de Sitter Constructions from String Theory

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(discussion with Shamit Kachru)
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S. AbdusSalam, S. Abel, M. Cicoli, FQ, P. Shukla 2005.11329
M. Cicoli, FQ, R. Savelli, A. Schachner, R. Valandro 2106.04592
M. Cicoli, I. Garcia-Etxebarria, FQ, A. Schachner, P. Shukla, R. Valandro 2106.11964
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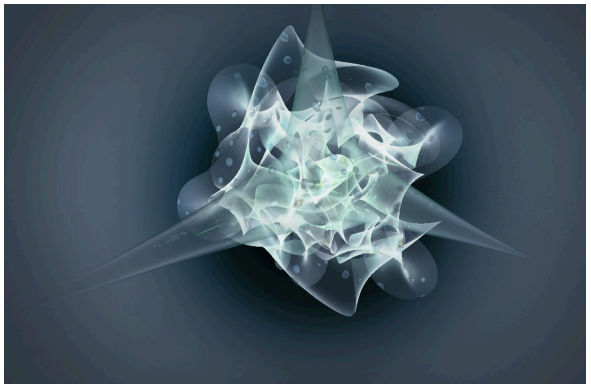
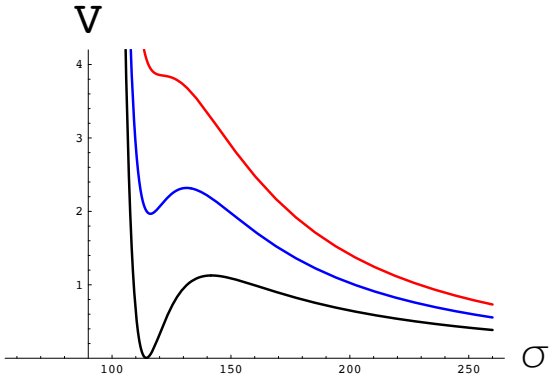
Two related string challenges

