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ABSTRACT

Dark matter–anti-dark matter ($\chi - \bar{\chi}$) oscillations can cause the reactivation of DM annihilations during structure formation, eliminating cusps from galactic DM profiles while respecting constraints from BBN, CMB, and the observed DM relic density.

OSCILLATION FORMALISM: TWO MODELS

$$\mathcal{L}_m = \frac{1}{2} \delta m (\bar{\chi} \chi^c + \text{H.c.})$$

$$\mathcal{L}_1 \supset -\frac{1}{2} m_V^2 V_\mu^2 - g' \bar{\chi} \not{V} \chi \quad (\text{vector mediator})$$

$$\mathcal{L}_2 \supset -\frac{1}{2} m_\phi^2 \phi^2 - \frac{1}{2} m_a^2 a^2 - g' \bar{\chi} (\phi + ia\gamma_5) \chi \quad (\text{scalar mediator})$$

$$\chi \bar{\chi} \rightarrow VV : \sin^2(\varphi - \varphi') \quad (\text{flavor sensitive})$$

$$\chi \bar{\chi} \rightarrow \phi a : \sin^2(\varphi + \varphi') \quad (\text{flavor blind})$$

For annihilations to recouple during structure formation, the oscillations should start before ~ 0.1 Gyr, so

$$10^{-31} \text{ eV} \lesssim \delta m \lesssim \frac{\sqrt{g_*} m_\chi^2}{M_p x_{f.o.}^2} \sim 10^{-14} \text{ eV},$$

assuming $m_\chi \sim 100$ MeV. Annihilations could decouple in the early universe while still being important in over-dense environments at late times.

EARLY COSMOLOGY

Following [1, 2], the quantum Boltzmann equations are

Model 1 (flavor-sensitive vector mediator)

