OSCILLATIONS IN THE SGWB
from Particle Production during Inflation

Jacopo Fumagalli (IFT/UAM-CSIC)

LISA CosmoWG - Workshop - 08/12/2021

with Sebastien Renaux-Petel & Lukas T. Witkowski

arXiv 2012.02761 / 2105.06481

(2110.09480 + G. Domenech / 2111.14664 + S.Sypsas, G.Palma, C. Zenteno / 2112.06903 + M. Pieroni)

Instituto de Física Teórica UAM-CSIC

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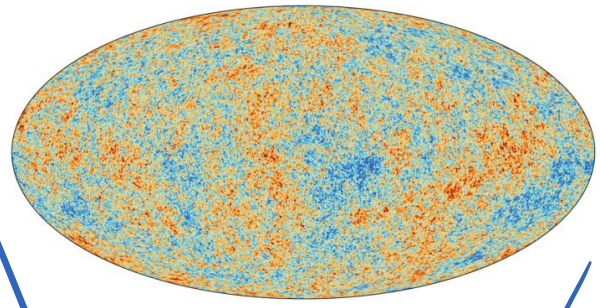
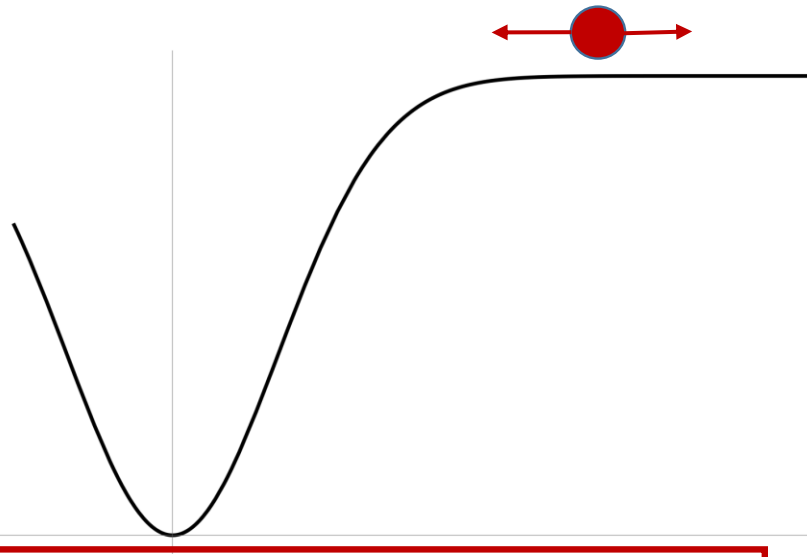
COSMIC INFLATION



$\ddot{a} > 0$

SIMPLEST SLOW-ROLL SCENARIO IN PERFECT AGREEMENT WITH DATA

Almost scale-invariant, Gaussian, super-Horizon...



Comoving curvature perturbation $\zeta \Rightarrow \delta T$

WHY GOING BEYOND THE SIMPLE SCENARIO?

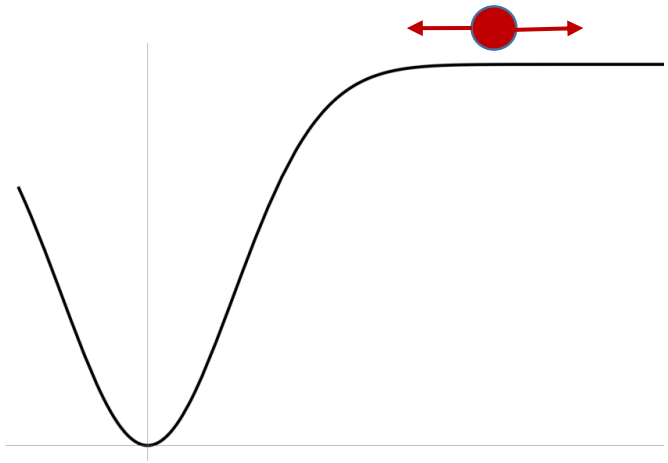
2 COMMENTS:

1. THEORETICALLY: HARD TO BELIEVE IT IS NOT JUST A PHENOMENOLOGICAL EFFECTIVE DESCRIPTION.

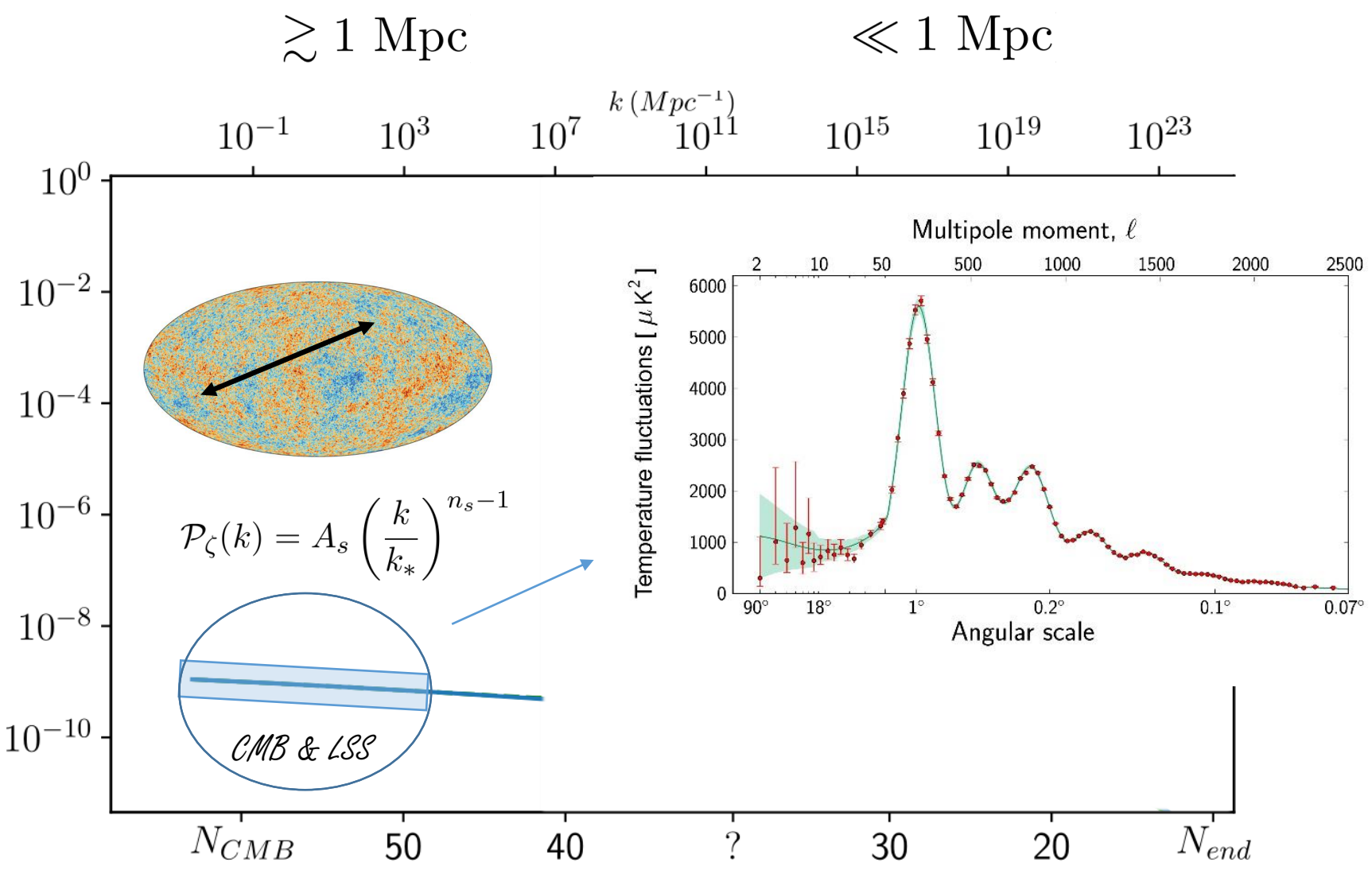
   SEVERAL ISSUE WHEN UV EMBEDDING (ETA-PROBLEM, ETC.)

