Holographic self-tuning of the cosmological constant

Francesco Nitti

Laboratoire APC, U. Paris Diderot

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work with Elias Kiritsis and Christos Charmousis, 1704.05075

Outline

- Introduction
- AdS/CFT mini-review
- Holographic model building
- The self-tuning model
- Emergent 4d gravity
  - Graviton propagator
  - Scales of brane-world gravity
- Linear perturbations and stability
- Conclusion and outlook

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    - (Scales of brane-world gravity)
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Introduction: the CC and QFT

The Cosmological Constant (CC) problem arises as a clash between classical GR and QFT (in the modern effective FT sense).

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For curvatures $R \ll M$ the flat result gets small corrections:

$$\langle T_{\mu\nu} \rangle = \mathcal{E}_{vac} \, g_{\mu\nu} + O\left((R/M)^2\right) \quad \Rightarrow \quad \Lambda_{eff} = \Lambda_0 + 8\pi G_N \mathcal{E}_{vac}$$

$\Rightarrow$ Solution to Einstein eq. has curvature of order Λ_{eff}

Possible way out

Modify gravity to disconnect vacuum energy from curvature: allow large $\mathcal{E}_{vac}$ but make it so it does not gravitate.

- Self-tuning: any mechanism which allows flat spcacetime solutions for generic values of $\mathcal{E}_{vac}$.

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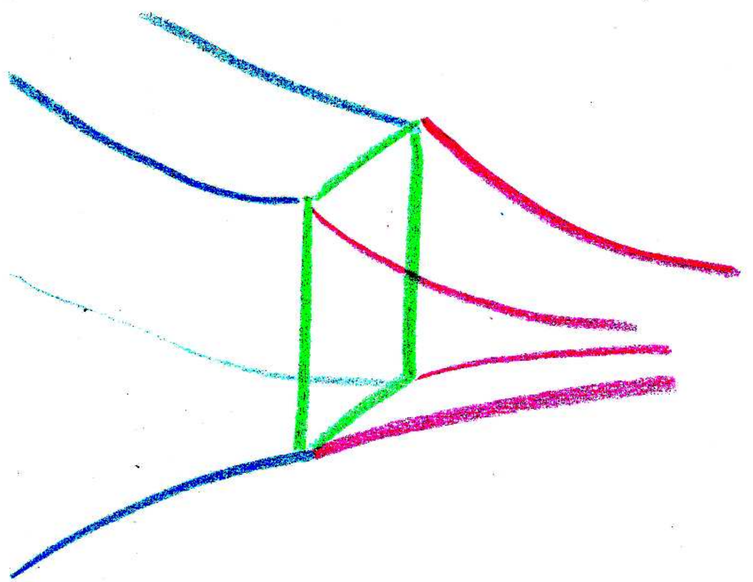
Modify gravity to disconnect vacuum energy from curvature: allow large $\mathcal{E}_{vac}$ but make it so it does not gravitate.

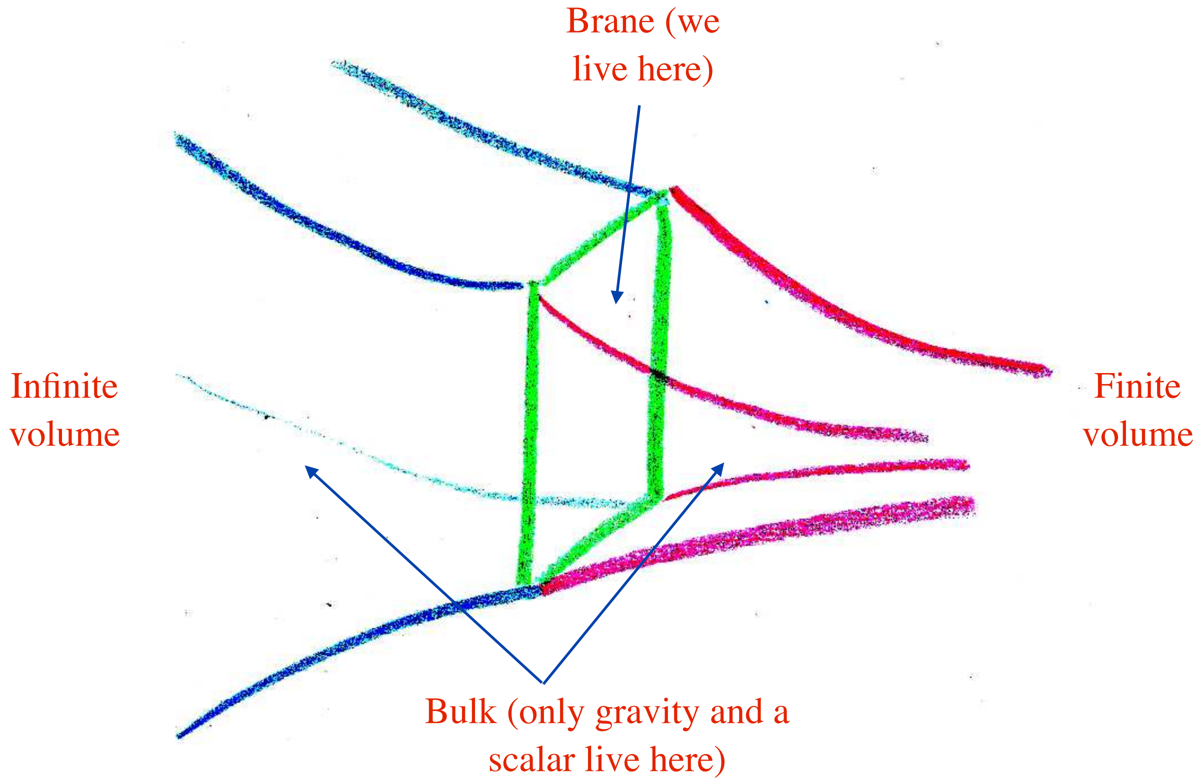
- Self-tuning: any mechanism which allows flat spcacetime solutions for generic values of $\mathcal{E}_{vac}$.
- Braneworld in extra dimension: $\mathcal{E}_{vac}$ curves the bulk, but not the brane.



Previous attempts: Arkani-Hamed *et al.* '00; Kachru,Schulz,Silverstein '00. They all either lead to bad singularities, or failure to reproduce 4d gravity, or need for fine-tuning. See also Charmousis, Gregory, Padilla '07

Content of this talk

- Self-tuning possible in the a general framework of a dilatonic, asymmetric braneworld with general 2-derivative induced terms.



