Dynamical Relaxation for Fine-Tuning

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with

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A New Approach to Fine-Tuning?

current approaches:

Anthropics/Multiverse

Dynamics (SUSY, compositeness, …)

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current approaches:

Anthropics/Multiverse

- currently lacks mathematical rigor

Dynamics (SUSY, compositeness, …)

- Hierarchy Problem

  lack new physics at weak scale (LHC, direct detection, EDMs,…)

- CC Problem

  probed meV scale a long time ago

- Strong CP Problem

  axion as instructive example?

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make fundamental constant dynamical

accept large (initial) value, drive parameter small naturally

replaces symmetry with dynamics in time

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- shares some elements of axion solution to strong CP (dynamical EDM)
- we present solution to hierarchy problem
- CC?? Abbott (1985)

Hierarchy Problem

Dynamics

- new physics at weak scale, cuts off loops
- theory natural above weak scale

Anthropics/Multiverse

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New class of solutions to hierarchy problem

- theory natural
- minimal model has no new physics at weak scale
- colliders may see new particles, but Higgs looks tuned

Caveats

- judge models by how much raise cutoff

  $\mu \sim 3 \times 10^4\,\mathrm{GeV} \to 10^8\,\mathrm{GeV}$

- goal: technically natural

- requires large (above cutoff) field excursions

Minimal Model

particle content below cutoff: SM + QCD axion + inflaton

changes to axion:

- softly-broken shift symmetry (via coupling to Higgs)
- large (non-compact) field range

Fuente, Saraswat, Sundrum (2014)
Silverstein, Westphal (2008)

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$$V \ni (-\mu^2 + g\phi)|h|^2 + g^2\phi^2 + \frac{\phi}{f}\tilde{G}^{\mu\nu}G_{\mu\nu}$$

g is small, dimensionful parameter ➜ helps set weak scale
technically natural since spurion

this + inflaton solves hierarchy problem

Mechanism

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call ϕ the "relaxion"

Axion Potential

$$V \ni (-\mu^2 + g\phi)|h|^2 + g^2\phi^2 + \Lambda^4 \cos(\phi/f)$$

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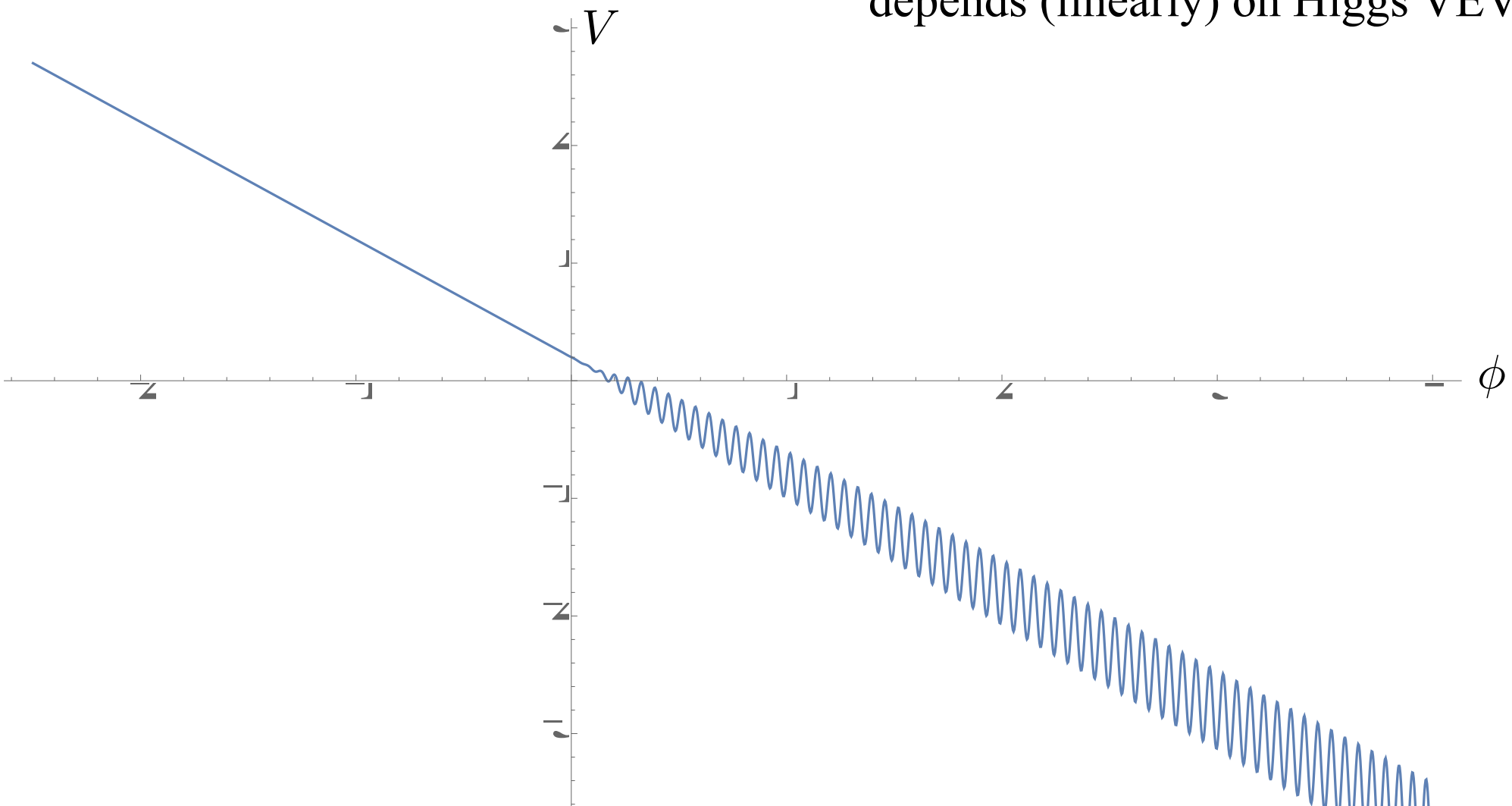


