Ameen Ismail

Pheno 2022 Symposium

10 May 2022

(how anomalies shape the dilaton action)

arXiv:2205.xxxxx (keep your eyes peeled!)

with C. Csáki, J. Hubisz, G. Rigo, and F. Sgarlata

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Conformal sectors are everywhere!

in model building:

- Composite Higgs
- Warped models
- Dark matter
- Continuum states
- CC, hierarchy problems

in formal theory...

The Minimal Composite Higgs Model

Kaustubh Agashe[a], Roberto Contino[a], Alex Pomarol[b]

A Warped Model of Dark Matter

Tony Gherghetta[1] and Benedict von Harling[2]

Continuum Dark Matter

Csaba Csáki,[a] Sungwoo Hong,[a,b,c] Gowri Kurup,[a,d] Seung J. Lee,[e] Maxim Perelstein,[a] and Wei Xue[f]

Crunching Dilaton, Hidden Naturalness

Csaba Csáki,[1] Raffaele Tito D'Agnolo,[2] Michael Geller,[3] and Ameen Ismail[1]

On Renormalization Group Flows in Four Dimensions

Zohar Komargodski[♠♡] *and Adam Schwimmer*[♠]

The big picture

Dilaton: NGB of spontaneously broken scale/conformal invariance

AdS/CFT relates dilaton to radion in holographic (warped) models

Weyl a-anomaly for the dilaton $\Leftrightarrow$ chiral anomaly for the pion

Three lessons:

- there are a-anomalous interactions at $\mathcal{O}(\partial^4)$,
- including four-dilaton interaction and dilaton-matter coupling,
- which have implications for collider pheno and cosmology

Dilaton effective Lagrangians I

Construct from coset methods (analogy: $\chi\mathcal{L}$ from $SU(3)_L \times SU(3)_R / SU(3)_V$)

$$S = \int d^4x \frac{1}{2} f^2 e^{-2\tau} (\partial\tau)^2 + \lambda e^{-4\tau} + \mathcal{O}(\partial^6)$$

τ: dilaton field; f: "decay constant"

Quartic allowed, unlike usual GBs

No terms at order ∂^4

Dilaton effective Lagrangians II

Anomaly manifests in curved background (analogy: background gauge field)

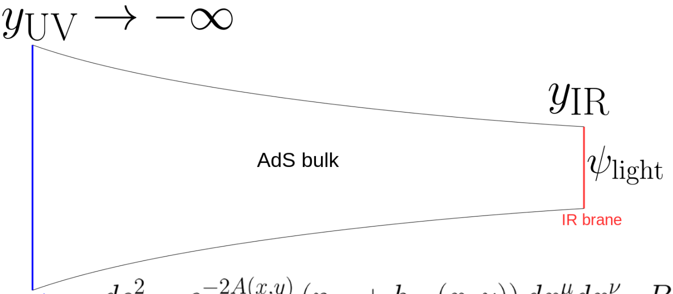
$$\langle T^\mu_\mu \rangle = cW^2_{\mu\nu\rho\sigma} - aE_4, \quad E_4 = \left(R^2_{\mu\nu\rho\sigma} - 4R^2_{\mu\nu} + R^2\right)$$

Leads to anomaly action (analogy: WZW term):

$$S_a = a \int d^4x\sqrt{g}\left[-\tau E_4 - 4G^{\mu\nu}\partial_\mu\tau\partial_\nu\tau + 4(\partial\tau)^2\Box\tau - 2(\partial\tau)^4\right]$$
$$\xrightarrow{\text{Minkowski}} 2a\int d^4x(\partial\tau)^4 + \mathcal{O}(\partial^6)$$

Upshot: a-anomalous interaction survives in flat space!

Dilatons in AdS/CFT



$$ds^2 = e^{-2A(x,y)}\left(\eta_{\mu\nu} + h_{\mu\nu}(x,y)\right) dx^\mu dx^\nu - B(x,y)^2 dy^2$$

Radion/dilaton mode + background bundled into A (e.g. $\langle A \rangle = ky$)

$h_{\mu\nu}$ parametrizes KK + massless graviton fluctuations

Holographic dilaton action: setup

Compactify on interval $(y_{\mathrm{UV}}, y_{\mathrm{IR}})$
5D Planck scale $M_5^3 = 1/(2\kappa^2)$, CC $\Lambda = -6k^2$

$$S_{5D,\mathrm{grav}} = -\frac{1}{2\kappa^2}\int d^5x\sqrt{g}(R+2\Lambda) - \frac{1}{\kappa^2}\sum_{i=\mathrm{UV,IR}}\int d^4x\sqrt{g_i}(K_i+\lambda_i)$$

