Moduli Portal between hidden and visible sectors

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Based on work in progress with Michele Cicoli

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Motivation

Moduli Portal Dark Matter

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We show that moduli fields as mediators between the Standard Model and the dark sector can naturally lead to the observed relic abundance. Indeed, even if moduli are very massive, the nature of their couplings with matter and gauge fields allows producing a sufficiently large amount of dark matter in the early Universe through the freeze-in mechanism. Moreover, the complex nature of the moduli fields whose real and imaginary part couple differently to the thermal bath gives an interesting and unusual phenomenology compared to other freeze-in models of that type.

arXiv:1811.01947v2

Motivation

Standard Model

$$\begin{aligned}\mathcal{L}_{SM} \supset\ & \frac{\alpha_H}{\Lambda} t |D_\mu H|^2 - \frac{\alpha_H}{\Lambda} \mu_0^2 t |H|^2 \\ & + \left(\frac{1}{2\Lambda} t \bar{f} i \gamma^\mu (\alpha_V^f - \alpha_A^f \gamma_5) D_\mu f + h.c. \right) \\ & + \frac{1}{2\Lambda} \partial_\mu a \bar{f} \gamma^\mu (\beta_V^f - \beta_A^f \gamma_5) f \\ & + \frac{1}{4} \frac{\alpha_G}{\Lambda} t G_{\mu\nu} G^{\mu\nu} + 2 \frac{\beta_G}{\Lambda} \partial_\mu a \epsilon^{\mu\nu\rho\sigma} G_\nu \partial_\rho G_\sigma\end{aligned}$$

Motivation

Dark Matter

$$\mathcal{L}^S = \frac{\alpha_S}{\Lambda} t |\partial_\mu S|^2$$

$$\mathcal{L}^\chi = \left(\frac{1}{2\Lambda} t \bar{\chi} i \gamma^\mu (\alpha_V^\chi - \alpha_A^\chi \gamma_5) D_\mu \chi + h.c. \right) + \frac{1}{2\Lambda} \partial_\mu a \bar{\chi} \gamma^\mu (\beta_V^\chi - \beta_A^\chi \gamma_5) \chi$$

$$\mathcal{L}^\mathcal{V} = \frac{1}{4} \frac{\alpha_\mathcal{V}}{\Lambda} t \mathcal{V}_{\mu\nu} \mathcal{V}^{\mu\nu} + 2 \frac{\beta_\mathcal{V}}{\Lambda} \partial_\mu a \epsilon^{\mu\nu\rho\sigma} \mathcal{V}_\nu \partial_\rho \mathcal{V}_\sigma$$

Motivation

Dark Matter Production

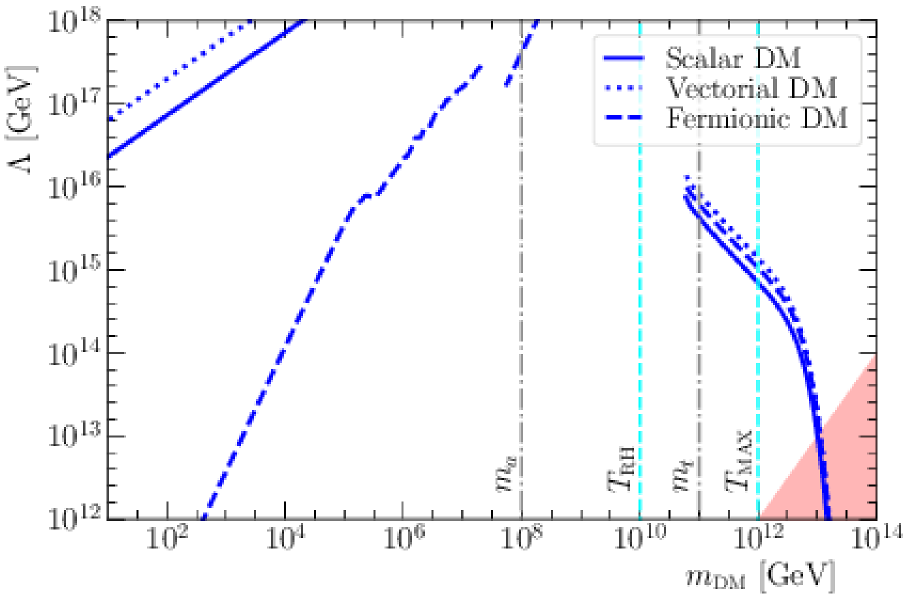
$$\frac{dn_{DM}}{dt} = -3H(t)n_{DM} + R(T)$$

