Yukawa Couplings at Infinite Distance and Swampland Towers in Chiral Theories

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Based on [2403.09775] + [240X.XXXXX]

w/ Fernando Marchesano and Luis Ibáñez

Motivations

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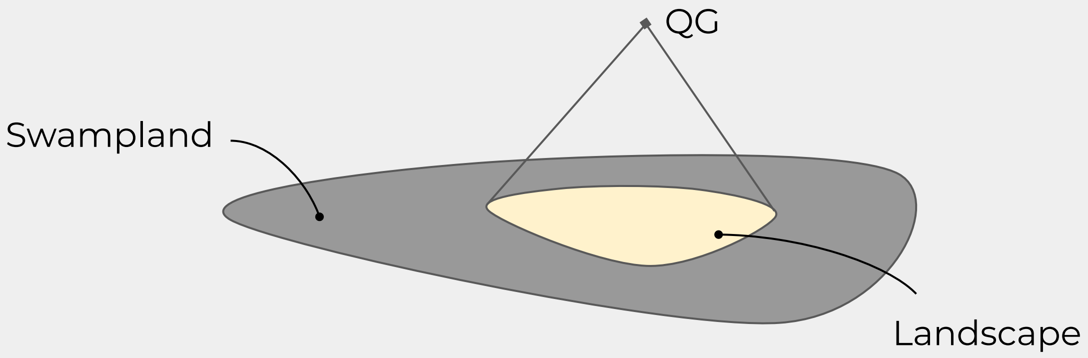
Not every EFT can be embedded in quantum gravity → there is a classification of such restrictions



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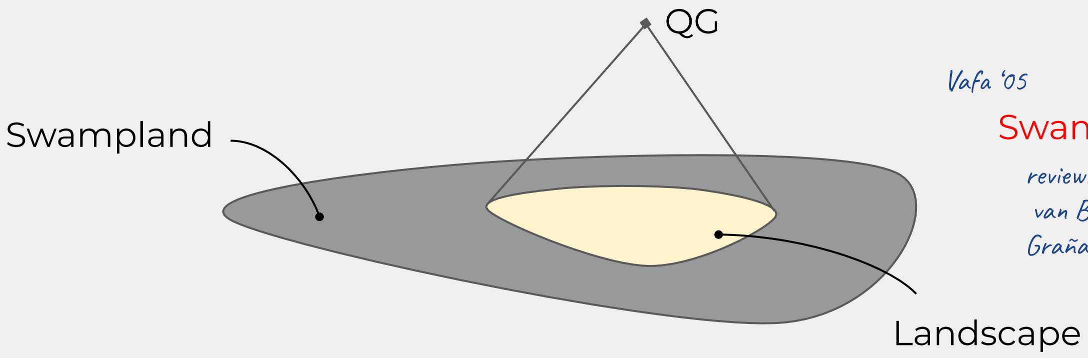

Vafa '05

Swampland conjectures

reviews: Brennan-Carta-Vafa '17 Palti '19
van Beest-Calderon-Mirfendereski-Valenzuela '21
Graña-Herraez '21

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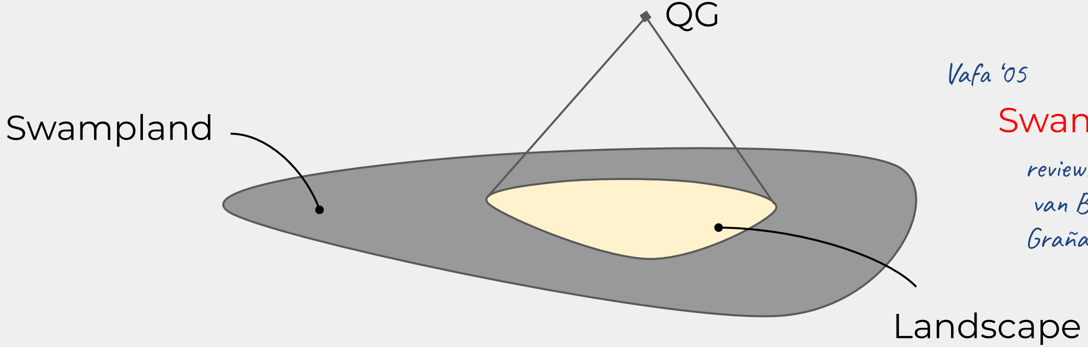

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No Global symmetries

Misner-Wheeler '57
Banks-Dixon '88
Banks-Seiberg '11

Any global symmetry must be broken or gauged in quantum gravity

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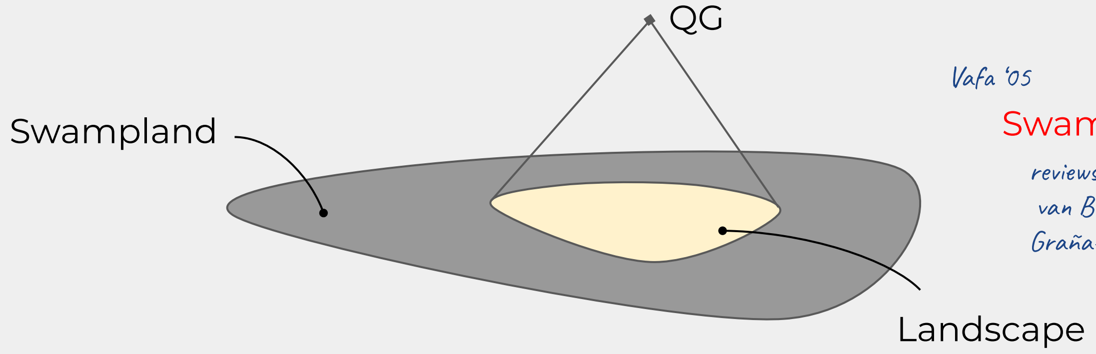

