Exploring Relationship between Assembly bias and Halo properties toward Dark Emulator II

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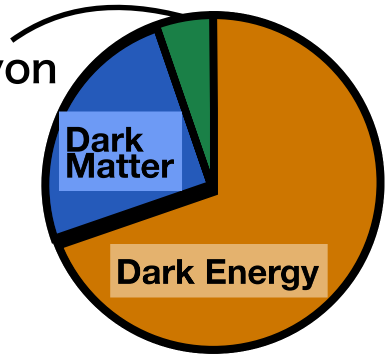
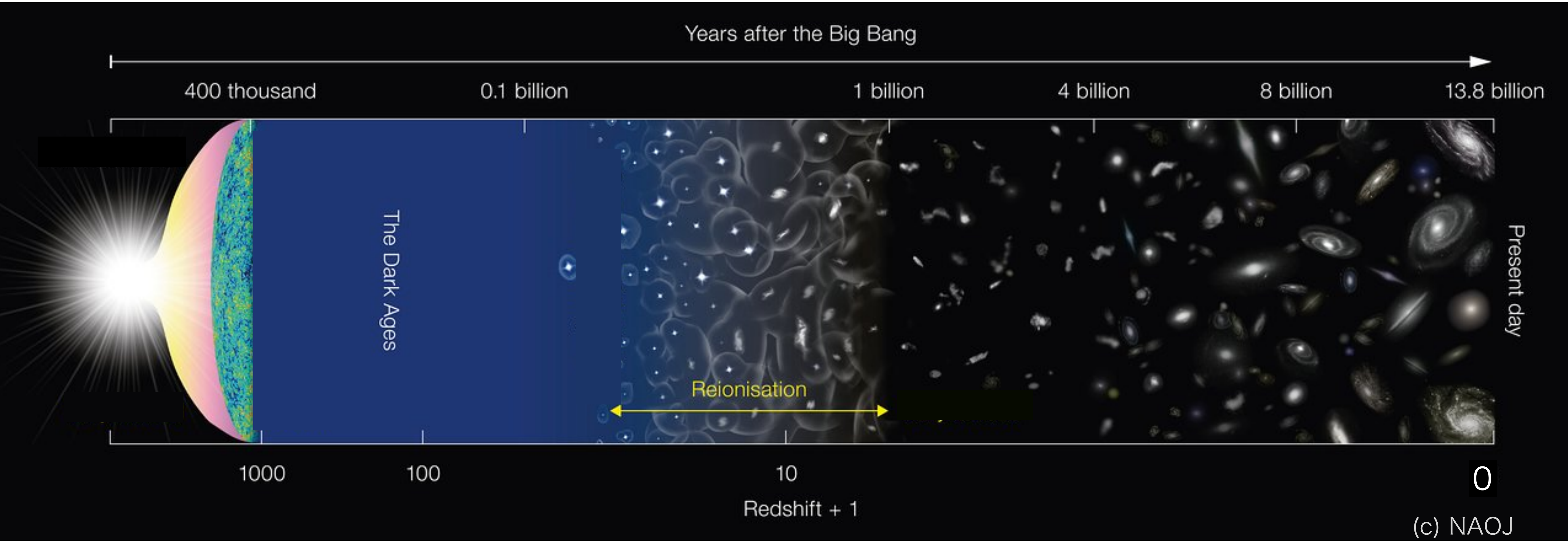
Challenging Theory with Roman 2024 2024/07/11

LSS as a Cosmological Prove

Structures on a scale larger than that of galaxy clusters, which are being formed in a struggle between dark matter and dark energy.





