SEARCHING FOR PRIMORDIAL FEATURES WITH LISA

JACOPO FUMAGALLI (ICCUB)

LIDA WORKSHOP - Toulouse

21st – 25th November 2022

Based on

2012.02761, 2105.06481, 2110.09480, 2111.14664, 2112.06903

with S. Renaux-Petel & L. T. Witkowski,

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

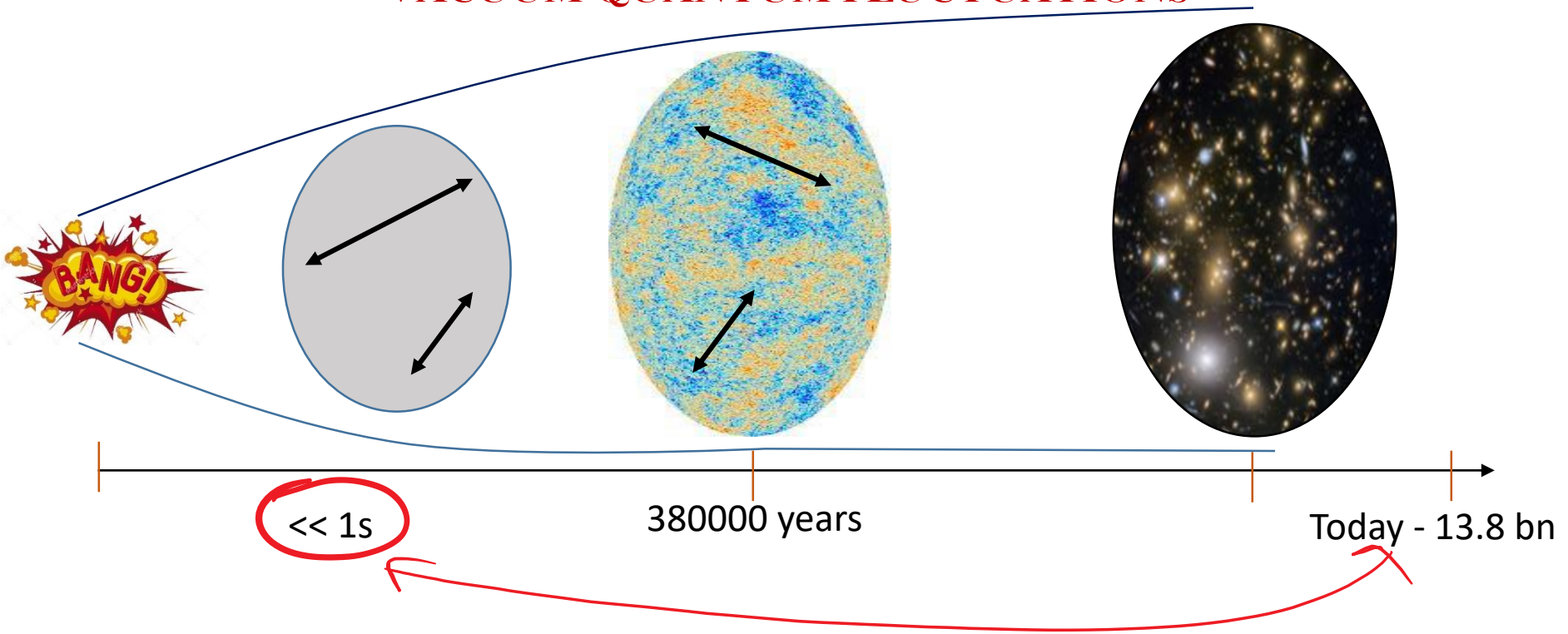
+ Work in Progress with CosWG LISA

ICCUB | Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA

EXCELENCIA MARÍA DE MAEZTU 2020-2023

INFLATION: WINDOW IN THE EARLY UNIVERSE

STRUCTURE IN THE UNIVERSE EMERGE FROM VACUUM QUANTUM FLUCTUATIONS



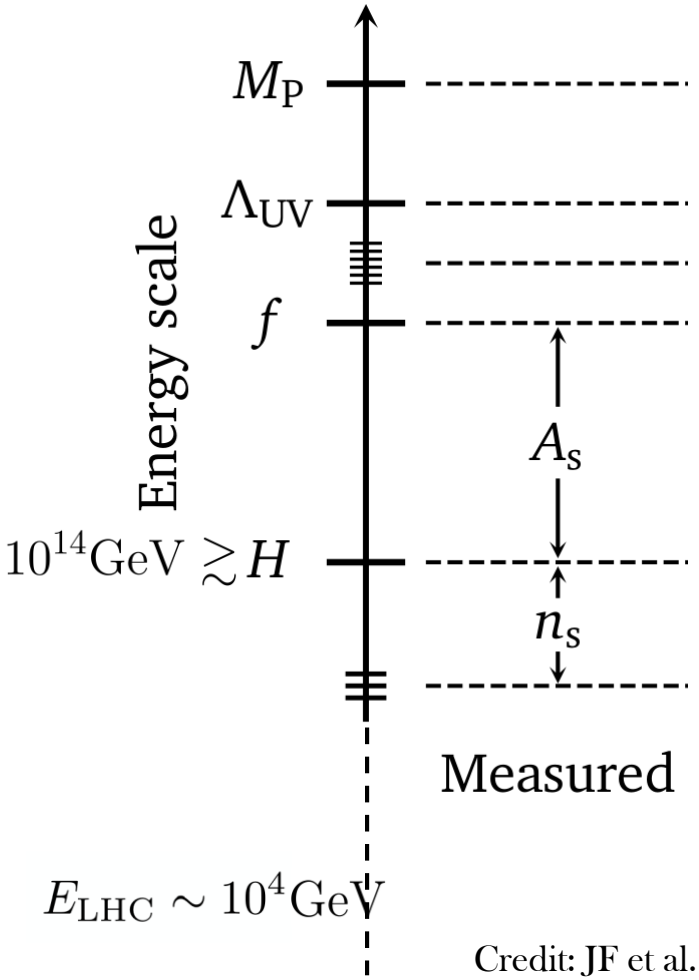
Perturbations: Almost scale-invariant, Gaussian, super-Horizon...

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

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

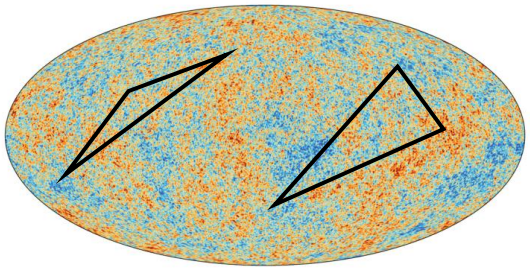
$$n_s \sim 0.9649$$

PROBING THE HIGHEST POSSIBLE ENERGY SCALES



Credit: JF et al.
Snowmass white paper

1) DEPARTURE FROM GAUSSIAN STATISTICS...

