COSMOLOGICAL GRAVITATIONAL WAVE BACKGROUND:
From theoretical modeling to detection prospects

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WINTER MEETING

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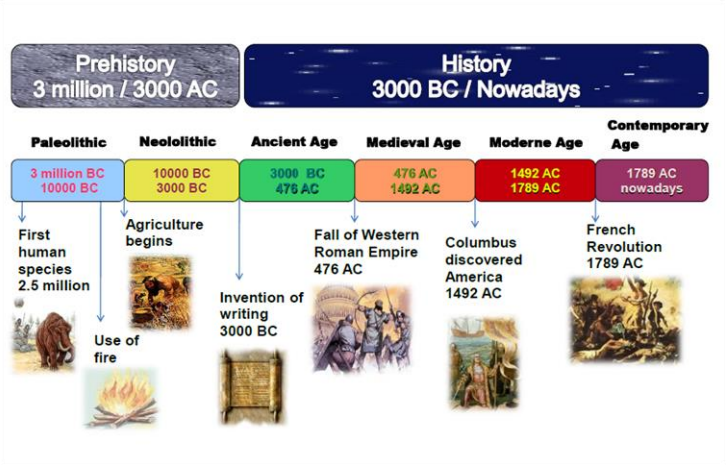
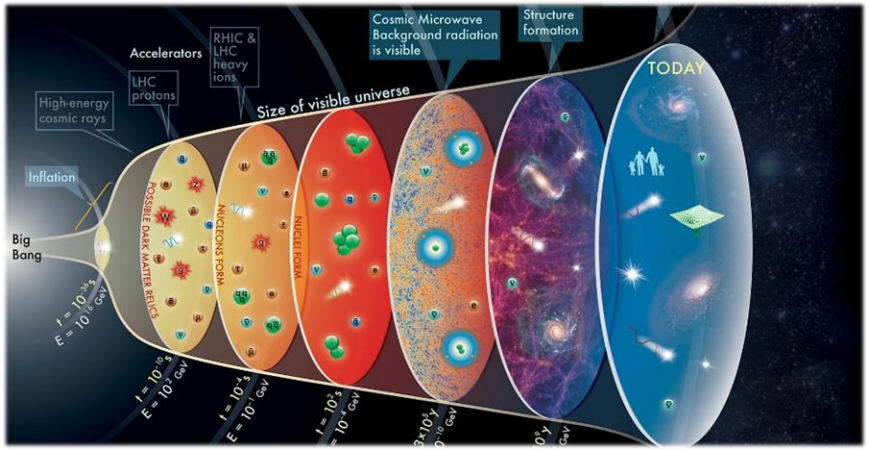
ICCUB

Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA

EXCELENCIA MARÍA DE MAEZTU 2020-2023

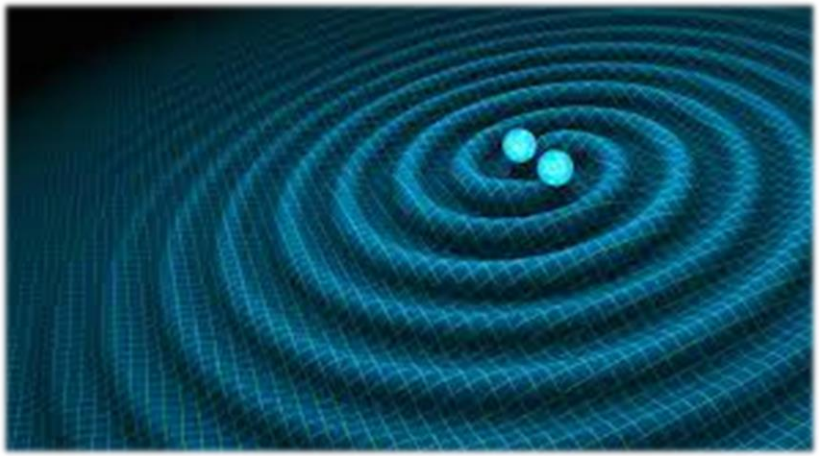
COSMIC ARCHAEOLOGY

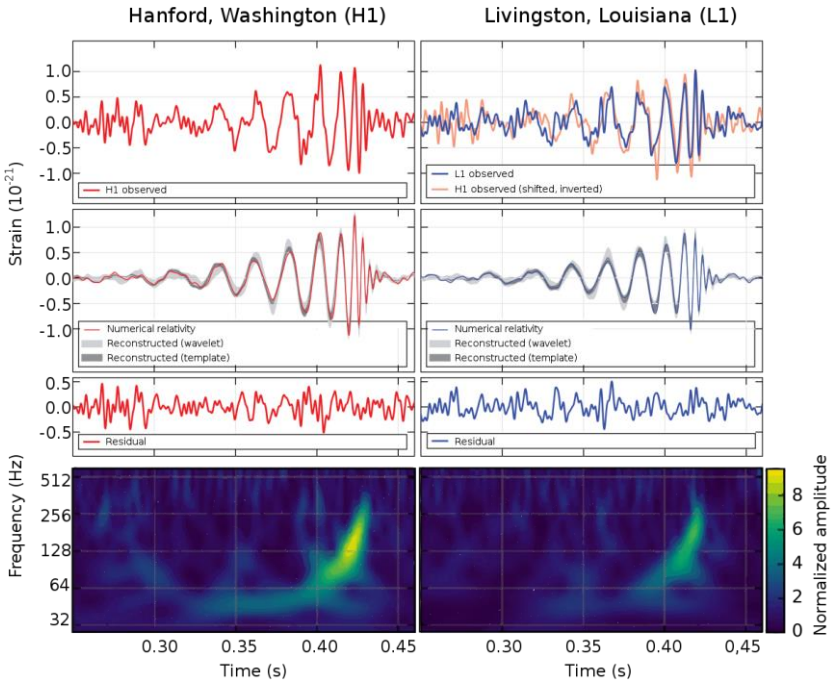




COSMIC ARCHAEOLOGY with GWs

GW150914 - The first direct detection of gravitational waves ...