2. EXPERIMENTALLY: THE PICTURE IS CONSISTENT WITH DATA BUT

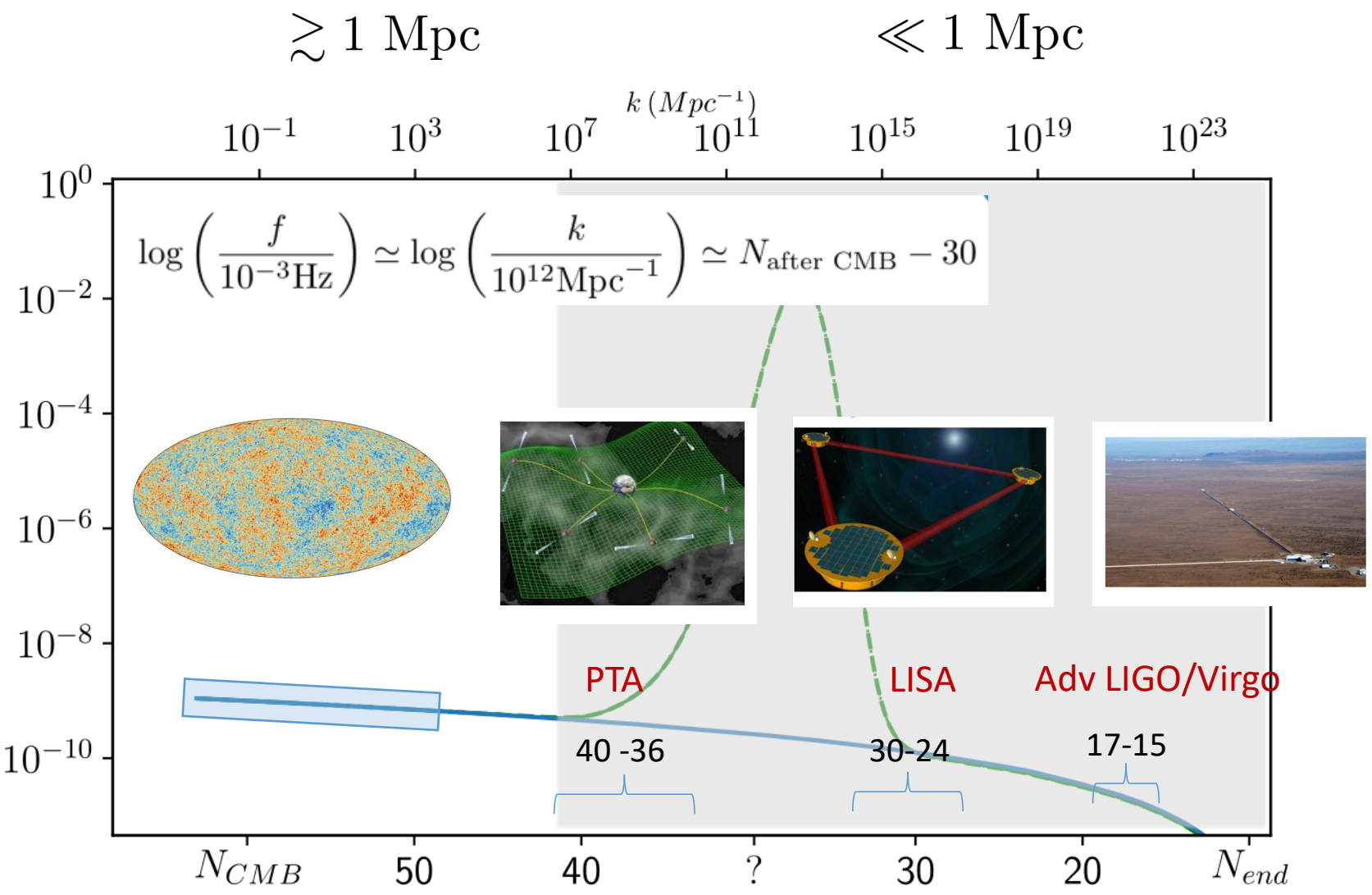
   DATA CONSTRAIN ONLY A SMALL PART OF THE INFLATIONARY HISTORY



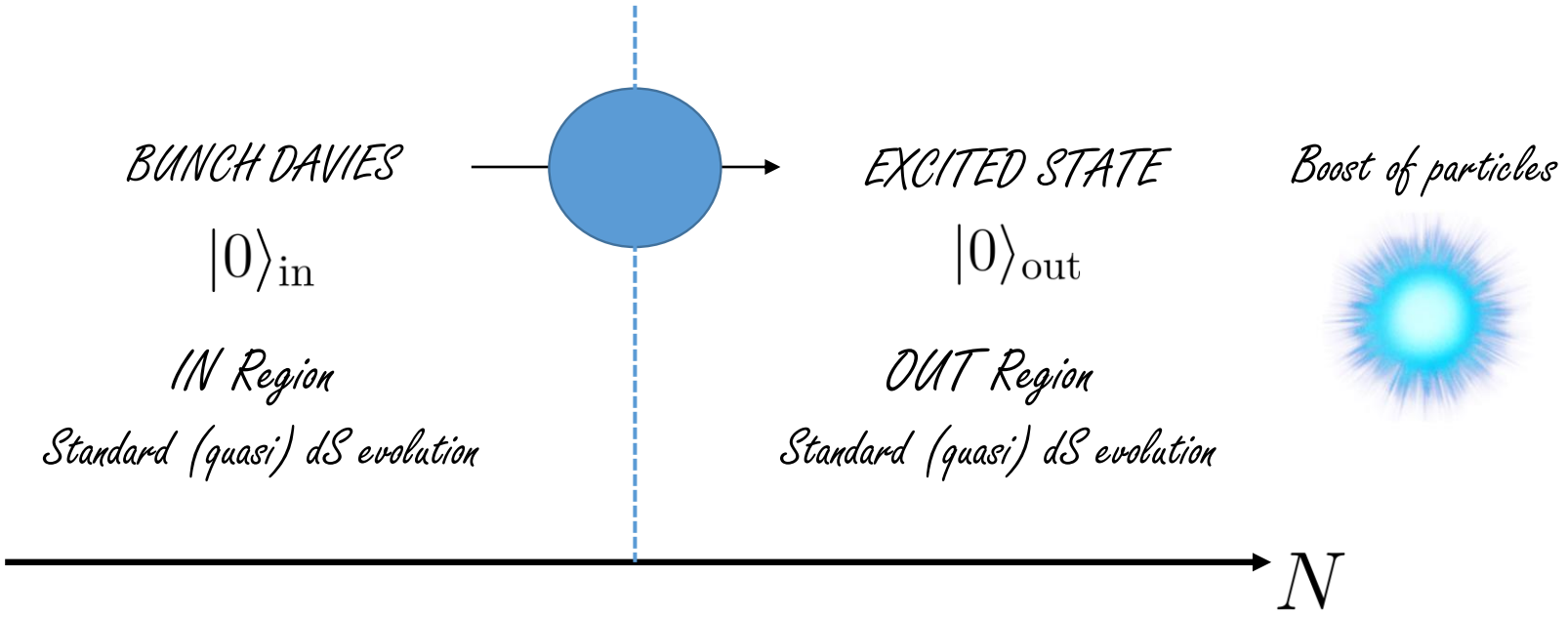
PRIMORDIAL SCALAR FLUCTUATIONS



INFLATION AT SMALL SCALES

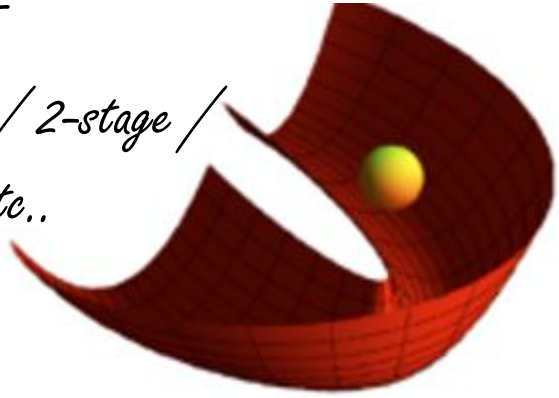


PARTICLE PRODUCTION



SHARP FEATURE

Step in the potential / 2-stage /
turn in field-space etc..



