Effects of Parity Violation on Polarization and Non-gaussianity of Primordial Gravitational Waves in Hořava-Lifshitz Gravity

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Polarizing primordial gravitational waves by parity violation

Anzhong Wang, Qiang Wu, Wen Zhao, Tao Zhu

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Effects of parity violation on non-gaussianity of primordial gravitational waves in Hořava-Lifshitz gravity

Tao Zhu, Wen Zhao, Yongqing Huang, Anzhong Wang, and Qiang Wu

Phys. Rev. D88, 063508 (2013)

Outline

Introduction

Nonprojectable General Covariant HL Gravity

Polarization of PGW

Detection of circular polarization of PGW

Bispectrum and Non-gaussianity

Summary

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- PGWs produce the TT, EE, BB and TE spectra of CMB, but TB and EB spectra only for violating parity effects
- Parity violation effects have contributions to PGW Polarization and Non-gaussianities.
- In general covariant Hořava-Lifshitz gravity, the Lorentz symmetry is broken in the UV, and parity-violating operators appear.

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$$[N^i] = [c] = \frac{[dx]}{[dt]} = [k]^2, \quad [g_{ij}] = [N] = [1],$$

$$[K_{ij}] = [k]^3, \quad [\Gamma^i_{jk}] = [k], \quad [R^i_{jkl}] = [k]^2.$$

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$$[k]^6 : K_{ij}K^{ij},\ K^2,\ R^3,\ RR_{ij}R^{ij},\ R^i_j R^j_k R^k_i,\ (\nabla R)^2,$$
$$(\nabla_i R_{jk})\left(\nabla^i R^{jk}\right),\ \left(a_i a^i\right)^2 R,\ \left(a_i a^i\right)\left(a_i a_j R^{ij}\right),$$
$$\left(a_i a^i\right)^3, a^i \Delta^2 a_i, \left(a^i{}_i\right) \Delta R, \ldots,$$
$$[k]^5 :\ K_{ij}R^{ij},\ \epsilon^{ijk} R_{il} \nabla_j R^l_k,\ \epsilon^{ijk} a_i a_l \nabla_j R^l_k,$$
$$a_i a_j K^{ij},\ K^{ij} a_{ij},\ \left(a^i{}_i\right) K,$$
$$[k]^4 :\ R^2,\ R_{ij}R^{ij},\ \left(a_i a^i\right)^2,\ \left(a^i{}_i\right)^2,\ \left(a_i a^i\right) a^j{}_j,$$
$$a^{ij} a_{ij},\ \left(a_i a^i\right) R,\ a_i a_j R^{ij},\ R a^i{}_i,$$
$$[k]^3 :\ \omega_3(\Gamma) \rightarrow Chern - Simons,$$
$$[k]^2 :\ R,\ a_i a^i,$$
$$[k]^1 :\ \text{None},$$
$$[k]^0 :\ \gamma_0,$$

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$$ik_s e^{rsj} p_{ij}^s = k\rho^s p_i^{rs}$$
$$\rho^R = 1,\ \rho^L = -1$$

with the normalization condition

$$p_j^{*is} p_i^{js'} = 2\delta^{ss'}$$

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$$S^{(2)}_{gw} = \frac{1}{2}\int d\eta d^3x \frac{\zeta^2 a^2}{2}\Bigg\{ (\partial_\eta h_{ij})^2 - (1 - \bar{A} + \alpha_0 \frac{\mathcal{H}}{a})(\partial h_{ij})^2 + \alpha_3 \frac{e^{ijk}}{a}(h^m_{i,l} h^l_{k,mj} - h_{im,l} h^{ml}_{k,j}) + \frac{\alpha_4}{a^2}\left(\partial^2 h_{ij}\right)^2 + \alpha_5 \frac{e^{ijk}}{a^3}\partial^2 h_{il}(\partial^2 h^l_k)_{,j} + \frac{\alpha_6}{a^4}\left(\partial\partial^2 h_{ij}\right)^2 \Bigg\}.$$

- Under the circular polarization tensor basis

$$
\begin{aligned}
S_{gw}^{(2)} \quad = \quad & \sum_{s=R,L} \int d\eta d^3k \frac{\zeta^2 a^2}{2} \Big\{ (\psi_{\mathbf{k}}^{\prime s})^2 - (1 - \bar{s} + \alpha_0 H) k^2 (\psi_{\mathbf{k}}^s)^2 \\
& + \alpha_3 \rho^s \frac{k^3}{a} (\psi_{\mathbf{k}}^s)^2 + \alpha_4 \frac{k^4}{a^2} (\psi_{\mathbf{k}}^s)^2 \\
& + \alpha_5 \rho^s \frac{k^5}{a^3} (\psi_{\mathbf{k}}^s)^2 + \alpha_6 \frac{k^6}{a^4} (\psi_{\mathbf{k}}^s)^2 \Big\}.
\end{aligned}
$$

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$$v^{s\prime\prime}_k(\eta) + [\omega^2_s(\eta) - \frac{a''}{a}]v^s_k(\eta) = 0,$$

$$\omega^2_s(\eta) = (1 - \bar{A} - \alpha_0 H)k^2 - \alpha_3\rho^s\frac{k^3}{a} - \alpha_4\frac{k^4}{a^2} + \alpha_5\rho^s\frac{k^5}{a^3} - \alpha_6\frac{k^6}{a^4}.$$

With the de Sitter background, $a = -1/(H\eta)$.