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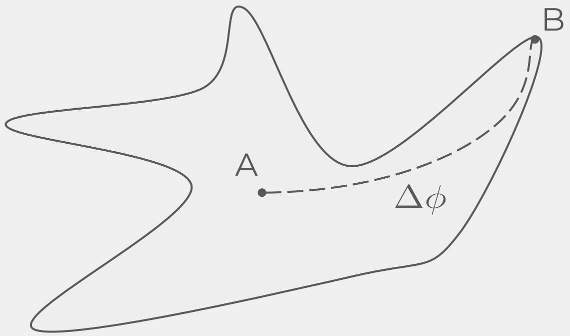
Ooguri-Vafa '05

Swampland distance conjecture

At any infinite distance limit in moduli space there is a tower of states becoming exponentially light

$$m_n \sim m_0 \, e^{-\alpha \Delta\phi}$$



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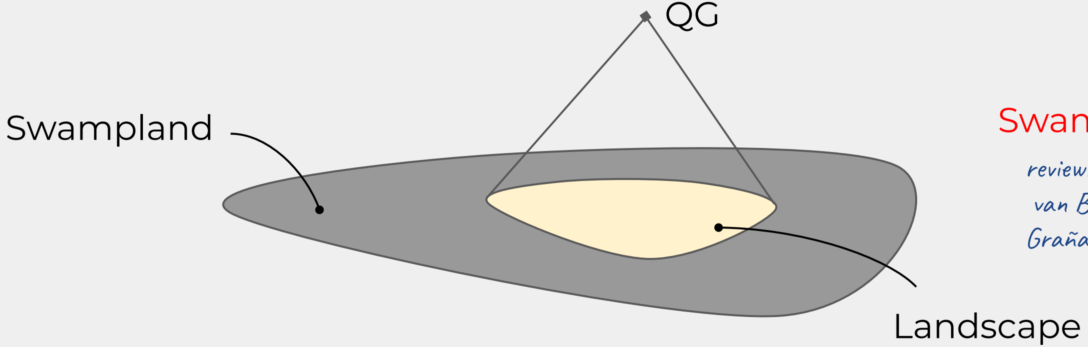
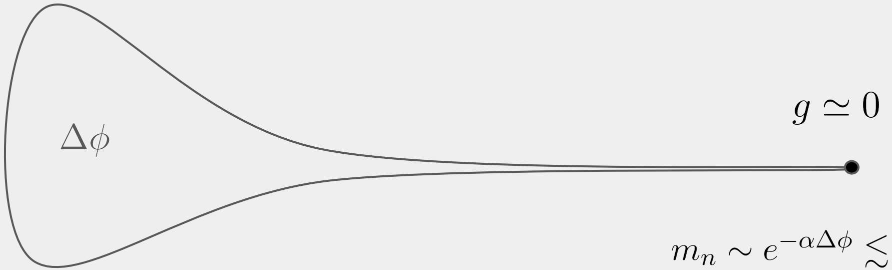
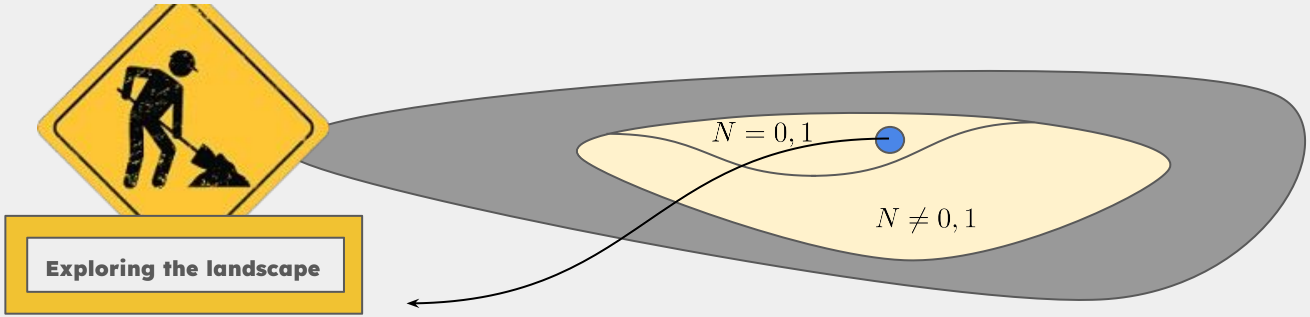


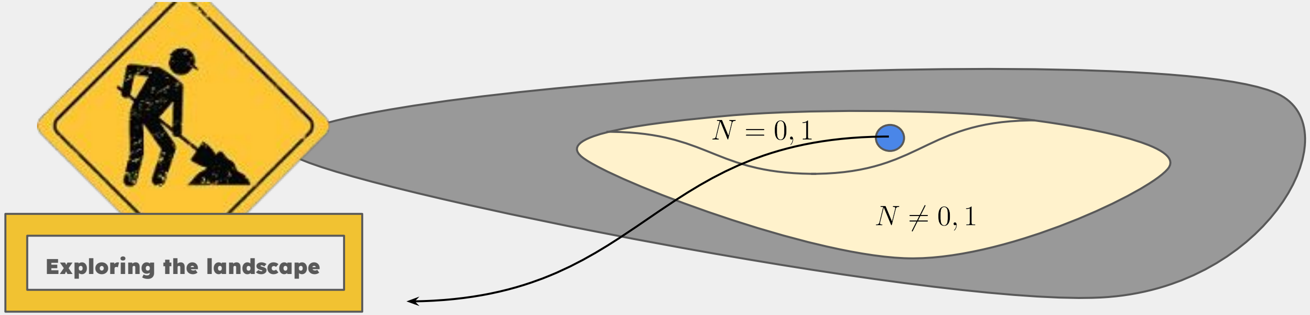
All the conjectures confabulate with each other



$$m_n \sim e^{-\alpha\Delta\phi} \lesssim g M_p^{D/2-1}$$



Infinite distance limits in 4d $N = 1, 0$ SUSY chiral theories are relatively unexplored. Most phenomenological interest



