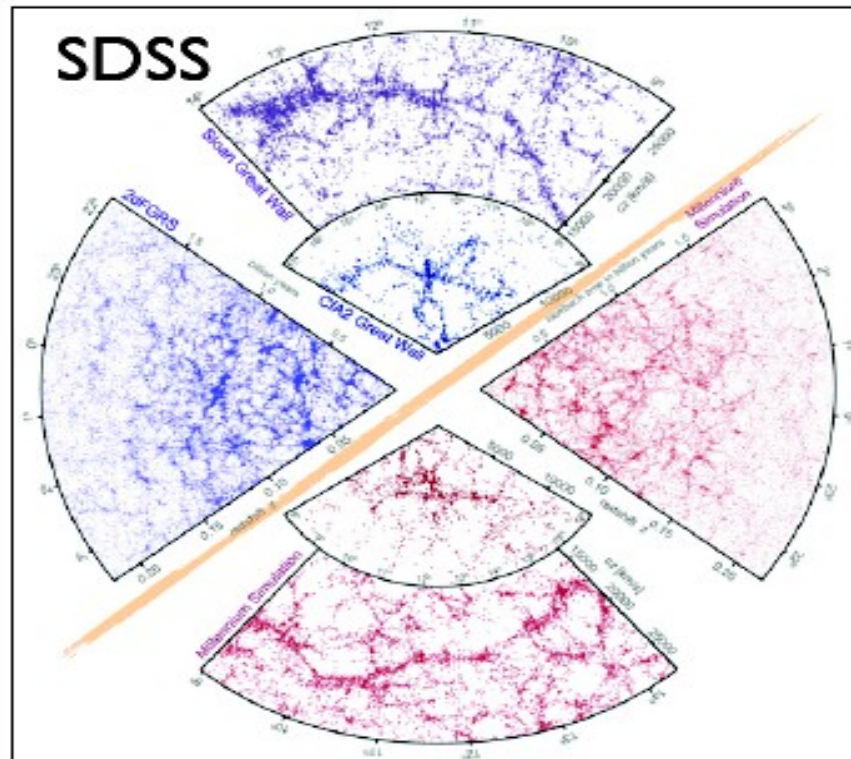


# Non-Thermal Dark Matter Mimicking An Additional Neutrino Species In The Early Universe.

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Fermilab Center for Particle Astrophysics  
Federal University of Paraiba

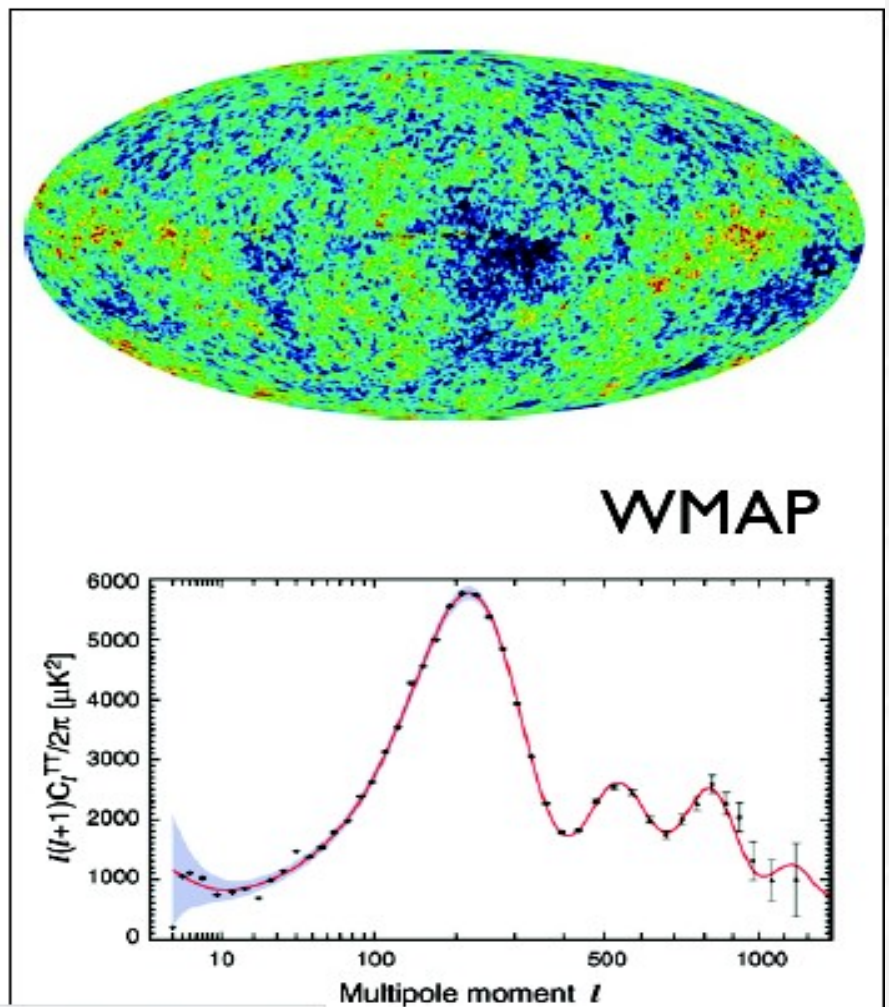
New Perspectives 14<sup>th</sup> June 2012

