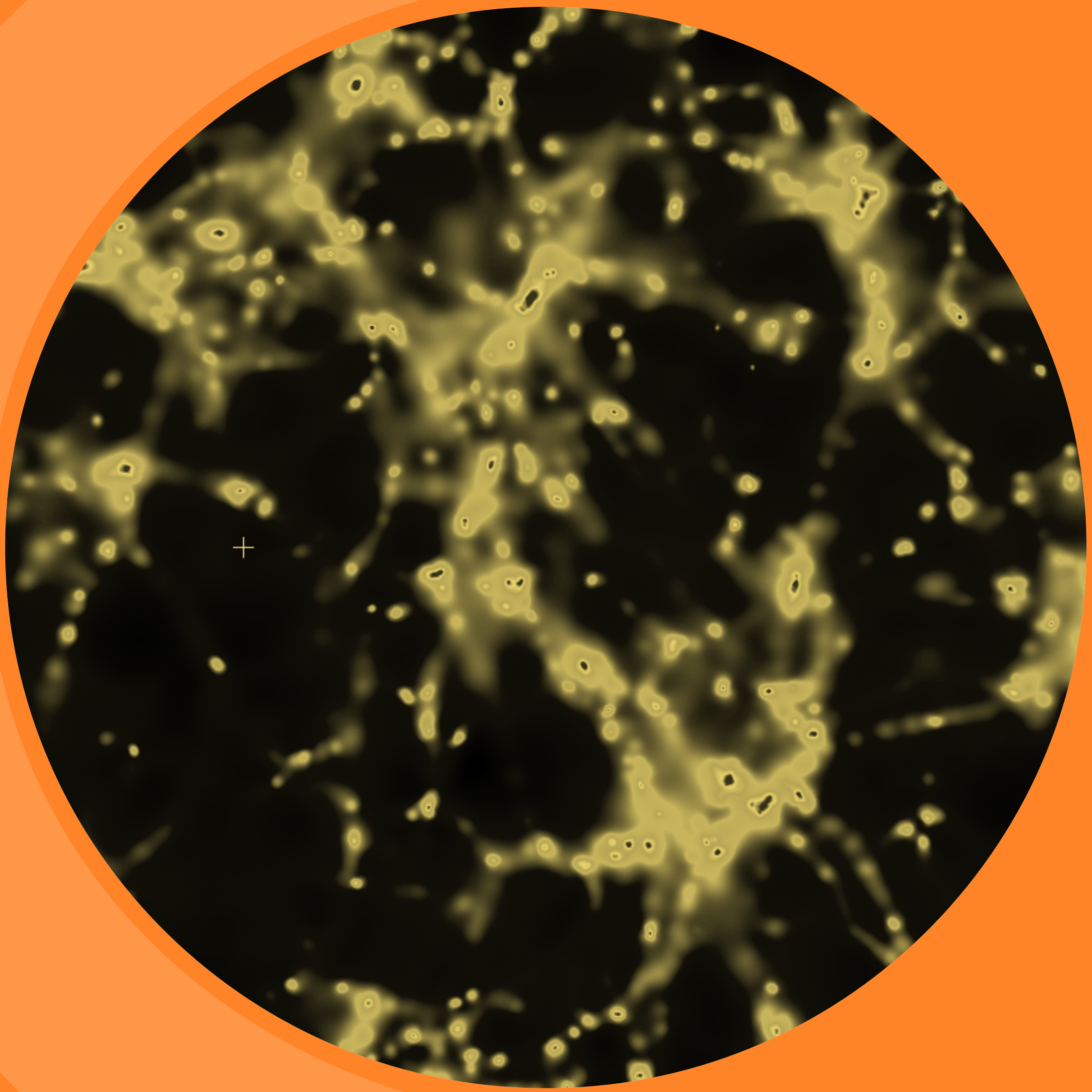

PROBING DARK MATTER MICROPHYSICS WITH GRAVITATIONAL WAVES AND COSMOLOGY

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Overview

- Linear predictions
- SKA constraints from 21 cm line intensity mapping
- Gravitational waves as a novel type of constraint

The relevant papers:

