SEARCHING for PRIMORDIAL FEATURES with LISA

JACOPO FUMAGALLI (IFT/UAM-CSIC)

ICHEP 2022 Bologna - 08/07/2022

with Sebastien Renaux-Petel & Lukas T. Witkowski,

+ G. Domenech, S.Sypsas, G.Palma, C. Zenteno , M. Pieroni

(2012.02761, 2105.06481, 2110.09480, 2111.14664 2112.06903

+ Work in Progress with CosWG LISA)

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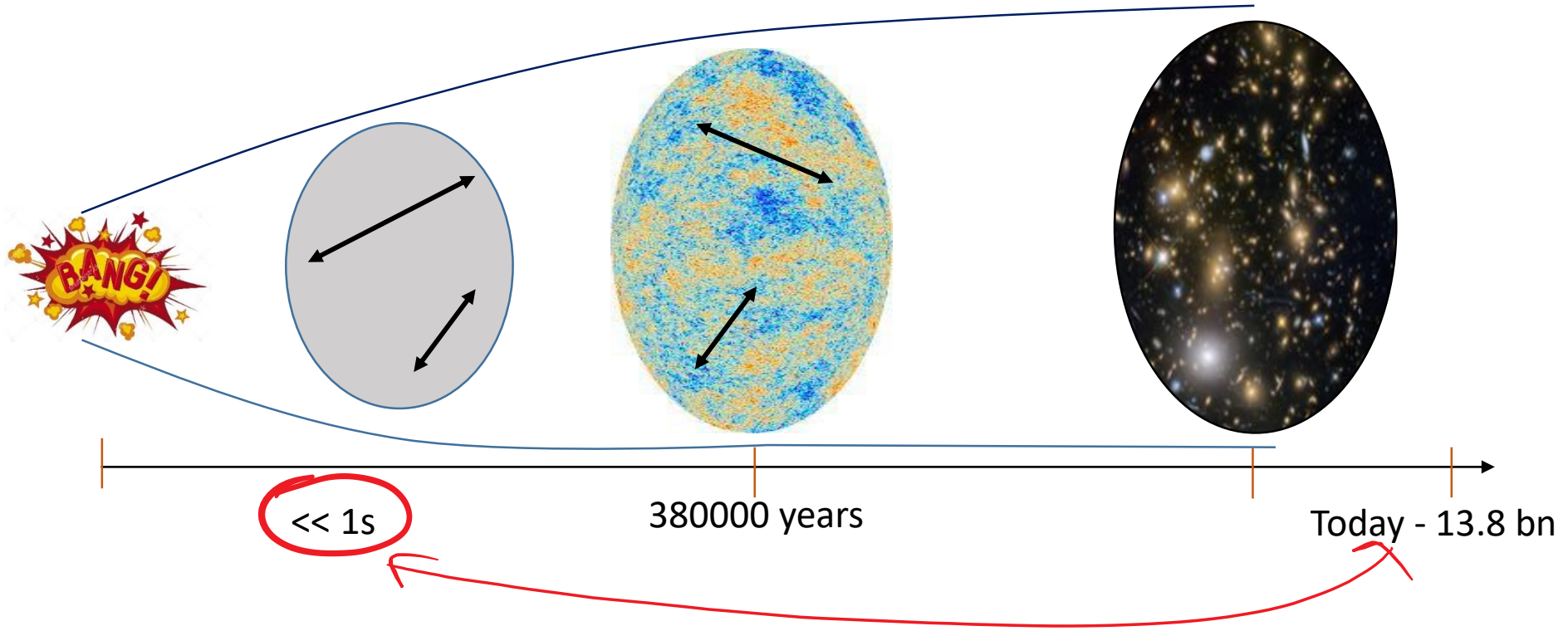
Instituto de Física Teórica UAM-CSIC

INFLATION: WINDOW IN THE EARLY UNIVERSE

STRUCTURE IN THE UNIVERSE EMERGE FROM VACUUM QUANTUM FLUCTUATIONS

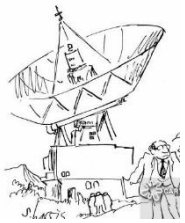


Perturbations: Almost scale-invariant, Gaussian, super-Horizon...

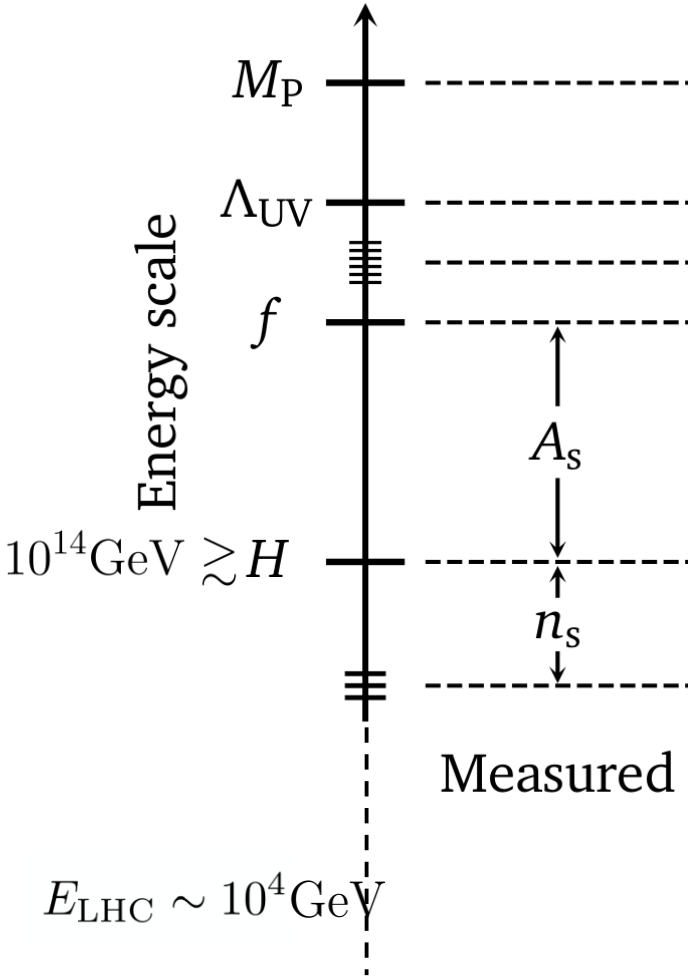
$$\mathcal{P}_\zeta(k) = A_s \left(\frac{k}{k_*}\right)^{n_s - 1}$$

$A_s \sim 2.2 \cdot 10^{-9}$

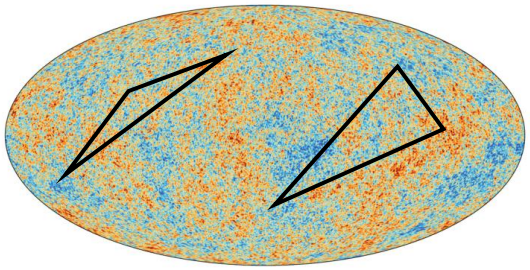
$n_s \sim 0.9649$



PROBING THE HIGHEST POSSIBLE SCALES



1) DEPARTURE FROM GAUSSIAN STATISTICS...

