Structure formation with primordial black holes

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MITP: The Phenomenology of Primordial Black Holes

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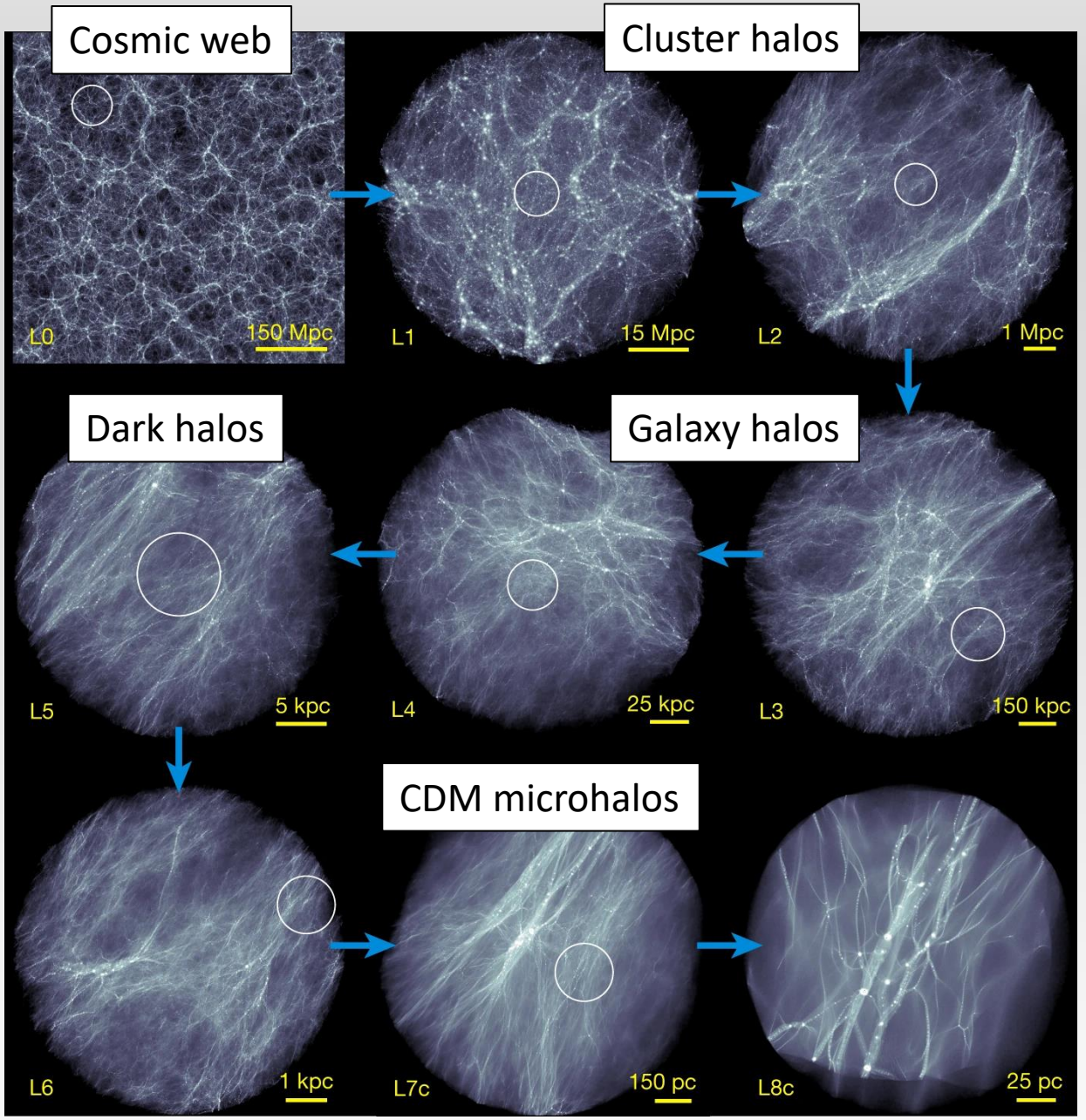
Structure formation with CDM