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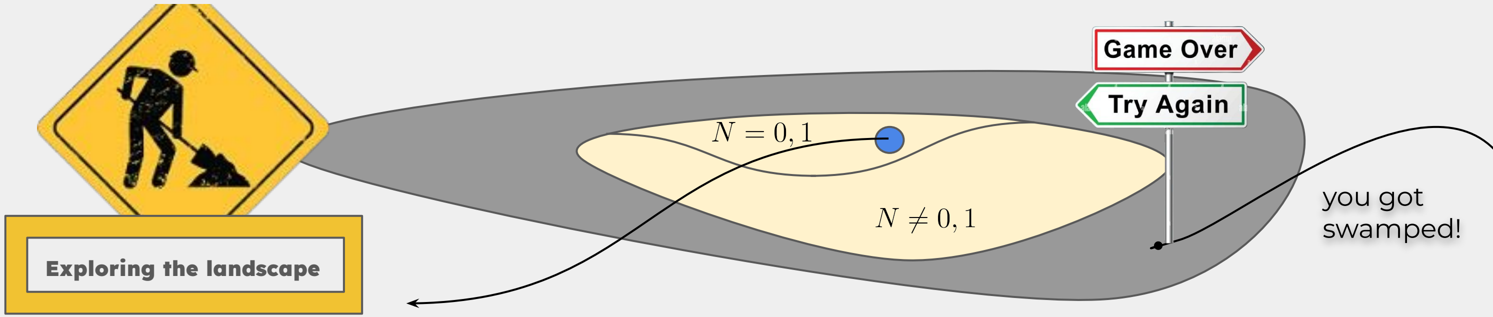
Such settings involve ingredients like e.g. perturbative trilinear Yukawa couplings Y_{ijk}. The natural question one could have is whether

$$Y_{ijk} \to 0$$

Cribiori-Farakos '23
Palti '20



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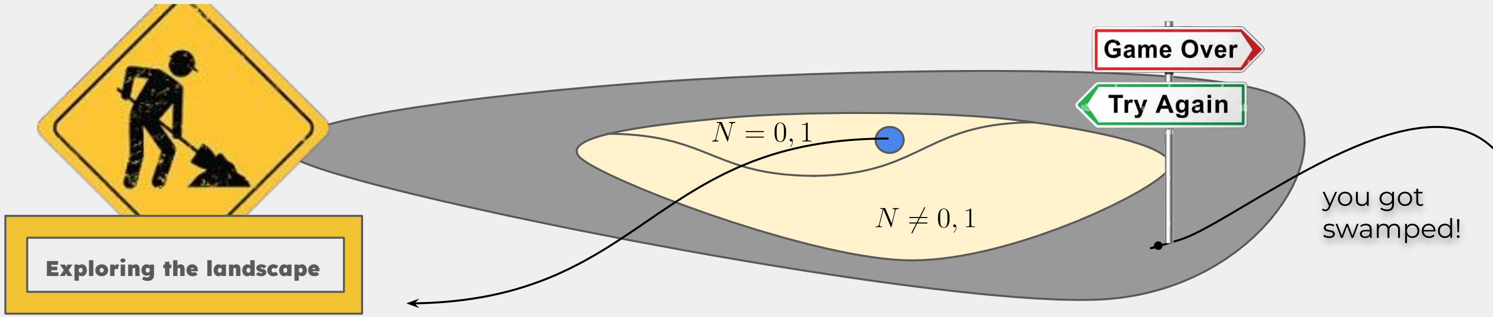

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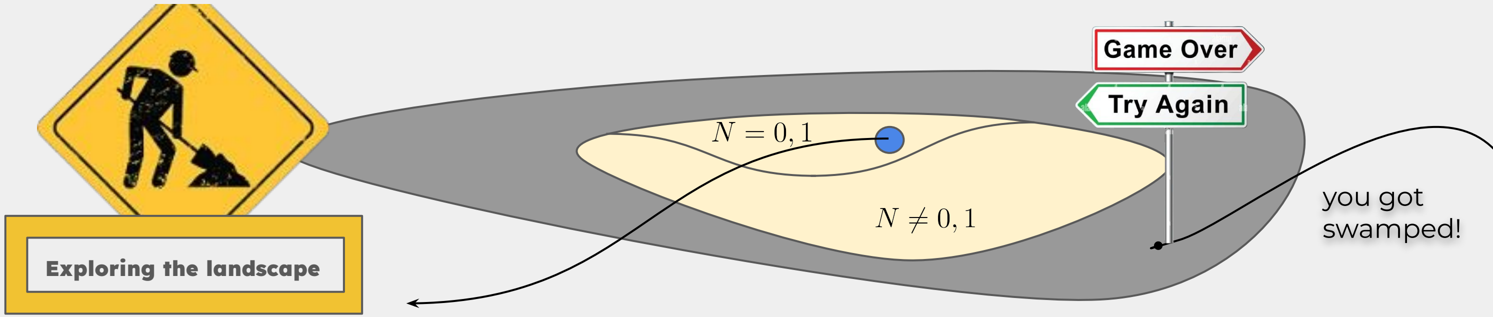
There is no obvious reason what goes wrong!



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There is no obvious reason what goes wrong!

