Unravelling the Nature of Dark Matter

with Large-Scale Structure

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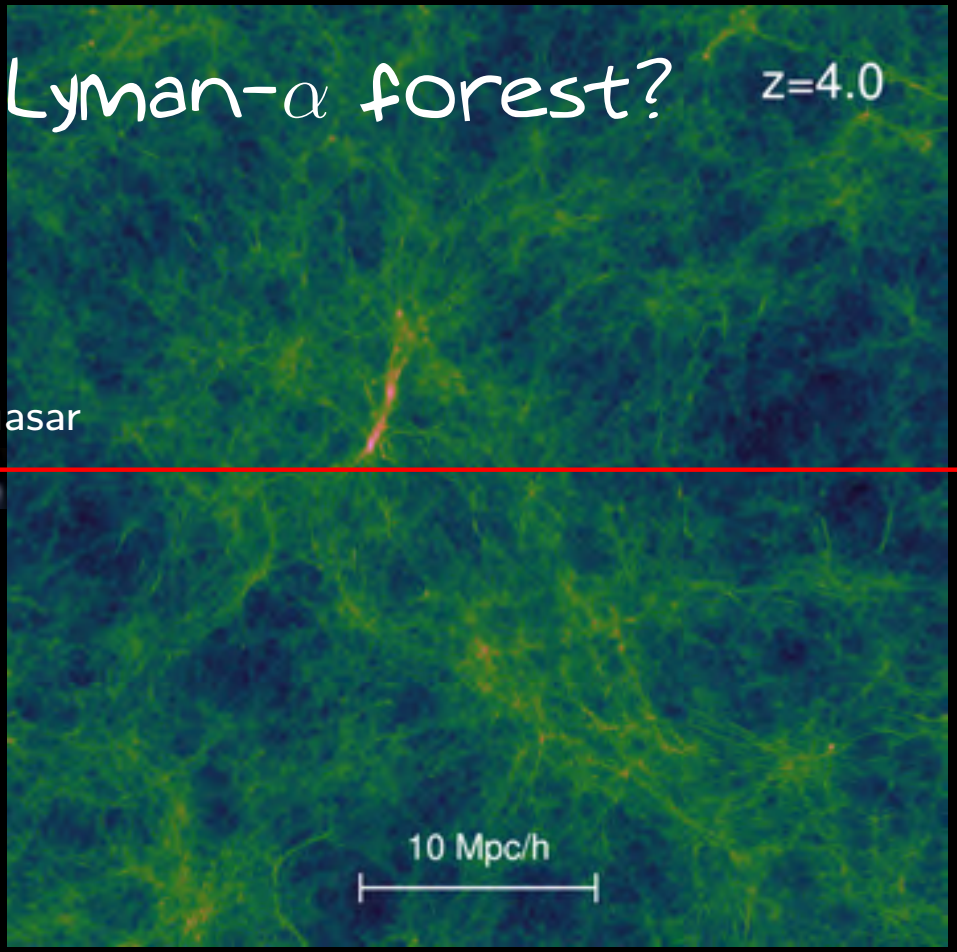
KICC mini symposium