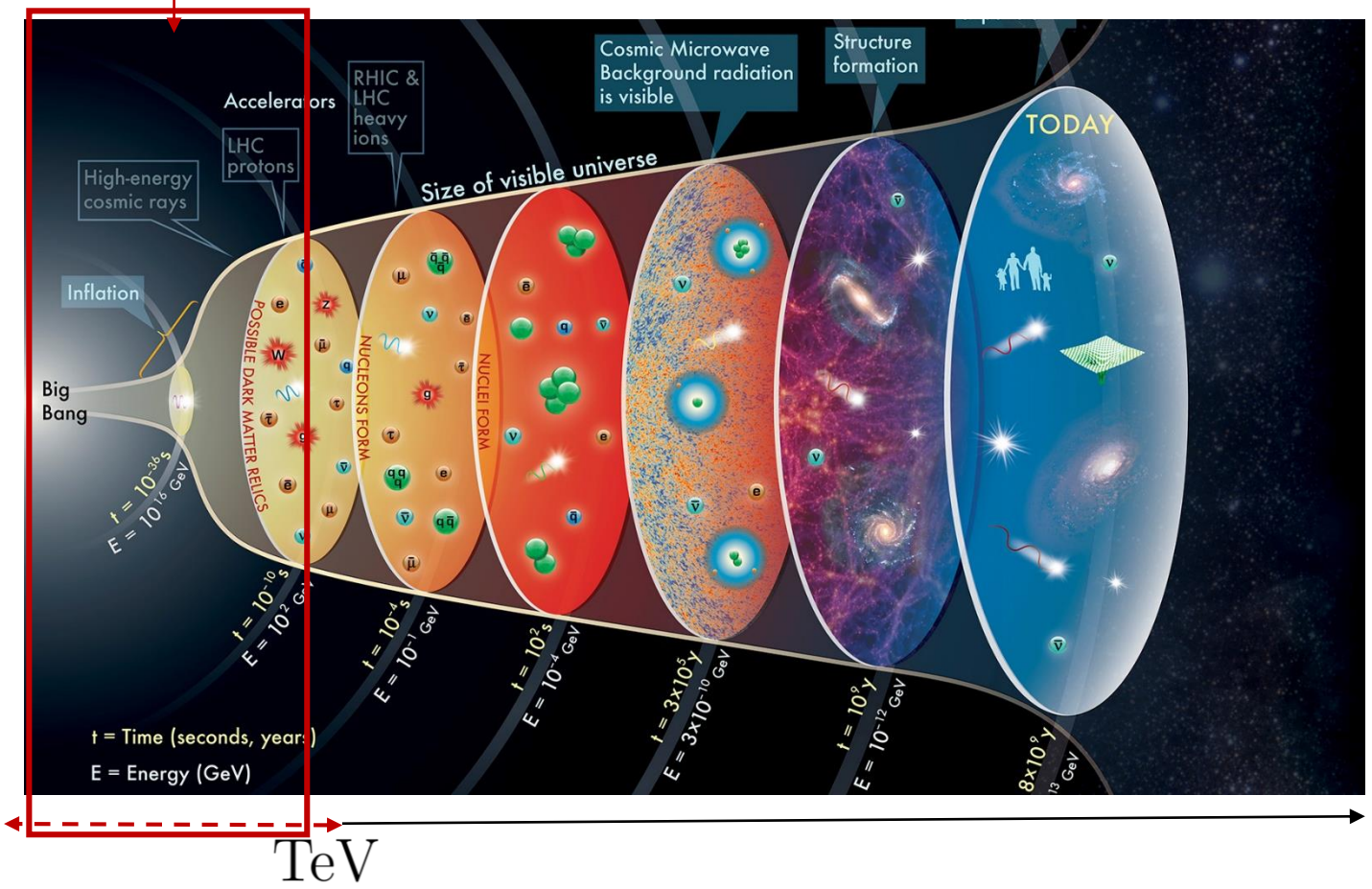




COSMIC ARCHAEOLOGY: SNAPSHOTS

UNKNOWN PHYSICS

Decoupling: $\Gamma \simeq H$



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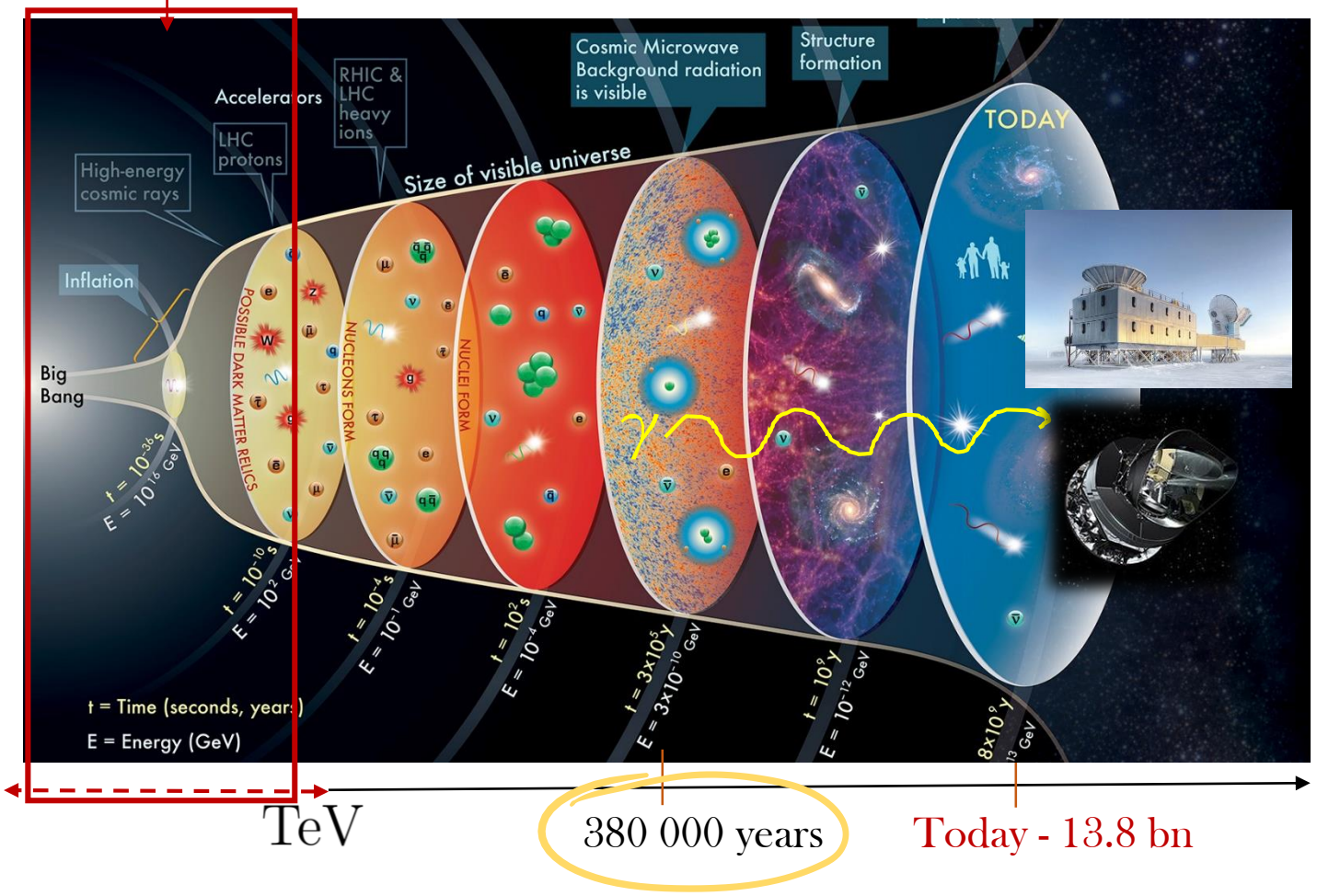

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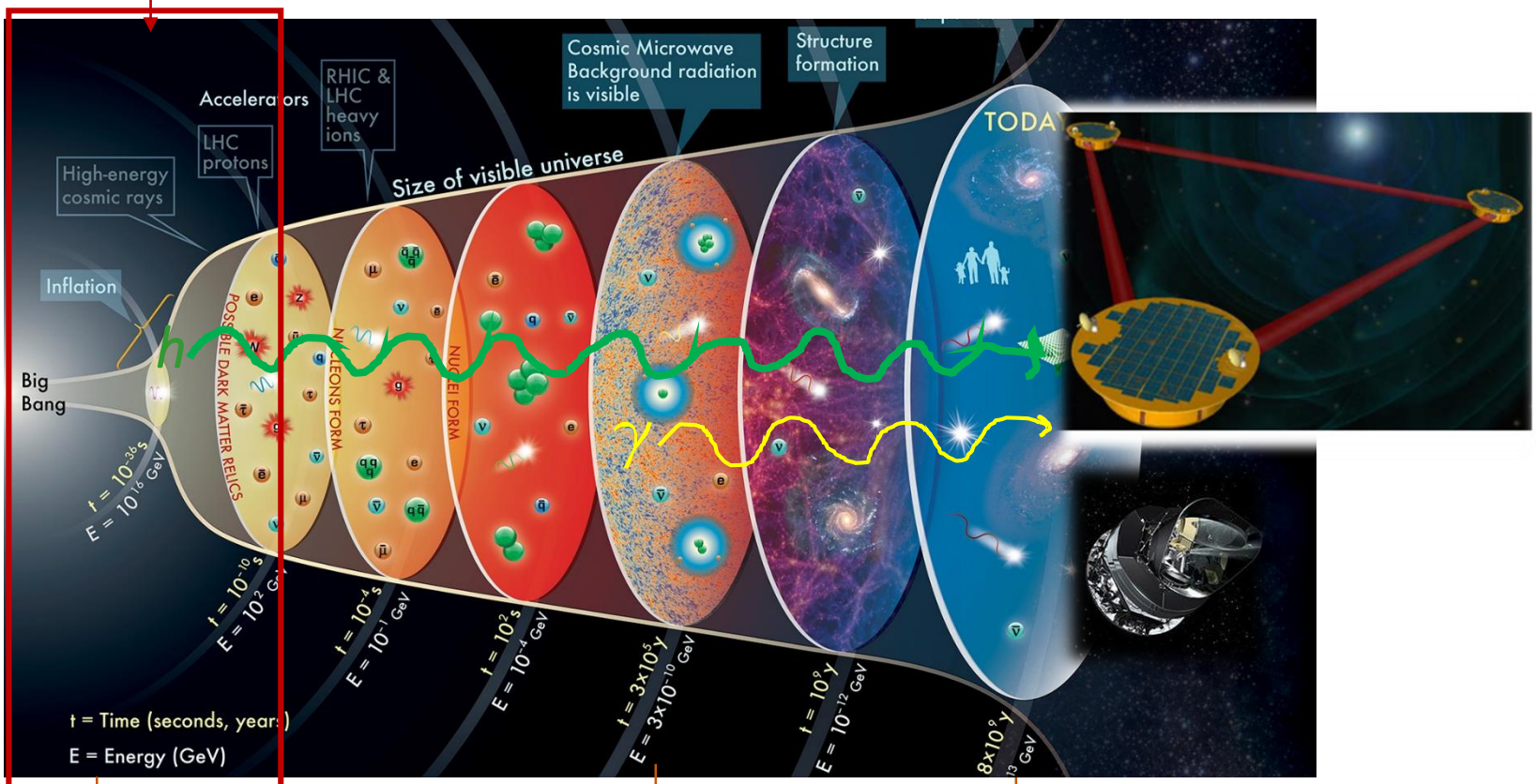


$M_{\rm pl} > T$

Gravitons keep memory of the very early universe!

