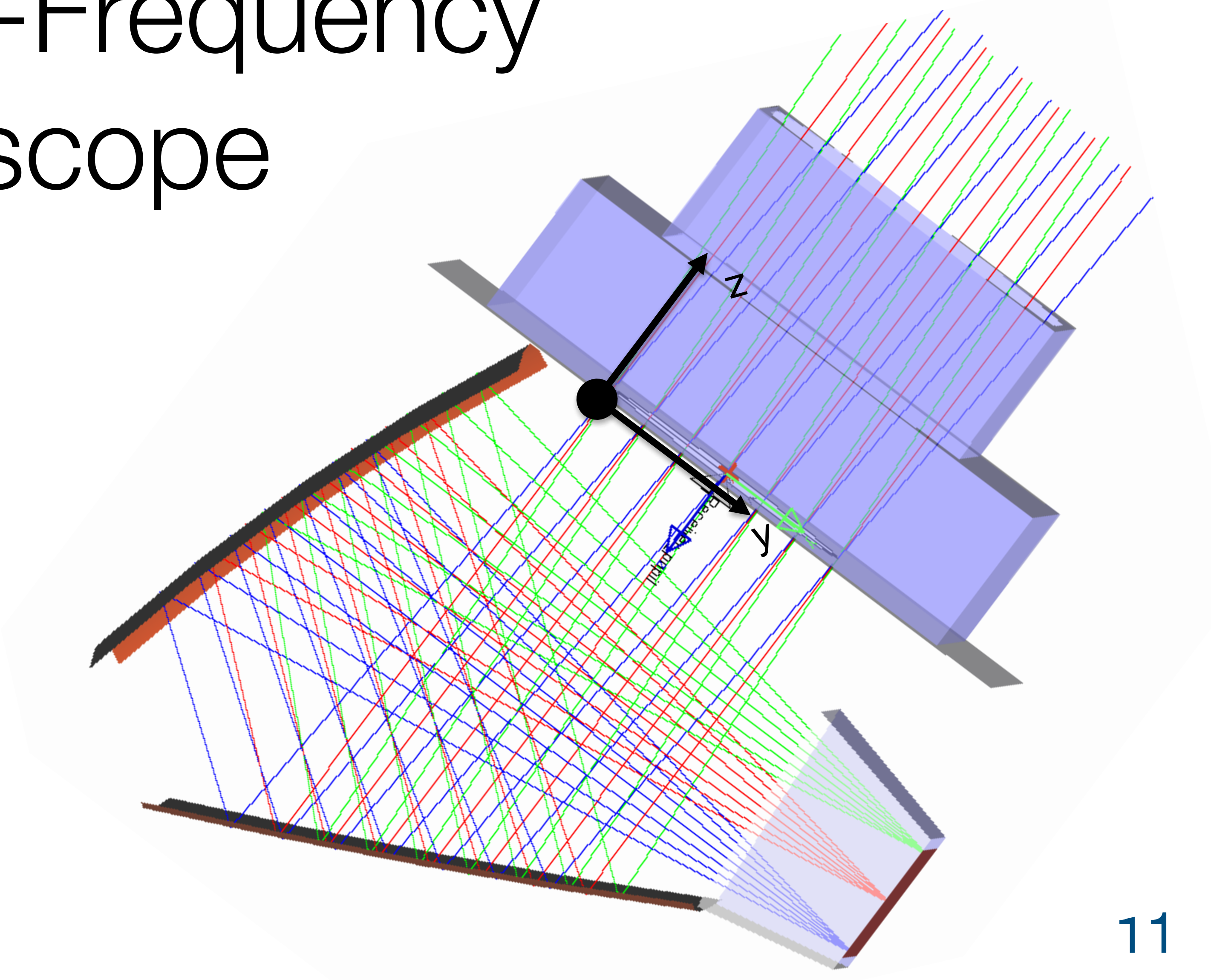
Medium- and High-Frequency Telescopes



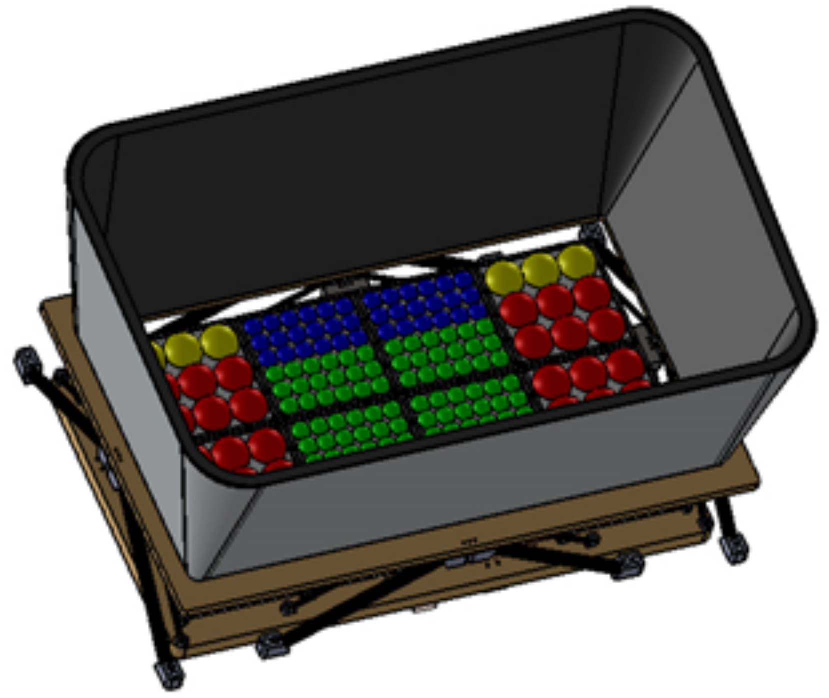
Rotating half-wave plate (HWP) for 1/f noise & systematics reduction