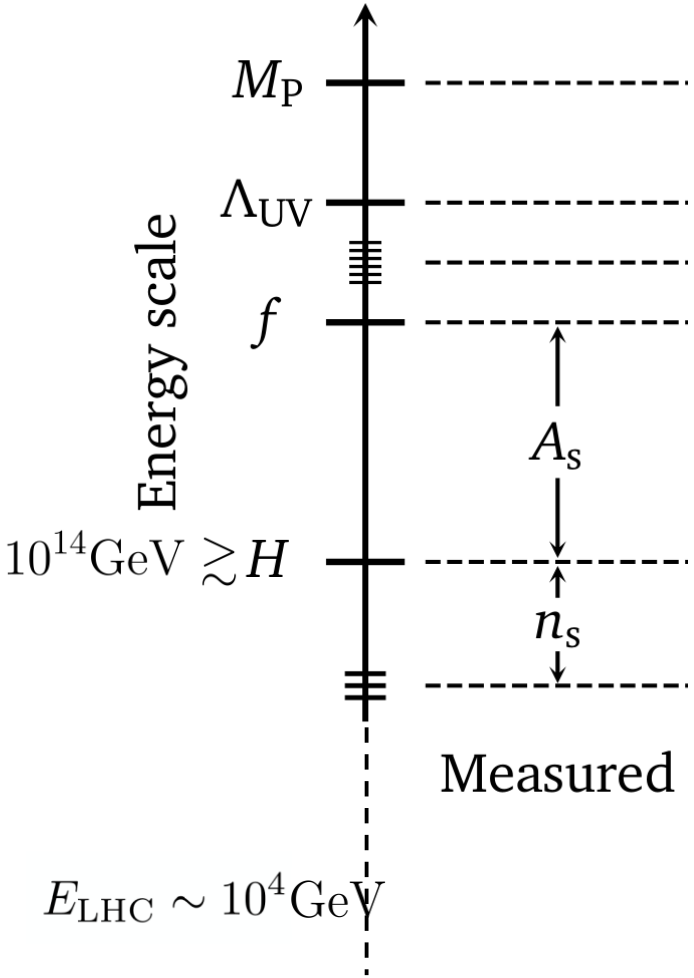


$$\langle \zeta_{k_L} \zeta_{k_S} \zeta_{k_S} \rangle \sim \left(\frac{k_L}{k_S}\right)^{3/2} \cos\left[\frac{m}{H} \log\left(\frac{k_L}{k_S}\right)\right] \mathbb{P}_S(\cos\theta)$$

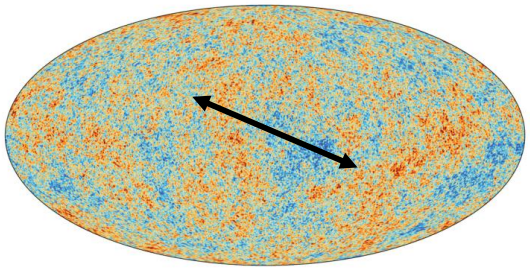
..COLLIDER PHYSICS: MASS & SPIN FROM SPECIFIC LIMITS OF THE THREE POINT FUNCTION

Chen, Wang '09
Baumann, Green '11
Arkani-Hamed, Maldacena '15
Baumann, Lee, Pimentel '16

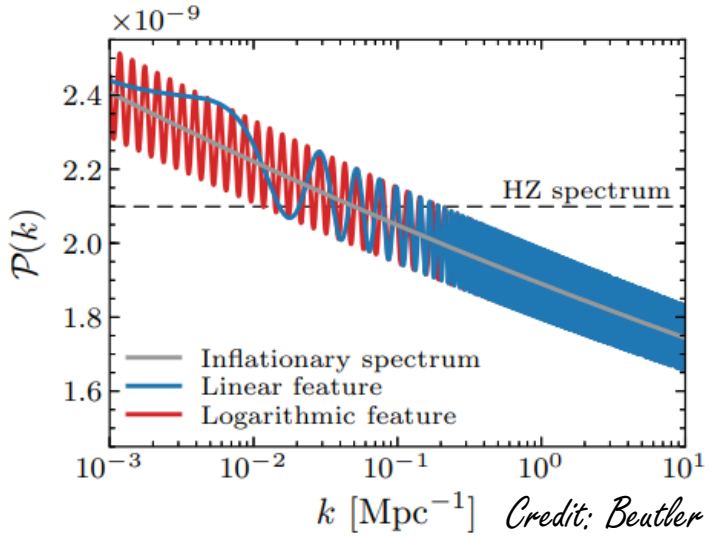
PROBING THE HIGHEST POSSIBLE SCALES



2) DEPARTURE FROM SCALE INVARIANCE...

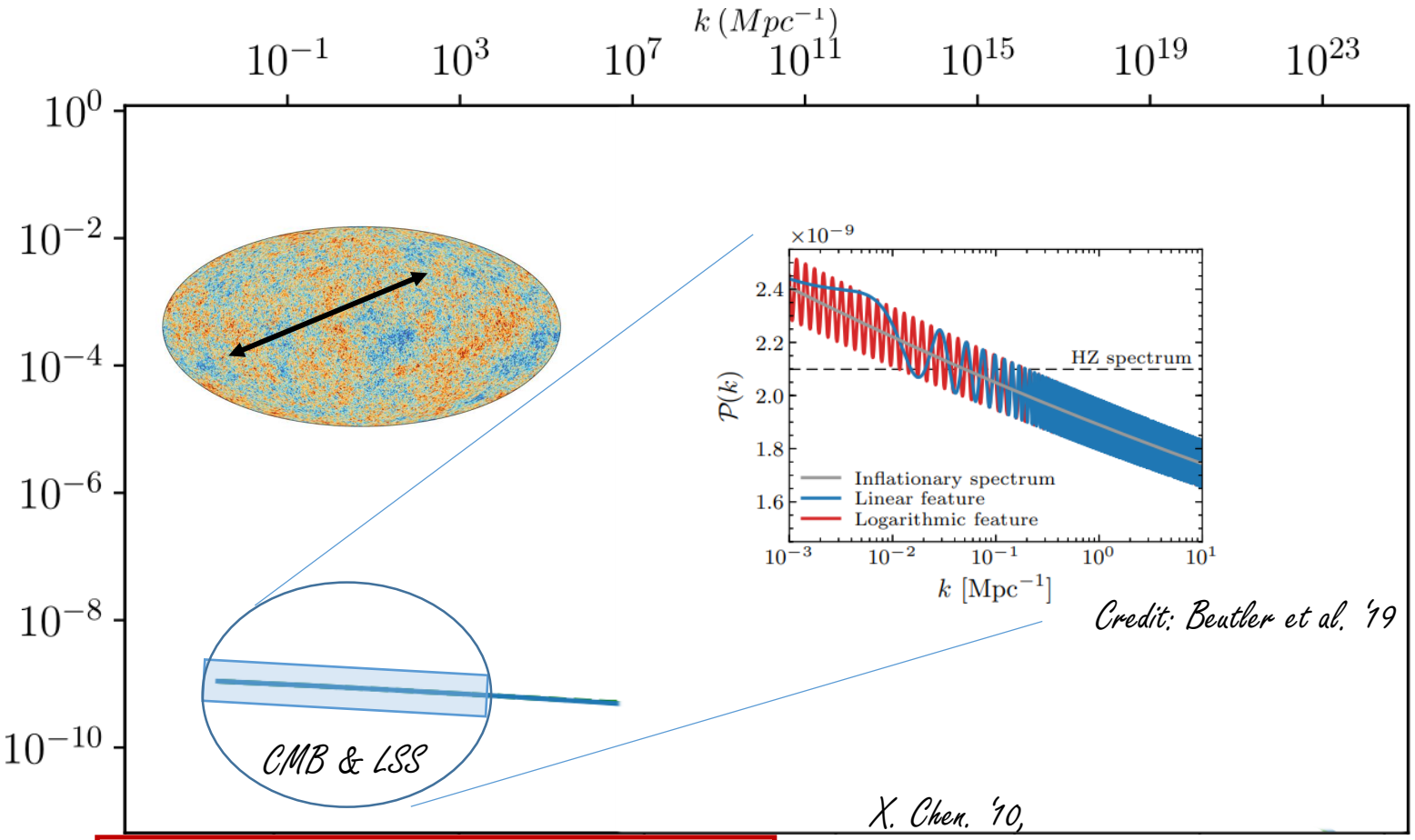


... OSCILLATIONS IN THE PRIMORDIAL POWER SPECTRUM PROBING NEW MASS SCALES, NEW COUPLINGS & EVEN THE INFLATIONARY PARADIGM...



