Is M-theory emergent?

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Infinite distances in QG

SDC [Ooguri, Vafa '06] : exponentially light, infinite towers at large distances

Refinement [Lee, Lerche, Weigand '19] : limit either decompact. (DEC) or emergent string (ES)

species scale [Dvali '07]

(ES) $g_s \ll 1$ → **perturbative type IIA**

(P) String modes $M_s \sim \tilde{\Lambda}$ — string loop expansion in g_s

(NP) $p-$branes $T_p \sim M_s^{p+1}/g_s^{\beta=1,2}$

(DEC) $g_s \gg 1$ → **M-theory limit**

$g_s = (M_* R_{11})^{\frac{3}{2}}$

What is P / NP? (→ Part 1)

$\tilde{\Lambda} = M_*$

11D Planck scale

How to compute terms in low-energy effective action? (→ Part 2)

Perturbative degrees of freedom

Define M-theory limit

Decompactify $d \to d+1$

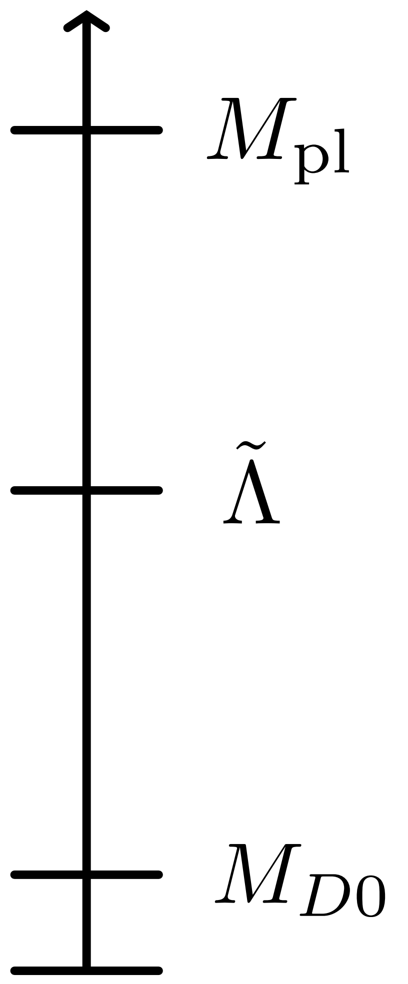
Type IIA on X_{10-d} (M-theory on $X_{10-d} \times S^1$)

(1) $\left(M_{\text{pl}}^{(d)}\right)^{d-2} = M_*^9\, V_{10-d}\, R_{11} = \text{const.}$ (2) $M_*^{10-d}\, V_{10-d} = \text{const.}$

Take $R_{11} \to \lambda R_{11}$ & co-scale $M_* \to \lambda^{-\frac{1}{d-1}} M_*$, $R_I \to \lambda^{\frac{1}{d-1}} R_I$ for $\lambda \to \infty$

Find perturbative states

Lightest states: $M_{D0}^{n} = \dfrac{M_{\text{pl}}^{(d)}}{\lambda}\, n \;\to\; \tilde{\Lambda} = \dfrac{M_{\text{pl}}^{(d)}}{\lambda^{\frac{1}{d-1}}} \sim M_{\text{pl}}^{(d+1)}$ Moreover $M_{D2,\,NS5,\,KK} \sim \tilde{\Lambda}$



Light DOF's: transverse (to S^1) $M2$ and $M5$ branes with KK momentum along S^1

The Emergence Proposal

How to derive low-energy data?