STOCHASTIC BACKGROUND OF GWS

Caprini and Figueroa '18

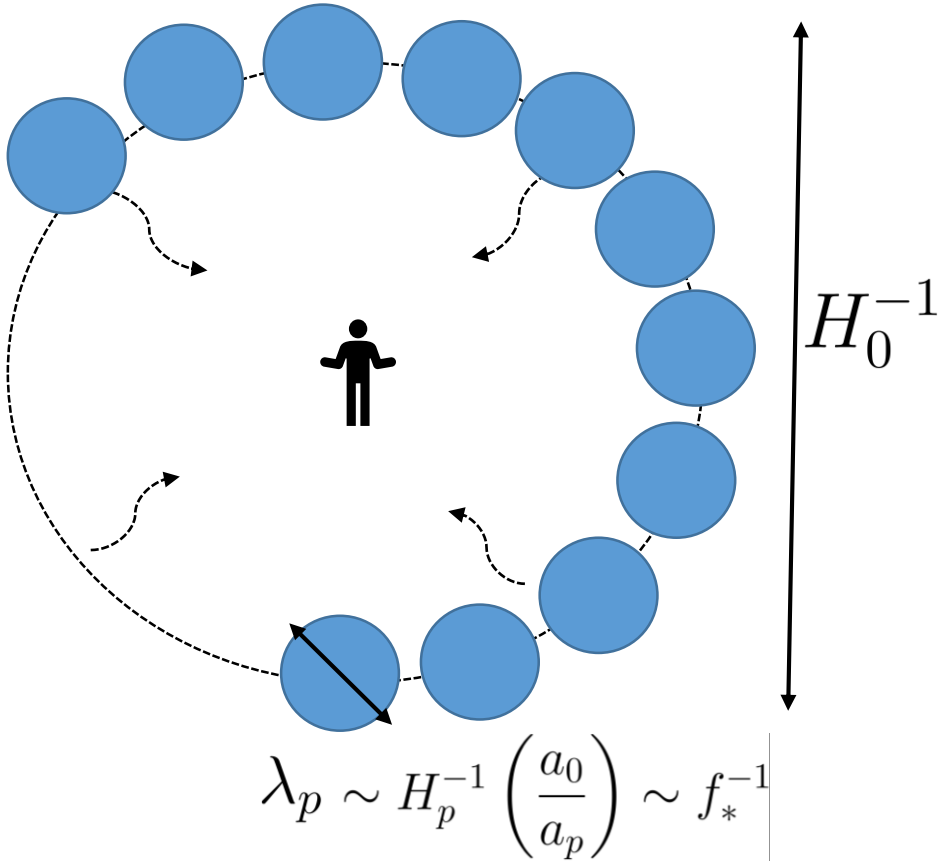
- Angular size on the sky (today) of a correlated region at the time of production $\ll$ detector resolution

  For instance, EW phase transition
  $T_{\rm EW} \sim O(10^2)\,{\rm GeV}$
  $\Longrightarrow$ 10^{24} uncorrelated regions
  with resolution $\Theta_{\rm Res} \sim 10\,{\rm deg}$
  $\Longrightarrow$ $z \lesssim 17$

- Characteristic frequency associated to the time of production/experiment

- $h_{ij} \longleftrightarrow$ STOCHASTIC VARIABLE

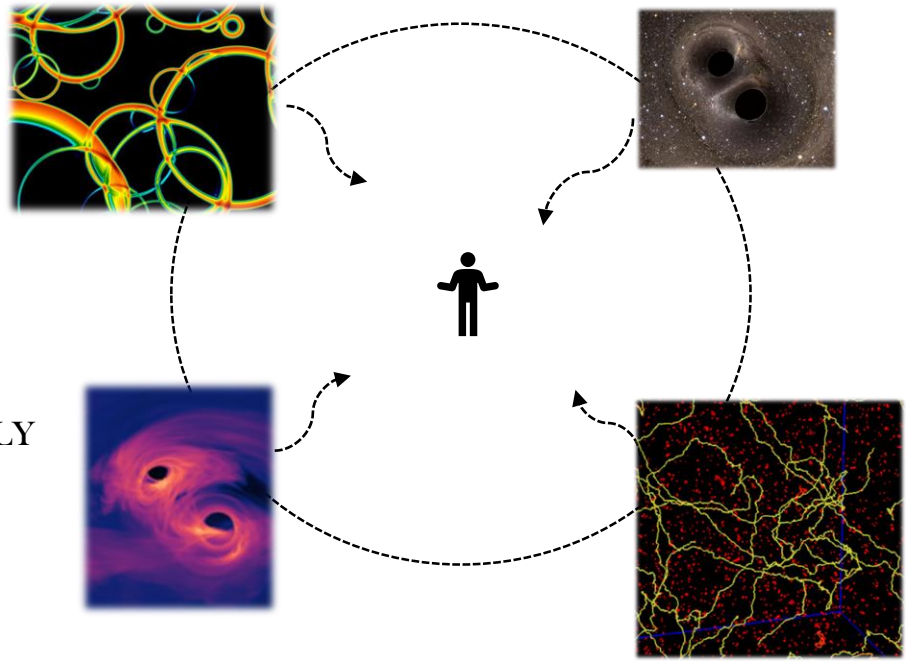
$$\Omega_{\rm GW}(k) = \frac{1}{\rho_c}\frac{d\rho_{\rm GW}}{d\ln k}$$



STOCHASTIC BACKGROUND OF GWS

STOCHASTIC BACKGROUND OF GWS

Random signal produced by many independent and unresolved sources



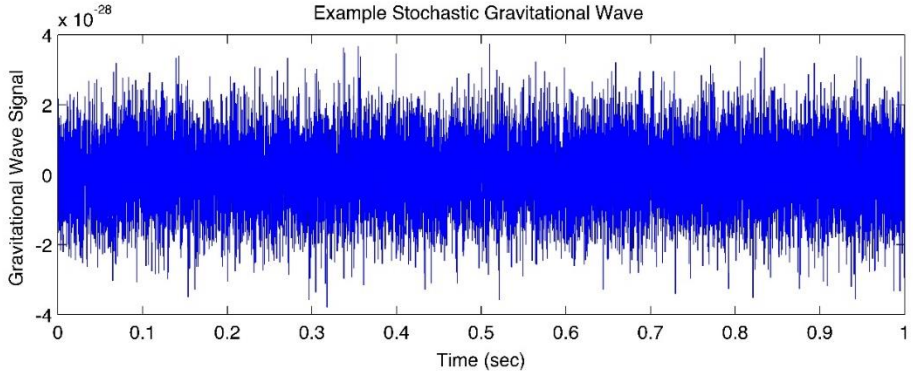
- ASTROPHYSICAL

CBCS, CORE COLLAPSE SUPERNOVAE, EARLY INSPIRAL PHASE OF COMPACT BINARIES...

- COSMOLOGICAL

EARLY UNIVERSE PROCESSES: INFLATION, FIRST ORDER PHASE TRANSITIONS, TOPOLOGICAL DEFECTS..

Searches in ground (LVK) and future space interferometers (LISA etc.)