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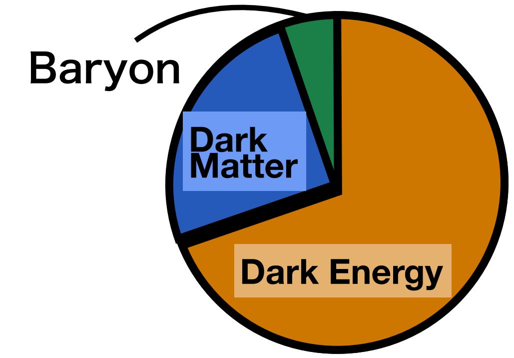
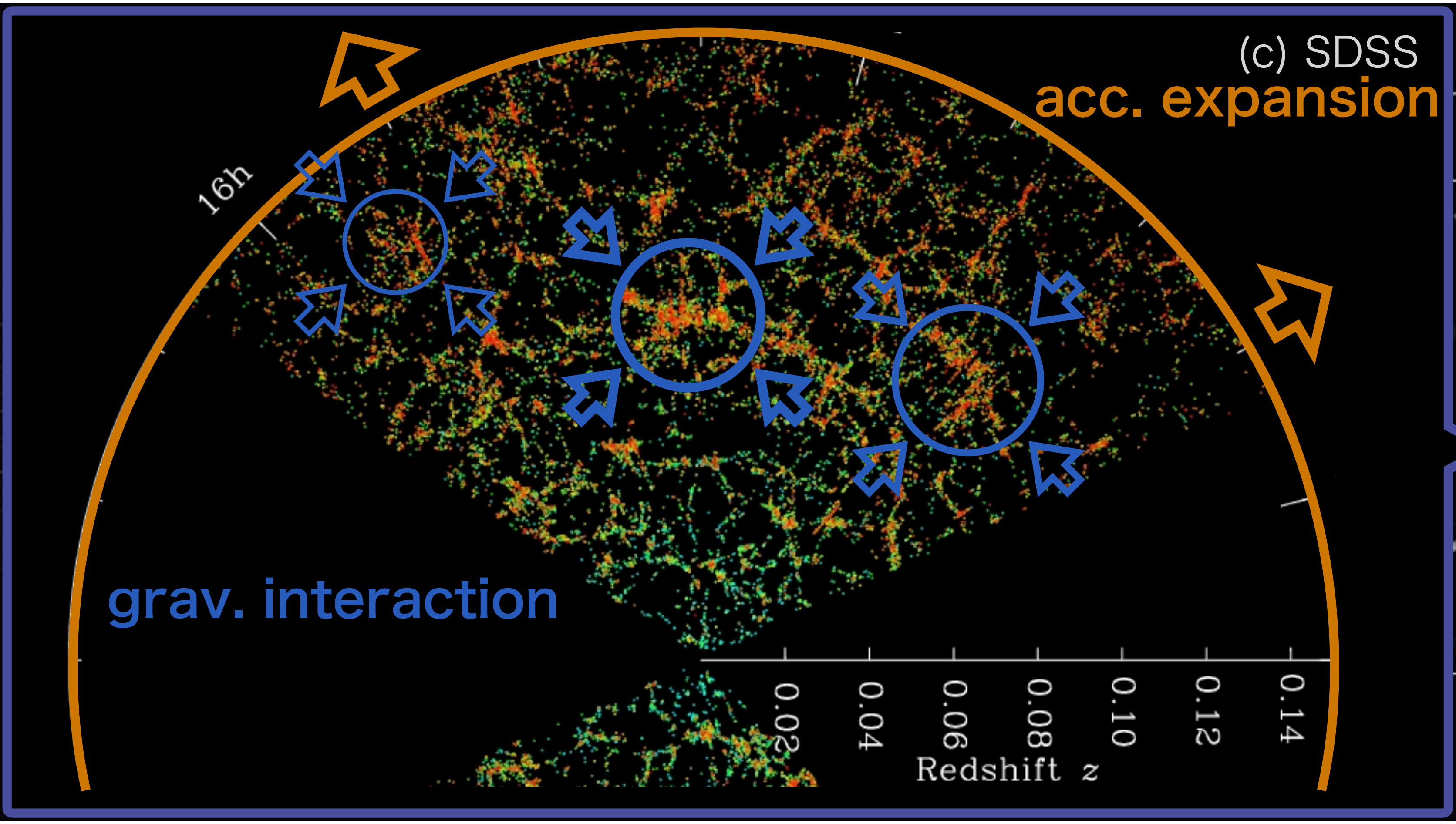
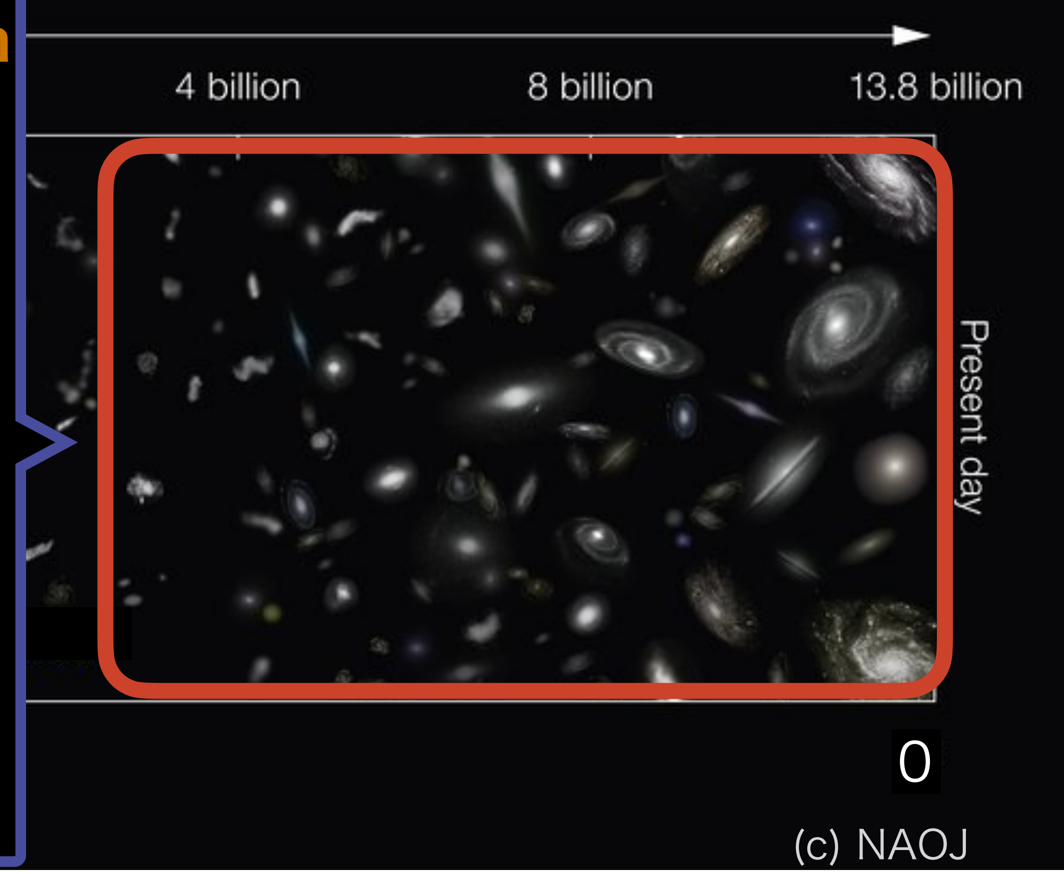
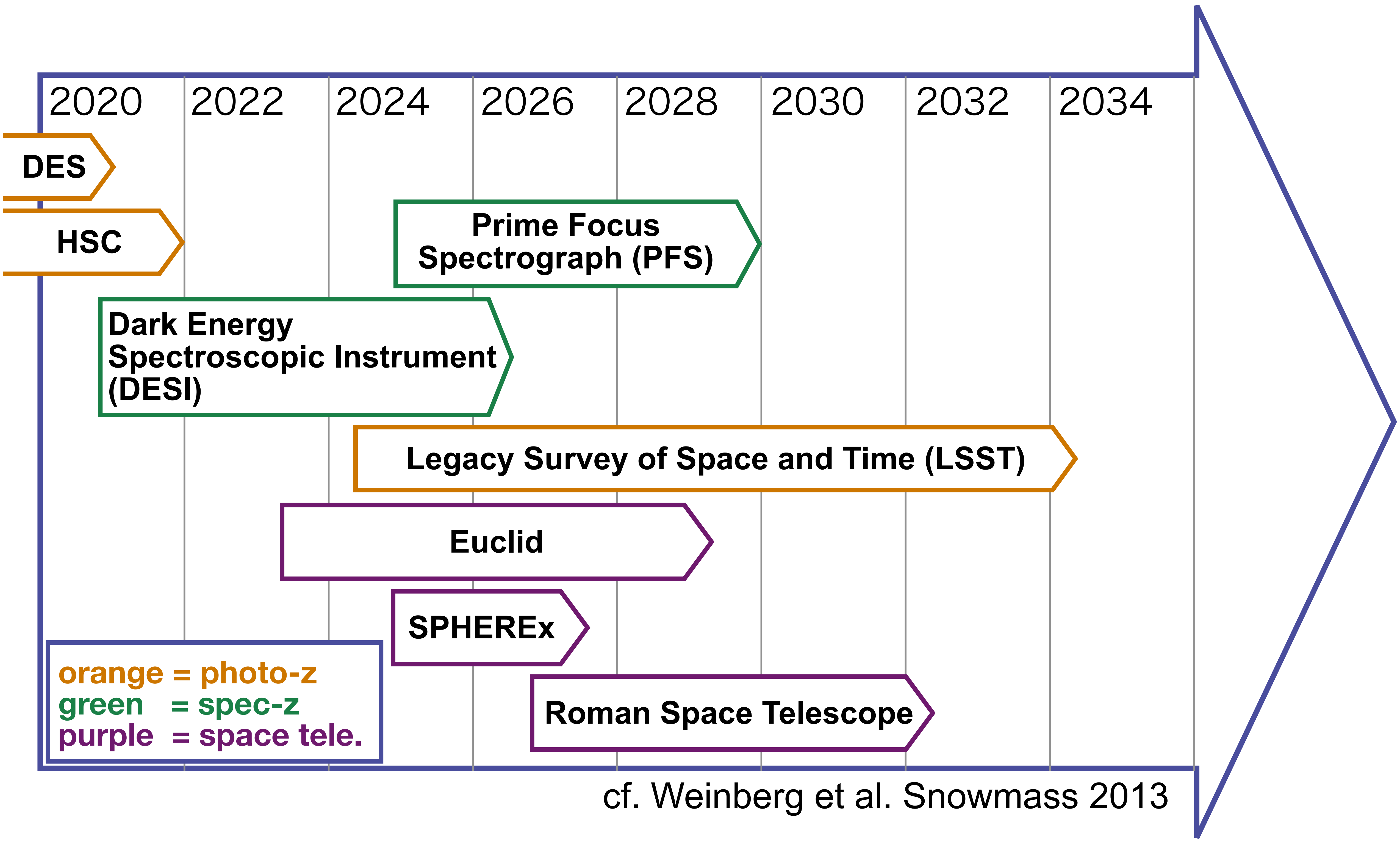






To understand nature of **dark energy** and **dark matter** through Large Scale Structure (LSS)

Current & Future Observation



cf. Weinberg et al. Snowmass 2013

Current & Future Observation

2020	2022	2024	2026	2028	2030	2032	2034

Systematic error > Statistical error

Need precise theoretical model…

⇩

Cosmological emulators that calculates
theoretical prediction of structure evolutions rapidly and accurately.

- Dark Emulator 2
- Euclid Emulator 2
- MiraTitan IV
- Baccoemu

etc.

Current & Future Observation

2020	2022	2024	2026	2028	2030	2032	2034

Systematic error > Statistical error

Observational

- Photo-z cf. KI+2023
- Galaxy shape
- Random catalog etc.

