GALILEON RADIATION FROM BINARY PULSARS

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Linearized massive graviton

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

Small

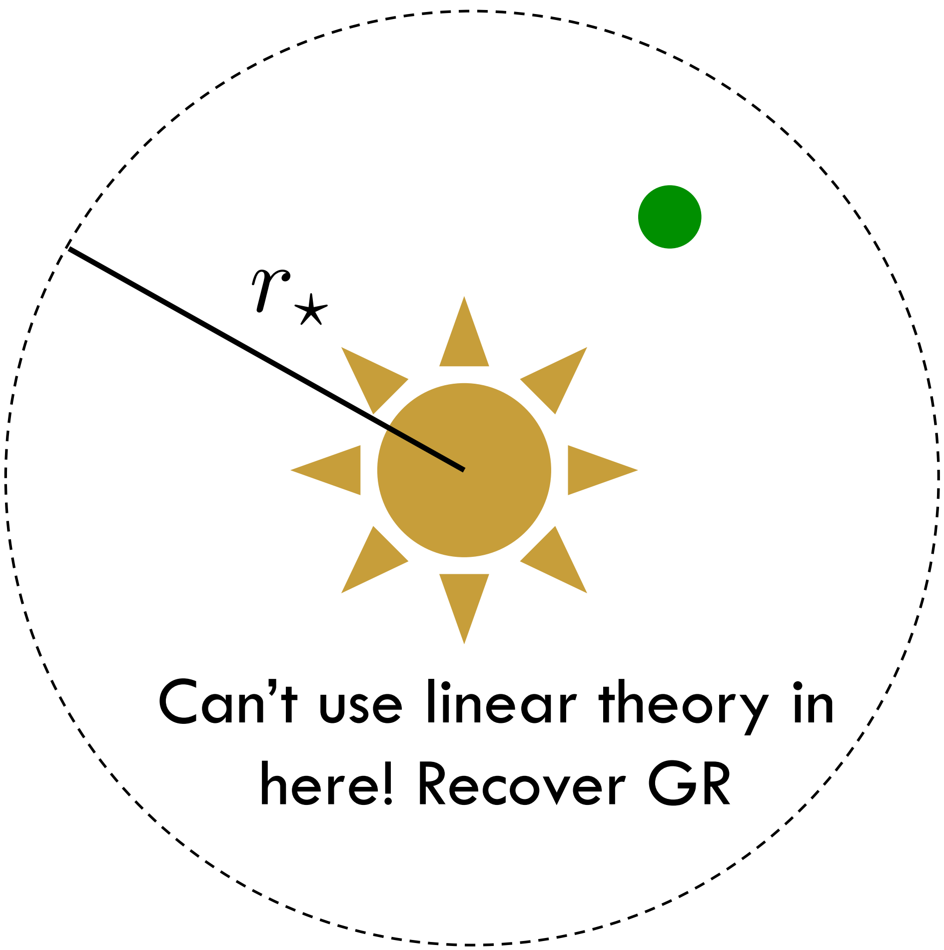
$$S_{FP} \sim \int \mathrm{d}^4x - \frac{1}{2}(\partial h)^2 - \frac{1}{2}m^2h^2 + \frac{hT}{M_{\rm Pl}}$$

A big puzzle:

$$\lim_{m\to 0} S_{FP} \neq S_{GR}$$

Problem is Helicity 0 mode

Vainshtein: Nonlinearities are key!



Vainshtein, Phys. Lett. B **39**, 393 (1972)

$$r_\star = \frac{(M/M_{\mathrm{Pl}})^{1/3}}{\Lambda}$$

Interesting cosmology if $\Lambda \sim (1000\ \mathrm{km})^{-1}$

$$r_{\star,sun} \approx 100\mathrm{pC}$$

Galileons

$$\pi \to \pi + c + v^\mu x_\mu$$

$$\mathcal{L}_2 = (\partial\pi)^2$$

$$\mathcal{L}_3 = \frac{1}{\Lambda^3}(\partial\pi)^2(\partial\partial\pi)$$

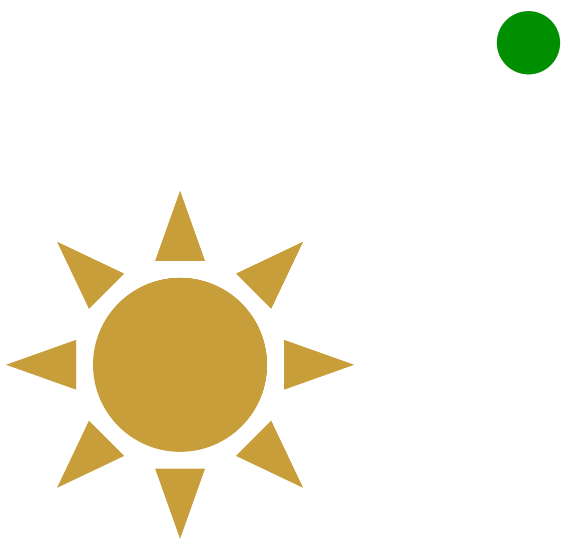
$$\mathcal{L}_4 = \frac{1}{\Lambda^6}(\partial\pi)^2(\partial\partial\pi)^2$$

$$\mathcal{L}_5 = \frac{1}{\Lambda^9}(\partial\pi)^2(\partial\partial\pi)^3$$

Galileons are derivatively self coupled and exhibit Vainshtein Mechanism

Helicity 0 of massive graviton looks like a galileon in 'decoupling limit'