Previously explored around 2000: Arkani-Hamed *et al.* ’00; Kachru,Schulz,Silverstein ’00; Csaki *et al*, ’00. See also Charmousis, Gregory, Padilla ’07

Effective brane-world action

$$S = M^3 \int d^4x \int du \sqrt{-g} \left[R - \frac{1}{2} g^{ab} \partial_a \varphi \partial_b \varphi - V(\varphi) \right]$$

5d gravity dual
of 4d CFT

$$+ M^3 \int_{\Sigma_0} d^4\sigma \sqrt{-\gamma} \left[-W_B(\varphi) - \frac{1}{2} Z(\varphi) \gamma^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi + U(\varphi) R^{(\gamma)} \right]$$

The QFT vacuum
energy is in here!

Localized Effective action induced by quantum
effects of weakly coupled QFT

(up to two derivative in the bulk fields)

We take this class of actions as the starting
point and the definition of our model

The unknown functions appearing in the localized action can be taken as a phenomenological input or motivated by weakly coupled calculation.

work in progress with E. Kiritsis and L. Witkowski

Bulk equations

$$S_5 = M^3 \int d^4x \int du\sqrt{-g}\left[R - \frac{1}{2}g^{ab}\partial_a\varphi\partial_b\varphi - V(\varphi)\right]$$

Vacuum (Poincaré invariant) solutions:

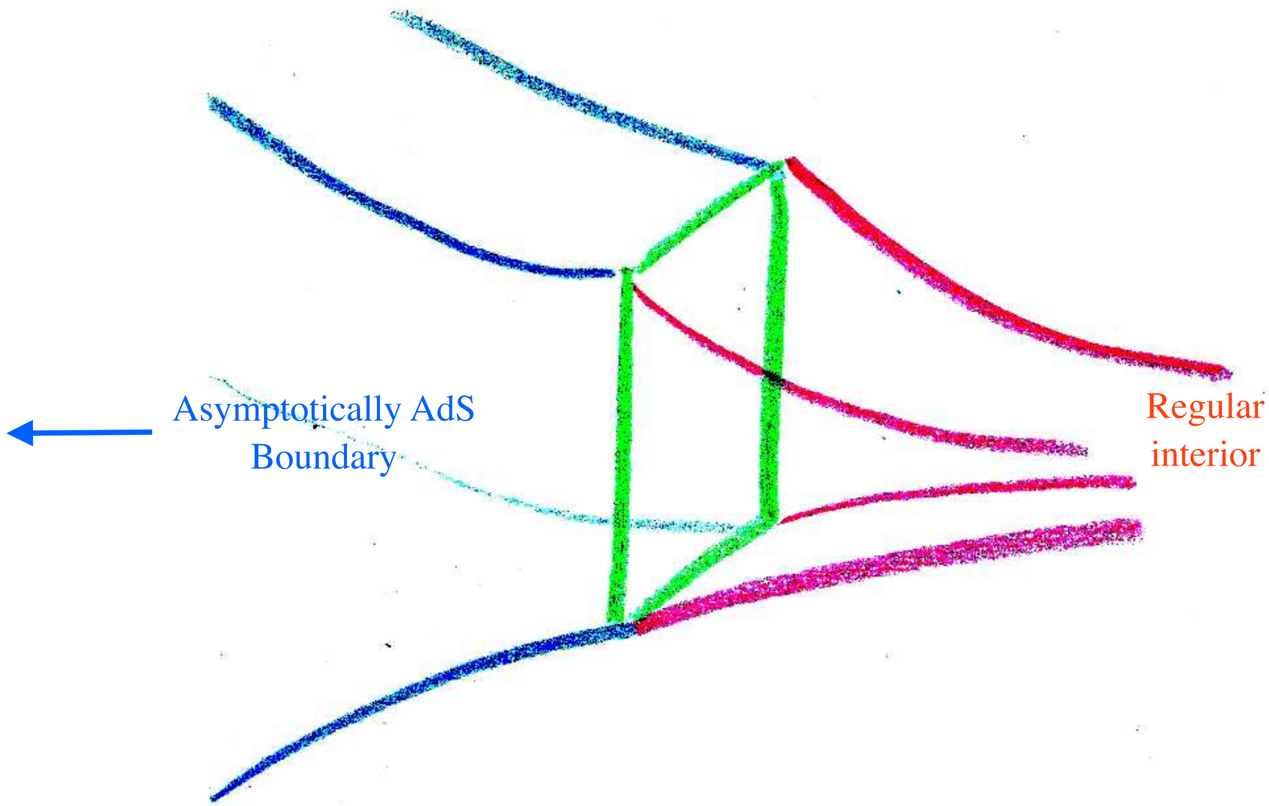
$$ds^2 = du^2 + e^{2A(u)}\eta^{\mu\nu}dx_\mu dx_\nu, \qquad \varphi = \varphi(u)$$

$$6\ddot{A} + \dot{\varphi}^2 = 0, \qquad 12\dot{A}^2 - \frac{1}{2}\dot{\varphi}^2 + V(\varphi) = 0.$$

One has to *solve independently on each side* of the defect (at $u = u_0$), and glue the solutions using Israel junction conditions:

$$\Big[A\Big] = \Big[\varphi\Big] = 0; \quad \Big[\dot{A}\Big] = -\frac{1}{6}W_B(\varphi(u_0)); \quad \Big[\dot{\varphi}\Big] = \frac{dW_B}{d\varphi}(\varphi(u_0))$$

Vacuum Geometry



$$A_{UV}(u), \varphi_{UV}(u) \qquad\qquad A_{IR}(u), \varphi_{IR}(u)$$

$e^{A_{UV}} \to +\infty, \; \varphi_{UV} \to 0$

UV-AdS boundary

$e^{A_{IR}} \to 0, \; \varphi_{IR} \to \varphi_*$

Interior of IR-AdS space

Superpotential

Write Einstein's equations as first order flow equations, with an auxiliary scalar function $W(\varphi)$ $\quad (' = d/d\varphi)$:

$$\dot{A} = -\frac{1}{6}W(\varphi) \qquad \dot{\Phi} = W'(\varphi),$$

$$-\frac{d}{4(d-1)}W^2 + \frac{1}{2}\left(W'\right)^2 = V$$

- Up to a rescaling of the scale factor, W completely determines the geometry.