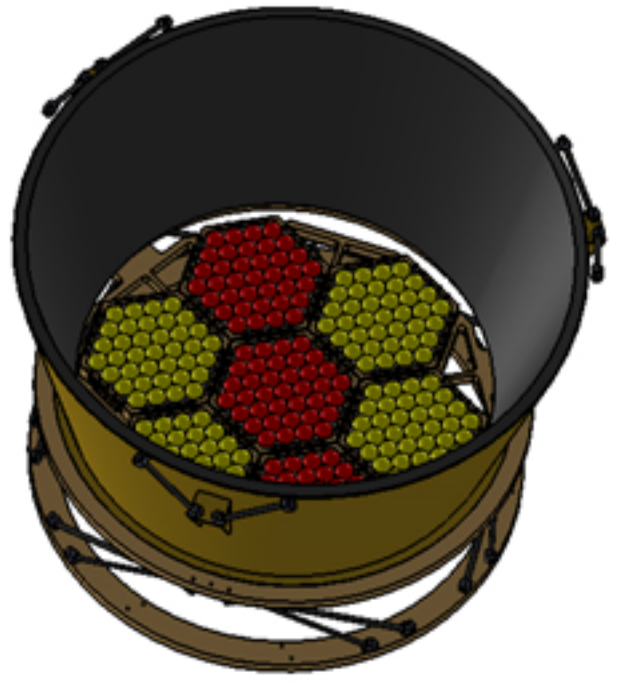


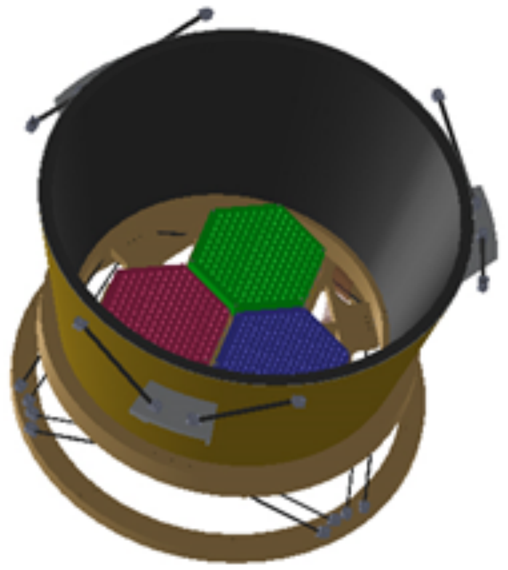
Low-Frequency Telescope

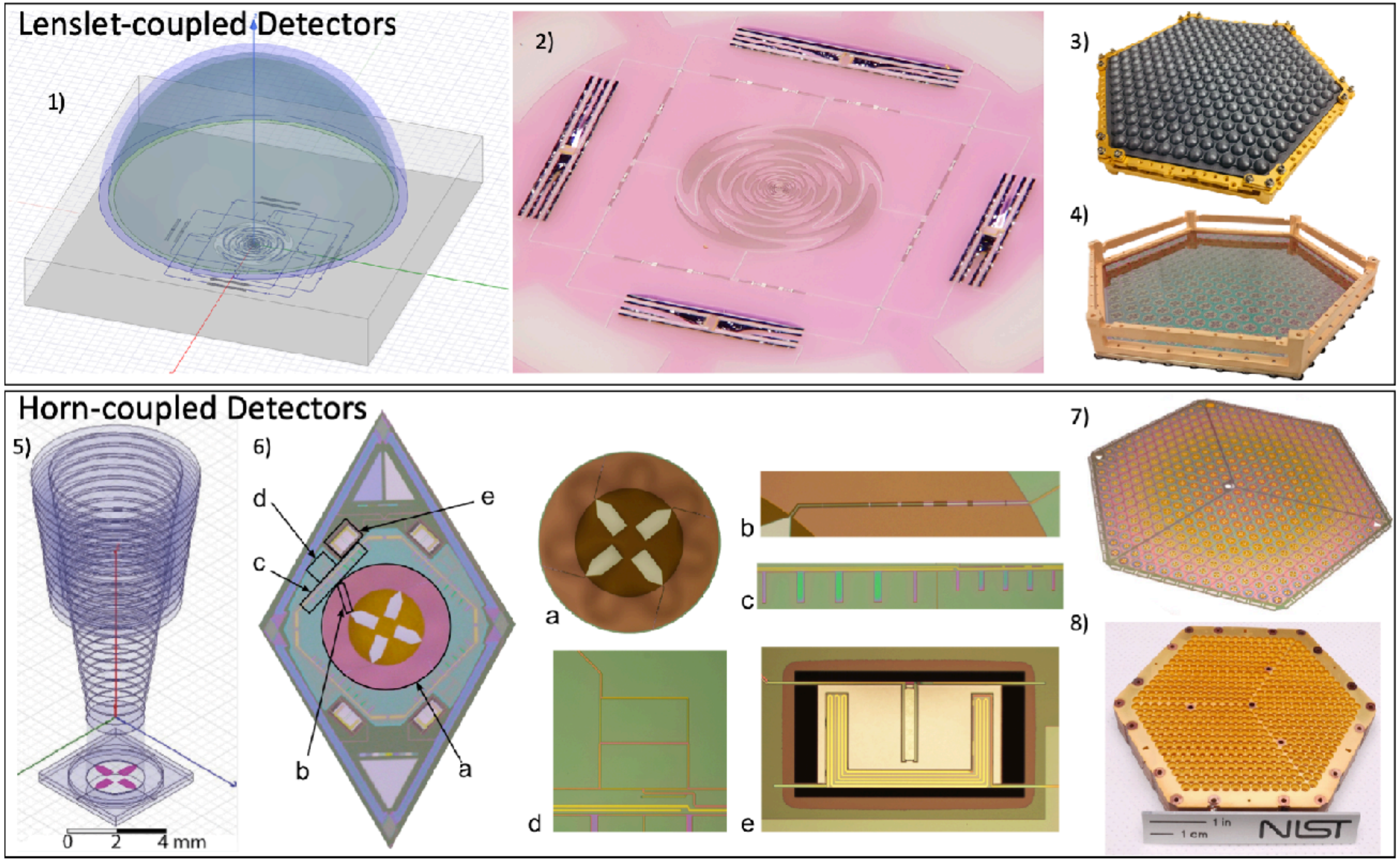


Focal plane units


a) LF-FPU


b) MF-FPU


c) HF-FPU



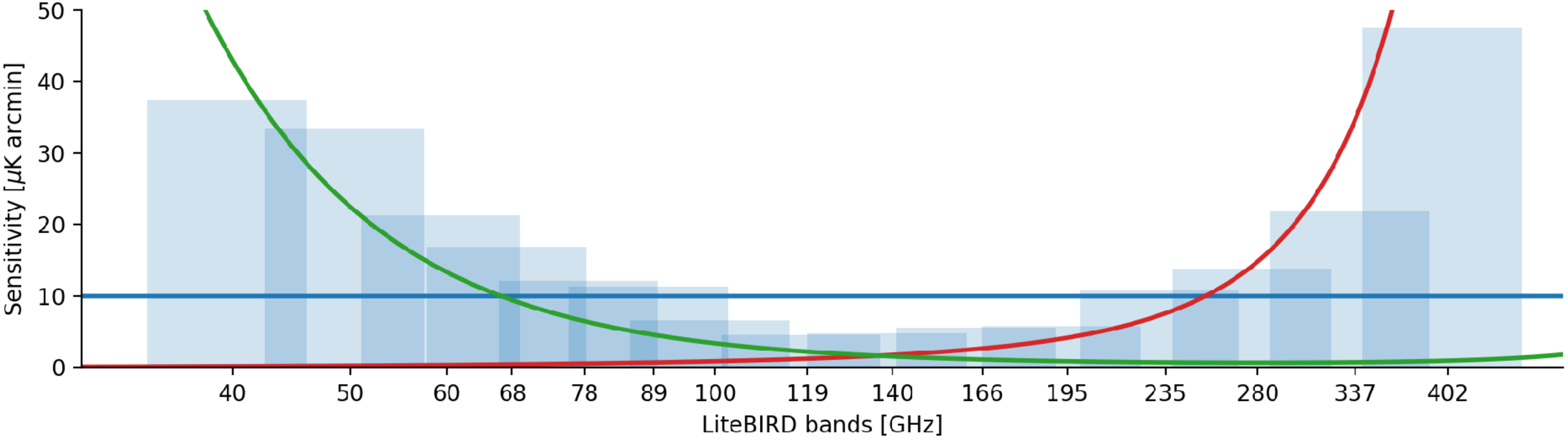
Westbrook+ (2021)

Polarized foregrounds and LiteBIRD bands

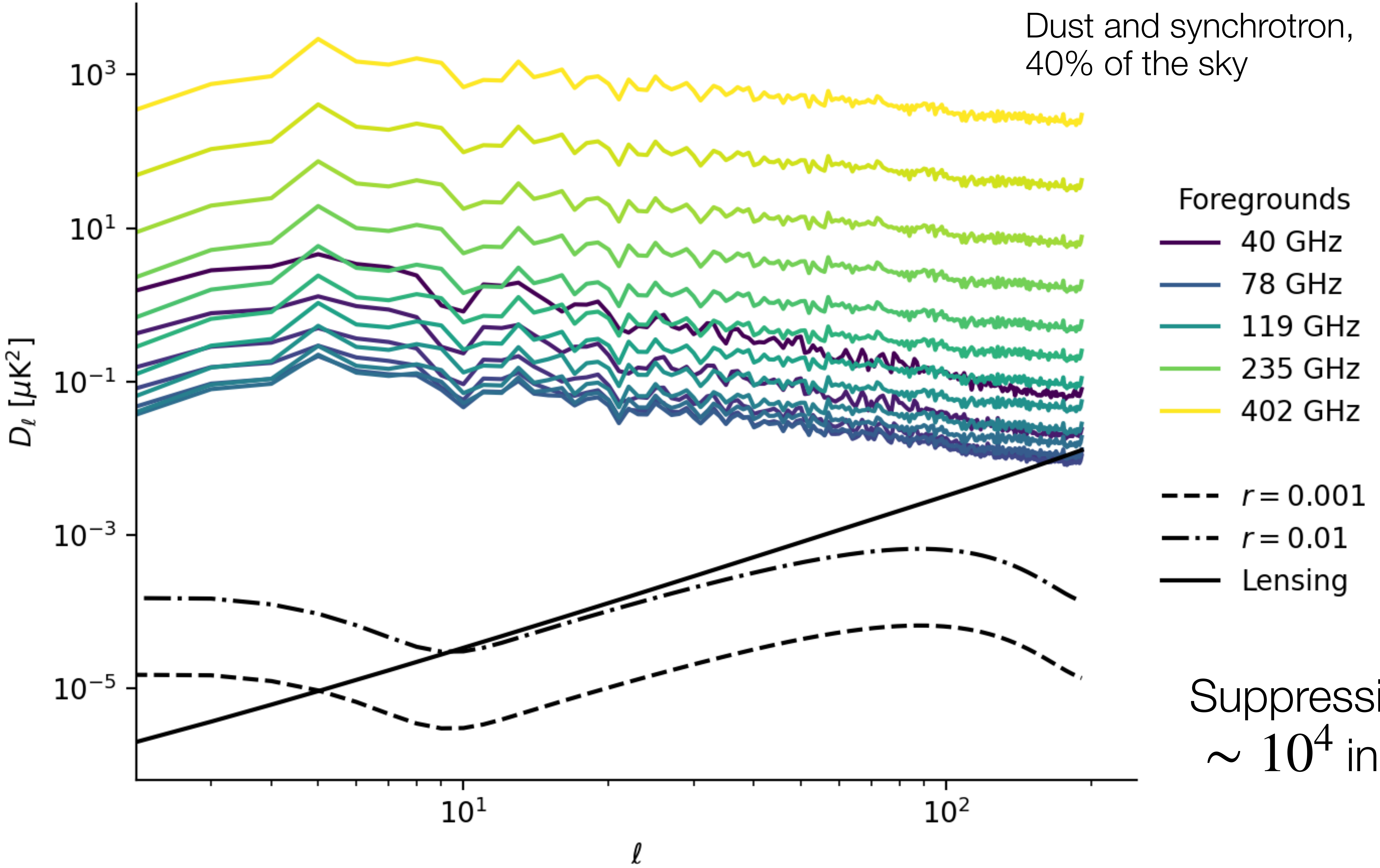
- Thermal dust: $A_d \left(\frac{\nu}{\nu_0}\right)^{\beta_d+1} \frac{e^{\frac{h\nu_0}{k_B T_d}}-1}{e^{\frac{h\nu}{k_B T_d}}-1}$
- Synchrotron: $A_s \left(\frac{\nu}{\nu_0}\right)^{\beta_s}$

Reference sky: pysm3 d1s1 (Thorne+, 2016)
Based on:

- Planck 2015 for dust
- Haslam and WMAP 9-year for synchrotron



Foregrounds amplitude



Dust and synchrotron,
40% of the sky

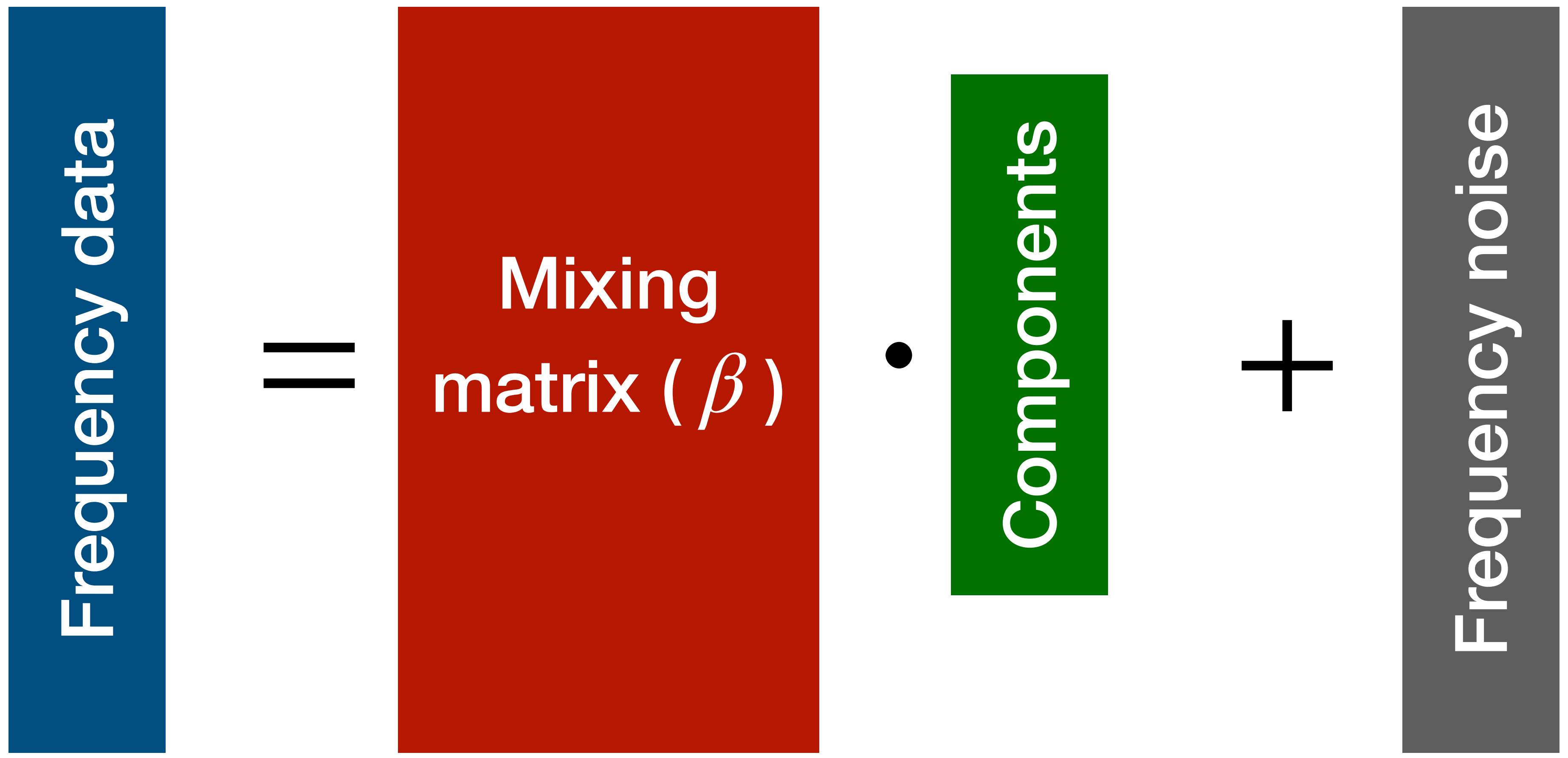
Suppression required:
$\sim 10^4$ in power