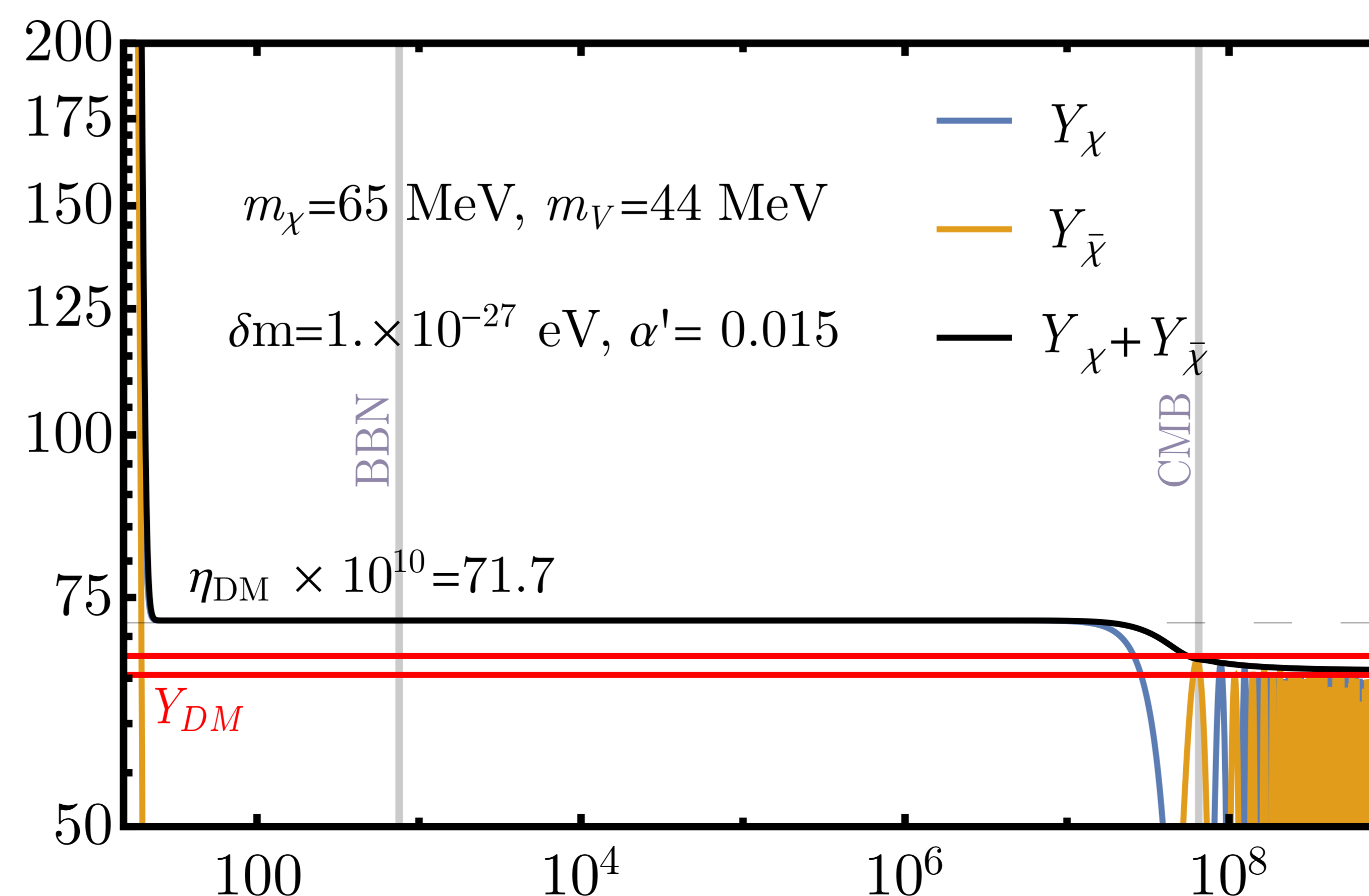
$$Y' = -\frac{i}{xH} [\mathcal{H}_0, Y] - \xi^3 \frac{\langle \sigma v \rangle_{ss}}{2xH} \begin{pmatrix} 0 & Y_{12} \\ Y_{21} & 0 \end{pmatrix} \text{Tr} Y \\ - \xi^3 \frac{\langle \sigma v \rangle_{aa}}{xH} (\det Y - Y_{\text{eq}}^2)$$

Model 2 (flavor-blind scalar mediator)

$$Y' = -\frac{i}{xH} [\mathcal{H}_0, Y] \\ - \xi^3 \frac{\langle \sigma v \rangle_{aa}}{xH} \left[\begin{pmatrix} \det' Y & Y_{12} \text{Tr} Y \\ Y_{12} \text{Tr} Y & \det' Y \end{pmatrix} - Y_{\text{eq}}^2 \right]$$

