preprint at arXiv.org/abs/2007.03394

Long-range scalar forces in 5-dimensional general relativity

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3 Classical Fields

corresponding to massless bosons

scalar (1) — missing

$$\phi' = \phi$$

vector (4) — found

$$A'^{\mu} = \frac{\partial x'^{\mu}}{\partial x^{\nu}} A^{\nu}$$

tensor (10) — found

$$g'_{\mu\nu} = g_{\alpha\beta} \frac{\partial x^{\alpha}}{\partial x'^{\mu}} \frac{\partial x^{\beta}}{\partial x'^{\nu}}$$

"If there is any truth in the proposition that nature is simple, this field should exist and play an important role, for it is the simplest of the 3 massless boson fields."

– Robert Dicke, 1962

Kaluza Field Equations: 5D Gravity

$$\tilde{g}_{ab} \sim \begin{pmatrix} g_{\mu\nu} & k A_\mu \\ k A_\nu & \phi^2 \end{pmatrix}$$

(schematic)

$$\tilde{G}_{ab} = \frac{8\pi G}{c^4} \tilde{T}_{ab}$$

$$\partial \tilde{g}_{ab} / \partial x^5 = 0$$

$$k = \sqrt{16\pi G \epsilon_0 / c^2} = 5.8 \times 10^{-19} \text{ mks}$$

$$\begin{pmatrix} G_{\mu\nu} - T^{\phi}_{\mu\nu} - \frac{k^2}{2}\phi^2 T^{EM}_{\mu\nu} & k\nabla^\nu(\phi^3 F_{\mu\nu}) \\ k\nabla^\mu(\phi^3 F_{\nu\mu}) & \frac{3}{4}k^2\phi^4 F_{\mu\nu}F^{\mu\nu} - \phi^2 R \end{pmatrix} \sim \begin{pmatrix} G T^M_{\mu\nu} & k\mu_0 J_\mu \\ k\mu_0 J_\nu & G\tilde{T}_{55} \end{pmatrix}$$

Kaluza Field Lagrangian

$$L = \tilde{g}^{1/2}\tilde{R} = g^{1/2}\left[\phi\,\frac{g^{\mu\nu}R_{\mu\nu}}{16\pi G} - \frac{1}{4\mu_0}\phi^3 g^{\alpha\mu}g^{\beta\nu}F_{\alpha\beta}F_{\mu\nu}\right]$$

- Ferrari (1989)
- Coquereaux & Esposito-Farese (1990)
- Williams (2015)

the Kaluza scalar field acts simultaneously as a variable gravitational constant, and as a variable electric constant

Cosmological Implications

cosmological scalar field equation

$$g^{\mu\nu}\nabla_\mu\nabla_\nu\phi=\frac{8\pi G}{c^4}\left(\frac{1}{3}\rho_u c^2-\phi^3\frac{B^2}{\mu_0}\right)$$

cosmological scalar field of order unity

$$\phi=\left(\frac{\rho_u c^2/3}{B^2/\mu_0}\right)^{1/3}\propto a^{1/3}\sim\frac{1}{G}$$

