Primordial GW from pseudoscalar inflation.

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July 6, 2016

Overview

Standard single field slow roll inflation.

Homogeneus scalar field ϕ in a homogeneous and isotropic universe:

$$S = \int \mathrm{d}^4x \sqrt{-g} \left(\frac{R}{2\kappa^2} + \frac{\dot{\phi}^2}{2} - V(\phi) \right), \qquad ds^2 = -dt^2 + a^2(t) d\vec{x}^2 \qquad (1)$$

Friedmann + e.o.m. for ϕ fix the evolution ($\kappa^2 = 1$):

$$\left(\frac{\dot{a}}{a}\right)^2 \equiv H^2 = \frac{\rho}{3}, \qquad -2\dot{H} = p + \rho \qquad \ddot{\phi} + 3H\dot{\phi} + \frac{\partial V}{\partial \phi} = 0 \,. \qquad (2)$$

Inflation $\Longleftrightarrow$ Early phase of exponential expansion

dS Spacetime $\Longleftrightarrow$ $H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \quad const$ $\Longleftrightarrow$ **Eternally inflating universe**

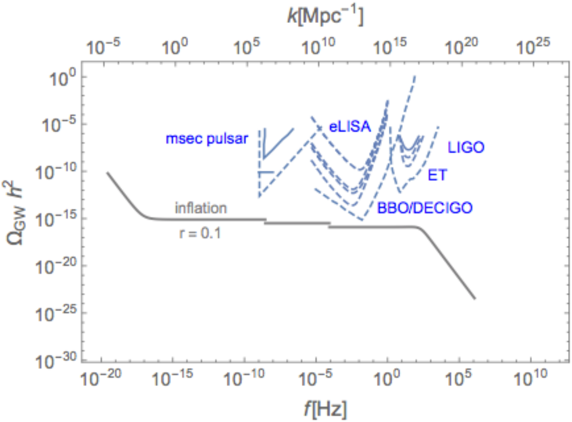
$$\left(\frac{\dot{a}}{a}\right)^2 \sim const \Longleftrightarrow \rho \sim -p \sim \quad const \Longleftrightarrow \left|\frac{\dot{\phi}^2}{2}\right| \ll |V| \sim const$$

Nearly dS space $\Longleftrightarrow$ Inflation

Good inflationary models $\Rightarrow$ Slow departure from $1 + p/\rho \sim 0$.

Direct GW detection.

Inflation predicts a nearly scale invariant scalar and tensor power spectra.



The produced signal is outside of the sensitivity curves both of present and future direct GW detectors.

Overview

Pseudoscalar inflation in presence of Gauge fields.

Pseudoscalar inflaton with a non-minimal coupling with some gauge fields:

$$\mathcal{L} = \frac{M_p^2}{2} R - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{\alpha}{4\Lambda}\phi F_{\mu\nu}\tilde{F}^{\mu\nu} \quad (3)$$

Turner, Widrow '88,
Garretson, Field, Caroll '92,
Anber, Sorbo '06./'10/'12,
Barnaby, Namba, Peloso '11,
Barnaby, Pajer, Peloso '12 ,
.....

The equations of motion for the fields are:

$$\ddot{\phi} + 3H\dot{\phi} + \frac{\partial V}{\partial \phi} = \frac{\alpha}{\Lambda}\langle \vec{E}\cdot\vec{B}\rangle \quad (4)$$

$$\frac{\mathrm{d}^2\, \vec{A}^a(\tau,\vec{k})}{\mathrm{d}\tau^2} - \vec{\nabla}^2\vec{A}^a - \frac{\alpha}{\Lambda}\frac{\mathrm{d}\phi}{\mathrm{d}\tau}\vec{\nabla}\times\vec{A}^a = 0 \quad (5)$$

$$\mathrm{d}t \equiv a\,\mathrm{d}\tau$$

Friedmann equation reads:

$$3H^2 = \frac{1}{2}\dot{\phi}^2 + V(\phi) + \frac{1}{2}\langle \vec{E}^2 + \vec{B}^2\rangle\ . \quad (6)$$

The equations of motion for the gauge fields in Fourier transform are:

$$\frac{\mathrm{d}^2\, \vec{A}^a(\tau,\vec{k})}{\mathrm{d}\tau^2} - \vec{k}^2\vec{A}^a + i\frac{\alpha}{\Lambda}\frac{\mathrm{d}\phi}{\mathrm{d}\tau}\vec{k}\times\vec{A}^a = 0 \quad (7)$$

Gauge field amplification.