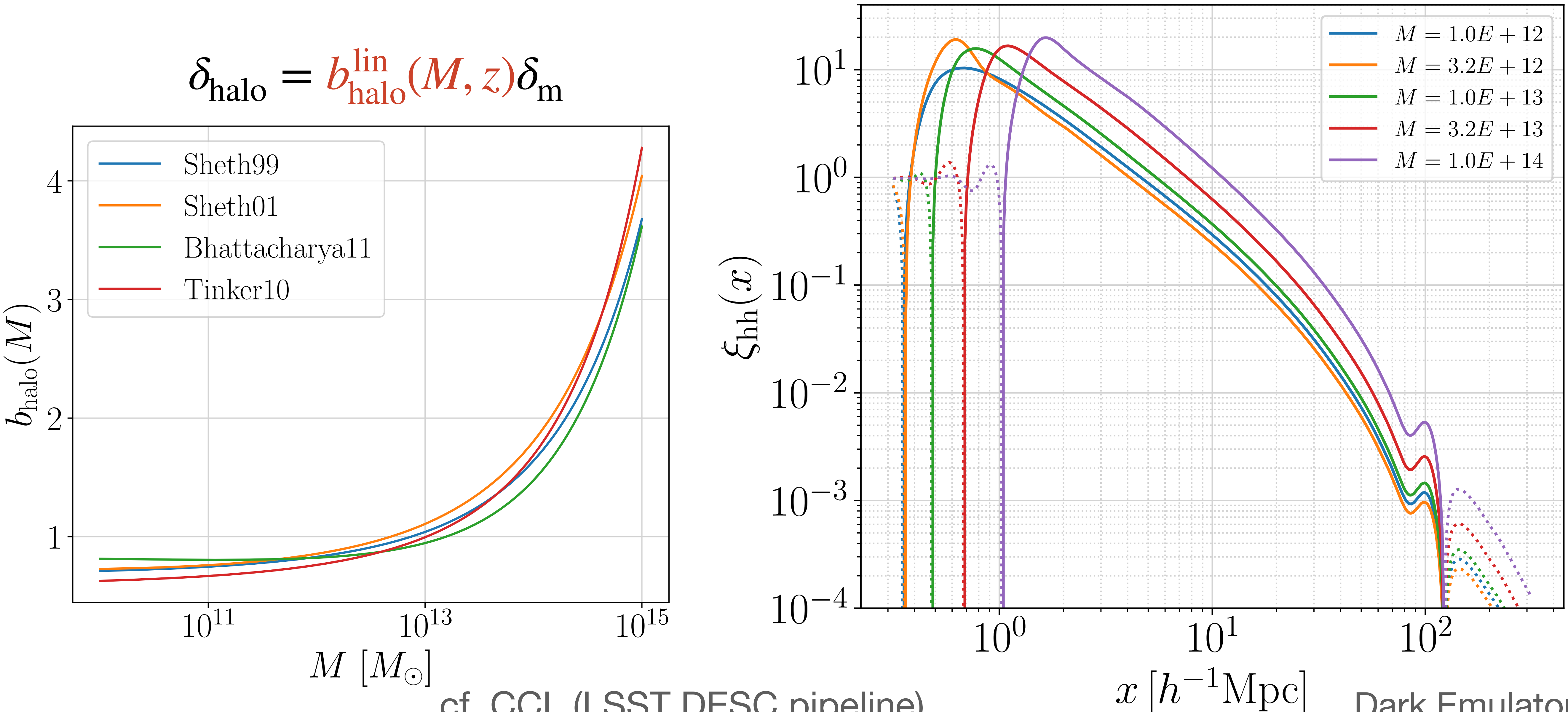
Astrophysical

- **Halo Assembly Bias**
- AGN feedback etc.

What is halo assembly bias?

linear halo bias

$$\delta_{\mathrm{halo}} = b^{\mathrm{lin}}_{\mathrm{halo}}(M, z)\delta_{\mathrm{m}}$$



cf. CCL (LSST DESC pipeline)

Dark Emulator

The linear halo bias primarily depends on halo mass.

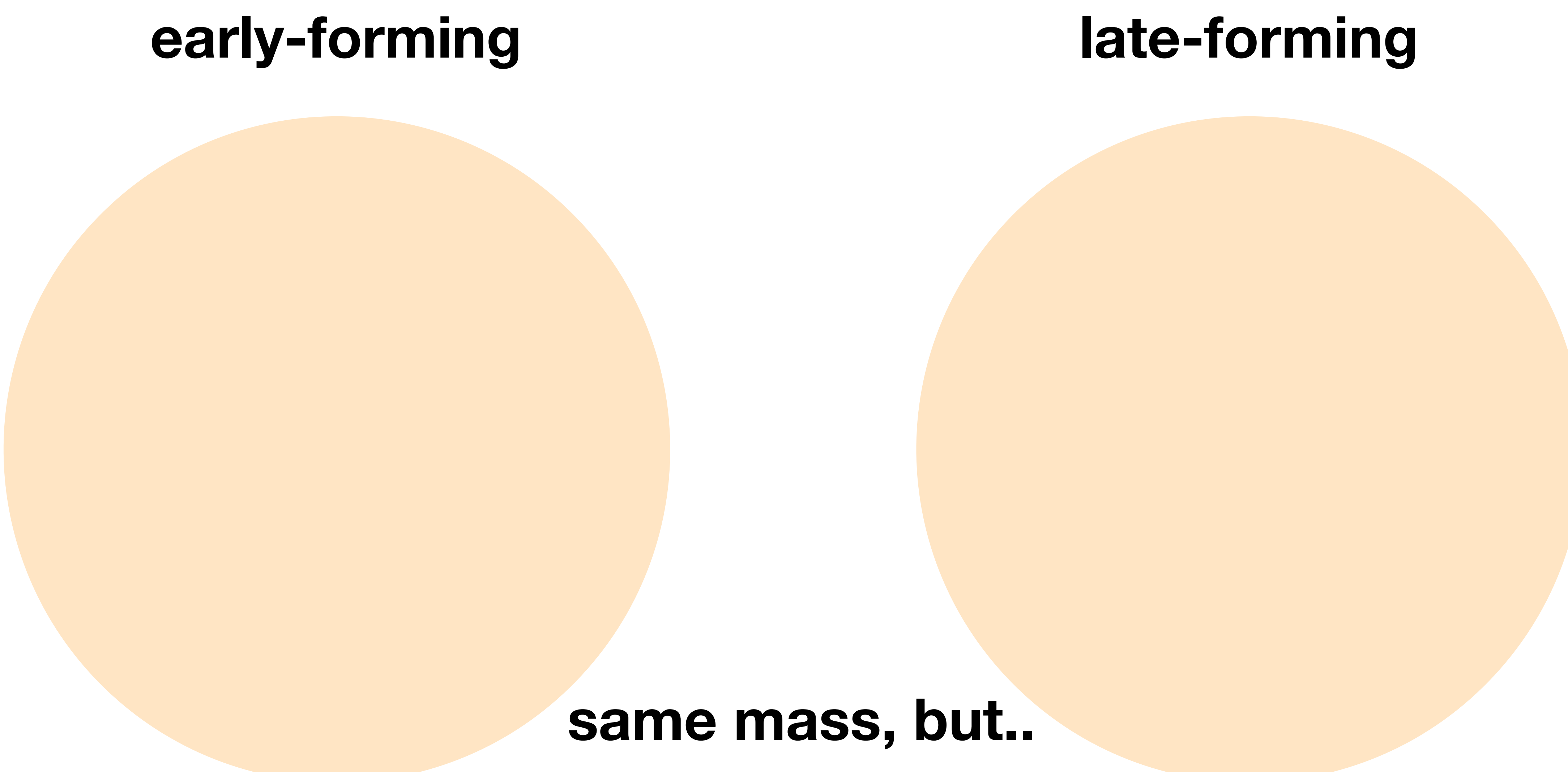
What is halo assembly bias?

Secondary dependence

on physical quantities other than halo mass

concentration, local overdensity, assembly history, …

ex. The case we focus on halo that has higher than typical collapsing mass



What is halo assembly bias?

