Holography, relaxions and the self-tuning of the cosmological constant

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1905.03663 and work in progress, w/ Elias Kiritsis, Francesco Nitti, Lukas T. Witkowski

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Fine tuning problems

- Cosmological constant

  natural value is (SUSY breaking)^4 >> (meV)^4

- Higgs mass

  natural value is (SUSY breaking)^2 >> (125GeV)^2

Our project: Try to solve these problems in the context of the brane world inspired by holography.

Fine tuning problems

- Cosmological constant (Holographic) self tuning

  natural value is (SUSY breaking)^4 >> (meV)^4

- Higgs mass relaxion

  natural value is (SUSY breaking)^2 >> (125GeV)^2

Our project: Try to solve these problems in the context of the brane world inspired by holography.

Self-tuning of cc

- In the brane world setup, the solution of eom with flat brane exists for generic parameter.

  [Arkani Hamed-Dimopoulos-Kaloper-Sundrum ’00]

  [Kachru-Schulz-Silverstein ’00]

  [Csaki-Erlich-Grojean ’00]

- Problems: For generic choice of integration constant of eom, the (bad) bulk singularity exists, whose interpretation is not clear.

[Charmousis-Kiritsis-Nitti, '17]

Holographic Self Tuning

- If fundamental theory is 4d QFT, dual to brane world setup, we should choose integration constant in such a way that there is no singularity, or there is "good" singularity.

[Gubser, '00]

- Good Singularity may be resolved in string theory. e.g. by adding KK states.

[Charmousis-Kiritsis-Nitti, '17]

Holographic Self Tuning

- 5d Einstein-Dilaton theory with brane.

$$S_{bulk} = M^{d-1} \int d^{d+1}x\sqrt{-g}\left[R - \frac{1}{2}g^{ab}\partial_a\varphi\partial_b\varphi - V(\varphi)\right] + S_{GH}$$

$$S_{brane} = M^{d-1} \int d^{d}x\sqrt{-\gamma}\left[-W_B(\varphi) - \frac{1}{2}Z_B(\varphi)\gamma^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi + U_B(\varphi)R^{(\gamma)}\right] + \cdots$$

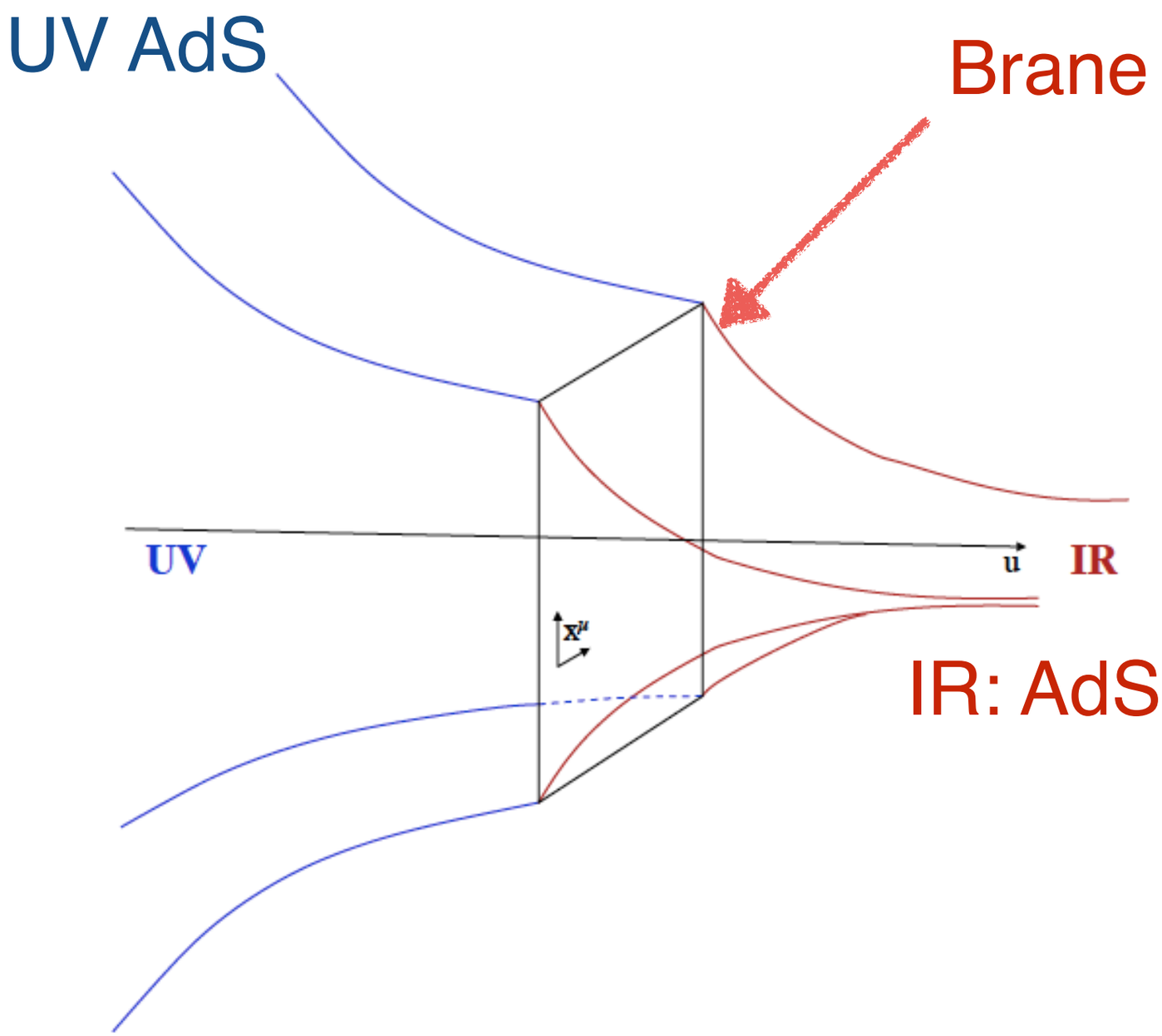
Ansatz: flat metric on the brane.

