Signatures of dark matter interactions at high and higher redshifts

Markus R. Mosbech – Cosmology from Home 2022

Overview:

- **Introduction to interaction**
- **Nonlinear predictions and comparison to warm dark matter**
- **Gravitational waves as a novel probe of suppressed structure**

Based on the works:

- M. Mosbech, C. Boehm, S. Hannestad, O. Mena, J. Stadler, & Y. Wong, JCAP03(2021)066, arXiv:2011.04206
- M. Mosbech, A. Jenkins, S. Bose, C. Boehm, M. Sakellariadou, & Y. Wong, in prep. 2022
- M. Mosbech, C. Boehm, & Y. Wong, in prep. 2022

A little bit of background

There is a lot of dark matter

It clusters – at least on large scales

We don’t know what it is

We know a lot about what it is not

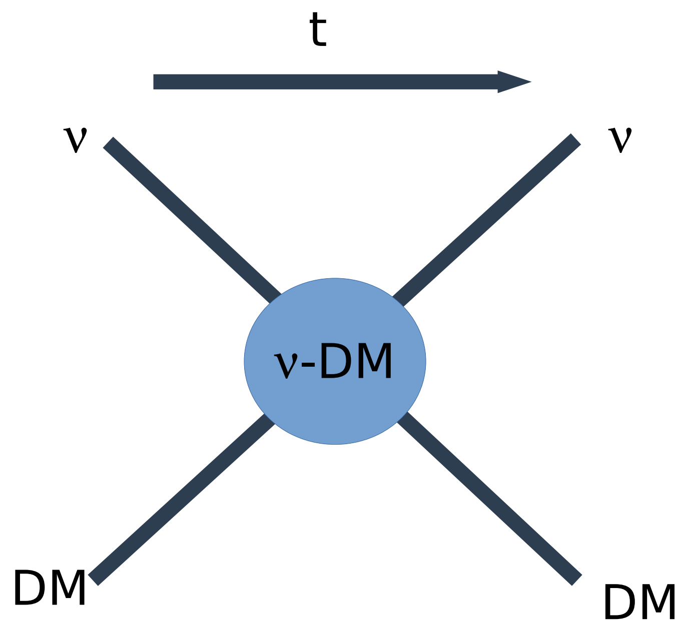
Let’s find a few more things it cannot be

Let’s introduce a scattering model (phenomenological)

Simple scattering with neutrinos

Ignore implications for creation/annihilation

Assume constant cross-section



Arguments in favor:
Neutrinos may be related to new physics
Cannot test in detector

$$u_\chi = \frac{\sigma_0}{\sigma_{\mathrm{Th}}}\left(\frac{m_\chi}{100\ \mathrm{GeV}}\right)^{-1}$$

Current status of model

- **CMB + BAO constrains** $u_\chi \lesssim 10^{-4}$
- **Including Lyman-α introduces a preference for** $u_\chi \sim 5 \cdot 10^{-6}$
  (Hooper & Lucca, arXiv:2110.04024)
- **These bounds both based on linear calculations.**