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$$\left\langle \psi_{k_1}^{s_1}(0)\psi_{k_2}^{s_2}(0) \right\rangle = \frac{\Delta_T^2}{2k_1^3 H^2}(2\pi)^5 \delta(\mathbf{k}_1 + \mathbf{k}_2).$$

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$$\begin{aligned}\Delta_T^2 &\equiv \frac{k^3(|\psi_k^R|^2 + |\psi_k^L|^2)}{(2\pi^2)} \\ &= \frac{H^2}{4\pi^2}\Big(1 + 21\delta_1^2 \varepsilon_{\mathsf{HL}}^2 + \mathcal{O}(\varepsilon_{\mathsf{HL}}^3)\Big),\end{aligned}$$

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- Degree of circular polarization

$$\begin{aligned}\Pi &\equiv \frac{|\psi_k^R|^2-|\psi_k^L|^2}{|\psi_k^R|^2+|\psi_k^L|^2} \\ &= 3\delta_1\varepsilon_{\mathsf{HL}}+\left(17\delta_1^3-3\delta_2\right)\varepsilon_{\mathsf{HL}}^3/2+\mathcal{O}(\varepsilon_{\mathsf{HL}}^5).\end{aligned}$$

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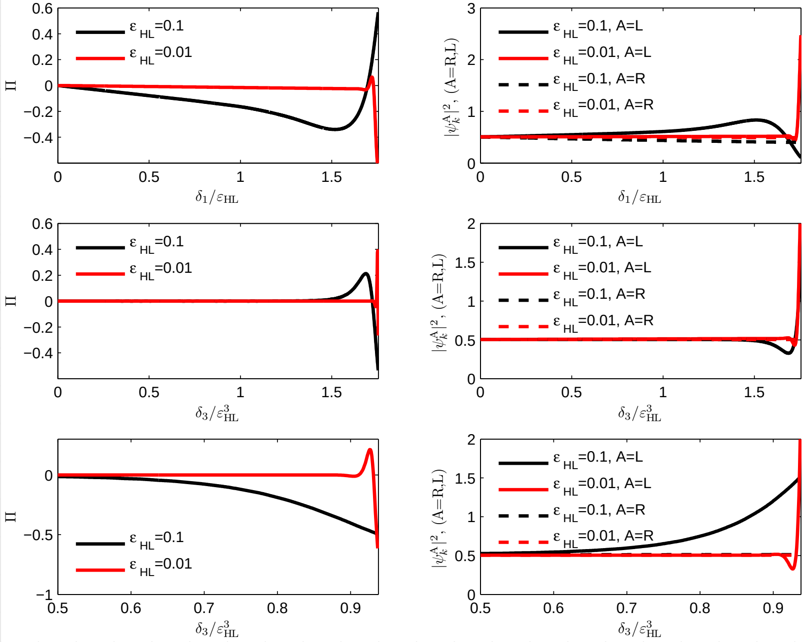
$$\varepsilon_{\mathsf{HL}} \equiv H/M_* \ll 1$$



Π
ε HL=0.1
ε HL=0.01
$\delta_1/\varepsilon_{\rm HL}$
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where, Ω_{GW} is the density parameter of the GW and SNR is the signal to the nose ratio for $f \simeq 1Hz$

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$$\left\langle \psi_{k_1}^{s_1}(\eta)\psi_{k_2}^{s_2}(\eta)\psi_{k_3}^{s_3}(\eta) \right\rangle \\ = -i\int_{\eta_i}^{\eta} d\eta' \left\langle [\psi_{k_1}^{s_1}(\eta)\psi_{k_2}^{s_2}(\eta)\psi_{k_3}^{s_3}(\eta), H_{\mathsf{int}}(\eta')] \right\rangle,$$

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$$\left\langle \psi^{s_1}_{k_1}(0)\psi^{s_2}_{k_2}(0)\psi^{s_3}_{k_3}(0) \right\rangle$$
$$= (2\pi)^7 \delta^3(k_1 + k_2 + k_3) \frac{\Delta^4_{\mathsf{T}}}{2^3 k_1^3 k_2^3 k_3^3} B^{s_1 s_2 s_3}_{k_1,k_2,k_3}.$$