Requirements

$$V \ni (-\mu^2 + g\phi)|h|^2 + g^2\phi^2 + \Lambda^4 \cos(\phi/f)$$

field range: $\Delta\phi \sim \mu^2/g$

e-folds required: $N \gtrsim \dfrac{H_{\rm i}^2}{g^2}$

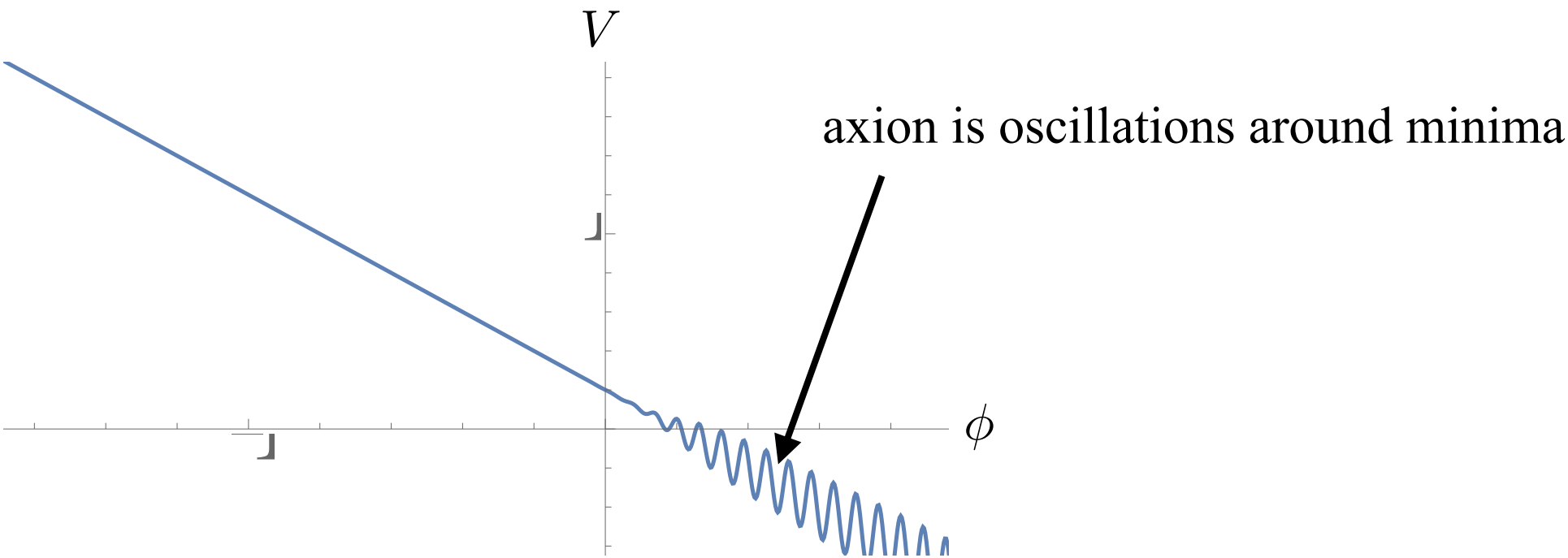
inflaton dominates: $H_{\rm i} > \dfrac{\mu^2}{M_{\rm pl}}$

classical beats quantum: $H_{\rm i} < (g\mu^2)^{\frac{1}{3}}$

barriers form: $g\mu^2 f \sim \Lambda^4$

interestingly, there is parameter space that works!