Time to go nonlinear

Turns out, our model is convenient for this

Realistically, model decouples at $z \gg 1000$

N-body starts at $z \ll 1000$

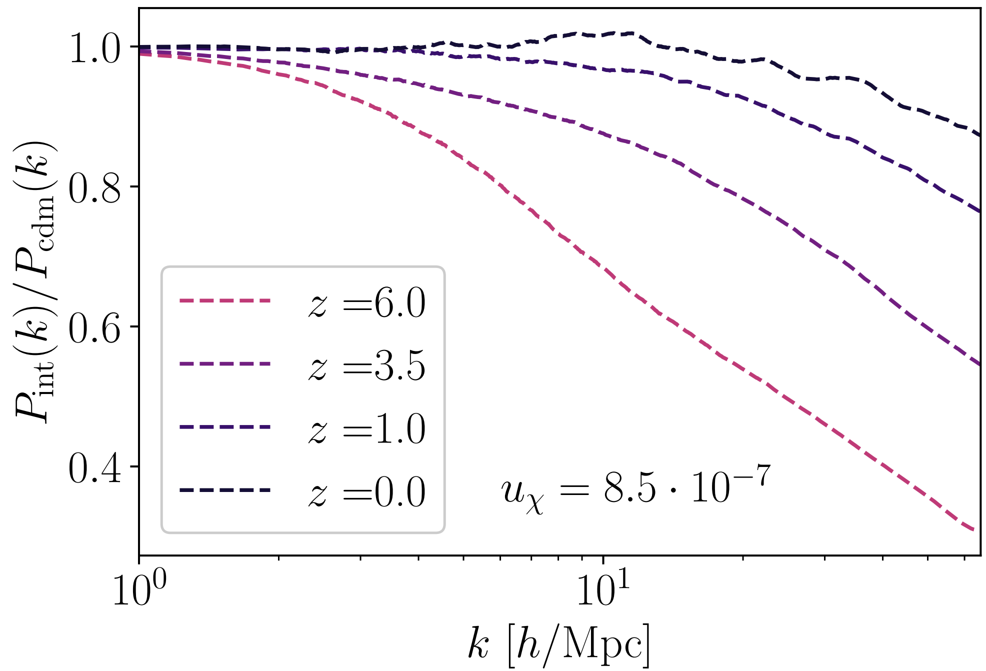
No need to modify N-body code, just provide ICs

What happens when we evolve in N-body?

Suppression gets smaller, oscillations disappear

What does it look like?

