Cosmology of models with primordial power spectrum cutoff

Workshop on competing structure formation models
University of Iceland
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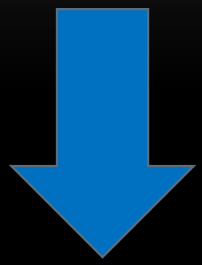
Cosmology of models with primordial power spectrum cutoff



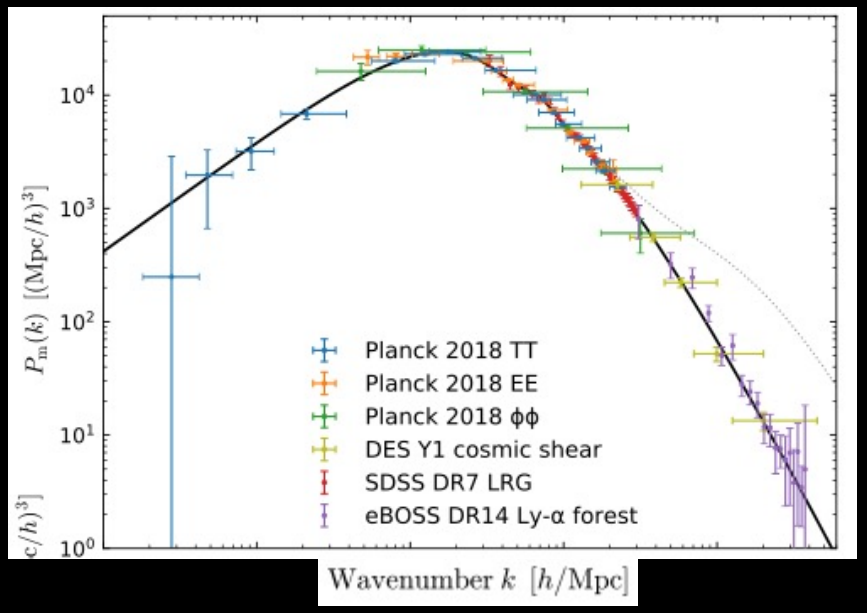
Cosmology of models with primordial power spectrum cutoff beyond WDM

The eternal degeneracy

- Disclaimer: The statistics of the matter distribution we observe today are influenced by both the primordial spectrum of fluctuations and the matter transfer function.

$$P_{\rm m}(k) = T^2_{\rm m}(k) P_\zeta(k)$$

Usually assumed to be nearly scale invariant.



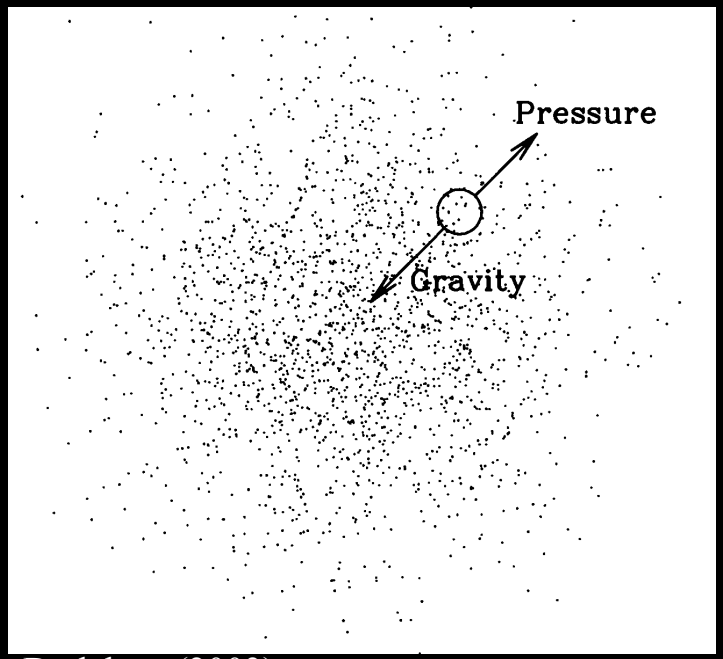
Chabanier et al. (2019)

- Not unreasonable to assume that this breaks down on small scales!

Power spectrum cutoff: Transfer function

- This talk: Focus on the transfer function and how it is influenced by the nature of dark matter.

$$P_{\rm m}(k) = T^2_{\rm m}(k) P_\zeta(k)$$



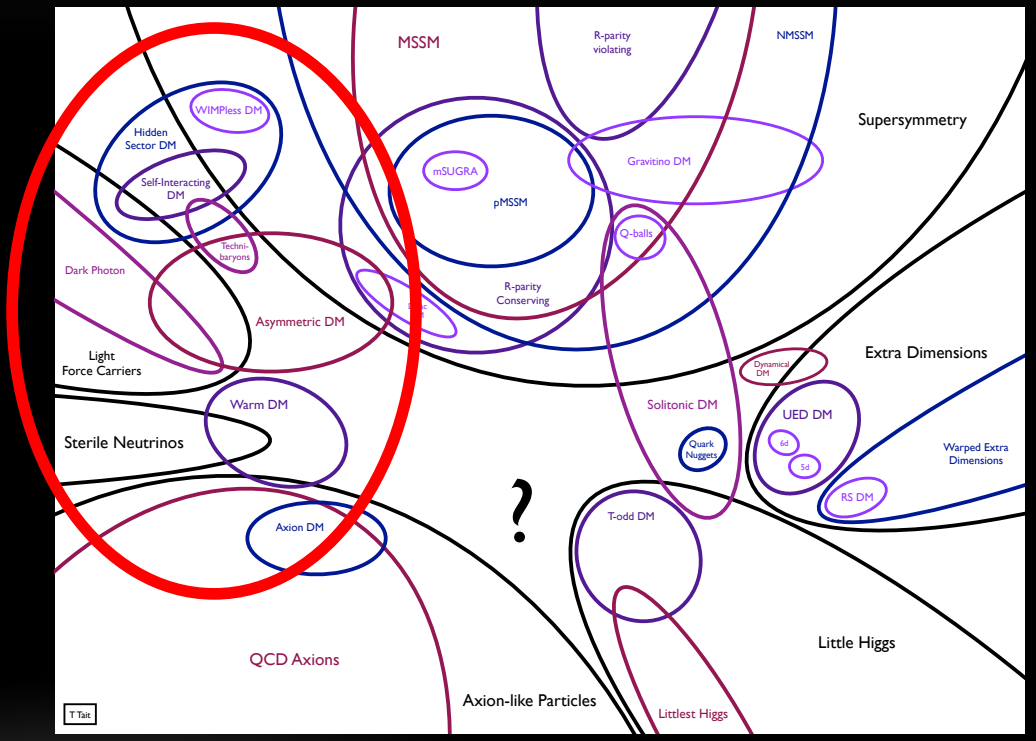
Dodelson (2003)

The transfer function characterizes the struggle between gravity and pressure.

$$\ddot{\delta} + [\text{Pressure} - \text{Gravity}]\, \delta = 0.$$

Power spectrum cutoff beyond warm dark matter

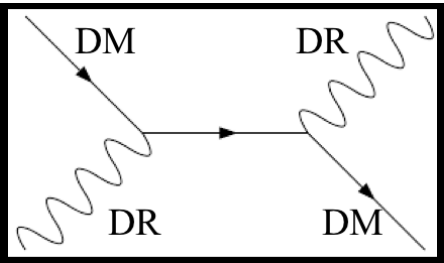
- Multiple physics could "pressurize" dark matter:
  - Large thermal velocity (WDM).
  - Coupling to relativistic species.
  - Boost from DM decay.
  - Quantum pressure.
  - Others?



Focus: Coupling dark matter to light relativistic species

- Example 1: Dark matter interacting with a massless photon.

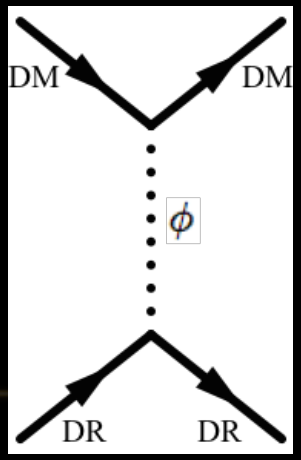
$$\mathcal{L}_{\rm int} = -(D^\mu \chi)^\dagger D_\mu \chi - m_\chi^2 \chi^\dagger \chi, \qquad \text{where} \qquad D_\mu = \partial_\mu - i g_\chi \tilde{A}_\mu.$$



- Example 2: Dark matter interacting with a massless neutrino via a massive mediator.

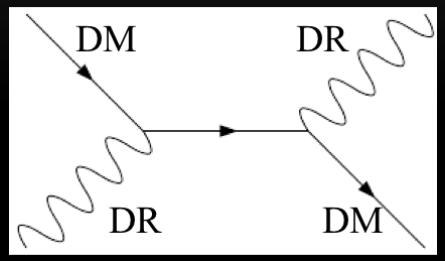
$$\mathcal{L}_{\rm int} = -g_\chi \phi_\mu \bar{\chi} \gamma^\mu \chi - \frac{1}{2} g_\nu \phi_\mu \bar{\nu}_{\rm s} \gamma^\mu \nu_{\rm s} - \frac{1}{2} m_\phi^2 \phi_\mu \phi^\mu - \frac{1}{2} m_\chi \bar{\chi} \chi$$

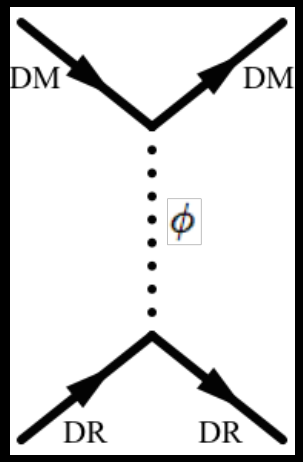
…and many more!



Hofmann et al. 2001; Chen et al. 2001; Bœhm et al. 2002; Green et al. 2004; Bertschinger 2006; Bringmann & Hofmann 2007; van den Aarssen et al. 2012; Cyr-Racine & Sigurdson 2013,

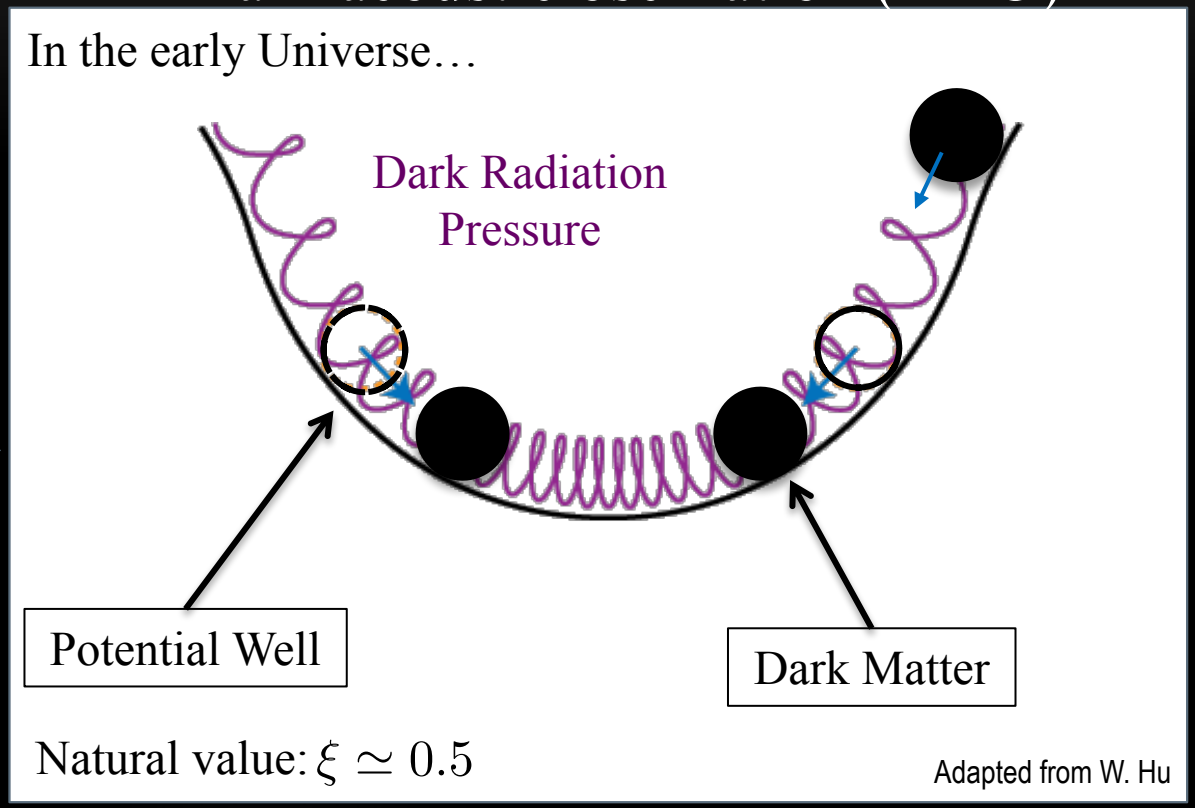
Phenomenology of dark matter-dark radiation (DR) interaction





