UNIVERSITY OF CAMBRIDGE

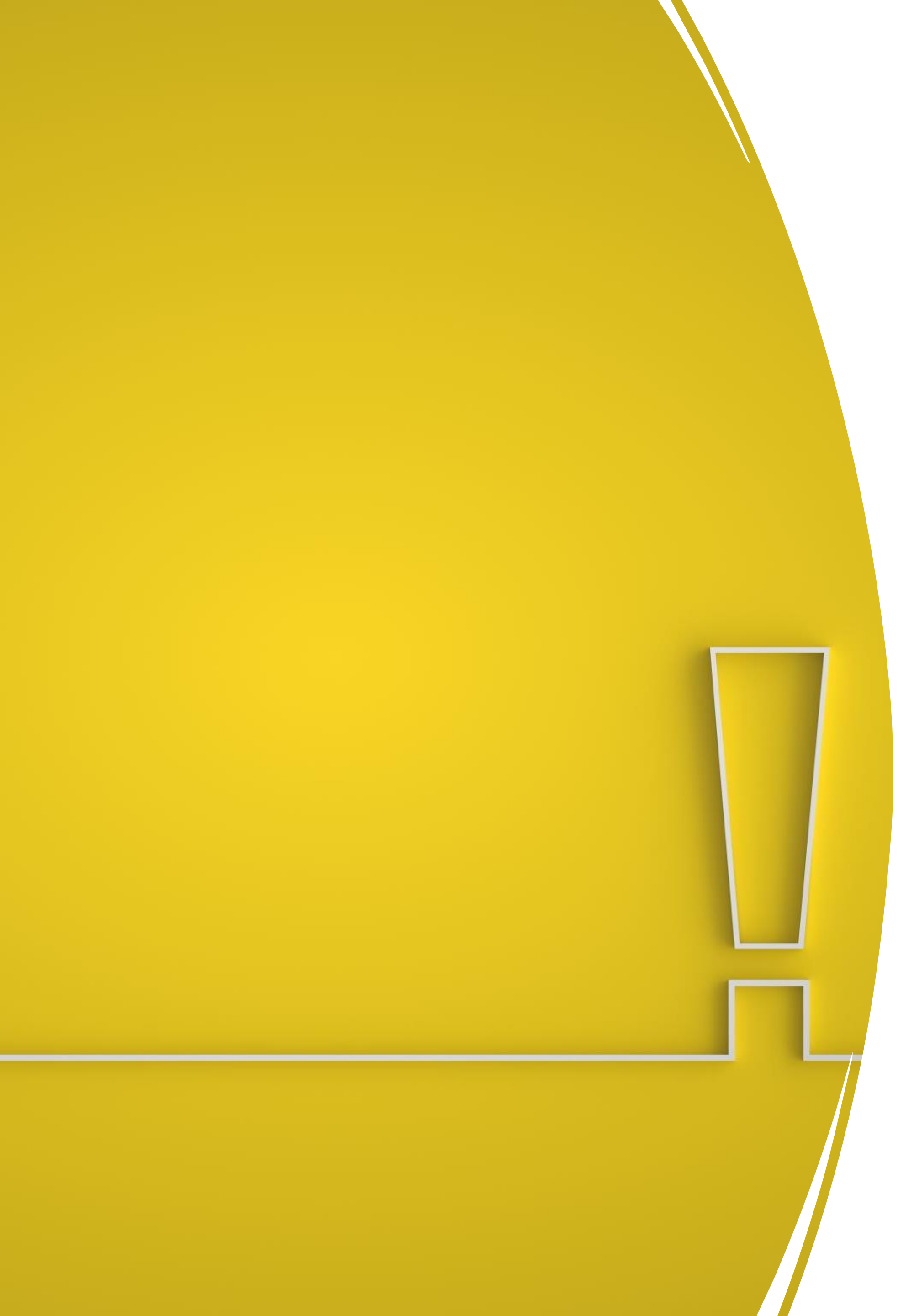
Testing BSM Physics with Gravitational Waves