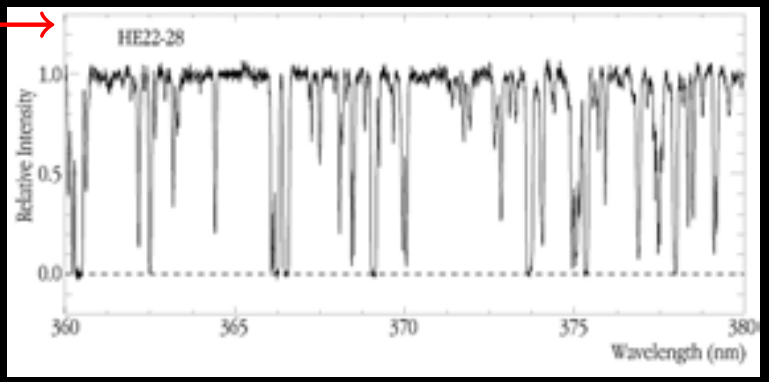
September 15, 2022

with: Matteo Viel, Martin Haehnelt, James Bolton, Margherita Molaro

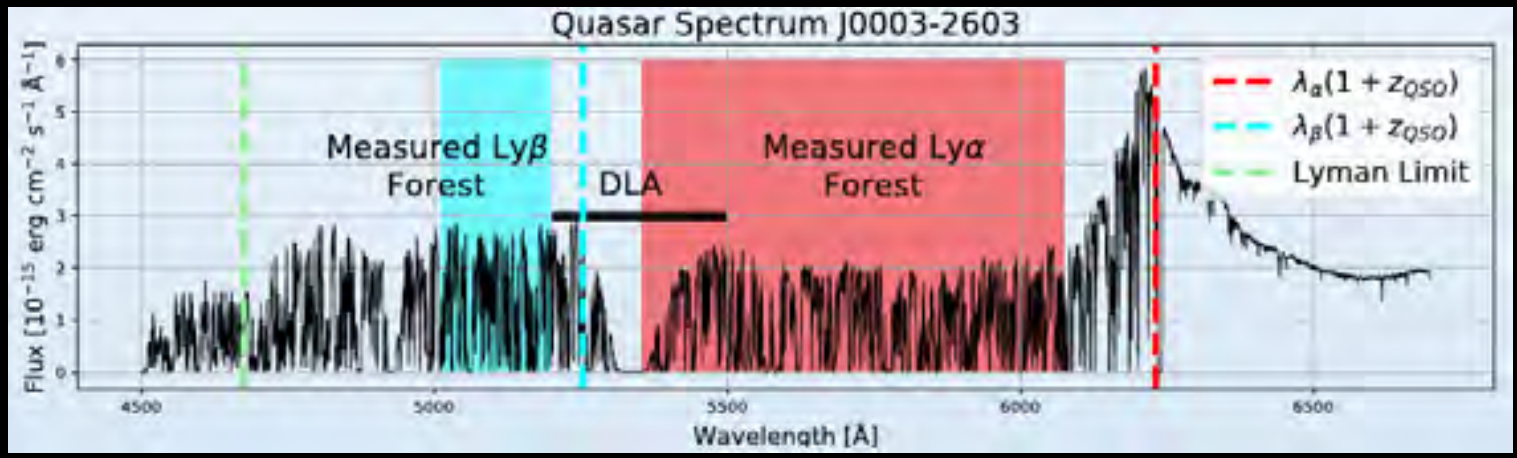
Lyman-α forest?



Scattering of the electron: $n = 1 \rightarrow n = 2$
Hydrogen transition (Lyman-α)

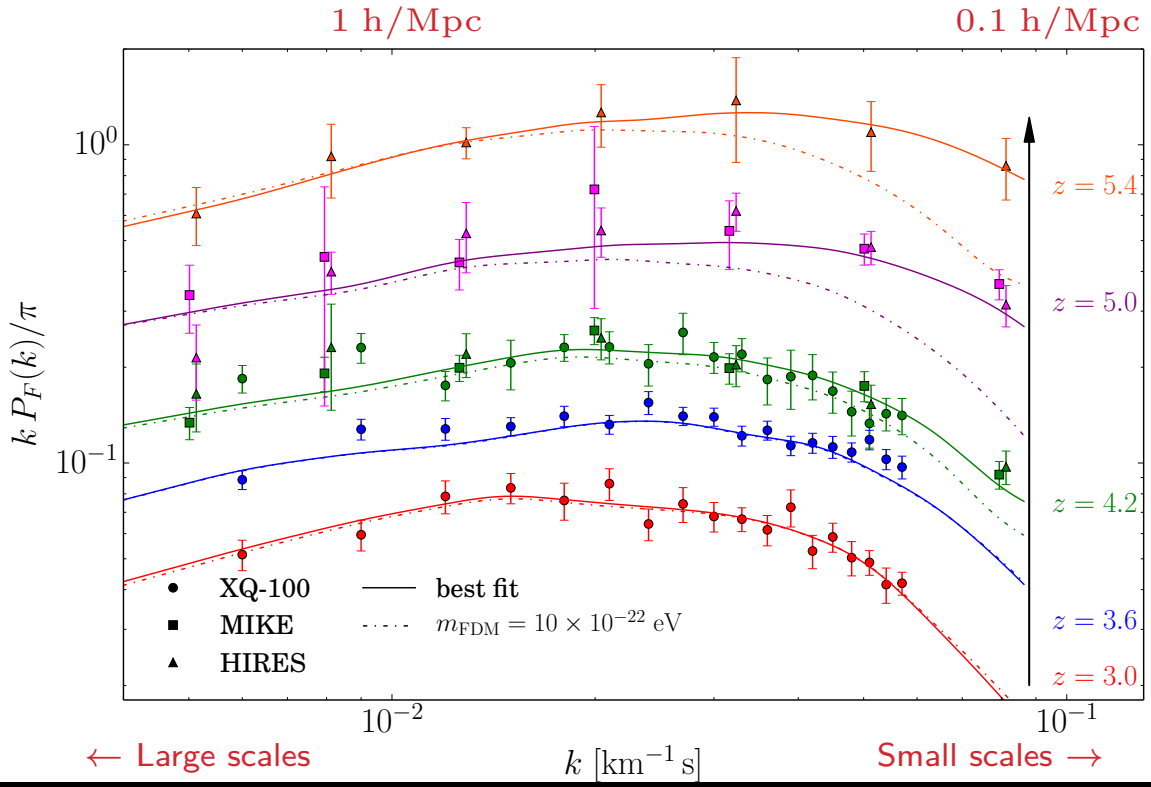


Absorption in Quasar spectra along the line of sight



Small-scales (< 1 Mpc/h)

Testing Dark Matter models



- Relative suppression of small-scale clustering
- Robust constraints for variety of models
  ← Looking for a feature!