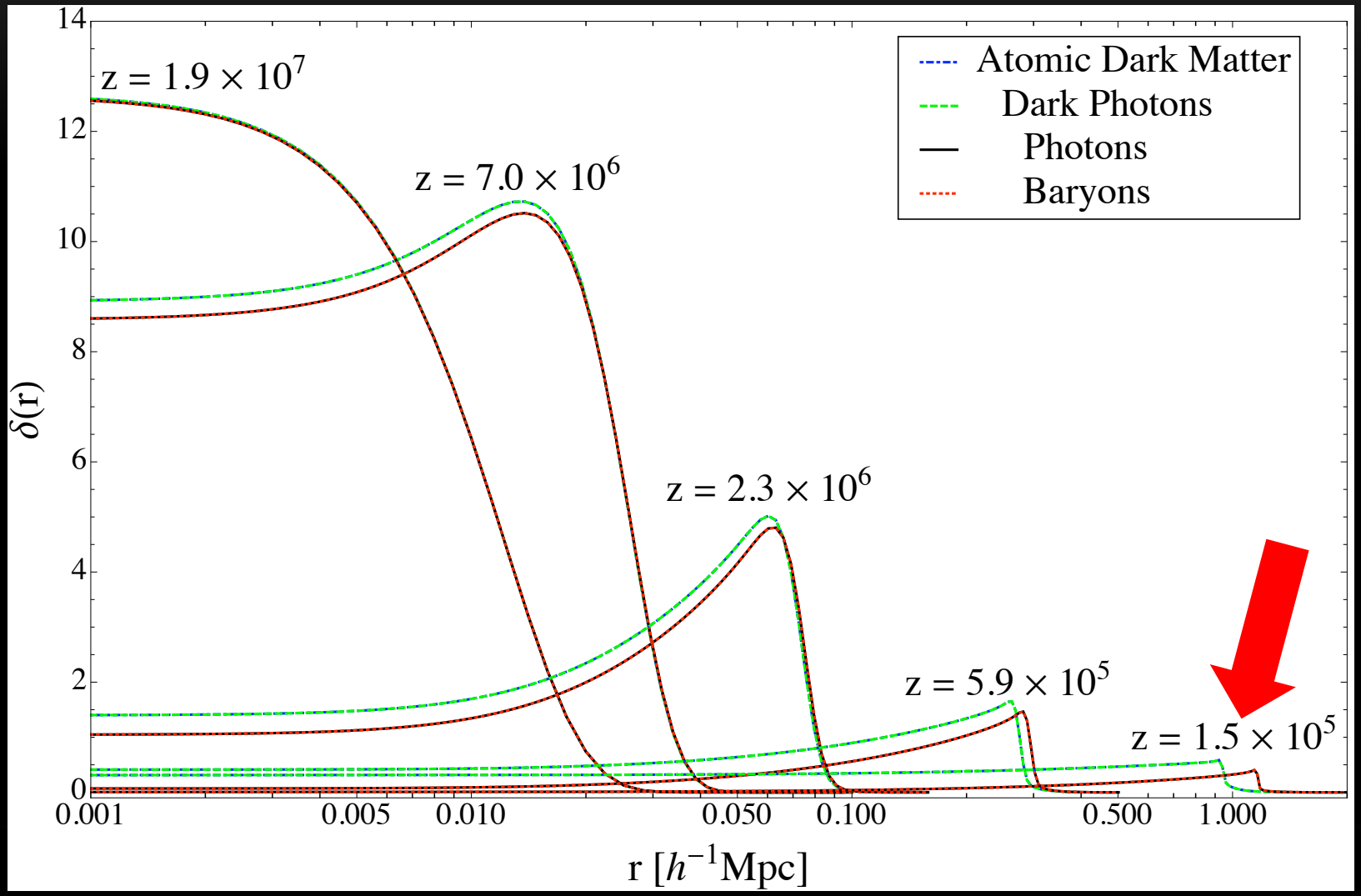
Cyr-Racine et al. (2016)
Cyr-Racine et al. (2014)
Cyr-Racine & Sigurdson (2013)

Dark acoustic oscillation (DAO)