β_d
T_d
β_s
1.2
1.8
14
K
31
-3.3
-2.7
Sky fraction
0-20%
20-40%
40-60%
60-100%
1.3
1.4
1.5
1.6
1.7
1.8
15
20
25
30
K
−3.3
−3.2
−3.1
−3.0
−2.9
−2.8

Component separation in LiteBIRD

- (G)NILC (Delabrouille+, 2008; Remazeilles+, 2011; Basak+, 2012, …)
- Harmonic moment expansion (Chluba+, 2017; Mangilli+, 2021; Vacher+,in prep)
- B-SeCRET (de la Hoz, 2020)
- Delta-map (Ichiki+, 2019)
- COMMANDER (Eriksen+, 2004; Eriksen+, 2008, …)
- FGBuster (Stompor+, 2016; Errard+, 2019; Poletti+, in prep)

Parametric fitting



Data model $d_p^{(\nu)} = \Sigma_c \, A_{\nu,c} \, s_p^{(c)} + n_p^{(\nu)}$

Likelihood $-2 \ln \mathscr{L}(s, \beta) = [d - As]^\top N^{-1} \, [d - As] + \text{const}$

Solution

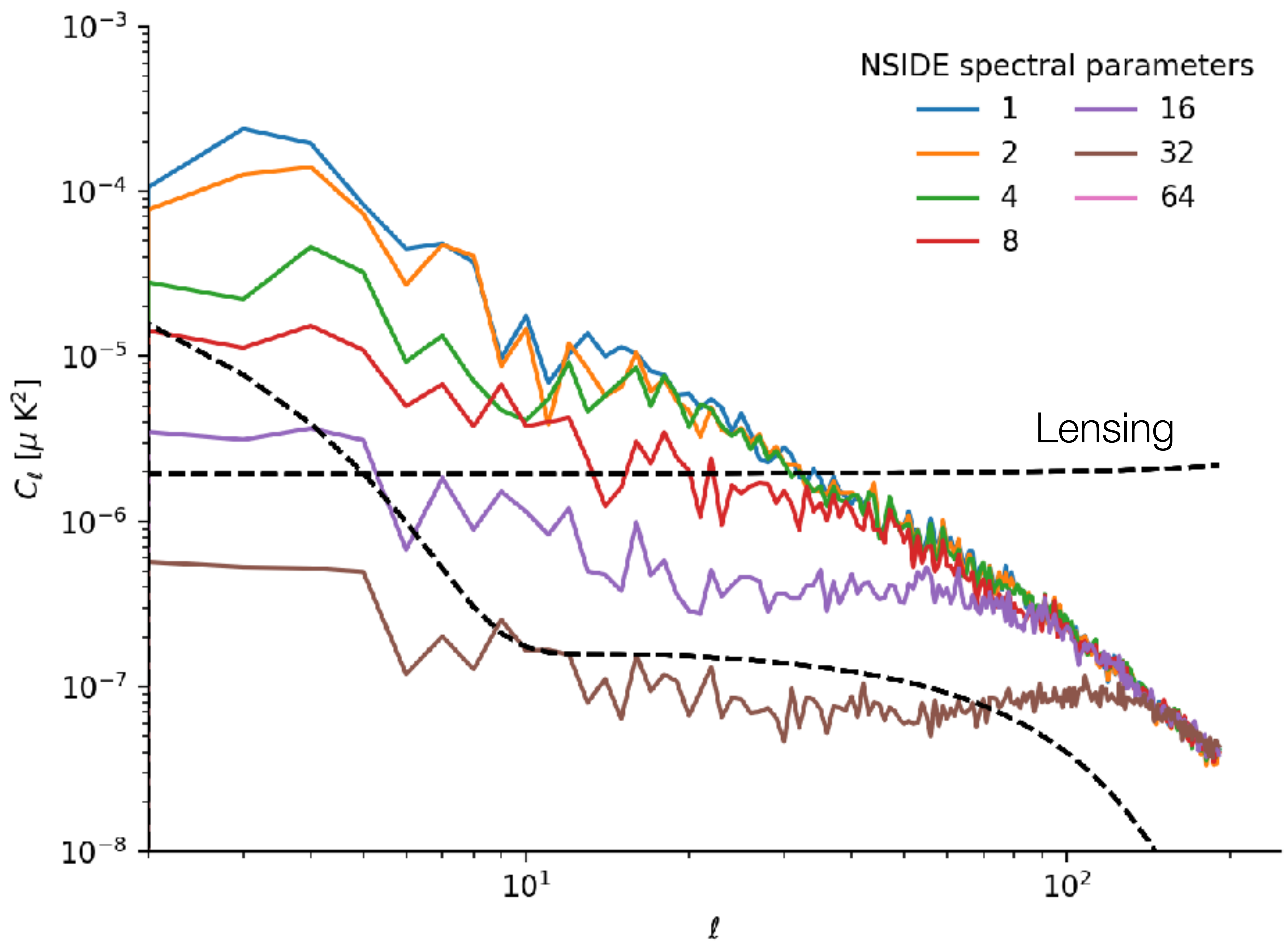
1. Numerical optimization problem to fit the non-linear parameters
2. Closed-form to fit the component amplitudes $\hat{s} = (A^\top N^{-1} A) \, A^\top N^{-1} d$

How to choose the non-linear parameters? What resolution?

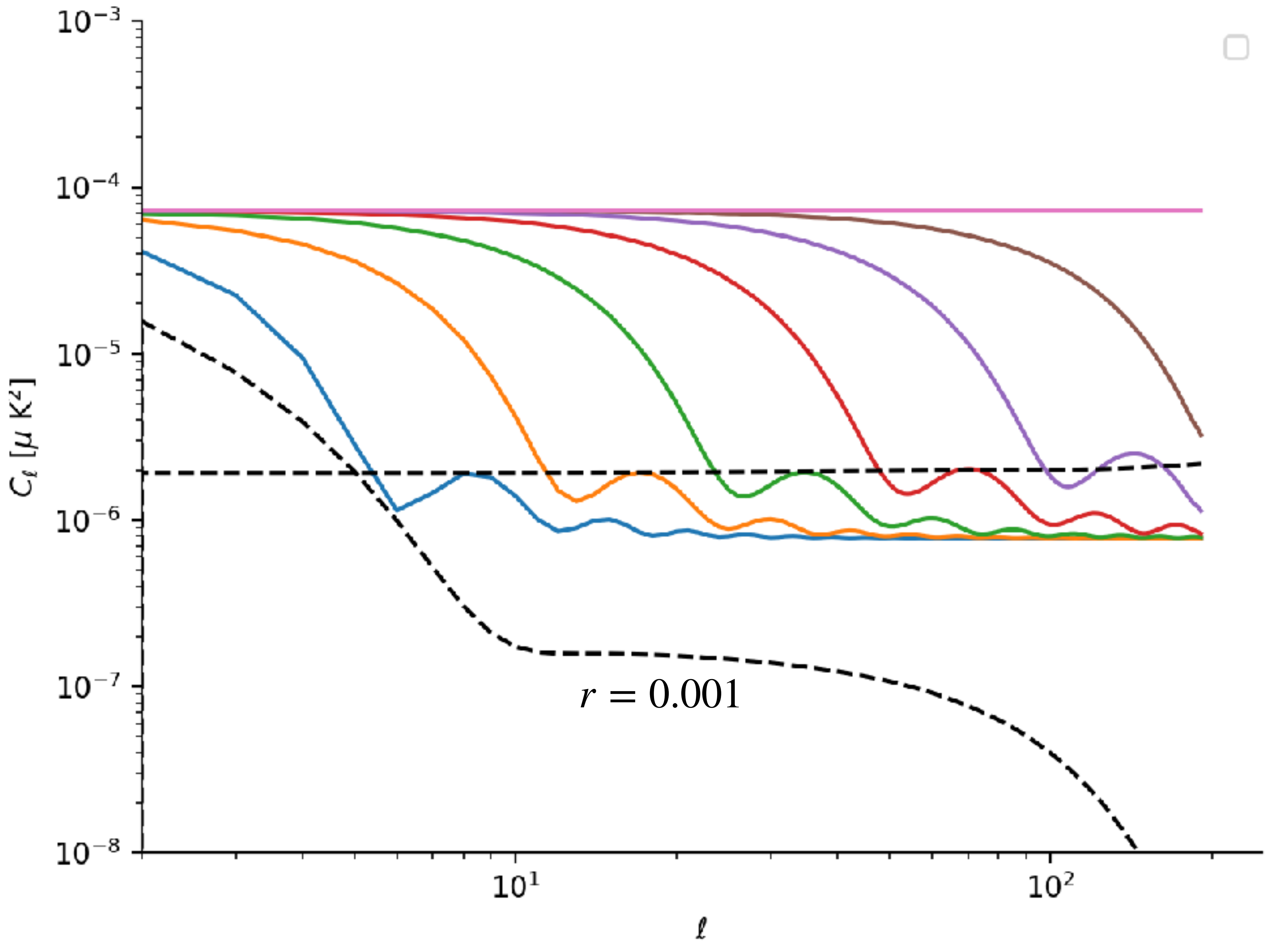
Multipatch approach (Errard and Stompor, 2019)

