Characterizing Ultralight Scalarons in f(R) Gravity Using Gravitational Lensing of GWs

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Abstract: *We aim to investigate the evolution of gravitational waves signals, and go beyond the eikonal approximation in modified gravity theory. We analytically discuss the Kirchhoff's diffraction integral within modified gravity backgrounds for point-like lens model, and explore the massive scalaron signature through gravitational lensing.*

$f(R)$ theory of Gravity (Massive Scalaron)

$$\mathcal{S} = \frac{1}{2}\int \sqrt{-g}\left[\frac{1}{8\pi G_N} f(R)\right] d^4x + \mathcal{S}_m(g_{\mu\nu}, \Psi_m) \quad \text{with}$$

$$f(R) = \frac{R^{1+\delta}}{R_c^{\delta}}$$

δ: dimensionless physical parameter

R_c: *Weight constant*

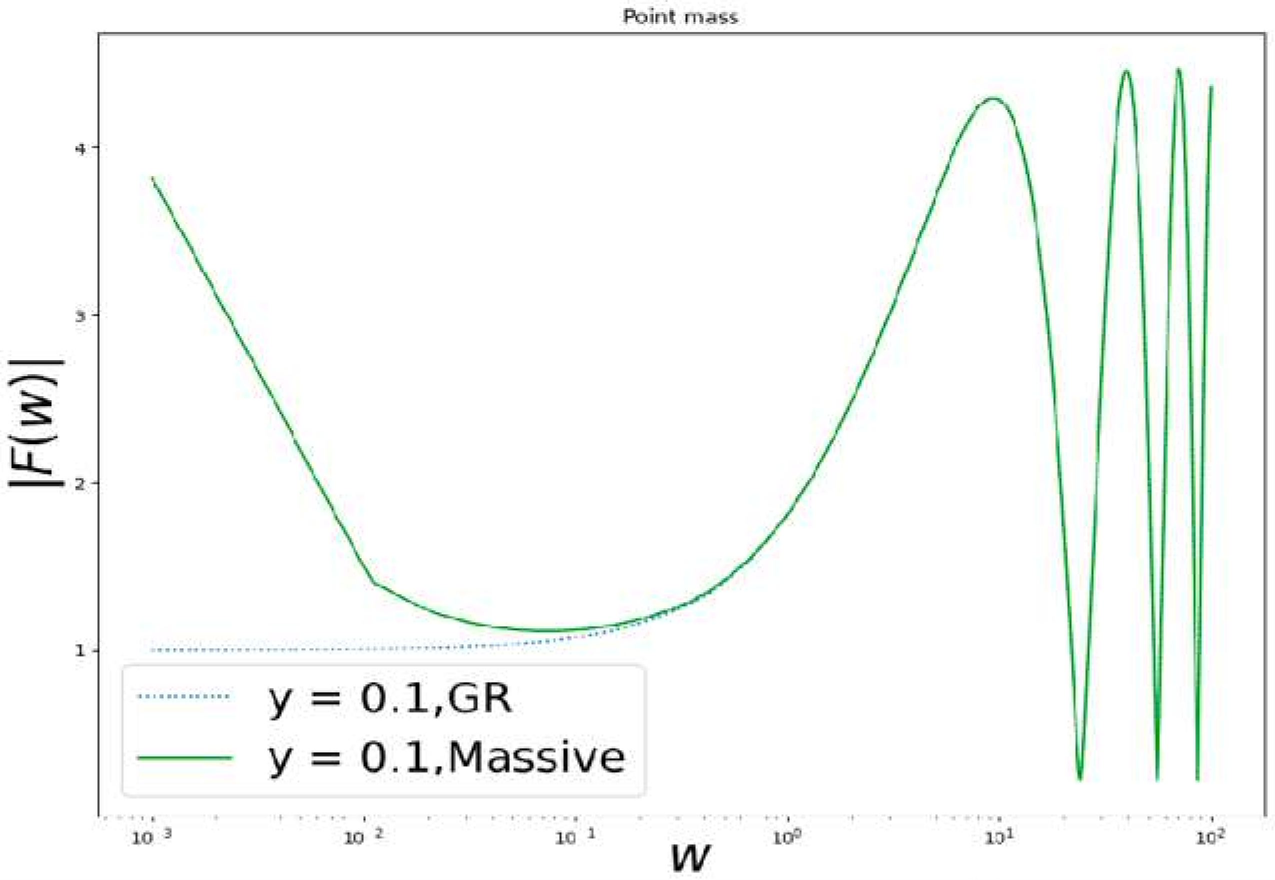
$\delta < 1$ leads to dispersion with Massive scalaron

$$p^\mu p_\mu = -m_\phi^2 \left(\equiv \frac{f_R - R f_{RR}}{3 f_{RR}} \right)\Bigg|_{R=R^{(\text{Background})}}$$

Amplification Factor

$$F(f; M_{len}, y, m_\phi) = \exp\left[\frac{\pi}{4}\mathrm{w}\beta\right] \times \left(\frac{\mathrm{w}}{2}\beta\right)^{i\frac{\mathrm{w}}{2}\beta} \times \Gamma\left(1 - i\frac{\mathrm{w}}{2}\beta\right) \times {}_1F_1\left(i\frac{\mathrm{w}}{2}\beta, 1, i\frac{\mathrm{w}}{2}\beta y^2\right)$$

$$\beta(f)\left(\equiv \frac{c}{v_{group}(f)}\right) \approx 1 + \frac{m_\phi^2}{8\pi f^2}$$



Results: For $\delta \sim 10^{-7}$, $m_\phi \sim 10^{-15}$ eV

Conclusion: Massive scalarons in f (R) can be characterized through the amplification of the wave amplitude by lensing. Such nice features in f (R) gravity can be explored with the space based GW probes (like LISA, etc.)

Ref: 1. T. Nakamura, and R. Takahashi, Astrophys. J 595, 1039 (2003);

2. V. K. Sharma, and M. M. Verma, Eur. Phys. J. C 82, 400 (2022).