

# Early Structure Formation in $\Lambda$ PBH Cosmologies

---

DEREK INMAN, NEW YORK UNIVERSITY

COSMO19, RWTH AACHEN UNIVERSITY

SEPTEMBER 2, 2019

More information:

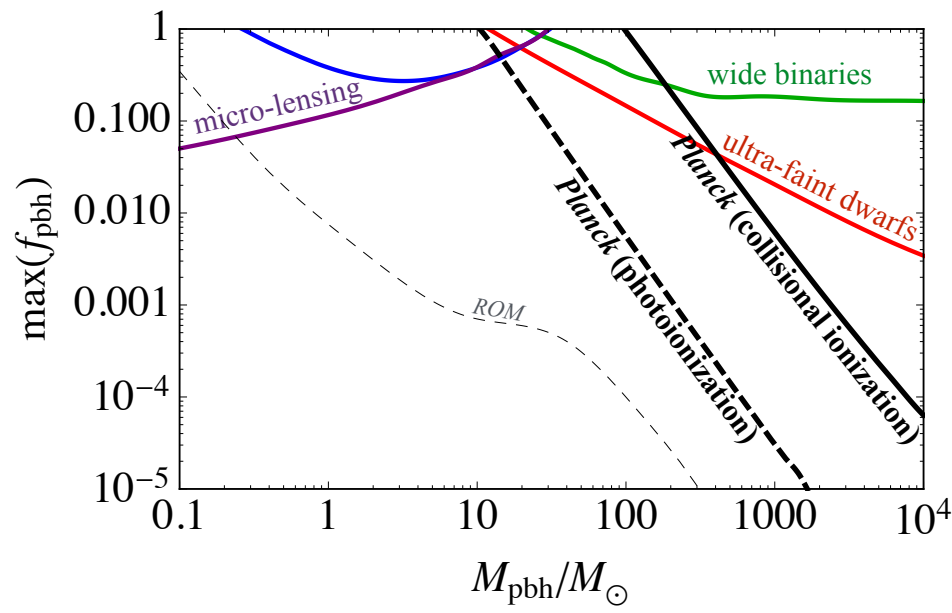
Inman and Ali-Haïmoud (arXiv:1907.08129)

# Primordial Black Holes (PBH)

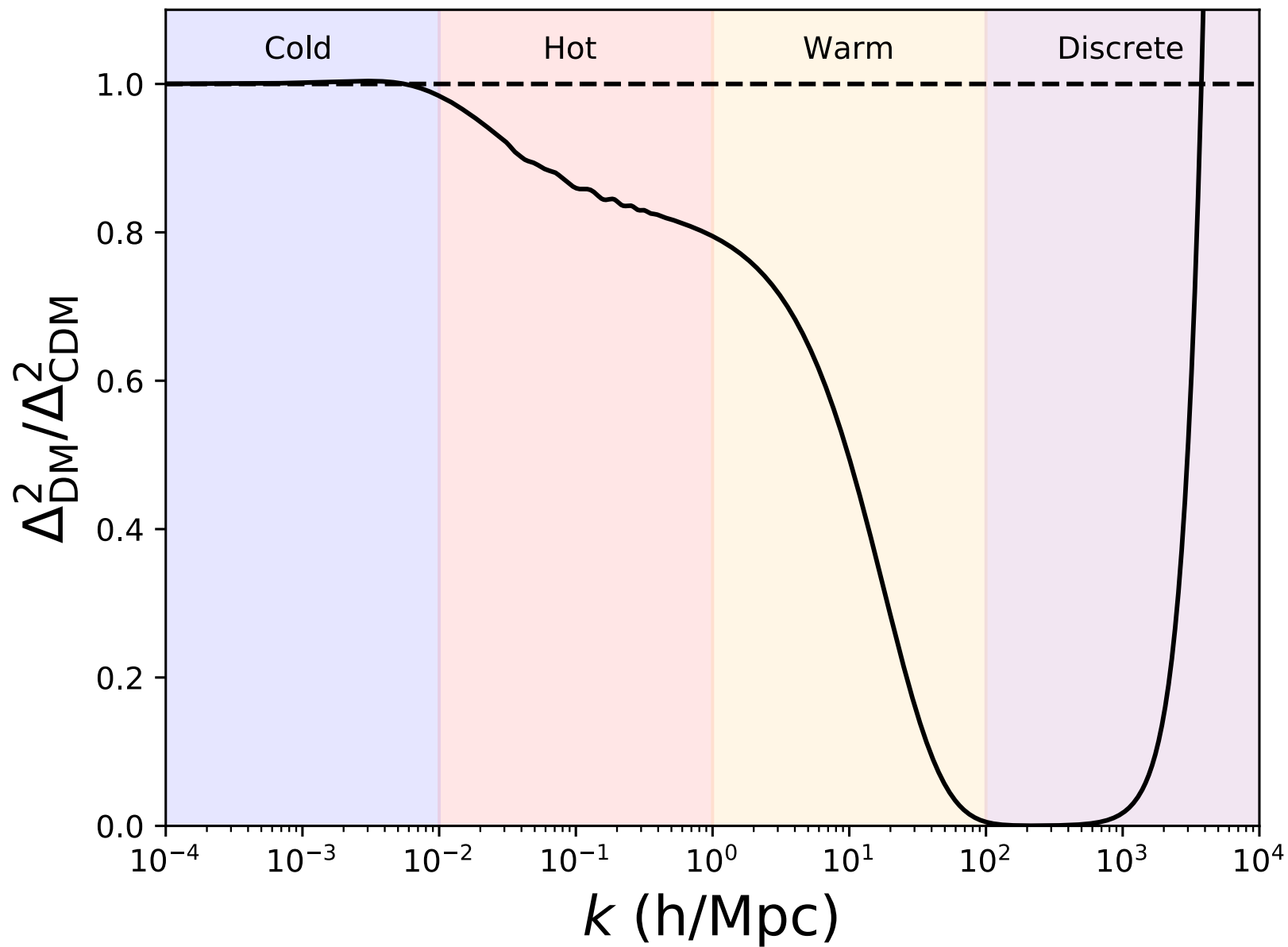
## Why PBH?

