Title: Reheating in warped throats: helping relics decay

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Abstract: The process of reheating in warped brane world models was initially thought to be quite efficient. However, the identification of long-lived Kaluza-Klein (KK) relics associated with isometries along the internal directions suggests that reheating may not be efficient, and may conflict with BBN and baryogenesis constraints. This talk discusses processes which may accommodate their decay and quantifies their expectant lifetimes, resulting in strong constraints on the parameters of the underlying theory. We also point out several shortcomings of other, recent investigations into the decay mechanisms of the KK relics.

Warped reheating and the possibility of KK relics

(arXiv/0710.1299—accepted by Phys. Rev. D!)

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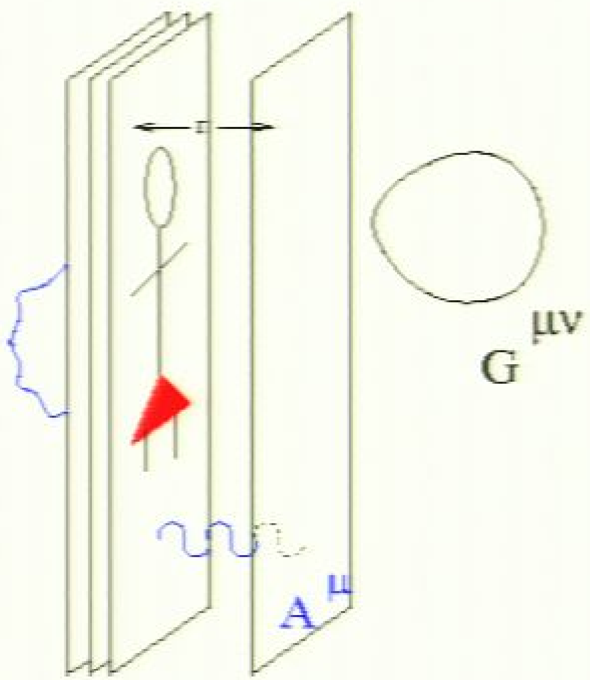
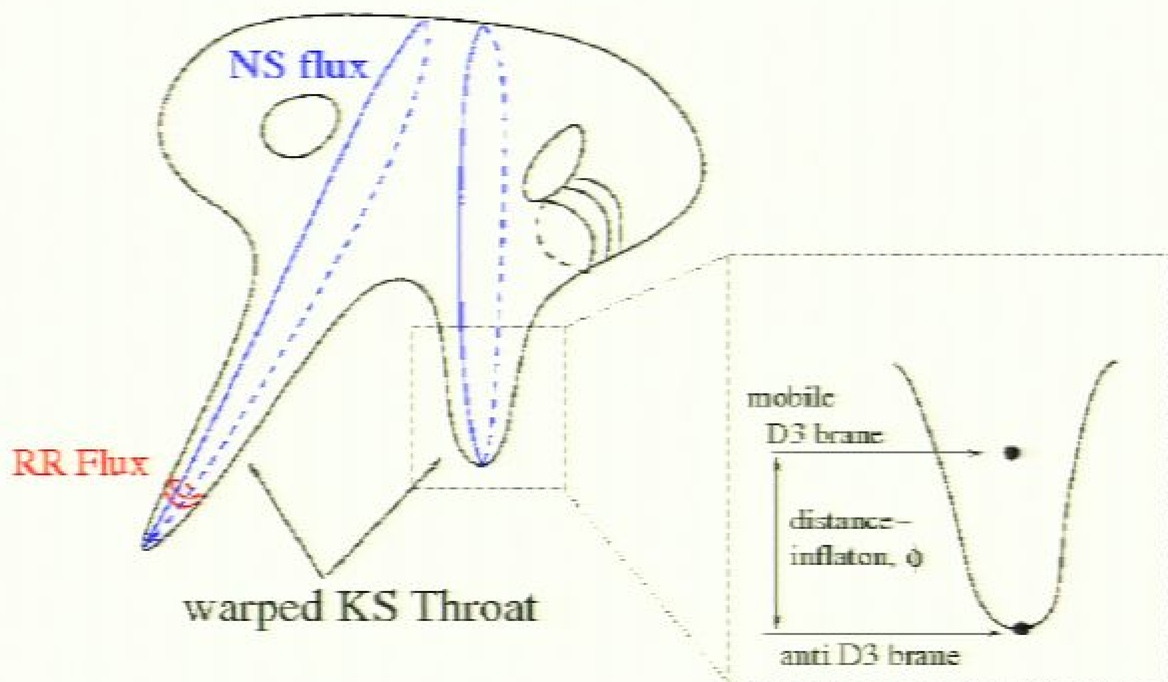
a pictoral introduction Dvali and Tye [arXiv:hep-ph/9812483]

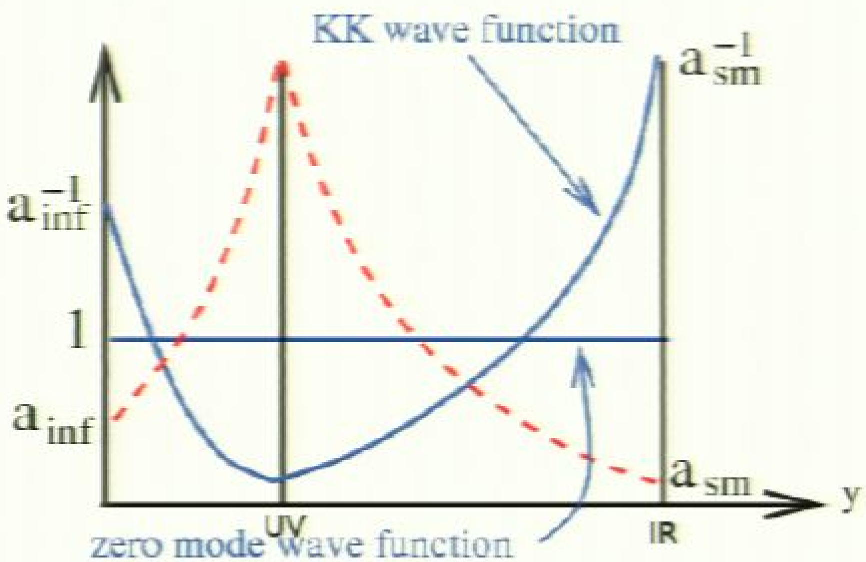




warped benefits

- fluxes stabilize moduli and dilaton [hep-th/0105097]
- helps with η-problem
- explanation of the hierarchy problem [hep-ph/9905221]
- unique signatures:
  - DBI inflation gives large non-gaussianities [arXiv:0704.3426]
  - small r (scalar-to-tensor ratio) for most parameter space [arXiv:0704.0647]
  - creation of cosmic strings with viable string tensions [hep-th/0204074]

scale of physics determined by radial behaviour



arXiv:hep-th/0412040v3 (Barnaby, Burgess, Cline)

massive modes are:

- peaked in the IR
  $R_{\nu,n}(IR) \simeq \sqrt{k}w^{-1}$
- suppressed in the UV
  $R_{\nu,n}(0) \simeq \sqrt{k}w^{1+\nu}$
- gravitons don't feel the warping

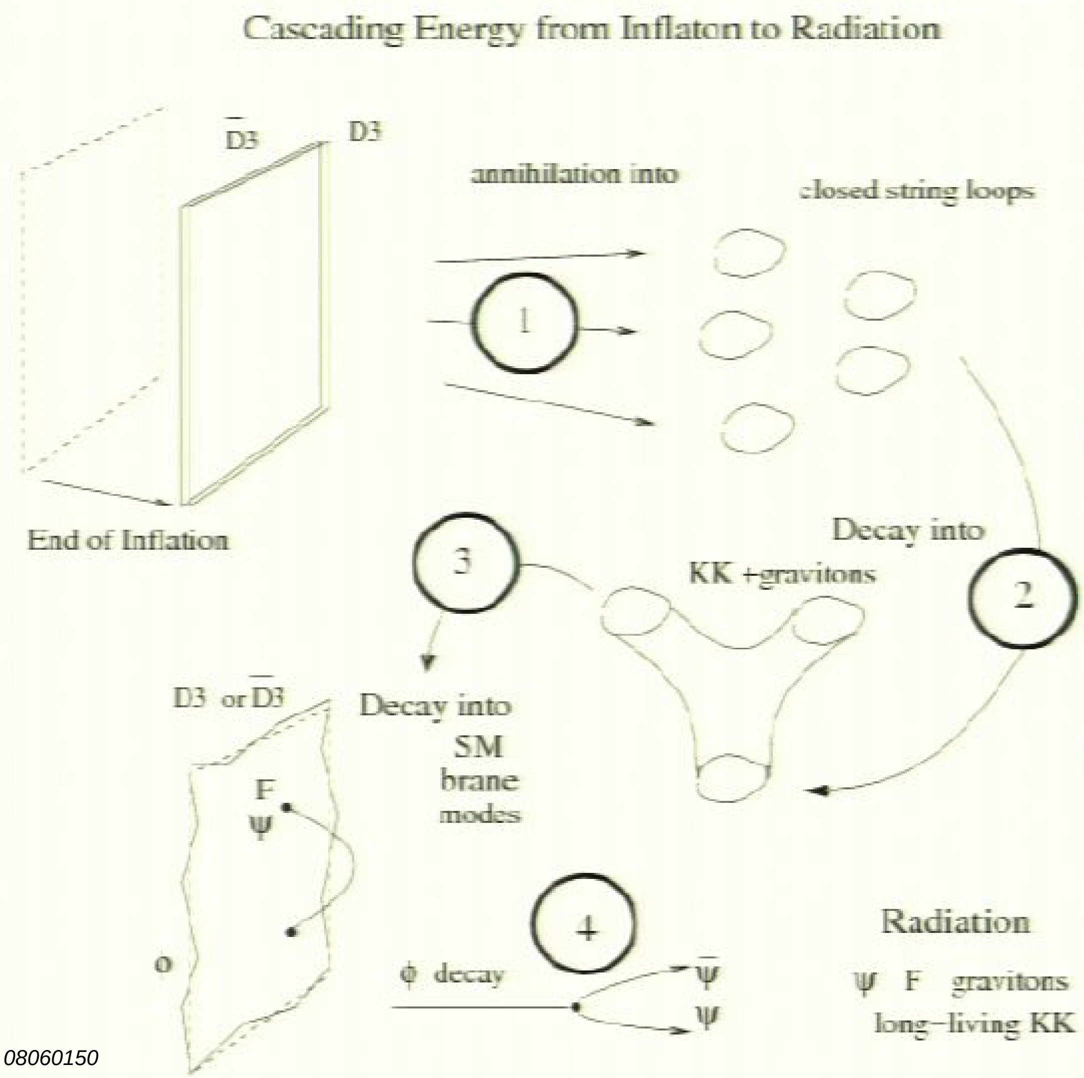
$\Rightarrow$ prefers decay to light KK states (good for BBN)

radial eom:

$$\Box_r R_{\nu,n} - m_{5D}^2 e^{-4kr} R_{\nu,n} = -m_n^2 e^{-2kr} R_{\nu,n}$$

$$R_{\nu,n}(r) = \frac{\sqrt{k}\, we^{2kr}}{J_\nu(x_n)} \left[J_\nu\left(x_n we^{kr}\right) + b_{n\nu} Y_\nu\left(x_n we^{kr}\right)\right],\ \nu = \sqrt{4 + m_{5D}^2}$$

Reheating Kofman and Yi [hep-th/0507257]



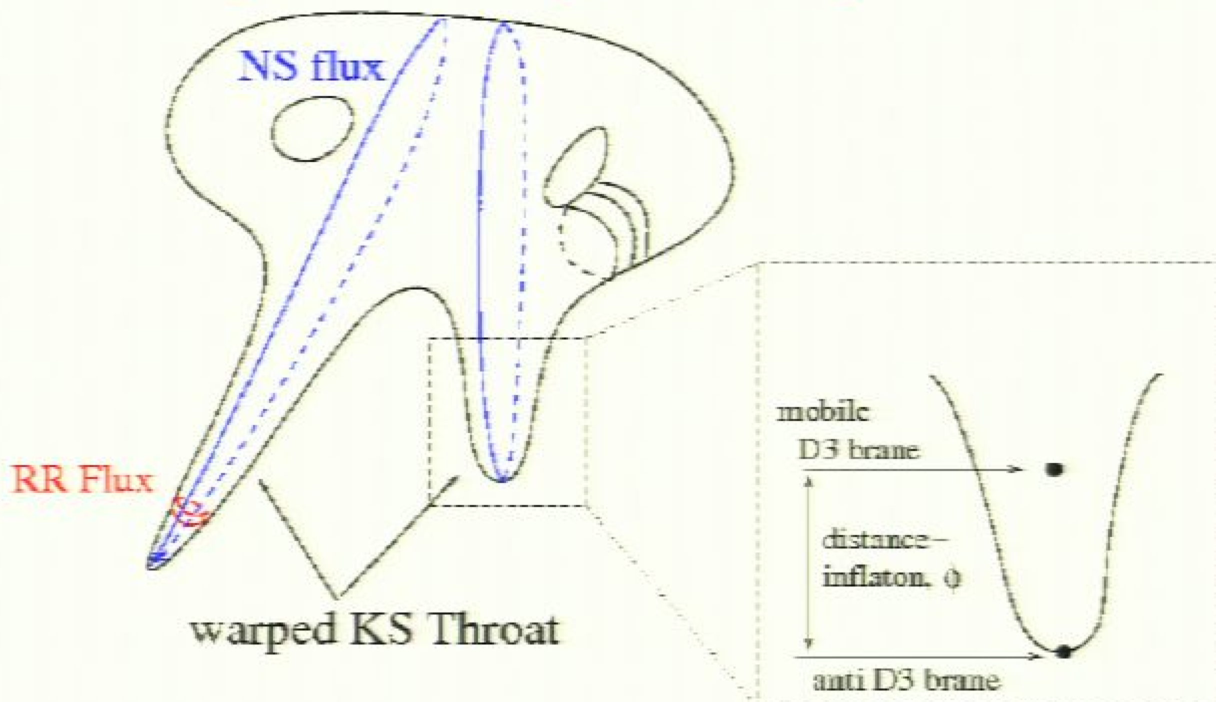
1. tachyonic decay into closed strings
2. effecient thermalization into graviton KK states
3. decay into fluctuations of the SM brane
4. decay into SM particles on the brane

we forgot something...

