Dark Matter Relics in Scalar Tensor Theories

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Abstract

The expansion rate of the universe had a strong influence on the origin of the dark matter abundance during the early stages of the universe's evolution, mainly prior to big-bang nucleosynthesis. Any departure of the expansion rate of the universe from the standard cosmological model during that time can modify the dark matter abundance. In this poster, I show the role played by a scalar field on the modification of the expansion rate of the universe arising from scalar-tensor theories of gravity coupled both conformally and disformally to matter, and also, I present how these variations to the expansion rate would impact the correlation between thermal annihilation rate of dark matter and the 27% content of the Universe in comparison to the standard cosmology.

Motivation

In the standard ΛCDM scenario, DM species with weak scale interaction cross-section freeze-out with an abundance that matches the present observed value. This weak interaction is reflected in the predicted thermally-averaged annihilation cross section, $\langle \sigma v \rangle$, which is around $3.0\times10^{-26} cm^3 s^{-1}$. Despite such a small value, the Fermi-LAT and Planck experiments have been exploring upper bounds on $\langle \sigma v \rangle$. So, our main goal is to find out wheter the DM content can still have a thermal origin with larger or smaller $\langle \sigma v \rangle$ by utilising non-standard cosmology.

Scalar Tensor Theories of Gravity

These theories come from higher dimensional theories. Here, gravity is mediated by both a tensor field and a scalar field. The most general physically consistent relation between two metrics in the presence of a scalar field is given by

$$\tilde{g}_{\mu\nu} = \underbrace{C(\phi)}_{\text{Conformal}}\, g_{\mu\nu} + \underbrace{D(\phi)}_{\text{Disformal}}\, \partial_\mu\phi\partial_\nu\phi \tag{1}$$

Expansion Rate of the Universe

One can study modifications to the expansion rate of the Universe, $\tilde{H}$, for different conformal and disformal couplings. For example, $C(\varphi) = (1 + 0.1\,e^{-8\varphi})^2$ [1] or more general scenarios like $D = \frac{1}{M^4 C}$ [2]. See Figure 1.