[Heidenreich, Reece, Rudelius ’17] [Grimm, Palti, Valenzuela ’18]

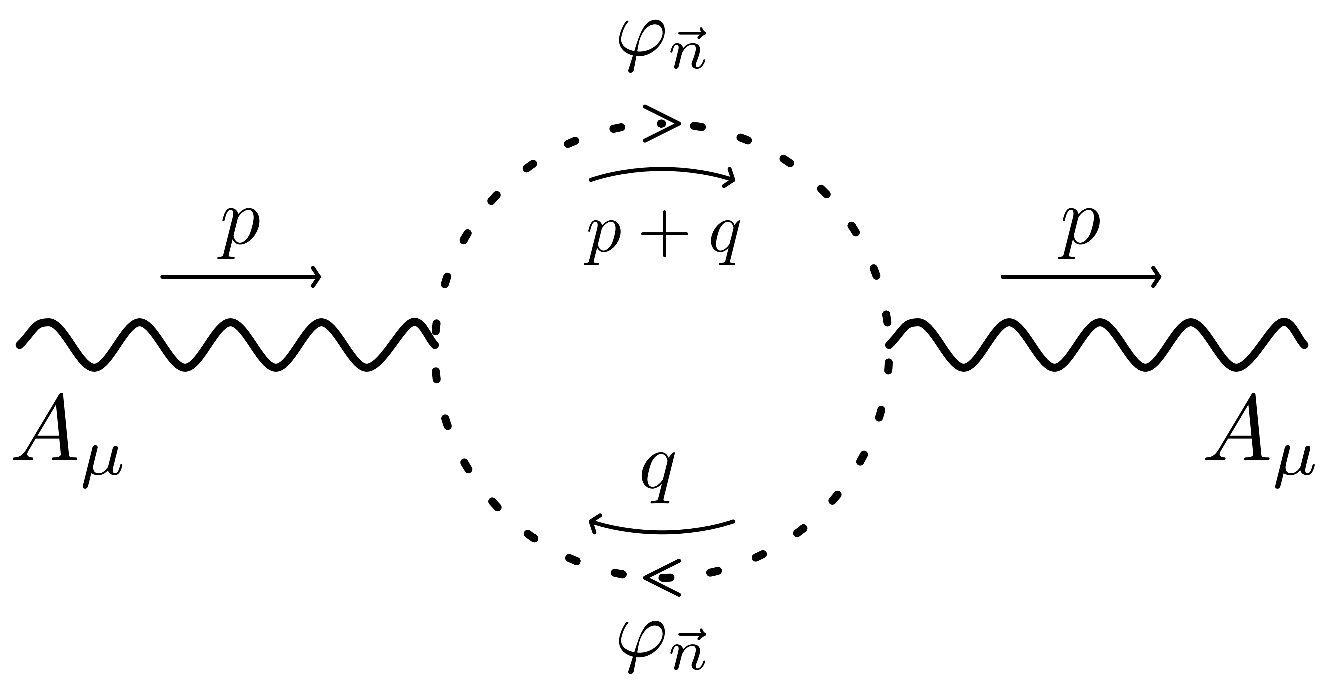
Strong Emergence: The dynamics (kinetic terms) for all fields are emergent in the infrared by integrating out towers of states down from an ultraviolet scale, which is below the Planck scale.

from: review [Palti ’19]

Example: 4D $U(1)$ gauge theory $m_n = |q_n| = n\,\Delta m\,,\quad n \in \mathbb{N}\,,\quad n_{\max} \to \infty$

$$\frac{1}{g^2_{U(1)}} \simeq \sum_{n=1}^{n_{\max}} q_n^2 \log\left(\frac{m_n^2}{\mu^2}\right) \simeq \sum_{n=1}^{n_{\max}} \int_0^\infty \frac{dt}{t^2}\, e^{-\pi t\,(n\Delta m)^2}$$

UV-divergence



- To which extent does emergence hold for both DEC and ES?
- How to regularize?

Emergence in M-theory?

Evidence? 1/2-BPS saturated amplitudes

Example: R^4 couplings

see [Green, Gutperle, Vanhove '97]

$$S_{R^4} \simeq M_*^{d-8} \int d^d x \sqrt{-g}\, \mathcal{V}_k\, r_{11}\, a_d\, t_8 t_8\, R^4$$

from four-graviton scattering
at one-loop in 11D

only one-loop ← ($g_s \ll 1$) | Schwinger integral | → ($g_s \gg 1$) tree-level, one-loop and NP in g_s

Proposal

Emergence (M-theory): Low-energy effective field theory emerges via quantum effects by integrating out infinite towers with mass parametrically not larger than the 11D Planck scale.