Title: Dark Matter in Holographic Geometry

Date: Jul 17, 2009 04:00 PM

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Abstract: TBA

Holographic DM

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Dark Matter in Holographic Geometry

Andrew R. Frey

McGill University

with Jim Cline and Rebecca Danos
to appear shortly

Motivation

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Exploring a Corner of the Landscape

- Looking for UV understanding of our EFT
- Generic constraints possible, generic predictions harder
- So hammer on specific class of models
- Pointer to interesting cases for details
- Eventually connect to dark matter modeling

Also a nice case study of traditional holography in cosmology

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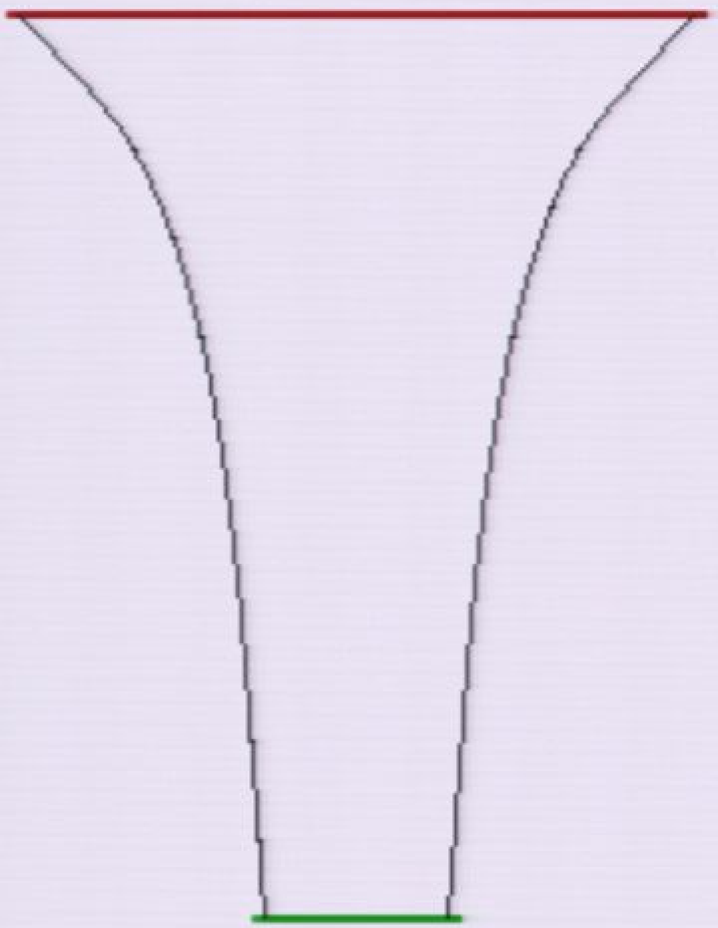
Outline

1. History of Holography & String Cosmology
2. Reheating and Kaluza-Klein Relics
3. The Spectrum & Dark Matter Candidates
4. Interactions and Decay Rates
5. Discussion of Results

History of Holography & String Cosmology

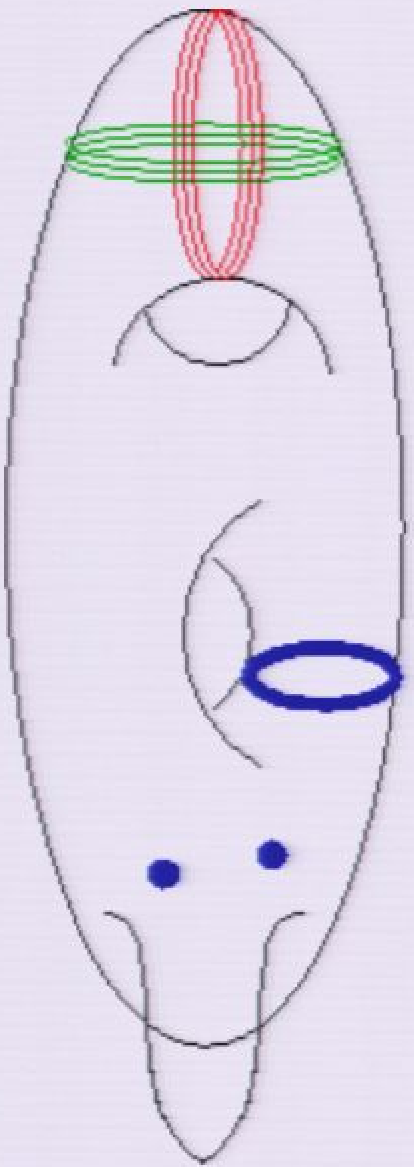
In place of the normal obligatory review:



AdS_5 and Compactification

- Two roles for AdS_5 (*Maldacena; Randall & Sundrum*)
  - Dual gravity to CFT
  - Warping for hierarchies
  - Similar timing
- Build RS with $D3$ (*Verlinde*)
  - Just put branes on torus
  - Infinite throat, moduli

Moduli Stabilization and KS Throats



Early Flux Compactifications

- M-theory on CY_4 with fluxes (*Beckers*)
- Dualized to IIB strings (*Dasgupta, Rajesh, & Sethi*)
- Crossed flux stabilizes complex structure, not Kähler

Holographic Catalyst

- Dual of confinement (*Klebanov & Strassler*)
  - Finite warping at smooth tip
  - Same class of geometry
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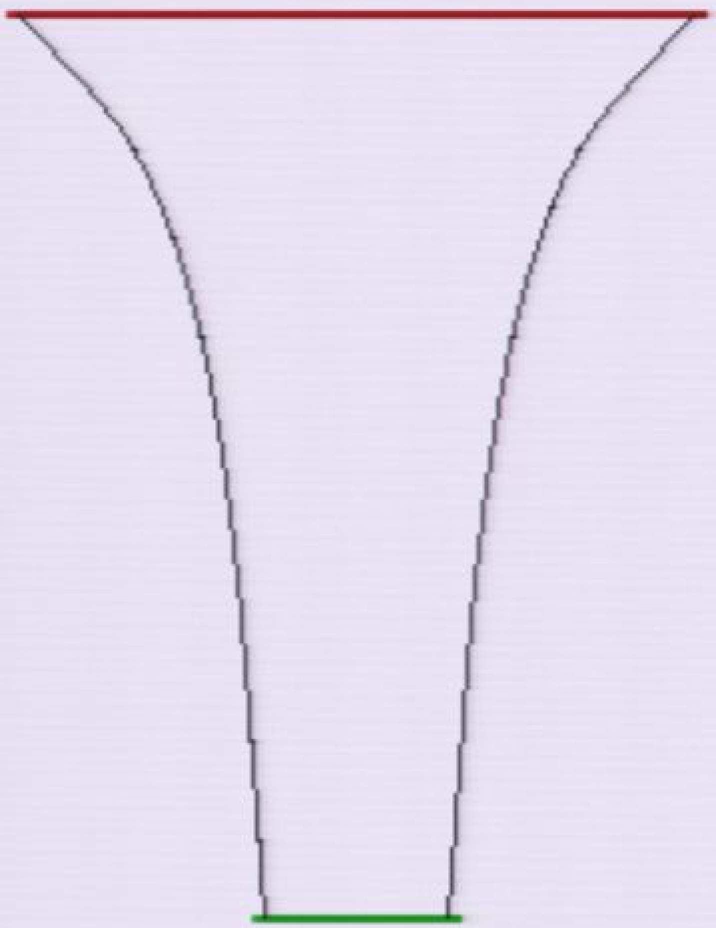