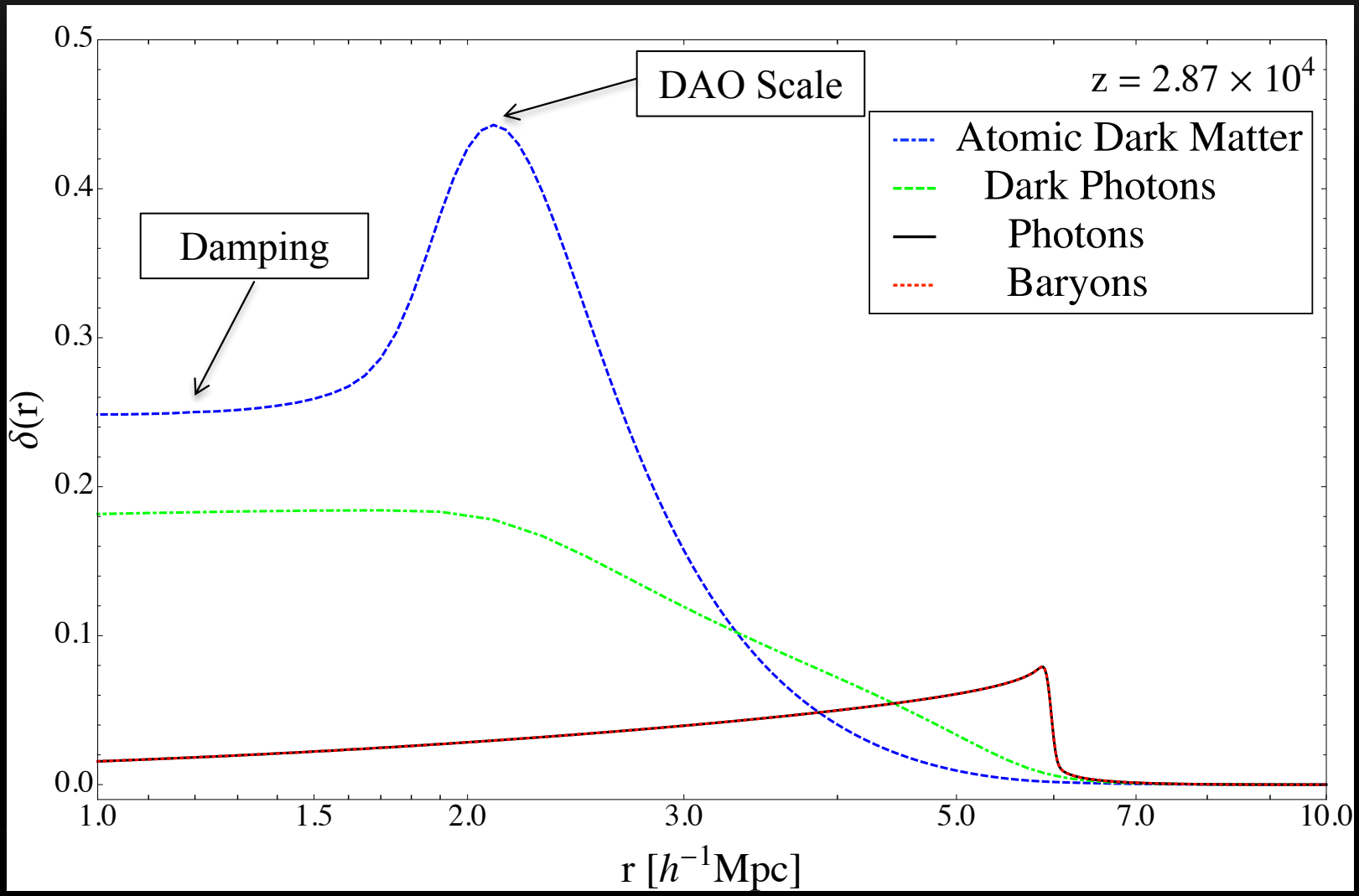


$$\xi \equiv \left(T_D / T_{\rm CMB}\right)\big|_{z=0}$$

Phenomenology of dark matter-dark radiation interaction: Sound wave

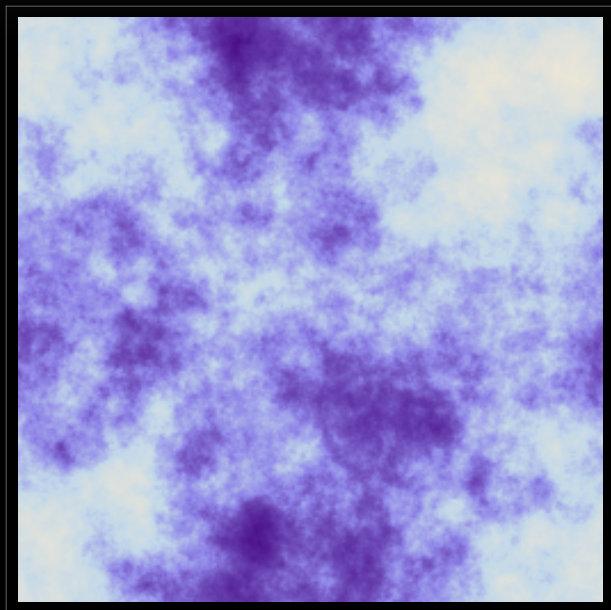


Phenomenology of dark matter-dark radiation interaction: Sound wave

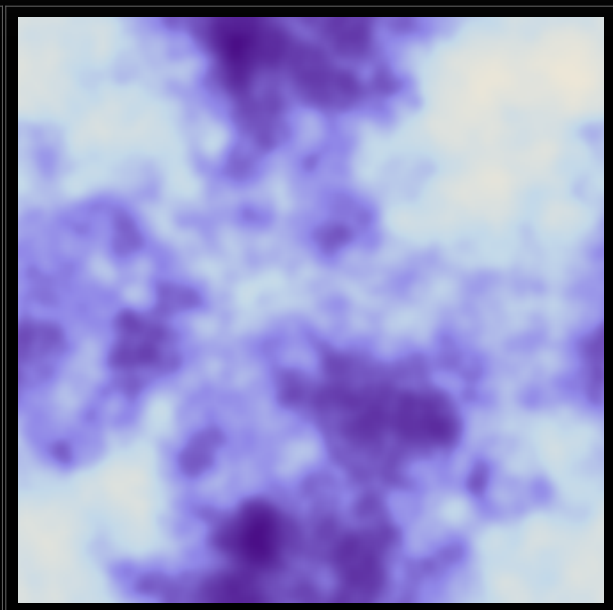


The structure of the dark matter density field is distinctly different

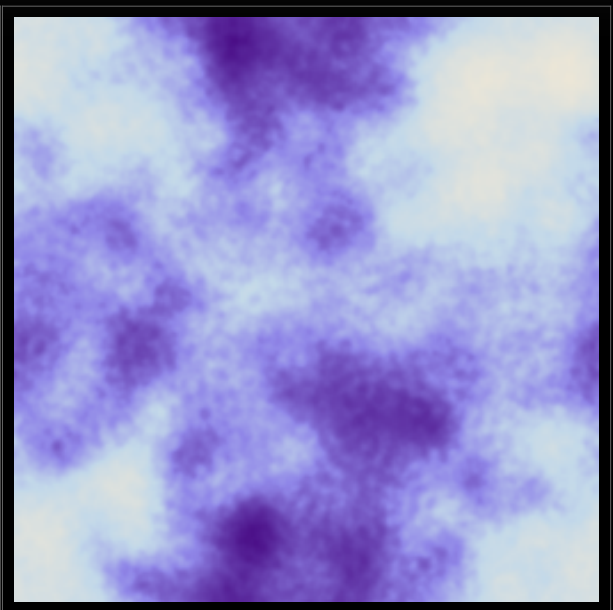
Cold DM



Warm DM

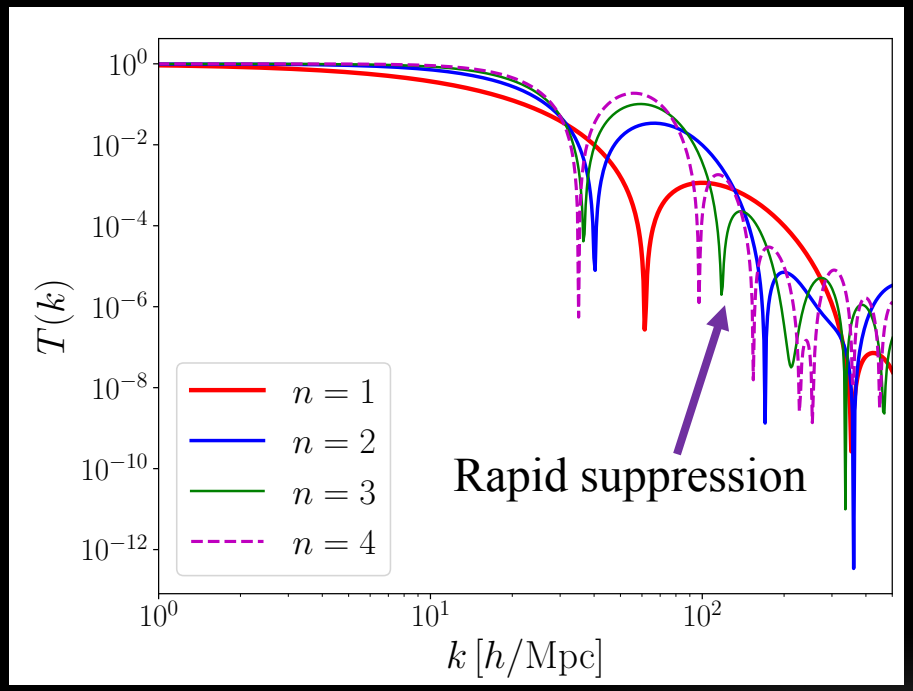


DM-DR interaction

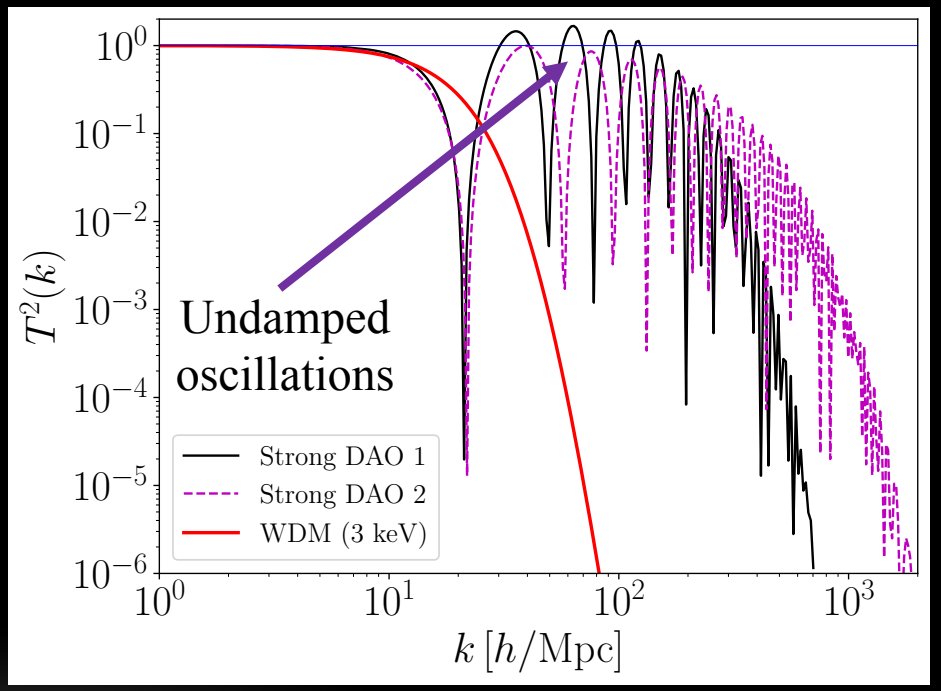


Broad diversity of matter power spectrum shapes

Weak DAO



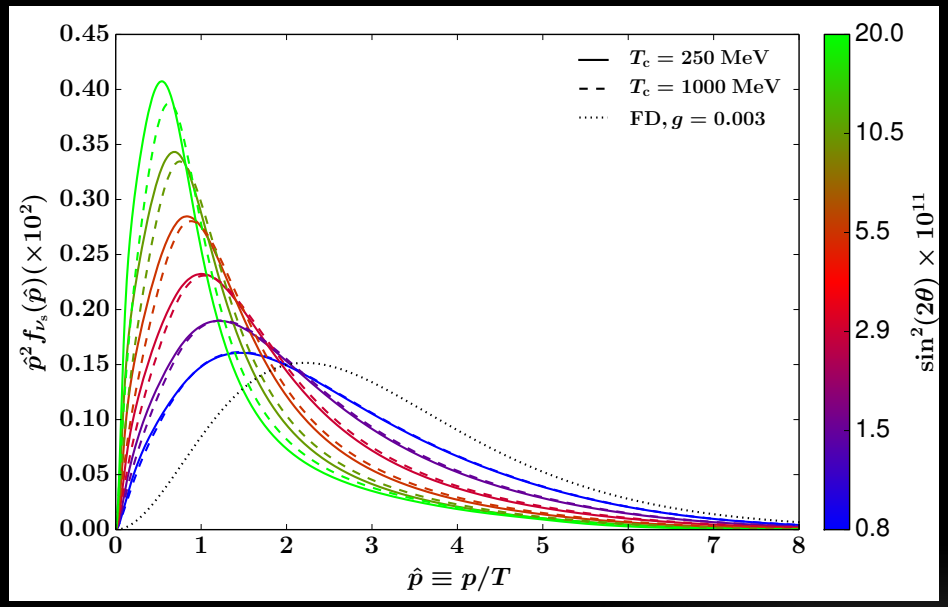
Strong DAO

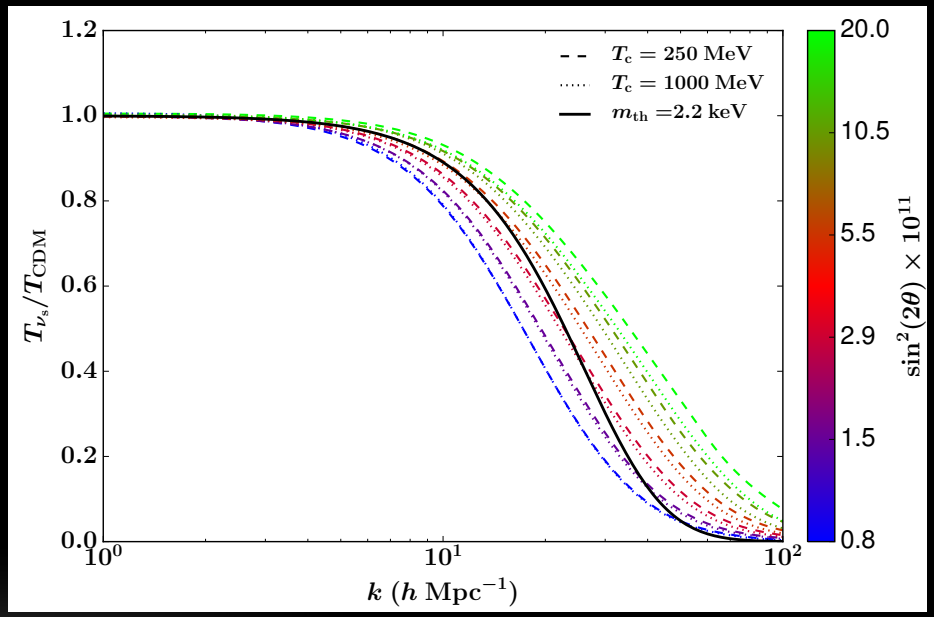


Cyr-Racine et al. (2016)

What determines the shape of the matter power spectrum?

WDM example: The momentum distribution function determines the shape of the cutoff.



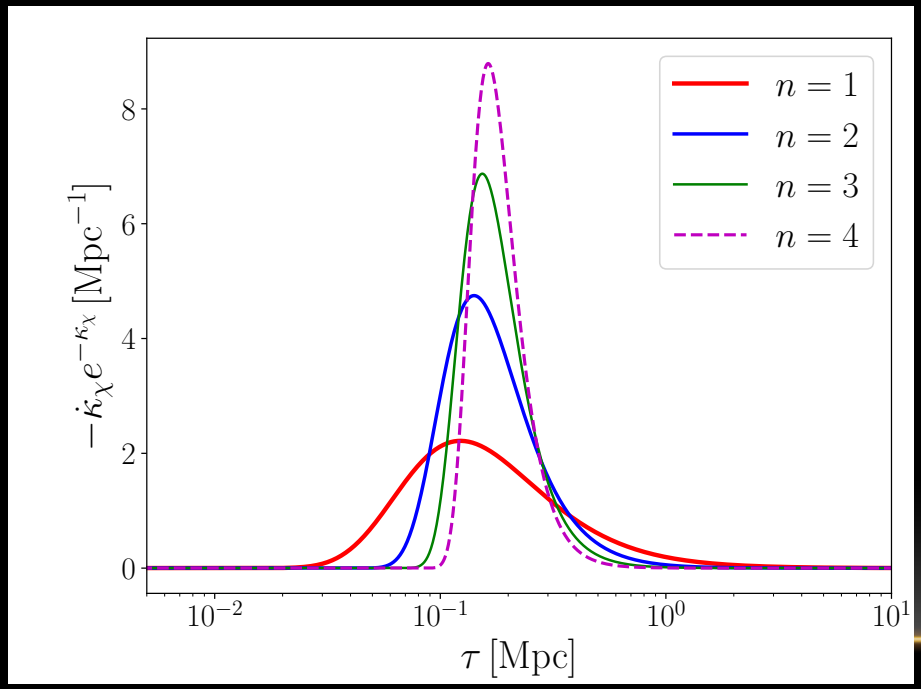


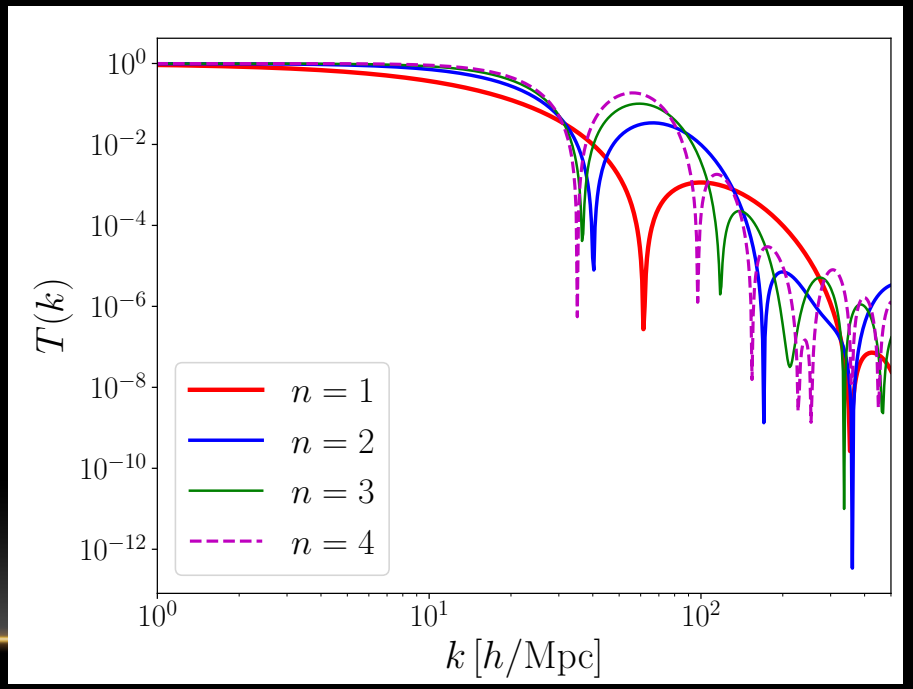
Venumadhav , Cyr-Racine+ (2015)

What determines the shape of the matter power spectrum?

