Scalar radiation from symmetron field oscillations

PIC1 Scientific project

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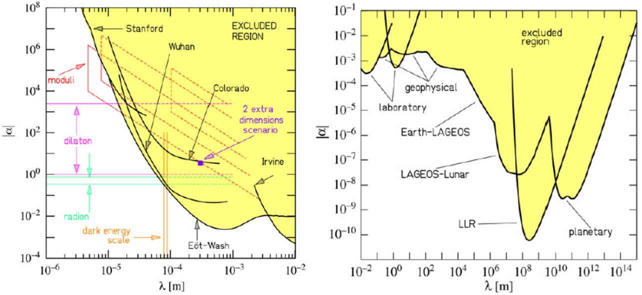
Introduction

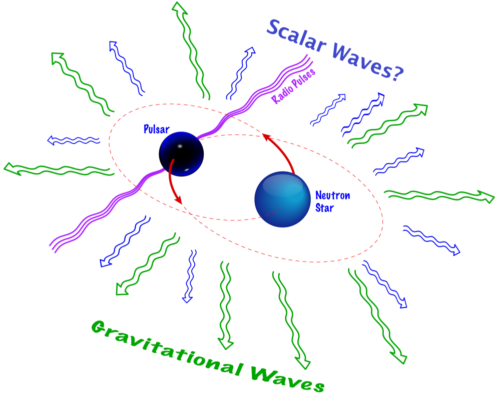
- In the standard model of cosmology, (ΛCDM), the acceleration of the universe is explained by a cosmological constant Λ
- Modified theories of gravity have emerged as an alternative by introducing a new scalar field mediating a fifth force, altering the behaviour of gravity
- General relativity has been tested with high precision, placing constraints on this new force



Adelberger et al. (2009)

Screening mechanisms and scalar waves

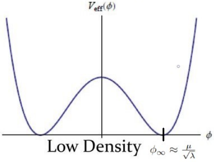
- Screening mechanisms suppress the field in regions of high matter density, hiding fifth forces from local gravity tests
- Due to the coupling of these fields to mass density, radially pulsating astrophysical objects can source scalar waves.
- These waves would cause deviations from General Relativity which could be tested by gravitational wave detectors

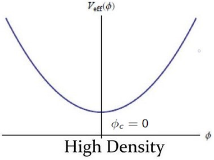


The symmetron

The symmetron screening mechanism works by combining a symmetry breaking potential with a coupling to the local matter density

$$\boxed{V_{\rm eff}(\phi) = \frac{1}{2}\left(\frac{\rho}{M_s^2} - \mu^2\right)\phi^2 + \frac{1}{4}\lambda\phi^4}$$





$$\rho \ll \mu^2 M_s^2$$

$$\rho \gg \mu^2 M_s^2$$

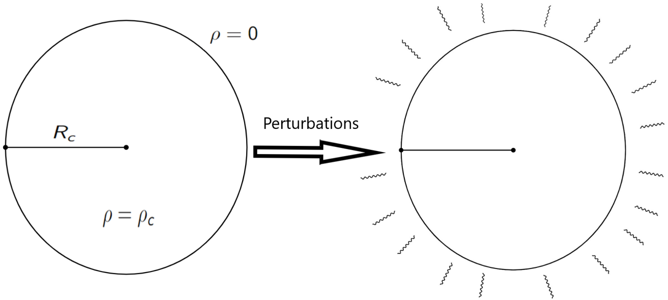
$$\boxed{\phi_\infty \approx \mu/\sqrt{\lambda}} \qquad m_\infty \approx \sqrt{2}\mu$$

$$\boxed{\phi_c = 0} \qquad m_c = \sqrt{\frac{\rho}{M_s^2} - \mu^2}$$

The model

Approximations:

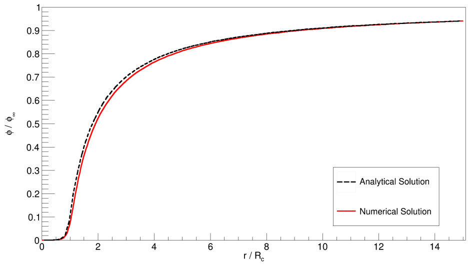
1. Newtonian limit
2. Constant density and radius
3. Radial pulsations with constant amplitude and frequency
4. The surrounding region is a perfect vacuum