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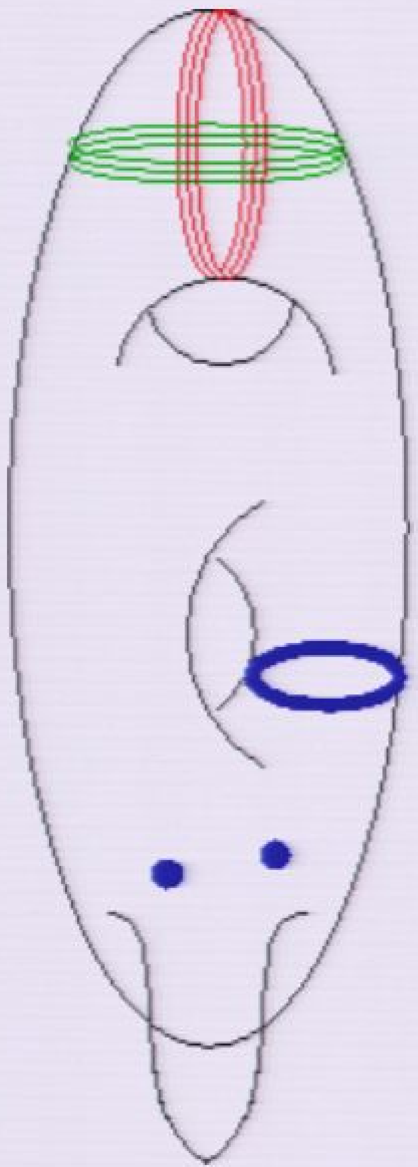

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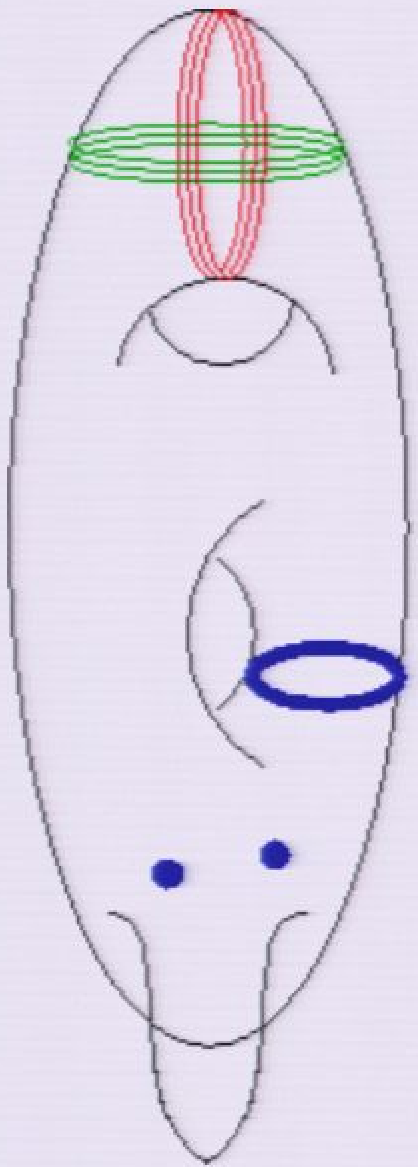

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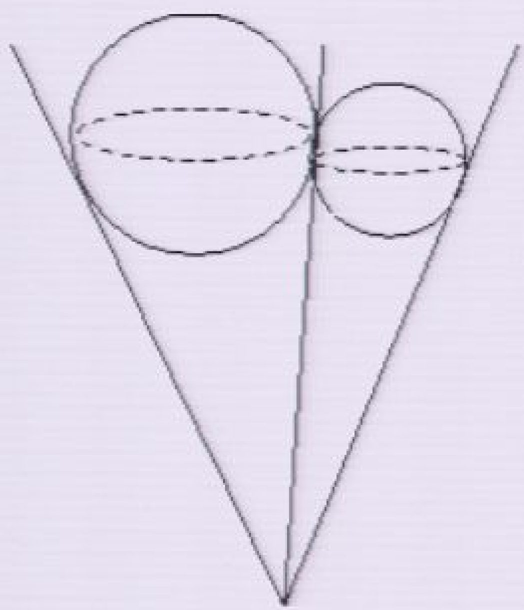


