RELAXION MONODROMY IN STRING THEORY

John Stout

based on work in progress (1607.xxxxx) with

Liam McAllister, Geraldine Servant, Pedro Schwaller, and Alexander Westphal

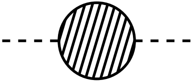
Cornell University

DESY

StringPheno2016 June 21, 2016

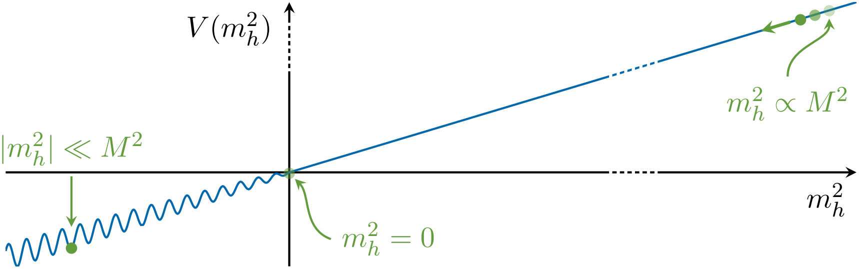
Cosmological Relaxation of the EW Scale

Problem:

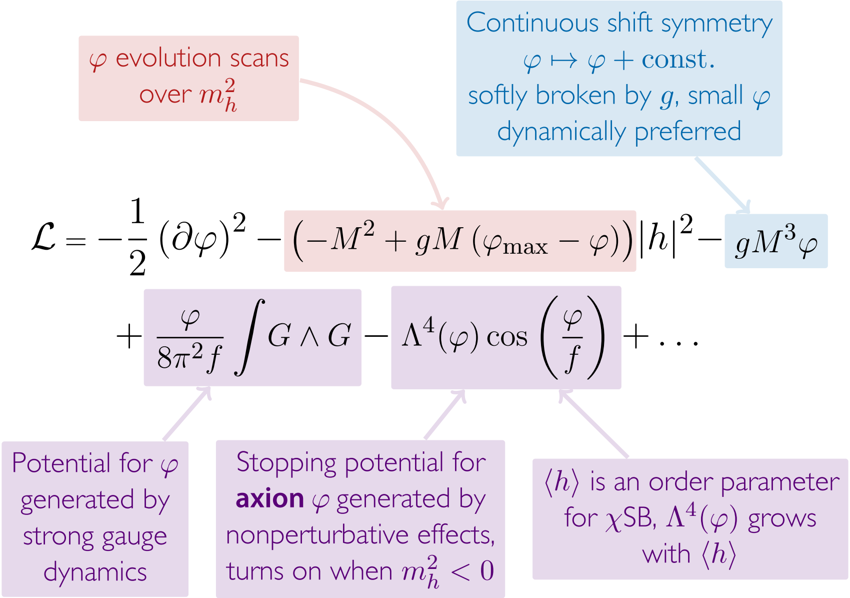
$\delta m_h^2 =$  $\propto M^2$ and $|m_h^2| \ll M^2$

Solution: Allow m_h^2 to dynamically evolve to $|m_h^2| \ll M^2$.

Graham, Kaplan, Rajendran '15



The Relaxion



φ evolution scans over m_h^2

Continuous shift symmetry $\varphi \mapsto \varphi + \text{const.}$ softly broken by g, small φ dynamically preferred

$$\mathcal{L} = -\frac{1}{2}(\partial\varphi)^2 - \left(-M^2 + gM\left(\varphi_{\max} - \varphi\right)\right)|h|^2 - gM^3\varphi + \frac{\varphi}{8\pi^2 f}\int G \wedge G - \Lambda^4(\varphi)\cos\left(\frac{\varphi}{f}\right) + \ldots$$