- Dark matter
- WIMPs
- Super massive black holes
- Initial conditions

$$\delta_i \sim 1 \rightarrow \text{PBH}$$



Ali-Haïmoud & Kamionkowski (2017)



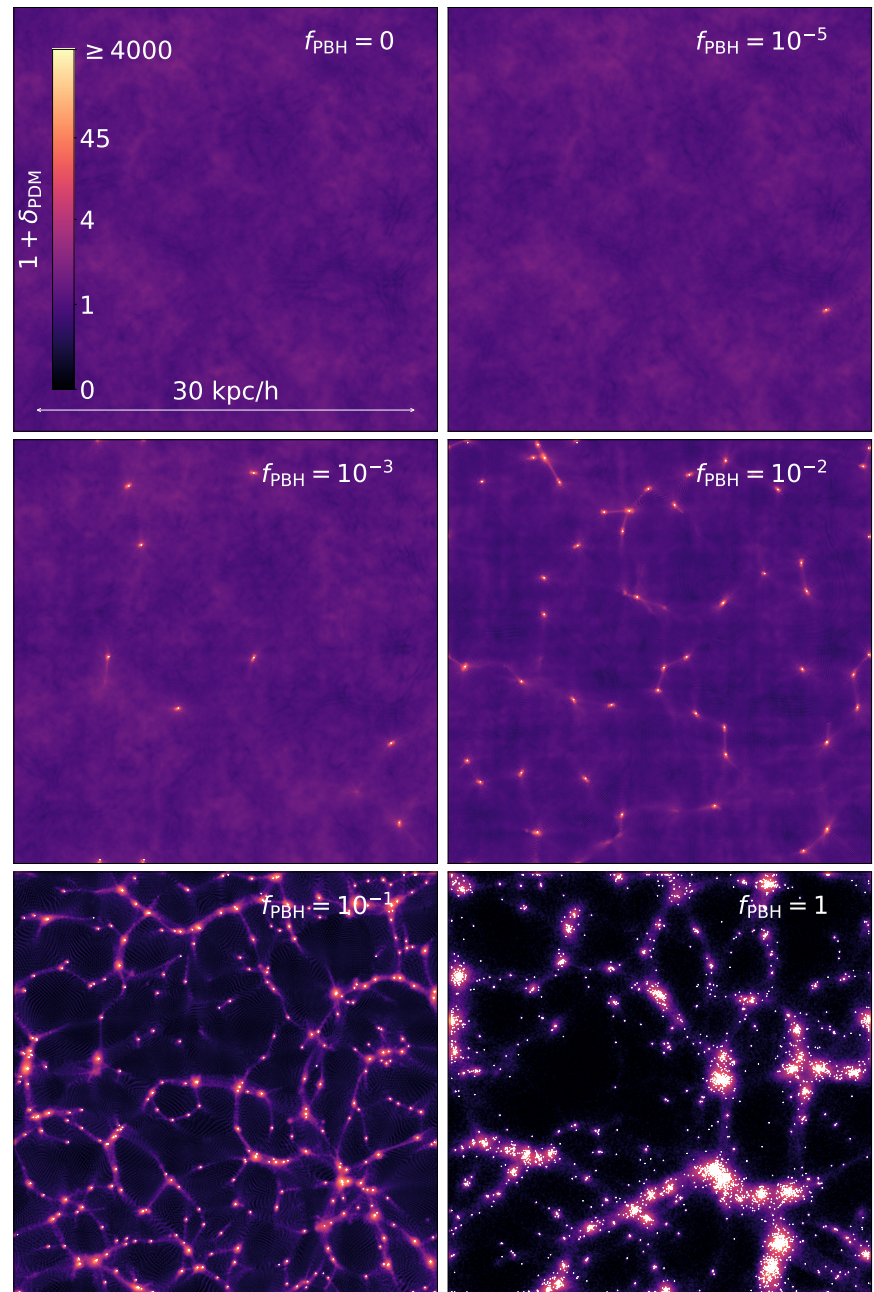
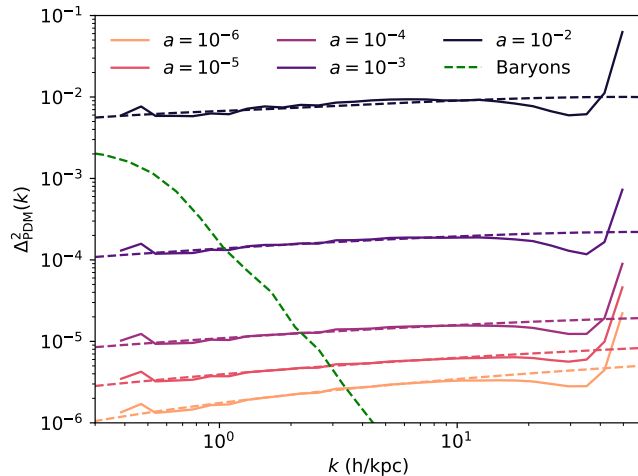
# Simulation Setup