- M. Mosbech, C. Boehm, S. Hannestad, O. Mena, J. Stadler, & Y^3 Wong
  The full Boltzmann hierarchy for dark matter-massive neutrino interactions
  arXiv:2011.04206
- M. Mosbech, C. Boehm, & Y^3 Wong
  Probing dark matter interactions with SKA
  arXiv:2207.03107
- M. Mosbech, A. Jenkins, S. Bose, C. Boehm, M. Sakellariadou , & Y^3 Wong
  Gravitational-wave event rates as a new probe for dark matter microphysics
  arXiv:2207.14126

Our example scenario and its constraints

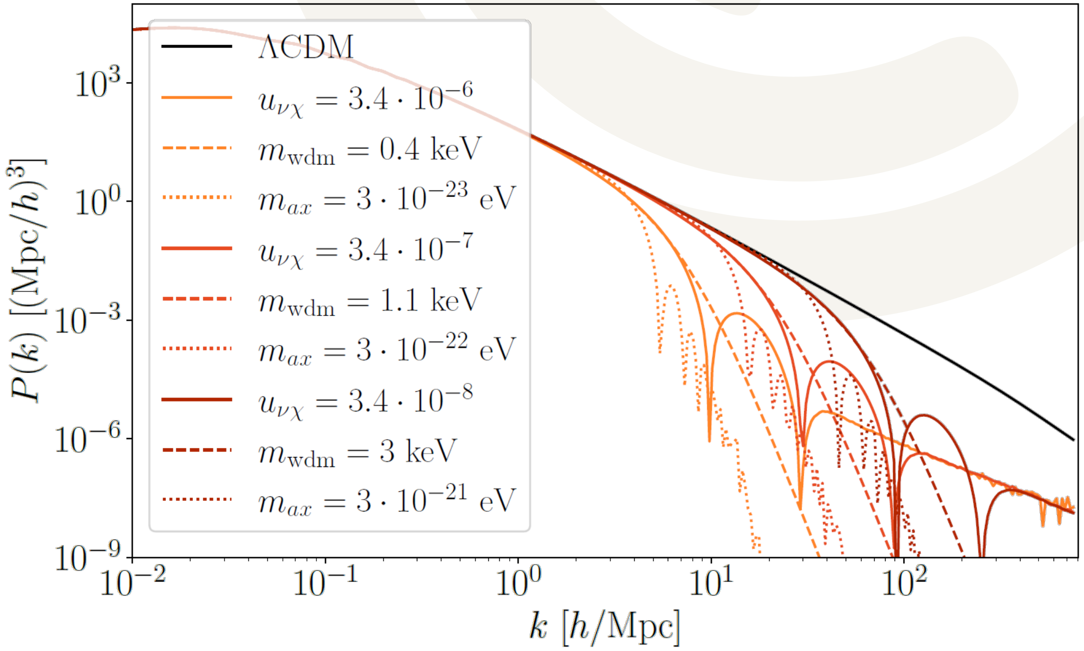
- Our analysis is mainly based on a model with interactions between a heavy DM particle and the standard model neutrinos
- Interaction strength parameterised through

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

Data	Max $u_{\nu DM}$	Source
Planck + SDSS	$\sim 3 \times 10^{-4}$	Mosbech et al. arXiv:2011.04206
Planck + SDSS+Lyα	$\sim 10^{-5}$	Hooper & Lucca arXiv:2110.04024