Credit: Beutler et al. '19

LARGE SCALE FEATURES: CMB & LSS



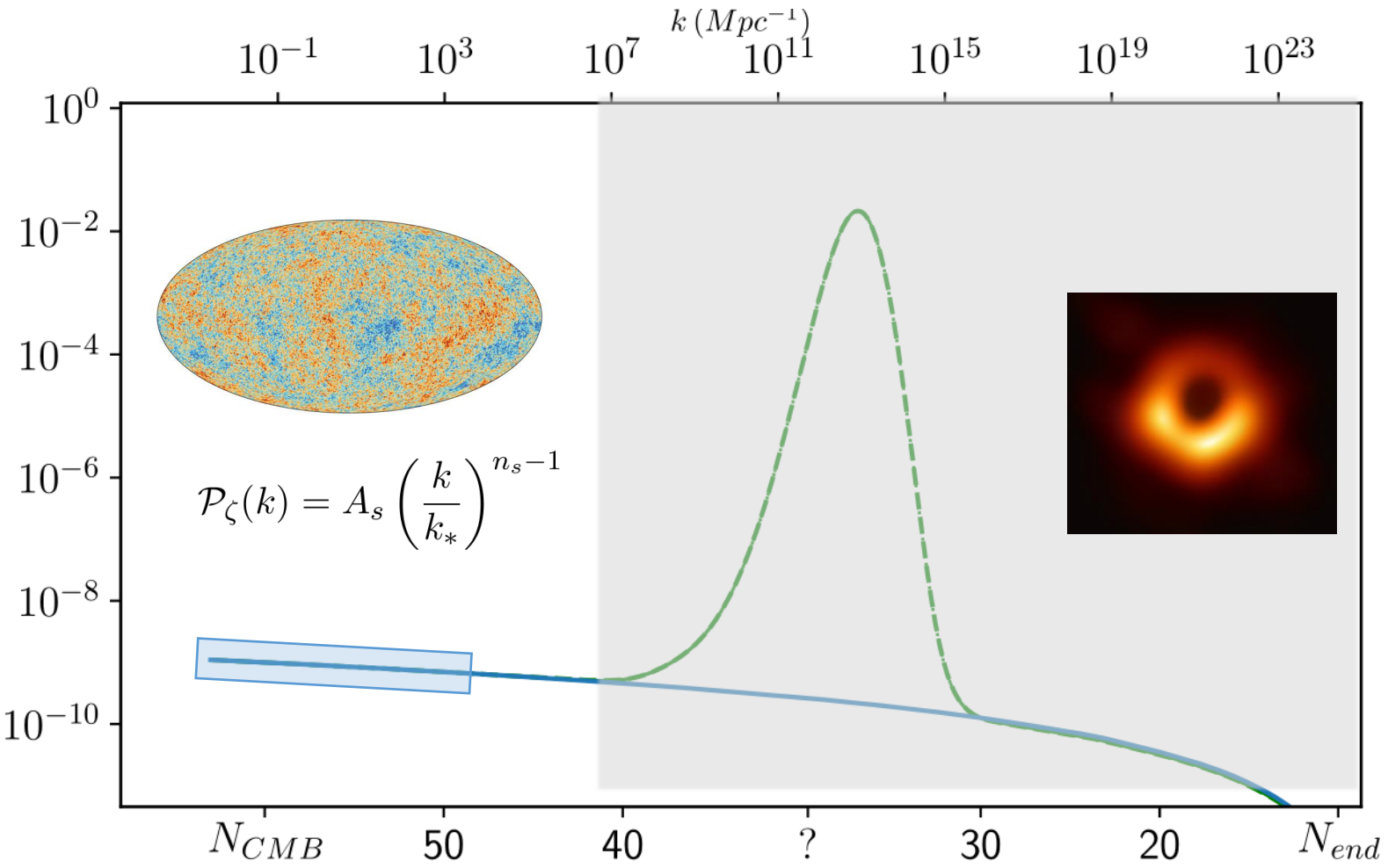
Credit: Beutler et al. '19

Departure from vanilla scenario leading to oscillations in $\mathcal{P}_\zeta(k)$

X. Chen. '10,
J. Chluba, J. Hamann, and S. P. Patil '15
A. Slosar '19 .. ...
M. Braglia et al. '21

DEVIATION FROM SCALE INVARIANCE AT SMALL SCALES

... AN ALL INDUSTRY MOTIVARED BY DARK MATTER IN THE FORM OF PBH



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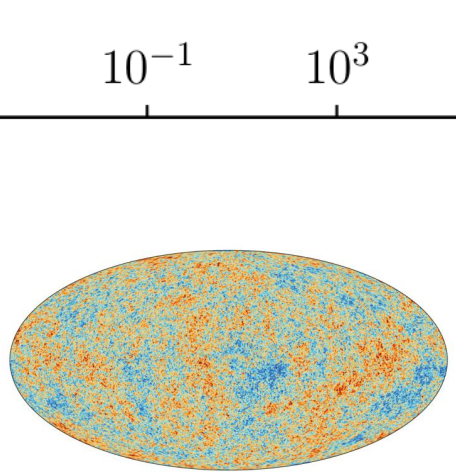