# Evidences for Dark Matter



- Structure Formation
- Cosmic Microwave  $\gamma$  s

Anisotropies and their evolution require  $\sim 5$  times more weakly interacting matter than baryonic matter.



BBN  $\rightarrow$   $N_{eff}^{\nu} = 3.04$

## Recent Measurements



South Pole Telescope  $\rightarrow$   $N_{eff}^{\nu} = 3.86 \pm 0.42$

Atacama Cosmology Telescope  $\rightarrow$   $N_{eff}^{\nu} = 4.6 \pm 0.8$

WMAP  $\rightarrow$   $N_{eff}^{\nu} = 4.34^{+0.86}_{-0.888}$



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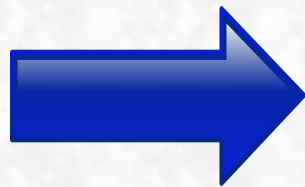
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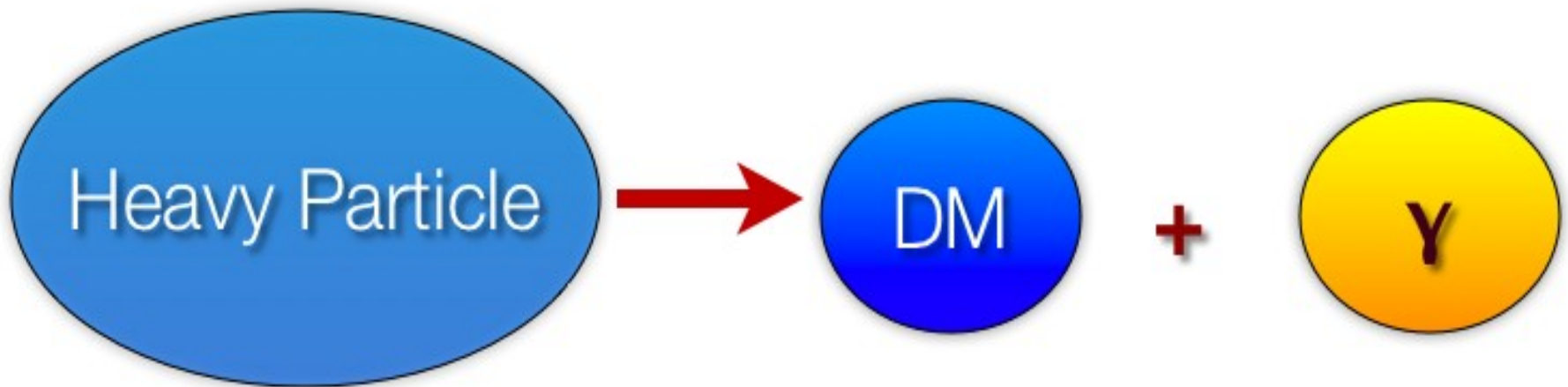
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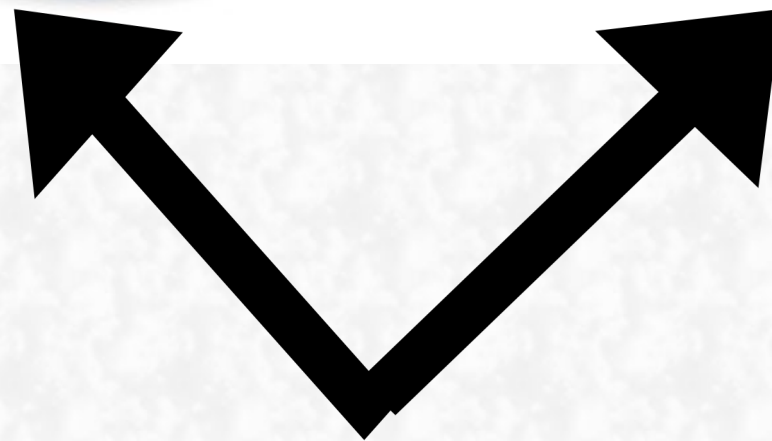
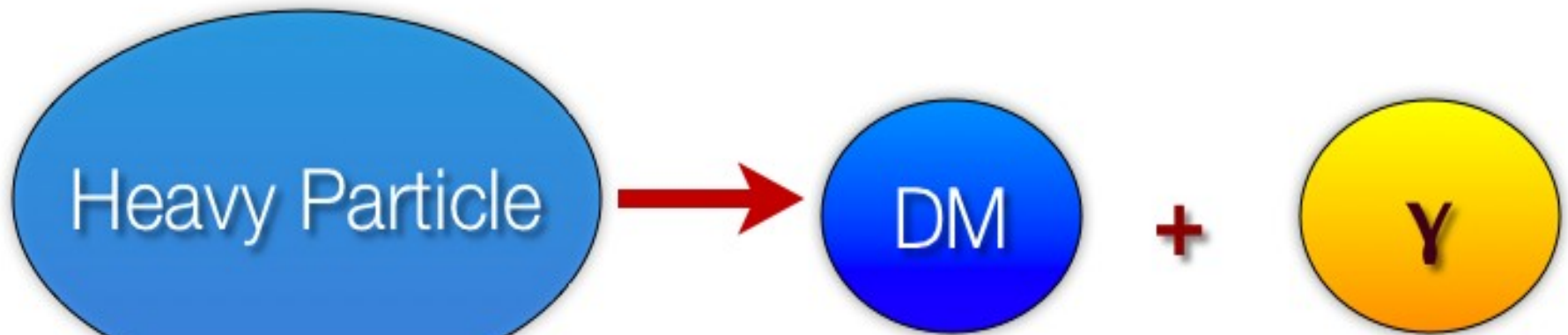
ruled out at 99% C.L.

