Title: Energy transfer in warped string compactifications and warped Kaluza-Klein modes as a dark matter candidate

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Abstract: Strongly warped regions, or throats, are a common feature of string theory compactifications. In the early, hot universe, energy will be transferred between these throats and between throats and the standard model. Using the gauge-gravity duality, we calculate the rate of this energy transfer. Due to the warping, the resulting decay rate of throat-localized Kaluza-Klein states to other throats or the standard model is strongly suppressed. If their lifetime is longer than the current age of the universe, these states are an interesting dark matter candidate. We discuss a scenario along these lines.

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Based on wo
with A. Hebecke
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Introduction: Throats from flux

- We consider type IIB string theory. Lives in 10 spacetime dimensions.
- The 6 extra dimensions are thought to be compactified.
- Type IIB string theory has form fields (generalizations of U(1) gauge field) which can carry energy density or flux.
- Backreaction of flux on geometry can create strongly warped regions, so-called throats.

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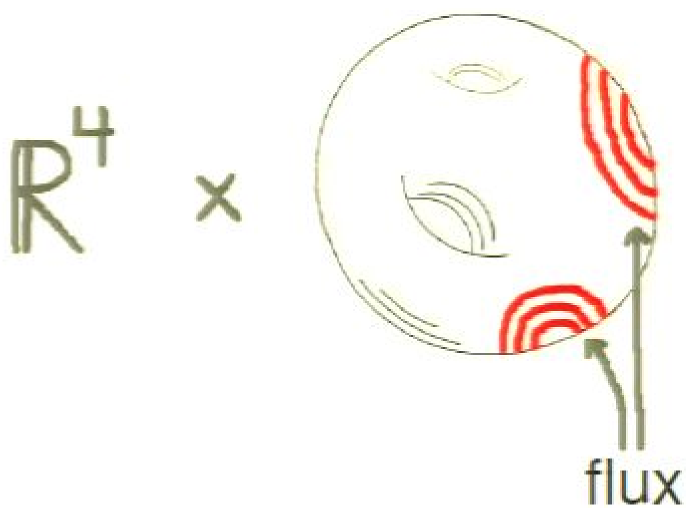

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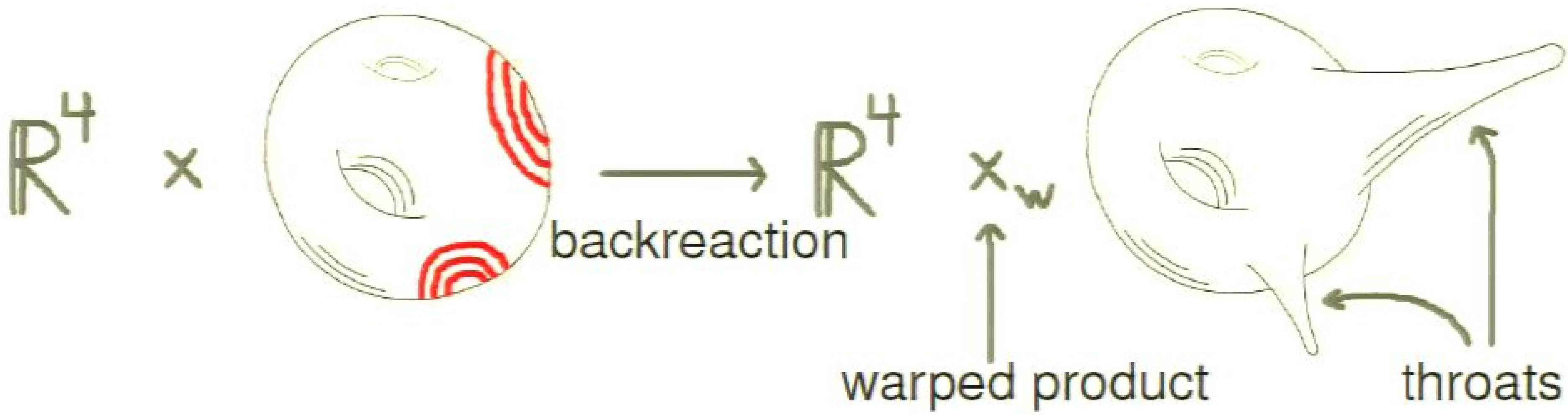
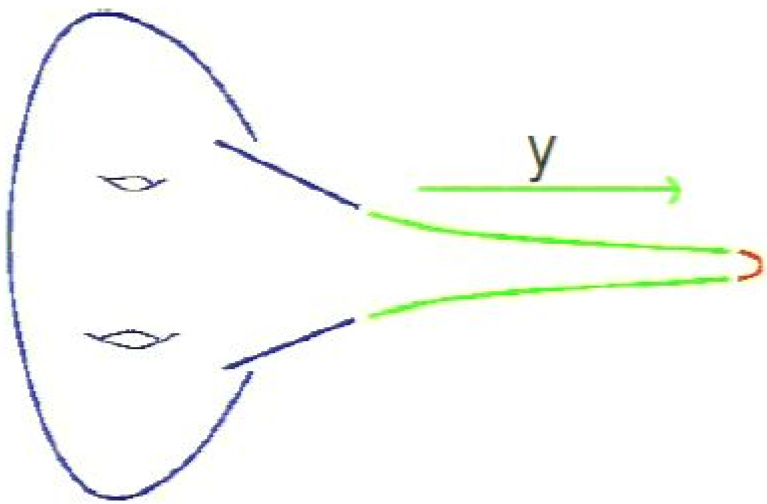


Introduction: Throats as RS models



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$$ds^2 = e^{-2\pi y/R}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2 + .$$

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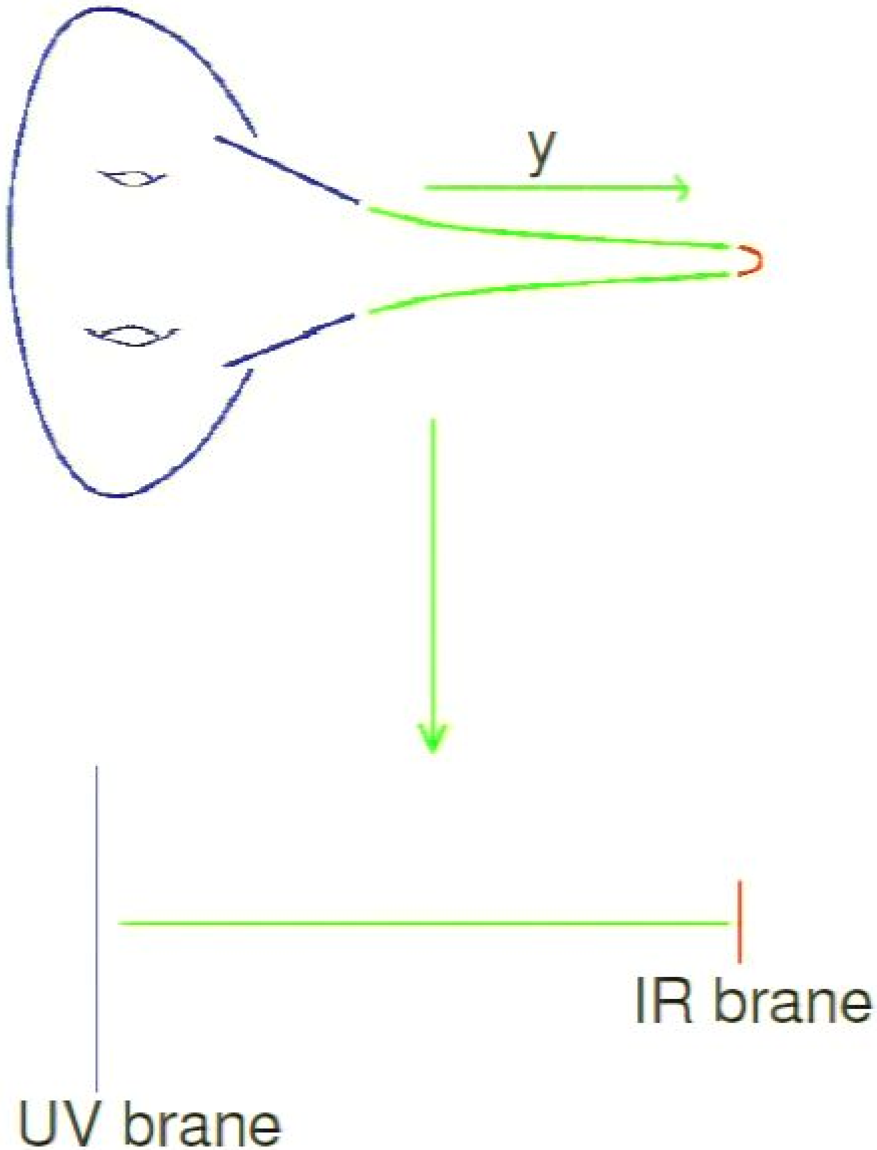

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$\Rightarrow$ Throats are string realizations of the Randall-Sundrum model.

MOTIVATION: HEATED THROATS

- Throats are believed to be a common feature in the landscape of string theory vacua [Hebecker,March-Russell].
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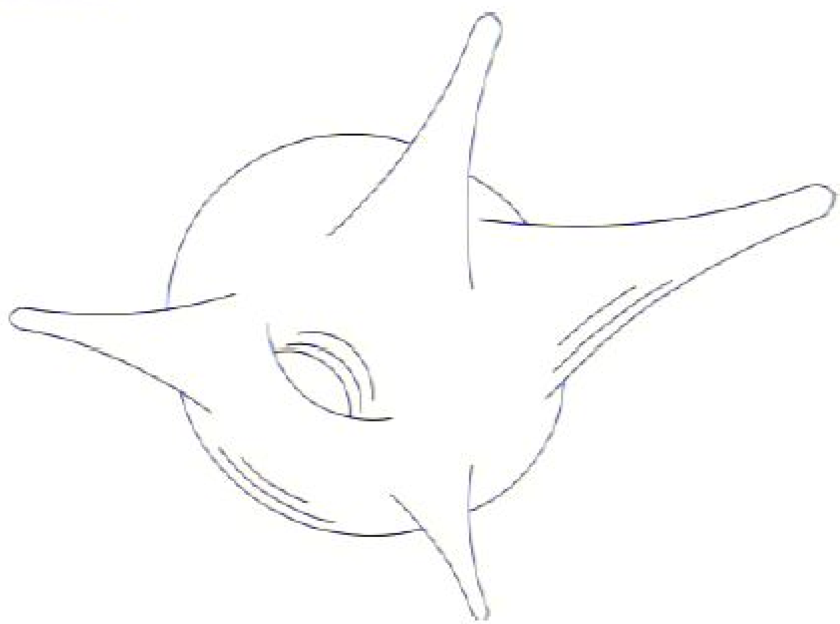

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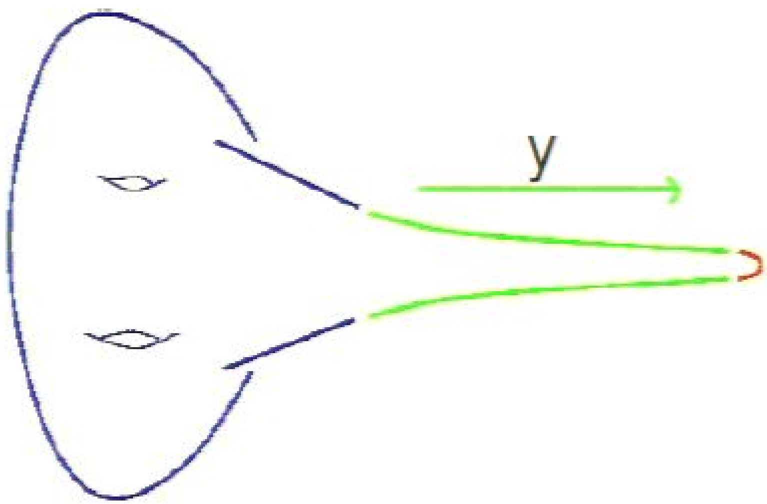

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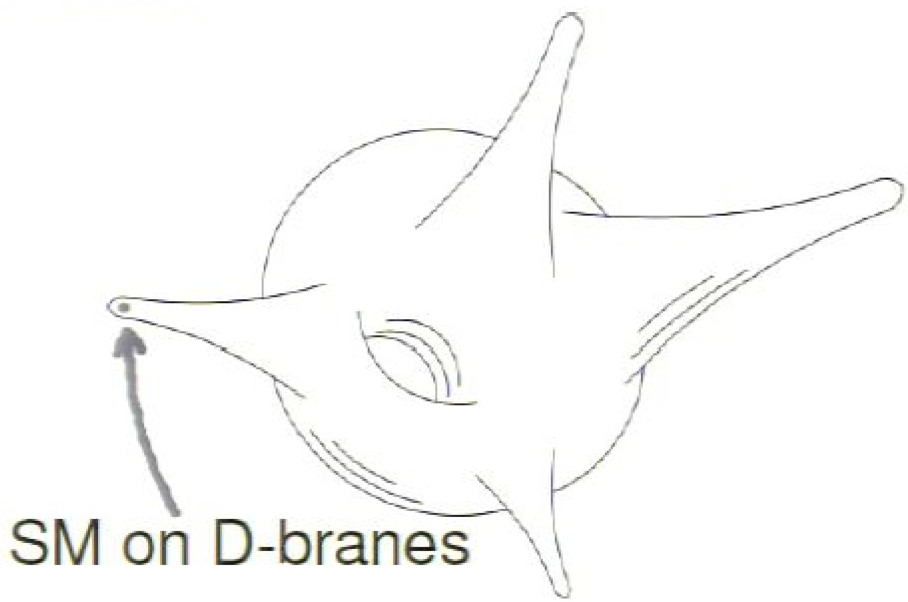

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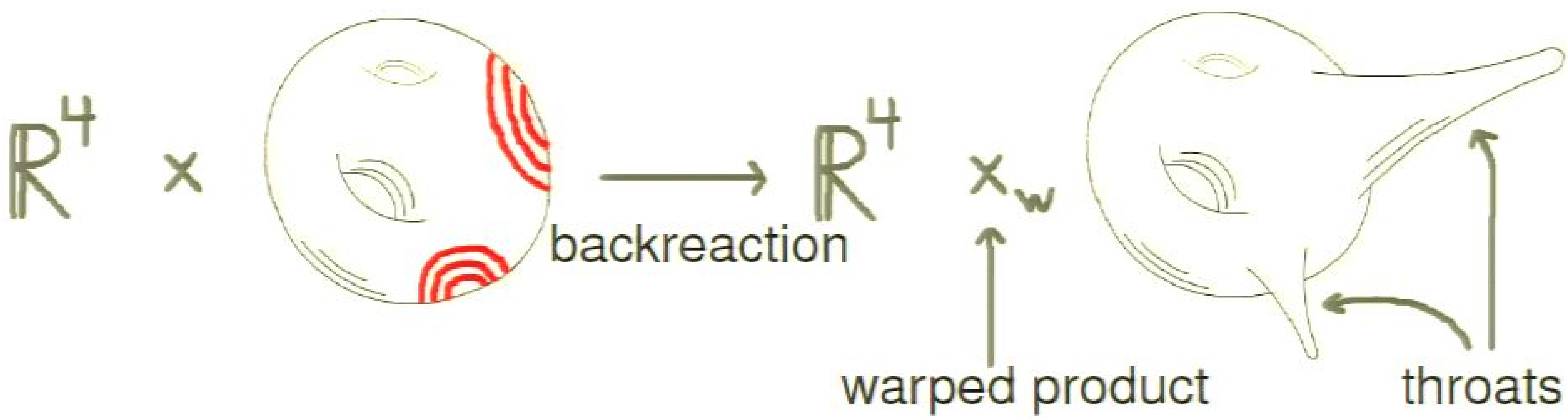

