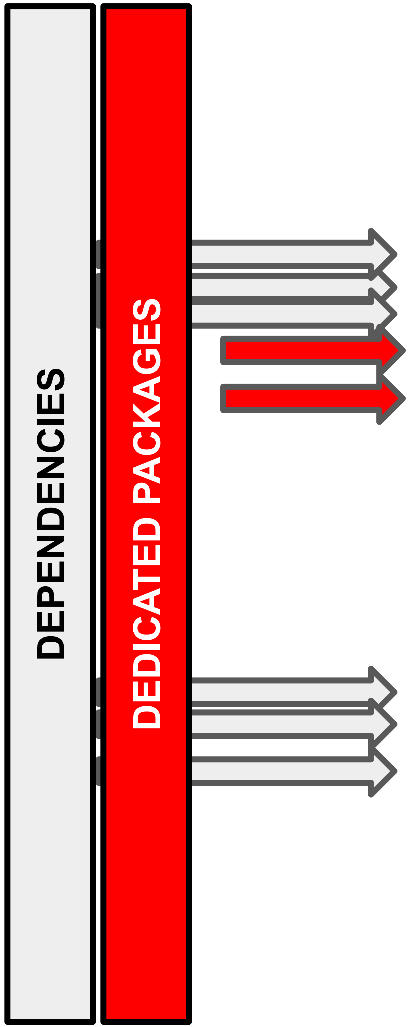
Inflation and gravitational waves & ASI - LiteBIRD

NICOLA BARTOLO



ACCORDO ASI/LITEBIRD

I Riunione di Avanzamento

2-6A	Gestione Enti	UNITOR	Nicola Vittorio
3-6X11	CMB XC	SISSA	Carlo Baccigalupi
3-6X12	Large-scale galaxy distribution	UNITOR	Marina Migliaccio
3-6X13	Non-Gaussian statistics	UNIPD	Daniele Bertacca
3-6X21	Astroparticle	UNIFE	Massimiliano Lattanzi
3-6X22	Non-standard signatures from CMB polarization	INAF	Alessandro Gruppuso
3-6X31	Modelling the primordial GW background and pri-mordial spectral distortions	UNIPD	Nicola Bartolo
3-6X32	Forecasts for new space missions	INAF	Fabio Finelli
4-6X11	Science Ground Segment - D. Tavagnacco, INAF-OATS	INAF	Daniele Tavagnacco
4-6X21	Level-S	UNIMI	Davide Maino
4-6X22	Systematics from electronics	UNIMIB	Federico Nati
4-6X23	Systematics from HWP modulator	UNIROMA1	Fabio Columbro
4-6X24	Map-making	UNIFE	Paolo Natoli
4-6X25	Electronics calibrations	INFN	Andrea Tartari
4-6X31	In flight calibration	UNIMI	Maurizio Tomasi
4-6X32	Noise properties reconstruction	UNIROMA1	Luca Lamagna
4-6X41	Modelling the Galaxy in the microwave	SISSA	Nicoletta Krachmalnicoff
4-6X42	Cleaning techniques for foreground removal	SISSA	Davide Poletti
4-6X51	De-lensing	SISSA	Carlo Baccigalupi
4-6X52	Power Spectrum & Likelihood	UNIFE	Luca Pagano
4-6X53	Parameter estimations	INAF	Daniela Paoletti
4-6X54	Reionization	UNITOR	Marina Migliaccio
5-6X11	HWP Rotator	UNIROMA1	Paolo de Bernardis
5-6X12	Optical components	UNIROMA1	Luca Lamagna
5-6X21	Sub-system calibration	UNIMI	Cristian Franceschet
5-6X22	Cryogenics testing	INAF	Gianluca Morgante
5-6X31	SQUID Controller Enclosure	INFN	Giovanni Signorelli
5-6X32	SQUID Controller Electronic Boards	UNIMIB	Mario Zannoni
5-6X33	SQUID Controller Unit tests	UNIPI	Donato Nicolò

WP3-6X3 - Inflation and Gravitational Waves
Coordinator: Nicola Bartolo

WP 3-6X31 Modelling primordial GW background & primordial spectral distortions (Nicola Bartolo, PD)
WP 3-6X32 Forecasts for new space missions (F. Finelli INAF OAS BO)

Main scientific goals:

- New predictions, observational tests & tools *beyond power spectra* to fully characterize the *nature* of primordial GWs, e.g. statistical characterization of B-modes, to exploit for LiteBIRD
- Exploit complementarities with other observables, e.g. GWs at small scales
- Science perspectives for next CMB experiments for inflationary models and parameters
- Forecasts for next CMB experiments with increasing complexity (foregrounds, lensing etc) to optimize experimental specifications

- ***Strong involvement of PhD students within various projects started (e.g. A. Greco, G. Galloni, N. Barbieri)***

- **Coordination by N. Bartolo & F. Finelli of LiteBIRD Project paper team "Tests of Cosmic Inflation"**

18 People involved: N. Bartolo, C. Baccigalupi; D. Bertacca, L. Caloni; F. Finelli; G. Galloni; A. Greco; A. Gruppuso; G. Jung; M. Lattanzi; M. Liguori; M. Migliaccio; P. Natoli; D. Paoletti; S. Matarrese; A. Ravenni; A. Ricciardone; N. Vittorio

Tests of Cosmic Inflation

Nicola Bartolo

on behalf of the “Tests of Cosmic Inflation” project team

Carlo Baccigalupi, Mario Ballardini, Nicola Bartolo, Paolo Campeti, Alessandro Carones, Josquin Errard, Fabio Finelli, Raphael Flauger, Silvia Galli, Giacomo Galloni, Serena Giardiello, Kazunohri Kohri, Eiichiro Komatsu, Masashi Hazumi, Sophie Henrot-Versille, Lukas Hergt, Clement Leloup, Julien Lesgourgues, Enrique Martinez-Gonzalez, Sabino Matarrese, Tomotake Matsumura, Ludovic Montier, Toshiya Namikawa, Daniela Paoletti, Davide Poletti, Mathieu Remazeilles, Maresuke Shiraishi, Bartjan Van Tent, Leo Vacher, Nicola Vittorio, Gilles Weymann-Despres

Workshop LiteBIRD-ITALIA 2023 @INFN-LNF

Tests of Cosmic Inflation

Goals: assess the capabilities of the LiteBIRD tests of Cosmic Inflation, by exploiting both power spectrum and bispectrum (i.e. non-Gaussianity) information.Three papers have been submitted to the IPB:

1. **LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation**
2. LiteBIRD: Tests of Cosmic Inflation beyond B-mode polarization
3. **Constraining SU(2) gauge field inflation with LiteBIRD**

with the plan to cover the broad survey of tests of Cosmic Inflation which will be allowed by LiteBIRD data. Given the schedule, highest priority was given to the projects aiming at B-mode science, i.e. I and III. IPB has approved paper I and III, and deferred paper II until progress is made.

Tests of Cosmic Inflation

Wiki: https://wiki.kek.jp/display/cmb/Project+paper%3A+Tests+of+Cosmic+Inflaton

Telecons: every 2/3 weeks.

Talks: Foregrounds inputs (Clement Leloup), analysis of SU(2) gauge field inflation with LiteBIRD (Paolo Campeti), tensor non-Gaussianity (Maresuke Shiraishi), PPS (Lukas Hergt), treatment of systematics (Davide Poletti and Clement Leloup), Reionization (Clement Leloup), Lensing (Toshiya Namikawa), Beyond r (Daniela Paoletti), Constraints on single field inflationary models (Mario Ballardini), deviations from standard consistency relation (Giacomo Galloni)

People: 31 people signed-in. ~13 people very active.

Tests of Cosmic Inflation

PTEP: LiteBIRD Coll., "Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey", PTEP 2023 (2023) 4 042F01

Paper 1:

Power-spectrum analysis: we are adopting PTEP specifications and cosmology consistent with Planck 2018 baseline results, the same assumptions adopted in Figs. 2, 3 of PTEP.

- For T,E we use an inverse noise weighting of the IMOv1 central frequency channels, ie in the range [78,195] GHz (also as in Figs. 2, 3 of PTEP); no foreground residuals. Inverse Wishart. When adding Planck (Planck-like) in T,E, LiteBIRD cut at l=800 as in Figs. 2, 3 of PTEP (Paoletti, Finelli et al.)
- For B-mode polarization we use average of FGBuster Noise and Residual FGs power spectra from the 1000 component separated maps used in PTEP and lensing power spectra which is added to BB primordial tensor signal (we use $r=0$ and $r \neq 0$); fsky=0.495. Inverse Wishart added to T,E as in Fig. 2,3 of PTEP.