Linear theory can't screen



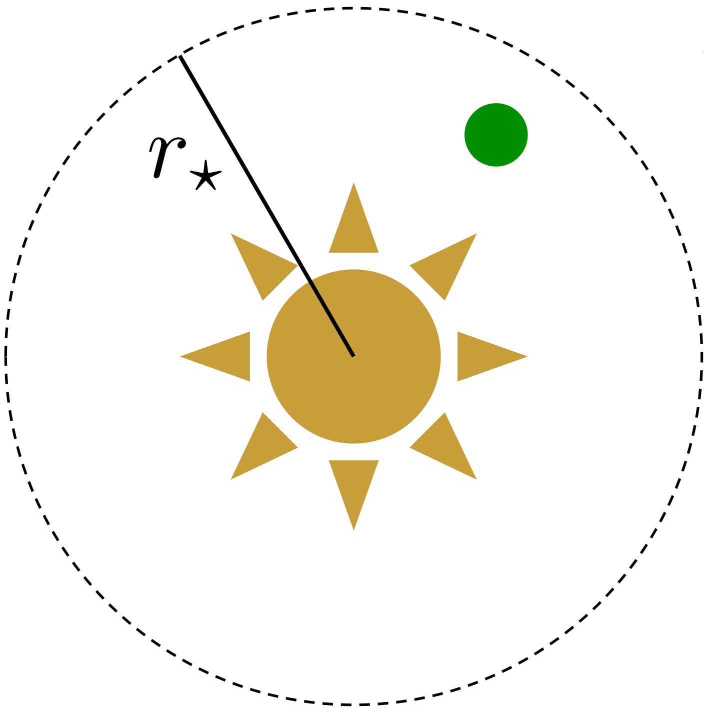
$$\nabla^2 \phi = \frac{1}{M_{\mathrm{Pl}}} 4\pi \rho$$

$$E = \nabla \phi \sim \frac{M/M_{\mathrm{Pl}}}{r^2}$$

If this is helicity 0 mode of the graviton in the linearized theory—unscreened forces, unsmooth massless limit

Nicolis et al, Phys Rev D **79**, 064036 (2009)

Nonlinearities introduce screening



$$\nabla^2 \pi_{gal} + \frac{1}{\Lambda^3} (\nabla^2 \pi_{gal})^2 = \frac{1}{M_{\rm Pl}} 4\pi\rho$$

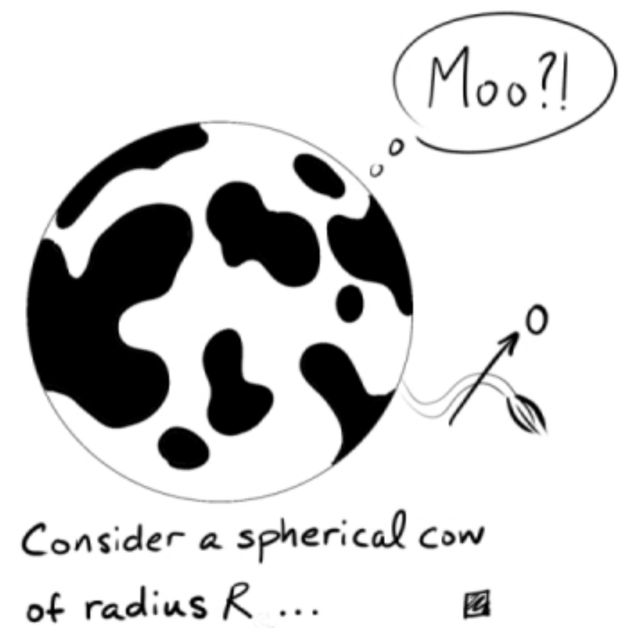
$$E_{gal}(r > r_\star) \sim \frac{M/M_{\rm Pl}}{r^2}$$

$$E_{gal}(r < r_\star) \sim \boxed{\left(\frac{r}{r_\star}\right)^{3/2}} \frac{M/M_{\rm Pl}}{r^2}$$