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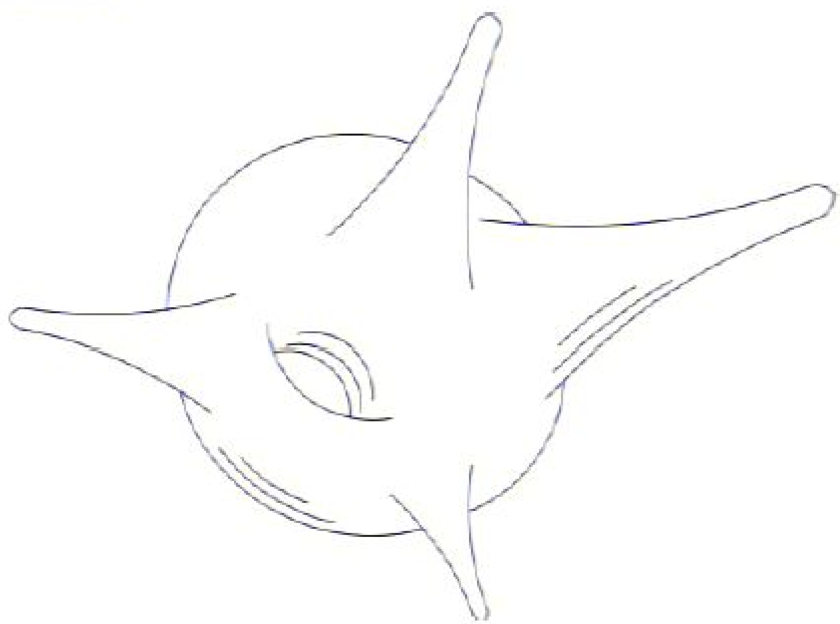

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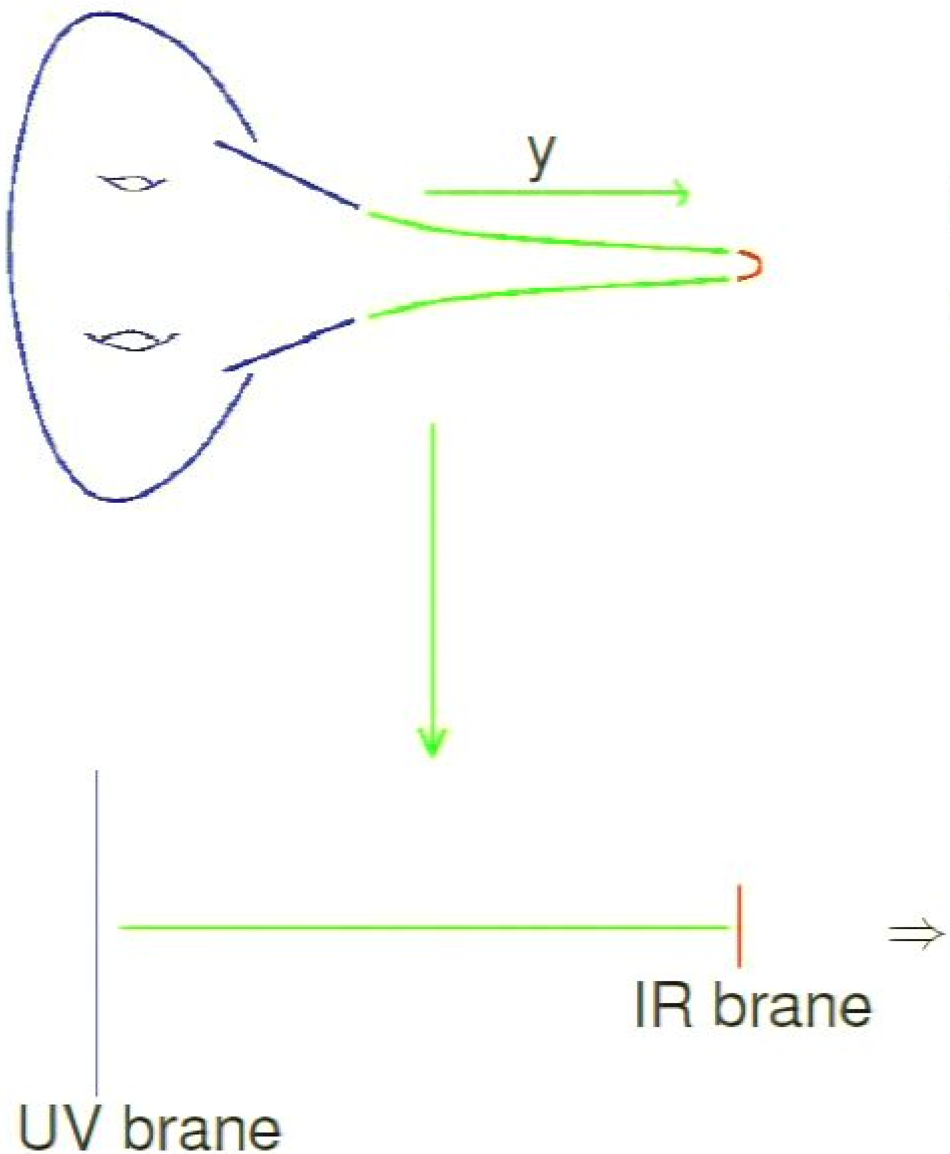

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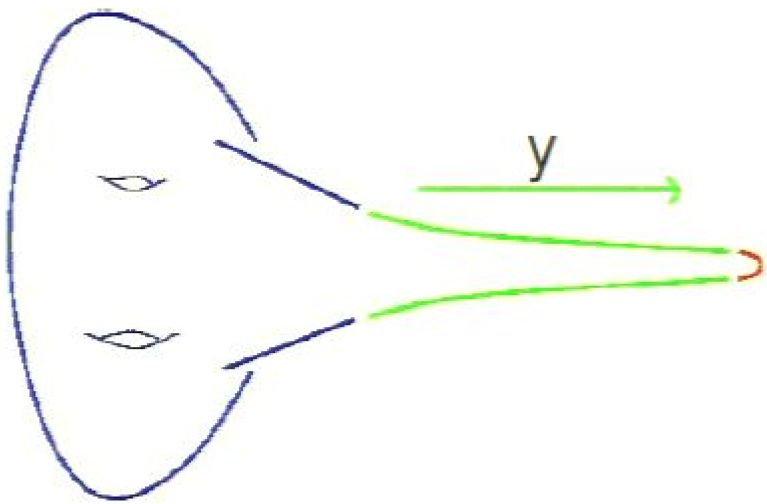

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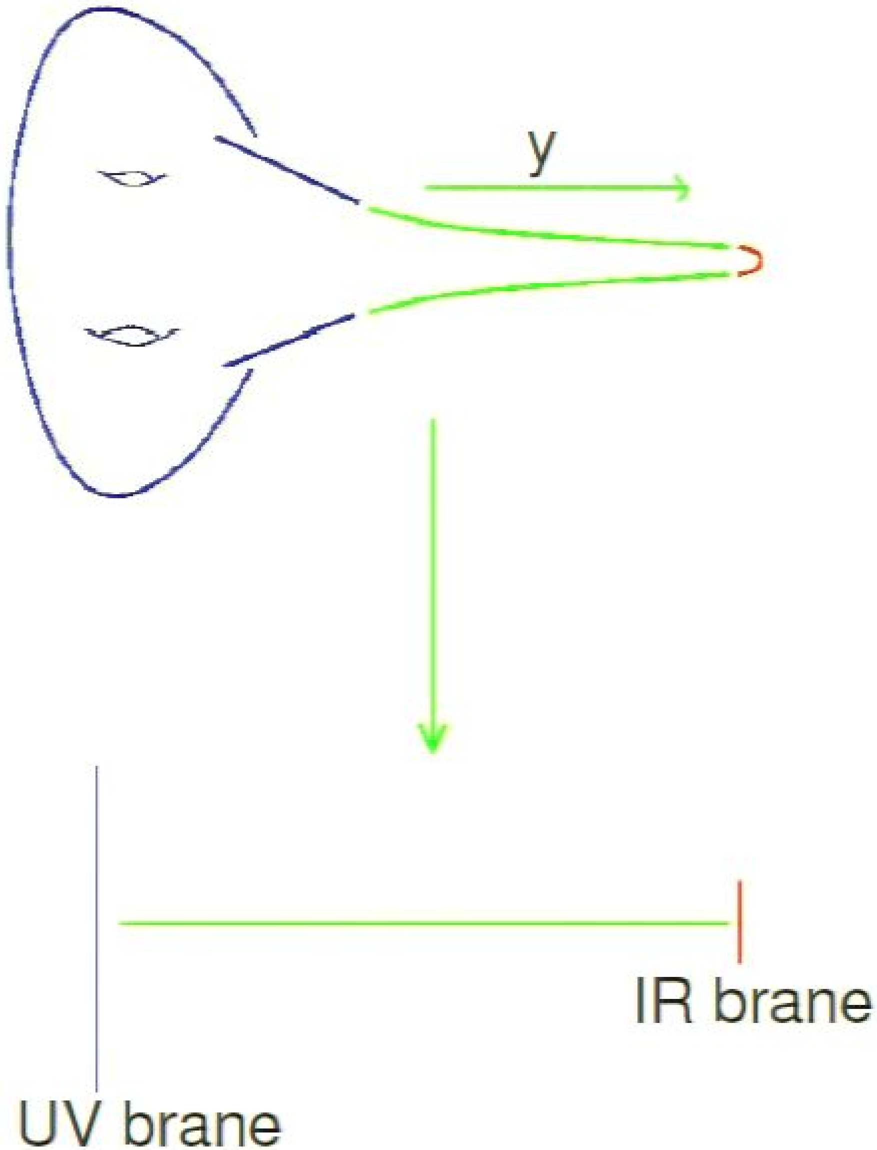

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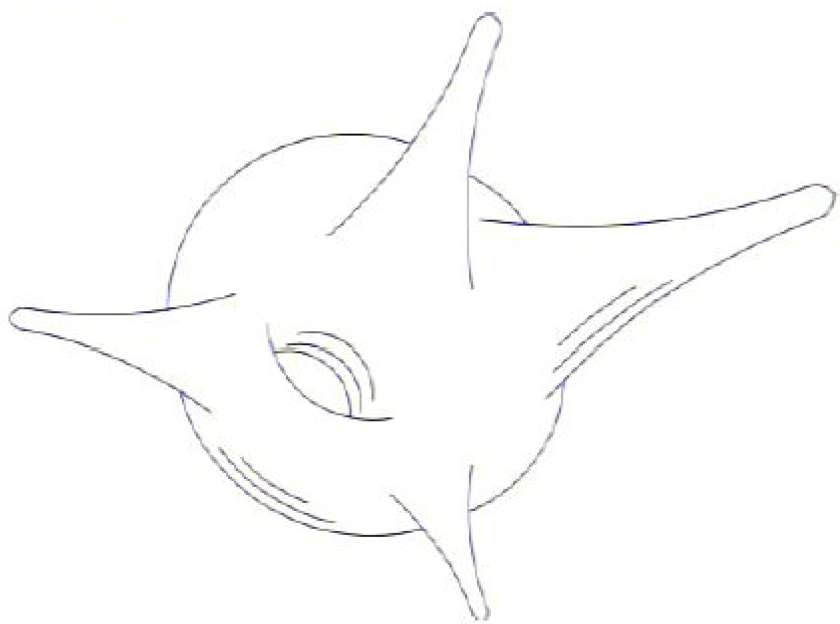

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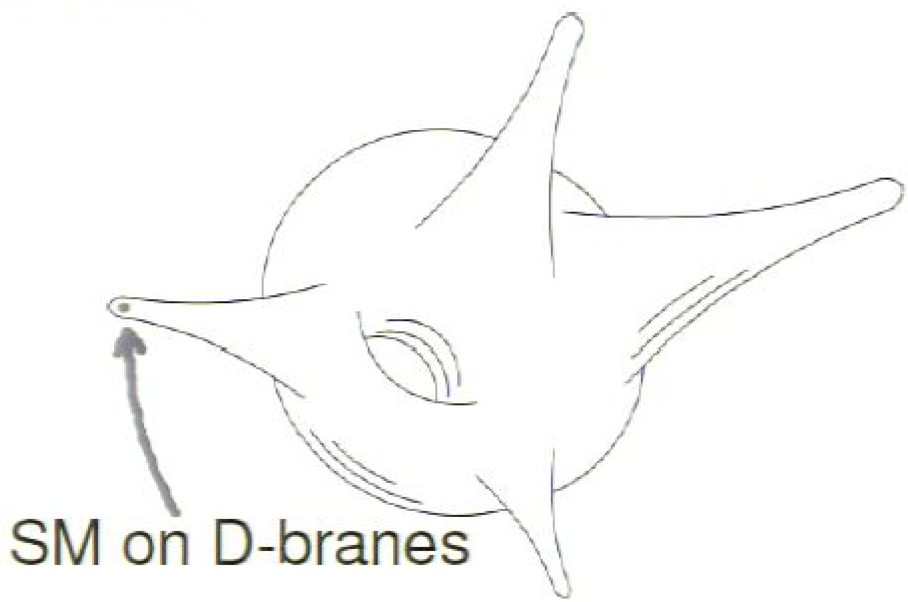