# Proposal: Non-Thermal Production of WIMPs



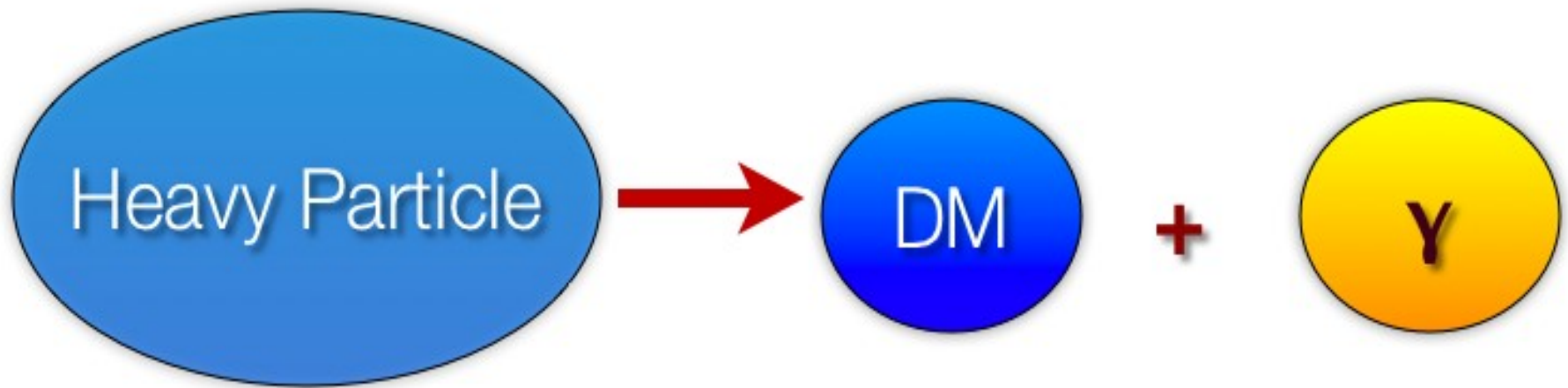
Lifetime

# Proposal: Non-Thermal Production of WIMPs



Ratio of the masses

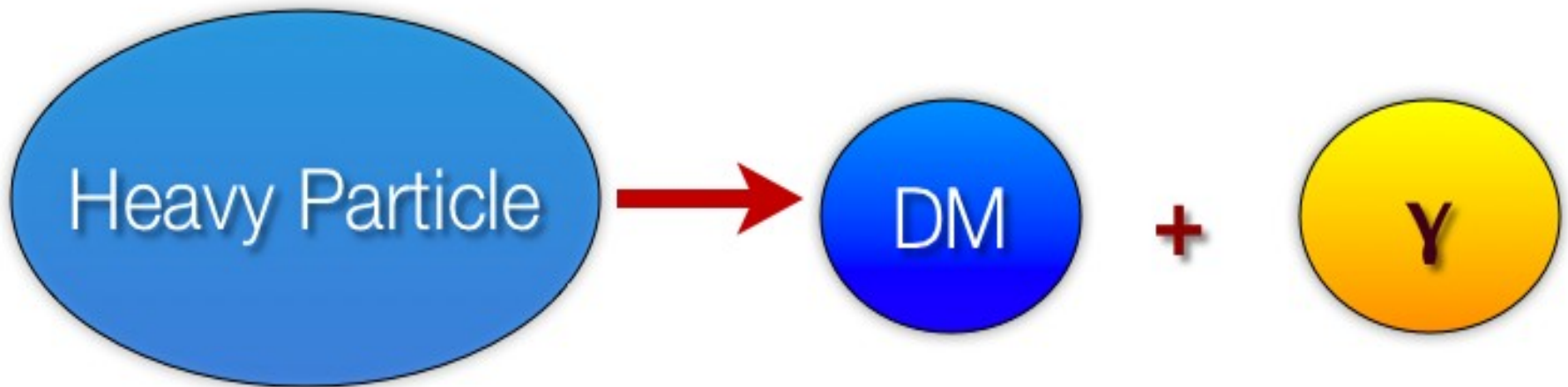