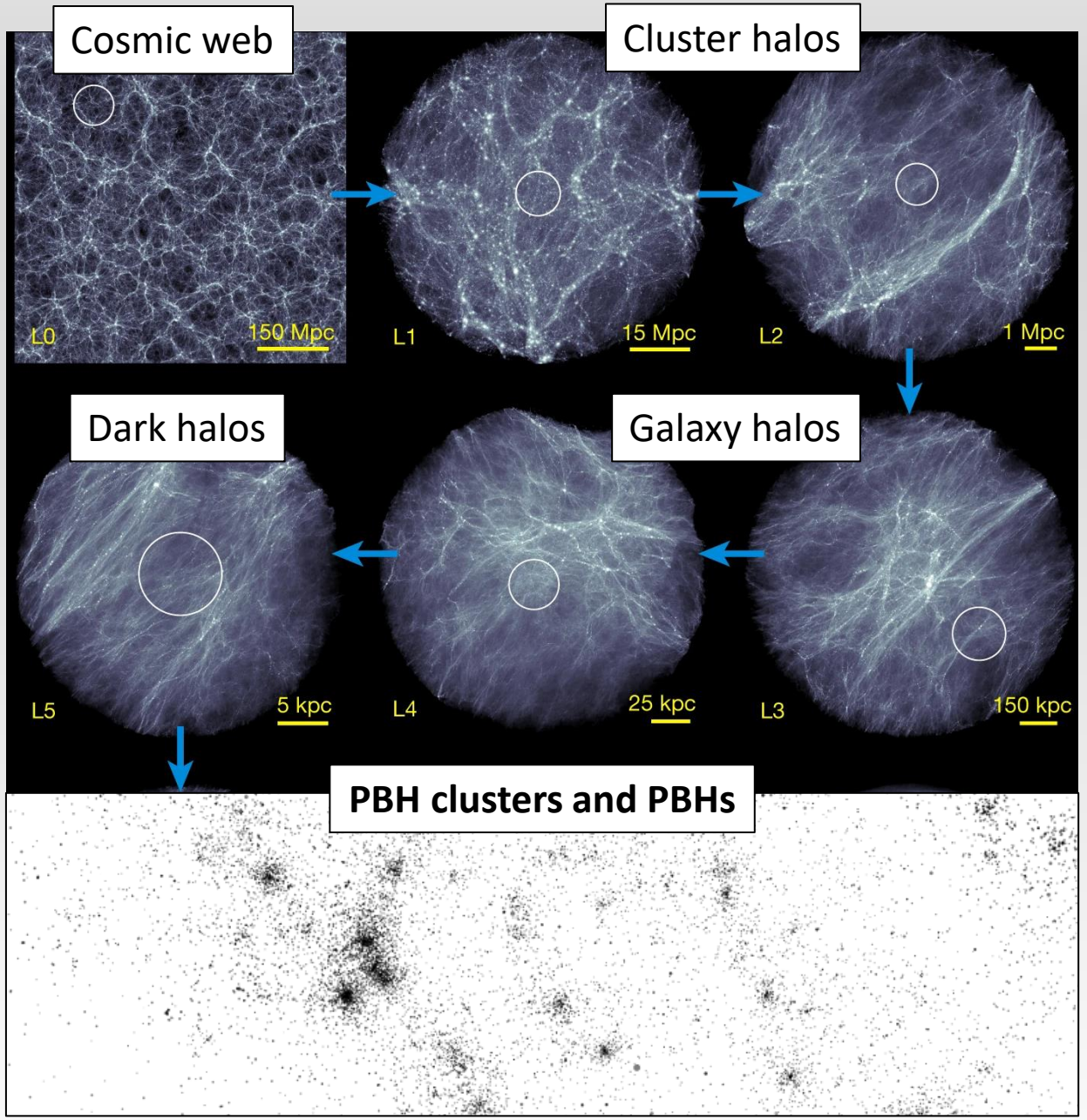
Hierarchy of cosmic structure:



Wang et al (2020)

Structure formation with PBH dark matter

Hierarchy of cosmic structure:

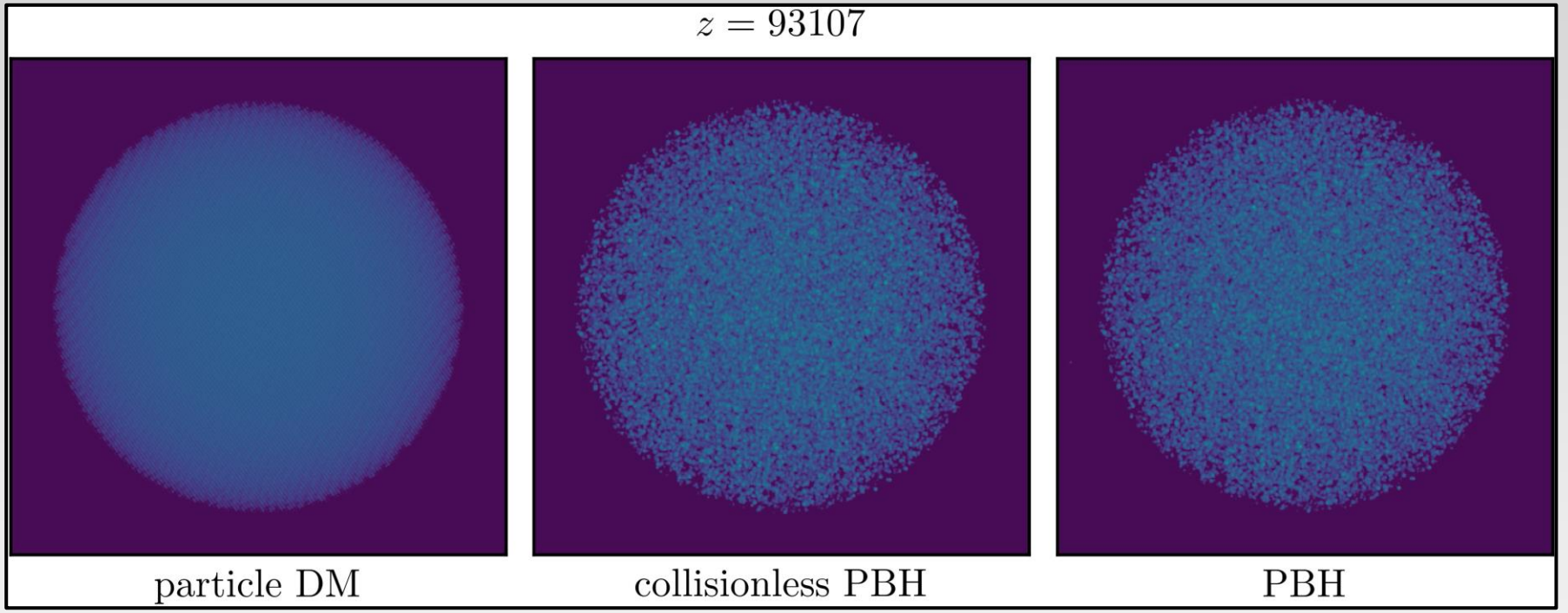


Wang et al (2020)

Simulating PBH dark matter

with Antti Rantala (Cambridge)
Sam Young (Pisa)
Fabian Schmidt (MPA)

Cosmological simulation with PBH DM that fully resolves collisional+relativistic dynamics



~ 40 kpc cosmological volume

MSD, Rantala, Young, Schmidt (2024)

Poisson noise due to independently distributed PBHs ($\sim 10\ M_\odot$)