KS Throat Geometry

- External & internal warping

$$ds^2 = e^{2A} dx_\mu dx^\mu + e^{-2A} d\tilde{s}^2$$

- Locally conifold geometry

$$d\tilde{s}^2 = e^{-2kz}\left[dz^2 + \frac{1}{k^2} d\hat{s}^2\right]$$

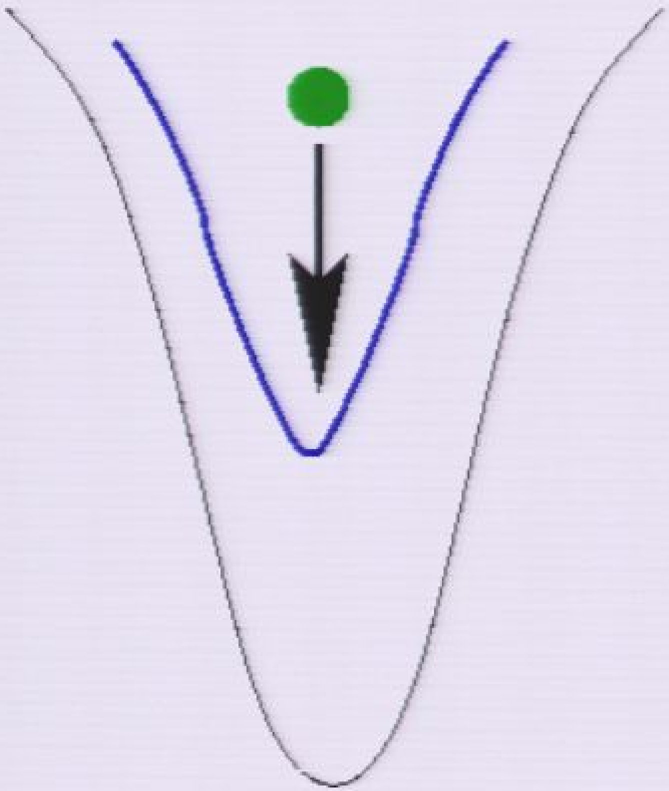
- $d\hat{s}^2$ is $T^{1,1} \sim S^3 \times S^2$
- Spacetime and radius form AdS_5

$$ds_5^2 = e^{-2kz} dx_\mu dx^\mu + dz^2$$

- Dual to CFT with log corrections
- Smooth tip with finite S^3 at z_0

Inflation in the Throat

Kähler and brane moduli stabilized by quantum or α' physics
Drives inflation (which will yield our relics)



Brane Inflation

- Motion driven by stabilization
  (*Baumann et al*)
- Interaction dual to chiral VEVs
- Generally from deformed throat
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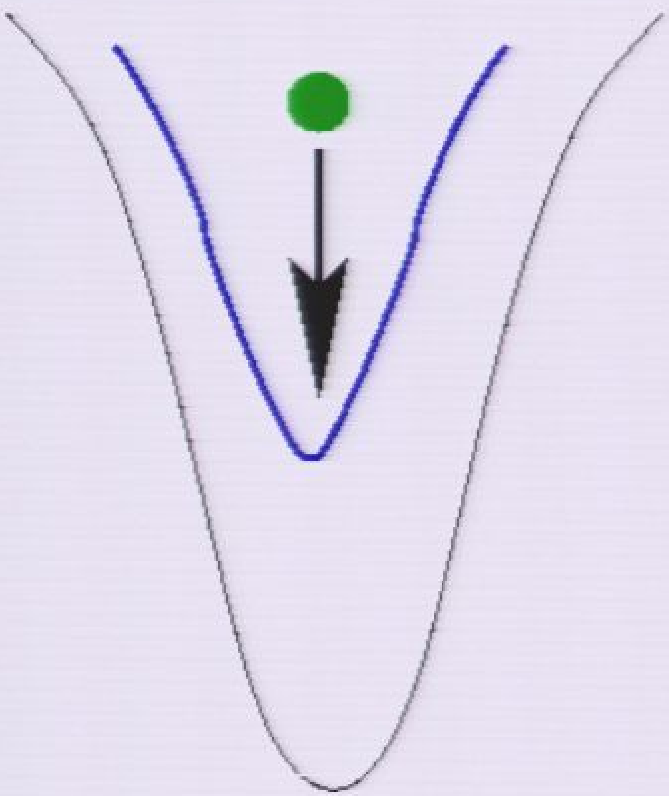

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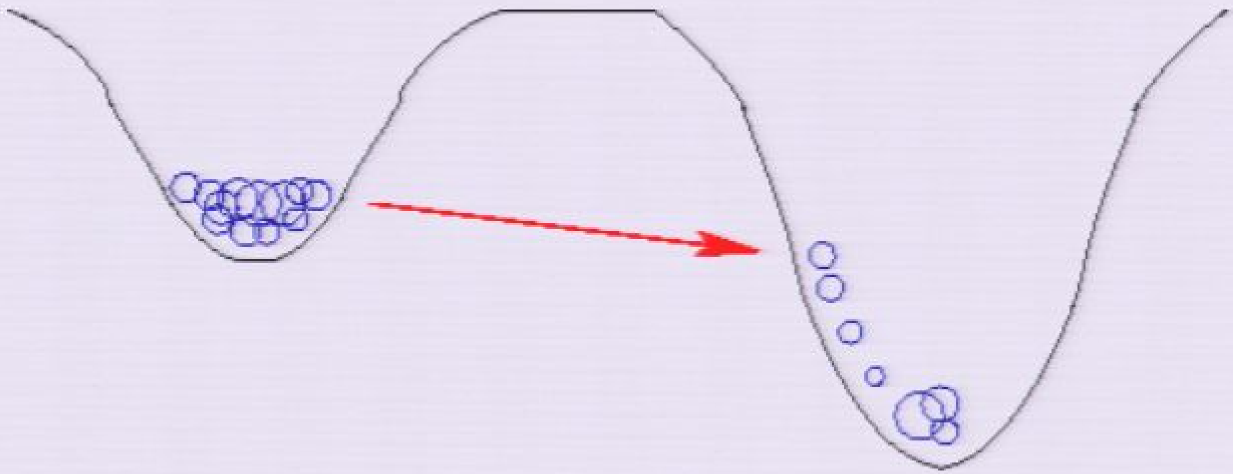
Reheating and Kaluza-Klein Relics



Many Modes Excited in Reheating

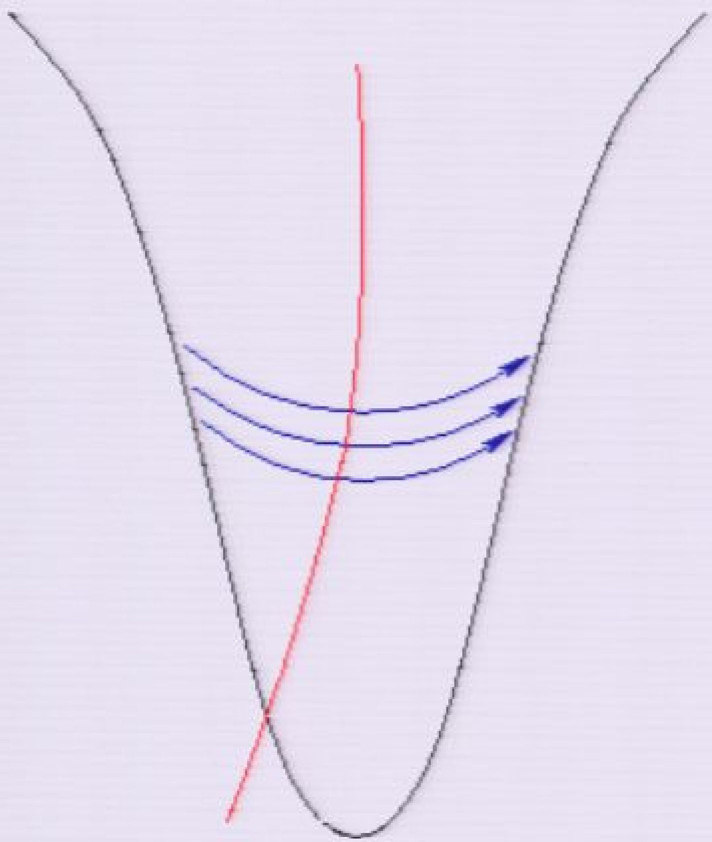
- Inflaton couples to many sectors, not just SM
- KK modes typically excited
- Must spread or tunnel through extra dimensions