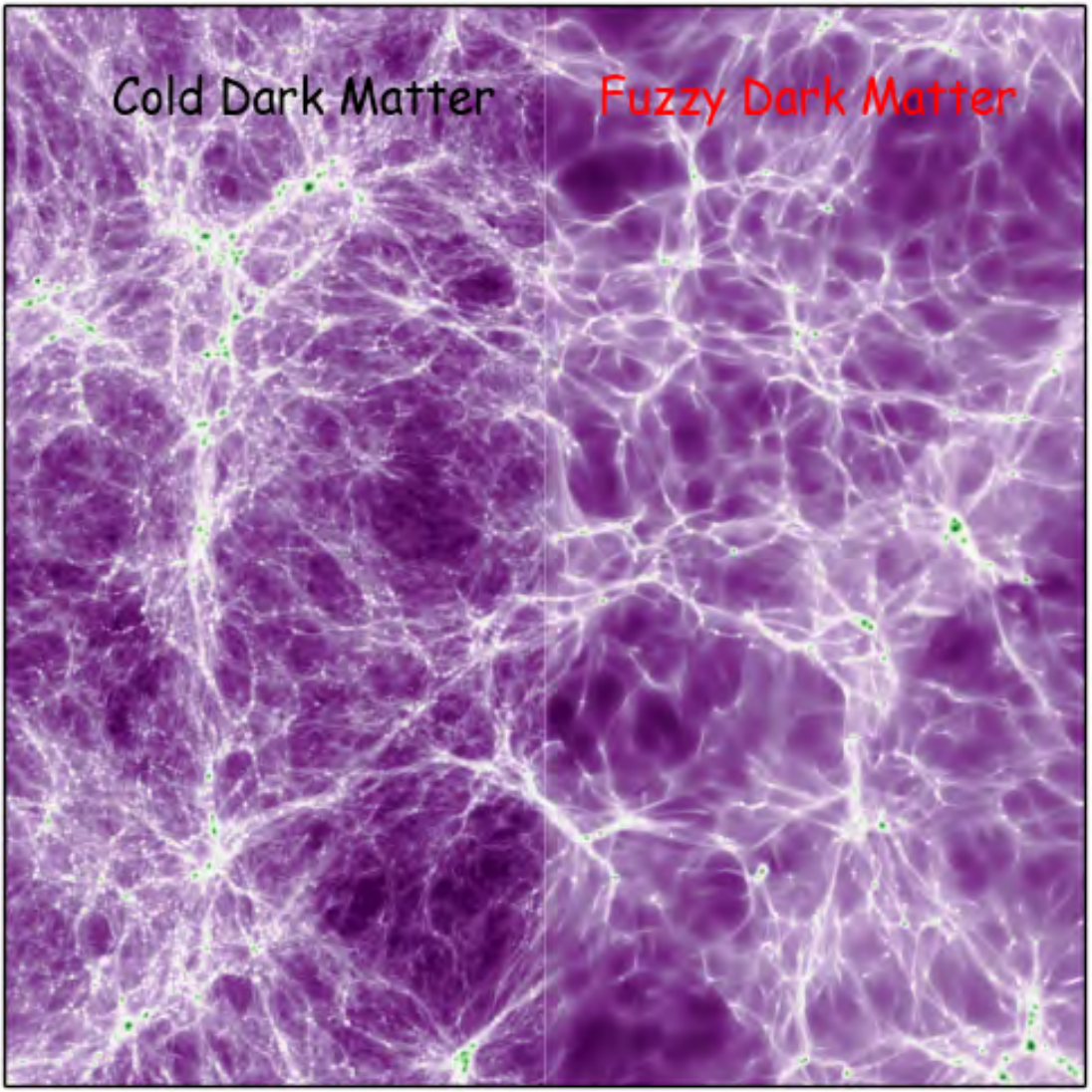
Effect of nCDM is larger on small-scales

- The typical scale imprinted by nCDM is on smaller scales for heavier particle masses.

Effect of nCDM is larger at higher redshifts

- Nonlinear evolution is stronger at lower redshifts
- Relative effect of baryons (Doppler broadening, pressure smoothing) is weaker at higher redshift.

non-CDM erases small scale structure



Warm Dark Matter (WDM):

Free-streaming of DM particles

(From the time they decouple until they become non-relativistic)