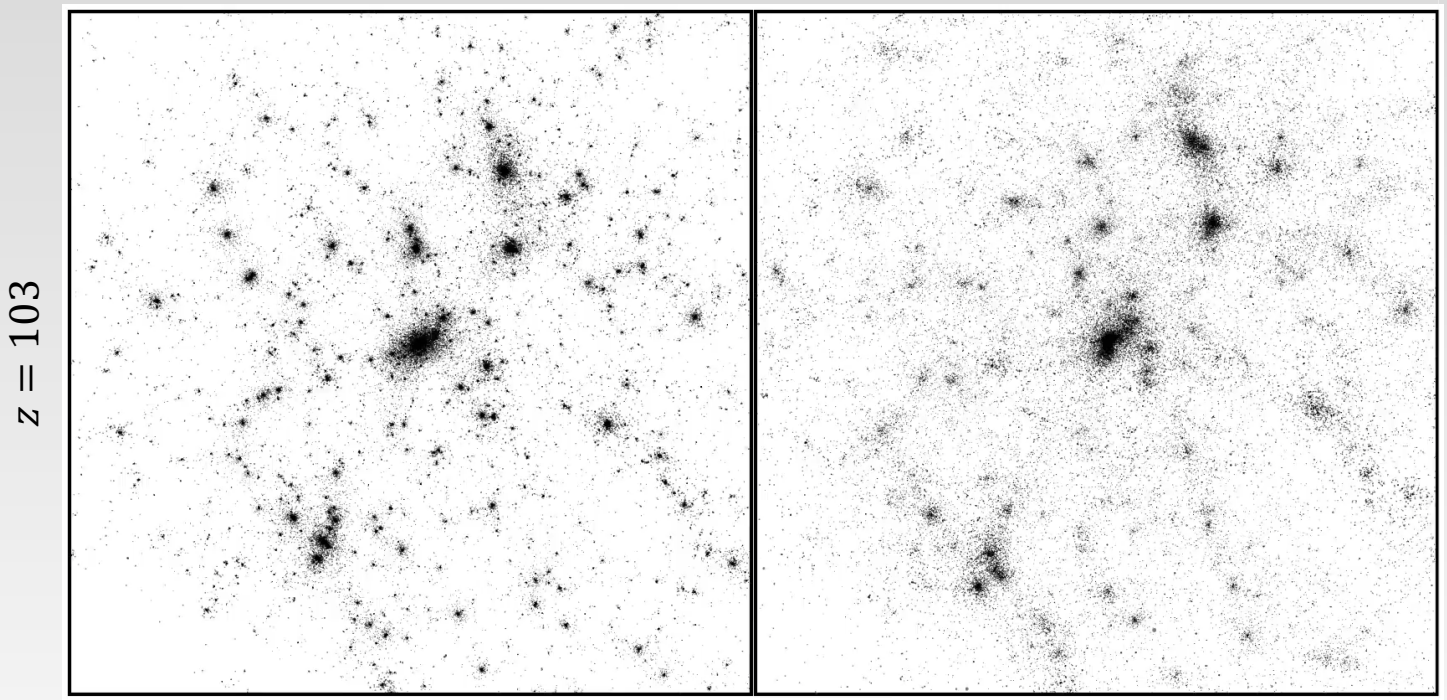
interparticle dynamics:

- large-angle scattering
- binaries
- relativistic gravity
- etc.

BIFROST simulation code (Rantala et al. 2023)

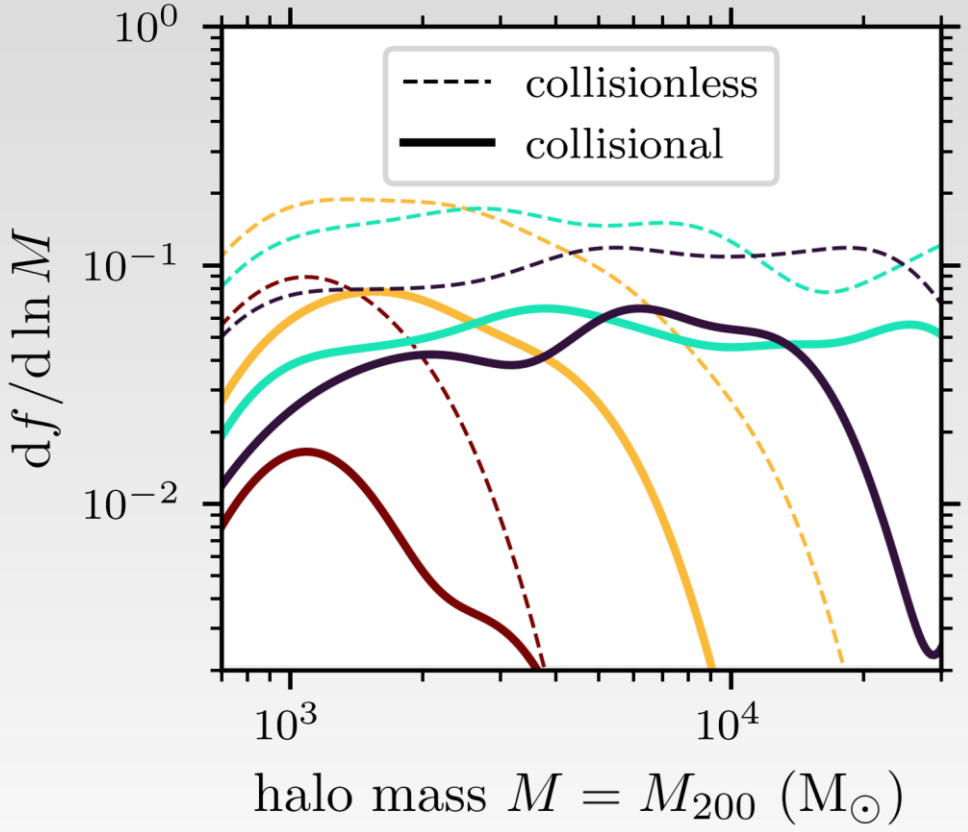
Abundance of PBH halos

Halos of $N \lesssim 1000$ PBHs are less abundant by a factor of about 2



Collisionless
(no short-range gravity)