Strong CP Problem



slope shifts minima ➜ strong CP problem!

QCD Axion

$$V \ni (-\mu^2 + g\phi)|h|^2 + g^2\phi^2 + \Lambda^4 \cos(\phi/f)$$

Two solutions:

1. decrease slope dynamically after inflation: e.g. $g^2 \to k\sigma^2\phi^2$

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result:

$$\mu < \left(\frac{\Lambda^4 M_{\rm pl}^3}{f}\right)^{\frac{1}{6}} \theta^{\frac{1}{4}} \sim 3 \times 10^4\,\text{GeV} \times \left(\frac{10^9\,\text{GeV}}{f}\right)^{\frac{1}{6}} \left(\frac{\theta}{10^{-10}}\right)^{\frac{1}{4}}$$

(or $\sim 10^6$ GeV if loosen eternal inflation constraint)

solves hierarchy, strong CP, and can give DM

Non-QCD Axion

2. non-QCD axion: same constraints, now Λ up to ~ 100 GeV

$$V \ni (-\mu^2 + g\phi)|h|^2 + g^2\phi^2 + \Lambda^4 \cos(\phi/f)$$

add new weak scale fermions charged under new strong group

$$\mathcal{L} \supset m_L L L^c + m_N N N^c + y h L N^c + \tilde{y} h^\dagger L^c N$$

$$\mu < \left(\frac{\Lambda^4 M_{\rm pl}^3}{f}\right)^{\frac{1}{6}} \sim 10^8\,\text{GeV} \times \left(\frac{\Lambda}{10\,\text{GeV}}\right)^{\frac{2}{3}} \left(\frac{10^9\text{GeV}}{f}\right)^{\frac{1}{6}}$$

rich phenomenology of new bound states

Relaxion Baryogenesis?

(in progress with T. Wiser and K.V. Tilburg)

Can the axion cause baryogenesis?

during electroweak phase transition, axion couples to baryon number current

Servant (2014), …

sphalerons violate B, axion violates CP

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➔ non-zero chemical potential for B

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goal: single field does hierarchy, strong CP, baryogenesis, and DM

requires some model-building for large enough B

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SUSY, etc. predicts WIMP

dynamical relaxation predicts “other kind” of DM

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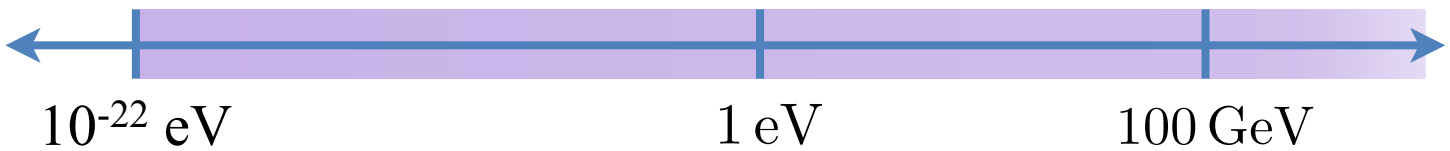
DM mass:



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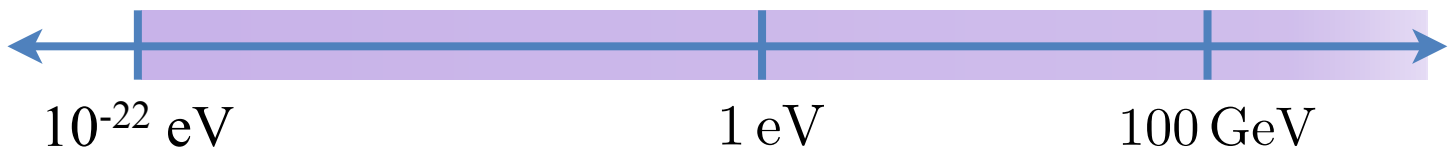

