The origin of scatter in the stellar mass - halo mass relation

in hydrodynamical simulations

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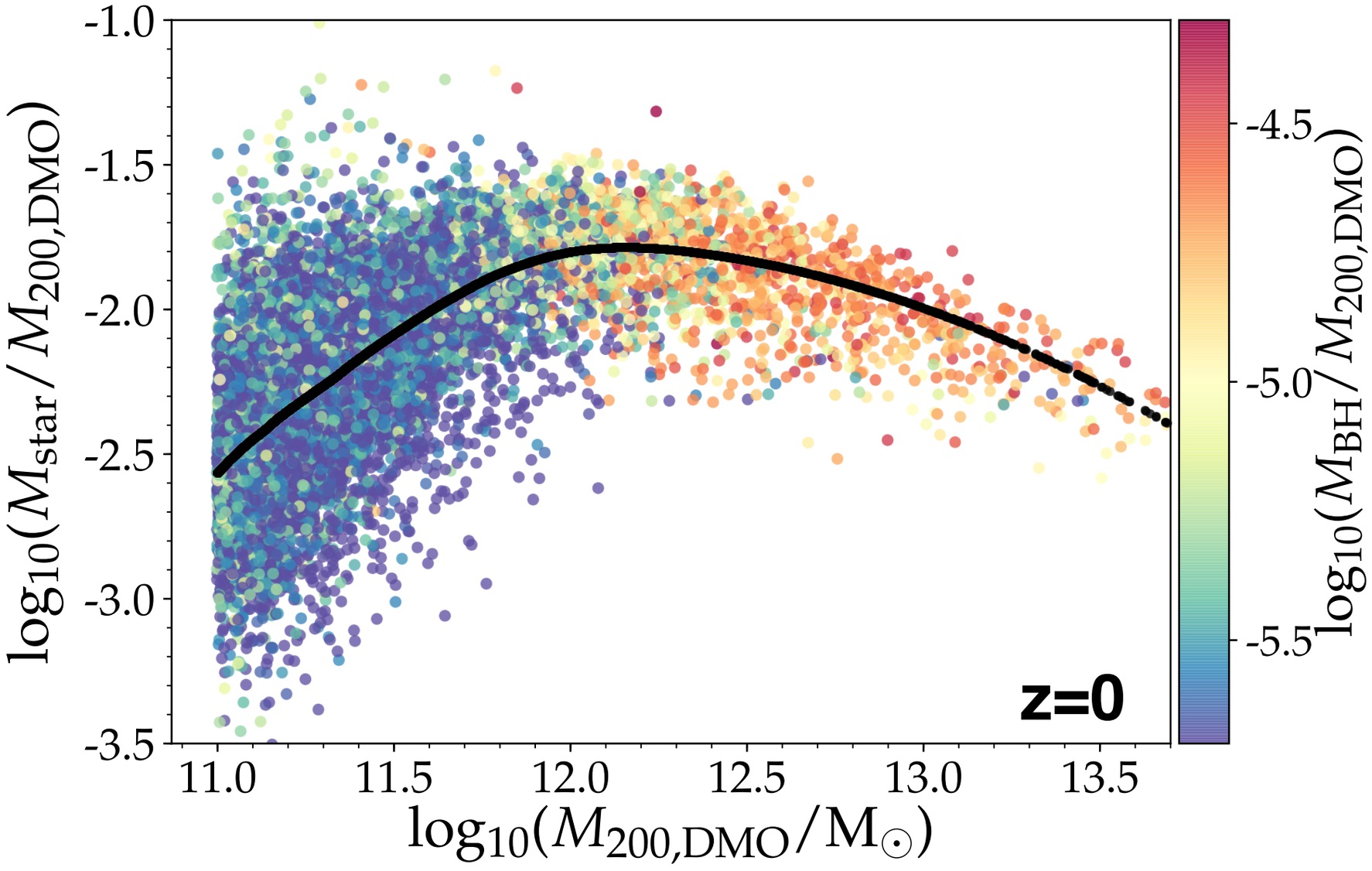
in collaboration with Joop Schaye and the EAGLE team

Scatter in SMHM from “Observations” of simulated galaxies

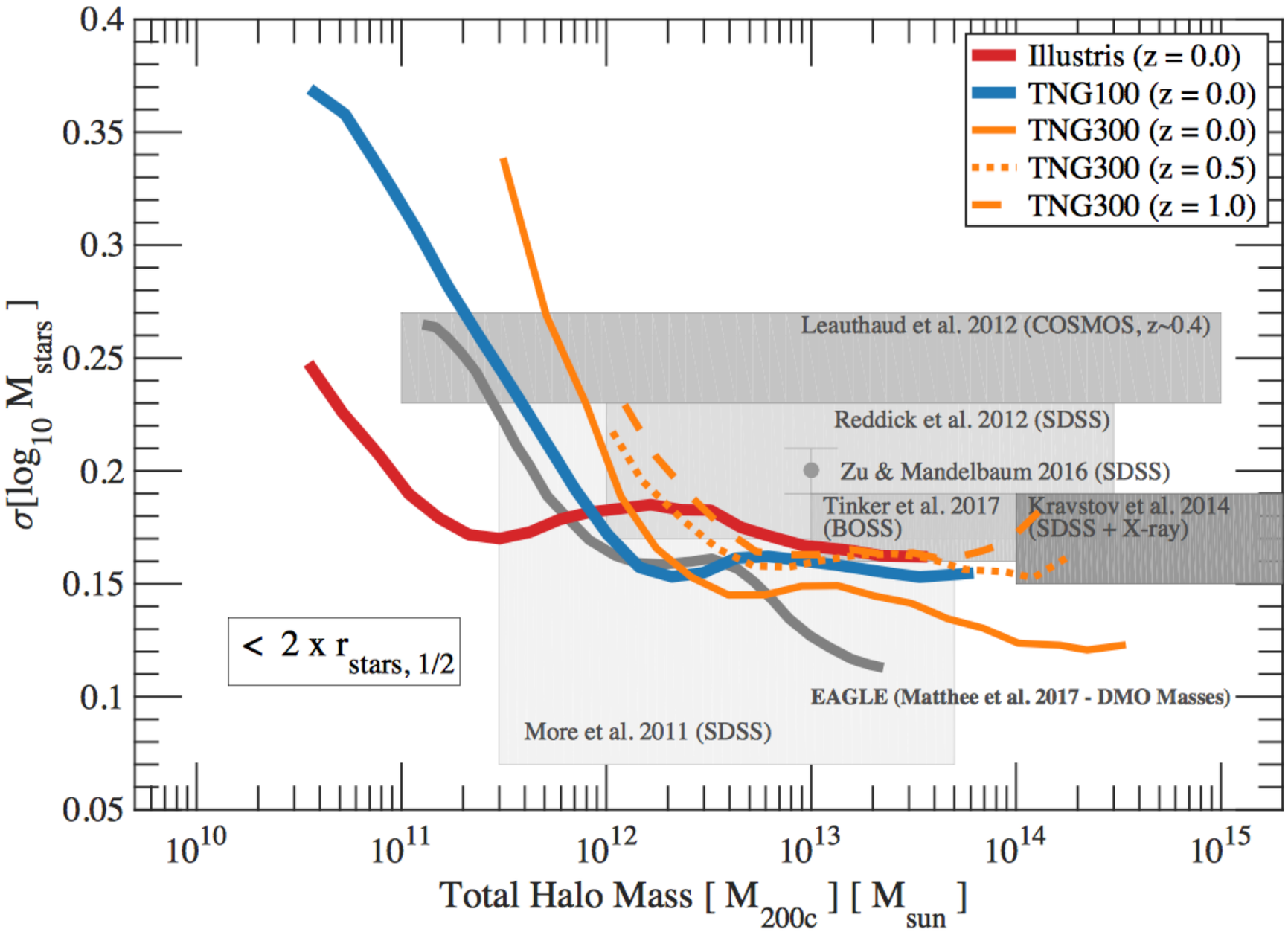
Note that I include only central galaxies



EAGLE (Schaye+2015)

Matthee et al. 2017a, MNRAS, 465, 2381

At fixed halo mass, the scatter in M_{star} is mass dependent

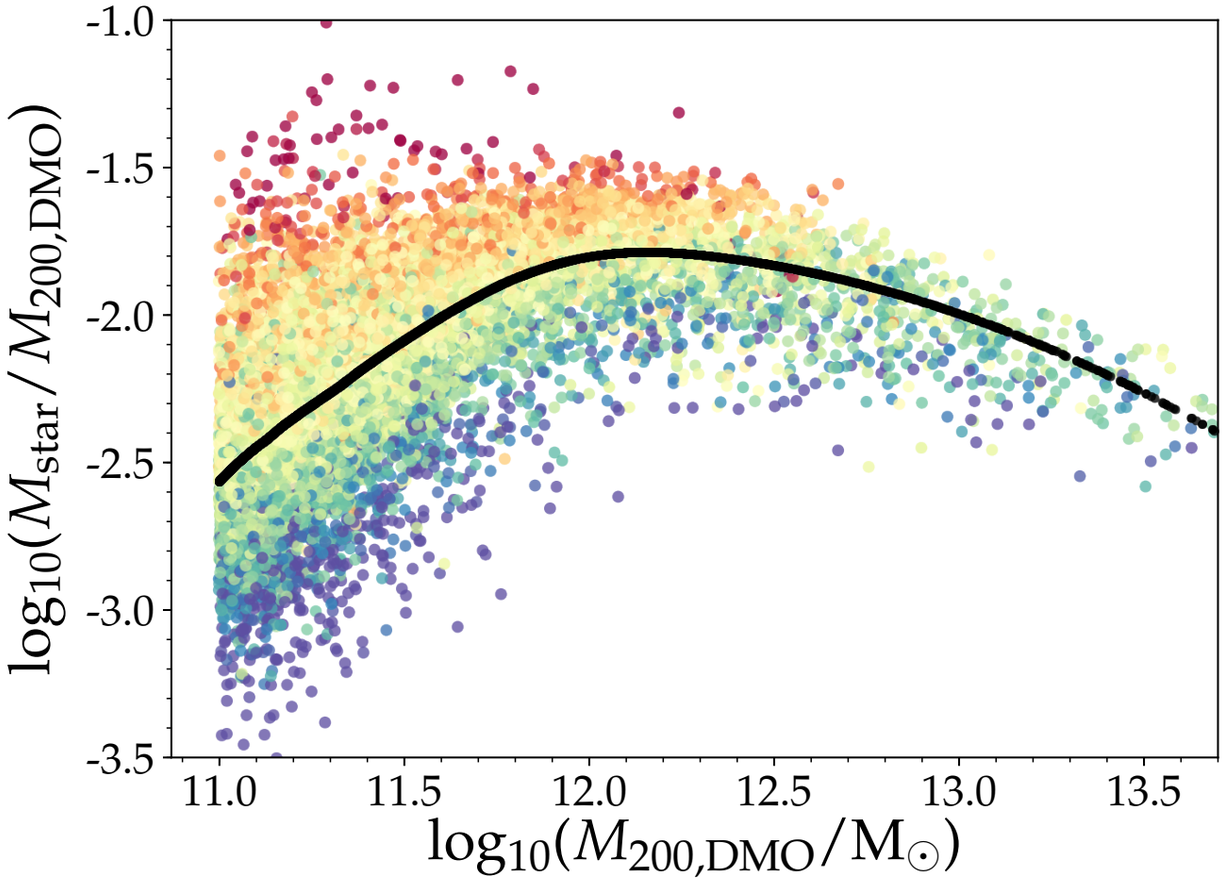


Pillepich et al. 2018, MNRAS, 475, 648

$\log_{10}(M_{200})$~11.3: scatter is 0.25 dex
$\log_{10}(M_{200})$~12.3: scatter is 0.15 dex

The origin of scatter : Separating cause & effect

Colour: concentration **Here: concentration = V_{max}/V_{200}**



Baryonic simulation
this traces cause & effect

very strong correlation

DMO simulation
this isolates causation

mild correlation

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Matthee et al. 2017a, MNRAS, 465, 2381