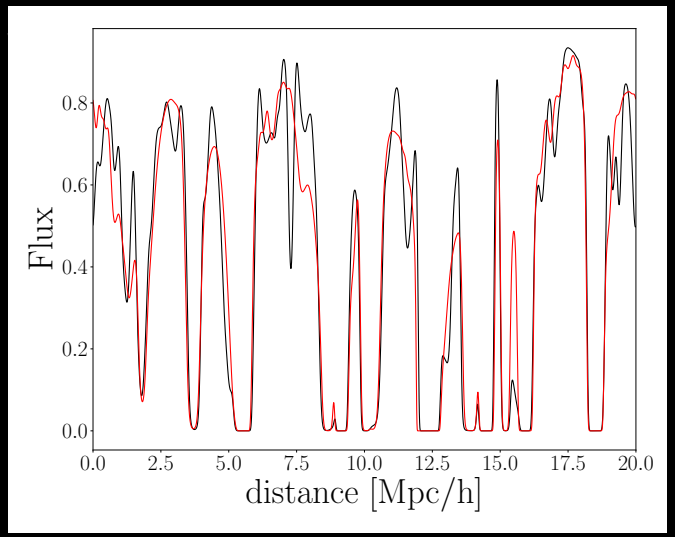
Fuzzy Dark Matter (FDM):

Jeans scale of ultra-light DM scalar

$$k_{J,\mathrm{eq}} = 9 \left(\frac{m_{\mathrm{FDM}}}{10^{-22}\ \mathrm{eV}} \right)^{1/2} \mathrm{Mpc}^{-1}$$

Nonlinear soliton solutions $\sim$ kpc

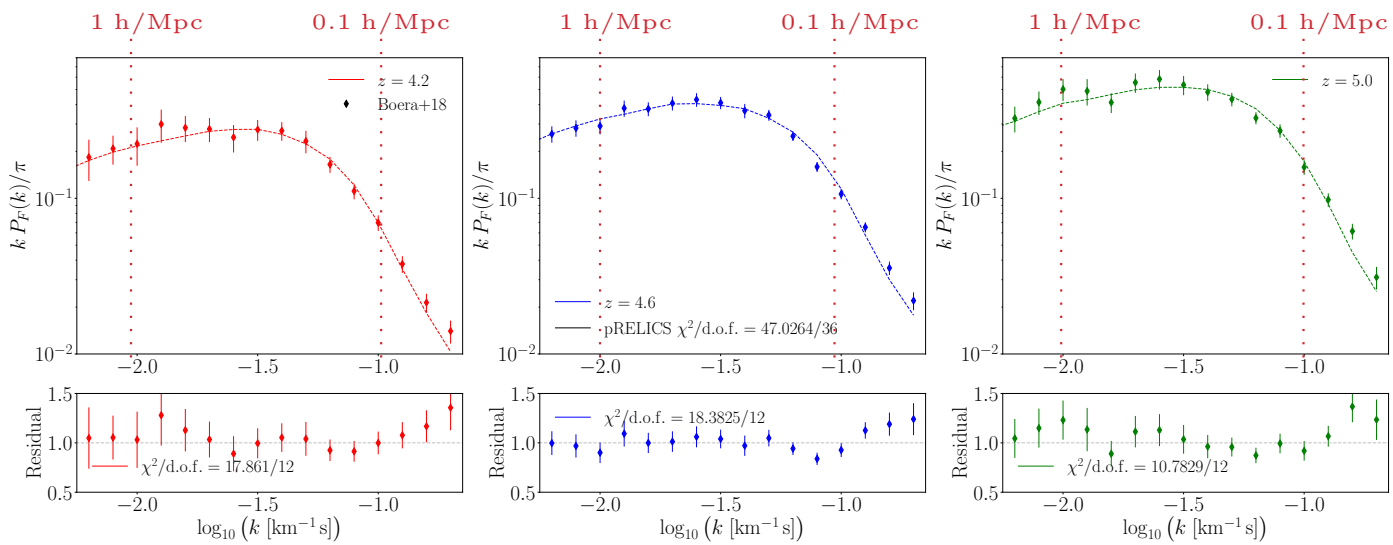
$\Longrightarrow$ erases small scale structure

