Exercises 7

1. DM halo mass function:

- Download the .list files containing data of a halo catalogue at z=0 (out_94), 1 (out_27), and 2 (out_44) from a DM-only simulation (size: $(72\text{Mpc}/h)^3$, Planck cosmology, etc see header) in the following format:

  ID, DescID, **Mvir**, Vmax, Vrms, Rvir, Rs, Np… more columns

  Note: Mvir is in $M_\odot/h$

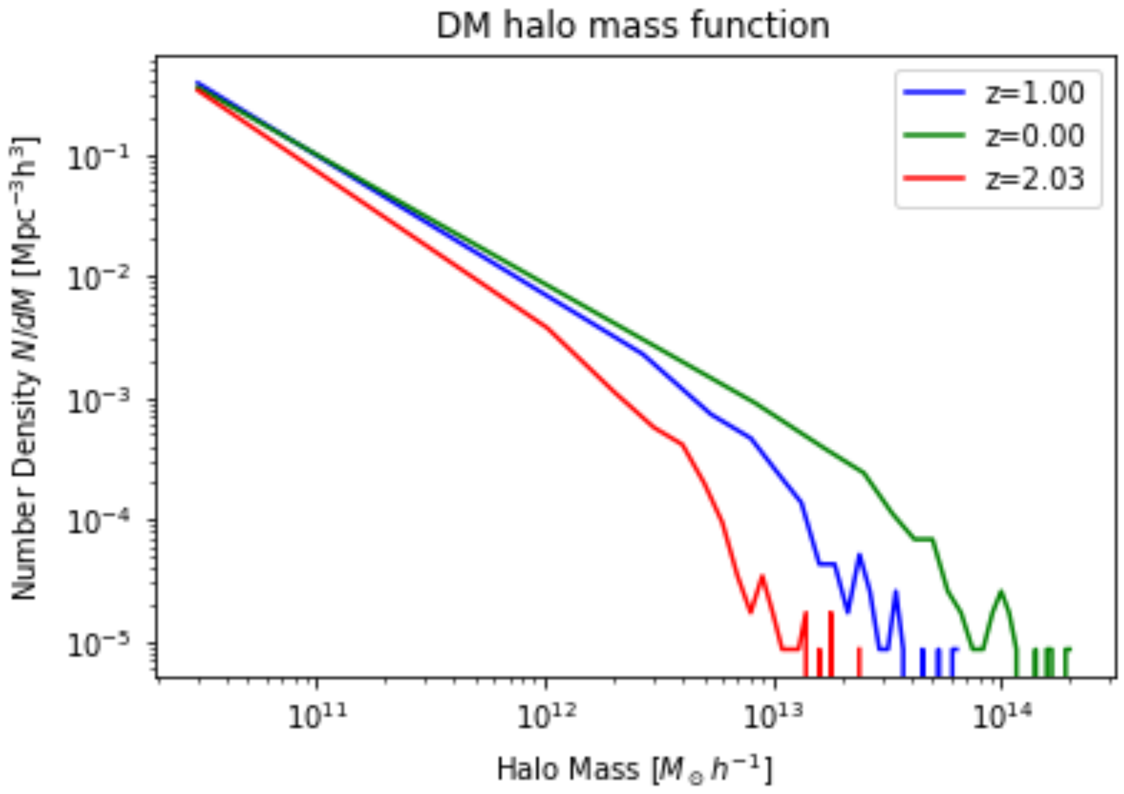
- Choose your preferred language (python, matlab etc) for data analysis and visualisation (of ascii files)
  1. Select halos with masses > $3*10^{10}$ $M_\odot/h$ at z=0,1,2 (why is this important?)
  2. Plot their *halo mass function*: number density, i.e. amount of halos per unit volume, Mpc^3, versus halo mass at z=0,1,2
  3. How do you think the halo mass fct would qualitatively change when adopting a warm dark matter cosmology? Explain your thought.

Exercises 7

Data analysis: DM halo mass function

1. It is important to select halos with masses > $3*10^{10}$ $M_\odot$/h to ensure that we only include properly resolved halos.

2.