Bispectrum analysis: same input as PTEP paper (see above). Fisher with CMB+PTEP FGbuster noise and residual power-spectrum+lensing+sky fraction (same methodology as, e.g., in 1905.12485)

Tests of Cosmic Inflation: Inputs, Likelihoods

Paper 3:

Inputs: CMB Gaussian signal realizations+ PTEP FGBuster Noise and Residual FGs 1000 maps

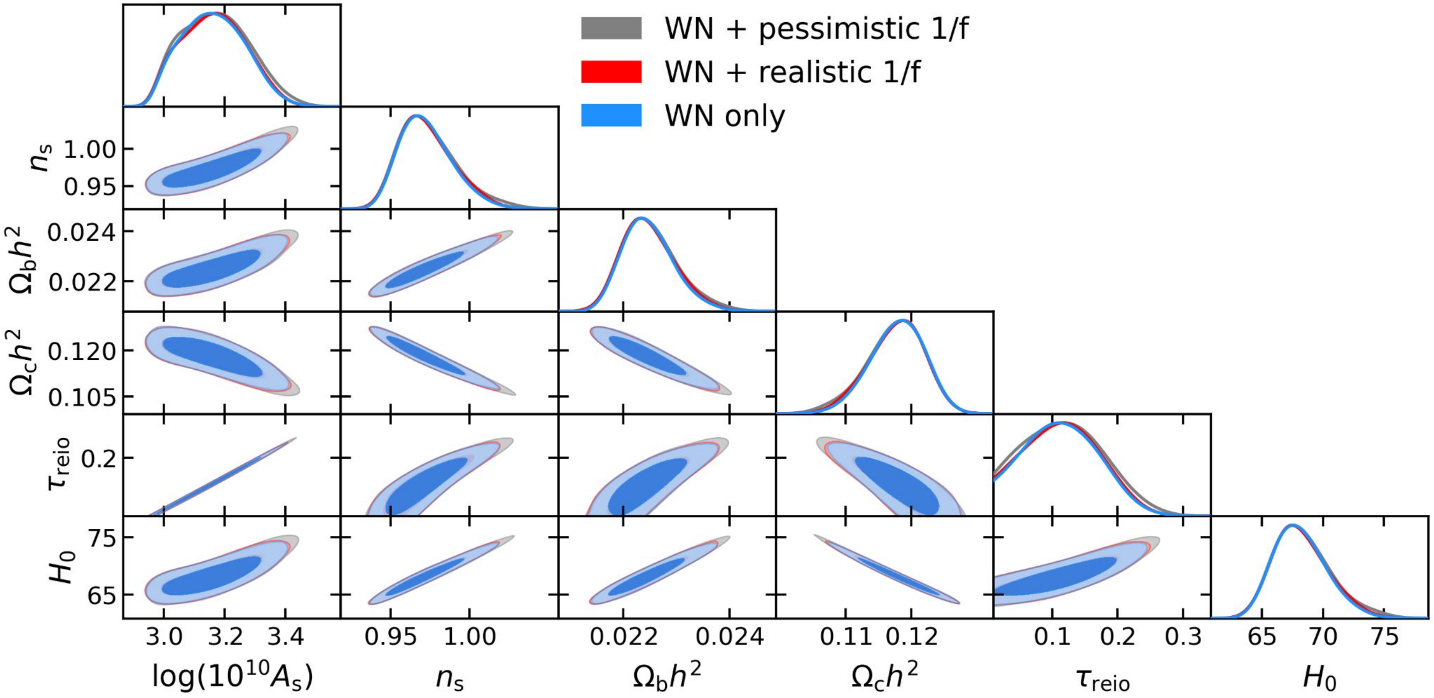
Likelihood: Hammimeche-Lewis on QML estimates at l< 35 and pseudo-Cls at l> 35

Tests of Cosmic Inflation: Likelihoods

- In the need of shared objects (e.g. noise TT, TE, EE, BB, spectra, FG residuals, corresponding f_{sky}) Giacomo Galloni is coding likelihood models (LiLit) for the Cross-Correlation and Tests of Cosmic Inflation PSGs, with a repository being coded and functions interfacing with common objects being developed, to be shared with PSGs and other Likelihood models.
- This is one of the results of very productive discussions taking place within PSG general meetings, whose aim is to coordinate among various post-PTEP papers, sharing needs, tools and objects for the analyses.
- One of the main points recently discussed is the characterization and possible impacts of 1/f noise for T analyses.

Impact of 1/f on parameter estimations

LCDM results with realistic 1/f noise



Details and products at:
https://wiki.kek.jp/display/~ggalloni/Temperature+Analysis+Products

from Giacomo Galloni & simulation team

LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation

Contents

LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation

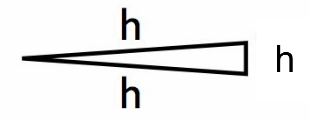
Contents

LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation: Tensor non-Gaussianities

- **Selection of well motivated NG models (templates)** that give rise to <BBB> bispectra and mixed bispectra (e.g. <TBB>, <EBB>)

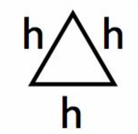
<u>Extra source fields</u>

$$\mathcal{L} = -\frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) - \frac{1}{4}f(\phi)F^{\mu\nu}F_{\mu\nu}$$



<u>Axion-couplings can add parity violation</u>

axion= inflaton: $\mathcal{L} = -\frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4f}\phi\tilde{F}^{\mu\nu}F_{\mu\nu}$



(Barnaby et al.: 1102.4333)

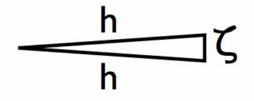
axion ≠ inflaton: $\mathcal{L} = -\frac{1}{2}(\partial\phi)^2 - V(\phi) - \frac{1}{2}(\partial\sigma)^2 - U(\sigma) - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4f}\sigma\tilde{F}^{\mu\nu}F_{\mu\nu}$ ⟶ <u>specific scale dependence</u> depending on U(σ) *(Namba et al. 1509.0752)*

if SU(2) gauge-coupling more efficient GWs production (Dimastrogiovanni et al. ‘17; Agrawal et al. ‘17)

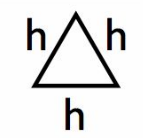
<u>Modified gravity</u>

Chern-Simons gravity: $\mathcal{L} \sim f(\phi)W\widetilde{W}$ ⟶ parity-odd

(Bartolo, Orlando & Shiraishi ‘17,’19)

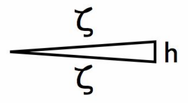


or: $\mathcal{L} \sim f(\phi)W^2\widetilde{W}$ ⟶



(Maldacena & Pimentel ‘11; Shirarishi et al. ‘11)

massive gravity: $\mathcal{L} \sim M_p^2\frac{m_g^2}{H^2}h_{ij}(\partial_i\zeta)(\partial_j\zeta)$ ⟶



LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation: Bispectrum

Observational bounds

	$f_{NL}^{ttt,eq}$	$f_{NL}^{ttt,sq}$	$f_{NL}^{tss,sq}$
WMAP T-only	600 ± 1500 [1409.0265]	220 ± 170 [1304.7277]	84 ± 49 [1710.06778]
Planck 2018 T-only	600 ± 1600 [1905.05697]	290 ± 180 [1502.01594]	err ~ 15
Planck 2018 T+E	800 ± 1100 [1905.05697]	err ~ 150	err ~ 10

$\frac{m_g^2}{H^2} < 30$

$B_{1\mathrm{Mpc}} < 3\mathrm{nG}$

- axion-U(1) model: $\xi = \frac{\alpha|\dot{\phi}|}{2fH} < 3.3$

[Cook & Sorbo: 1307.7077, MS +: 1308.6769]

- axion-SU(2) model: $\frac{r^2}{\Omega_A} < 1200$

(Weyl)³ from other equal NG

$$r^4\left(\frac{M_p}{\Lambda}\right)^2 = (6 \pm 20) \times 10^{18}$$

LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation: Bispectrum results

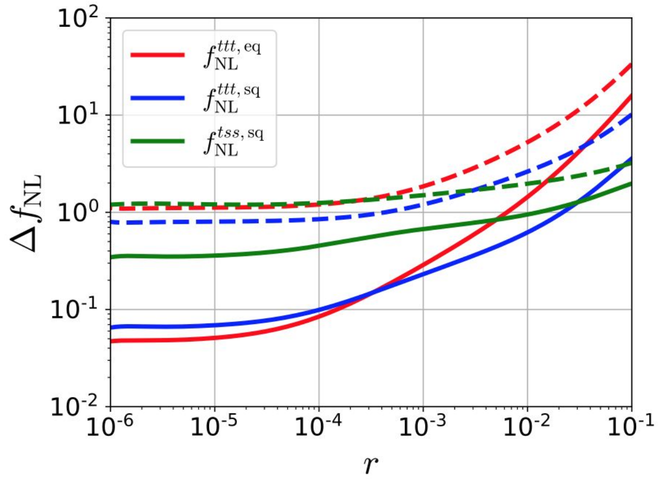
- ***A complete new analysis, not addressed inthe PTEP paper. Various forecasts already obtained with the PTEP-inputs***. We have updated the analysis for various models and added new ones (e.g. Chern-Simons parity violating $f(\varphi)W\hat{W}$, see Bartolo, Orlando, Shiraishi '17',19).

- Some constraints already obtained from CMB data, which however are mainly based on T and E data. ***B-mode data are a unique window into tensor non-Gaussianities. LiteBIRD has the unique possibility to drastically reduce the error bars, and to pin down the nature of primordial GWs.***

- Possible refinements of the scheme above: off-diagonal modes of the covariance matrix: use CMB signal map realization (including lensing) + PTEP noisy foreground residuals maps and apply estimators to compare with Fisher. *This depends on manpower.* Now main focus on forecasts.

LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation: Tensor non-Gaussianities

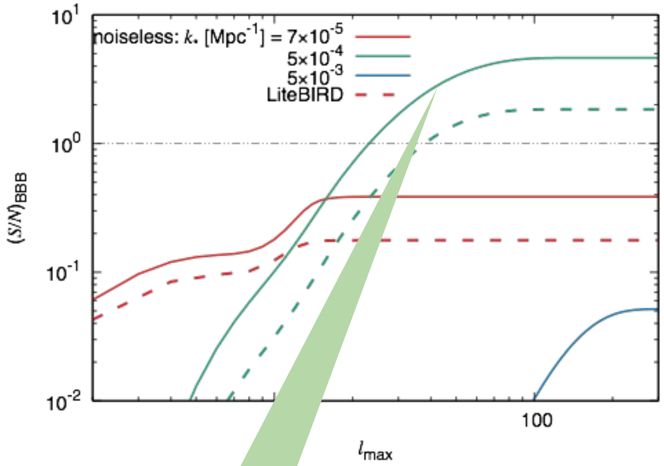
Scale-invariant bispectra



error bars on f_{NL} amplitudes 2-3 orders of magnitude better than present limits;

Bumped axion-U(1) models

Shiraishi, Hikage, Namba, Namikawa, Hazumi: 1606.06082



In allowed parameter space visible BBB is realized

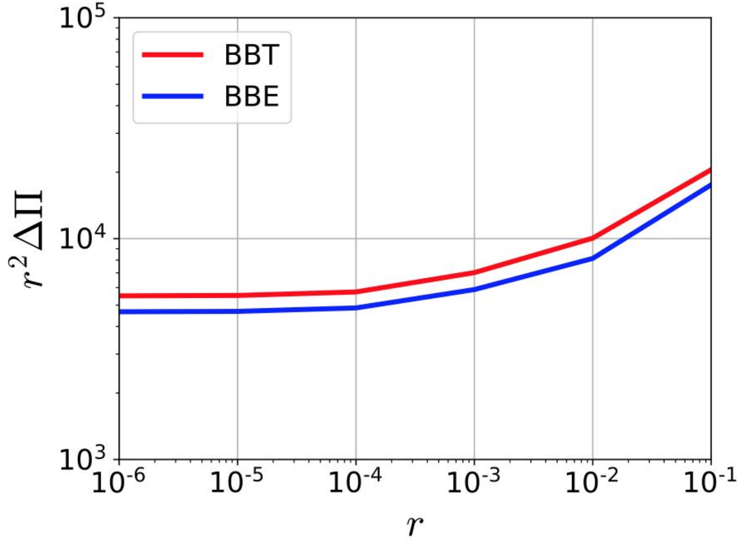
from Maresuke Shiraishi

LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation: Tensor non-Gaussianities

Chern-Simons Gravity $S = \int d^4x f(\phi)\tilde{W}W$

(Bartolo, Orlando & Shiraishi '17,'19)

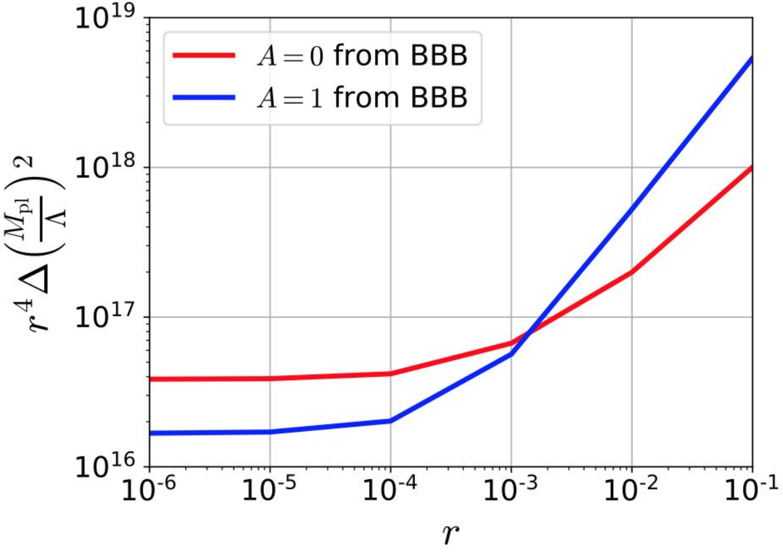
$r^2\Pi \propto < h^2\zeta >$



Weyl Gravity $S = \int d\tau d^3x \frac{f(\phi)}{\Lambda^2}(\sqrt{-g}W^3 + \tilde{W}W^2)$

(Maldacena & Pimentel '11; Shiraishi et al. '11)

$r^4\left(\frac{M_{\rm pl}}{\Lambda}\right)^2 \propto < h^3 >$



from Maresuke Shiraishi

Tests of Cosmic Inflation

Fabio Finelli

on behalf of the "Tests of Cosmic Inflation" project team

Carlo Baccigalupi, Mario Ballardini, Nicola Bartolo, Paolo Campeti, Alessandro Carones, Josquin Errard, Fabio Finelli, Raphael Flauger, Silvia Galli, Giacomo Galloni, Serena Giardiello, Kazunohri Kohri, Eiichiro Komatsu, Masashi Hazumi, Sophie Henrot-Versille, Lukas Hergt, Clement Leloup, Julien Lesgourgues, Enrique Martinez-Gonzalez, Sabino Matarrese, Tomotake Matsumura, Ludovic Montier, Toshiya Namikawa, Daniela Paoletti, Davide Poletti, Mathieu Remazeilles, Maresuke Shiraishi, Bartjan Van Tent, Leo Vacher, Nicola Vittorio, Gilles Weymann-Despres

Workshop LiteBIRD-ITALIA 2023 @INFN-LNF

WP 3-6X32 - Forecasts for new space missions
Coordinator: Fabio Finelli

WP 3-6X32 Forecasts for new space missions (F. Finelli INAF OAS BO)

Main scientific goals:

- ❑ Forecasts for next CMB experiments with increasing complexity (foregrounds, lensing etc) to optimize experimental specifications
- ❑ Investigate inflationary models + parameters usually constrained by observations (e.g., r, scalar spectral index, running) including forecasts for new space mission

- Coordination by N. Bartolo & F. Finelli of LiteBIRD Project paper team “Tests of Cosmic Inflation”

- Collaboration with WP 3-6X31, WP 4-6X53 (coord. Daniela Paoletti), LiteBIRD Foregrounds JSG, LiteBIRD Cross JSG, ..

- *Contribution of staff, postdocs and master students (e.g. M. Braglia, M. Galaverni, M. Tagliazucchi, J. Valiviita)*

LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation

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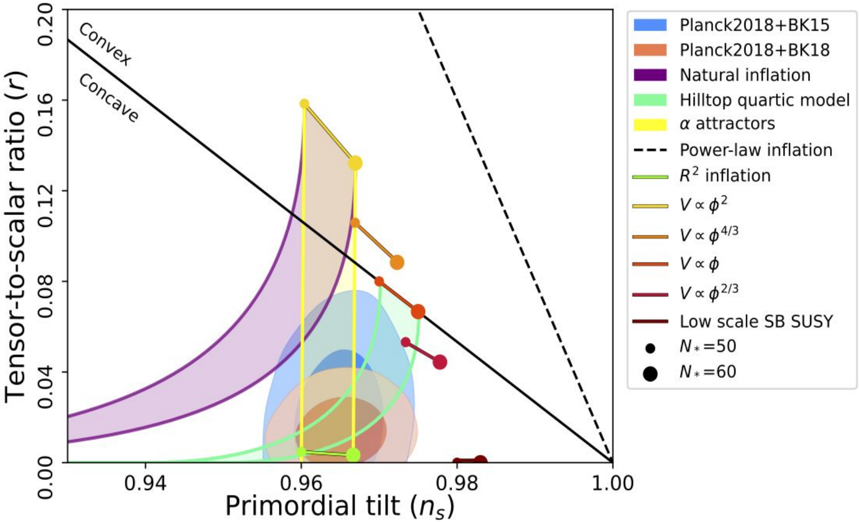


Paoletti, Finelli, Valiivita, Hazumi, PRD 106 (2022)

Modified version of Fig. 12 from “Planck 2018 results. X. Constraints on inflation”