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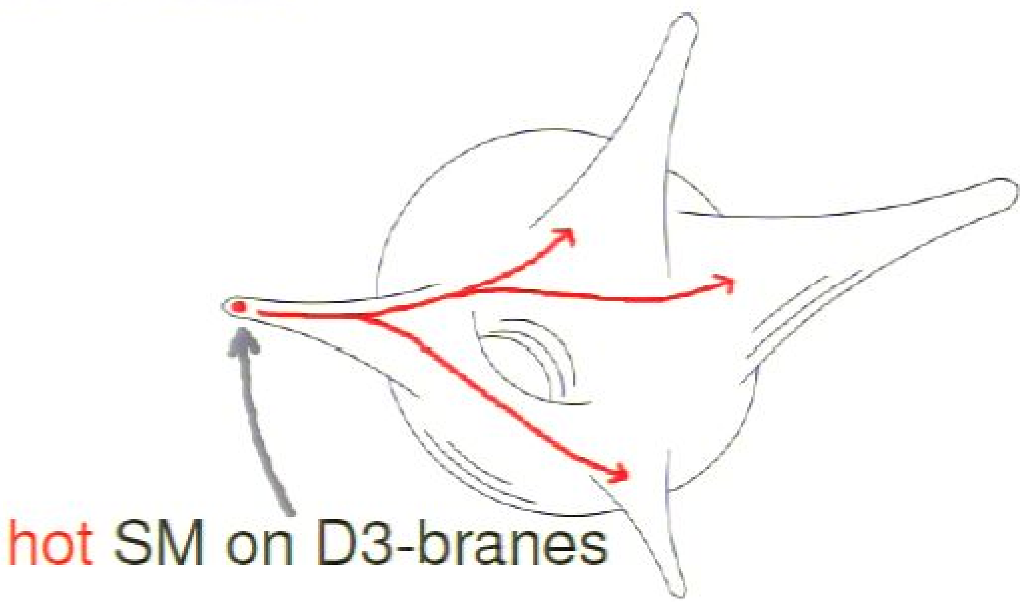

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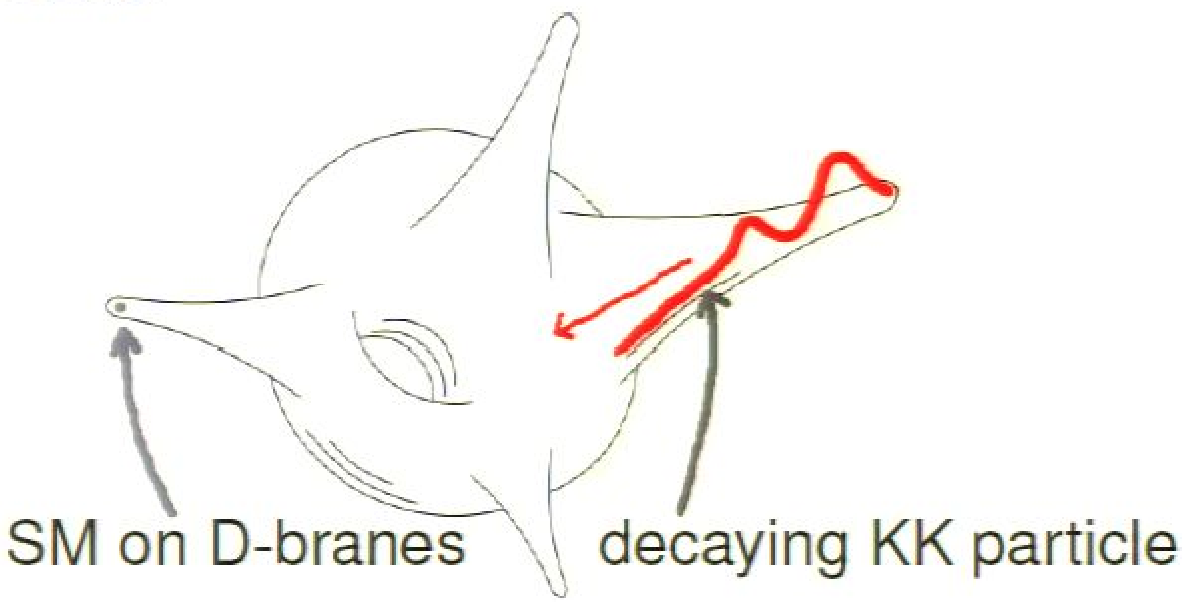

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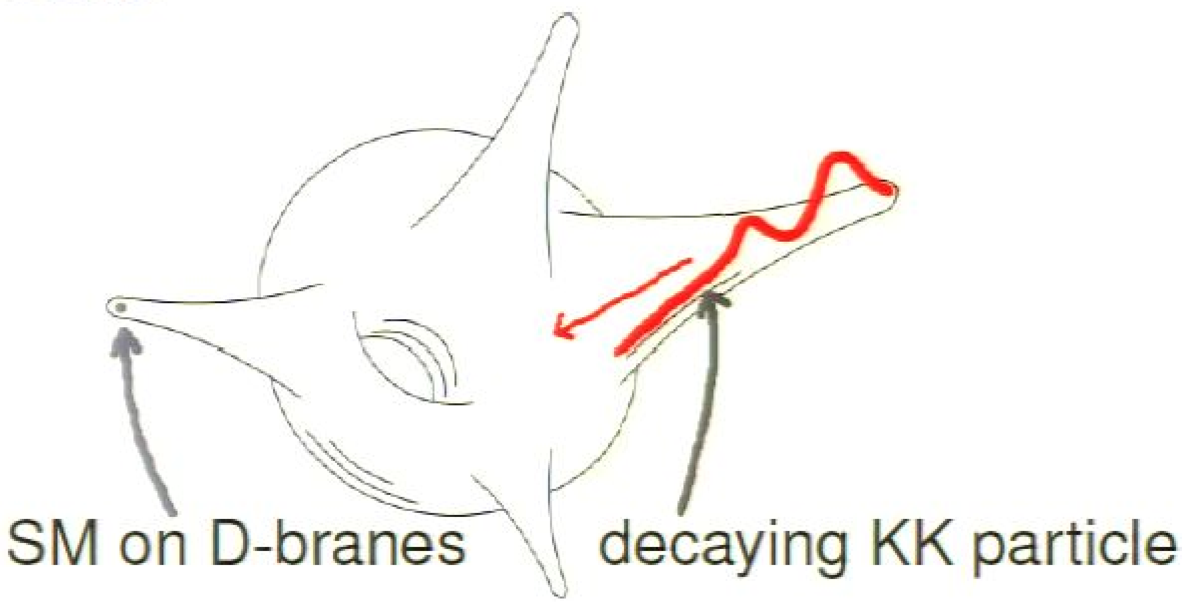

Outline of the talk

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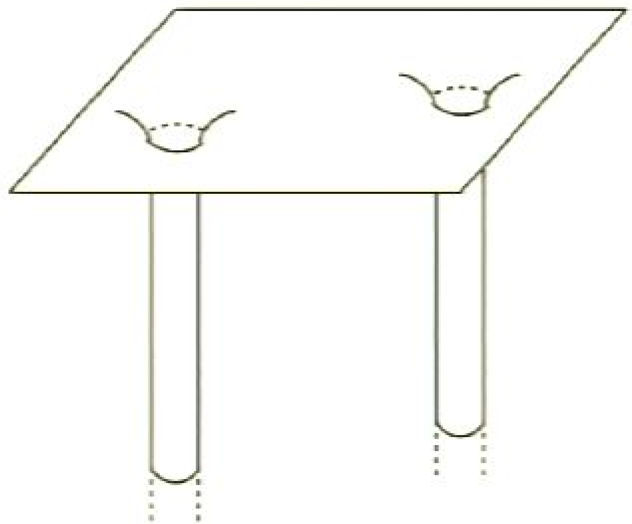
3. Dark Matter in a throat: Decay

Heat transfer rate



- We consider two $AdS_5 \times S^5$ throats embedded in a 6d torus.
- Heat transfer rate determined by transition probability of particles between the two throats.
- Problem turns out to be a multi-dimensional tunneling problem. $\Rightarrow$ Difficult to solve.
- Way out via AdS/CFT duality: String theory on $AdS_5 \times S^5$ is dual to $\mathcal{N} = 4$ U(N) gauge theory realized on stack of D3-branes.

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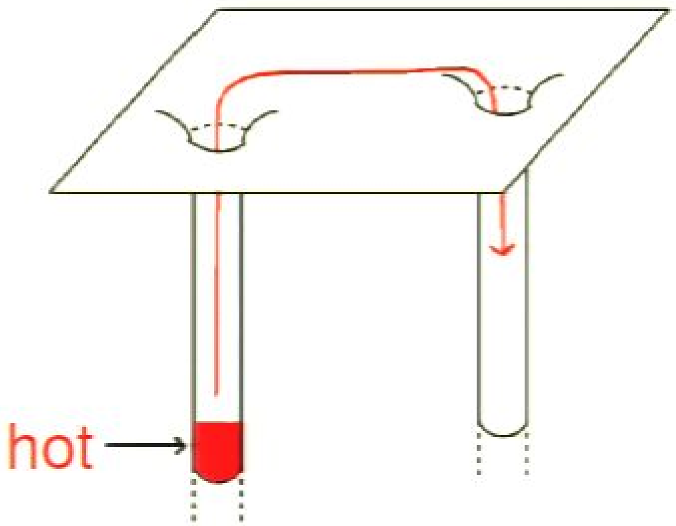

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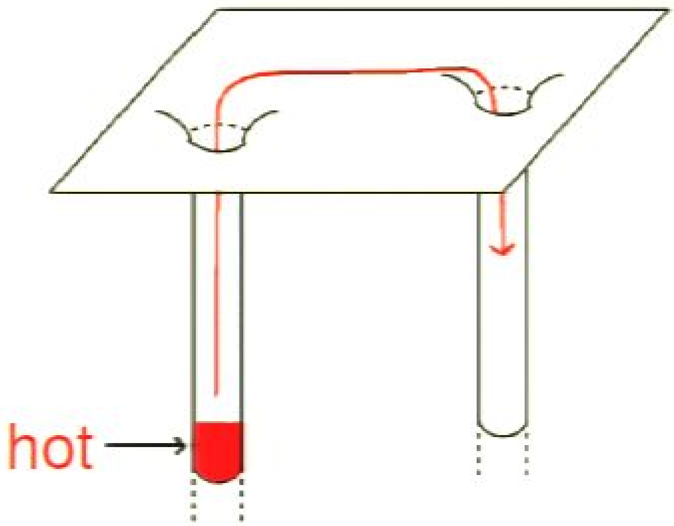

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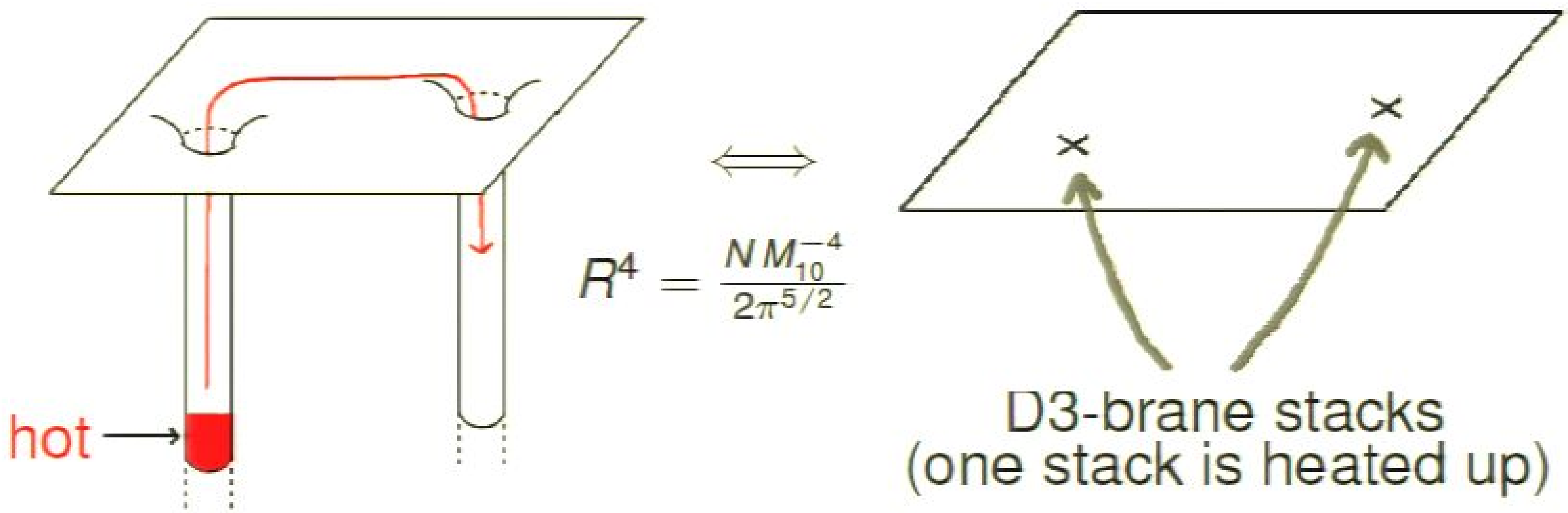

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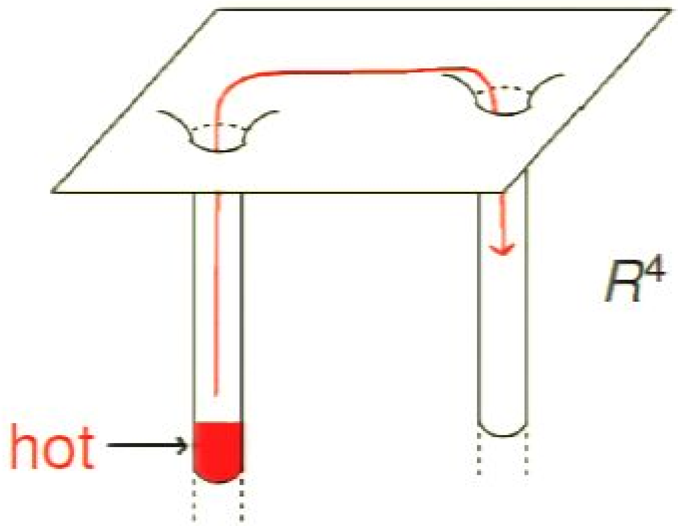
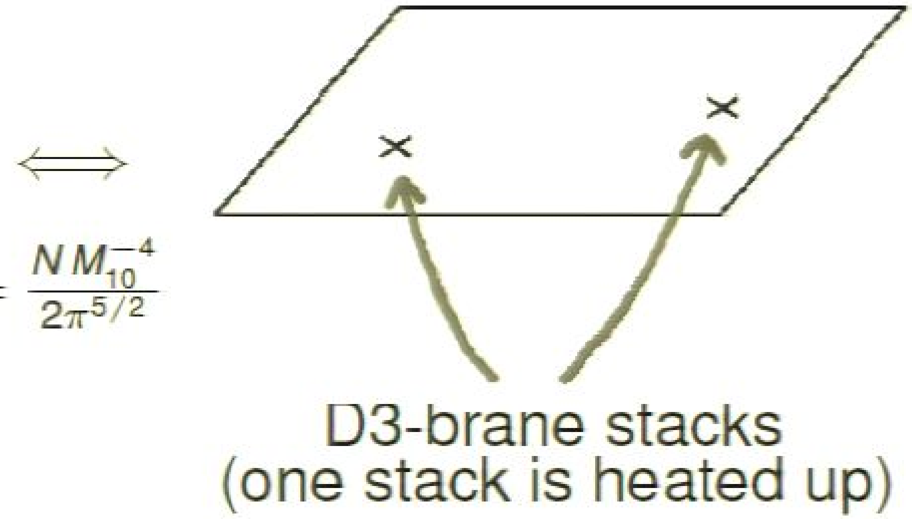


$$R^4 = \frac{N M_{10}^{-4}}{2\pi^{5/2}}$$



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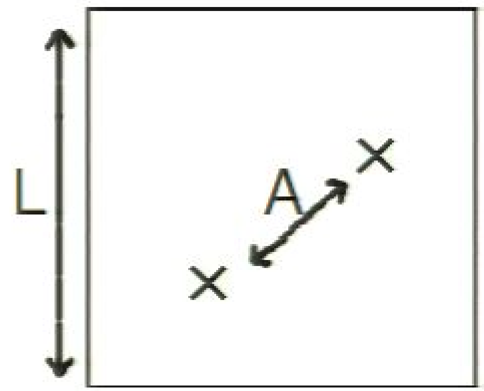