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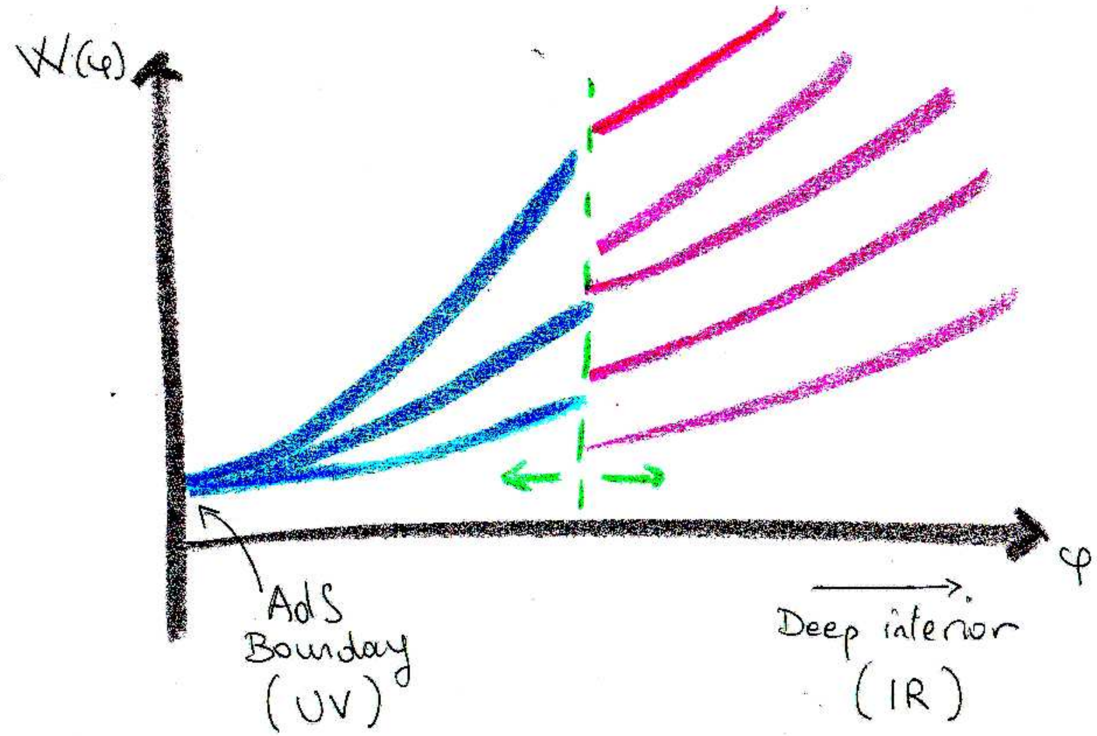
$$W(\varphi) = \begin{cases} W^{UV}(\varphi) & \varphi < \varphi_0 \\ W^{IR}(\varphi) & \varphi > \varphi_0 \end{cases}$$

- On each side of the interface ($\varphi = \varphi_0$), W is determined by one integration consntant C.

Junction conditions for the superpotential



Junction conditions take a simple form:

$$W^{IR}(\varphi_0) - W^{UV}(\varphi_0) = W_B(\varphi_0), \qquad \frac{dW^{UV}}{d\varphi}(\varphi_0) - \frac{dW^{IR}}{d\varphi}(\varphi_0) = \frac{dW_B}{d\varphi}(\varphi_0)$$

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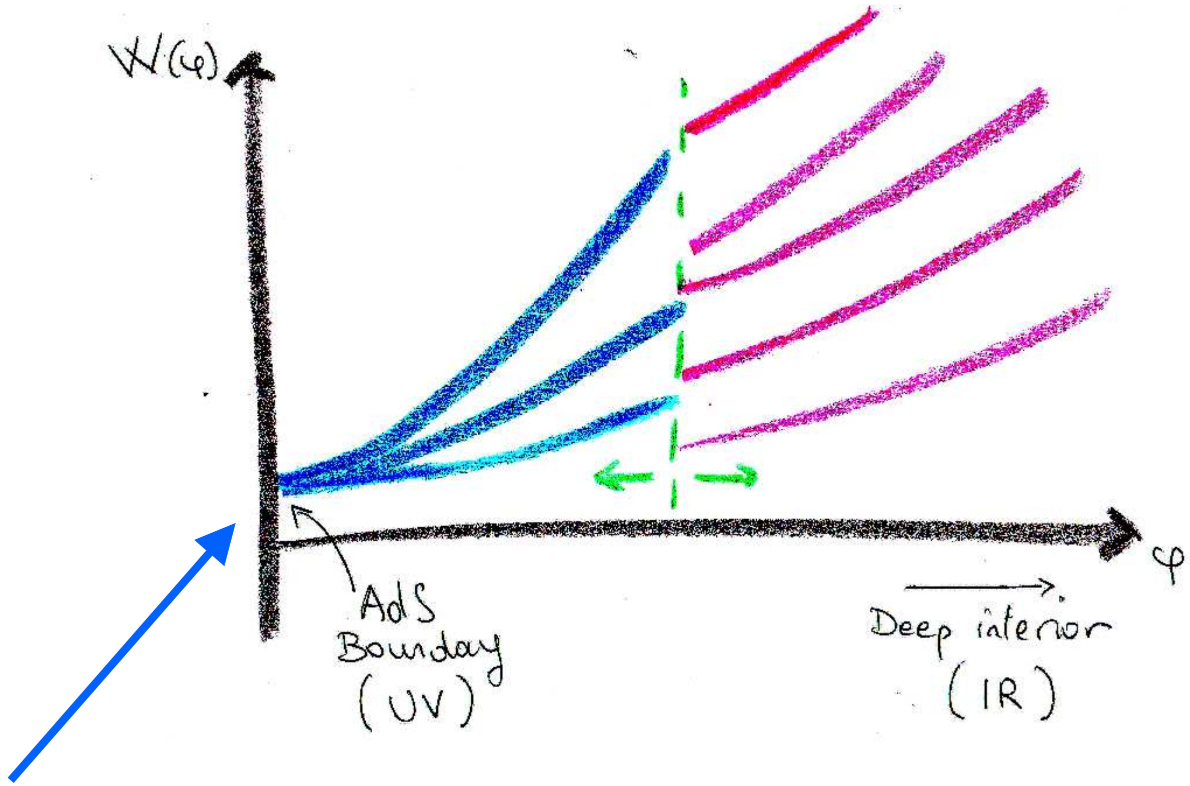

UV side: Solutions arrive at the AdS fixed point for all values of the integration constant C_{UV}: UV fixed point is an attractor.