Planck18 + BK15, r < 0.06 @ 95 %CL

Planck18 + BK18, r < 0.036 @ 95 %CL

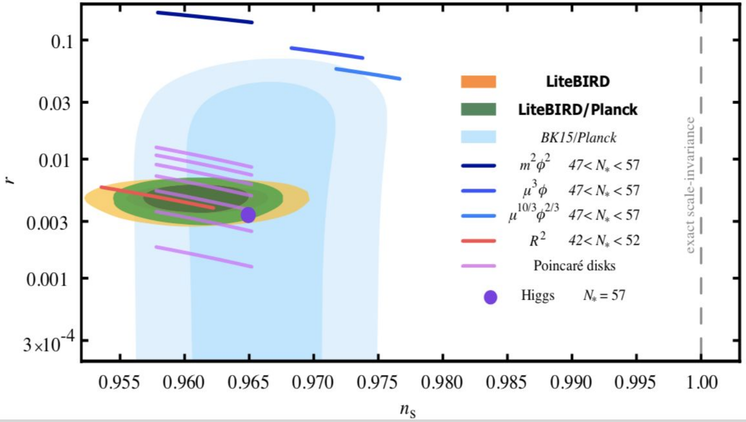


Fig. 2 from PTEP

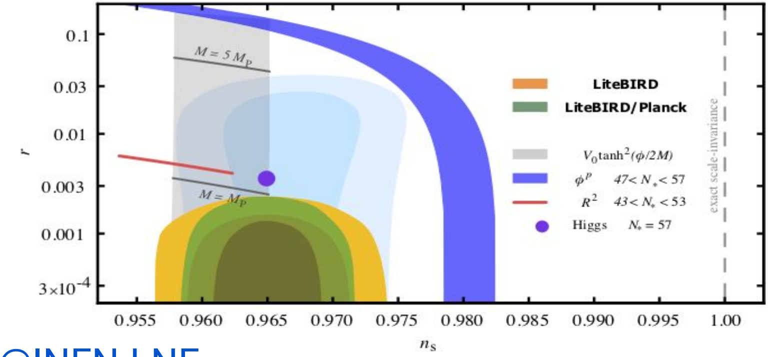


Fig. 3 from PTEP

We plan

LiteBIRD: Implications of B-mode polarization measurements for Cosmic Inflation

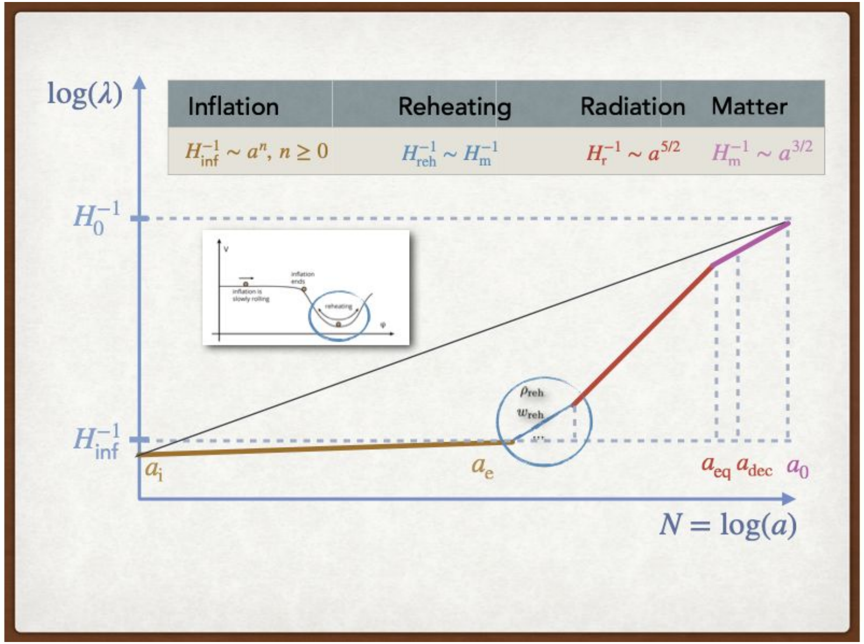
Standard slow-roll inflationary models

We plan a quantitative assessment of the discriminating power among the simplest inflationary models with theoretical predictions to second order in slow-roll parameters by taking into account uncertainties in N* through the phenomenological parameters which describe the reheating stage:

$$N_* \approx 67 - \ln\left(\frac{k_*}{a_0 H_0}\right) + \frac{1}{4}\ln\left(\frac{V_*^2}{M_{\rm pl}^4 \rho_{\rm end}}\right) + \frac{1-3w_{\rm int}}{12(1+w_{\rm int})}\ln\left(\frac{\rho_{\rm reh}}{\rho_{\rm end}}\right) - \frac{1}{12}\ln(g_{\rm th})$$

Planck 2013 results XXII: Constraints on inflation

$\rho_{\rm reh}$ energy density when the Universe is completely thermalized
$w_{\rm int}$ average parameter of state during the thermalization epoch
$g_{\rm th}$ number of bosonic degrees of freedom



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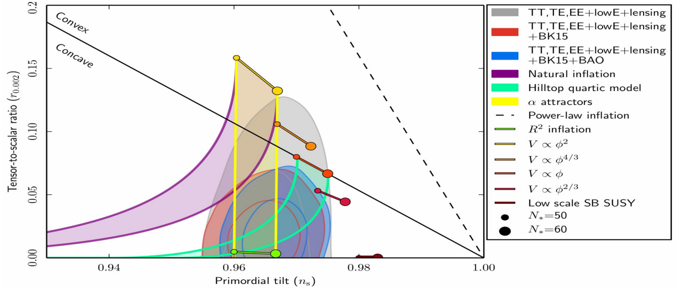

Inflationary model	Potential $V(\phi)$	Parameter range	$\Delta\chi^2$	ln B
$R + R^2/(6M^2)$	$\Lambda^4\left(1 - e^{-\sqrt{2/3}\phi/M_{\rm Pl}}\right)^2$	...	...	...
Power-law potential	$\lambda M_{\rm Pl}^{10/3}\phi^{2/3}$	...	4.0	−4.6
Power-law potential	$\lambda M_{\rm Pl}^3\phi$	...	6.8	−3.9
Power-law potential	$\lambda M_{\rm Pl}^{8/3}\phi^{4/3}$	...	12.0	−6.4
Power-law potential	$\lambda M_{\rm Pl}^2\phi^2$	...	21.6	−11.5
Power-law potential	$\lambda M_{\rm Pl}\phi^3$	...	44.7	−13.2
Power-law potential	$\lambda\phi^4$	...	75.3	−56.0
Non-minimal coupling	$\lambda^4\phi^4 + \xi\phi^2 R/2$	$-4 < \log_{10}\xi < 4$	0.4	−2.4
Natural inflation	$\Lambda^4[1 + \cos(\phi/f)]$	$0.3 < \log_{10}(f/M_{\rm Pl}) < 2.5$	9.9	−6.6
Hilltop quadratic model	$\Lambda^4\left(1 - \phi^2/\mu_2^2 + \ldots\right)$	$0.3 < \log_{10}(\mu_2/M_{\rm Pl}) < 4.85$	1.3	−2.0
Hilltop quartic model	$\Lambda^4\left(1 - \phi^4/\mu_4^4 + \ldots\right)$	$-2 < \log_{10}(\mu_4/M_{\rm Pl}) < 2$	−0.3	−1.4
D-brane inflation ($p = 2$)	$\Lambda^4\left(1 - \mu_{D2}^2/\phi^p + \ldots\right)$	$-6 < \log_{10}(\mu_{D2}/M_{\rm Pl}) < 0.3$	−2.0	0.6
D-brane inflation ($p = 4$)	$\Lambda^4\left(1 - \mu_{D4}^4/\phi^p + \ldots\right)$	$-6 < \log_{10}(\mu_{D4}/M_{\rm Pl}) < 0.3$	−3.5	−0.4
Potential with exponential tails	$\Lambda^4[1 - \exp(-q\phi/M_{\rm Pl}) + \ldots]$	$-3 < \log_{10} q < 3$	−0.4	−1.0
Spontaneously broken SUSY	$\Lambda^4[1 + \alpha_h \log(\phi/M_{\rm Pl}) + \ldots]$	$-2.5 < \log_{10}\alpha_h < 1$	6.7	−6.8
E-model ($n = 1$)	$\Lambda^4\left\{1 - \exp\left[-\sqrt{2}\phi\left(\sqrt{3\alpha_1^{\rm E}}M_{\rm Pl}\right)^{-1}\right]\right\}^{2n}$	$-2 < \log_{10}\alpha_1^{\rm E} < 4$	0.8	−0.3
E-model ($n = 2$)	$\Lambda^4\left\{1 - \exp\left[-\sqrt{2}\phi\left(\sqrt{3\alpha_2^{\rm E}}M_{\rm Pl}\right)^{-1}\right]\right\}^{2n}$	$-2 < \log_{10}\alpha_2^{\rm E} < 4$	0.8	−1.6
T-model ($m = 1$)	$\Lambda^4\tanh^{2m}\left[\phi\left(\sqrt{6\alpha_1^{\rm T}}M_{\rm Pl}\right)^{-1}\right]$	$-2 < \log_{10}\alpha_1^{\rm T} < 4$	−0.1	−1.2
T-model ($m = 2$)	$\Lambda^4\tanh^{2m}\left[\phi\left(\sqrt{6\alpha_2^{\rm T}}M_{\rm Pl}\right)^{-1}\right]$	$-2 < \log_{10}\alpha_2^{\rm T} < 4$	0.8	−0.6

Table 5. Bayesian comparison for a selection of slow-roll inflationary models with $w_{\rm int}$ fixed (see text for more details). We quote 0.3 as the error on the Bayes factor. Models are strongly disfavoured when ln $B < -5$.