Simple IR-localized matter model:

$$S_{\mathrm{matter}} = \int d^4x\sqrt{g_{\mathrm{IR}}}\mathcal{L}_{\mathrm{matter}}(\psi_{\mathrm{light}})$$

Strategy: integrate out KK gravitons in a derivative expansion
(to do this, solve Einstein equations)

Holographic dilaton action: order ∂^2

Set $h_{\mu\nu} = 0$: $ds^2 = e^{-2A}\eta_{\mu\nu}dx^\mu dx^\nu - B^2 dy^2$

Kinetic + quartic,

$$S_{\mathrm{radion}} = \int d^4x \frac{f^2}{2} e^{-2\tau}(\partial\tau)^2 - (\lambda + 6k^2/\kappa^2)e^{-4\tau}$$

with $\tau = A(y_{\mathrm{IR}}) - \langle A(y_{\mathrm{IR}})\rangle$

"Decay constant" $f^2 = 6/(\kappa^2 k)e^{-2\langle A(y_{\mathrm{IR}})\rangle}$—not the same as KK scale $M_{\mathrm{KK}} = ke^{-\langle A(y_{\mathrm{IR}})\rangle}$

Quartic leads to runaway potential unless tuned, $\lambda = -6k^2/\kappa^2$

Holographic dilaton action: order ∂^4

After a lot of calculation (no longer have $h_{\mu\nu} = 0$!)...

$$S_{\rm radion} = 2a \left[(\partial\tau)^4 + \partial^\mu\tau\partial^\nu\tau \left(T_{\mu\nu} - \frac{1}{6}\eta_{\mu\nu} T \right) \right]$$

with $a = 1/(8\kappa^2 k^3)$

Self-interaction and dilaton-matter couplings

In terms of N of dual CFT $(N^2 \sim 1/(\kappa^2 k^3))$:

$$a = N^2/(64\pi^2)$$

agrees with anomaly-matching arguments!

Phenomenology

Change variables to $\phi = fe^{-\tau}$, expand about vev $\phi = f + \varphi$:

$$\mathcal{L}_{\text{radion}} \supset \frac{1}{2}(\partial\varphi)^2 + \frac{\pi^2}{3N^2 M_{\text{KK}}^4}\partial^\mu\varphi\partial^\nu\varphi\left(T_{\mu\nu} - \frac{1}{6}\eta_{\mu\nu}T\right)$$

Novel dimension-8 operator; can probe N via e.g. radion production cross-sections

Contrast usual matter coupling to trace of $T_{\mu\nu}$ ($\sim \phi T$)

—contact interaction with scale-invariant fields (g, γ)

Toy cosmology

Homogeneous $\phi = \phi(t)$, $\lambda > 0$

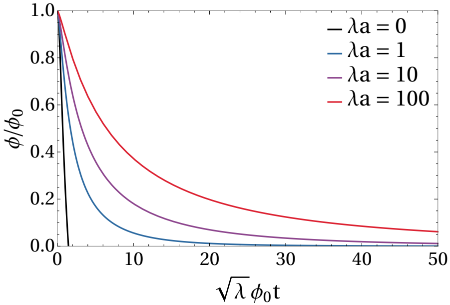
$$\mathcal{L}_{\text{radion}} \supset \frac{1}{2}\dot{\phi}^2 - \lambda\phi^4 + 2a\frac{\dot{\phi}^4}{\phi^4}$$

a-term acts as field-dependent viscosity, an "anomaly drag"

Effects qualitative change in behaviour

- smooths out singularity
- changes EOS

$\phi(t)$:



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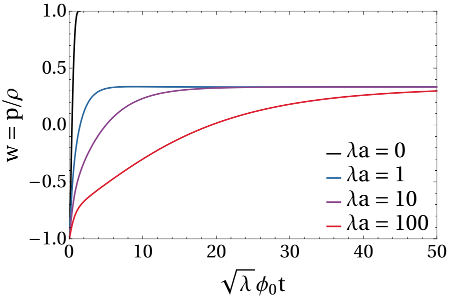
w:



Thank you!

Images: eBay, Particle Zoo

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