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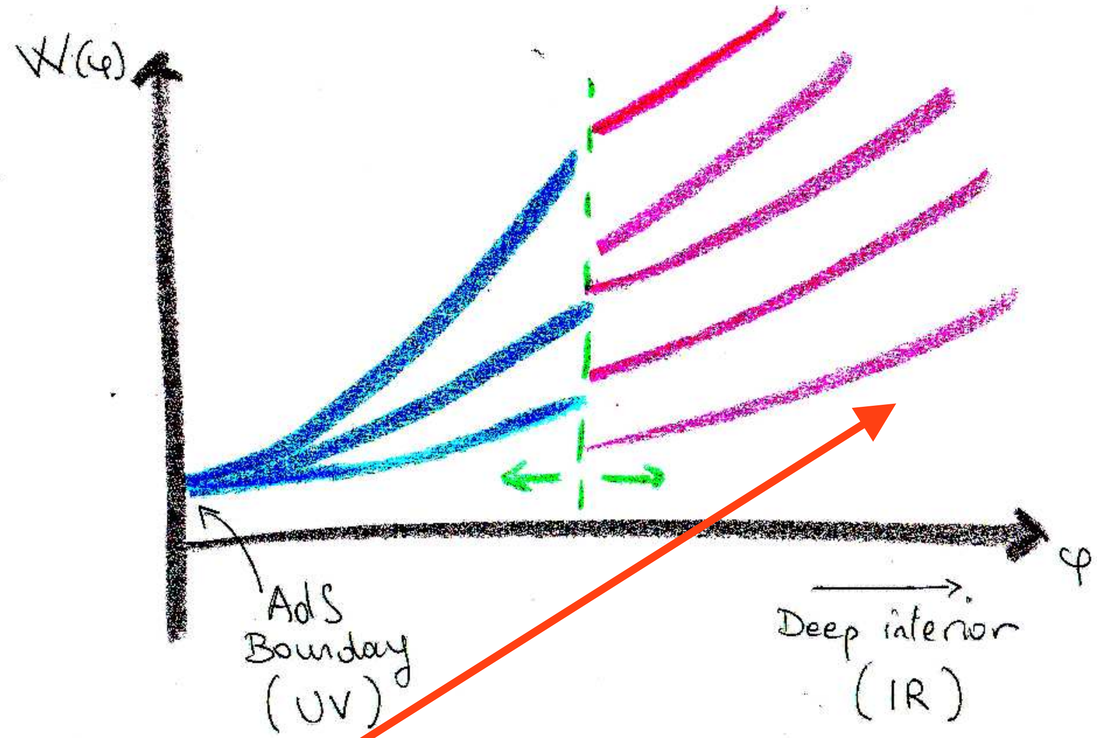

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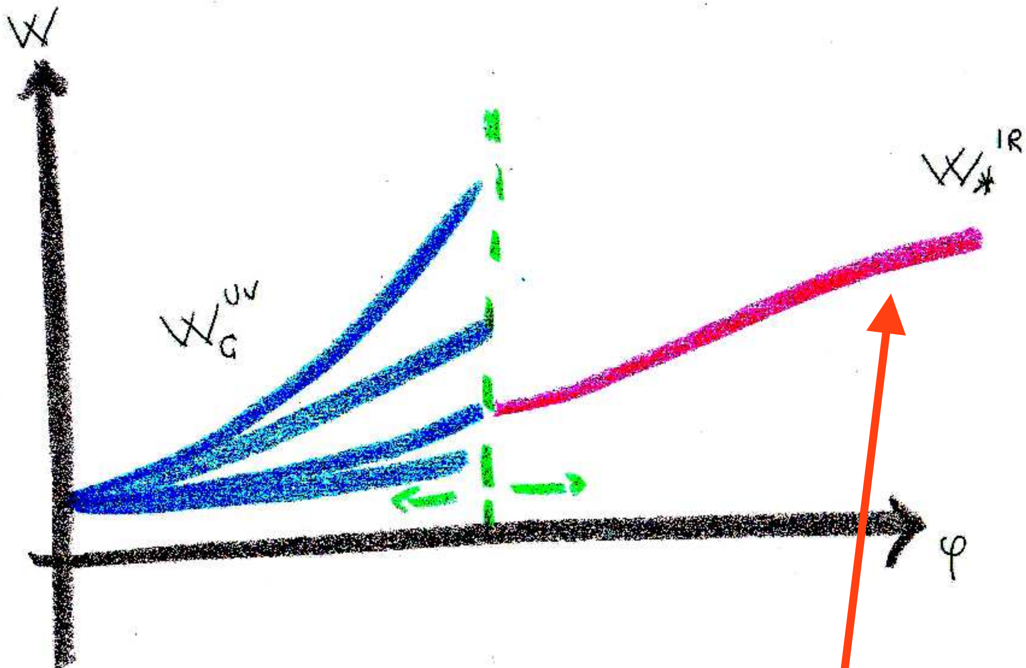
IR side: Only certain IRs are acceptable (e.g. IR AdS fixed point) This picks out a single solution W_*^{IR} and fixes $C_{IR} = C_*$

IR Selection



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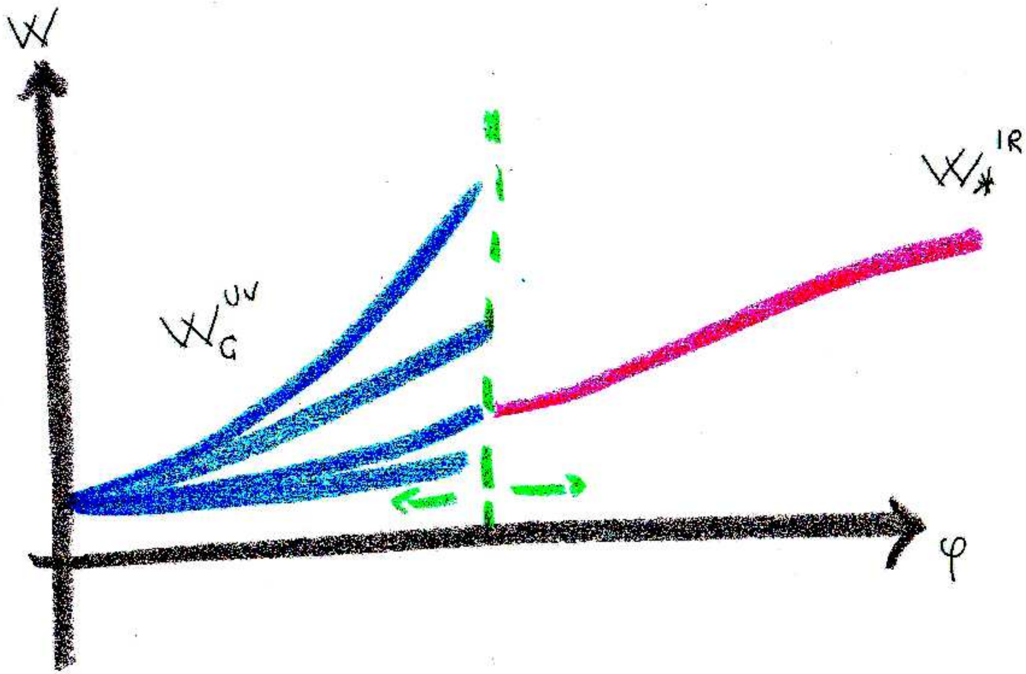
Equilibrium solution



$$W^{UV}(\varphi_0) = W_*^{IR}(\varphi_0) - W_B(\varphi_0), \qquad \frac{dW^{UV}}{d\varphi}(\varphi_0) = \frac{dW_*^{IR}}{d\varphi}(\varphi_0) - \frac{dW_B}{d\varphi}(\varphi_0)$$

Two equations for two unknowns C_{UV}, φ_0. Generically there exist a unique (or a discrete set of) solutions with C_{UV}, φ_0 determined.