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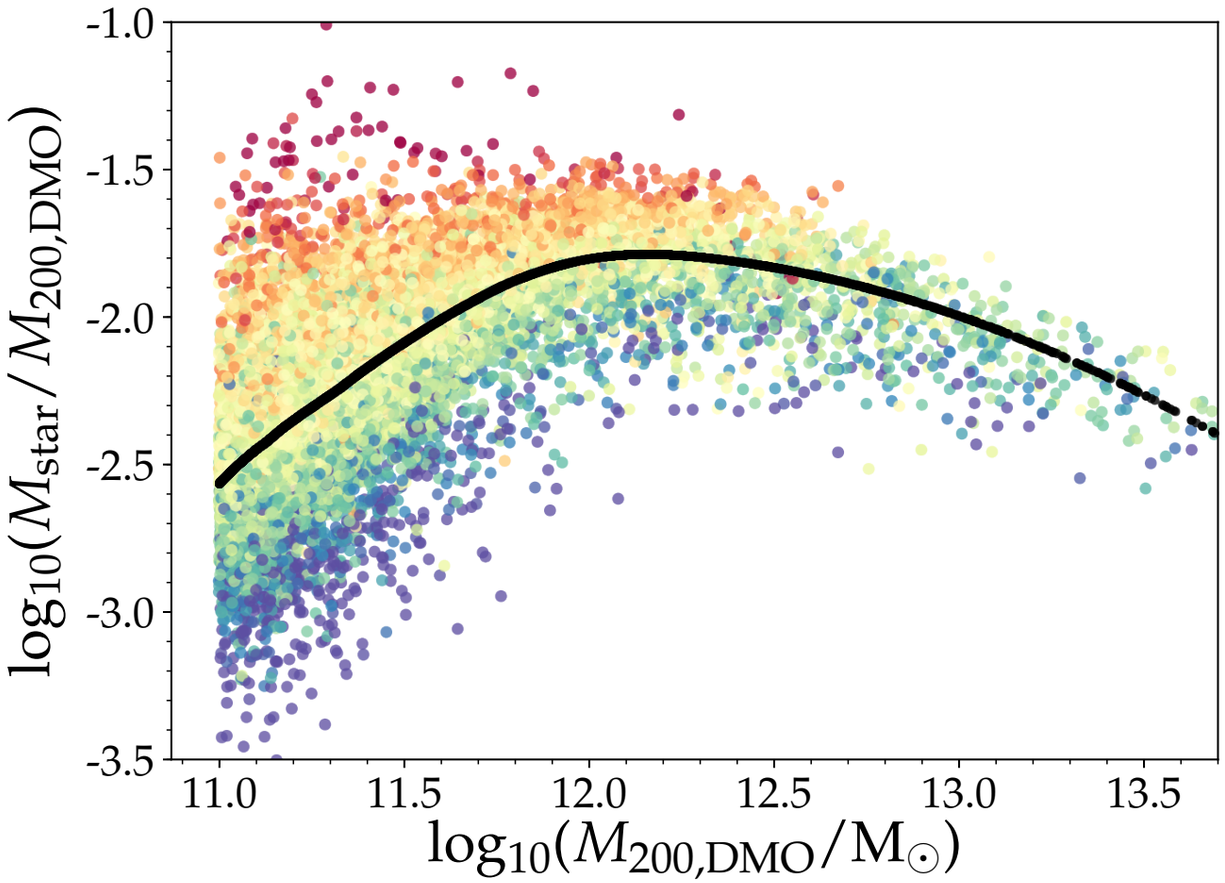

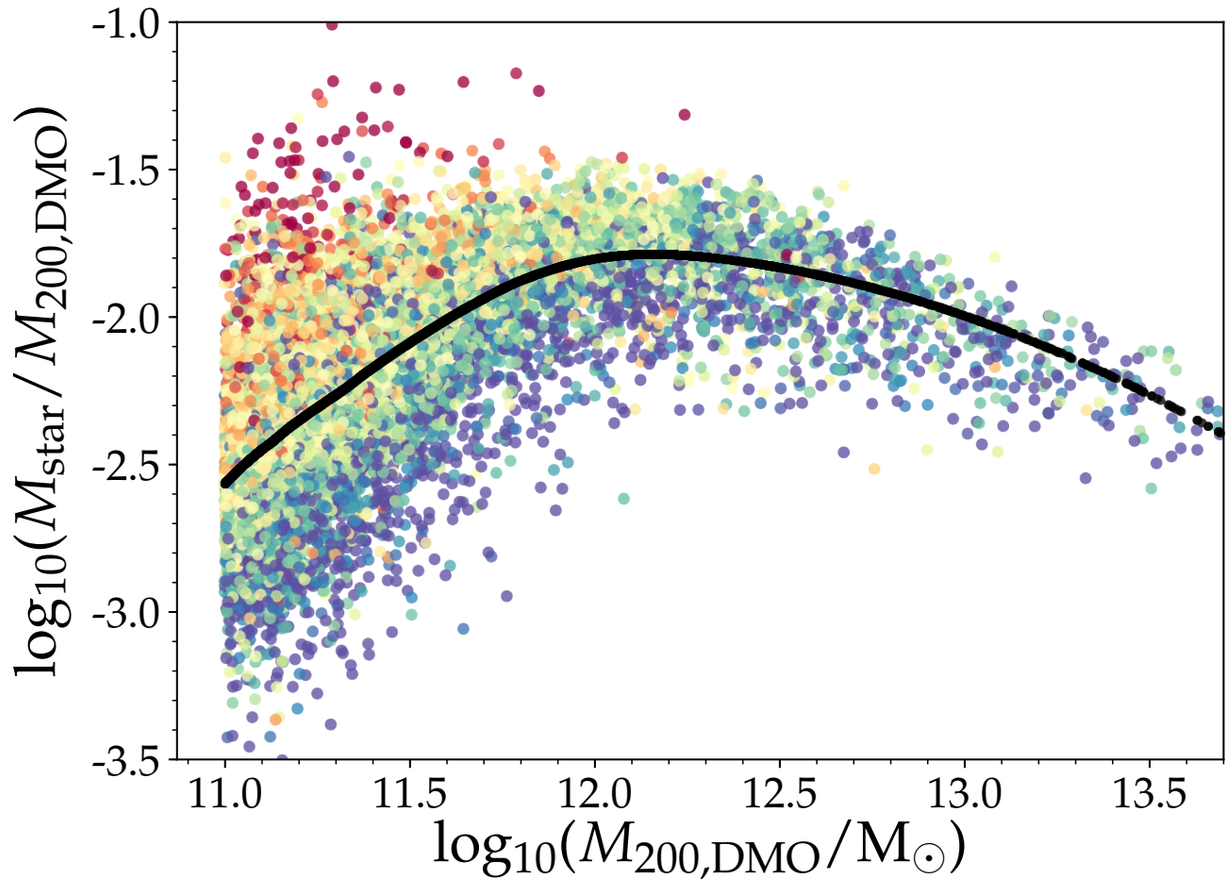

Baryonic simulation

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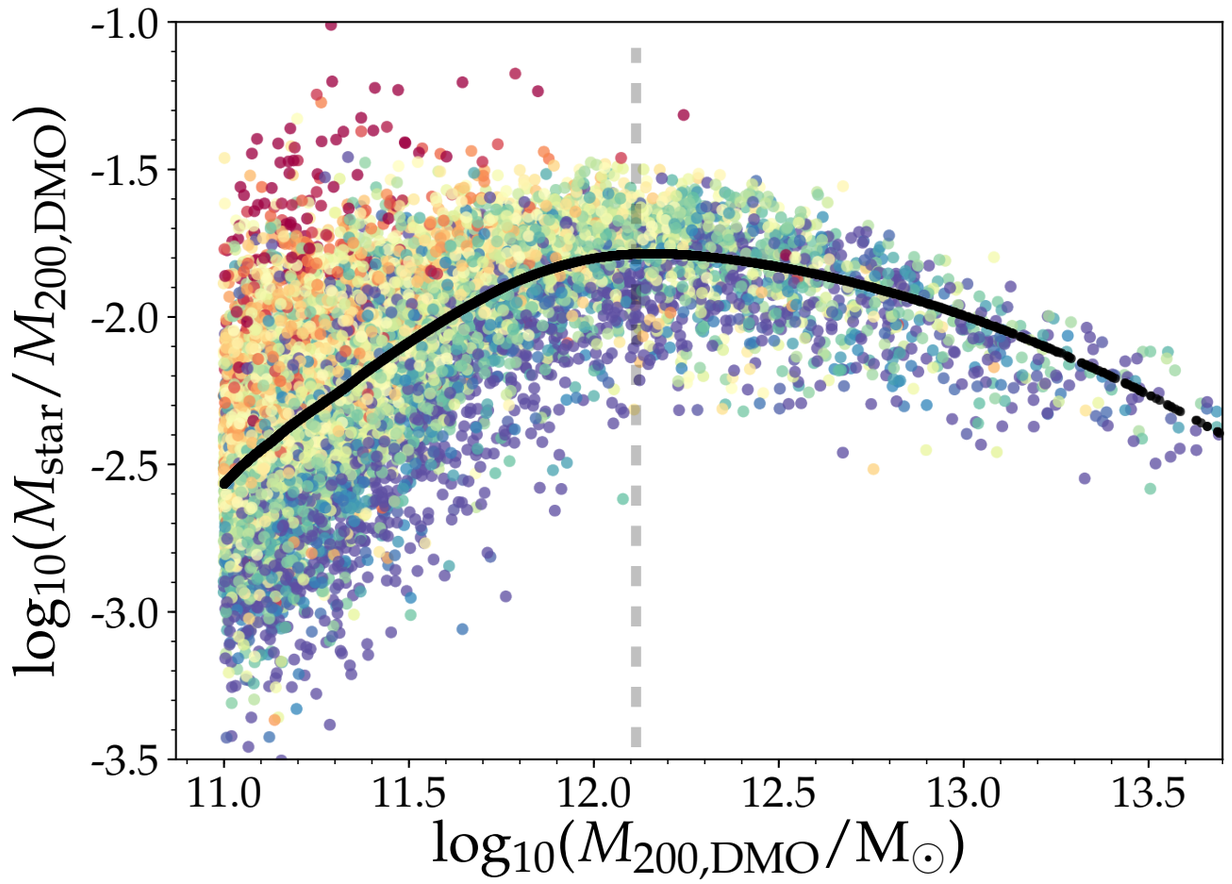
Matthee et al. 2017a, MNRAS, 465, 2381

The origin of scatter : concentration / formation time



Below the characteristic mass:
A halo with a higher concentration will lead to a higher stellar mass (cause),

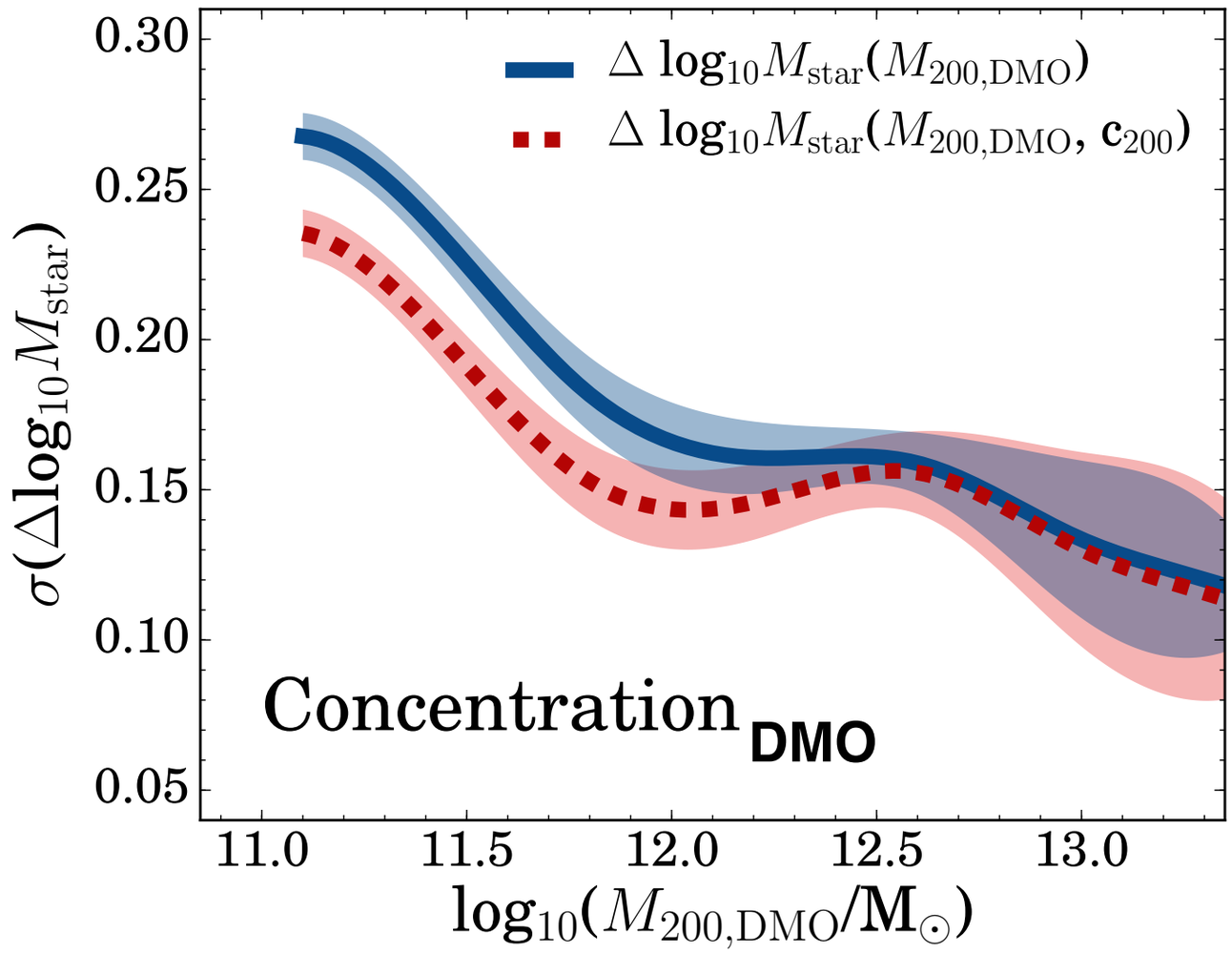
this will be amplified and increase the concentration even more (effect)

implies binding energy or V_{max} better tracers of M_{star} than M_{200} is

trend also seen in IllustrisTNG (Martizzi+2020)

Matthee et al. 2017a, MNRAS, 465, 2381

How much scatter is due to concentration / formation time?