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

- For generic choice of the potential, flat brane solution exists. [Charmousis-Kiritsis-Nitti, '17]

[Charmousis-Kiritsis-Nitti, ’17]

Setup



IR: AdS or good singularity

[Graham-Kaplan-Rajendran, '15]

Relaxion

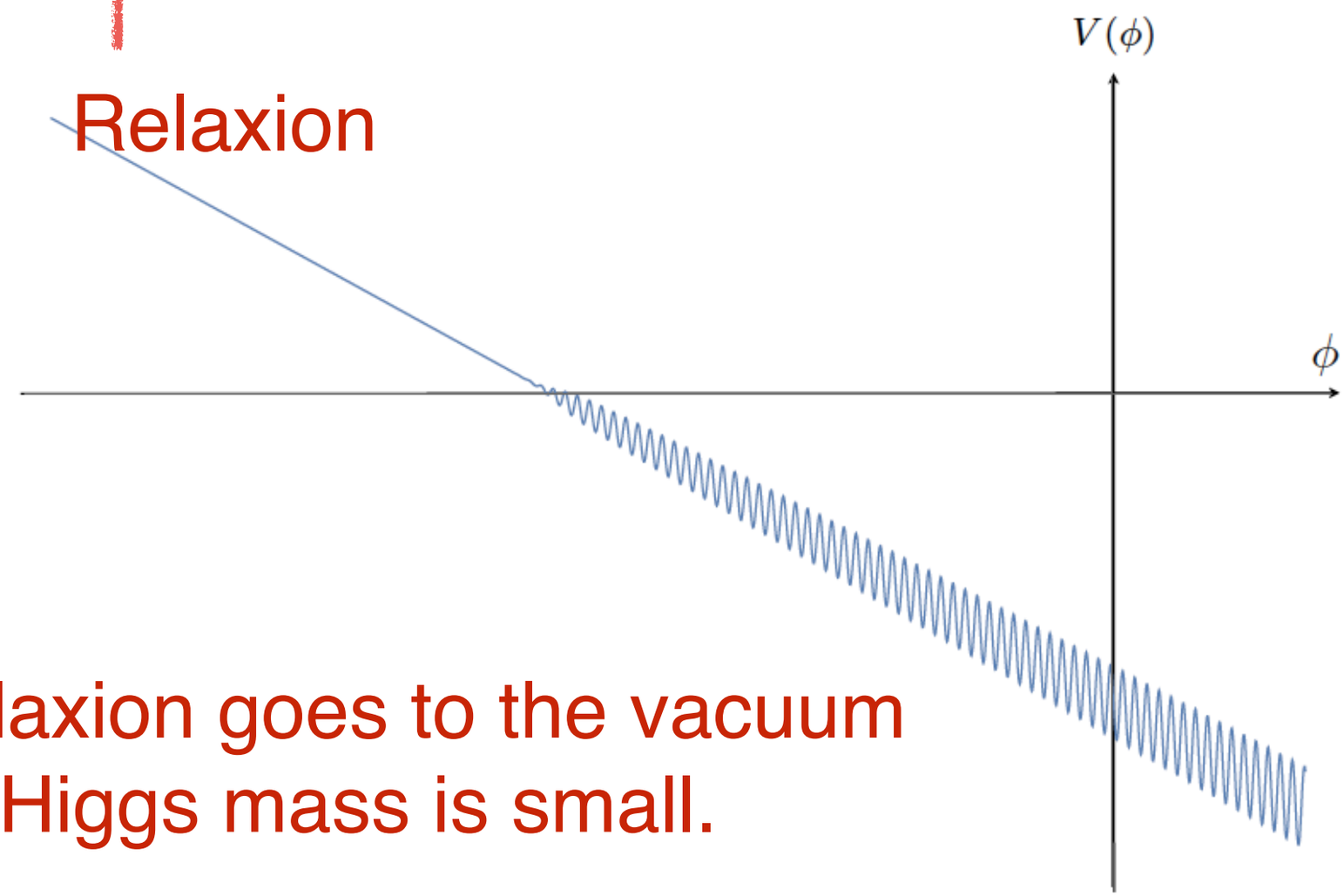
- The smallness of Higgs mass is explained by
  - Many vacua, one of which realized the small negative Higgs mass.
  - Mechanism to relax into desired vacuum through cosmological evolution.