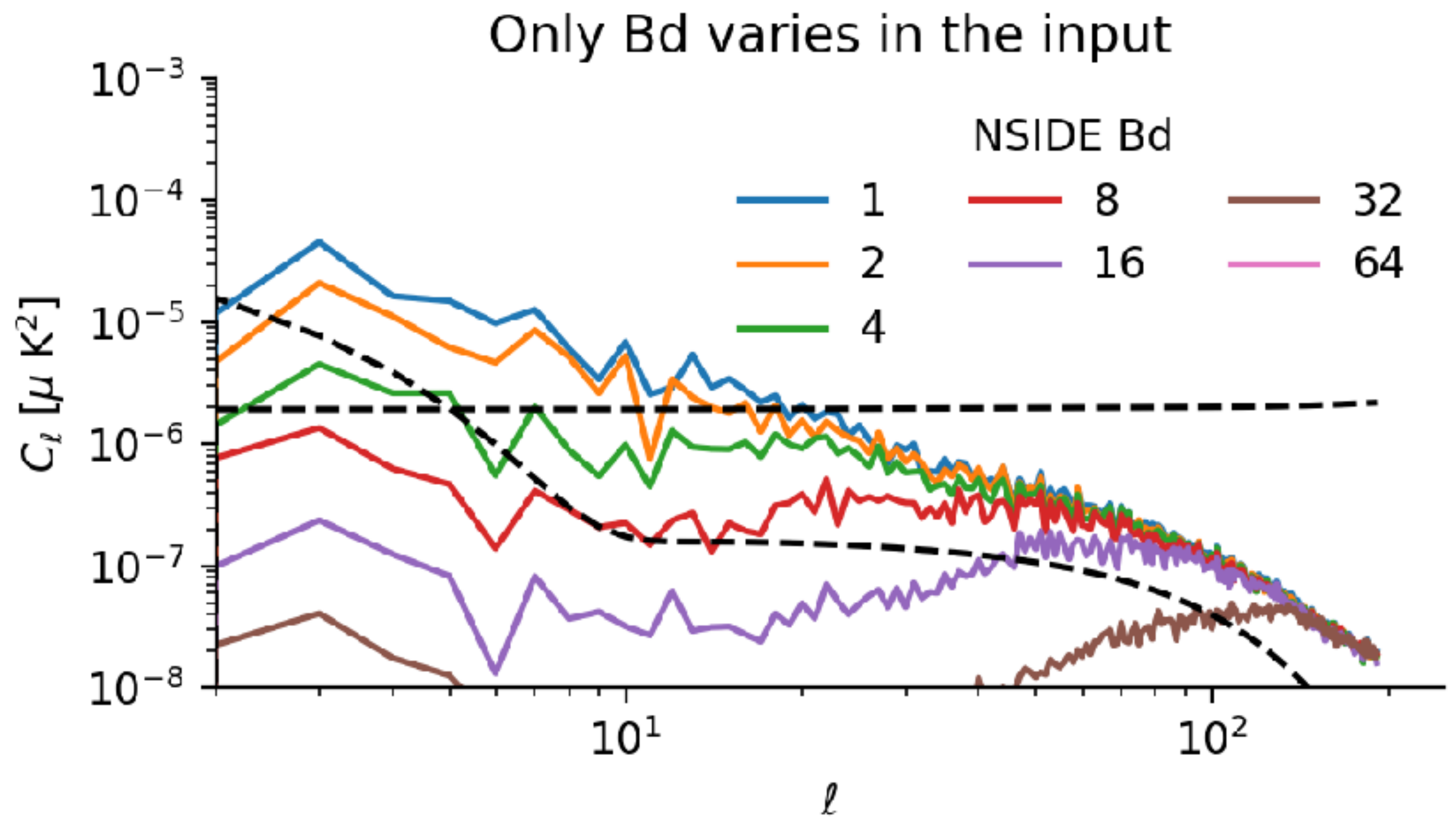
constant spectral parameters over healpix pixels of given nside

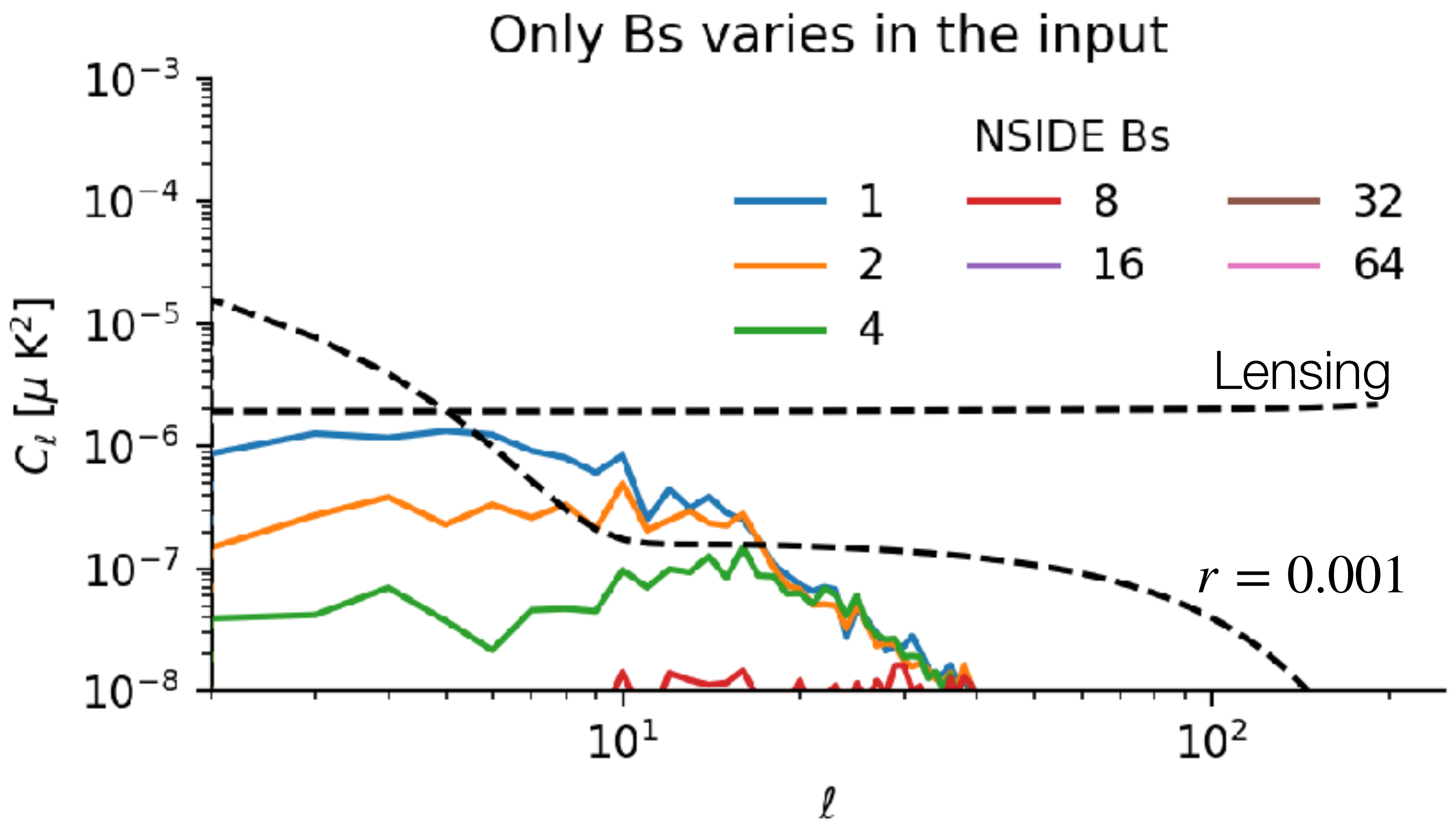
d1s1 noiseless sims
40% sky → High resolution spectral parameters are needed

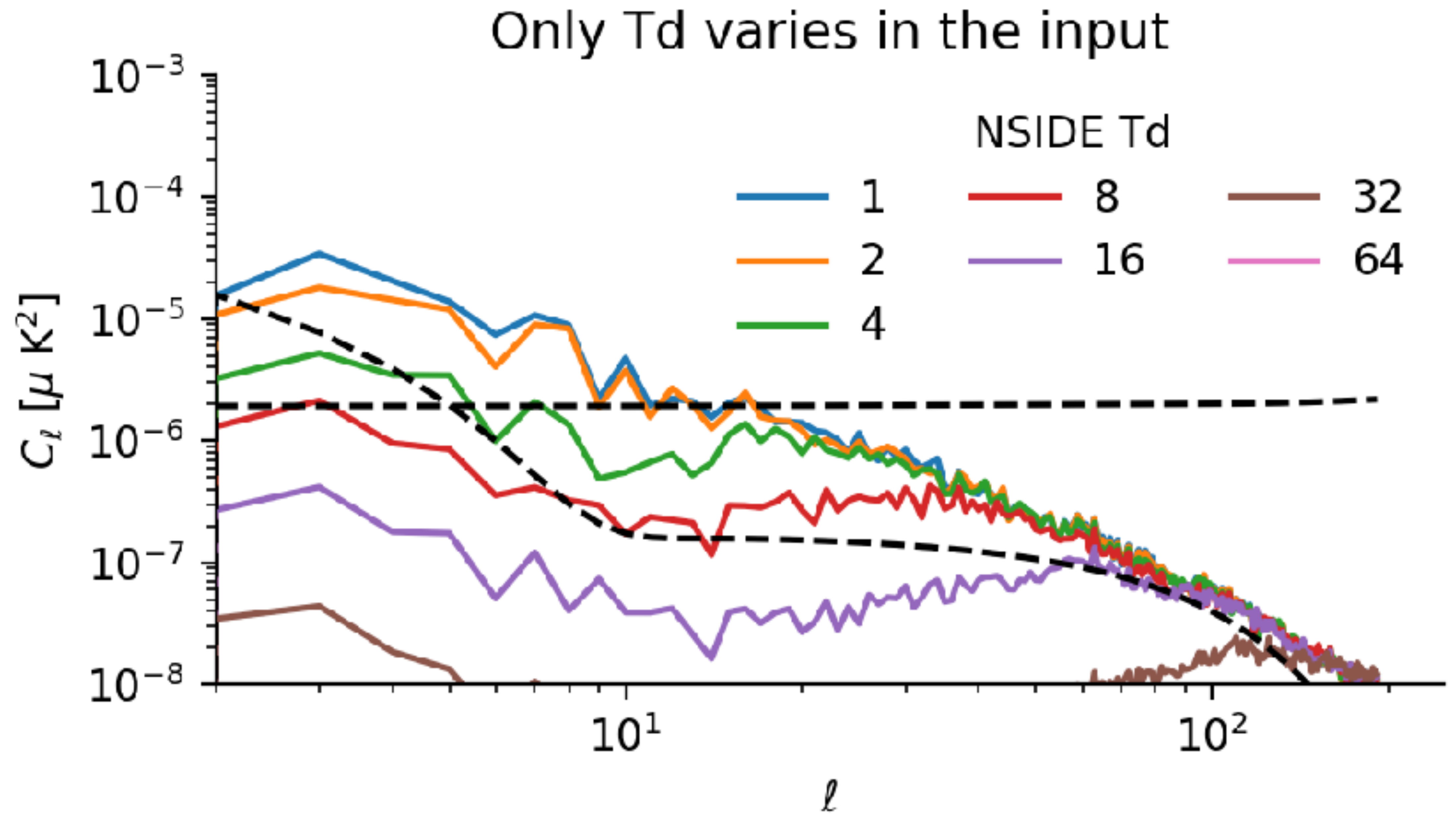


Post-component separation noise and statistical residuals (analytic model)
→ high-resolution degrades performances