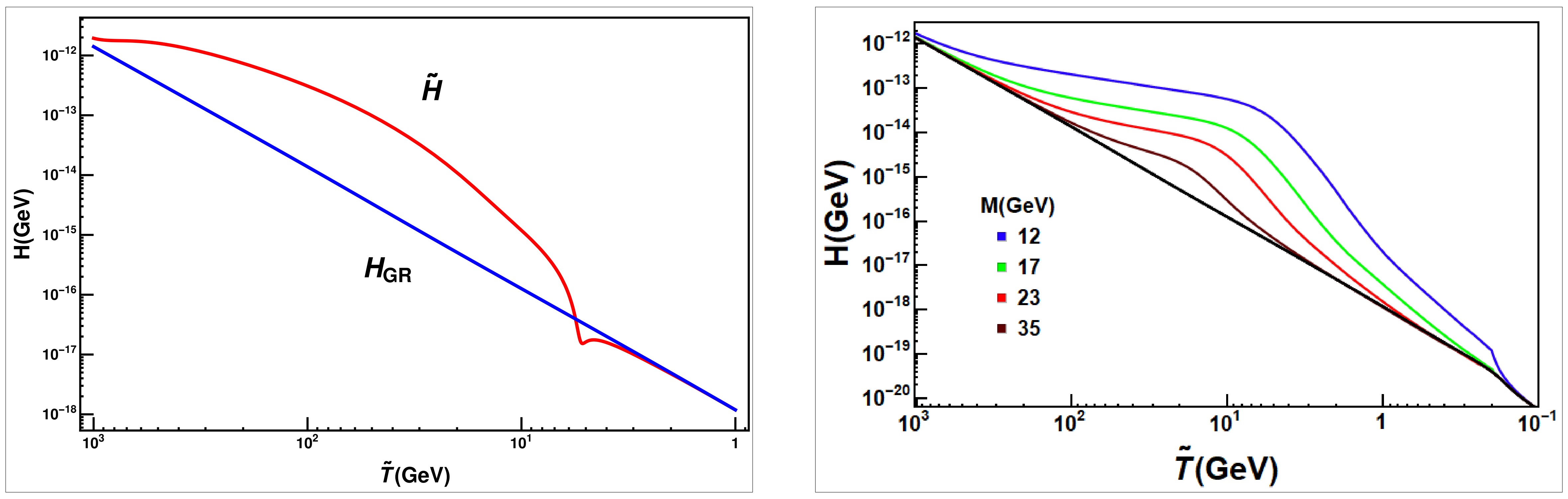

Figure 1: Left plot shows a modified expansion rate under the influence of the conformal coupling $C(\varphi) = (1 + 0.1\,e^{-8\varphi})^2$ [1]. The right plot shows the effect of a pure disformal scenario where $C = 1$ and $D = \frac{1}{M^4 C}$ [2].

Dark Matter Relic Abundance

For a DM species with mass m_χ and a thermally-averaged annihilation cross-section $\langle \sigma v \rangle$, the dark matter abundance evolves according to the Boltzmann equation

$$\frac{dY}{dx} = -\frac{\tilde{s}\langle \sigma v \rangle}{x\tilde{H}}\left(Y^2 - Y_{eq}^2\right) , \tag{2}$$

where $x = m_\chi/\tilde{T}$, $\tilde{H}$ is the expansion rate , $Y = \frac{n_\chi}{\tilde{s}}$ and $\tilde{s} = \frac{2\pi}{45} g_s(\tilde{T})\tilde{T}^3$ is the entropy density. Solutions to (2) can be found using the expansion rates shown in Figure 1.

