First look at cosmoDC2 catalog

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in collaboration with Vincent for the theoretical interpretation and for python help

Thanks to Thibault for providing a python macro example !

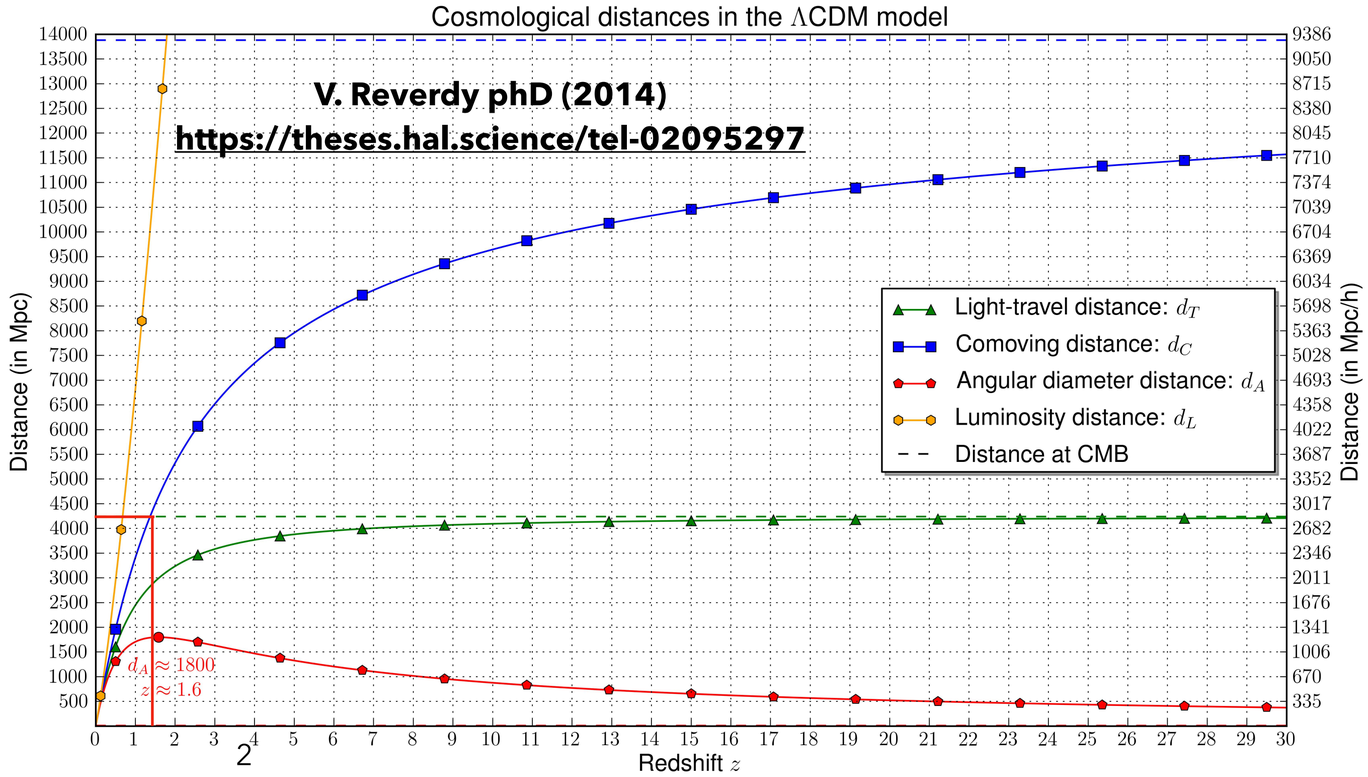
LSST group meeting - January 9th 2024

CosmoDC2 catalog

- « The catalog is based on a trillion-particle, (4.225 Gpc)^3 box cosmological N-body simulation. It covers 440 deg^2 of sky area to a redshift of $z = 3$ » (https://arxiv.org/pdf/1907.06530.pdf)

The extremely large volume that will be probed by LSST poses a challenge when solving for an observer's past light-cone. In particular, the DC2 catalog effort needs to model galaxies out to redshift $z \lesssim 3$, where the comoving distance is in excess of 6 Gpc, while Outer Rim extends only to 4.225 Gpc in each dimension. Our strategy, then, is to build a lattice of replicated simulation volumes which is large enough to host the cosmoDC2 lightcone. To prevent duplicate structures from being projected atop of one another, we follow the approach of previous sky simulations (Blaizot et al. 2005; Kitzbichler & White 2007; Bernyk et al. 2016), and choose to randomly rotate each box replication.

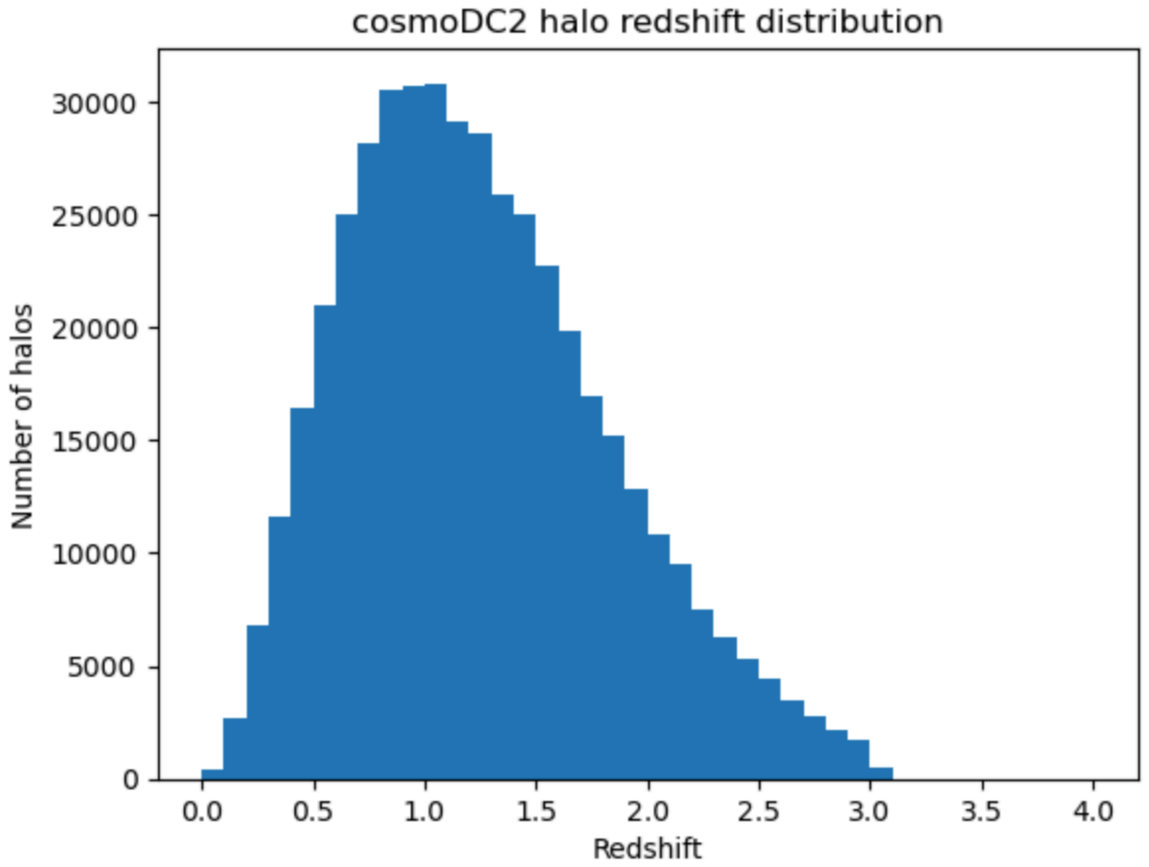
While this strategy does decorrelate particle pairs at each box edge, we only need to replicate the Outer Rim volume once per axis at a depth of $z \approx 1.3$, so the impact of this decorrelation is relatively minimal. Though, in principle, this effect is present in the results shown in Figure 2, we find it to be negligible in practice. We refer the reader to Blaizot et al. (2005) for an in-depth study of these and other considerations related to generating lightcones from cosmological simulations.



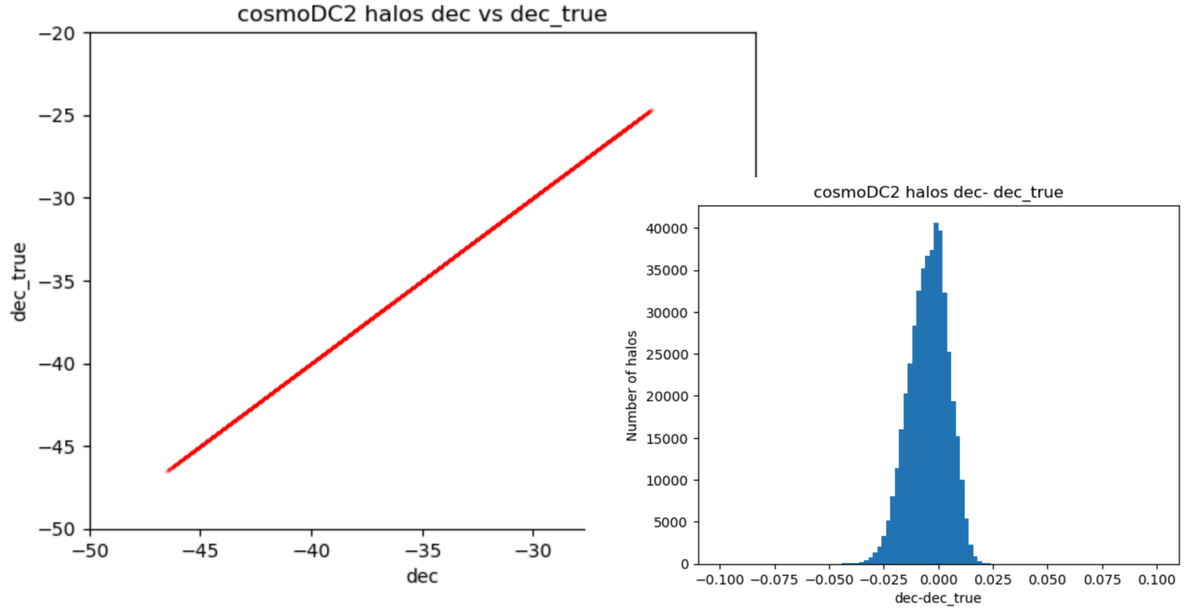
CosmoDC2 catalog

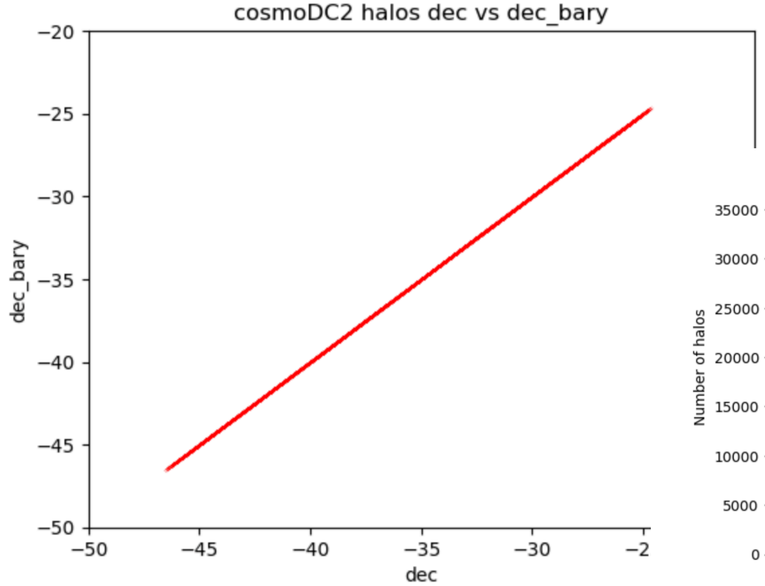
- For this study, take all halos from catalogue, no restrictions
- Catalog available at: /sps/lsst/groups/clusters/dc2/cosmoDC2_v1.1.4/extragal/halos/halos_m200c_13.0.fits
- List of variables in cosmoDC2 for halos: ['halo_id', 'ra_true', 'dec_true', 'ra', 'dec', 'redshift_true', 'mass_fof', 'm200c', 'r200c', 'skysim_halo_id', 'NMEM', 'richness', 'NMEM_g_star2', 'NMEM_r_star2', 'NMEM_i_star2', 'NMEM_z_star2', 'NMEM_y_star2', 'richness_g_star2', 'richness_r_star2', 'richness_i_star2', 'richness_z_star2', 'richness_y_star2', 'ra_bary', 'dec_bary']
- *For halos members: ['galaxyID', 'halo_id', 'halo_mass', 'is_central', 'ra_true', 'dec_true', 'ra', 'dec', 'mag_true_u', 'mag_true_r', 'mag_true_g', 'mag_true_i', 'mag_true_z', 'mag_true_y', 'redshift_true']* ***-> next time***
- **For today, just a first look at all variables to see if their trend and correlations make sense to me**