Gonzalo Villa de la Viña

1st general meeting of COST Action COSMIC WISPers, Bari, Italy

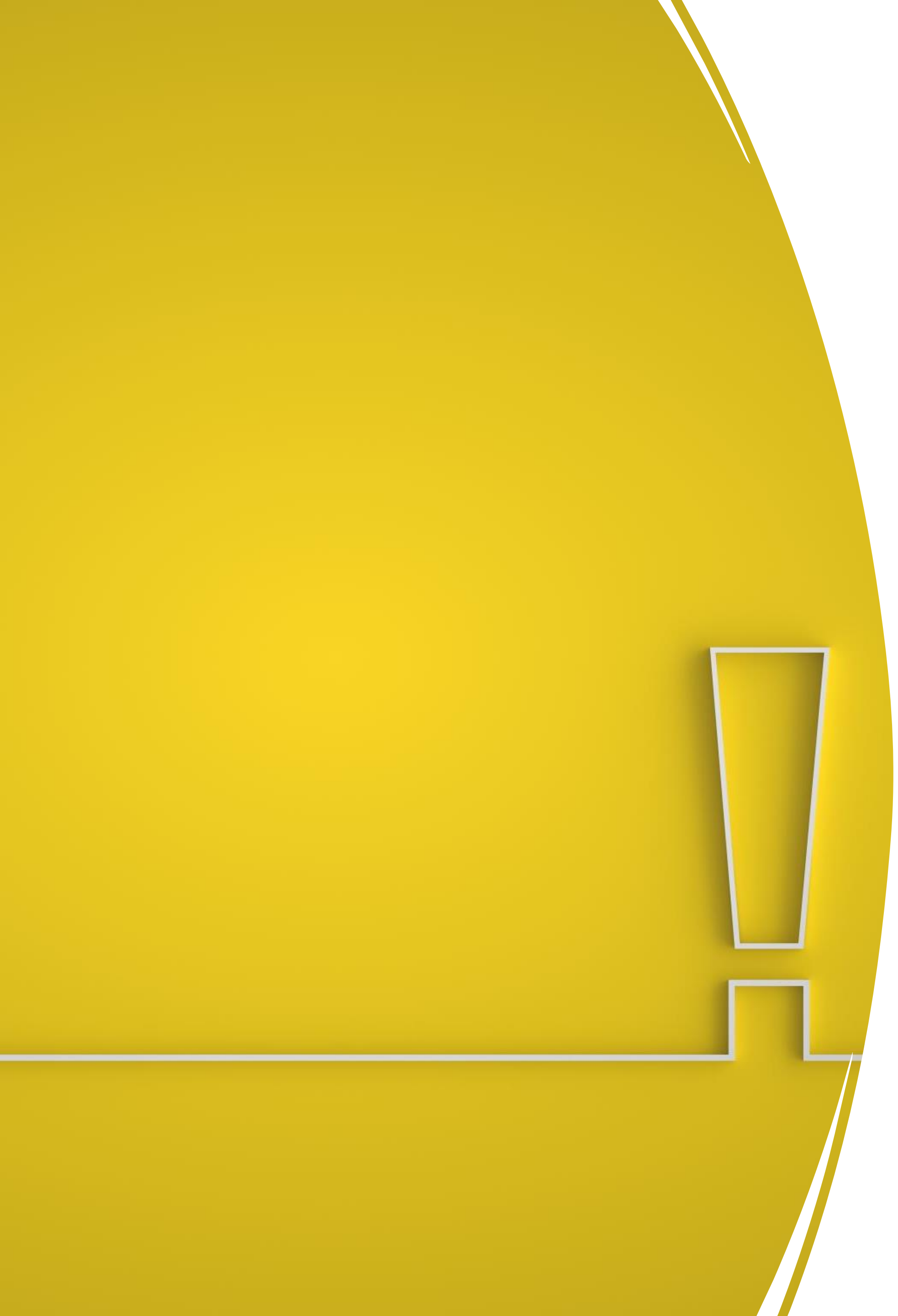
05/09/2023

Based on [2303.01548] with Francesco Muia, Fernando Quevedo and Andreas Schachner



Key points

- Thermal plasmas source Gravitational Waves (CGWB).



