Phenomenology of the Feebly Interacting Massive Particle (FIMP)

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Abstract

We study the phenomenology of a dark matter mechanism, the Feebly Interacting Massive Particle (FIMP). In this mechanism, a heavy baryonic matter particle (the FIMP) decays into a dark matter particle, χ, which is assumed to have no initial abundance. This process is called freeze-in; while the universe is expanding and cooling down, χ's abundance starts to increase. Because of the feeble interaction, the FIMP never exists in thermal equilibrium with the thermal bath around it. The yield of the dark matter particle increases with a larger FIMP mass (m_{B_1}) and a stronger interaction coupling constant (λ).

Boltzmann Equation

The process in which χ is produced is a decay from the FIMP, $B_1 \rightleftharpoons B_2 + X$

The equation that governs how the number density of a particle evolves through time is the Boltzmann equation:

$$\frac{dn}{dt} + 3Hn = \frac{g}{(2\pi)^3}\int_{-\infty}^{+\infty} d^3p \frac{C[f]}{E}$$

If we make some simplifying assumptions, namely that the two amplitudes ($|M|^2$) are equal for both processes, and that B_1 and B_2 can be approximated as thermal bath particles; ($1 \pm f_{B_1}$) = ($1 \pm f_{B_2}$)≈1, then we can rewrite the Boltzmann equation as:

$$\dot{n_X} + 3Hn_X \approx g_{B_1}\int \frac{d^3p_{B_1}}{(2\pi)^3}\frac{f_{B_1}\Gamma_{B_1}}{\gamma_{B_1}}$$

From this, we can obtain an integral for the yield of the dark matter particle:

$$Y_X = \frac{45}{1.66(4\pi)^4}\frac{g_{B_1}M_{Pl}\Gamma_{B_1}}{m_{B_1}^2 g_*^S\sqrt{g_*^\rho}}\int_{x_{min}}^{x_{max}} K_1(x) * x^3 dx$$

$$= \frac{135 g_{B_1}}{8\pi^3 * 1.66 * g_*^S\sqrt{g_*^\rho}}\frac{M_{Pl}\Gamma_{B_1}}{m_{B_1}^2}$$

Then, we can obtain the relic abundance ($\Omega_X h^2$):

$$\Omega_X h^2 = \frac{1.09 * 10^{27} g_{B_1}}{g_*^S\sqrt{g_*^\rho}}\frac{m_X\lambda^2}{16\pi m_{B_1}}$$

Freeze-in vs Freeze-out

The most commonly explored way of explaining the abundance of dark matter is the freeze-out process. In this process, dark matter is in thermal equilibrium with the thermal bath in the beginning of the universe. As the universe expands and cools down, the Weakly Interacting Massive Particle (WIMP) starts decoupling from the bath and the dark matter abundance starts decreasing. This happens when the temperature of the universe falls below the order of magnitude of the mass of the WIMP. On the other hand, the dark matter particle in the freeze-in process starts with no abundance and begins approaching (but never reaches) thermal equilibrium with the bath particles. Instead, at temperatures approaching the mass of the FIMP, the FIMP itself starts decaying into the dark matter particle. All these masses are in the order of the weak scale (10-100 GeV).