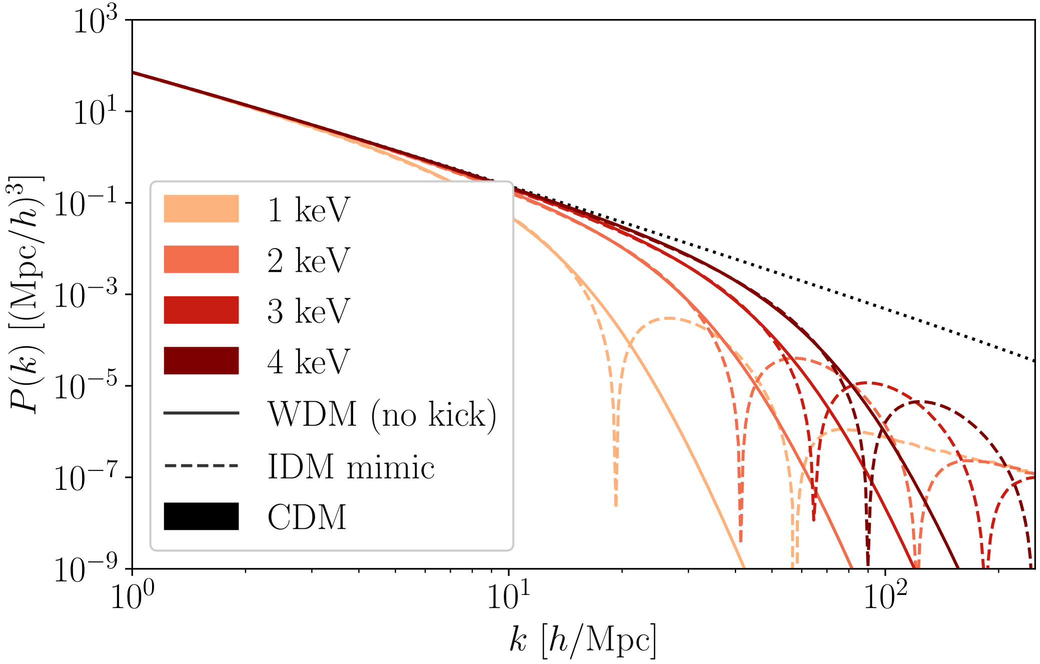
It looks like warm dark matter



WDM-IDM comparison

We start by tuning our ICs to match

Difference is in oscillations



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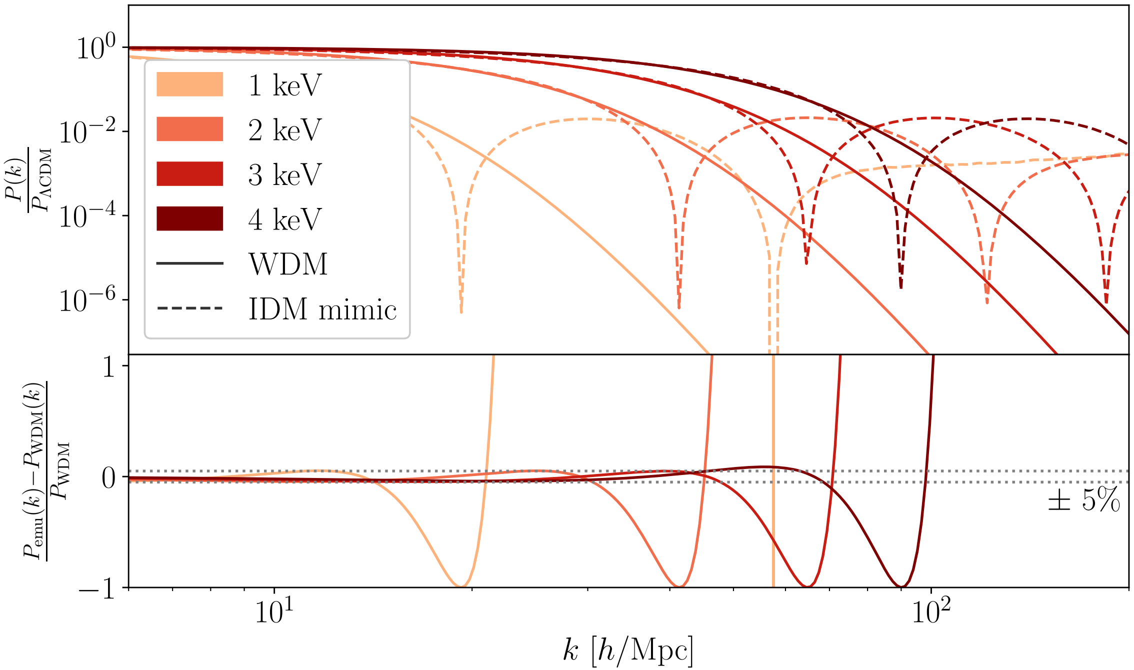

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“Late” time predictions

m_{WDM}	Mimic $u_{\nu\chi}$
1 keV	$8.5 \cdot 10^{-7}$
2 keV	$1.75 \cdot 10^{-7}$
3 keV	$7.0 \cdot 10^{-8}$
4 keV	$3.6 \cdot 10^{-8}$

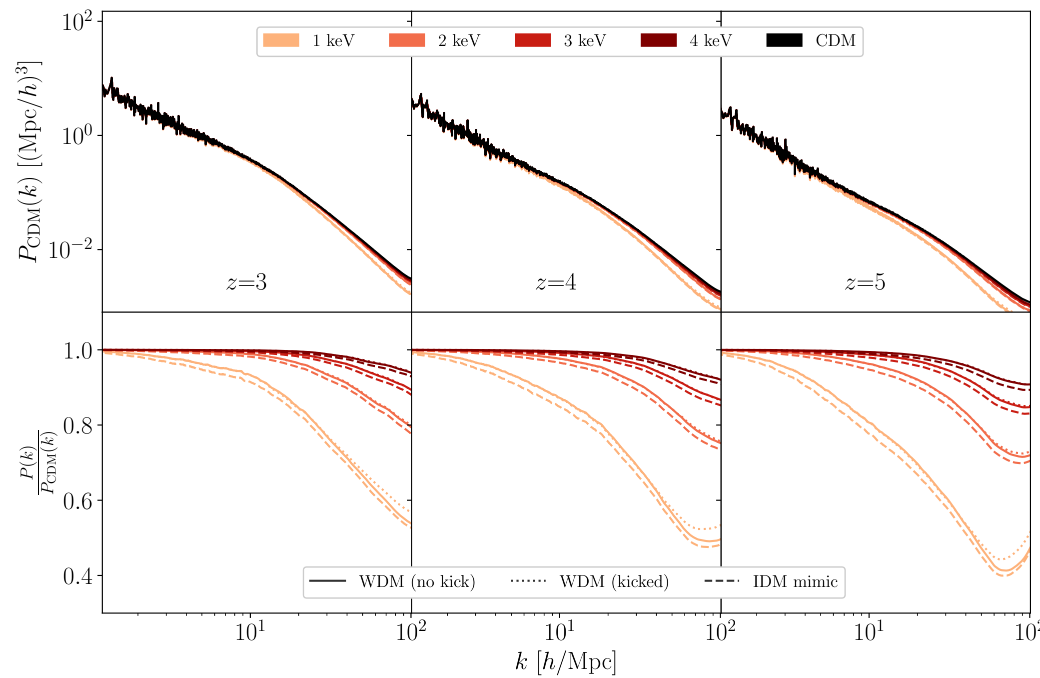
Looks like the oscillations are gone!