Secondary dependence
on physical quantities other than halo mass

ex. The case we focus on halo that has higher than typical collapsing mass

early-forming

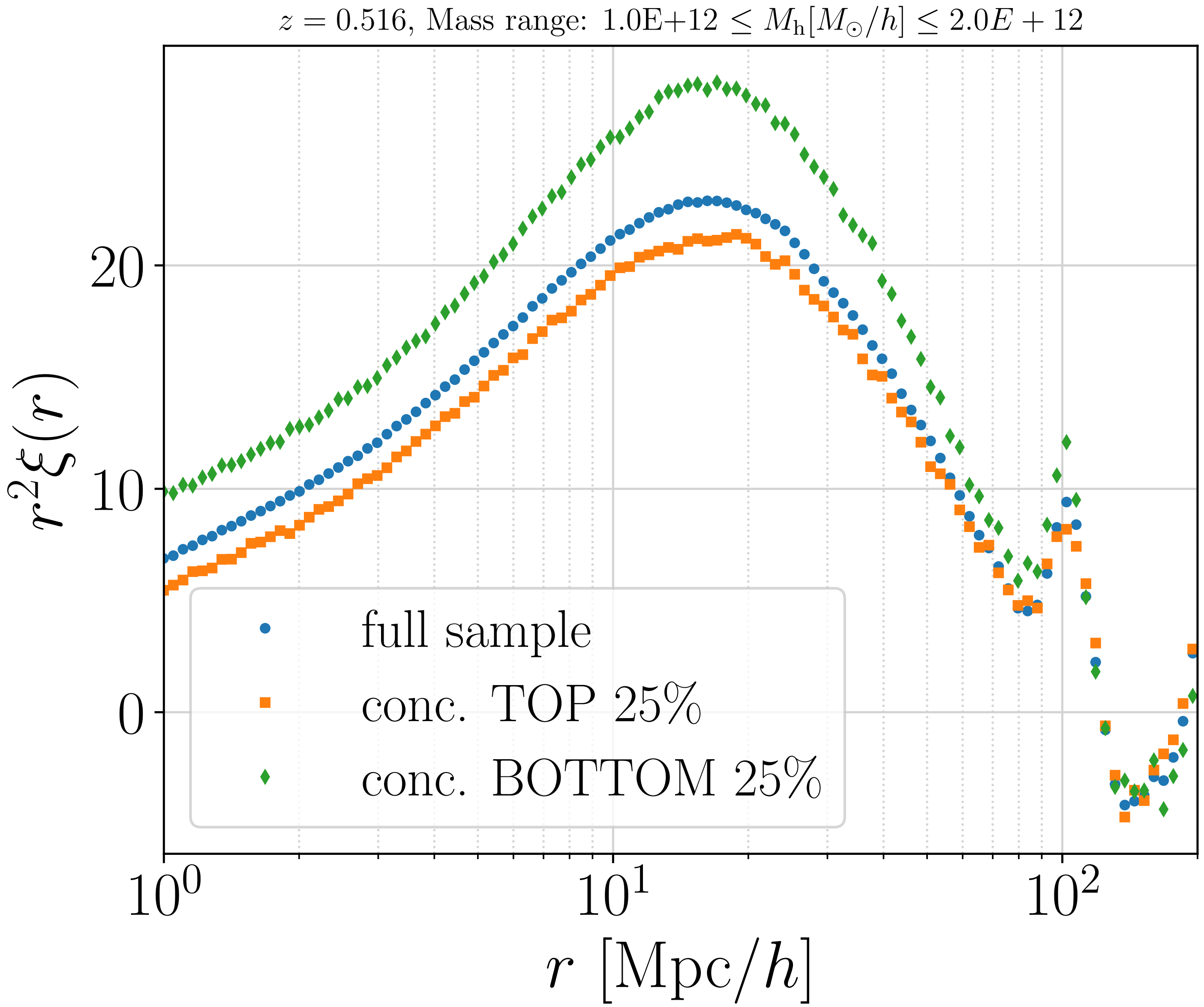
less strong clustering

late-forming

more strong clustering

What is halo assembly bias?

Secondary dependence



early-forming
(= high concentration)

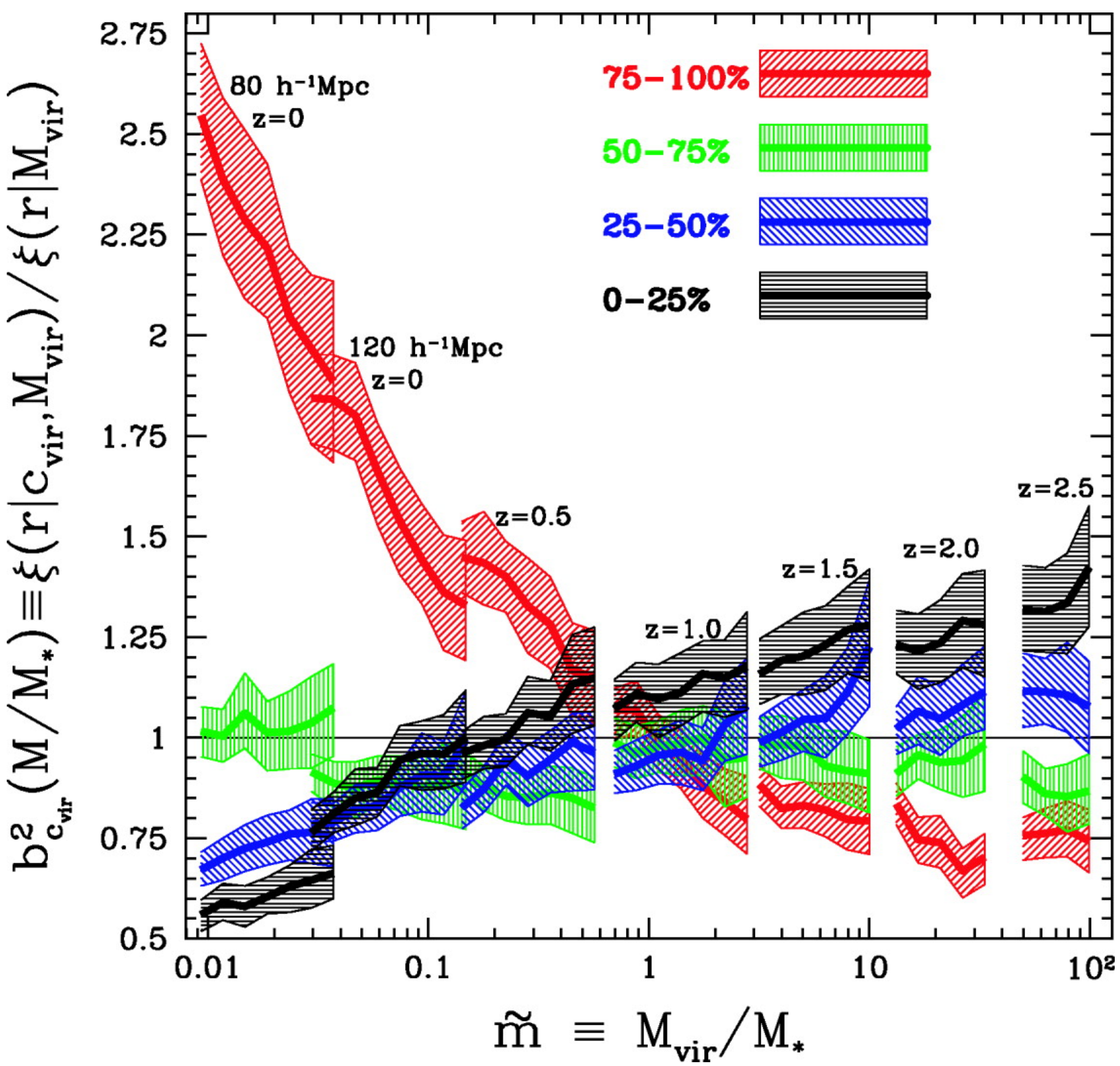
less strong clustering

late-forming
(= low concentration)