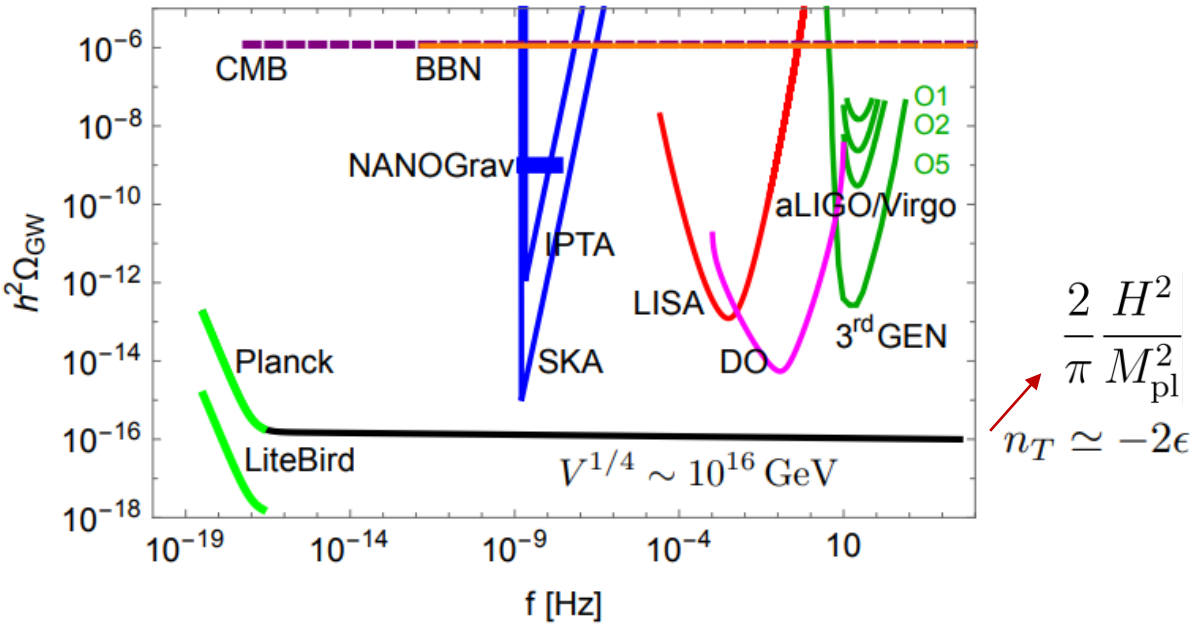


SGWB FROM INFLATION:

the Holy Grail of Theoretical cosmology

Standard: enhancement of the vacuum fluctuations due to the inflationary exp. Expansion

$$\Box h_{ij} = 0$$



$$\frac{2}{\pi}\frac{H^2}{M_{\rm pl}^2}$$

$$n_T \simeq -2\epsilon$$

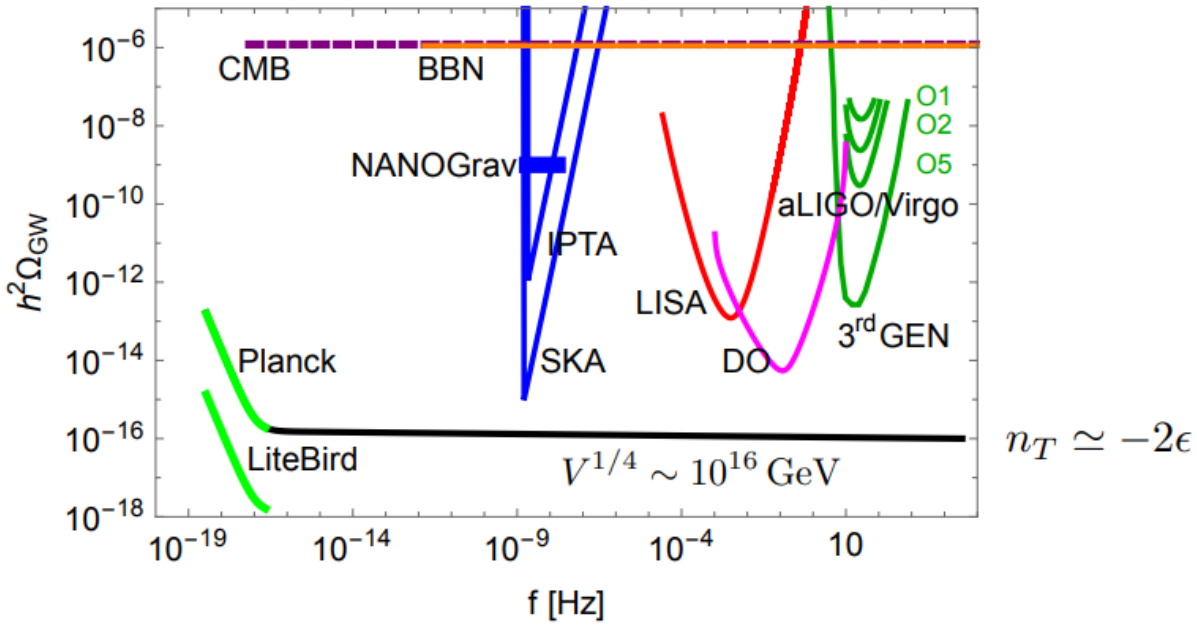
Too tiny to be seen directly in future GW detector !

SGWB FROM INFLATION

Tensor sourced at second order (or adding extra fields etc.)...

$$\Box h_{ij} = S_{ij}^{TT}$$

.. might be seen in future GW detector !



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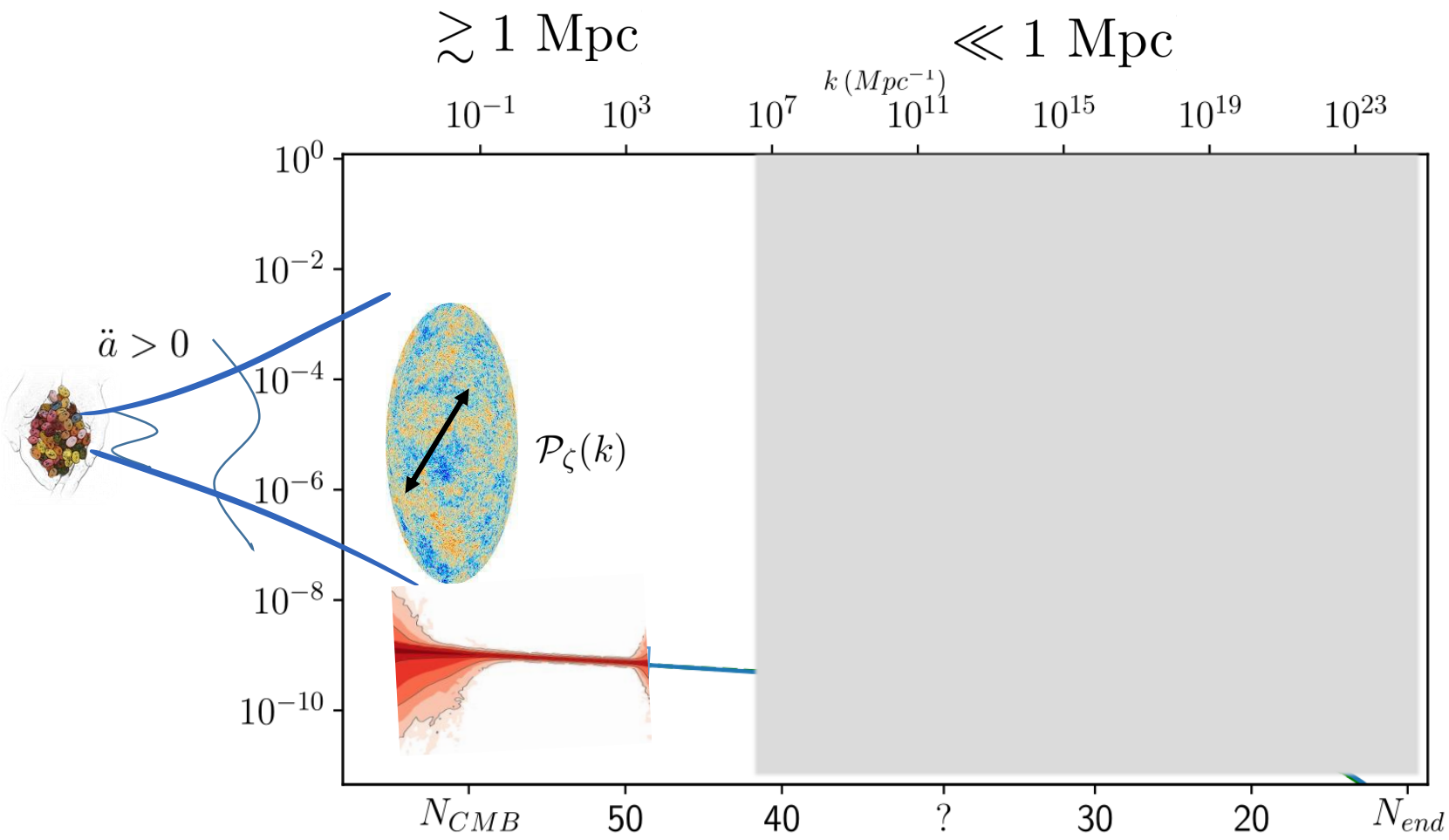
SGWB FROM INFLATION AT SMALL SCALES



