

Dark Matter in an Evanescent Three-Brane Randall–Sundrum Scenario

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Motivation

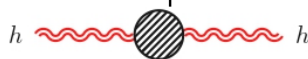
- Original motivation:

- SM **hierarchy problem**: fine tuning of the Higgs boson mass.
- Randall-Sundrum (RS) models $\Rightarrow$ geometric solution via one warped extra dimension. *Randall, Sundrum (1999)*

$$\mathcal{L}_h \sim \frac{1}{2} m_0^2 h^2 + \dots$$

+

M_{P}^2



The diagram shows a Higgs boson h (represented by a red wavy line) entering a shaded circle from the left, and another h exiting to the right. Above the circle is the label M_{P}^2 . This represents a self-energy correction to the Higgs mass.

$$\Rightarrow$$
$$m_h^2 \sim m_0^2 + M_{\text{P}}^2 + \dots$$
$$m_h \sim \mathcal{O}(100 \text{ GeV})$$
$$M_{\text{P}} \sim \mathcal{O}(10^{19} \text{ GeV})$$

- Our motivation:

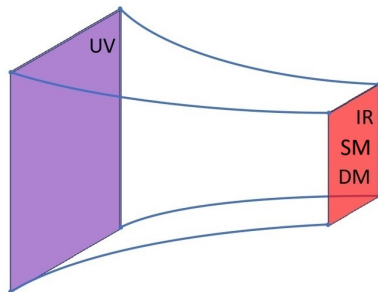
- Larger gravitational interaction with a smaller (warped) scale Λ .
- Two-brane RS setup $\Rightarrow$ **restricted** parameter space for DM candidates.

The Randall–Sundrum Setup

- Extra dimension $y \in [0, \pi r_c]$, compactified on S^1/Z_2 .
- Two 3-branes located at $y = 0$ (UV) and $y = \pi r_c$ (IR).
- 5D metric: $ds^2 = e^{-2ky} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$.
- Masses on the IR brane are redshifted:

$$m_h^2 \sim (m_0^2 + M_P^2 + \dots) e^{-2\pi k r_c},$$

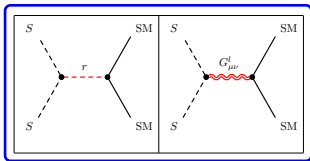
$$\text{if } k r_c \approx 10 \Rightarrow M_P e^{-\pi k r_c} \sim \mathcal{O}(100 \text{ GeV}).$$



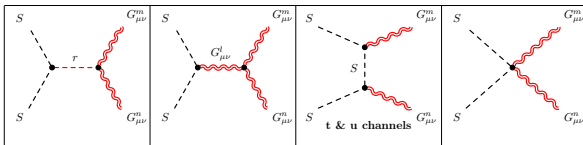
DM Freeze Out

- Scalar singlet DM candidate in the IR brane (**WIMP DM Freeze Out**).
- KK graviton modes: $h_{\mu\nu}^{(n)}$, and a scalar: radion.
- KK mass spectrum m_n are **model dependent**.
- **Universal coupling** with KK gravitons $\sim 1/\Lambda_{\text{IR}} \equiv 1/(M_{\text{P}} e^{-kr_c\pi})$.

$$\mathcal{L} = -\frac{1}{M_{\text{P}}} T^{\mu\nu}(x) h_{\mu\nu}^0(x) - \frac{1}{\Lambda_{\text{IR}}} \sum_{n=1} T^{\mu\nu}(x) h_{\mu\nu}^n(x) + \frac{1}{\sqrt{6}\Lambda_{\text{IR}}} r T$$



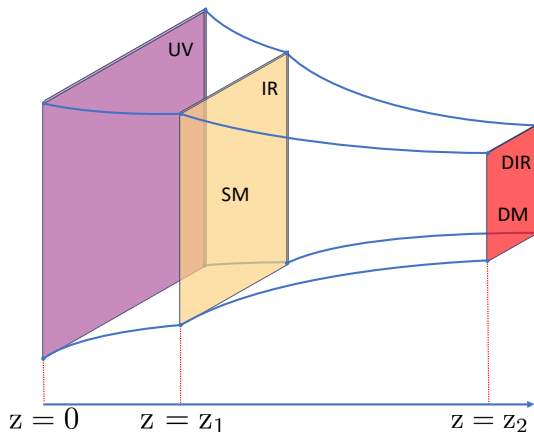
**Very constrained
parameter space**



*Chivukula et al.
(2020,...),
de Giorgi and Vogl
(2021,...)...*

Three-Brane Extension

- Extra brane in between UV and DIR: the *evanescent* brane (IR).
- SM in IR brane and DM in DIR brane. **Different Branes!!**
- **Different coupling** of KK gravitons with SM and DM.



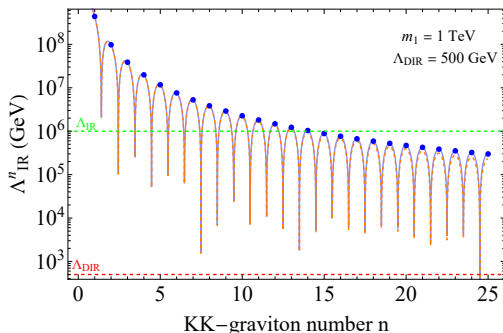
Cai et al. (2022), Koustroulis et al. (2024)...