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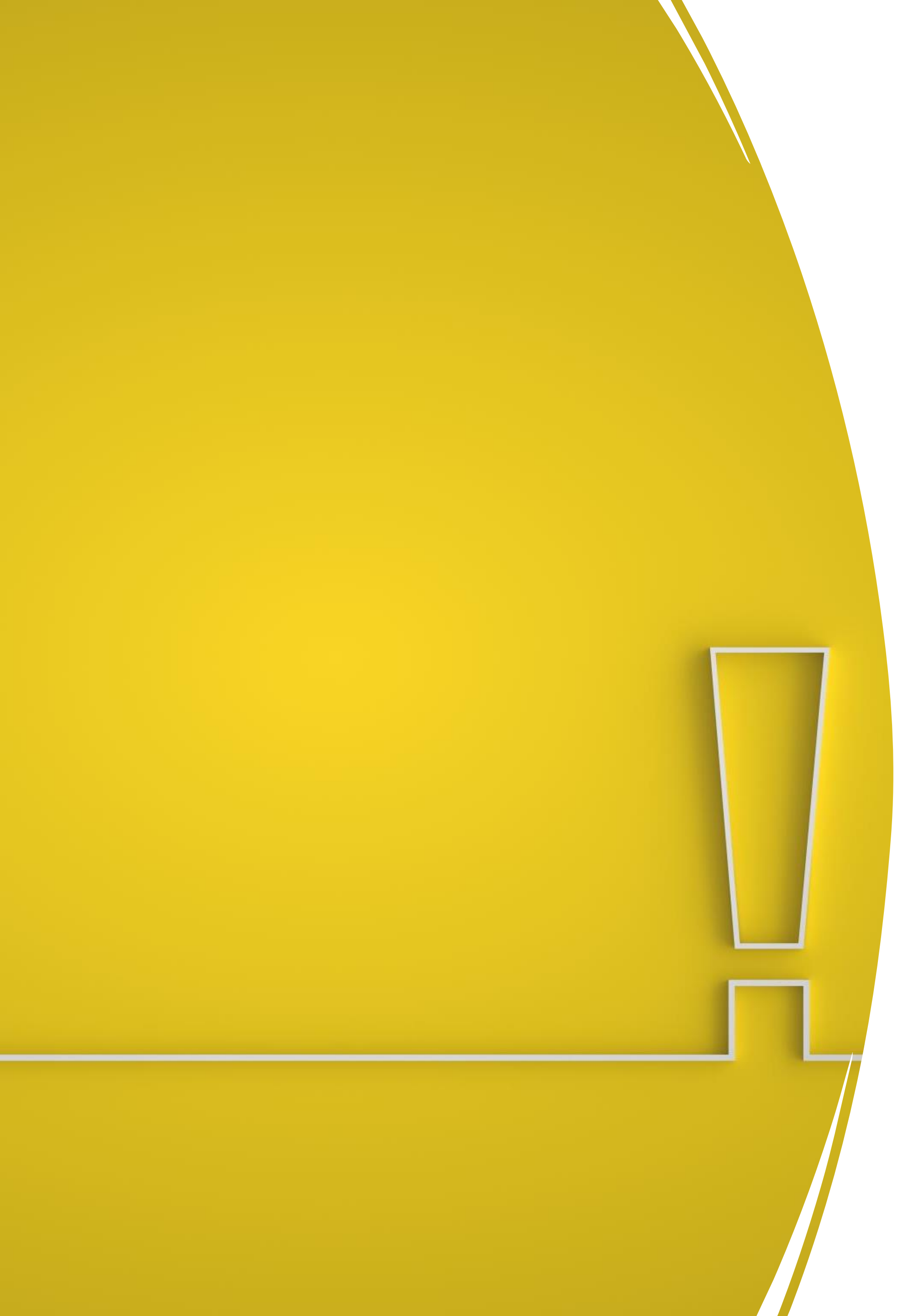

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- This GW signal carries a snapshot of what the Universe looked like at its highest temperature.
- The features of this signal depend on the posterior evolution of the background, thus can be used to address non-standard cosmologies.
- A GW signal at ultra-high frequencies… Which is the generic regime for cosmological sources!

Review: Caprini & Figueroa ´18

Cosmological GWs

- Cosmological GWs form a stochastic background.
- Characterised by their fractional energy density.

$$\Omega_{\rm GW} = \frac{1}{\rho_c}\frac{d\rho_{\rm GW}}{d\log k}\,, \qquad \rho_{\rm GW} = \frac{M_p^2}{4}\langle \dot{h}_{ij}\dot{h}_{ij}\rangle$$

- This contributes at BBN!

$$\text{BBN bound:} \quad \rho_h \lesssim \frac{\pi^2}{30}\times\frac{7}{4}\Delta N_{\rm eff}T_{\rm vis}^4 \qquad\qquad \Omega_{GW} < 10^{-6}$$

The Cosmic Gravitational Wave Background

- Any thermal QFT sources out-of-equilibrium gravitons:

$$\frac{d\rho_{\rm GW}}{dt\, d\log k} = \frac{8k^3}{\pi M_p^2} \int_{\mathcal{X}} e^{ik(t-z)} \langle T_{12}(0) T_{12}(\mathcal{X}) \rangle$$

- These form a stochastic background.
- Its shape is determined by the particles and interactions!