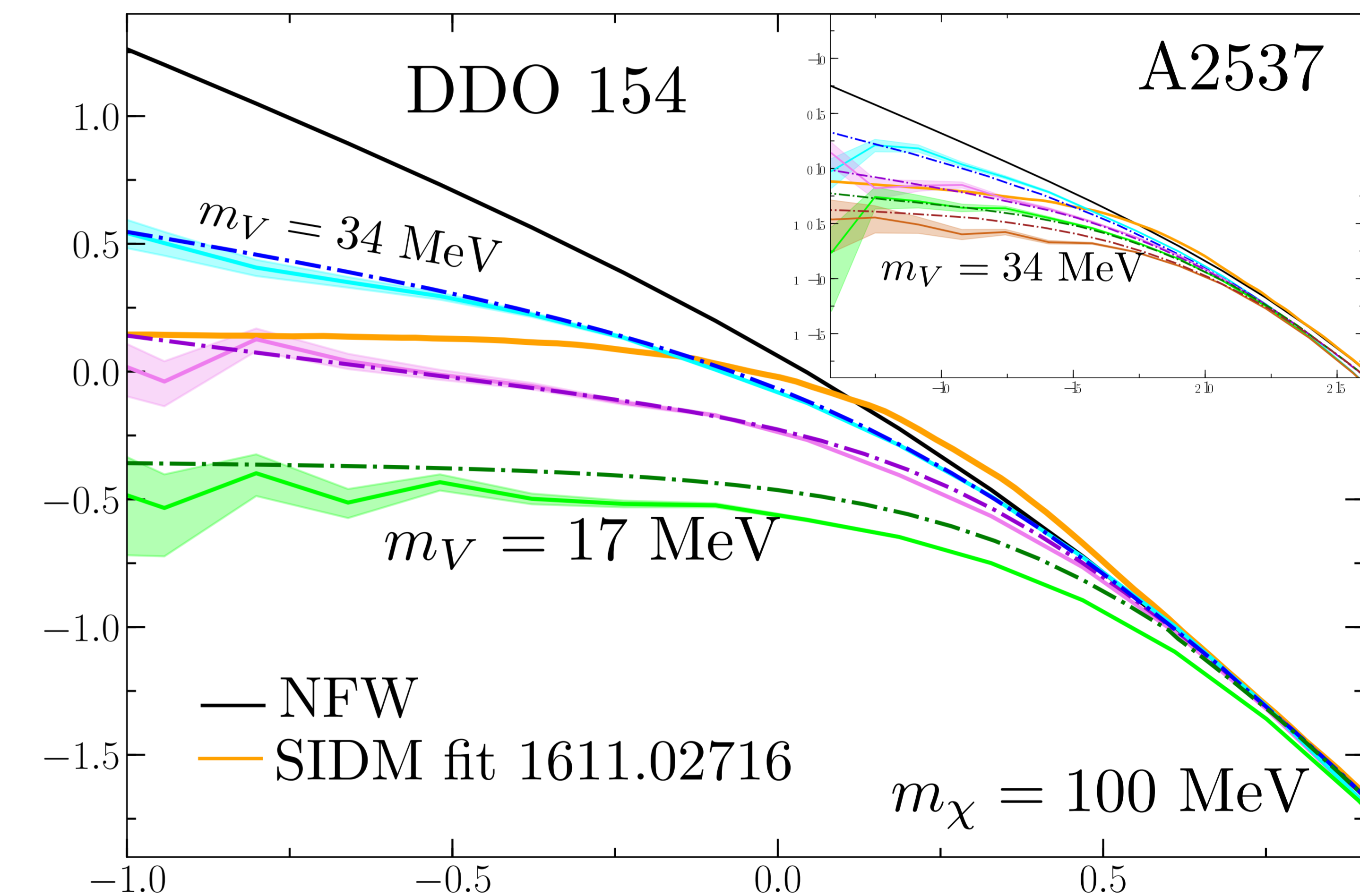
where $\det' Y \equiv Y_{11} Y_{22} + Y_{12} Y_{21}$ and $\xi = T_\chi / T$.

Figure 1: Comoving density $Y \times 10^{10}$ vs. $x = m_\chi / T$.



STRUCTURE FORMATION & N-BODY SIMULATIONS

Figure 2: $\log_{10} \rho_\chi$ vs. $\log_{10} r$. Evolving $\rho_{\chi,0}^{\text{NFW}}$ for ~ 10 Gyr in a dwarf spheroidal galaxy and a cluster of galaxies.



REFERENCES

- [1] Marco Cirelli, Paolo Panci, Geraldine Servant, and Gabriella Zaharijas. Consequences of DM/antiDM oscillations for asymmetric WIMP dark matter. *Journal of Cosmology and Astroparticle Physics*, 2012(03):015, 2012.
- [2] Sean Tulin, Hai-Bo Yu, and Kathryn M Zurek. Oscillating asymmetric dark matter. *Journal of Cosmology and Astroparticle Physics*, 2012(05):013, 2012.

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