# Proposal: Non-Thermal Production of WIMPs



Fraction of DM produced from the mother particle



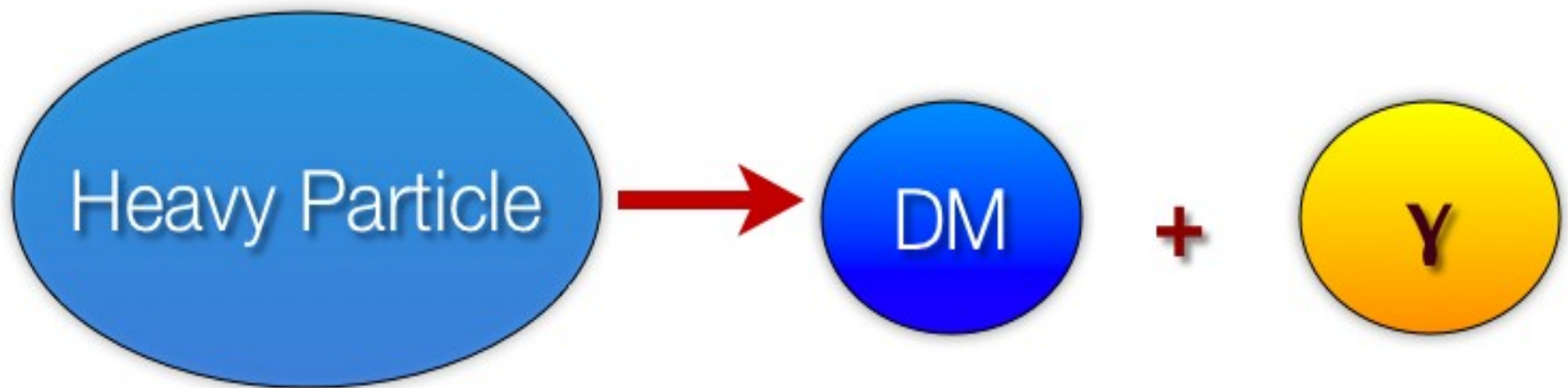
# Proposal: Non-Thermal Production of WIMPs