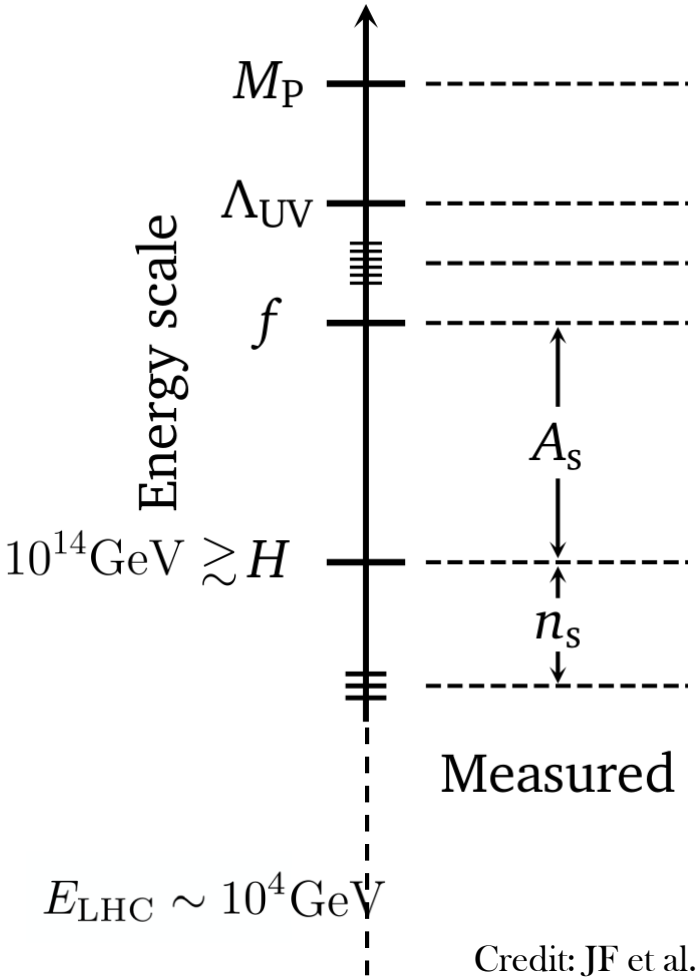


$$\langle \zeta_{k_L} \zeta_{k_S} \zeta_{k_S} \rangle \sim \left(\frac{k_L}{k_S}\right)^{3/2} \cos\left[\frac{m}{H} \log\left(\frac{k_L}{k_S}\right)\right] \mathbb{P}_S(\cos\theta)$$

..COLLIDER PHYSICS: mass & spin from specific limits of the three point function

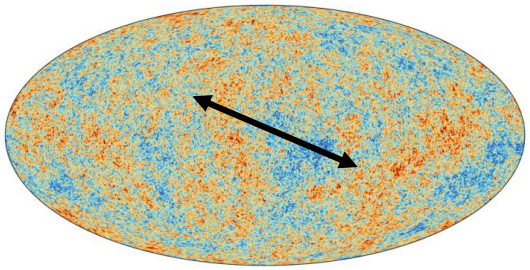
Chen, Wang '09
Baumann, Green '11
Arkani-Hamed, Maldacena '15
Baumann, Lee, Piementel ''16

