Freezing-in dark matter through Spin-1 and Spin-2 portals

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Freezing-in dark matter through a heavy invisible Z′, G. Bhattacharyya, MD, Y. Mambrini, M. Pierre [arXiv: 1806.00016]
Spin-2 portal dark matter N. Bernal, MD, Y. Mambrini, K. Olive, M. Peloso, M. Pierre [arXiv: 1803.01866]

Why to change the paradigm?

WIMPs
Weakly Interacting Massive Particles

- Masses between 100s GeV - 10s TeV
- Weak (but sizeable!) interactions with SM
- Initially **present** and in thermal equilibrium with SM in the Early Universe } FREEZE-OUT

Many experiments, no signal yet...

FIMPs
Feebly Interacting Massive Particles

- "any" mass range
- Very weak interactions with SM
- Initially **absent** and in not in thermal equilibrium with SM in the Early Universe } FREEZE-IN

See talk of Señor Bernal!

DM: dark matter particles
SM: Standard Model particles

The Waning of the WIMP?
G. Arcadi, MD, P. Ghosh, M. Lindner, Y. Mambrini, M. Pierre, S. Profumo, F. S. Queiroz [arXiv: 1703.07364]

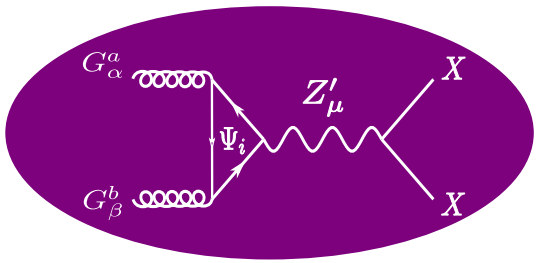
The Dawn of the FIMP
N. Bernal, M. Heikinheimo, T. Tenkanen, K. Tuominen, V. Vaskonen [arXiv: 1706.07442]

- Why SM-DM interactions would be so feeble?
- When DM was generated in the Universe?

Spin-1 portal to dark matter

Why SM-DM interactions would be so feeble?

- Z': gauge boson of a BSM abelian gauge group, $U(1)'$;
- X: fermionic, Abelian or non-Abelian dark matter candidates;
- $\{\Psi_i\}$: anomaly-free set of heavy fermions (heavier than $T_{\rm MAX}$). They are chiral under $U(1)'$ but vectorlike with respect to $SU(3)_c$.



$$\mathcal{L}_{eff} = \frac{1}{\Lambda^2}\partial^\alpha Z'_\alpha \epsilon^{\mu\nu\rho\sigma} Tr[G^a_{\mu\nu} G^a_{\rho\sigma}] + \mathcal{L}_{DM}$$

$$\mathcal{L}_{DM} = \begin{cases} \alpha\ \bar{X}\gamma^\mu\gamma_5 X Z'_\mu & \text{(fermionic DM)} \\ \beta\ \epsilon_{\mu\nu\rho\sigma} Z'^\mu X^\nu X^{\rho\sigma} & \text{(Abelian DM)} \\ \gamma\ \partial^\alpha Z'_\alpha \epsilon_{\mu\nu\rho\sigma} \mathrm{Tr}[X^{\mu\nu} X^{\rho\sigma}] & \text{(non-Abelian DM)} \end{cases}$$

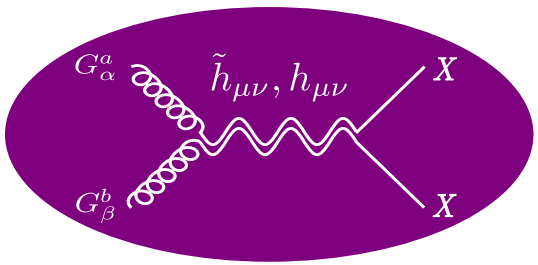
$$M_{Z'} \sim 10^{10}\ \text{GeV};\ \Lambda \sim 10^{16}\ \text{GeV}$$

G. Bhattacharyya, MD, Y. Mambrini, M. Pierre [arXiv: 1806.00016]

Spin-2 portal to dark matter

Why SM-DM interactions would be so feeble?