PARTICLE PRODUCTION

BUNCH DAVIES

$|0\rangle_{\rm in}$

IN Region

Standard (quasi) dS evolution

EXCITED STATE

$|0\rangle_{\rm out}$

OUT Region

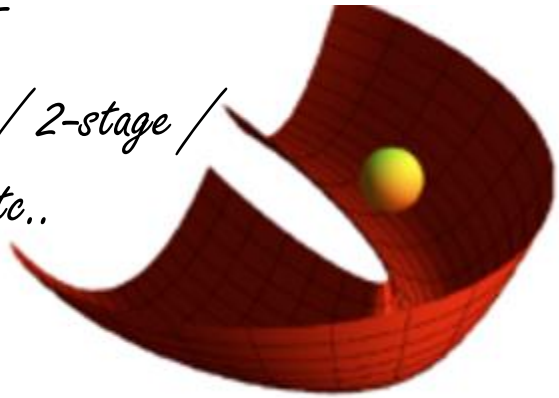
Standard (quasi) dS evolution

Boost of particles

N

SHARP FEATURE

Step in the potential / 2-stage / turn in field-space etc..

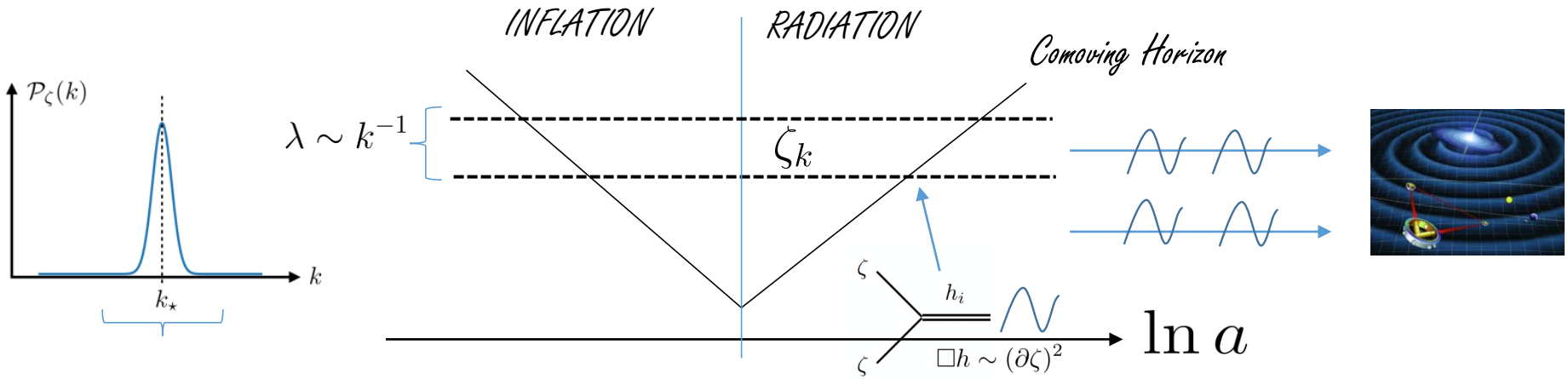


SOURCE GWs

- After inflation
- During inflation

SCALAR INDUCED (post-inflationary) SGWB

Acquaviva et al. '02; Mollerach, Harari, Matarrese '03; Ananda, Clarkson, Wands '06; Baumann et al. '07



$$\Omega_{\rm GW}(k) = \int\int \mathcal{T}(u,v)\mathcal{P}_\zeta(ku)\mathcal{P}_\zeta(kv) \simeq 10^{-5}\mathcal{P}_\zeta^2$$

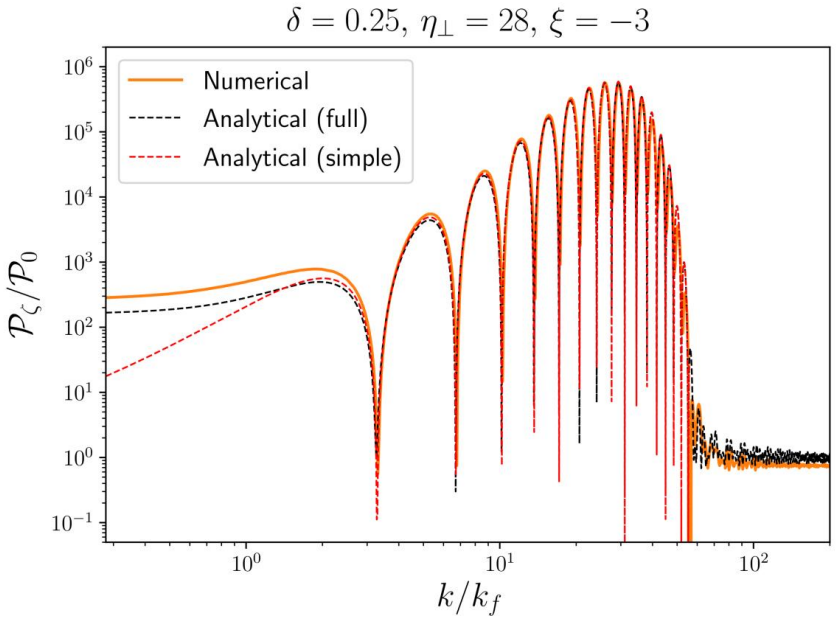
SENSITIVE TO THE PRIMORDIAL POWER SPECTRUM

SIGNATURES IN THE (post-inflationary) SGWB

SHARP FEATURE: $\mathcal{P}_\zeta(k) = \overline{\mathcal{P}}(k)\left(1 + A_{\rm lin}\cos\left(\omega_{\rm lin}k + \phi_{\rm lin}\right)\right)$