Relaxion potential

$$(-M^2 + g\phi)|h|^2 + \left(gM^2\phi + g^2\phi^2 + \cdots\right) + \Lambda^4 \cos(\phi/f)$$

Cutoff scale

Relaxion



The relaxion goes to the vacuum where Higgs mass is small.

[YH-Kiritsis-Nitti-Witkowski, work in progress]

Our setup

- We use the idea of relaxion in the holographic self tuning setup.

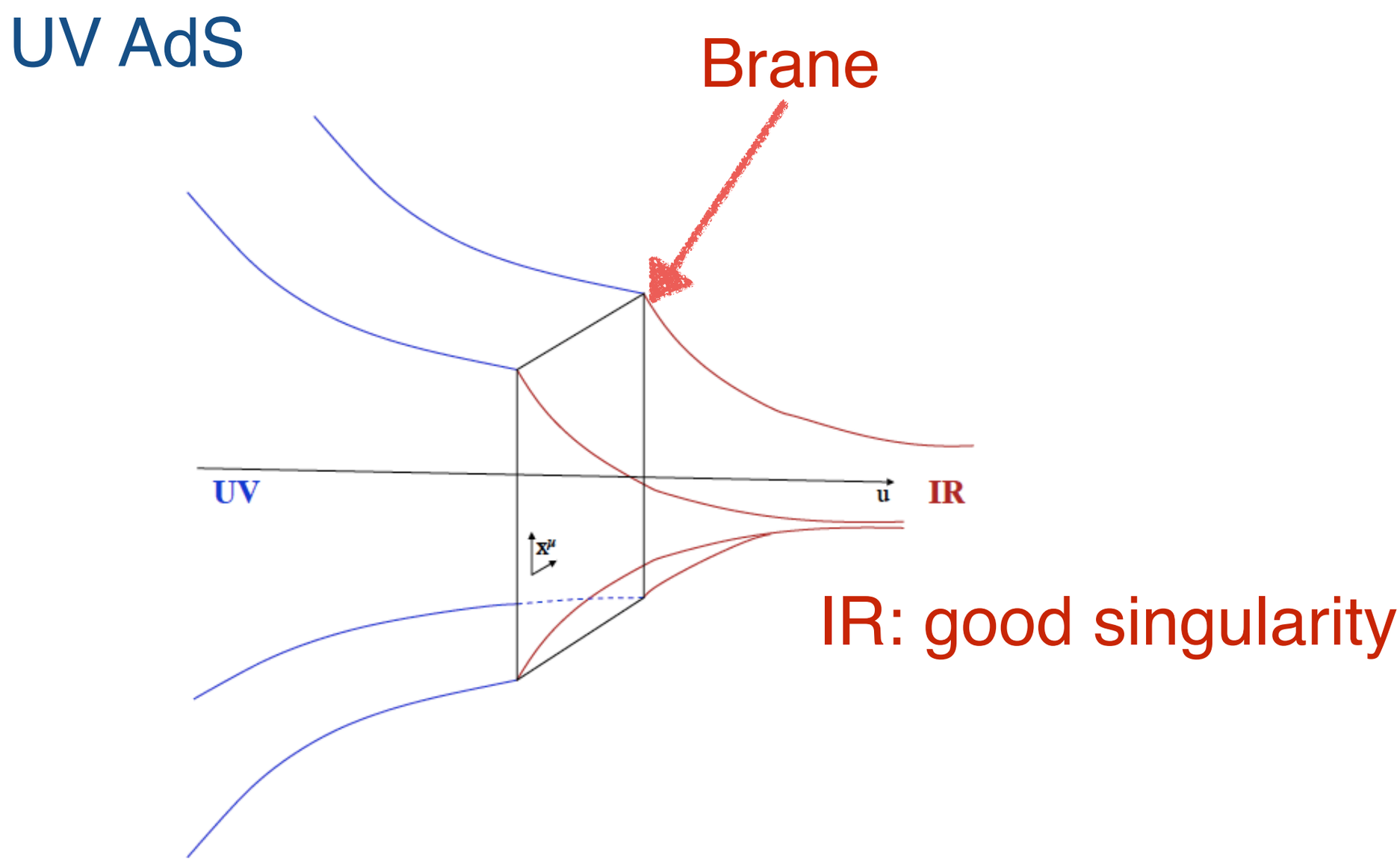
- We work in Einstein-Axion-Dilaton theory with brane where SM lives.