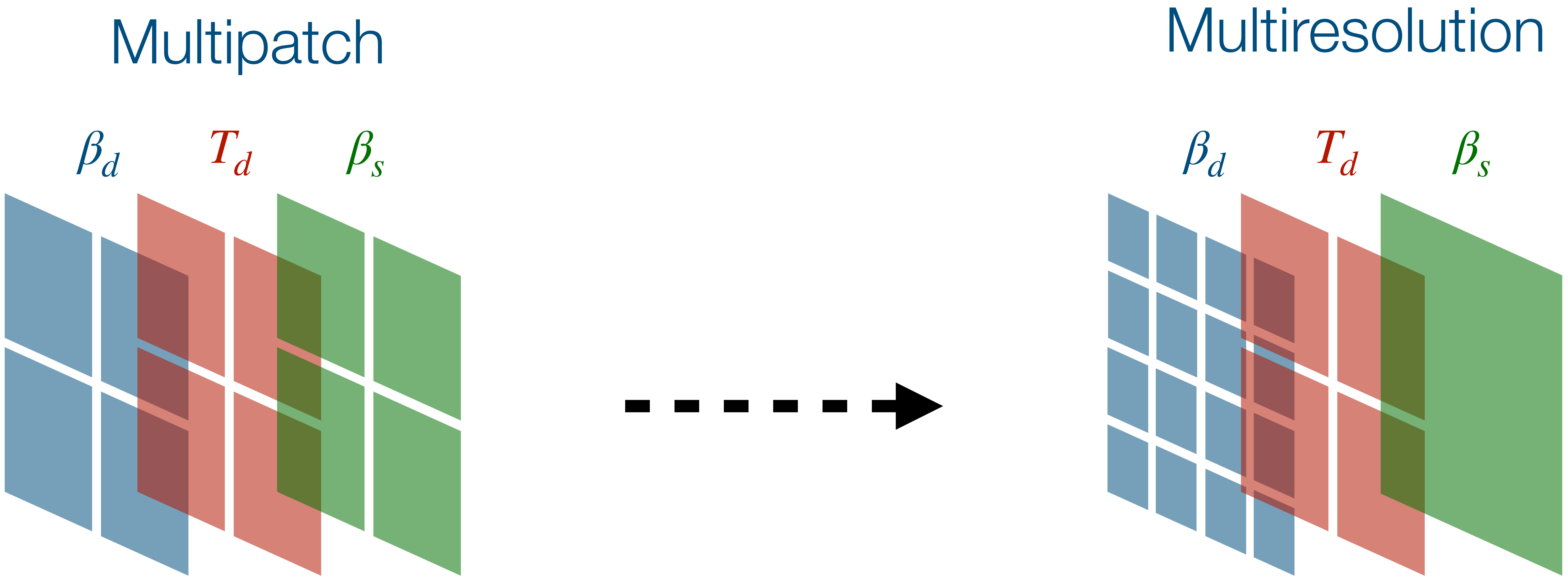
→ different parameters have very different requirements

Sky: spectral indices vary

Cleaning:

- Very localized fit → high statistical residuals
- High S/N fit → high systematic residuals

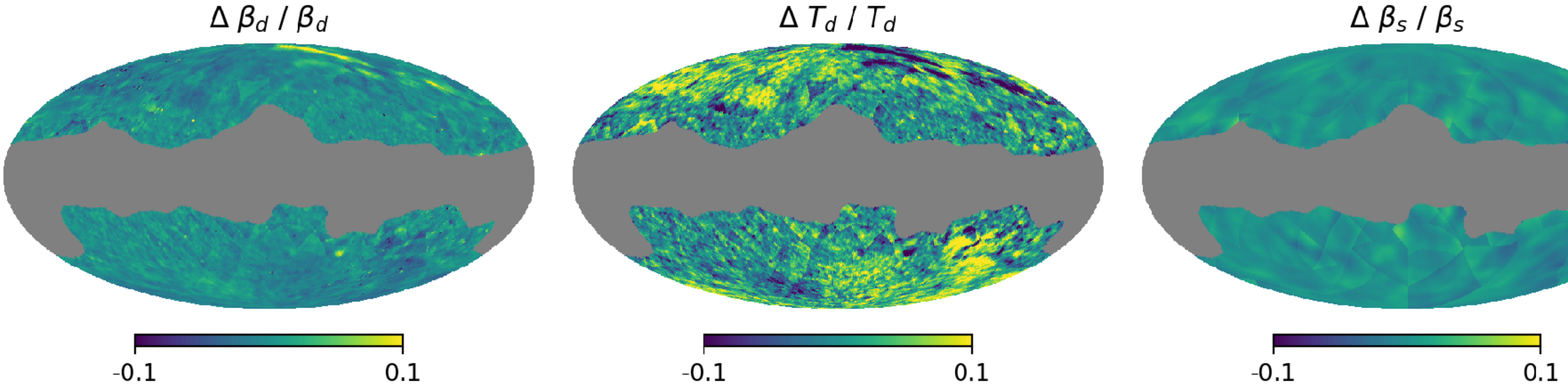
} Different tradeoff for different parameters



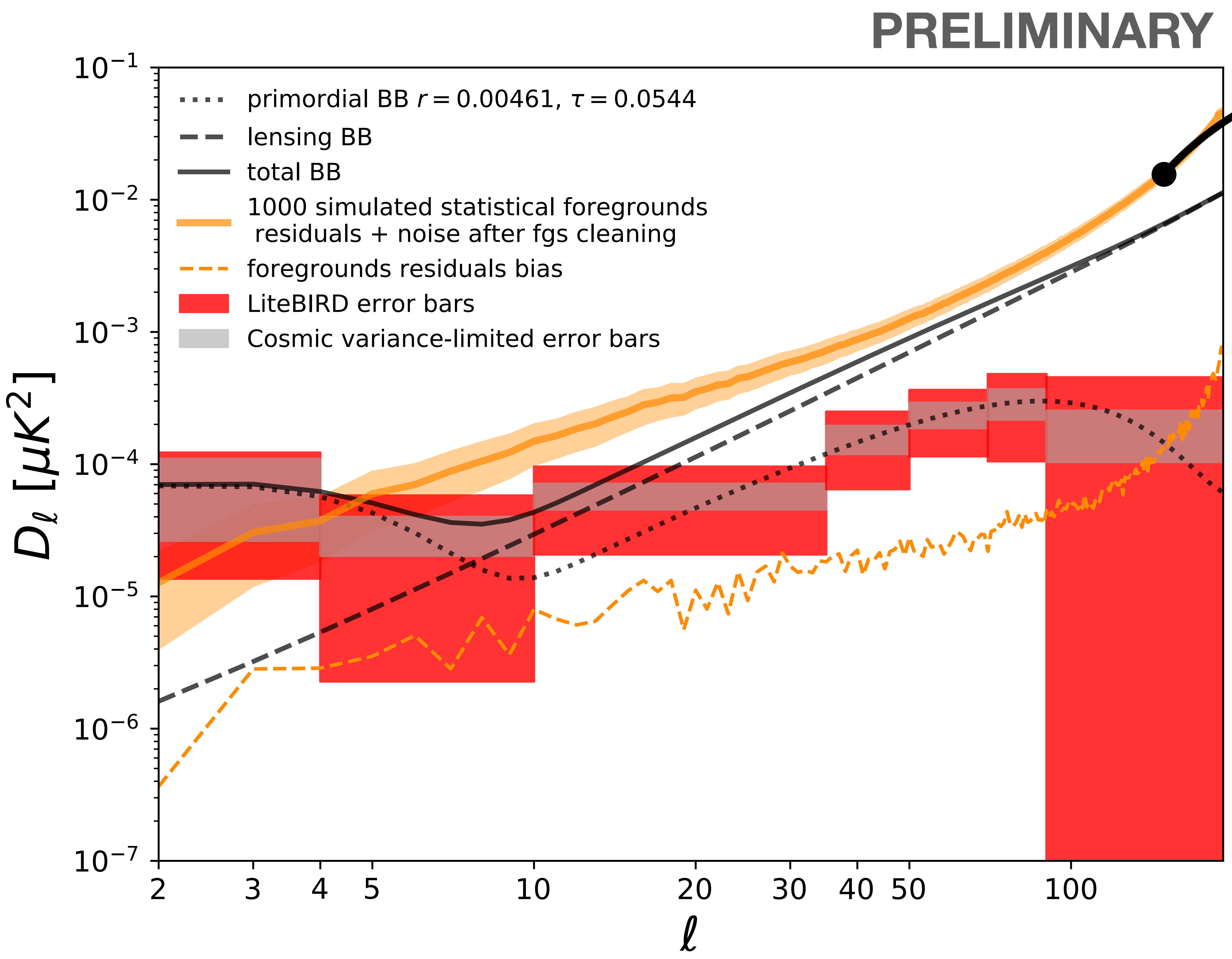
Multiresolution setup for LiteBIRD: different resolution for different parameters AND sky area

Multiresolution independent patches

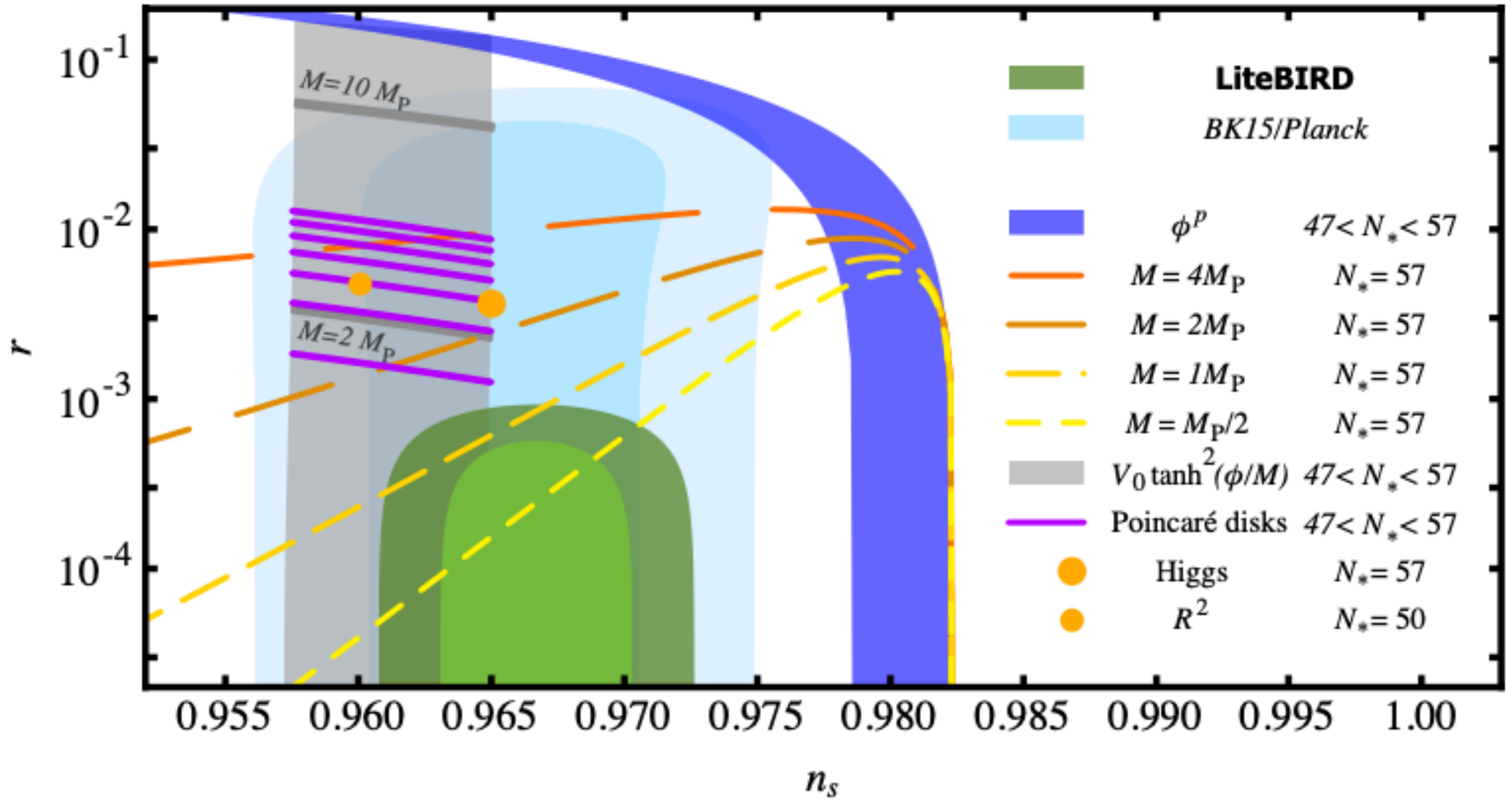
Systematic relative error



Power spectrum and parameters



"Small" scale performance can be improved with harmonic/hybrid methods like NILC or COMMANDER



Path forward

- Optimizing further the balance between statistical and systematic residuals
- Keep increasing the complexity of the foregrounds (or decrease it?!)