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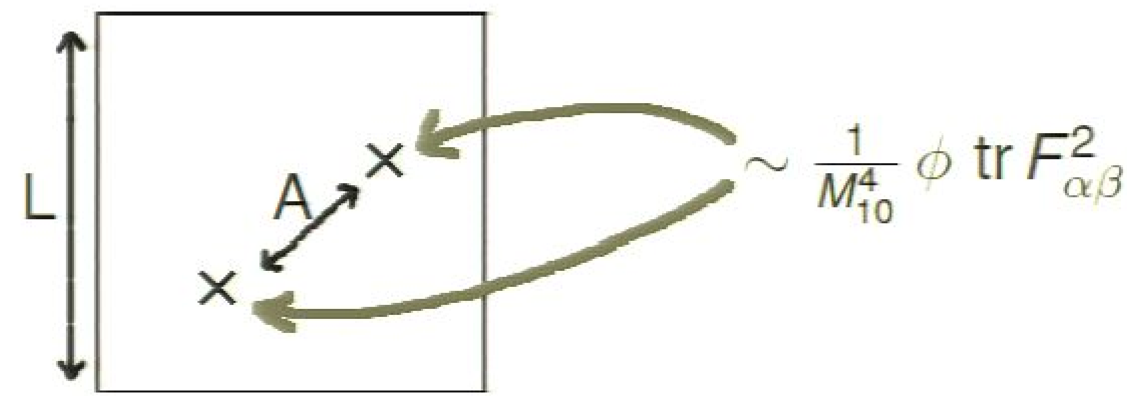

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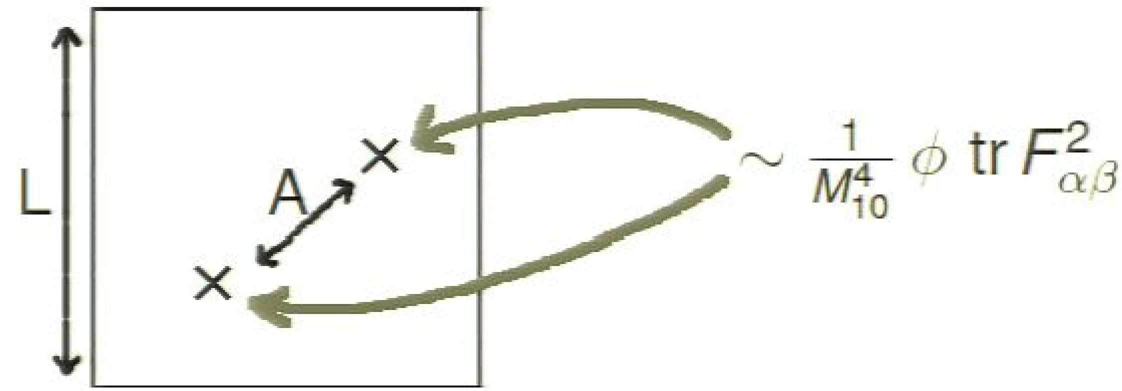

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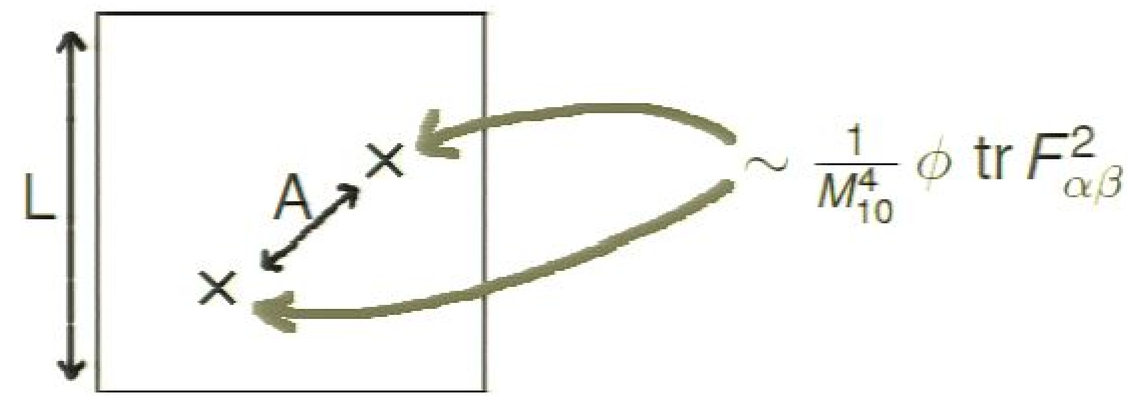

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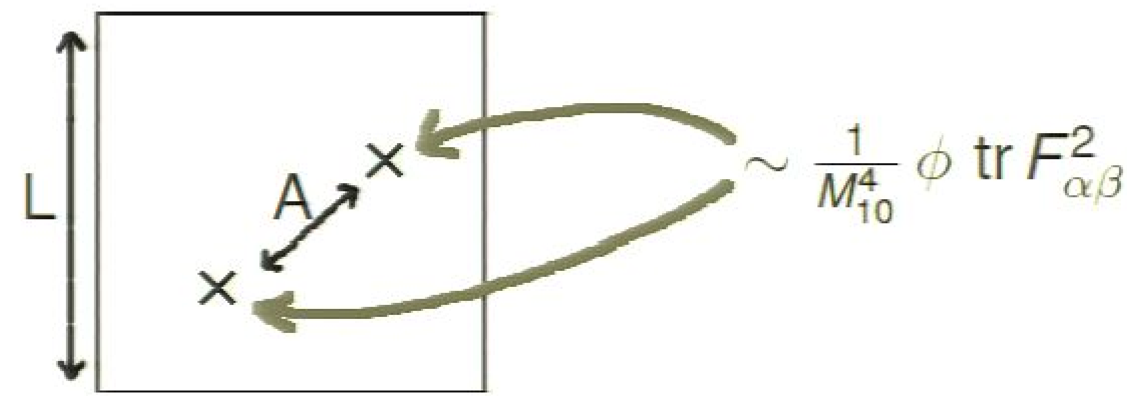

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Heat transfer rate

- KK expansion of SUGRA fields. $\Rightarrow$ From 4d viewpoint one has two gauge theories coupled by tower of KK modes.
- Heated throat corresponds to heated gauge theory. Energy transfer due to processes of the type

- Thermally averaging the above process gives heat transfer rate (per 4d volume):

$$\dot{Q} \sim \frac{R_1^8 R_2^8}{A^8} T^{13} \sim \frac{R_1^8 R_2^8}{L^{12}} T^9 .$$

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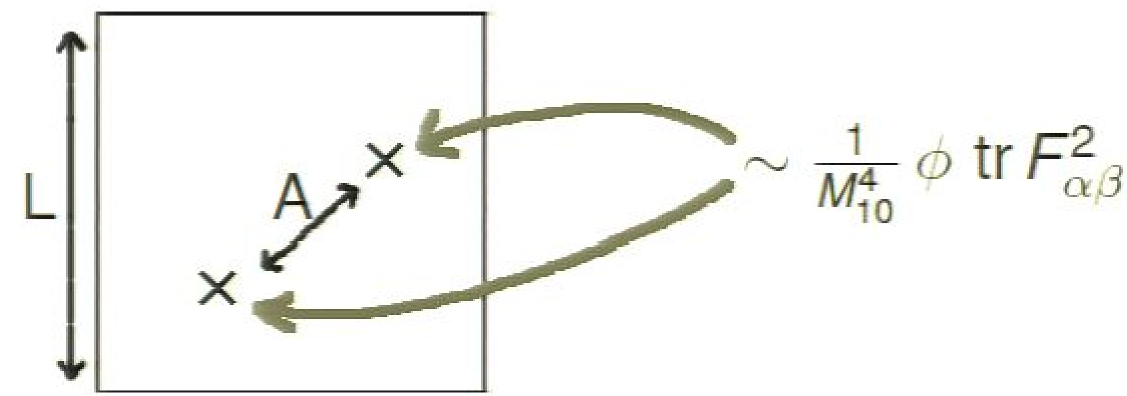

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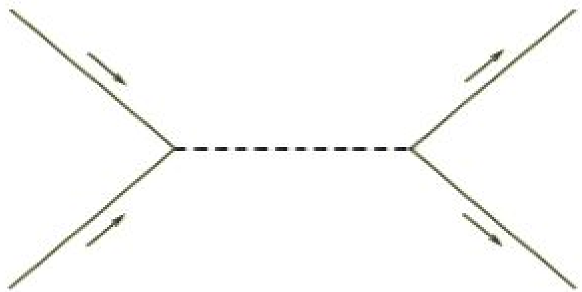

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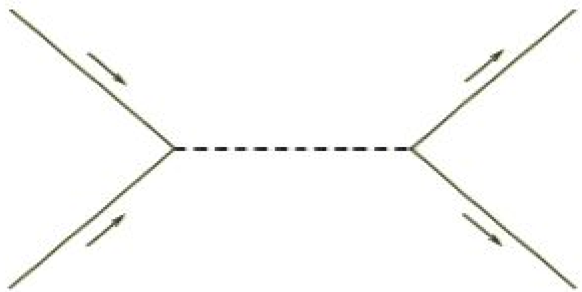

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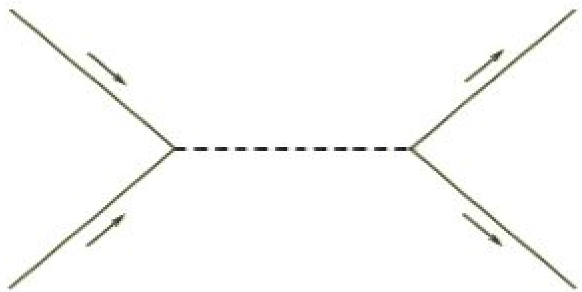

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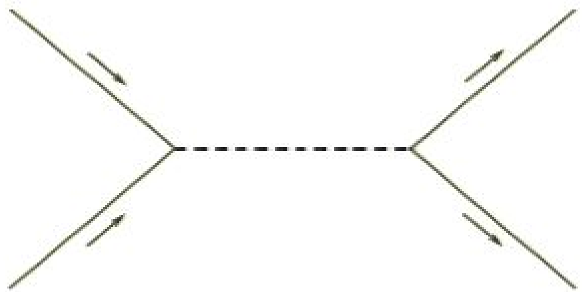

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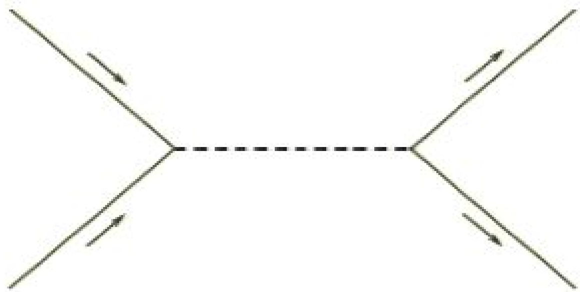

$\Longrightarrow$ summing over KK modes

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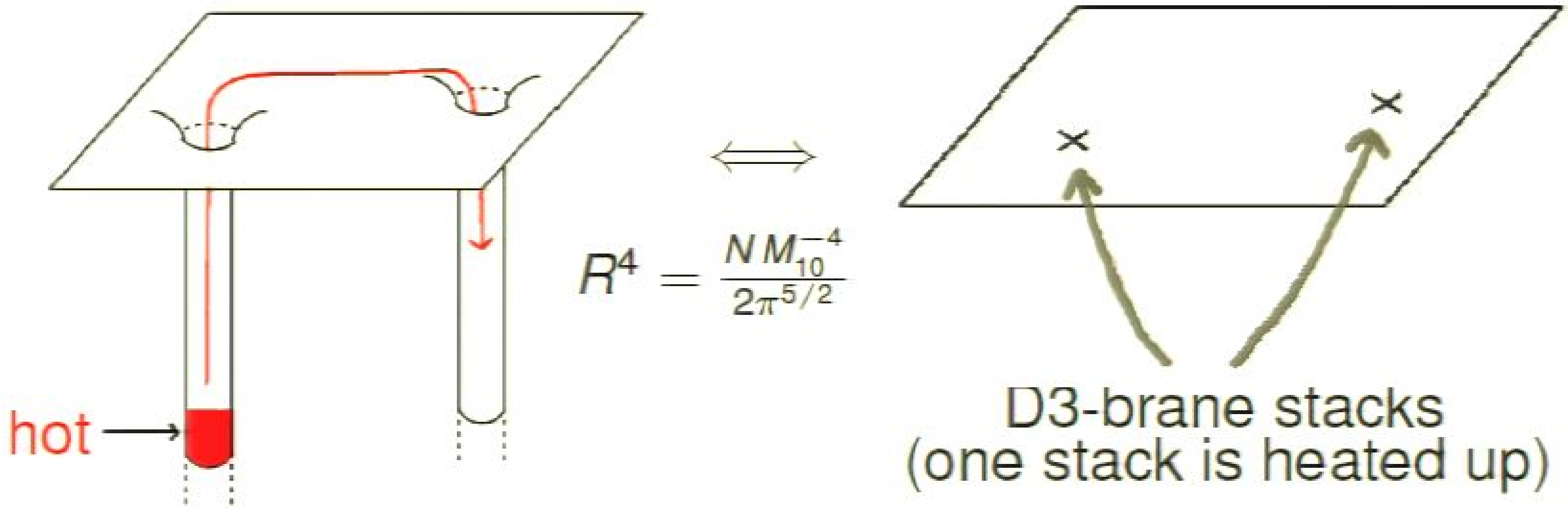

$$R^4 = \frac{N M_{10}^{-4}}{2\pi^{5/2}}$$

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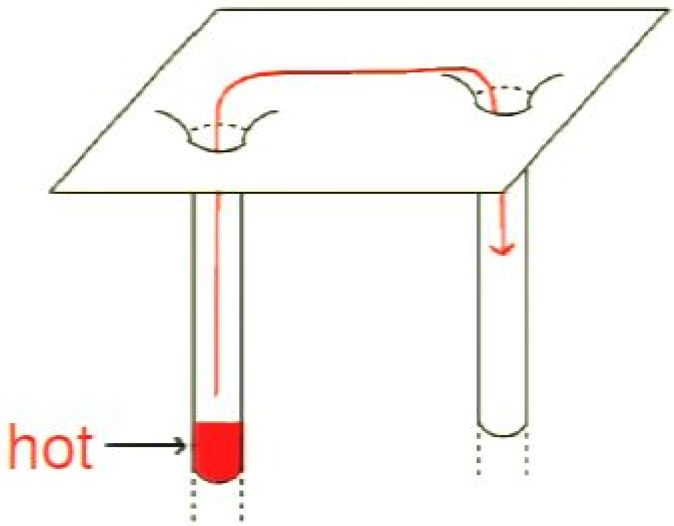