Ghiglieri and Laine ´15

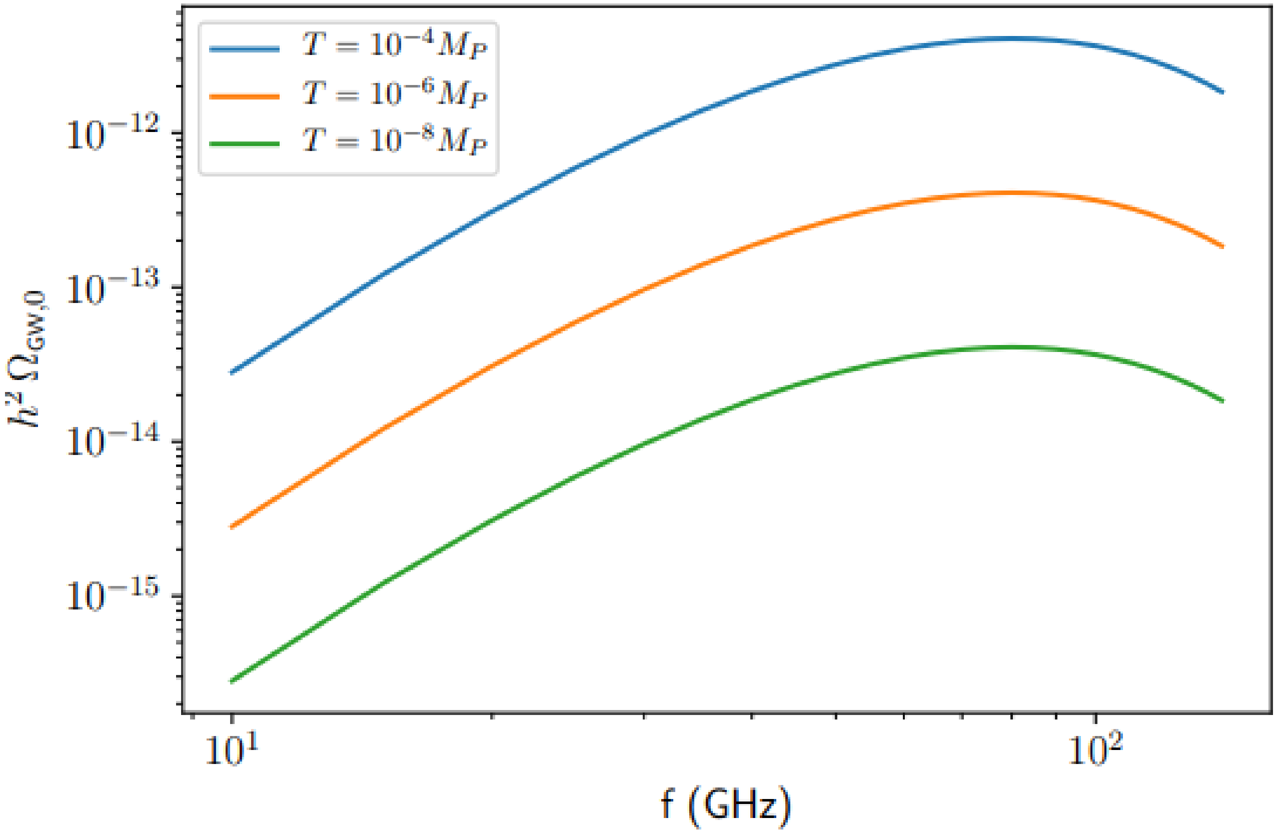
Ghiglieri, Jackson, Laine, Zhu ´20

Ringwald, Schütte-Engel, Tamarit ´20

The Standard Model

- Much below the BBN bound.
- An example of cosmologically sourced GWs at ultra-high frequencies.

Aggarwal et al ´20



Lessons to learn

- The contribution to the energy density per efold can be written as

$$\frac{d}{d\log a}\left(\frac{d\rho_{\mathrm{GW}}^{(i)}}{d\log k}\right) \sim T_i\,\frac{\rho^{(i)}a(t)^4}{\sqrt{g_{*,tot}}}F(\hat{k})\,.$$

