The Cosmological Constant Problem and Dark Energy from Non-Supersymmetric String Theory

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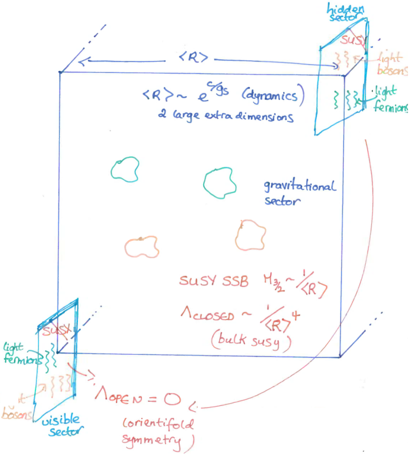
PASCOS 2026
Sheffield, 26th June 2026

based on 2512.20570
with Emilian Dudas and Marco Serra

Preview

An string construction in which symmetries and dynamics lead to a suppression of the one-loop vacuum energy down to the observed scales!



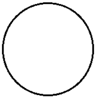
dovetailing $\Lambda \sim 1/R^4$ with moduli stabilisation?
SM?
higher loops?

Building on:
Antoniadis, Dudas & Sagnotti ’99
Aghababaie, Burgess, SLP & Quevedo ’03
Antoniadis & Angelantonj ’03
Angelantonj & Cardella ’04
Dudas, Coudarchet & Partouche ’21
Montero, Valenzuela & Vafa’22

Plan

- Vacuum energy in string theory
- Orientifolds and susy breaking in string theory
- A string construction where $\Lambda_{\text{open}} = 0$ and $\Lambda_{\text{closed}} \sim \frac{1}{R^4} \sim \Lambda_{\text{obs}}$
- A moduli stabilisation scenario where $\frac{1}{R^4} \sim \frac{1}{e^{4c/g_s}} \sim \Lambda_{\text{obs}}$
- Open questions

We can compute vacuum energy unambiguously in string theory



- In QFT, the vacuum energy is a renormalised parameter:

$$\rho_{\text{phys}} = \rho_{\text{bare}} + \sum_i (-1)^{F_i} n_i \frac{m_i^4}{16\pi^2} \ln\left(\frac{m_i^2}{\mu^2}\right) + \rho_{\text{vac}}^{\text{EW}} + \rho_{\text{vac}}^{\text{QCD}} + \ldots ,$$

expected at $\mathcal{O}(10^8 \text{GeV}^4) - \mathcal{O}(M_{\text{Pl}}^4)$ c.f. observed Dark Energy $\rho_{\text{obs}} \sim \mathcal{O}(\text{meV}^4)$.

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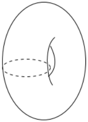

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$$\mathcal{T}_{\text{IIB}} = \int_{\mathcal{F}} \frac{d^2\tau}{\tau_2^2} \frac{1}{\tau_2^4} \text{Str}_{\mathcal{H}} \left(e^{-\tau_2 \ell H} e^{i\tau_1 \ell P}\right)$$

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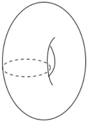

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  written in terms of modular functions and showing an infinite tower of states mass$^2 \sim n/\alpha'$ with degeneracies that grow exponentially with n:

$$V_8 = \frac{\vartheta_3^4(0|\tau) - \vartheta_4^4(0|\tau)}{2\,\eta^4(\tau)} = 8 + 56\,q + 224\,q^2 + 720\,q^3 + \cdots\,,$$

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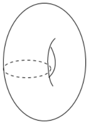

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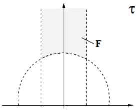

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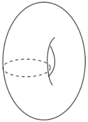

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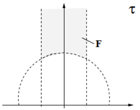

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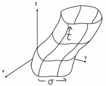
- Finite thanks to modular invariance. $\mathcal{N} = 2$ susy and $V_8 = S_8$ implies $\mathcal{T}_{\text{IIB}} = 0$.

String theory offers new symmetries – orientifolds

$\Sigma \ni (t,\sigma) \mapsto X^M(t,\sigma) \in \mathcal{M}$



- The embedding coordinates for the fundamental string into spacetime $X^M(t,\sigma)$ satisfy a 2d wave equation with solutions decomposing as:

$$X^M(t,\sigma) = X_L^M(t+\sigma) + X_R^M(t-\sigma) \qquad M = 0,\ldots,9\,.$$

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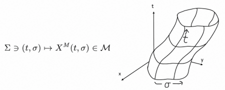

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$$\Omega : \quad \sigma \leftrightarrow -\sigma \quad \text{and} \quad X_L(t+\sigma) \leftrightarrow X_R(t-\sigma)\,.$$

This symmetry can be gauged, i.e. keeping only Ω-invariant states in the vacuum amplitude via $\mathrm{Str}_{\mathcal{H}}(\frac{1}{2}(1+\Omega)\ldots)$.