Large particle production → O(1) oscillations

Preferred scale selected $2/k_f$



JF, S. Renaux-Petel, L. T. Witkowski, 2012.02761

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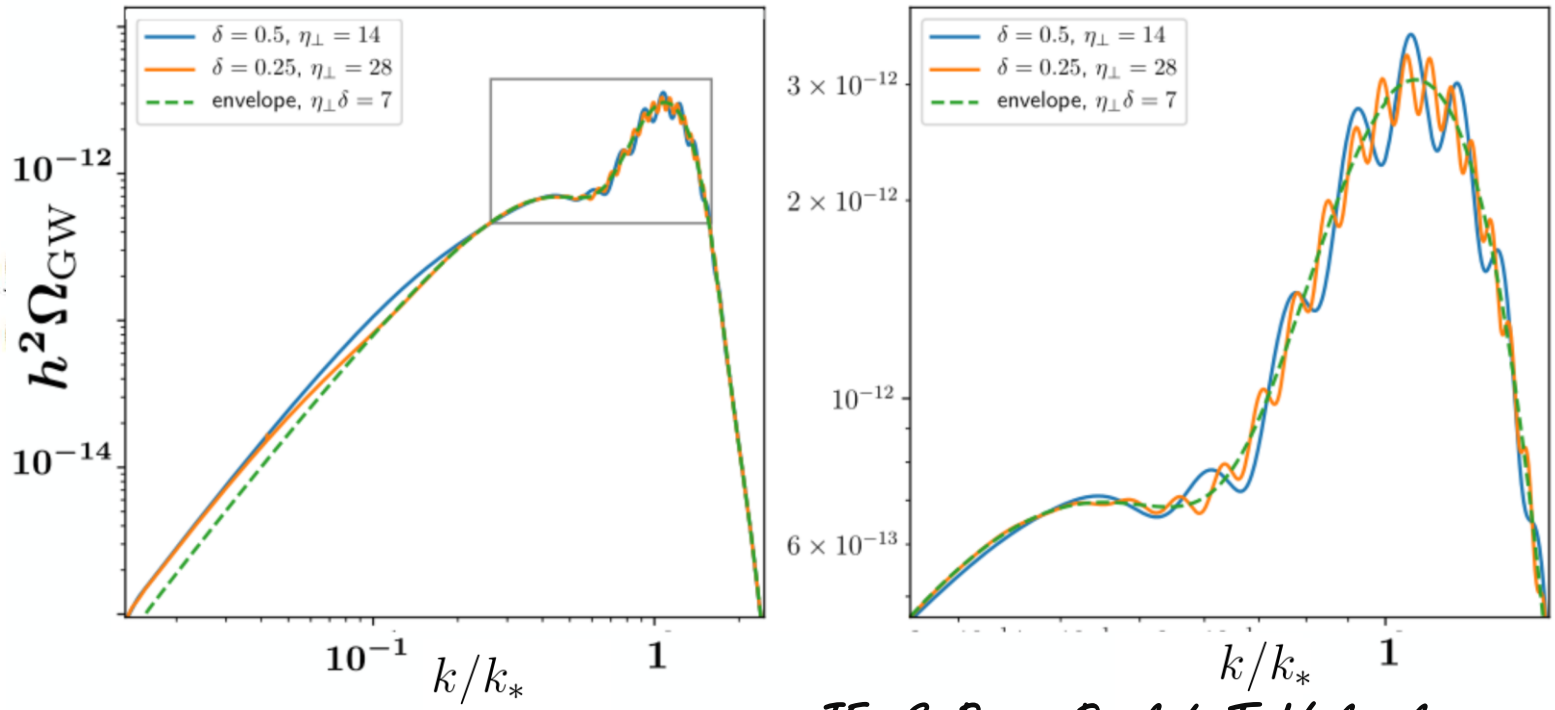
$$\omega^{\rm GW}_{\rm lin} = \sqrt{3}\,\omega_{\rm lin}$$



JF, S. Renaux-Petel, L. T. Witkowski, 2012.02761

See also M. Braglia, X. Chen, D.K. Hazra 2012.05821

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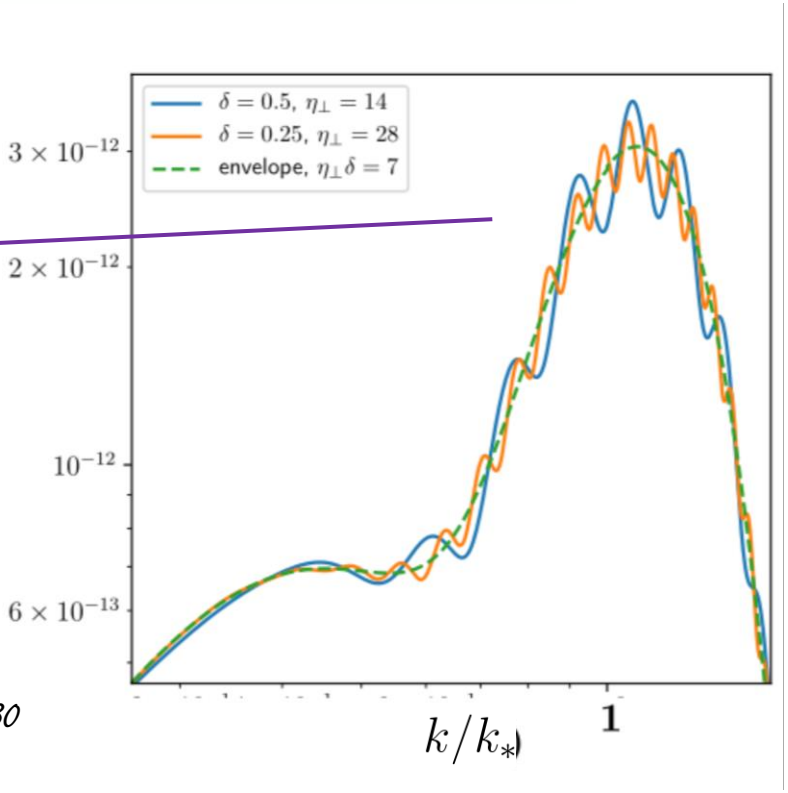
$$\omega_{\rm lin}^{\rm GW} = \sqrt{3}\,\omega_{\rm lin}$$

- Energy scale
- When during inflation?
- For how long?