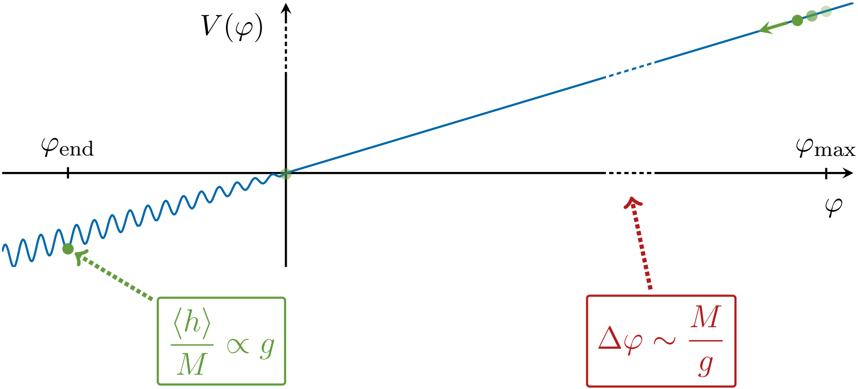
Potential for φ generated by strong gauge dynamics

Stopping potential for **axion** φ generated by nonperturbative effects, turns on when $m_h^2 < 0$

$\langle h \rangle$ is an order parameter for χSB, $\Lambda^4(\varphi)$ grows with $\langle h \rangle$

The Relaxion

$$V \supset gM^3\varphi + \Lambda_c^3\langle h\rangle \cos\left(\frac{\varphi}{f}\right) + \left(-M^2 + gM\left(\varphi_{\max} - \varphi\right)\right)|h|^2$$



$$\boxed{\frac{\langle h\rangle}{M} \propto g}$$

technically natural

$$\boxed{\Delta\varphi \sim \frac{M}{g}}$$

potentially problematic

Dangerously Large Field Ranges

Typical models have ultra-Planckian displacements.

$$\Delta\varphi \sim 10^9 - 10^{12} M_{\text{pl}}$$

Well-controlled, marginally super-Planckian field ranges have proved very difficult to achieve.

See, for instance: [Hardeman, Oberreuter, Palma, Schalm, van der Aalst '10], [Banks, Dine, Fox, Gorbatov '03] [Long, McAllister, J.S. '16]

WGC: [Arkani-Hamed, Motl, Nicolis, Vafa '06], [Rudelius '14], [Cheung, Remmen, '14],
[de la Fuente, Saraswat, Sundrum '14], [Montero, Uranga, Valenzuela '15], [Brown, Cottrell, Shiu, Soler '15]
[Bachlechner, Long, McAllister '15], [Junghans '15], [Heidenreich, Reece, Rudelius '15]

Such large field displacements necessitate an understanding of the relaxion mechanism in quantum gravity.

How exactly might this fail? What can we learn from its failures?

Weak Gravity Conjecture?

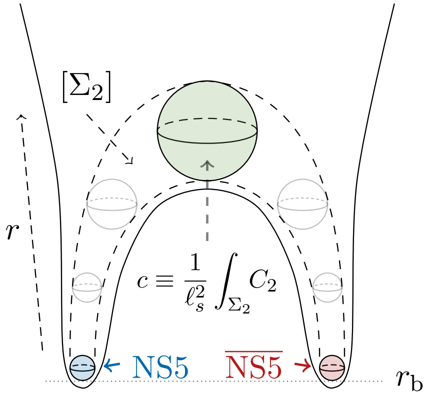
[Ibáñez, Montero, Uranga, Valenzuela '15], [Hebecker, Rompineve, Westphal '15]

Main Points

- **Height of the stopping potential Λ_c^3 is exponentially suppressed by small g, in warped compactifications.**
  - Relaxion must couple locally to strongly coupled gauge theory and the same mechanism for $g \ll 1$ forces gauge coupling $g_7 \ll 1$.

- **Technical naturalness is more subtle in the presence of monodromy.**
  - Monodromy charge is physical, can enter into quantum corrections.