PROBING THE HIGHEST POSSIBLE ENERGY SCALES



Credit: JF et al.
Snowmass white paper

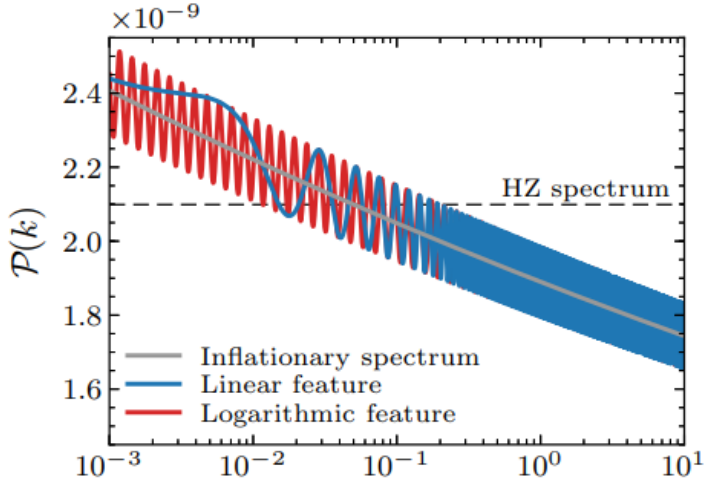
2) DEPARTURE FROM SCALE INVARIANCE



PRIMORDIAL FEATURES

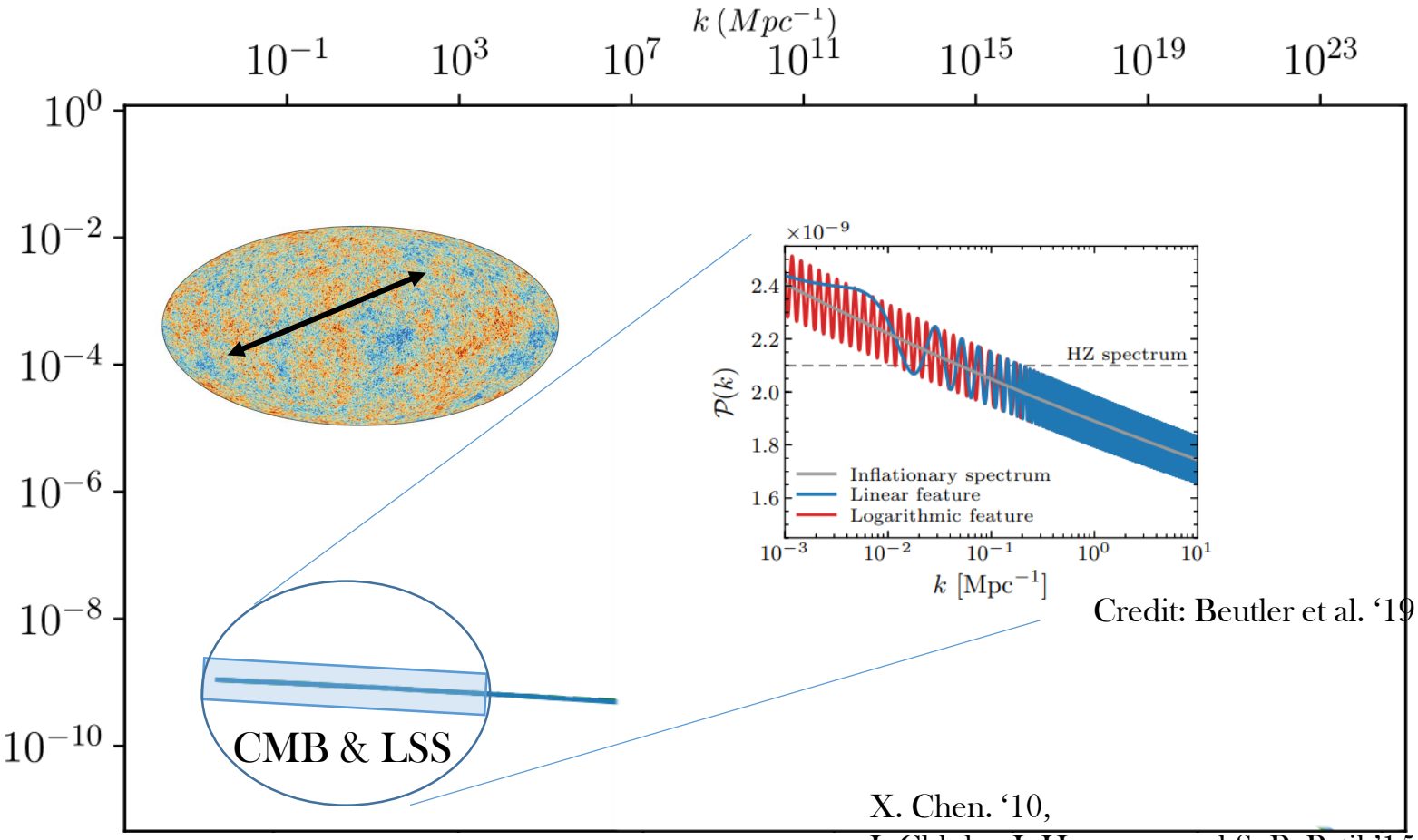
OSCILLATIONS IN THE PRIMORDIAL POWER SPECTRUM

- Probing new mass scales, new couplings
& even the inflationary paradigm...