  ⟶ More spatial variations? Decorrelation? (See, e.g., Tassis, 2015; Pelgrims+, 2021)

  See next talk by K. Tassis

  - Up to which complexity the performances are robust?
  - Are we able to detect an incorrect modeling of the SEDs?

- Keep increasing the integration between foreground cleaning, calibration and systematics mitigation

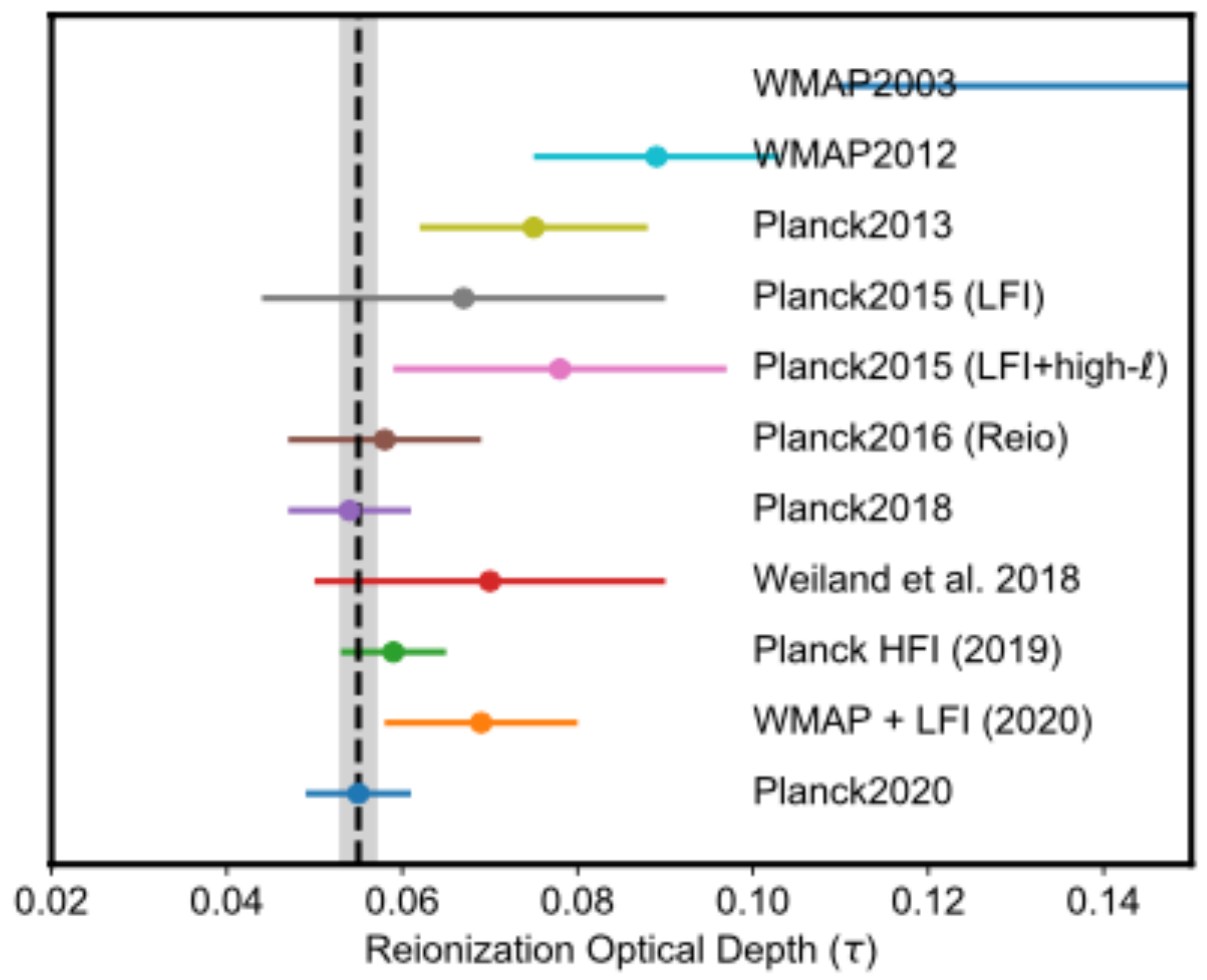
Coming soon

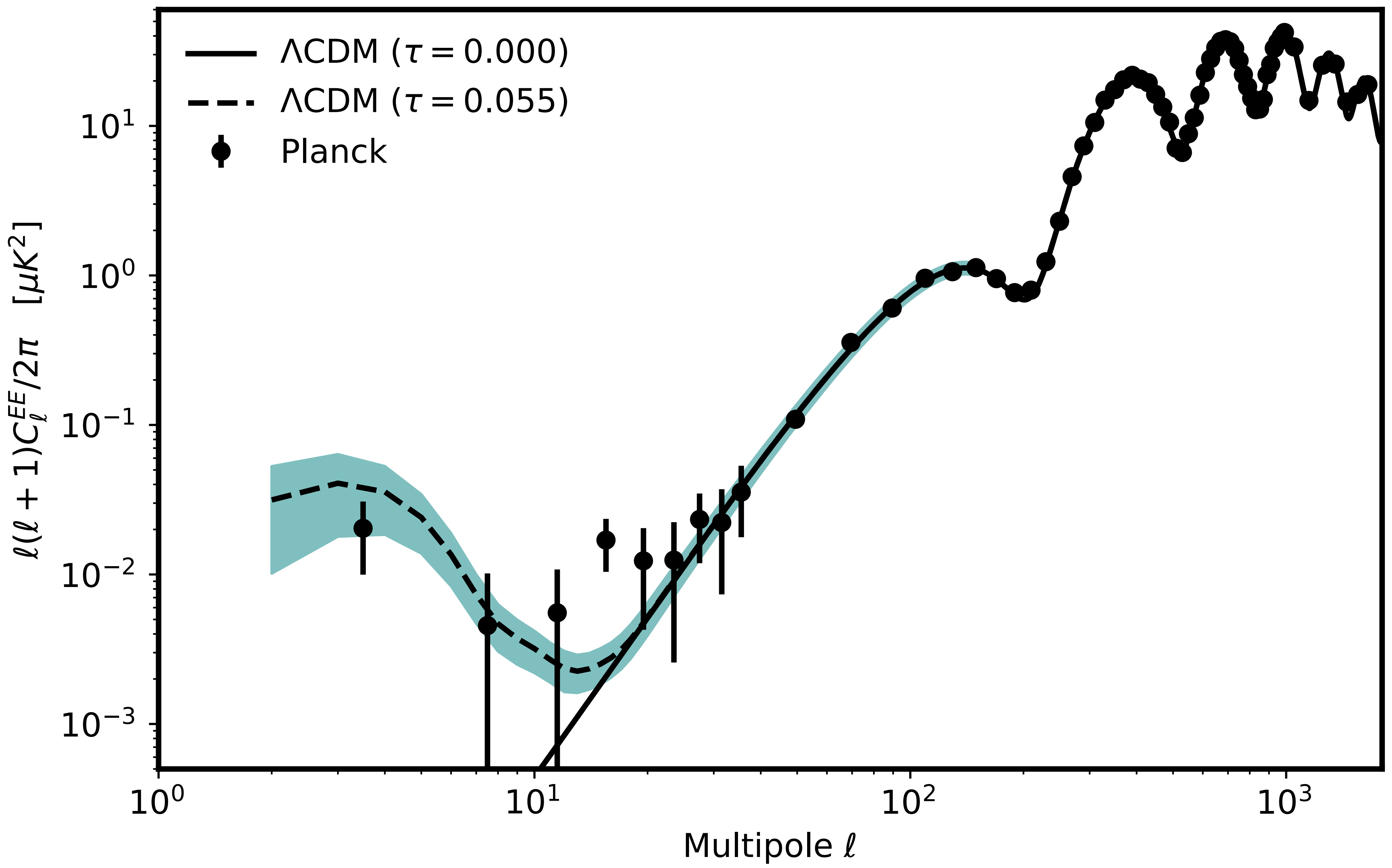
A comprehensive review of LiteBIRD is in preparation.