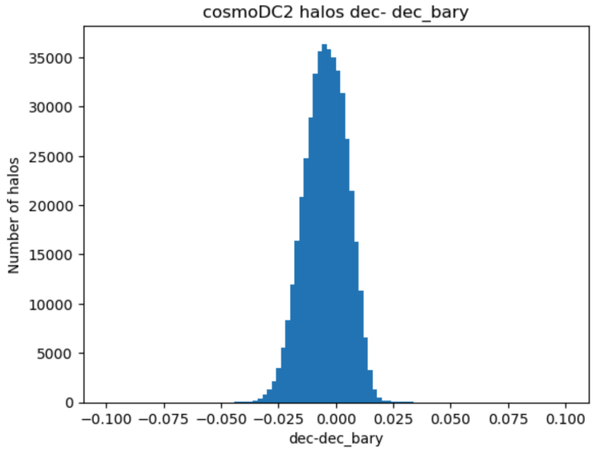
Redshift Distribution

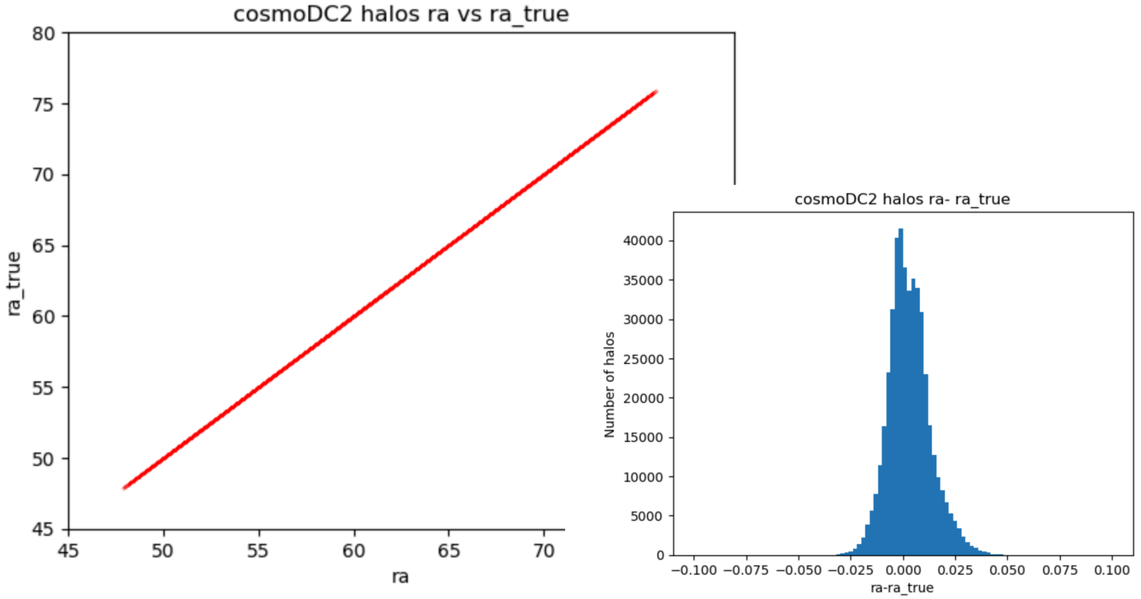


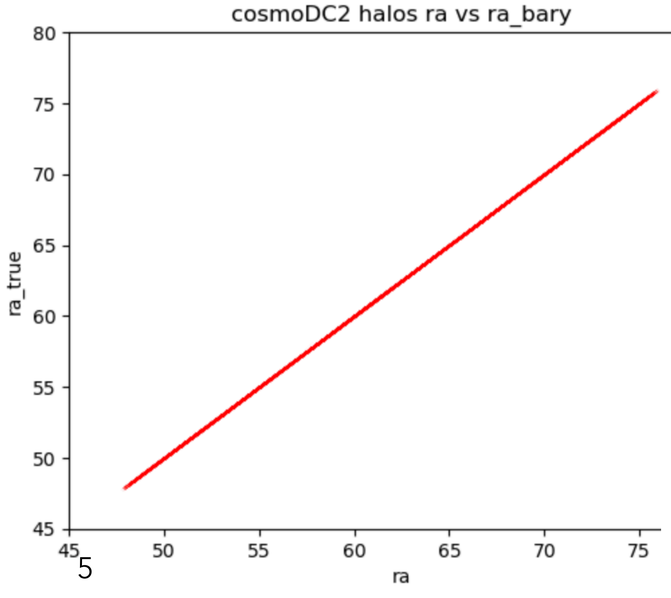
Understanding coordinates

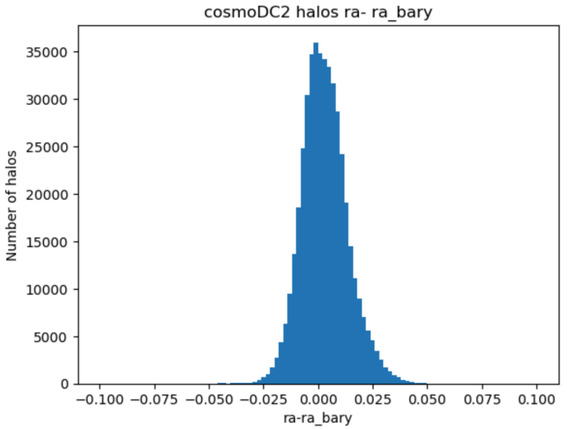






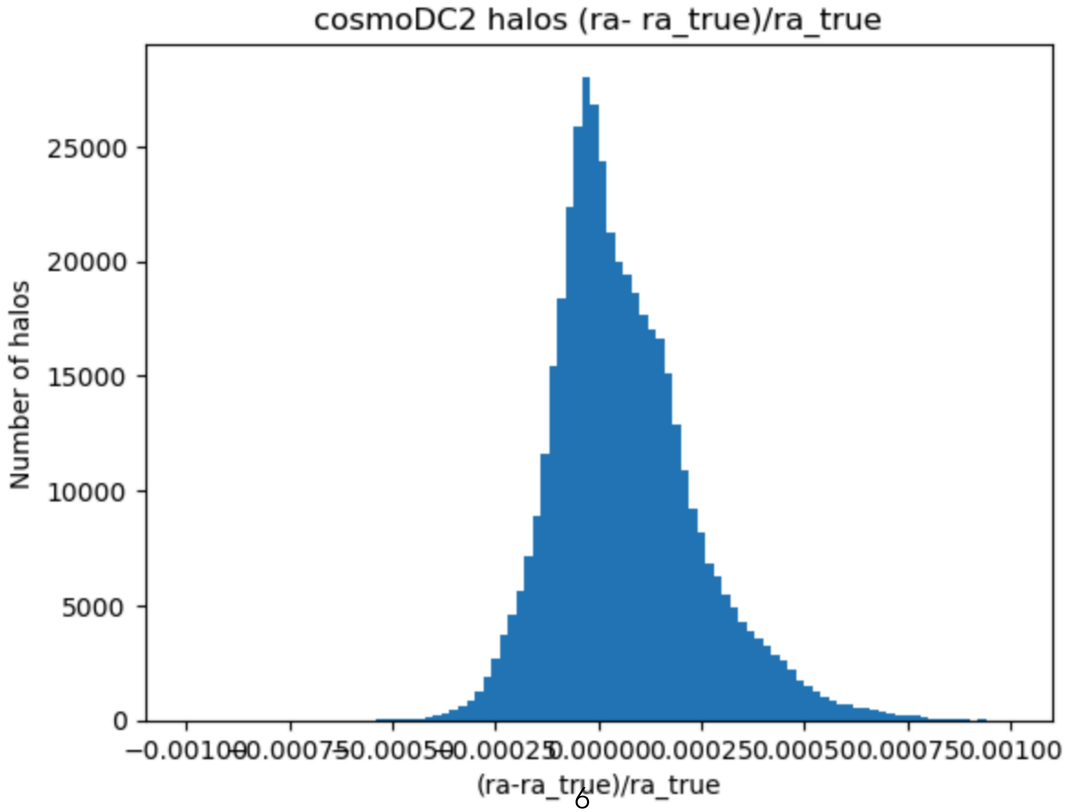






Understanding coordinates differences

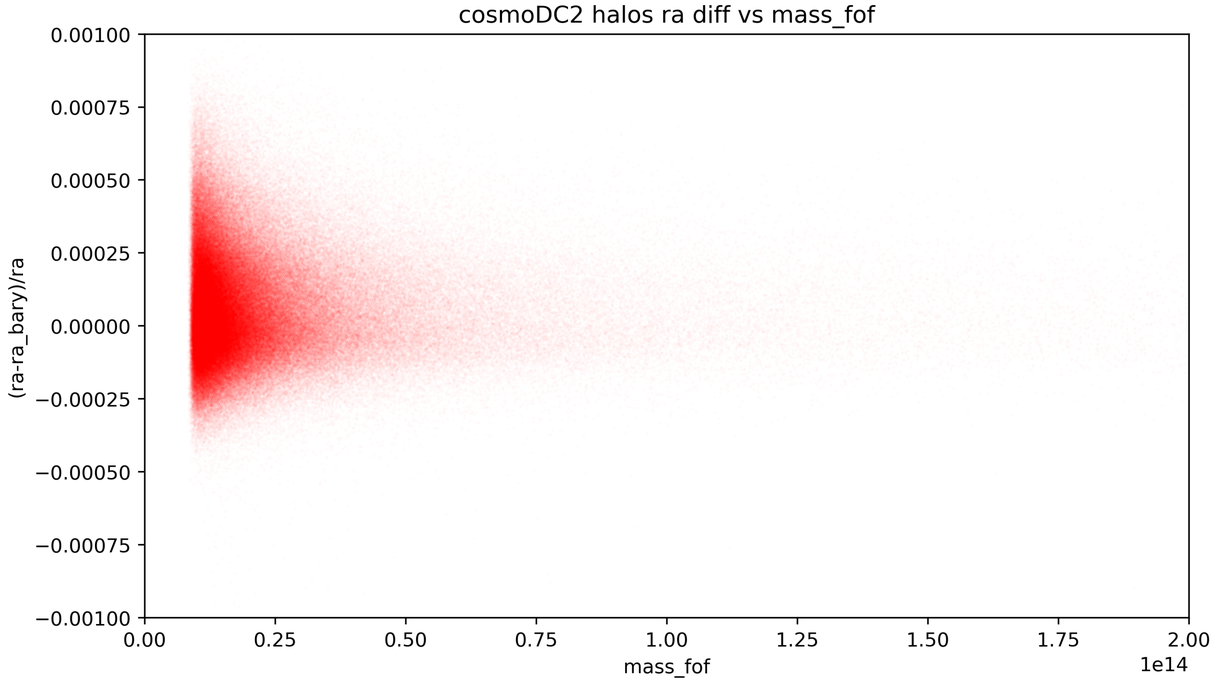
- Typically Per-mil difference between dec and dec_true or dec_bary (and same for rad)

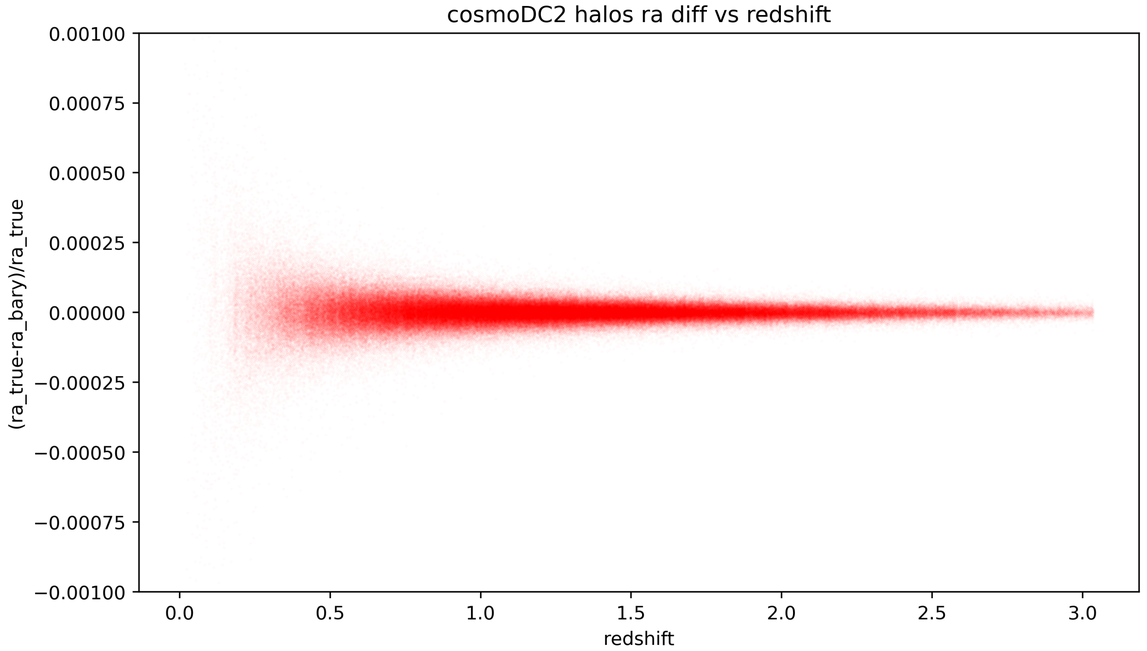


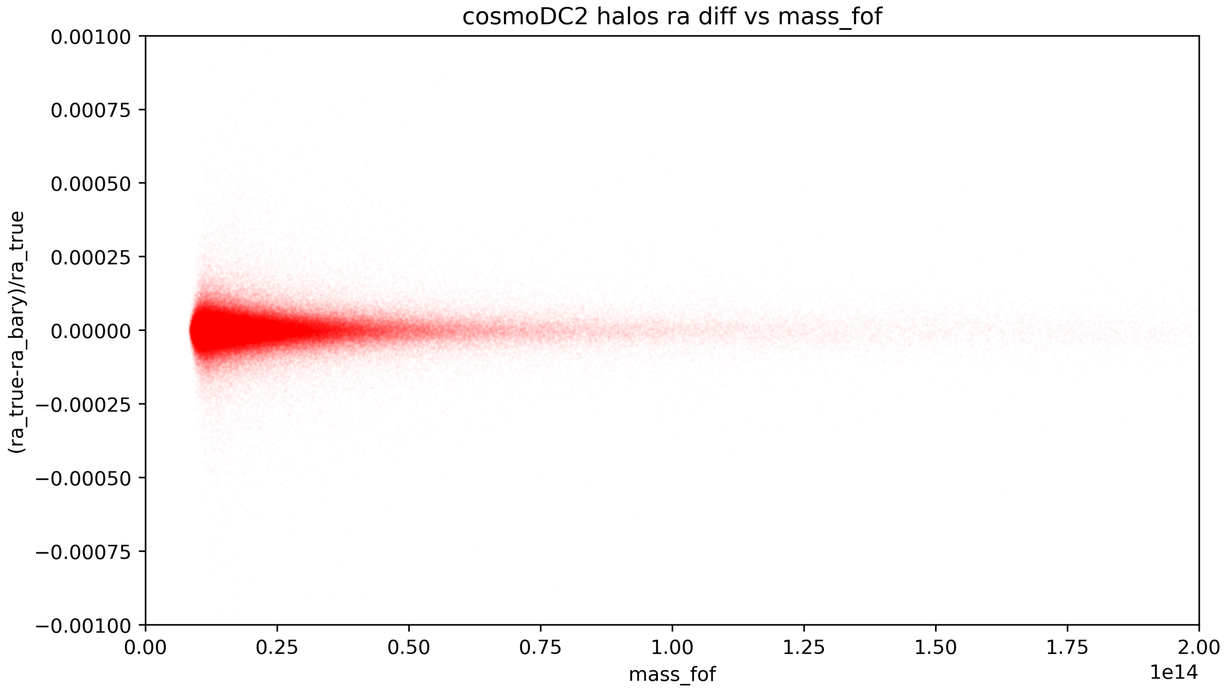
A nice way to visualise rad/dec
http://astro.unl.edu/classaction/animations/coordsmotion/radecdemo.html

ra_bary

- Difference between ra_bary and ra is smaller for larges masses ?
- Less difference between ra_bary and ra_true
- Difference smaller for higher redshifts -> cluster more spherical for higher redshifts ?



