Quantum gravity effects in primordial gravity waves

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Quantum Gravity Phenomenology (our work thus far)

- Relativistic Generalized Uncertainty Principle arXiv:1810.11761[1]

$$[x^\mu, p^\nu] = i\hbar\,(1+\gamma p^\rho p_\rho)\,\eta^{\mu\nu} + i\,\hbar\gamma p^\mu p^\nu$$

where $\gamma = \gamma_0/(M_{Pl}c)^2$

- Field theory with Minimum length arXiv:2005.03771[2]

$$\underbrace{\Box_0(1+2\alpha\gamma\Box_0)\phi = -m^2\phi}_{\text{RGUP modified Klein-Gordon equation}} \qquad \underbrace{\left[i\tau^\mu\partial_\mu(1+\alpha\gamma\partial_\rho\partial^\rho) - m\right]\psi = 0}_{\text{RGUP modified Dirac equation}}$$

- Maximal momentum GUP leads to quadratic gravity arXiv:2106.04141[3]

$$S_{Stelle} = \int d^4x\,\sqrt{-g}\left[\frac{1}{2\kappa^2}R - \gamma\,R^{\mu\nu}R_{\mu\nu} + \frac{\gamma}{2}\,R^2\right],$$

[1] V. Todorinov, P. Bosso, S. Das, Ann. of Phys. **405**, 2019, 92-100
[2] P. Bosso, S. Das, V. Todorinov, Ann. of Phys. **422**, 2020, 168319
[3] V. Nenmeli, S. Shankaranarayanan, V. Todorinov, S. Das, Phys. Lett. B **821**, 2021

Quadratic Gravity to $f(R) + C^2$

- Stelle gravity shortcomings:
  Spherically symmetric solutions are perturbatively isolated.

$$S_{EH} = \int d^4x \sqrt{-g} \left[\frac{1}{2\kappa^2} R - \gamma\, R^{\mu\nu} R_{\mu\nu} + \frac{\gamma}{2} R^2 \right]$$

Describes the same dynamics as

$$S_f = \frac{1}{2\kappa} \int d^4x \sqrt{-g} \left[\underbrace{R + \frac{1}{6}\gamma R^2}_{f(R)} - \underbrace{\gamma C_{\alpha\beta\rho\sigma} C^{\alpha\beta\rho\sigma}}_{\mathcal{L}_{\mathrm{Weyl}}} \right] ,$$

Inflation observables

- Fakeon Quantization

$$\tilde{S} = \int d^4x \sqrt{-\tilde{g}} \left[\frac{1}{2\kappa}\tilde{R} - \underbrace{\frac{1}{2}\tilde{g}^{\mu\nu}\partial_\mu\chi\partial_\nu\chi - U(\chi)}_{inflaton\ \chi} - \underbrace{\frac{\gamma}{2\kappa}\mathcal{L}_{\text{Weyl}}}_{fakeon\ \phi} \right],$$

- Yields the following observables

$$A_{\mathcal{R}} = \frac{m_\phi^2 N^2}{3\pi M_{\text{Pl}}^2} = \frac{N^2}{18\pi\gamma_0}$$

$$A_T = \frac{8m_\chi^2 m_\phi^2}{\pi(m_\phi^2 + 2m_\chi^2)M_{\text{Pl}}^2} = \frac{4}{7\pi\gamma_0}$$

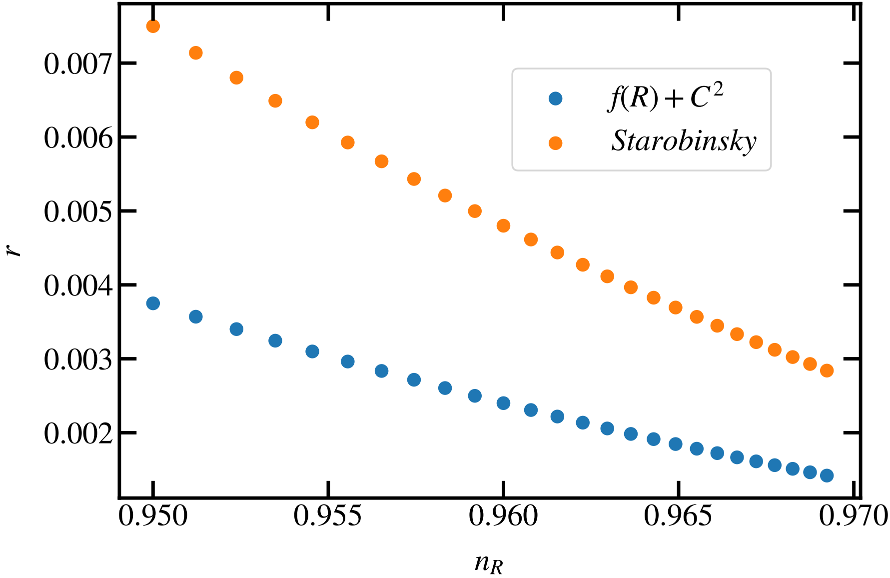
- Comparing to experimental estimations arXiv:1502.02114 [4]