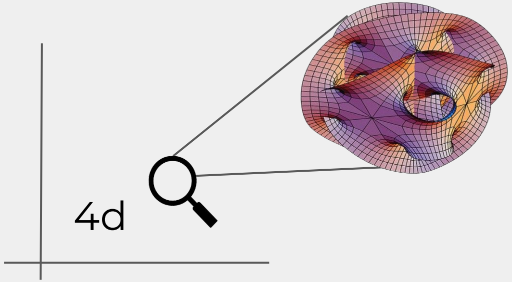
This limit MUST be explored!

In the SM $Y_\nu \sim 10^{-12}$

Laboratory: Intersecting branes (Type IIA)

Compactify Type IIA string theory on a CY orientifold

SUSY is broken from N=2 to N=1



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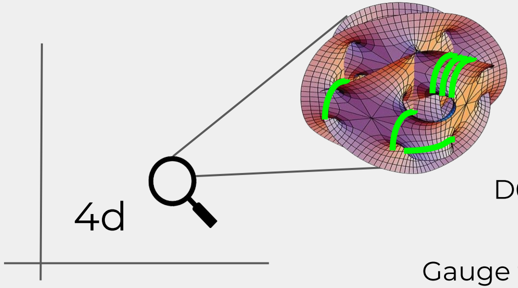

D6-branes

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Gauge theories in 4d

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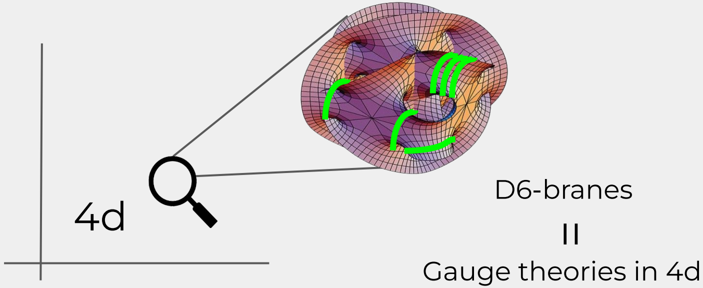
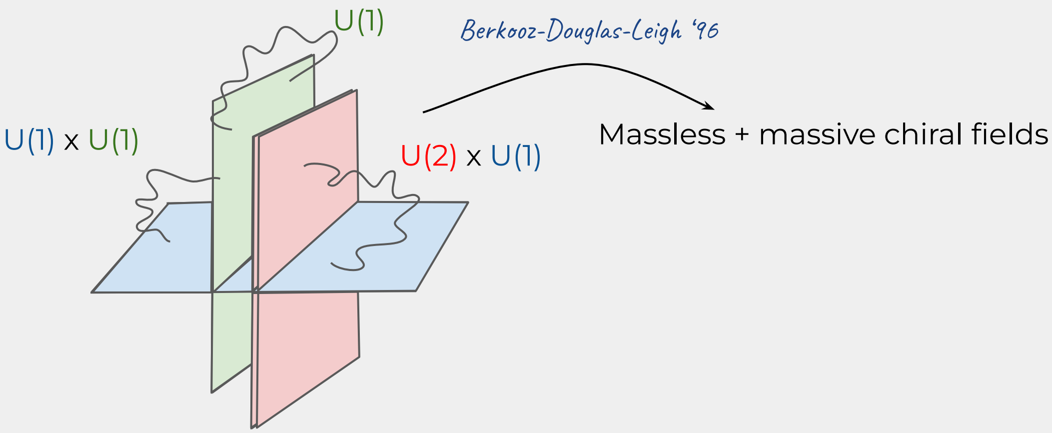


How does it work?



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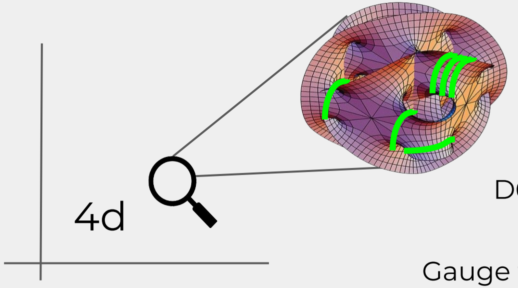

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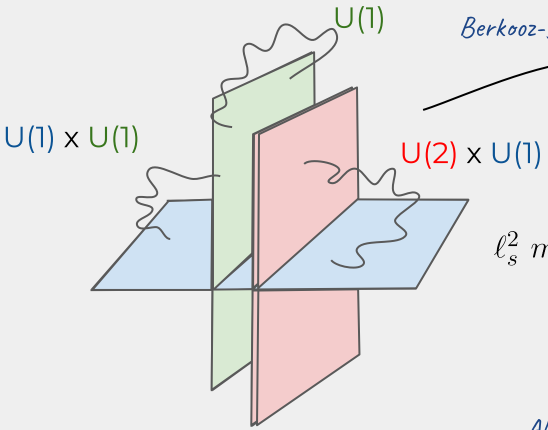

Berkooz-Douglas-Leigh '96

Massless + massive chiral fields

$$\ell_s^2 \, m_{\alpha\beta}^2 \simeq n_1 \, |\theta_{\alpha\beta}^1| + n_2 \, |\theta_{\alpha\beta}^2| + n_3 \, |\theta_{\alpha\beta}^3|$$

→ Gonions

Aldazabal-Franco-Ibañez-Rabadan-Uranga '00

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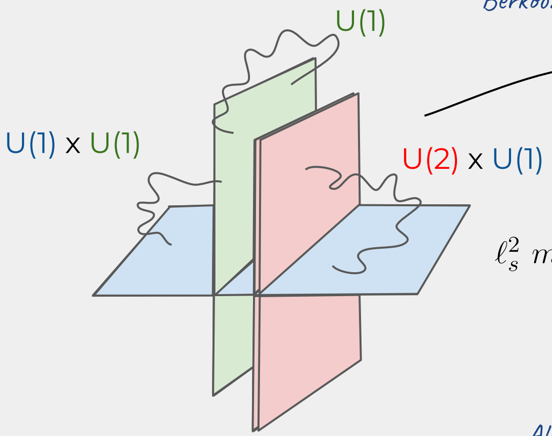

