Warm Dark Matter Promises and Problems

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WDM Structure Suppression in SCDM

- Early 1990's → problems with SCDM

  (too much structure and high vely at ~ 1 Mpc)

→Doddleson & Widrow propose massive 'sterile' neutrinos, produced through oscillations of SM neutrinos, as WDM

Idea appealing from current BSM phys. viewpoint

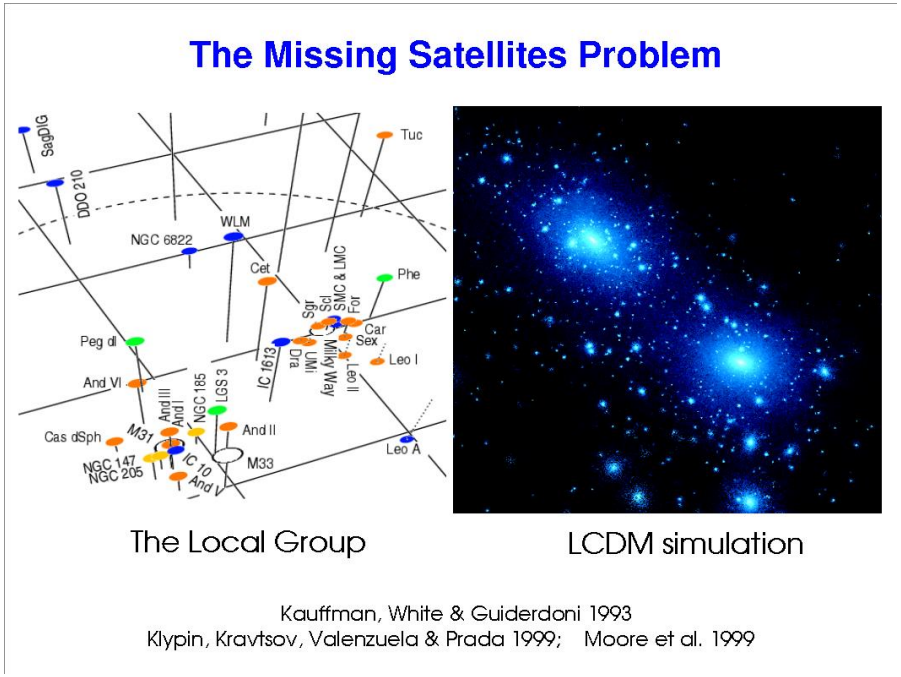
Problems with Contemporary 'Concordance' (~2000 AD..)

- **At smaller scales ~ 10 kpc and less:**

→**Too dense central regions in galaxies**

- **Too many haloes than small galaxies… some 'too big to fail' and with 'wrong' dynamical properties**

(consequence of above?)



A Host of Proposed Remedies

- ‘Heating’ CDM via interaction with baryonic component during galaxy formation

- Heating central halo via ‘heat transfer’: (collisional SIDM)

(++broken scale invariance of primordial power spectrum; degeneracy and kpc scale quantum effects etc.)

Or already preheated *‘warm’ dark matter*

WDM and Structure Suppression II

- For a thermal particle $m\ v^2$ ~ K T → 'faster → streams further till MR equality'

WIMPS many GeV's .vs. WDM few keV

→ At keV → smallest galaxy scales washed out

++ 'Intuitively', expect smaller central density

→ cusped structures have divergent central phase space density, along with divergent central density

In Practice…

- Even in HDM, or various cutoffs, in PS→ central density cusps for haloes that form
  (e.g., Moore et. al. 1999)

- 'Catch 22': larger initial velys to lead to significant central halo core → 'free stream away' the structure (galaxy does not form at all
  (Maccio et. Al. 2012)