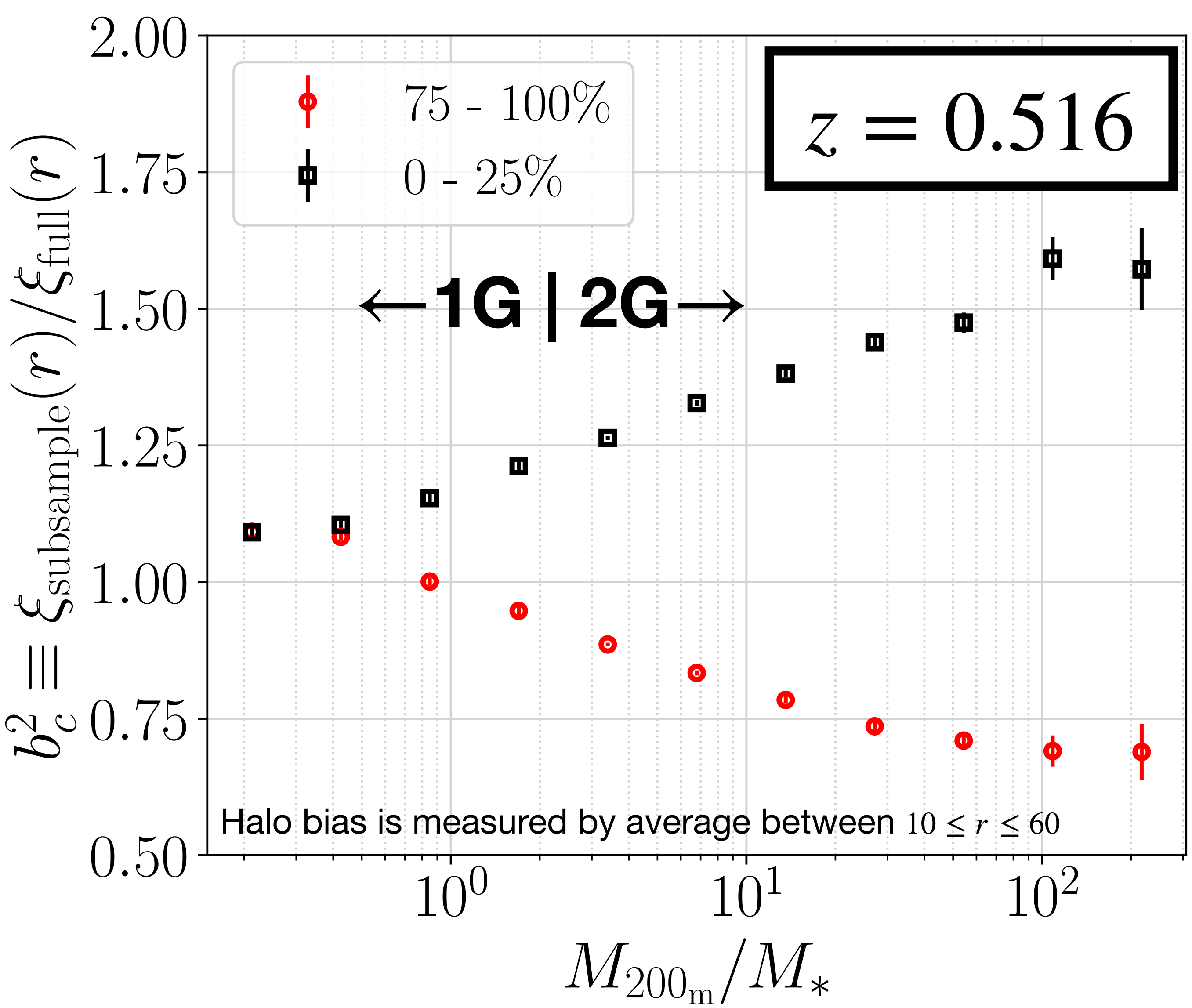
more strong clustering

Non-trivial dependence

Wechsler et al. 2006



Dark Quest II (in prep.)

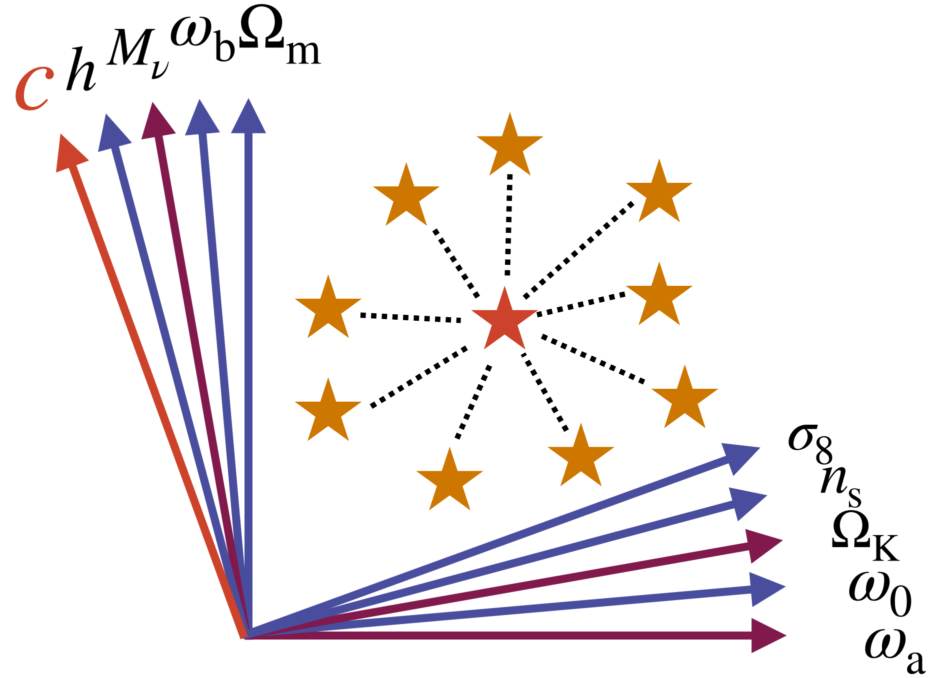


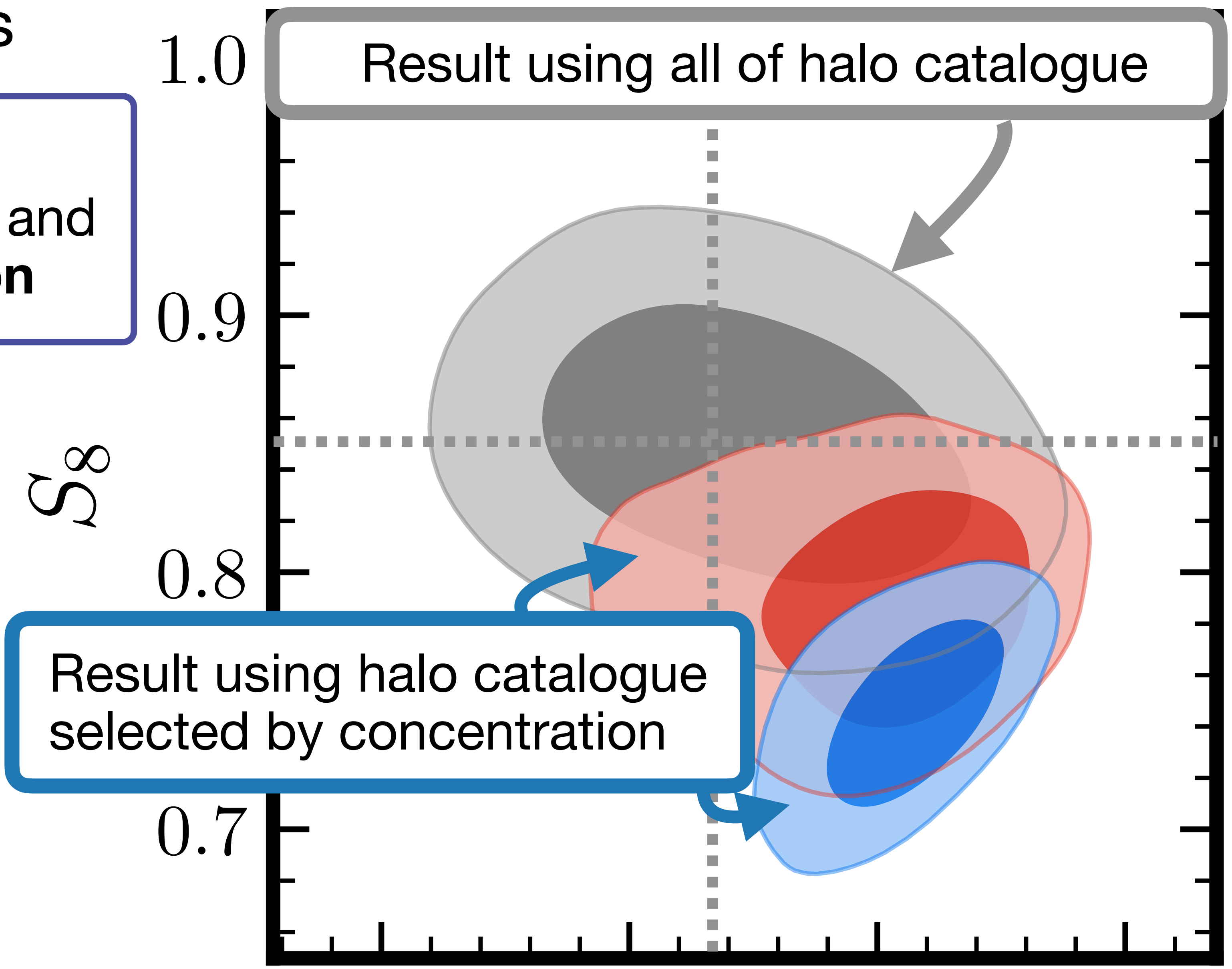
- Non-trivial dependence between halo mass and concentration
- Smaller systematic error is required in the future → Need to consider

It affects cosmological params.

