Moduli and the Cosmic Photon Background

Joseph P. Conlon (DAMTP, Cambridge)

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Moduli

- In string compactifications, moduli are scalar fields parametrising the size and shape of the extra dimensions.
- Typical compactifications give $\mathcal{O}(100 - 1000)$ moduli.
- The moduli must be stabilised and given masses to evade fifth force constraints.
- Heavy moduli decay rapidly, but light moduli can be very long-lived.
- This talk is about light moduli ($m \lesssim 100$MeV).

Motivation: GMSB

- In gauge-mediated supersymmetry breaking, the gravitino mass is low,

$$m_{3/2} \ll 1\text{TeV}.$$

- The moduli masses are also low,

$$m_\phi \sim m_{3/2} \ll 1\text{TeV}.$$

Motivation: Large-Volume Models

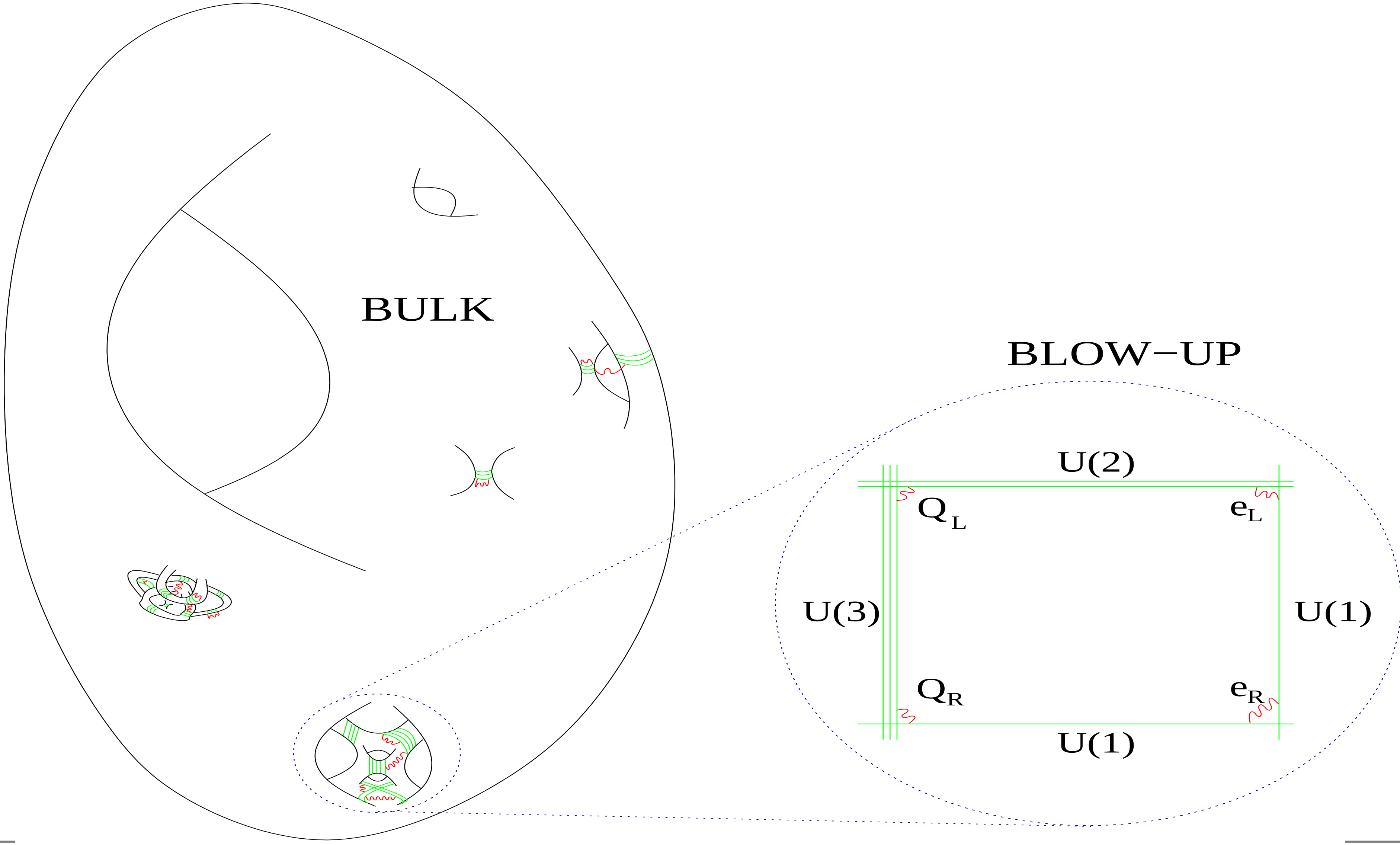
- Large-volume models (Balasubramanian, Berglund, JC, Quevedo) occur in IIB flux compactifications with α' and non-perturbative effects.
- The stabilised extra-dimensional volume is exponentially large,

$$\mathcal{V} \sim e^{\frac{c}{g_s}}.$$

- This can generate the weak hierarchy in a natural way,

$$m_{3/2} \sim \frac{M_P}{\mathcal{V}}.$$

Motivation: Large-Volume Models



Motivation: Large-Volume Models

The scales and particle spectrum for the large-volume models is as follows ($\mathcal{V} \sim 10^{15} l_s^6$):