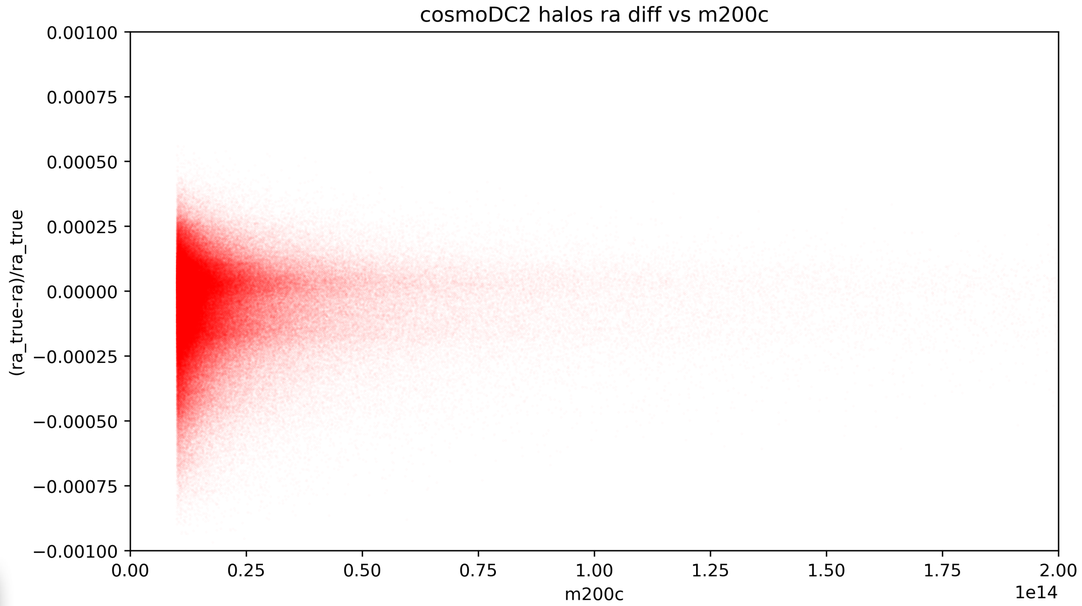


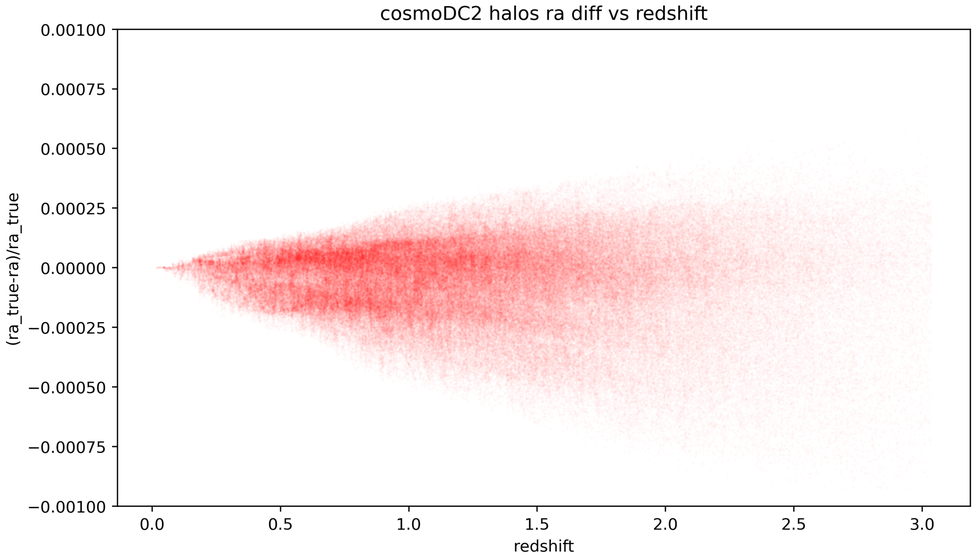


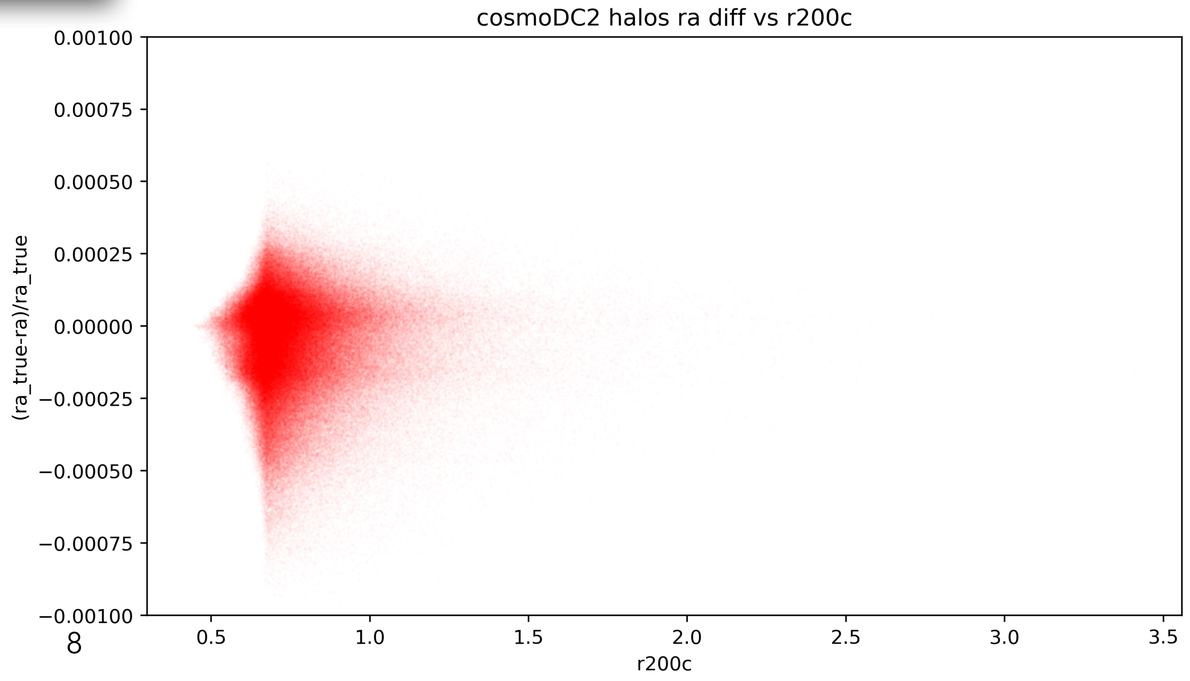
ra_true

- Difference between ra and ra_true is larger at higher redshift
  - make sense if ra_true is indeed the not lensed coordinate (link)?

`ra`	degree	Right ascension, lensed
`ra_true`	degree	Right ascension, not lensed

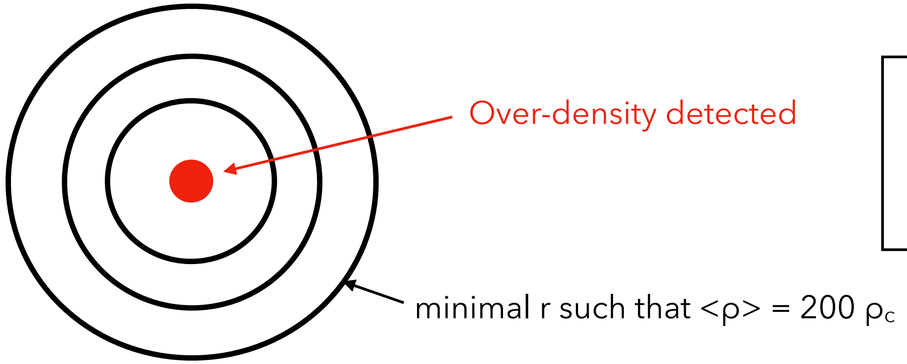






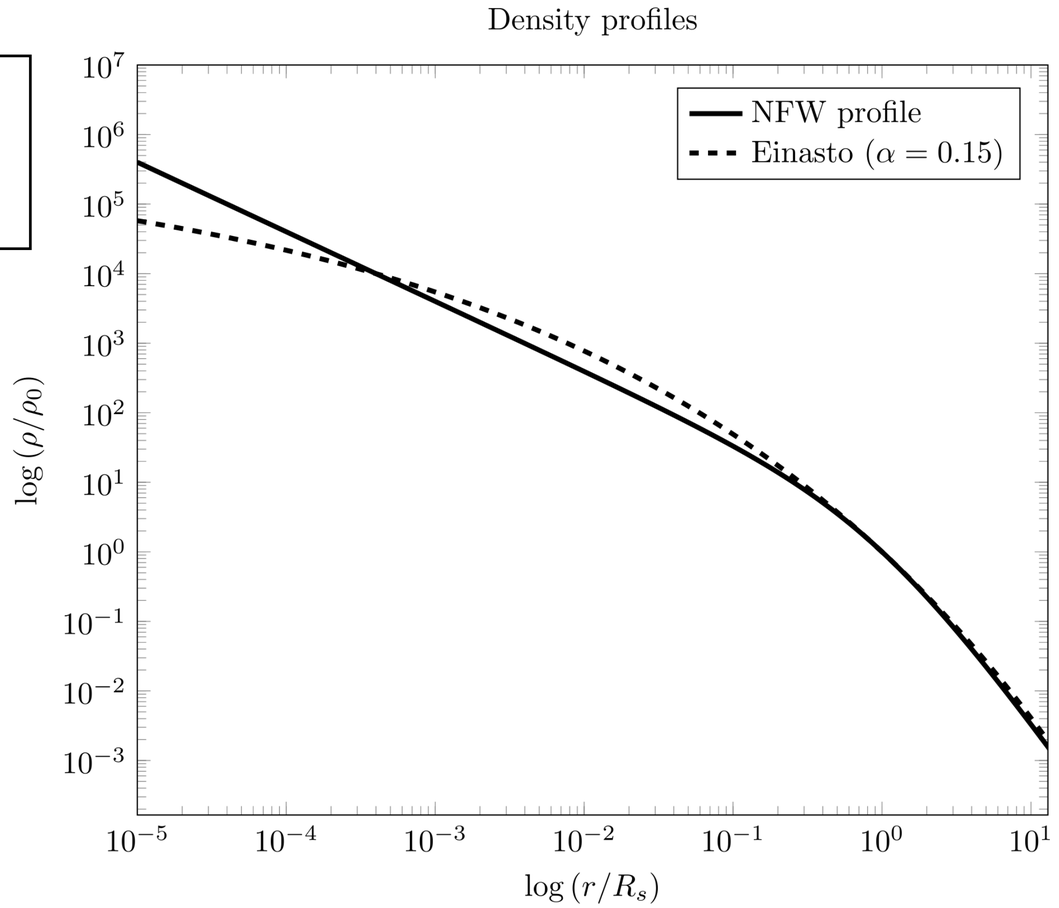
Detecting a cluster with 200c method

- Way cluster are detected in simu:



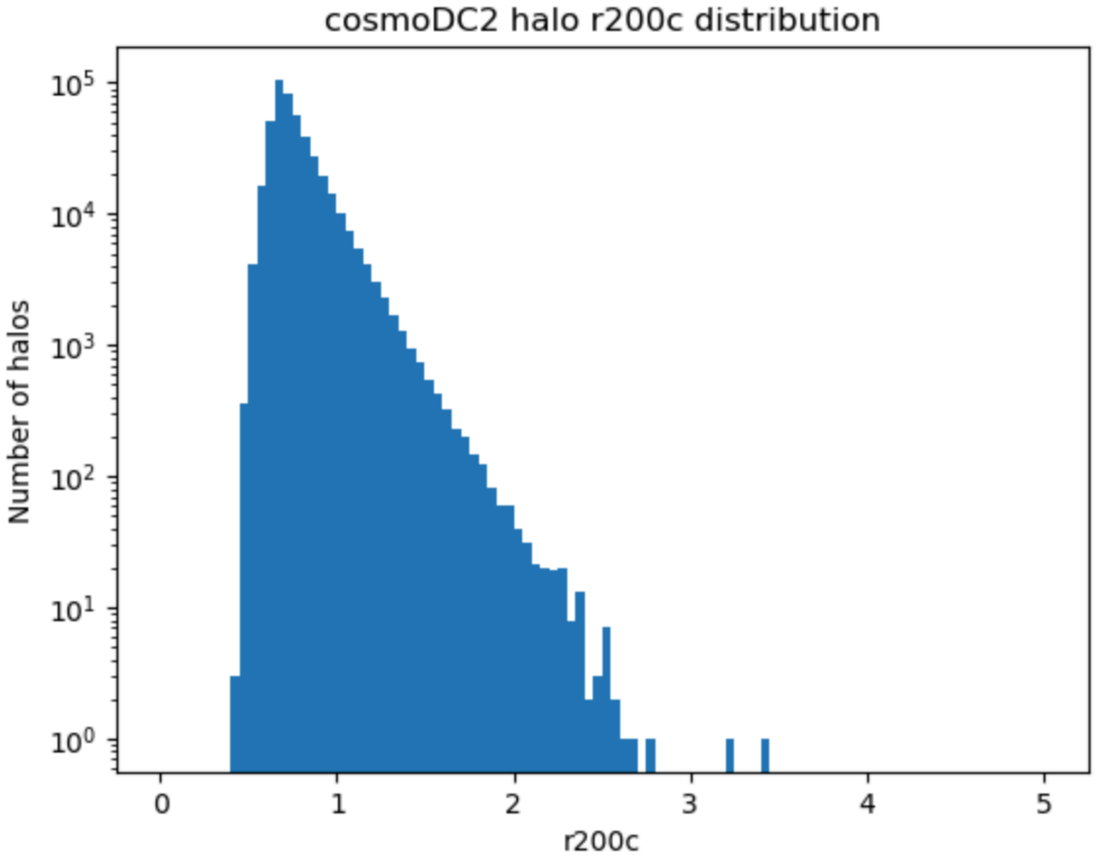
$$\rho_c^0 = \frac{3c^2 H_0^2}{8\pi G},$$