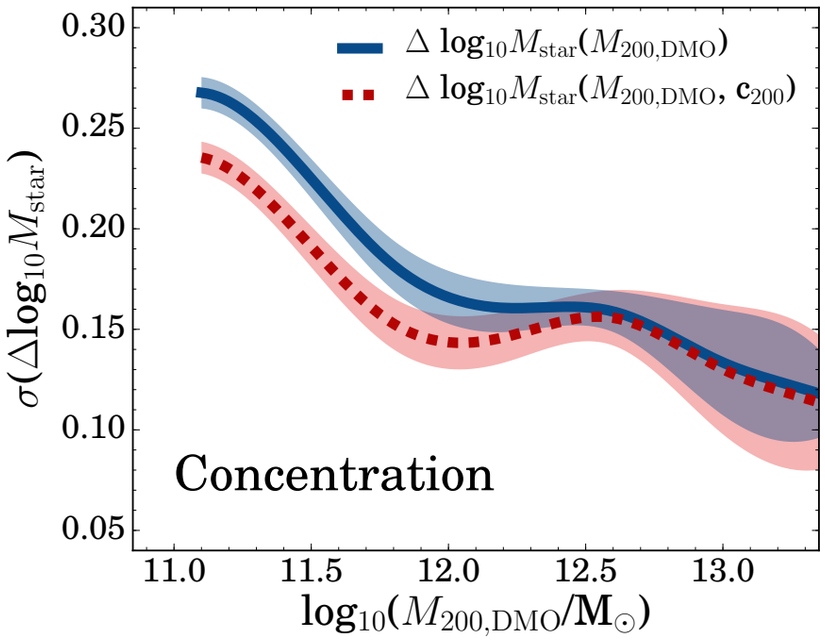


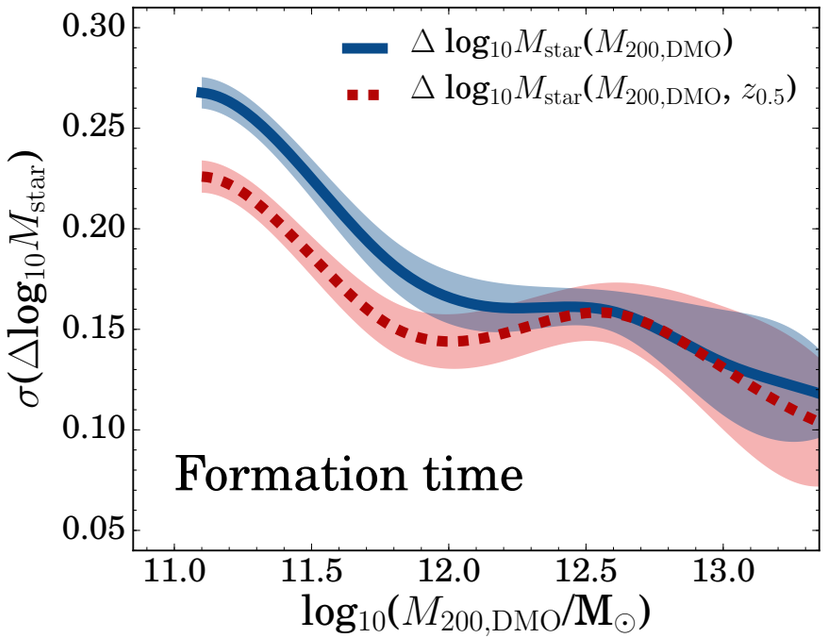
Note that the secondary correlation is only moderate *and* mass dependent (absent at high mass)

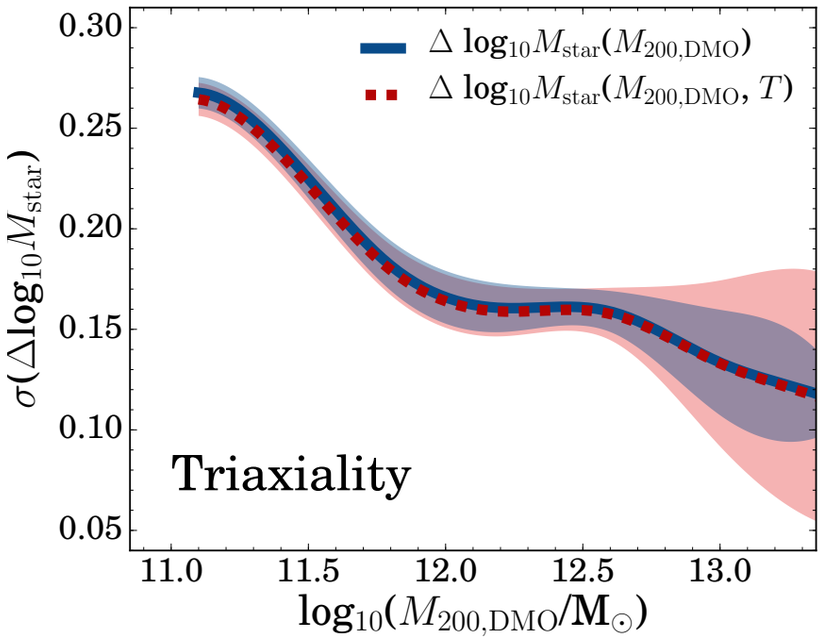
concentration/ formation time causes ~0.15 dex of scatter

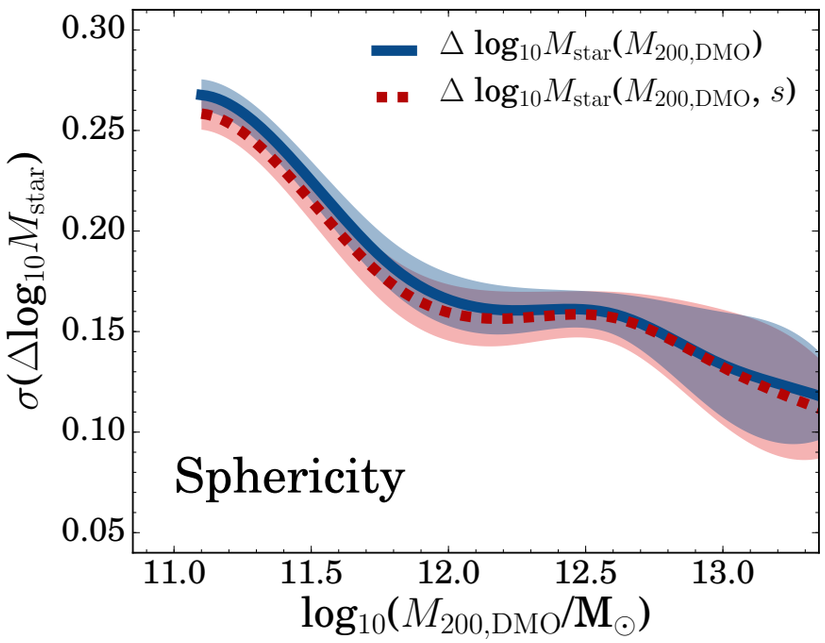
Matthee et al. 2017a, MNRAS, 465, 2381

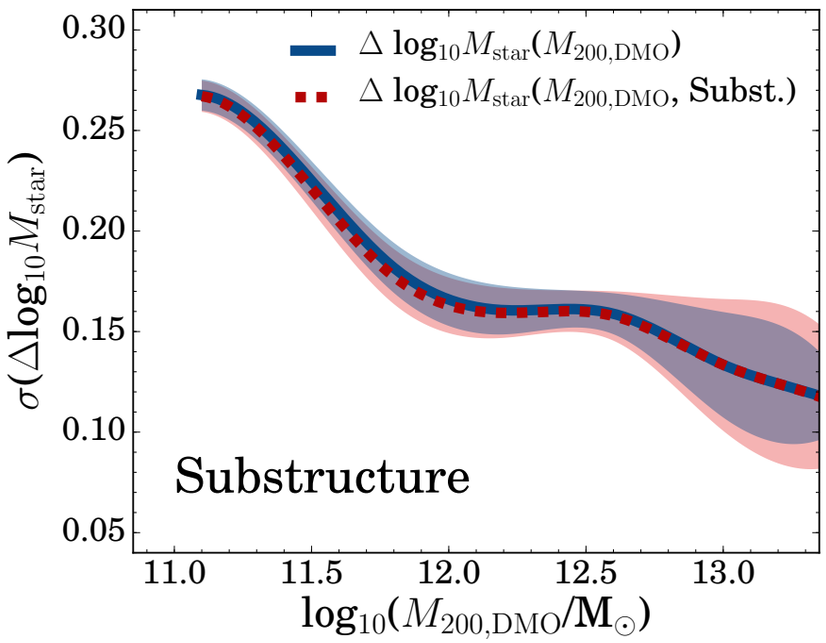
Majority of scatter is actually *not* explained by DMO properties
-> galaxy formation is to significant degree chaotic (?)

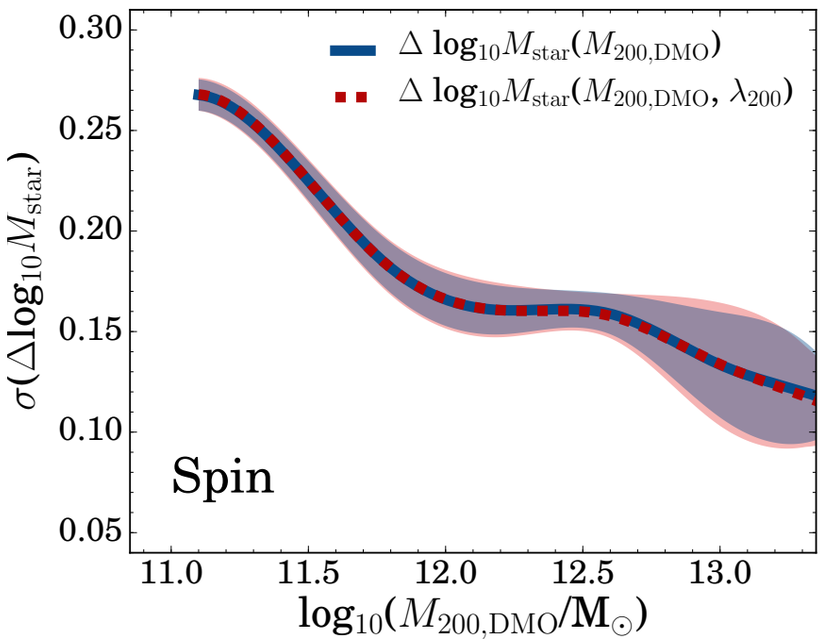






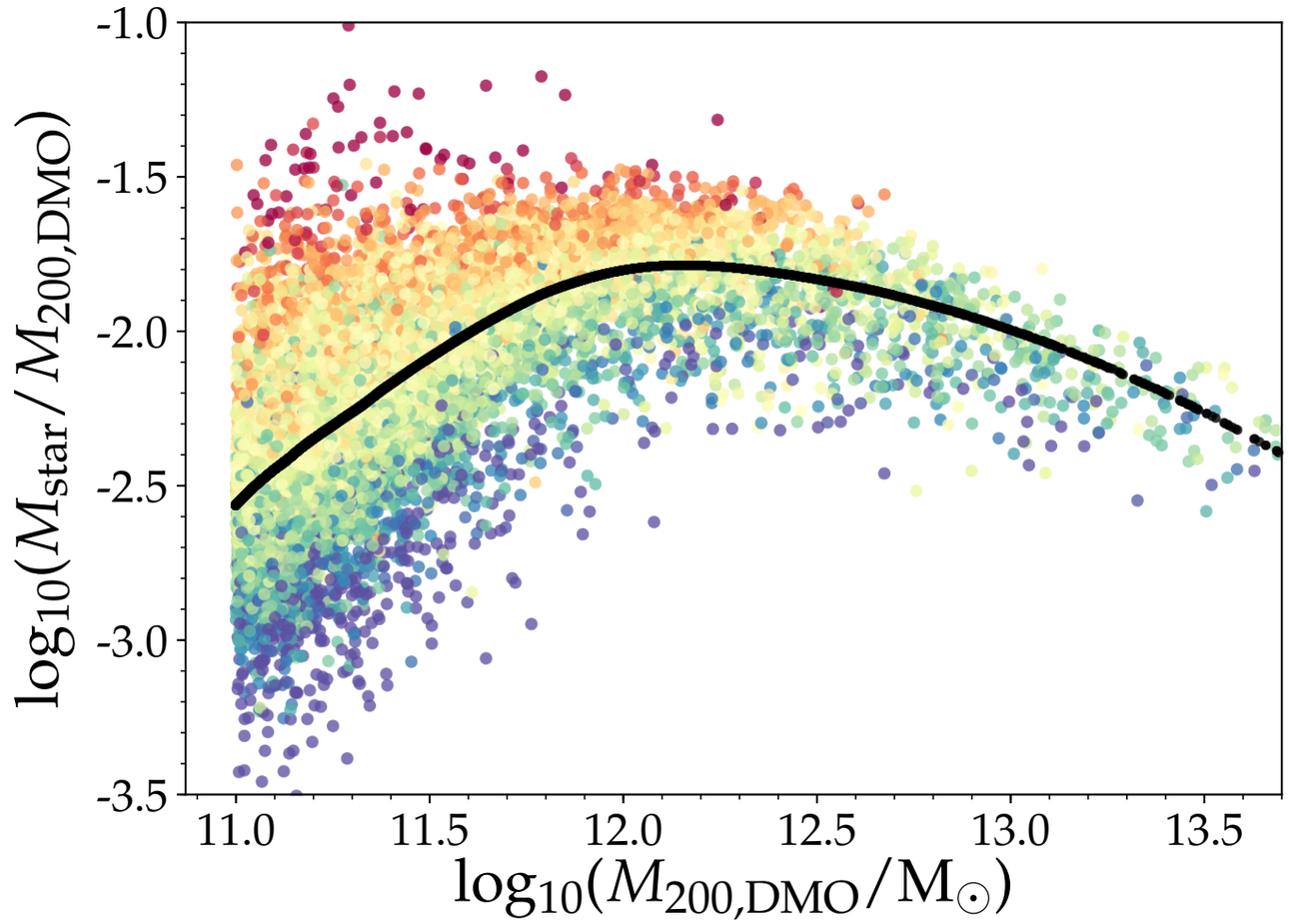






Matthee et al. 2017a, MNRAS, 465, 2381

Why does the scatter correlate with concentration?