Interacting and warm look almost the same.

Close enough that it could just be a different WDM mass.

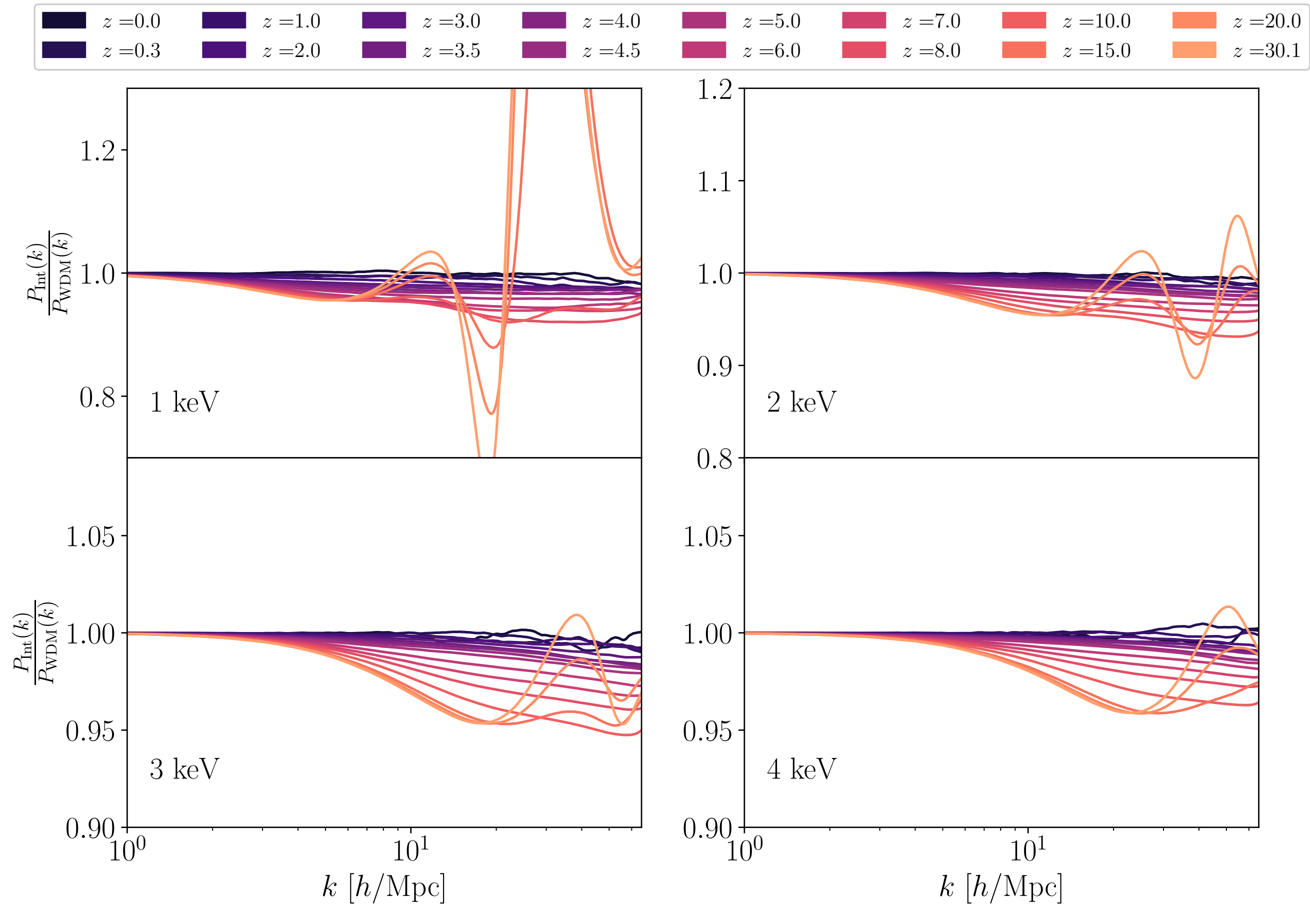
The SKA will be able to constrain WDM masses up to 4 keV at z~3-5 with 21cm intensity mapping.