Results

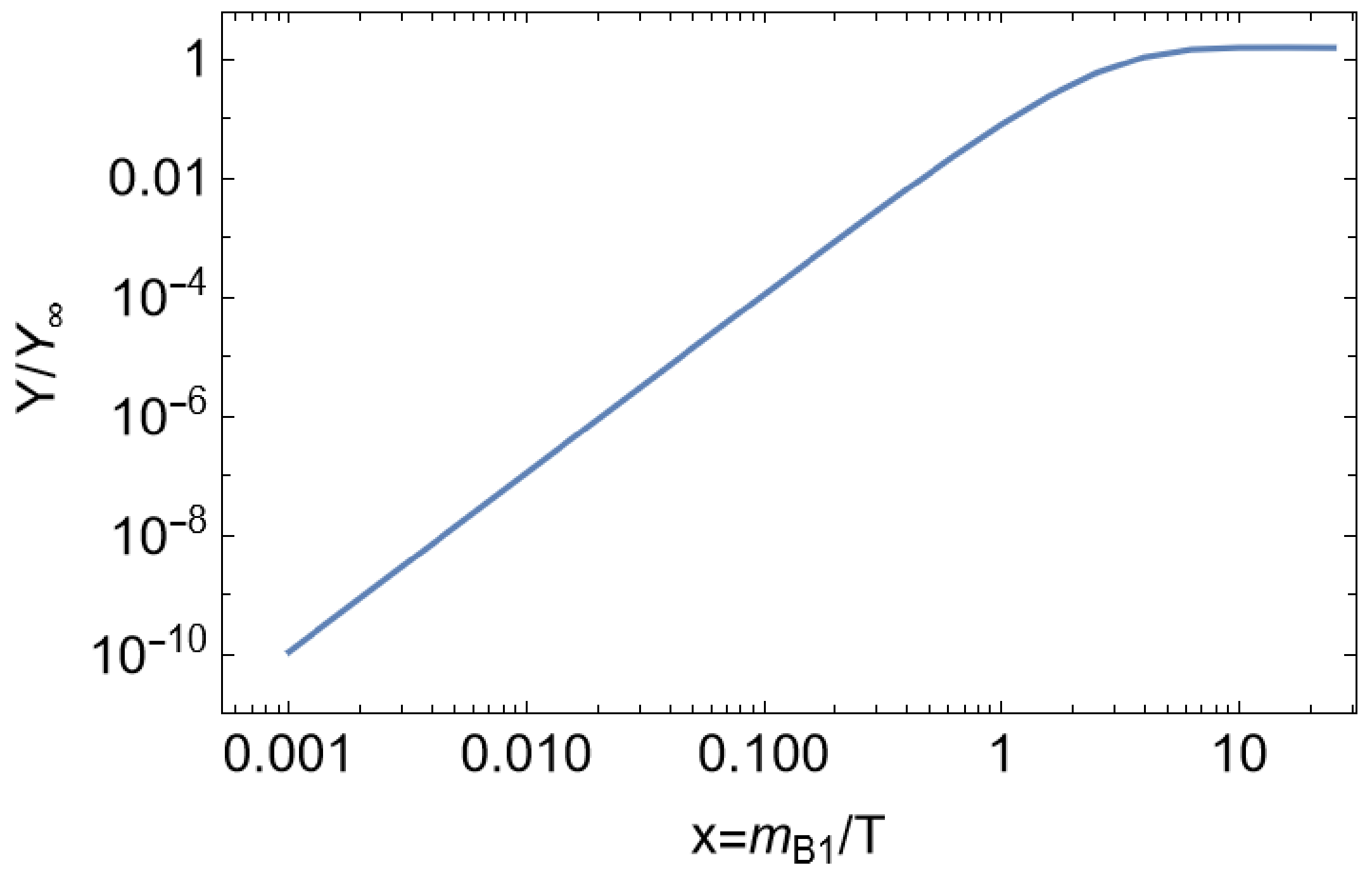

Figure 1: The yield approaches a specific value that gives us the dark matter abundance.