A: concentration correlates with *formation time*, so older halos had more time to form stars

B: a higher concentration leads to halos that are more bound and feedback is less efficient in expelling gas

Matthee et al. 2017a, MNRAS, 465, 2381

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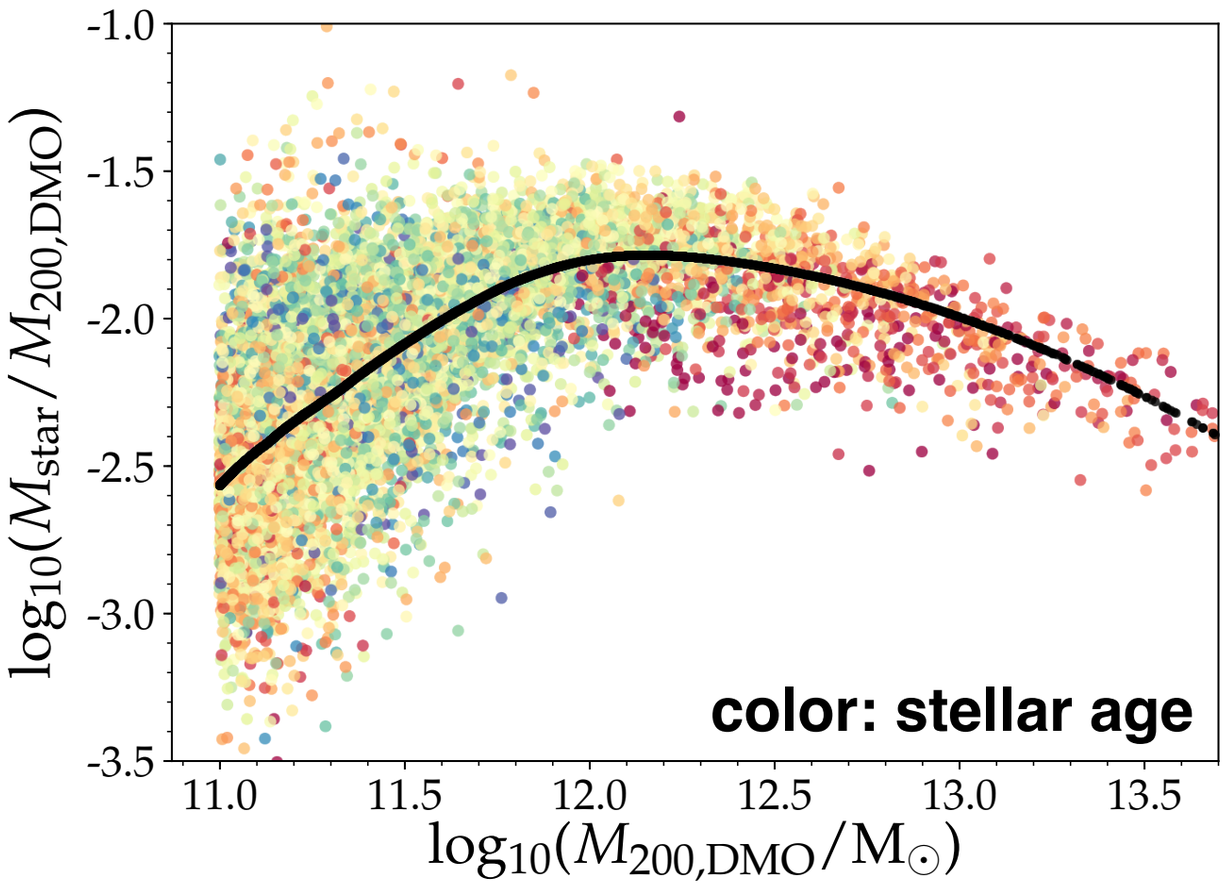
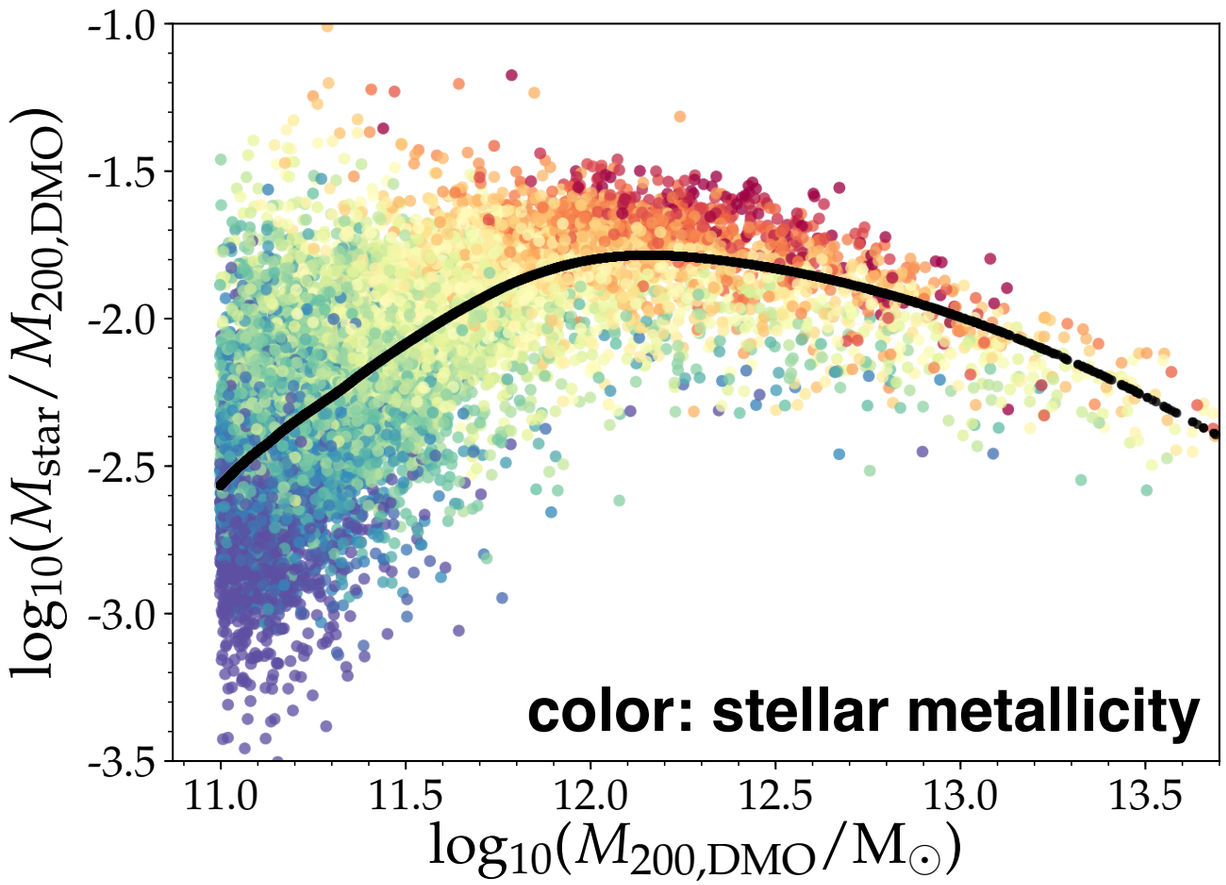


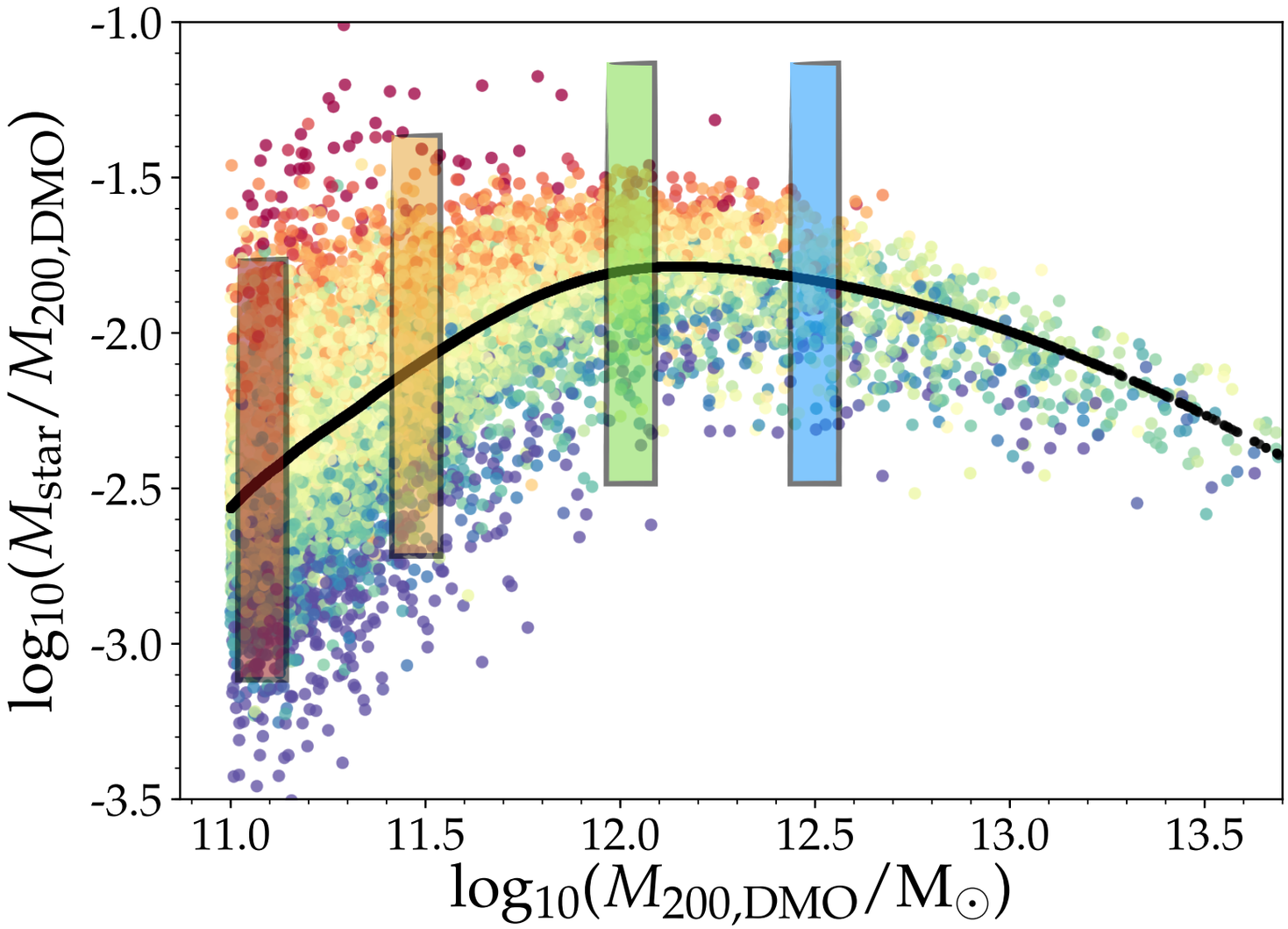


A: concentration correlates with formation time, so older halos had more time to form stars — ***but no strong age dependence?***

B: a higher concentration leads to halos that are more bound and feedback is less efficient in expelling gas — ***indicated by metallicity dependence?***