Dark Emulator mock analysis

The cosmological emulator based on N-body that enables fast and accurate **halo statistics calculation**





Construct an emulator that also predicts assembly bias parameters

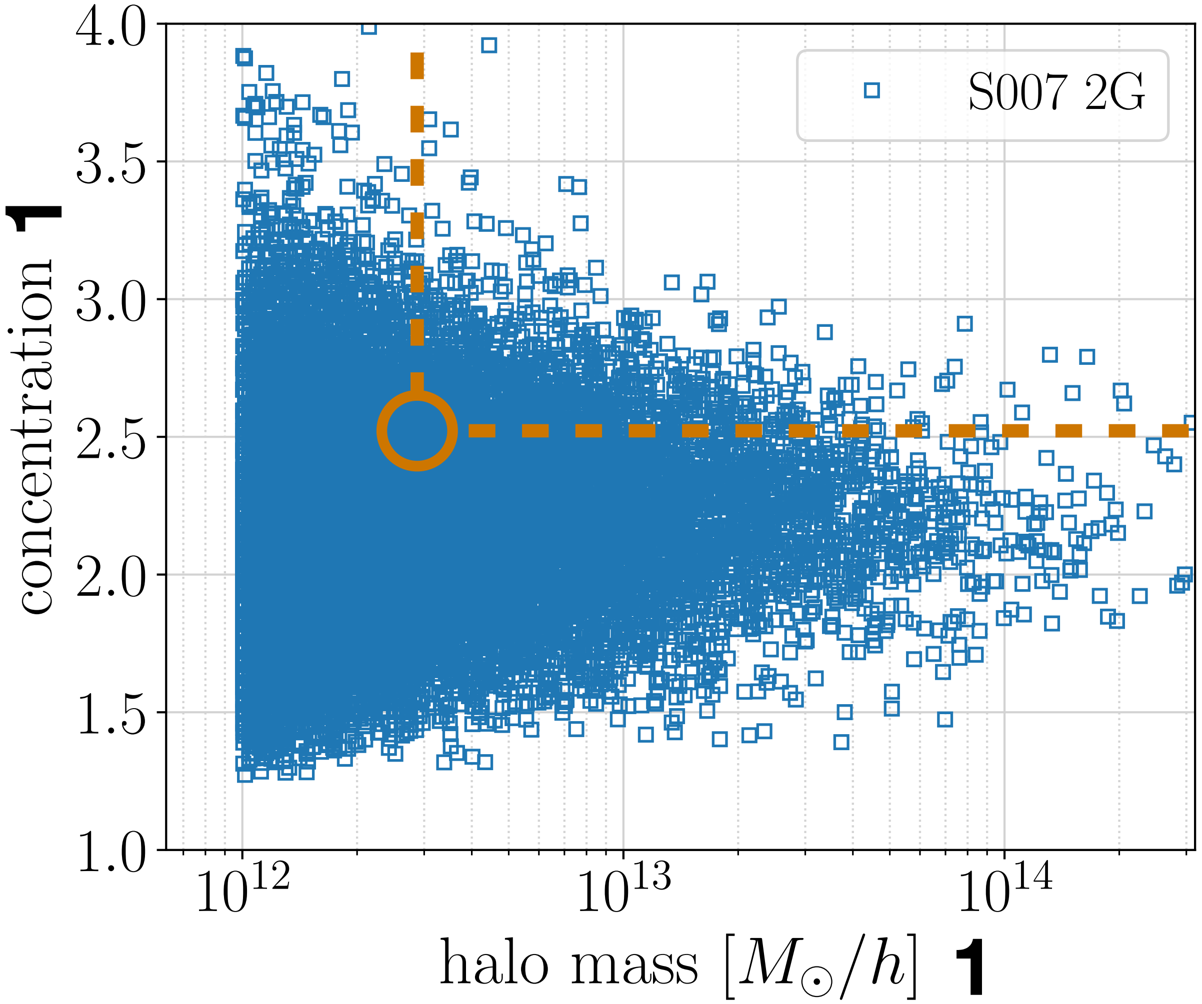
To implement assembly bias effect

Efficiently sample $M_{\rm threshold}$, $c_{\rm threshold}$ in 4D space

- sample range:

$12 \leq \log_{10} M \leq 15,\ 1 \leq c \leq 4$

⇨ **Check out all the cross-corr.**



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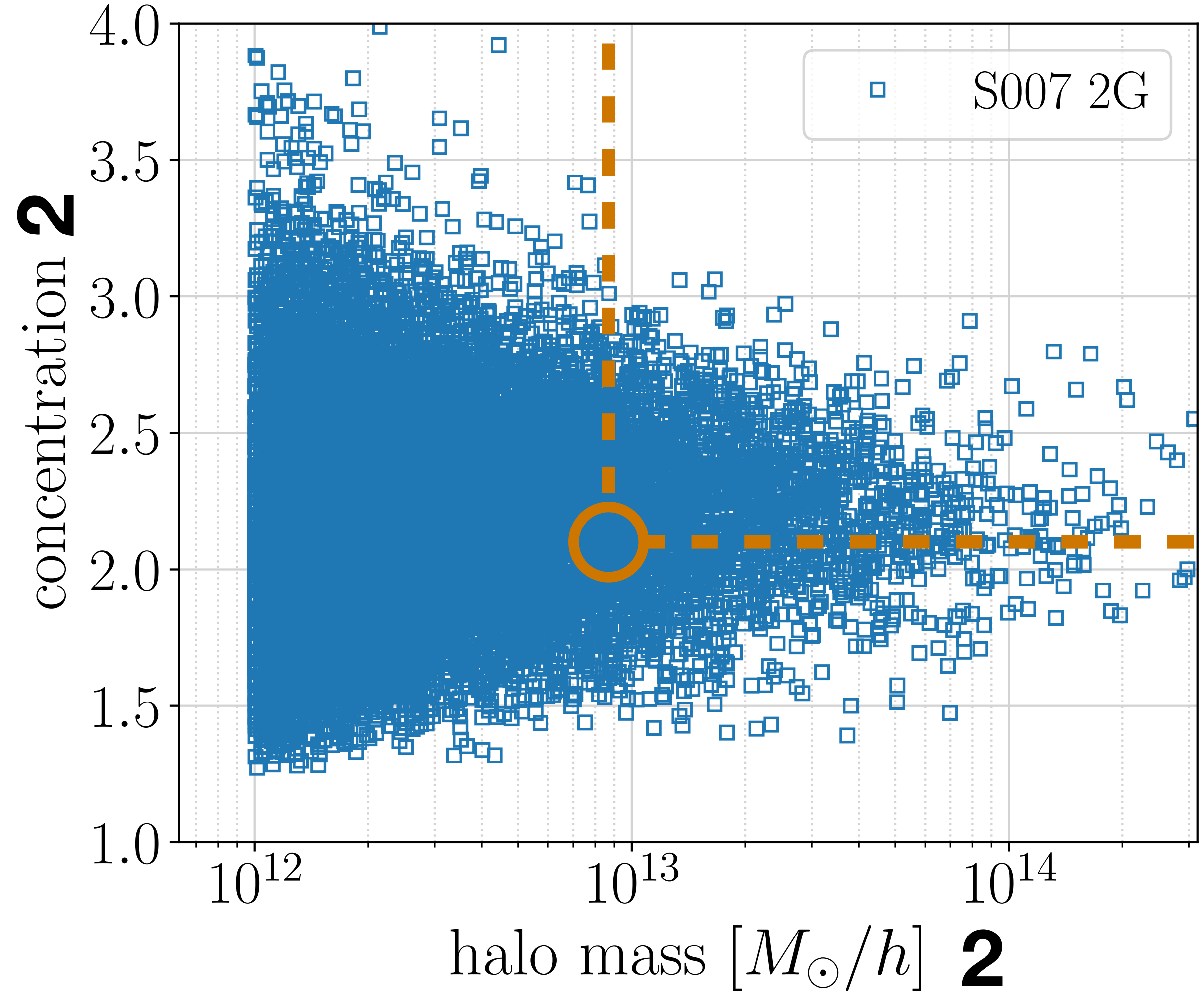

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$$\langle \delta_{\rm halo}(>M_1, >c_1)\delta_{\rm halo}(>M_2, >c_2)\rangle$$