- PBHs are separate set of particles coevolved with generic “particle dark matter”
- Modified initial conditions:

$$\delta_{\text{PDM}}(a) = T_{\text{ad}}(a)\delta_{\text{ad}}^0 + \frac{3}{2} \frac{\Omega_c}{\Omega_m} \frac{a}{a_{\text{eq}}} f_{\text{PBH}} \delta_{\text{PBH}}^0$$

$$\delta_{\text{PBH}}(a) = \delta_{\text{PBH}}^0 + \delta_{\text{PDM}}(a)$$

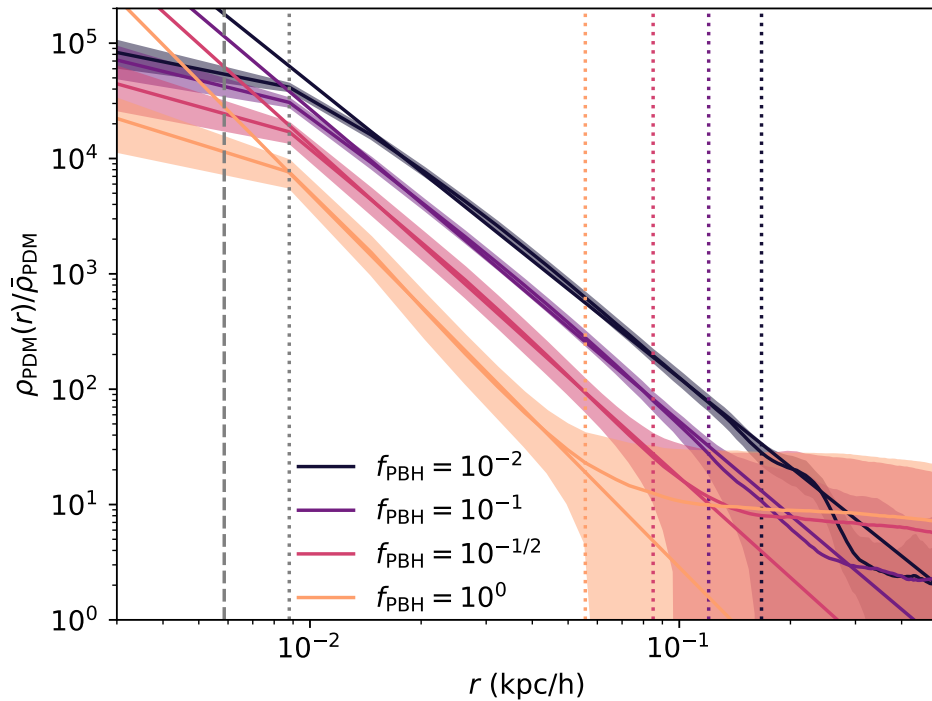
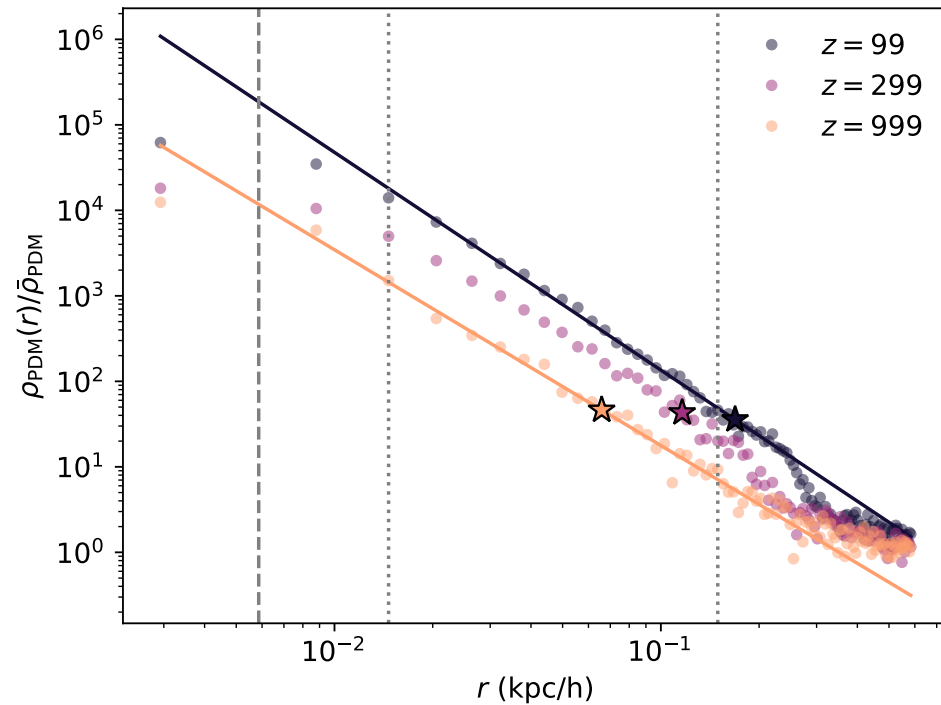
- If no PBHs:



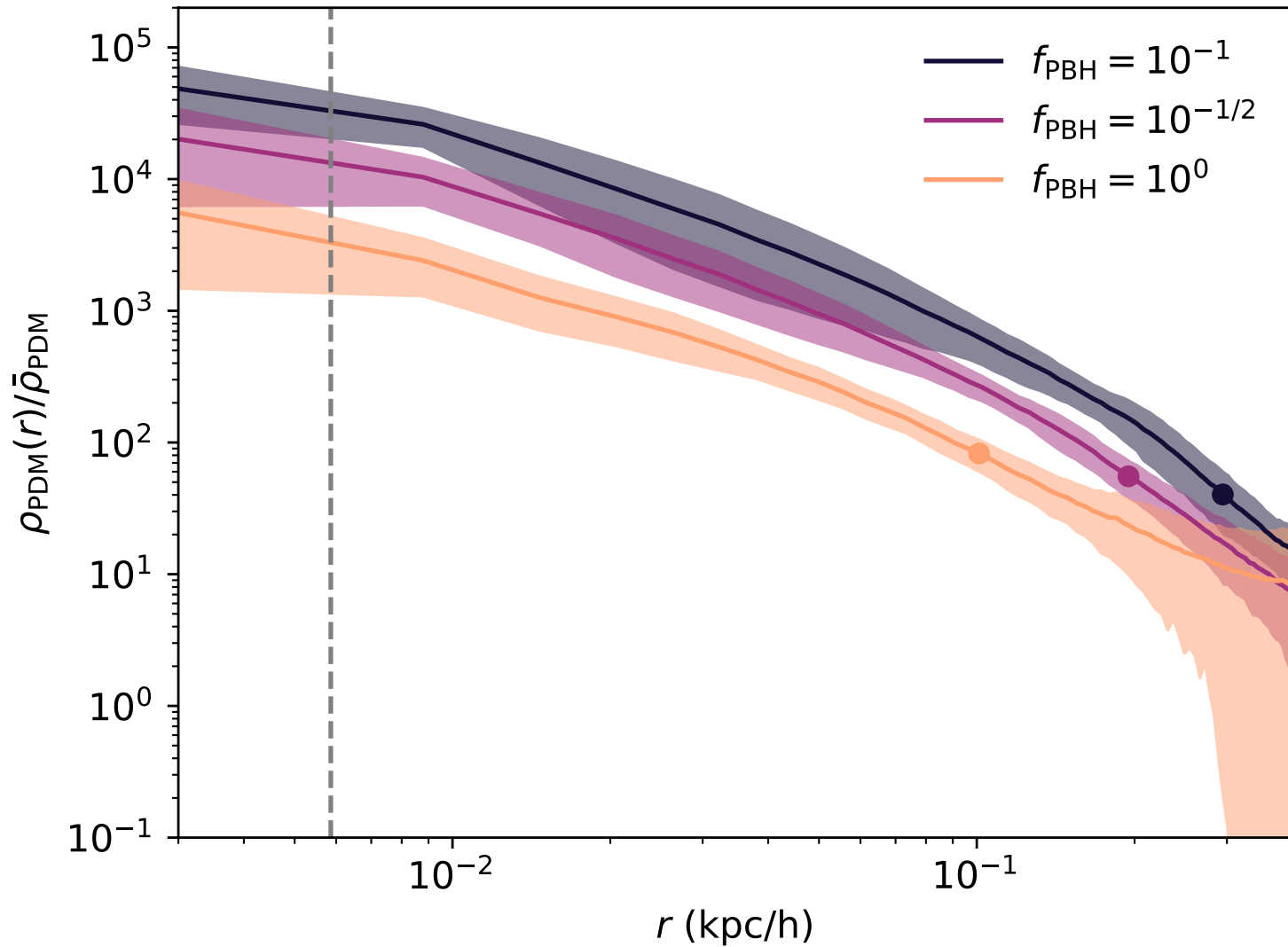
# Halo Profiles: $N_{\text{PBH/HL}} = 1$