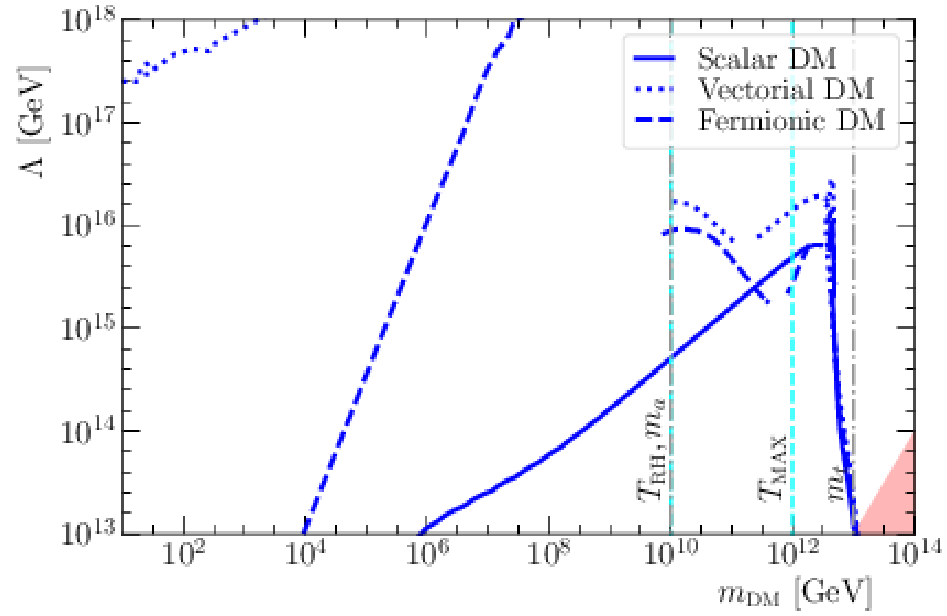
$$\frac{d\rho_\gamma}{dt} = -4H(t)\rho_\gamma + \Gamma_\phi \rho_\rho + 2\langle\sigma v\rangle\langle E_{DM}\rangle[n_{DM}^2 - (n_{DM}^{eq})^2]$$

$$\frac{d\rho_\phi}{dt} = -3H(t)\rho_\phi - \Gamma_\phi \rho_\phi$$

Motivation

Results





BUT: All the couplings are set to 1!

arXiv:1811.01947v2

LARGE Volume Scenario

We see hierarchies in nature, e.g.

- **Planck scale:** $M_P = 2.4 \times 10^{18}\ GeV$
- **GUT scale:** $M_{GUT} \approx 3 \times 10^{16}\ GeV$
- **Axion scale:** $10^9\ GeV \leq f_a \leq 10^{12}\ GeV$
- **Weak scale:** $M_W \approx 100\ GeV$
- **Fermion masses:** $m_e \approx 0.5\ MeV - m_t \approx 170\ GeV$

LARGE Volume scenario

- String compactifications generically have moduli parametrising the geometry
- Moduli are naively massless scalars with unfixed classical vev’s
- These vev’s determine the scales and couplings of the 4d-field theory
- Moduli are uncharged and interact gravitationally
- Such massless scalars generate long-range, unphysical fifth forces