- ρ_c is the critical density for which k=0
- k = universe curvature **(0 = flat universe**) in **Friedmann-Lemaître-Robertson-Walker metric (FLRW)**
- Density is in theory not flat but rather vary as a function of radius (Navarro-Frenk-White profile: link)



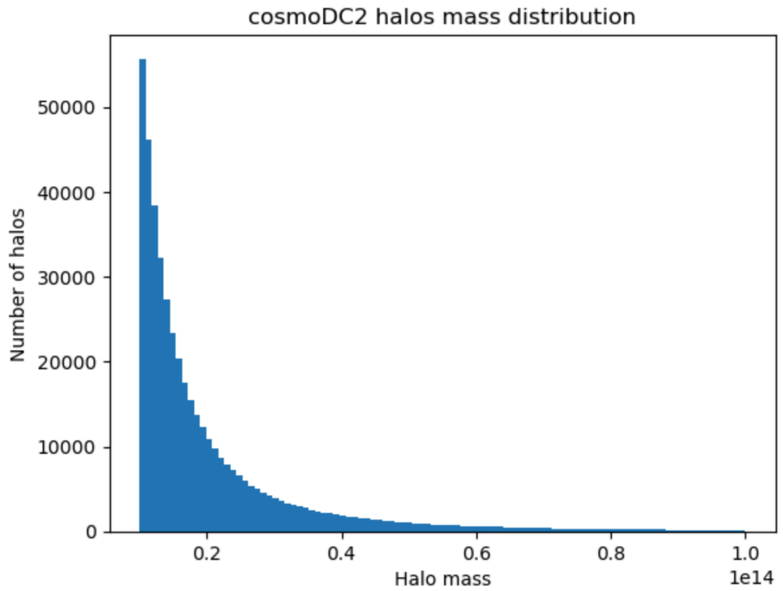
r200c
= Cluster Size

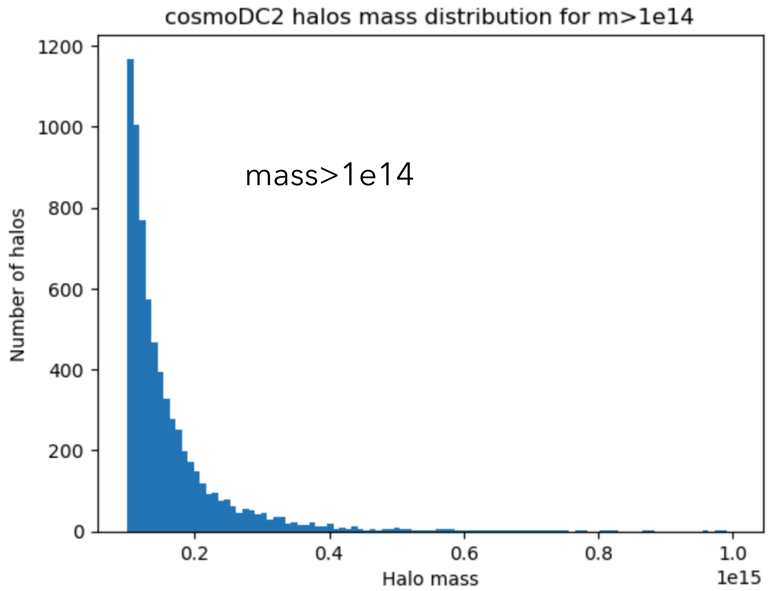
- **Sphere** radius for which density = 200xρ_c
- **Equivalent to virial** radius: radius at which system is supposed to be stabilized
- Unity ? Mpc ?
  - 1 pc: 3.26 a.l
  - 1 a.l = 9.5e15 m = 9.5e12 km
  - 1 Mpc: 1e9*3.26*9.5e12 km = 3.1e22 km
- Cluster typical size : 1 Mpc ?



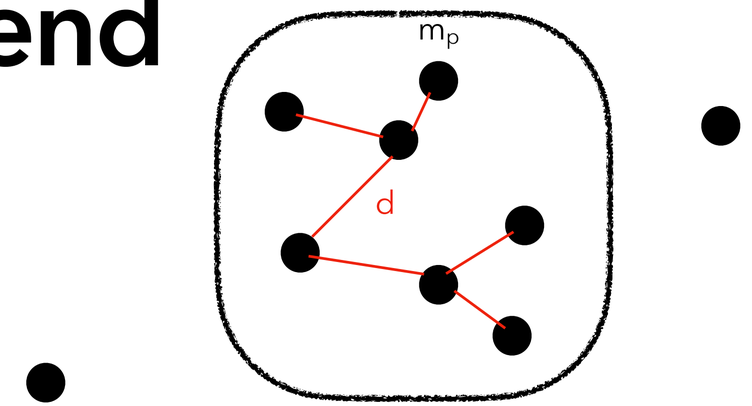
Halo mass

- 2 different masses provided in simu: m200c and mass_fof
- Both masses typically between 1e13 and 1e15 solar mass

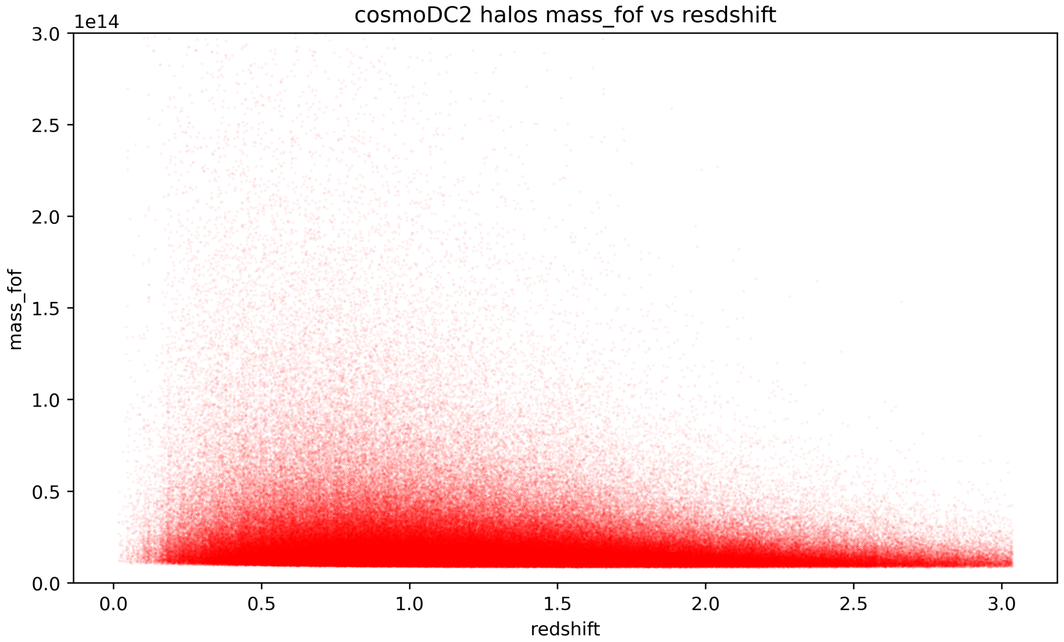




Mass friend-of-friend

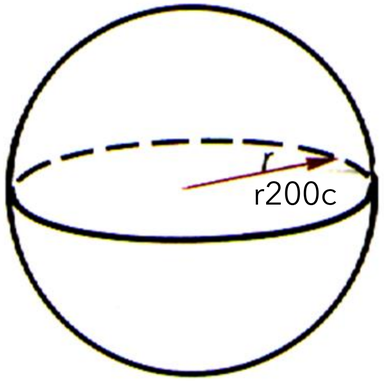


- mass_fof: friend-of-friend algorithm used to identify haloes
  - done by using a linking length « d »: any « *particule* » that finds another one within this distance is linked to form a group
  - allows to obtain non-spherical halos
  - mass : sum of mass of « *particules* » $\Sigma(m_p)$
    - *particule* = a cell of the grid simulation
    - mass of a *particule* obtained via average universe density / number of cells in grid simulation
- At higher redshifts, mass is smaller

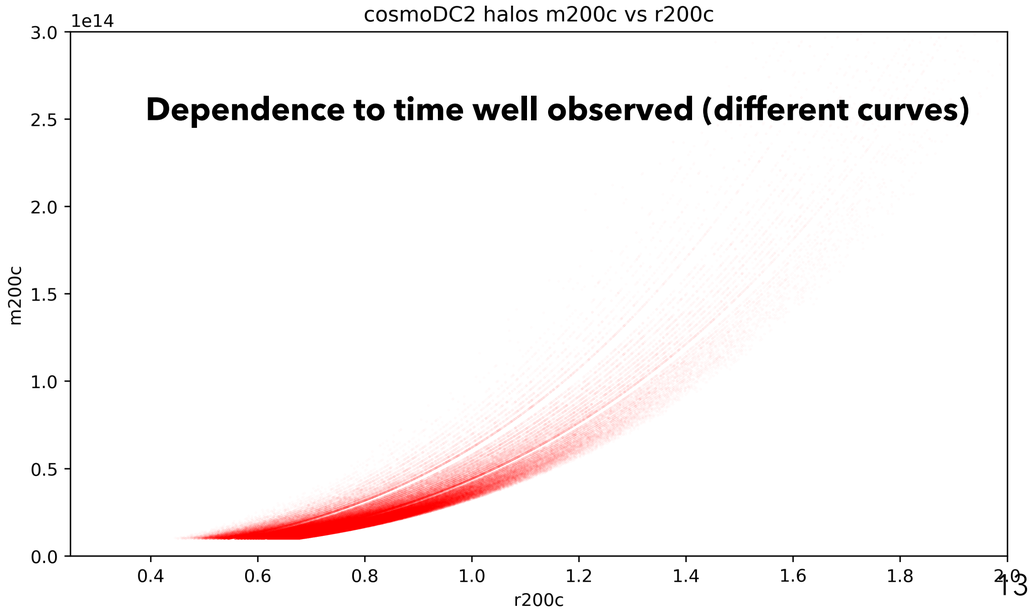


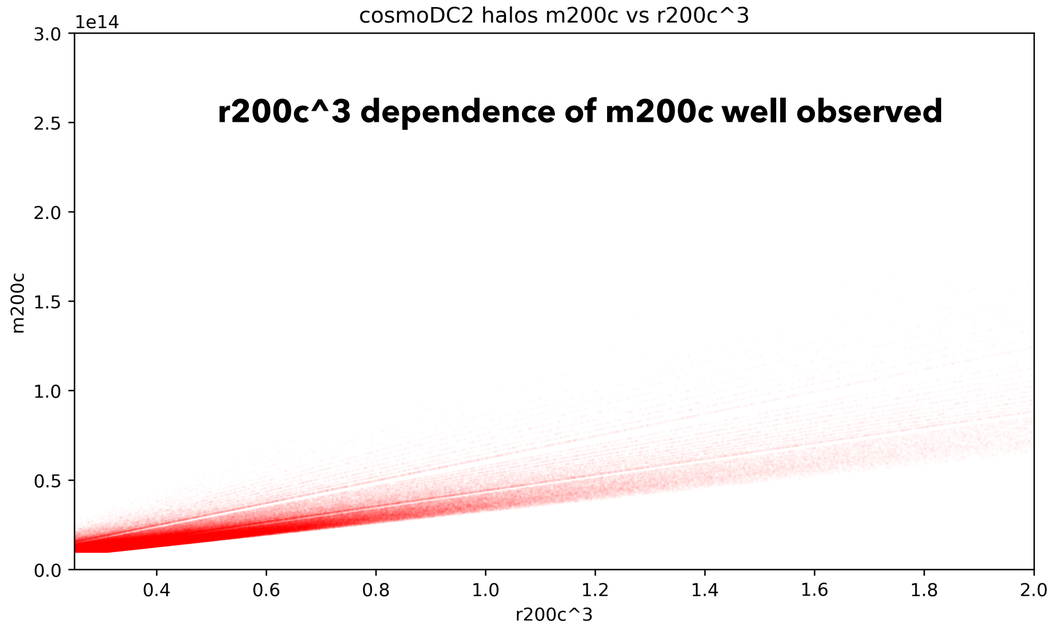
m200c

- m200c: mass of the spherical cluster with radius r200c



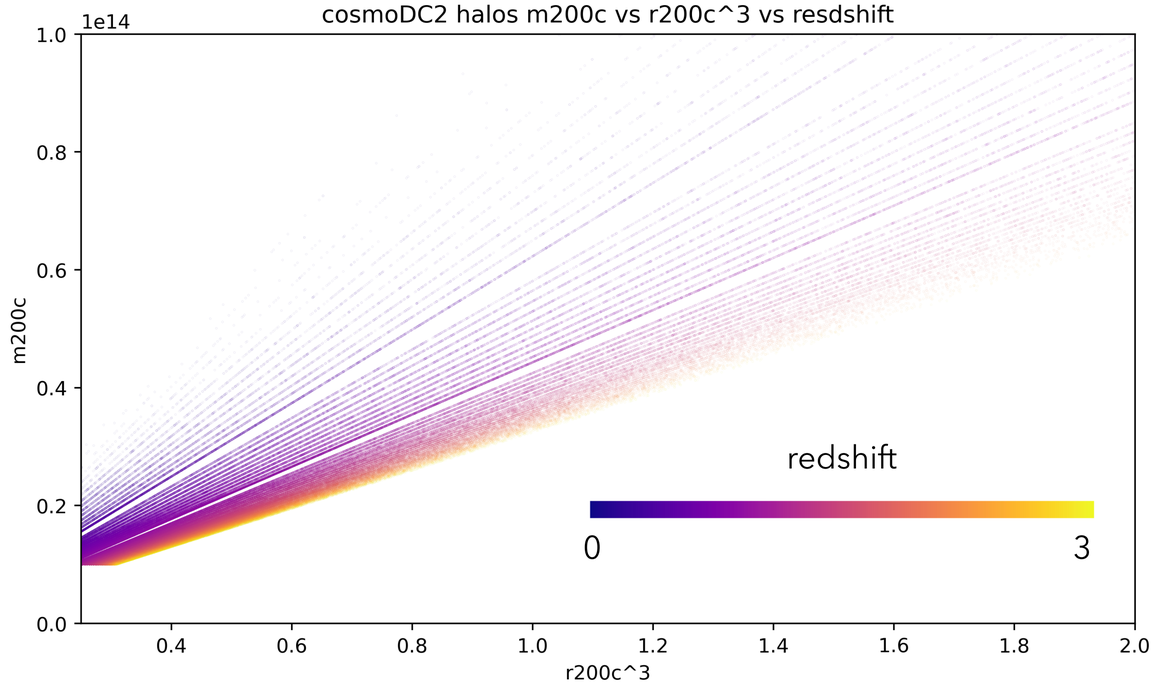
$$M_{200} = \frac{4}{3}\pi r_{200}^3 200\rho_c = \frac{100 r_{200}^3 H^2(t)}{G},$$