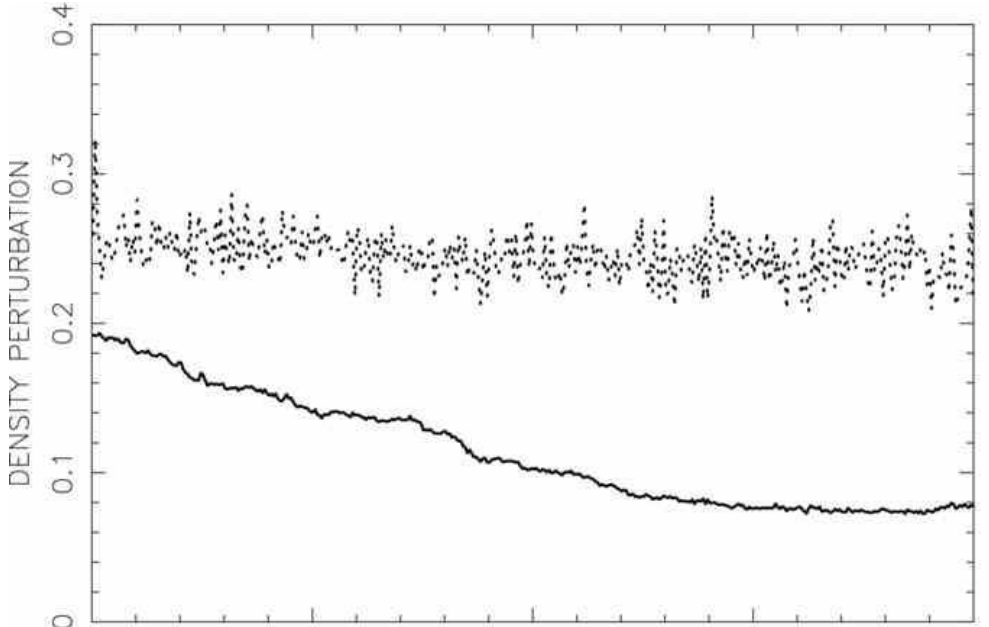
→ (standard) WDM structure formation seems to at most only ameliorates missing sat problem (problems too with 'too big to fail'; Schneider et. al. 2014)

(Top Hat) Collapse ~ Cold
and
Cold Collapse → Large Density Contrasts

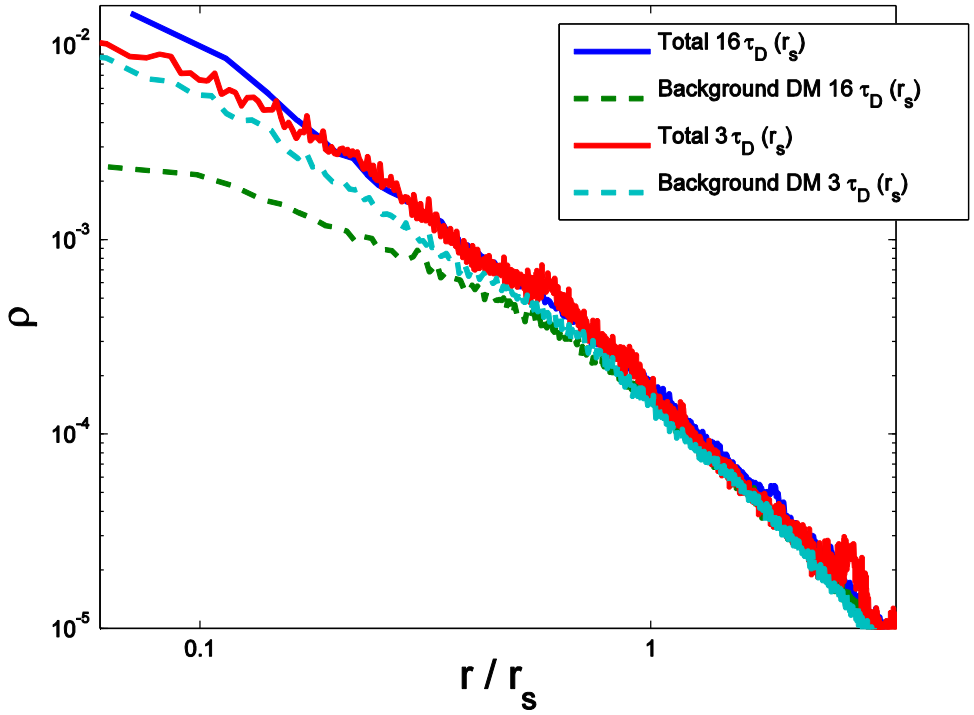
- Many arguments for this; here's one:

Centrally concentrated systems are robust because they wash out perturbations

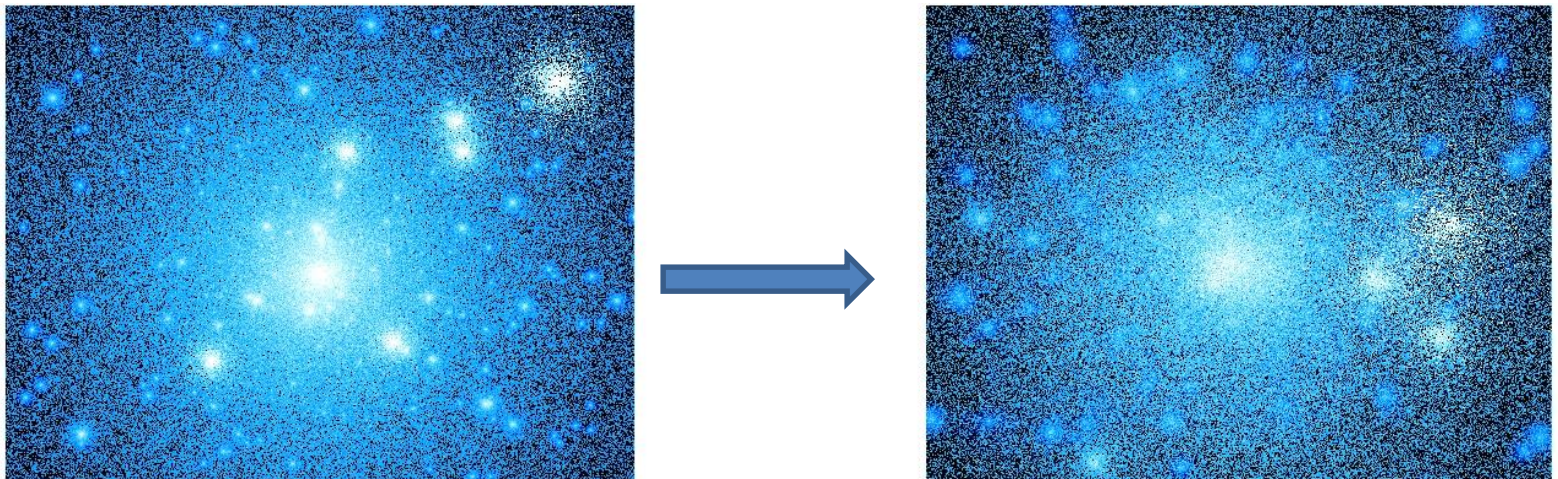
El-Zant (2013)



Central cusps invariant under merging



(El-Zant 2008 and ongoing work)



‘Standard’ WDM Deficient

- Reduces small sats but constrained by Lyman-alpha AND

→ this is arguably easiest to solve via feedback

→ new small galaxies discovered all the time..

→ exacerbates early galaxy and BH formation

WDM is also **hard to produce in right amounts**;

Standard D-W mechanism ruled out by Lyman and X-ray bounds (Seljak et. Al. 2006; Viel et. al 2006; Abazajian & Koushiappas 2006; Viel et. al 2013) ++ GT bound

* Resonant production (from Lepton asymmetry, Shi-Fuller 99)?