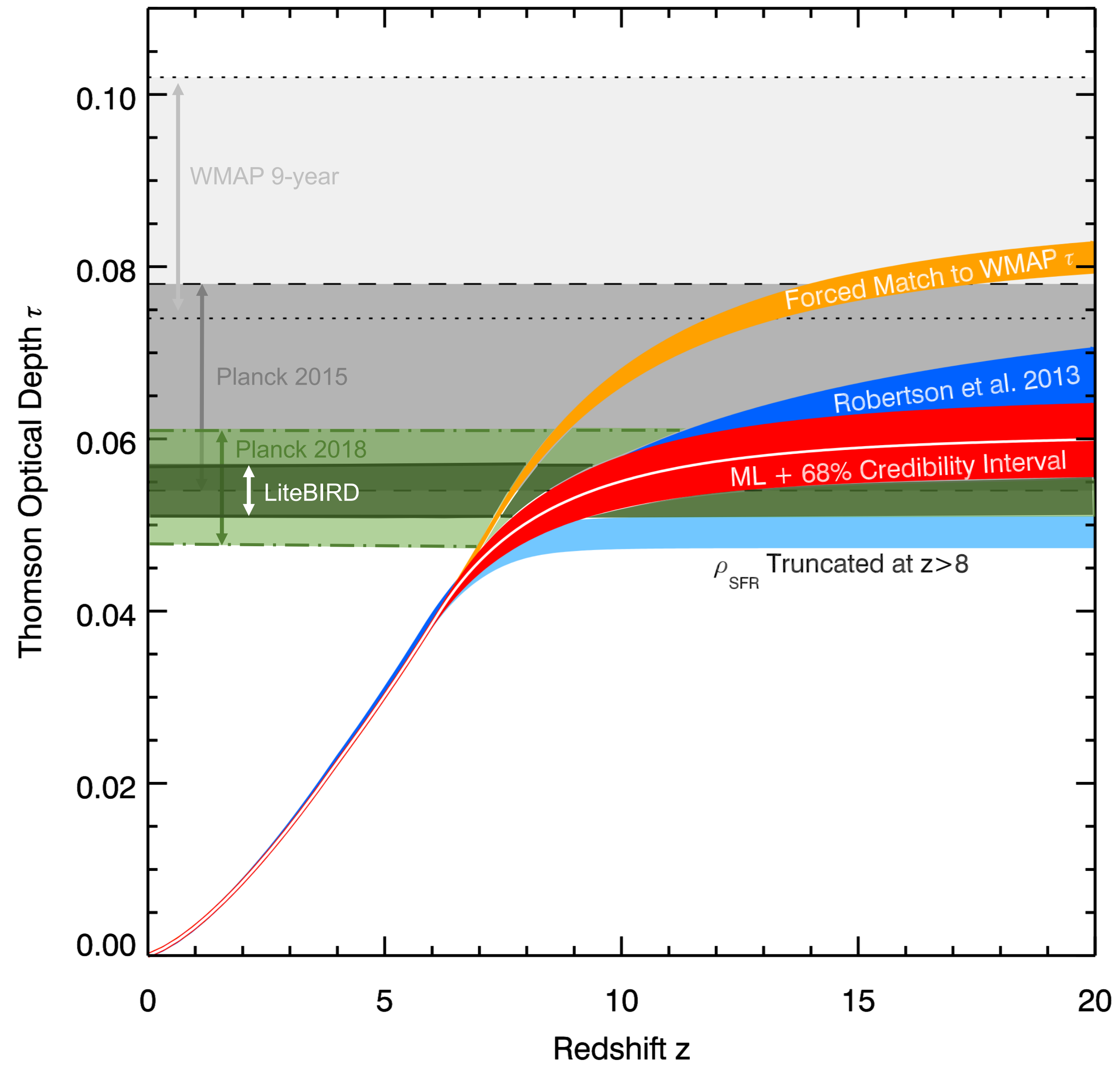
- Mission concept
- Instrumental design
- Calibration strategy
- Systematics assessment
- Component separation
- Science outcome
    - r
    - Extra science

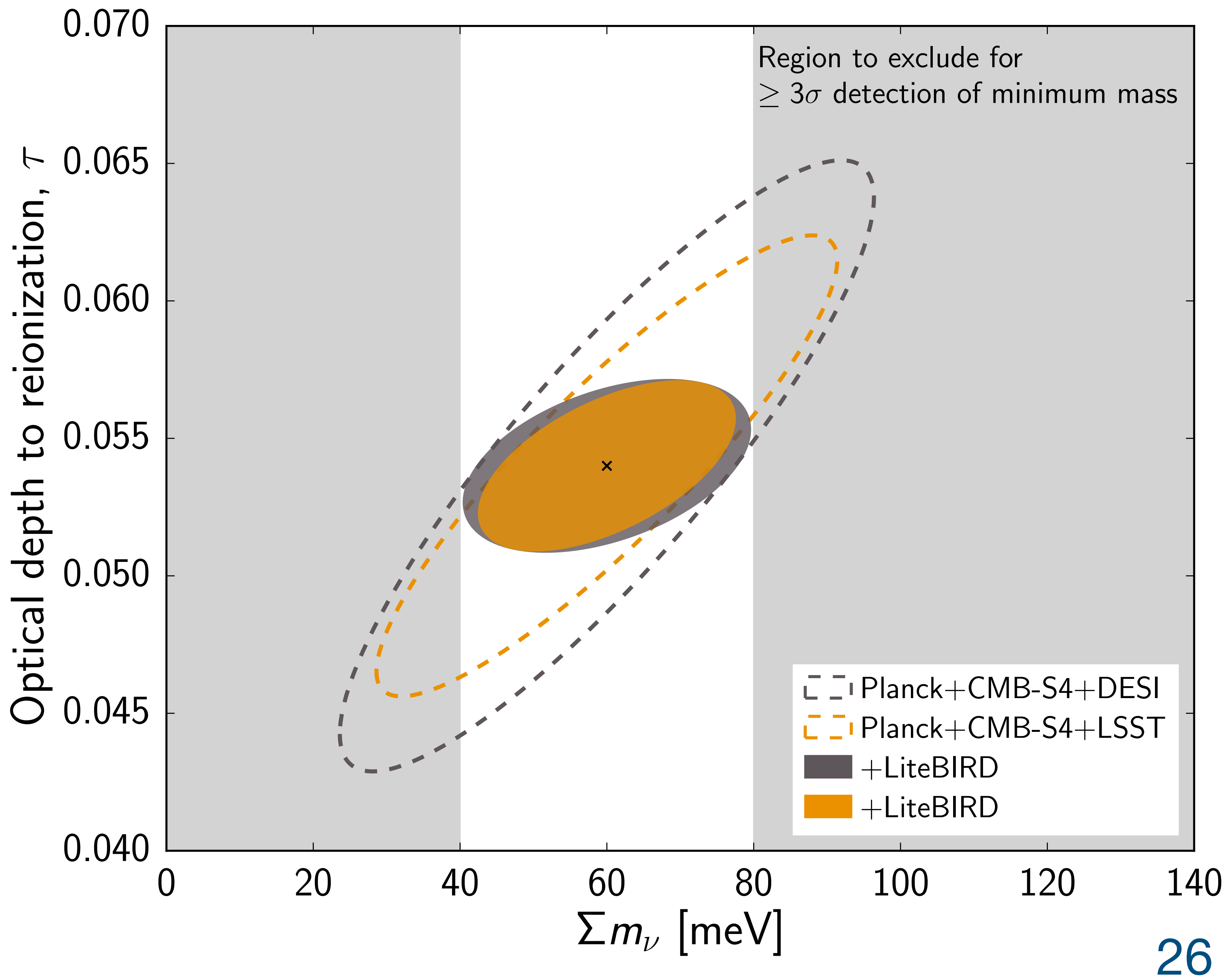
Beyond B-modes

- Cosmic-variance-limited E-modes:
  an important, and guaranteed, legacy for LiteBIRD
- Constrain the reionization history, $\sigma(\tau) = 0.002$
- Contribute to the measurement of $\sum m_\nu$ by constraining τ