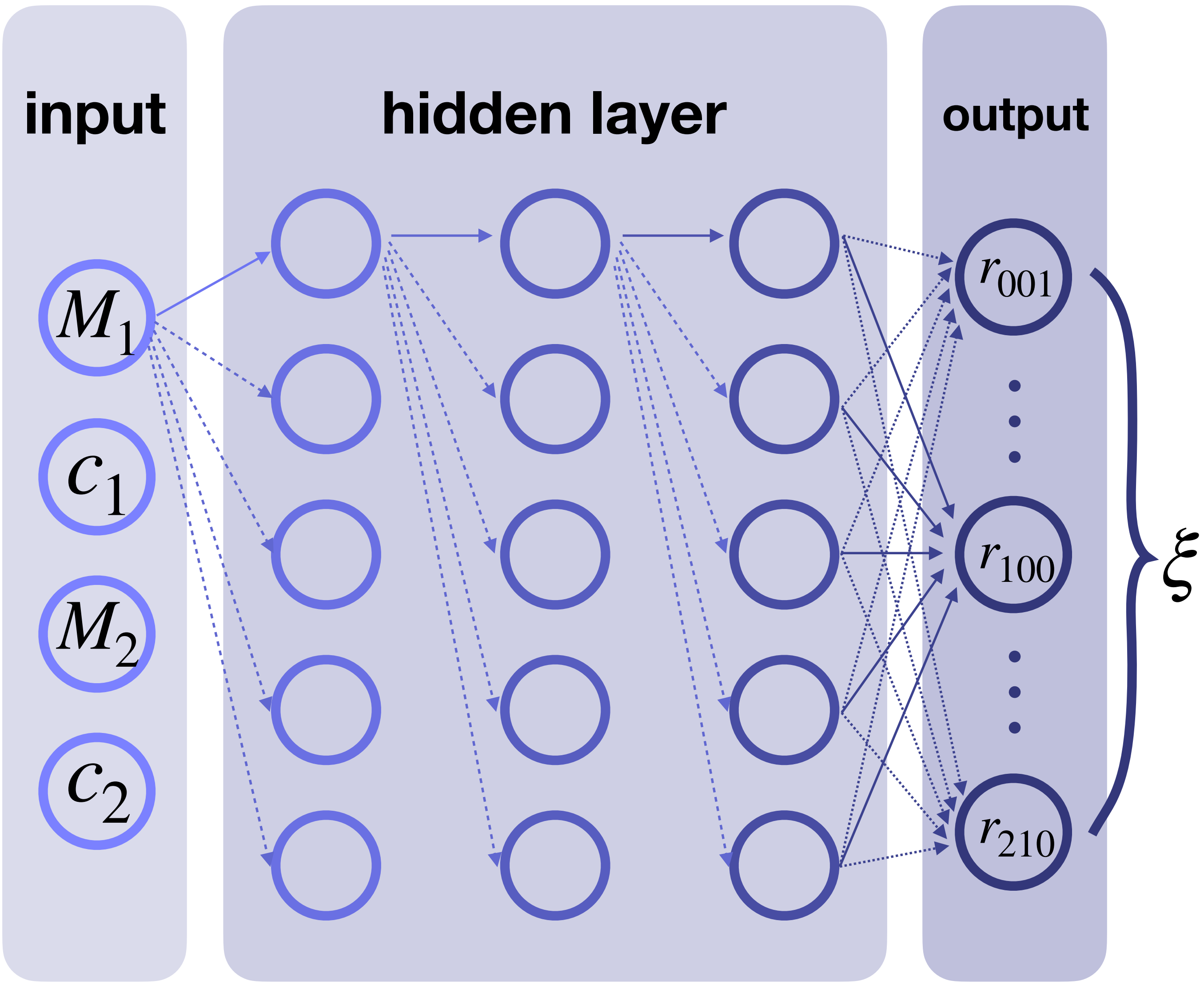
Measure in real-space, redshift-space ($l = 0,2,4,6$)

*normalizing flow + scrambled Sobol sequence

To implement assembly bias effect

Feed Forward Neural Network (FFNN)

Regress cross-corr. as a function of $M_{\rm threshold}, c_{\rm threshold}$

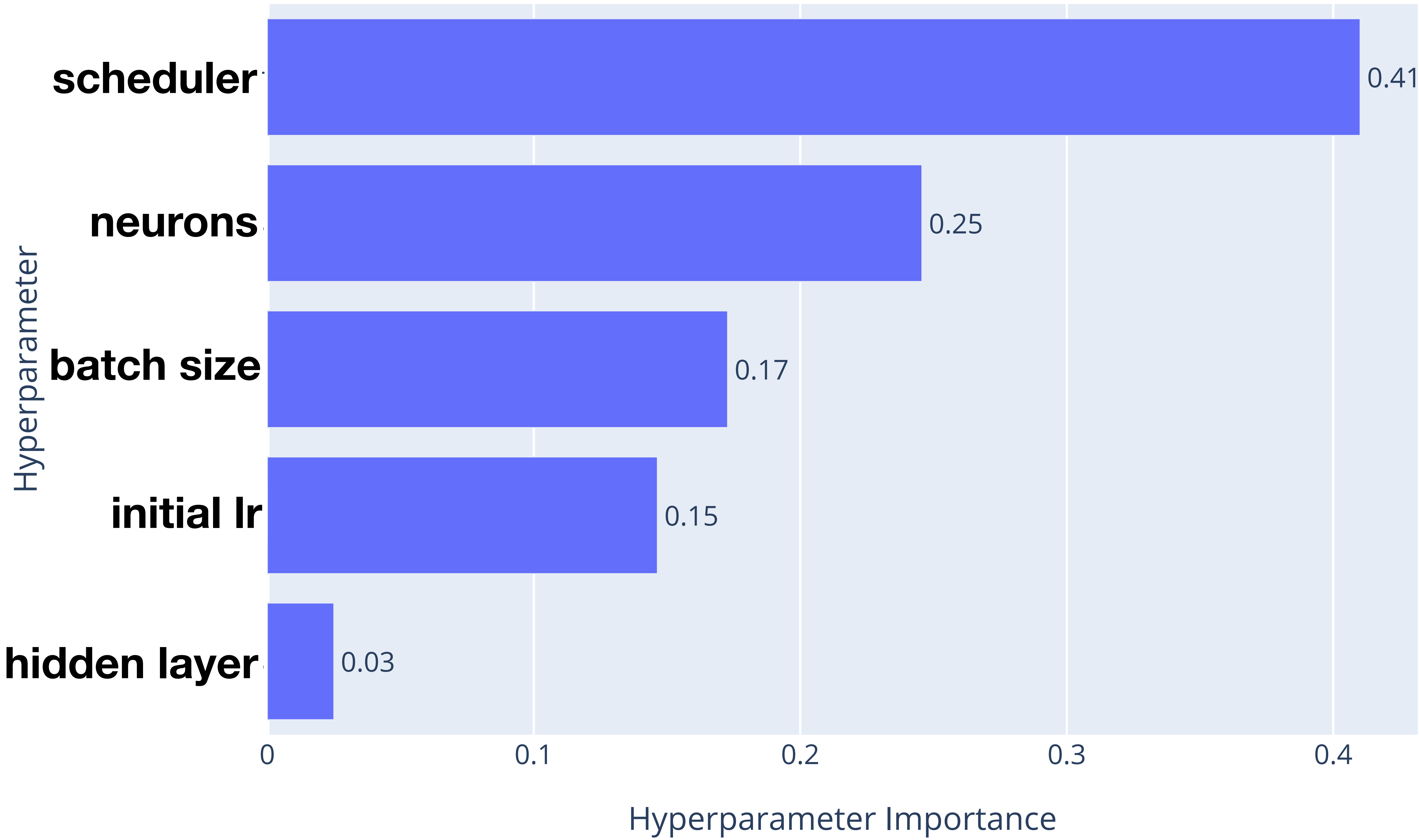


- loss function: χ^2
- covariance: Jackknife
- r : [0.1,200] Mpc/h
- suppress cosmic variance
- sample size: 24,780
  (90% of # : train, validation, 10%: test)
- automatic survey of hyper params
  (hidden layer, # of neuron, batch size, scheduler, initial learning rate)