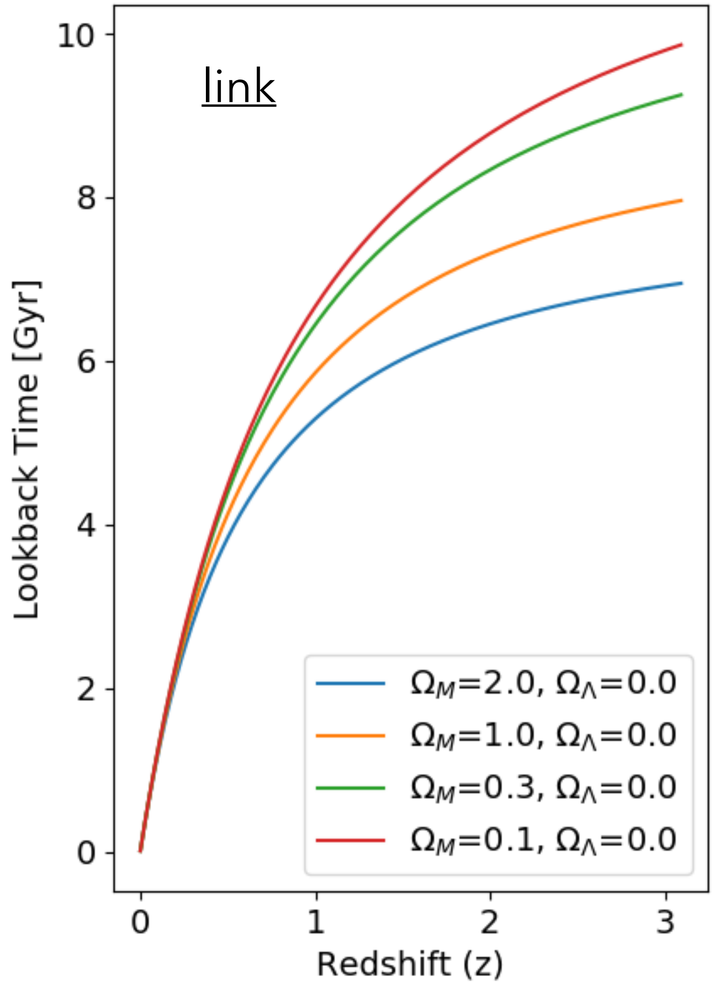




Dependence with time/redshift

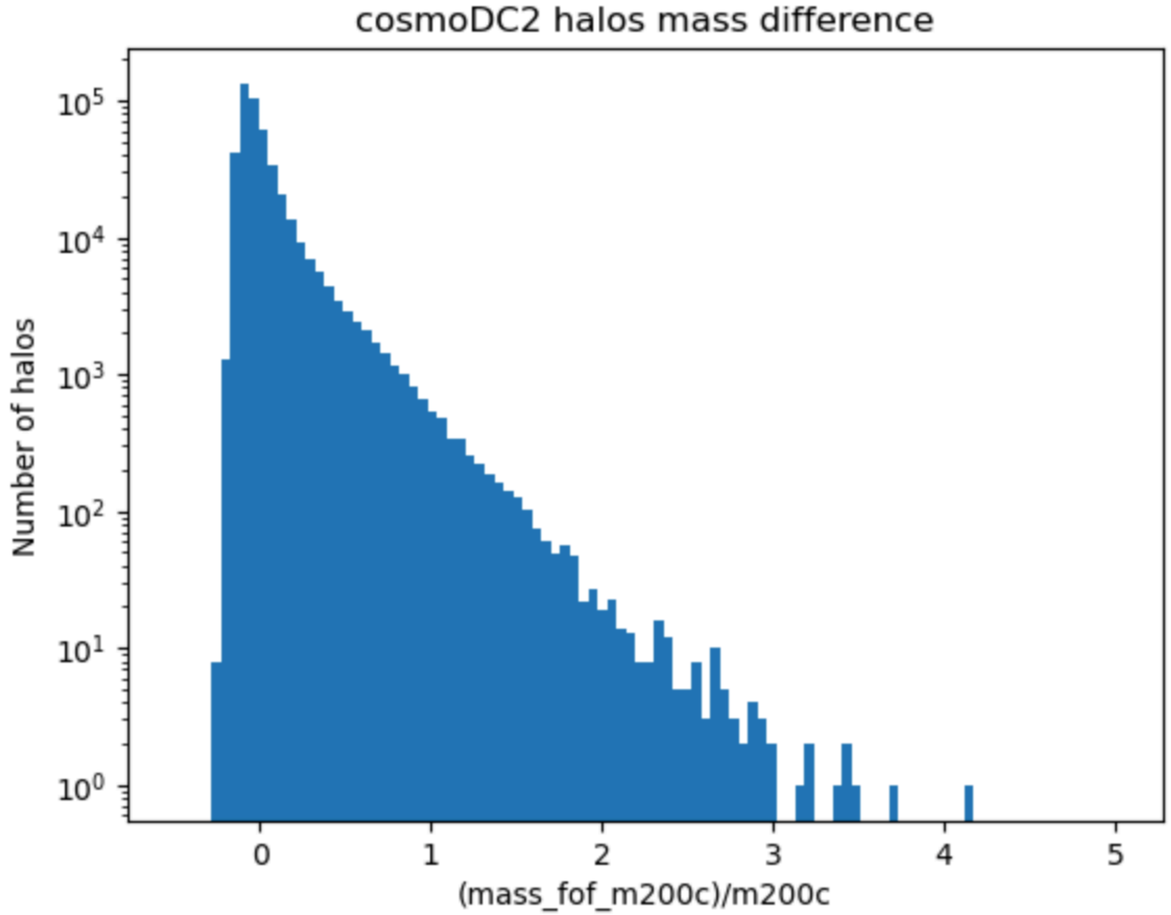
- redshift varies a lot for large lookback times and vary much less for small lookback times
  - as expected
- expect high sensitivity to cosmological model at high redshift !
- time step in simu seems to change during time (small steps for recent ages, large steps for older ages)

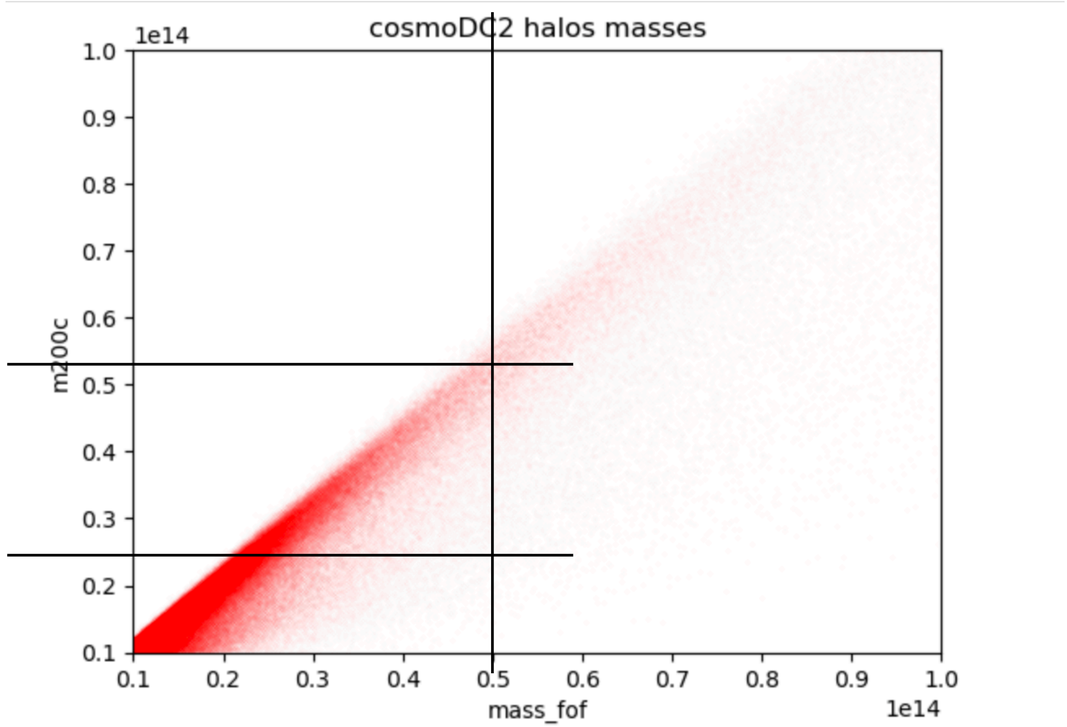




Halo mass difference

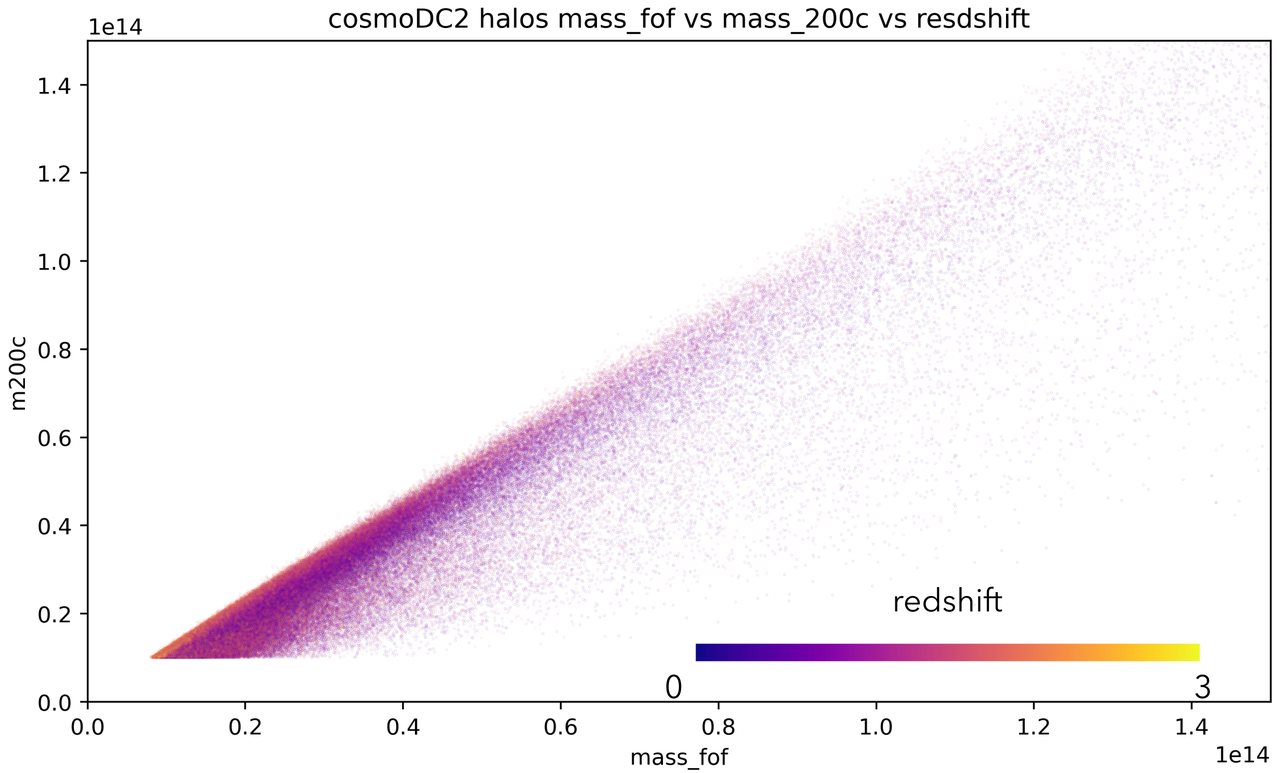
- Up to 400% difference between two mass estimations : mass_fof and m200c
- Mass_fof usually larger than m200c