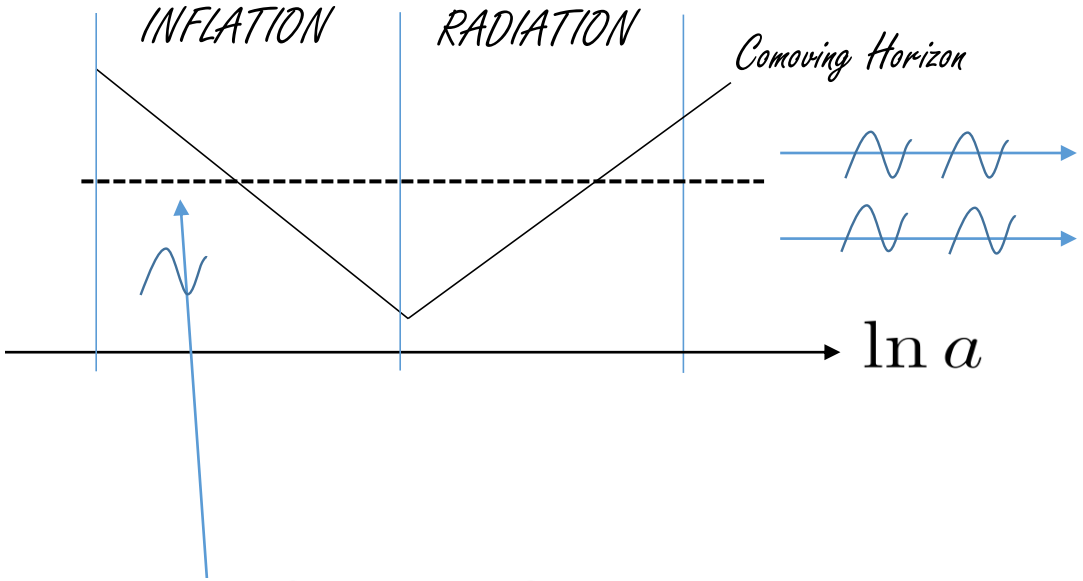
JF, S. Renaux-Petel, L. T. Witkowski, 2012.02761

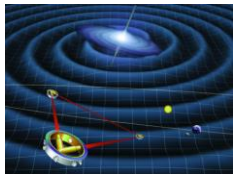
- Cosmic expansion at horizon re-entry

L. T. Witkowski, G. Domenech, JF, S. Renaux-Petel 2110.09480



SIGNATURES IN THE (inflationary) SGWB





$$\Box h_{\mu\nu} \propto (\partial Q)^2 \propto \epsilon(\partial\zeta)^2$$

Q : Scalar Fluctuation

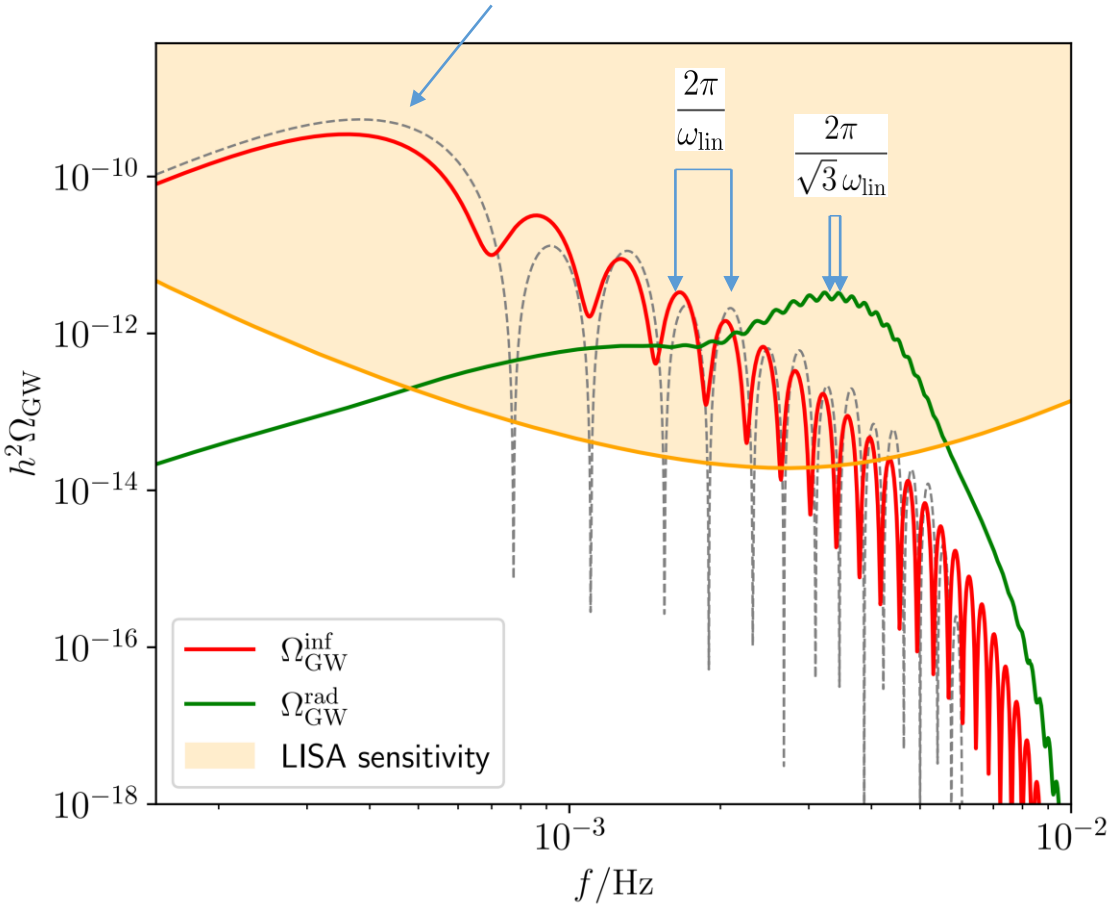
IF TRIVIAL TIME DEPENDECE ON SUB-HUBBLE SCALES

$$\Omega_{\rm GW}^{\rm inf}(k,\tau) \propto \epsilon^2 \int\int \mathcal{P}_\zeta^2 \simeq \epsilon^2 \Omega_{\rm GW}^{rad}$$