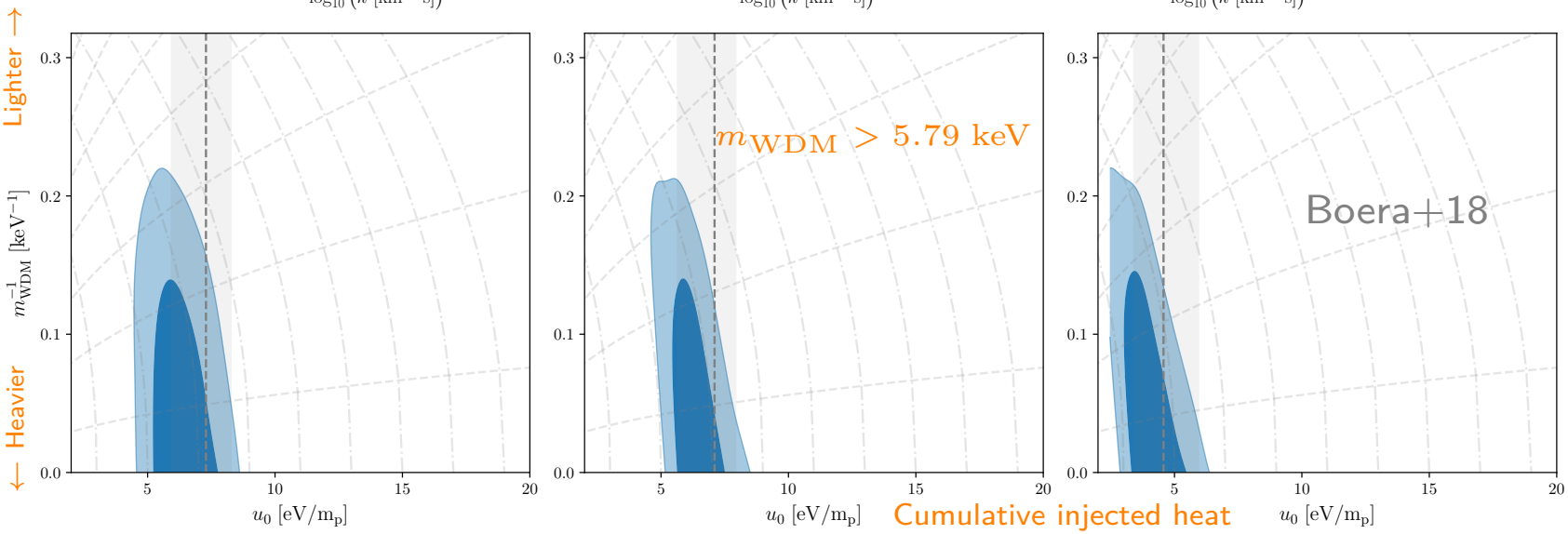


Typical nCDM particle mass from local small-scale structure

- $m_{\mathrm{WDM}} \sim 2 - 3$ keV
- $m_{\mathrm{FDM}} \sim 1 - 10 \times 10^{-22}$ eV

