a-Anomalous Interactions of the Holographic Dilaton

[arXiv:2205.15324 [hep-ph]]

Gabriele Rigo (IPhT, Saclay)

Csaba Csáki, Jay Hubisz,
Ameen Ismail, Francesco Sgarlata

Beyond the Standard Models. . .

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Dilatons Everywhere

Spontaneously broken conformal sector:

- Stringy models
- Composite Higgs models
- Hidden conformal sectors
- Continuum naturalness

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COMMON FEATURE

Dilaton-like particle

A Standard Model Analogy

Anomalous $\mathrm{U}(1)_A$ in the chiral Lagrangian:

$$\Gamma(\pi_0 \longrightarrow \gamma\gamma) = \frac{\alpha^2}{576\pi}\frac{m_\pi^3}{f_\pi^2}N_C^2.$$

- Low energy experimental probe
- High energy UV physics
- Can anomalies teach us about conformal sectors?

Outline

1. **Effective Theory of the Dilaton**

2. **The Holographic Dilaton**

3. **Phenomenological Signatures**

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Dilaton Action

Dilaton τ: Goldstone boson of conformal symmetry

- Easy to write effective actions
- Define $\tilde{g}_{\mu\nu} = e^{-2\tau} g_{\mu\nu}$
- Under Weyl $g_{\mu\nu} \longrightarrow e^{2\alpha} g_{\mu\nu}$ and $\tau \longrightarrow \tau + \alpha$
- Natural derivative expansion

$$S = \frac{f^2}{12} \int \mathrm{d}^4 x \, \sqrt{|\tilde{g}|} \left(\tilde{R} + 2\Lambda \right) \longrightarrow \frac{f^2}{12} \int \mathrm{d}^4 x \left[6 e^{-2\tau} (\partial \tau)^2 + 2\Lambda e^{-4\tau} \right].$$

Z. Komargodski, A. Schwimmer, "On Renormalization Group Flows in Four Dimensions", *JHEP* **12**, 099 (2011) [arXiv:1107.3987 [hep-th]].

Next Order in Derivatives

We continue the derivative expansion:

- Regular terms vanish on-shell
- We still have trace anomalies from $\langle T^\mu_\mu \rangle \neq 0$
- a-theorem of Schwimmer and Komargodski

$$S_a = 2a \int \mathrm{d}^4 x \, (\partial\tau)^4 \quad (+\text{ higher derivative terms}).$$

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Reminder on the a-Theorem

Monotonic function interpolating between UV and IR?

$$a(\mu) = a_{\text{UV}} - \frac{f^4}{\pi} \int_{s>\mu} \mathrm{d}s \, \frac{\sigma(s)}{s^2}.$$

- Unitarity through the optical theorem
- Strongly constrains the renormalization group flow
- Automatically implies $a_{\text{IR}} < a_{\text{UV}}$
- Effective counting of degrees of freedom

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Outline

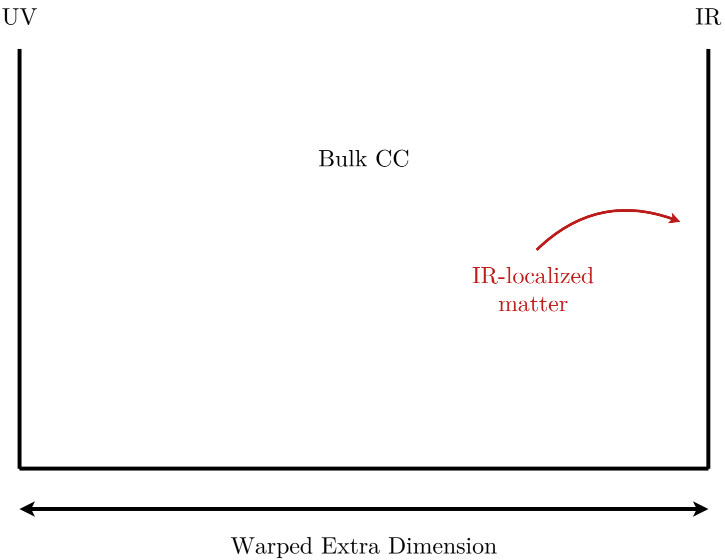
General Strategy

Simplest example: Randall–Sundrum geometry

- 4D strongly coupled problem to a 5D perturbative one
- Integrate out KK gravitons at tree level
- Compute radion effective action
- All orders in field fluctuations

$$S = S_{\text{bulk}} + S_{\text{branes}} + S_{\text{matter}},$$
$$\mathrm{d}s^2 = e^{-2A(x,y)}(\eta_{\mu\nu} + h_{\mu\nu}(x,y))\,\mathrm{d}x^\mu \mathrm{d}x^\nu - B^2(x,y)\,\mathrm{d}y^2.$$