- KS throat (and, likely, most background solutions) have non-trivial topology $AdS_5 \times \mathcal{M}_5$
- What are the effects of the other internal directions?

  → internal isometries give rise to conserved currents

  → lightest charged state may not decay



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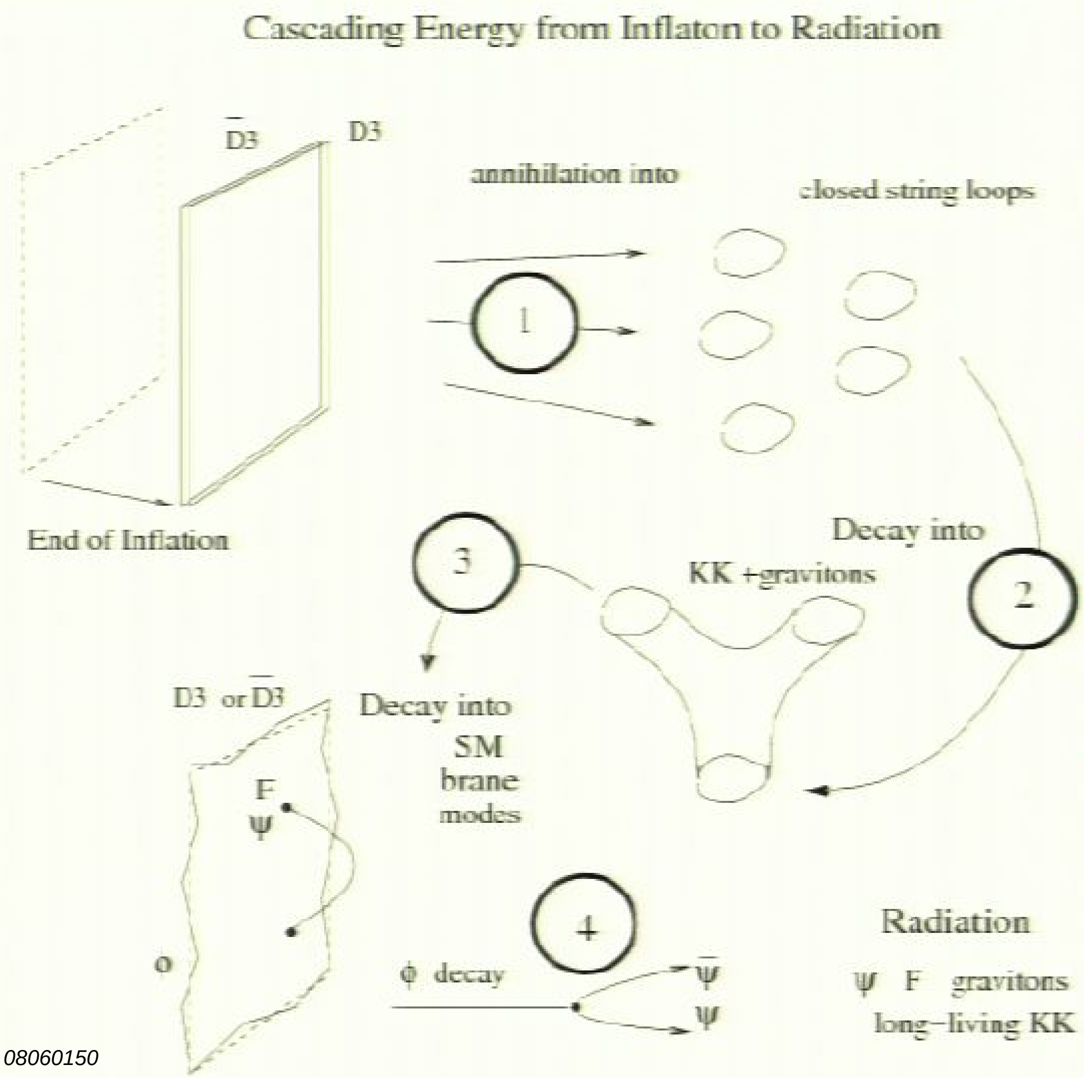

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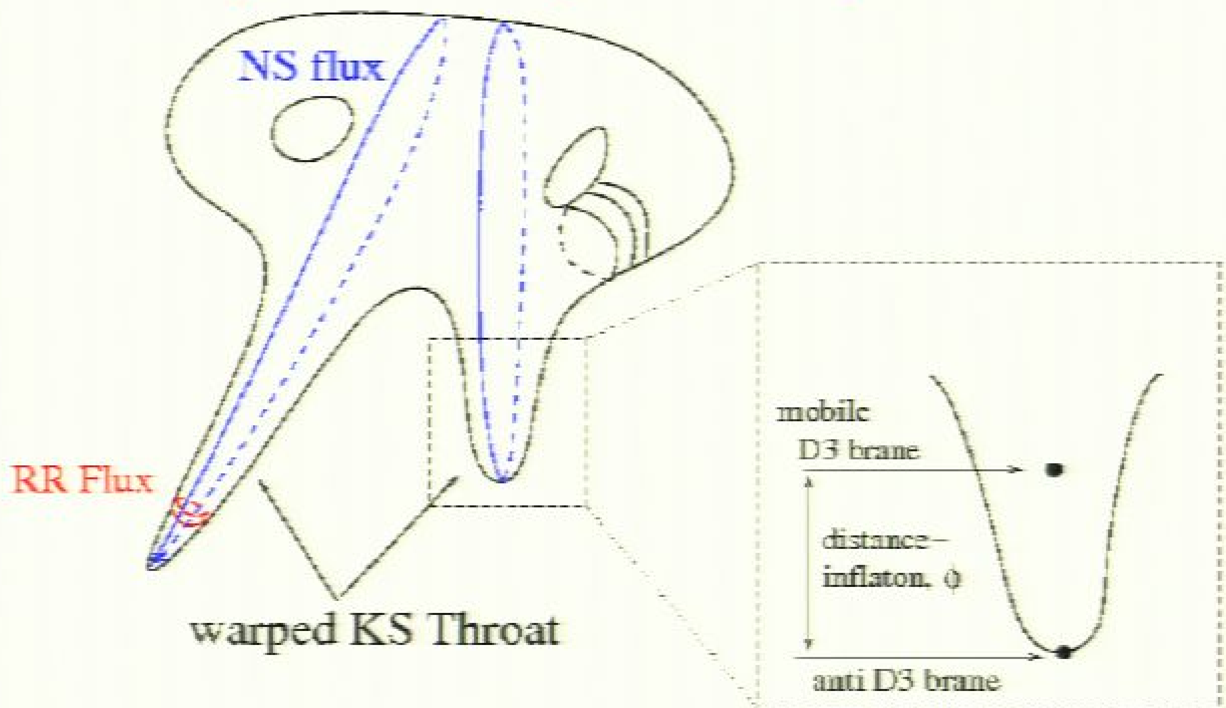