DM-DR interaction: The dark matter drag visibility function determines the shape of the transfer function.

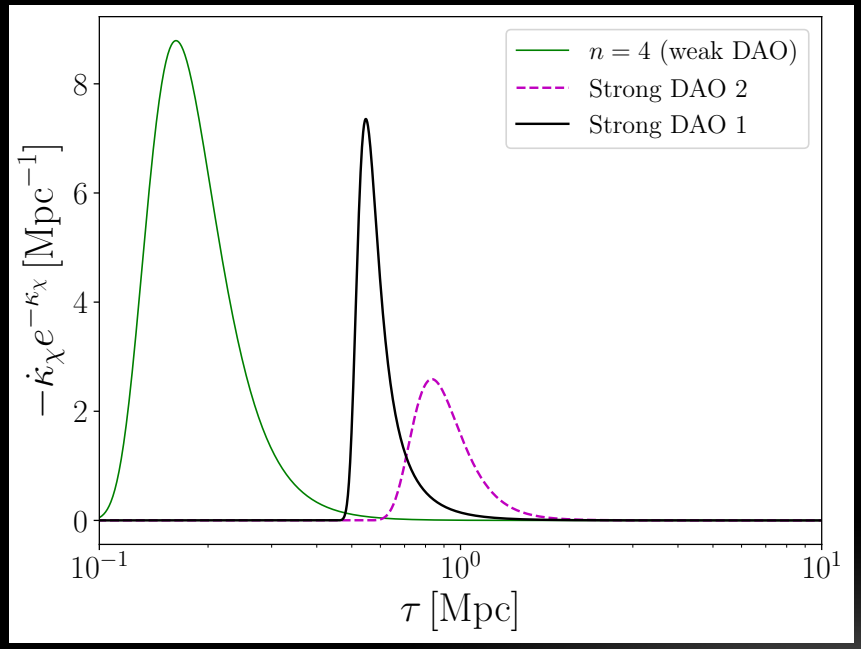
$$\dot{\kappa}_\chi = -a\frac{4}{3}\frac{\rho_{\rm DR}}{m_\chi}\langle\sigma_{\rm DM-DR}\rangle \approx -\left(\frac{z}{z_{\rm D}}\right)^{n+1}\mathcal{H}$$

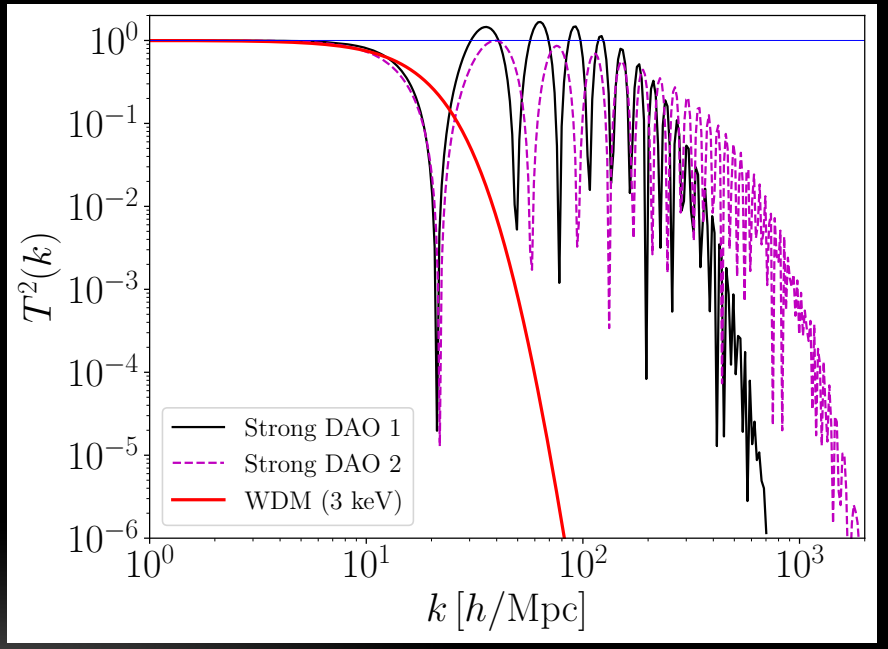




What determines the shape of the matter power spectrum?

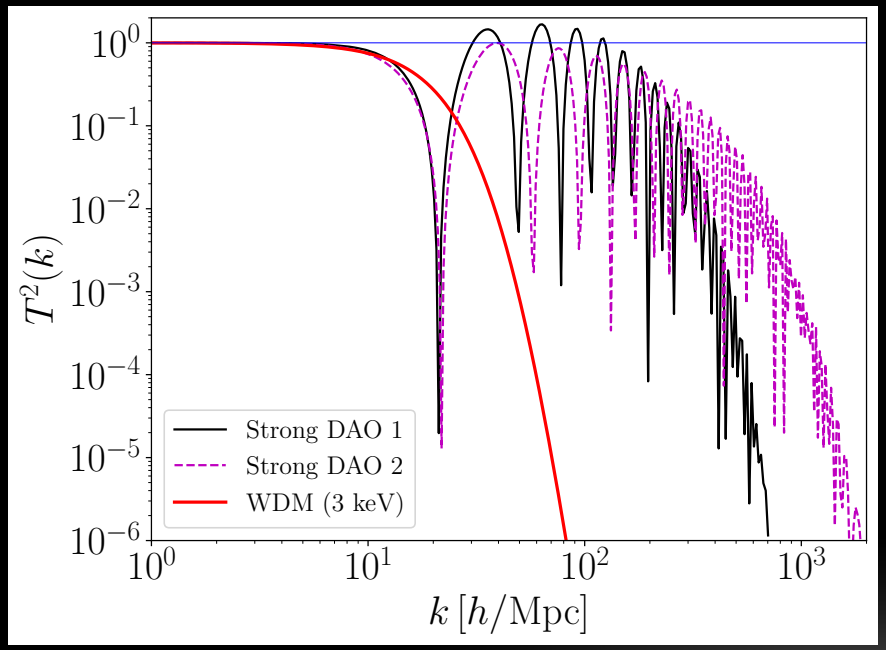
A narrow dark matter drag visibility function maximizes differences between DM-DR models and WDM.

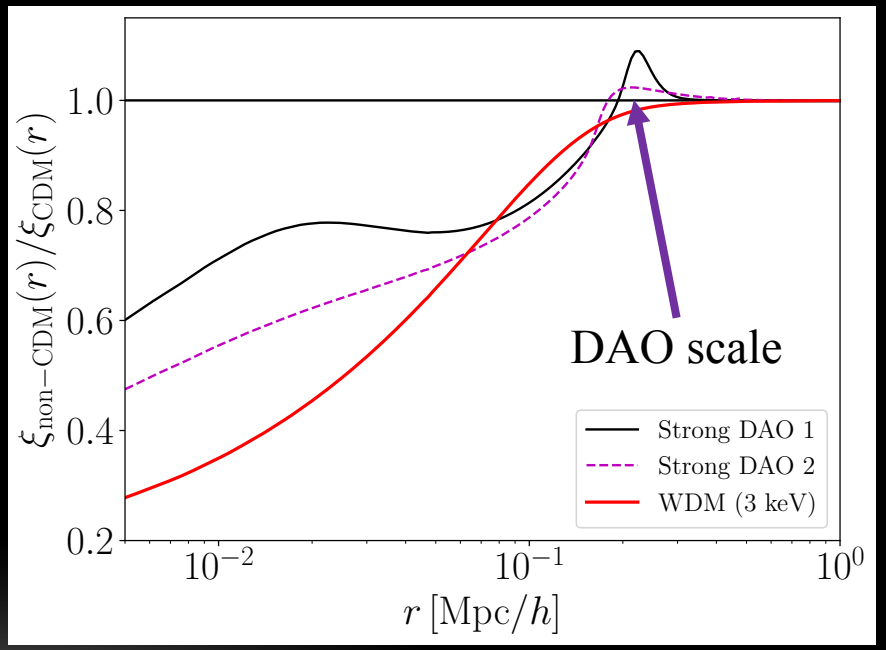




The correlation function: A more intuitive picture?

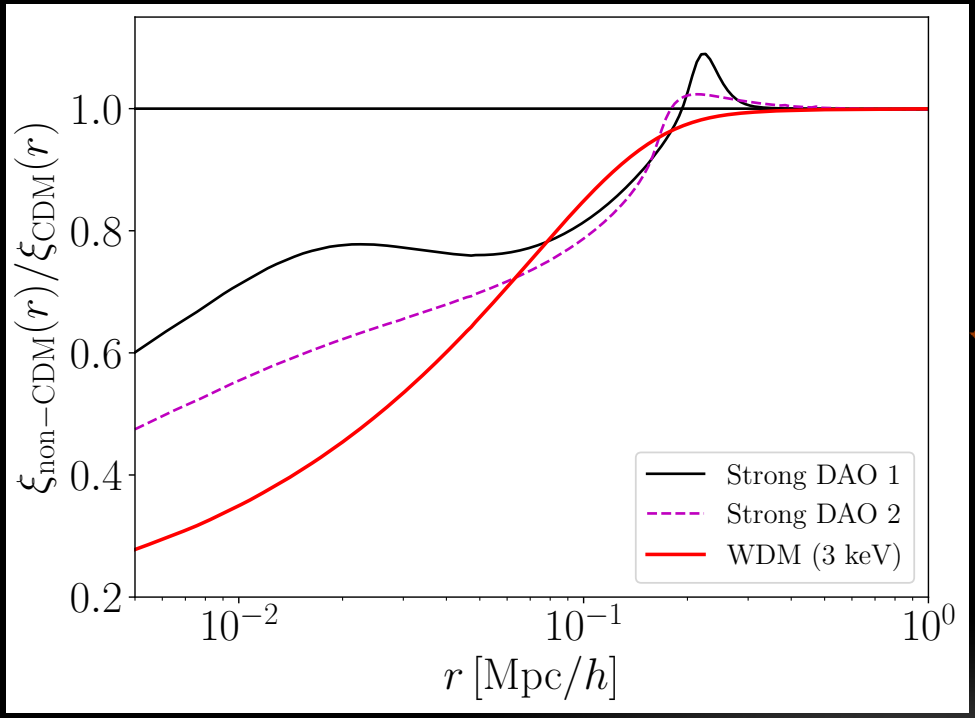
- In general, the phenomenology of these models is not described by a single parameters (i.e. half-mode mass).