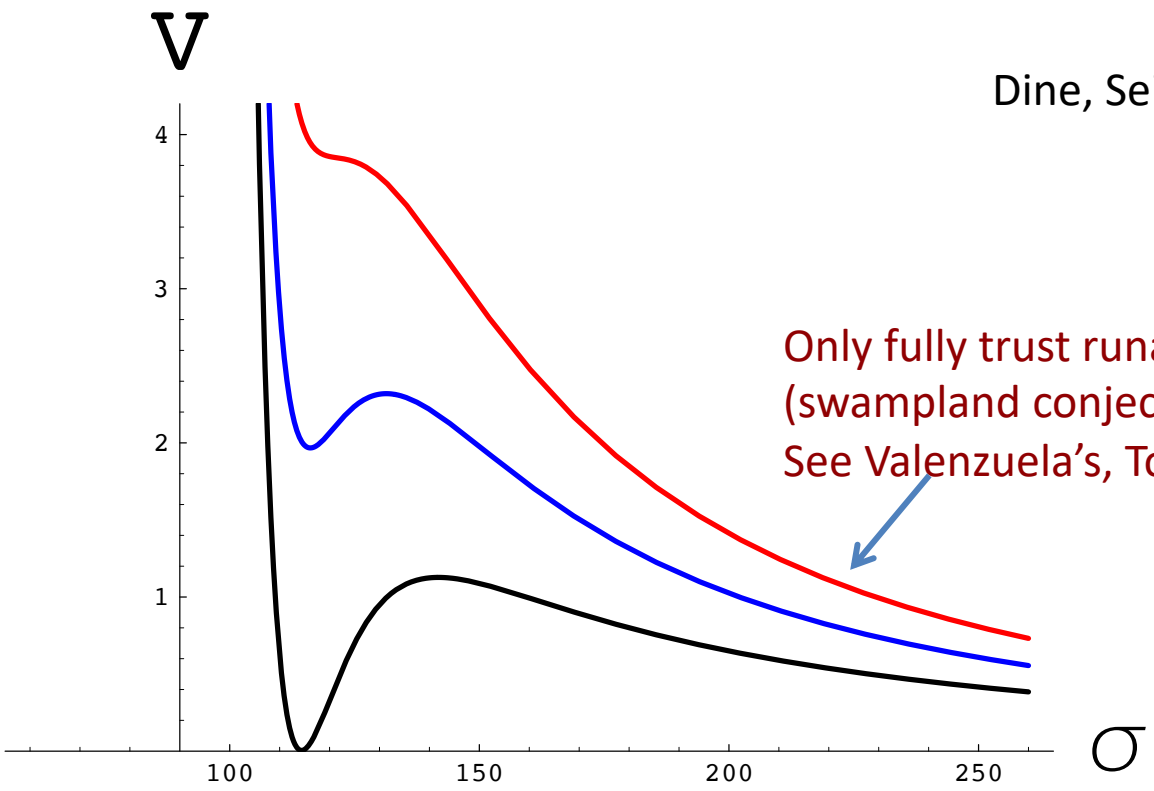
- **Moduli stabilization**



- **De Sitter**



Dine-Seiberg Problem



Dine, Seiberg 1985

Only fully trust runaway part
(swampland conjecture, Vafa et al
See Valenzuela's, Torroba's talks)

$V \longrightarrow 0$ at weak coupling and large volume.

If quantum corrections lead to another minimum it most probably be at strong coupling, unless…

String Compactifications

- **No free parameters in string theory**
- **But many discrete parameters after compactification:** (topological numbers of compact manifold, ranks of gauge groups, dimensionality of spacetime, fluxes of different forms,…)
- **Not only g_s and 1/V expansions but many expansions if there are many moduli.**
- **Never have full control but may lead to weak enough coupling and large enough volumes**

Moduli Stabilisation in IIB

- **Moduli S, T_i, U_a** $V_F = e^K \left(K^{-1}_{M\overline{N}} D_M W \overline{D}_{\overline{M}} \overline{W} - 3|W|^2 \right)$

$W_{\rm tree} = W_{\rm flux}(U,S)$ $K^{-1}_{i\bar{j}} K_i K_{\bar{j}} = 3$ No-scale

$V_F = e^K \left(K^{-1}_{a\bar{b}} D_a W D_{\bar{b}} W \right) \geq 0$

Fix S,U but T arbitrary

- **Quantum corrections** $\delta V \propto W_0^2 \delta K + W_0 \delta W$
- **Three options:** $W_0 \gg \delta W$ $\delta K \gg \delta W$ Runaway: Dine-Seiberg problem

$W_0 \sim \delta W = W_{\rm np}.$
$W_0 \ll 1$

Fix T-modulus: KKLT

$\delta K \sim W_0 \delta W$
$\delta K \sim 1/\mathcal{V}$ and $\delta W \sim e^{-a\tau}$

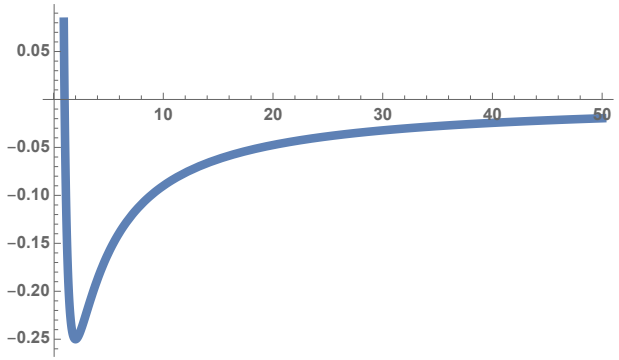
Fix T-moduli: LVS

AdS: N=1, 4D Effective Field Theory

$$K = -2\log\left(\mathcal{V}_{\rm CY}\right) - \log\left(S+\bar{S}\right) - \log\left(\int \Omega\wedge\bar{\Omega}\right)$$

$$W = W_0 + Ae^{-aT_i}$$

$$W_0 = \int G_3\wedge\Omega$$



e.g. KKLT

$$V/M_{\rm Pl}^4 = \frac{e^{K_{\rm cs}}}{6\tau^2}\left(aA^2(3+a\tau)e^{-2a\tau} - 3aAe^{-a\tau}W_0\right) \qquad V_{\rm up} \simeq \left(\frac{T+\bar{T}}{2}\right)^{-2}$$