- $h_{\mu\nu}$: graviton, massless spin-2 field;
- $\tilde{h}_{\mu\nu}$: massive spin-2 field;
- X: scalar, fermionic or vectorial dark matter candidates.



$$\mathcal{L} \supset \frac{1}{2M_P} h_{\mu\nu}\left(\sum_i T^{\mu\nu}_{SM,i} + T^{\mu\nu}_{DM,i}\right) + \frac{1}{\Lambda}\tilde{h}_{\mu\nu}\left(g_{SM}\sum_i T^{\mu\nu}_{SM,i} + g_{DM} T^{\mu\nu}_{DM,i}\right)$$

$$T^{\mu\nu}_{DM/SM,i} = \begin{cases} \frac{1}{2}\left(\partial_\mu\phi\ \partial_\nu\phi + \partial_\nu\phi\ \partial_\mu\phi - g_{\mu\nu}\partial^\alpha\phi\ \partial_\alpha\phi\right) & (\text{i = scalar}) \\ \frac{i}{4}\bar{\psi}\left(\gamma_\mu\partial_\nu + \gamma_\nu\partial_\mu\right)\psi - \frac{i}{4}\left(\partial_\mu\bar{\psi}\gamma_\nu + \partial_\nu\bar{\psi}\gamma_\mu\right)\psi & (\text{i = fermion}) \\ \frac{1}{2}\left(F^\alpha_\mu F_{\nu\alpha} + F^\alpha_\nu F_{\mu\alpha} - \frac{1}{2}g_{\mu\nu}F^{\alpha\beta}F_{\alpha\beta}\right) & (\text{i = vector}) \end{cases}$$

$$m_{\tilde{h}} \sim 10^{10}\ \text{GeV};\ \Lambda \sim 10^{16}\ \text{GeV}$$

N. Bernal, MD, Y. Mambrini, K. Olive, M. Peloso, M. Pierre [arXiv: 1803.01866]

Freeze-in during reheating

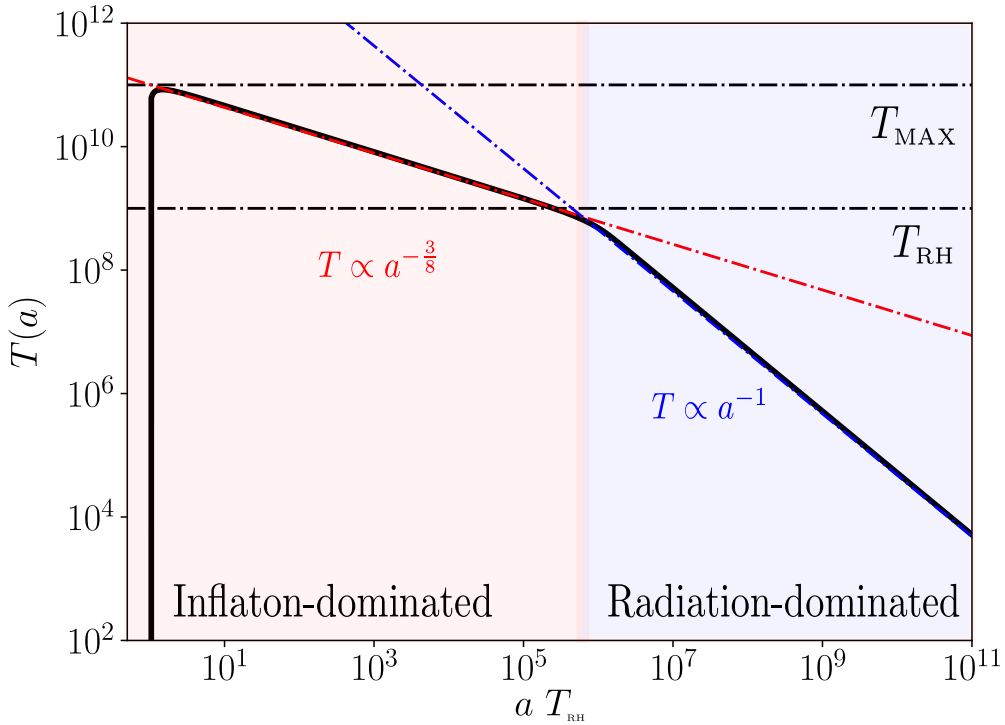
When DM was generated in the Universe?