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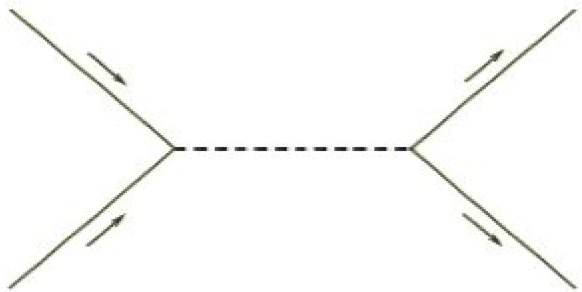

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- Consider a compactification with a large number of throats.
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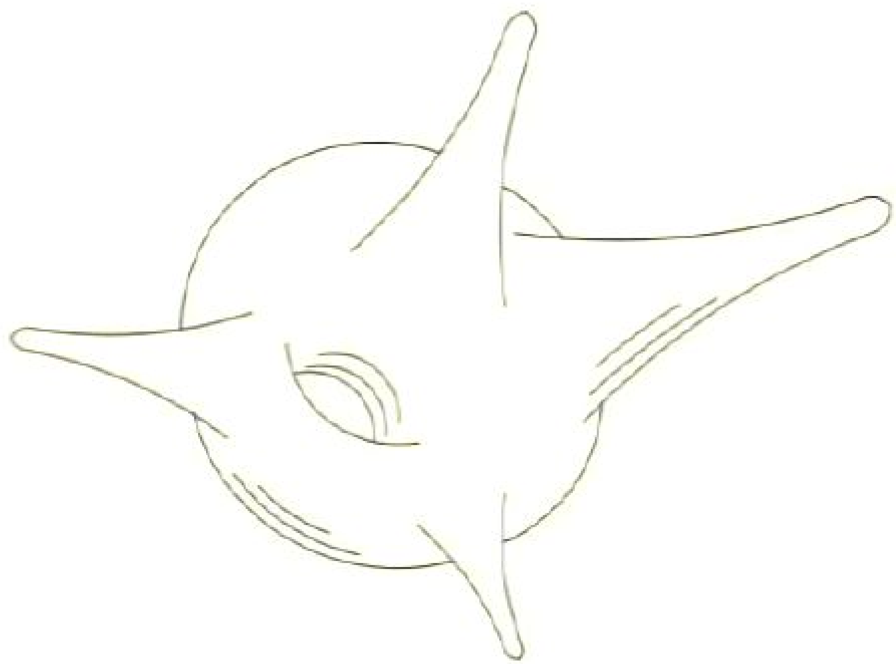
- Assume that only the standard model is heated up directly by the reheating mechanism.
- Throats are then heated up by heat transfer from the hot standard model.



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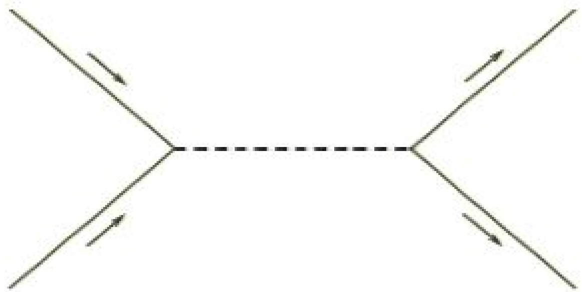

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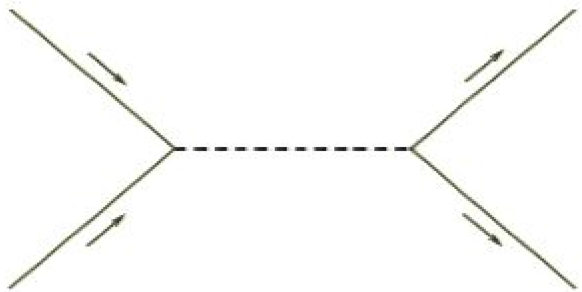

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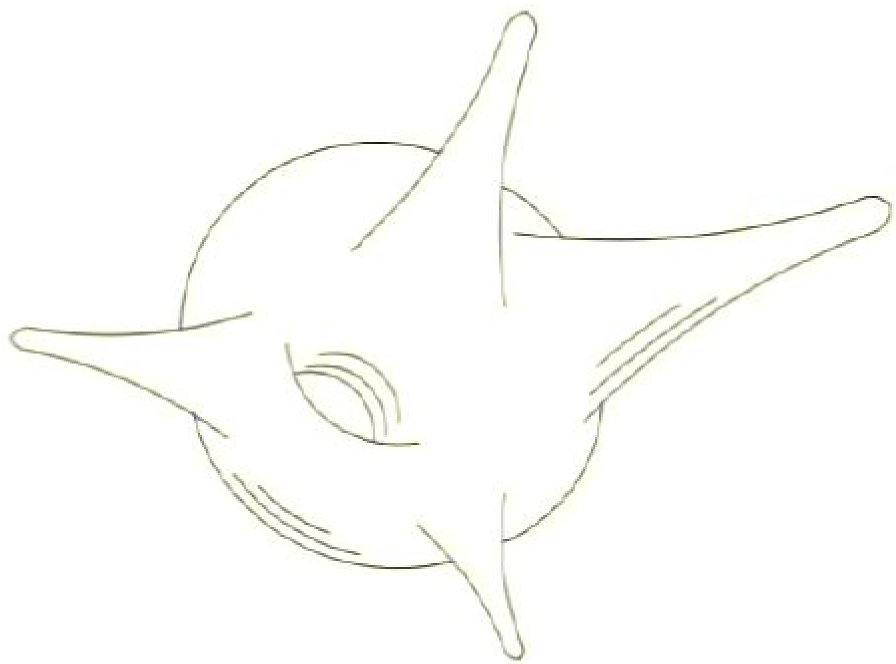

HEAT TRANSFER TO THE THROAT

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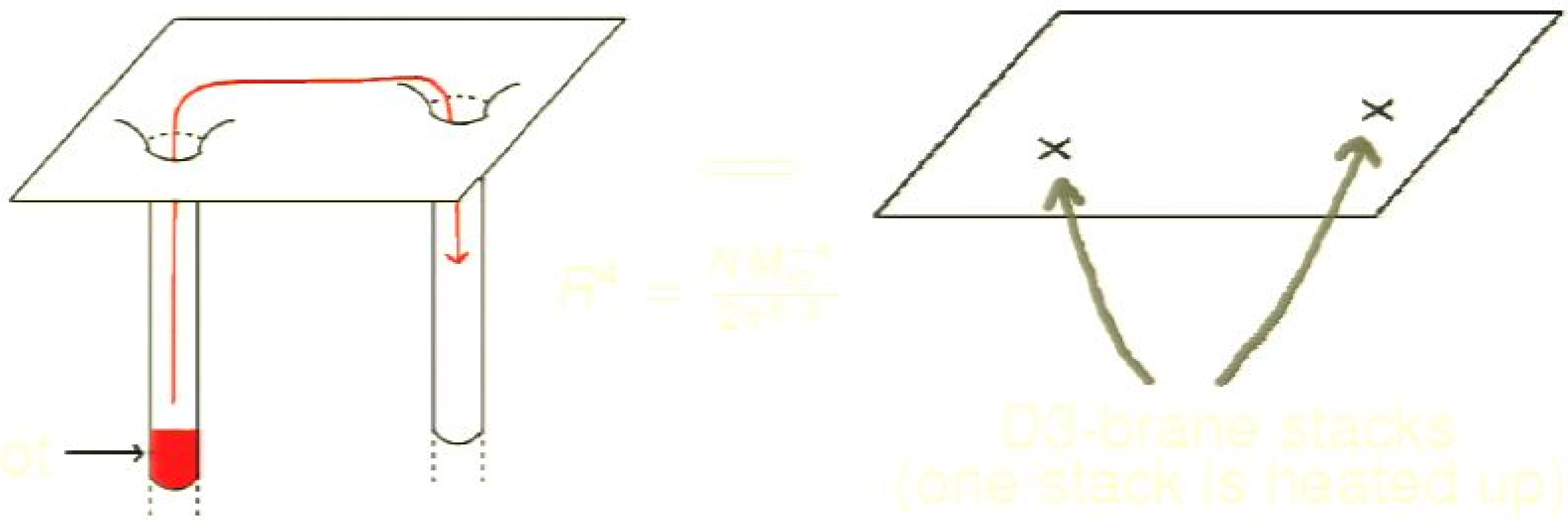

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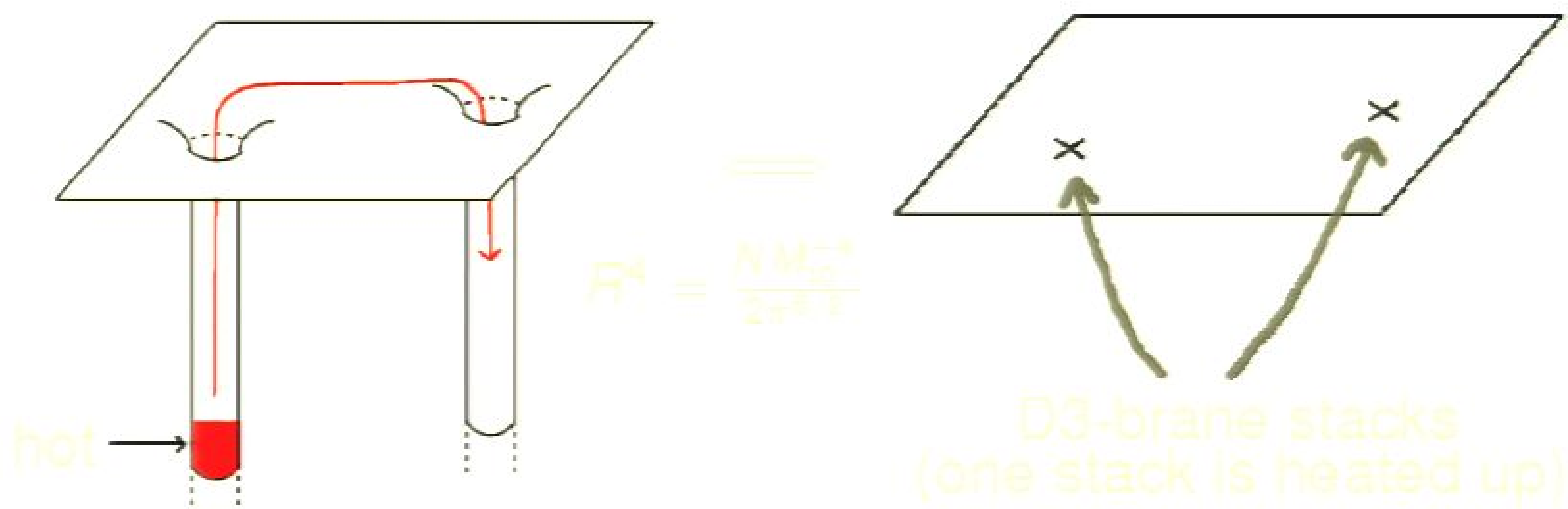

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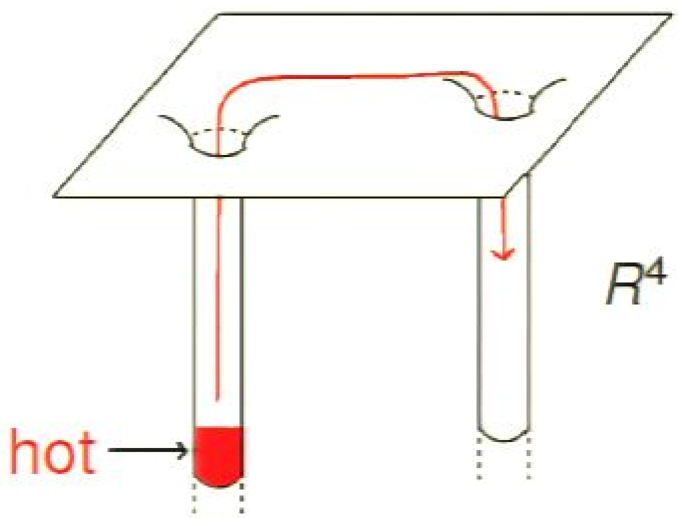

$\Longleftrightarrow$

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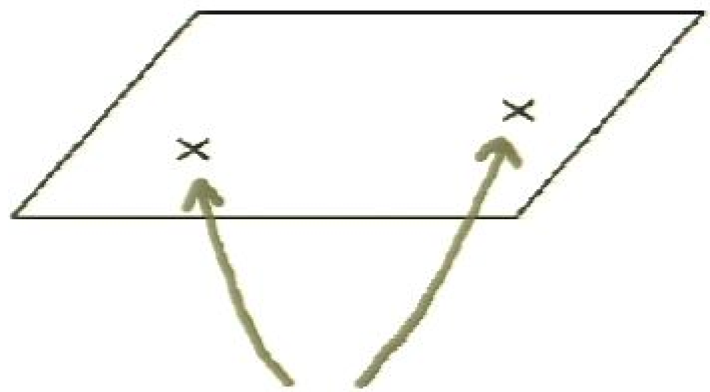

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- Energy density in throat directly after reheating then is