- Can energy get stuck in closed strings?

(Barnaby, Burgess, & Cline; ARF, Mazumdar, & Myers; Chialva, Shiu, & Underwood; Kofman & Yi; ...)

Angular KK Modes as Relics

Approximate isometries of throats lead to relics (*Kofman & Yi*)



Isometries of KS Throat

- $T^{1,1}$ has $SU(2)^2/U(1)$ isometry
- Broken by bulk effects
- Angular modes localized at tip
- Potentially long-lived
- Similar for other throats

Conflicting views of relics

- Overclose the universe
- Relics thermalize: DM candidate (*Chen & Tye*)
- Assume TeV scale DM

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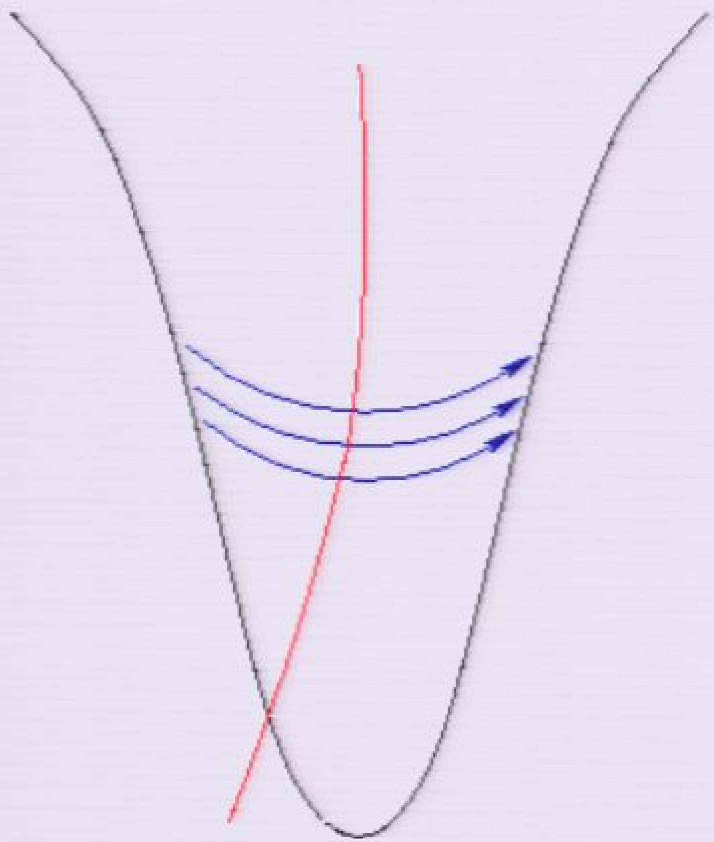

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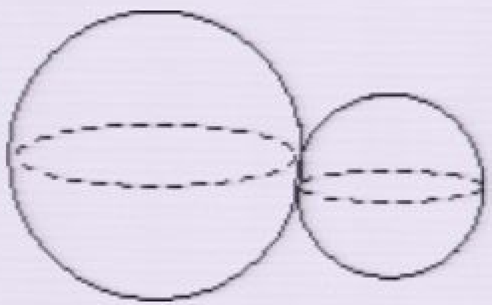
Previous Studies

- Thermalization estimated in reheating papers
  (*Kofman & Yi; Chialva, Shiu, & Underwood; von Harling, Hebecker, & Noguchi*)
- KK modes as glueballs without angular charge
  (*von Harling & Hebecker*)
- Graviton KK modes:
  - More detailed thermal history
    (*Chen & Tye; Dufaux, Kofman, & Peloso*)
  - Interactions and decays not generic among KK modes
- Classification of angular KK modes (*Berndsen, Cline, & Stoica*)
  - Tentative identification of lightest long-lived state
- All considered only classical throat deformations
- We will reconsider angular KK modes and scan decay rates

The Spectrum & Dark Matter Candidates



Angular charges

- Classify states & deformations by $SU(2) \times SU(2)/U(1)$ charge
- Total spins j, l and $r = (j_3 - l_3)/2$
- Sum $j_3 + l_3$ constrained (for ex, $= 0$ for scalars)

States of interest

- Light states: moduli, D-brane ("SM") degrees of freedom: Decay products and possible end states of thermalization
- KK modes: charged and uncharged (intermediate states)

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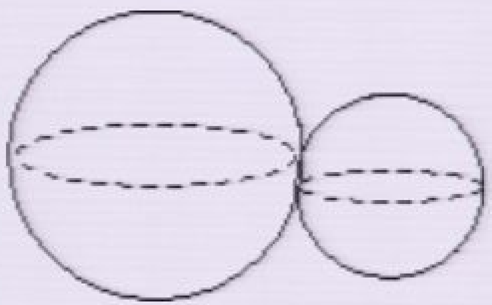