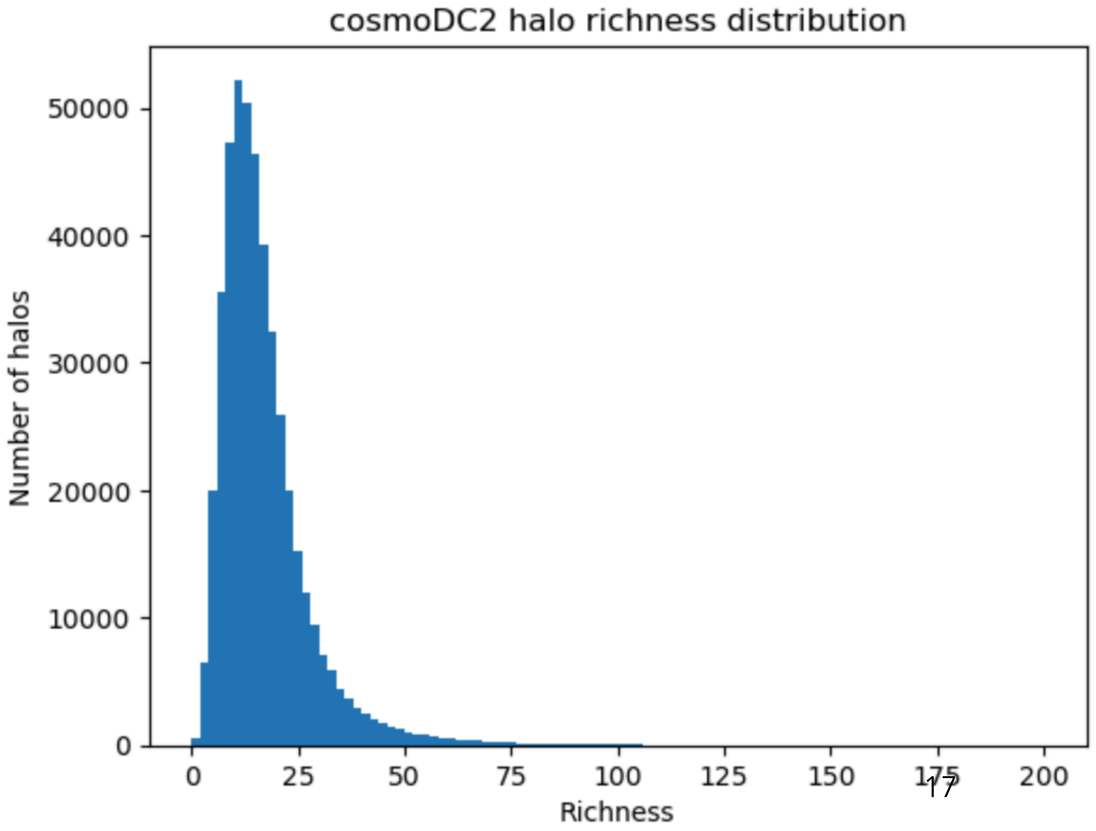
Mass difference

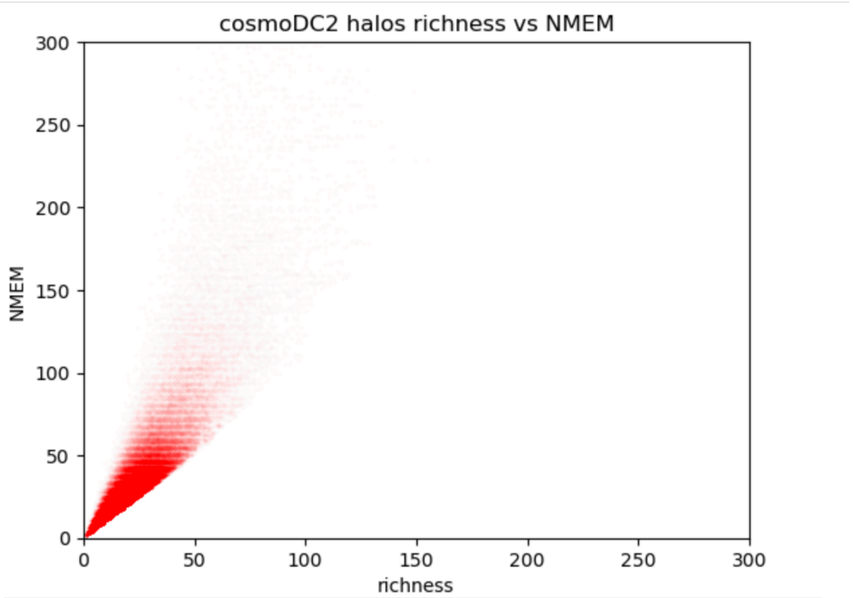
- Masses are more similar for large redshifts
  - clusters were more spherical at older times ? (linear structure formation principle)
  - less massive clusters can more reliably be modeled with a sphere than more massive ones ?

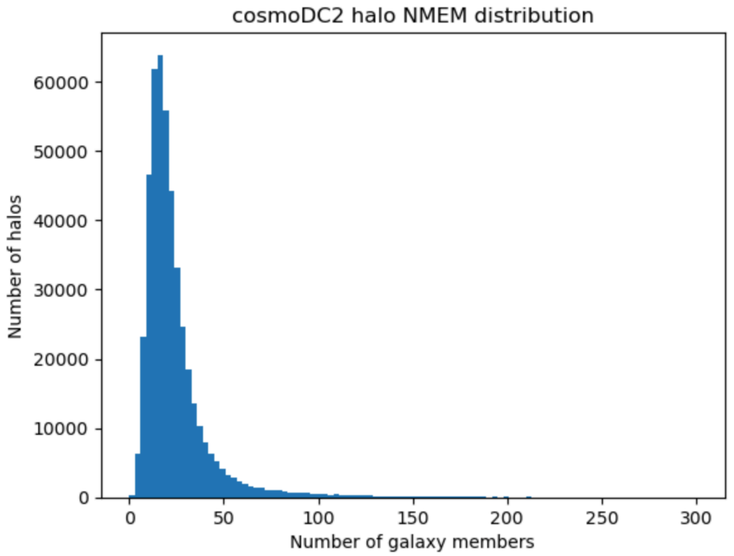


Number of galaxies per halo

- 2 quantities: NMEM and richness
- In average ~12-15 galaxies per halo -> small ?
- NMEM larger than richness -> richness apply more selection
- Seems cluster with small number of galaxies are kept in simu ?

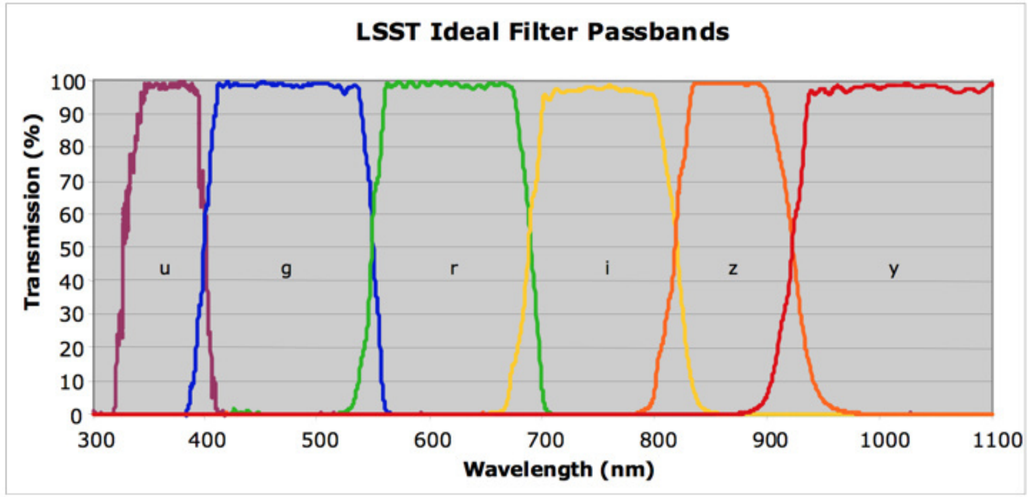


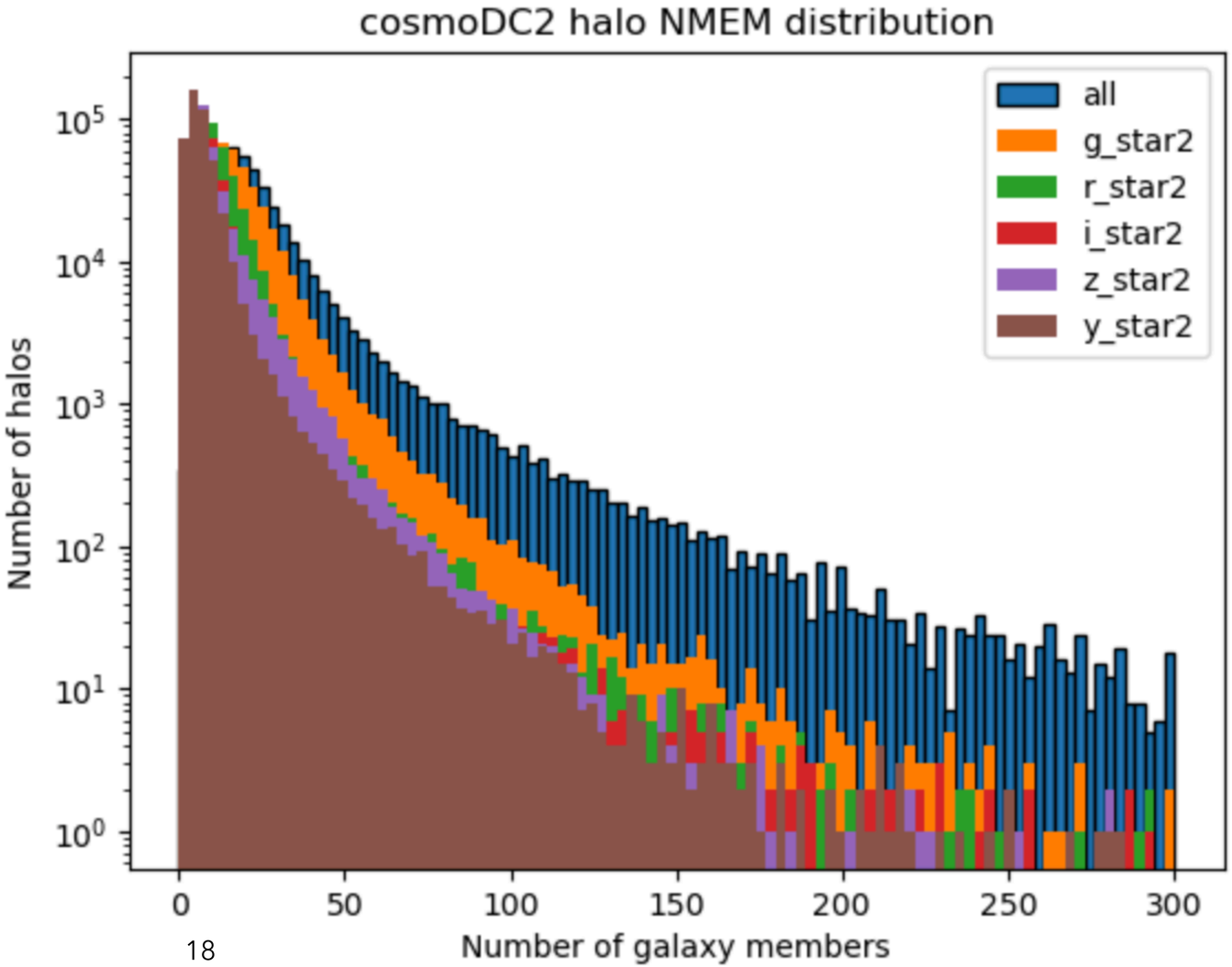




NMEM with different filters

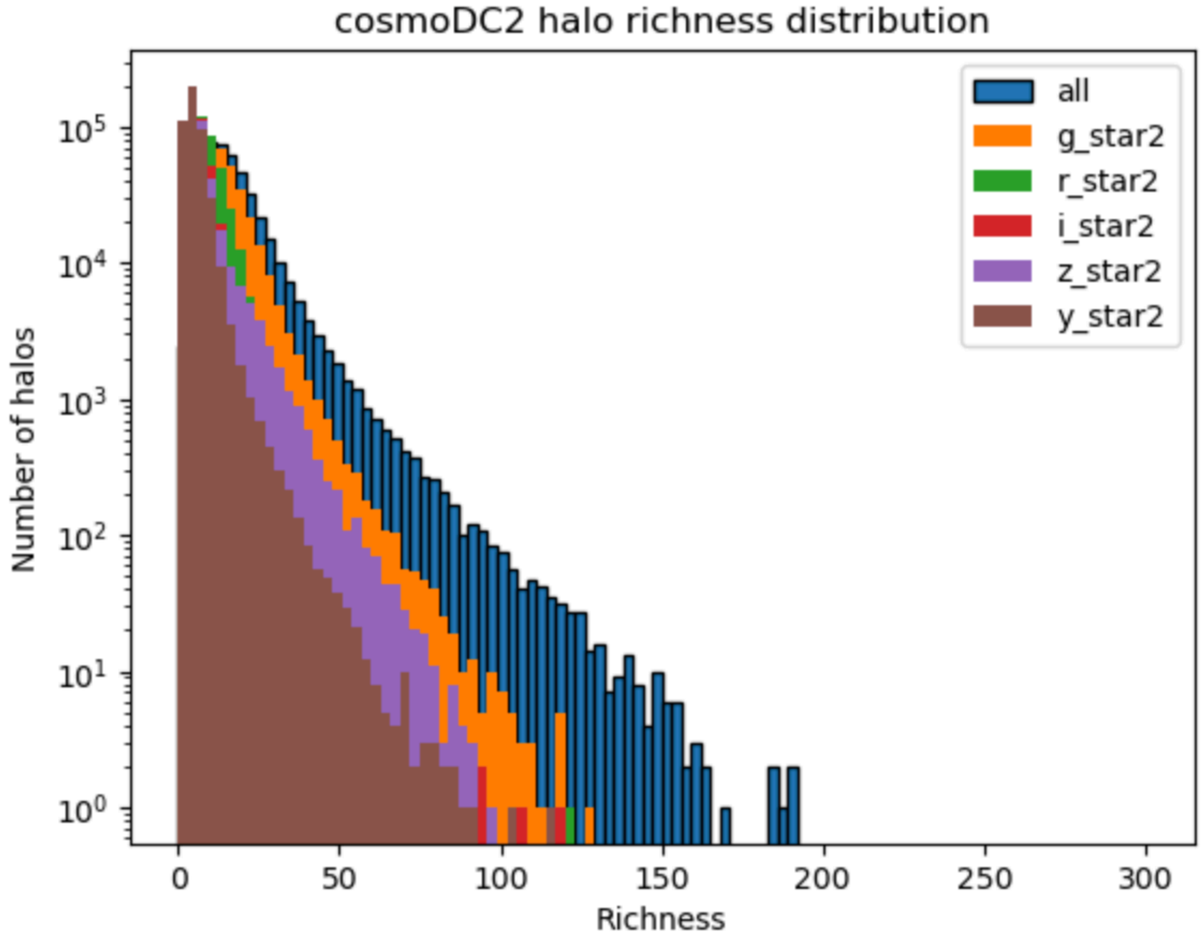
- g filter is the one that is most powerful to detect galaxies (and y one the least efficient)