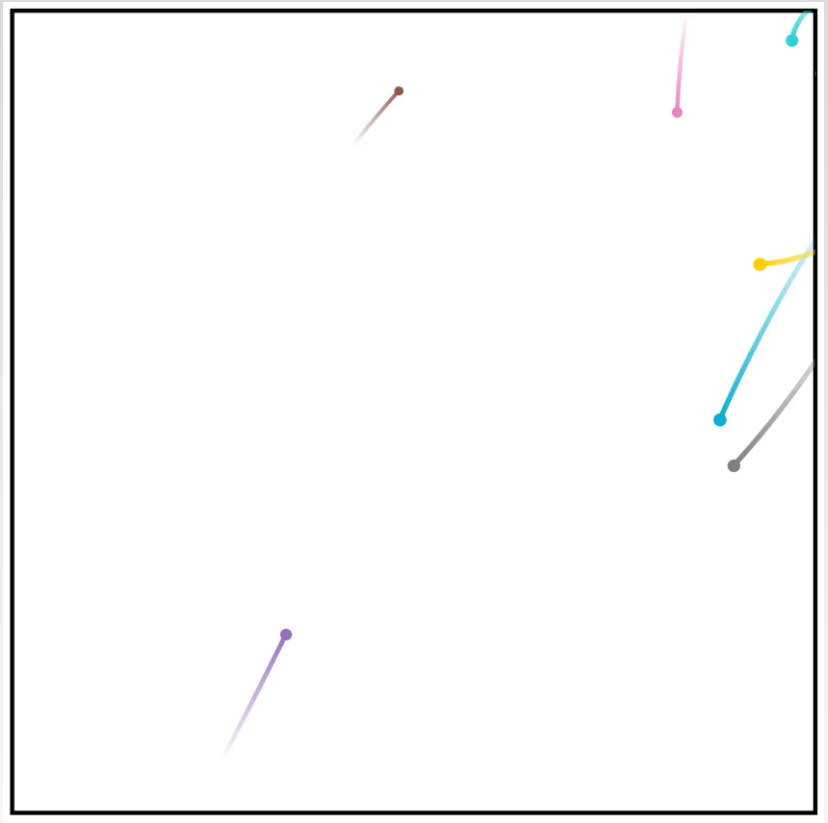
Collisional



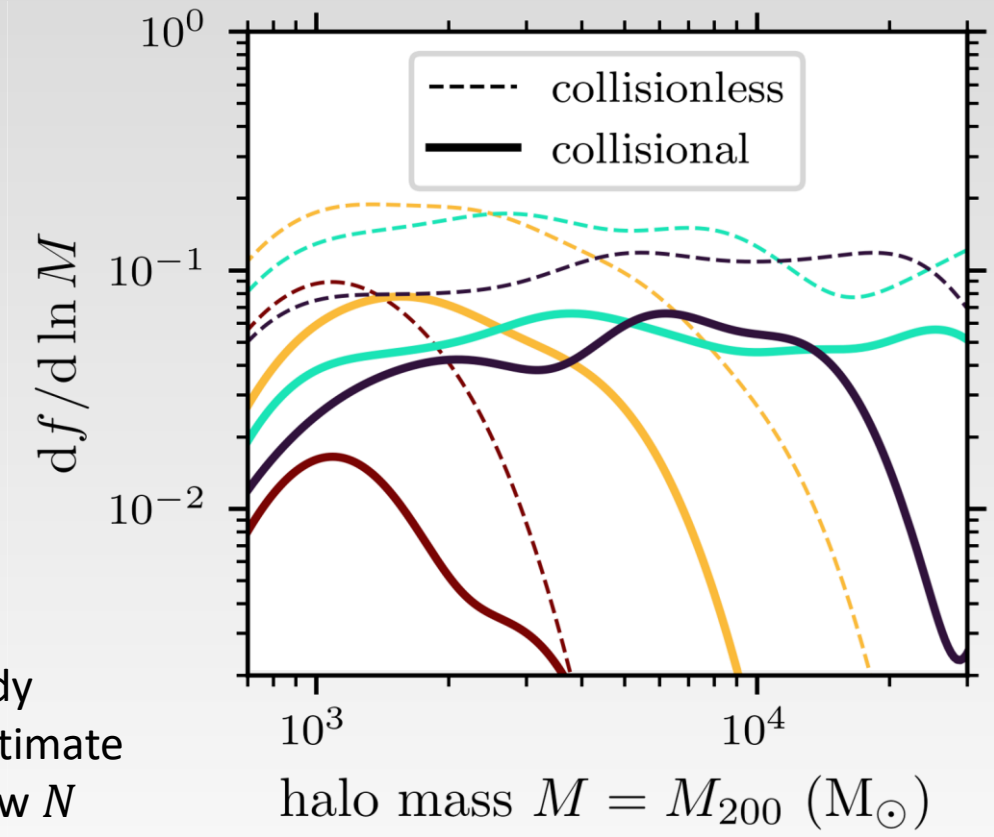
Abundance of PBH halos

Halos of $N \lesssim 1000$ PBHs are less abundant by a factor of about 2

Potentially due to collisional evaporation:

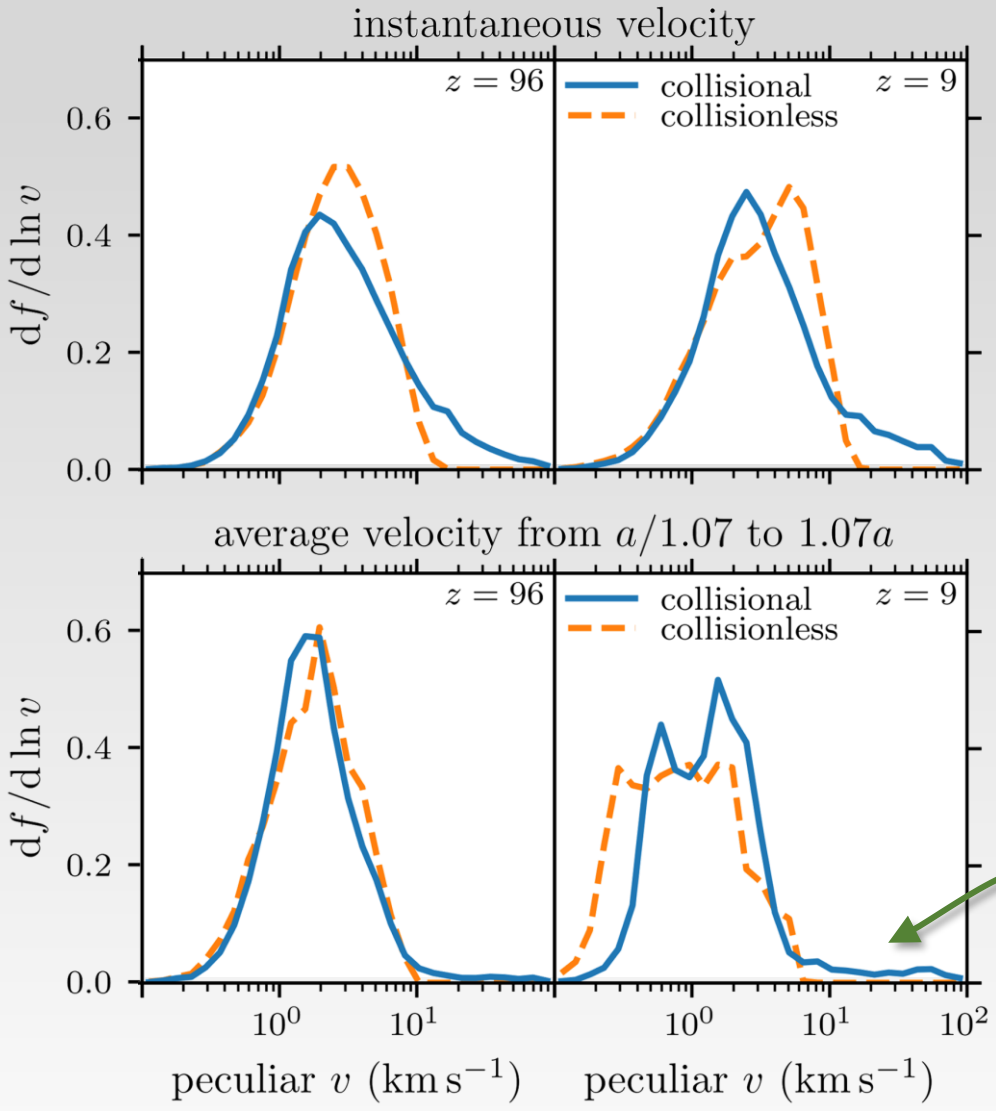


$z = 51$
$z = 147$
$z = 417$
$z = 1178$



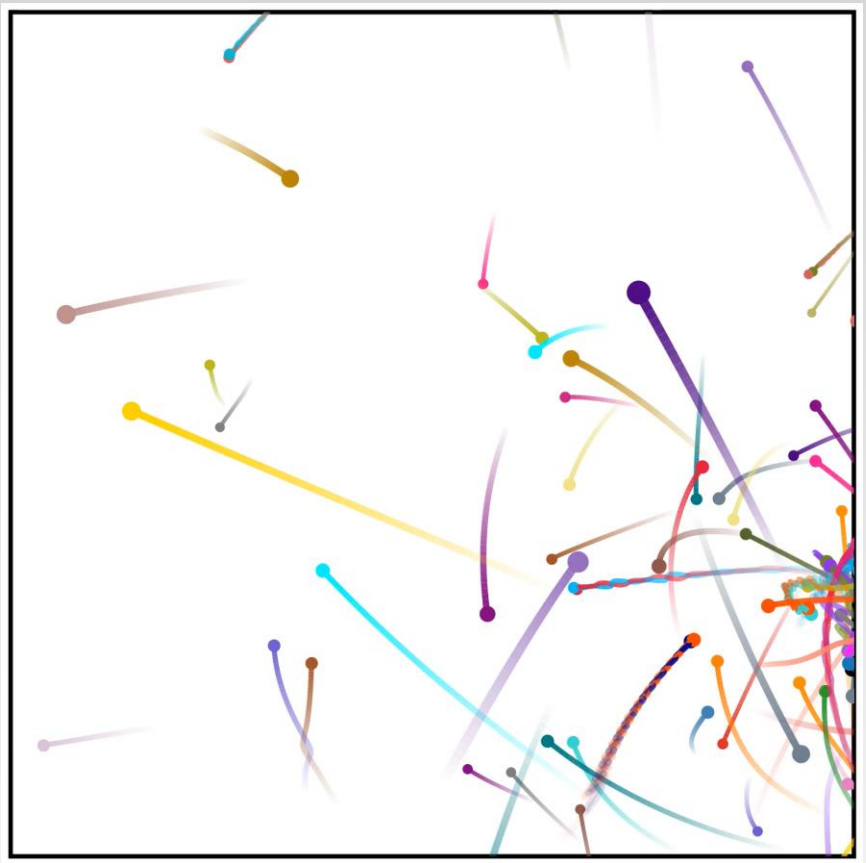
Standard 2-body arguments underestimate evaporation at low N