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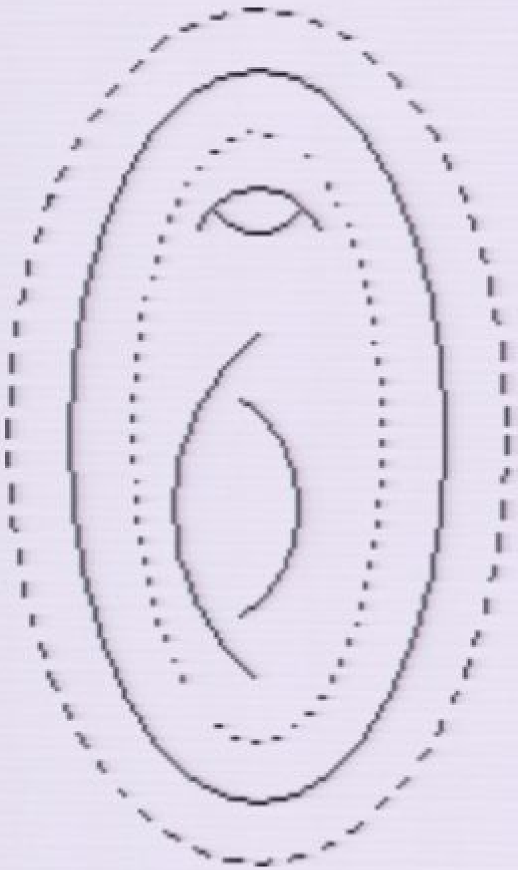

Supergravity states

- Graviton, of course
- Universal volume modulus & axion
- Kähler moduli, possibly some charged
- Deformation modulus lifted by flux
  Like other complex structure moduli
  (May be lighter than warped scale)
- Possibly charged gauge fields
- Spread through bulk of CY

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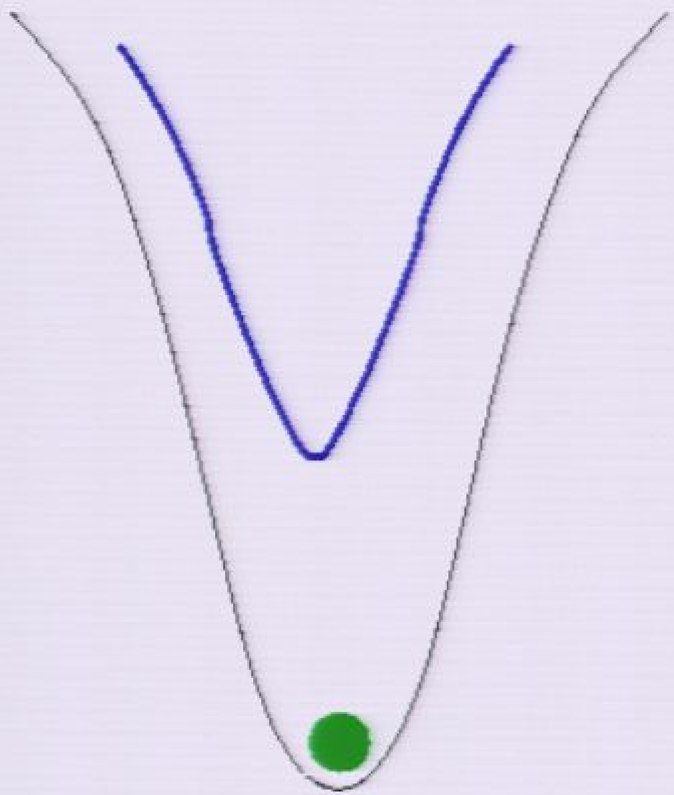

$$w = e^{-kz_0}$$

$D3$-brane Standard Model

- Drawn to tip of throat
- Brane scalars as SUSY partners
- Fermions from 10D superspace

$$\mathcal{L} = -\frac{\mu_3}{2} w^3 \bar{\Theta} \not{\partial} \Theta$$

- Gauge fields

$D7$-brane Standard Model

- 4-cycle from bulk to z_1
- Normalization dominated by bulk
- KK couplings by throat
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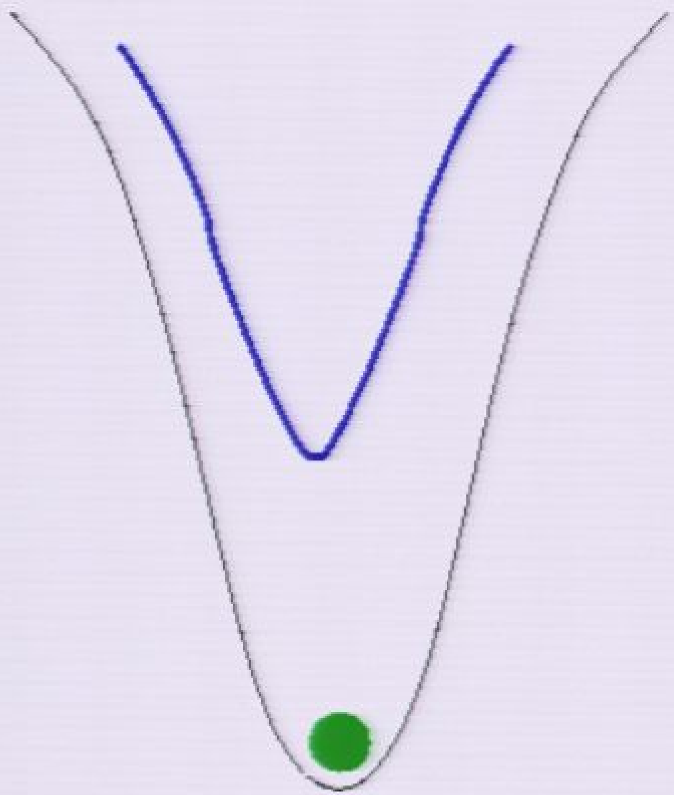

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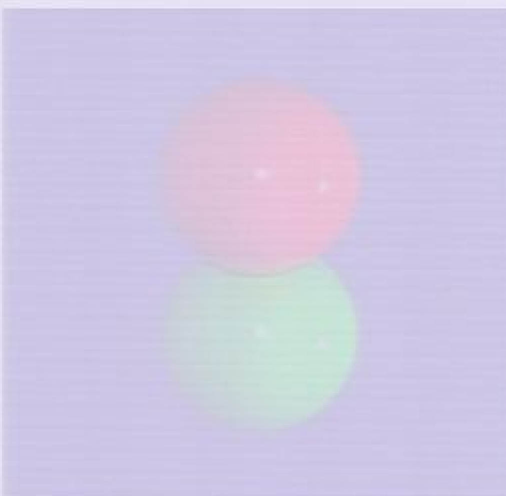
Kaluza-Klein Modes for Dark Matter

Finding a DM Candidate

- Want lightest charged state for DM candidate
- Known spectrum of $T^{1,1}$ KK masses (*Ceresole et al*)
- Mass from flux (or quantum/α') model-dependent
- Use lightest KK mass as proxy DM candidate



