Primordial GW in Modified Gravity & Cosmology

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Based on -
arXiv: 1905.10410
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History of the Universe

Big Bang

Primordial Gravitational Waves

quantum-gravity era

inflation

cosmic microwave background

light

gravitational waves

now

IAS Preparation Online

Big Bang plus $10^{-43}$ seconds

Big Bang plus $10^{-35}$ seconds?

Big Bang plus 380,000 years

Big Bang plus 14 billion years
The idea: Naively

Propagation of Primordial GW generated during Inflation:

\[ \ddot{h}_{ij} + 3H \dot{h}_{ij} + \frac{k^2}{a^2} h_{ij} = 16\pi G \Pi_{ij}^{TT}, \tag{1} \]

Solution:

\[ h_{ij}(t, \vec{x}) = \sum_P \int \frac{d^3k}{(2\pi)^3} h^P(t, \vec{k}) \epsilon_{ij}^P(\vec{k}) e^{i \vec{k} \cdot \vec{x}}, \tag{2} \]

\[ h^P_{-k} = h^P_{+k},_0 U(t, k), \tag{3} \]

\[ \Pi_{ij} = \frac{T_{ij} - pg_{ij}}{a^2} \tag{4} \]

\[ \Omega_{GW}(\eta, k) = \frac{1}{12 a^2(\eta) H^2(\eta) P_T(k)} [U'(\eta, k)]^2 \tag{5} \]
On the GW sensitivity Map

\[ V_{\text{inf}} = (1.5 \times 10^{16})^4 \text{ GeV} \]

Scale Invariant Spectrum Assumed
Non-standard Cosmology

- History of the Universe before BBN is unknown.
- Non-standard cosmology predicts scalar field $\phi$ and its energy density dominates in the Early Universe.
- Its Equation-of-state $\omega_\phi$.
- Modifies the Hubble expansion: $H^2 \propto \rho_\phi$.
- Parameter $\xi = \frac{\rho_\phi}{\rho_R}$. 
On the GW sensitivity Map

\[ \omega_\phi = 1/3, \xi = 10^{25} \]

\[ T_{\text{dec}} = 10 \text{ MeV} \]

Radiation domination like scenario

[Fazollah, GGI, Florence 2019]
On the GW sensitivity Map

\[ \omega_\phi = 0, \xi = 10^{-11} \]

\[ T_{\text{dec}} = 10 \text{ MeV} \]

Modulus or matter domination like scenario

[Fazollah, GGI, Florence 2019]
On the GW sensitivity Map

$\omega_\phi = 2/3, \xi = 10^{10}$

$T_{\text{dec}} = 10 \ MeV$

[Fazollah, GGI, Florence 2019]
Modified Gravity

• Modify cosmological expansion (motivated from modified gravity theories)

\[
H_{MC}(T) = A(T)H_{GR}(T),
\]  

(6)

• Strategy:

\[
A(T) = 1 + \eta \left( \frac{T}{T_*} \right)^\nu,
\]  

(7)

where \( T_* \) is a parameter with dimensions of the temperature, and \( \{\eta, \nu\} \) are free parameters.

\[
A(T) = \begin{cases} 
1 + \eta \left( \frac{T}{T_*} \right)^\nu \tanh \frac{T - T_{re}}{T_{re}} & \text{for } T > T_{BBN} \\
1 & \text{for } T \leq T_{BBN}
\end{cases}
\]  

(8)

• \( \nu \) labels cosmological models:

1. \( \nu = 2 \) in Randall-Sundrum type II brane cosmology, \( \nu = 1 \) in kination models,
2. \( \nu = 0 \) in cosmologies with an overall boost of the Hubble expansion rate like in the case of a large number of additional relativistic degrees of freedom in the thermal plasma
3. \( \nu = -1 \) in scalar-tensor cosmology,
4. \( \nu = 2/n - 2 \) in \( f(x) \) cosmology, with \( f(x) = x + \alpha x^n \), with \( x = R, T \) where \( R \) and \( T \) stand for the scalar curvature and the scalar torsion, respectively.
On the GW sensitivity Map

Some Preliminary results only -

\[ \eta = 1, \nu = 0, T = 1 \text{ GeV} \]
\[ \eta = 1, \nu = 1, T = 1 \text{ GeV} \]
\[ \eta = 100, \nu = 1, T = 1k \text{ GeV} \]
CONCLUSION:

_Probe of Modified Cosmological Expansion History in Early Universe!_
On the GW sensitivity Map

Some Preliminary results only -

$\eta = 1, \nu = 0, T = 1 \text{ GeV}$

$\eta = 1, \nu = 1, T = 1 \text{ GeV}$

$\eta = 100, \nu = 1, T = 1k \text{ GeV}$
Thank You