Taking $\vec{k}$ parallel to $\hat{x}$, we use the helicity vectors $\vec{e}_\pm = (\hat{y} \pm i\hat{z})/\sqrt{2}$ to get:

$$\vec{A}^a = \vec{e}_\pm A^a_\pm \qquad \rightarrow \qquad \vec{k} \times \vec{A}^a = A^a_\pm \vec{k} \times \vec{e}_\pm = \mp i A^a_\pm |\vec{k}| \vec{e}_\pm \tag{8}$$

The equations of motion for the Fourier transform of the gauge fields read:

$$\frac{\mathrm{d}^2 A^a_\pm(\tau, \vec{k})}{\mathrm{d}\tau^2} + \left[k^2 \pm 2k\frac{\xi}{\tau}\right] A^a_\pm(\tau, \vec{k}) = 0 \,, \qquad \xi \equiv \frac{\alpha \dot{\phi}}{2H\Lambda} \propto \sqrt{\epsilon_H} \,. \tag{9}$$

If ξ is nearly constant the gauge fields are exponentially growing with ξ.

As $\langle \vec{E} \cdot \vec{B} \rangle \simeq 2.4 \cdot 10^{-4} \mathcal{N} \left(\frac{H}{\xi}\right)^4 e^{2\pi\xi}$, and the equation of motion for ϕ is:

$$\ddot{\phi} + 3H\dot{\phi} + \frac{\partial V}{\partial \phi} = \frac{\alpha}{\Lambda} \langle \vec{E} \cdot \vec{B} \rangle \,. \tag{10}$$

The friction term induced by the gauge fields is exponentially growing with ξ.
This term dominates the last part of the evolution.

Modified dynamics also affects the scalar and tensor power spectra!

Modified scalar spectrum.

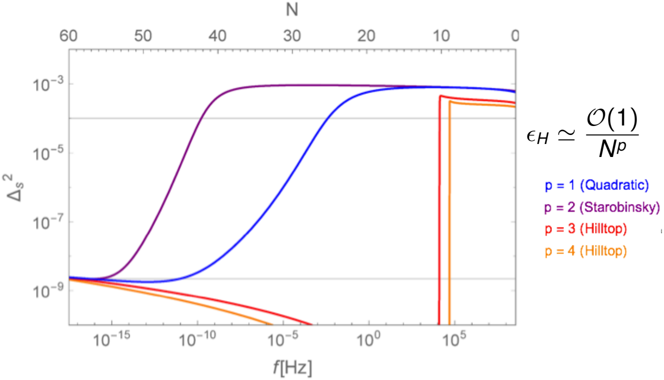
Scalar spectrum $\longrightarrow$

$$\mathcal{P}_s(k) = \left(\frac{H^2}{2\pi\dot{\phi}}\right)^2 + \left(\frac{\alpha\langle\vec{E}\cdot\vec{B}\rangle}{3bH\dot{\phi}}\right)^2 \tag{11}$$

where:

$$b \equiv 1 - 2\pi\xi\frac{\alpha\langle\vec{E}\cdot\vec{B}\rangle}{3\Lambda H phi} \tag{12}$$

- COBE normalization fixes V_0
- Stong increase at small scales $\rightarrow$ PBHs
- Nearly universal behavior at large scales
- $\mathcal{P}_s(k) \simeq \frac{1}{\mathcal{N}(2\pi\xi)^2}$ at small scales



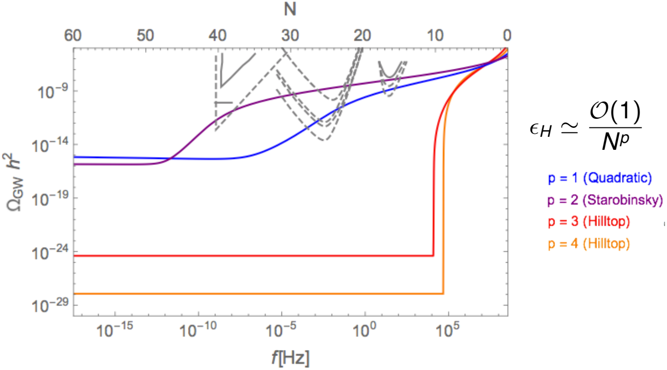
V. Domcke, M.P. and P. Binétruy, arXiv:1603.01287 [astro-ph.CO].

Modified tensor spectrum.