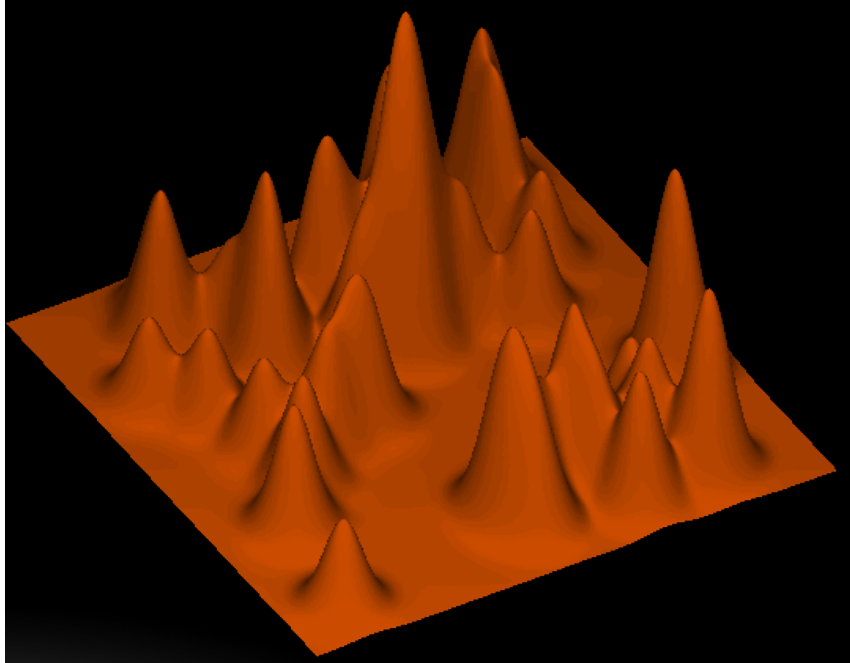




Extra correlation in the density field

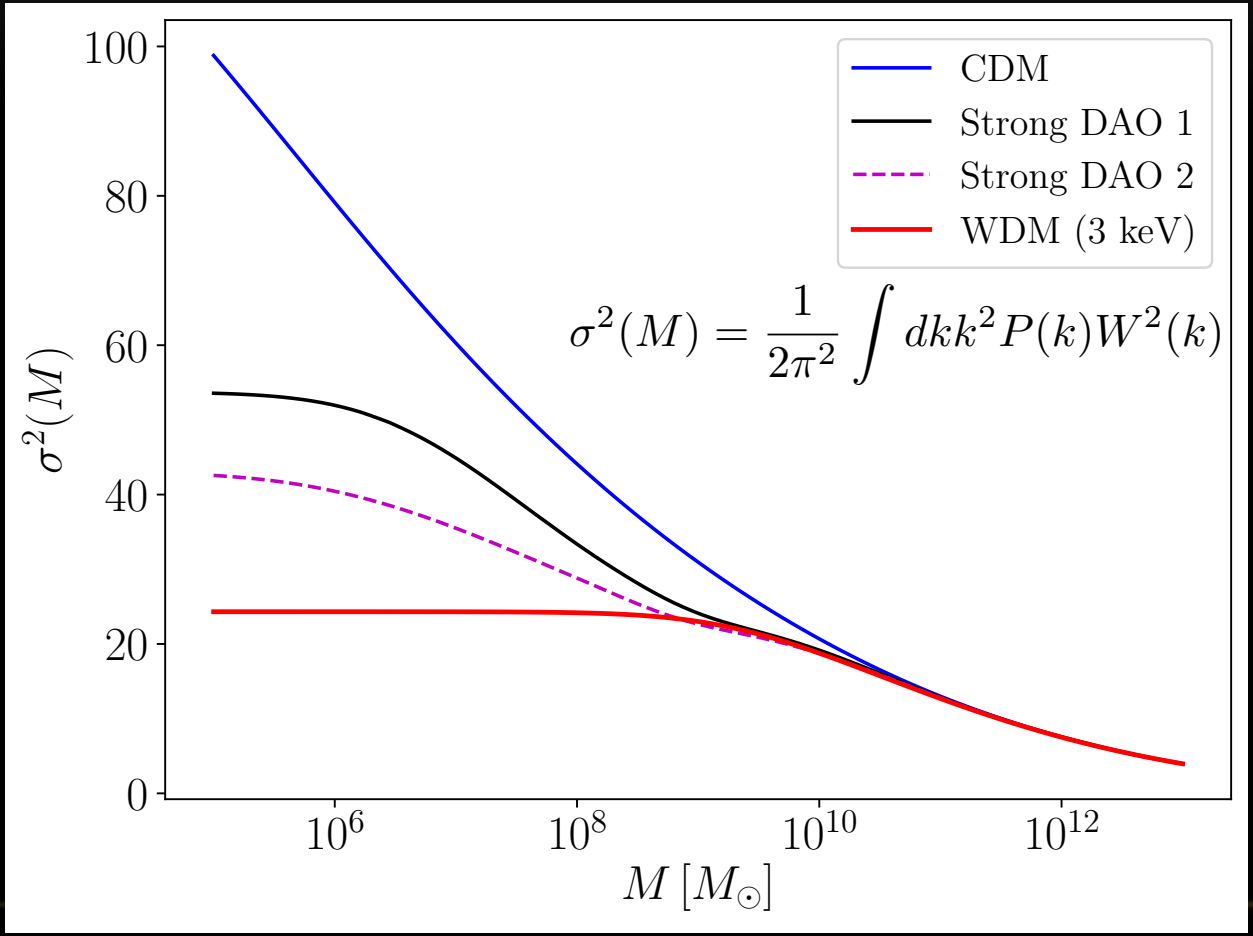
- Enhancement beyond CDM?





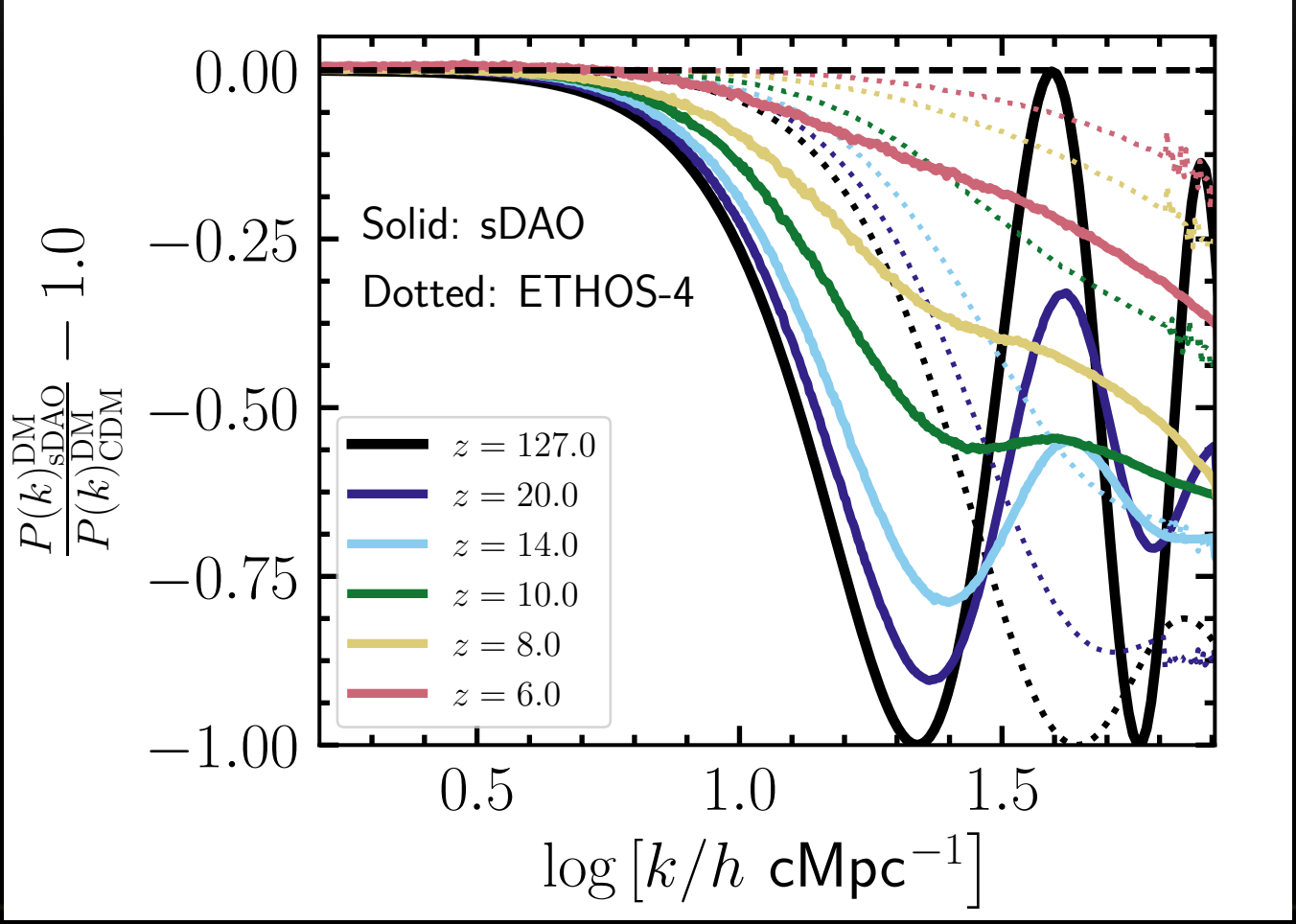
What about the halo mass function?

- Mass variance is seems to suggest that this is a 3-scale problem.



Non-linear evolution of DAOs

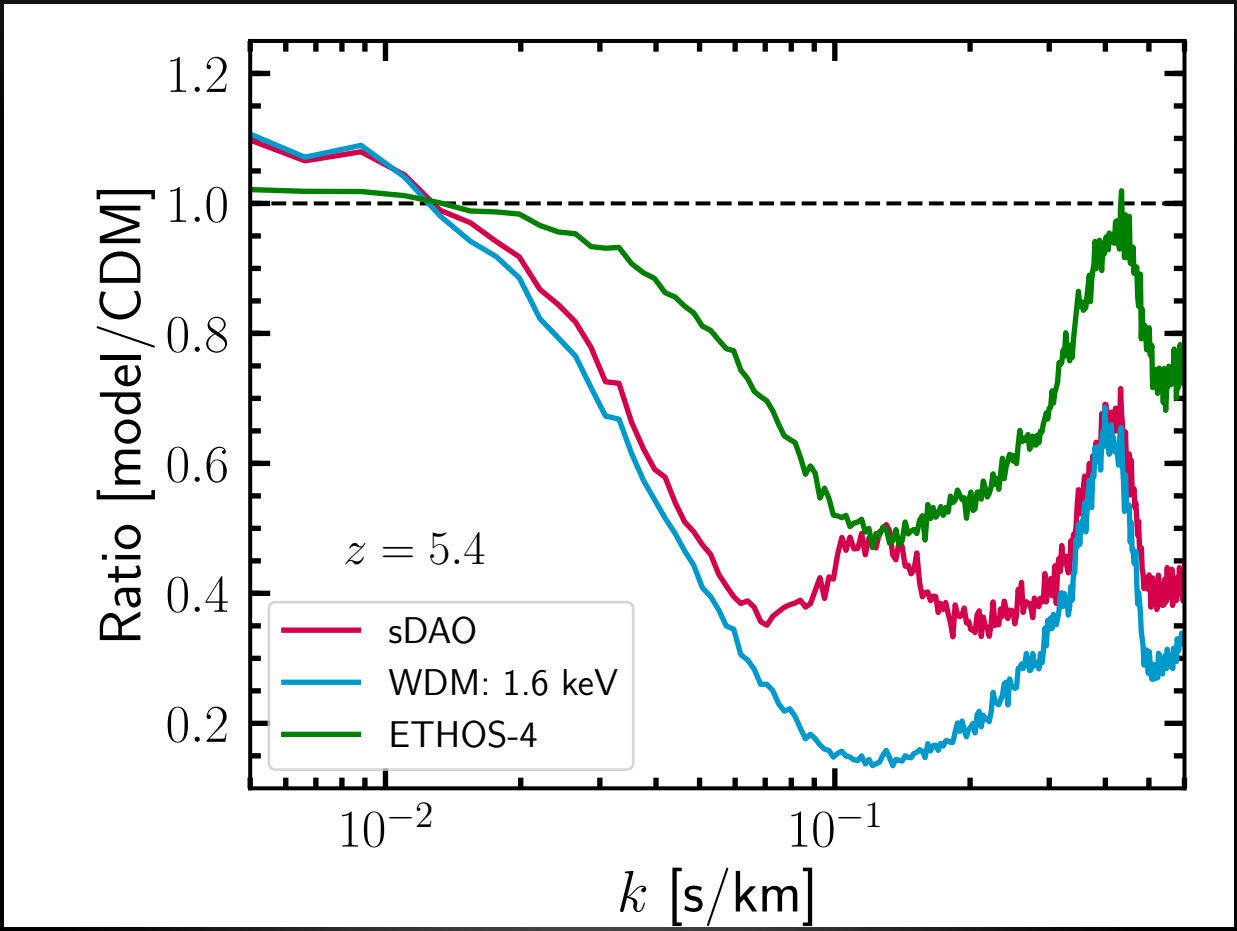
- Mode-coupling erases acoustic oscillations over time