Three-Branes RS Couplings

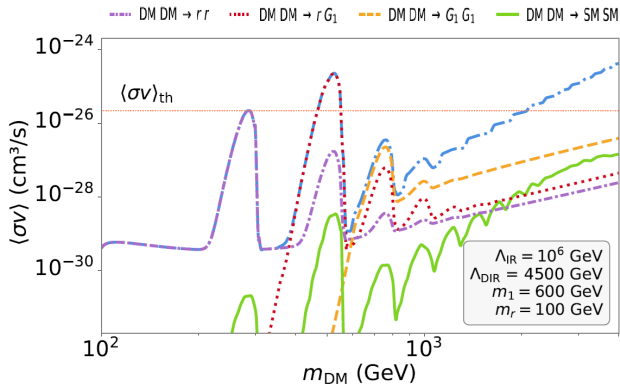
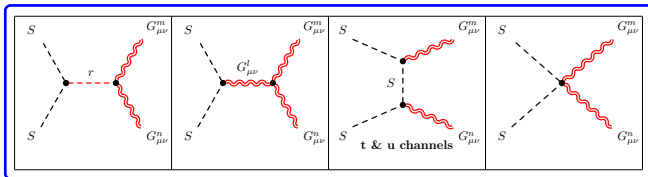
- Couplings to IR brane fields mode-dependent $\sim 1/\Lambda_{\text{IR}}^n$.
- Universal coupling to DIR brane: $\sim 1/\Lambda_{\text{DIR}}$.

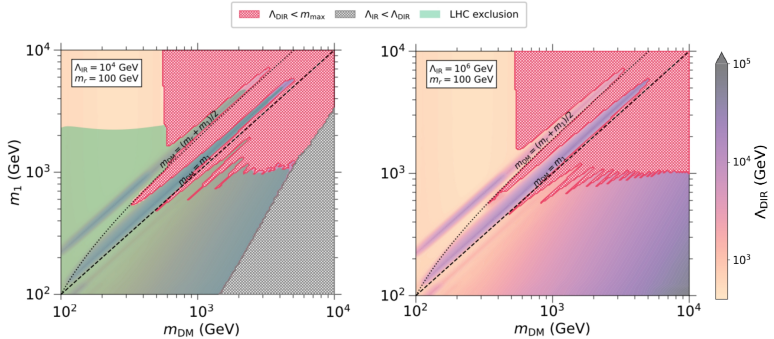
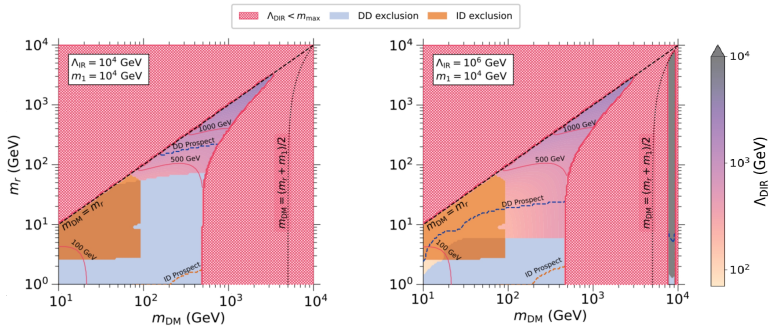
$$\mathcal{L}_h = \frac{1}{\bar{M}_{\text{P}}} h_{\mu\nu}^{(0)}(x) T^{\mu\nu}(x) + \sum_{n=1}^{\infty} \frac{1}{\Lambda_{\text{IR}}^n} h_{\mu\nu}^{(n)}(x) T_{\text{IR}}^{\mu\nu}(x) + \sum_{n=1}^{\infty} \frac{1}{\Lambda_{\text{DIR}}} h_{\mu\nu}^{(n)}(x) T_{\text{DIR}}^{\mu\nu}(x) + \frac{1}{\sqrt{6}\Lambda_{\text{IR}}} r T_{\text{IR}} + \frac{1}{\sqrt{6}\Lambda_{\text{DIR}}} r T_{\text{DIR}}$$

Brane	$h_{\mu\nu}^0$	$h_{\mu\nu}^{n \geq 1}$	r
IR (SM)	$\frac{1}{\bar{M}_{\text{P}}}$	$\frac{1}{\Lambda_{\text{IR}}^n}$	$\frac{1}{\sqrt{6}\Lambda_{\text{IR}}}$
DIR (DM)	$\frac{1}{\bar{M}_{\text{P}}}$	$\frac{1}{\Lambda_{\text{DIR}}}$	$\frac{1}{\sqrt{6}\Lambda_{\text{DIR}}}$



Relevant DM Annihilations Channels

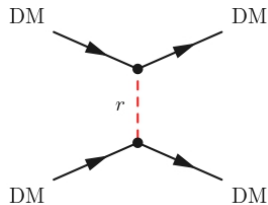




Fermion DM (p -wave) or
Asymmetric DM

+

Light radion mediator



SIDM

$$\frac{\sigma_{\text{self}}}{m_{\text{DM}}} \sim \frac{\text{cm}^2}{\text{g}} \left(\frac{m_r}{40 \text{ MeV}} \right)^{-4} \left(\frac{m_{\text{DM}}}{10 \text{ GeV}} \right) \left(\frac{m_{\text{DM}}/\Lambda_{\text{DIR}}}{0.1} \right)^4$$

Conclusions

- The *evanescent* three-brane RS model opens the parameter space of scalar DM.
- Possibility of experimentally detecting the number of populated branes.
- Warped geometry still able to solve the hierarchy problem.
- Future Work: Possibility of significant SIDM for light radions.

Thank you!