GW spectrum $\longrightarrow$
$$\mathcal{P}_t(k) = \frac{1}{12}\left(\frac{H}{\pi M_p}\right)^2 \left(1 + 4.3 \cdot 10^{-7} \frac{H^2}{M_p^2 \xi^6} e^{4\pi\xi}\right) \quad (14)$$

N-frequency relation $\longrightarrow$
$$N = N_{\text{CMB}} + \ln \frac{k_{\text{CMB}}}{0.002\ \text{Mpc}^{-1}} - 44.9 - \ln \frac{f}{10^2\ \text{Hz}}\,. \quad (15)$$

- Spectra asymptote to an universal value at small scales
- Low scale models ($p = 3, 4$) have a stronger increase
- Some models produce GW in the observable range of direct GW detectors

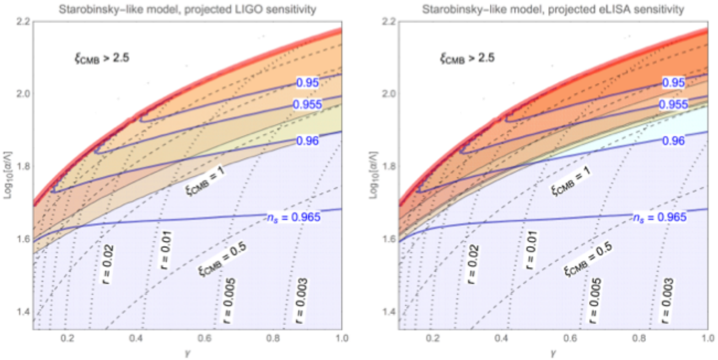


$$\epsilon_H \simeq \frac{\mathcal{O}(1)}{N^p}$$

V. Domcke, M.P. and P. Binétruy, arXiv:1603.01287 [astro-ph.CO].

Starobinsky-like model parameter space.

Models with $p = 2$ give a potential : $V(\phi) \simeq V_0 \left(1 - \exp\{-\gamma\phi\}\right)^2$



(a) *LIGO plot.* (b) *eLISA plot.*

V. Domcke, M.P. and P. Binétruy, arXiv:1603.01287 [astro-ph.CO].
The complementarity between different measures can be used to restrict the parameter space!

Overview

1. A review on inflation.
2. GW from a Pseudoscalar inflaton.
3. Conclusions and future perspectives.

Conclusions and future perspectives.

Main results:

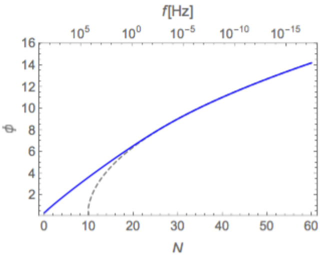
- Possible generation of Primordial GWs in the observable ranges for direct GW detectors.
- If this GW are observed, we get important informations on the microphysics of inflation.
- Models with large n_s may be recovered.

Future perspectives:

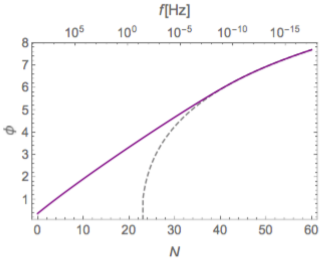
- More models.
- Extension to Non-abelian gauge fields.
- Consequences on reheating.
- Generation of PBH.
- Embedding in a UV complete theory.

The End

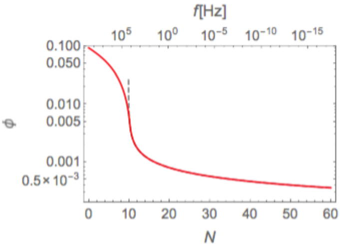
Thank you



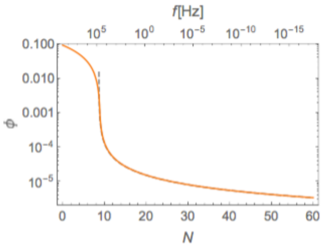
(a) *Quadratic model with* $\alpha/\Lambda = 35$ *and* $V_0 = 1.418 \cdot 10^{-11}$.



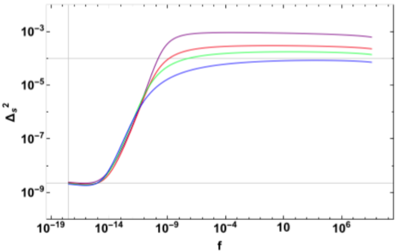
(b) *Starobinsky model with* $\alpha/\Lambda = 75$, $\gamma = 0.3$, $V_0 = 1.17 \cdot 10^{-9}$.



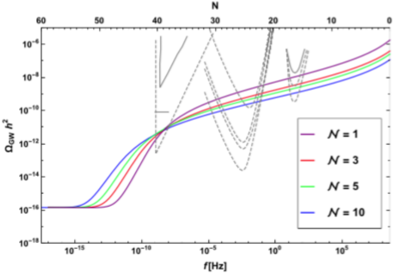
(c) *Hilltop model with* $q = 4$, $\alpha/\Lambda = 2000$, $v = 0.1$ *and* $V_0 = 1.0 \cdot 10^{-21}$.



(d) *Hilltop model with* $q = 3$, $\alpha/\Lambda = 2000$, $v = 0.1$ *and* $V_0 = 3.6 \cdot 10^{-18}$.



(a) *Scalar power spectra.*



(b) *Tensor power spectra.*