A new approach to chameleon theories

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Motivations

- A variation of a fundamental constant is in contradiction with EEP since it violates LPI.
- Most theories that predict variation of fundamental constants, also predict violations of the WEP:
  - Bekenstein 1982 and 2002, Barrow et al 2002, Olive & Pospelov 2002, Kraiselburd & Vucetich 2011
  - Wu & Wang 1986, Damour & Polyakov 1994
  - Youm 2001, Palma et al 2003, Brax et al 2003
  - Kaluza 1921, Klein 1926, Overduin & Wesson 1997
- WEP is strongly constrained by Eötvös type experiments $\eta = \frac{\Delta a}{a} \simeq 10^{-14}$ (Adelberger et al 2009)

Motivations

- However, some theories can avoid this problem:
  - Dilaton-matter-gravity models with strong coupling (Damour et al 2002),
  - Chameleon models: Strong coupling between a scalar field and matter fields (Khoury and Weltman 2004, Brax et al 2004, Mota & Shaw 2008, Olive & Pospelov 2008).
- Mota & Shaw have shown that the linear and cuasi-linear solutions predict violations of WEP but, the non-linear solution DOES NOT at the particle level, since the scalar field does not depend on the composition of the free falling body.
- We present an alternative preliminary calculation that shows that violation of WEP may be a prediction of chameleon models.

Chameleon models

- Khoury $\&$ Weltman 2004, proposed a strong coupling of a scalar field to matter: the “chameleon” (ϕ); whose action is:

$$S = \int d^4x\sqrt{-g}\left[\frac{M_{pl}}{2}R - (\partial\phi)^2 - V(\phi)\right] - \int d^4x L_m\left(\Psi_m^{(i)}, g_{\mu\nu}^{(i)}\right)$$

where L_m is the matter fields lagrangian, $g_{\mu\nu}^{(i)} = \exp\left[\frac{2\beta_i\phi}{M_{pl}}\right]g_{\mu\nu}$, and $V(\phi) \propto \phi^{-n}$; being n and β_i dimensionless constants.

The key ingredient: The non-linear effects are only relevant for a small region near to the body surface named thin shell;

$$\frac{\phi_\infty - \phi_{\mathrm{C_j}}}{6\beta M_{pl}\Phi_{\mathrm{N_j}}} = \frac{\Delta R_j}{R_j} << 1. \quad (1)$$

Chameleon models

- The equation of motion is:

$$\Box\phi_j = \frac{\partial V^j_{eff}}{\partial\phi_j} = \frac{\partial[V(\phi_j) + \rho_j \exp(\frac{\beta\phi_j}{M_{pl}})]}{\partial\phi_j} \tag{2}$$

$$V^j_{eff}(\phi) \simeq V^j_{eff}(\phi_{j\min}) + \frac{1}{2}\partial_{\phi\phi}V^j_{eff}(\phi_{j\min})(\phi_j - \phi_{j\min}). \tag{3}$$

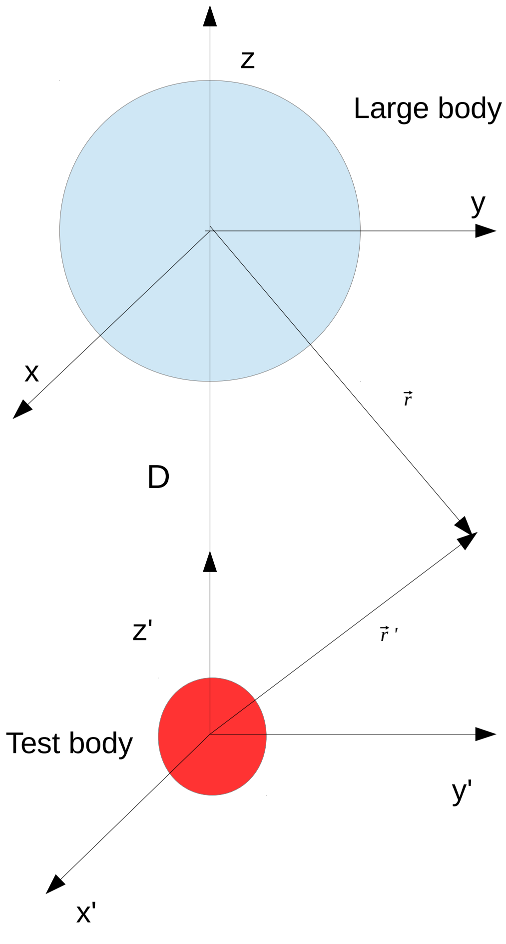
- Redefining:

$$m^{j2}_{eff} = \partial_{\phi\phi}V^j_{eff}(\phi_{j\min}), \tag{4}$$

$$\frac{1}{r}\partial r(r^2\partial r\phi_j) = m^{j2}_{eff}(\phi_j - \phi_{j\min}) \tag{5}$$