$T^{1,1}$ Breathing Mode

- KK mass at BF bound for $(1,0,0)$
- Simple structure but couples generally
- Graviton modes much heavier
- Wavefunction

$$\delta\gamma \propto w^{1+\nu}\, e^{(2+\nu)z}\,, \quad \nu^2 = 4 + m_5^2$$

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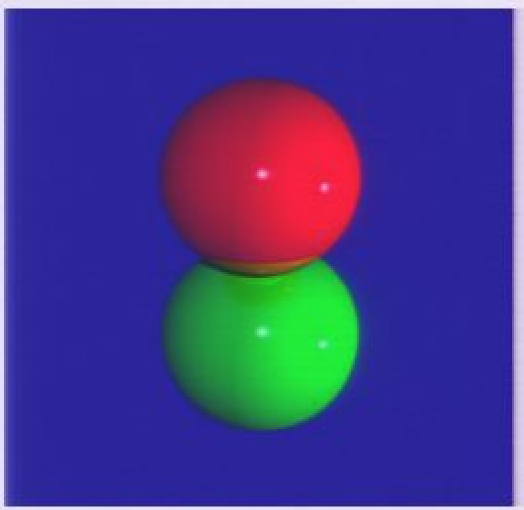

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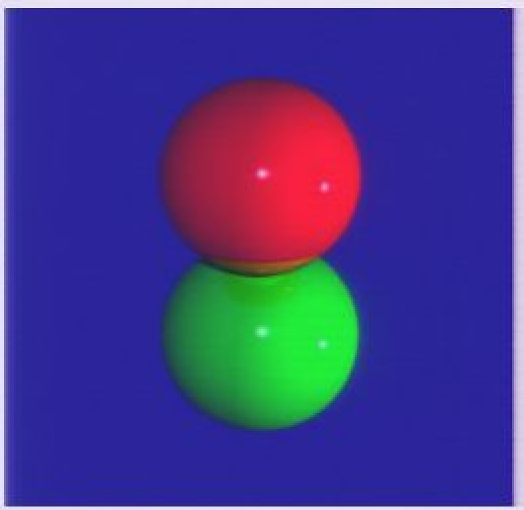

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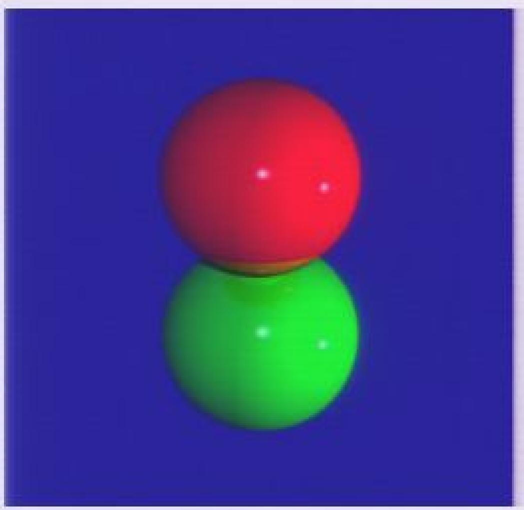

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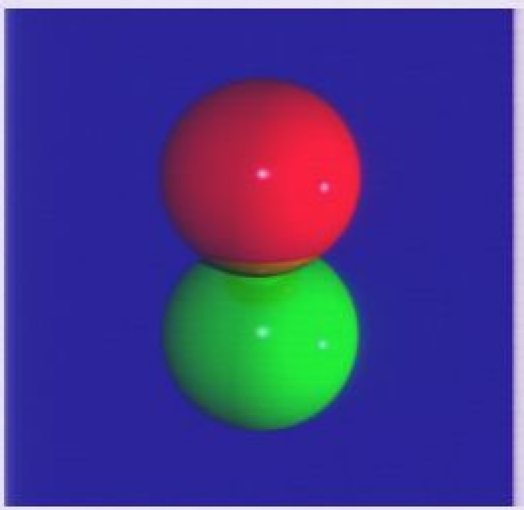

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Decays need some access to symmetry breaking

Isometry Breaking by Throat Deformation

- The compactification breaks the isometry
- Deformations controlled by dual CFT
- Focus on non-classical, growing deformations
- KK scatters from deformation, loses charge, decays

Background Isometry Breaking

- Brane positions break some isometries
- Moduli with nontrivial angular motion in throat
  Spread through bulk with explicit breaking

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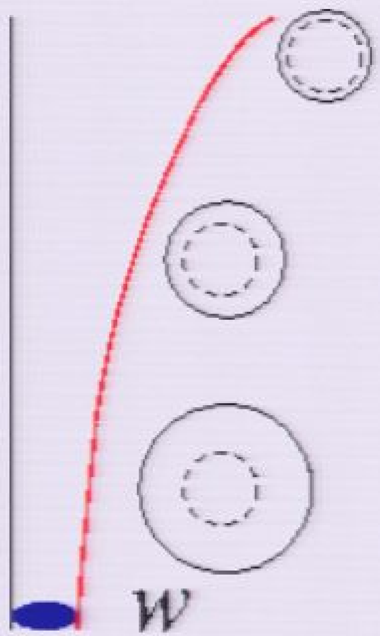

Deformation by Breathing Mode

- $T^{1,1}$ breathing has relevant deformations Charge $(1, 0, 0)$, $(0, 1, 0)$, or $(1/2, 1/2, \pm 1)$
- Not allowed in classical compactification
- Supersymmetric (*Baumann et al*)
- Protected by dual CFT
- Leading for us: $\Delta\gamma \approx w^4 e^{2kz}$

Other Deformations

- All supergravity fields support deformations
- Classically allowed have larger prefactors but are irrelevant
- Different KK states scatter from different deformations
- Tabulate rules to modify decay rates

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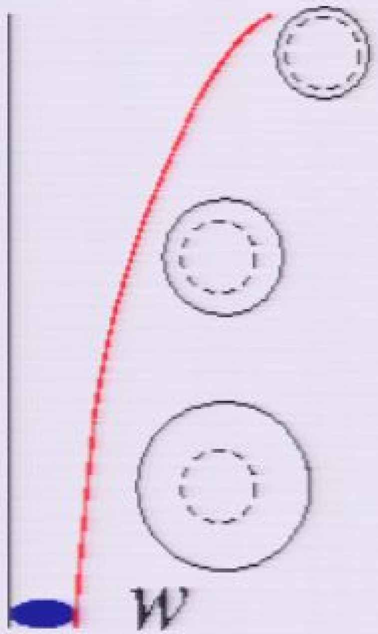