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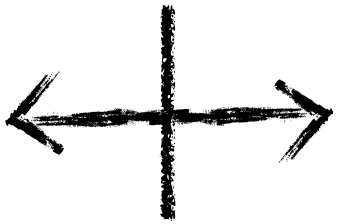
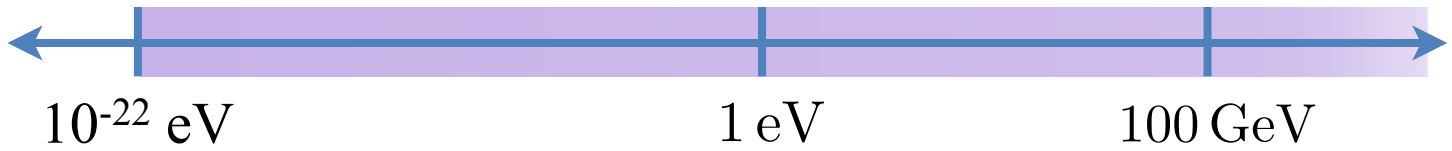
field-like (e.g. axion)
new detectors required



particle-like (e.g. WIMP)
particle detectors best

Light Field Dark Matter

DM mass:



Effective field theory predicts only a few DM candidates

Spin	Type	Operator	Interaction	Effect(s)
0	scalar	$\phi h^\dagger h$	Higgs portal	new force, m_e, m_p oscillation
	pseudo-scalar	$aG^{\mu\nu}\tilde{G}_{\mu\nu}$	axion-QCD	oscillating nucleon EDM
		$aF^{\mu\nu}\tilde{F}_{\mu\nu}$	axion-E&M	axion-photon mixing
		$(\partial_\mu a)\bar{\psi}\gamma^\mu\gamma_5\psi$	axion-fermion	axion wind?
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		$F^{\mu\nu}F'_{\mu\nu}$	vector-photon mixing	xx
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Light Field Dark Matter

DM mass: 10^{-22} eV — 1 eV — 100 GeV

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DM is an (EP violating) force field

Use torsion pendulums, atom interferometry, others?

(in progress with EOT-Wash and Kasevich/Hogan groups)

Cosmic Axion Spin Precession Experiment (CASPEr)

Axion dark matter induces oscillating EDM, detectable with NMR

Complementary reach to existing axion experiments

Construction beginning at Mainz and BU

target ~ 3 years for initial phases of CASPEr-Wind and CASPEr-Electric

Boston University
Alexander Sushkov

Cal State
Derek J. Kimball

JGU Mainz
Dmitry Budker
Peter Blümler
Arne Wickenbrock

Helmholtz Institute Mainz
John Blanchard
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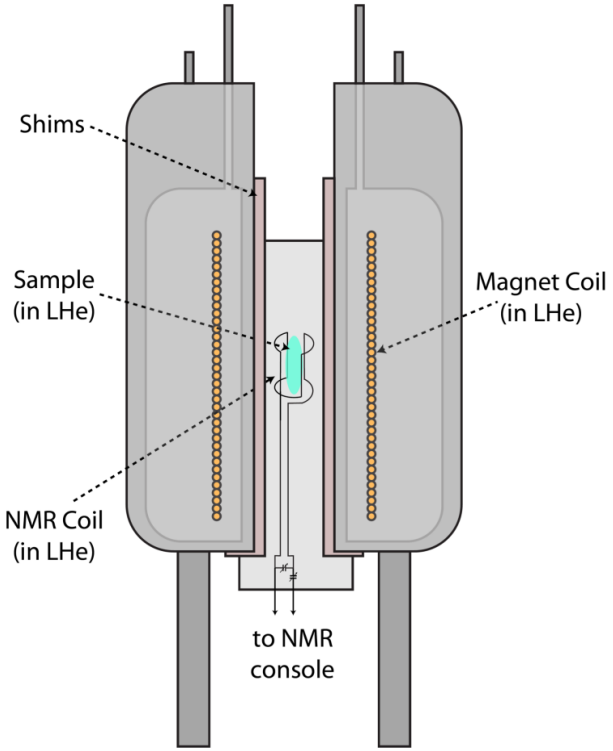
Surjeet Rajendran



CASPEr-Electric

PRX **4** (2014) arXiv: 1306.6089

SIMONS FOUNDATION

HEISING - SIMONS FOUNDATION

Observables

- axion (or axion-like) physics set by f
- changed predictions for axion DM
- preference for large nucleon EDM in QCD axion case
- low inflationary Hubble scale (falsifiable)
- either new particles at weak scale (charged under new strong group) or next collider-accessible cutoff ~ 30 TeV
  either case theory looks tuned
- axion DM fluctuates Higgs VEV ➜ oscillates all scales (electron mass…)
  potentially observable (at low cutoff), would be true proof of mechanism

Future Work

- more dynamical relaxation models, raise cutoff?
- UV completion (axion monodromy)
- DM models
- rich phenomenology of non-QCD model
- models of inflation that fit with our model
- our model gives a new, natural hybrid inflation model
- CC??