※ consider cosmological dependence as a future work

Result: hyper parameters search

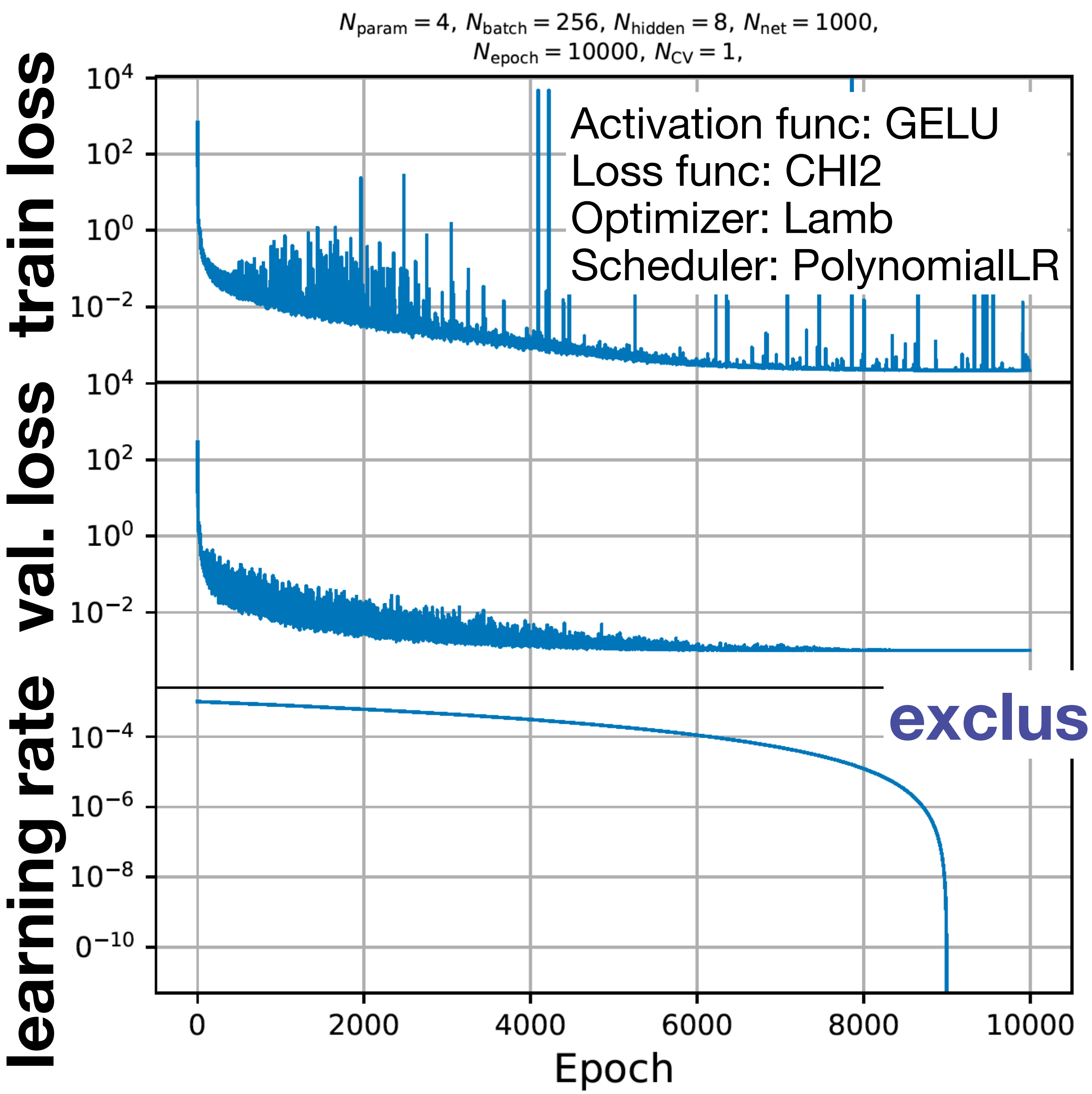
Real space



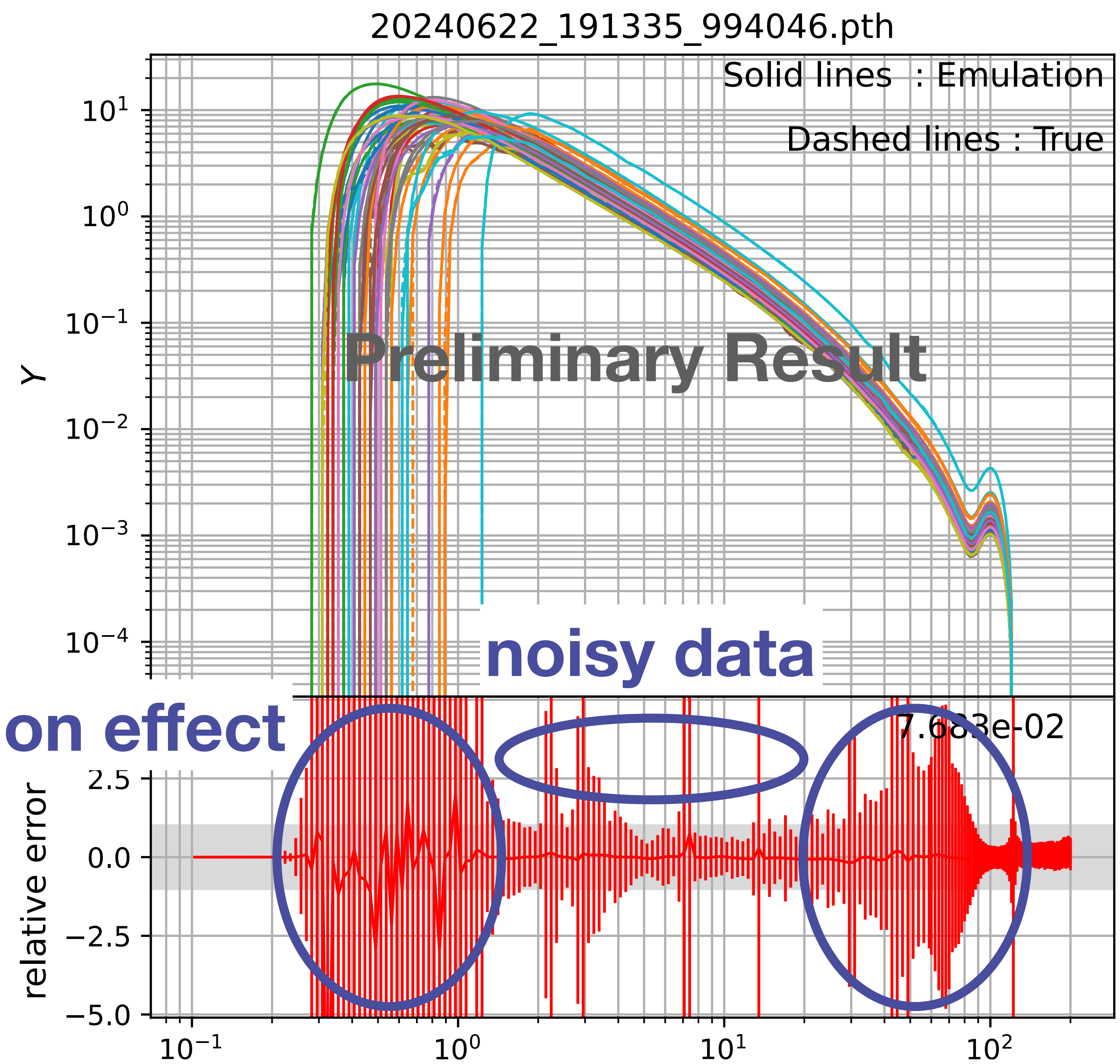
Result: achieve 1% accuracy (2-40 [Mpc/h])

Real space

loss function



correlation function (test data)



Summary

- The goal of this study:
  - **Implement halo assembly bias effect into Dark Emulator II**
- What exactly do we do?:
  - **Efficiently sample in multi-dimensional space**
  - **Learn params. dependence in 4D input space by FFNN**
- Result:
  - Achieved 1% accuracy (2-40 [Mpc/h]) in prediction on FFNN
  - Automatic hyper parameters search with **Optuna**
- Next Step:
  - Redshift dependence
  - Cosmological parameters dependence
  - **Implementing Dark Emulator 1 into Roman analytical pipeline**