Distinguishing models (or not) I: linear results

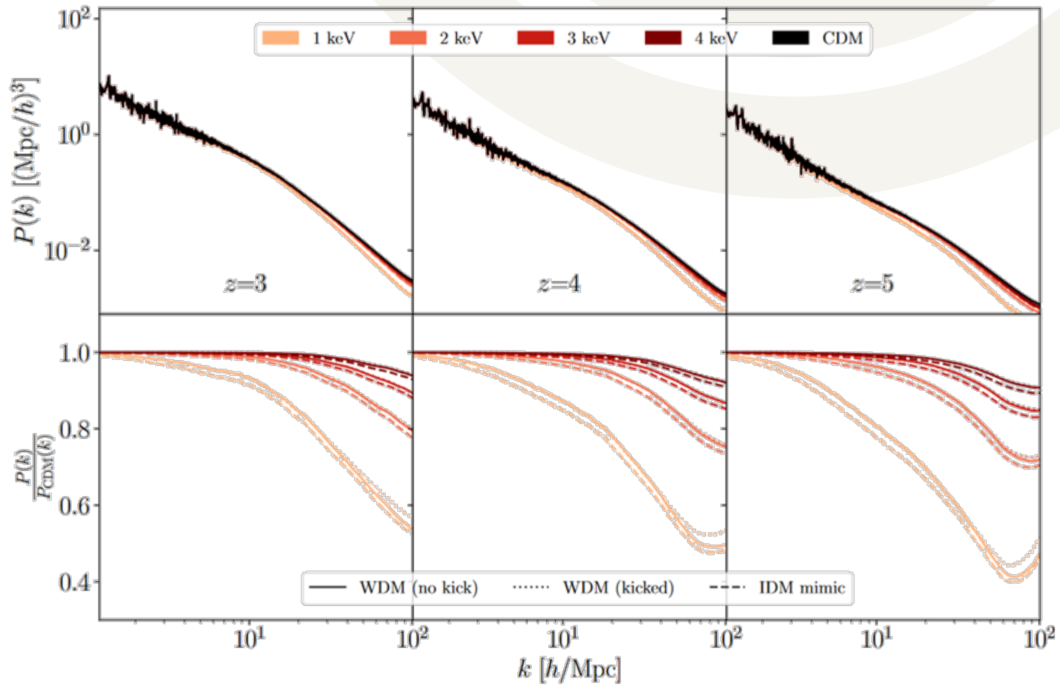
- “Canonical” warm dark matter suppresses small-scale structure due to free-streaming
- Models with early interactions between DM and relativistic species suppresses small-scale structure through collisions. Contains oscillations.



m_{wdm}	$u_{\nu DM}$
1 keV	8.5×10^{-7}
2 keV	1.75×10^{-7}
3 keV	7×10^{-8}
4 keV	3.6×10^{-8}

Distinguishing models (or not) II: The "late"

- We find that interacting models are indistinguishable from warm dark matter at $z \leq 10$
- The upside of which: constraints on warm dark matter can be directly mapped to interacting models



Constraining with the Square Kilometre Array

- SKA will be able to map the density of neutral hydrogen at high redshift with the 21 cm line through line intensity mapping.
- SKA 21 cm intensity mapping forecasts have already been done for warm dark matter, so we can adapt to interacting.

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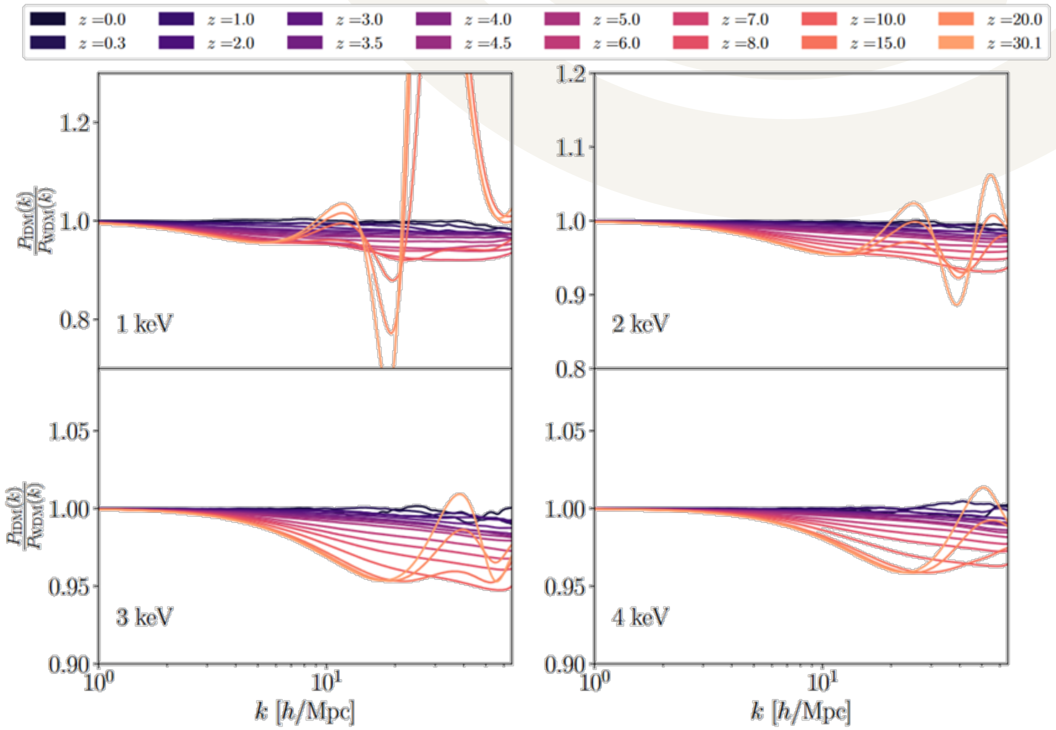
SKA 21cm line intensity map	$\sim 4 \times 10^{-8}$*	Mosbech, Boehm, & Wong arXiv.2207.03107