Since the mass scale of our mediators are close to the reheating scale, we need to consider the possibility of dark matter being produced from radiation *while the inflaton dominates*. We need to solve therefore:

$$\dot{n}_X + 3\,\mathbf{H(t)}\,n_X = R(t)$$

$$\dot{\rho}_I + 3H(t)\rho_I = -\Gamma_I \rho_I$$

$$\dot{\rho}_R + 4H(t)\rho_R = +\Gamma_I \rho_I - \mathcal{R}_{R\to X}$$



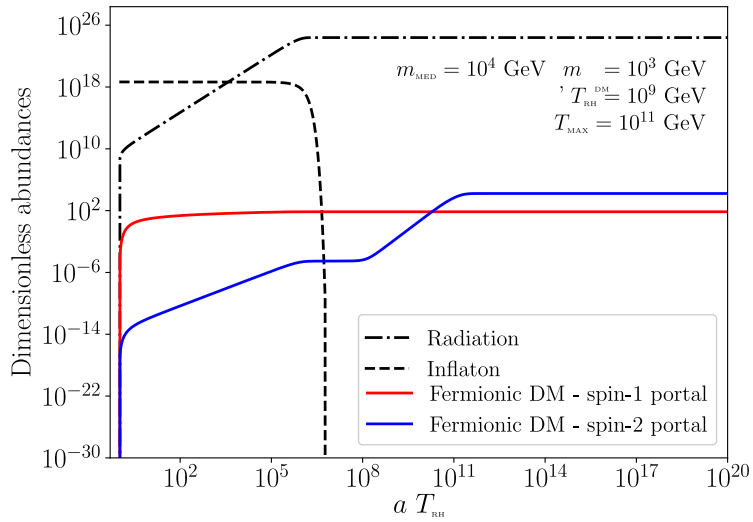
Freeze-in during reheating

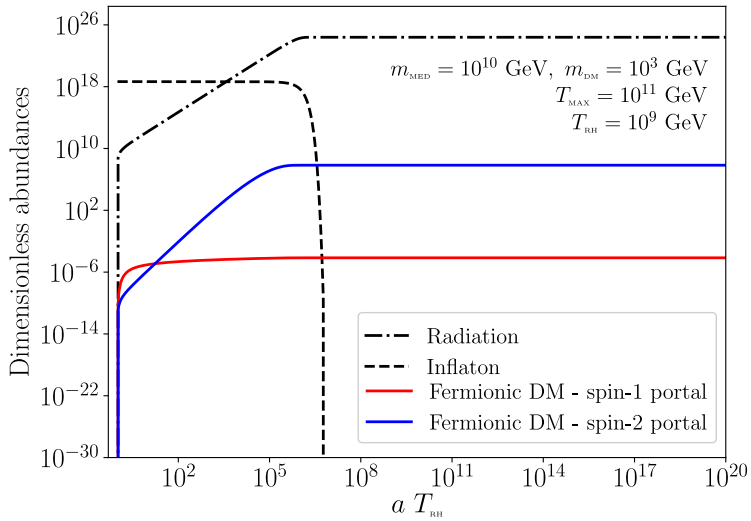
- When DM was generated in the Universe?