Controversy concerning 3.5 keV line… (mass dependent)

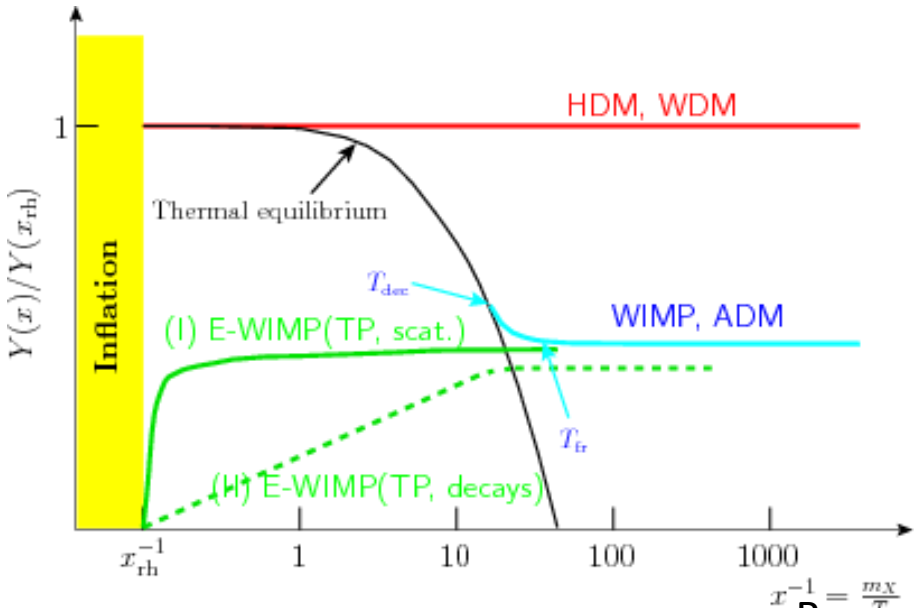
Also

- Thermal production
- Direct decay from scalar field

Thermal Production

keV WDM particles decouple while relativistic (E-density proportional to a^3
→ commoving density constant
→ **no Boltzaman suppression ~ $e^{-m/kt}$**

Ων ≈ mν/ 91.5h 2 eV .



Baer et. Al 2014)