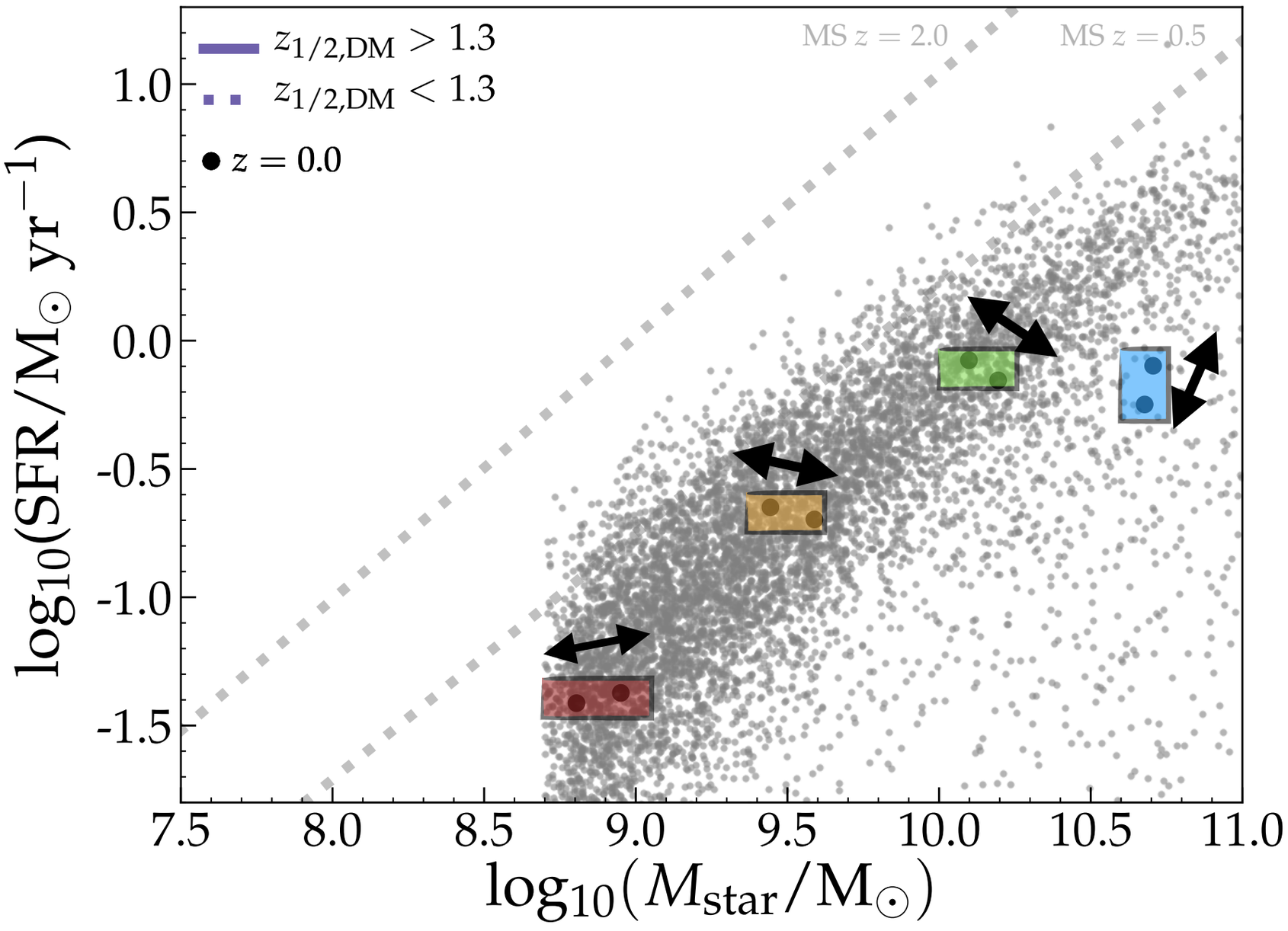
Unpublished quick results — to be explored :-)

Connection to star formation histories and ongoing (s)SFR



Bins in M_{200} and *formation time (i.e. concentration)*

Paths through SFR-M_{star} space in bins of halo mass & formation time



Matthee & Schaye 2019, MNRAS, 484, 915

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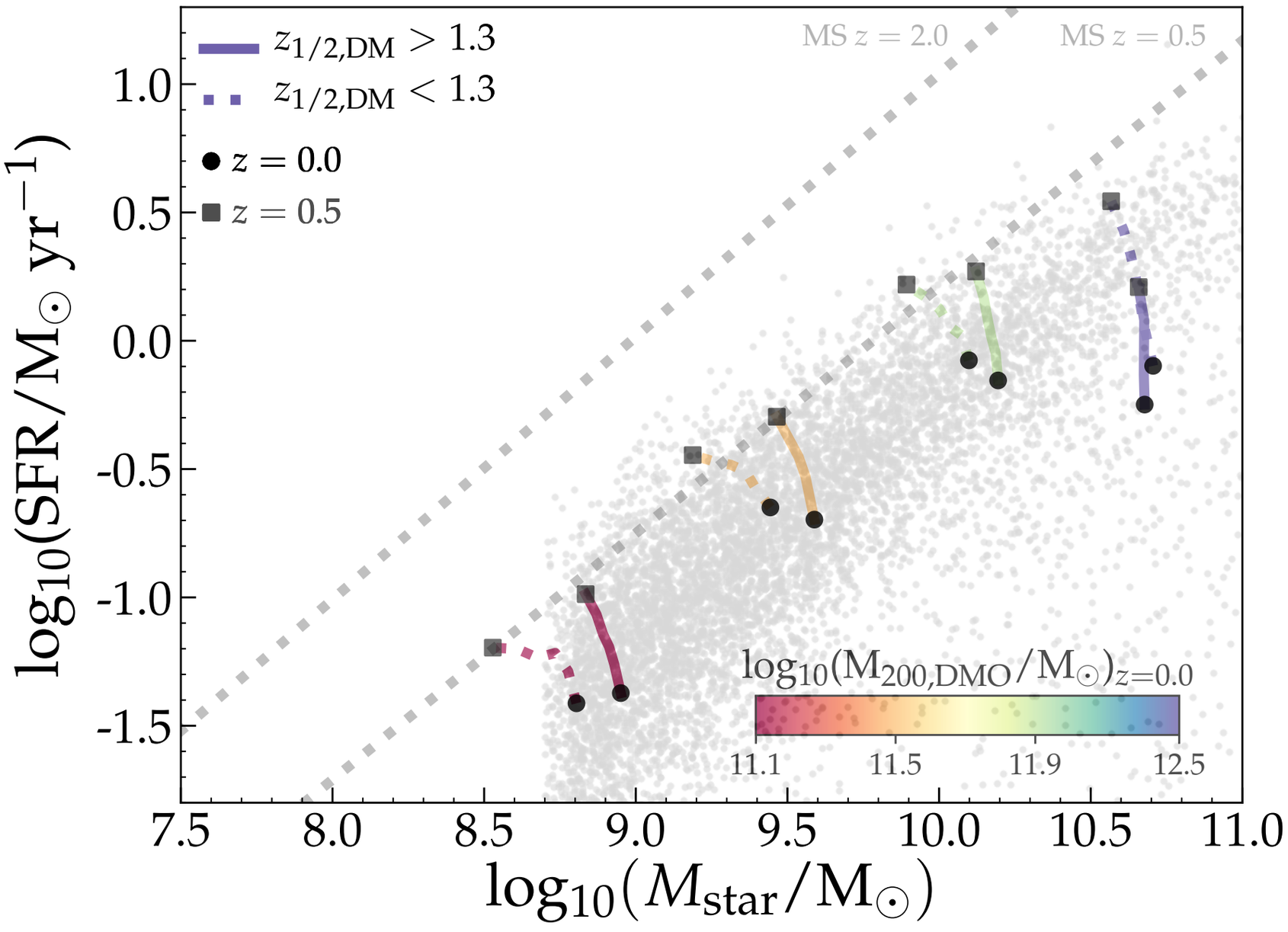

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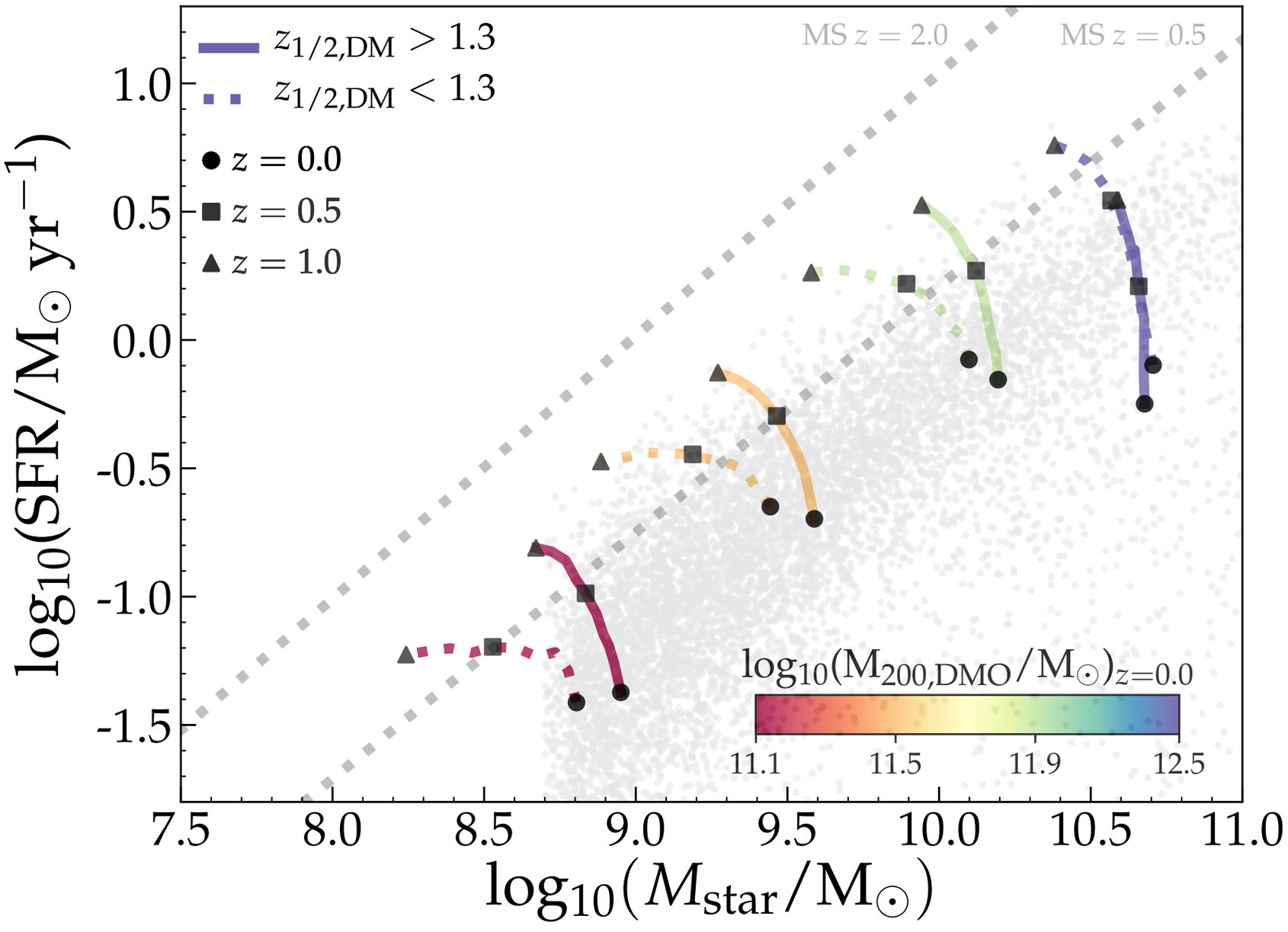

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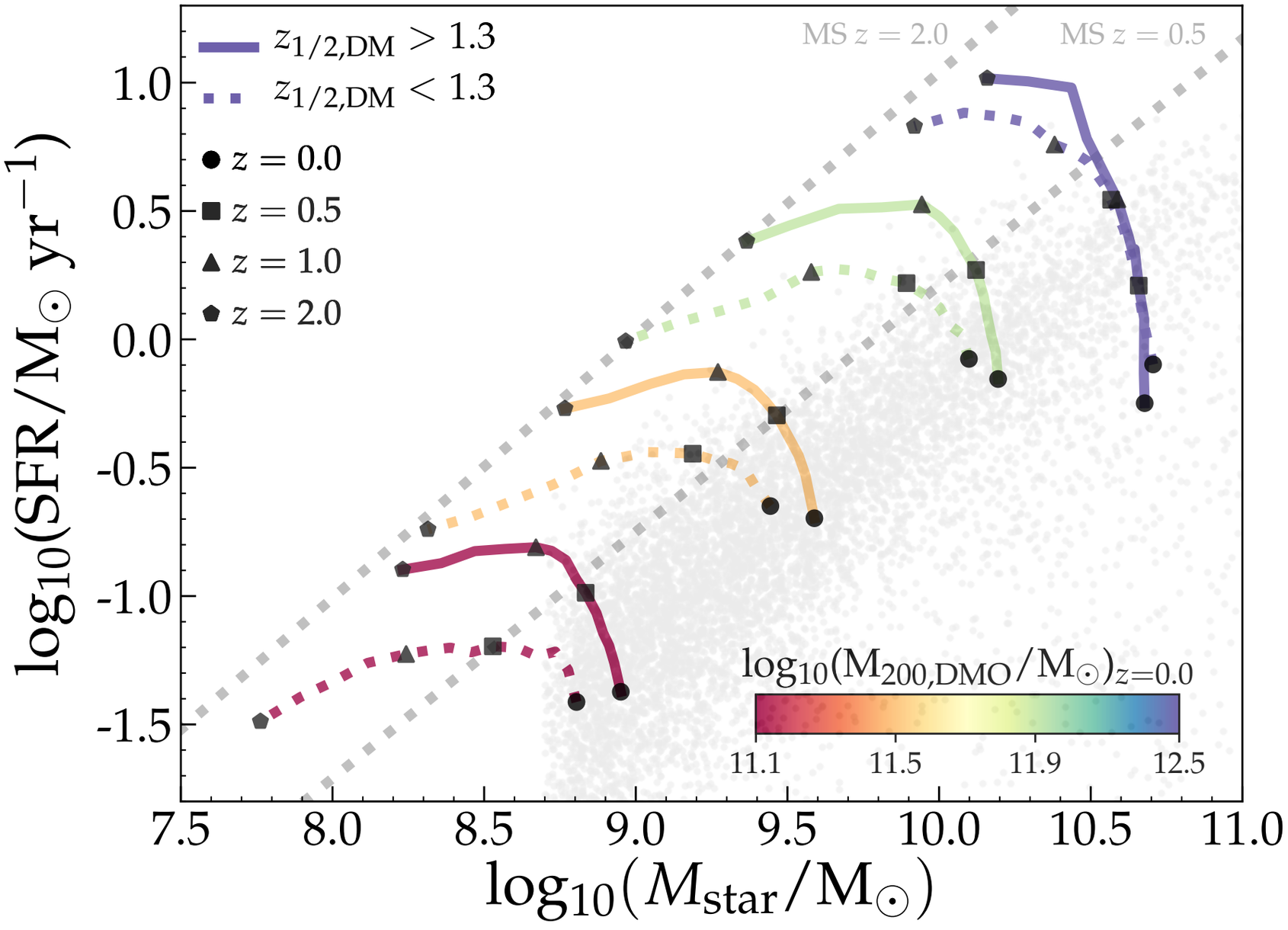