$$\gamma_0^{N=40} \approx 3.430 \times 10^{10}$$

$$\gamma_0^{N=60} \approx 7.719 \times 10^{10}$$

[4] Planck Collaboration Astron.Astrophys. **594** (2016) A20

Inflation observables



Quantum Gravity relics in Primordial Gravitational Waves

- Tensor modes EoMs

$$\Box \bar{h}_{ij} - 2\mathcal{H}\,\bar{h}'_{ij} - \underbrace{\frac{\gamma}{a^2}\Box\Box\bar{h}_{ij}}_{RGUP} = 0$$

- Split by polarization

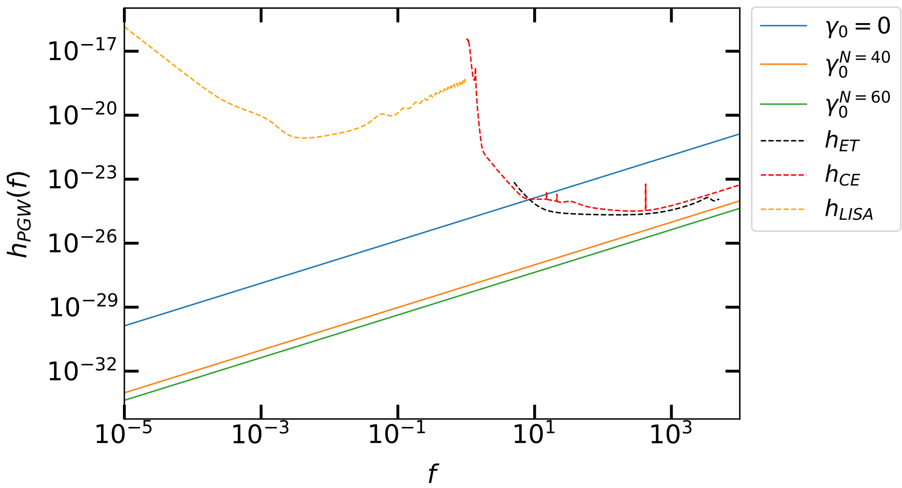
$$\frac{d^2\mu_k^{(1)}}{dz^2} + \left(1 - \frac{2}{z^2}\right)\mu_k^{(1)} = 0\,,$$

$$\frac{d^2\mu_k^{(2)}}{dz^2} + \left(1 + \frac{1}{\gamma\,H^2\,z^2}\right)\mu_k^{(2)} = 0$$

- Primordial Gravitational wave Power spectrum

$$\mathcal{P}(k) = \frac{2\kappa\,H^2}{\pi^2}\,\frac{1}{1 + 2\gamma\,H^2}\left(1 + \left(\frac{k}{k_*}\right)^2 - \frac{\pi}{2}\,\left(\frac{k}{k_*}\right)^3\,|\mathrm{e}^{\mathrm{i}\pi\,\nu/2}\,H_\nu^{(1)}(\left(\frac{k}{k_*}\right))|^2\right)$$

Detectability of corrections in next generation detectors



Conclusions

1. We were able to find **values** for the additional Lorentz invariant scale.
2. There are **Quantum Gravitational signatures present in the power spectrum of primordial gravitational waves.**
3. The characteristic strain of PGWs is a few orders of magnitude lower than the projected LISA sensitivity.
4. Future land based telescopes might be able to detect PGWs and the QG signatures in them.
5. The powrer spectrum of PGWs contains information of the exact number of e-folds the universe expanded.
6. A preview available at arXiv:2208.11095

Thank you for your attention!