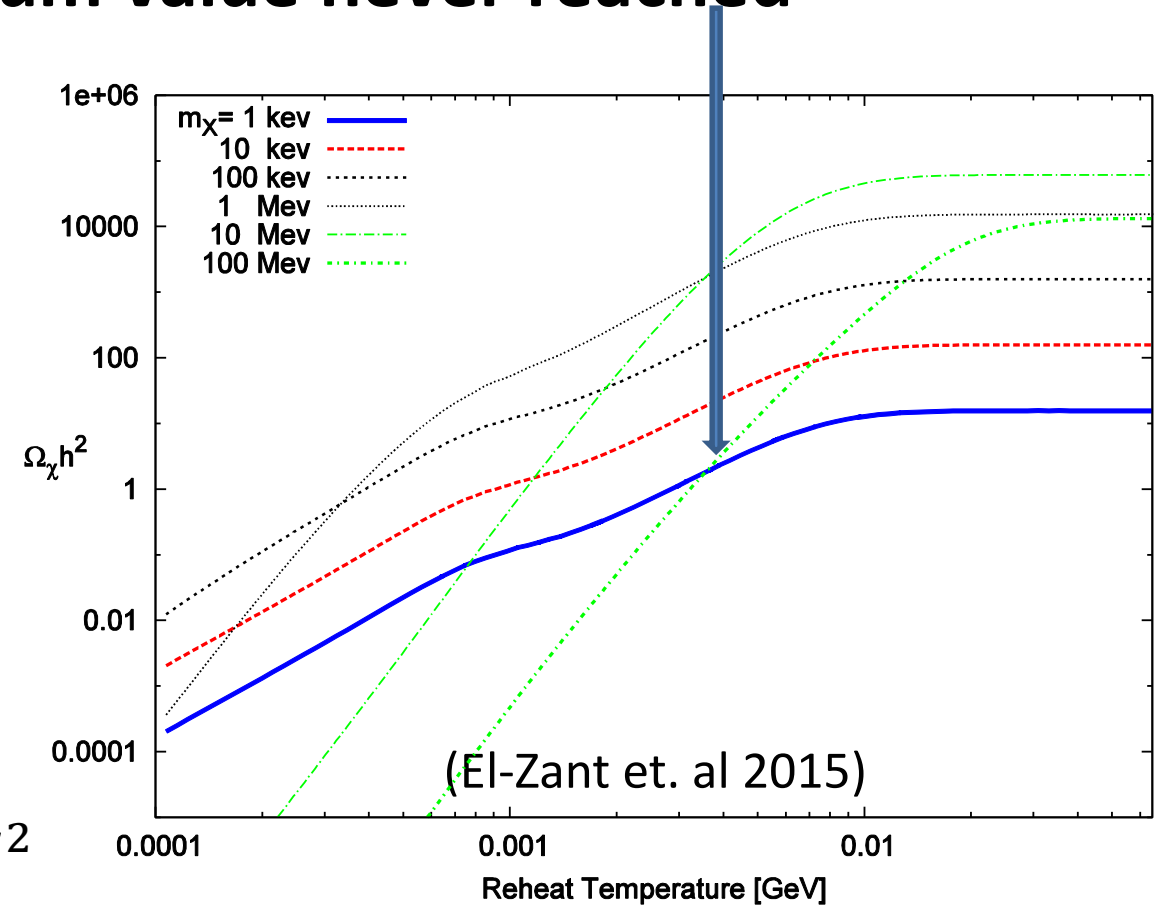
Overproduced by huge factors in the keV range