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Mass Mixing from Deformation

Quadratic Terms in Potential

- Scan for $\delta\gamma^\star\Delta\gamma\delta\gamma$ terms in potential

$$U \propto \int d^6y\sqrt{\tilde{g}}\tilde{R} - \frac{g_s}{12}\int d^6y\sqrt{\tilde{g}}e^{4A}G_{mnp}\left(\bar{G} - i\tilde{\star}_6\bar{G}\right)^{\widetilde{mnp}}$$

- KS flux about constant $G_{z\theta\phi} \sim kG_{\theta\phi\psi}$
- Finally $U \approx k^2w^4\gamma^\star(x)\gamma(x)$ KK mixing
- Coefficient model-dependent, up to 100
- Similarly mixing with moduli: for universal

$$U \approx (M_s^4/kM_p)w^{5+\nu_\star}u(x)\gamma^\star(x)\ ,\ \nu_\star < 4$$

through $e^{-4A} \to e^{-4A} + u$

Decays to Supergravity Modes

Decays to Moduli

- 1 KK/2 moduli couplings vanish before deformation
  Otherwise a tadpole for KK mode
- So $\gamma^\star$ decay to charged moduli suppressed
- Two decays to uncharged moduli:
  - Cubic vertex from $\delta\gamma\Delta\gamma u^2$ term
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$$\Gamma \approx \frac{M_s^8}{M_p^4 k^3} w^{9+2\nu_\star} \approx 10^{-89-26\nu_\star} s^{-1}$$

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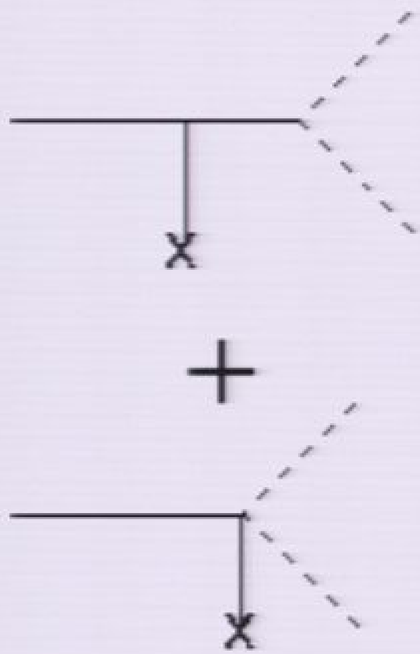

Decay to Universal Axion

- Sketchily $C_4 \sim a(x)\tilde{J}^2 \propto e^{-4kz}$

  (*ARF, Torroba, Underwood, Douglas*)
- Angular legs couple to $\delta\gamma$ and $\Delta\gamma\delta\gamma^\star$
- Induced dimension-5 couplings

$$\frac{M_s^4}{M_p^2}\frac{p_1 \cdot p_2}{k^3} w^{1+\nu}\gamma a^2 \,,\; \frac{M_s^4}{M_p^2}\frac{p_1 \cdot p_2}{k^3} w^{5+\nu_\star}\gamma^\star a^2$$

- Gives weak lower bound for decay rate

$$\Gamma \approx \frac{M_s^8}{k^3 M_p^4} w^{13+2\nu_\star} \approx 10^{-141-26\nu_\star} s^{-1} \quad (\nu > \nu_\star + 2)$$

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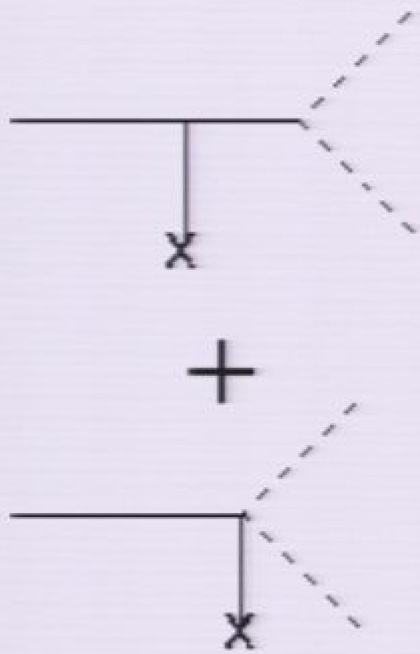

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Decays to Supergravity Modes

Decays to Charged Axions

- Can directly couple to $\delta\gamma^\star$
- Take wavefunction as e^{-4kz} or constant in z
- Appears as dimension 5 "off-diagonal kinetic term"

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Replace $w^{1+\nu_\star} \to w^5$ for $\nu_\star > 4$ for constant wavefunction

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Still plenty long for TeV scale throats

Decays to Supergravity Modes

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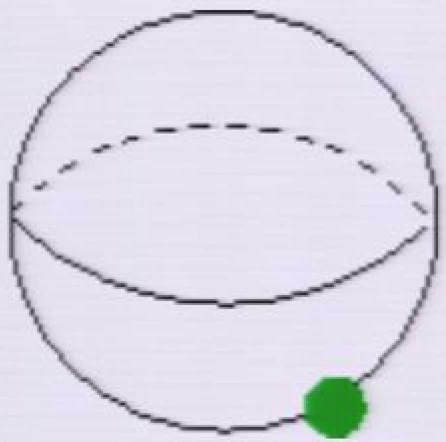
D3-brane Standard Model



Brane Position Breaks Isometry

- Direct coupling to scalar kinetic term

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Extremely fast!

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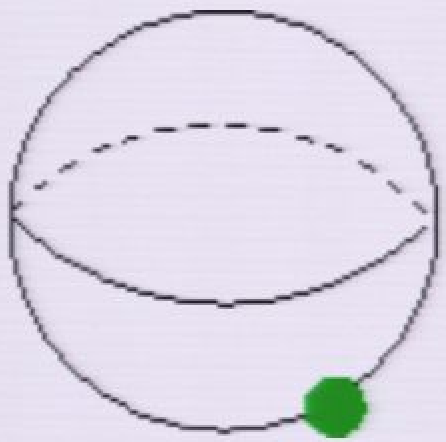

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D7-brane Standard Model

Scalars vs Fermions

- $D7$ scalars have similar dimension 5 coupling
- Additionally couple to volume modulus
- Fermions also have flux-induced Yukawa
  But form unknown with warping
- Estimate: multiply dim 5 coupling by cutoff $w_1 k \equiv k e^{-kz_1}$
- No flux-induced Yukawa with volume modulus
  But possibly light complex structure