Collisional heating



Binary orbital motion contributes to velocity distribution

Through interactions, this can turn into streaming motion



Hot dark matter component, which would suppress structure growth up to billion-PBH scales

MSD, Rantala, Young, Schmidt (2024)

Binary mergers

Pairs of PBHs can merge, producing detectable gravitational radiation

Predictions for GWs from PBHs consider **merge times from relativistic orbital decay**

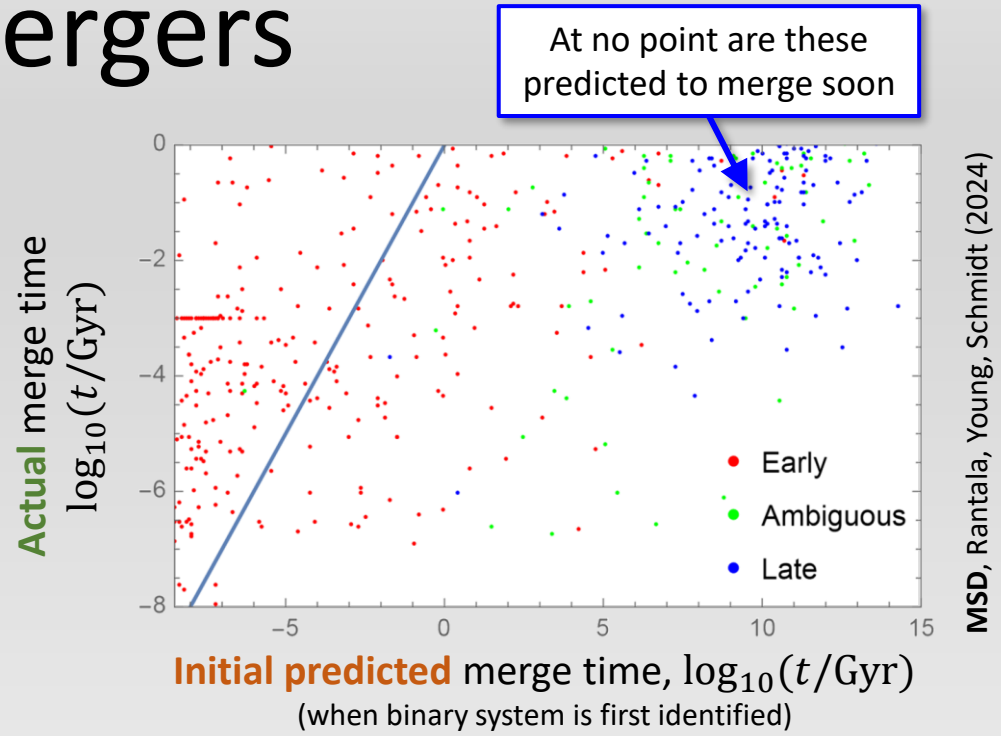
$$\tau = \frac{3}{85}\frac{c^5}{G^3}\frac{r_{\rm a}^4 j^7}{m_1 m_2 (m_1+m_2)}$$

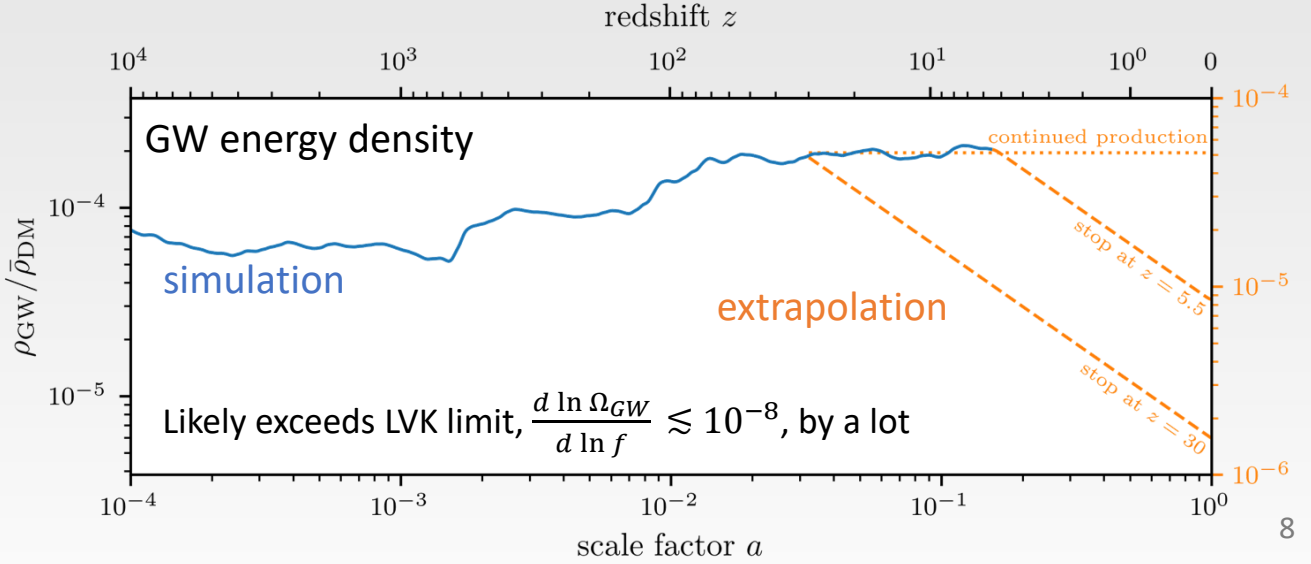
(for $j \to 0$ limit; j is normalized angular momentum)