*: Forecast – constraint assuming non-detection

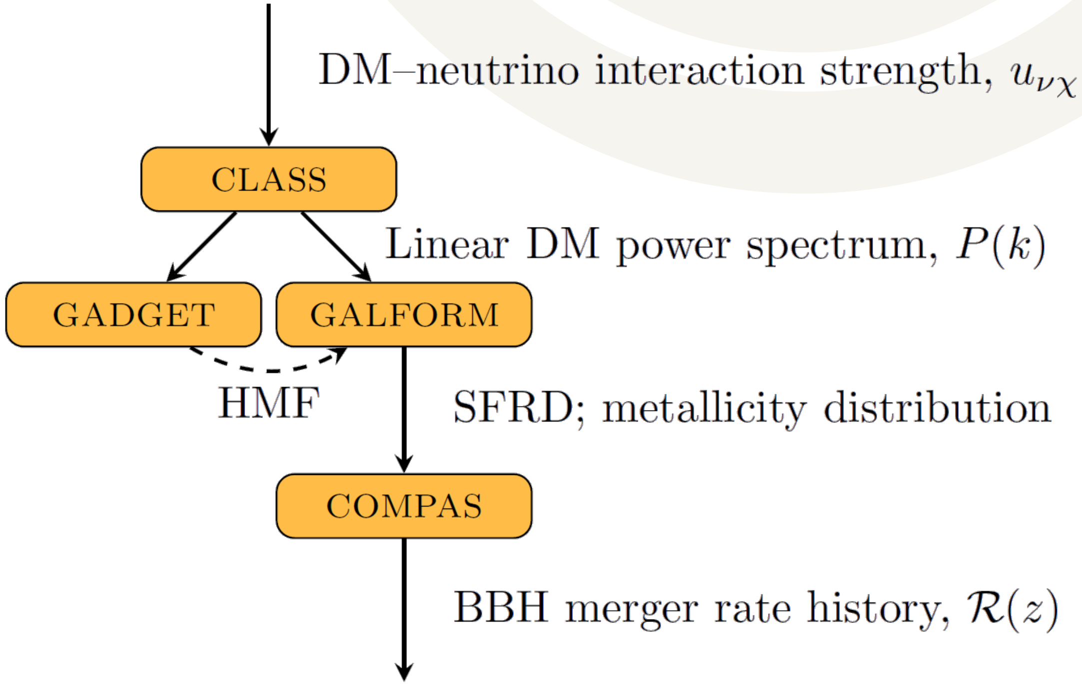
Distinguishing models (or not) II: The "early"

- At early times, nonlinear evolution has not yet erased oscillations
- High-precision, high redshift measurements at high k needed to distinguish
- SKA can in principle measure the 21 cm line at these redshifts.
- Dedicated high-resolution, high-redshift studies warranted