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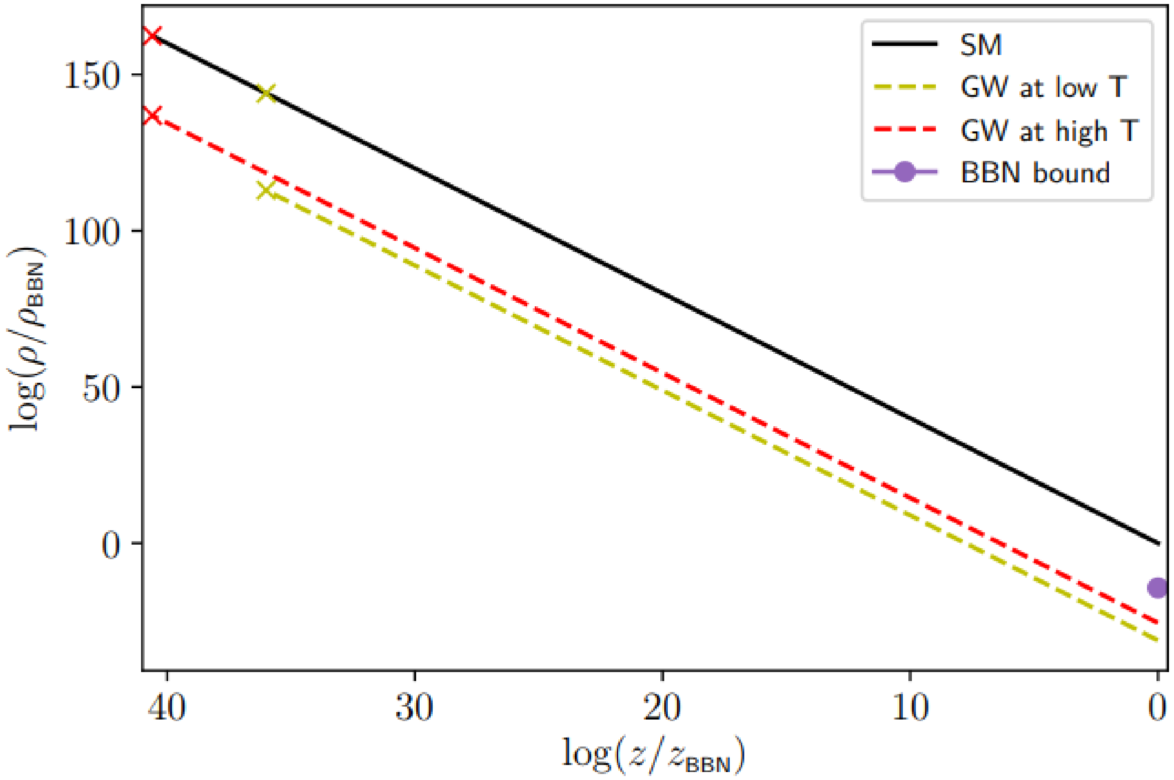
1. The dominant part of the spectrum was sourced at highest T (a "Big Bang thermometer").
2. The shape of the spectrum is dictated by the sector dominating the energy density

Dilluting with cosmic expansion



Hidden sectors

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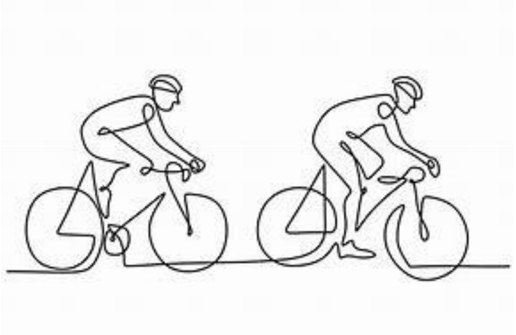
- We compute the spectrum for an arbitrary number of hidden sectors described by an arbitrary renormalizable gauge theory.

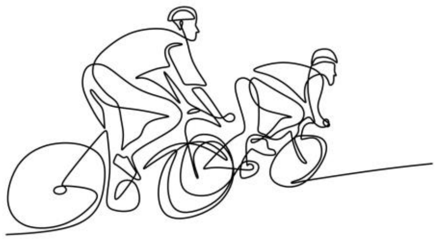
- The sector dominating the energy density after reheating dictates the shape of the CGWB: we *could* study their particle content and interactions through gravity!

Catching up at BBN

- The field content of any hidden sector must satisfy the BBN bound on extra contributions to the energy density.