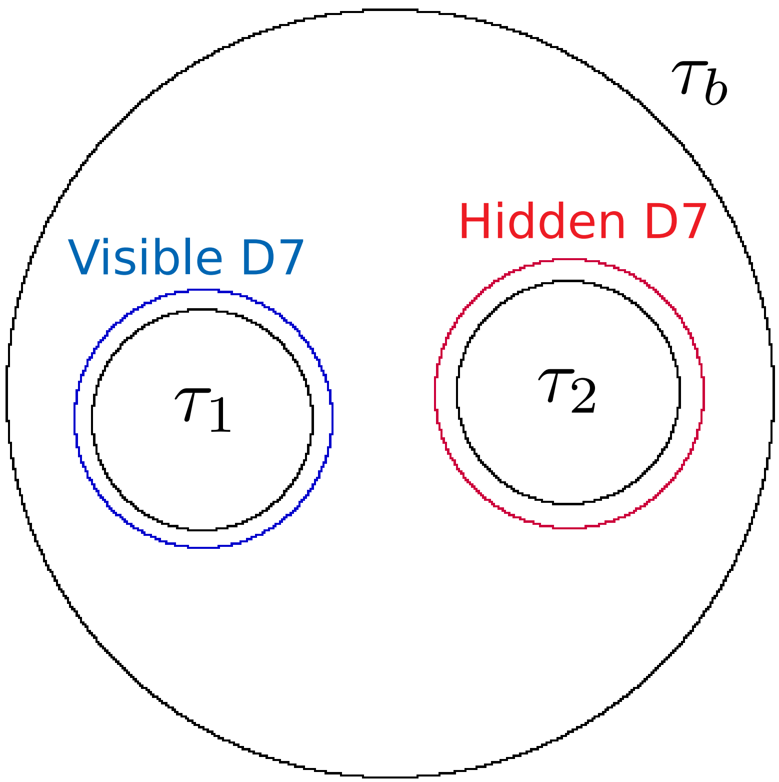
LARGE Volume scenario

- **Background fluxes stabilize complex structure moduli and dilaton**
- **Interplay between Non-perturbative corrections and α'-corrections stabilize Kähler moduli**

→ large volume non-susy AdS vacuum

LARGE Volume scenario

Volume: $$\mathcal{V} = \alpha(\tau_b^{3/2} - \gamma_1 \tau_1^{3/2} - \gamma_2 \tau_2^{3/2}).$$



LARGE Volume scenario

- **Kähler potential:**

$$K = -2\ln\left(\mathcal{V} + \frac{\xi}{2g_s^{3/2}}\right)$$

- **Superpotential:**

$$W = W_0 + A_b e^{-a_b T_b} + A_1 e^{-a_1 T_1} + A_2 e^{-a_2 T_2}$$

Results

General procedure

- **Scalar Potential:** $V = e^{\frac{K}{M_{Pl}^2}} \left(K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3 \frac{|W|^2}{M_{Pl}^2} \right)$

- **Moduli Lagrangian:**

$$\mathcal{L}_{Moduli} = K_{i\bar{j}} \partial_\mu (\delta\tau_i) \partial^\mu (\delta\tau_{\bar{j}}) - \langle V \rangle - \frac{1}{2} V_{i\bar{j}} \delta\tau_i \delta\tau_{\bar{j}} + \mathcal{O}(\delta\tau)^3$$

→ **Diagonalize:** $\frac{1}{2} (K^{-1})_{ik} V_{kj}$

Results

- **Coupling to Gauge Bosons:**

$$\mathcal{L}_{Gauge} = \frac{\tau_1}{4\pi} F_{\mu\nu} F^{\mu\nu} + \frac{c_1}{4\pi} F_{\mu\nu} \tilde{F}^{\mu\nu}$$