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Mutual supersymmetric branes are related by a SU(3) rotation

$$\theta_{\alpha\beta}^1 + \theta_{\alpha\beta}^2 + \theta_{\alpha\beta}^3 = 2\mathbb{Z}$$

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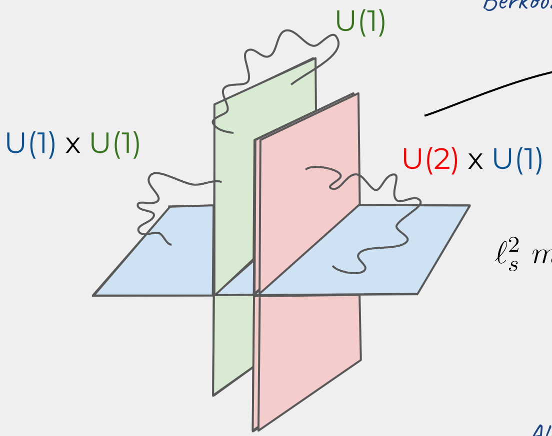

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Gonion masses may be understood as Fayet- Iliopoulos generated by the branes

Cremades-Ibañez-Marchesano '02

$$m^2_{\alpha\beta} = q^i_\alpha g^2_\alpha \xi_\alpha + q^i_\beta g^2_\beta \xi_\beta$$

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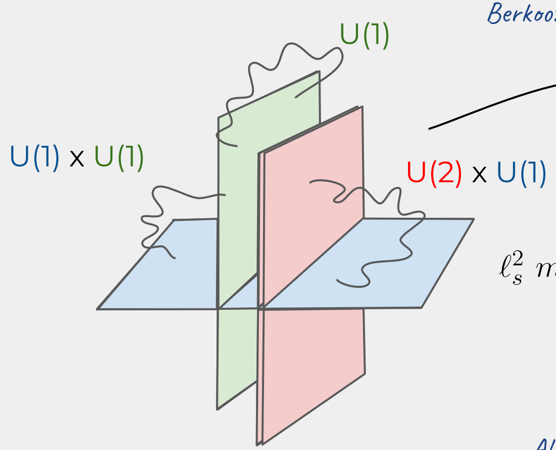

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It vanishes for SUSY configurations and a scalar partner of the fermion becomes massless

$$\ell_s^2 m_{\alpha\beta}^2 = \theta_{\alpha\beta}^1 \pm \theta_{\alpha\beta}^2 \pm \theta_{\alpha\beta}^3 = 0$$

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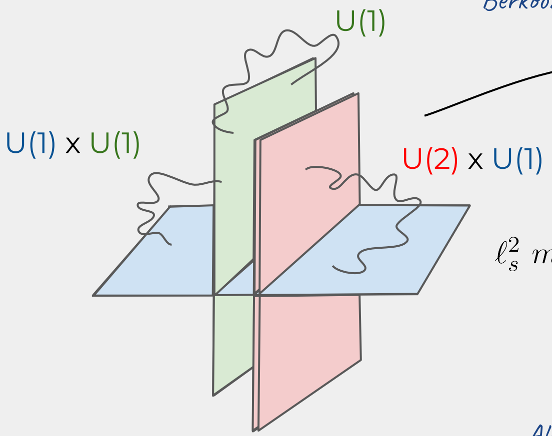

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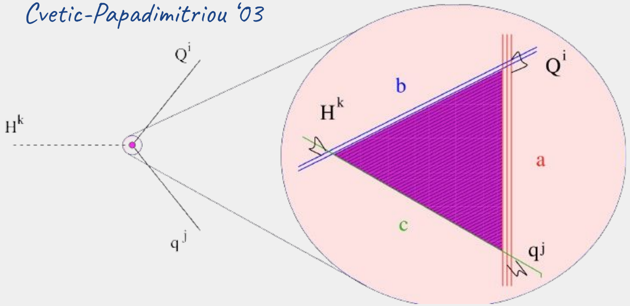
YUKAWA COUPLINGS IN TOROIDAL COMPACTIFICATIONS

Perturbative Yukawas are generated by worldsheet disc instantons connecting three D6-brane intersections

$$Y_{ijk} = \frac{e^{\phi_4/2}}{\mathrm{Vol}_X^{1/2}} \prod_{r=1}^{3} \left[2\pi \frac{\Gamma(1-|\chi^r_{ab}|)}{\Gamma(|\chi^r_{ab}|)} \frac{\Gamma(1-|\chi^r_{bc}|)}{\Gamma(|\chi^r_{bc}|)} \frac{\Gamma(1-|\chi^r_{ca}|)}{\Gamma(|\chi^r_{ca}|)}\right]^{1/4} W_{ijk}$$

$\chi^r_{\alpha\beta} = |\theta^r_{\alpha\beta}|$ or $1 - |\theta^r_{\alpha\beta}|$

Cremades-Ibañez-Marchesano '03 '04
Aldazabal-Franco-Ibañez-Rabadan-Uranga '00
Cvetic-Papadimitriou '03



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$\chi^r_{\alpha\beta} = |\theta^r_{\alpha\beta}|$ or $1 - |\theta^r_{\alpha\beta}|$

Depends on local geometry.