JF et al. 2012.02761, 2105.06481, 2110.09480, 2111.14664, 2112.06903

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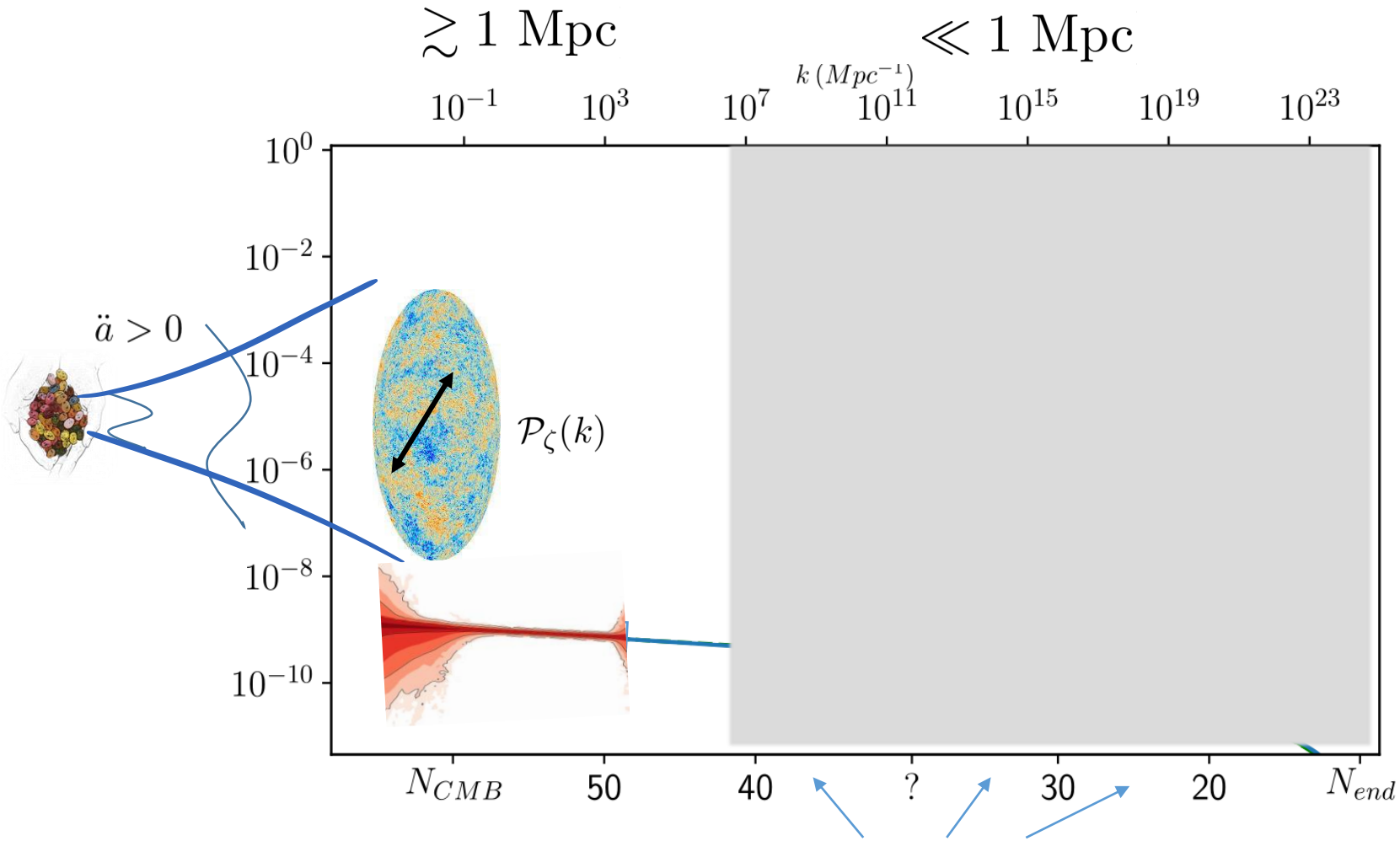
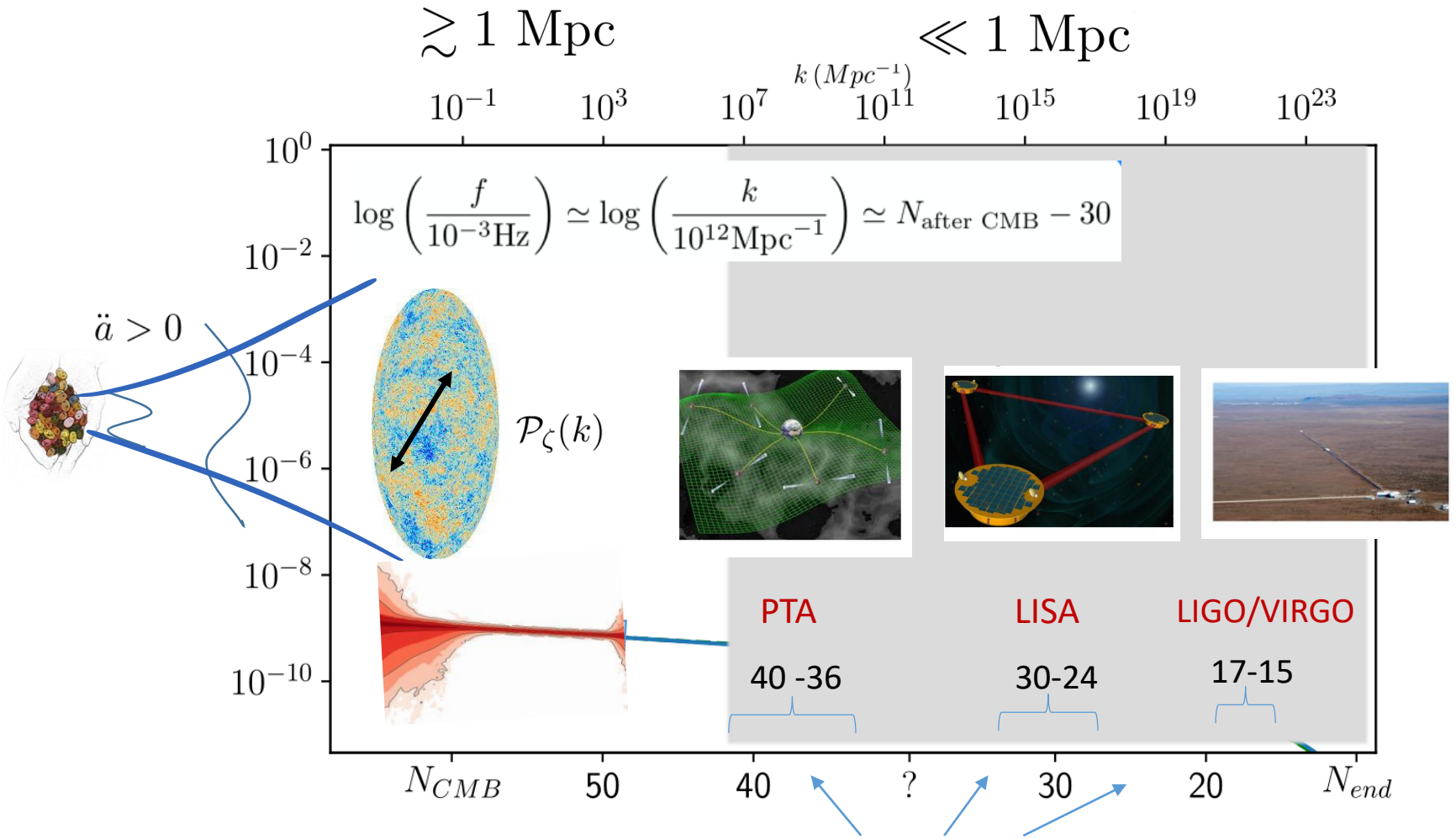