$$\text{Theory : } \rho \propto r^{-2.25}$$

Bertschinger (1985)



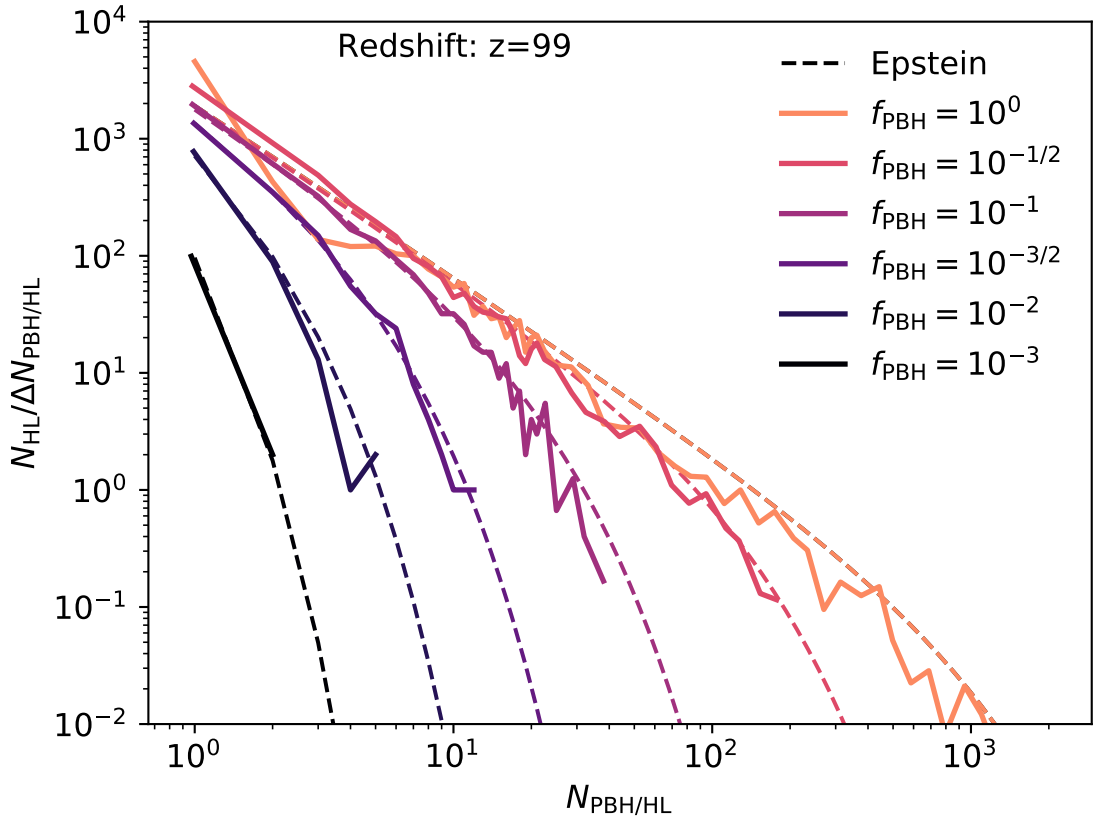
# Halo Profiles: $13 < N_{\text{PBH/HL}} < 17$



