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Membrane Limits in Quantum Gravity

based on arXiv:2112.09136 (Phys .Rev. D 105)
with R. Álvarez-García and T. Weigand

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String Phenomenology 2022 - Liverpool

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30 Second Summary of My Talk

universality at infinite distance $\Delta\phi \to \infty$

↓ distance conjecture

must $\exists$ infinite tower of states (which dictates the physics)

↙ emergent string conjecture ↘

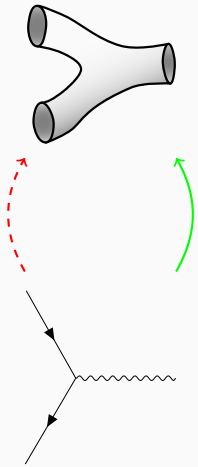
Kaluza-Klein (decompactification) string excitations (duality)

what about higher dimensional objects?

New result: (critical) membranes must decouple!

Infinite Distance & Emergent String Conjecture

[Vafa '05]
Review: [Palti '19]

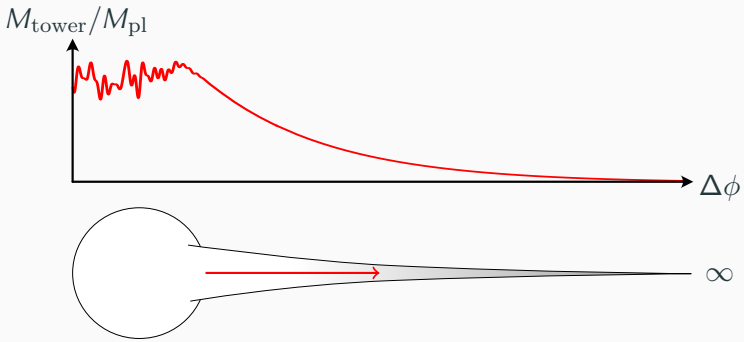


Landscape:
EFT consistent with quantum gravity

Swampland:
EFT inconsistent with quantum gravity

Swampland conjectures:
landscape vs. swampland

What is the physics of extremely large scalar field displacements in quantum gravity?



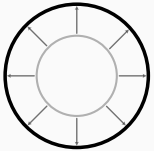
$\exists$! Infinite tower of states with $m \sim e^{-\alpha\Delta\phi} M_{\text{pl}}$, where $\Delta\phi$ is distance in field space.

[Ooguri, Vafa '06]

Emergent String Conjecture: Infinite distance limits in the moduli space of a consistent theory of quantum gravity fall into two classes:

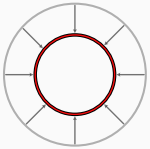
Decompactification

Kaluza-Klein tower—arising e.g. from an expanding component of the geometry—dominates the limit.



Emergent String

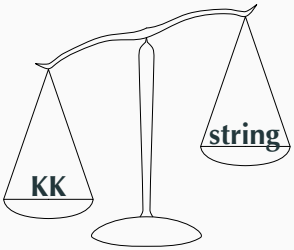
Excitations of a unique string—arising e.g. from wrapping an extended object on a shrinking component of the geometry—dominate the limit.



[Lee, Lerche, Weigand '19]

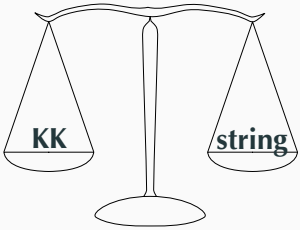
- Strong evidence for the conjecture: compactifications of string and M-theory.
  [Lee, Lerche, Weigand '18–'21] [Baume, Marchesano, Wiesner '19] [Xu '20]
  [DK, Lee, Weigand, Wiesner '20] [Basile '22] [...]
- Backreaction of EFT strings
  [Lanza, Marchesano, Martucci, Valenzuela '20–'22] [Marchesano, Wiesner '22]
- Most evidence in supersymmetric settings
  (but see [Basile '22] for non-SUSY)

Often we have both towers. What *exactly* do we mean by "dominate"?