Baysian Likelihood Analysis





m_{WDM} limits

Viel+05:
> 2.0 keV

Seljak+05:
> 2.1 keV

Viel+13:
> 3.5 keV

Baur+15:
> 4.1 keV

Garzilli+15:
> 1.9 keV

Vl+17:
> 5.3 keV

Yeche+17:
> 4.6 keV

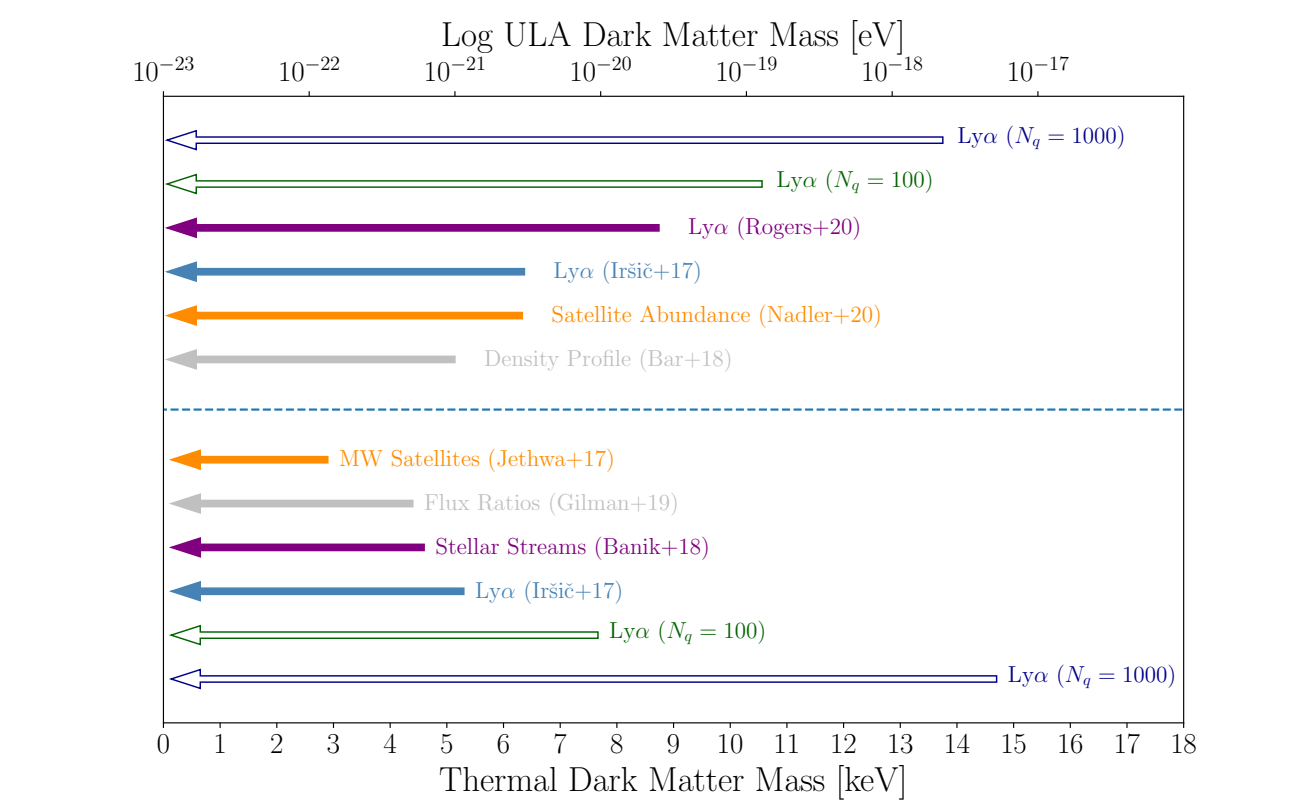
Palanque+20:
> 5.3 keV

Vl+22 (in prep.):
> 5.8 keV

- Simulation based likelihood (Likelihood-free inference)
  - Sherwood-Relics (Puchwein et al. 2022): 48 simulations + postprocessing
  - 3x matched RT simulations (patchy reionization)
  - 48x simulations for mass resolution (thermal history dependent)

Small-scales (< 1 Mpc/h)

Testing Dark Matter models



- Relative suppression of small-scale clustering
- Robust constraints for variety of models

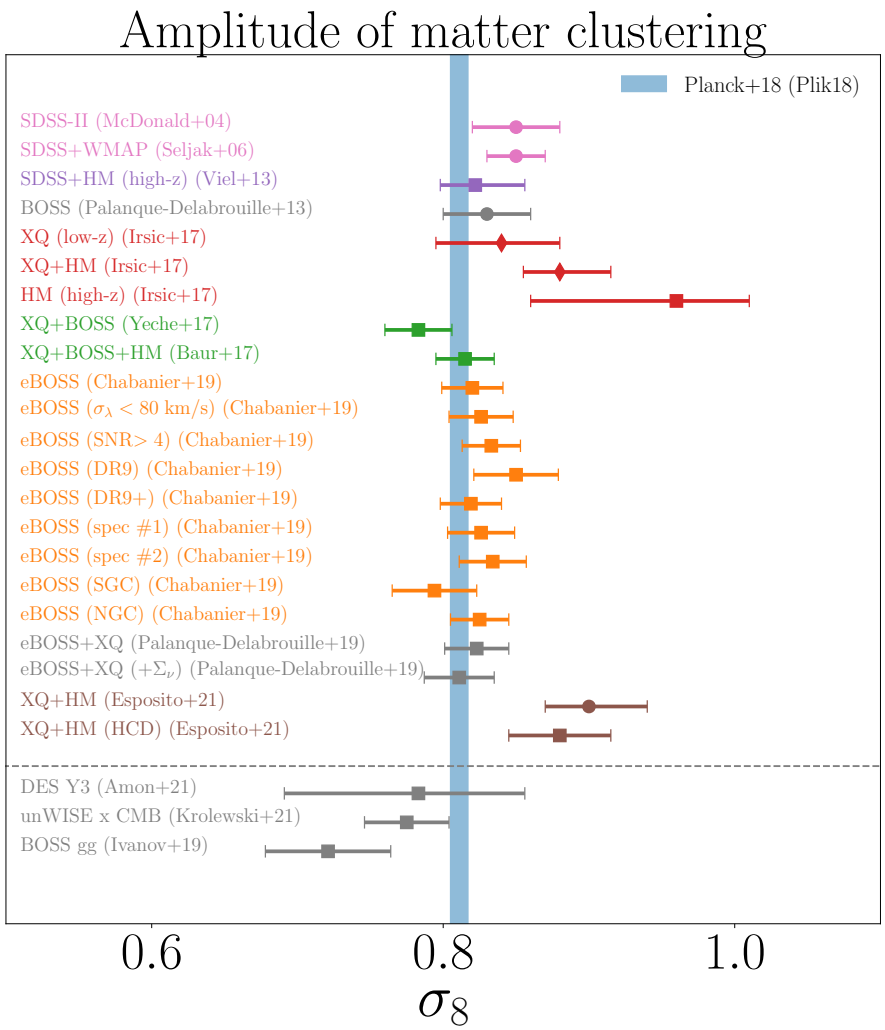
Can we rule out large ranges in DM particle mass?

Motivation: non-resonant sterile neutrino (3.5 keV), excluding ultra-light axions with $m_{\rm a} > 10^{-14}$ eV

Can we distinguish between DM models?