Is this scenario consistent with BBN and Structure Formation constraints?



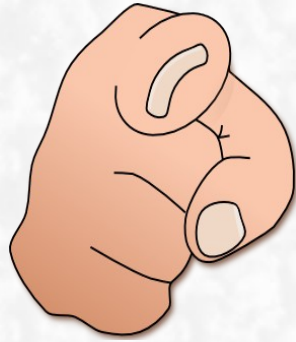
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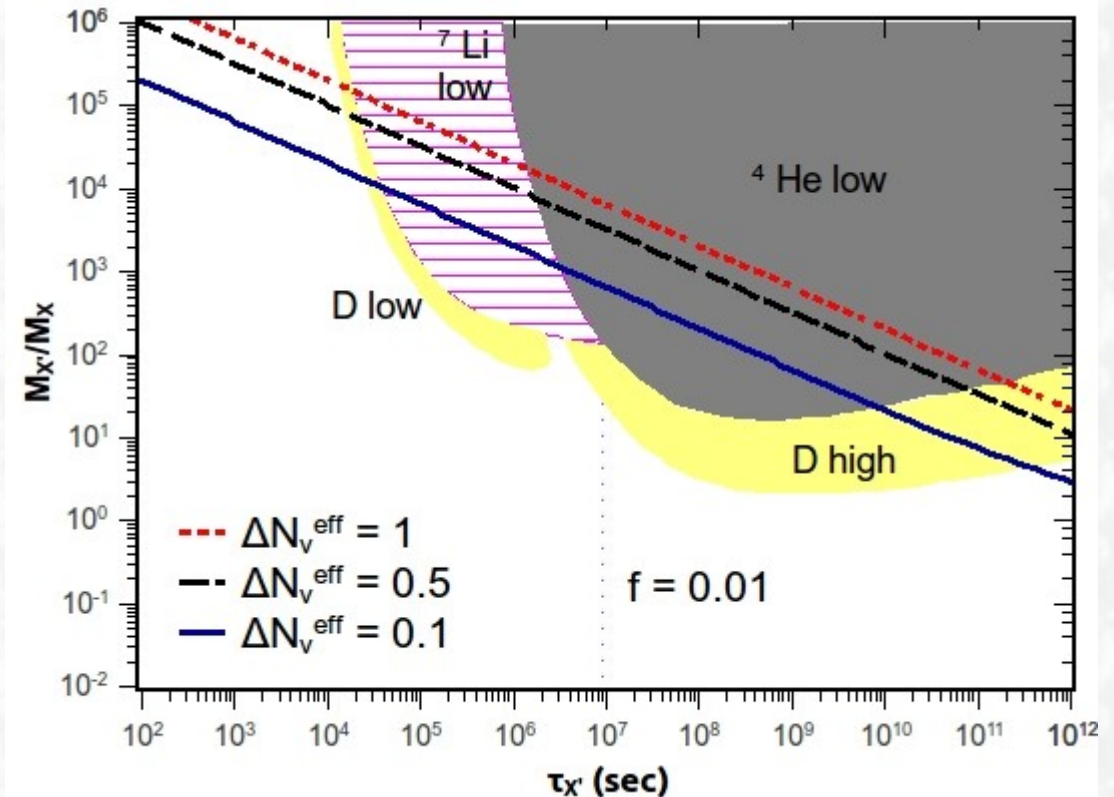
Is this scenario consistent with BBN and Structure Formation constraints?