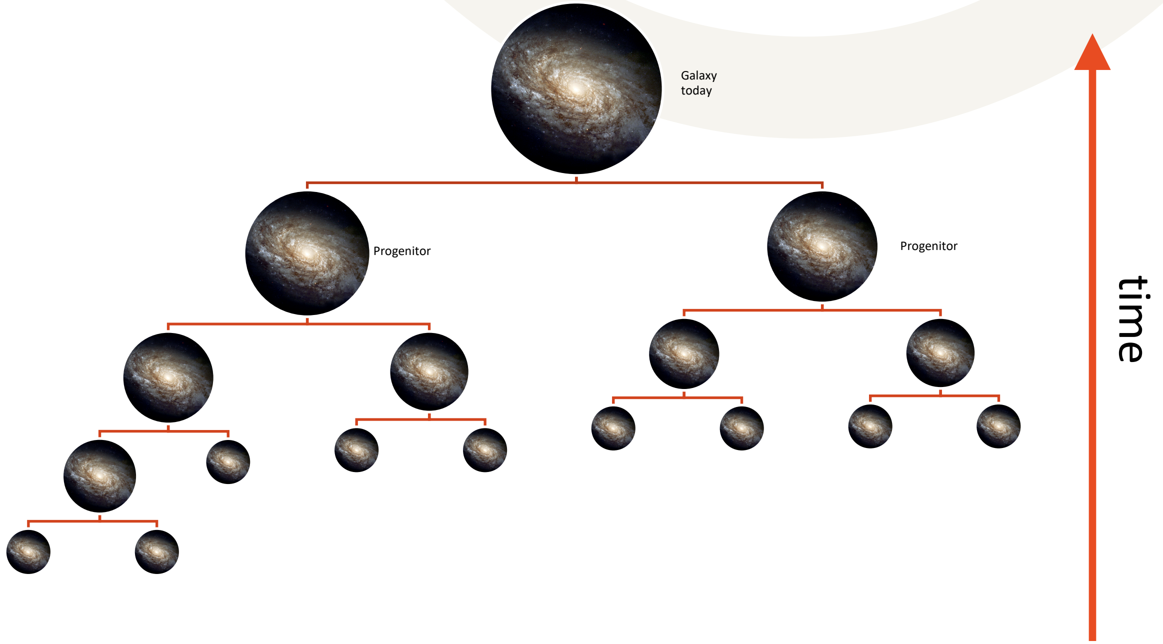
From suppressed structure to gravitational waves

1. Suppressed structure
2. Less/delayed galaxy/progenitor formation
3. Less/delayed star formation
4. Fewer/delayed black hole binaries formed
5. Fewer binary black hole mergers detected