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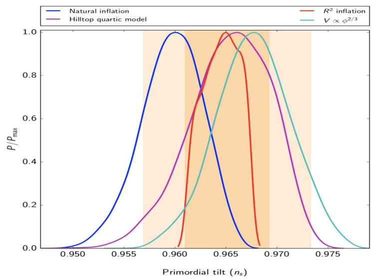
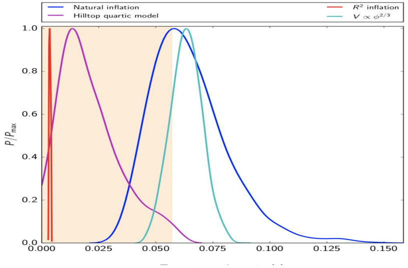
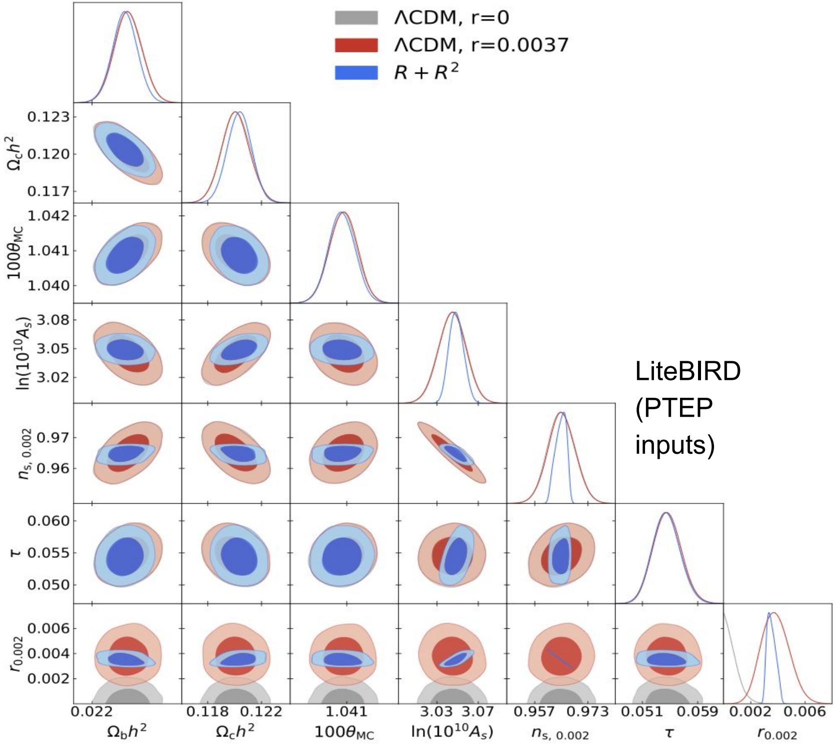
$g_{\rm th}$ number of bosonic degrees of freedom





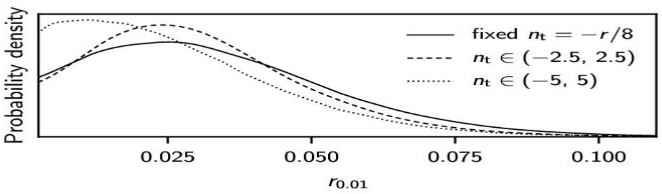


LiteBIRD (PTEP inputs)

Workshop LiteBIRD-ITALIA 2023 @INFN-LNF from Mario Ballardini (+Finelli)

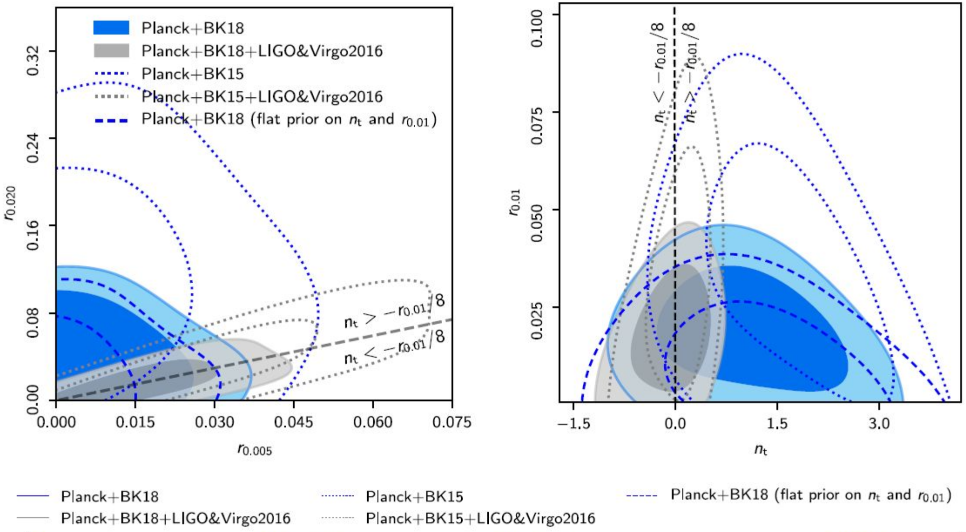
Beyond r

We plan to provide forecasts with PTEP inputs when the standard slow-roll single field relation $n_t = -r/8$ is relaxed for a tensor power-law $\mathcal{P}_t(k) = A_t \left(\frac{k}{k_*}\right)^{n_t}$ as happens for theoretical models beyond standard slow-roll single field models with BD initial conditions for quantum fluctuations.



Two scale analysis (allows to adopt the same uniform priors used for r when n_t is fixed, also in Planck 15 & 18 papers)

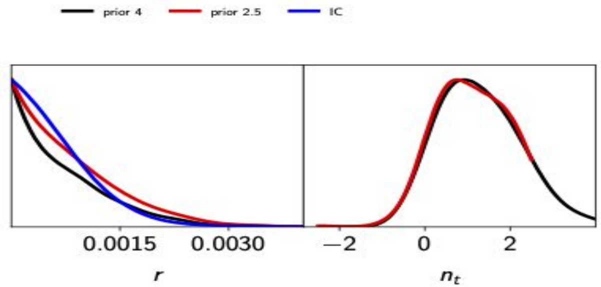
$$\mathcal{P}_t(k) = \exp\left\{\frac{\ln k - \ln k_1}{\ln k_2 - \ln k_1}\ln[r_2\mathcal{P}_\mathcal{R}(k_2)] - \frac{\ln k - \ln k_2}{\ln k_2 - \ln k_1}\ln[r_1\mathcal{P}_\mathcal{R}(k_1)]\right\}.$$

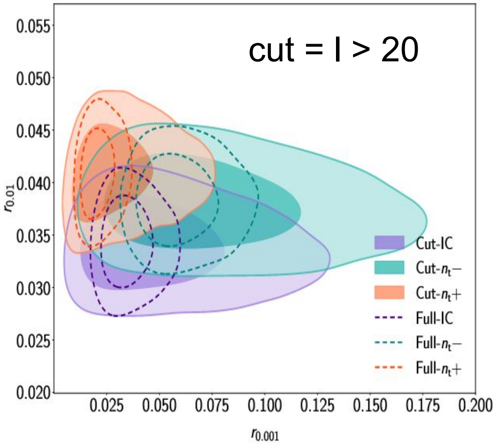


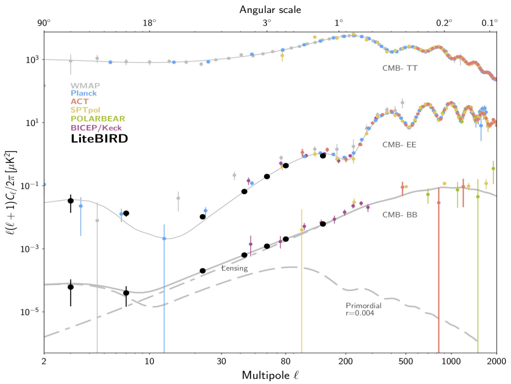
Paoletti, Finelli, Valiivita, Hazumi, PRD 106 (2022)

Beyond r

Two scale analysis studied for the first time for future experiments (LiteBIRD-like) including foreground residuals and testing different choice of the two scales in preparation of the post-PTEP paper. It is the minimal case of a binned approach (see e.g. Hiramatsu et al. (2018), Campeti et al. (2019) for its use in the LiteBIRD context)







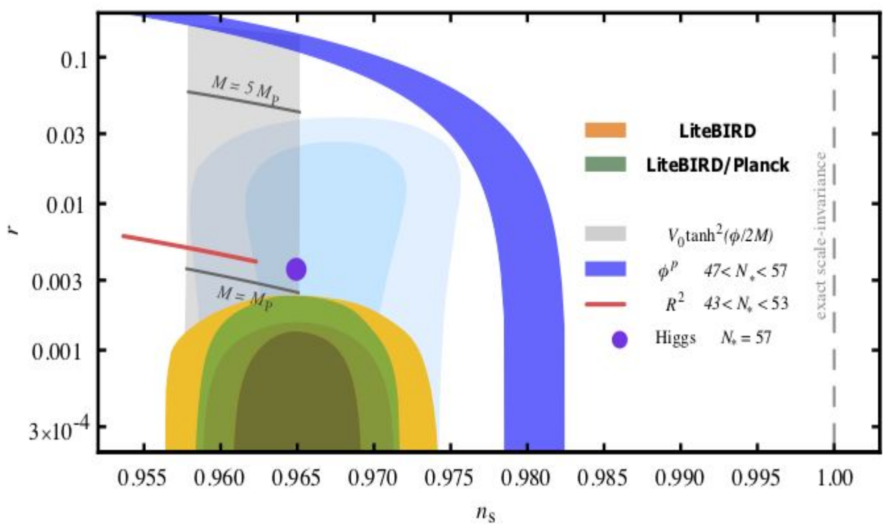
Various fiducial studied:

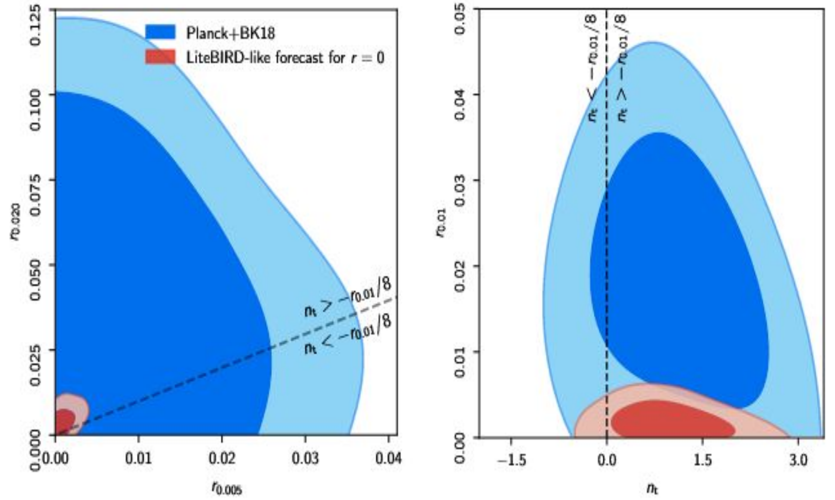
- nt=-r/8
- nt=-r/(8 cs) with cs=0.02
- nt=0.3
- r=0

Paoletti, Finelli, Valiviita, Hazumi, PRD 106 (2022)

Beyond r

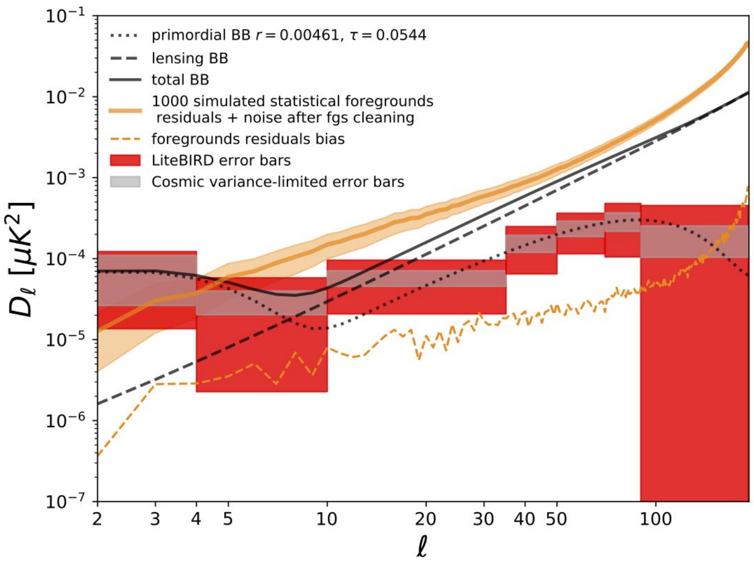
LiteBIRD discovery potential in 2D!

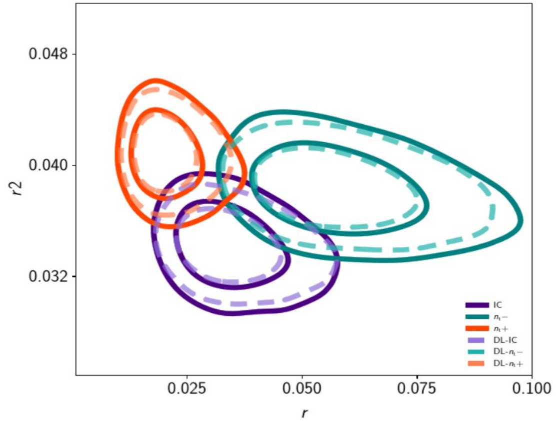




Paoletti, Finelli, Valiivita, Hazumi, PRD 106 (2022)

Beyond r in paper I





Runs with official PTEP specs OK

Runs with PTEP Planck+CIB-like delensing OK

Runs with lower r as fiducial models SOME

Runs with LiteBIRD plus Planck NOT YET

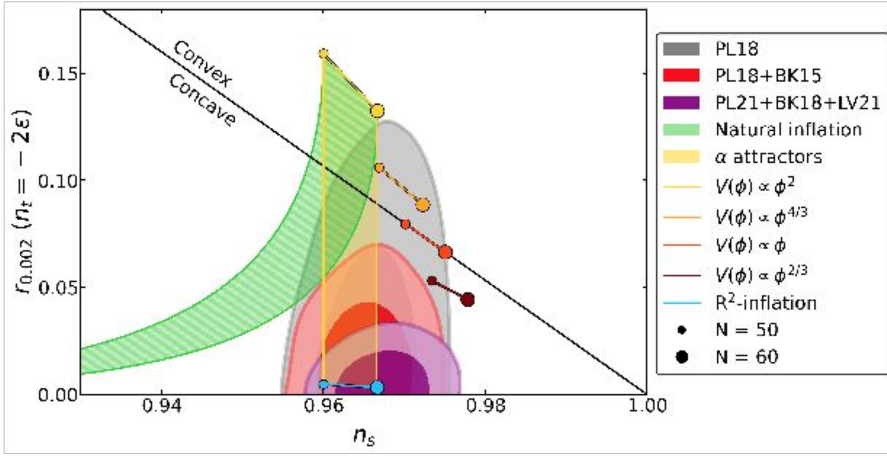
from Daniela Paoletti (+Finelli)

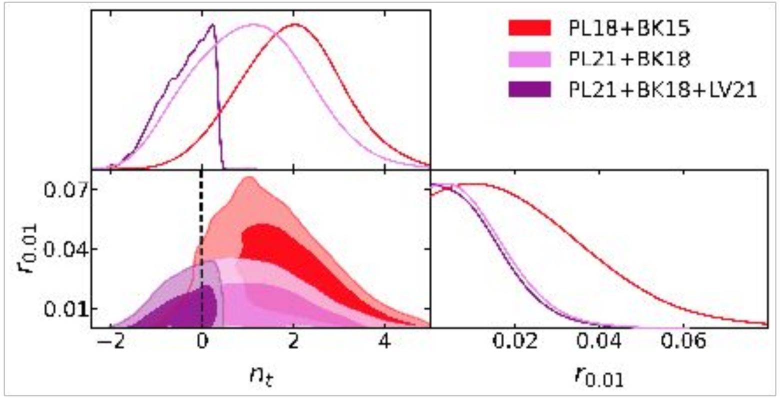
Non-standard consistency relations in paper I

Methodology (Galloni, Bartolo, Matarrese, Migliaccio, Ricciardone, Vittorio JCAP04, 062 (2023)):

- Single-scale approach on tensors
- Exact likelihood
- Residuals contributing only to the variance
- Probed range of tensors in accordance with updated 95% CL bounds

$r_{0.01} < 0.028$ and $-1.37 < n_t < 0.42$





Likelihood package at:
https://github.com/ggalloni/LiLit

Non-standard consistency relations

sound-speed of scalar perturbations

$$r = -8 n_t c_s$$

time variation of GWs sound-speed

$$r = -\frac{32}{\pi} \frac{n_t - s_t}{c_t c_s'^2} \left(\alpha_0 + \sqrt{\beta_0} \right)^{3/2} \left| \Gamma \left(\frac{5}{4} + \frac{\alpha_0}{4\alpha_0 - 4i\sqrt{\beta_0}} \right) \right|^2$$