PRIMORDIAL FEATURES AT SMALL SCALES AND THEIR IMPRINTS ON THE SGWB

JF et al. 2012.02761, 2105.06481, 2110.09480, 2111.14664, 2112.06903

SGWB FROM INFLATION AT SMALL SCALES



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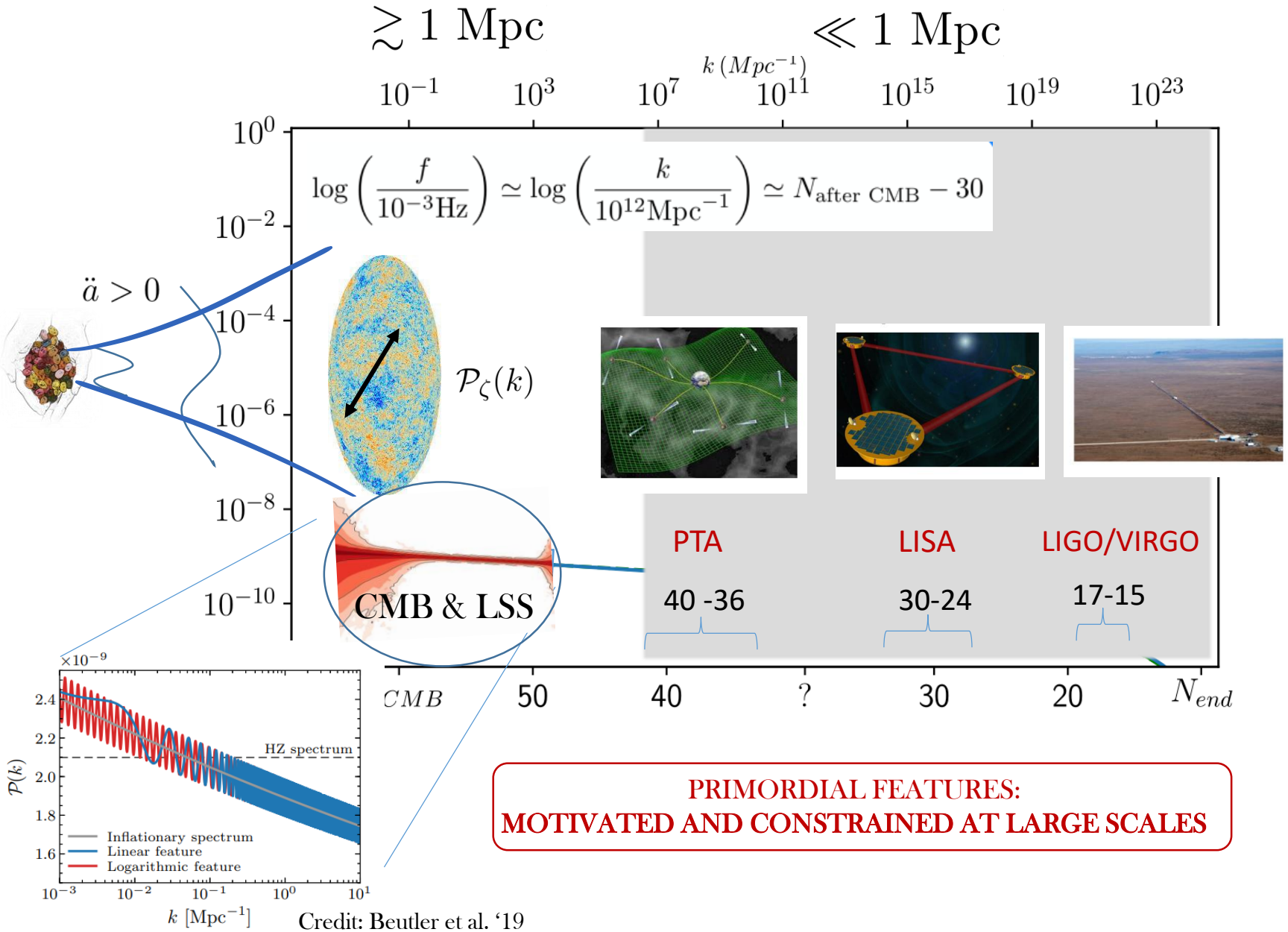
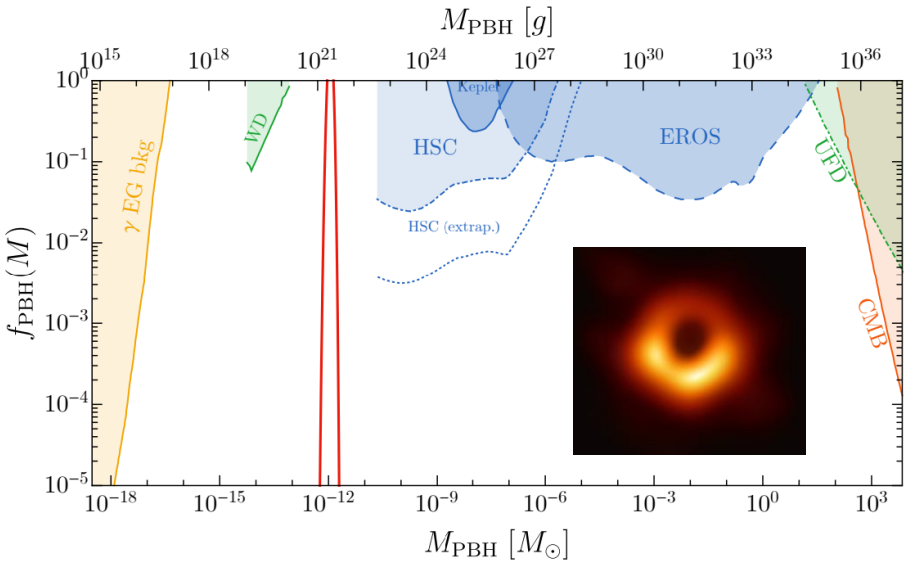


PRIMORDIAL FEATURES:
MOTIVATED AND CONSTRAINED AT LARGE SCALES

Credit: Beutler et al. '19

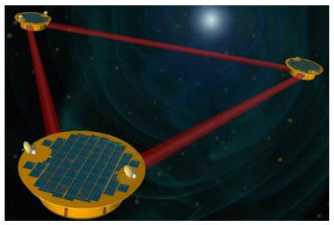
PBH / SGWB & LISA COINCIDENCE

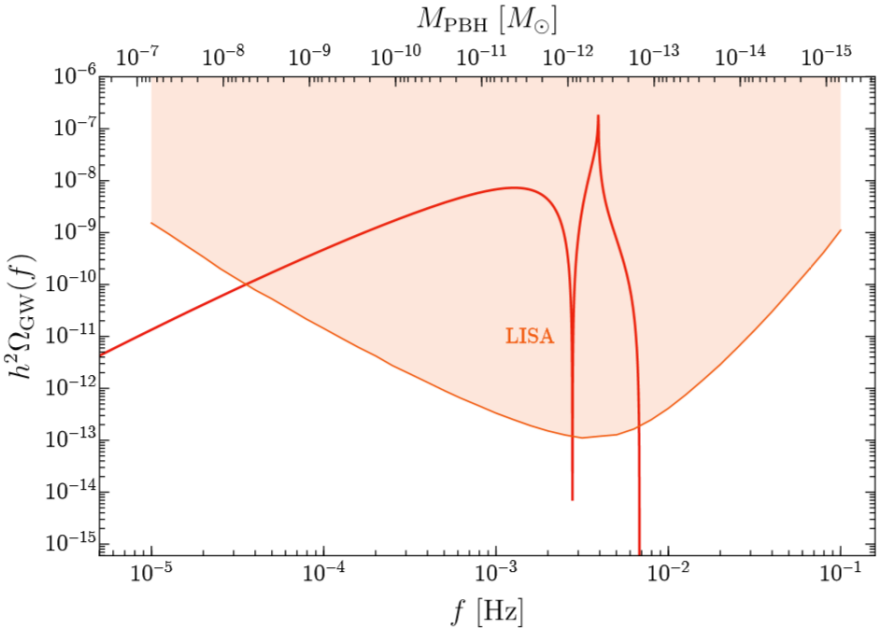


$$\Omega_{\rm GW}(k) \propto \int\int I(u,v)\mathcal{P}_\zeta(ku)\mathcal{P}_\zeta(kv)$$