Bose et al. (2019)

Non-linear evolution of DAOs

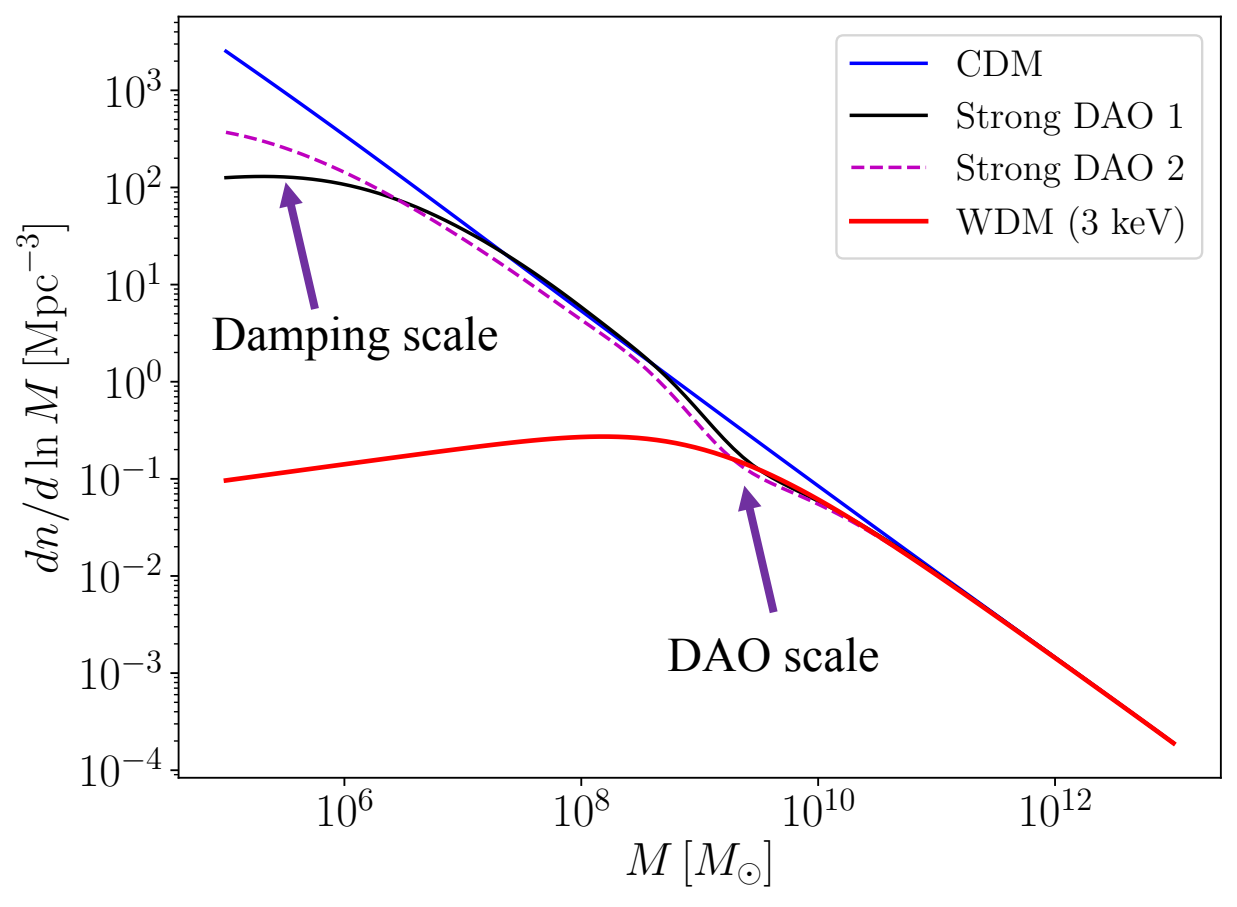
- They might survive long-enough to be observed at high redshifts



Bose et al. (2019)

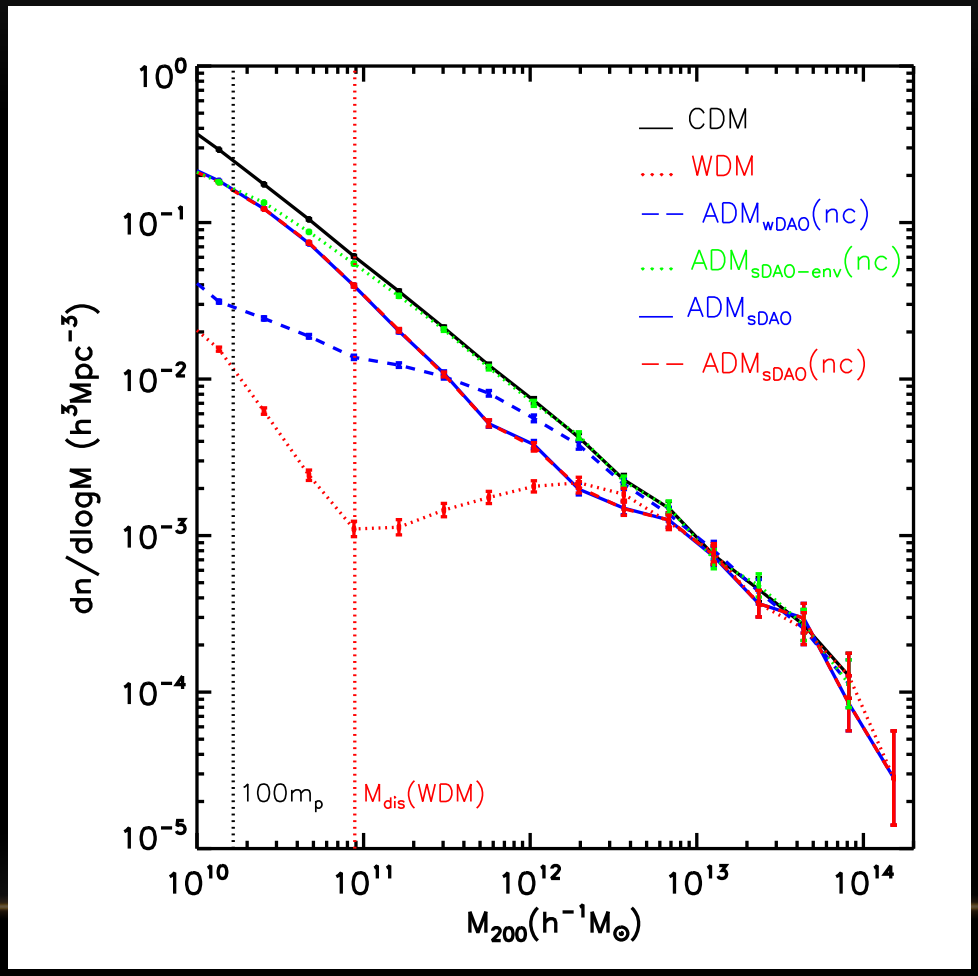
What about the halo mass function?

- DAO: Sowing confusion in the halo mass function



What about the halo mass function?

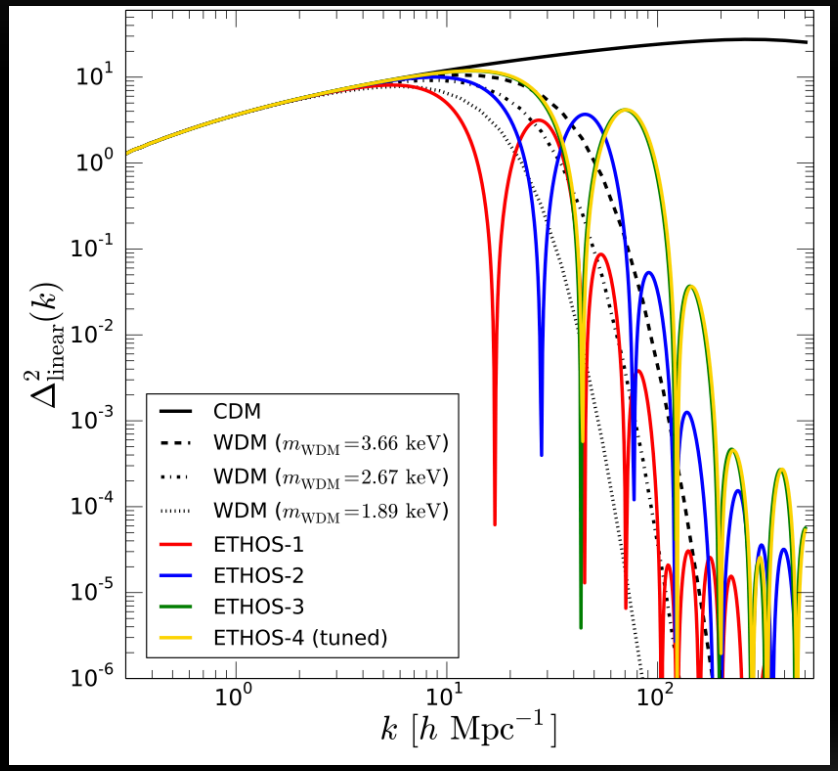
- We might already have seen this in simulations!



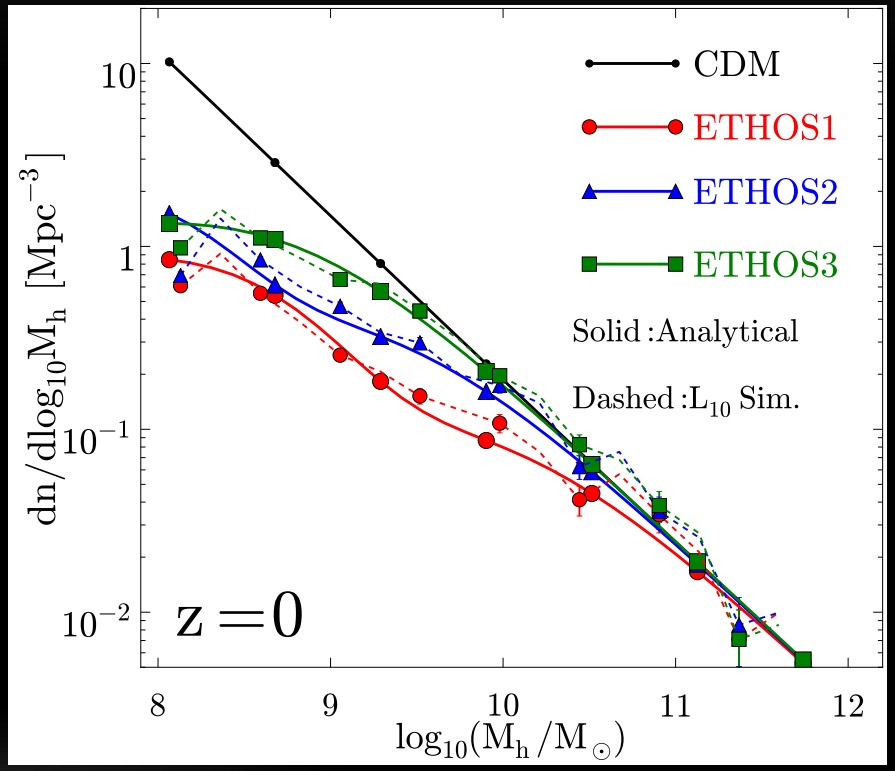
Buckley et al. (2014)

Halo mass function: Weak DAO case

- We might already have seen this in simulations!



