Hyperweak Gauge Groups in LARGE Volume Models

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This talk is particularly based on the paper

0805.4037 (hep-th), C. P. Burgess, J. P. Conlon, L-H. Hung, C. Kom, A. Maharana, F. Quevedo

Talk Structure

1. LARGE Volume Models
2. Hyper-Weak Gauge Groups

LARGE Volume Models

- Semi-realistic string compactifications require four dimensions and compactification on a Calabi-Yau.
- The size and shape of the Calabi-Yau appear in four dimensions as scalar particles (moduli).
- The moduli control all couplings and are naively massless with gravitational-strength interactions.

  This is bad: the moduli must be given masses and stabilised.
- The LARGE volume models are an attractive method of moduli stabilisation.

  These models arise in flux compactifications of IIB string theory.

Moduli Stabilisation: Fluxes

- Fluxes carry an energy density which generates a potential for the cycle moduli.
- In IIB compactifications, 3-form fluxes generate a superpotential

$$\begin{aligned} K &= -2\ln(\mathcal{V}) - \ln\left(i\int \Omega\wedge\bar{\Omega}\right) - \ln(S+\bar{S}) \\ W &= \int (F_3 + iSH_3)\wedge\Omega \equiv \int G_3\wedge\Omega. \end{aligned}$$

- This stabilises the dilaton and complex structure moduli.

$$D_S W = D_U W = 0.$$

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

Moduli Stabilisation: Fluxes

$$
\begin{aligned}
\hat{K} &= -2\ln\left(\mathcal{V}(T_i+\bar{T}_i)\right) , \\
W &= W_0 \, . \\
V &= e^{\hat{K}}\left(\sum_T \hat{K}^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2\right) \\
&= 0
\end{aligned}
$$

No-scale model :

- vanishing vacuum energy
- broken susy
- T unstabilised

No-scale is broken perturbatively and non-pertubatively.

Moduli Stabilisation: KKLT

$$\hat{K} = -2\ln(\mathcal{V}),$$
$$W = W_0 + \sum_i A_i e^{-a_i T_i}.$$

- Non-perturbative ADS superpotential.
- The T-moduli are stabilised by solving $D_T W = 0$.
- An uplift is included to generate susy breaking.

Moduli Stabilisation: LARGE Volume

$$\hat{K} = -2\ln\left(\mathcal{V} + \frac{\xi}{2g_s^{3/2}}\right), \qquad \left(\xi = \frac{\chi(\mathcal{M})\zeta(3)}{2(2\pi)^3 g_s^{3/2}}\right)$$

$$W = W_0 + \sum_i A_i e^{-a_i T_i}.$$

- Include perturbative α' corrections as well as non-perturbative corrections to the scalar potential.
- This leads to dramatic changes in the large-volume vacuum structure.

Moduli Stabilisation: LARGE Volume

The simplest model $\mathbb{P}^4_{[1,1,1,6,9]}$ has two Kähler moduli.

$$\mathcal{V} = \left(\frac{T_b + \bar{T}_b}{2}\right)^{3/2} - \left(\frac{T_s + \bar{T}_s}{2}\right)^{3/2} \equiv \left(\tau_b^{3/2} - \tau_s^{3/2}\right).$$