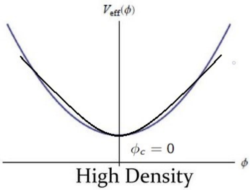


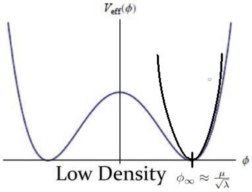
Static profile

Static equation of motion in spherical coordinates

$$\boxed{\frac{d^2\phi_0}{dr^2} + \frac{2}{r}\frac{d\phi_0}{dr} = \left(\frac{\rho_0}{M_s^2} - \mu^2\right)\phi_0 + \lambda\phi_0^3}$$







Perturbations profile

Introducing the perturbations into the system

$$\phi(r,t) = \phi_0(r) + \delta\phi(r,t) \qquad\qquad R(t) = R_c + \Delta R sin(\omega t)$$

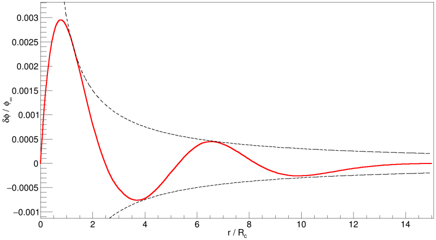
$$\Longrightarrow \boxed{\rho(r,t) = \rho_0(r)\left(1 + 3\frac{\Delta R}{R_c}\sin(\omega t)\right)}$$

$$x \equiv \frac{r}{R_c} \qquad \tau \equiv \frac{t}{R_c} \qquad \varphi \equiv \frac{\phi}{\phi_\infty}$$

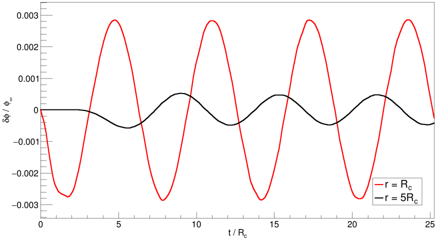
$$\boxed{-\frac{\partial^2\delta\varphi}{\partial\tau^2} + \frac{\partial^2\delta\varphi}{\partial x^2} + \frac{2}{x}\frac{\partial\delta\varphi}{\partial x} = R_c^2\left[\frac{\delta\rho}{M_s^2}\varphi_0 + \left(\frac{\rho_0}{M_s^2} - \mu^2\right)\delta\varphi + 3\mu^2\varphi_0^2\delta\varphi\right]}$$

Time dependent equation of motion

Perturbations profile (cont.)



Perturbations profile at $\tau = 11$ as a function of x

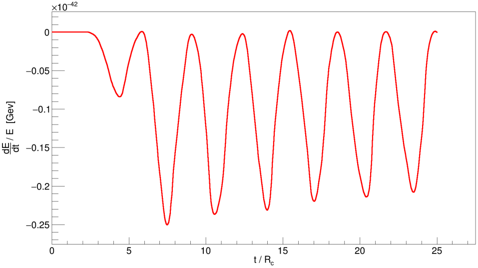


Perturbations profile at $x = 1$ and $x = 5$ as a function of τ

Scalar energy loss

$$\boxed{\frac{dE}{dt} = \int_{\partial V} \dot{\phi}\partial_i\phi n_i \, dS = 4\pi R^2 \frac{\partial\phi}{\partial t}\frac{\partial\phi}{\partial r}\bigg|_{r=R}}$$

$$E = \frac{4}{3}\pi R_c^3 \rho_c$$

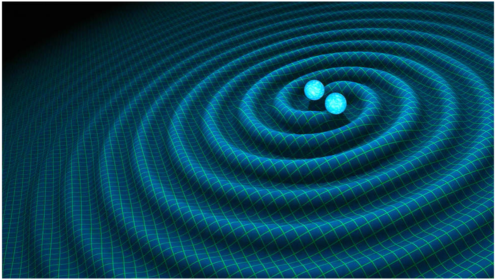


Relative power loss $\frac{1}{E}\frac{dE}{dt}$ over time

$$\boxed{\left\langle \frac{1}{E}\frac{dE}{dt} \right\rangle \approx 10^{-19} s^{-1}}$$

Conclusions

- Radial pulsations of astrophysical objects source scalar waves
- These waves carry energy with them in the form of scalar radiation
- Scalar radiation is subdominant when compared to gravitational waves, making them harder to detect
- A more realistic result can be obtained by considering GR and using a more accurate model of binary systems



Acknowledgements

Thank you!