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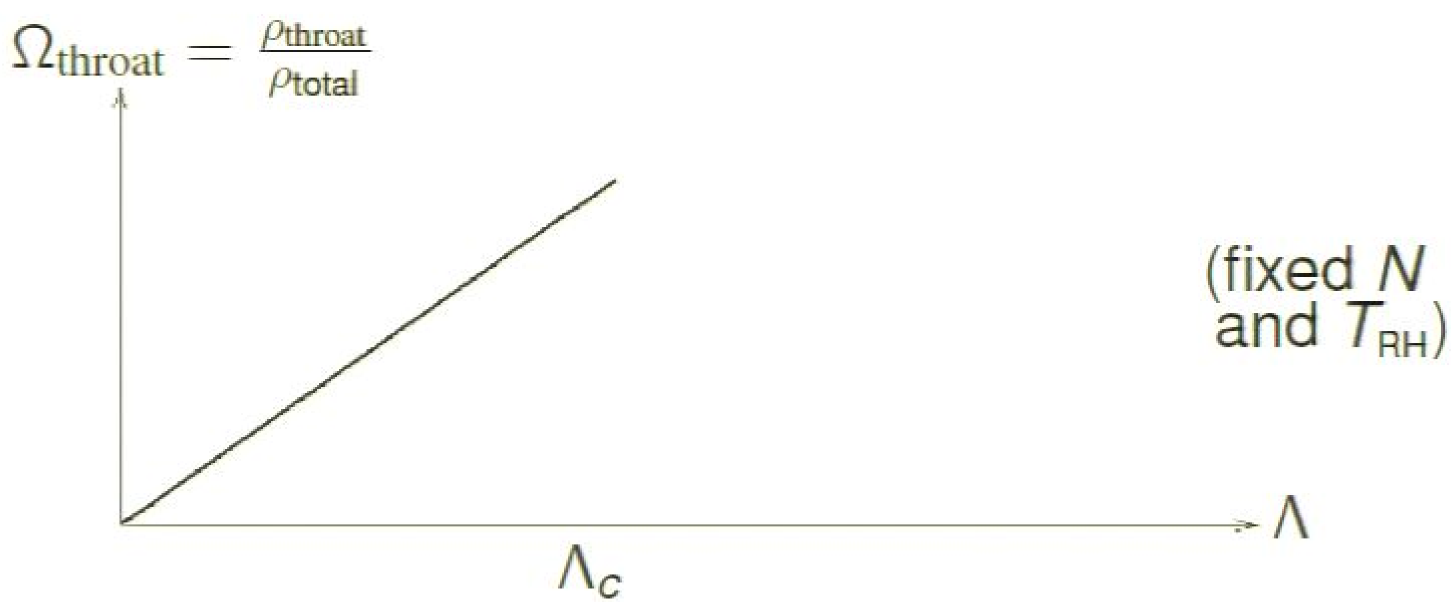

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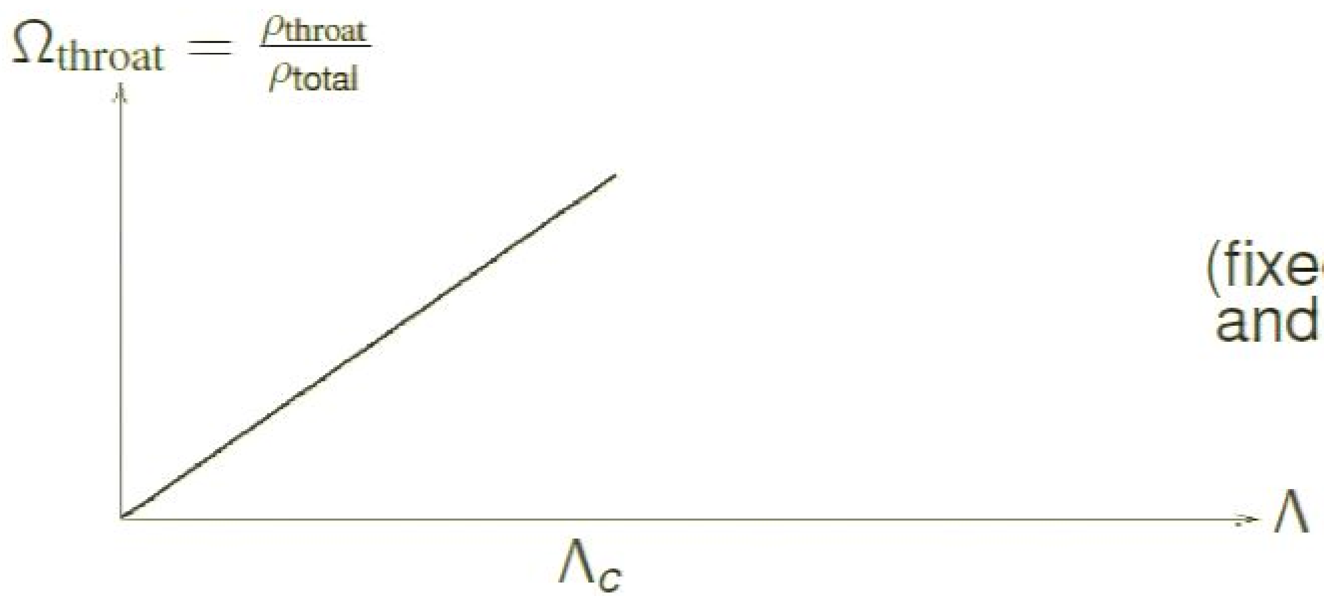

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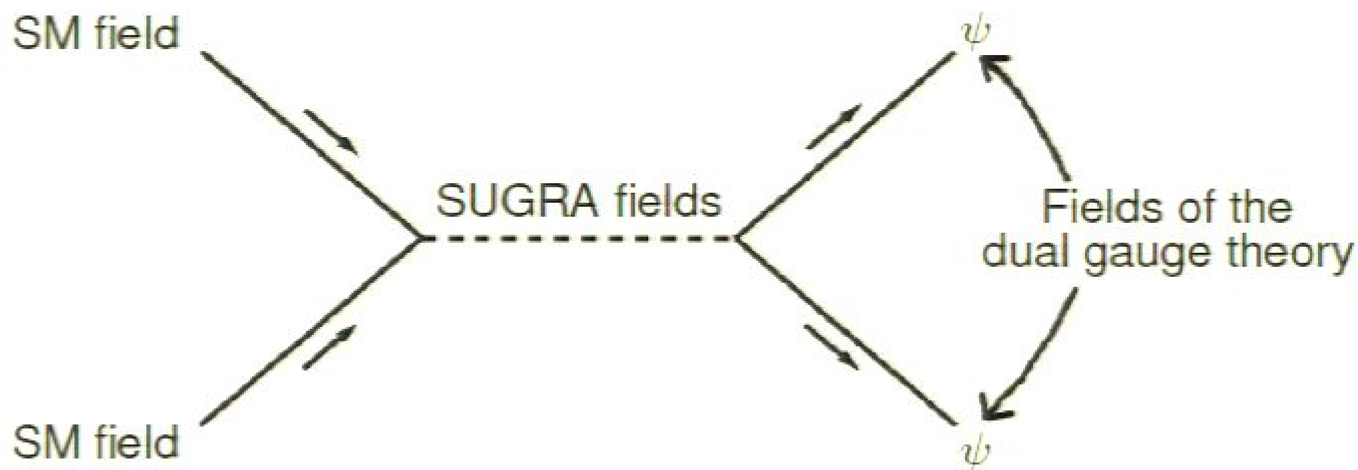

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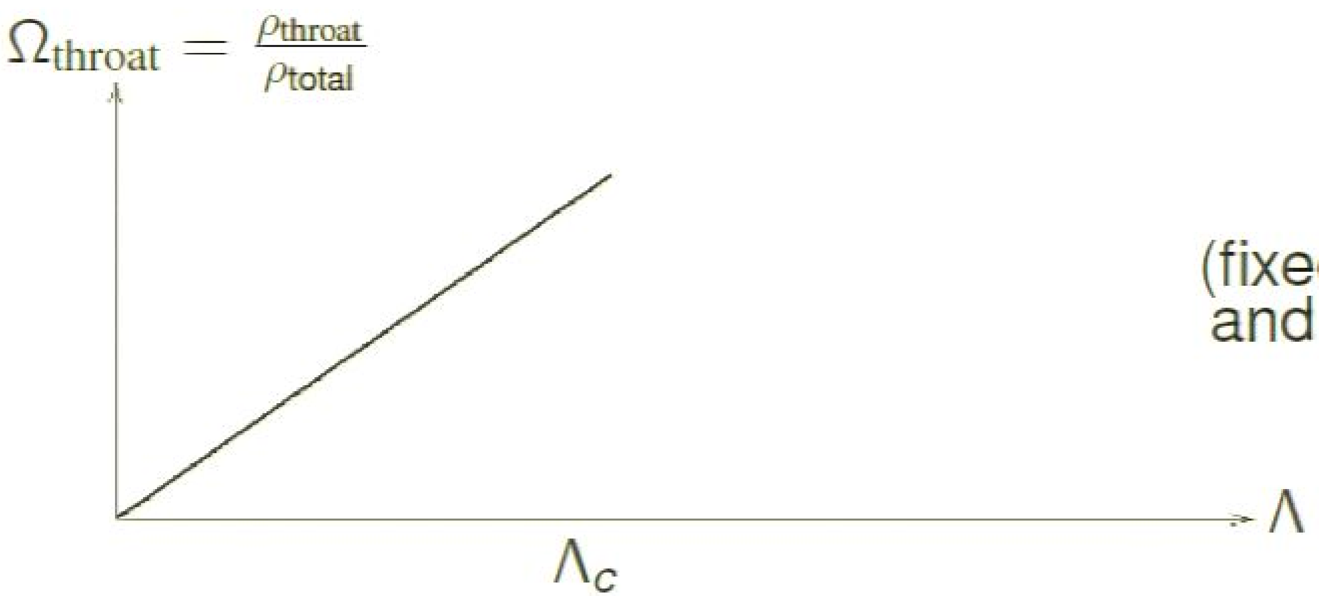

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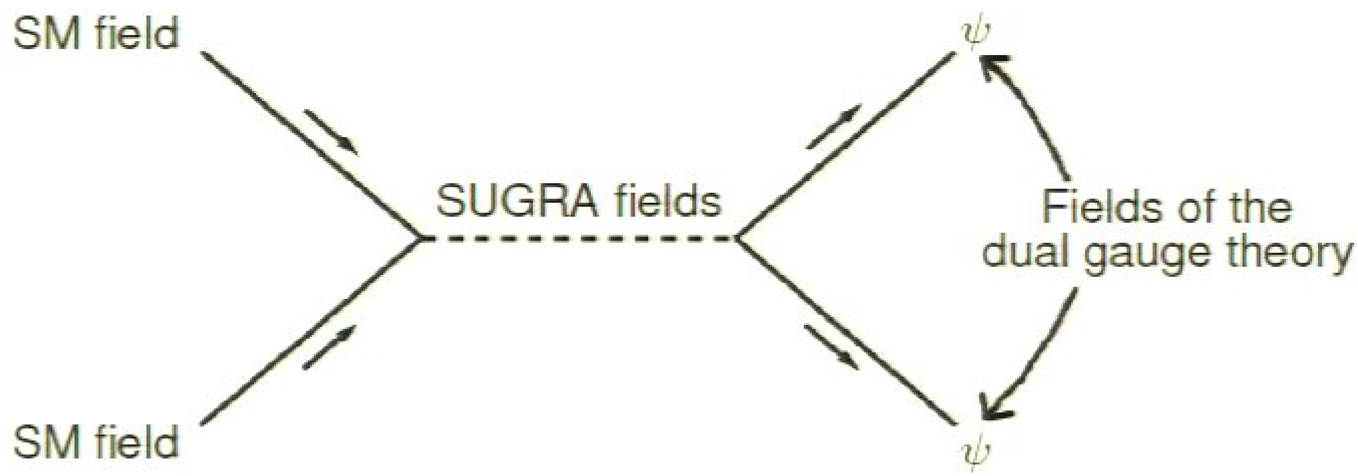

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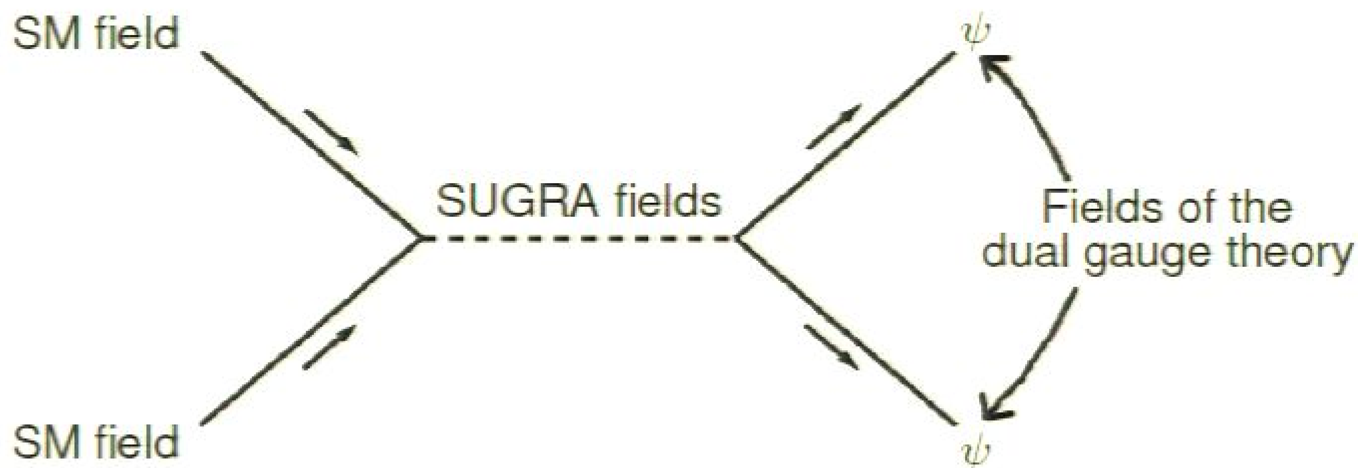

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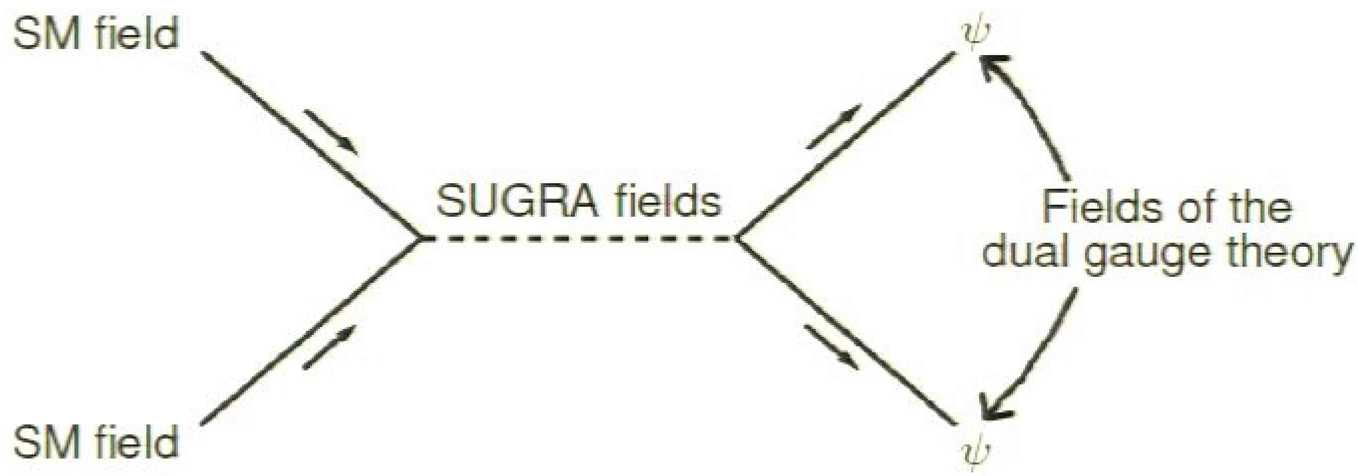