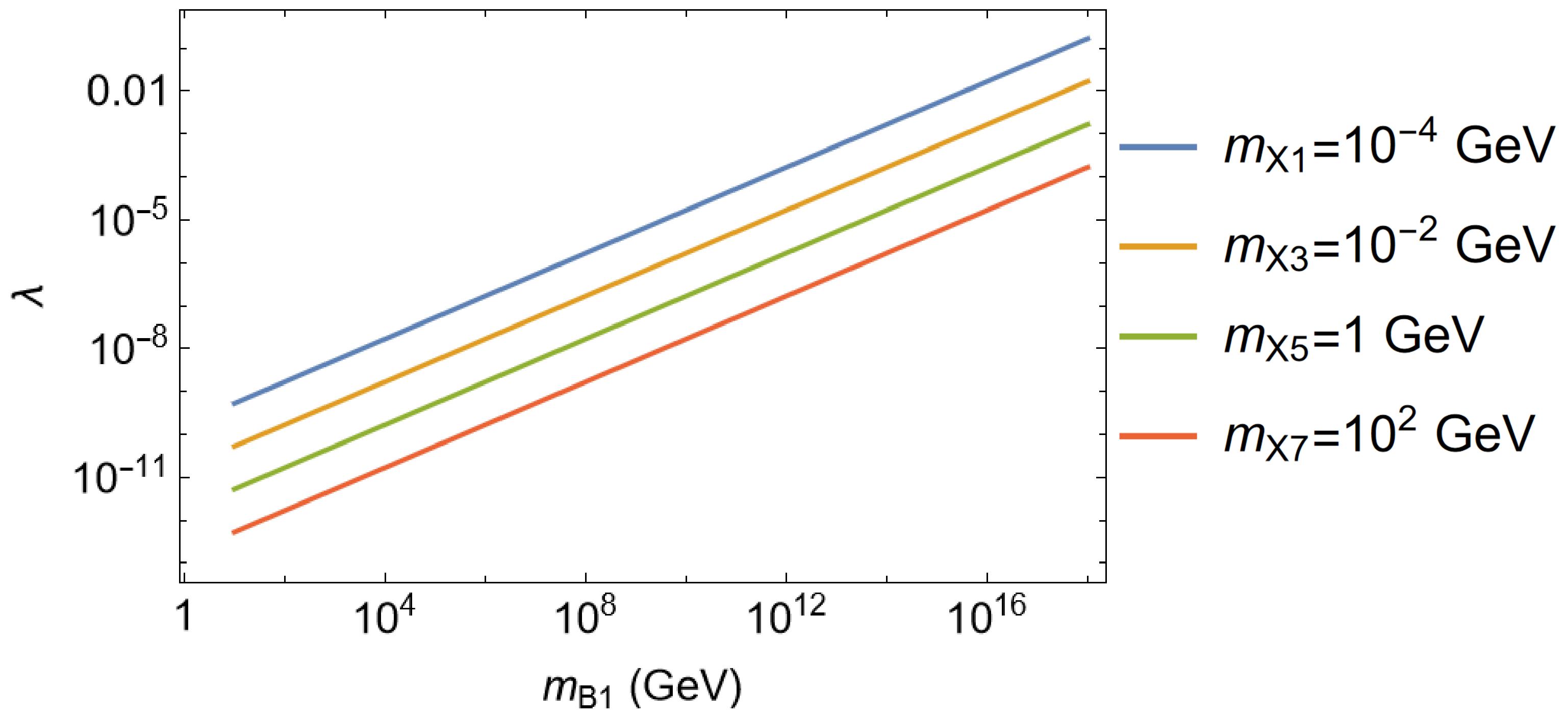

Figure 2: Interaction strength has to increase as m_{B_1} increases.

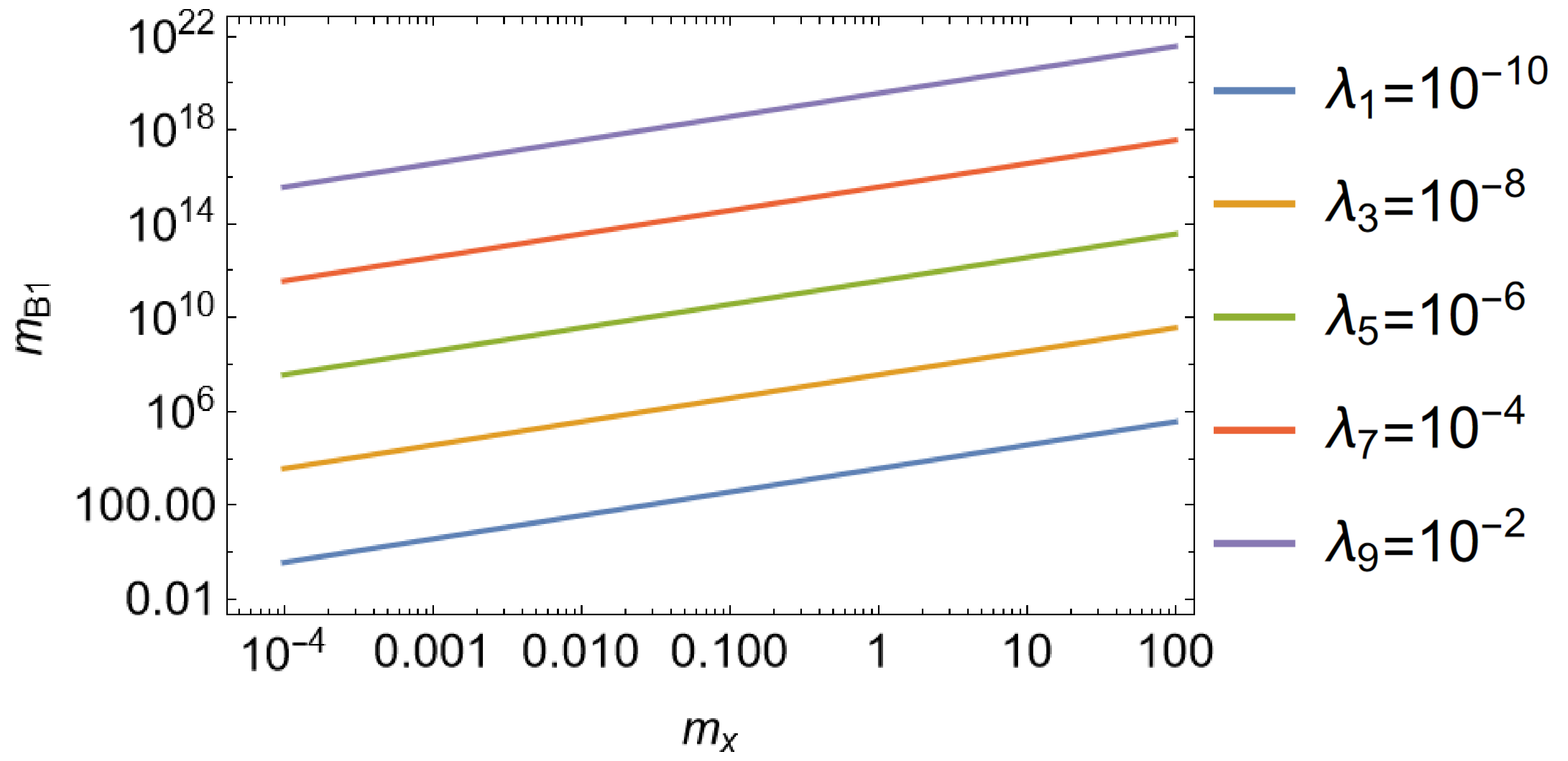

Figure 3: The dark matter mass increases as the mass of the FIMP increases.

Future outlook:

We will look into imposing direct and indirect experimental constraints on the mass of the dark matter particle.

References

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W.T work is supported by NSF grant #PHY_2013052