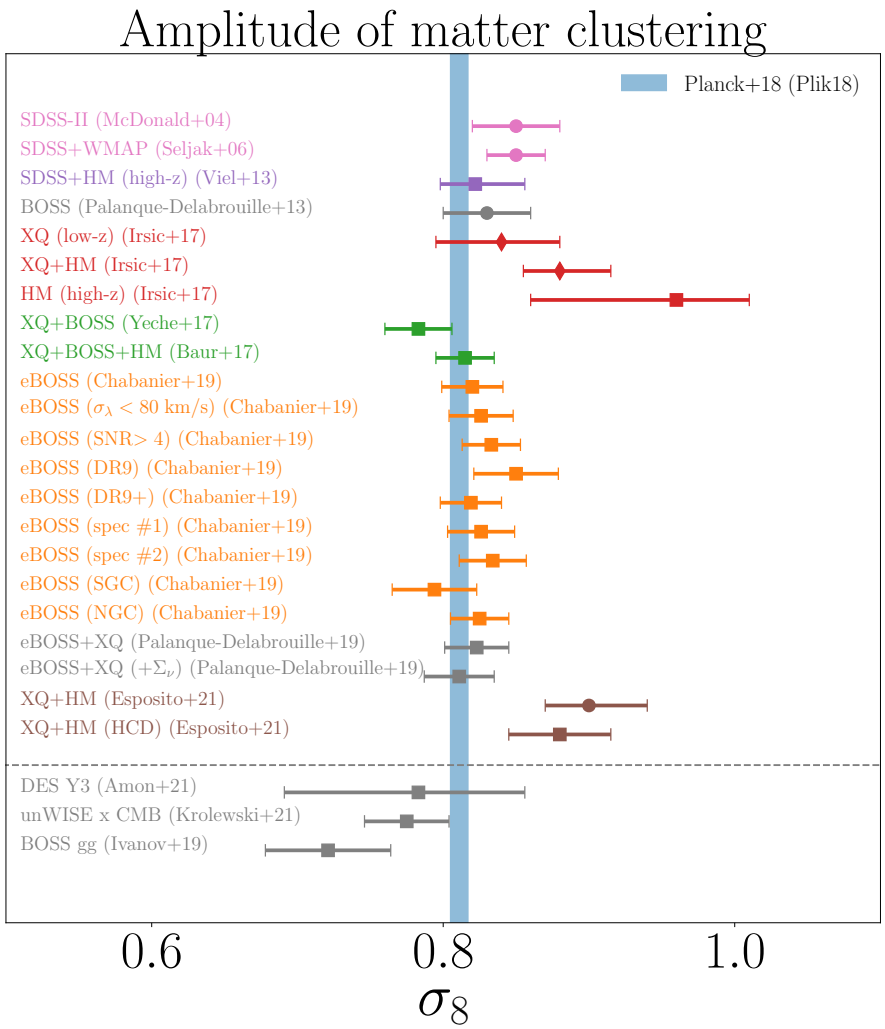
Motivation: information on production mechanism

Intermediate-scales ($1 - 10$ Mpc/h)

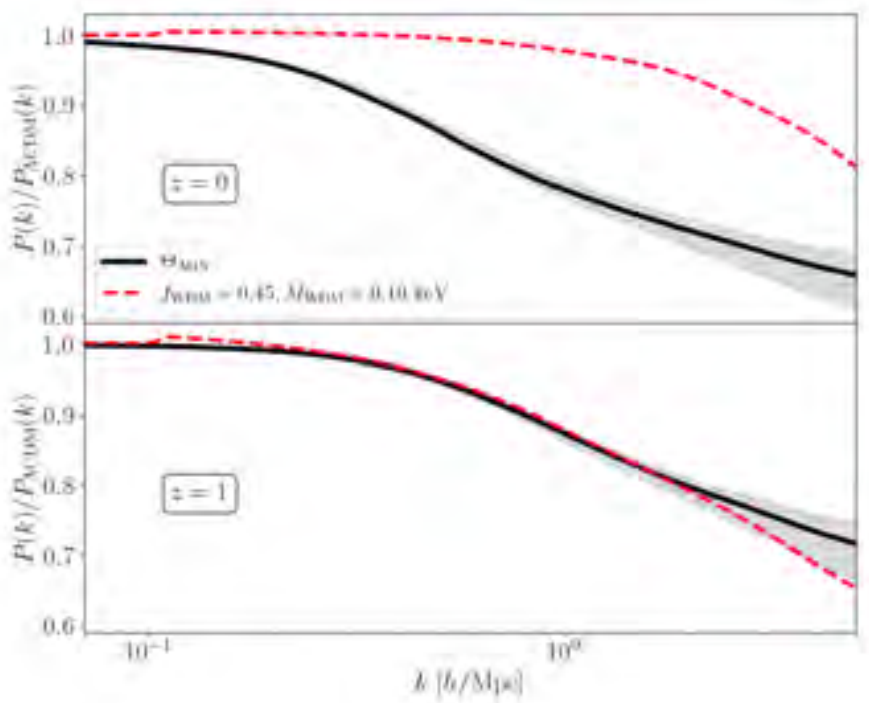


Is there a σ_8 tension?