SM Hidden



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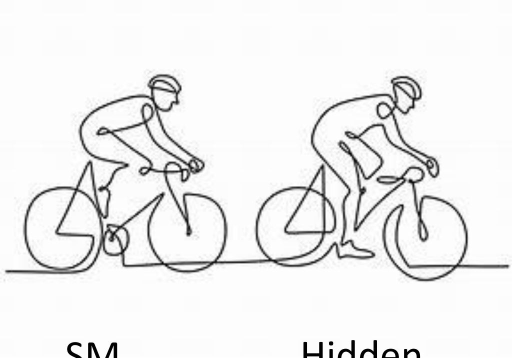
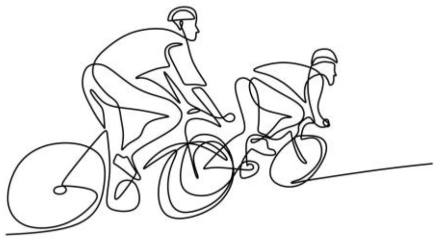


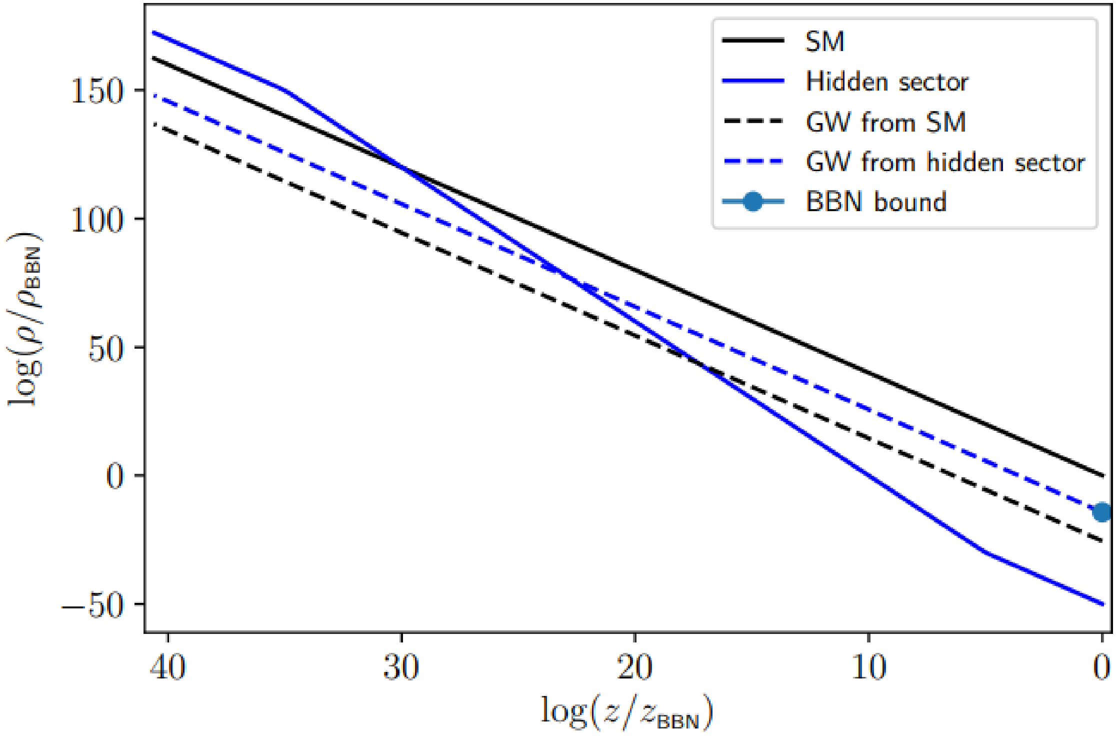


- For this, either:

1. The visible sector dillutes slower than radiation.
2. The hidden sector dillutes fast than radiation.

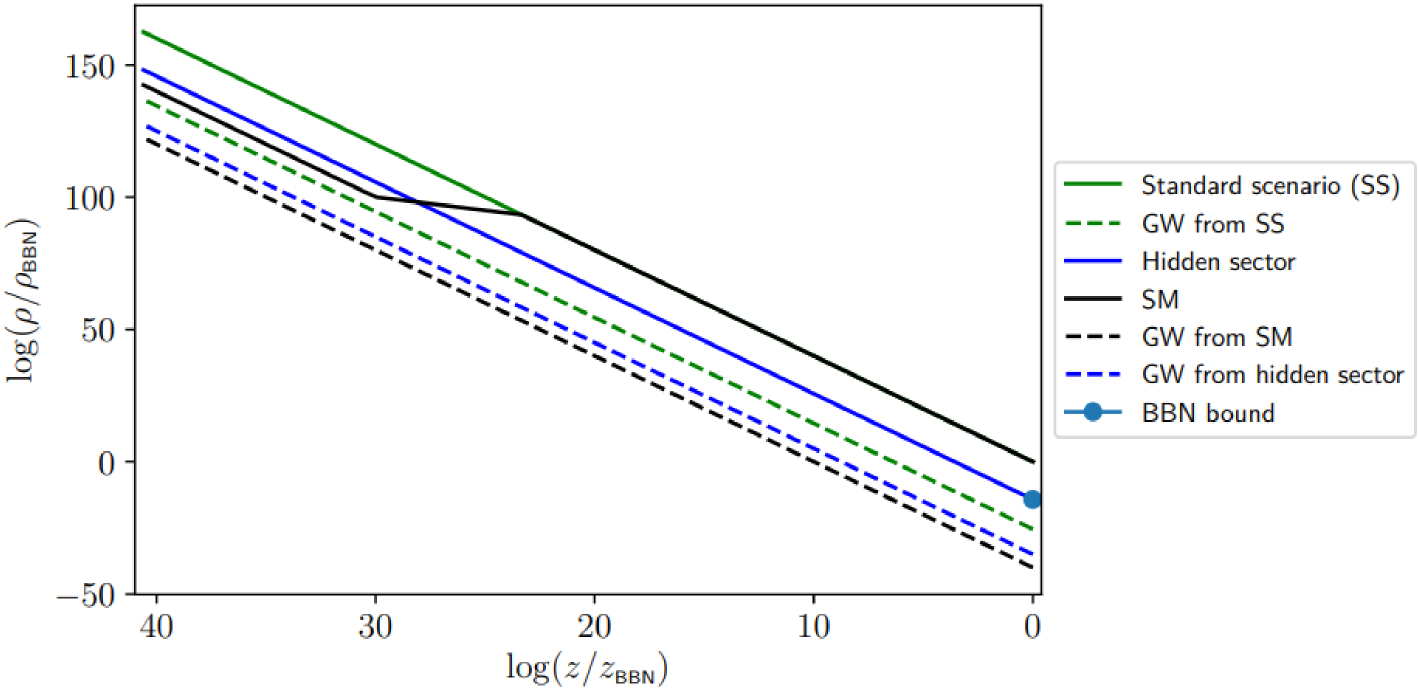
The scenarios

“Kination”