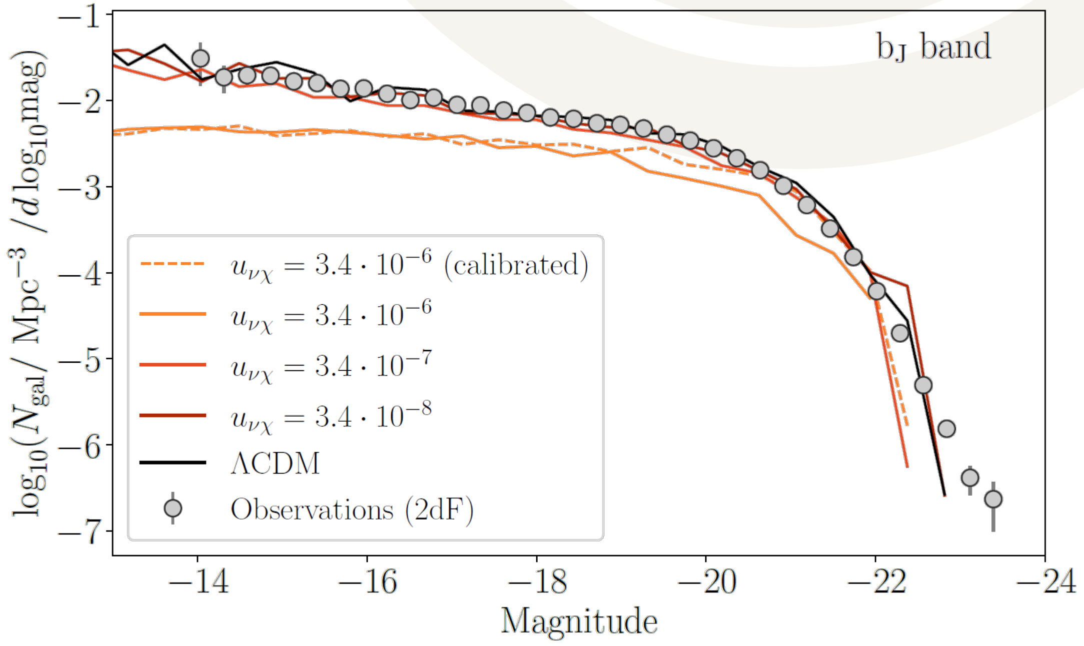
Hierarchical Merger tree

- Progenitors generated through Monte Carlo
- Galaxy merger physics determines star formation, metallicity etc
- Resolution set by smallest tracked progenitor



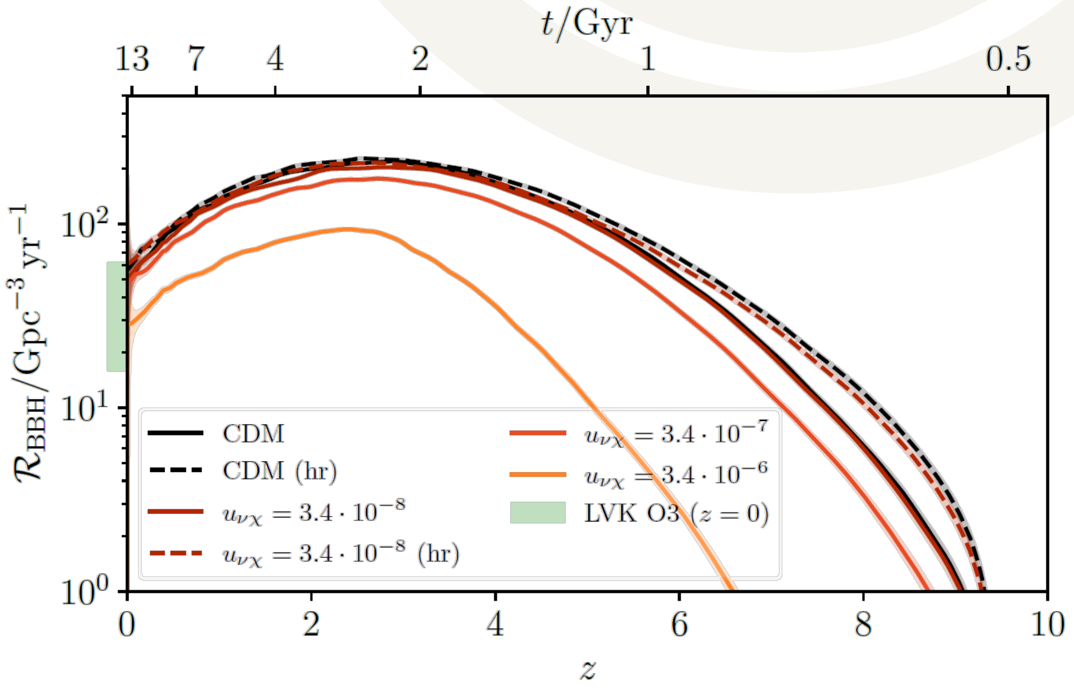
Impact on galaxy formation

- Less structure means fewer galaxies, significant if the suppression affects large enough scales
- Rules out $u_{\nu DM} \geq 3 \times 10^{-6}$