Since the mass scale of our mediators are close to the reheating scale, we need to consider the possibility of dark matter being produced from radiation *while the inflaton dominates*.
The dark matter yield will have the following contributions:

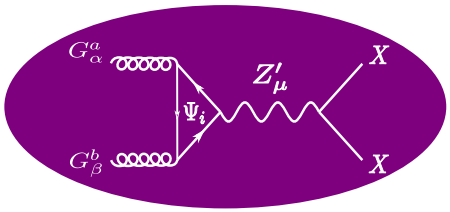
$$Y_0 \sim M_P \int_{T_{fr}}^{T_{rh}} dT \, \frac{1}{g_s \sqrt{g_e}} \, \frac{R(T)}{T^6}$$

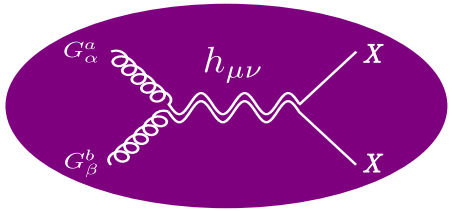
$$+ \; M_P \, T_{rh}^7 \int_{T_{rh}}^{T_{max}} dT \, \frac{g_s}{g_e^5} \, \frac{R(T)}{T^{13}} \, .$$

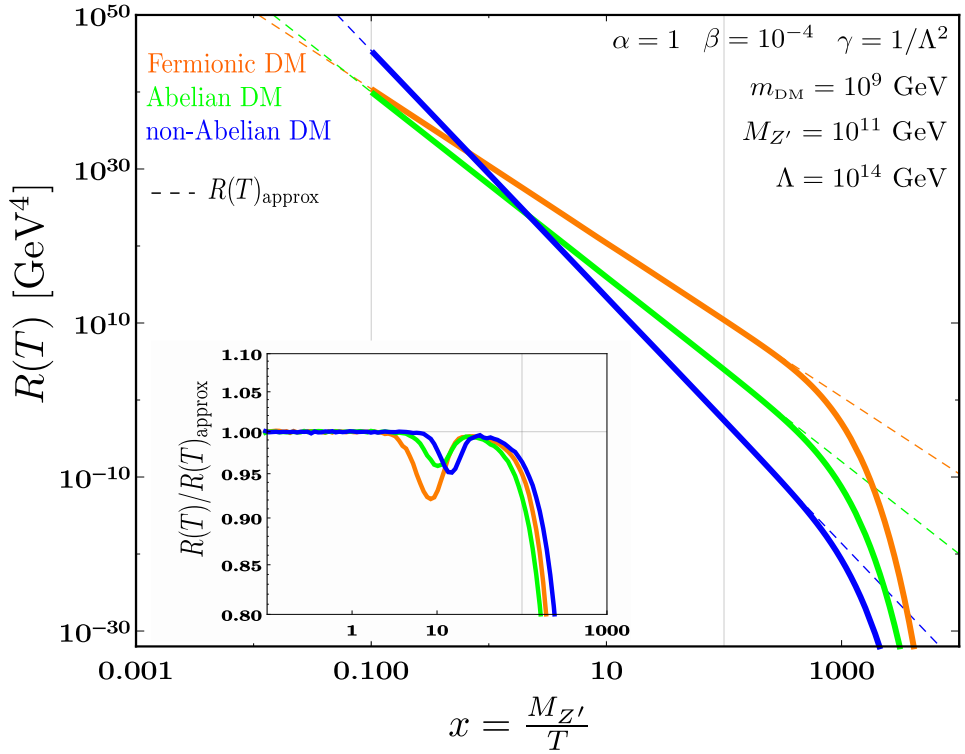


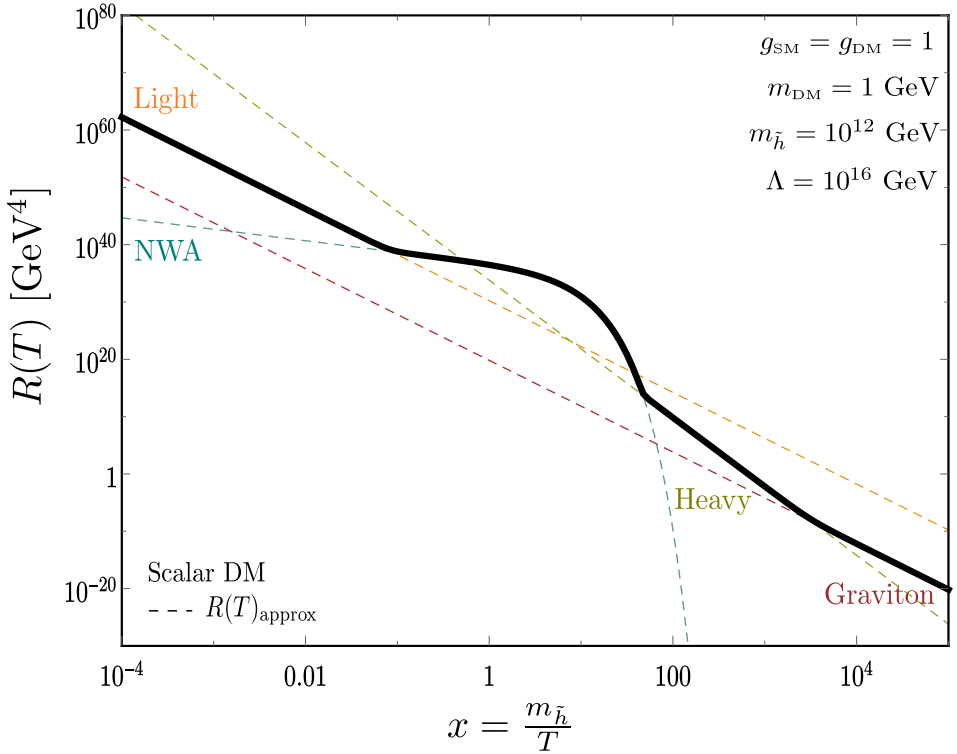


Production rates

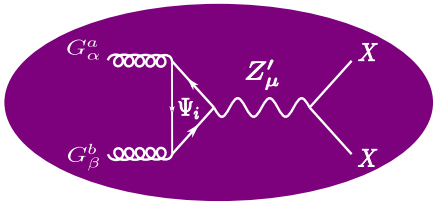


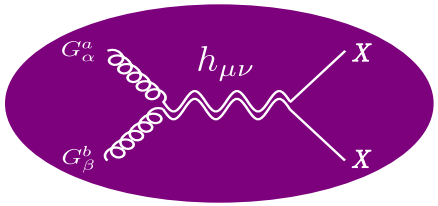


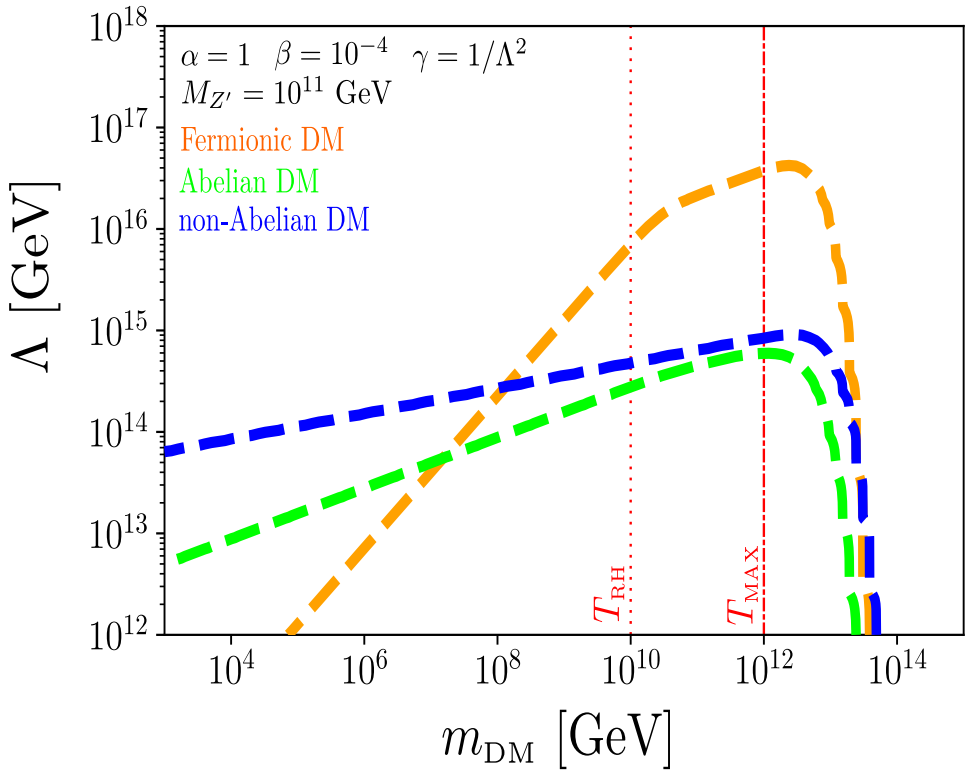


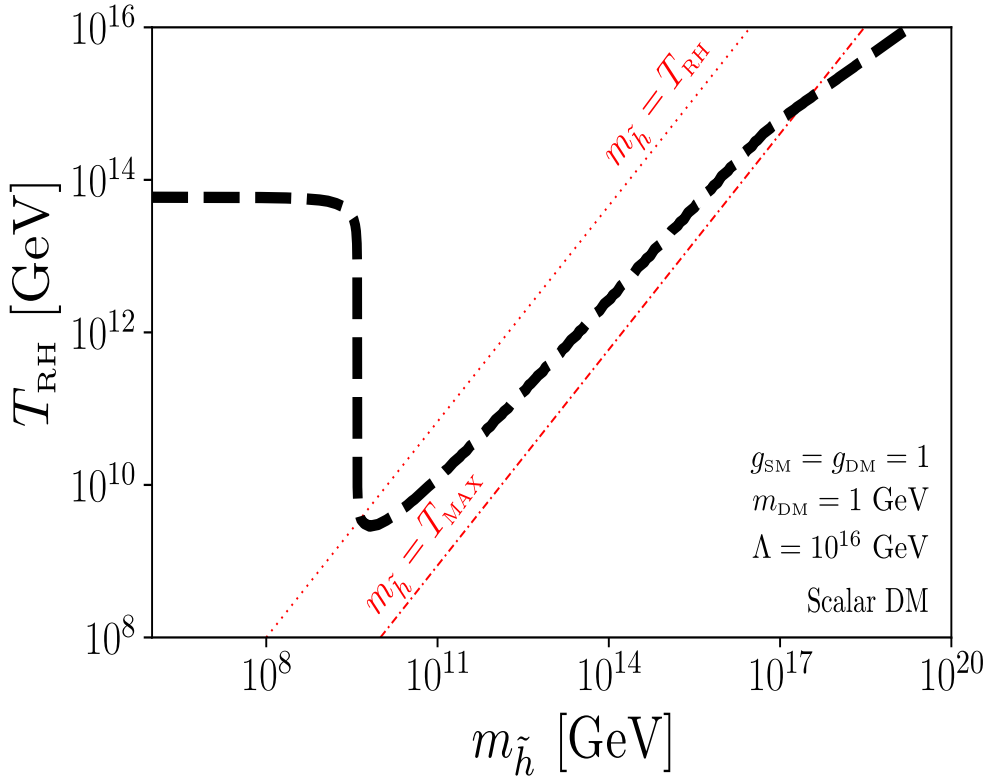


Parameter space in agreement with the relic density









Conclusions

- Why SM-DM interactions would be so feeble?
- When DM was generated in the Universe?

We have considered models in which the answer of the questions above are related:

- The interaction between the dark and visible sectors are suppressed because of the exchange of heavy mediators;
- Agreement with the relic density bring the dark matter freeze-in temperature to the scales of the reheating process, what lead us to consider the dark matter production in the inflaton era. As we can see in the figure beside, that contribution to the relic density may dominate depending on the mediator masses.