Credit: Beutler et al. '19

LARGE SCALE FEATURES: CMB & LSS



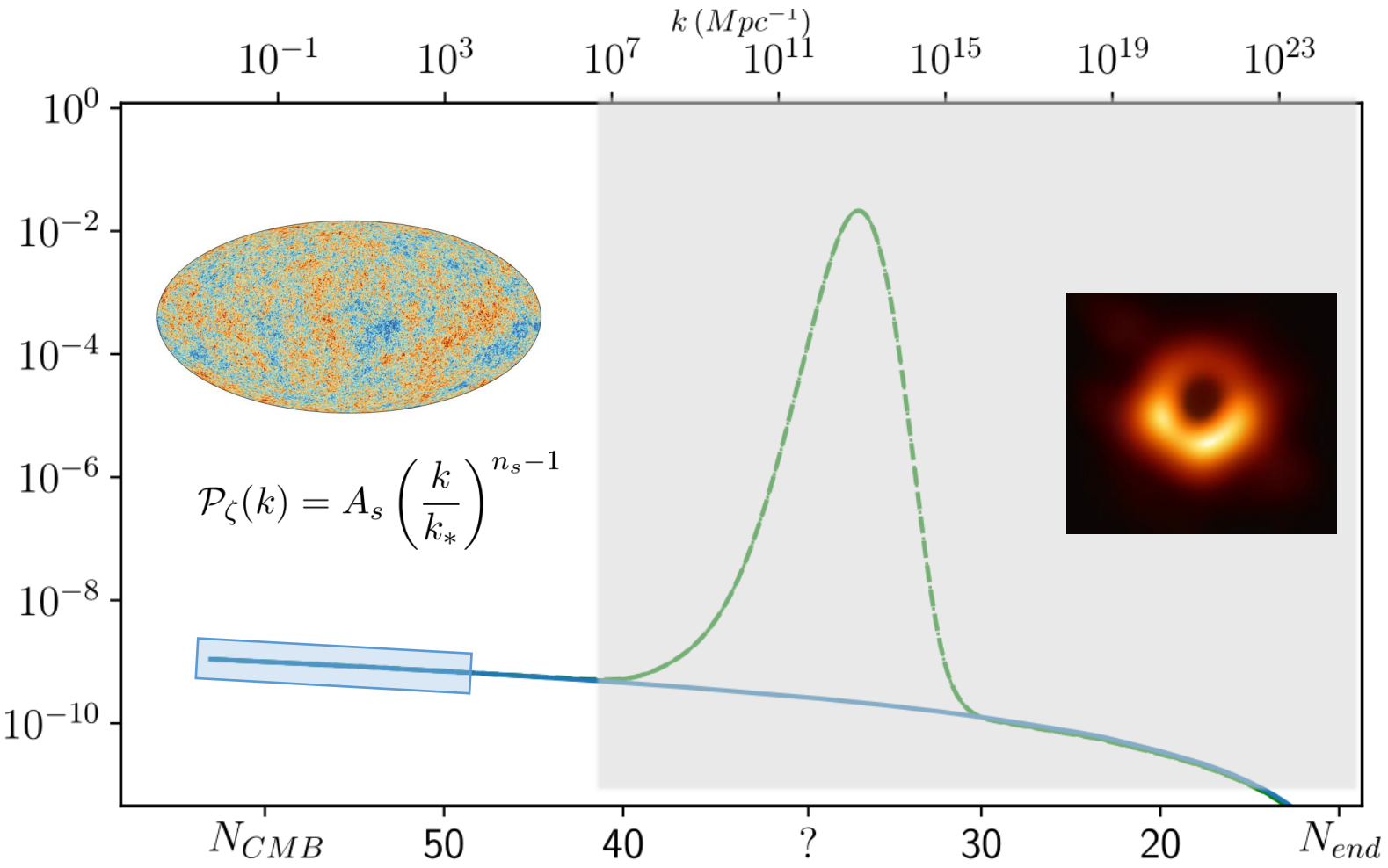
Credit: Beutler et al. '19

Constrained at large scales

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

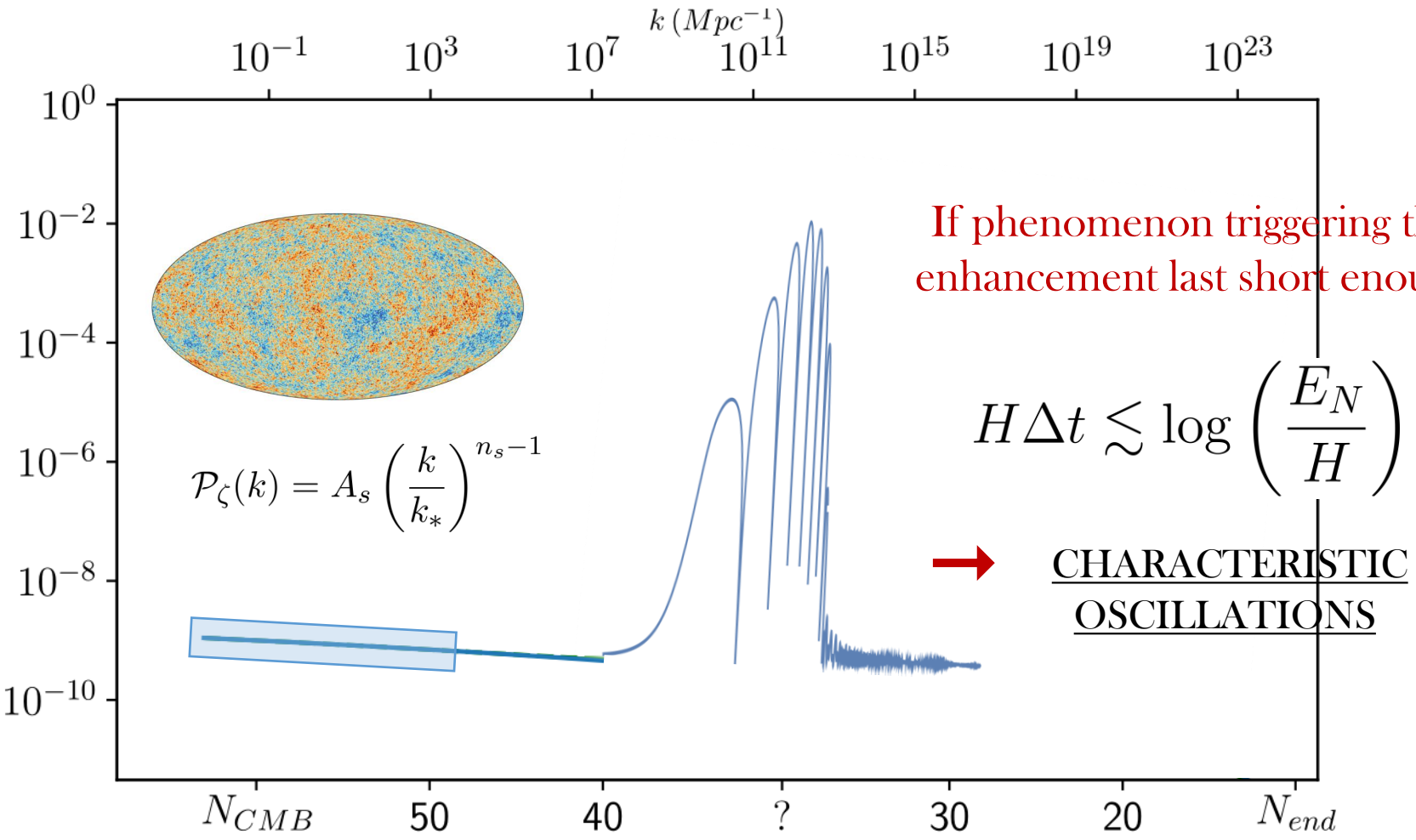
DEVIATION FROM SCALE INVARIANCE AT SMALL SCALES

... an all industry motivared by dark matter in the form of PBH



PRIMORDIAL FEATURES AT SMALL SCALES

... an all industry motivared by dark matter in the form of PBH



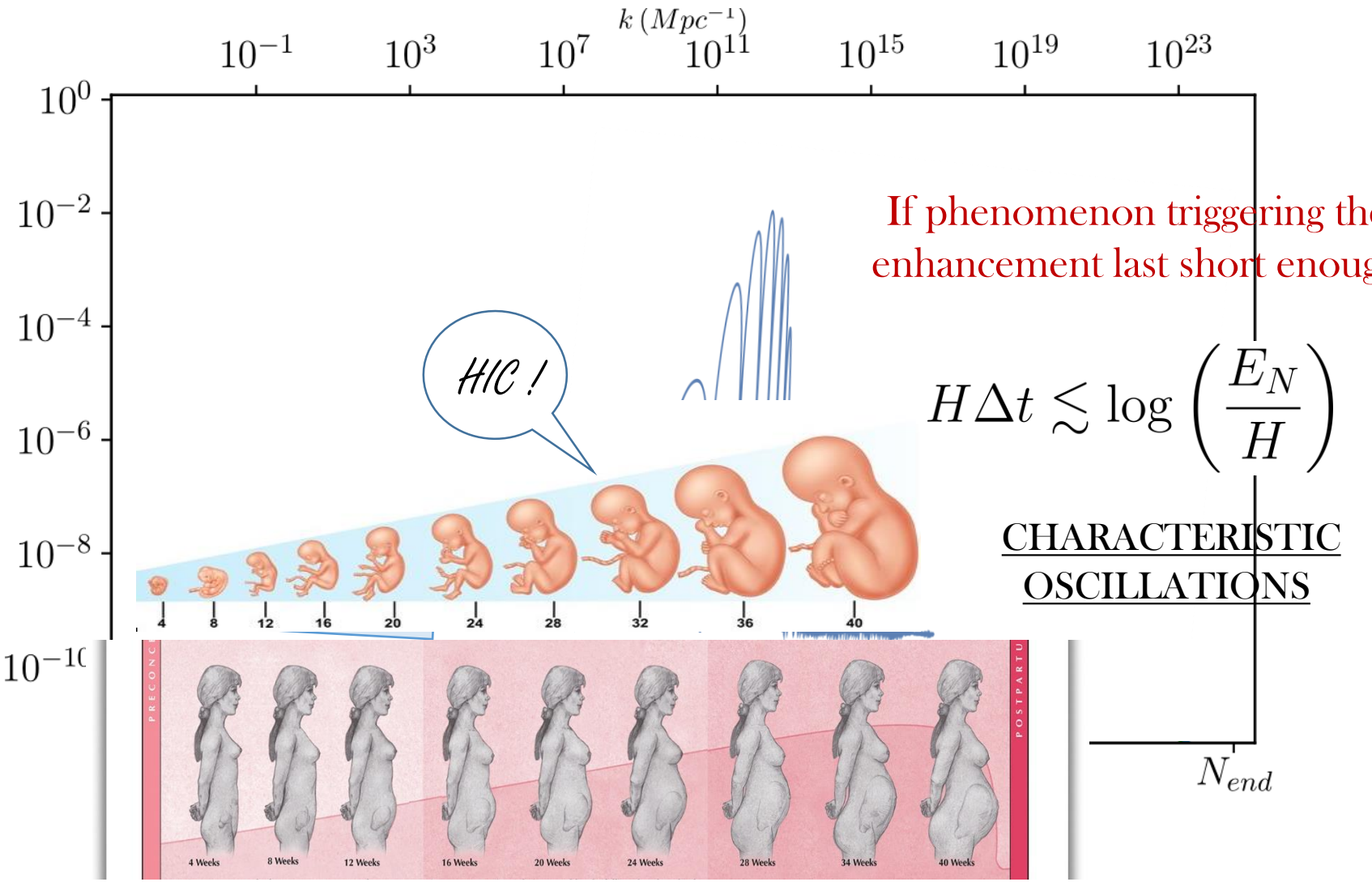
If phenomenon triggering the enhancement last short enough

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

→ CHARACTERISTIC OSCILLATIONS

PRIMORDIAL FEATURES AT SMALL SCALES

... Waiting for an HICCUPS IN THE WOMB ...