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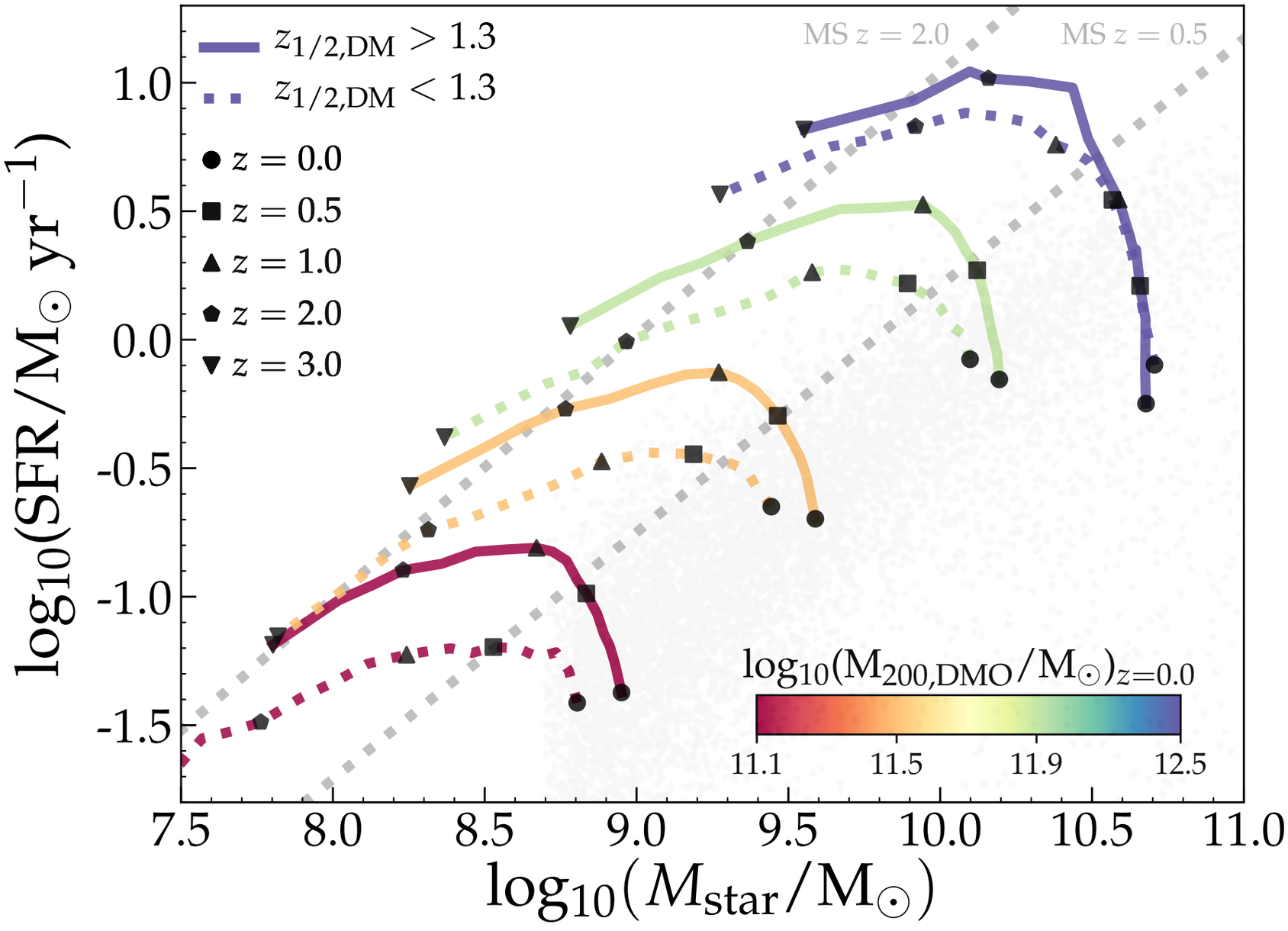

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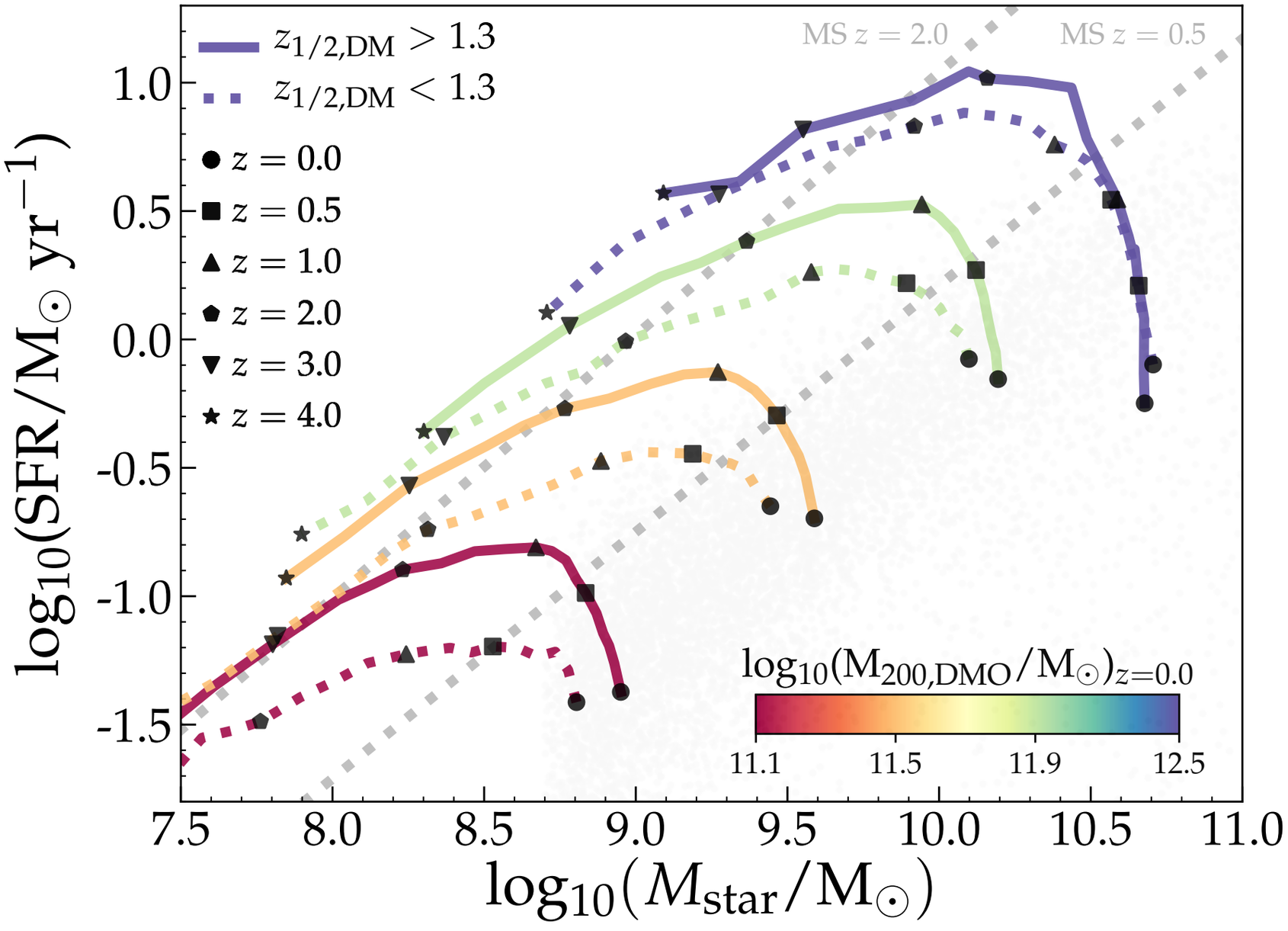

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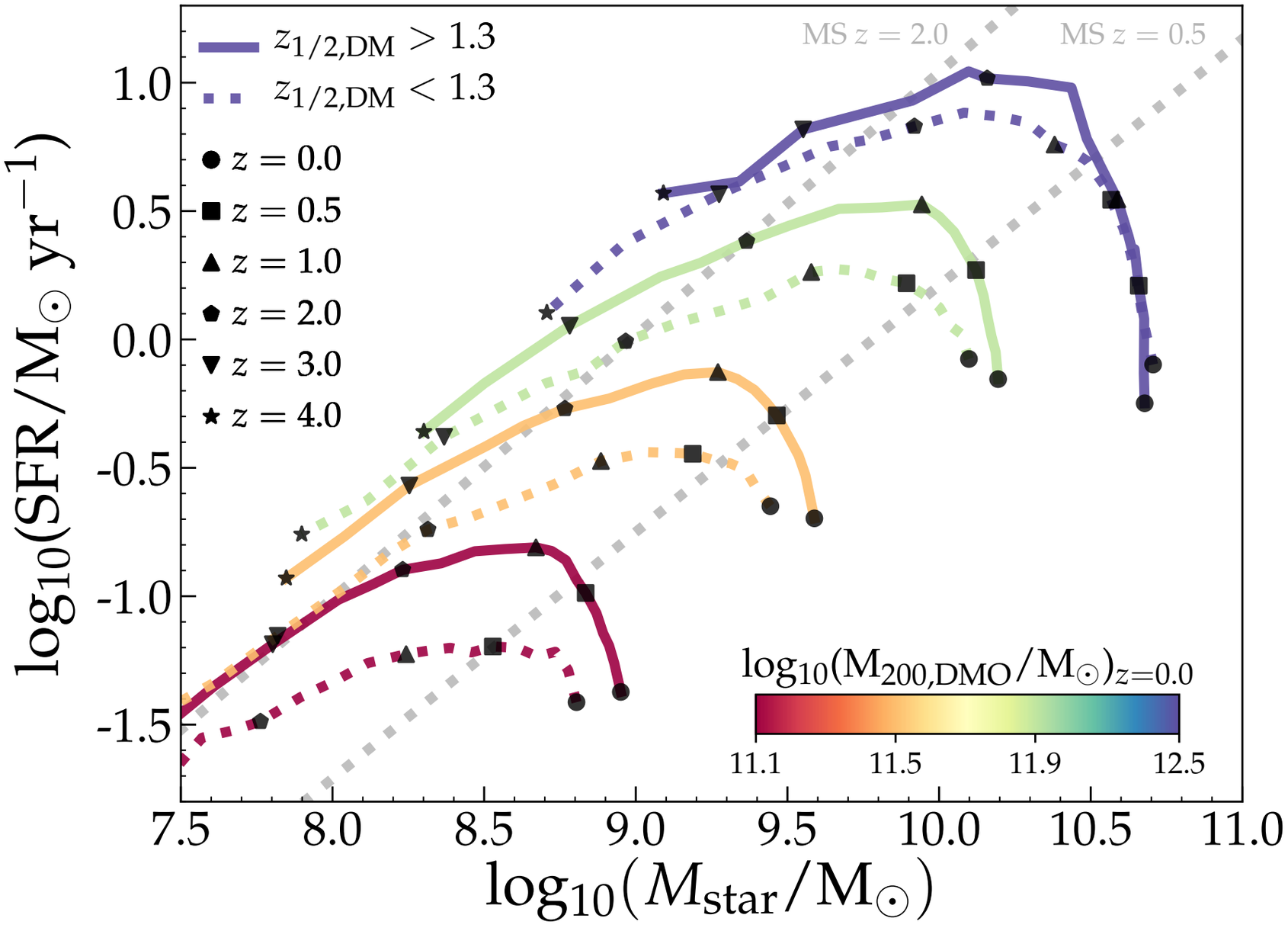
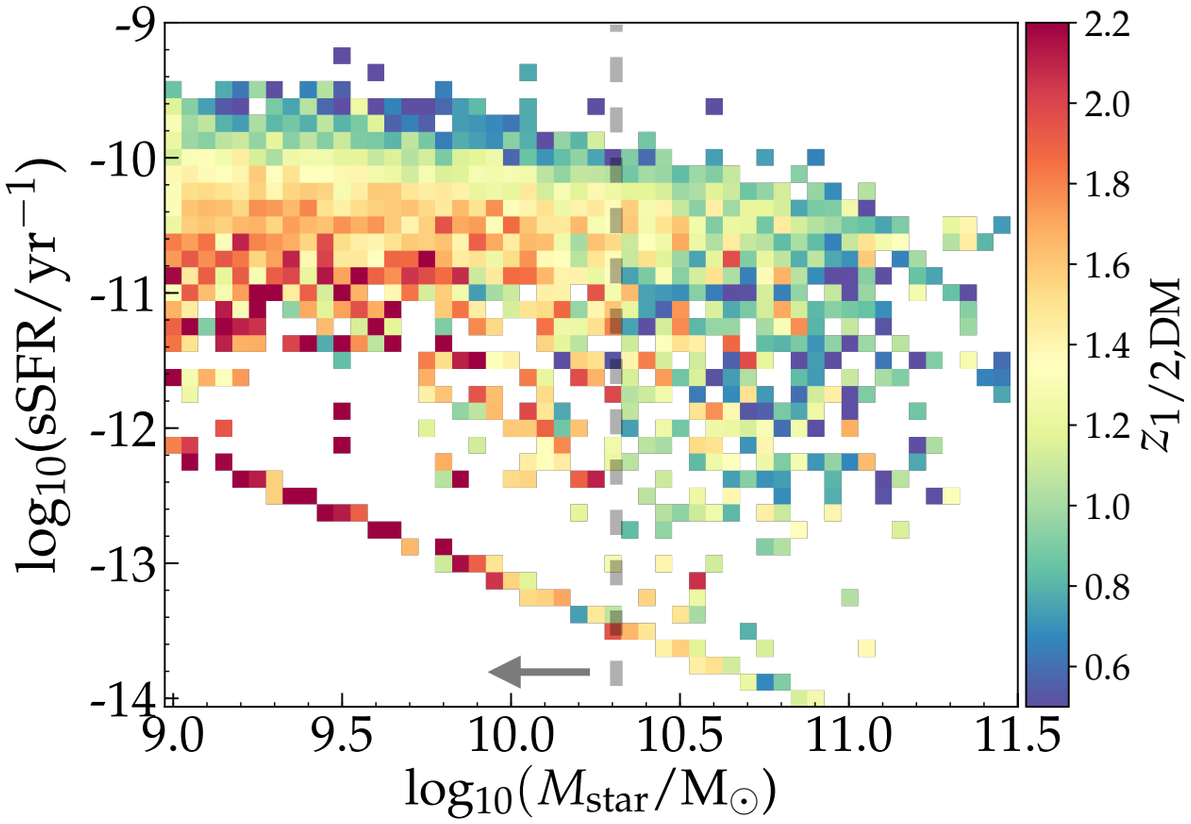
Paths through SFR-M_{star} space in bins of halo mass & formation time