Bulk $$S = M_p^{d-1} \int d^{d+1}x\sqrt{-g}\left[R - \frac{1}{2}g^{ab}\partial_a\varphi\partial_b\varphi - \frac{1}{2}Y(\varphi)g^{ab}\partial_a a\partial_b a - V(\varphi)\right] + S_{GHY}$$

Brane $$S_{brane} = M_p^{d-1} \int d^d x\sqrt{-\gamma}\left[-W_B(\varphi,a) - X_H(\varphi,a)|H|^2 - S_H(\varphi,a)|H|^4 + \cdots\right]$$

[YH-Kiritsis-Nitti-Witkowski, work in progress]

Setup



Axion & θ angle

- a_{UV} : source of axion (field value in the UV).

  θ_{UV} : θ angle in dual QFT.

$$\theta_{UV} + 2\pi k = N_c a_{UV}, \quad k \in \mathbb{Z}, \quad 0 \leq \theta_{UV} < 2\pi.$$

- For large N_c,

One θ_{UV} ⟺ many a_{UV} $\quad k = 0, \pm 1, \pm 2, \cdots$

$$a_{UV} = \frac{\theta_{UV} + 2\pi k}{N_c}$$

Axion & θ angle

- There are many saddle point (vacua) parametrized by integer k.

$$a_{UV} = \frac{\theta_{UV} + 2\pi k}{N_c} \qquad k = 0, \pm 1, \pm 2, \cdots$$

- The small Higgs mass would be realized in one of the vacua.

Numerics

- We numerically check the existence of vacuum where Higgs mass is small.

- Solve the equation of motion w/ ansatz

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

- Israel junction condition at brane position.

- Regularity condition at IR.

- Only free integration constant is axion source (axion field value at UV)

Functions

- Bulk&Brane functions are chosen as

$$S = M_p^{d-1} \int d^{d+1}x\sqrt{-g}\left[R - \frac{1}{2}g^{ab}\partial_a\varphi\partial_b\varphi - \frac{1}{2}Y(\varphi)g^{ab}\partial_a a\partial_b a - V(\varphi)\right] + S_{GHY}$$

$$S_{brane} = M_p^{d-1} \int d^d x\sqrt{-\gamma}\Big[-W_B(\varphi,a) - X_H(\varphi,a)|H|^2 - S_H(\varphi,a)|H|^4 + \cdots\Big]$$

$$W_B = \Lambda^4(-1-\varphi+e^{\varphi/s}), \quad X_H = \Lambda^2 - \Lambda_a^2 a, \quad S_H = 1$$

$$V = -\frac{1}{\ell^2}\left[d(d-1) + \left(\frac{1}{2}(d-\Delta_-)\Delta_- - b^2V_\infty\right)\varphi^2 + 4V_\infty \sinh^2\left(\frac{b\varphi}{2}\right)\right], \quad Y = Y_\infty e^{\gamma\varphi}$$