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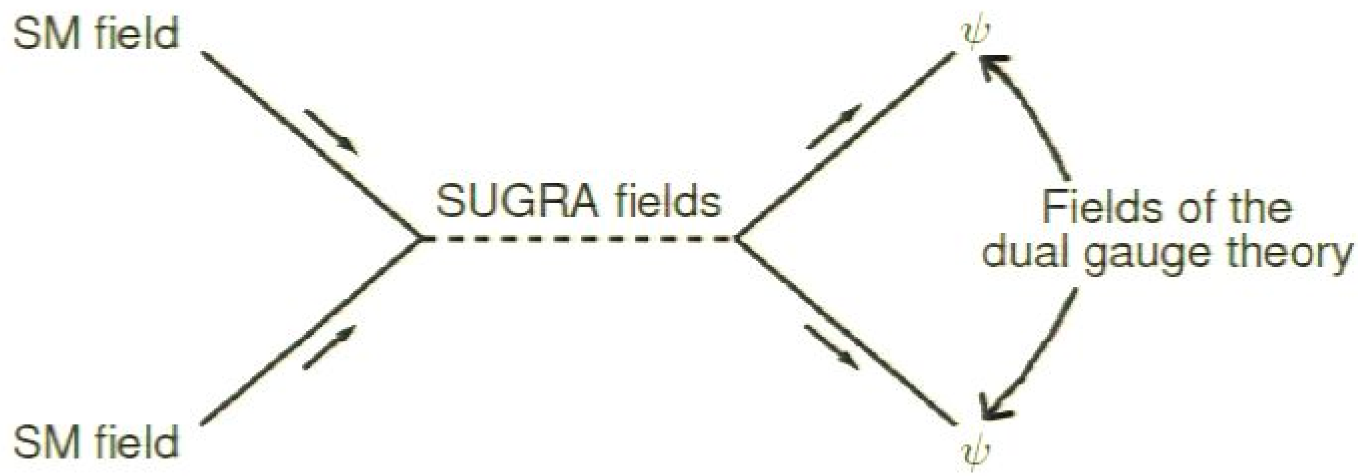

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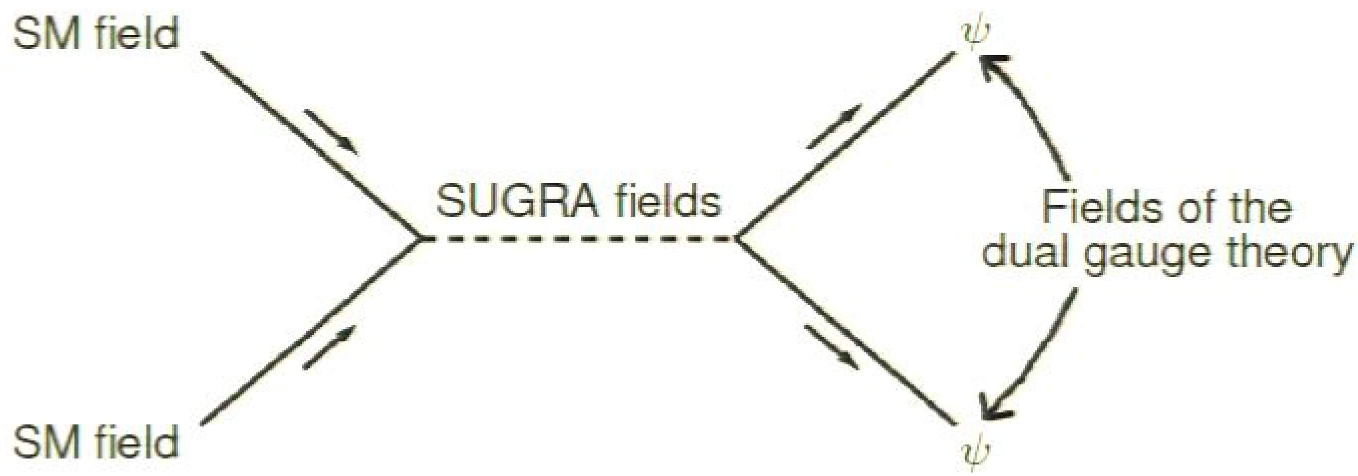

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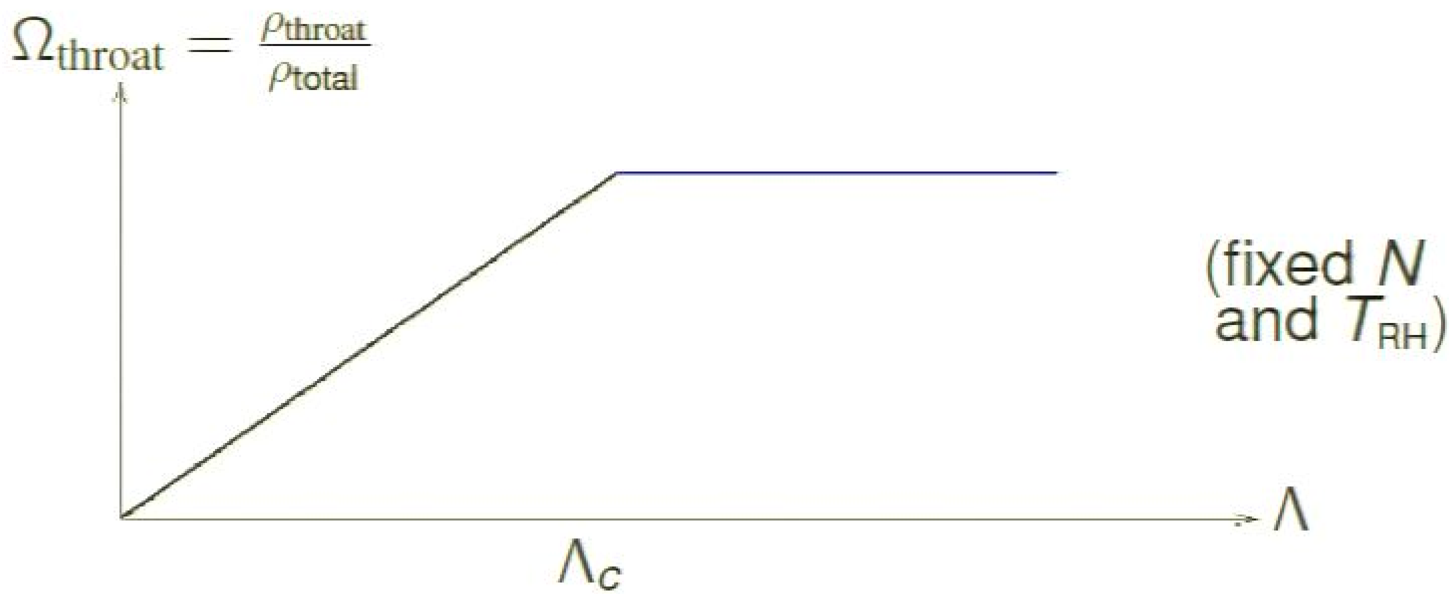

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$$\Omega_{\text{throat}} \sim \left(\frac{T_{RH} N^{1/2}}{6 \cdot 10^{11}\,\text{GeV}} \right)^4 .$$

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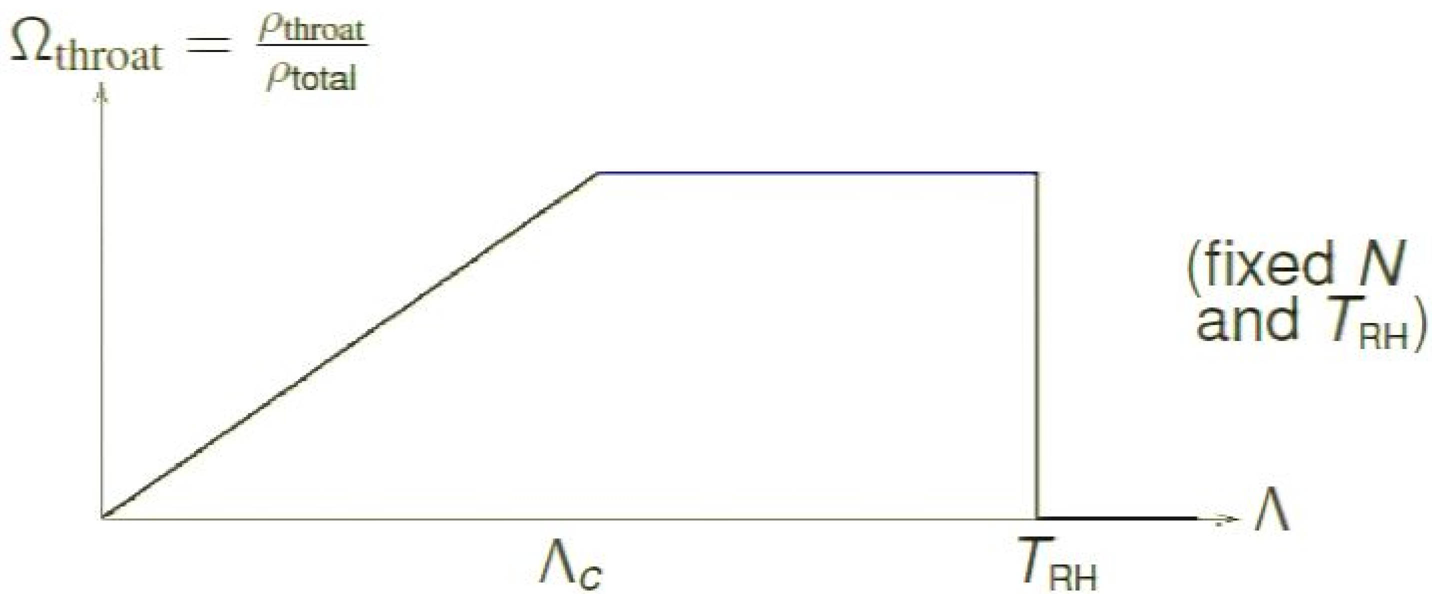

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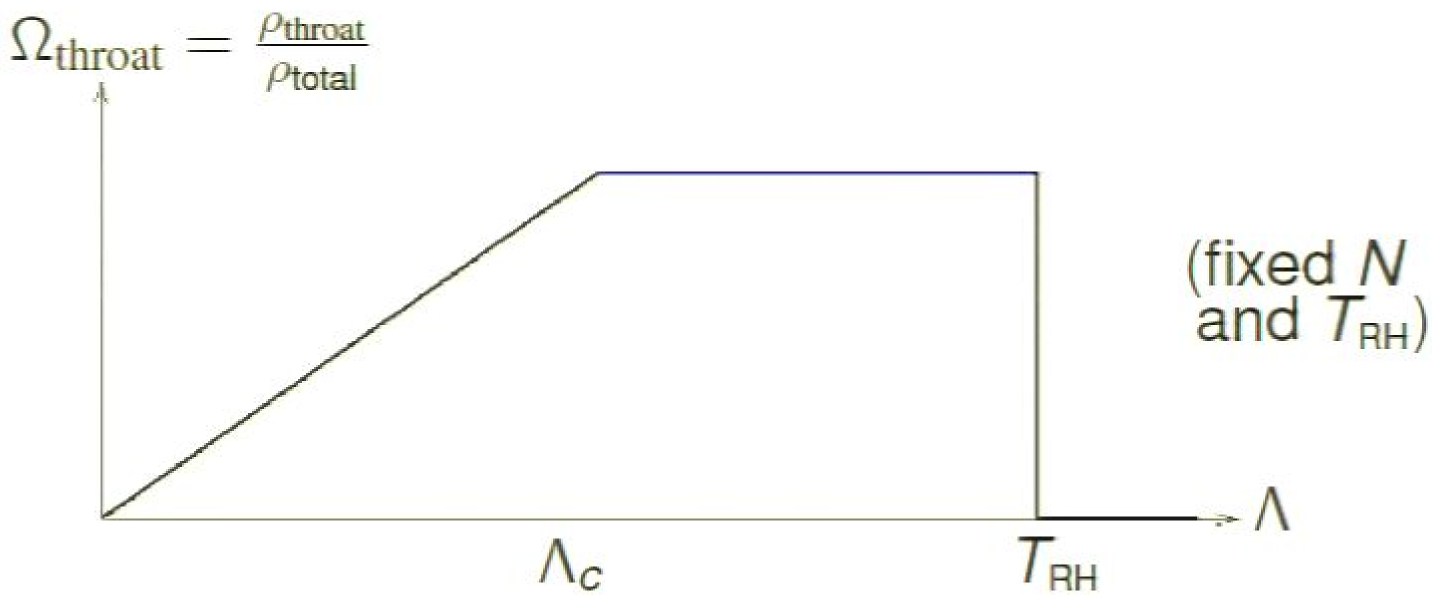

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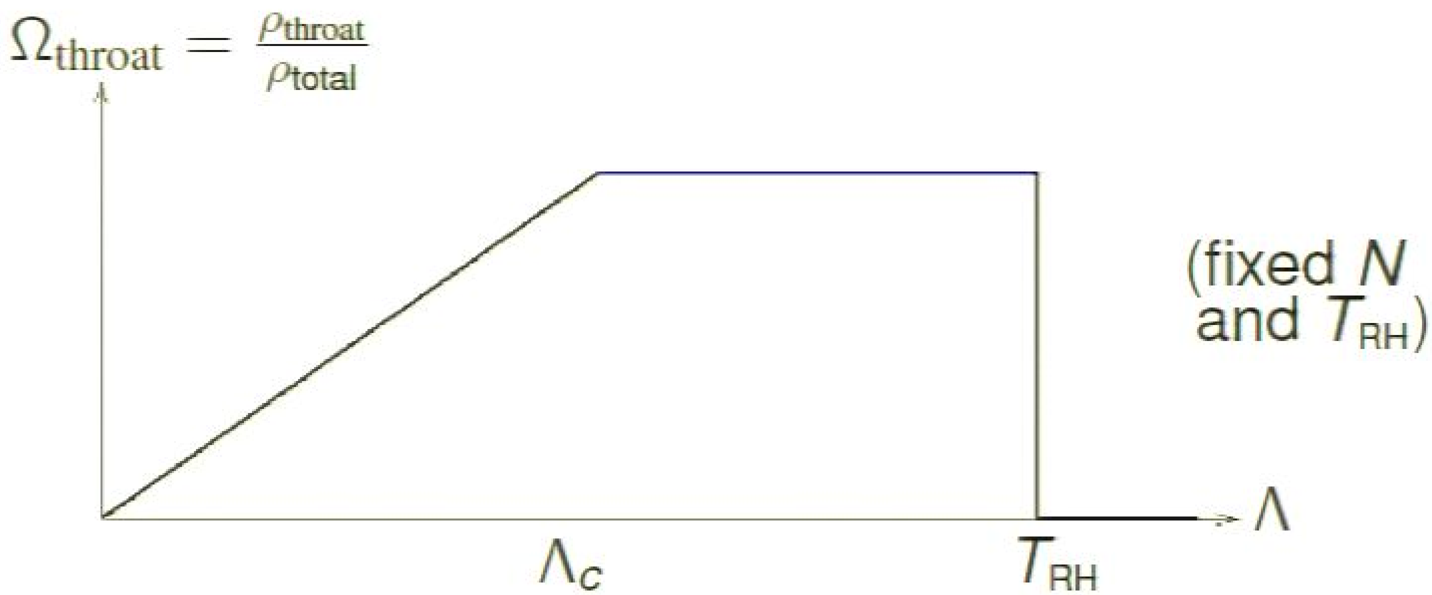