$$\mathcal{P}_\zeta = A_p\,\delta(\log k/k_\star)$$

LISA Serendipity
Bartolo et al. '18

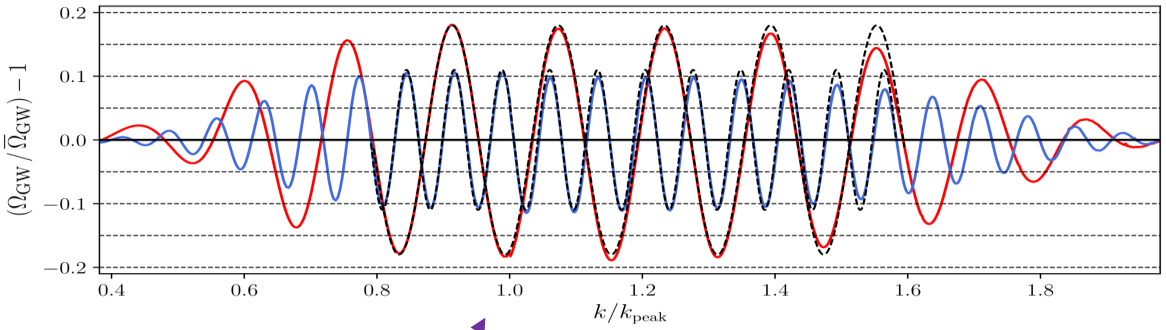


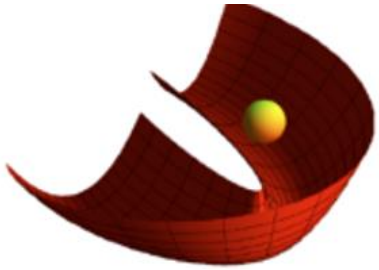


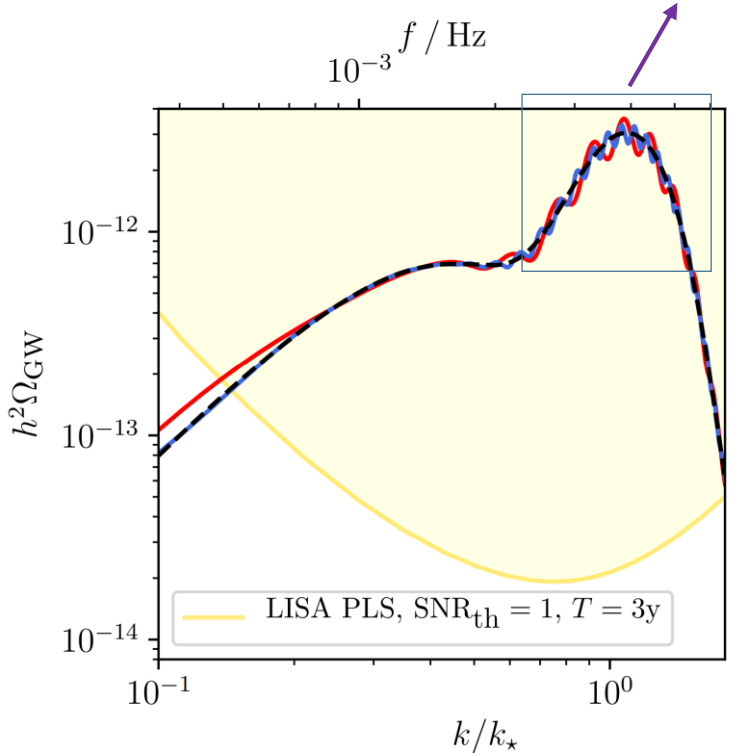
EXAMPLE: SHARP FEATURES & SIGNATURES IN THE SGWB

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

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







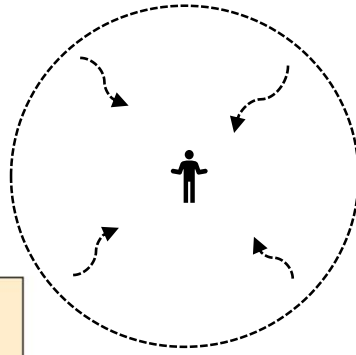
GENERIC PREDICTION: LINEAR OSCILLATIONS IN THE SGWB

We could learn:
Energy scale/ when and for how long during inflation?
More..

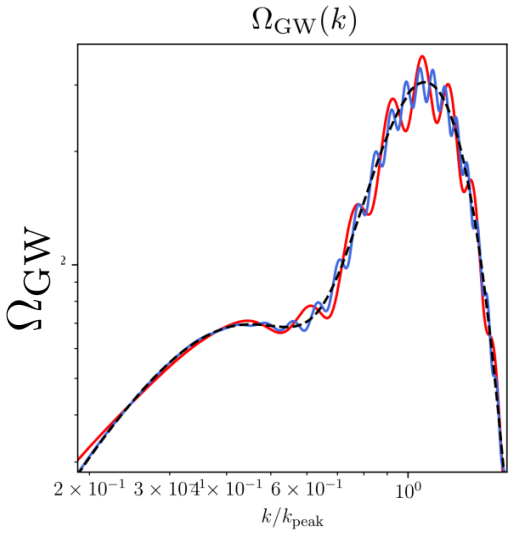
JF , S. Renaux-Petel, L. T. Witkowski, JCAP 2012.02761

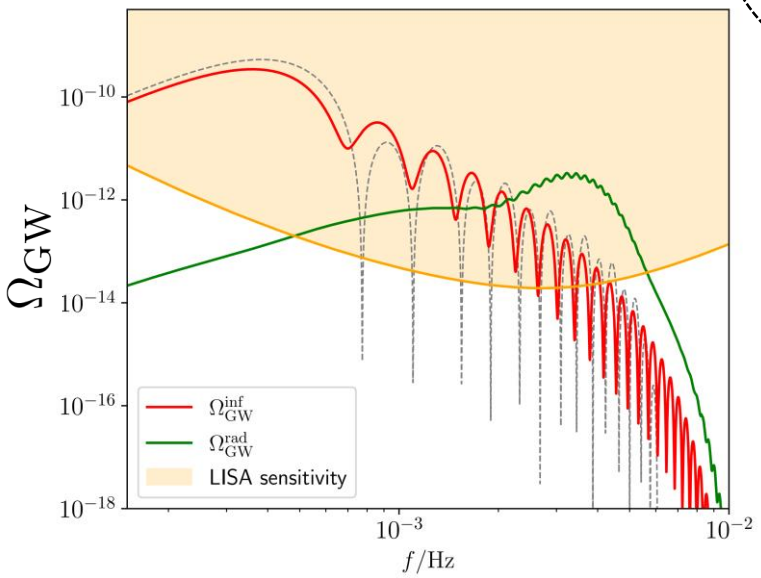
MORE: SMALL SCALE FEATURES in the SGWB

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

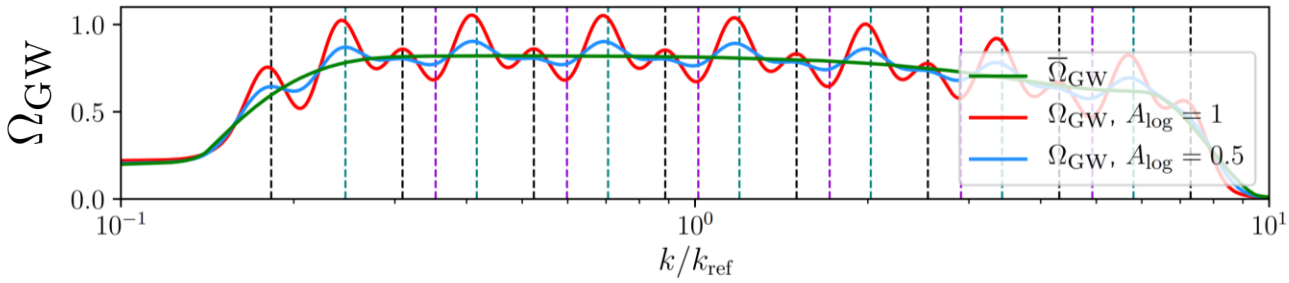


SHARP FEATURES





RESONANT FEATURES



JF et al.

2012.02761,

2105.06481,

2110.09480,

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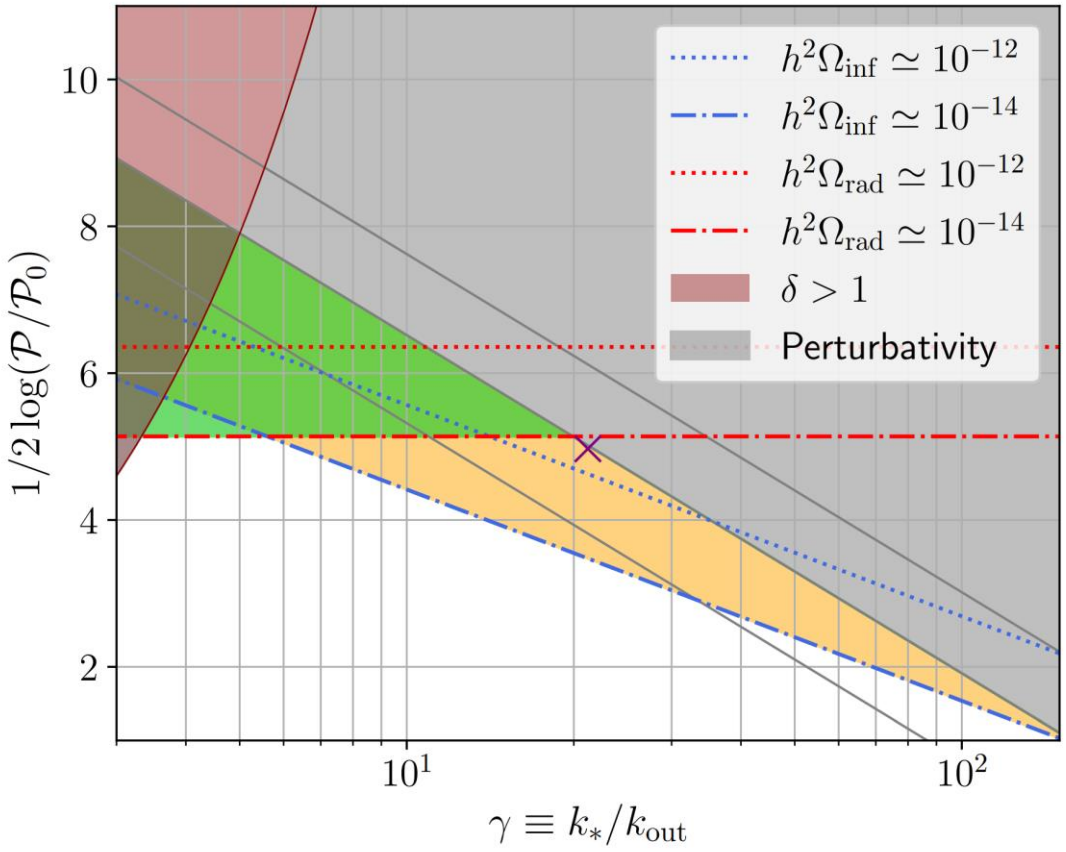
...