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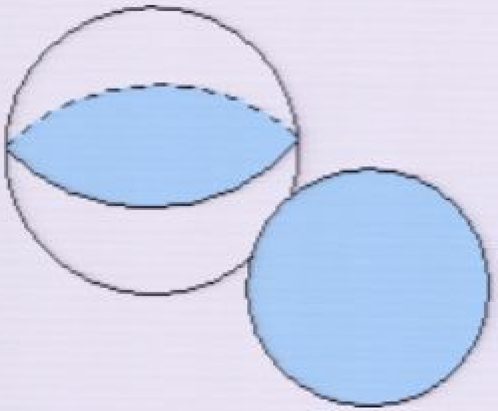
D7-brane Standard Model



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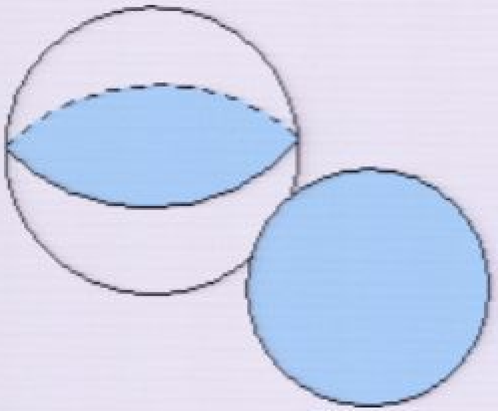

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- Similar coupling via kinetic terms
- Coupling via uncharged KK or modulus
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Discussion of Results

Taking $w \sim 10^{-13}$, $k \sim M_s$, $M_s \sim 10^{16} GeV$, $w_1 \sim 10^{-4}$
We find

- Decays within supergravity slower due to spread wavefunctions
- $D3$-brane decays fast
- Symmetry breaking $D7$-branes have potentially observable decays

Comparison to Previous Results

Classical Decays

(*Berndsen, Cline, & Stoica*)

- Considered just inflationary throat
- Allowed only irrelevant deformations (classically allowed)
- Found decay $\Gamma \sim w^{7.4} k M_s^4 / M_p^4$
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(*Dufaux, Kofman, & Peloso*)

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- Many models have very long-lived KK modes
- $D3$-type Standard Models on verge of being ruled out
- Fermionic couplings (including fermionic DM)
- Cosmic history:
  - Return to reheating in brane and other inflation models
  - Does angular motion affect tunneling rates?
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Summary

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1. History of Holography & String Cosmology
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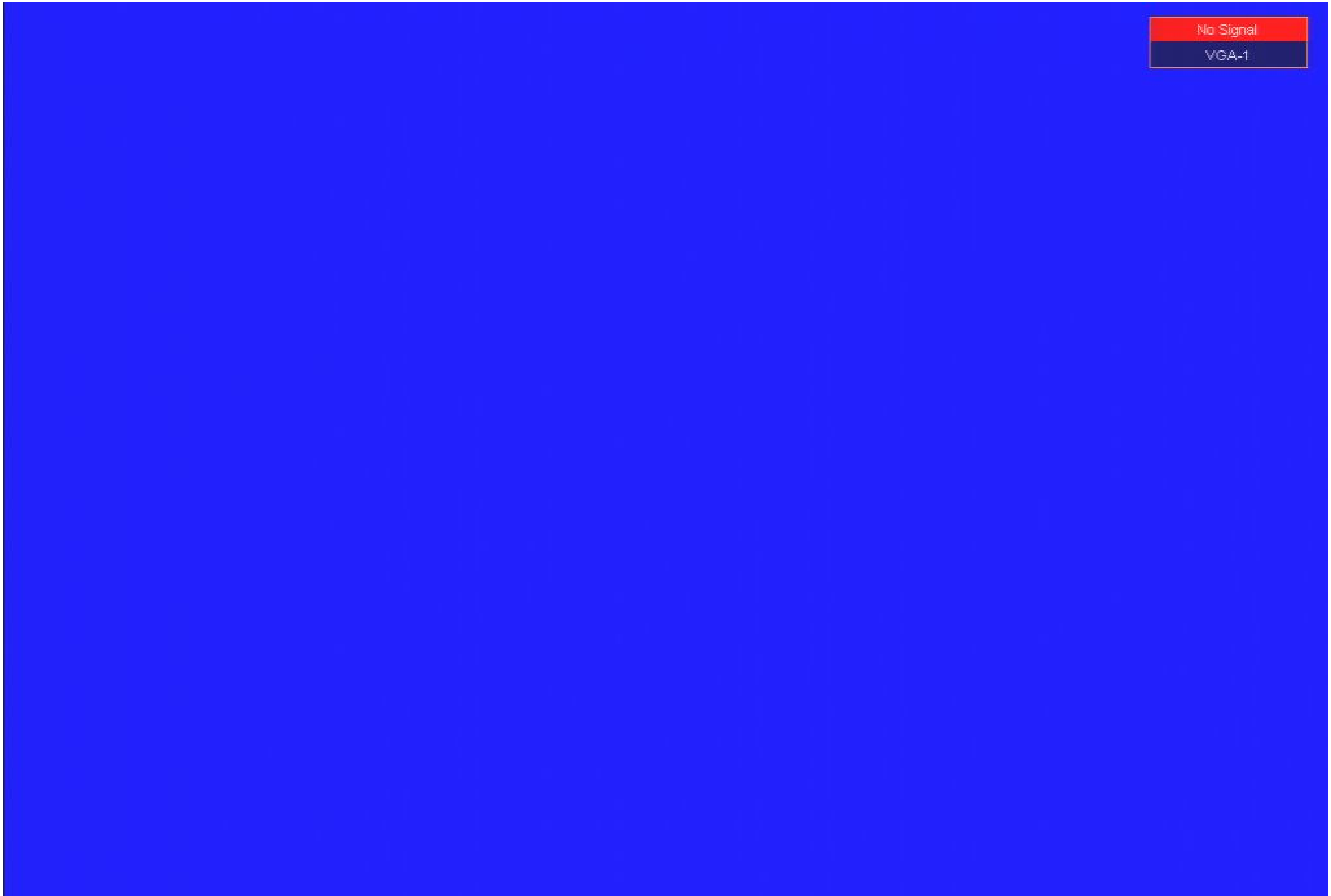
3. The Spectrum & Dark Matter Candidates
4. Interactions and Decay Rates
5. Discussion of Results

No Signal

VGA-1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