Applications of Hydrodynamical Simulations for Clustering of Emission Line Galaxies

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Ref.

KO and Okumura (2022; ArXiv: 2206.08678)

Galaxy Bias: Matter vs Galaxy

- We observe **galaxy distribution**, not matter (baryon+DM) distribution.
  The galaxy distribution follows background matter distribution at some level
  but the relation (***galaxy bias***) is governed by complex astrophysics
  and thus challenging to model it analytically.

- The ***galaxy formation simulations*** numerically solve
  gravitational growth and **formation and evolution of galaxies** simultaneously.

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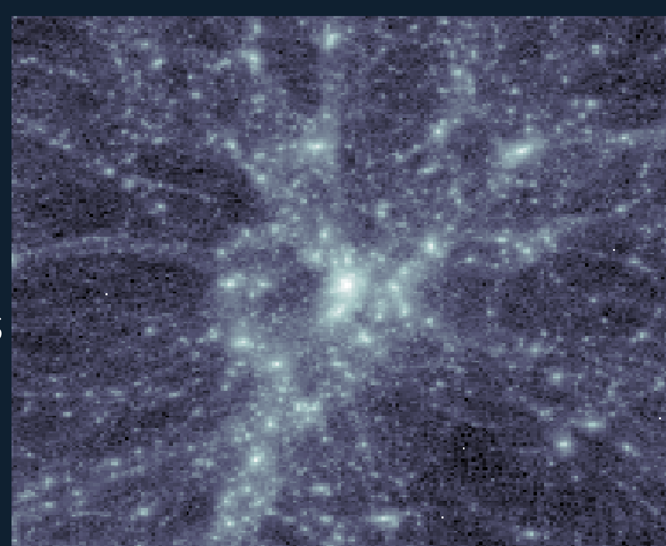
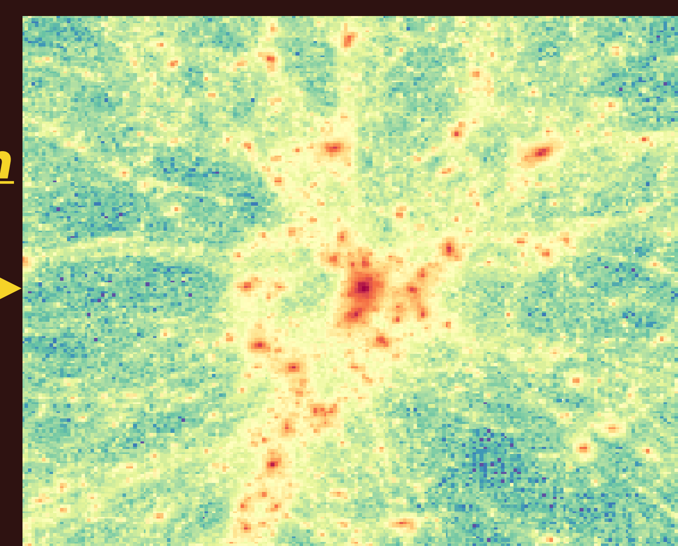
Matter