**YES!**

**But structure formation requires  $f \sim 1\%$ !**



$$X' \rightarrow X + \gamma$$



$\tau$  → Lifetime of the mother particle

$M_{X'}$  → Mass of the mother particle

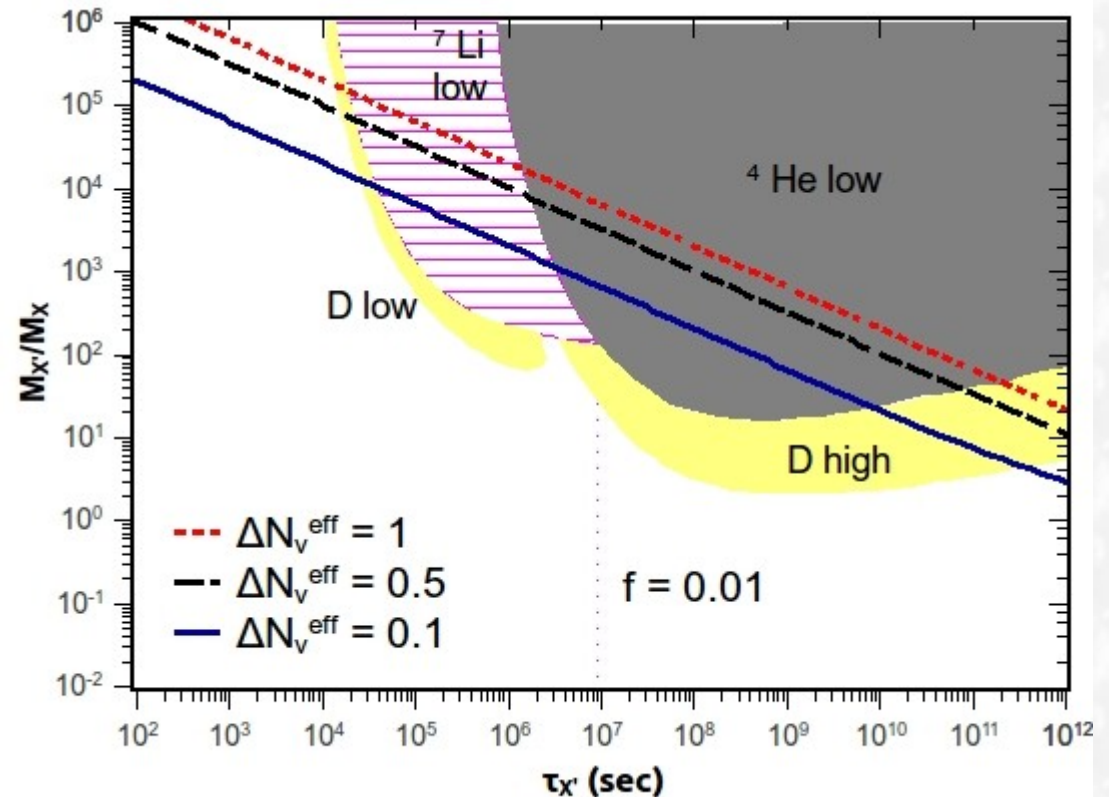
$M_X$  → Mass of the WIMP

$f$  → fraction of WIMPs produced by the decay of  $X'$

An interesting region for lifetime  $< 10^4$  s and large mass ratios  $M_{X'}/M_X > 10^5$