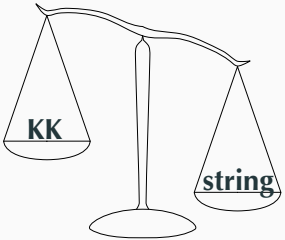
pathological string limit

$M_{\rm KK}^2 \gg T_{\rm str}$



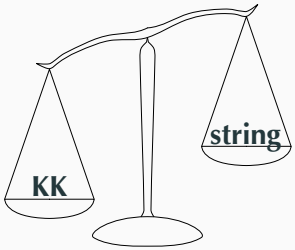
emergent string limit

$M_{\rm KK}^2 \sim T_{\rm str}$



decompactification limit

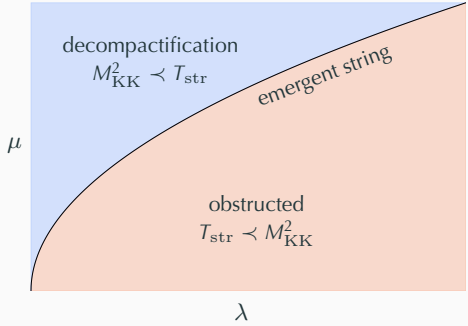
$M_{\rm KK}^2 \ll T_{\rm str}$



$T_{\text{str}} \ll M_{\text{KK}}^2$

- Limit with $M_{\text{KK}}^2/T_{\text{str}} \to \infty$ decouples a KK tower.
- The new critical string appears to propagate in less than 10 dimensions.
- Not expected in string theory. Try to decouple KK tower $\to$ get dual winding tower.
- We consider such behavior pathological.
- Should be censored in a consistent theory.

- Pathological situation does appear in tree-level string compactifications.
- But: Quantum corrections (e.g. α') obstruct such limits.
  [DK, Lee, Weigand, Wiesner '20].
- After taking quantum corrections into account, all limits are of decompactification or emergent string type.
- Upshot: Theory is smart, but we have to be smart and compute all the corrections, too!



Censorship of Emergent Membranes

Censorship of Emergent Membranes

"Emergent membrane limits"?!

$$T_{\text{brane}} \sim M_{\text{KK}}^{p}$$

- Consider a theory in D dimensions with a (2+1)-dimensional *critical* brane.
- Terminology: critical brane on a circle $\rightarrow$ critical string.

emergent membrane limit in the D-dimensional theory

emergent string limit in the (D-1)-dimensional theory?

Censorship of Emergent Membranes

- For the critical membrane:

$$\frac{T^{(D)}_{\text{brane}}}{\left(M^{(D)}_{\text{pl}}\right)^3} \to 0 \quad \text{while} \quad \frac{T^{(D)}_{\text{brane}}}{\left(M^{(D)}_{\text{KK}}\right)^3} \sim 1$$

- Compactification ($R_{S^1} = \text{const.}$) $\to$ pathological string limit

$$\frac{T^{(D-1)}_{\text{str}}}{\left(M^{(D-1)}_{\text{KK}}\right)^2} = \frac{T^{(D)}_{\text{brane}} \cdot R_{S^1}}{\left(M^{(D)}_{\text{KK}}\right)^2} = \frac{T^{(D)}_{\text{brane}}}{\left(M^{(D)}_{\text{KK}}\right)^3} \cdot \frac{M^{(D)}_{\text{KK}}}{M^{S^1}_{\text{KK}}} = \frac{M^{(D)}_{\text{KK}}}{M^{(D)}_{\text{pl}}} \longrightarrow 0$$

Consistent dimensional reduction of ESC $\to$ constrains membrane limits!

- Consistency under dimensional reduction as guiding principle:

[Heidenreich, Reece, Rudelius '15, '16, '19]

[Palti '19] [Cremonini, Jones, Liu, McPeak, Tang '20] [Rudelius '21]

[Etheredge, Heidenreich, Kaya, Qiu, Rudelius '22]

Censorship of Emergent Membranes

Marginally consistent scaling as $\mu \to \infty$:

$$\frac{\left(M_{\rm KK}^{(D)}\right)^3}{\left(M_{\rm pl}^{(D)}\right)^3} = \frac{1}{\mu^3} \quad \text{and} \quad \frac{T_{\rm brane}}{\left(M_{\rm pl}^{(D)}\right)^3} = \frac{1}{\mu^2}$$

Membrane decouples $\to$ decompactification!

Censorship of Emergent Membranes

- Concrete realization: 11-dimensional M-Theory on Calabi-Yau three-fold X_6 $\rightarrow$ 5D theory with N=2 supersymmetry.
- Scalars organized by SUSY: vector multiplets and hypermultiplets.
- Hypermultiplets: volume $\mathcal{V}_{X_6}$ and complex structure z^i.
- Complex structure moduli control volumes of three-cycles $\Sigma_3 \subset X_6$.
- M-Theory contains a (5+1)-dimensional object: M5-brane
- **Idea:** Find infinite distance limit where $\text{vol}(\Sigma_3) \rightarrow 0$.
  M5-brane wrapped on Σ_3:

  (2+1)-dimensional tensionless membrane.