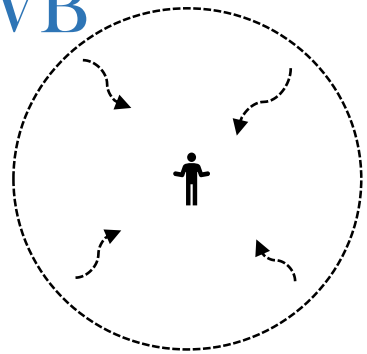
If phenomenon triggering the enhancement last short enough

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

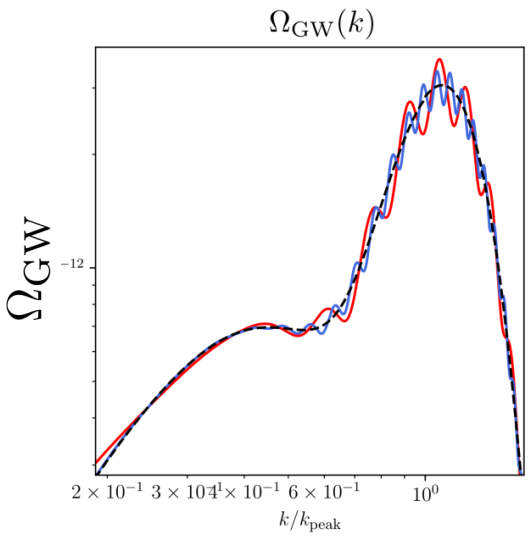
CHARACTERISTIC OSCILLATIONS

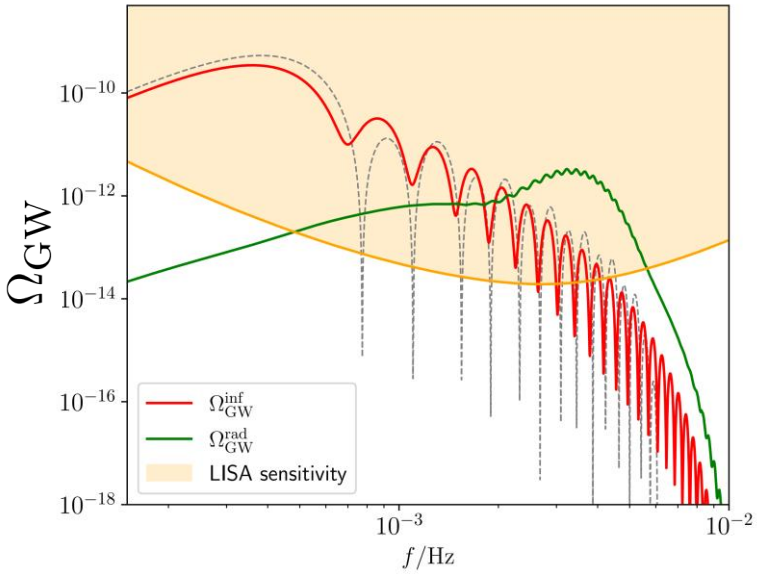
SMALL SCALE FEATURES in the SGWB

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

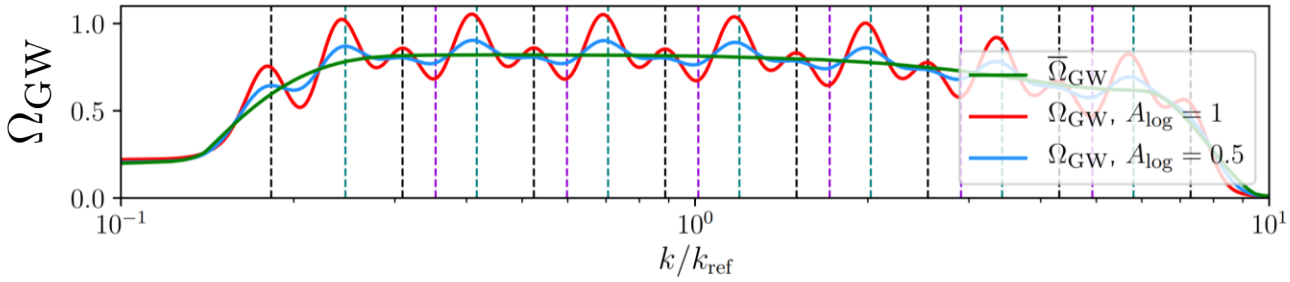


SHARP FEATURES





RESONANT FEATURES



JF et al.

2012.02761,

2105.06481,

2110.09480,

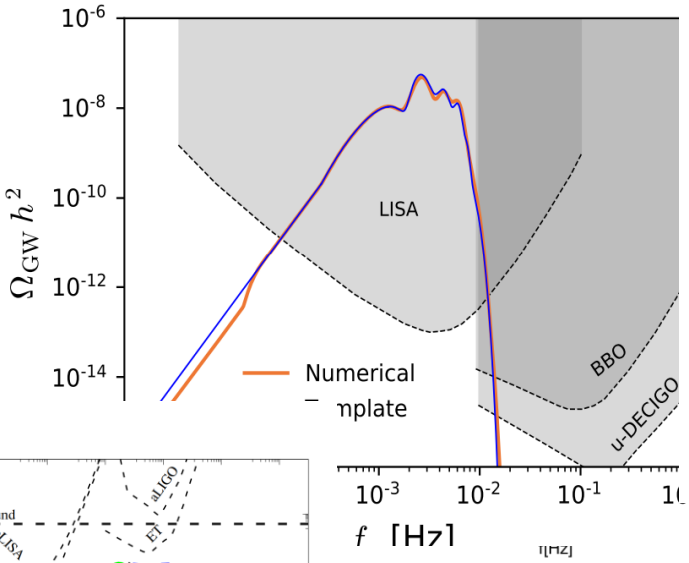
2111.14664,

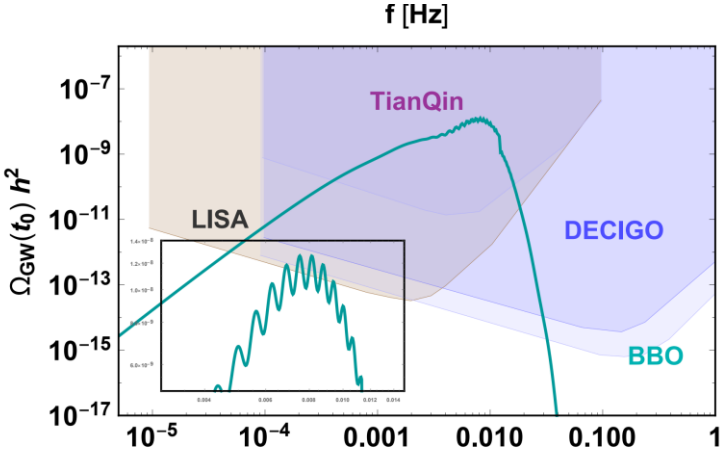
2112.06903

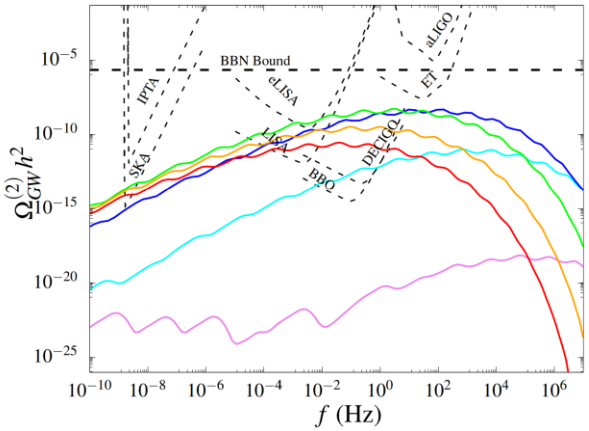
...