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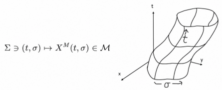

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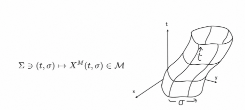

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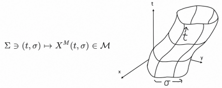

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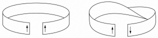

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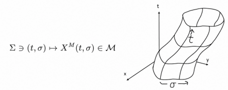

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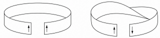
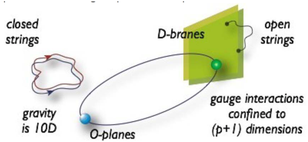


  which give rise to massless gauge multiplets in adjoint of SO(32).
- Spacetime interpretation is an $O9^-$-plane and 32 D9-branes, filling 10d.

String theory contains new sources

O-planes and D-branes offer interesting possibilities for model building.



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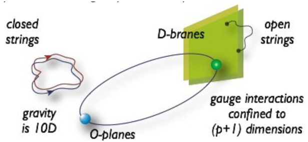

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- Compactifying on $\mathbb{T}^{9-p}$ and combining Ω with spacetime parity inversions $\Pi_m: \quad X^m \to -X^m$, gives rise to O$p$-planes and D$p$-branes.
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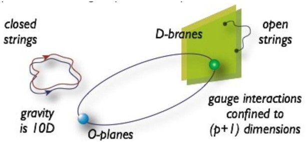

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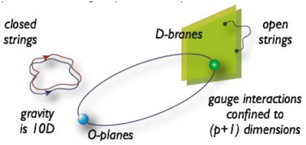

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- They carry tension T and RR-charge q as follows:

	D-branes		O-planes			
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RR charge	+	-	-	+	+	-
Gauge group	U(N)	U(N)	SO(N)	SO(N)	USp(N)	USp(N)
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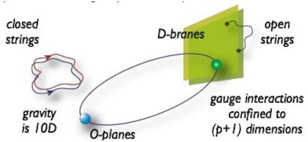

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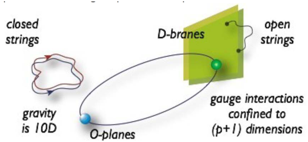

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- O/Ds preserve different susy to $\overline{\text{O}}/\overline{\text{D}}$s.

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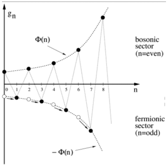

open strings have no superpartners, but a misaligned susy that helps finiteness.
Dienes '94; Cribiori, SLP, Tonioni & Wrase '20

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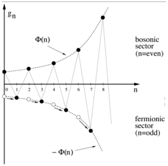

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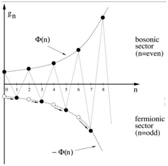

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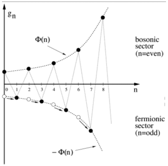

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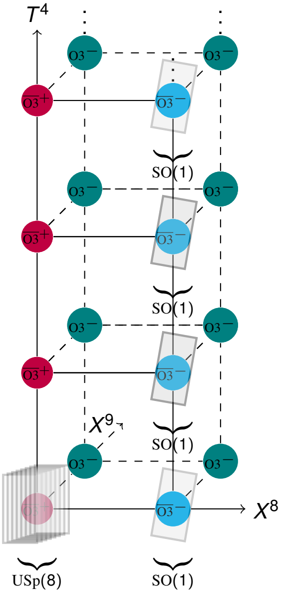
- The gravitino acquires mass $M_{3/2} \sim 1/R \sim M_{\text{KK}}$ and the closed strings contribute $\rho_{\text{closed}} \sim \mathcal{O}(M_{\text{KK}}^4)$ - matches ρ_{obs} for $R \sim \mathcal{O}(\mu\text{m})$! But swamped by tree-level ρ_{open} and pushed into instabilities...

How symmetry and dynamics give rise to $\rho_{\text{open}} = 0$ and $\rho_{\text{closed}} = \rho_{\text{obs}}$!

Compactify to 4d and use orientifold $\Omega' = \Omega\Pi_4 \ldots \Pi_9(-1)^{F_L}(-\delta_{w_9})^F$ and Scherk-Schwarz $g = (-1)^F \delta_{w_8}\delta_{p_9} \Rightarrow$ 16 ($\overline{\text{O3}}^+$, $\overline{\text{O3}}^-$, O3$^-$, O3$^-$) plus 16 D3-branes.



Place eight D3-branes on an $\overline{\text{O3}}^+$ and one D3-brane on eight of the $\overline{\text{O3}}^-$s $\Rightarrow$ USp(8) $\times$ SO(1)^8 gauge group.

