

Probing the maximal temperature ever reached in the universe with ET

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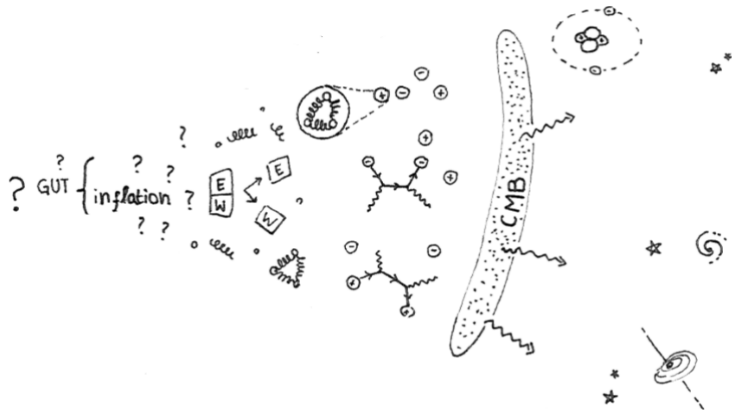
UNIVERSITÉ
DE GENÈVE

in collaboration with

H. Kolesova, M. Laine and A. Rogelj

ET Symposium 2025 - Bologna

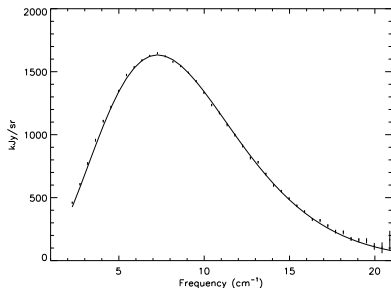
GWs could probe the early universe... but so many models!



is there something we are already sure about? yes!

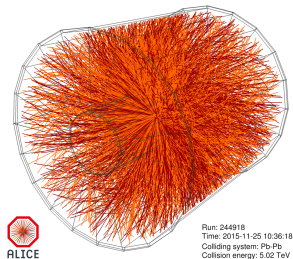
Cosmic Microwave Background originates from a thermal system

the CMB temperature spectrum
as a perfect blackbody



D.J. Fixsen *et al.*, *Astrophys.J.* 473 (1996) 576

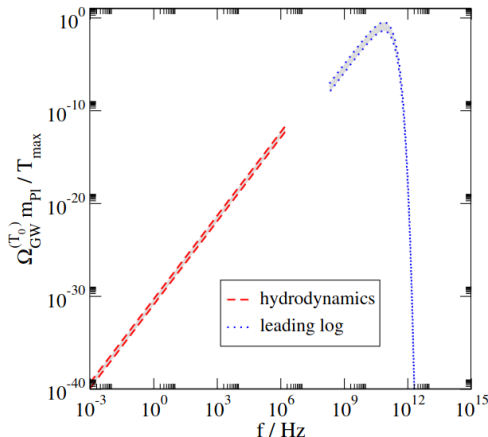
collider searches test
the primordial plasma



tracks from a lead-lead collision
recorded by the ALICE TPC at CERN

and anisotropies in a thermal plasma can source GWs!¹

from J. Ghiglieri and M. Laine, JCAP 07 (2015) 022



hydrodynamic fluctuations

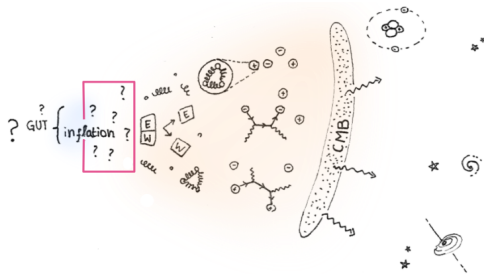
$$\Omega_{\text{gw}} \sim \underbrace{\hat{\eta}}_{\text{viscosity}} T_{\text{max}} \times f^3$$

particle scatterings

$$\Omega_{\text{gw}} \sim T_{\text{max}} \times f^4 \underbrace{n_{\text{B}}(f/T_{\text{max}})}_{\text{Boltzmann distr.}}$$

¹ J. Ghiglieri, G. Jackson, M. Laine and Y. Zhu, JHEP 07 (2020) 092,
J. Ghiglieri, M. Laine, J. Schütte-Engel and E. Speranza, JCAP 04 (2024) 062.

can we predict the maximal temperature?