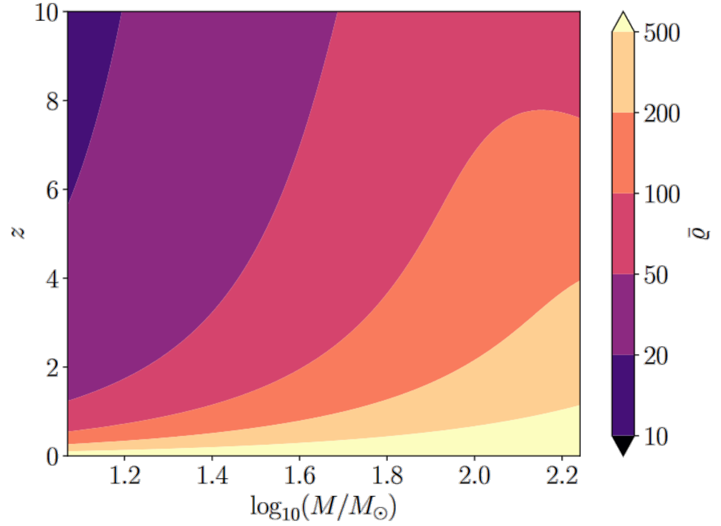
The gravitational wave merger rate

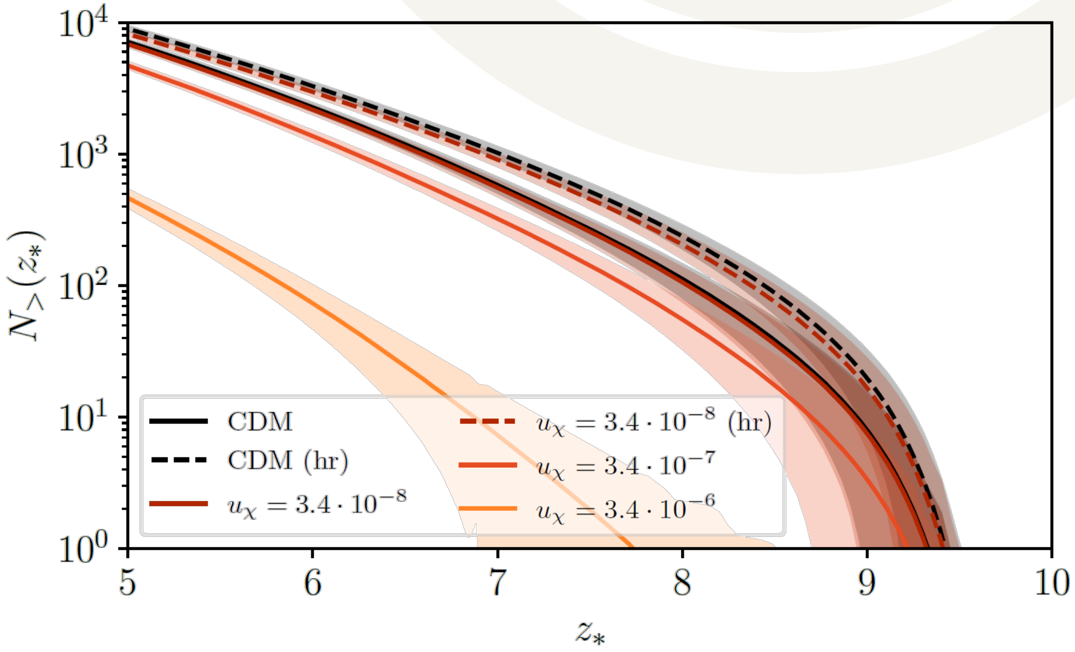
- The effect of suppressed structure formation is clear on the merger rate
- Effect is stronger at early times
- The base cold dark matter model is only just compatible with current data (for our choice of astro parameters)



Next generation GW observatories

- The next generation can see almost every event





- This will be able to set powerful constraints

Conclusions

- SKA will be able greatly constrain DM models with suppressed structure
- Next generation GW observatories can be used for complementary constraints
- High redshift measurements will be key to distinguishing between models suppressing small scale power

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SKA 21cm line intensity map	$\sim 4 \times 10^{-8}$*	Mosbech, Boehm, & Wong arXiv.2207.03107
2dF galaxy counts	$\sim 3 \times 10^{-6}$-10^{-7}	Mosbech et al. arXiv:2207.14126
Einstein Telescope + Cosmic Explorer	$\sim 4 \times 10^{-8}$*	Mosbech et al. arXiv:2207.14126

*: Forecast – constraint assuming non-detection