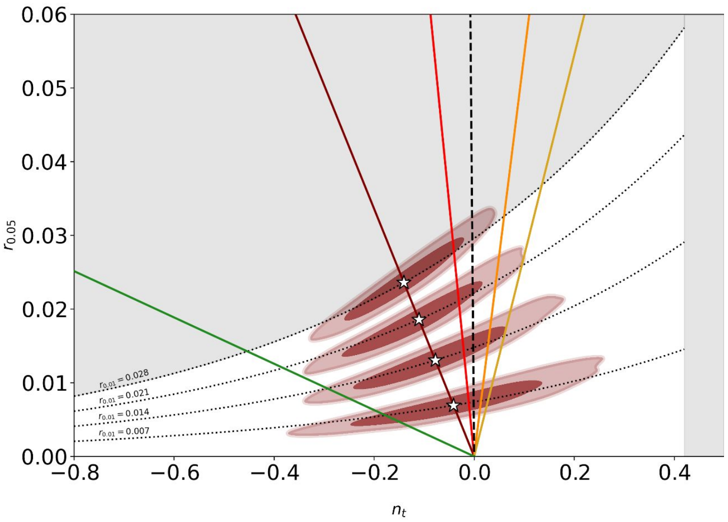
sound-speed of GWs

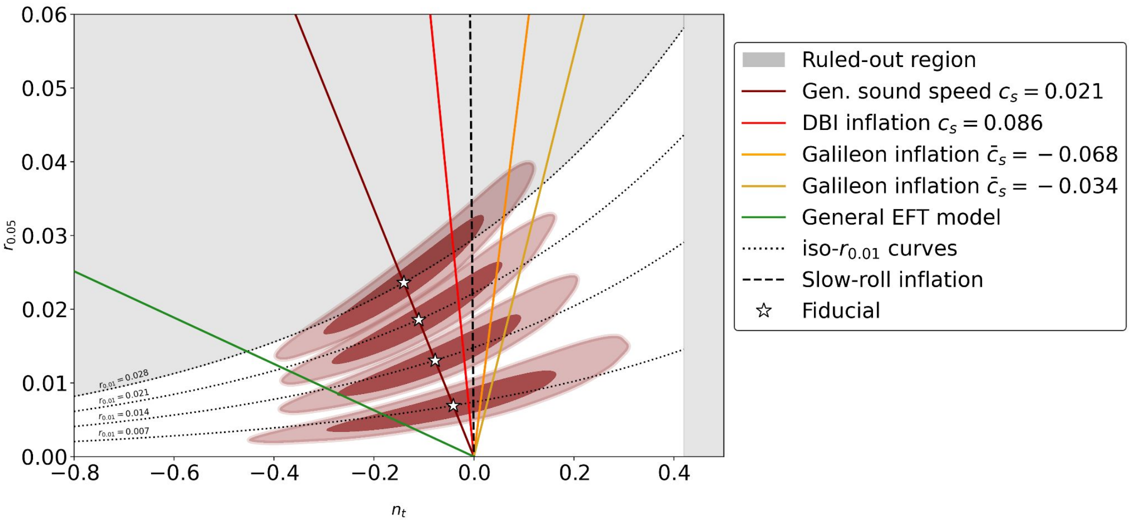
dispersion relation parameters

Capurri, Bartolo, Maino, Matarrese, *JCAP* 11 (2020) 037

Non-standard consistency relations in paper I

BB alone (LCDM fixed) → EE + BB (LCDM free)





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from Giacomo Galloni (+Bartolo)

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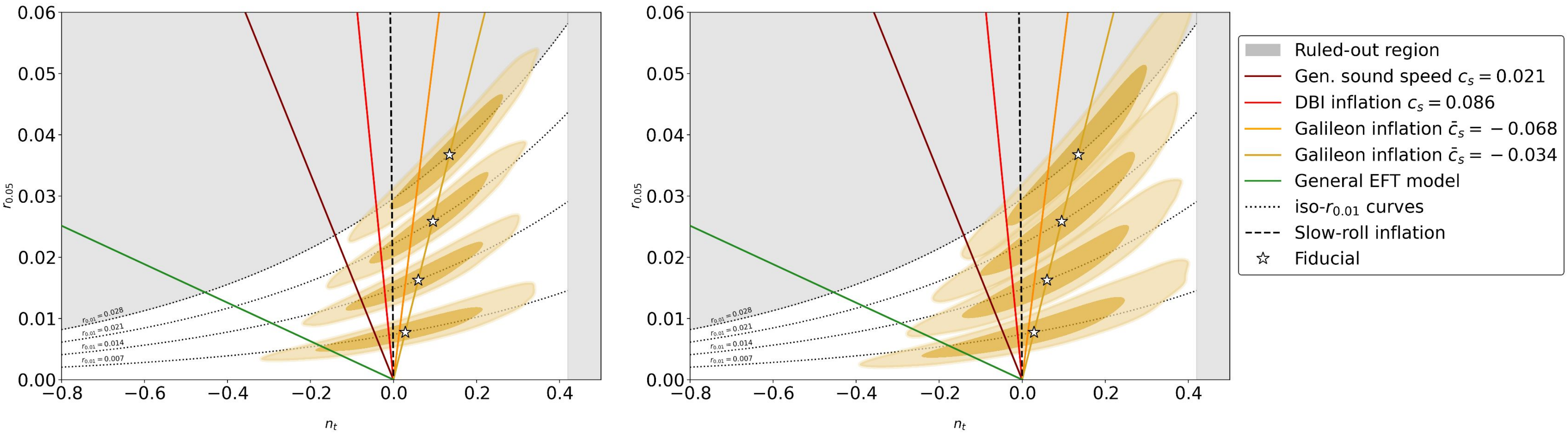

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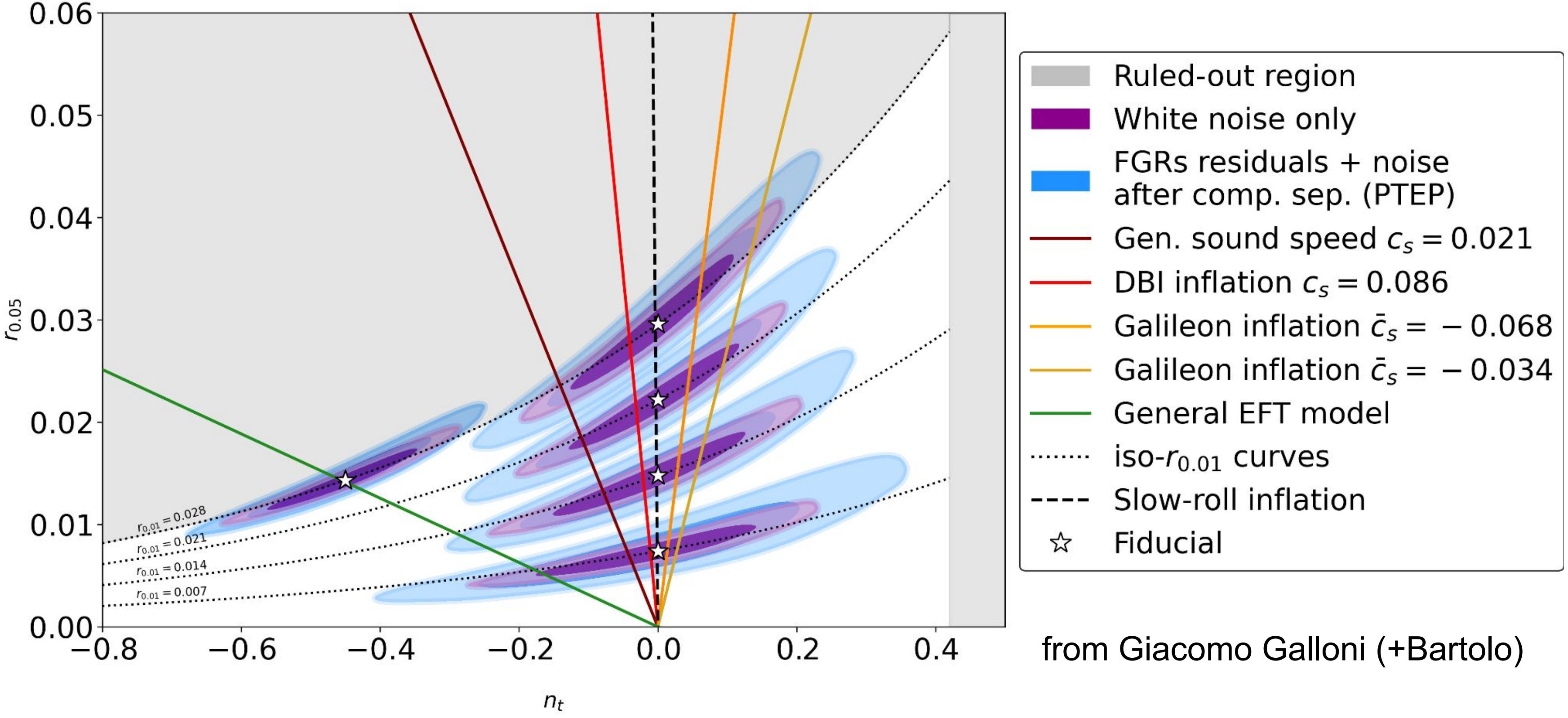
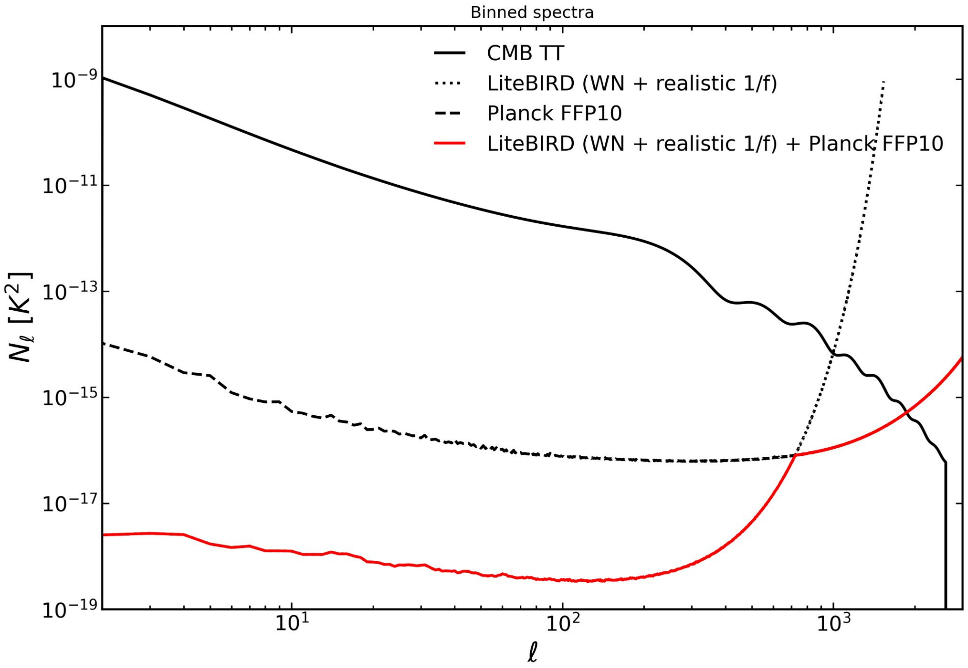
from Giacomo Galloni (+Bartolo)