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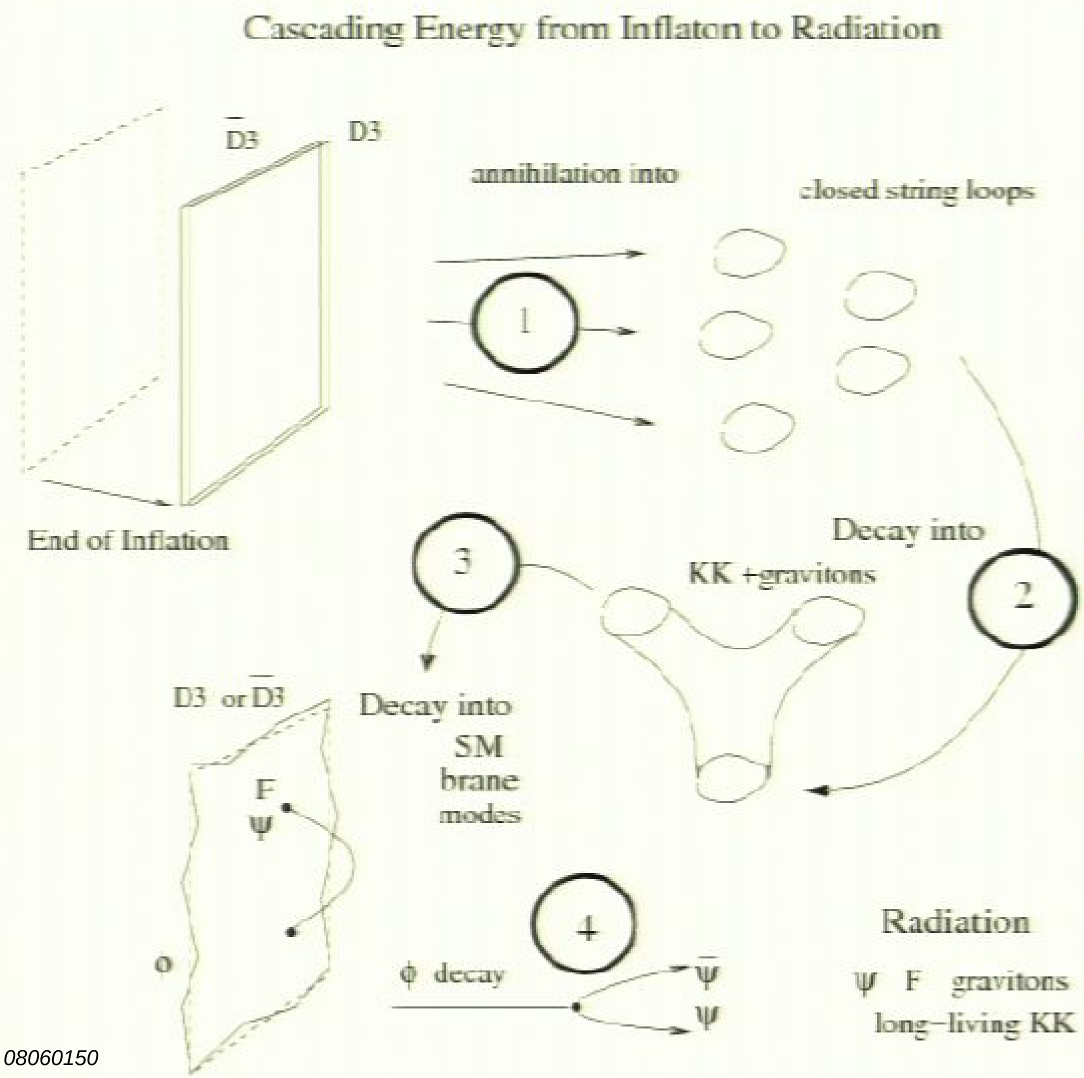

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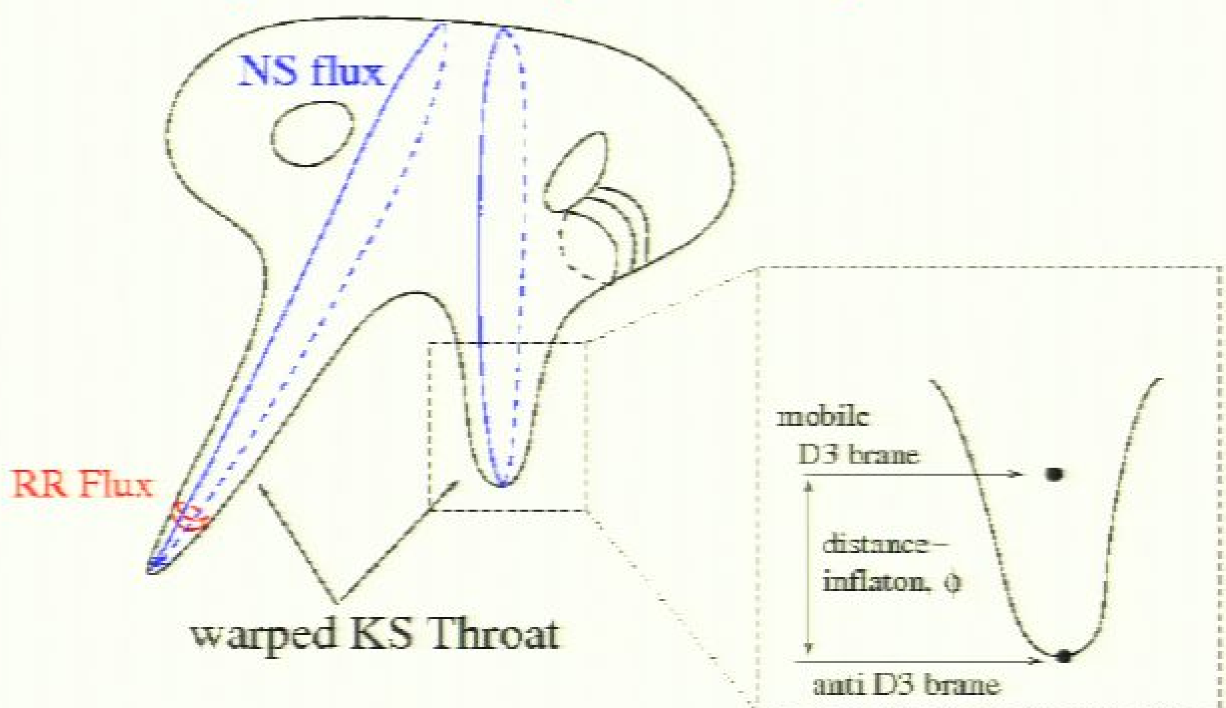
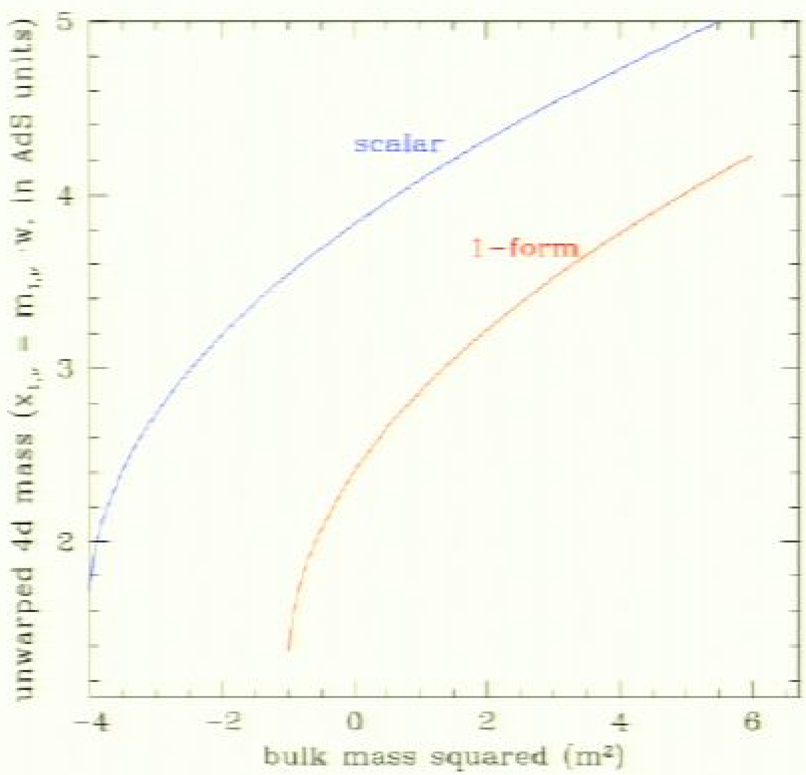