$$\mathcal{P}_\zeta(k) = A_s \left(\frac{k}{k_*}\right)^{n_s - 1}$$

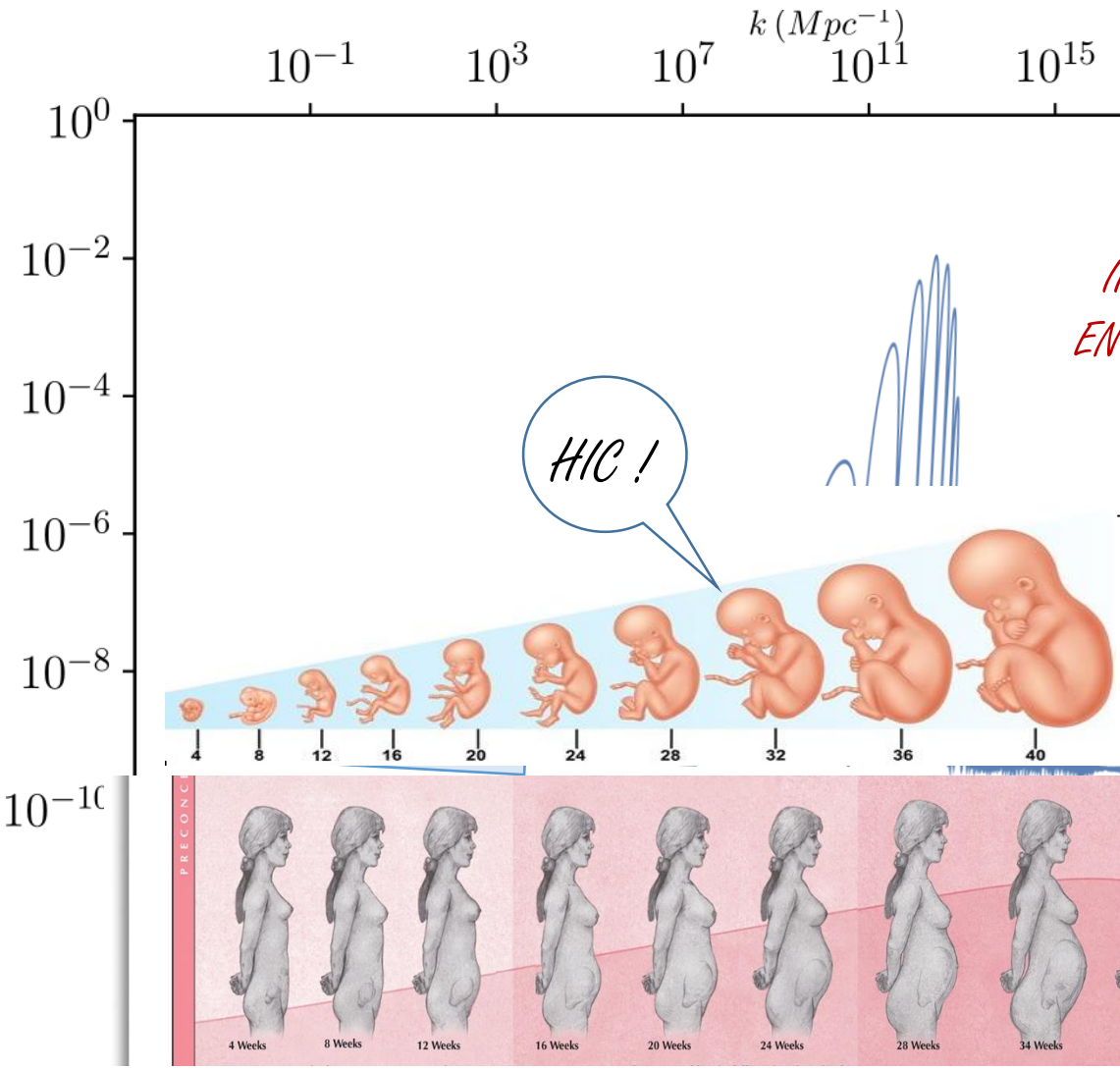
IF PHENOMENON TRIGGERING THE ENHANCEMENT LAST SHORT ENOUGH

$$H\Delta t \lesssim \log\left(\frac{E_N}{H}\right)$$

→ CHARACTERISTIC OSCILLATIONS

DEVIATION FROM SCALE INVARIANCE AT SMALL SCALES

... HICCUPS IN THE WOMB ...



IF PHENOMENON TRIGGERING THE ENHANCEMENT LAST SHORT ENOUGH

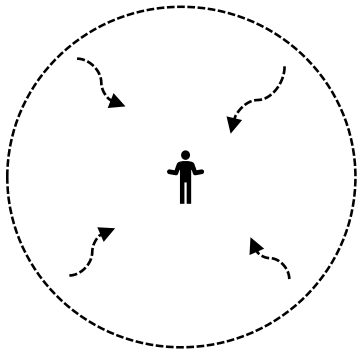
$$H\Delta t \lesssim \log\left(\frac{E_N}{H}\right)$$