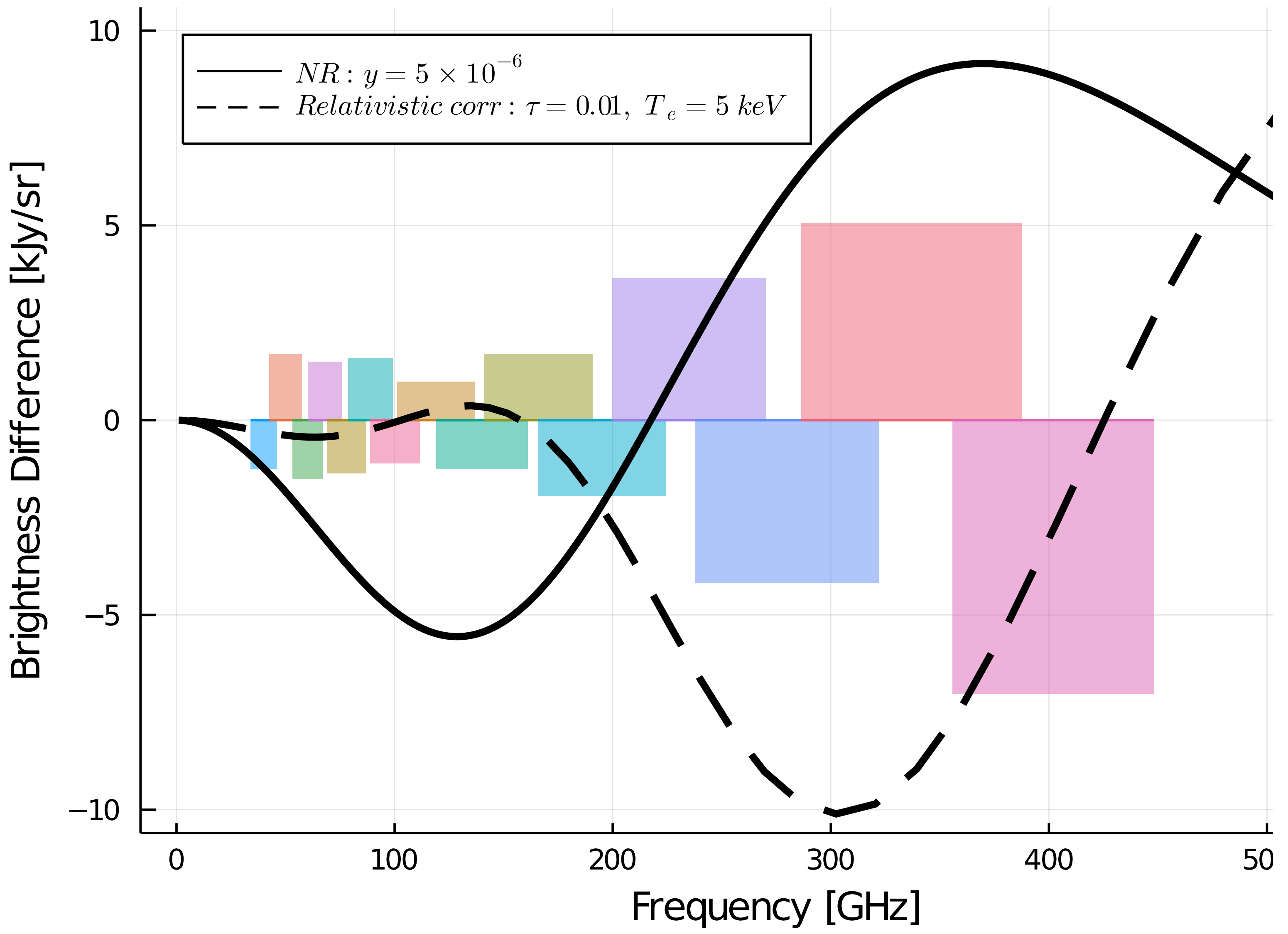


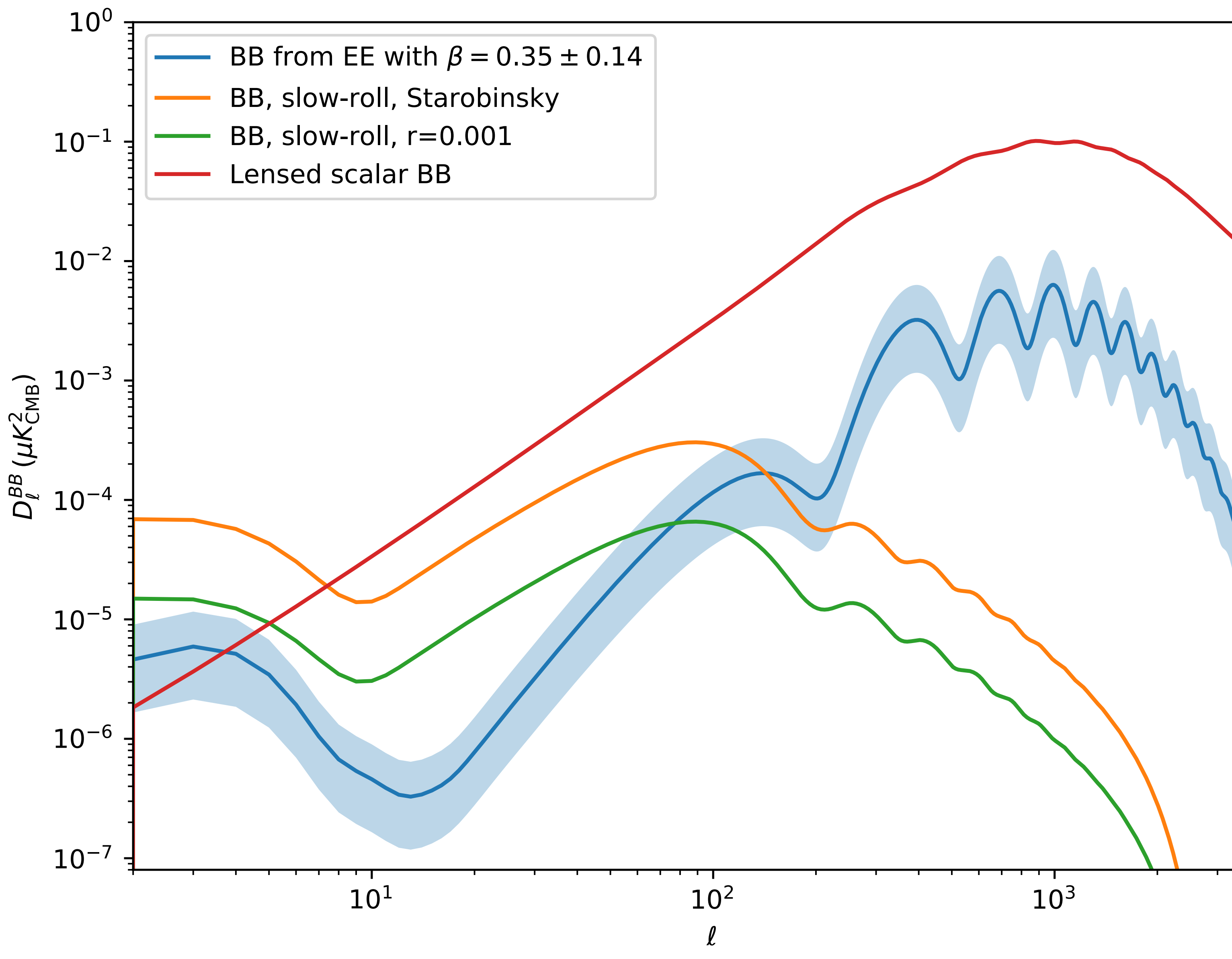


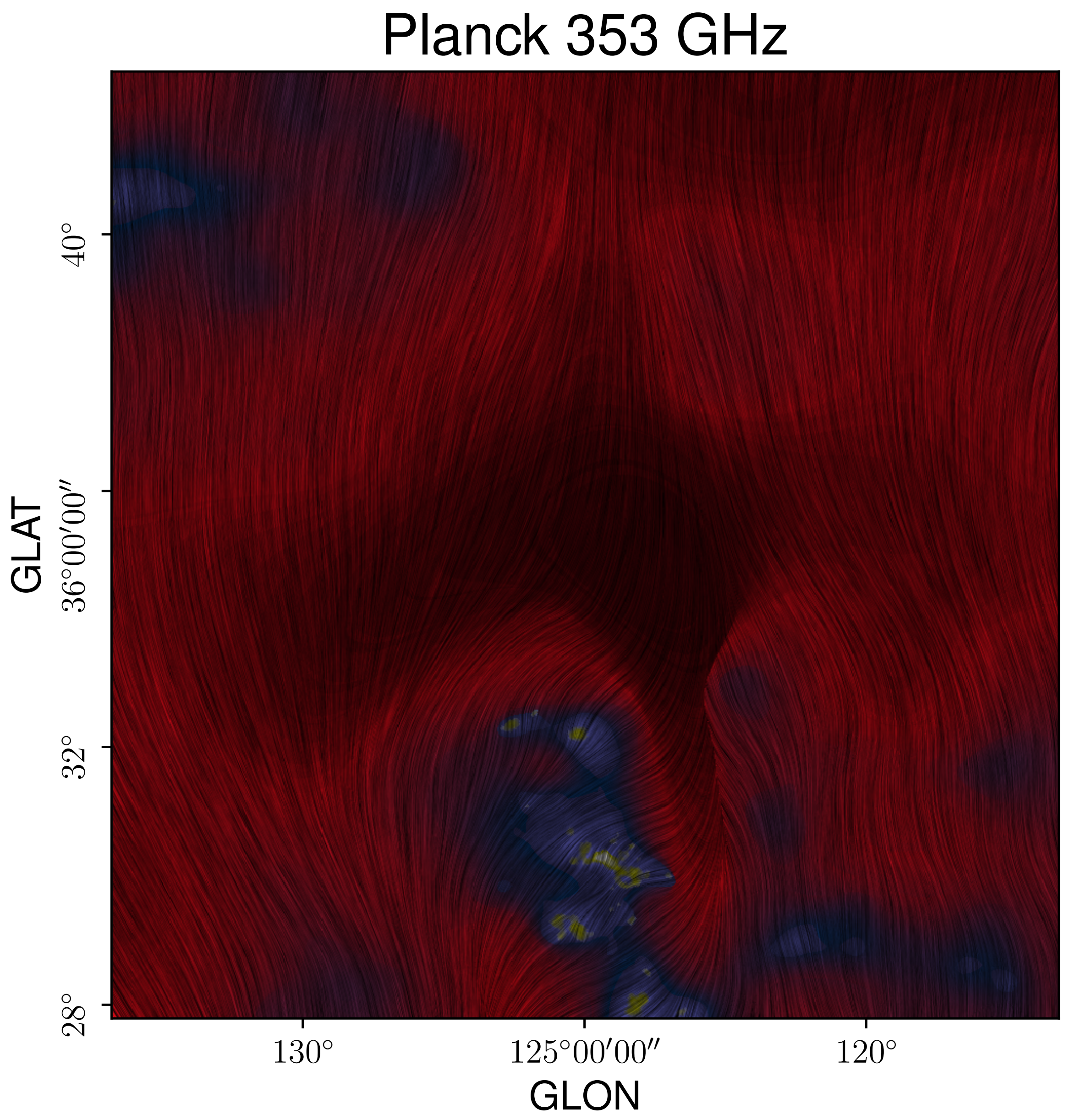
Beyond B-modes

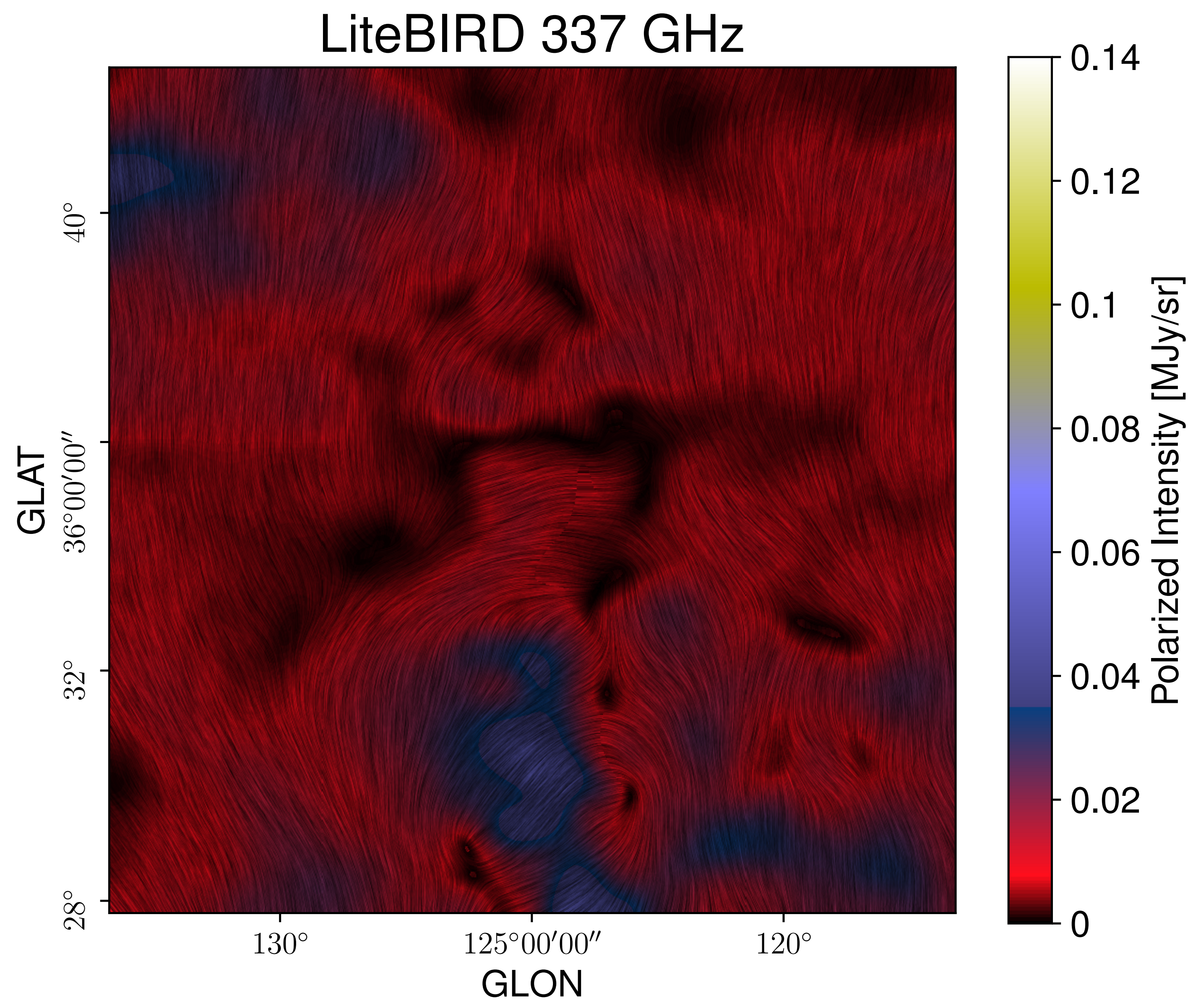
Large number of frequency bands and high sensitivity

- Map hot gas in the universe with thermal Sunyaev-Zeldovich effect
- Rayleigh scattering
- Constrain cosmic birefringence
- Primordial magnetic fields
- Galactic science









Summary

- LiteBIRD: selected as the next CMB space mission. Launch in late 2020s.
- Probe for inflation: $\delta r < 0.001$ if $r = 0$ or 5σ-detection of reionisation and recombination bump if $r = 0.01$
- Rich extra-science and legacy
- Foreground rejection is central
  - 15 bands from 34 to 448 GHz
  - Tailored component separation techniques are being developed

A comprehensive review of the mission concept and expected science outcome is in preparation, stay tuned