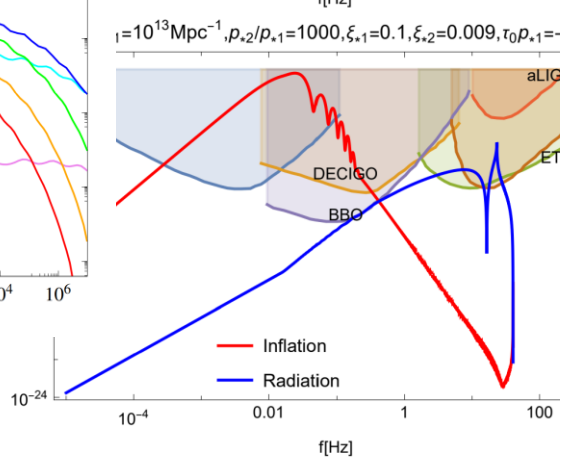
After first proposal 2012.02761

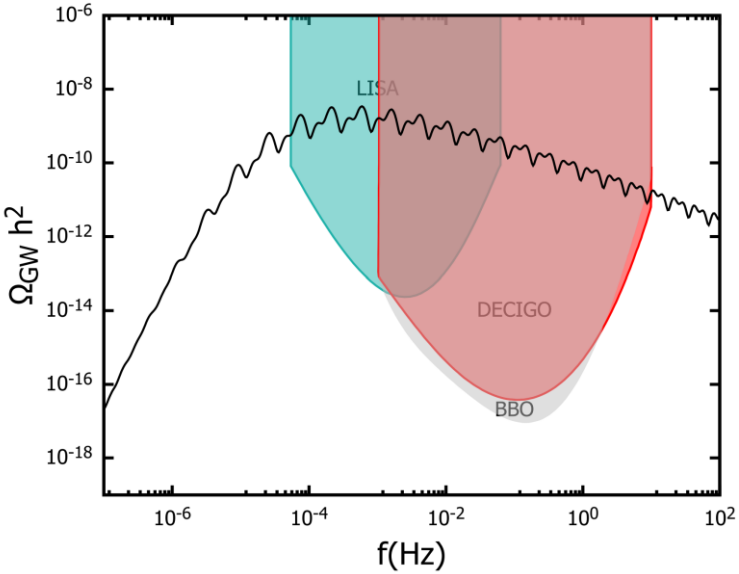
EXPLICIT MODELS LEADING TO FEATURES PROLIFERATE









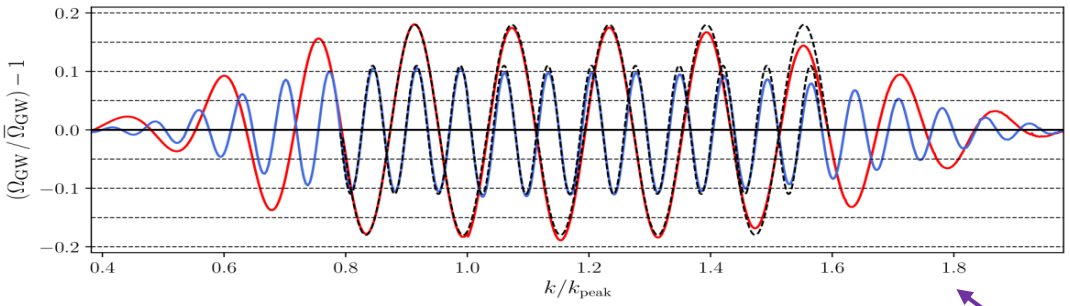


Braglia, Chen '20
Dalianis, G.P. Kodaxis, I.D. Stamou, N. Tetradis and A. Tsigkas-Kouvelis '21
Battacharya, Zavala '22 ..

Addazzi, Capoziello, Gan '22
N. Mavromotos, V. Spanos, I. Stamou '22 ..

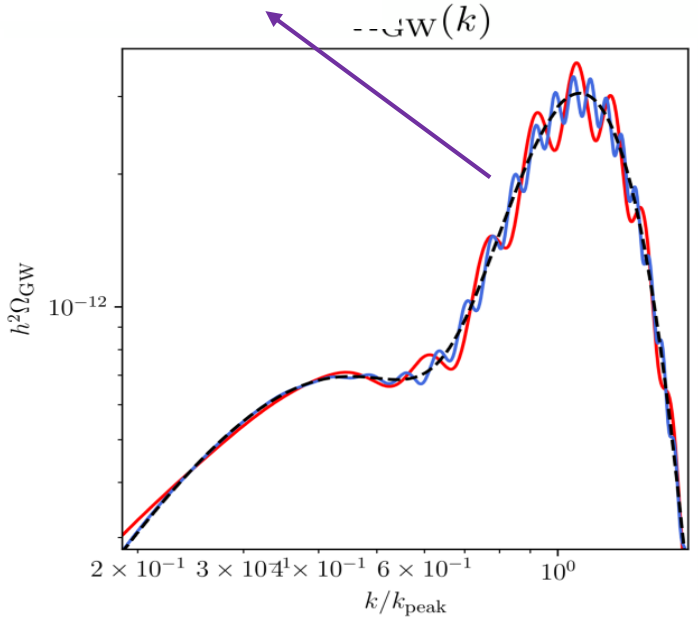
SIGNATURES IN THE (post-inflationary) SGWB

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



WHAT CAN BE LEARNED FROM THE PATTERN

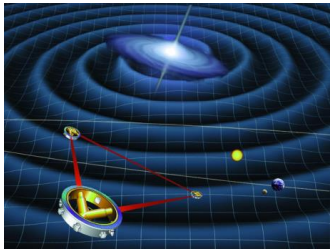
- Energy scale
- When and for how long during inflation?
- Cosmic expansion at horizon re-entry



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)