Carucci et al. 2015, arXiv:1502.06961



Can we never tell the difference?

Hopefully at high z!
SKA can probe
21cm up to z~25.



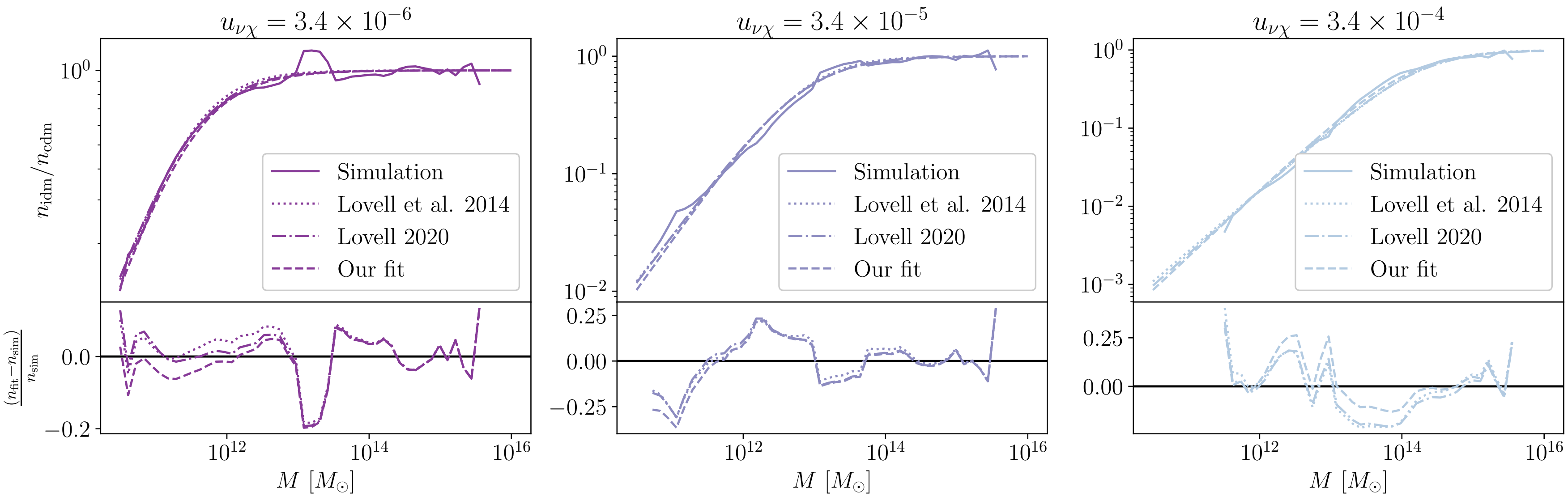
Alternative probes: Halo mass function

When structure is suppressed, fewer halos form.

$$\frac{n_{\rm int}}{n_{\rm cdm}} = \frac{1}{1 + \left(\frac{M_{10}}{M}\right)^{\alpha}}$$