In a cosmological simulation we find

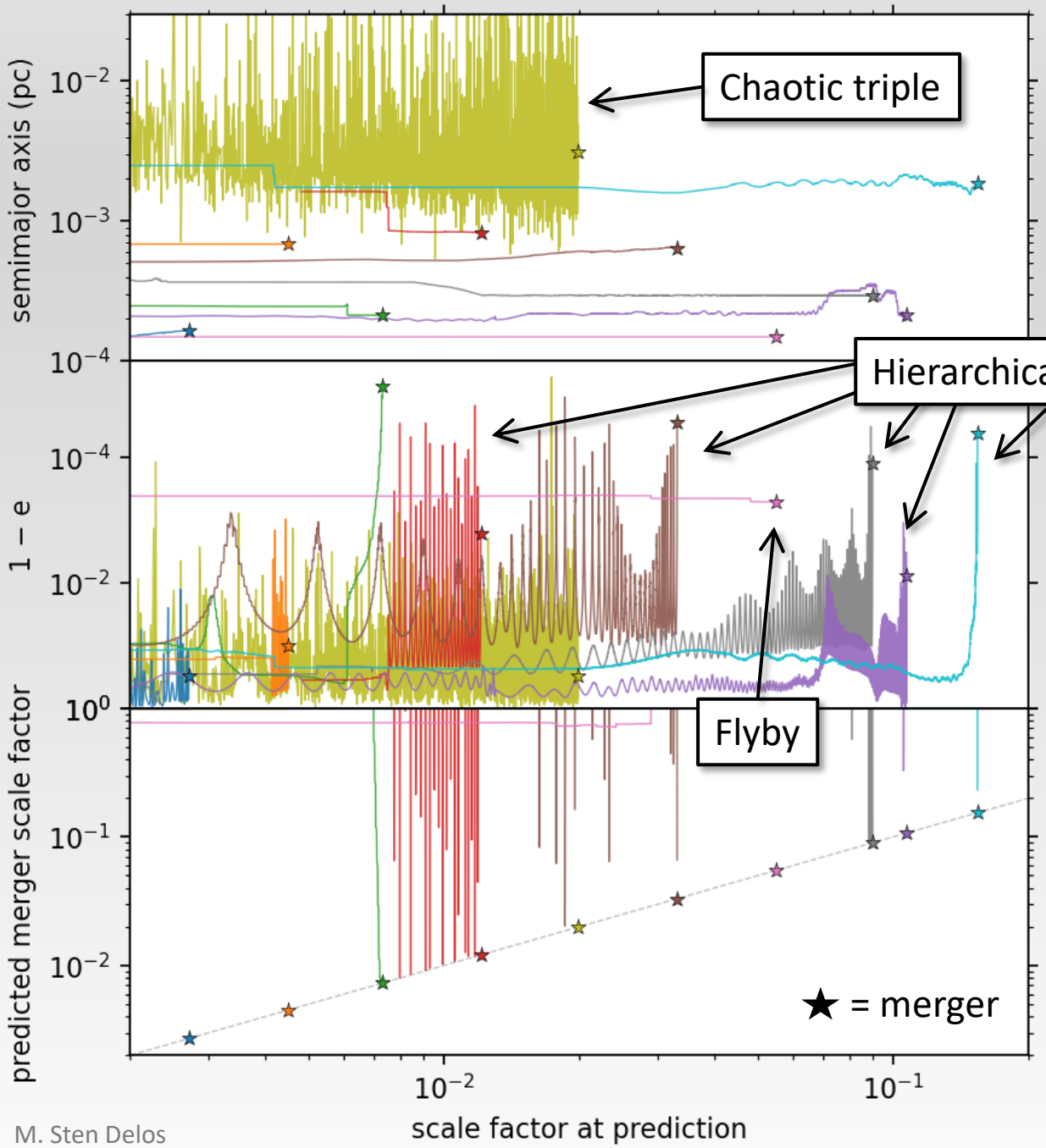
- no correlation between **initial prediction** and **actual** merge time
- certain populations not predicted to merge soon, but they do

Mergers are highly stochastic due to randomization of j in N-body interactions?
(already recognized by the star cluster community)