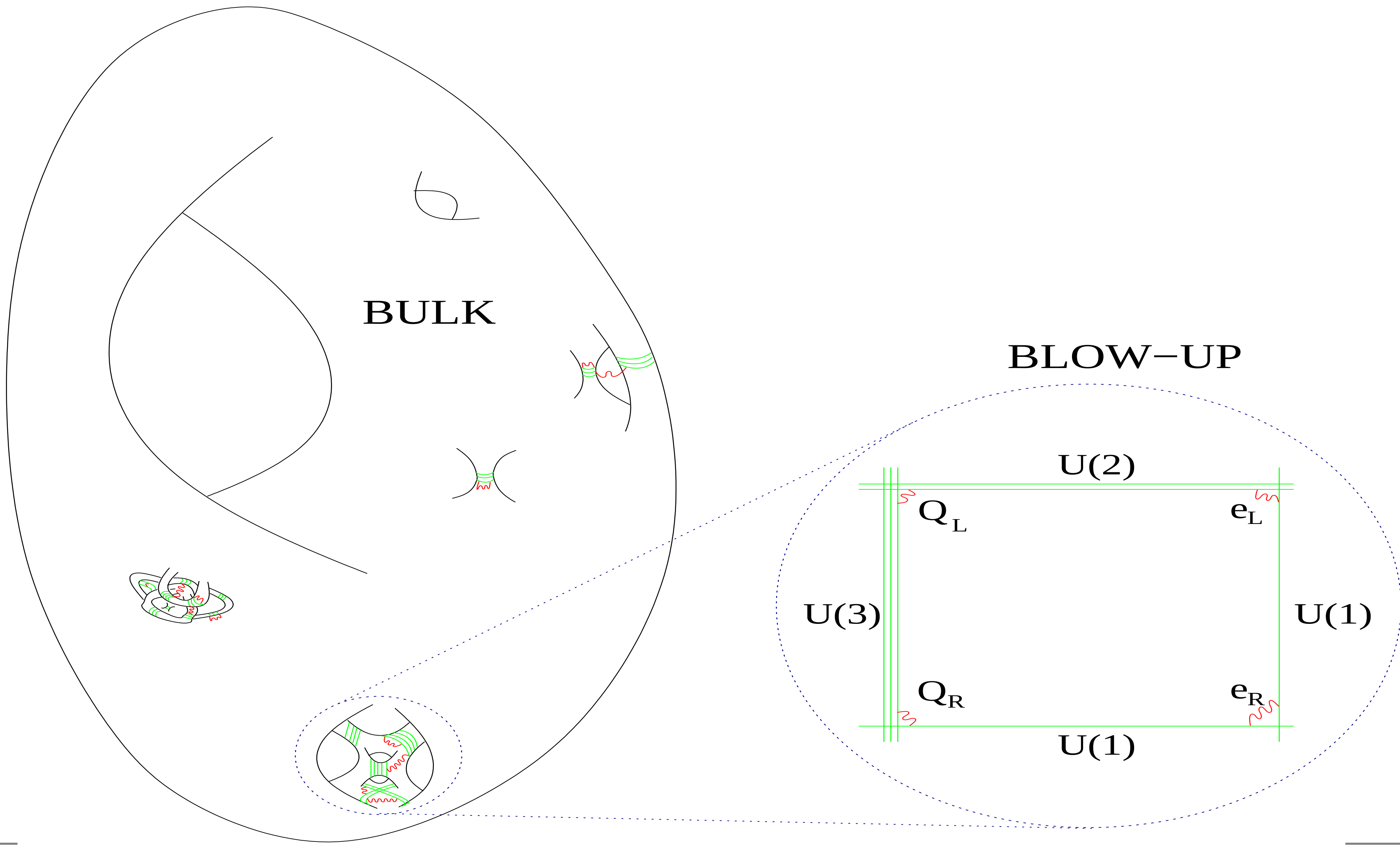
If we compute the scalar potential, we get for $\mathcal{V} \gg 1$,

$$V = \frac{\sqrt{\tau_s} a_s^2 |A_s|^2 e^{-2a_s\tau_s}}{\mathcal{V}} - \frac{a_s |A_s W_0| \tau_s e^{-a_s\tau_s}}{\mathcal{V}^2} + \frac{\xi |W_0|^2}{g_s^{3/2}\mathcal{V}^3}.$$

A minimum exists at exponentially LARGE volume

$$\mathcal{V} \sim |W_0| e^{a_s\tau_s}, \qquad \tau_s \sim \frac{\xi^{2/3}}{g_s}.$$

LARGE Volume Models



LARGE Volume Models

- The stabilised volume is exponentially large.
- The large volume lowers the string scale and gravitino mass through

$$m_s = \frac{M_P}{\sqrt{\mathcal{V}}}, \qquad m_{3/2} = \frac{M_P}{\mathcal{V}}.$$

- To solve the gauge hierarchy problem, need $\mathcal{V} \sim 10^{15}$.
- D7-branes wrapped on small cycle carry the Standard Model: need $T_s \sim 20(2\pi\sqrt{\alpha'})^4$.
- The vacuum is pseudo no-scale and breaks susy...

LARGE Volume Models

The mass scales present are:

Planck scale:	$M_P = 2.4 \times 10^{18}$GeV.
String scale:	$M_S \sim \frac{M_P}{\sqrt{\mathcal{V}}} \sim 10^{11}$GeV.
KK scale	$M_{KK} \sim \frac{M_P}{\mathcal{V}^{2/3}} \sim 10^9$GeV.
Gravitino mass	$m_{3/2} \sim \frac{M_P}{\mathcal{V}} \sim 30$TeV.
Small modulus	$m_{\tau_s} \sim m_{3/2} \ln\left(\frac{M_P}{m_{3/2}}\right) \sim 1000$TeV.
Complex structure moduli	$m_U \sim m_{3/2} \sim 30$TeV.
Soft terms	$m_{susy} \sim \frac{m_{3/2}}{\ln(M_P/m_{3/2})} \sim 1$TeV.
Volume modulus	$m_{\tau_b} \sim \frac{M_P}{\mathcal{V}^{3/2}} \sim 1$MeV.