SIGNATURES IN THE (inflationary) SGWB

...BUT ENHANCED for EXCITED STATES

$$\frac{\Omega_{\rm Inf}|_{k_{\rm max}}}{\Omega_{\rm Rad}|_{2k_*/\sqrt{3}}} = O(1)\epsilon^2 \left(\frac{k_*}{k_f}\right)^5$$



JF, G.Palma, S.R.Petel, S.Sypsas, L.T.Witkowski, C. Zenteno 2111.14664

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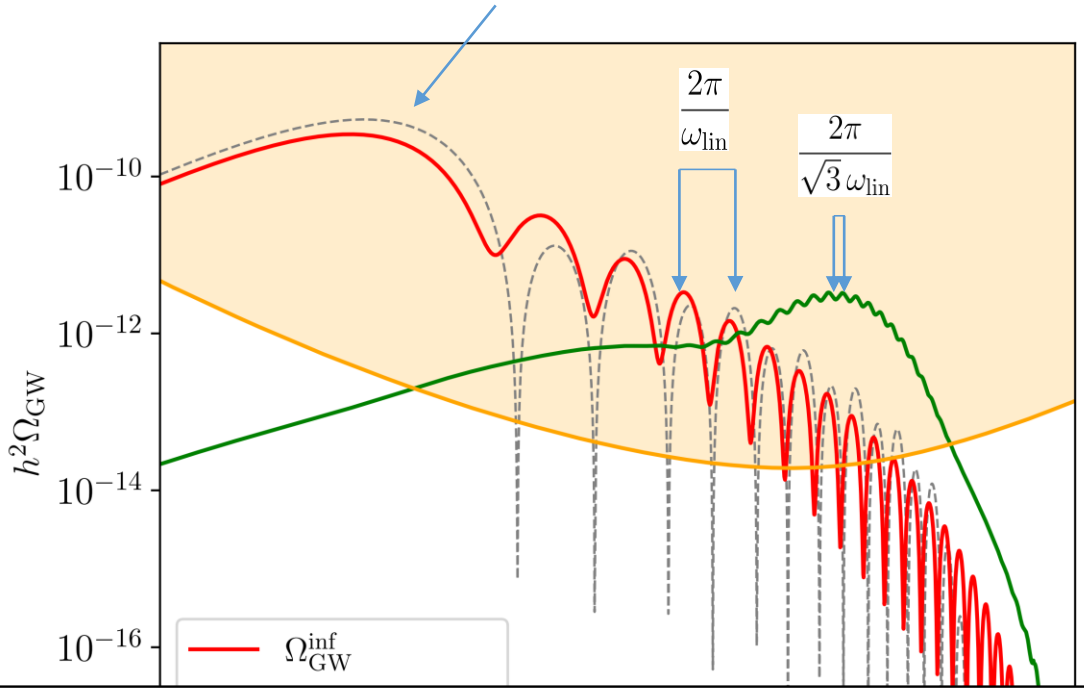

GENERIC TEMPLATE FOR GWs sourced by EXCITED STATES with large occupation number

$$h^2\Omega_{\rm GW}(f) = \left(\frac{h^2\overline{\Omega}_{\rm GW}}{0.0065}\right)\frac{1}{(\omega_{\rm lin}f)^3}\left(1-\frac{(\omega_{\rm lin}f)^2}{16\gamma^2}\right)^2 \times \left[\sin\left(\tfrac{1}{2}\omega_{\rm lin}f\right) - \frac{4\left(1-\cos\left(\tfrac{1}{2}\omega_{\rm lin}f\right)\right)}{\omega_{\rm lin}f}\right]^2 \Theta(4\gamma/\omega_{\rm lin}-f)\,,$$

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MORE....

- RESONANT FEATURES IN THE SGWB - TEMPLATE

  JF, S.Renaux-Petel, L. T. Witkowski 2105.06481

- INFLUENCE OF THE COSMIC EXPANSION HISTORY

  L. T. Witkowski, G. Domenech, **JF**, S. Renaux-Petel 2110.09480

- DETECTABILITY WITH LISA

  First hints: JF, M. Pieroni, S. Renaux-Petel , L. T. Witkowski 2112.xxxxx

MORE....