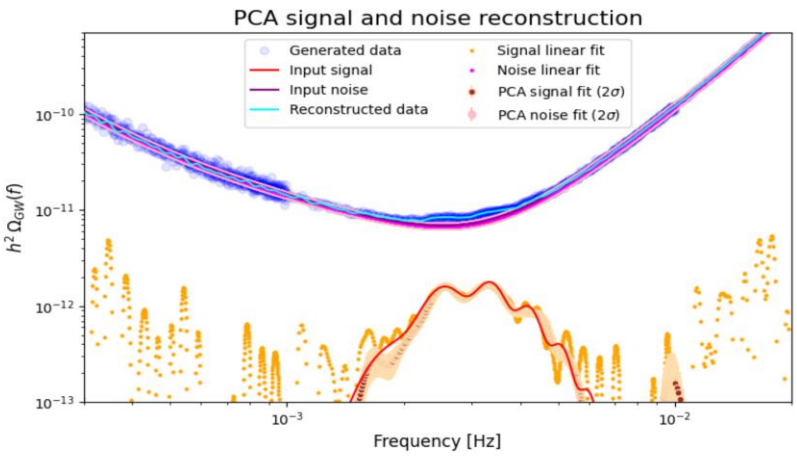


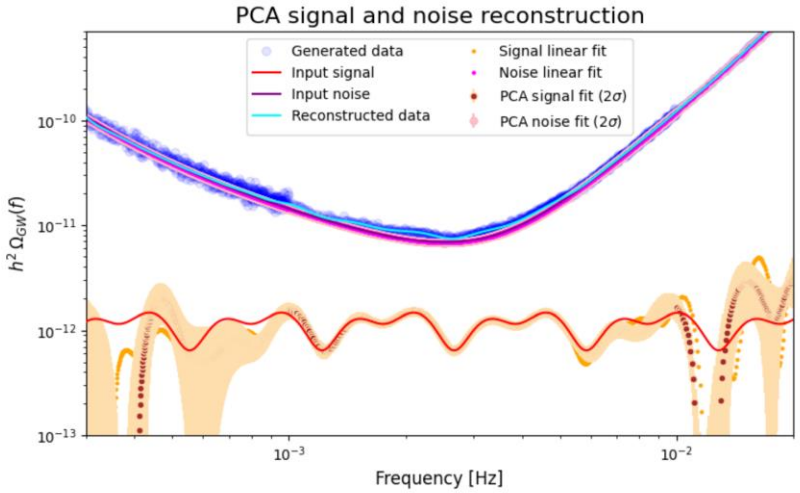
JF, S. Renaux-Petel, M. Pieroni, L. Witkowski JCAP 2112.09480

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

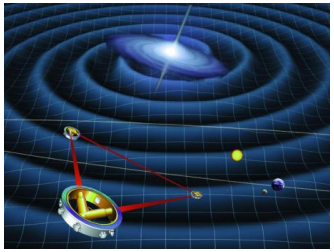
+ PCA reconstruction algorithm for a few benchmarks

M.Pieroni, E. Barausse '20





SEARCHING FOR FEATURES in LISA (with LISA CosWG)



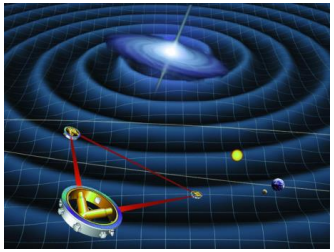
within a wider project: "Inflation parameter estimation working package"

GOALS:

1. Build a template bank for sgwb signals from inflation
2. Agnostic search with Binner algorithm 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

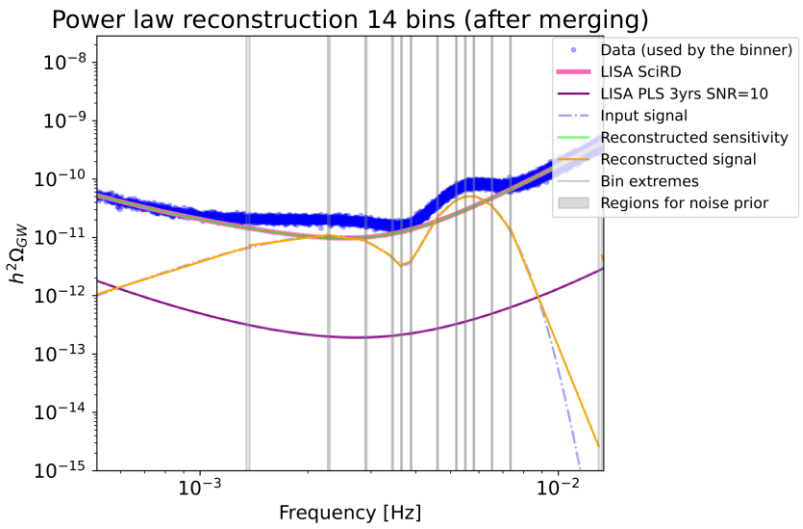
SEARCHING FOR FEATURES in LISA (with LISA CosWG)

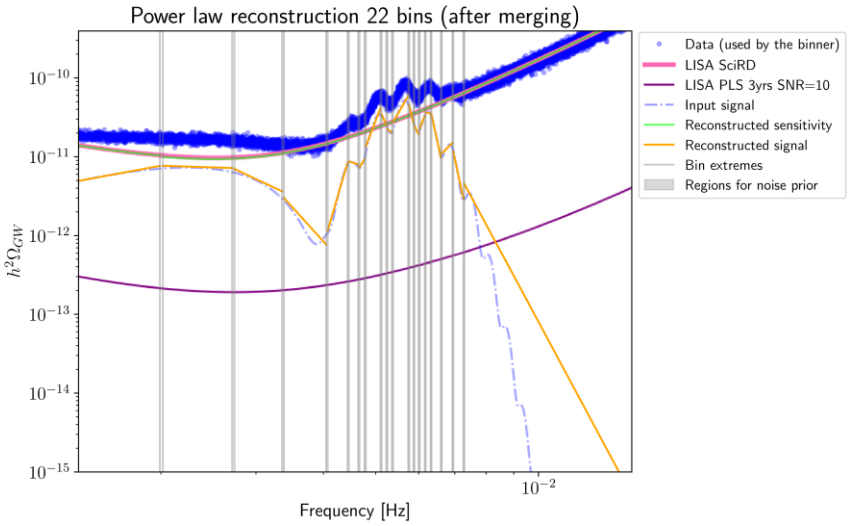
within a wider project: "Inflation parameter estimation working package"



GOALS:

1. Build a template bank for sgwb signals from inflation
2. Agnostic search with Binner algorithm 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