Relaxion Monodromy



[McAllister, Silverstein, Westphal '08]
[Flauger, McAllister, Pajer, Westphal, Xu '09]

$$\mathrm{d}s_{10}^2 = e^{2A(y)}\eta_{\mu\nu}\mathrm{d}x^\mu\,\mathrm{d}x^\nu + e^{-2A(y)}\left(\mathrm{d}r^2 + r^2\mathrm{d}\Omega_5^2\right)$$

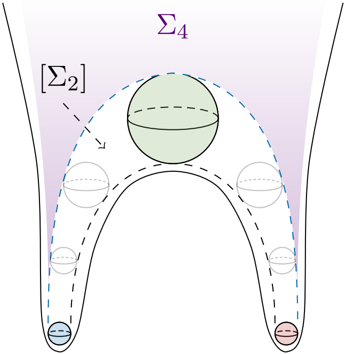
$$e^{4A(r)} \sim \frac{r^4}{L^4} \qquad L^4 \sim g_s \ell_s^4 N_{\mathrm{D3}}$$

$$\underbrace{gM^3}_{\frac{4\pi}{\ell_s^4 f}\, e^{4A}\big|_\mathrm{b}}\;\underbrace{\varphi}_{fc}$$

$$S_{\mathrm{NS5}} = -\mu_5 \int \mathrm{d}^6\xi\, e^{-2\Phi}\sqrt{-\det\left(G_{ab} - e^{\Phi}C_{ab}\right)}$$

Physical source of monodromy: N_w units of induced D3 charge

Stopping Potential



- A brane must intersect $[\Sigma_2]$ in order to generate a potential for φ

$$S_{\mathrm{CS}} \supset \mu_7 \int_{\mathcal{W}} \mathcal{F} \wedge \underbrace{C_2}_{\Sigma_2} \wedge \underbrace{\mathcal{F} \wedge \mathcal{F}}_{\mathcal{M}^{1,3}}$$

- 7-brane gauge coupling

$$\frac{1}{g_7^2} = \frac{1}{2\pi \ell_s^4} \int_{\Sigma_4} e^{-4A}$$

$$\Lambda_c^3 \propto \exp\left(-\frac{8\pi^2}{g_7^2}\right) \propto \exp\left(-\underbrace{\alpha}_{\text{Geometric tuning}} g_s N_{\mathrm{D3}}\right)$$

Suppression of the Stopping Potential

- Relaxion mechanism requires small g.

$$\frac{\langle h \rangle}{M} \propto g$$

- However, one must pay a geometric price: strong warping.

$$g \propto e^{4A}\big|_{\mathrm{b}} \propto N_{\mathrm{D3}}^{-1}$$

- Strong gauge dynamics must couple **locally**—also subject to strong warping.

$$\frac{1}{g_7^2} \sim \alpha g_s N_{\mathrm{D3}}$$

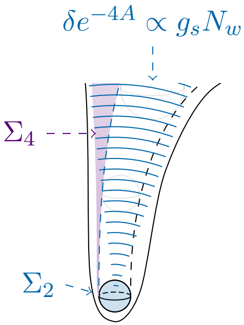
- Barriers of stopping potential are exponentially suppressed as $g \to 0$.

$$\Lambda_c^3 \propto \Lambda_0^3 e^{-\alpha g_s N_{\mathrm{D3}}}$$

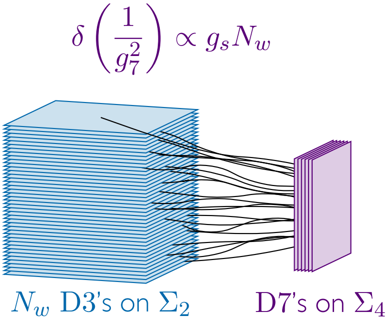
Difficult to sequester a very small (or very large) number.

Failure of Technical Naturalness

Closed String Channel



Open String Channel



Monodromy must be associated with a **physical source**, typically associated with additional (light) degrees of freedom.
Large multiplicities can induce **large quantum corrections.**