

UDC 530.12

Screening of Polarisation Modes of Gravitational Waves in Modified Gravity

Murli Manohar Verma^(*)

sunilmmv@yahoo.com

Utkal Keshari Dash

cosmokunal94@gmail.com

Sakshi Srivastava

srivastavasakshi696@gmail.com

Department of Physics, University of Lucknow, India

Abstract. We explore the screening of the scalar modes of polarisation of gravitational waves travelling across the evolving galaxies. This is done in the modified $f(R)$ gravity background. The observation of such modes is found to be dominantly suppressed by a chameleon mechanism in the gas rich environment of the galaxies. We constrain the dark matter equivalence of the scalar mode contributions. The degree of suppression is also found to constrain the future observations which are dominated by tensor modes. It is proposed that the influence on the polarisation by the varying density galactic backgrounds serves as a new and strong approach to distinguish the Λ CDM model from the alternative gravity theories. We compare our results with the current galactic observations.

Keywords: gravitational waves, scalar modes, polarisation, modified gravity, $f(R)$ gravity, chameleon mechanism

Introduction. The direct observation of gravitational waves (GWs) has greatly enhanced our capability to test fundamental features of gravity beyond general relativity predictions. Modified theories of gravity predict extra polarization modes. Especially, in $f(R)$ gravity models we find the presence of additional scalar modes. Their observation would be a very strong evidence for physics beyond Einstein's framework. However, the propagation of these scalar modes through relativistic astrophysical environments is highly complex due to nonlinear screening mechanisms [1, 2]. One such mechanism is the chameleon effect where scalar field interactions are dynamically suppressed in high-density environments such as galaxies, thus showing results of general relativity at solar system scales.

We demonstrate that the scalar modes are heavily suppressed in gas rich galaxies such that their direct detection would be hard. Through the study of the extent of the suppression, we limit the scalar mode's effective contribution to the gravitational field and establish analogies with dark matter like behavior [3]. The results indicate that the suppression of scalar modes as a function of environment may provide a novel observation path for distinguishing Λ CDM from modified gravity theories through several gravitational wave observations [4].

Methods and materials; results. Our approach involves generalizing the Einstein-Hilbert action by introducing a function $f(R)$ in place of only Ricci scalar R . Further, by applying the principle of least action we derive the set of field equations for $f(R)$ gravity. We observe the additional degree of freedom in $f(R)$ gravity

appearing from scalar field. This scalar field changes the background for GW propagation. We study the polarization of GWs in weak field limit in $f(R)$ gravity background in which we obtain an additional massive polarization mode — a longitudinal mode that exists due to scalar field in the form of scalar perturbations. The mass of scalar field quanta (scalon mass) m_ϕ becomes too large in galactic regions and its Compton wavelength becomes reduced to extreme limit, where this leads to the collapse of scalar field [5]. Thus, longitudinal polarization mode of GWs is significantly suppressed [7].

Conclusion. Our results demonstrate that scalar modes in $f(R)$ gravity are significantly suppressed in dense galactic environments due to chameleon screening. This suppression limits their detectability but provides a novel way to effectively distinguish modified gravity from Λ CDM using gravitational wave polarization signatures across astrophysical structures.

References

- [1] De Felice A., Tsujikawa S. $F(R)$ theories. *Living Rev. Rel.*, 2010, vol. 13. <https://doi.org/10.48550/arXiv.1002.4928>
- [2] Katsuragawa T., Nakamura T., Ikeda T., Capozziello S. Gravitational waves in $F(R)$ gravity: Scalar waves and the chameleon mechanism. *Phys. Rev. D*, 2019, vol. 99, art. no. 124050.
- [3] Yadav B.K., Verma M.M. Dark matter as scalaron in $f(R)$ gravity models. *JCAP*, 2019, vol. 10, art. no. 052.
- [4] Sharma V.K., Harikumar S., Grespan M., Biesiada M., Verma M.M. Probing massive gravitons in $f(R)$ with lensed gravitational waves. *Phys. Lett. B*, 2024, vol. 859, art. no. 139093.
- [5] Katsuragawa T., Matsuzaki S. Dark matter in modified gravity? *Phys. Rev. D*, 2017, vol. 95, art. no. 044040.
- [6] Capozziello S., Corda C., De Laurentis M.F. Massive gravitational waves from $f(R)$ theories of gravity: Potential detection with LISA. *Phys. Lett. B*, 2008, vol. 669, pp. 255–259.
- [7] Dash U.K., Yadav B.K., Verma M.M. Scalar Modes of Polarization and Speed of Gravitational Waves in $f(R)$ gravity. 2024, arXiv:2401.07664.