PERTURBATIVITY & OBSERVATIONS

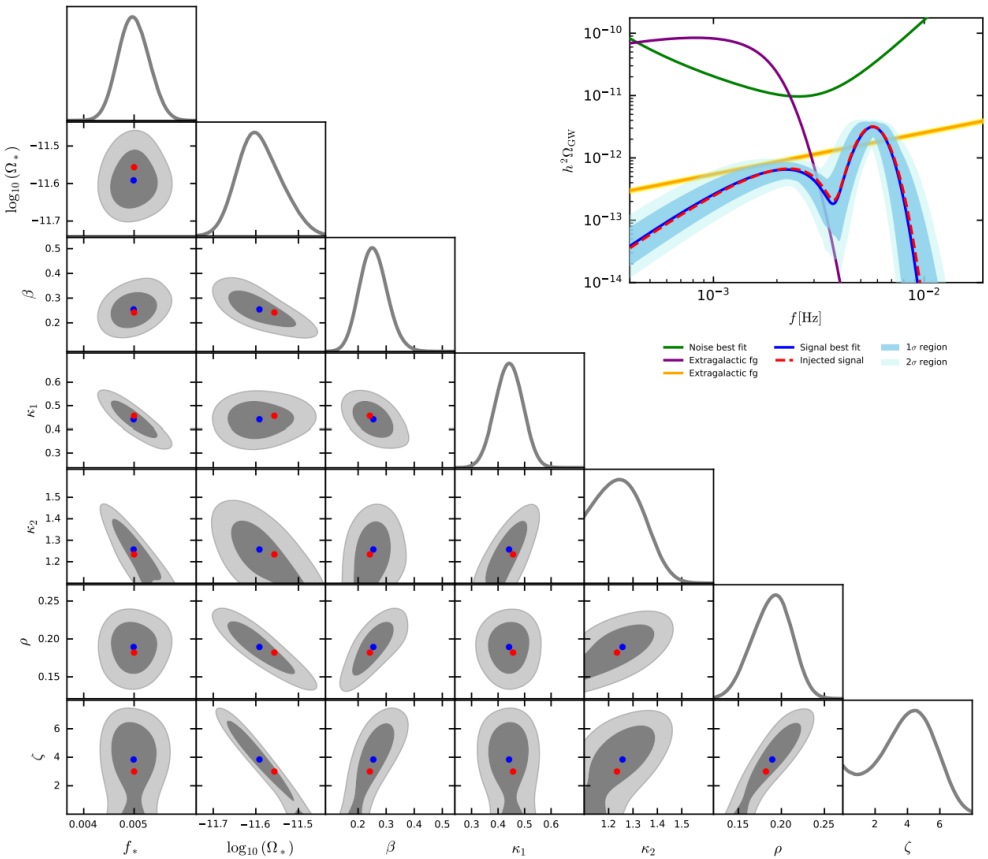
Theoretical scenarios may be tightly constrained just from perturbativity requirements. (One example from 2111.14664)



...more recent issues in the literature about one-loop corrections

SEARCHING FOR FEATURES in LISA (with LISA CosWG)

Example: PEAK IN THE SPECTRUM



PRELIMINARY

SEARCHING FOR FEATURES in LISA (with LISA CosWG)

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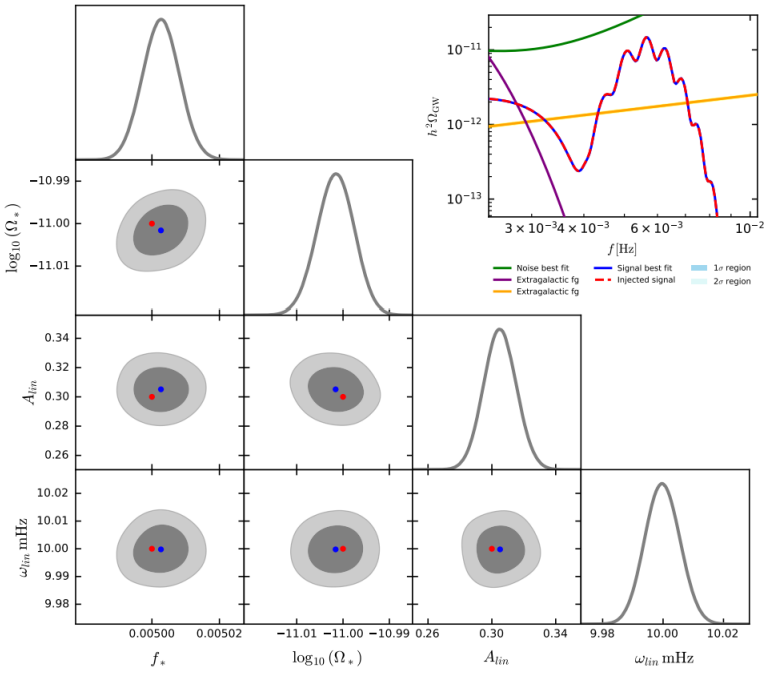

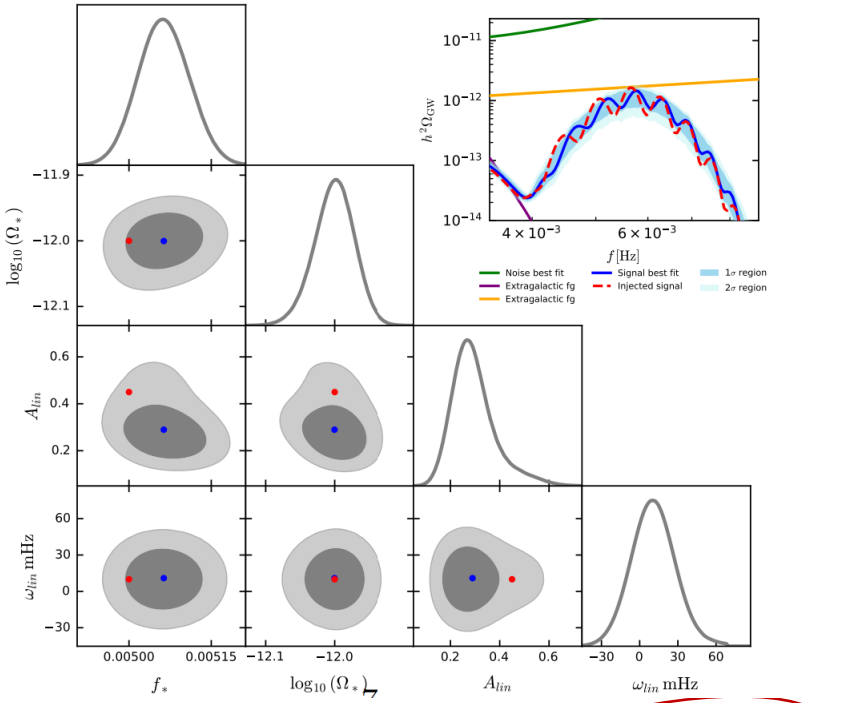

PRELIMINARY

CONCLUSIONS

- Stochastic gravitational wave background has the potential to unveil new physics not reachable by any other means

- It provides a new window to test inflation at small scales
- Reasons to go beyond the vanilla inflationary scenarios lead to features in the SGWB

Huge amount of information hidden behind

IT MAY BE REWARDING TO LOOK FOR OSCILLATORY PATTERN IN THE SGWB

QUESTIONS:

- Detectability with LISA and other GWs observatories

  To what extend we can reconstruct 10%-20% oscillations?

- Building consistent theoretical frameworks – one loop corrections
- Determine shapes / features unique of a cosmological background
- How to differentiate between cosmological and astrophysical background
- How to reconstruct the shape of a signal from its anisotropies
- Synergies among network of detectors

.....