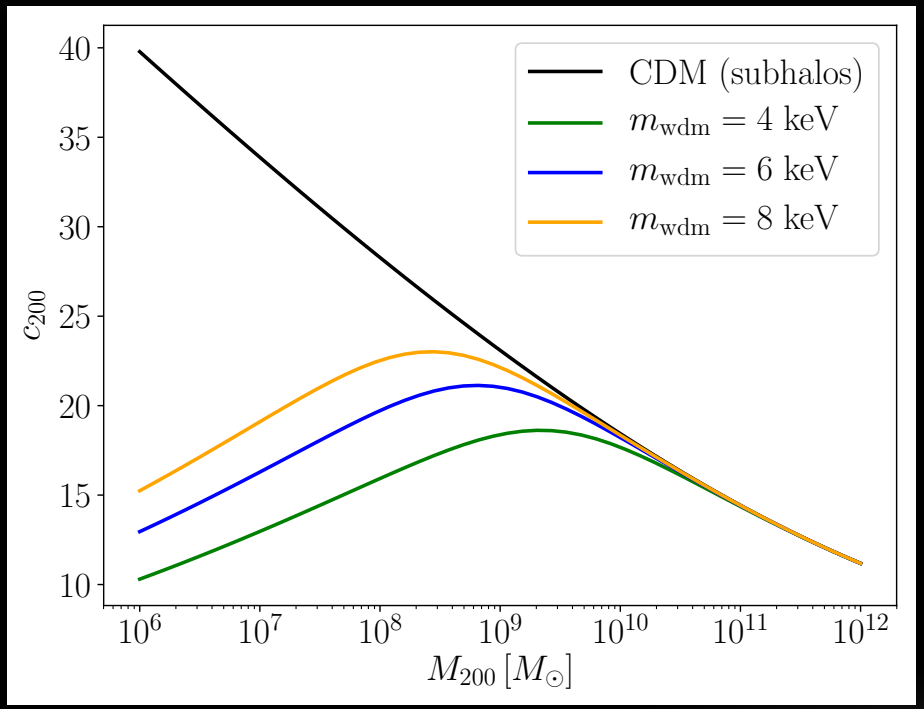
Vogelsberger et al. (2016)

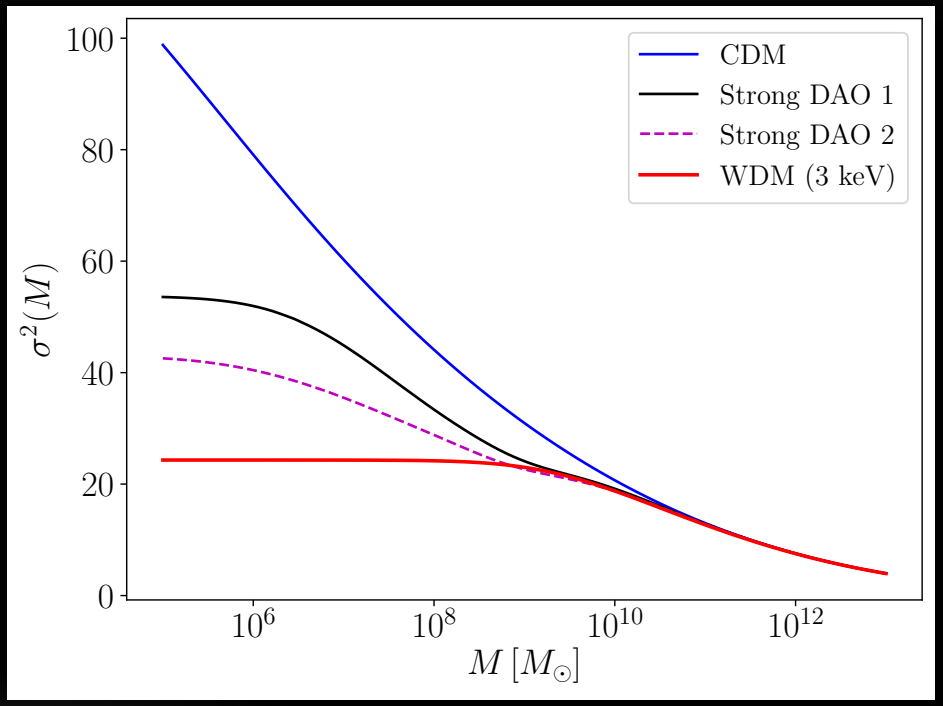


Samei et al. (2019)

A comment on halo concentration

- A DAO-like power spectrum cutoff could have an interesting effect on the mass-concentration relation



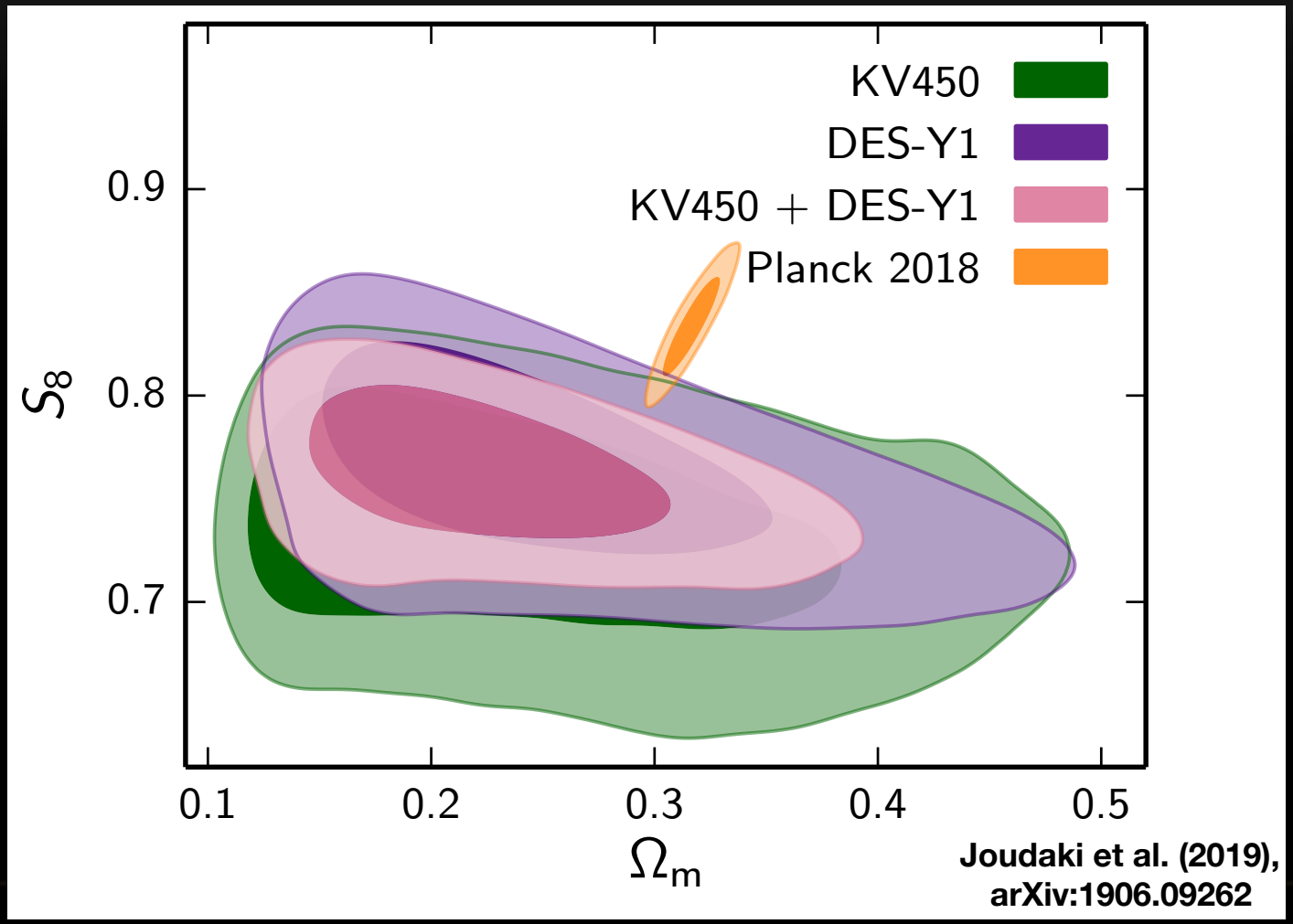


Moliné et al. (2017)
Bose et al. (2015)
Lovell et al. (2014)
Schneider et al. (2012)

TBD!

Applications, or why do we care?