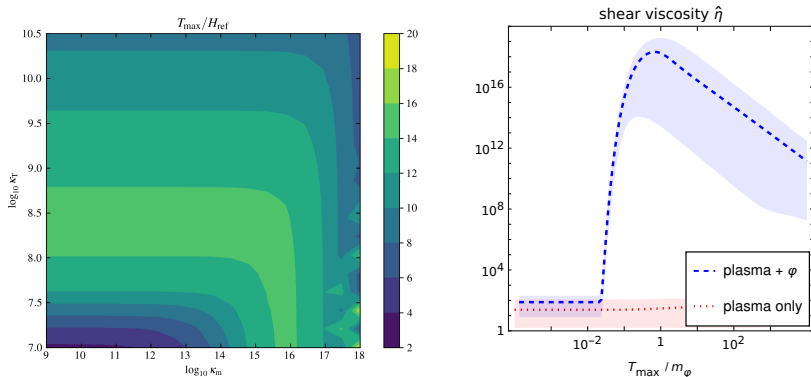


- * thermal equilibrium expected down to $t_{\text{BBN}} \sim 10\text{ s}$
- * early vacuum domination predicted at $t \sim 10^{-32}\text{ s}$
- * T_{max} reached in transition period²

Big Bang Nucleosynthesis $\Rightarrow T_{\text{max}} \in [10^{-2}, 10^{18}] \text{ GeV}$

²H. Kolesova, M. Laine and S. Procacci, JHEP 05 (2023) 239

$T_{\max}$ depends on initial conditions of thermal epoch⁵



* $T_{\max}$ can reach up to energy scale of inflation $\sim H_{\text{ref}}$ ³

* viscosity $\hat{\eta}$ enhanced by weakly-interacting extensions⁴

³ M. Laine, S. Procacci and A. Rogelj, JCAP 10 (2024) 040.

⁴ P. Klose, M. Laine and S. Procacci, JCAP 05 (2022) 021.

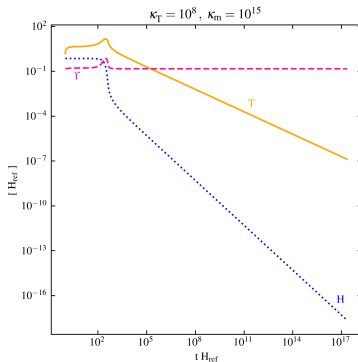
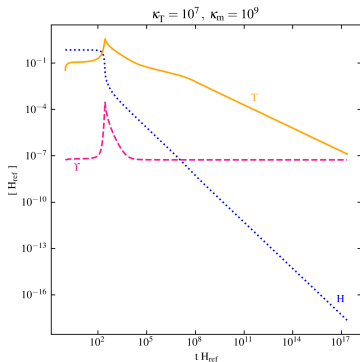
⁵ H. Kolesova, M. Laine and S. Procacci, JHEP 05 (2023) 239.

benchmark evolution scenarios

* the universe expands at rate H

* $\Upsilon \sim \frac{\kappa_T T^3 + \kappa_m m^3}{f_a^2}$ transfers energy to the plasma⁶

* plasma at T dominates at some point after inflation



⁶ M. Laine, L. Niemi, S. Procacci and K. Rummukainen, JHEP 11 (2022) 126,
M. Laine, S. Procacci, A. Rogelj, JCAP 10 (2024) 040.

ET could help constraining a mysterious stage!

$$\Omega_{\text{gw}} h^2 \approx 10^{-24} \times \frac{\hat{\eta} T_{\text{max}}}{m_{\text{pl}}} \times \left(\frac{f}{\text{kHz}} \right)^3$$

- * prediction within standard particle cosmology
- * $\sim f^3$ simple power-law
- * $\hat{\eta}$ known to high precision for the Standard Model⁷
- * extensions could make the signal visible at ET

⁷ J. Ghiglieri and M. Laine, JCAP 07 (2015) 022,
J. Ghiglieri, G. Jackson, M. Laine and Y. Zhu, JHEP 07 (2020) 092,
J. Ghiglieri, M. Laine, J. Schütte-Engel and E. Speranza, JCAP 04 (2024) 062.