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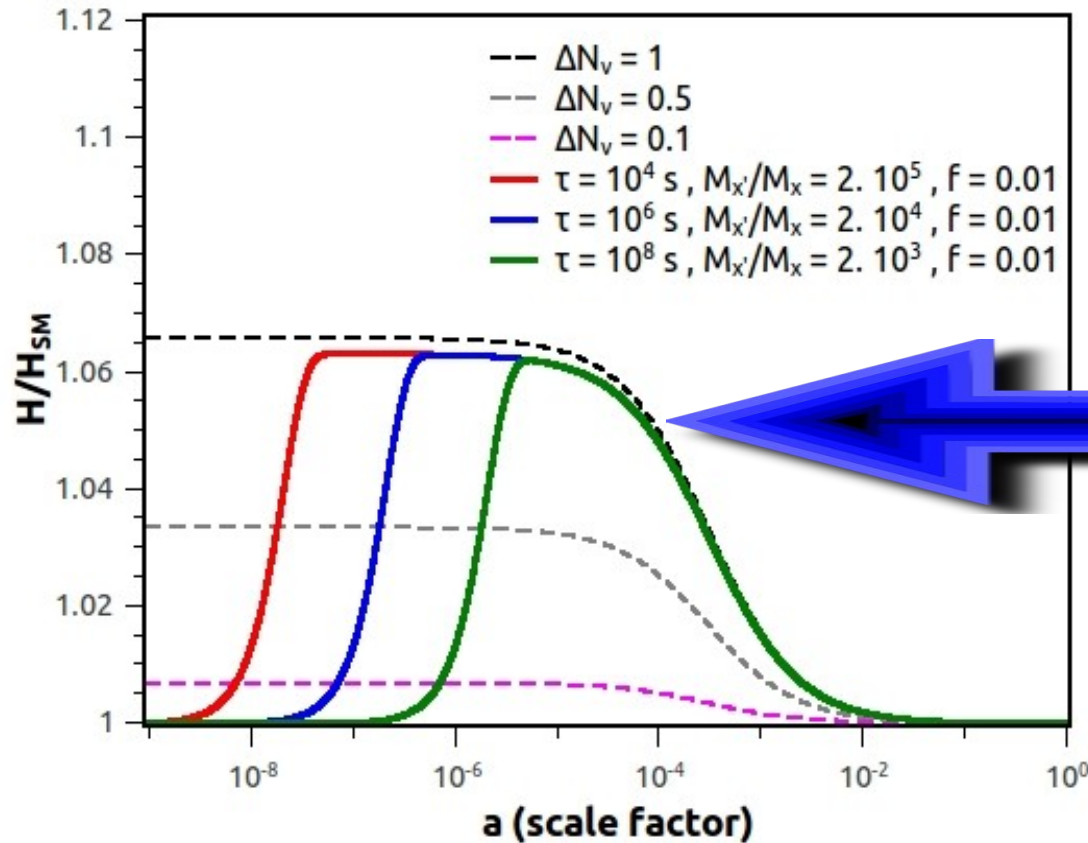
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**Matter-radiation  
equality happens**

$H \rightarrow$  Expansion rate of the Universe (our model)

$H_{SM} \rightarrow$  Expansion rate of the Universe (Standard Model)

# Conclusions

1. Structure Formation → fraction of WIMPs non-thermally produced to be  $\sim 1\%$
2. BBN → Small lifetimes  $< 10^4$  s  
→ Large mass ratios
3. Non-thermally produced WIMPs can mimic an additional neutrino species in the early Universe

# Conclusions

**Thank you**

1. Structure Formation → fraction of WIMPs non-thermally produced to be  $\sim 1\%$
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# Extra Material

The CMB power spectrum is sensitive to the redshift at matter-radiation equality.

$$Z_{eq} = \frac{\rho_m}{\rho_{rad}} - 1$$

## Standard Cosmological Model

$$\rho_{rad} = \rho_\gamma + \rho_\nu = \left[1 + \frac{7}{8} \left(\frac{4}{11}\right)^{4/3} N_{eff}\right] \rho_\gamma$$

## Our model

$$\rho_{rad} = \rho_\gamma + \rho_\nu = \left[1 + \frac{7}{8} \left(\frac{4}{11}\right)^{4/3} (N_{eff} + \Delta N_{eff})\right] \rho_\gamma$$