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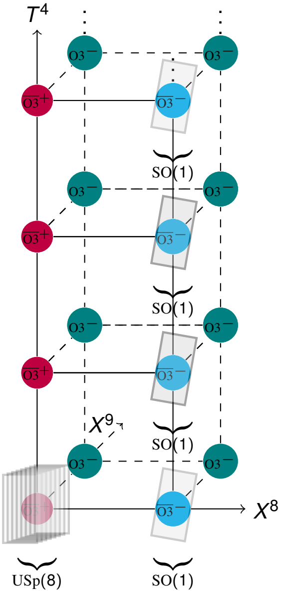

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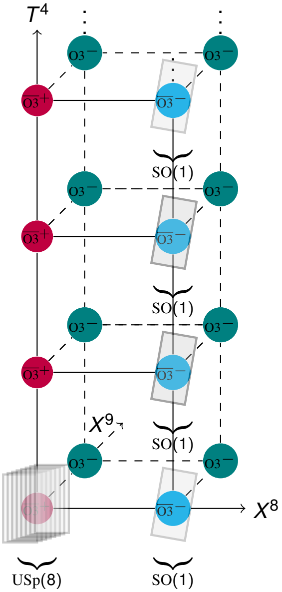

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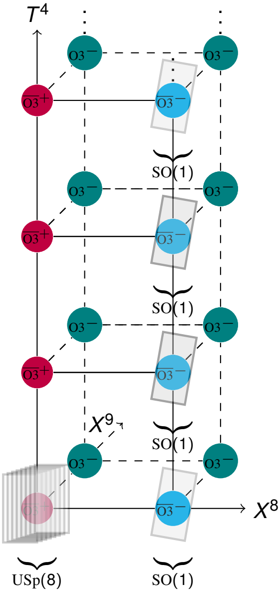

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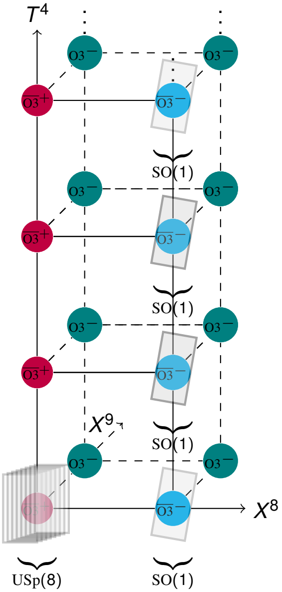

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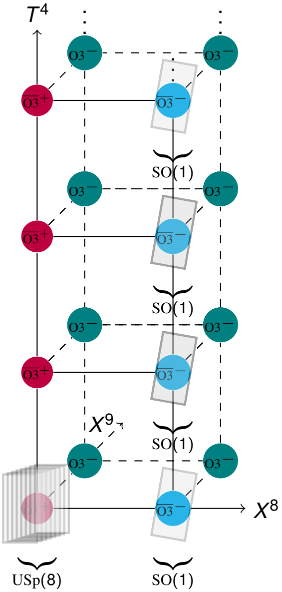

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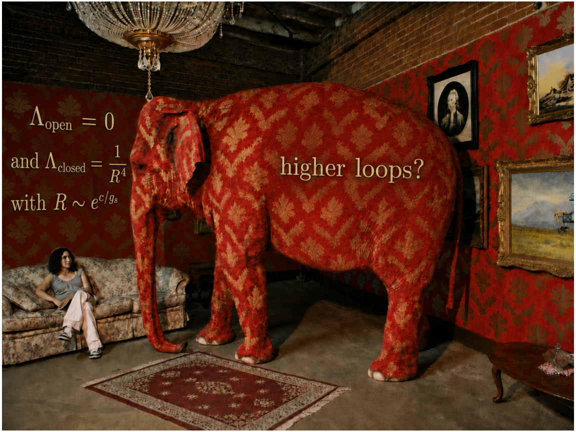
All closed string dofs can be stabilised by an interplay between Λ_{closed}, fluxes and D-instantons, with

$$V \sim \frac{e^{-4c/g_s}}{R^4} - \frac{C}{R^8} \Rightarrow R \sim e^{c/g_s}.$$

Summary



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Observational and Experimental Constraints on 2 LEDs

Expt/Obs	Probe	Constraint
Table-tops	deviation from inverse-square law due to light KK gravitons	$R \lesssim 30\,\mu$m
Old neutron stars	excess heat due to trapped KK gravitons decaying to photons (assuming no hidden channels)	$R \lesssim 75\,\mu$m
SN 1987A	shortening of neutrino burst due to KK graviton production and escape from core	$R \lesssim 0.33\,\mu$m
LHC	absence of string resonances	$M_s \gtrsim 8$TeV

Our best working solution with $\Lambda \sim 7.4 \times 10^{-121} M_{\rm Pl}^4$ has $M_s \sim 3$ TeV and $R \sim 1.58\mu$m, c.f. observational bounds $M_s \gtrsim 8$TeV and $R \lesssim 0.33\mu$m