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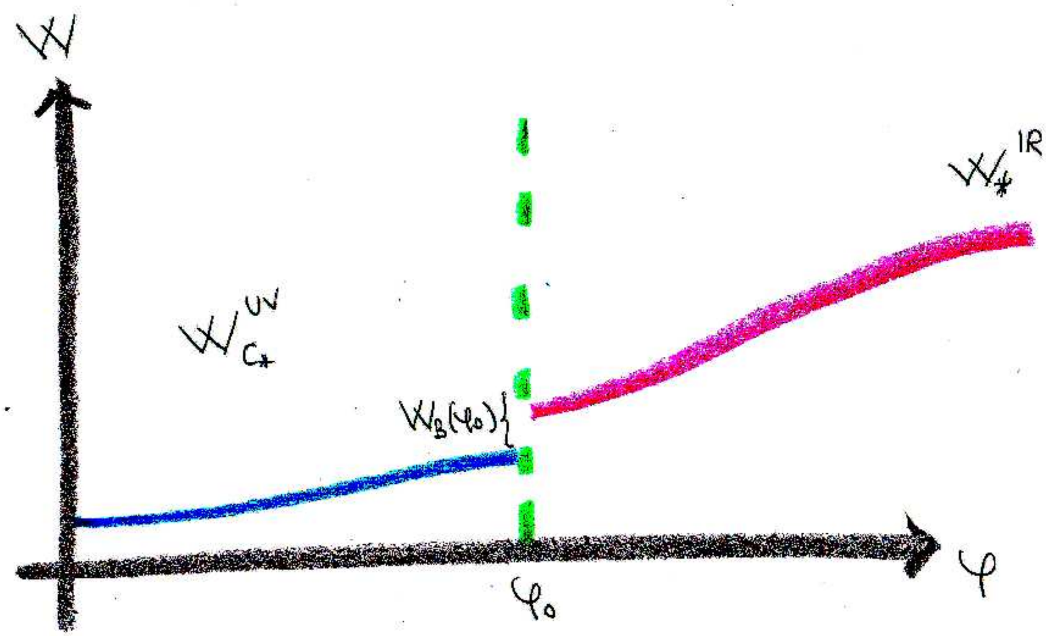

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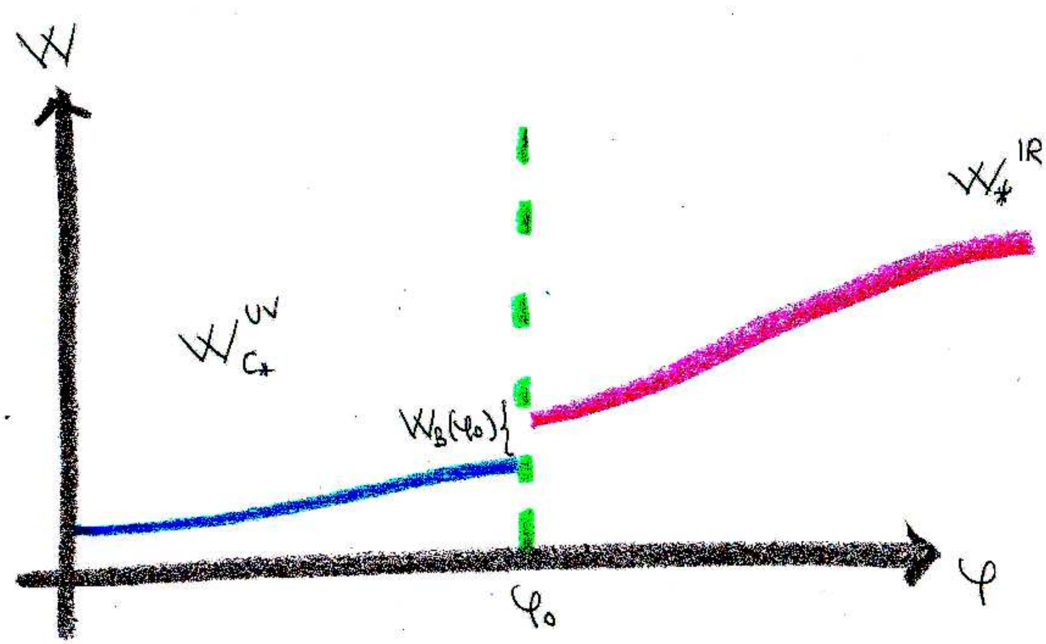

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For generic brane vacuum energy $\sim \Lambda^4$, geometry and brane position adjust so that the brane is flat and the UV glues to the regular IR (*self-tuning*).

Emergent gravity on the brane

In the model considered, solutions with flat 4d brane are generic. Do gravitational interactions between brane sources look 4d?

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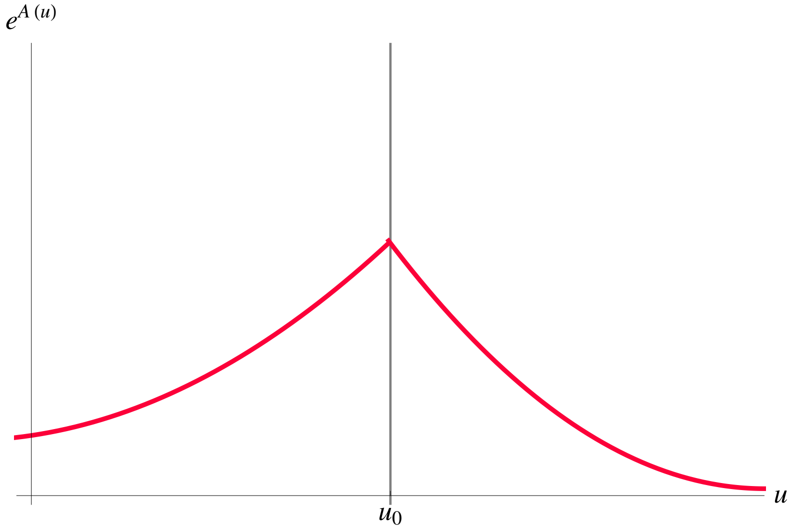
Recall Randall-Sundrum type braneworld