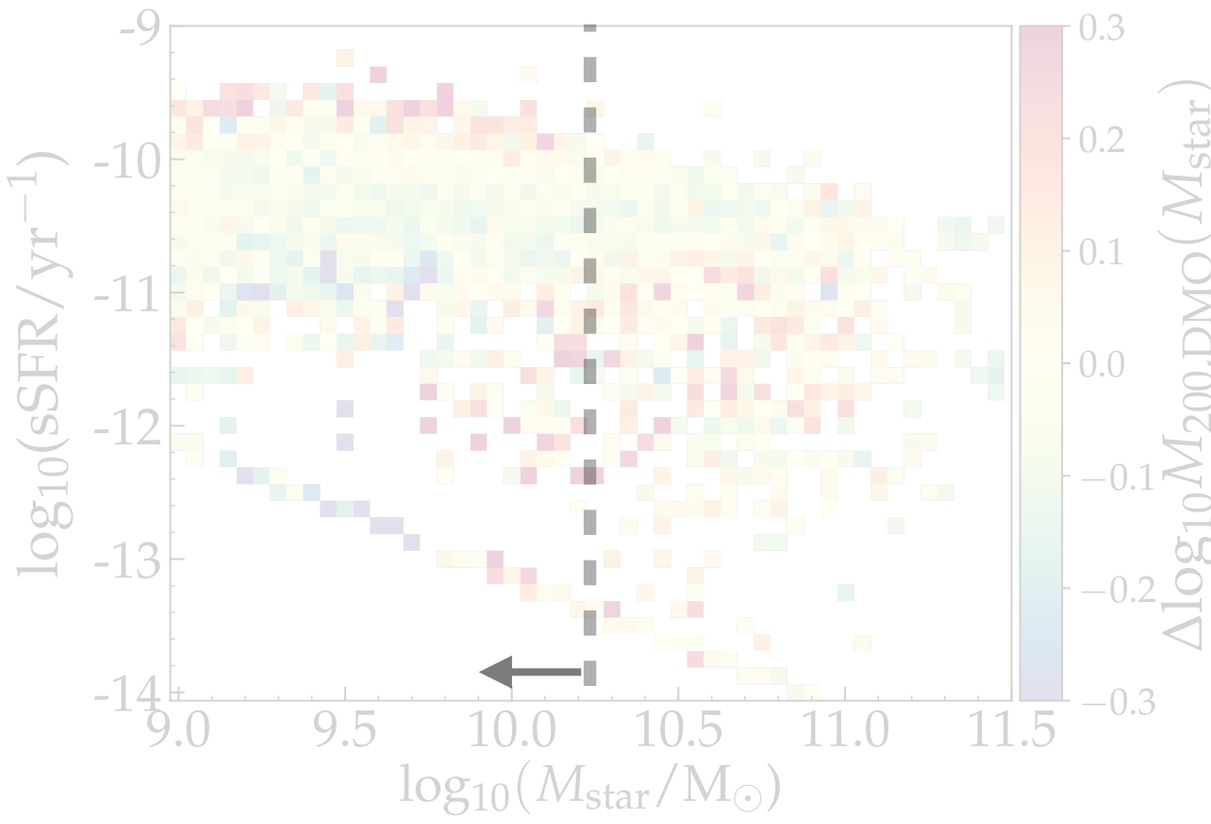
both halo mass & formation time influence star formation history
this also impacts the scatter in SFR-M_{star} plane

Matthee & Schaye 2019, MNRAS, 484, 915

Scatter in SFR-M_{star} also connected to scatter in Mhalo-Mstar



At low mass, sSFR correlates with formation time (concentration)

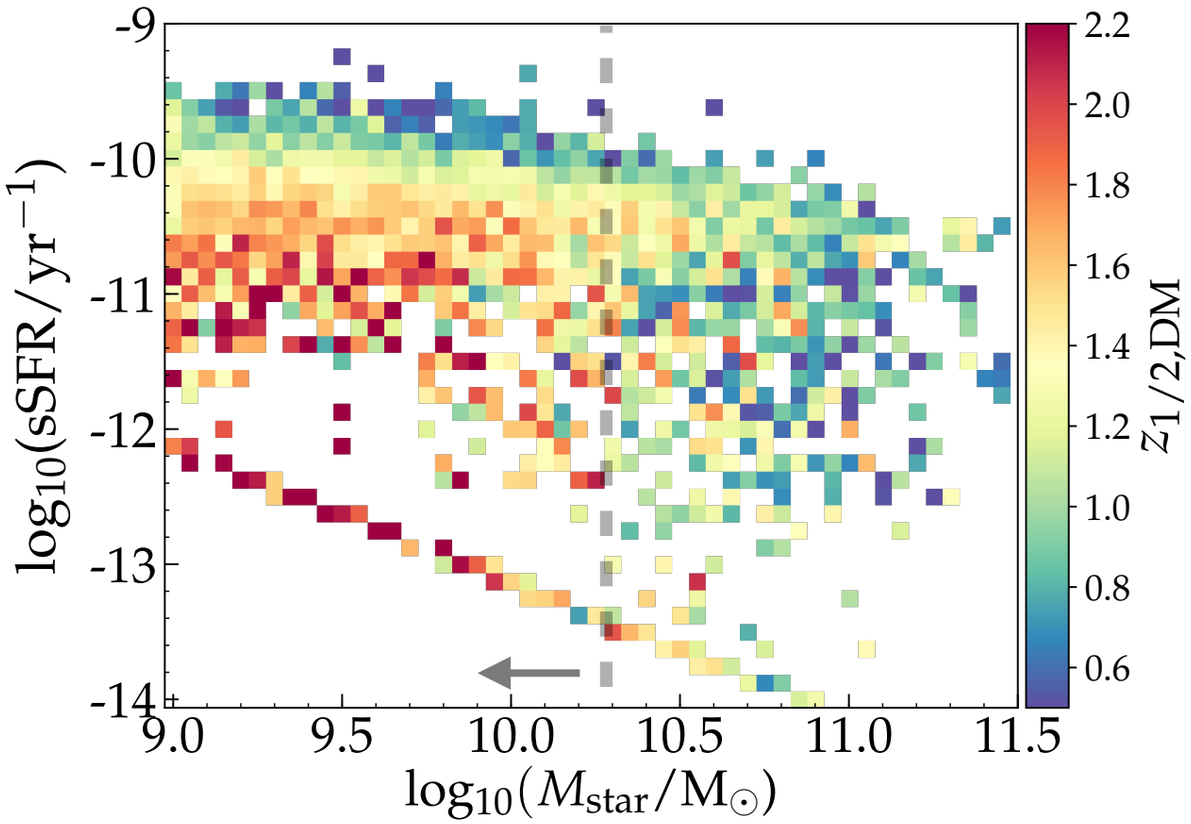


At low mass, sSFR correlates somewhat with scatter SMHM

correlation flips at high M

Matthee & Schaye 2019, MNRAS, 484, 915

Scatter in SFR-M_{star} also connected to scatter in Mhalo-Mstar



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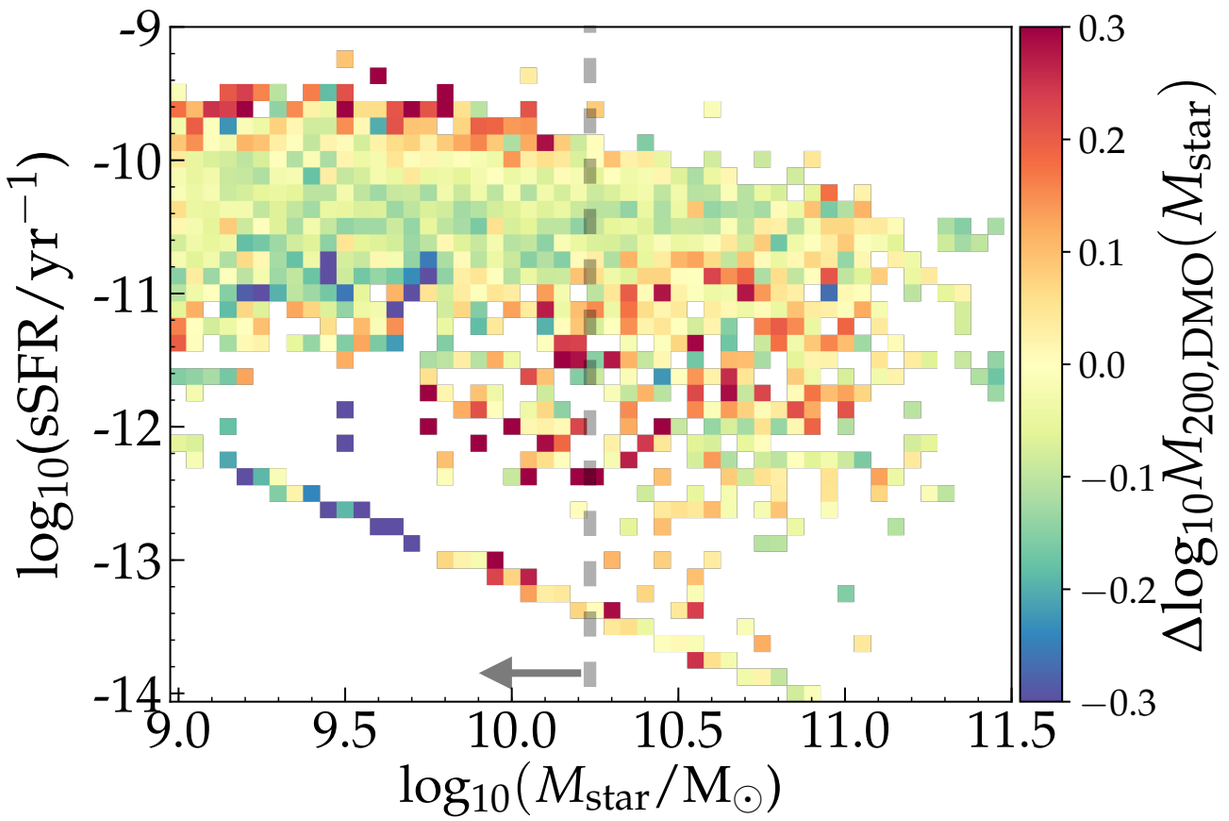


At low mass, sSFR correlates somewhat with scatter SMHM

correlation flips at high M_{star}

Matthee & Schaye 2019, MNRAS, 484, 915

Scatter in SMHM, in cosmological hydro simulations (EAGLE):

* **Below M_{200}~10^12 M_{sun}, there is a causal secondary dependence of the scatter on formation time / concentration:**
  - **DM halos with higher concentration / earlier formation time have a higher stellar mass at z=0**

  - **This is connected to galaxies' trajectories through SFR-M_{star} plane, and the scatter in the SFR-M_{star} relation**