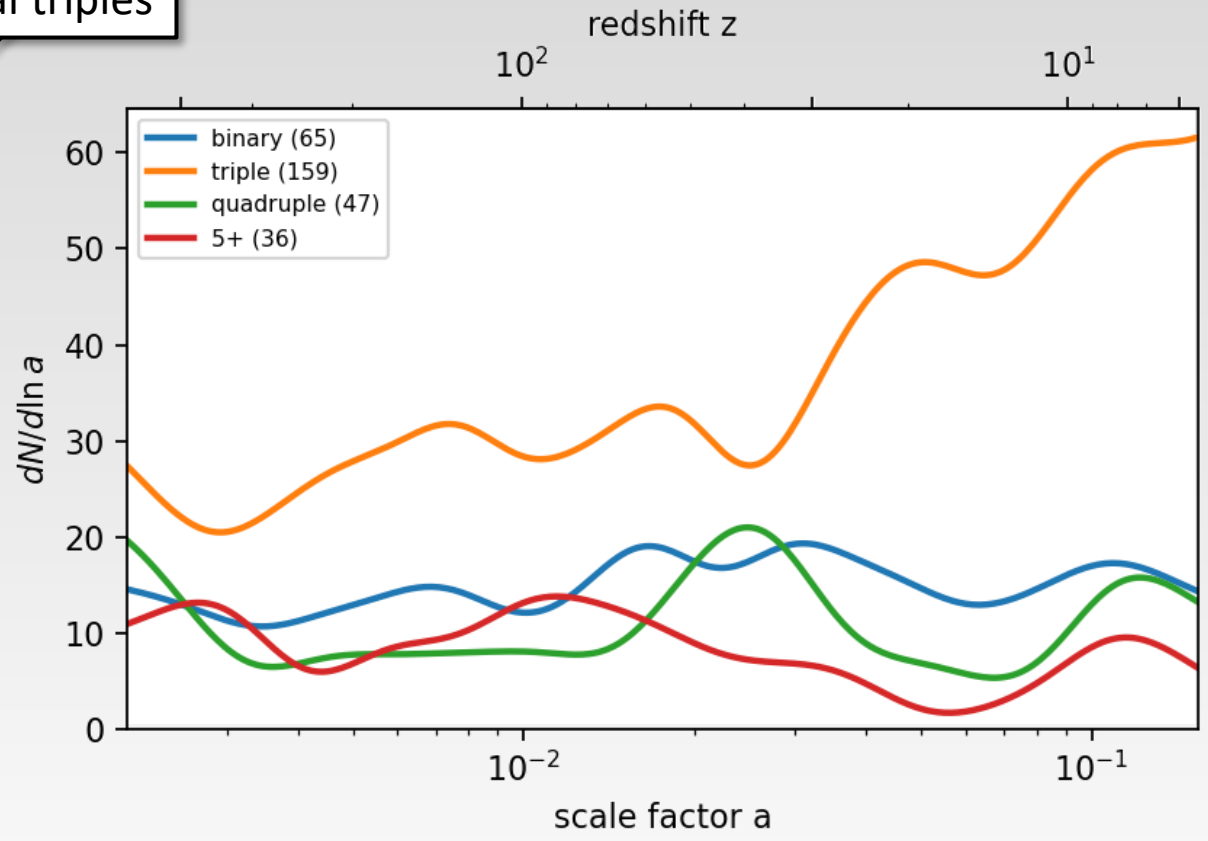


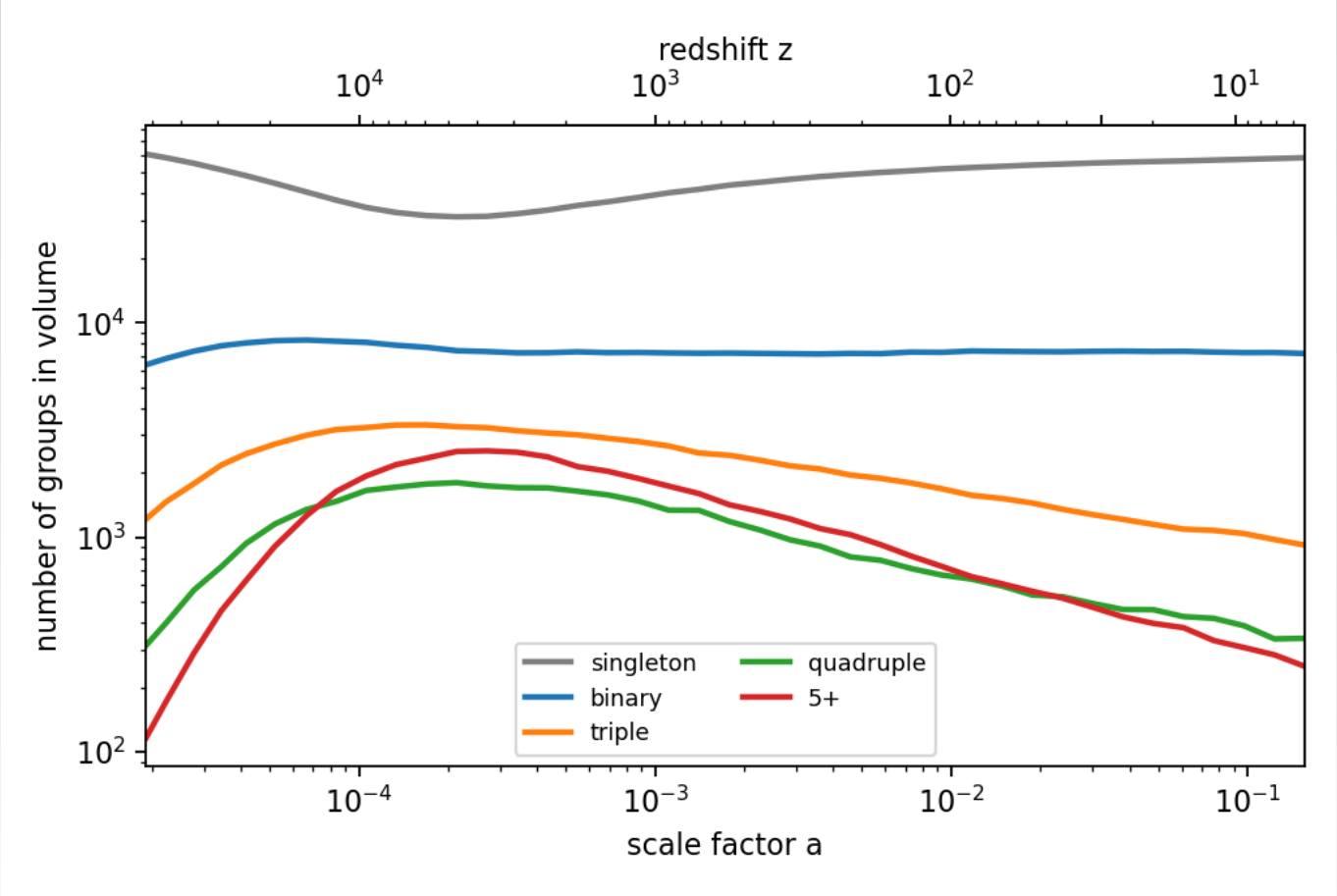


Binary orbit evolution



Bound triples dominate the merger rate




redshift z
10^4
10^3
10^2
10^1
number of groups in volume
10^4
10^3
10^2
singleton
binary
triple
quadruple
5+
10^{-4}
10^{-3}
10^{-2}
10^{-1}
scale factor a