- Thin-shell condition: $m^j_{eff}R >> 1$

The problem



Our proposal

- We expand the most general solution for $\Box\phi_j = m^{j2}_{eff}(\phi_j - \phi_{j\min})$ in terms of complete sets of solutions in three regions:
  - Inside the Large Body (LB) ϕ_1, inside the Test Body (TB) ϕ_2, and outside both bodies ϕ_3
- Outside the bodies we keep both contributions from LB and TB.
- The boundary conditions are:

$$\lim_{r\to 0}\partial_r\phi_{1,2} = 0 \qquad \text{so as} \qquad \lim_{r\to 0}\phi_{1,2} = \phi_{\mathrm{C}_{1,2}}; \tag{6}$$

$$\lim_{r\to\infty}\partial_r\phi_3 = 0 \qquad \text{so as} \qquad \lim_{r\to\infty}\phi_3 = \phi_\infty; \tag{7}$$

$$\phi_j = \phi_3|_{R_j}; \qquad \frac{\partial\phi_j}{\partial r} = \frac{\partial\phi_3}{\partial r}|_{R_j}, \qquad j = 1,2 \tag{8}$$

Our proposal

We write the general solution to a modified Helmholtz equation by using modified spherical bessel functions and spherical harmonics:

$$\phi = \begin{cases} \phi_1 = \sum_{lm} C^1_{lm} i_l(\mu_1 r) Y_{lm}(\theta, \Phi) + \phi_{C_1} & r \leq R_{\text{large body}} \\ \phi_3 = \sum_{lm} C^{3.1}_{lm} k_l(\hat{\mu} r) Y_{lm}(\theta, \Phi) + & \text{outside both} \\ \qquad C^{3.2}_{lm} k_l(\hat{\mu} r') Y_{lm}(\theta', \Phi') + \phi_\infty & \text{bodies} \\ \phi_2 = \sum_{lm} C^2_{lm} i_l(\mu_2 r') Y_{lm}(\theta', \Phi') + \phi_{C_2} & r' \leq R_{\text{test body}} \end{cases}$$

$\hat{\mu} = m^{out}_{eff}$, $\mu_j = m^j_{eff}$ and $u_{lm}(r', \Phi', \theta') = \sum_{xy} \alpha^{lm}_{yx} u_{yx}(r, \Phi, \theta)$ a solution of (mHeq). The force on a free falling test body is:

$$F_{z_2} = \int_{V_2} T \frac{\partial \phi_2}{\partial z} d^3x, \qquad (9)$$

Our proposal

$$T = \sum_i T_i^{\mu\nu} g^i_{\mu\nu} \simeq (\rho - 3P) \exp\left(\frac{\phi\beta}{M_{pl}}\right), \tag{10}$$

$$F_{z_2} \approx (\rho_2 - 3P_2) \frac{2\pi R_2^2 \beta}{M_{pl}} \sum_y C_y^2 \frac{(1-(-1)^y)}{4\Gamma(\frac{3}{2}-\frac{y}{2})\Gamma(2+\frac{y}{2})} \sqrt{\frac{2y+1}{4}}\, i_y(\mu_2 R_2), \tag{11}$$

being

$$C_y^2 = \frac{\sum_w C_w^{3.1} \alpha_{y0}^{*w0} \partial_r i_y(\hat{\mu} R_2) + C_y^{3.2} \partial_r k_y(\hat{\mu} R_2)}{\partial_r i_y(\mu_2 R_2)}. \tag{12}$$

Consequently, the force on a free falling body depends on the composition of the body.

Results, preliminary conclusions and work in progress

- We evaluate the expression $\eta \sim \frac{|\vec{a}_A - \vec{a}_B|}{|\vec{a}_A + \vec{a}_B|}$ to compare with Be-Al-Earth experiment (WEP).
- In all these cases the Earth has thin shell, but NOT the test bodies.
- For $n = 1$ with $\beta = 10^{-11}, 10^{-12}$, $n = 2$ with $\beta = 10^{-12}, 10^{-13}, 10^{-14}$, and $n = 3$ with $\beta = 10^{-13}, 10^{-14}$; the η values that we obtained are $\sim 10^{-1}$, showing violations of the WEP.
- We will evaluate the expression using other types of test bodies, other n and larger β, in order to study cases where the test bodies also have thin-shell.
- Thank you very much for your time.