LARGE Volume Models

- The LARGE volume dynamically generates the $\frac{M_{weak}}{M_{Planck}}$ hierarchy through low-scale supersymmetry.
- The volume also gives axion and neutrino mass scales at the correct order

$$f_a \sim \frac{M_{Planck}}{\sqrt{\mathcal{V}}} \sim 10^{11}\text{GeV}.$$

(JC, 2006)

$$m_\nu \sim \frac{M_{weak}^2 \mathcal{V}^{1/3}}{M_{Planck}} \sim \mathcal{O}(0.4\text{eV})$$

(JC, Cremades 2006)

- Here I discuss a different application of the LARGE volume models.

Hyper-Weak Gauge Groups

- In LARGE volume models, the Standard Model is a local construction and branes only wrap small cycles.
- There are also bulk cycles associated to the overall volume. These have cycle size

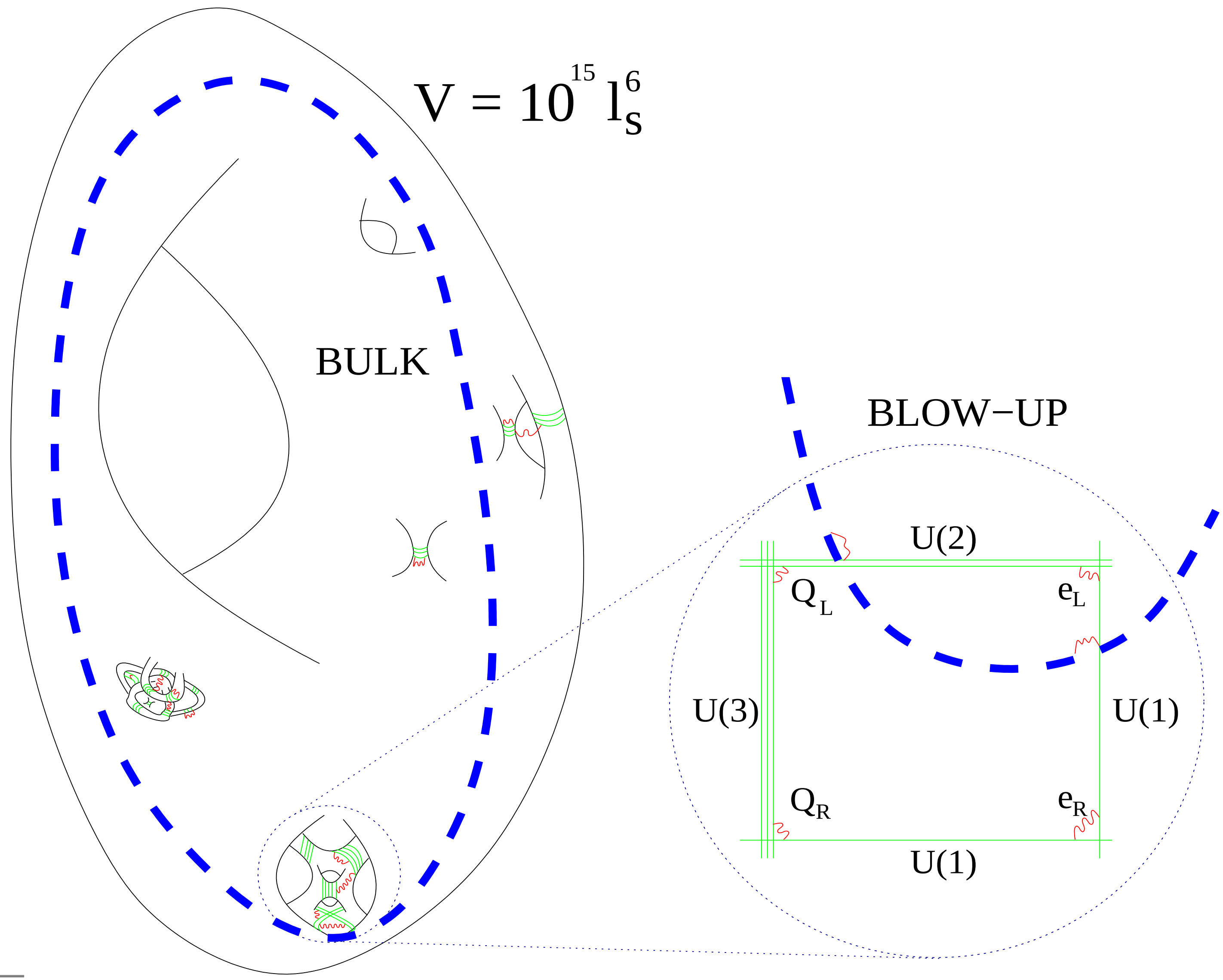
$$\tau_b \sim \mathcal{V}^{2/3} \sim 10^{10}.$$

- There is no reason not to have D7 branes wrapping these cycles!
- The gauge coupling for such branes is

$$\frac{4\pi}{g^2} = \tau_b$$

with $g \sim 10^{-4}$.