Holographic Setup



The a-Anomaly

Integrating out the KK gravitons gives a total y-derivative:

$$S_{\text{radion}} = \int \mathrm{d}^4x \, \frac{f^2}{2} e^{-2\tau} (\partial\tau)^2 - \lambda f^4 e^{-4\tau} + \tau T^\mu_\mu$$
$$+ \frac{1}{4\kappa^2 k^3} \left\{ \left[\partial_\mu \tau \partial_\nu \tau + \frac{3e^{2\tau}}{f^2} \left(T_{\mu\nu} - \frac{1}{4} \eta_{\mu\nu} T \right) \right]^2 + \frac{e^{2\tau}}{2f^2} (\partial\tau)^2 T \right\}.$$

We can read off the a-anomaly:

$$a_{\text{RS}} = \frac{1}{8\kappa^2 k^3} = \frac{N^2}{4(16\pi^2)}.$$

Explicit Breaking and $1/N$

What about corrections to this result?

- Explicit breaking suppressed by $\exp(A_0 - A_1)$
- $1/N$ probed by Gauss–Bonnet

$$a_{\mathsf{GB}} = a_{\mathsf{RS}} \left(1 - 12\lambda_{\mathsf{GB}} \left[\frac{2\kappa^2 k^3}{24\pi^3} \right]^{2/3} \right).$$

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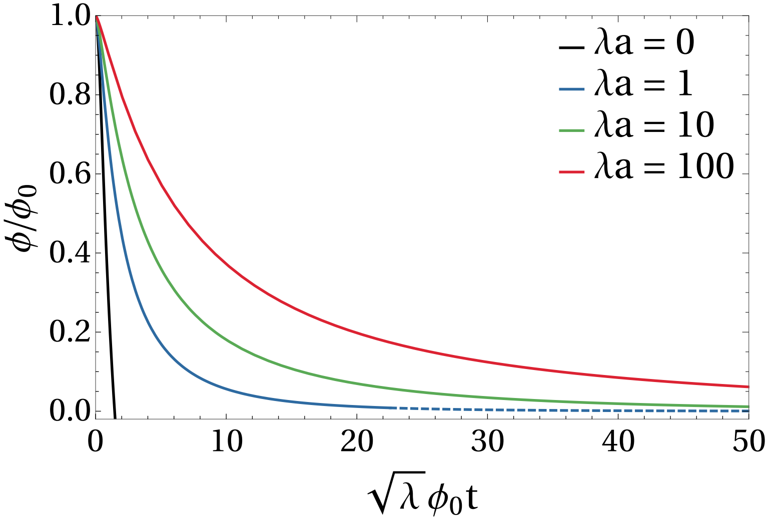
Collider Probes

Let's expand around a VEV, $\exp(-\tau) = 1 - \varphi/f$:

$$S_{\text{radion}} \supseteq \int \mathrm{d}^4x \, \frac{\pi^2}{3N^2 M_{\mathrm{KK}}^4} \partial^\mu\varphi\partial^\nu\varphi\left(T_{\mu\nu} - \frac{1}{6}\eta_{\mu\nu}T\right).$$

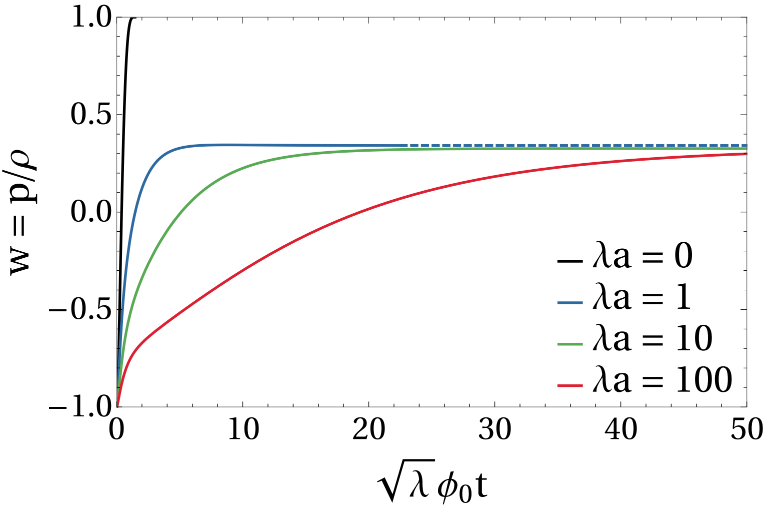
- a-dependent coupling
- Also for classically scale-invariant fields
- Relevant for collider studies?

Cosmological Evolution



Nonzero a smooths out the singularity

Equation of State



Transition from "vacuum energy" to "pure radiation"

Conclusions and Future

- Systematic derivative expansion of dilaton EFT
- Explicit calculation in holographic setup
- Collider and cosmology signatures
- More detailed phenomenology?
- Other geometries: soft wall?

Thank you!