Yukawa couplings give information about the Kähler metric of chiral fields

$$Y_{ijk} = e^{K/2} \left(K_{i\bar{i}} K_{j\bar{j}} K_{k\bar{k}} \right)^{-1/2} W_{ijk}$$

$$K_{i\bar{i}} = e^{\phi_4} (2\pi)^{-1/2} \prod_{r=1}^{3} \left(\frac{\Gamma(|\chi^r_i|)}{\Gamma(1-|\chi^r_i|)} \right)^{1/2}$$

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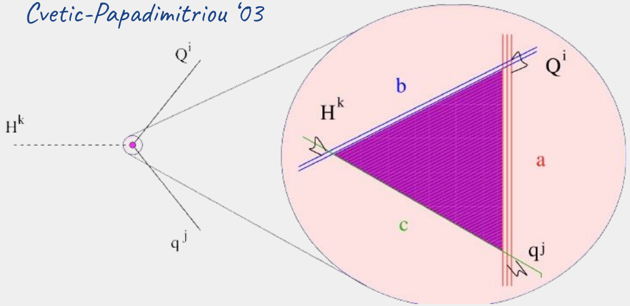

Infinite distance in Kähler moduli

$$Y_{ijk} = \frac{W_{ijk}}{\mathrm{Vol}_X^{1/2}} \; e^{\phi_4/2}\Theta_{ijk}^{1/4}$$

$$J_c \equiv B + iJ = (b^a + it^a)\omega_a$$

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Take the infinite distance limit (at fixed cc)

$$\mathrm{Vol}_X^{1/2} \to \infty$$

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$$m_{D0}^2 \sim \frac{M_P^2}{\text{Vol}_X}, \longrightarrow |Y| \simeq \frac{m_{D0}}{M_P}$$

Decompactification
to M-theory

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Infinite distance in c.c moduli

$$Y_{ijk} = \frac{W_{ijk}}{\mathrm{Vol}_X^{1/2}} \; e^{\phi_4/2}\Theta_{ijk}^{1/4}$$

$$\Omega_c \equiv C_3 + ie^{-\phi}\mathrm{Re}\Omega = (\xi^K + iu^K)\alpha_K$$

Take the infinite distance limit (at fixed cc)

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Take the infinite distance limit (at fixed t)

$$u^K = u_0^K + e^K\lambda, \quad \lambda \to \infty$$

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see also Castellano-Herraez-Ibañez '23

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Decompactification to M-theory

$$|Y| \simeq e^{-\phi_4}\left(\frac{m_{\mathrm{gon}}^i}{M_P}\frac{m_{\mathrm{gon}}^j}{M_P}\frac{m_{\mathrm{gon}}^k}{M_P}\right)^{1/2}$$

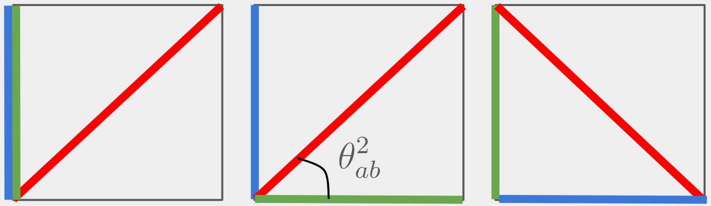
↳ Tower of gonions

Toy model example

GFC-Ibañez-Marchesano '24

Consider the following stack of branes

$$\Pi_a = 2(1,1)(1,1)(1,-1)$$
$$\Pi_b = 2(0,1)(1,0)(0,-1)$$
$$\Pi_c = 2(0,1)(0,-1)(1,0)$$



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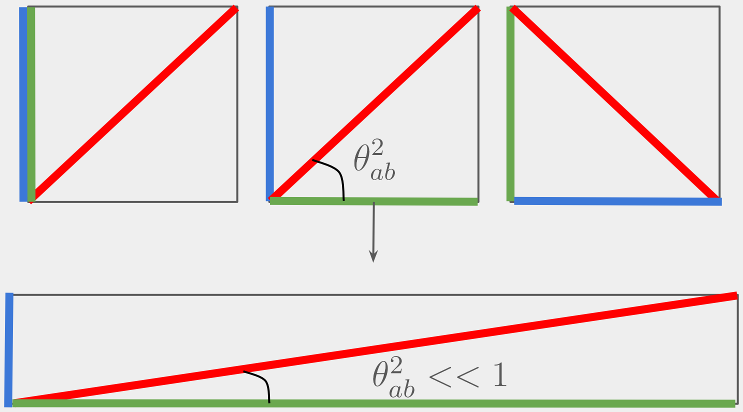
Take the complex structure limit

$$u^{(0)},\ u^{(2)} \sim u \to \infty$$

We find a gonion tower in sectors aa* and ab with masses



$$m_{\rm gon} = e^{\phi_4}|\theta^2_{ab}|^{1/2} M_P \simeq \frac{M_P}{u}$$

KK modes at the same scale

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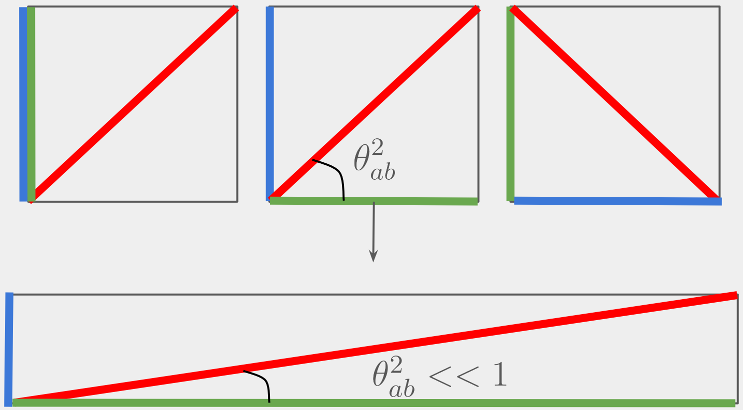