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- The parity violation non-gaussianity contributions come from only 3-dimensional Chern-Simons operator $\omega(\Gamma)$

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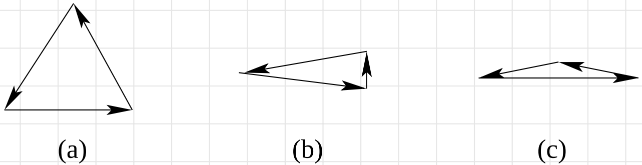

(a) equilateral, (b) squeezed, (c) folded

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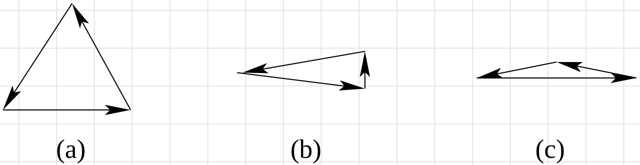

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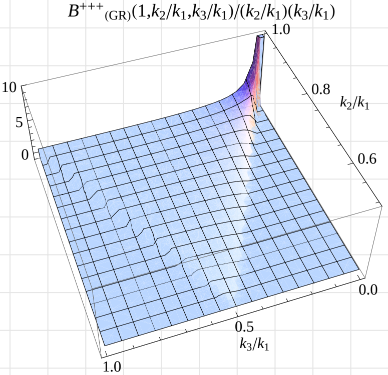
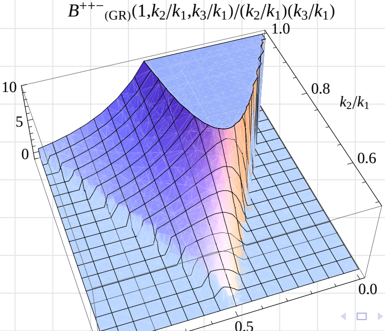

$B^{+++}{}_{(GR)}(1,k_2/k_1,k_3/k_1)/(k_2/k_1)(k_3/k_1)$
10
5
0
1.0
0.8
0.6
k_2/k_1
0.0
0.5
1.0
k_3/k_1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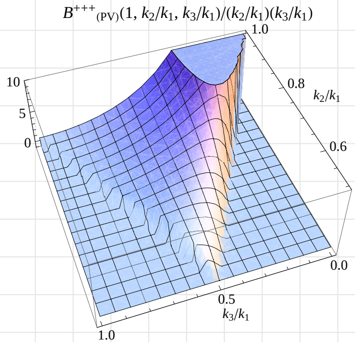
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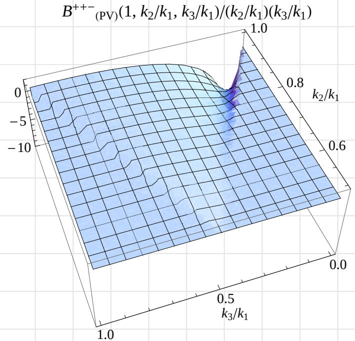
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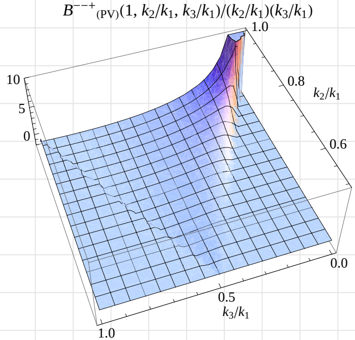
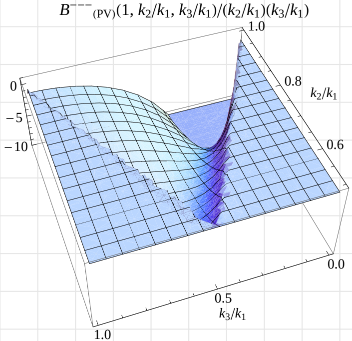
1.0


$B^{--+}{}_{(PV)}(1, k_2/k_1, k_3/k_1)/(k_2/k_1)(k_3/k_1)$
10
5
0
1.0
0.8
0.6
k_2/k_1
0.0
0.5
k_3/k_1
1.0


$B^{---}{}_{(PV)}(1, k_2/k_1, k_3/k_1)/(k_2/k_1)(k_3/k_1)$
0
−5
−10
1.0
0.8
0.6
k_2/k_1
0.0
0.5
k_3/k_1
1.0

Summary

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Summary

- In Hořava-Lifshitz gravity, the parity violation spatial derivative terms have contributions for PGW polarization and non-gaussianity
- The 3-dimensional gravitational Chern-Simons operator $\omega(\Gamma)$ is the only one that violates the parity and meantime has non-vanishing contributions to the non-gaussianities of PGWs.
- The large polarization and non-gaussianities are expected if the adiabatic condition fails to hold. We still keep working on this subject.

Thanks!