Thermal Production with Low Reheating

** Scalar field decays (also similar to end of inflation but lower T than standard models)

→ **Chemical equilibrium value never reached**

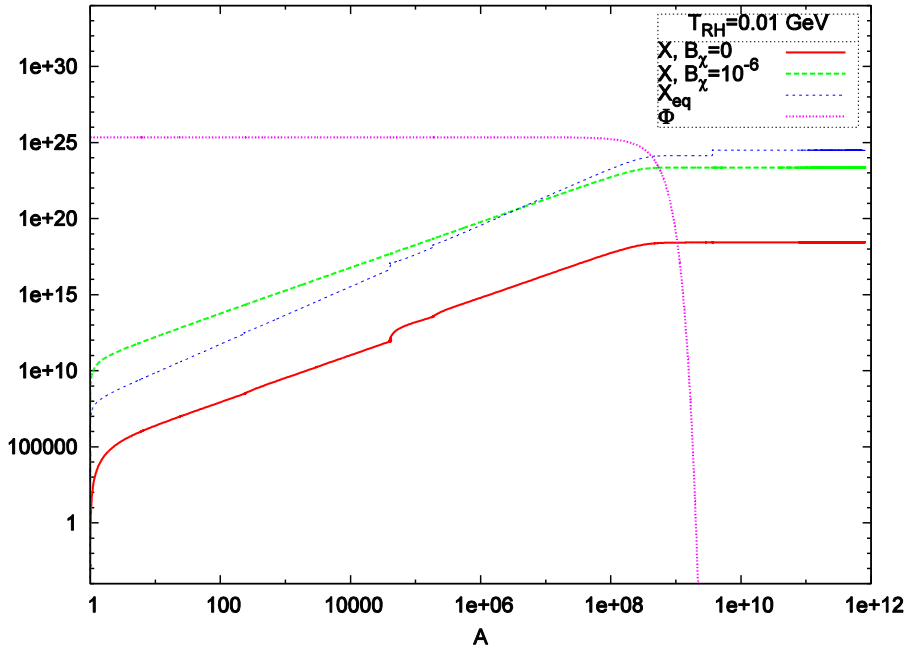
But tension with BBN

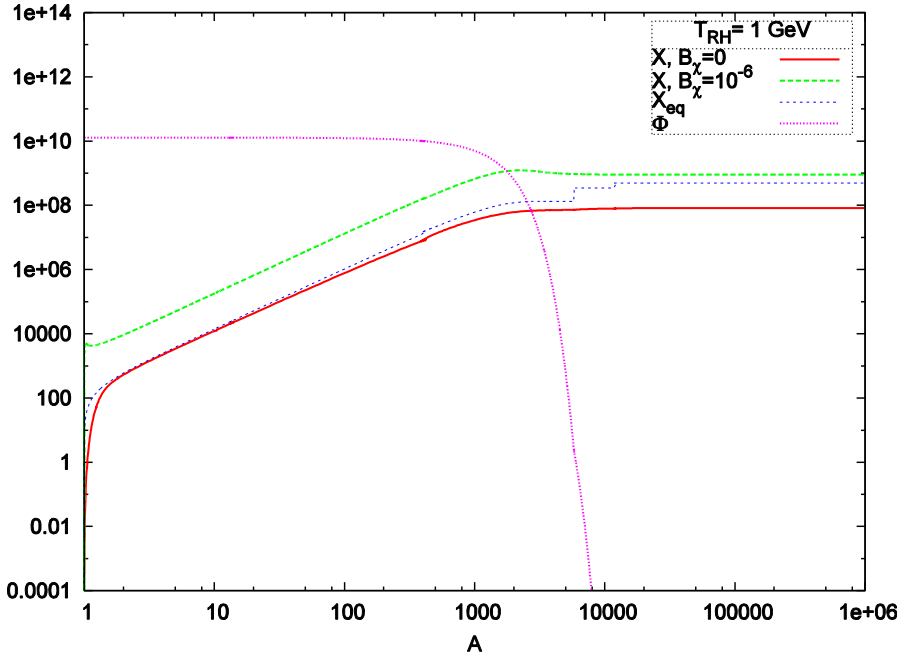


Production rate ~ Crossection ~ T^2

Particle either never thermalizes, or does *after* reheating

(not much room for simple entropy production scenario)

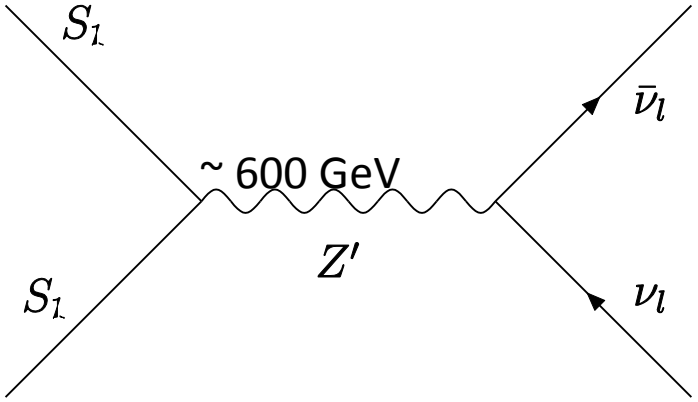




Models with no Oscillations and Suppressed Coupling (e.g., B-L)