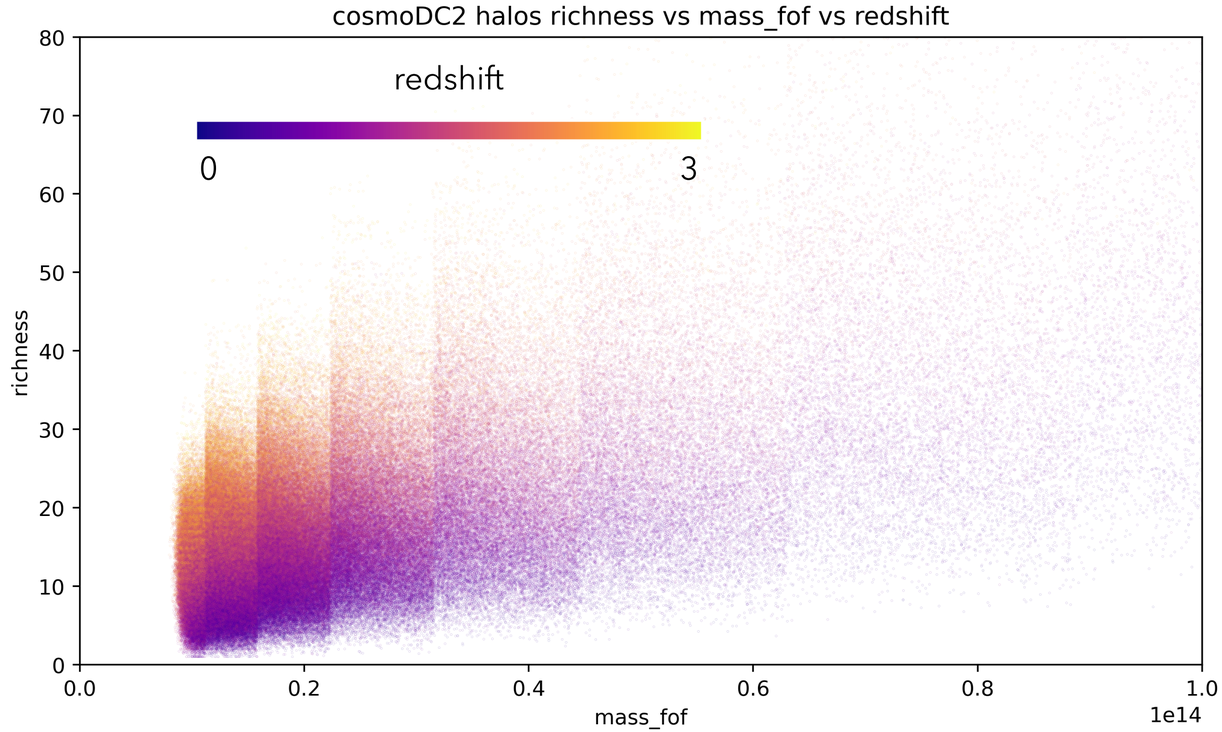
Richness with different filters

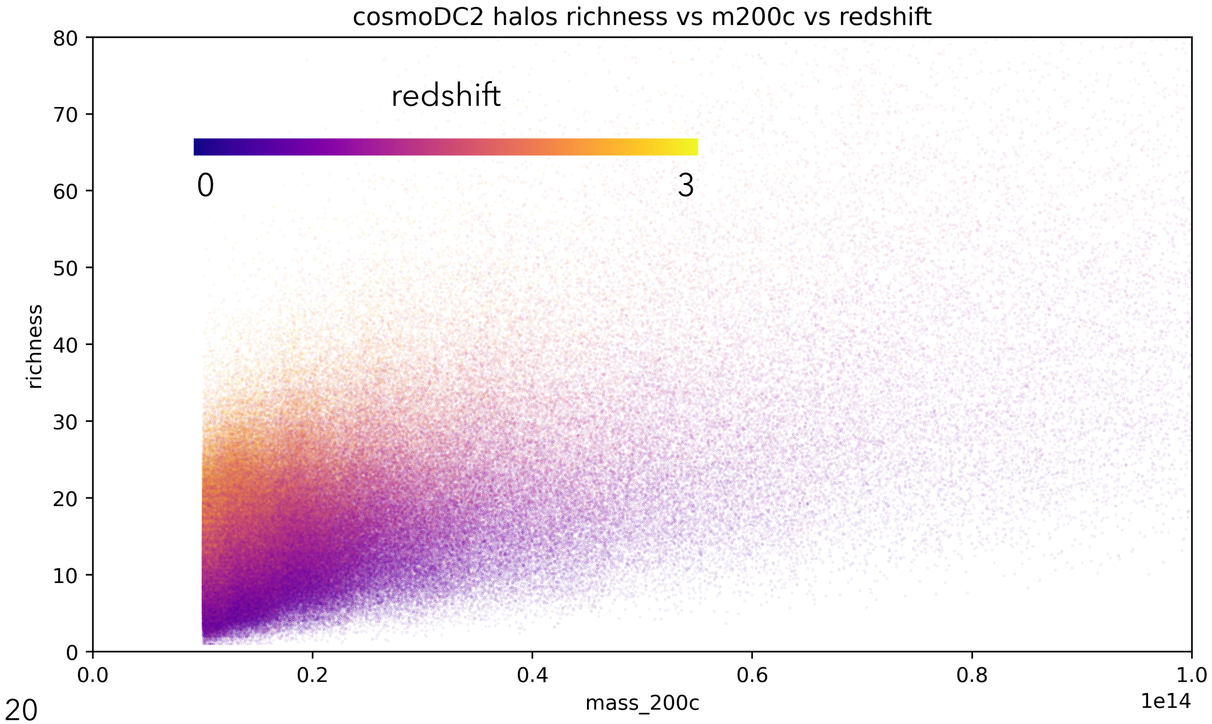
- Same conclusion than for NMEM



Richness vs mass

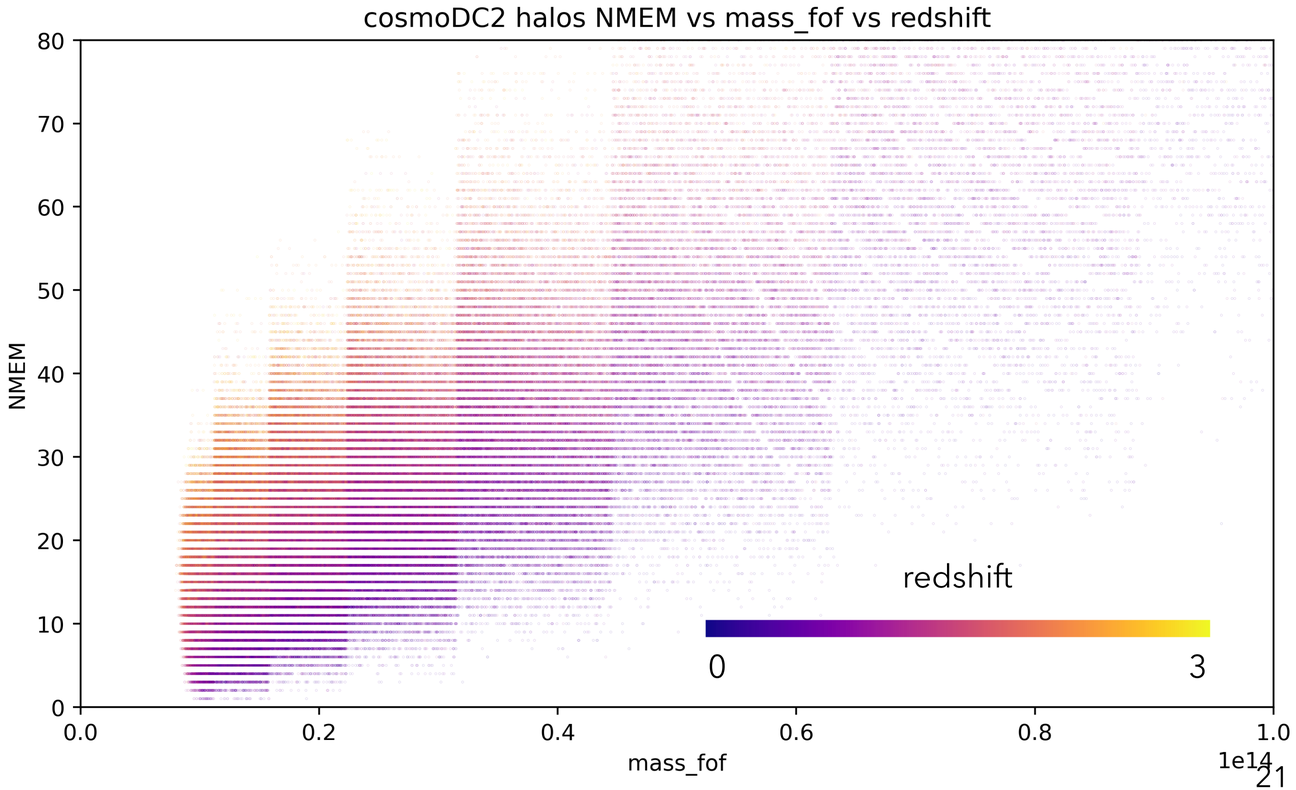
- Richness higher for higher redshifts ???
- What are the lines we see on the plot ? Artefact from the simulation ?
  - not seen for m200c





NMEM vs mass

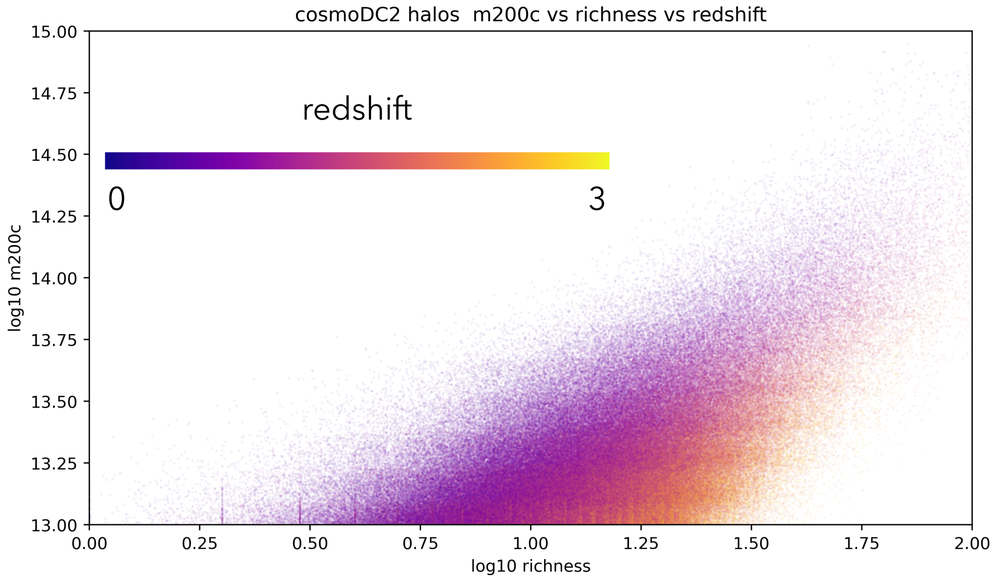
- Why is richness continuous while NMEM is not ?
  - both richness and NMEN should be integers ?



Mass richness relation (MRR)

- Trying to reproduce MRR from paper below
- Looks similar (not same scales of m200c and N200, different catalog)
- what are the small lines in richness axis ?