Non-standard consistency relations in paper I



from Giacomo Galloni (+Bartolo)

Non-standard consistency relations in paper I



Next step is adding post-PTEP TT

- LiteBIRD alone
- LiteBIRD + Planck

Details and products at:
https://wiki.kek.jp/display/~ggalloni/Temperature+Analysis+Products

from Giacomo Galloni (+Bartolo)

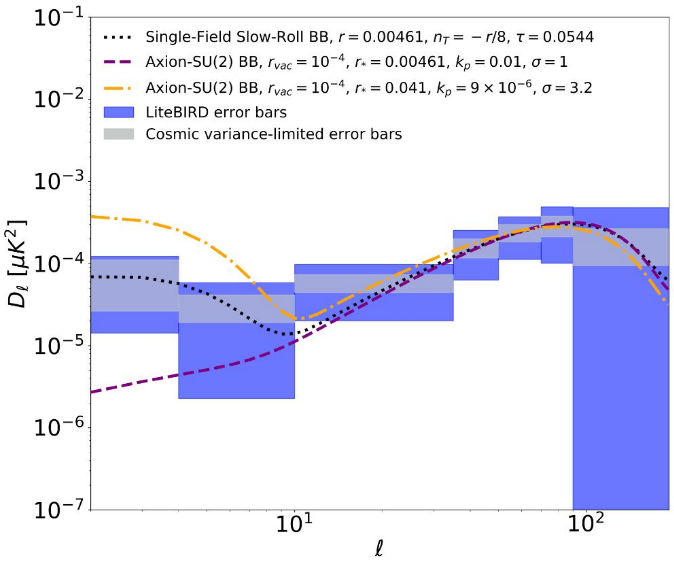
Paper III: Constraining SU(2)-gauge field inflation

Contents

Constraining SU(2)-gauge field inflation

Goal: Understanding the origin of primordial gravitational waves

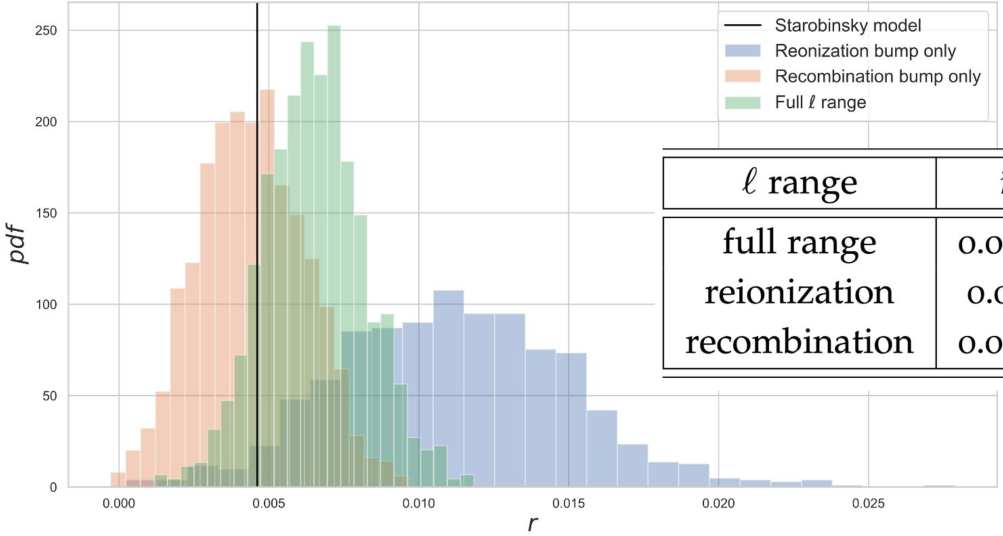
- Goal: show that full-sky survey with access to reionization bump is necessary to understand the origin of primordial GWs
- axion-SU(2) can source GWs that exceed vacuum contribution at reionization bump scales by factor ~ 5 (Ishiwata + '21)
- Recombination bump indistinguishable from Starobinsky model
- Reionization bump very different!



Constraining SU(2)-gauge field inflation

Fitting for SU(2) with the wrong model

- Underlying simulations from high reionization bump model (with same rec. bump as Starobinsky)
- Fit only r using full multipole range, only reionization and only recombination bump
- Histogram of best-fit r values



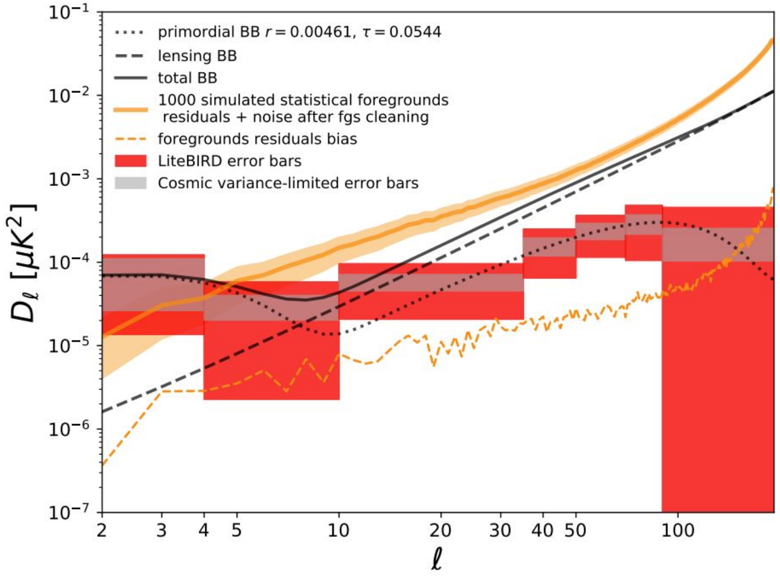
ℓ range	$\bar{r}$	σ_r
full range	0.0065	0.0017
reionization	0.011	0.0039
recombination	0.0044	0.0018

Paper II: Tests of Cosmic Inflation beyond B-mode polarization

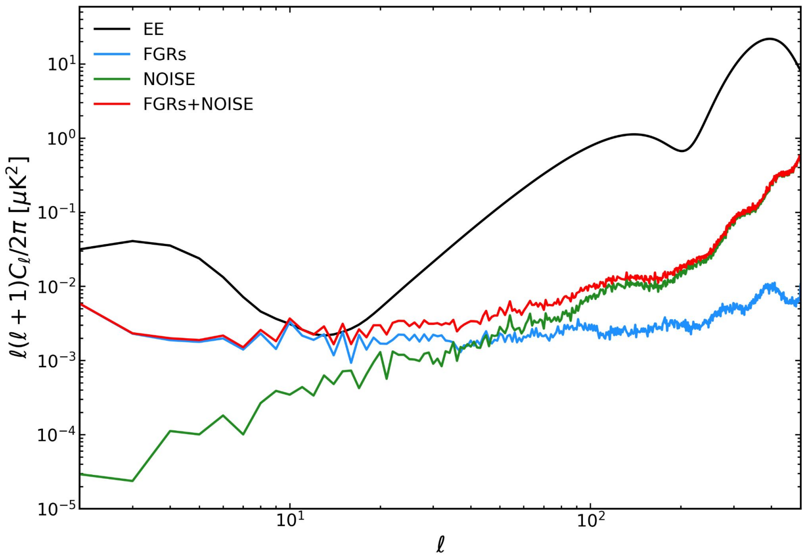
In this project we will extend the forecasts for the LiteBIRD tests of cosmic inflation beyond those which will be critically achievable through B-mode polarization. With its full sky coverage and unprecedented sensitivity in polarization, LiteBIRD has the capability to provide stringent tests on the power spectrum, initial conditions and statistics of primordial fluctuations. In particular we will provide forecasts for a. inflationary models not satisfying the slow-roll conditions and predicting a strongly scale-dependent power spectrum of primordial perturbations, b. the allowed fraction of isocurvature initial conditions as predicted by multi-field inflationary models c. limits either on standard (local, equilateral, orthogonal) scalar non-Gaussianity shapes, or on additional mixed bispectra signals involving E- and B-polarization, complementing the analyses of the other papers.

Paper I: Tests of Cosmic Inflation beyond B-mode polarization

B-modes from PTEP



E-modes from full-sky NILC comp. sep. (preliminary)



Workshop LiteBIRD-ITALIA 2023 @INFN-LNF

from Giacomo Galloni (+Bartolo)

Tests of Cosmic Inflation: Timescale

Status

- **Paper 1: Various results already obtained with PTEP-inputs both for power-spectrum and bispectrum forecasts.**

  Forecasts with increasing level of complexity: e.g. include de-lensing.

  We aim at a readable draft for paper I after summer 2023

- **Paper 2:**

  In the meantime contribute to the E-mode project paper developed within the FG-JSG: for the scientific application → Lukas Hergt volunteered to help, and this might be a leverage for starting paper II

- **Paper 3: this paper is completed, and it has employed the PTEP specs.** Reviewed within the Inflation Project team; under review within the IPB.