Hyper-Weak Gauge Groups



Hyper-Weak Gauge Groups

No reason for such branes not to exist!

In LARGE volume models it is a generic expectation that there will exist additional gauge groups with very weak coupling

$$\alpha^{-1} \sim 10^9.$$

Two phenomenological questions to ask:

1. How heavy is the hyper-weak Z' gauge boson?
2. Does it mix with the photon?
3. How does Standard Model matter couple to the hyper-weak force?

Hyper-Weak Gauge Groups

- If bulk D7 intersects Standard Model branes, SM matter can couple directly to bulk D7.

  SM matter may be charged directly under the new hyper-weak gauge group.
- Gauge group may couple directly to electrons or quarks, but with

$$g_e \sim 10^{-4}, \qquad g_e^2 \sim 10^{-8}.$$

- This motivates a new (relatively) light very weakly coupled gauge boson.

Hyper-Weak Gauge Groups

Hyper-weak Z' may get a mass by a Higgs mechanism in either visible or hidden sectors.

- If hyperweak gauge group is broken by weak-scale vevs of H_1, H_2,

$$M_{Z'} \sim gv \sim 10^{-4} \times 10 \to 100\text{GeV} \sim 1 \to 10\text{MeV}.$$

- If hyperweak gauge group is broken by chiral condensate $\langle \bar{q} q \rangle \sim \Lambda^3_{QCD}$,

$$M_{Z'} \sim gv \sim 10^{-4} \times 100\text{MeV} \sim 10\text{keV}.$$

- If hyperweak gauge group is broken by hidden sector physics $\langle \phi_{hid} \rangle \sim v$, $M_{Z'} \sim gv \sim 10^{-4} \times v$.

Hyper-Weak Gauge Groups

Hyper-weak Z' may also get a mass by anomalies (Ignatios's talk)

$$M_{Z'} \sim \xi g_{Z'} M_s \sim 10^5 \to 10^6 \text{GeV}$$

Too heavy to be relevant here.

A motivation for a super-LHC....?

Hyper-Weak Gauge Groups

- There may also be kinetic mixing between the new gauge boson and the photon.
- If the new gauge boson is light, the mixing allows the new boson to couple to electromagnetic currents:

$$\mathcal{L}_{int} = \frac{(\bar{\psi}\gamma^{\mu}\psi)A_{\mu}}{\sqrt{1-\lambda^2}} - \frac{(\bar{\psi}\gamma^{\mu}\psi)\lambda Z^{'}_{\mu}}{\sqrt{1-\lambda^2}}$$

  where λ is the mixing parameter.
- This can give SM matter milli-charged under the new gauge boson $Z^{'}$, and exotic matter milli-charged under the photon.

Hyper-Weak Gauge Groups

Bounds on an MeV-scale gauge boson: axial and vector couplings $g_V(\bar{\psi}\gamma^\mu\psi)Z'_\mu$ or $g_A(\bar{\psi}\gamma^5\gamma^\mu\psi)Z'_\mu$.

Coupling	Bound	Experimental measurement
g_e^V	$10^{-4}m_U$	g_e-2
g_e^A	$5\,10^{-5}m_U$	g_e-2
g_μ^V	10^{-3}	$g_\mu-2$
g_μ^A	$5\,10^{-6}m_U$	$g_\mu-2$
$\lvert g_e g_\nu\rvert$	$10^{-11}m_U^2$	$\nu-e$ scattering
$g_{c(b)}^A$	$10^{-6}m_U$	$B(\psi(\Upsilon)\to\gamma+\text{invisible})$
$\lvert g_e^A g_q^V\rvert$	$10^{-14}m_U^2$	atomic parity violation

Conclusions

- LARGE volume models are an attractive method of moduli stabilisastion and generating TeV supersymmetry.
- They motivate the existence of new hyper-weak gauge groups with $g^2 \sim 10^{-9} \sim \left(\frac{M_W}{M_P}\right)^{2/3}$.
- Such hyper-weak gauge groups can naturally be light with $M_{Z'} \lesssim 10$MeV.