CHARACTERISTIC OSCILLATIONS

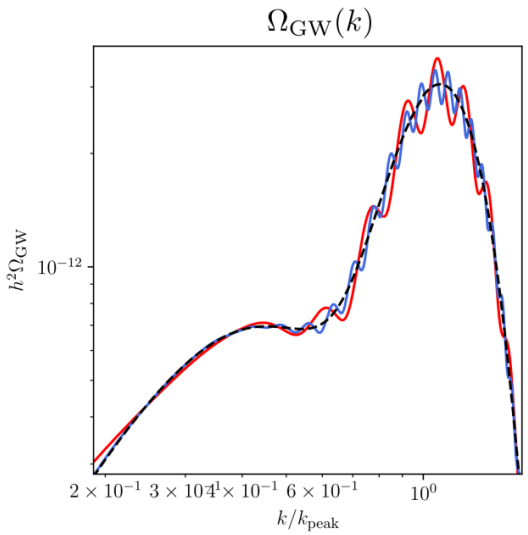
N_{end}

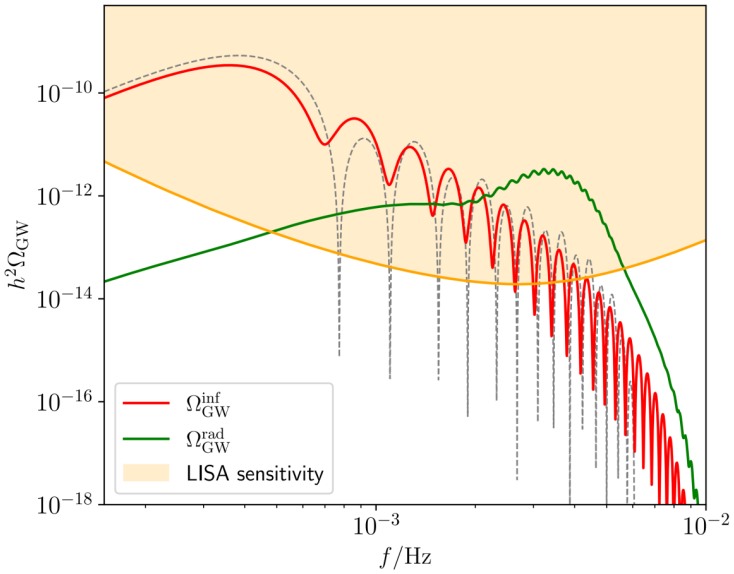
SMALL SCALE FEATURES in the SGWB

FEATURES IN THE PRIMORDIAL FLUCTUATIONS IMPRINT UNIQUE OSCILLATORY PATTERNS TO THE SGWB

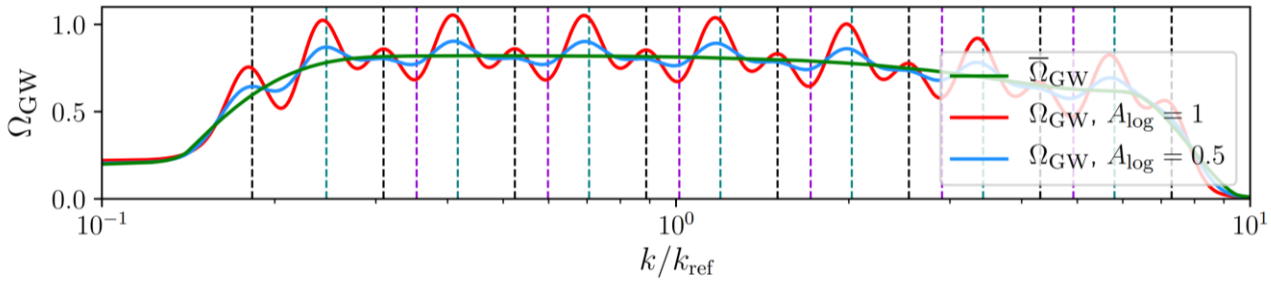


SHARP FEATURES





RESONANT FEATURES

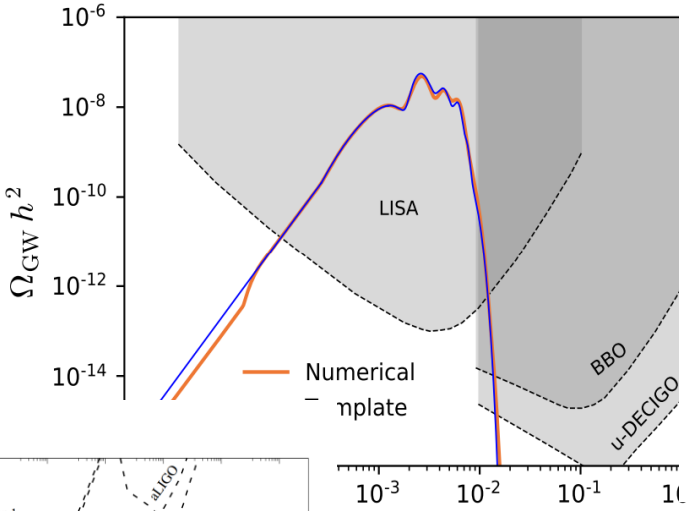


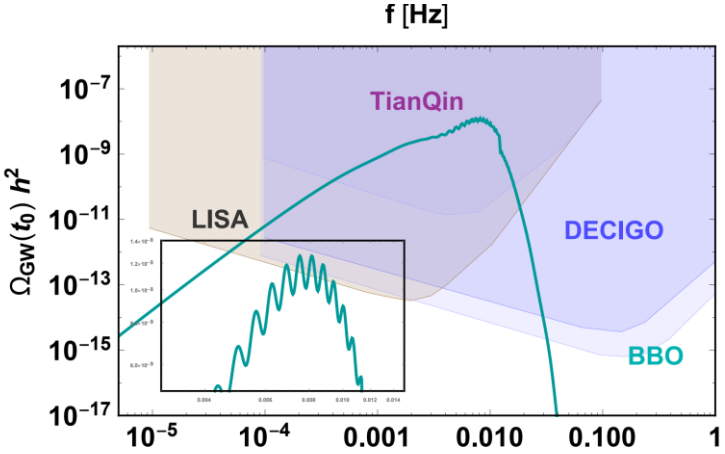
JF et al.

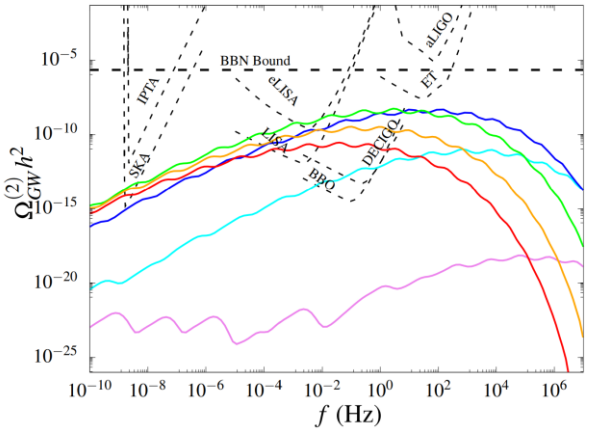
2012.02761,
2105.06481,
2110.09480,
2111.14664,
2112.06903
...

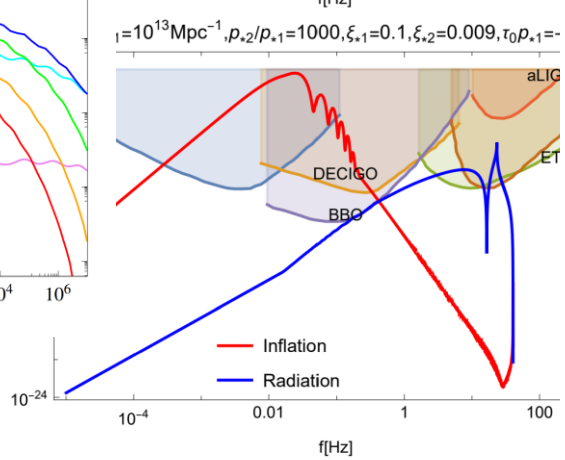
After first proposal 2012.02761

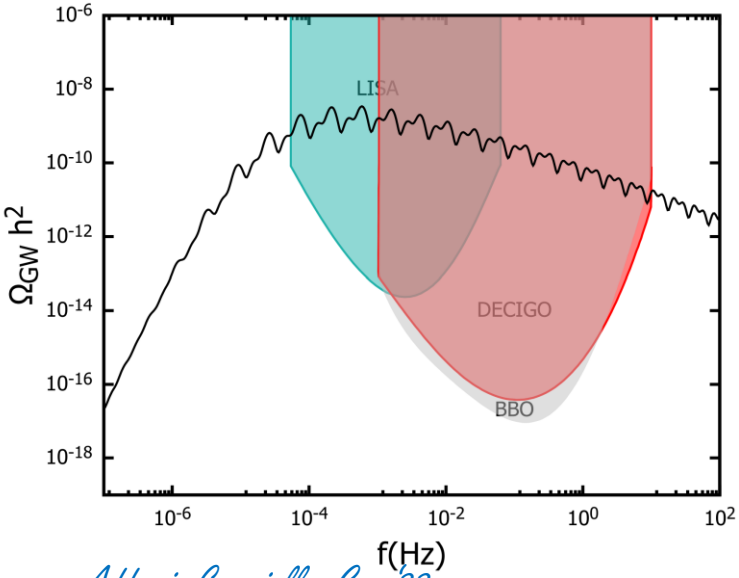
EXPLICIT MODELS LEADING TO FEATURES PROLIFERATE











Braglia, Chen '20

Dalianis, G.P. Kodaxis, I.D. Stamou, N. Tetradis and A. Tsigkas-Kouvelis '21

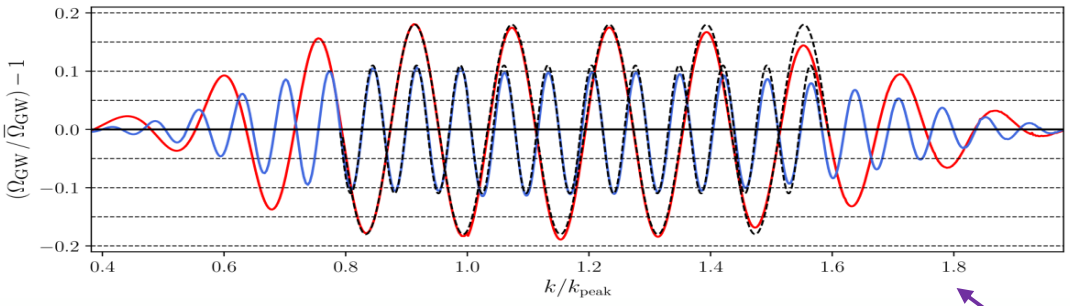
Battacharya, Zavala '22 ..