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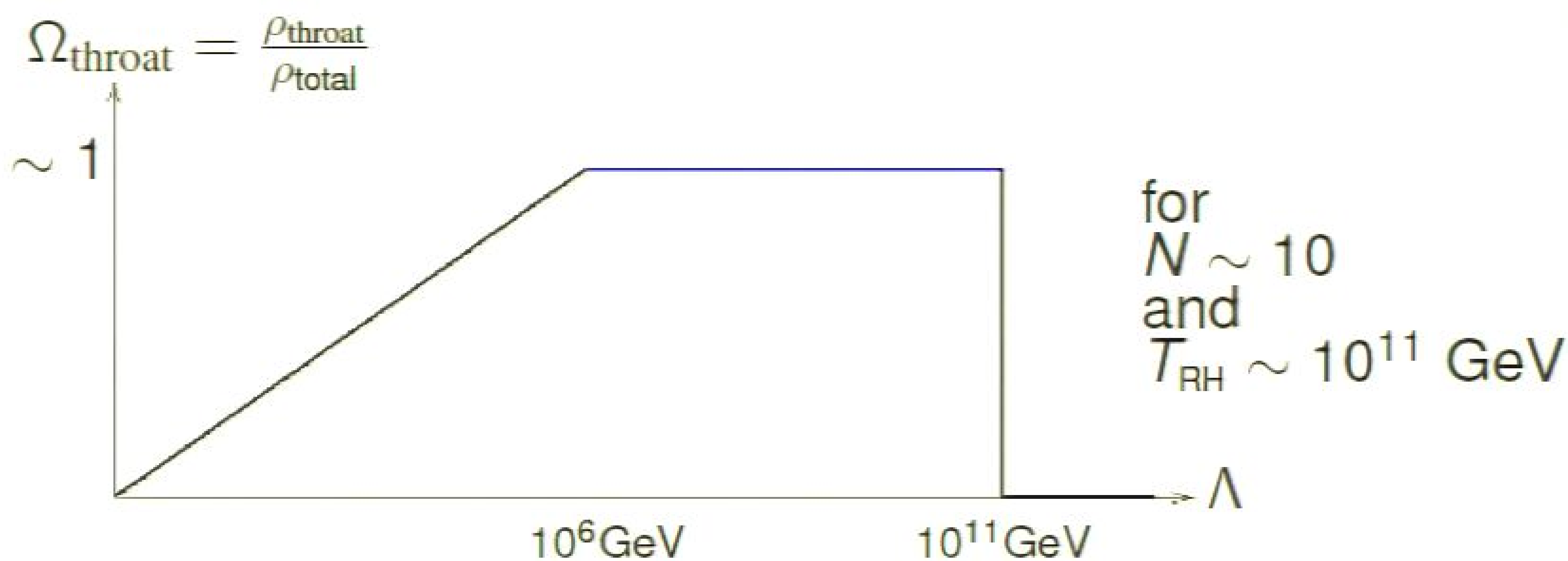

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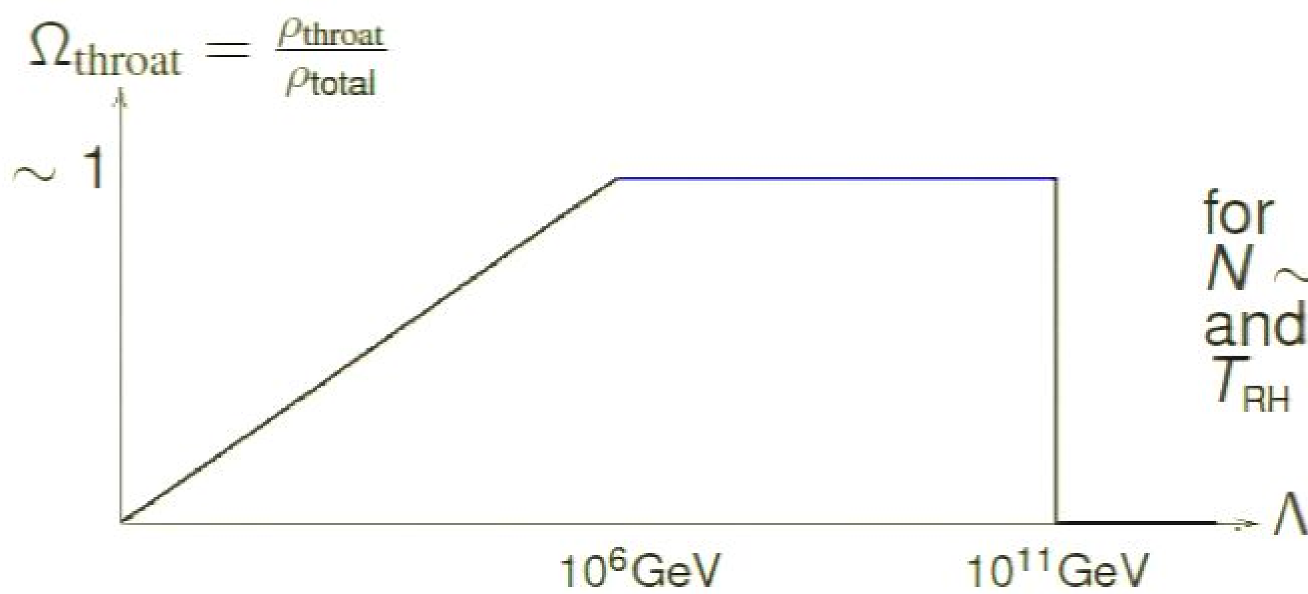

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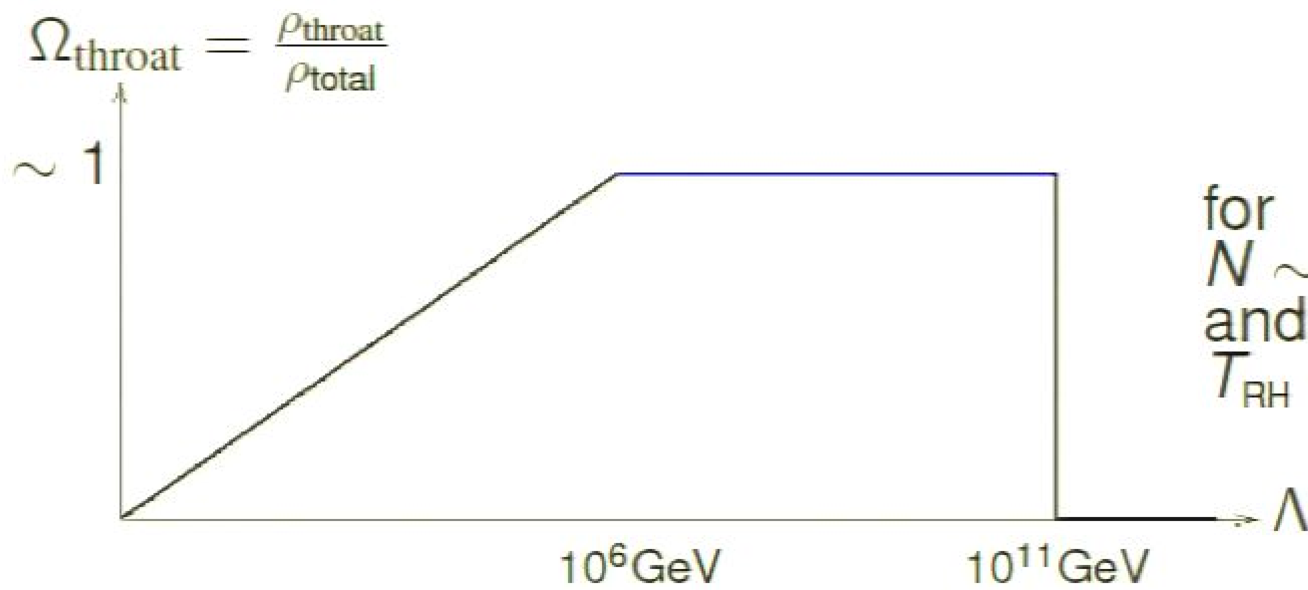

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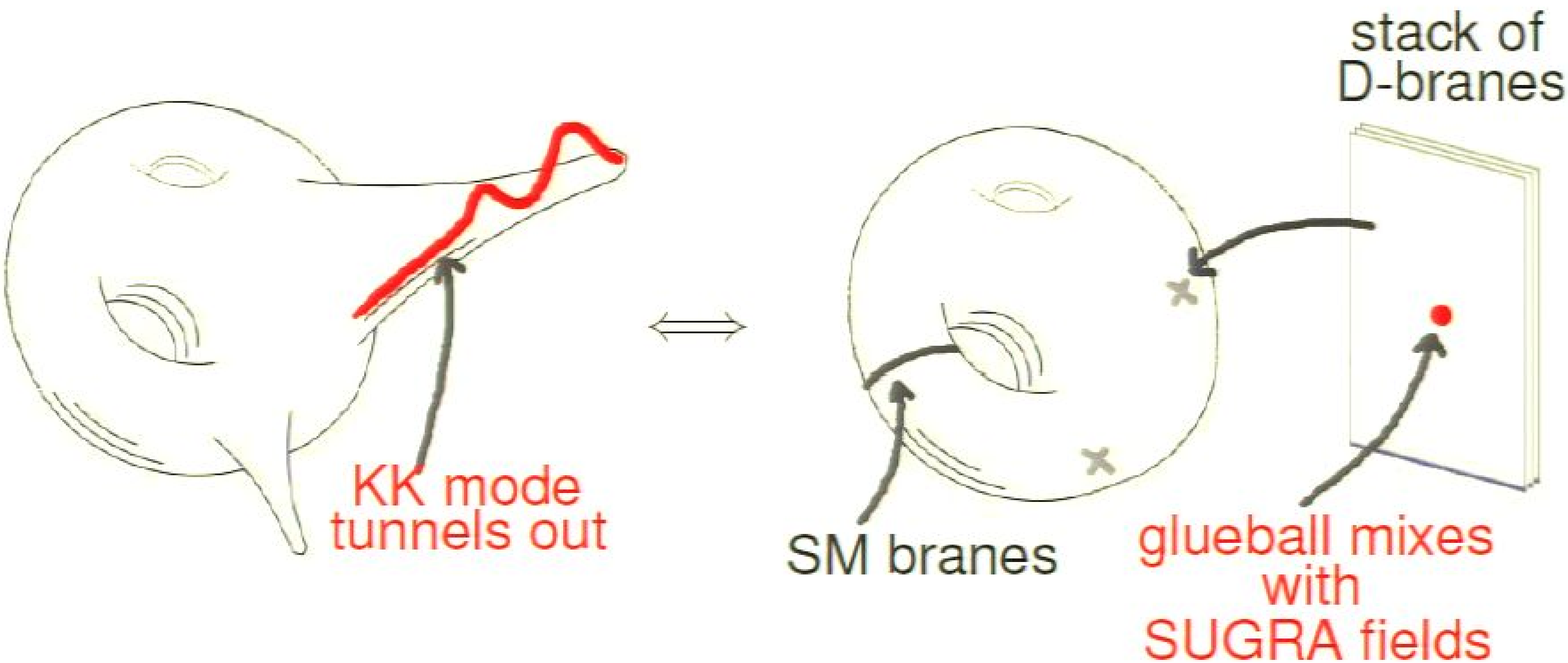
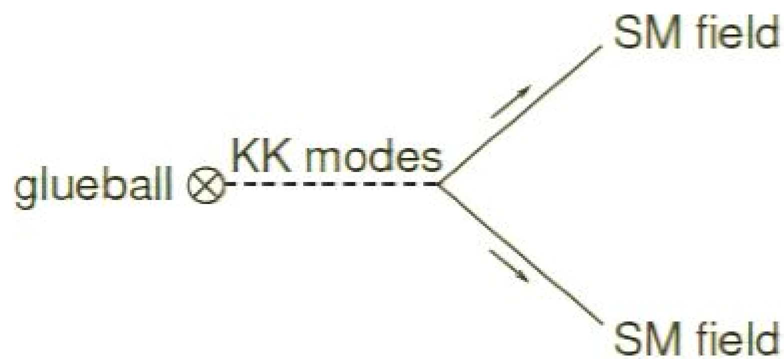
DECAYING DARK MATTER

- Glueballs mix with SUGRA fields in compact space which in turn couple to SM sector. $\Longrightarrow$ Dark matter can decay to SM fields.



Decay of scalar glueballs

- Glueballs decay to SM via KK modes of SUGRA fields in compact space:



- For $A \sim L$ and $\Lambda < L^{-}1$: Dominant contribution from zero mode.
- E.g. Spin-2-glueball mixing vertex $\propto N/M_4$ (from calculation in throat picture).
- Coupling to SM is $\propto M_4^{-1}$. Decay rate then is

$$\Gamma_{\text{glueball}} \sim g N^2 \frac{\Lambda^5}{M_4^4}.$$

OBSERVABLE SIGNATURES

- Lifetime of glueballs (for $N \sim 10$) is:

$$\tau_{\text{glueball}} \sim 10^{27} \left(\frac{7 \cdot 10^3 \text{ GeV}}{\Lambda} \right)^5 \text{ s.}$$

- Only for $\Lambda \lesssim 10^6$GeV are the Spin-2-glueballs stable until our epoch ($\sim 10^{17}$s).
- But glueballs decay to photons, hadrons, etc. $\Rightarrow$ Need $\tau_{\text{glueball}} \gtrsim 10^{27}$ s to avoid bounds from γ-ray observations.
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- We have calculated the heat transfer rate and glueball/KK particle decay rate between throats and between a throat and the SM.
- These rates are important in the early-universe cosmology of multi-throat compactifications (e.g. reheating after brane inflation in a throat).
- We have presented another application: KK modes in a throat/glueballs of the dual gauge theory are an interesting dark matter candidate.
- Thermal production of glueballs can be efficient if the glueballs become nonrelativistic quickly after reheating.
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