Planck scale	M_P	2.4×10^{18}GeV
String scale	$\frac{M_P}{\sqrt{\mathcal{V}}}$	$\sim 10^{11}$GeV
KK scale	$\frac{M_P}{\mathcal{V}^{2/3}}$	$\sim 10^{9}$GeV
Blow-up moduli	$\frac{M_P \ln(\mathcal{V})}{\mathcal{V}}$	$\sim 10^{6}$GeV
Gravitino mass	$\frac{M_P}{\mathcal{V}}$	$\sim 3 \times 10^{4}$GeV
Soft terms	$\frac{M_P}{\mathcal{V} \ln(\mathcal{V})}$	$\sim 10^{3}$GeV
Bulk modulus	$\frac{M_P}{\mathcal{V}^{3/2}}$	~ 1MeV

Is the bulk modulus observable?

Moduli Decays: Photons

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}m_\phi^2\phi^2 - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{\lambda}{4}\frac{\phi}{M_P}F_{\mu\nu}F^{\mu\nu}.$$

The decay time to photons is

$$\tau_{\phi\to 2\gamma} = \frac{64\pi M_P^2}{\lambda^2 m_\phi^3} = \frac{7.5\times 10^{23}s}{\lambda^2}\left(\frac{1\text{MeV}}{m_\phi}\right)^3.$$

Moduli with masses $m_\phi \lesssim 100$MeV are stable across the lifetime of the universe.

Moduli Decays: e^+e^-

$$\mathcal{L} = -\frac{1}{2}m_\phi^2\phi^2 - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \bar{e}\left(\gamma^\mu\partial_\mu + m_e\right)e + \kappa\frac{\phi}{M_P}m_e\bar{e}e.$$

The decay $\phi \to e^+e^-$ is accessible if $m_\phi > 1$MeV.

$$\tau_{\phi\to e^+e^-} = \frac{8\pi M_P^2}{\kappa^2 m_\phi m_e^2}\left(1 - \frac{4m_e^2}{m_\phi^2}\right)^{-3/2}$$

Again, for $m_\phi \lesssim 100$MeV ϕ is stable on the lifetime of the universe.

Moduli and Dark Matter

- Any long-lived moduli must form some part of the dark matter.
- The $\phi \to 2\gamma$ and $\phi \to e^+e^-$ decays contribute to the galactic photon/positron population.
- 2γ decays from galactic dark matter would give a mono-energetic photon line (the galactic halo gives the strongest bounds).
- The rate of galactic 2γ decays is

$$\begin{aligned} \mathcal{N} &= \frac{M_{galaxy}}{m_\phi} \frac{\Omega_\phi}{\Omega_{dm}} \frac{1}{\tau_{\phi \to \gamma\gamma}} \\ &\sim \left(\frac{\Omega_\phi}{\Omega_{dm}}\right) \left(\frac{10^{26} s}{\tau_{\phi \to \gamma\gamma}}\right) \left(\frac{1\text{MeV}}{m_\phi}\right) 10^{45} s^{-1} \end{aligned}$$

Moduli Decays

- In the large-volume model, we can compute

$$\lambda_{\phi \to \gamma\gamma} \sim 0.04 \qquad \kappa_{\phi \to e^+e^-} \sim 0.41$$

For $m_\phi = 1.5$MeV, this gives

$$\tau_{\phi \to 2\gamma} = 1.4 \times 10^{26} s \qquad \tau_{\phi \to e^+e^-} = 3.8 \times 10^{24} s.$$

- The 2γ decay mode is suppressed by a factor ~ 700 compared to naive expectation.
- The dominant decay channel is to e^+e^- pairs.
- This may be interesting in view of the 511 keV line from the galactic centre.

Photon Fluxes

- With $m_\phi = 1.5$MeV, the 0.75MeV photon flux from the galactic centre

$$I_\gamma \sim 0.3 \left(\frac{\Omega_\phi}{\Omega_{dm}}\right) \text{photons } cm^{-2} s^{-1} sr^{-1}$$

- Comparison with the actual photon spectrum constrains

$$\left(\frac{\Omega_\phi}{\Omega_{dm}}\right) \lesssim 10^{-4}.$$

Conclusions

- The existence of light long-lived moduli fields is an interesting and well-motivated possibility.
- The dark matter abundance of such fields is constrained by the cosmic/galactic photon spectrum.
- The signal for such moduli is the line generated by the decay $\phi \to 2\gamma$.
- Low-energy observations can give information on high-energy physics.