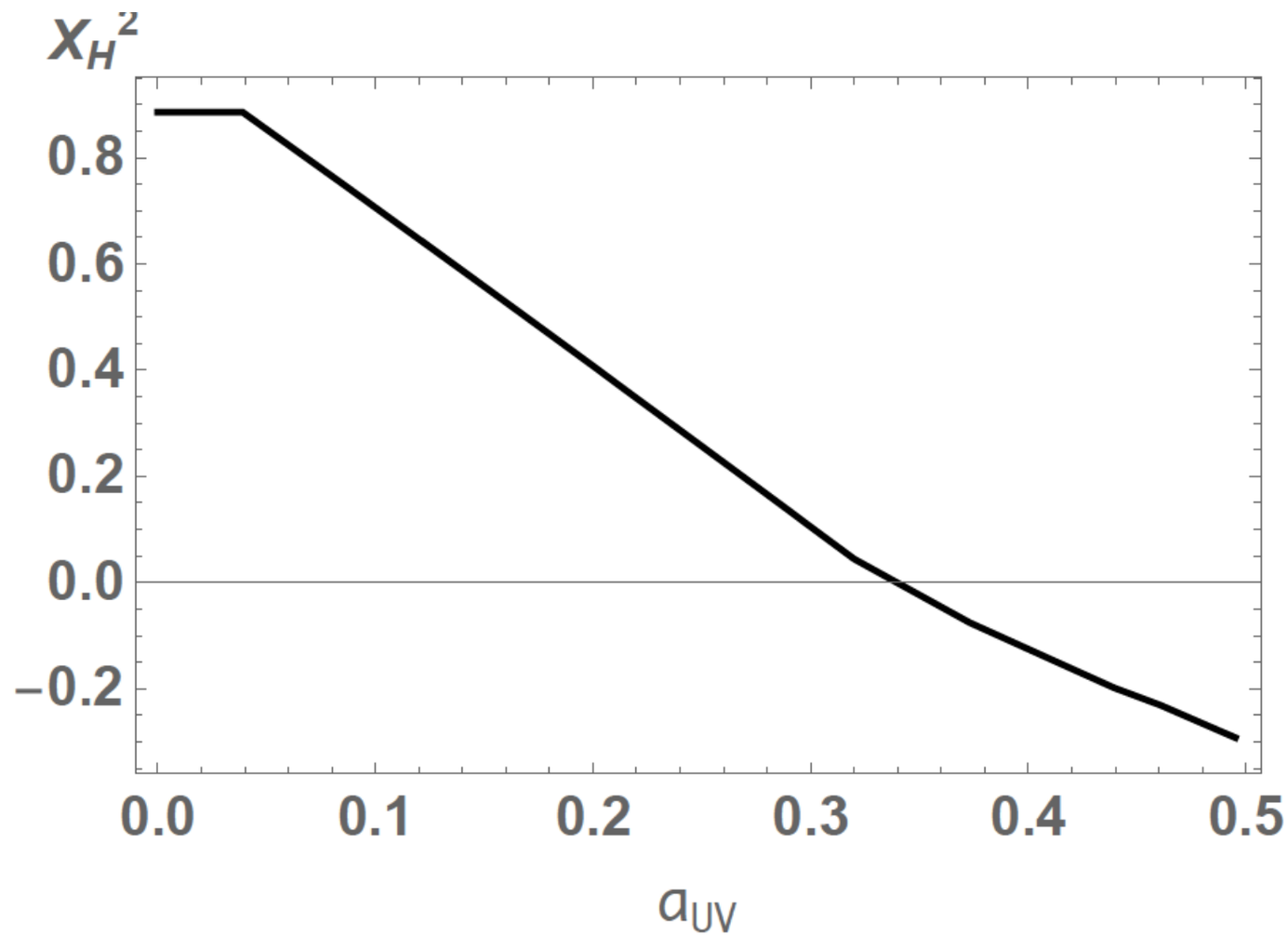
$$\Delta_- = 1.2, \quad d = 4, \quad b = 1.3, \quad \gamma = 1.5, \quad V_\infty = 1,$$
$$Y_\infty = 1, \quad s = 5, \quad \Lambda = 1, \quad \Lambda_a = 1.7$$