$$P = \omega\rho, \qquad \omega > 1/3$$

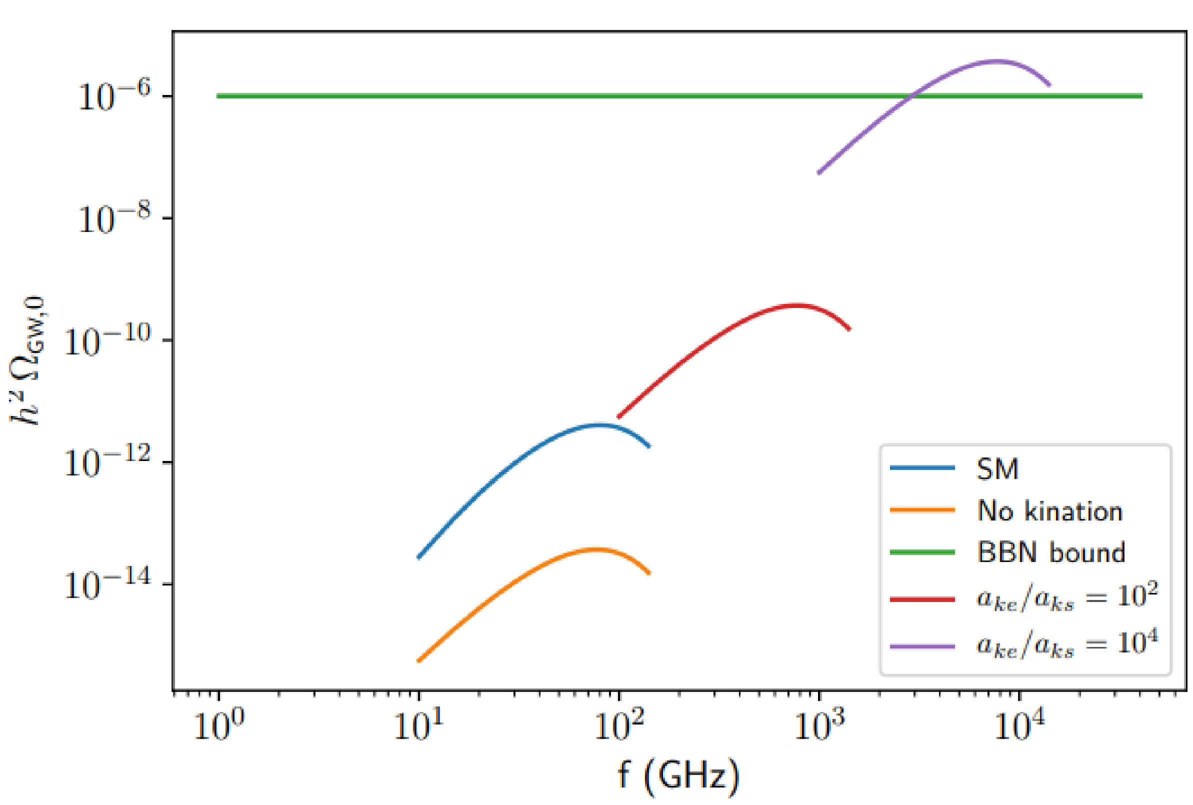
Entropy



Kination scenario

Gouttenoire, Servant, Simakachorn ’21

And in scalar-tensor theories!
Chowdhury, Tasinato, Zavala ’22



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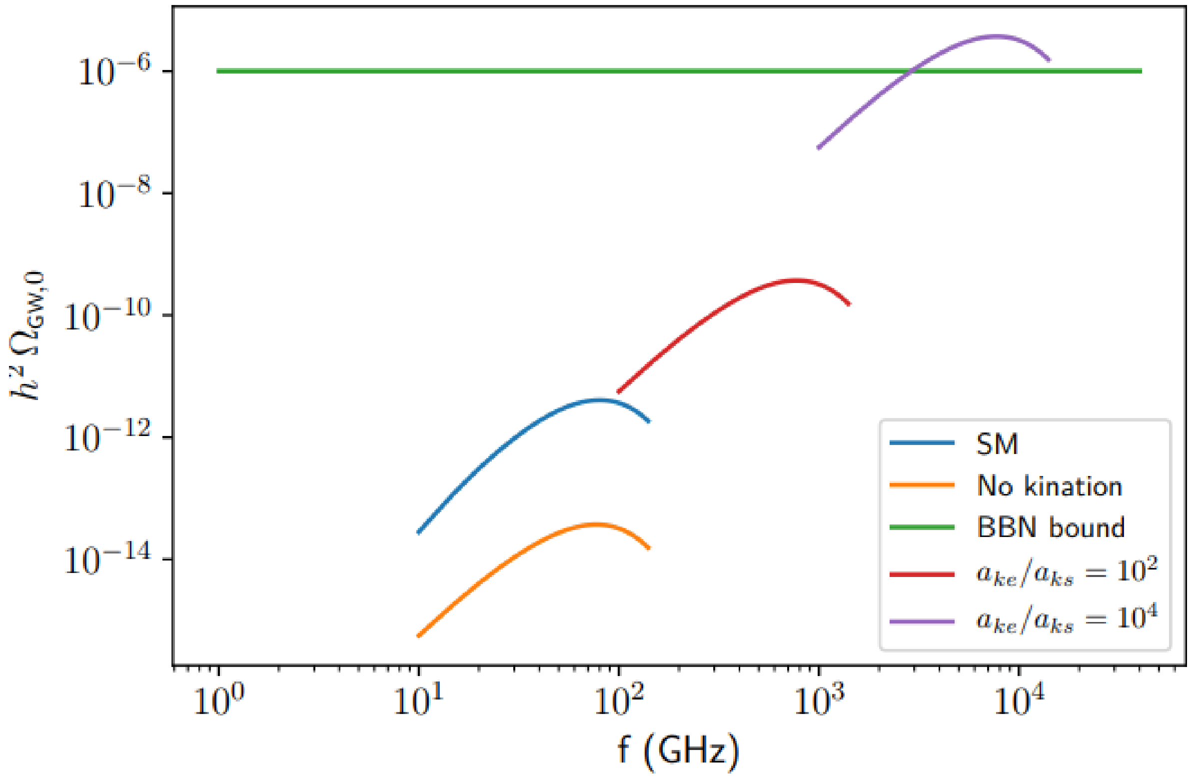

- A kination period post-emission significantly boosts the GW amplitude and frequency.
- We can rule out part of a parameter space containing maximum temperature and number of e-folds.

Conclusions

- We perform a model-independent study of the consequences of hidden sectors in the CGWB.
- We conclude that a blueshifted peak with respect to the SM prediction is a smoking-gun signature of a period with a stiff equation of state (e.g: kination).
- We rule out part of a parameter space of such scenarios (their GW signal is too big to allow for succesful BBN).