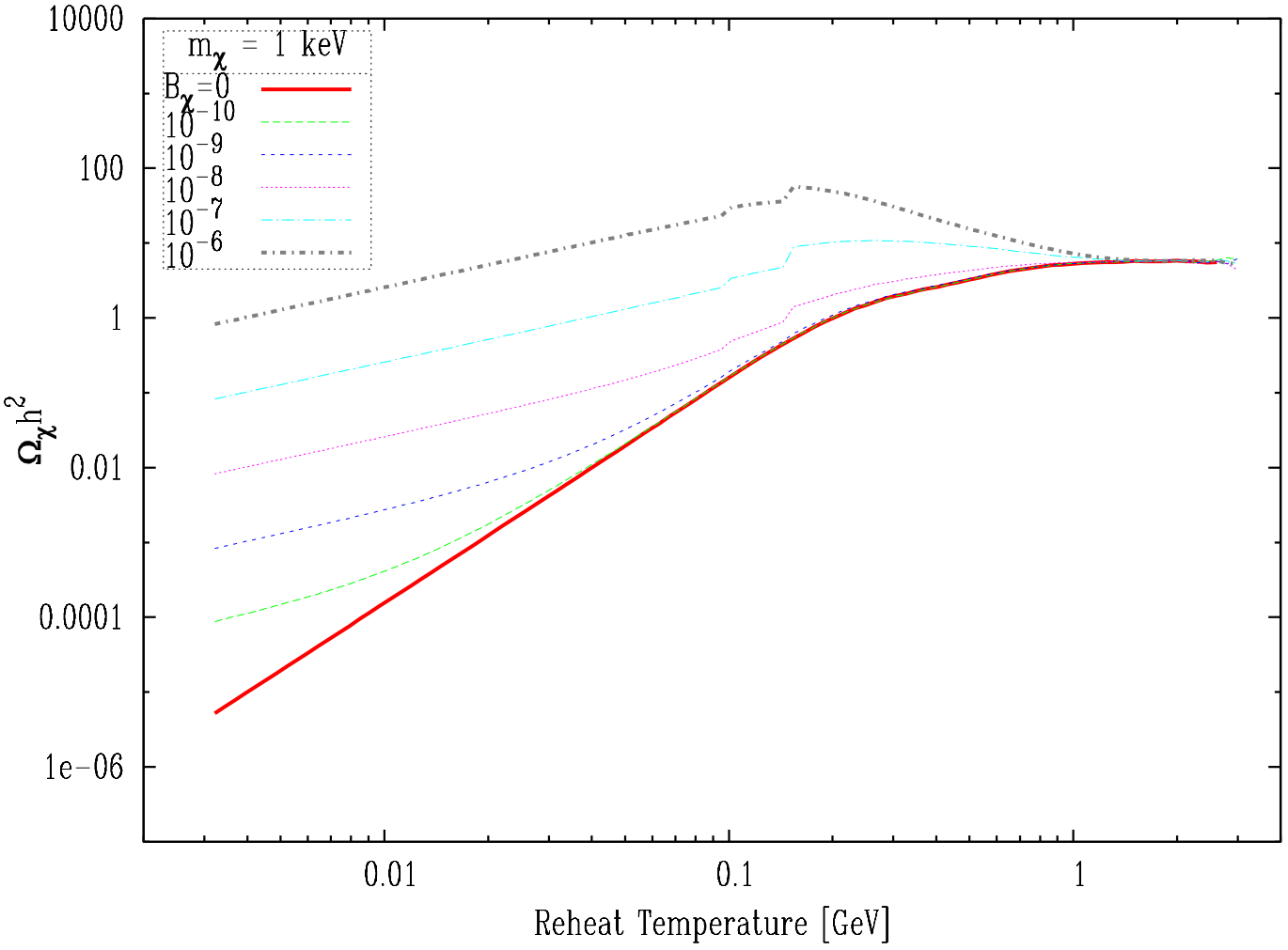
- Model predicts keV neutrino with mass matrix such that **mixing with SM particles evaded**

(circumvents X-ray bounds)



- Thermal production ~ crossection → suppressed
- WDM also produced by direct scalar field decay

Thermal and Non-Thermal Production in B-L



Conclusions

- WDM in principle promising from structure formation perspective
- Prime particle candidates also promising from BSM physics perspective (neutrino oscillations and various seesaw-type models explaining masses).
- However, large free steaming lengths do not straightforwardly solve most current small scale structure formation problems
- D-W and thermal scenarios severely constrained by X-ray and Lyman bounds

-> not straightforward to produce in right amounts