[YH-Kiritsis-Nitti-Witkowski, preliminary result]

Numerics

$$a_{UV} = \frac{\theta_{UV} + 2\pi k}{N_c}$$

(Higgs mass)^2



Axion source

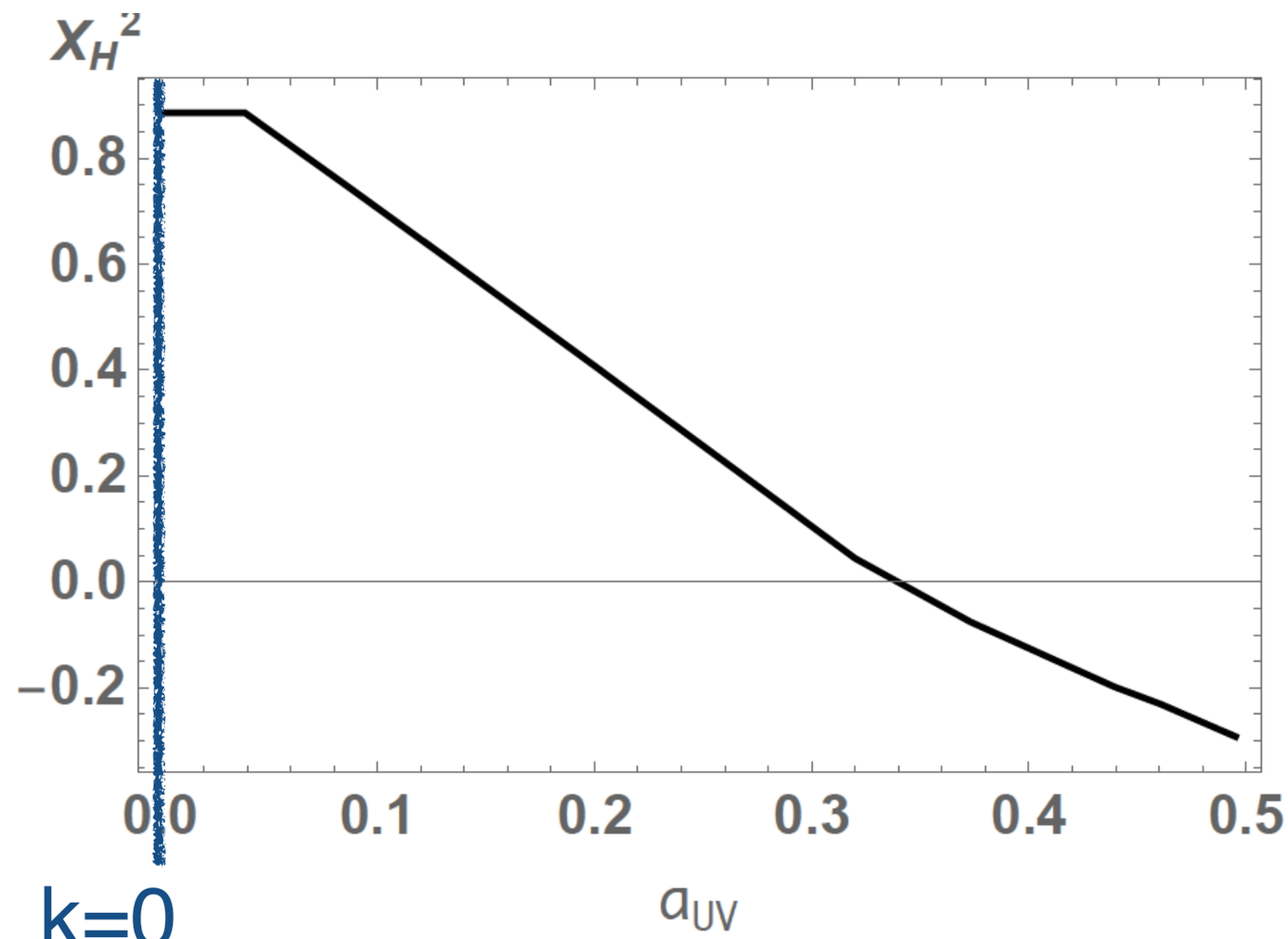
[YH-Kiritsis-Nitti-Witkowski, preliminary result]