https://arxiv.org/pdf/2210.09530.pdf



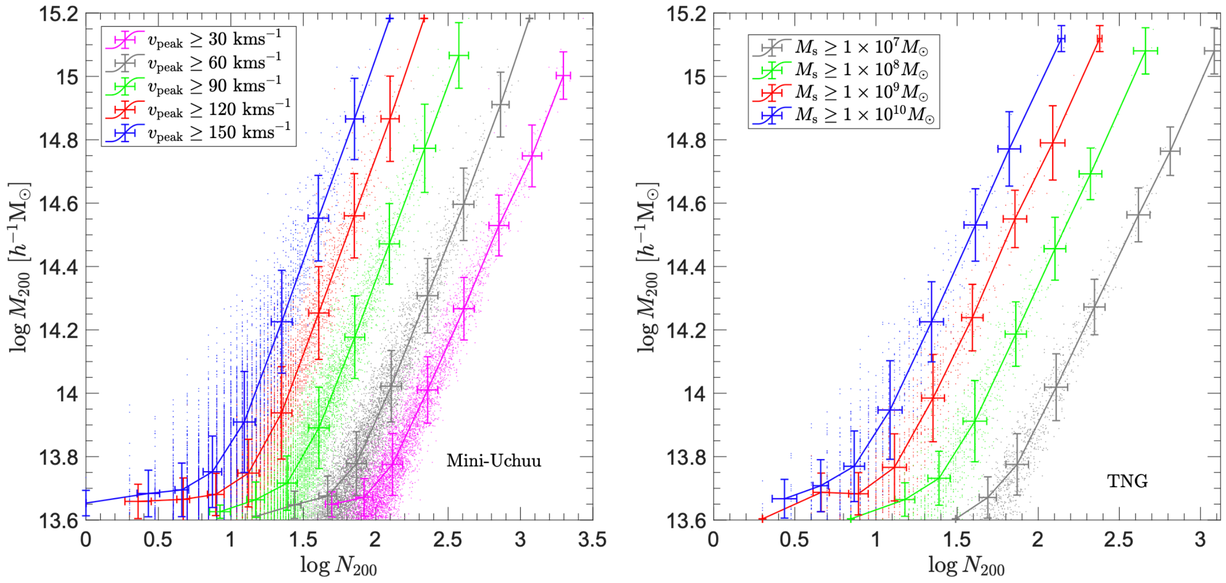
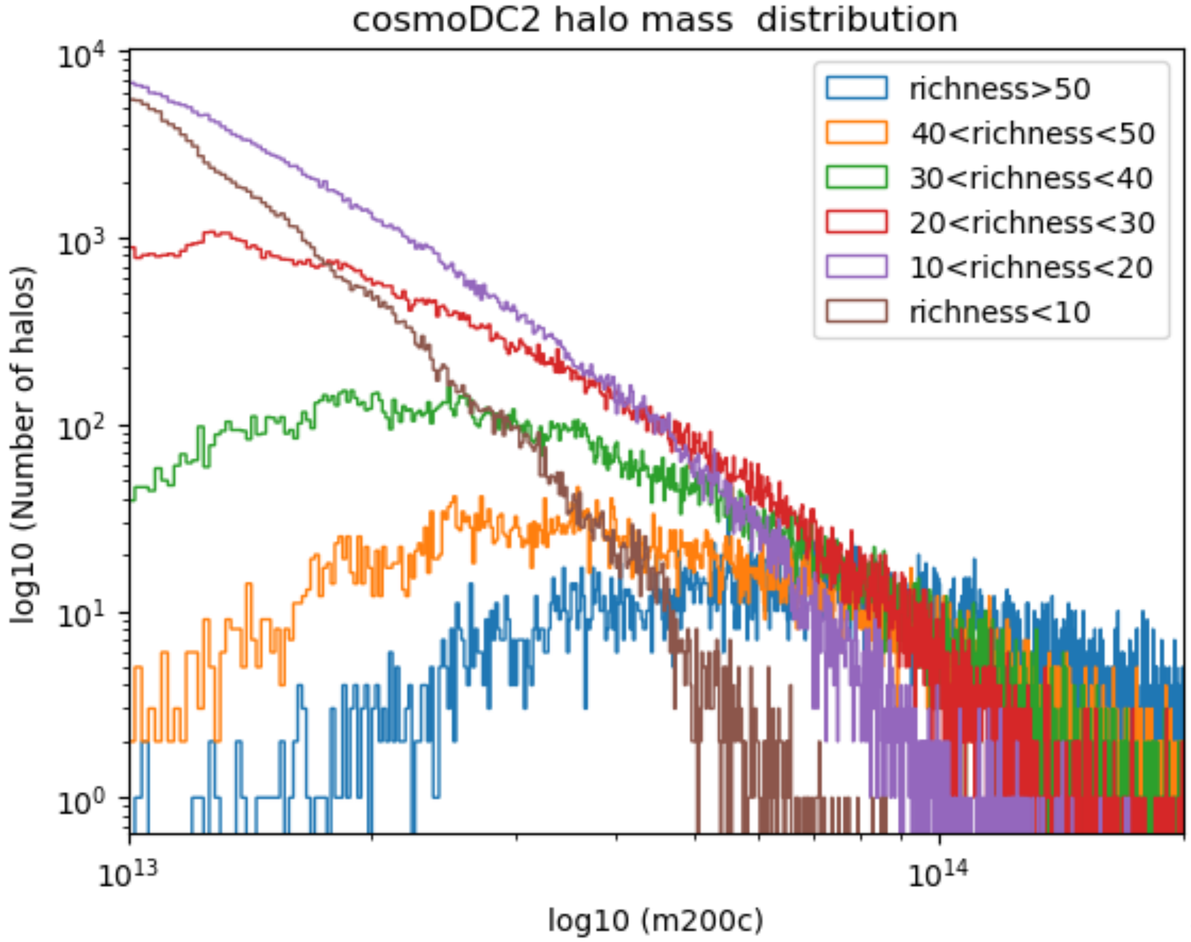
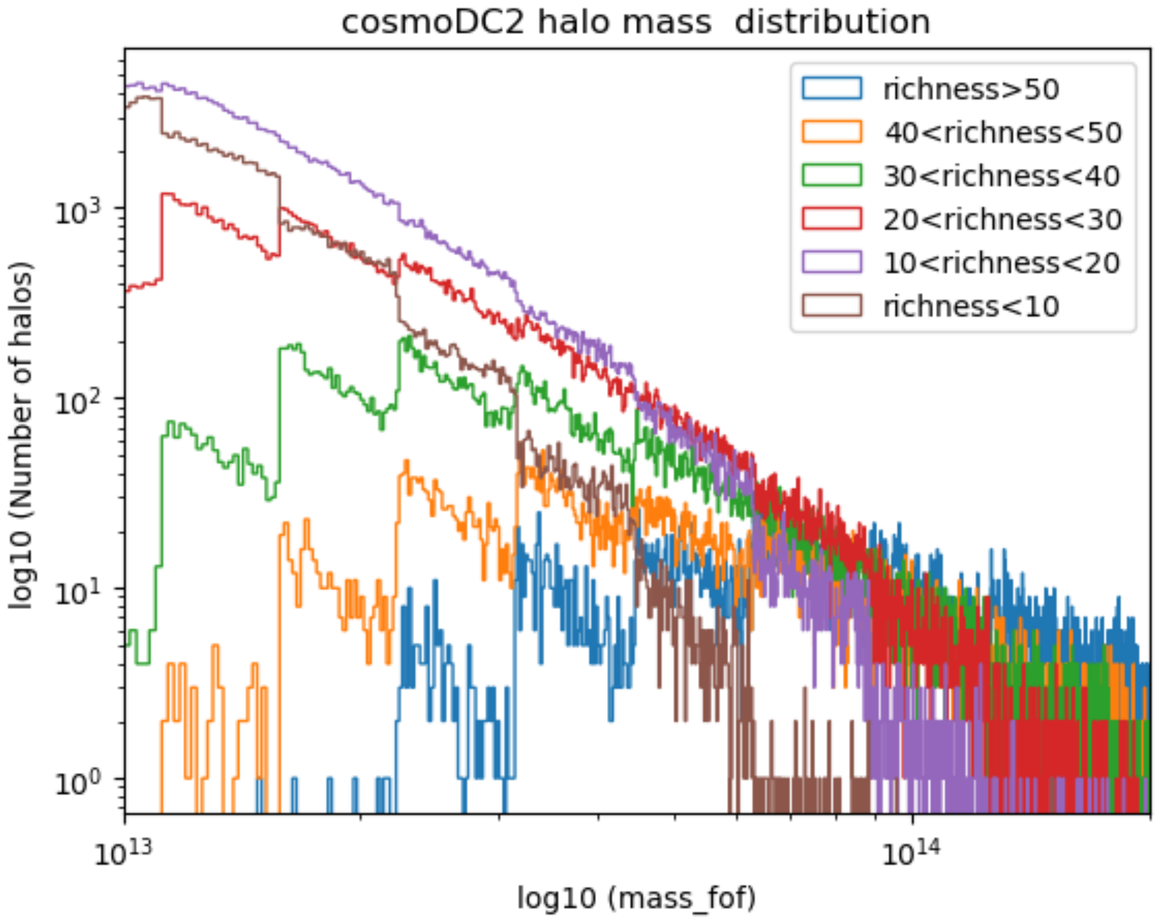


Figure A2. Mass-richness relation (MRR) for simulations. The mean mass at some richness bins is plotted for Mini-Uchuu (left) for five $v_{\rm peak}$ thresholds for subhalos and TNG (right) for four M_s thresholds for galaxies within r_{200} as shown in each legend. Error bars represent Poisson noise. The figure shows that MRR introduces a tail at low-richness end. The length of the tail increase with increases the thresholds of $v_{\rm peak}$ and M_s. This indicates that the tail is dependent on the selection of the threshold and it is not intrinsic.

Mass vs richness

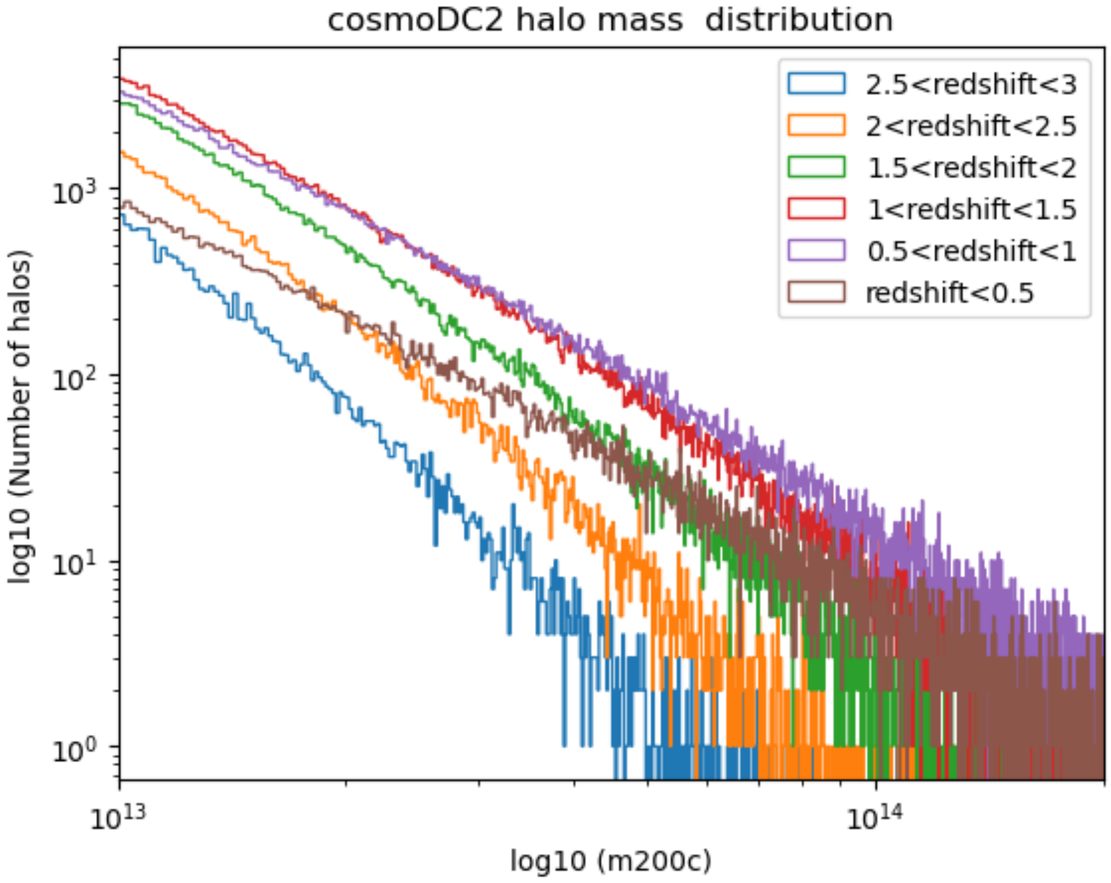
- As expected, halos with more galaxies are heavier
- Strange behavior of mass_fof …

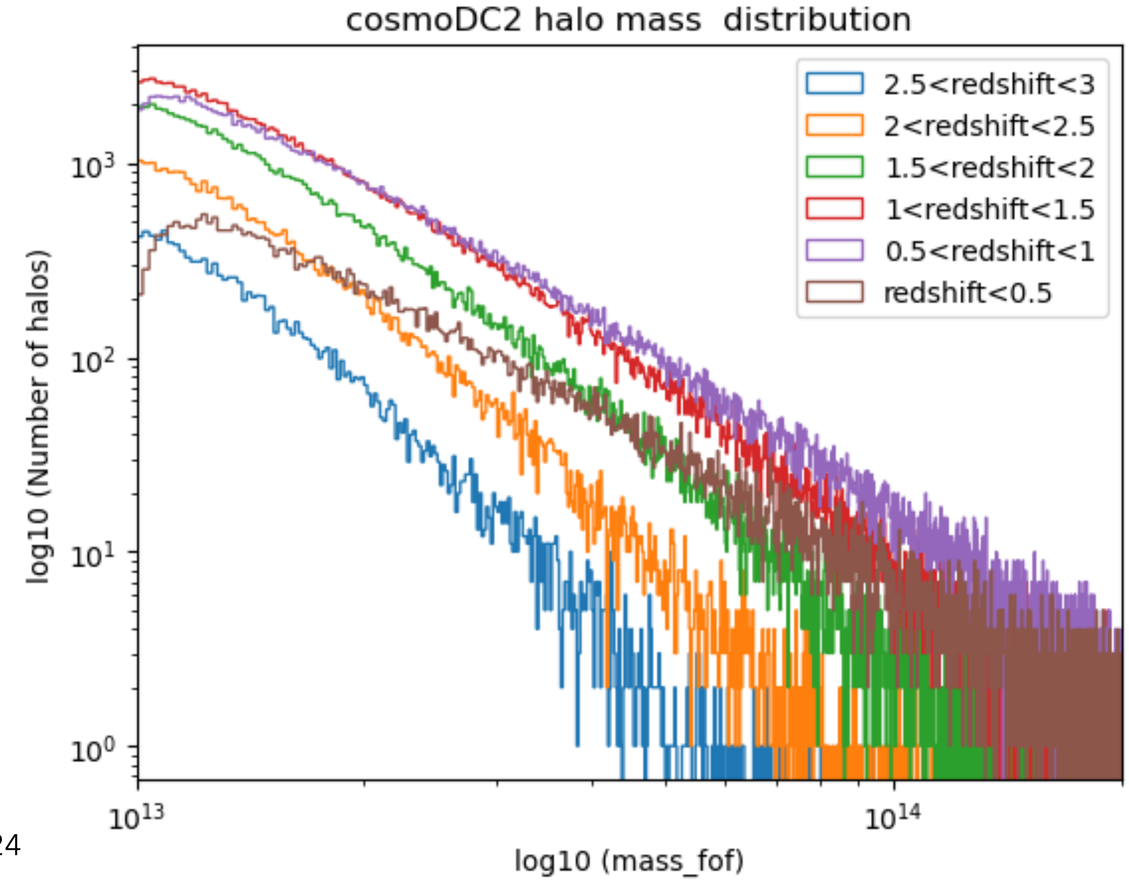




Mass vs redshift

- As expected, halos with higher redshift are smaller masses
- Quite some difference between mass_fof and m200c -> when extracting cosmological constraints, which one should we use ? Why ?





Mass vs redshift

- Comparison with https://arxiv.org/abs/1511.00692
- Similar trend