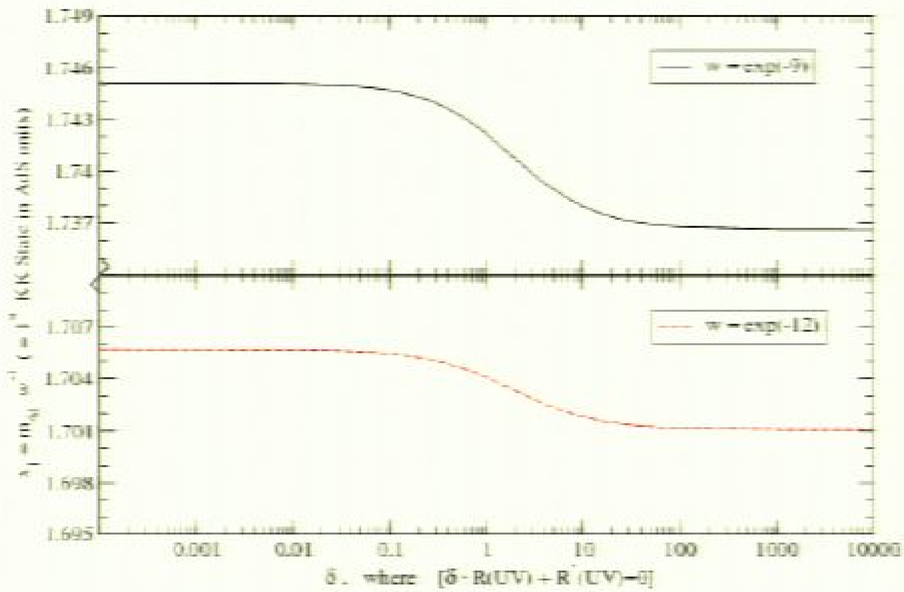
accommodating the decay

1. identify the lightest charged state and its couplings
2. recognize the UV is attached to a CY, and this spoils any isometries in the throat
3. find a UV correction which absorbs the LMCS charge
4. find the strength of this decay/mixing
5. place constraints on the system

identify the LMCS



- LMCS in 5D is LMCS in 4D



- insensitive to UV (and IR) boundary conditions

extension of Goldberger-Wise [hep-th/9907218]

identify the LMCS

Large field content in 10D

$$
\begin{aligned}
S_{IIB} \;=\; & \frac{1}{2\kappa_0^2}\int d^{10}x\sqrt{-G}\left\{e^{-2\phi}\left[R+4(\nabla\phi)^2-\frac{1}{12}\left(H^{(3)}\right)^2\right]\right. \\
& \left. -\frac{1}{12}\left(F^{(3)}+A^{(0)}\wedge H^{(3)}\right)^2-\frac{1}{2}\left(dA^{(0)}\right)^2-\frac{1}{480}\left(F^{(5)}\right)^2\right\} \\
& +\frac{1}{4\kappa_0^2}\int\left(A^{(4)}+\frac{1}{2}B^{(2)}\wedge A^{(2)}\right)\wedge F^{(3)}\wedge H^{(3)}
\end{aligned}
$$

Each 10D field has numerous 5D polarizations, and exists in numerous supermultiplet

Dim	fields					harmoni
10D AdS_5	$h_{\mu\nu}(x,y)$ $H_{\mu\nu}(x)$	$h^a_a(x,y)$ $\pi(x)$	$A_{abcd}(x,y)$ $b(x)$	$B(x,y)$ $B(x)$	$A_{\mu\nu}(x,y)$ $a_{\mu\nu}(x)$	$Y(y)$
10D AdS_5	$h_{a\mu}(x,y)$ $B_\mu(x)$	$A_{\mu abc}(x,y)$ $\phi_\mu(x)$	$A_{\mu a}(x,y)$ $a_\mu(x)$			$Y_a(y)$
10D AdS_5	$A_{\mu\nu ab}(x,y)$ $b^\pm_{\mu\nu}$	$A_{ab}(x,y)$ $a(x)$				$Y_{[ab]}(y$
10D AdS_5	$h_{ab}(x,y)$ $\phi(x)$					$Y_{(ab)}(x,$