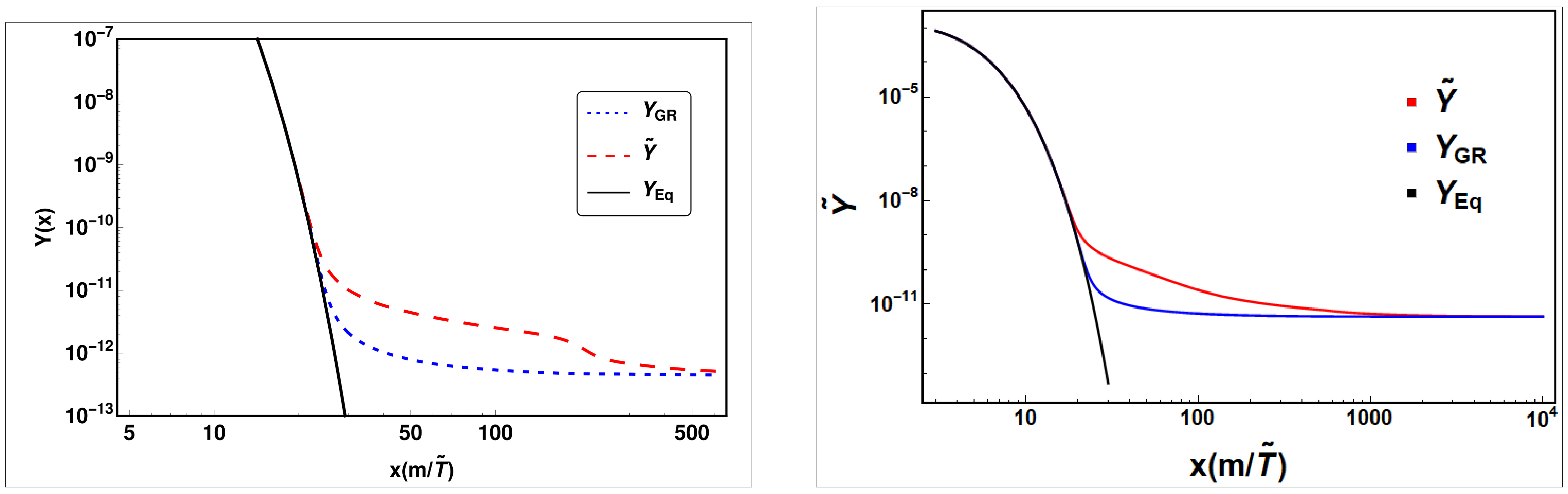

Figure 2: Solutions of the Boltzmann equation. Left plot shows the abundance of a DM mass of 1000 GeV using the expansion rate shown in left plot of Figure 1. Right plot shows the abundance for a DM of 100 GeV using the expansion rate corresponding to the mass scale $M = 12$ GeV shown in Figure 1.

DM Annihilation Cross Section

To satisfy the dark matter content of the universe, 27 %, we found that DM annihilation cross-section can be larger or smaller than the one predicted by standard cosmology.

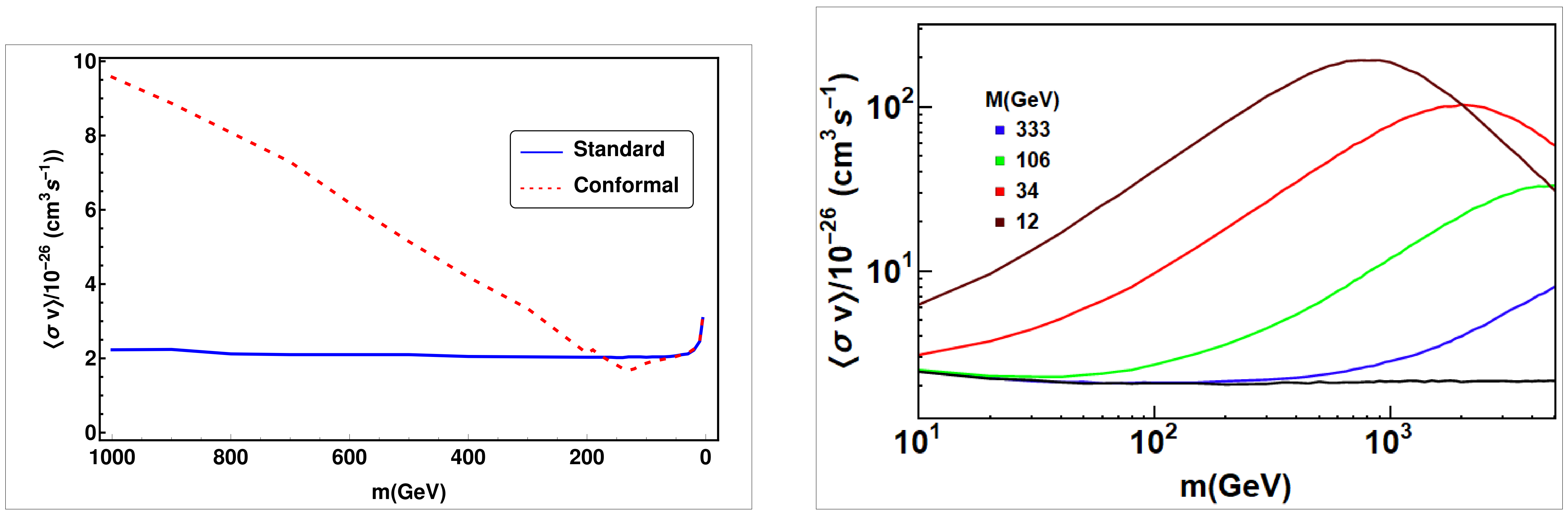

Figure 3: Annihilation cross section as function of mass. Left plot shows larger $\langle \sigma v \rangle$ for large masses, and smaller $\langle \sigma v \rangle$ for masses around 130 GeV [1]. In the right plot, different curves represent different predictions according to the mass scale M [2].

References

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