# Strong Coupling in Cascading DGP

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# The Model

$$S_{DGP} = M_5^3 \int d^4x dy \sqrt{-g_{(5)}} R_5 + M_4^2 \int d^4x \sqrt{-g_{(4)}} R_4. \qquad (1)$$

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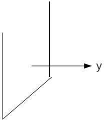


**Motivation**:

- Hierarchy Problem
- Cosmology
- Gravitational Measurements
- Holography

# IR Modification of Gravity

Scalar propagator:

$$\tilde{G}(p) = \frac{1}{\sqrt{p^2}/r_c + p^2}; \quad r_c = \frac{M_4^2}{M_5^3} \tag{2}$$

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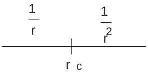


Interpolates between 4D and 5D Newtonian gravity.
Crossover: $r_c > H^{-1}$

# vDVZ Discontinuity

Tensor structure of the propagator:

$$D^{GR}_{\mu\nu;\alpha\beta}(p) = \frac{1}{p^2}\left(\frac{1}{2}\eta_{\mu\alpha}\eta_{\nu\beta} + \frac{1}{2}\eta_{\mu\beta}\eta_{\nu\alpha} - \frac{1}{2}\eta_{\mu\nu}\eta_{\alpha\beta}\right) \tag{3}$$

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$$\tilde{\eta}_{\mu\nu} = \eta_{\mu\nu} - r_c\frac{p_\mu p_\nu}{p} \tag{5}$$

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DGP: Tensor structure of massive gravity (5D massless graviton: 5 degrees of freedom) $\Rightarrow$ vDVZ discontinuity at the linearized level!

# Vainshtein effect

Solution: Vainshtein screening mechanism (Dvali et al., 2001)
Non-linearities important at a scale

$$r_* = (r_c^2 r_g)^{\frac{1}{3}}, \tag{6}$$

Full non-linear solution reduces to GR as $r_c \to \infty$.

# Strong Coupling

Strong coupling of scalar part of graviton in effective 4D description (Luty et al., 2003):

$$\mathcal{L}_{cubic} = \frac{1}{\Lambda_{strong}^3} \partial^\mu \pi \partial_\mu \pi \Box_4 \pi,$$
$$\Lambda_{strong} = \frac{M_5^2}{M_4}, \quad \pi \eta_{\mu\nu} = h_{\mu\nu} - \tilde{h}_{\mu\nu} \tag{7}$$

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Unfortunately, DGP is disfavoured by observations ⇒ look for higher-dimensional generalization

# Cascading DGP

Consistent higher-dimensional generalization of DGP (Dvali et al., 2007):

$$S_{cas} = M_6^4 \int d^4x dy dz \sqrt{-g_{(6)}} R_6 + M_5^3 \int d^4x dy \sqrt{-g_{(5)}} R_5 + M_4^2 \int d^4x \sqrt{-g_{(4)}} R_4. \quad (8)$$

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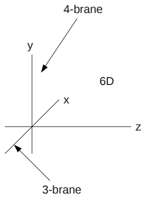

# Modification of Gravity

Propagator interpolates between 4D, 5D and 6D behaviour.
Crossover scales:

$$r_c = \frac{M_4^2}{M_5^3}, \qquad \rho_c = \frac{M_5^3}{M_6^4}. \tag{9}$$

# vDVZ and Vainshtein

- Tensor structure of 6D gravity!

$\Rightarrow$ Double Vainshtein effect

$$\rho_* = \left(\frac{M_6}{M_4^2}\rho_c^2 r_c\right)^{\frac{1}{4}}$$

$$r_* = (r_c^2 r_g)^{\frac{1}{3}} \quad (10)$$

# Effective Action

6D $\rightarrow$ 5D boundary effective action:

$$\mathcal{L}^{5D}_{cubic} \sim \partial^A \pi \partial_A \pi \Box_5 \pi$$
$$\Lambda^1_{strong} = (M_6^{16} M_5^{-9})^{\frac{1}{7}}. \quad (11)$$

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5D $\rightarrow$ 4D boundary effective action:

$$\mathcal{L} \sim \frac{1}{(\Lambda^2_{strong})^3} \partial_\mu(\pi + \chi) \partial^\mu (\pi + \chi) \Box_4 (\pi + \chi),$$
$$\Lambda^2_{strong} = \frac{M_5^2}{M_4}, \quad h_{\mu\nu} = \tilde{h}_{\mu\nu} + (\pi + \chi)\eta_{\mu\nu}. \qquad (12)$$

# Cut-Off

Consistency of black hole physics in $4+n$ dimensions (Dvali et al. 2007 ):

$$M_{N(4+n)} \equiv \frac{M_{4+n}}{N^{\frac{1}{2+n}}}. \tag{13}$$

$N$: Number of particle species.

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DGP: bulk $\sim 1$ species, brane $N$ species. Requiring the same cut-off for bulk and brane theory $\Rightarrow$ Gravity has to become weaker at a scale

$$r_c > L_{N5} = M_{N5}^{-1}. \tag{14}$$

# Scales from holography

Holography implies

$$M_4^2 = r_c M_5^3 = N M_5^2. \tag{15}$$

$\Rightarrow$ Non-perturbative derivation of the hierarchy!

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$\Rightarrow$ Non-perturbative derivation of the hierarchy!
Memory of higher dimensional origin:

$$r_* = (r_c^2 r_g)^{\frac{1}{3}} = N^{\frac{1}{3}} L_5 \equiv L_{N5}. \tag{16}$$

Strong coupling encoded in cut-off of 5D bulk theory!

# Holography in Cascading DGP

Similar arguments lead to the following hierarchy

$$M_4 \gg M_5 \gg M_6. \tag{17}$$

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Vainshtein scales:

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$$r_* = L_{N5} = (r_c^2 r_g)^{\frac{1}{3}} \tag{18}$$

# Summary

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Two ways to understand this effect:

- Field Theory
- Holography

# Thank You for Your Attention