Addazzi, Capoziello, Gan '22

N. Mavromotos, V. Spanos, I. Stamou '22 ..

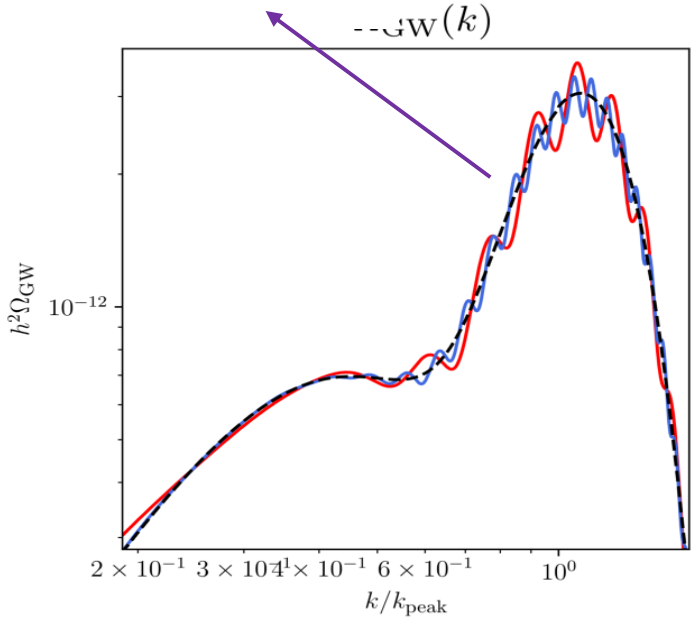
SIGNATURES IN THE (post-inflationary) SGWB

$$\Omega_{\rm GW}(k) \quad = \quad \overline{\Omega}_{\rm GW}\left(1+\mathcal{A}_{\rm lin}\cos\left(\omega_{\rm lin}^{\rm GW}k+\varphi_{\rm lin}\right)\right) \qquad \omega_{\rm lin}^{\rm GW}=\sqrt{3}\,\omega_{\rm lin}$$



WHAT CAN BE LEARNED FROM THE PATTERN

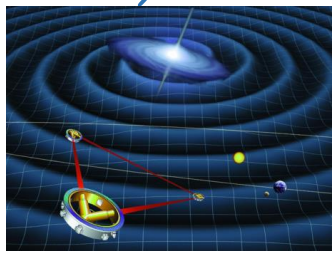
- ENERGY SCALE
- WHEN DURING INFLATION?
- FOR HOW LONG?
- COSMIC EXPANSION AT HORIZON RE-ENTRY



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

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

SEARCHING FOR FEATURES in LISA (HOMEMADE)

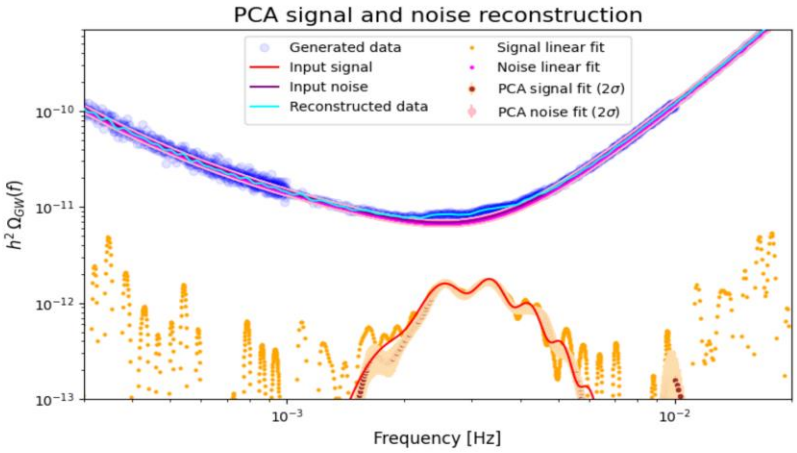


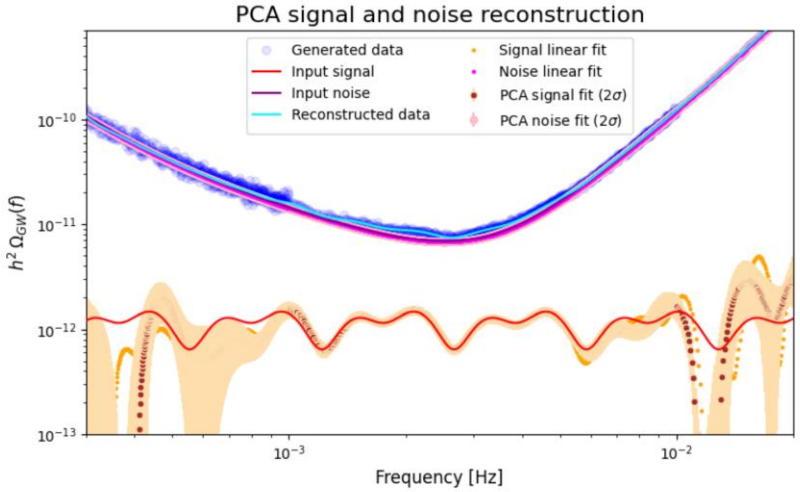
JF, S. Renaux-Petel, M. Pieroni, L. Witkowski JCAP 2112.09480

FISHER ANALYSIS: oscillations reconstructed at 10% if $h^2\Omega_{\rm GW} \gtrsim 10^{-12} - 10^{-11}$

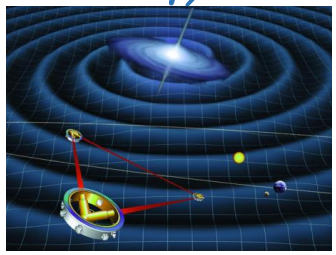
+ PCA reconstruction algorithm for a few benchmarks

M.Pieroni, E. Barausse '20





SEARCHING FOR FEATURES in LISA (with LISA CosWG)



within a wider project: "Inflation parameter estimation working package"

GOALS:

1. BUILD A TEMPLATE BANK FOR SGWB SIGNALS FROM INFLATION
2. AGNOSTIC SEARCH WITH BINNER Caprini et al. 1906.09244
3. FISHER FORECAST - SCAN OF THE TEMPLATE PARAMETER SPACE
4. MONTECARLO SAMPLING TO RECONSTRUCT SIGNALS from a few benchmark points

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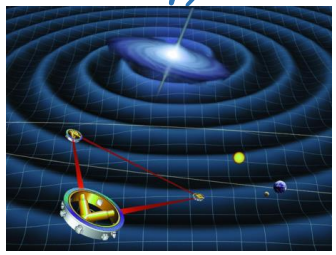

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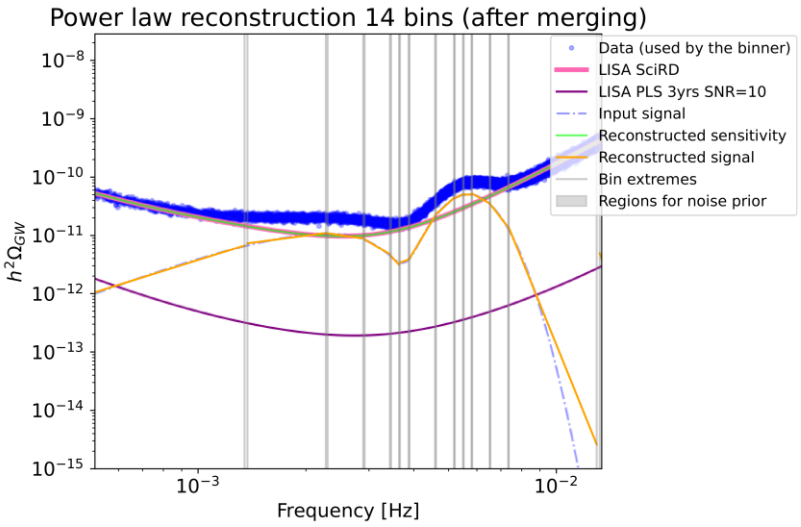