# Number of effective species

$$X' \rightarrow X + \gamma$$

$$\gamma_X(a) \approx 1 + \frac{a(t)}{a} \left( \frac{M'_X}{2M_X} - 1 \right)$$

$$\gamma_X(t_{EQ}) \approx 1 + 7.8 \times 10^{-4} \left( \frac{\tau}{10^6} \right)^{\frac{1}{2}} \left( \frac{M'_X}{2M_X} - 1 \right)$$

$$\Delta N_{eff}^\nu \approx 4.8 \times 10^{-3} \left( \frac{\tau}{10^6} \right)^{\frac{1}{2}} \left( \frac{M'_X}{2M_X} - 1 \right) \cdot f$$



# Structure Formation

$$\lambda_{FS} \approx 1.0 Mpc \left( \frac{\tau}{10^6 sec} \right)^{\frac{1}{2}} \left( \frac{M'_X}{2M_X} \right) \left\{ 1 + 0.14 \ln \left[ \left( \frac{10^6}{\tau} \right)^{1/2} \frac{2M'_X M_X}{M_{X'}^2 - M_X^2} \right] \right\}$$

Parameters which lead to the impact of one additional neutrino and using  $f = 1$

$$\lambda_{FS} \approx 50 Mpc$$

Excluded by Lyman-alpha

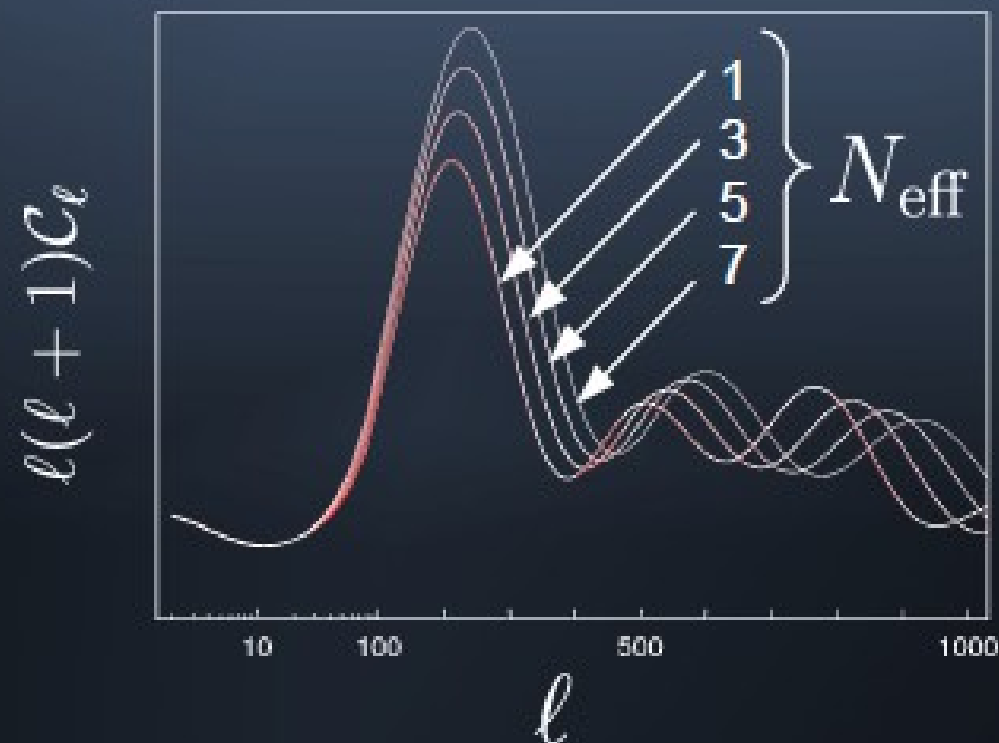
Lyman-alpha  $\rightarrow$

$$\lambda_{FS} \approx 0.3 Mpc$$

$\rightarrow$

$$f \approx 1$$

# $N_{\text{eff}}$ and the CMB



- Angular power spectrum is a function of  $\mathcal{O}(10)$  cosmological parameters (e.g.,  $\omega_b$ ,  $\omega_{\text{dm}}$ ,  $\omega_v$ ,  $\Omega_{\text{de}}$ ,  $N_{\text{eff}}$ , ...)