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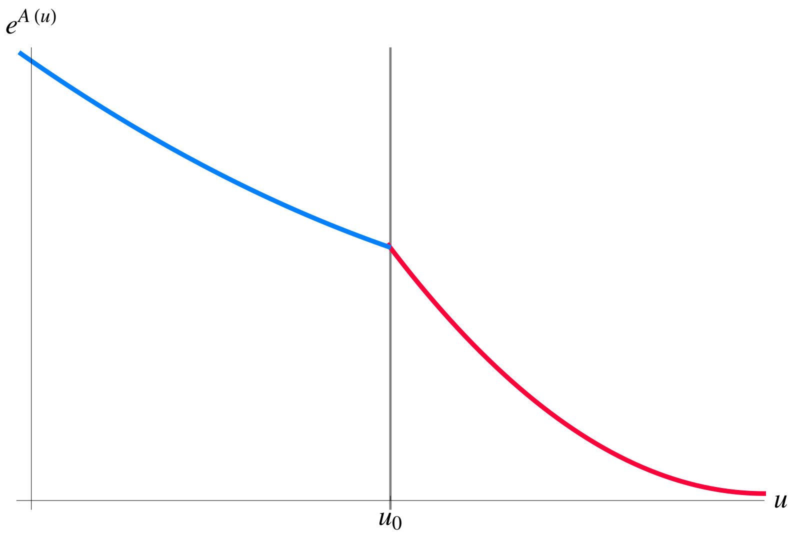
Recall Randall-Sundrum type braneworld

- Volume is finite on both sides $\Rightarrow$ Normalizable 4d graviton zero mode mediates 4d gravity at large distances
- Brane connects two "IR" special solutions $\Rightarrow$ Need fine-tuning of the brane tension for the brane to stay flat.
  $\Rightarrow$ self-tuning impossible

Emergent gravity on the brane

"Holographic" asymmetric braneworld:



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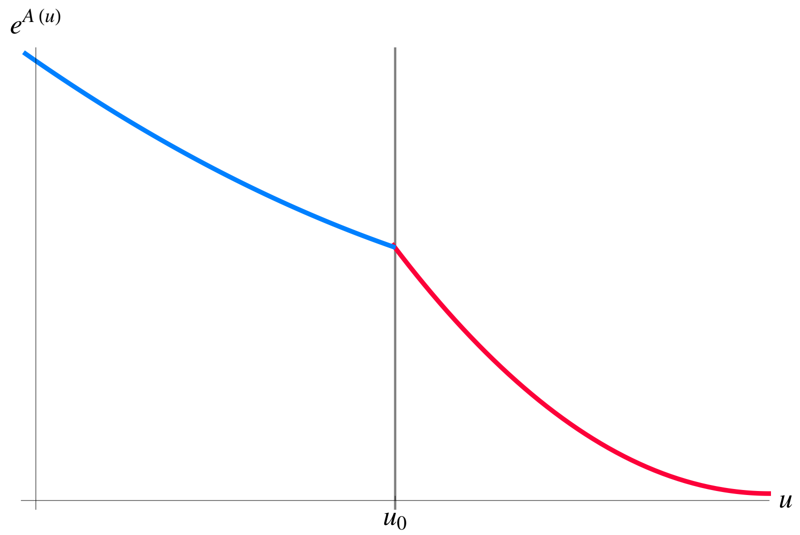

- Can choose generic "UV" solutions ⇒ self-tuning possible
- Volume is infinite on the UV side ⇒ No Normalizable 4d graviton zero mode.

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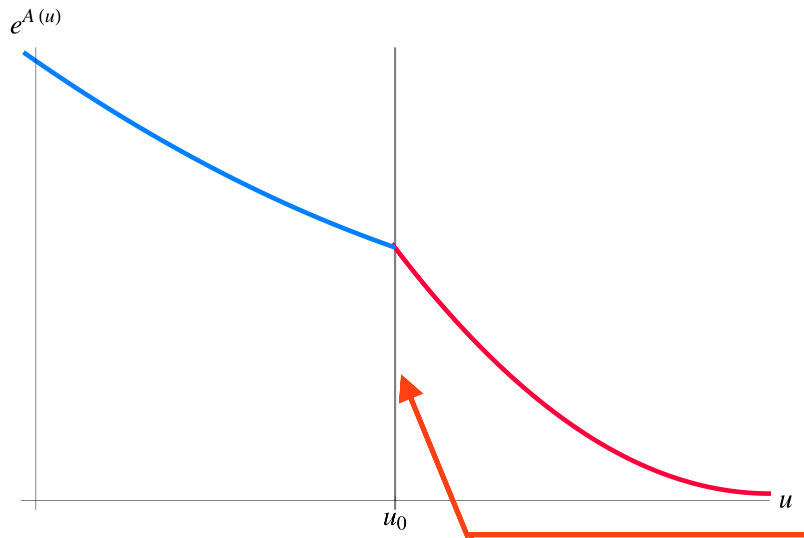

$$S = M^3 \int du\, d^4x\, \sqrt{g} R_5 + \ldots + \boxed{M^3 \int_{u=u_0} d^4x\, \sqrt{\gamma}\, U(\varphi_0) R_4}$$

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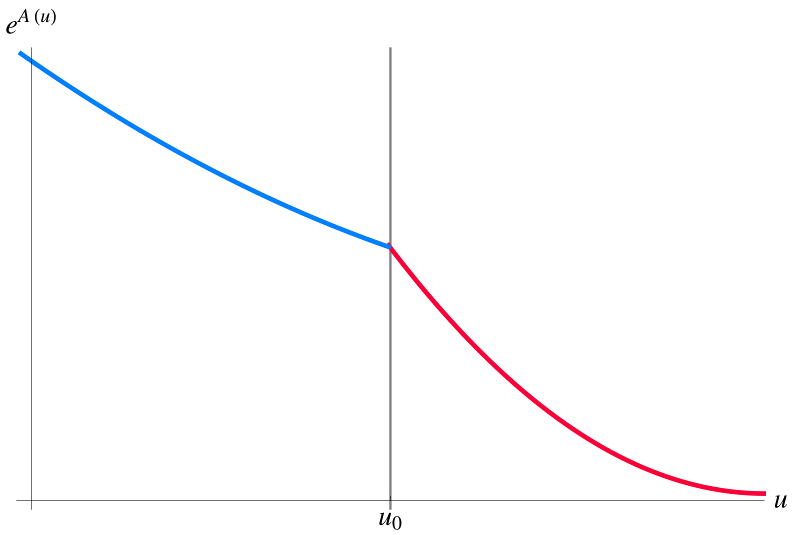

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- Localized Einstein-Hilbert term on the brane $\Rightarrow$ 4d-like graviton resonance (Dvali,Gabadadze,Porrati, '00): gravity is effectively 4d at short distances.
- Bulk curvature $\Rightarrow$ 4d massive graviton at *very* large distances.