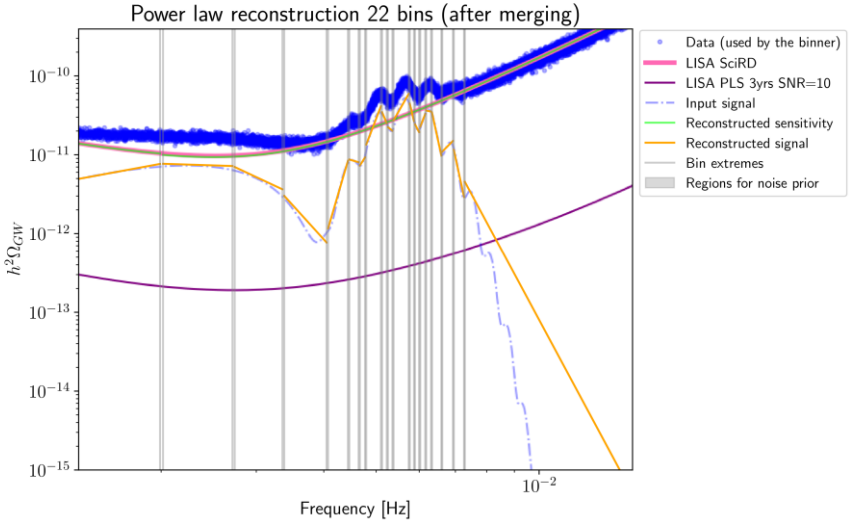

SEARCHING FOR FEATURES in LISA (with LISA CosWG)

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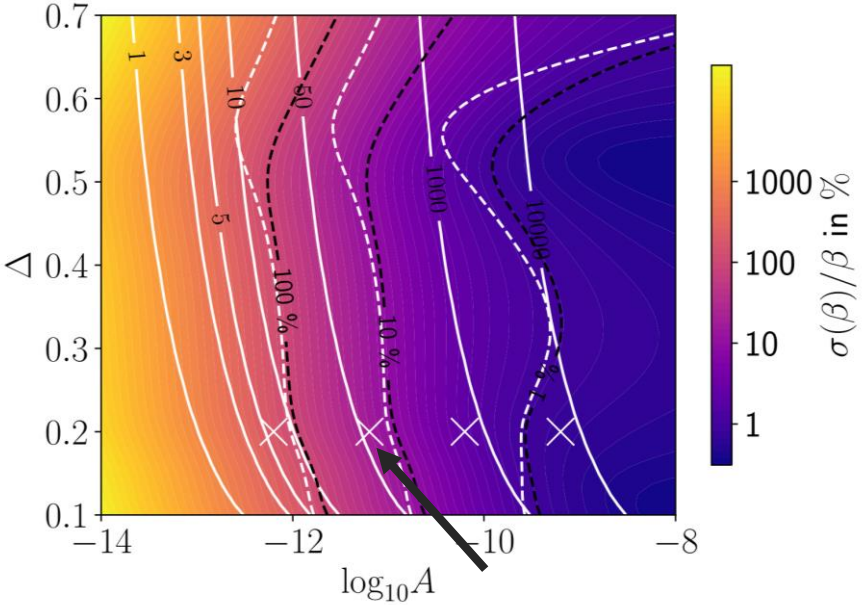
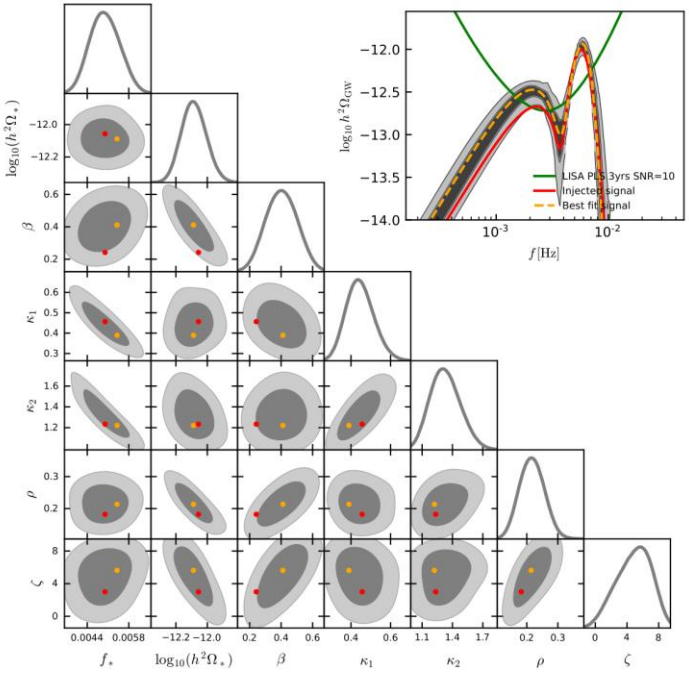
PEAK IN SPECTRUM



PRELIMINARY



SEARCHING FOR FEATURES in LISA (with LISA CosWG)

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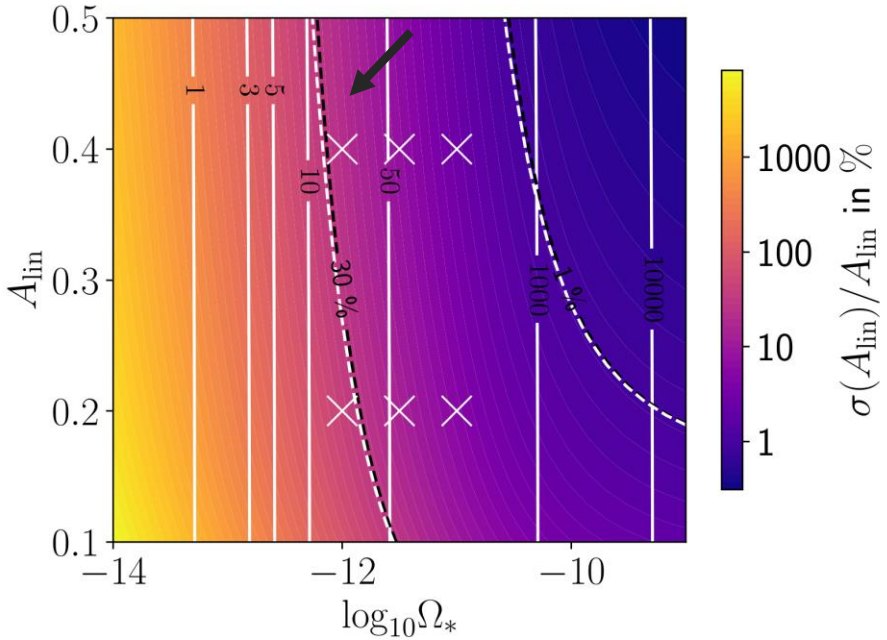
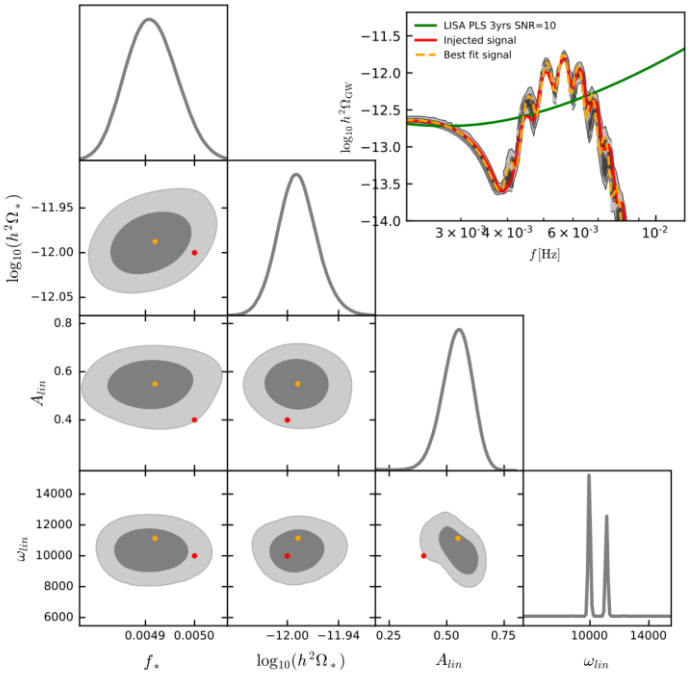
SHARP FEATURE