Numerics

$$a_{UV} = \frac{\theta_{UV} + 2\pi k}{N_c}$$

If we take
θ_{UV}=0.1, N_c=100

(Higgs mass)^2



k=0

Axion source

[YH-Kiritsis-Nitti-Witkowski, preliminary result]

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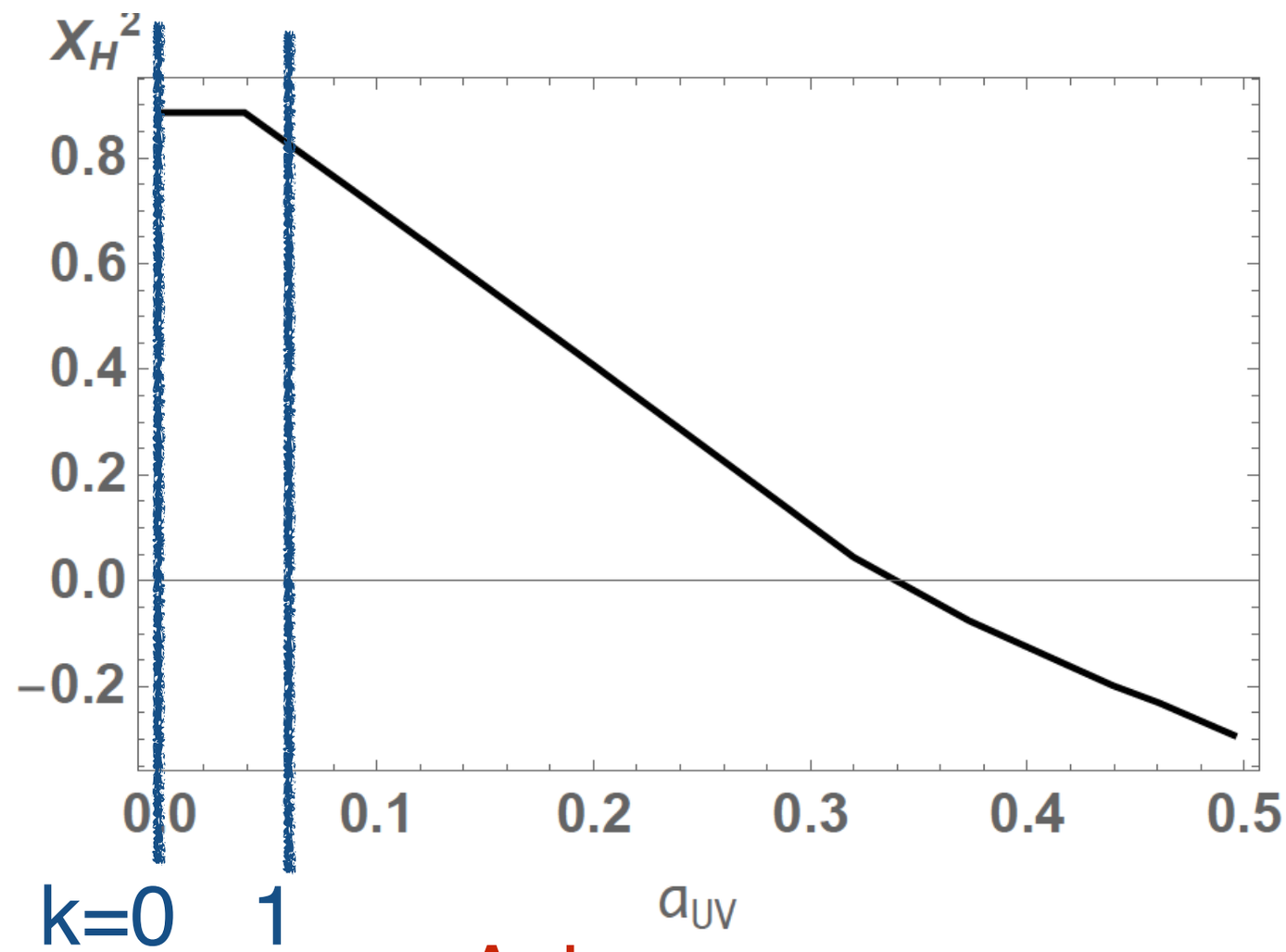