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KK modes at the same scale

The Yukawa coupling involved takes the form

$$Y_{abc} \simeq \left(\frac{m_{\text{gon}}}{M_P}\right)^{1/2} \quad \text{with} \quad K_{ab} \simeq \frac{M_P}{m_{\text{gon}}}$$

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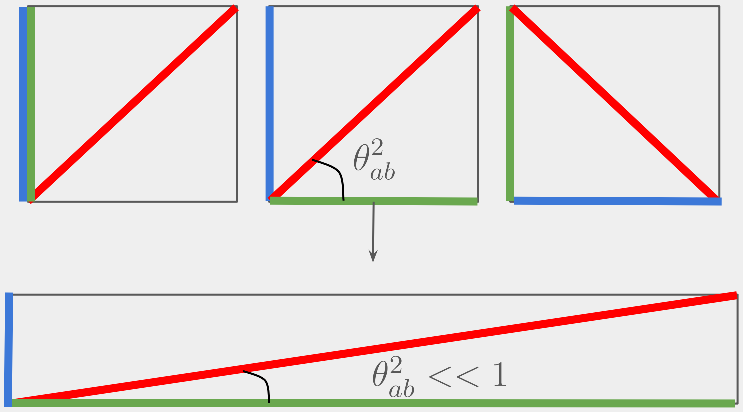

Take the complex structure limit

$$u^{(0)},\, u^{(2)} \sim u \to \infty$$

We find a gonion tower in sectors aa* and ab with masses

$$m_{\rm gon} = e^{\phi_4} |\theta^2_{ab}|^{1/2} M_P \simeq \frac{M_P}{u}$$

KK modes at the same scale

The Yukawa coupling involved takes the form

$$Y_{abc} \simeq \left(\frac{m_{\rm gon}}{M_P}\right)^{1/2} \quad \text{with} \quad K_{ab} \simeq \frac{M_P}{m_{\rm gon}}$$

$$Y_{abc} \sim g_a \sim g_b \longrightarrow$$ Recovering a global symmetry

Standard Model and Dirac neutrinos

GFC-Ibañez-Marchesano '24 (to appear)

$$N_a = 3 \qquad N_b = 2 \qquad N_c = N_{\tilde{c}} = N_d = 1$$

$$N_a = 3 \;\longrightarrow\; SU(3)_a \times U(1)_a$$

$$N_b = 2 \;\longrightarrow\; SU(2)_b \times U(1)_b$$

$$N_c = N_{\tilde{c}} = N_d = 1 \;\longrightarrow\; U(1)_c \times U(1)_{\tilde{c}} \times U(1)$$

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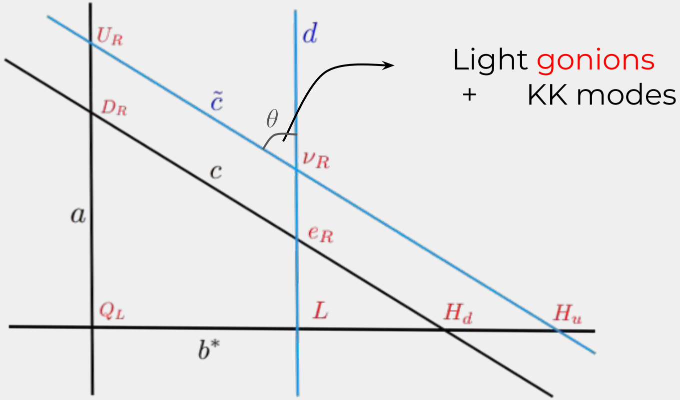

Anomaly FREE $\quad y = \frac{2}{3}Q_a - \frac{1}{2}Q_b + Q_c$

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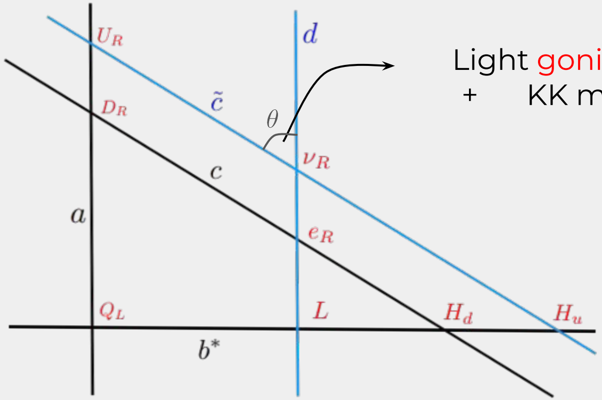

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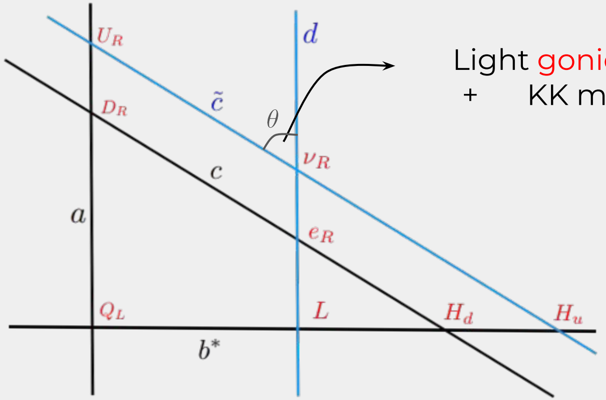

Light gonions
+ KK modes

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but the hypercharge g_y

$$Y_\nu \simeq \left(\frac{m_{\text{gon},\nu}}{M_P}\right)^{1/2}$$

This makes it possible to design a limit with suppressed neutrino yukawa coupling at the expense of having gonions and KK states around the corner.