Ceresole, Dall'Agata, D'Auria: **KK Spectroscopy of Type IIB Supergravity on** $AdS_5 \times T^{1,1}$ **[arXiv:hep-th/9907216]**

a closer look at the $\mathrm{T}^{1,1}$ LMCS

- $A^{(4)}$ polarized along the $T^{1,1}$

$$A_{abcd}(x,y) = b(x)\epsilon_{abcd}{}^{e}\mathcal{D}_e Y_{(1,0,0)}(y)$$

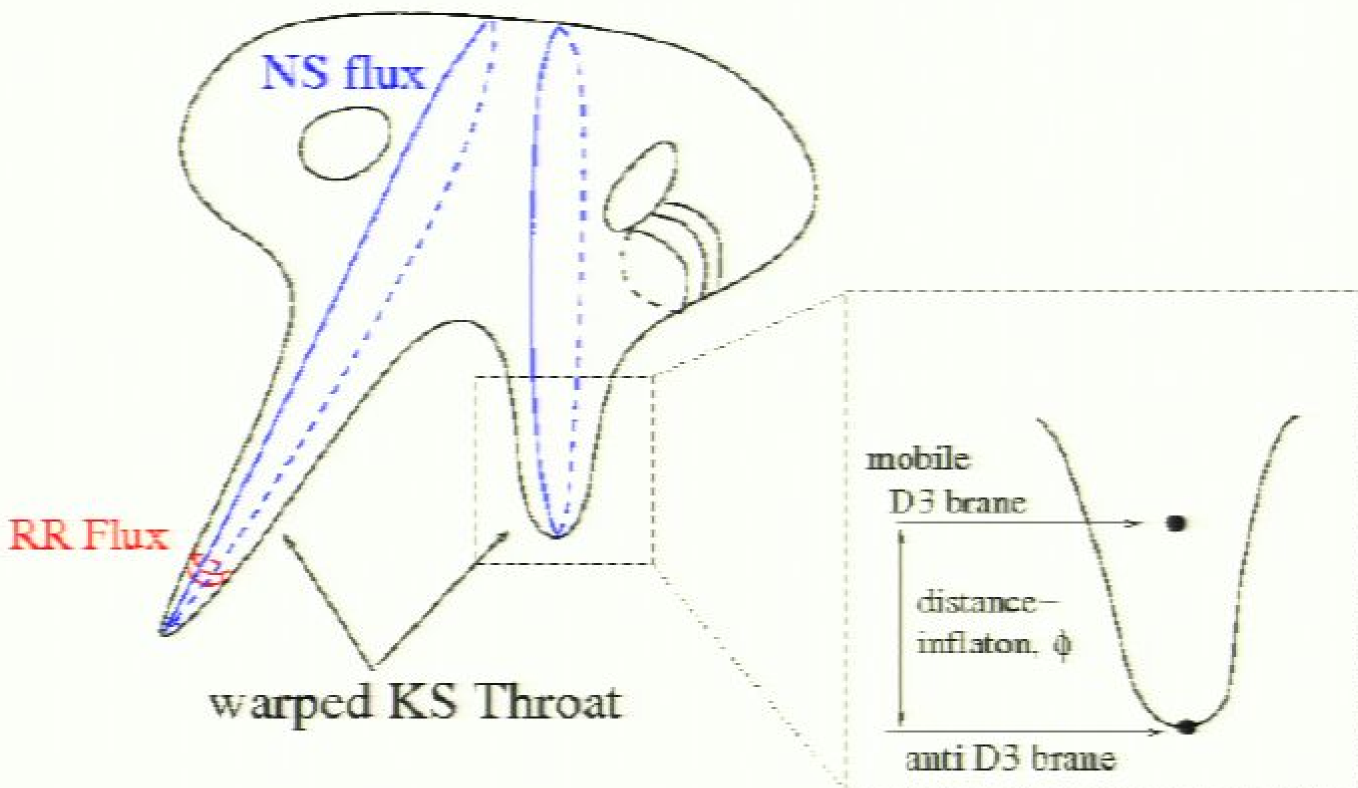
- $SU(2) \times SU(2) \times U(1)$ charge $(1,0,0)$ or $(0,1,0)$
- has $m^2_{5d} = -4$ (the AdS bound)
- possible interactions:

$$S_{int} = \frac{1}{2\kappa_0^2}\int d^{10}x\sqrt{-G}\left\{-\frac{1}{480}\left(F^{(5)}\right)^2\right\} + \frac{1}{4\kappa_0^2}\int A^{(4)} \wedge F^{(3)} \wedge H^{(3)}$$

- has kinetic term and Chern-Simons term interactions
  but $F^{(3)}$ and $H^{(3)}$ are always massive in $T^{(1,1)}$
- does **not** lay in the gravity sector

[2] UV deformations

- $\nexists$ direct decay of LMCS in the KS throat but throat is attached to a CY



deformations characterized by a UV source

- introduce a source: $S_{IIB} \rightarrow S_{IIB} + \sum_{\{\nu\}} S_{\{\nu\}}\,, \qquad \{\nu\} \in \mathrm{T}^{1,1}$

$$\text{e.g.} \qquad S_{\{\nu\}}(A^{(4)}) \;=\; \int d^{10}x\sqrt{-G}\, \underbrace{S^{abcd}_{\{\nu\}}}_{\text{source}} \underbrace{A_{abcd}}_{\text{field}}$$

- gives a particular solution to the radial eom

$$\Box_r R_{0,\{\nu\}} - m^2_{5D} e^{-4kr} R_{0,\{\nu\}} \;=\; \tilde{\phi}\delta(r)$$

$$\Rightarrow R_{0,\{\nu\}}(r) \;\cong\; \sqrt{k}\tilde{\phi}e^{(2-\nu)kr} = \sqrt{k}\,\tilde{\phi}\, e^{(4-\Delta)kr}$$

$\Rightarrow$ need $\Delta > 4$ (irrelevant operators)

consistent with Aharony, Antebi, and Berkooz [hep-th/0508080]

Large number of possible interactions from 4D point of view

$$S_{IIB}(A_{abcd}) = \frac{-g_s^2 M^2}{480} \int d^{10}x \sqrt{-G}\, G^{A_1 B_1} G^{a_2 B_2} G^{a_3 B_3} G^{a_4 B_4} G^{a_5 B_5} \cdot \partial_{A_1} \underbrace{A_{a_2 a_3 a_4 a_5}}_{LmCS} \partial_{[B_1} A_{B_2 B_3 B_4 B_5]}$$