3. Predictions based on warm dark matter are similar to those for cold dark matter on large scales, but with less small-scale density perturbations. This reduces the predicted abundance of dwarf galaxies and may lead to lower density of dark matter in the central parts of large galaxies. Thus, for the halo mass function, we would expect lowered number densities at the lower halo mass end.

Exercises 7

2. The build-up of galactic dark matter halos in a CDM universe:

Using merger tress for different halo masses in Selected_trees_*.dat, examine the DM halo mass assembly and answer these questions.

1. How do the mass assembly histories differ for 3 different z=0 halo masses (1e10, 1e12, 5e13 $M_\odot$) in a CDM universe?

BONUS: 2. How many major (1:1-1:4) and minor mergers (1:4-1:10) do occur at what cosmic time?

BONUS: 3. How different are assembly and formation times (see lecture) and how do they vary with halo mass? Can you give an explanation for your results?

Coding instructions:

- For each halo tree, follow the *main branch tree* until the highest redshift (look at the progenitors of a halo one time step earlier via "desc_id=id_halo" and choose the most massive one)
- Plot halo main progenitor mass versus redshift and/or scale factor for the different halo masses, indicate as vertical lines when major merger happens
- Plot formation/assembly times versus halo mass

Note: if you are wondering how such plots look like, Maulbetsch+07 may help…

Exercises 7

Details for the dark matter-only simulation

- WMAP7 cosmology adopted
- Boxsize: ~72 Mpc/h
- DM particle mass: 3.5e8 $M_\odot$
- Merger trees constructed by post-processing the simulation with the open-source code "Rockstar"

Exercises 7

An example output file for Rockstar trees

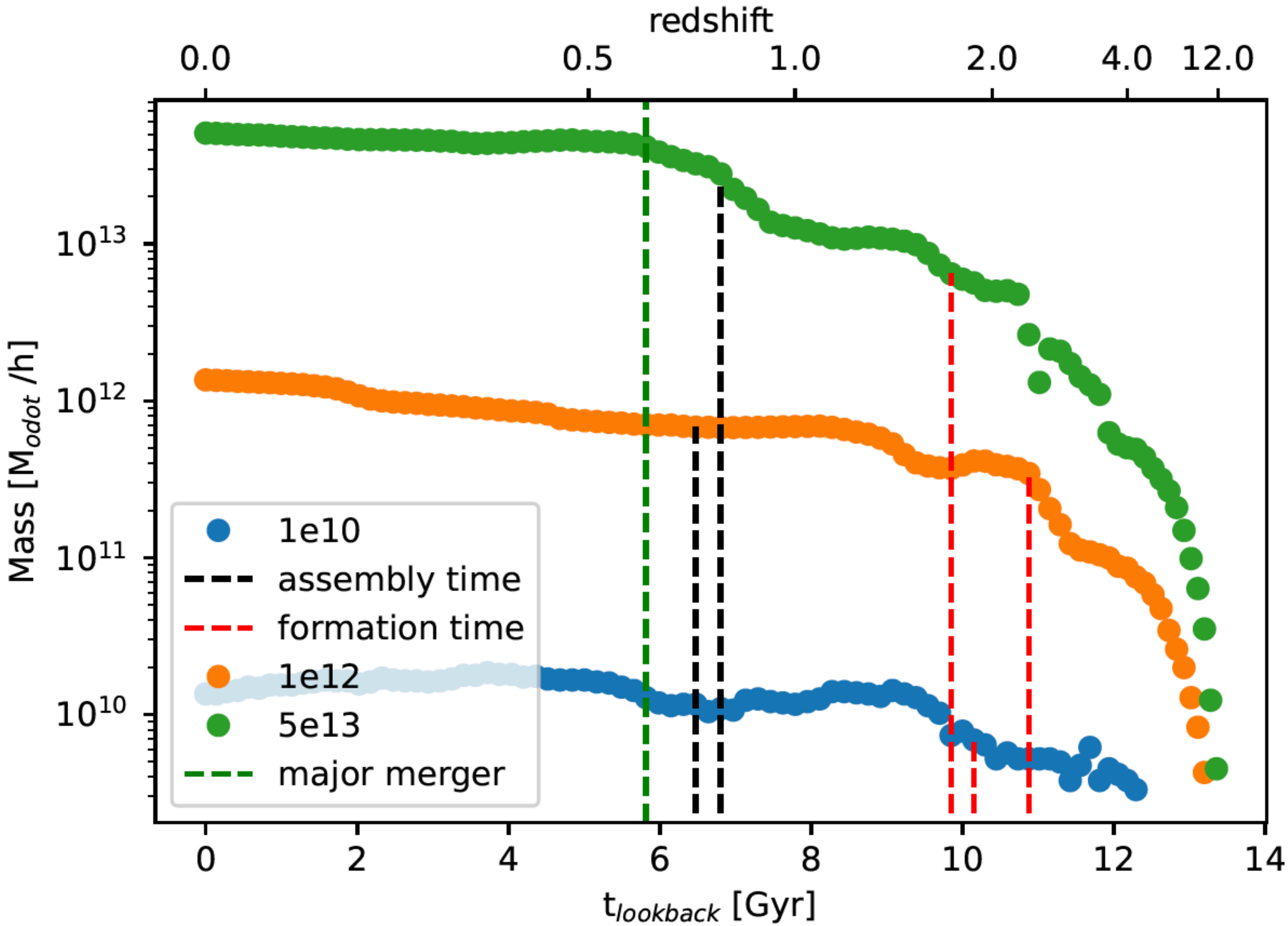
Each row is one halo, columns are:

Scale factor of halo(0) halo ID(1) scale factor of descendent(2) halo ID of descendent (3) number of progenitors (4) viral mass(5)

(simplified compared to original Rockstar output)

1.0000	29882328	0.0000	-1	5	
0.9900	29584929	1.0000	29882328	4	Most massive prog.
0.9900	29584930	1.0000	29882328	1	
0.9900	29584932	1.0000	29882328	1	
0.9900	29584934	1.0000	29882328	1	
0.9900	29584935	1.0000	29882328	1	
0.9800	29281236	0.9900	29584929	4	Most massive prog.
0.9800	29281238	0.9900	29584929	1	
0.9800	29281239	0.9900	29584929	1	
0.9800	29281241	0.9900	29584929	1	
0.9800	29281243	0.9900	29584930	1	

Exercises 7



redshift
0.0
0.5
1.0
2.0
4.0
12.0
Mass [M$_{odot}$ /h]
10^{13}
10^{12}
10^{11}
10^{10}
1e10
assembly time
formation time
1e12
5e13
major merger
0
2
4
6
8
10
12
14
t$_{lookback}$ [Gyr]

Exercises 7

	scale factor	redshift
5e13, formation time	0.3	1.7
5e13, assembly time	0.56	0.79

(3 minor mergers at 0.25, 0.15 and 0.1 (z=3.17, 5.67, 9);
1 major merger at 0.62 (z=0.61))

	scale factor	redshift
1e12, formation time	0.3	2.33
1e12, assembly time	0.58	0.72

(2 minor mergers at 0.36 and 0.16, z=1.8, 5.25)

	scale factor	redshift
1e10, formation time	0.35	1.86
1e10, assembly time	0.35	1.86

(No minor and major mergers)

Main Conclusions:

The larger the halo mass, the later the halo has assembled half of its final mass, a consequence of a CDM-dominated Universe

Formation times are small due to hierarchical clustering

Difference between formation and assembly time is larger for more massive objects

Exercises 7

Detailed conclusions: The 1e10Msun halo does not experience any minor or major mergers and thus has only one main branch. As a result, the assembly and formation time are identical. This halo has assembled its mass due to accretion of DM particles. Fluctuations occur due to tidal stripping and dynamic interactions. For the other two halos half of the mass is already present long in the progenitors long before they merge into the main branch halo.

The difference in assembly and formation time and presence of mergers lets us conclude that both of these massive halos are the end result of hierarchical clustering, starting with a system of smaller, gravitationally bound halos that grow by accreting DM particles just like the 1e10Msun halo and have merged together at some point.

Additionally, minor mergers have been identified relatively early in time, at the beginning of the halos evolution, whereas the major merger of the most massive halo happens about 3.3 Gyr after its last minor merger. We can interpret this as follows: more massive objects are less affected by the gravity of a companion than less massive ones and, as a result, take longer to merge.