This scalar-tensor theory implicates a cosmological bulk magnetic field

Long-range Scalar Forces

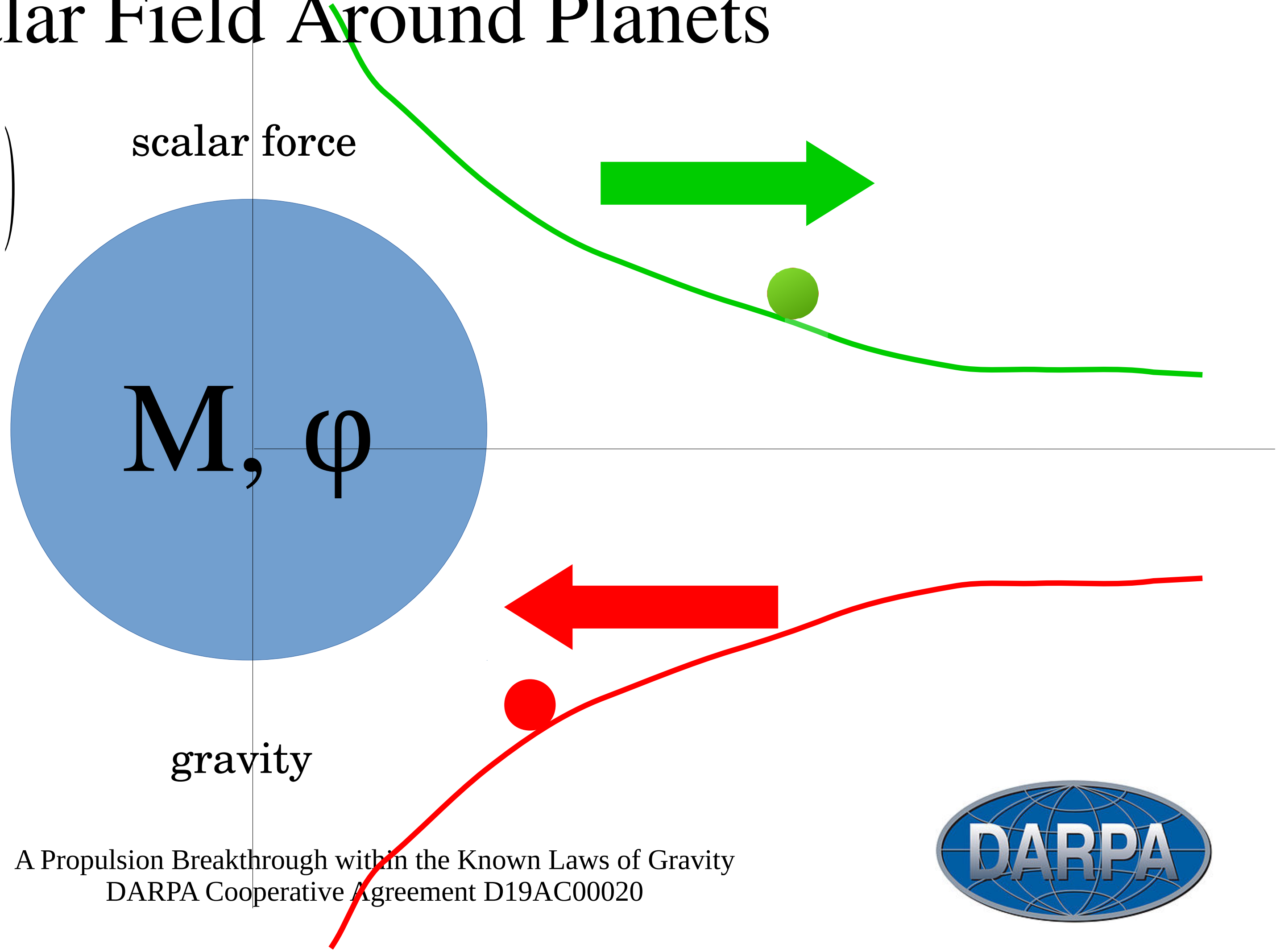
$$M\left(\frac{dU^{\nu}}{d\tau} + \Gamma^{\nu}_{\alpha\beta} U^{\alpha} U^{\beta}\right) = Q\, g^{\mu\nu} U^{\alpha} \phi^{2} F_{\mu\alpha} + \frac{\mu_0 c^4}{16\pi G}\frac{Q^2}{M}(\partial_{\alpha}\phi)\left[g^{\nu\alpha} - U^{\nu} U^{\alpha}/c^2\right]$$

gravity | electromagnetism | scalar force

Scalar Field Around Planets

$$\frac{d\mathbf{p}}{dt} = -\frac{c^2 Q^2/m}{16\pi G \epsilon_0} \nabla \left(\frac{GM}{3 r c^2} \right)$$

$$\frac{d\mathbf{p}}{dt} = -mc^2 \nabla \left(\frac{-GM}{r c^2} \right)$$



A third new lengthscale of physics for a massive, charged body

Reissner-Nordstrom metric => $L_g = \frac{GM}{c^2}$ $L_e = (G\mu_0)^{1/2} \frac{Q}{c}$

Kaluza scalar lengthscale => $L_s = \frac{\mu_0 Q^2}{M}$

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Scalar Charge and Field

scalar charge $$\frac{Q^2/M}{16\pi G \epsilon_0} c^2$$

scalar field perturbation $$\phi - 1 \equiv \xi(r) = \frac{\mu_0}{12\pi} \frac{Q^2/M}{r}$$

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Scalar Radiation

Dicke | this work | classic Kaluza

$$\nabla^2 \xi - \frac{1}{c^2}\frac{\partial \xi}{\partial t^2} = \frac{\rho}{3\,g^{1/2}}\left(\frac{8\pi G}{c^2} - \mu_0 Q^2\right) + \frac{4\pi G}{\mu_0 c^4} F^{\mu\nu} F_{\mu\nu}$$

- sources in neutral matter, electrically-charged matter, bulk electromagnetic fields (but not EM waves)
- behaves like a "scalar EM wave"
- behaves like a sound wave
- deep-penetrating, like a gravitational wave

Future Work

- predicted forces seem unrealistically large
- the predicted scalar field matches cosmological constraints
- an undiscovered scalar field seems likely to exist

➔ Perhaps the error in the theory of the forces is in the theory of the coupling.

➔ Is there a way to “squelch” the apparently strong coupling?

➔ If so, “residual” effects could exist.