# Halo Mass Function

$$(L^3 M_{\text{PBH}}) \frac{dn}{dm} \rightarrow \frac{N_{\text{HL}}}{\Delta N_{\text{PBH/HL}}} = \frac{N_{\text{PBH}}}{N} \frac{d}{1+d} \left[ \frac{N}{1+d} \right]^{N-1} \frac{\exp \left[ -\frac{N}{1+d} \right]}{(N-1)!}$$

Epstein (1983)



$$d = \delta_{\text{cr}} / D_+(a) / f_{\text{PBH}}$$

$$+ \left[ \frac{N}{N_{\text{PBH}}} \frac{N_{\text{HL}}}{\Delta N_{\text{PBH/HL}}} \right]_{N=1} = \frac{1}{2}$$

$$= \text{Transition : } f_{\text{PBH}} \simeq 0.02 \frac{1+z}{100}$$

# PBH Velocities

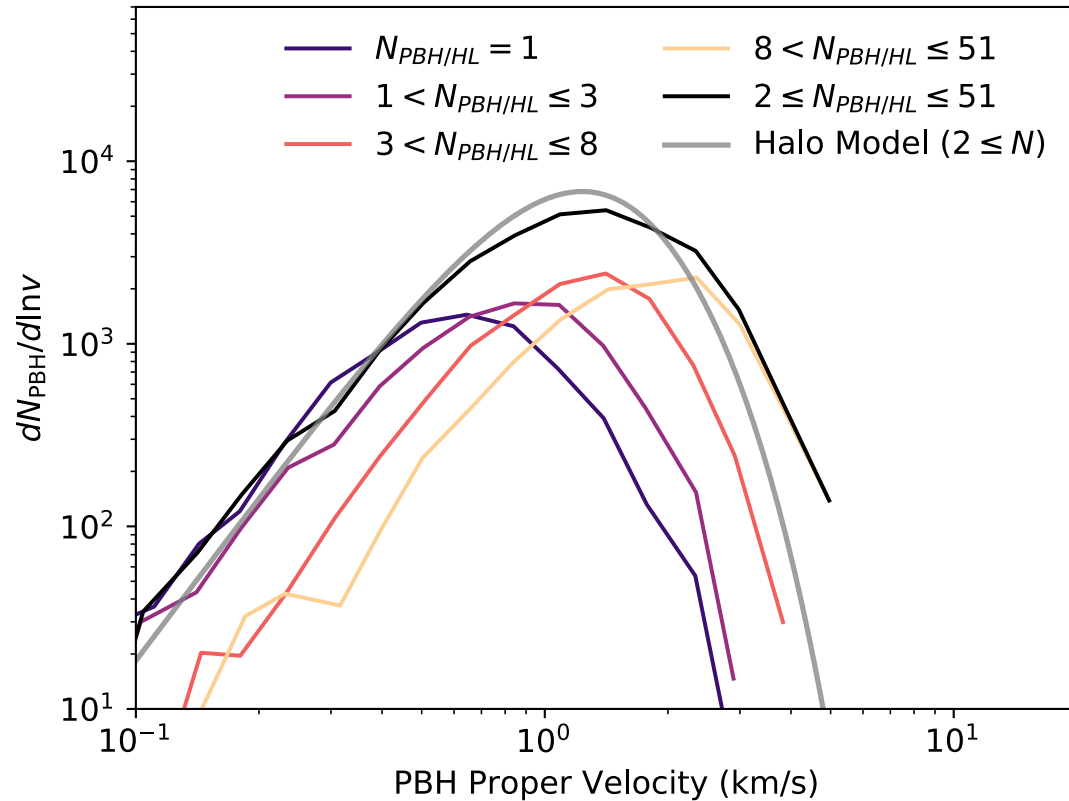
## CMB constraints:

- Gas accretion onto PBH depends on Bondi radius:

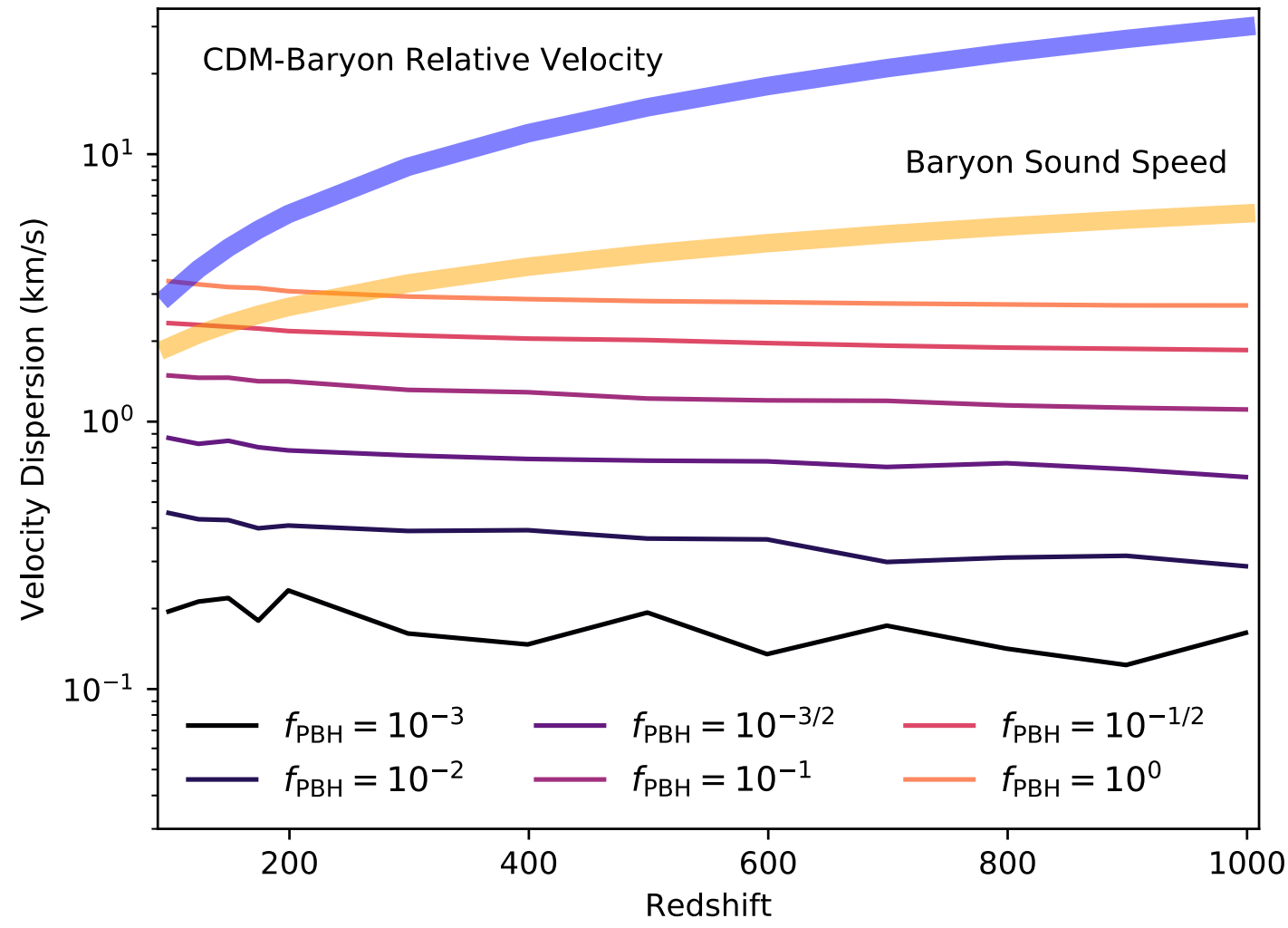
$$R_B = \frac{GM_{\text{PBH}}}{V^2}$$

- Relevant velocity scales (at  $z=1000$ ):

- Sound speed: 5km/s
- Relative Velocity Effect: 30 km/s
- Halo virial velocities: ?



# PBH Velocities



# PBH To-do list:

---

- Super Massive Black Hole seeds – can we improve CMB constraints by modelling PDM halo?
- Primordial PBH Binaries – are they disrupted by clustering?
- Star Formation – halos form early, do stars?
- Hydrodynamics – include gas for more precise simulations?