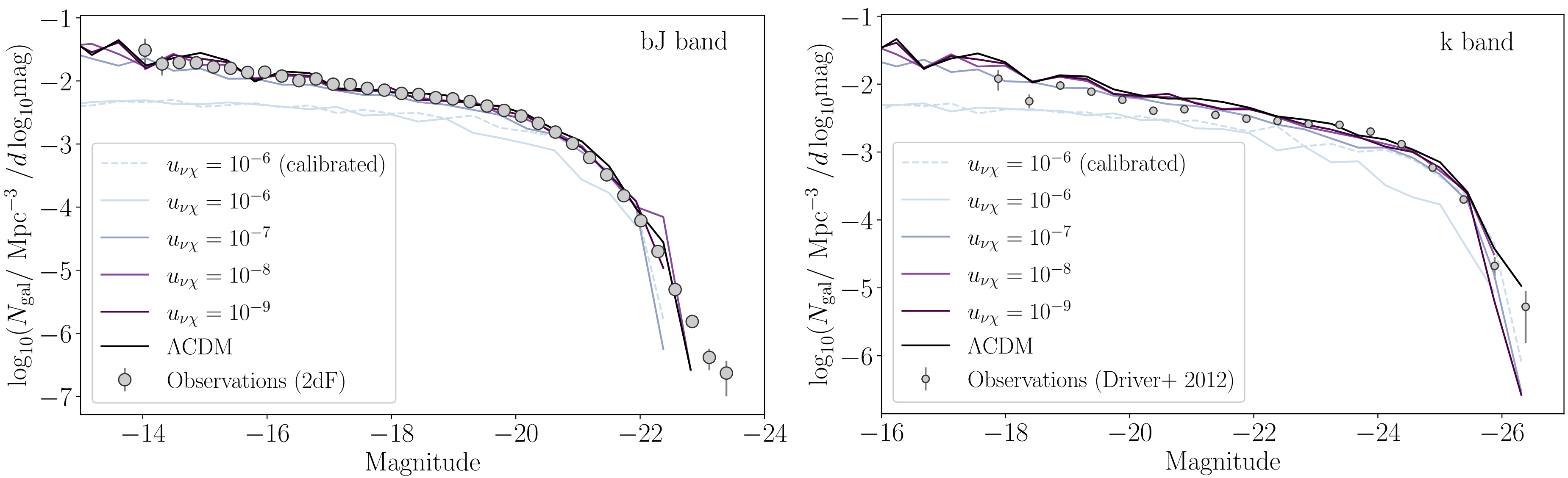
α=0.9

$u_{\nu\chi}$	M_{10}
$3.4 \cdot 10^{-4}$	$1.0 \cdot 10^{14} M_\odot$
$3.4 \cdot 10^{-5}$	$5.3 \cdot 10^{12} M_\odot$
$3.4 \cdot 10^{-6}$	$2.3 \cdot 10^{11} M_\odot$
$3.4 \cdot 10^{-7}$	$8.3 \cdot 10^{9} M_\odot$
$3.4 \cdot 10^{-8}$	$2.9 \cdot 10^{8} M_\odot$
$3.4 \cdot 10^{-9}$	$9.6 \cdot 10^{6} M_\odot$



What can the HMF tell us?

Galaxies!



We can already rule out the Hooper & Lucca best fit

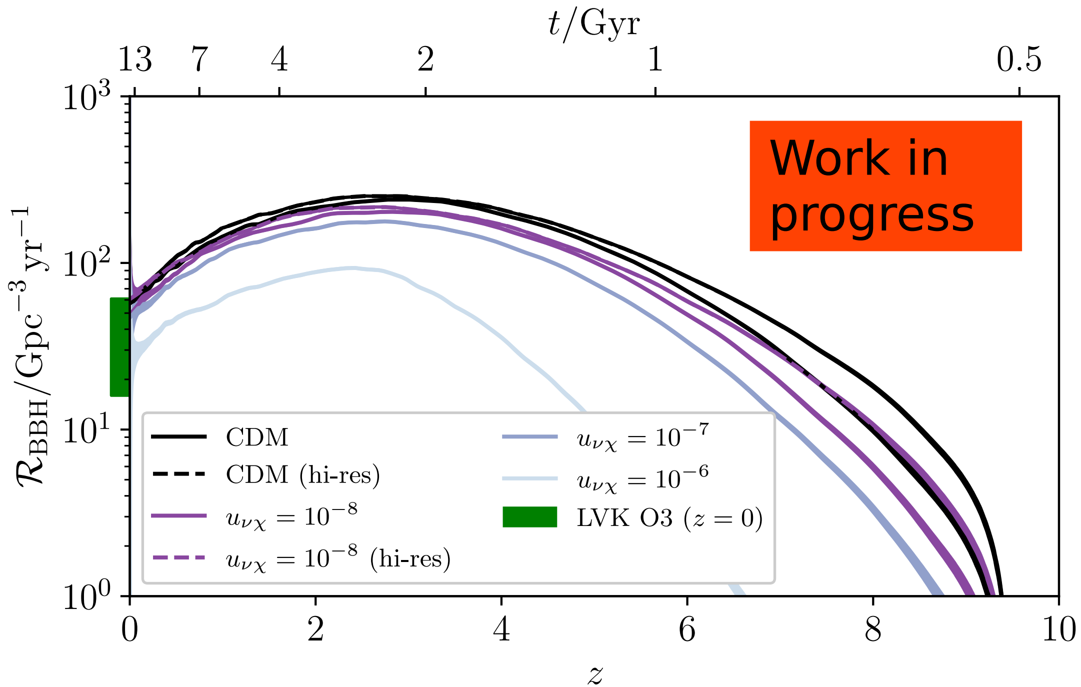
Gravitational waves:
A new probe of structure