PRELIMINARY

CONCLUSIONS

FACT:

- STOCHASTIC BACKGROUND NEW WINDOW TO PROBE INFLATION at SMALL SCALES and TO SEARCH FOR PRIMORDIAL FEATURE

Huge amount of information hidden behind a possible discovery

PROSPECTS:

- DETECTABILITY WITH LISA AND OTHER GWS OBSERVATORIES UNDER INVESTIGATION

Many assumptions: Noise, Foreground etc.

To what extend we can reconstruct 10% oscillations?

- BUILDING CONSISTENT THEORETICAL FRAMEWORKS

SPECULATION:

- WAY TO DIFFERENTIATE COSMOLOGICAL AND ASTROPHYSICAL BACKGROUND? INDUCED ANISTOTROPIES? ....

BACKUP

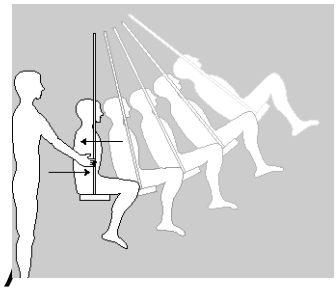
PRIMORDIAL FEATURES

- SHARP FEATURE - Localized Event

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

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

K periodic and a preferred scale selected $2/k_f$

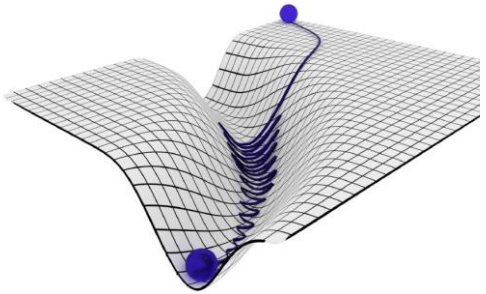


- RESONANT FEATURE - Oscillations of BkG

  (Ex. Monodromy inflation / double turn / in-out horizon

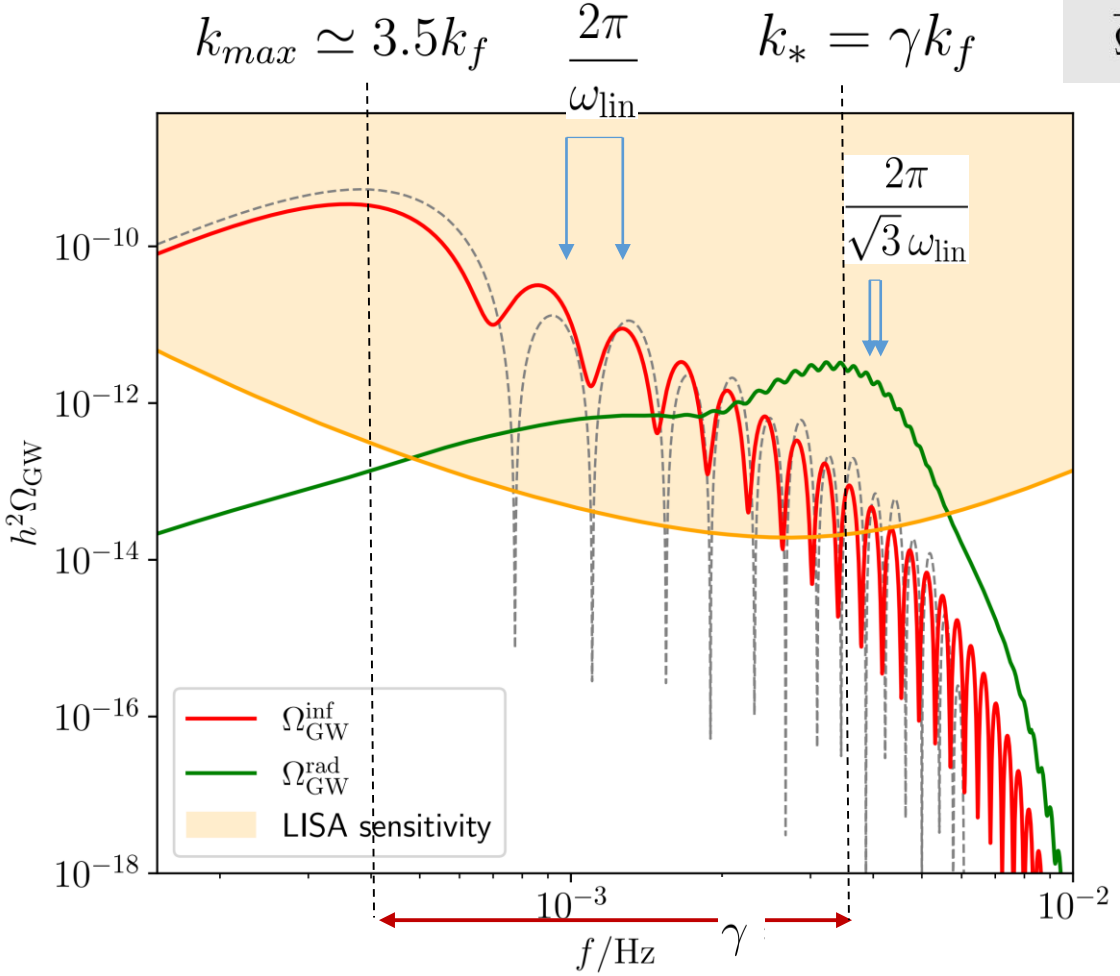
$$\mathcal{P}_\zeta(k) = \overline{\mathcal{P}}(k)\left(1 + A_{\log}\cos\left(\omega_{\log}\log(k/k_{\rm ref}) + \phi_{\log}\right)\right)$$

Log-K Periodic M/H



SPECTROSCOPY OF THE FULL SHARP FEATURE SIGNAL

$$\frac{\Omega_{\rm GW}^{\rm inf}|_{k_{\rm max}}}{\Omega_{\rm GW}^{\rm rad}|_{2k_*/\sqrt{3}}} = \mathcal{O}(1)10^{-2}\mathcal{N}^2\epsilon^2\gamma^5,$$



k_* : max power spectrum

k_f : scale corresponding to the emergence of the excited states

$$\omega = \frac{2}{k_f}$$

$$\gamma = \frac{k_*}{k_f} \gg 1$$

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