Scales of braneworld gravity

Two competing scales:

1. "DGP" transition length: $r_c \approx U(\varphi_0)$
2. Bulk curvature length $r_t = (e^{A_0}\mathcal{R}_0)^{-1}$, $\mathcal{R}_0 \approx W_{UV}(\varphi_0)$

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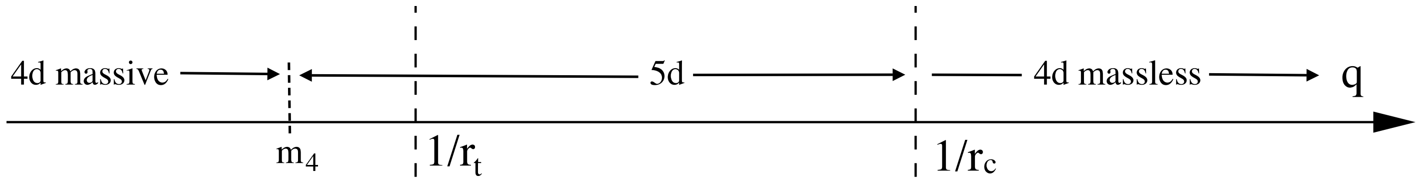

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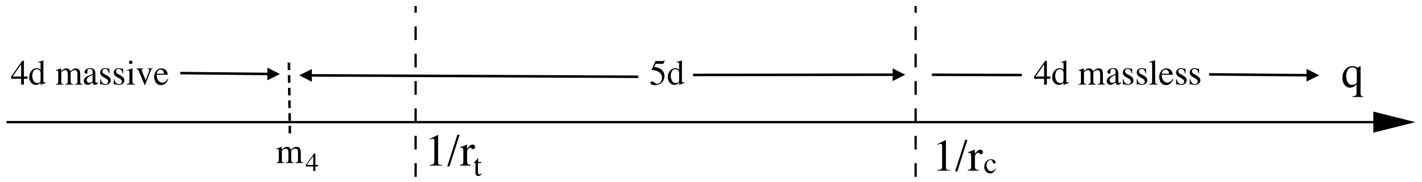

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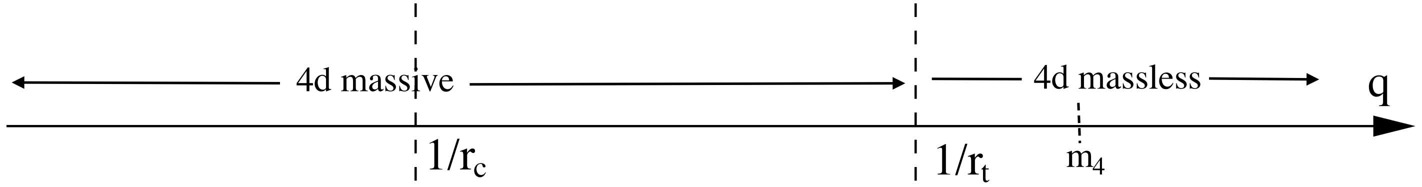

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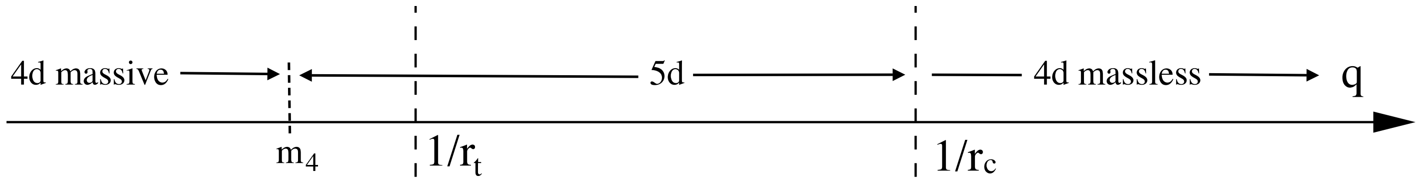

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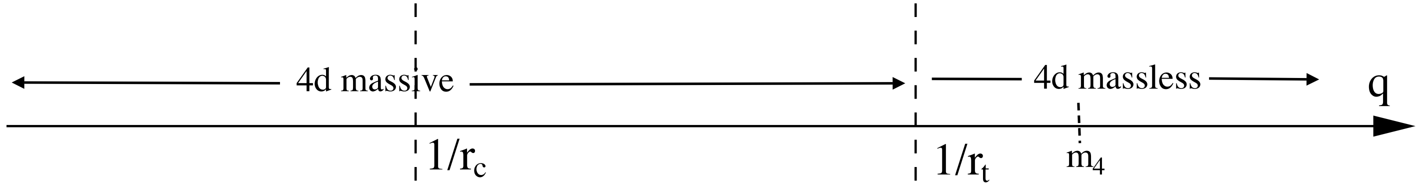
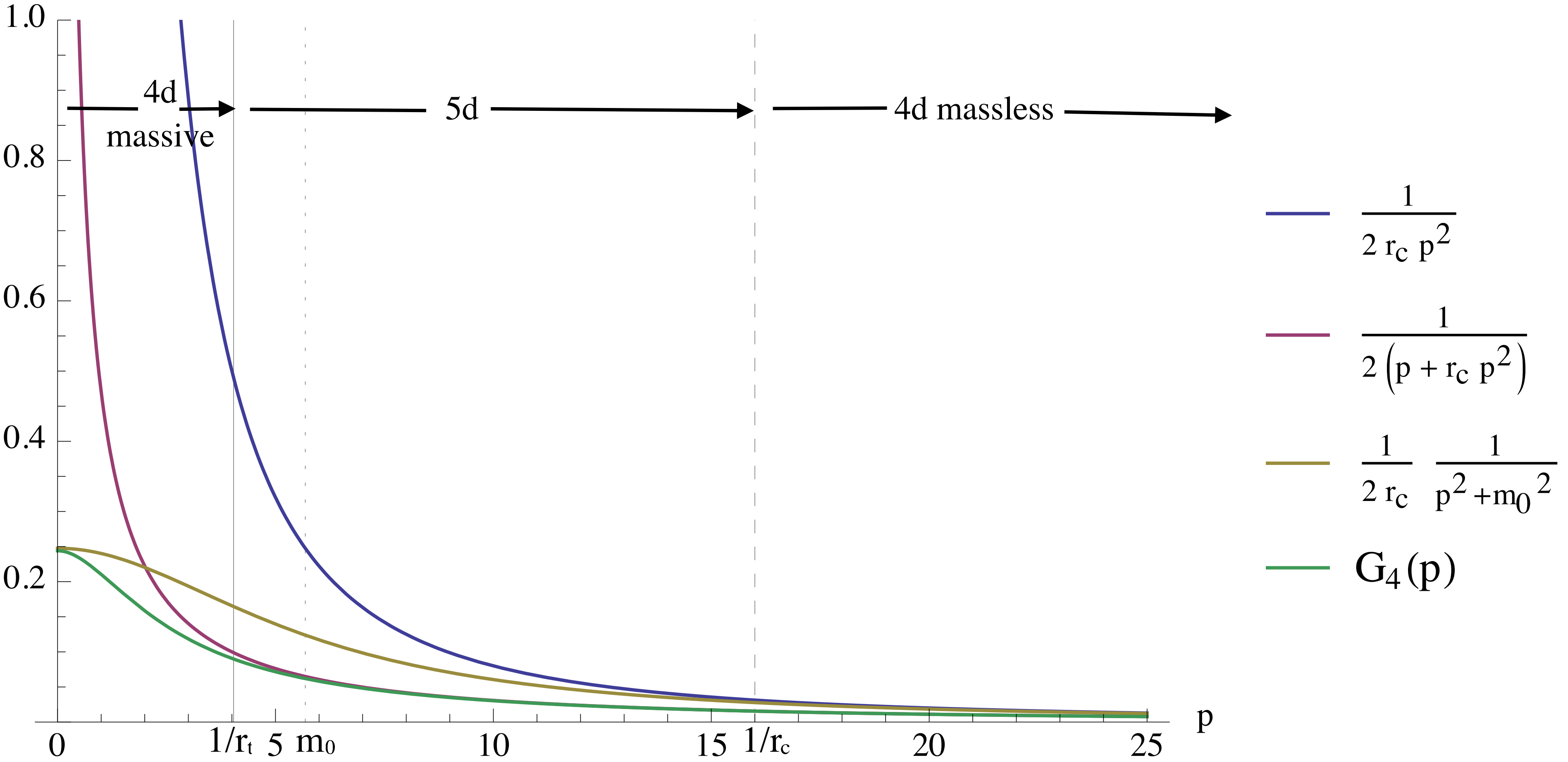