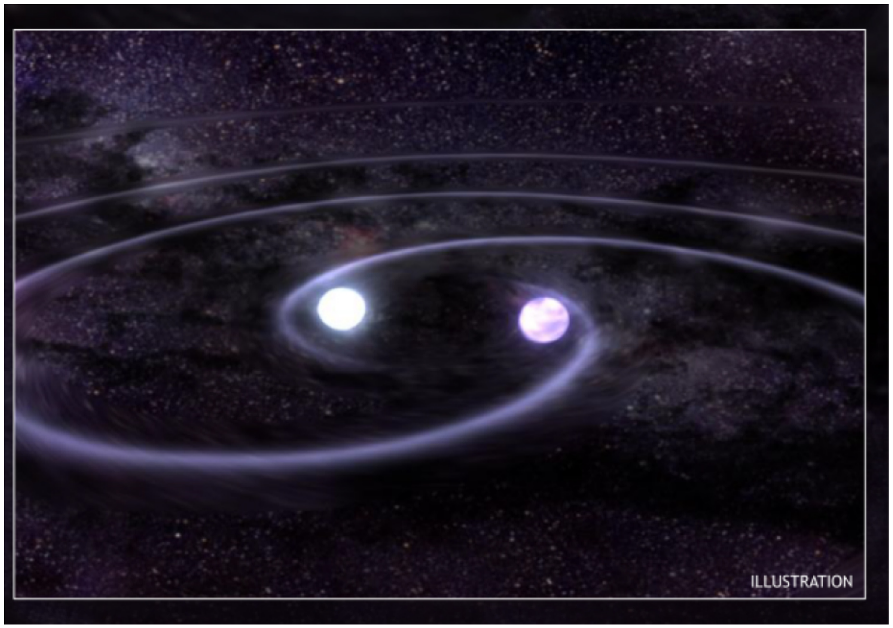
Within Vainshtein radius, we recover GR

Vainshtein beyond the sun

How does the Vainsthein mechanism work outside of the static, spherically symmetric case?



Binary Pulsars



Goal: Compute power emitted in Galileon waves by a binary pulsar system and compare to GR

	A	B	C	D	E
Pulsar	1913+16 Taylor-Hulse	B2127+11	B1534+12	J0737–3039 double pulsar	J1738+0333
$M_1/M_\odot$	1.386	1.358	1.345	1.338	1.46
$M_2/M_\odot$	1.442	1.354	1.333	1.249	0.181
T_P/days	0.323	0.335	0.420	0.102	0.355
e	0.617	0.681	0.274	0.088	3.4×10^{-7}

de Rham et al, arXiv:1208:0580

Philosophy of Calculation

$$\pi = \pi_b + \delta\pi$$

Spherical Background

Small Fluctuation

We compute energy carried away by small fluctuations living on the background

$$S[\delta\pi] = \int \mathrm{d}^4x - \frac{1}{2} Z^{\mu\nu}(\pi_b)\partial_\mu\delta\pi\partial_\nu\delta\pi + \frac{\delta\pi\delta T}{M_{\mathrm{Pl}}}$$

Cubic Galileon Only

Quadrupole power is largest contribution

$$\frac{P_{gal}}{P_{GR}} \sim \frac{1}{(\Omega_P r_\star)^{3/2}} \approx 10^{-9}$$

Experimental precision is 10^{-3}

Vainsthein screening is $\left(\frac{\Omega_P^{-1}}{r_\star}\right)^{3/2}$

Compare to static Vainsthein screening $\left(\frac{\bar{r}}{r_\star}\right)^{3/2}$

All Galileons

Quadrupole is screened compared to GR

$$\frac{P_{gal,quad}}{P_{GR}} \sim \frac{1}{(\Omega_P r_\star)^2} \approx 10^{-12}$$

But many multipoles contribute to the power!

$$\frac{P_{gal}}{P_{GR}} \sim \frac{1}{\Omega_P r_\star} N^4 = 10^8?$$

Cutoff

de Rham, Matas, Tolley, in preparation

Perturbation theory breaks down!

$$Z_{\mu\nu}\mathrm{d}x^\mu \mathrm{d}x^\nu \sim -\mathrm{d}t^2 + \mathrm{d}r^2 + r_\star^2 \mathrm{d}\Omega^2$$

Higher order multipoles not suppressed

Fluctuations think they are in 1D

$$\frac{\delta\pi^{(2)}(r_\star)}{\delta\pi^{(1)}(r_\star)} = \Omega_P r_\star v L^4 \approx 10^3 L^4$$

This is unexpected! The Vainshtein screening in this case is not just due to the static, spherical background.
The static Vainshtein mechanism is not enough.

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Summary

Vainshtein mechanism still exists in time dependent situations but is different than the standard picture

Cubic Galileon—Vainshtein mechanism is less effective

All Galileons—Simple perturbation theory breaks down! Surprising and requires future study. Static Vainshtein mechanism not sufficient to understand this case.