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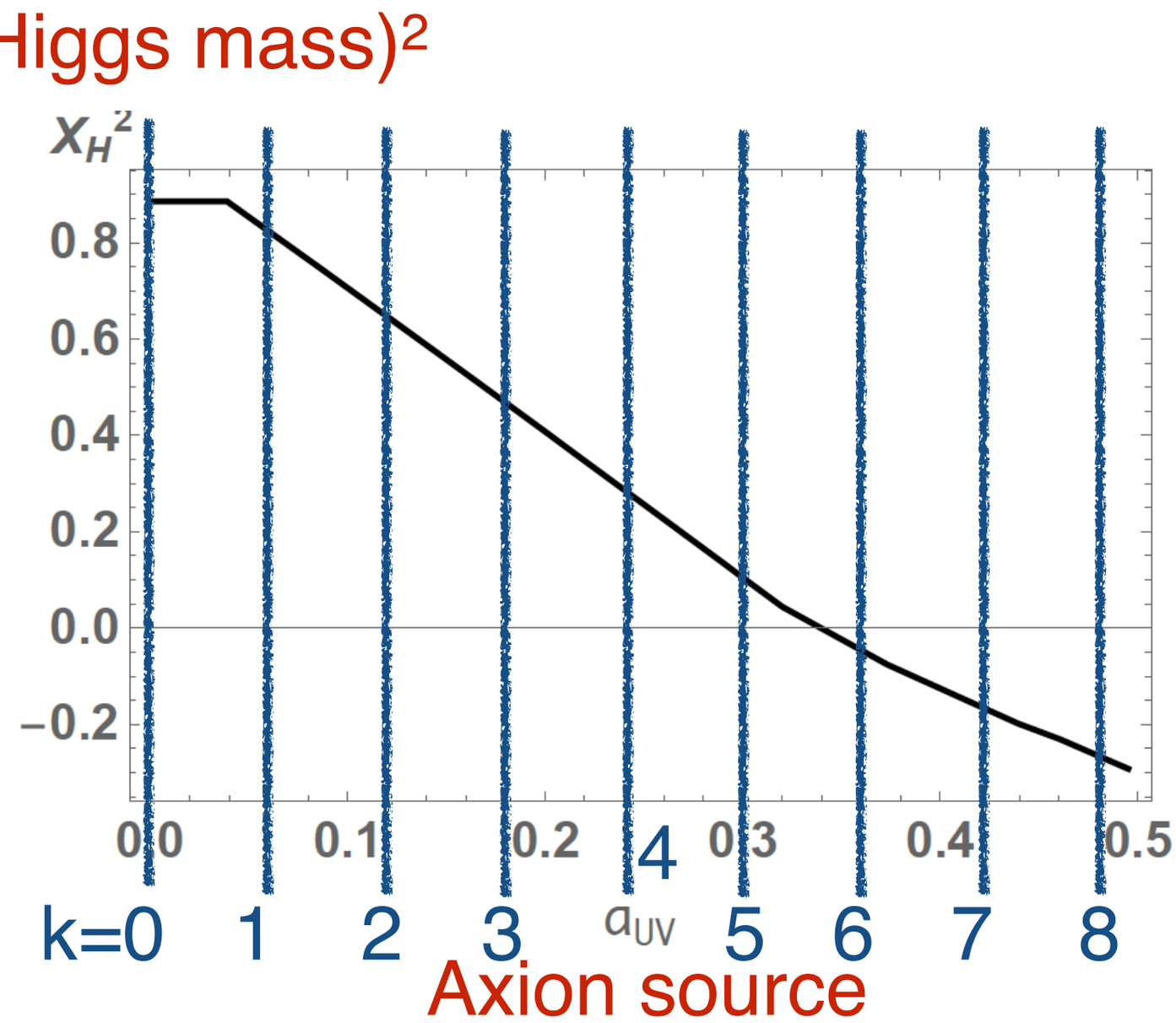

For large N_c, small Higgs mass is realized in one vacuum.

Possibilities

- If small Higgs mass saddle is lowest free energy, it is stable vacuum.
- If not, small Higgs mass is realized in metastable vacuum.
  - Cosmological evolution like relaxion case
  - Anthropic principle

Summary

- We investigate fine tuning problems in the brane world setup motivated by holography.

- The solution where the brane is flat exists.

- For fixed θ angle in QFT, there are many saddle points in bulk, one of which realizes the negative small Higgs mass.