This kind of DM physics could help alleviate cosmological tensions



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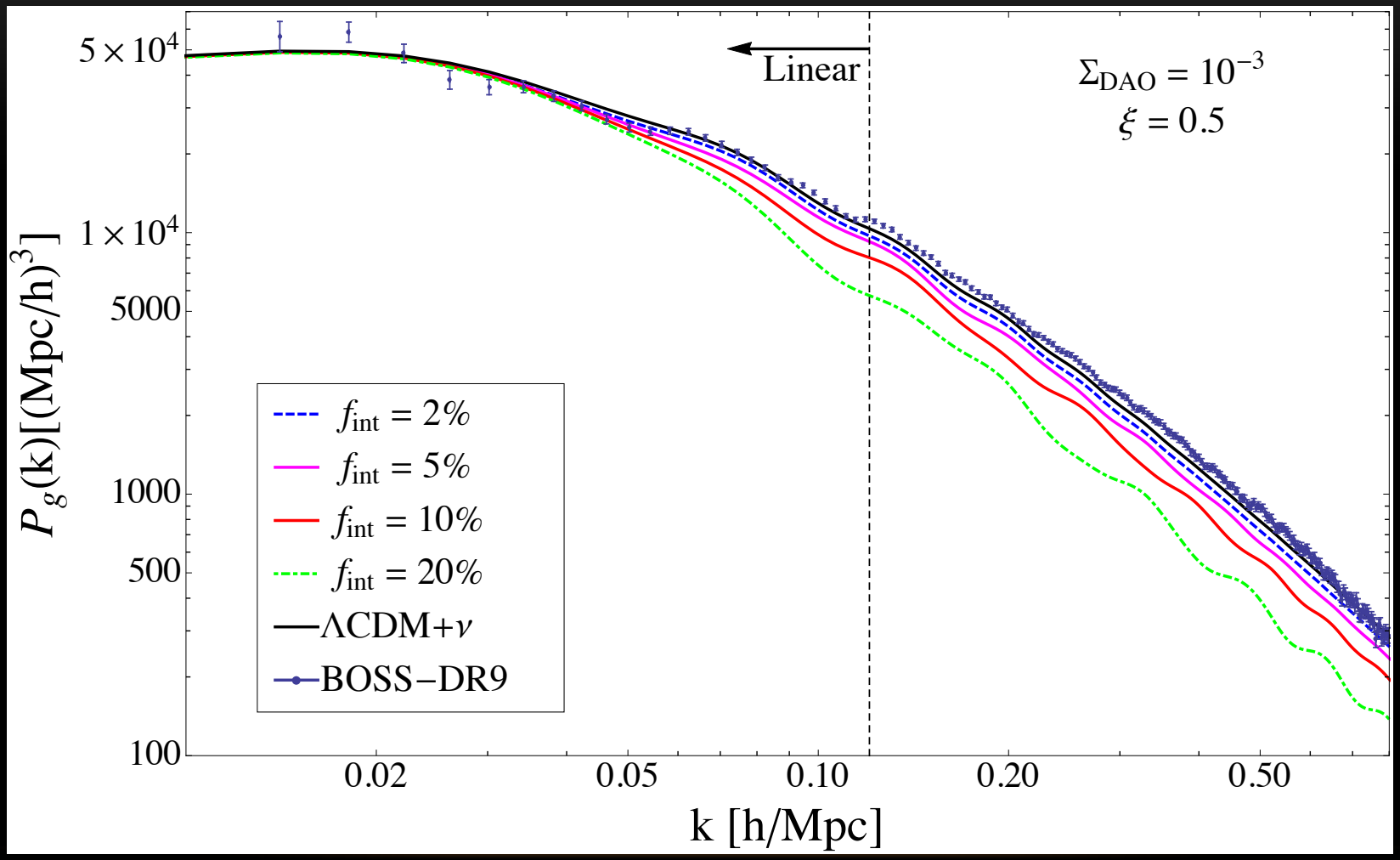
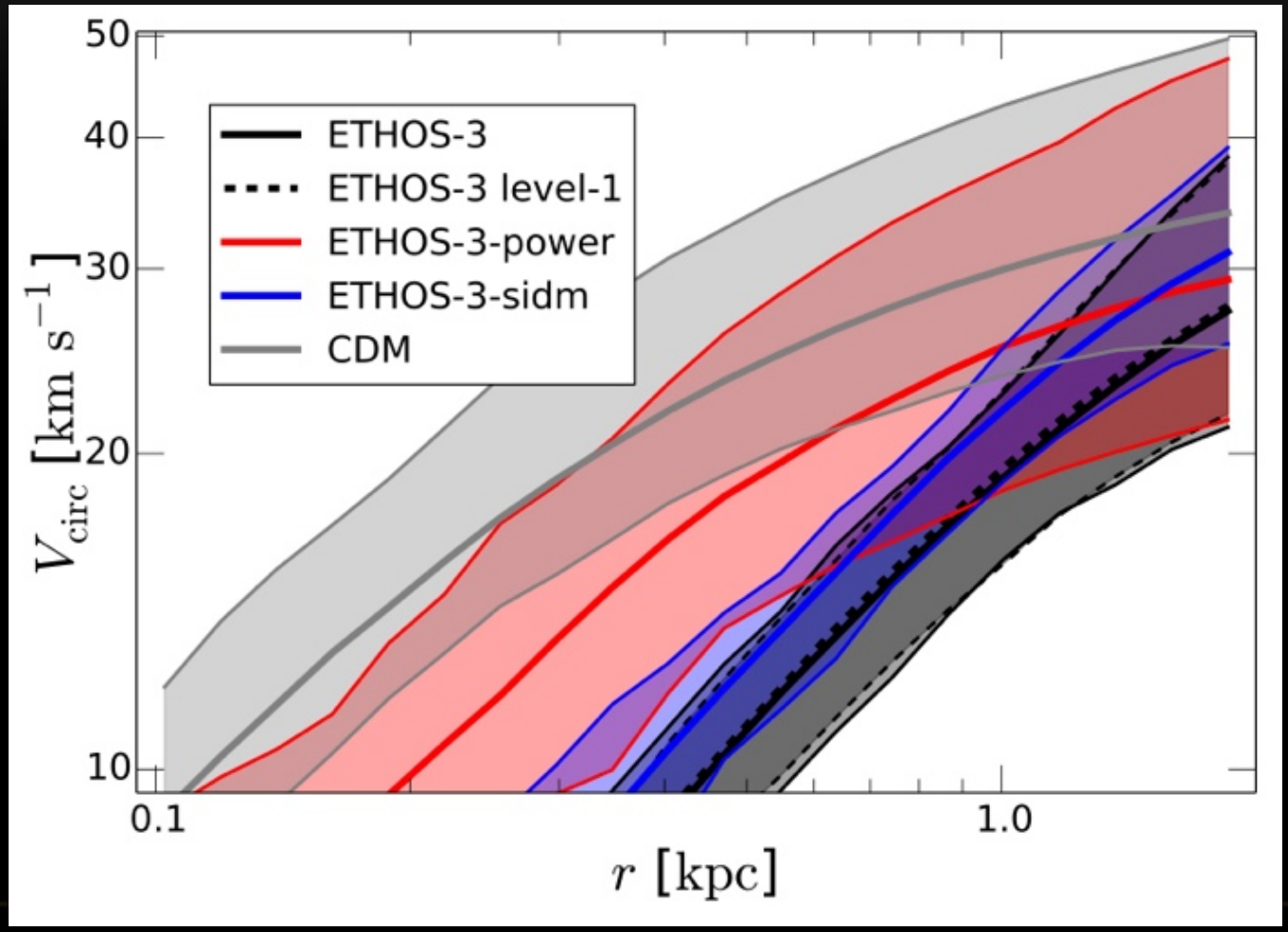


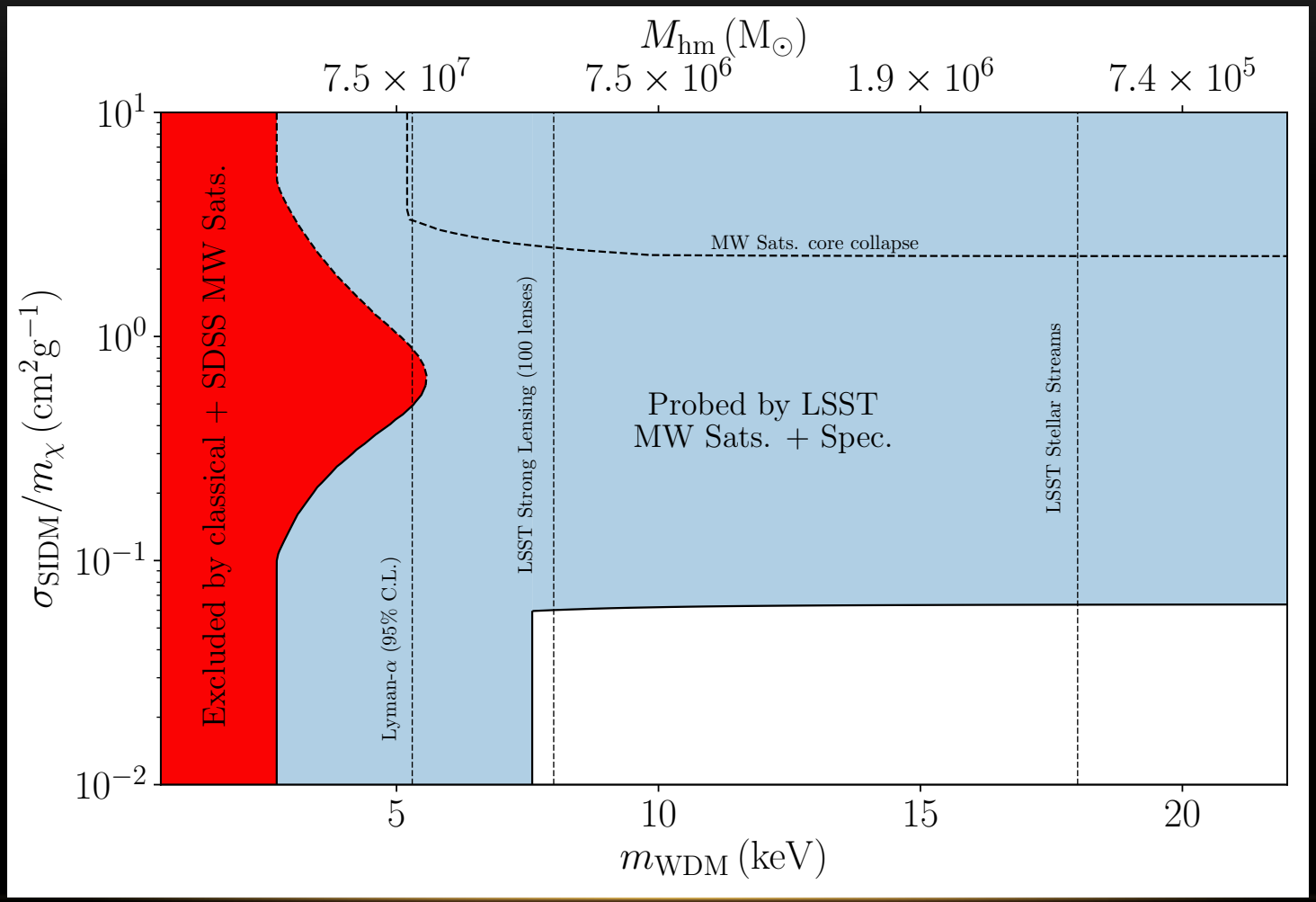
Cyr-Racine et al. (2013)

Exploring degeneracies between self-interaction and a cutoff



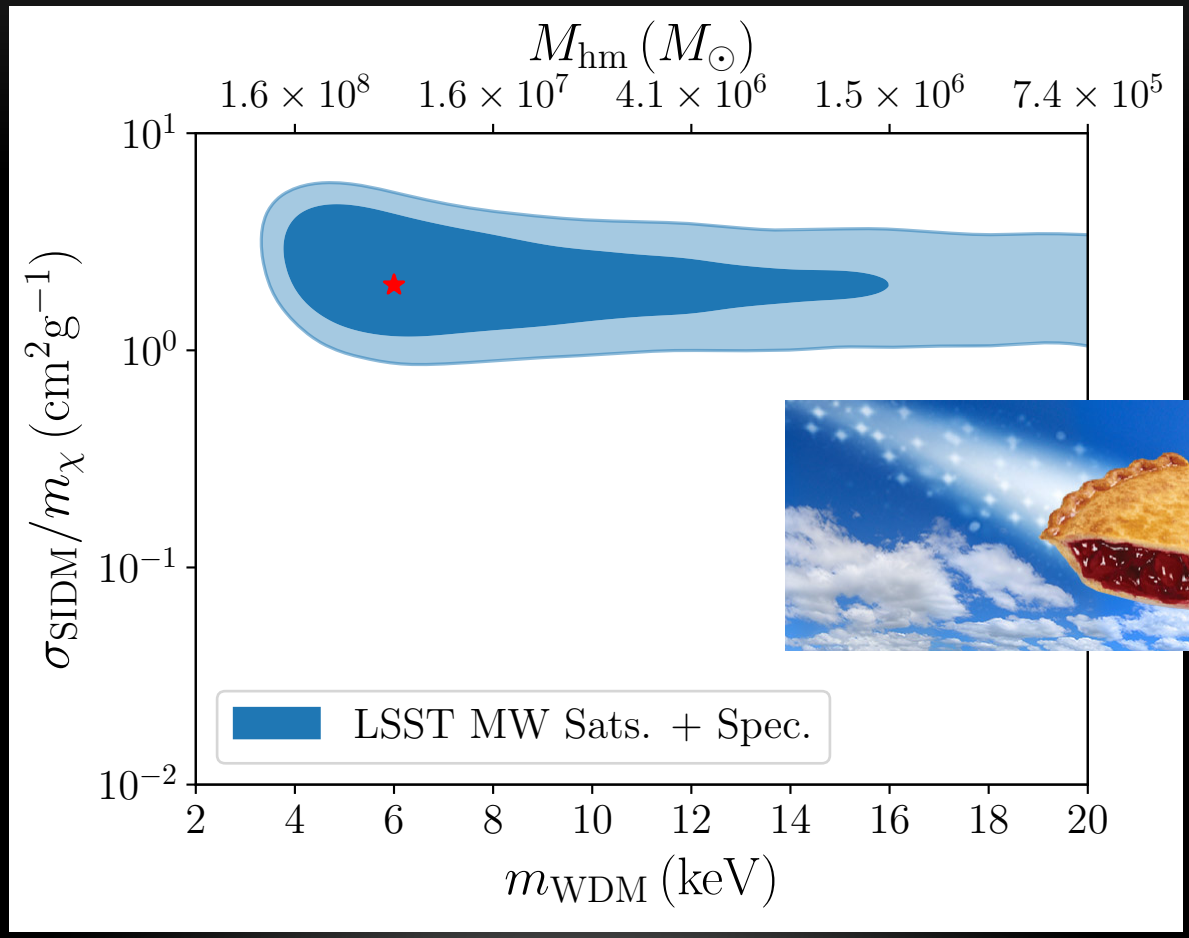
Vogelsberger et al. (2016)

Exploring degeneracies between self-interaction and a cutoff



Drlica-Wagner et al. (2019)

Exploring degeneracies between self-interaction and a cutoff



Drlica-Wagner et al. (2019)

Conclusions

- DM-DR interaction models can make quite diverse predictions from the matter power spectrum and halo mass function.

- In the strong DAO case, these predictions can be quite distinct as compared to either WDM or CDM, especially for the halo mass function.

- In general, these models are also self-interacting, and are thus important testbeds for studying the interplay between a cutoff and self-interaction.

Thank you!