$$M_p^2 \approx M^3 U_0, \qquad m_g^2 \approx \frac{\mathcal{R}_0}{U_0}$$

4d-5d transition

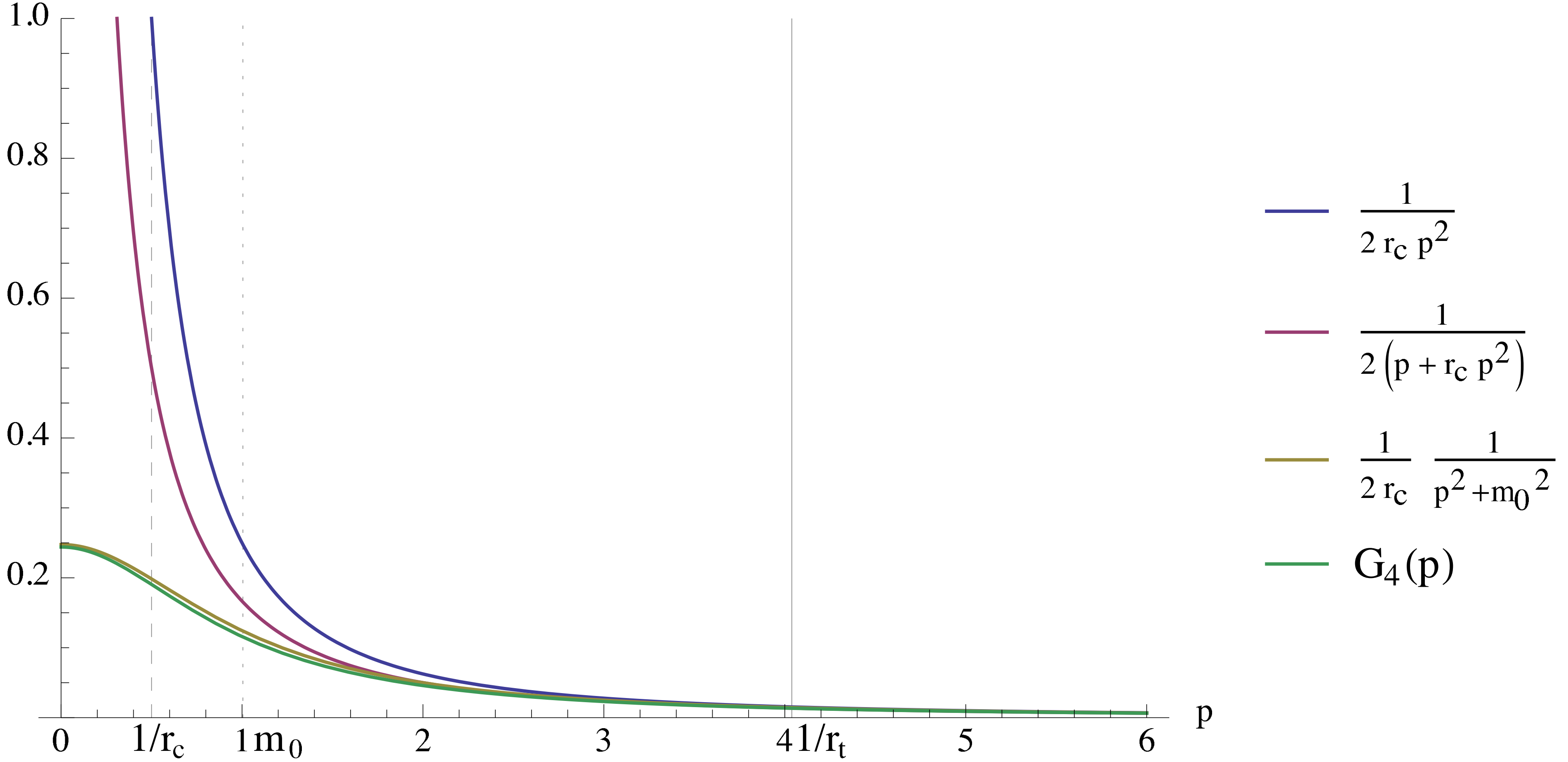
$r_c < r_t$: DGP-like transition, at intermediate distances.



$$r_c = U_0,\ r_t = \frac{e^{-A_0}}{\mathcal{R}_0}, \quad M_p^2 \approx M^3 U_0, \quad m_0^2 \approx \frac{\mathcal{R}_0}{U_0},$$

Massless/Massive gravity transition

$r_c > r_t$ massive graviton propagator all the way.



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Next:

- Time-dependent solutions (= cosmology)
- Incorporate Higgs sector explcitly on the brane
- Construct a realistic viable model