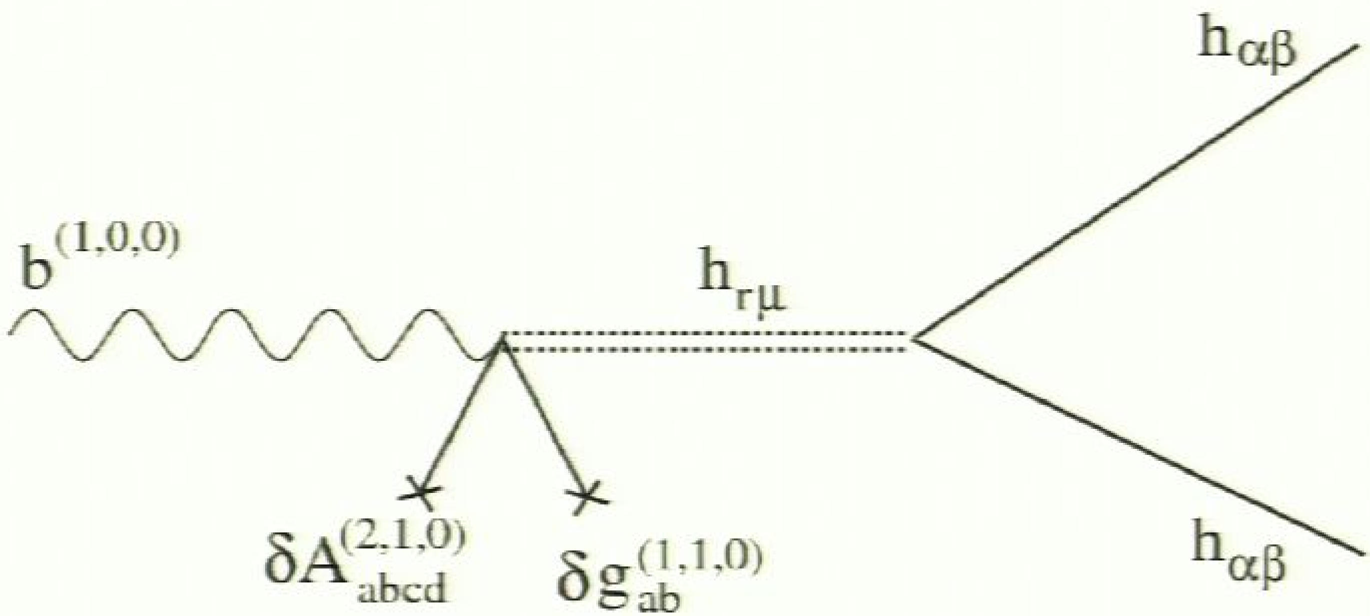
Choices aided by:

- decay products should be massless
- background correction should
  - not wreck 4d Lorentz invariance
  - (may want to) preserve SUSY
  - correspond to an irrelevant operator ($\Delta > 4$)
- vertex should form a group singlet under the internal isometries

a viable route (breaks SUSY)

LMCS mixing into massless graviphoton, accommodated by background corrections to the 4-form and graviton

$$\mathcal{L}_{\rm decay} = \int dr\, d^5y \sqrt{g_6}\, \underbrace{\delta g^{aa'}_{(1,1,0)}}_{corr.}\, h^{r\mu}\, \partial_r \underbrace{A^{(2,1,0)}_{abcd}}_{corr.}\, \partial_\mu \underbrace{A^{(1,0,0)}_{a'b'c'd'}}_{LMCS}\, g^{bb'} g^{cc'} g^{dd'}$$



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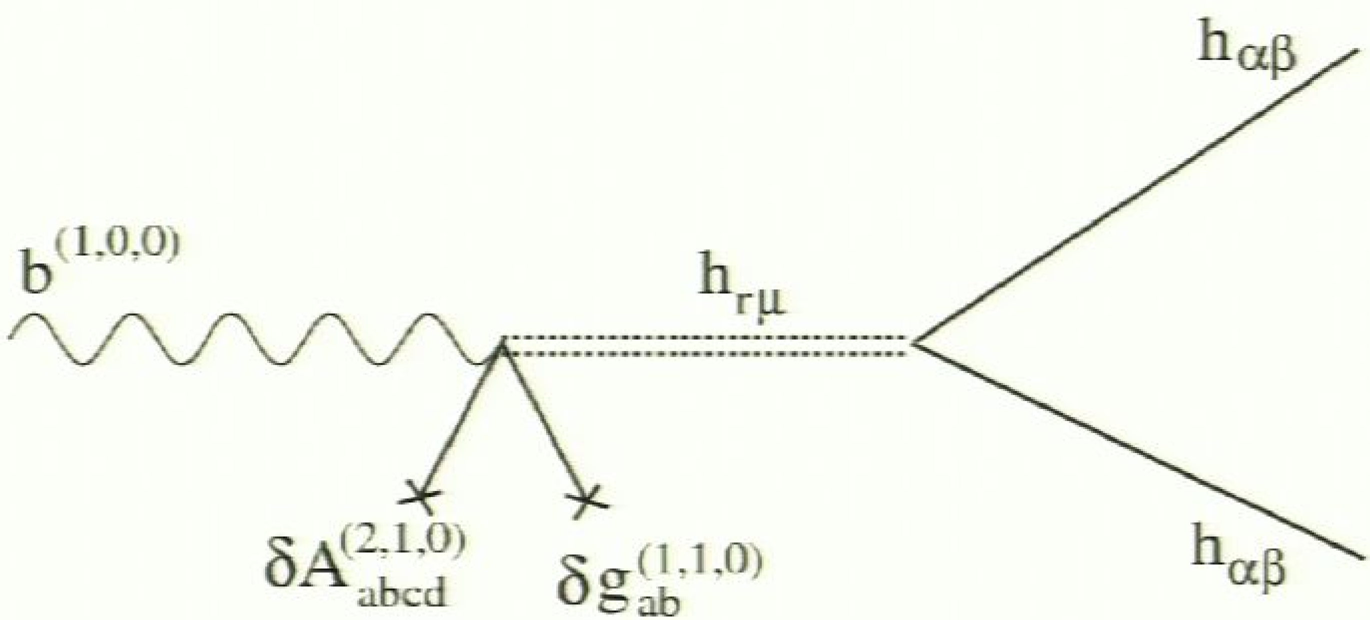
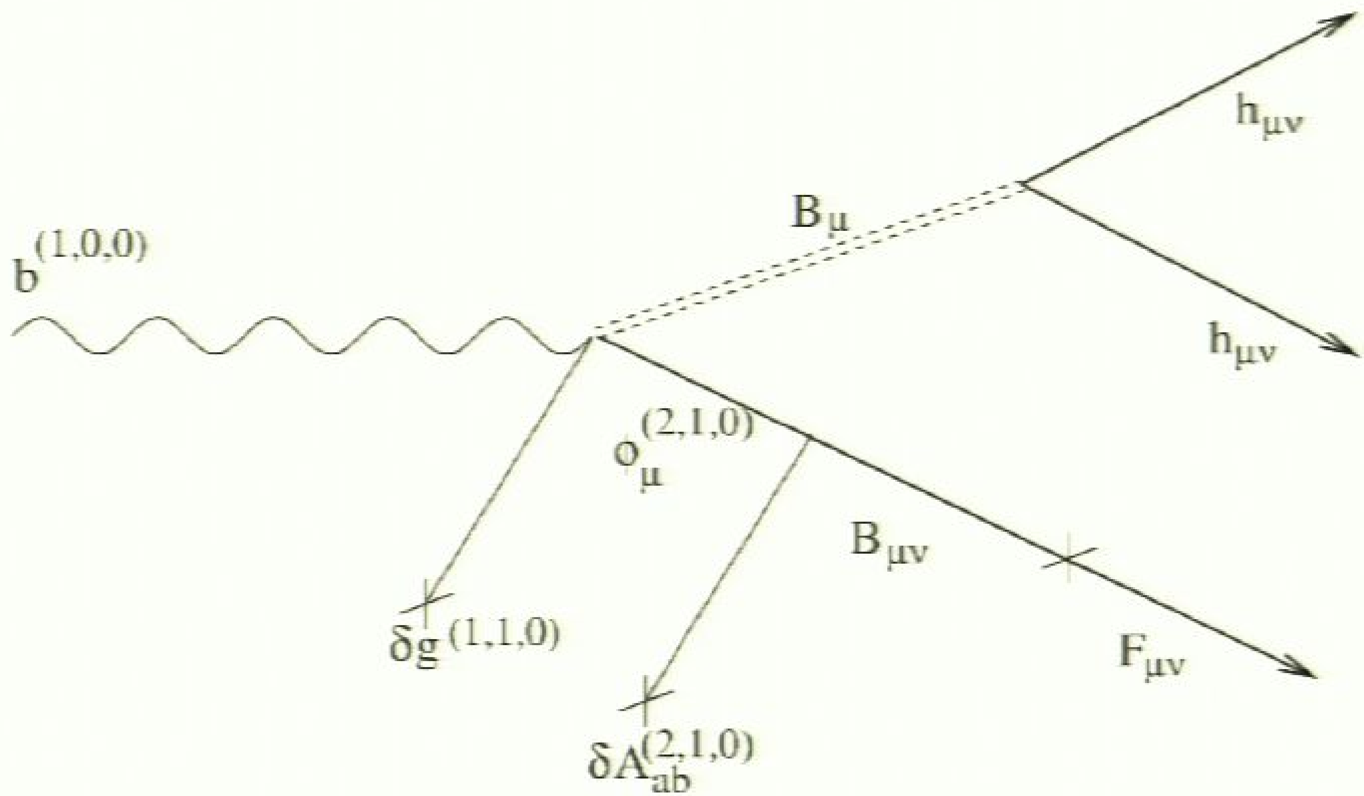