$$Y_\nu^{\text{EXP}} \sim 6.9 \cdot 10^{-13} \longrightarrow m_{\text{gon},\nu} \simeq m_{KK} \simeq 500 eV$$

$$M_s = Y_\nu M_P = 700 \text{ TeV}$$

CONCLUSIONS AND OUTLOOK

We studied c.c limits in different set-ups

GFC-Ibañez-Marchesano '24

- 'STU' Type IIA orientifold models models, dual to magnetized Type I and SO(32) models with U(1) bundles
  Blumenhagen-Honecker-Weigand '05
- EFT string limits Lanza-Marchesano-Martucci-Valenzuela '20' 21
- Type IIA toroidal orientifolds (e.g. Pati-Salam-like)

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Taking $Y \to 0$ is not innocuous →
- Large volume → M-theory decomp. (Tower of D0's)
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$$Y \sim \prod_i \left(\frac{m^i_{\text{gon}}}{M_P}\right)^{1/2}$$

$$Y \sim \frac{1}{u^r}, \; r = \frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1$$

Similar powers in: Constantin-Fraser-Talient-Harvey-Lukas-Ovrut '24

$$Y \sim g_*^{2r}$$

Pathological signalling

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Pathological signalling

$Y_\nu \sim 6.9 \cdot 10^{-13}$ (EXP) = $m_{\text{gon}}^{1/2}$?? → m_{KK}

Swampland predictions exist!

Large extra dimensions?

THANK $Y_\nu \, O\bar{\nu}\nu$

SUSY CONDITION FOR BRANES

CY compactification with orientifold quotient

$$\Omega_{\rm ws}(-1)^{F_L}\mathcal{R}\,, \qquad \mathcal{R}(J,\Omega) = (-J,\bar{\Omega})$$

Holomorphic three-form

Kähler form

D6-branes wrapping three-cycles do not break SUSY if

$$\Pi_\alpha \in \text{Slag submanifolds}$$

We can also characterize such calibration condition

$$\text{Im}e^{-i\pi\varphi_\alpha}\Omega|_{\Pi_\alpha} = 0$$

At the intersection of two branes this translates to

$$\varphi = \varphi_\alpha - \varphi_\beta = 2\mathbb{Z}$$

Long story short, mutual supersymmetric branes are related by a SU(3) rotation

Berkooz-Douglas-Leigh '96

$$\theta^1_{\alpha\beta} + \theta^2_{\alpha\beta} + \theta^3_{\alpha\beta} = 2\mathbb{Z}$$

Gonion masses may be understood as Fayet- Iliopoulos generated by the branes

Cremades-Ibañez-Marchesano '02

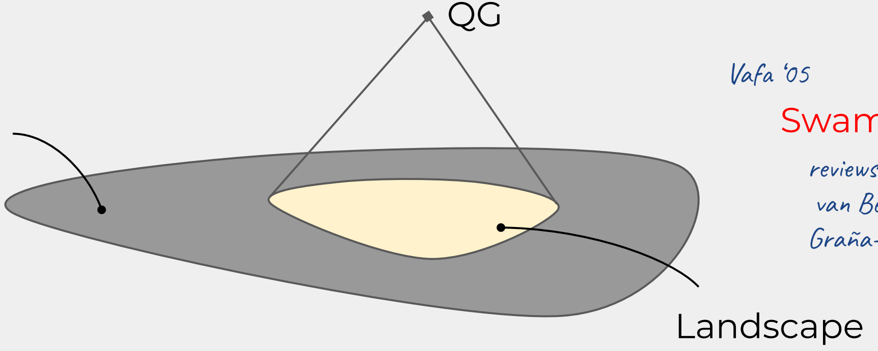
$$m^2_{\alpha\beta} = q^i_\alpha g^2_\alpha \xi_\alpha + q^i_\beta g^2_\beta \xi_\beta$$

Vanishes in a SUSY configuration in which a complex scalar partner of the chiral fermion becomes massless

$$\ell_s^2 m^2_{\alpha\beta} = \theta^1_{\alpha\beta} \pm \theta^2_{\alpha\beta} \pm \theta^3_{\alpha\beta} = 0$$

Motivations

Not every EFT can be embedded in quantum gravity → there is a classification of such restrictions



Vafa '05

Swampland conjectures

reviews: Brennan-Carta-Vafa '17 Palti '19
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Ooguri-Vafa '05

Swampland distance conjecture

At any infinite distance limit in moduli space there is a tower of states becoming exponentially light

$$m_n \sim m_0 \, e^{-\alpha \Delta\phi}$$

Arkani-Motl-Nicolis-Vafa '06

Weak gravity conjecture (and tWGC)

A gauge theory weakly coupled to gravity always contains a charged particle that satisfies

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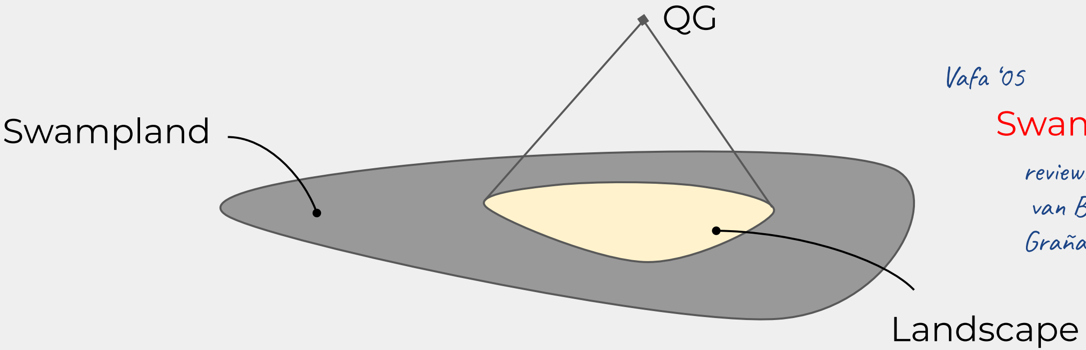

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