Let's talk about gravitational waves

- **Suppressed structure**
  - ↳ **Fewer halos**
    - ↳ **Fewer galaxies**
      - ↳ **Less star formation**
        - ↳ **Fewer BBH mergers**

Gravitational wave event rate

Next generation GW observatories may constrain models



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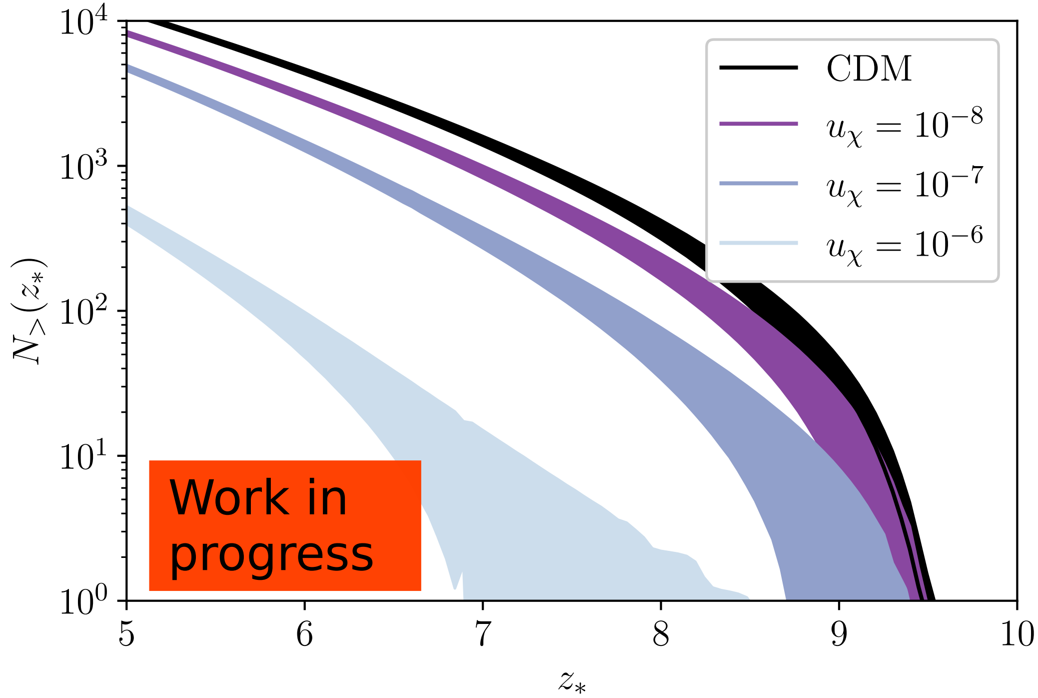

Key takeaways

- Interacting dark matter looks like warm dark matter at 'late' times → warm dark matter probes can be easily adapted
- High redshift ($z \geq 15$) measurements of the matter power spectrum are needed to distinguish warm and interacting dark matter
- The binary black hole merger rate can be used as a probe of models suppressing small scale structure