- **Coupling to Fermions+Scalars:**

$$\mathcal{L}_{ferm/Hig} = K_{\bar{f}f} i \bar{f} \partial f + K_{H\bar{H}} \partial_\mu H \partial^\mu \bar{H} + e^{K/2} \lambda H \bar{f} f$$

with $K_{\bar{f}f} \approx K_{\bar{H}H} \approx \frac{\tau_s^{1/2}}{\tau_b}$

arXiv:hep-th/0609180v2

Results

Moduli couplings to visible/hidden sector

	$\delta\phi_b$	$\delta\phi_1$	$\delta\phi_2$
$G^{(vis)}_{\mu\nu}G^{(vis)\mu\nu}$	$\mathcal{O}\left(\frac{1}{M_p \ln(\mathcal{V})}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$	$\mathcal{O}\left(\frac{\ln(\mathcal{V})^{3/4}}{M_p \mathcal{V}^{1/2}}\right)$
$G^{(hid)}_{\mu\nu}G^{(hid)\mu\nu}$	$\mathcal{O}\left(\frac{1}{M_p \ln(\mathcal{V})}\right)$	$\mathcal{O}\left(\frac{\ln(\mathcal{V})^{3/4}}{M_p \mathcal{V}^{1/2}}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$
$i\bar{f}^{(vis)}\partial f^{(vis)}$	$\mathcal{O}(1)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$	$\mathcal{O}\left(\frac{\ln(\mathcal{V})^{3/4}}{M_p \mathcal{V}^{1/2}}\right)$
$i\bar{f}^{(hid)}\partial f^{(hid)}$	$\mathcal{O}(1)$	$\mathcal{O}\left(\frac{\ln(\mathcal{V})^{3/4}}{M_p \mathcal{V}^{1/2}}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$
$\partial_\mu H^{(vis)}\partial^\mu \bar{H}^{(vis)}$	$\mathcal{O}(1)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$	$\mathcal{O}\left(\frac{\ln(\mathcal{V})^{3/4}}{M_p \mathcal{V}^{1/2}}\right)$
$\partial_\mu H^{(hid)}\partial^\mu \bar{H}^{(hid)}$	$\mathcal{O}(1)$	$\mathcal{O}\left(\frac{\ln(\mathcal{V})^{3/4}}{M_p \mathcal{V}^{1/2}}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$

Results

Axion coupling to visible/hidden sector

	$\delta\psi_b$	$\delta\psi_1$	$\delta\psi_2$
$G^{(vis)}_{\mu\nu}\tilde{G}^{(vis)\mu\nu}$	$\mathcal{O}\left(\frac{\mathcal{V}^2 e^{-\mathcal{V}^{2/3}}}{M_p \ln(\mathcal{V})^2}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{5/2} e^{-\mathcal{V}^{2/3}}}{M_p \ln(\mathcal{V})^{11/4}}\right)$
$G^{(hid)}_{\mu\nu}\tilde{G}^{(hid)\mu\nu}$	$\mathcal{O}\left(\frac{\mathcal{V}^2 e^{-\mathcal{V}^{2/3}}}{M_p \ln(\mathcal{V})^2}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{5/2} e^{-\mathcal{V}^{2/3}}}{M_p \ln(\mathcal{V})^{11/4}}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$
$\bar{f}^{(vis)} f^{(vis)}$	$\mathcal{O}\left(\frac{\mathcal{V}^2 e^{-\mathcal{V}^{2/3}}}{M_p \ln(\mathcal{V})^2}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{5/2} e^{-\mathcal{V}^{2/3}}}{M_p \ln(\mathcal{V})^{11/4}}\right)$
$\bar{f}^{(hid)} f^{(hid)}$	$\mathcal{O}\left(\frac{\mathcal{V}^2 e^{-\mathcal{V}^{2/3}}}{M_p \ln(\mathcal{V})^2}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{5/2} e^{-\mathcal{V}^{2/3}}}{M_p \ln(\mathcal{V})^{11/4}}\right)$	$\mathcal{O}\left(\frac{\mathcal{V}^{1/2}}{M_p \ln(\mathcal{V})^{3/4}}\right)$

Outlook

- **Dark Matter production rate with couplings included**

- **Different geometries (e.g. D3-branes at singularities)**

- **Different couplings for left/right handed matter fields**