# Conclusions

---

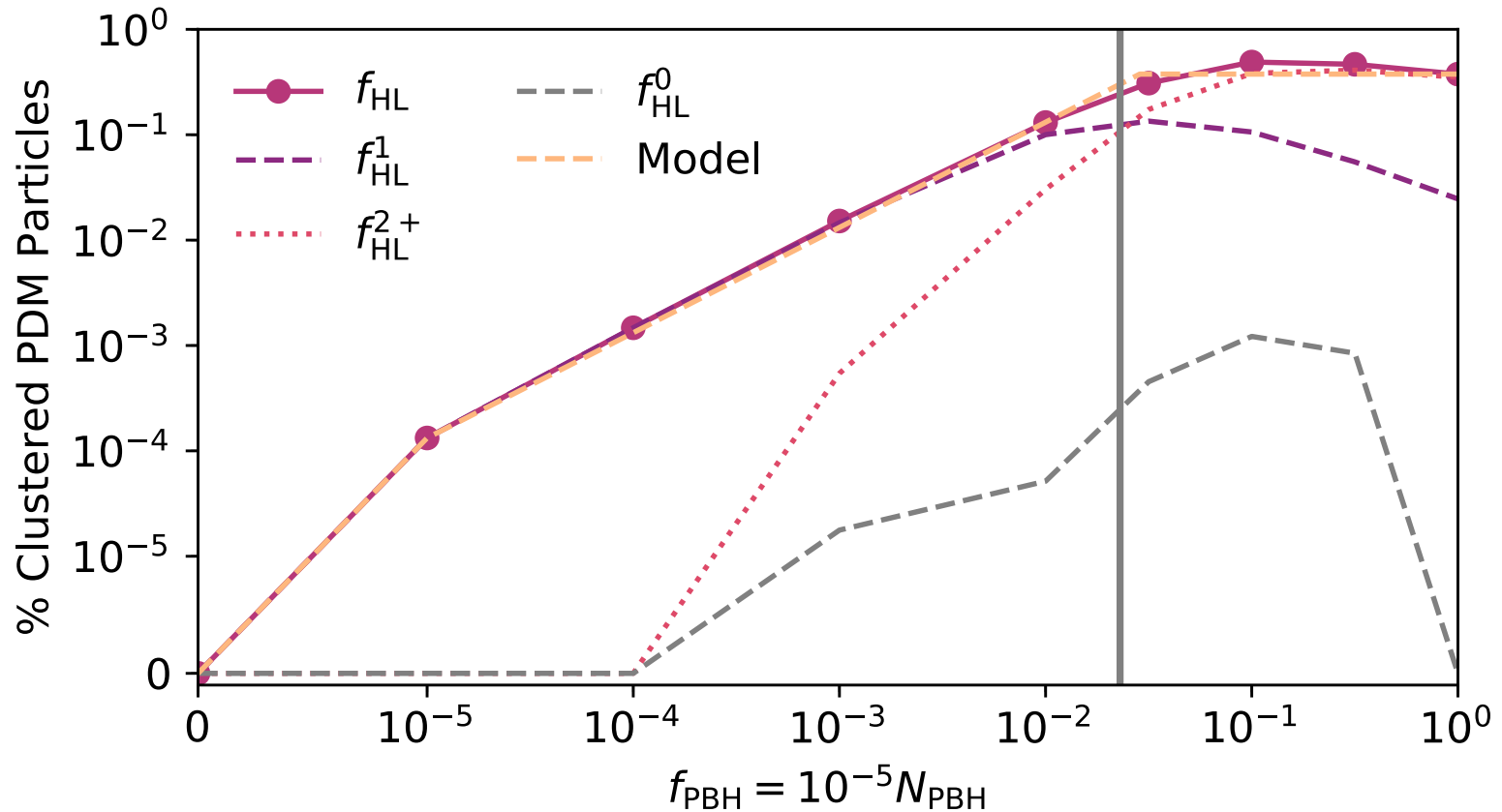
- Small scale dark matter perturbations can be nonlinear at very early times
- Used N-body simulations to study halo profiles, halo mass functions and typical velocity scales in mixtures of PBH and PDM
- More details in [arXiv:1907.08129](https://arxiv.org/abs/1907.08129)
- Many interesting problems still to study!

**THANK YOU FOR YOUR TIME!**

# Additional slides

---

# PDM Clustering



$$\text{Transition : } f_{\text{PBH}} \simeq 0.02 \frac{1+z}{100}$$

# Super Massive Black Hole Seeds

- PBHs around  $10^4$  solar masses with  $f_{PBH} \leq 10^{-9}$  could act as seeds for SMBH
- Modelled as Bondi accretion, but Bondi radius will be affected by the PDM halo:

$$\frac{1}{R} + \frac{\Phi_{\text{PDM}}}{GM_{\text{PBH}}} = \frac{1}{R_B}$$

In collaboration with Vivian Poulin, Pasquale Serpico