e.g. LVS

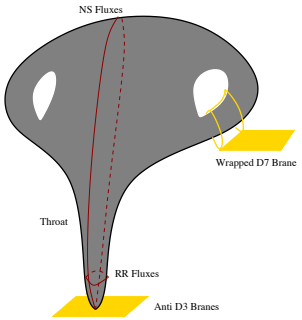
$$V_F \propto \left(\frac{K^{S\bar{S}}|D_S W|^2 + K^{a\bar{b}}D_a W\bar{D}_{\bar{b}}\bar{W}}{\mathcal{V}^2}\right) + \left(\frac{Ae^{-2a\tau}}{\mathcal{V}} - \frac{Be^{-a\tau}W_0}{\mathcal{V}^2} + \frac{C|W_0|^2}{\mathcal{V}^3}\right)$$

$$\mathcal{V} \sim e^{a_s\tau_s} \gg 1 \text{ with } \tau_s \sim \frac{\xi^{2/3}}{g_s}.$$

IIB Features

- Fluxes imply (warped) Calabi-Yau
- No-scale structure
- Scales $m_{3/2} << M_{KK} << M_s << M_p$
- Two sets of 3-fluxes F_3, H_3 (allows `tuning')
- GVW Superpotential W(S,U) not renormalised!
- Many loop (g_s) and α' corrections to K computed
- Kahler moduli gauge couplings $W_{np}(T)$

de Sitter?



- Anti D3 brane
- D+F terms in EFT or T-branes
- Complex structure/Dilaton uplift ($D_U W \neq 0$, $D_S W \neq 0$)
- Non critical strings, negative curvature
- Kahler uplift
- Nonperturbative effects on D3 branes, ...

Achievements

- **Well defined prescription exists that includes general stringy ingredients:** branes, orientifolds, warping, anti (T)-branes, perturbative, non-perturbative effects, etc.
- **W_0<<1 is plausible due to the large number of fluxes.**
- **Perturbative effects in LVS in control as the volume is exponentially large. All computed so far harmless.**
- **Antibrane: nonlinearly realised SUSY** (nilpotent goldstino)
- **Hierarchies:**

$$E \ll M_{\rm KK} = \frac{M_s}{\mathcal{V}^{1/6}} \ll M_s \equiv \frac{1}{\ell_s} \equiv \frac{1}{2\pi\sqrt{\alpha'}} = g_s^{1/4}\frac{M_p}{\sqrt{4\pi\mathcal{V}}}\,.$$

$$m_{3/2} \simeq W_0 M_P/\mathcal{V} \qquad\qquad m_{3/2}/M_{KK} \ll 1$$

Challenges to KKLT, LVS,...

- **Fluxes under control only in SUSY 10D?** (Sethi, Kachru-Trivedi, de Alwis et al…)
- **All SUSY breaking part is 4D EFT. Trust EFT?**(Carta, et al, Moritz et al, Kallosh, Gautason et al, Hamada et al, Kachru et al.)
- **Tuning W_0<<1? in KKLT** (Demirtas et al, Alvarez-Garcia et al)
- **Higher corrections in LVS?** (Cicoli et al.)
- **Antibranes (non susy, singularity?)** (Bena et al, Moritz et al, Cohen-Maldonado et al, Gao et al, Crino et al.)
- **Tadpole problem** (Bena et al., see Grana's talk)

Quintessence from Strings?

- **Need stabilise all moduli except for quintessence field: as difficult as getting de Sitter**
- **Or have many fields rolling but slower than quintessence. Difficult.**
- **Fifth force and varying couplings constraints (e.g. volume modulus or dilaton problematic)**

e.g. Banks, Dine, Douglas '00

Yukawa's

$$\hat{Y}_{ijk} = e^{K/2} \frac{Y_{ijk}(U)}{\sqrt{\tilde{K}_i \tilde{K}_j \tilde{K}_k}},$$

Open Questions

- **Control of quantum and α' corrections**
- **Realistic phenomenology** (de Sitter but no SM?)

See A. Schachner's poster

- **Moduli Stabilisation in F-Theory**
- **Populating the landscape** (large # of U moduli + vacuum transitions)
- …