a viable route (preserves SUSY)

Can find SUSY-preserving routes,
but most (all?) are subdominant processes



scale of susy-breaking

$$\mathcal{L}_{\text{decay}} = \int dr\, d^5y \sqrt{g_6}\, \underbrace{\delta g^{aa'}_{(1,1,0)}}_{corr.}\, h^{\mu r}\, \partial_r \underbrace{A^{(2,1,0)}_{abcd}}_{corr.}\, \partial_\mu \underbrace{A^{(1,0,0)}_{a'b'c'd'}}_{LMCS}\, g^{bb'} g^{cc'} g^{dd'}$$

• Decay in the $T^{1,1}$ background accommodated by SUSY-breaking operator

$$\Gamma \sim w^{3.4} \frac{M^2_{3/2} M_s}{M_p^2}$$

$$\Gamma > \Gamma_{BBN} \quad \Rightarrow \quad M_{3/2} > 100 w^{-1.7} \text{GeV} \simeq 10^8 \text{GeV}$$

- Decay not a problem provided SUSY broken at a high scale
  - † consistent with Kallosh and Linde (hep-th/0411011): $m_{3/2} > 10^{10}$GeV
  - † relaxes observational constraints on r (scalar-to-tensor ratio) (Kallosh and Linde hep-th/0704.0647)

general backgrounds

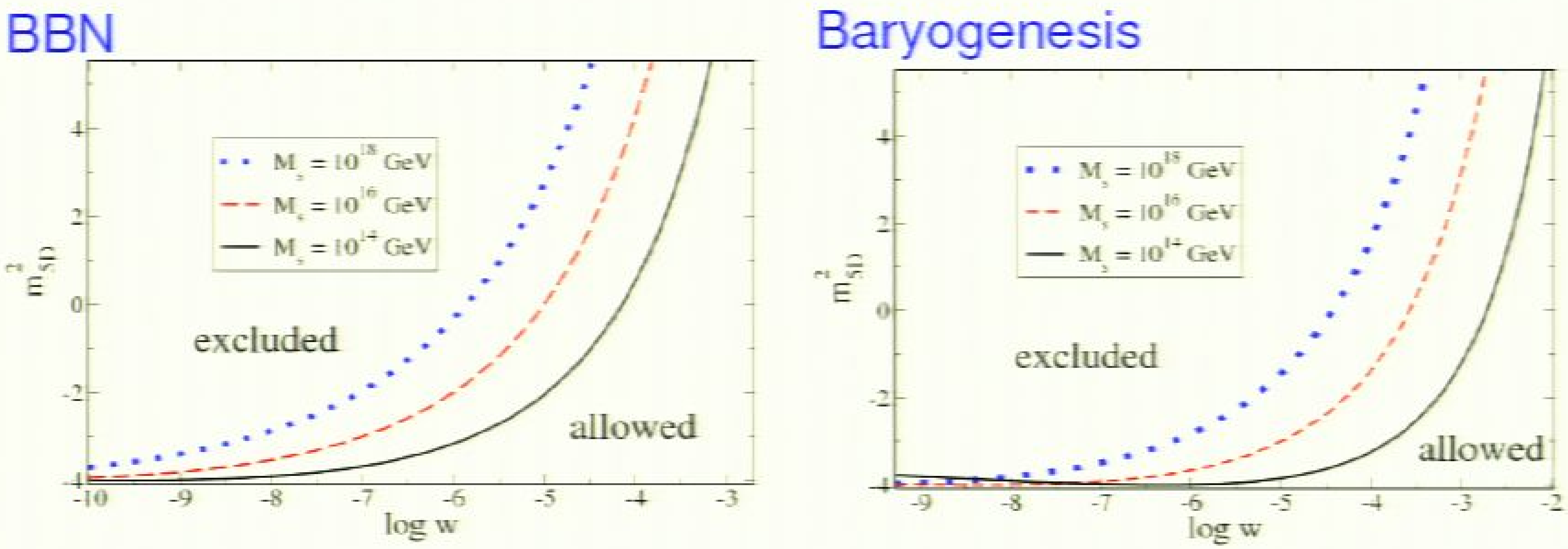
Decay determined by UV behaviour of LMCS, not IR behaviour of source

$$\Gamma \simeq \frac{M_s^3}{M_p^2} w^{2\nu+3}, \nu = \sqrt{4 + m_{5D}^2}, \quad \text{scalar LMCS}$$

- decay of the relic before Baryogenesis/BBN gives constraint

$$\nu \leq \left[\frac{\log\left(M_p T_{BBN}^2 / M_s^3\right)}{2\log(w)} - \frac{3}{2} \right]$$

constrain warping



summarizing/random thoughts

- reheating in string theory restricts phenomenological wiggle room
- reheating provides unique constraints on the parameters of the theory, and seems non-trivial
- look at other backgrounds (e.g. $T^{p,q}$ and $Y^{p,q}$)
- more details can be found in arXiv:0710.1299