Censorship of Emergent Membranes

- Setup: SYZ-fibration in large complex structure limit.
- Tension of the wrapped M5:

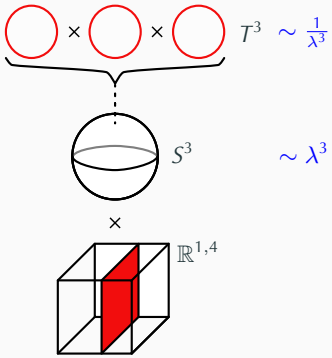
$$\frac{T_{\mathrm{M5}}}{\left(M_{\mathrm{pl}}^{(11)}\right)^3} \sim \frac{1}{\lambda^3}$$

- Kaluza-Klein tower from base scales in the same way:

$$\frac{M_{\mathrm{KK}}^3}{\left(M_{\mathrm{pl}}^{(11)}\right)^3} \sim \frac{1}{\lambda^3}$$

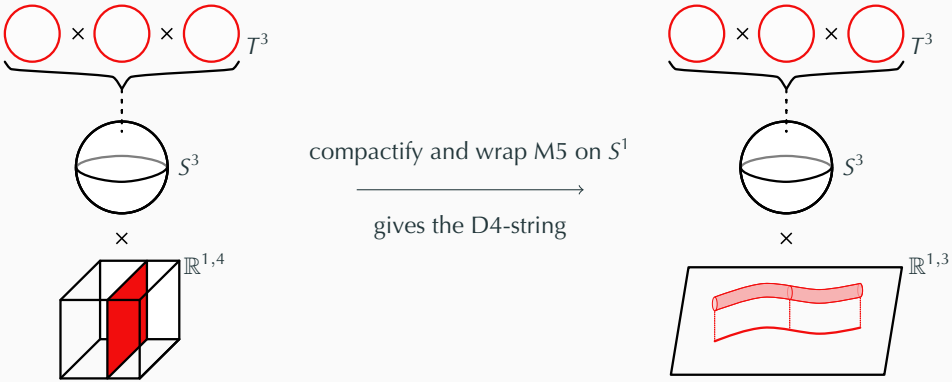
$\Rightarrow$ emergent membrane limit!

- Important: Corrections! M2- and M5-instantons.



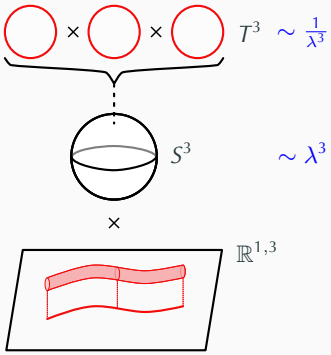
Censorship of Emergent Membranes

Idea: Relate to similar setup of [Baume, Marchesano, Wiesner '19]:

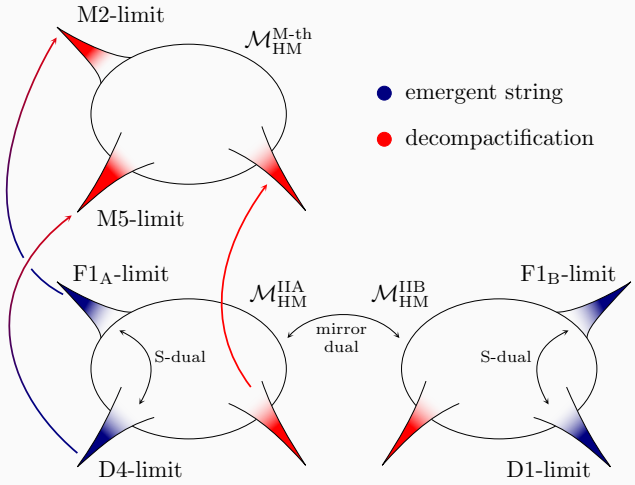


Censorship of Emergent Membranes

- Hypermultiplets of M-theory on X_6 (5D) and type IIA string theory on X_6 (4D) can be non-trivially identified.
- We show: emergent membrane limit (M5 on Σ_3) maps to pathological string limit (D4 on Σ_3), equivalent to D1-limit studied by [Baume, Marchesano, Wiesner '19].
- Pathological string limit is modified to emergent string limit by instanton corrections [B–M–W '19].
- **Result:** emergent membrane limit is modified to decompactificaton limit by instanton corrections. [DK, Álvarez-García, Weigand '21].



Censorship of Emergent Membranes



Summary

Summary

- Physics of infinite distance limits is universally governed by a tower of KK modes or string excitations.
- We have clarified the role of membranes in this picture:

Consistent dimensional reduction implies their decoupling!

Thank you!

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