Intermediate-scales (1 – 10 Mpc/h)



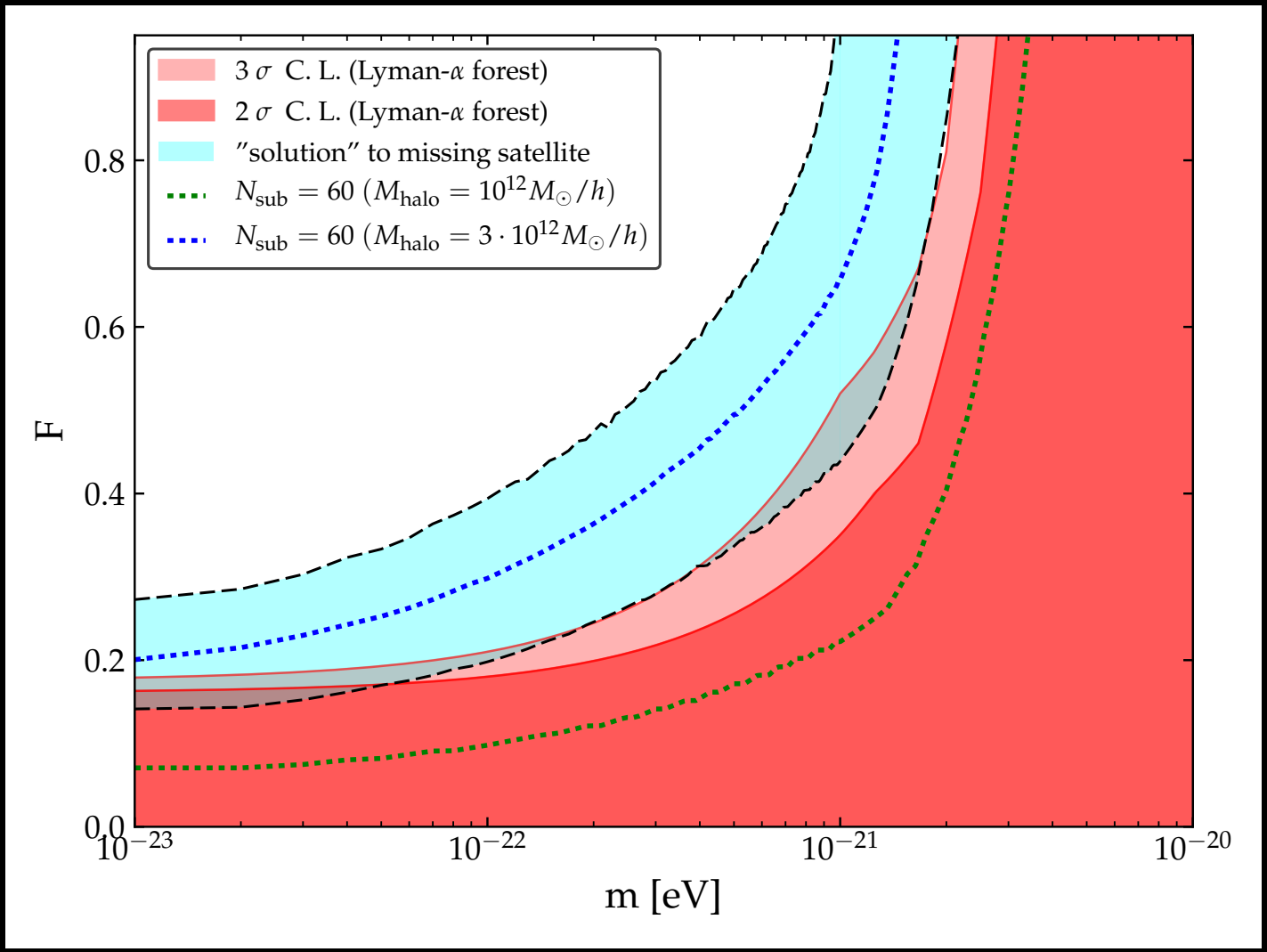
Is there a σ_8 tension?



Measurement: Amon & Efstathiou 2022
Model: Matteo Viel & Gabriele Parimbelli

Could mixed WDM/CDM models solve the σ_8 tension?

Only fraction of DM in the form of a light particle



with T. Kobayashi (SISSA)

Lyα data: $f_{\rm nCDM} \sim 10 - 20\%$

Conclusions

- Lyman-α forest as a high-z LSS tracer
- A unique probe of the IGM (redshift range, small scales)
- Intermediate-scales ($1 - 10\ \mathrm{Mpc/h}$): Amplitude/Slope of matter clustering
- Small-scales ($< 1\ \mathrm{Mpc/h}$): Robust constraints on DM models $m_{\mathrm{WDM}} > 5.8\ \mathrm{keV}$ (preliminary)
- Lyman-α is sensitive to the typical scale imprinted by DM particles onto the matter density distribution
- Mixed light/heavy DM models might help with σ_8 tension