* **Formation time / concentration accounts for ~0.15 dex of scatter**

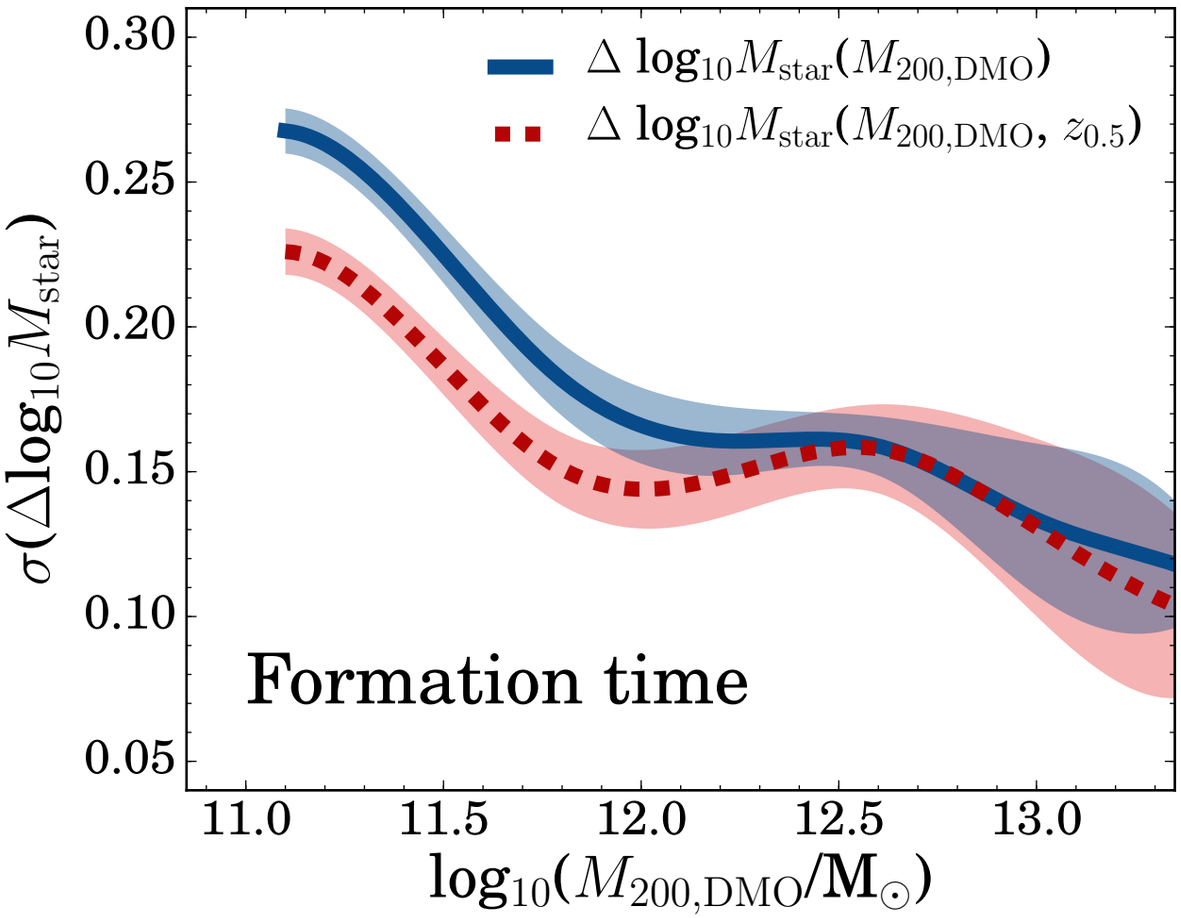
  Remaining ~0.2 dex of scatter is uncorrelated to various DM halo properties: galaxy formation to large degree a chaotic process?

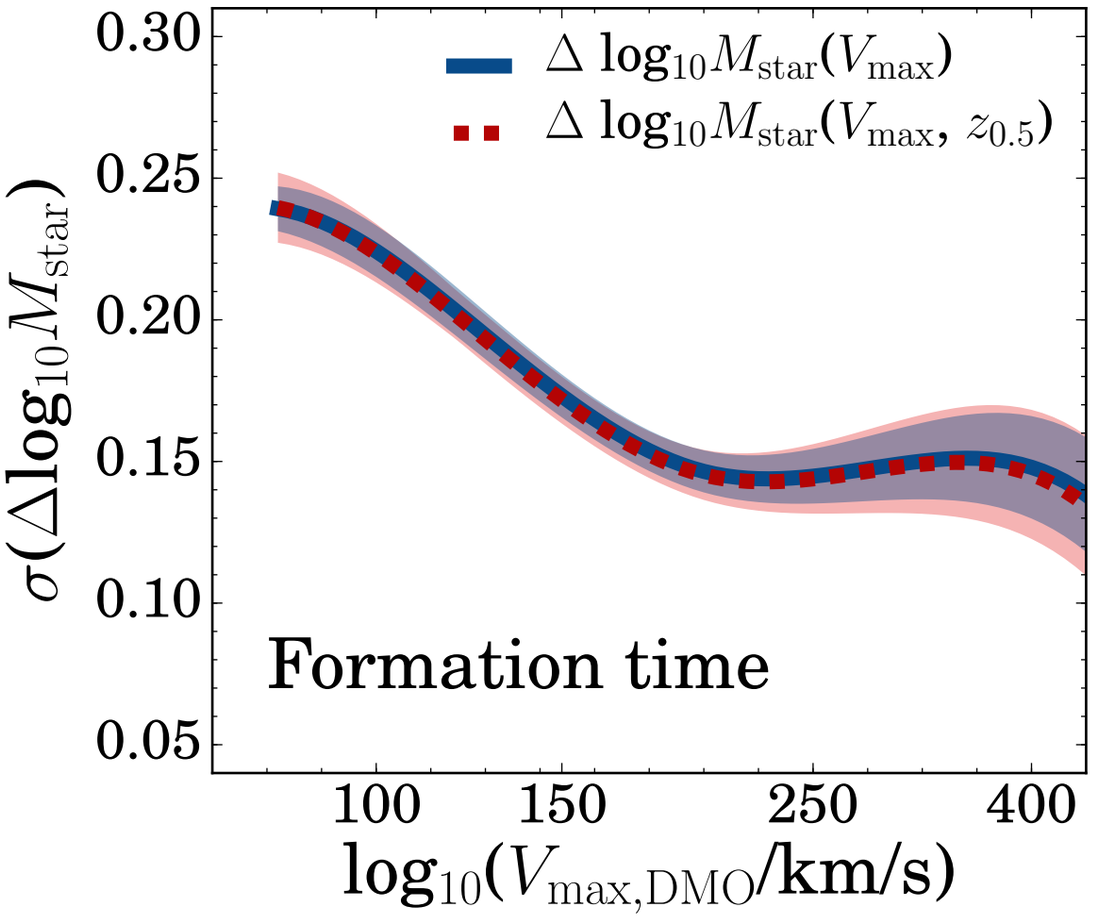
Matthee et al. 2017a, MNRAS, 465, 2381
Matthee & Schaye 2019, MNRAS, 484, 915

Extra slides

A consequence:

any property combing halo mass with concentration (such as V_{max}) is better correlated to M_{star} than M_{200} is

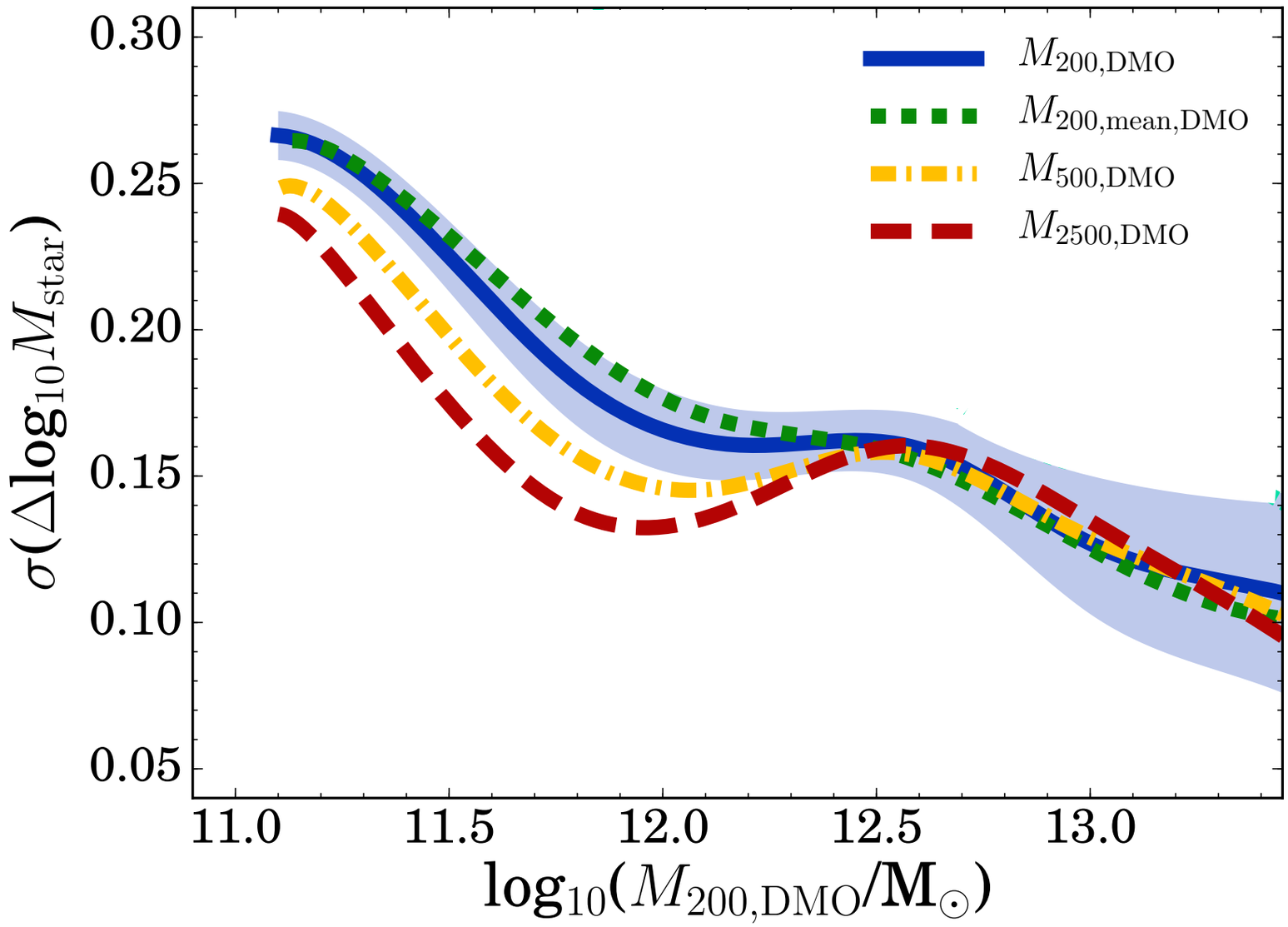




but formation time / concentration do not contribute to scatter in M_{star}-V_{max} relation

Matthee et al. 2017a, MNRAS, 465, 2381

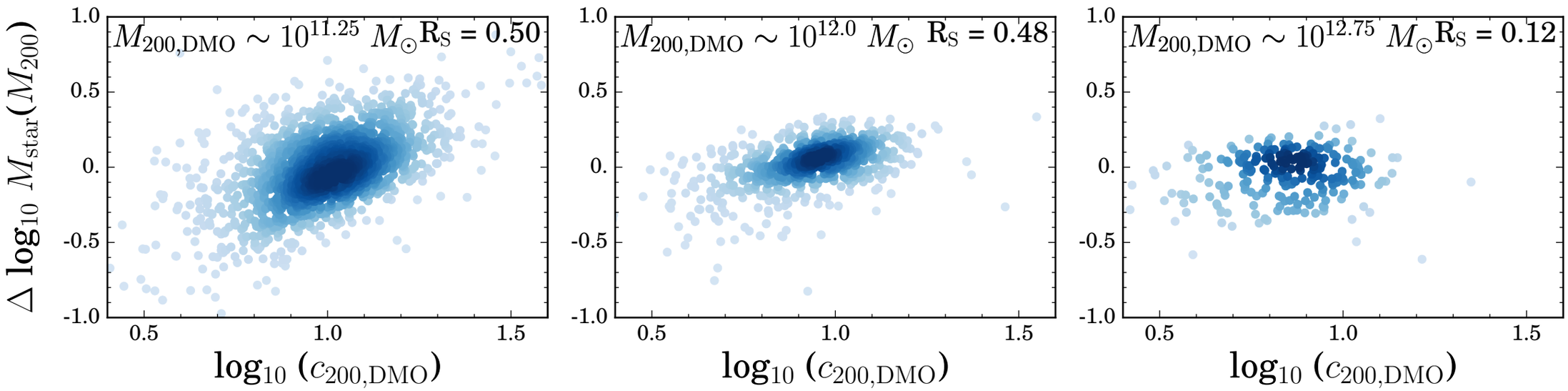
Scatter also depends on definition of halo mass (EAGLE)



Less scatter if halo mass is measured within smaller radius

Matthee et al. 2017a, MNRAS, 465, 2381

Origin of scatter at z=0 :
mass dependence of secondary correlation



Second-order correlation with concentration present up to the characteristic mass

Matthee et al. 2017a, MNRAS, 465, 2381