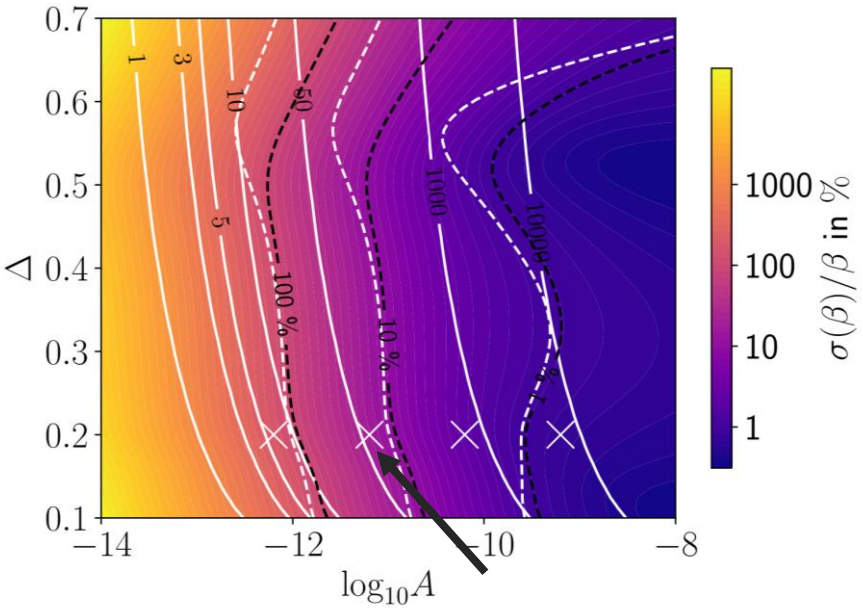




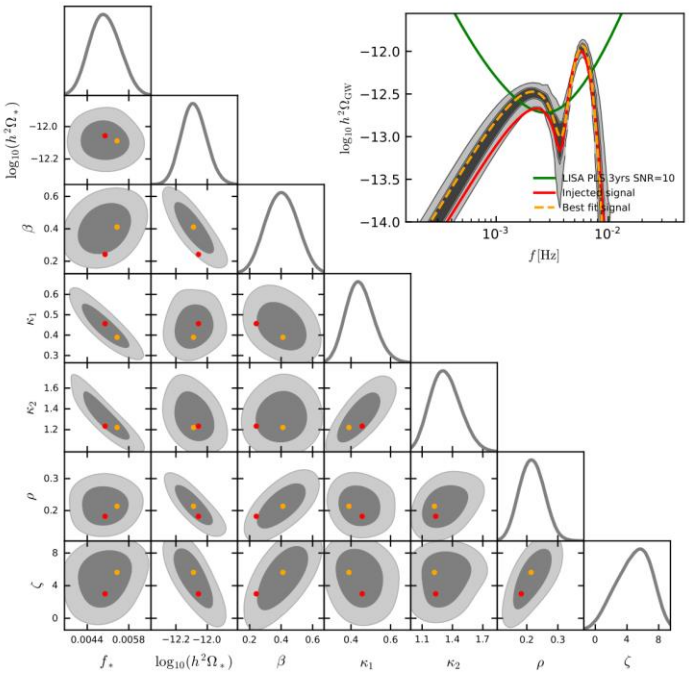
SEARCHING FOR FEATURES in LISA (with LISA CosWG)

3. Fisher forecast – scan of the template parameter space
4. Montecarlo sampling to reconstruct signals from a few benchmark points

PEAK IN SPECTRUM



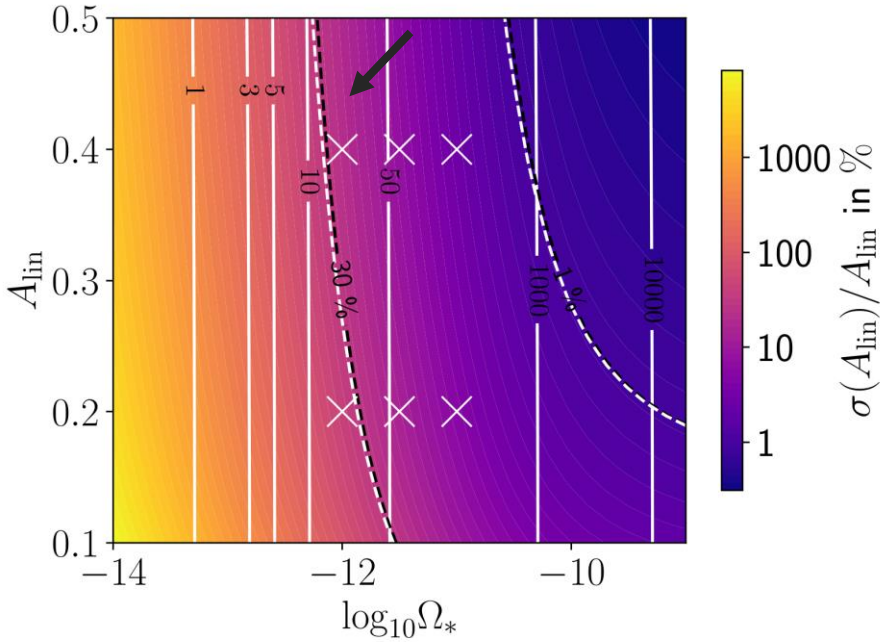
PRELIMINARY

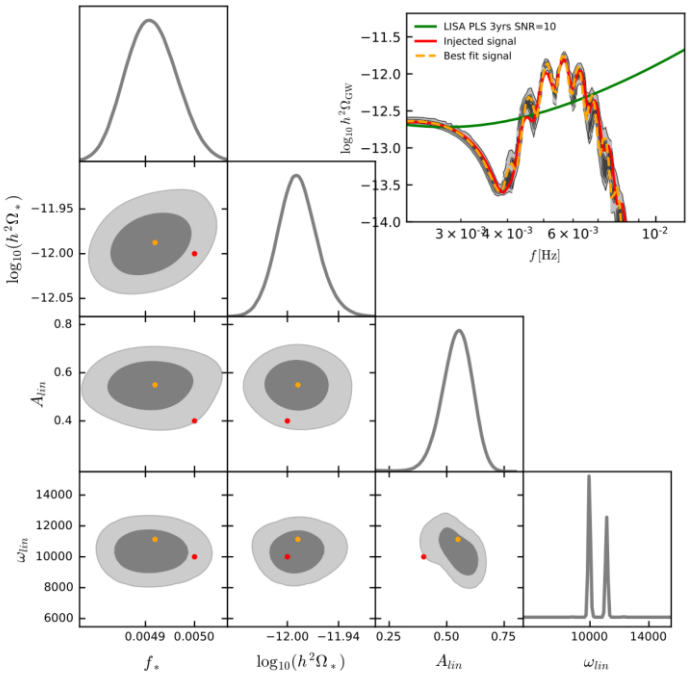


SEARCHING FOR FEATURES in LISA (with LISA CosWG)

3. Fisher forecast – scan of the template parameter space
4. Montecarlo sampling to reconstruct signals from a few benchmark points

SHARP FEATURE





PRELIMINARY

CONCLUSIONS

FACT:

- Stochastic background new window to probe inflation at small scales and to search for primordial features

  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

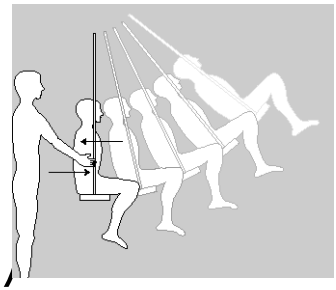
PRIMORDIAL FEATURES

- 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