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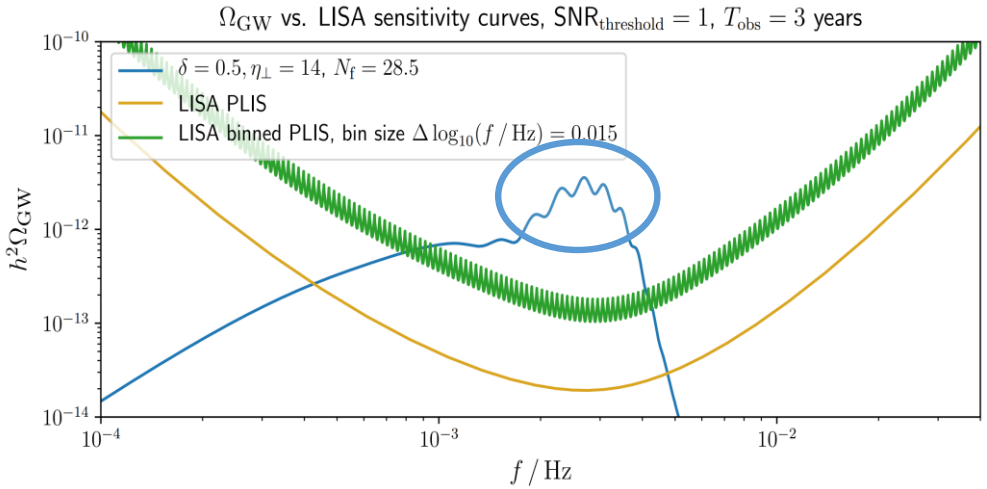
➡ DEMANDS MORE SOPHISTICATED METHODS OF SIGNAL RECONSTRUCTION, (BINNING)

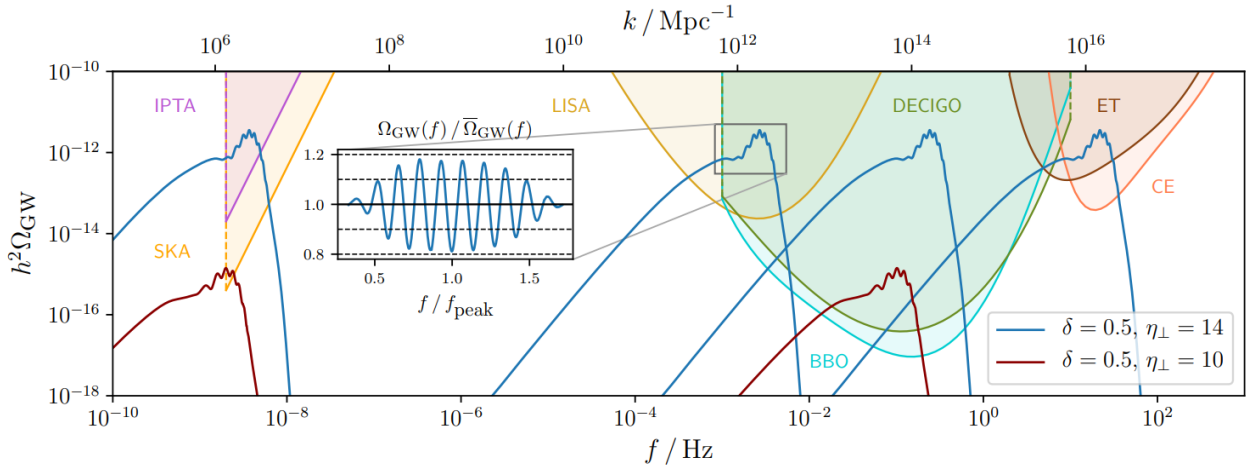
Caprini et al. 1906.09244

ONGOING EFFORT WITH THE INFLATION PARAMETER ESTIMATION WORKING PACKAGE



SUMMARY

- CMB/LSS PROVIDE INFORMATION ON A **LIMITED PART** OF THE INFLATIONARY HISTORY
- REASONS TO GO BEYOND THE VANILLA SCENARIOS LEAD TO FEATURES IN THE SGWB



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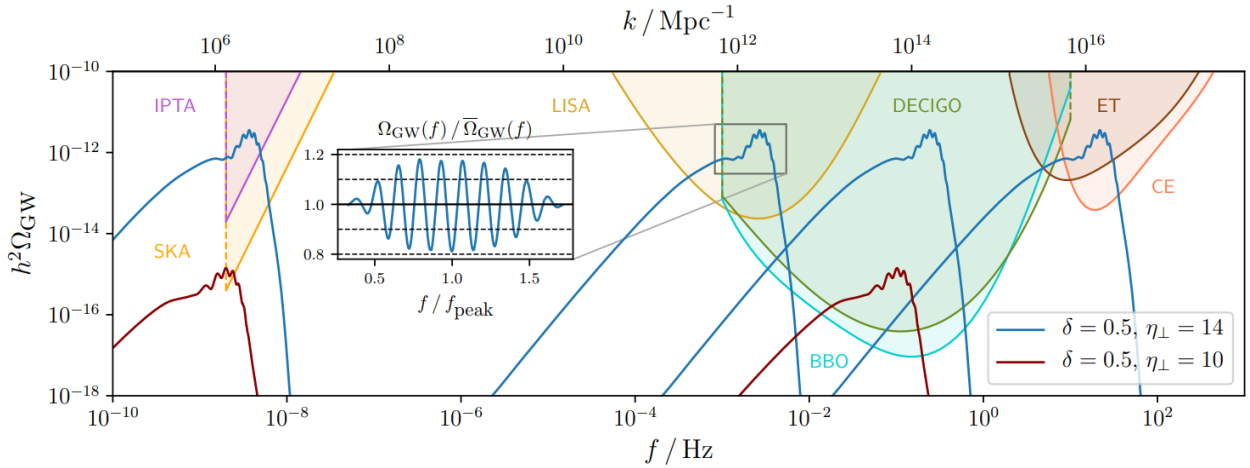

OPEN THOUGHTS

- THEORY: BACKREACTION/PERTURBATIVITY CONSTRAINTS / NON-GAUSSIANITIES
- OBSERVATION: DETECTABILITY WITH LISA AND OTHER GWS OBSERVATORIES

  To what extend we can reconstruct 10-30% oscillations?
- SPECULATIVE: WAY TO SEPARATE COSMOLOGICAL AND ASTROPHYSICAL BACKGROUND?