Density/velocity fields
Halo catalogues
Merger history of halos
…



Direct comparison

Galaxy

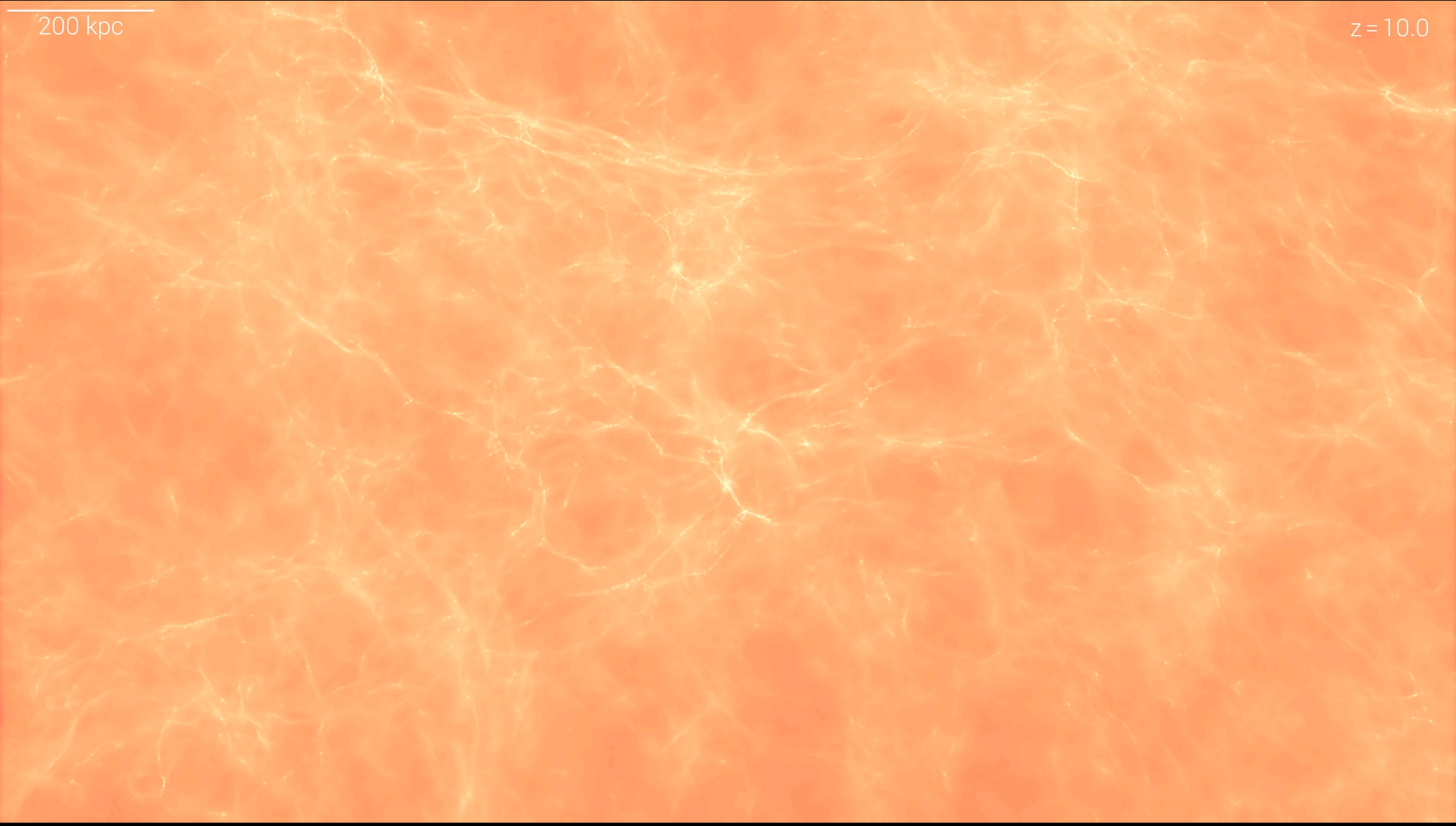


Luminosity
Galaxy catalogues
Star formation rate
Age
Metallicity
…

➡ ***The ideal tool to dissect the galaxy-matter relation!***

Galaxy Formation Hydrodynamical Simulations

✦Numerical simulations are the powerful tool to address the **multi-scale physics**



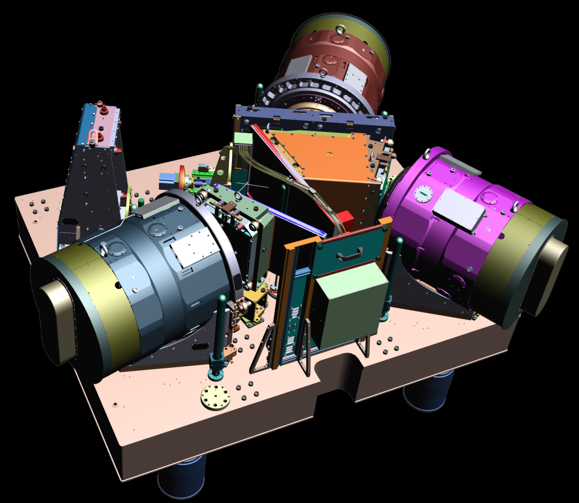
Credit: IllustrisTNG team

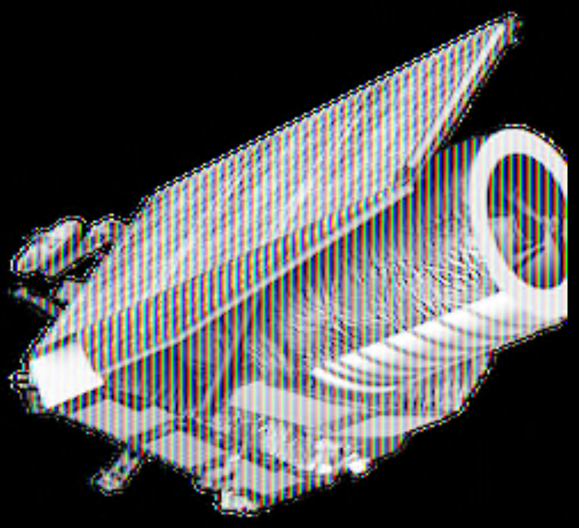
Observations of Emission Line Galaxies

✦ Upcoming surveys will target ***emission line galaxies (ELGs)***. ELGs are characterised by strong emission line (Hα, [O II], etc.) from nebular emission. The emission is sourced by **short-lived massive stars.**

➡ ELGs are **blue star-forming galaxies** and thus likely to be found in **young halos**.

✦Current and future spectroscopic surveys

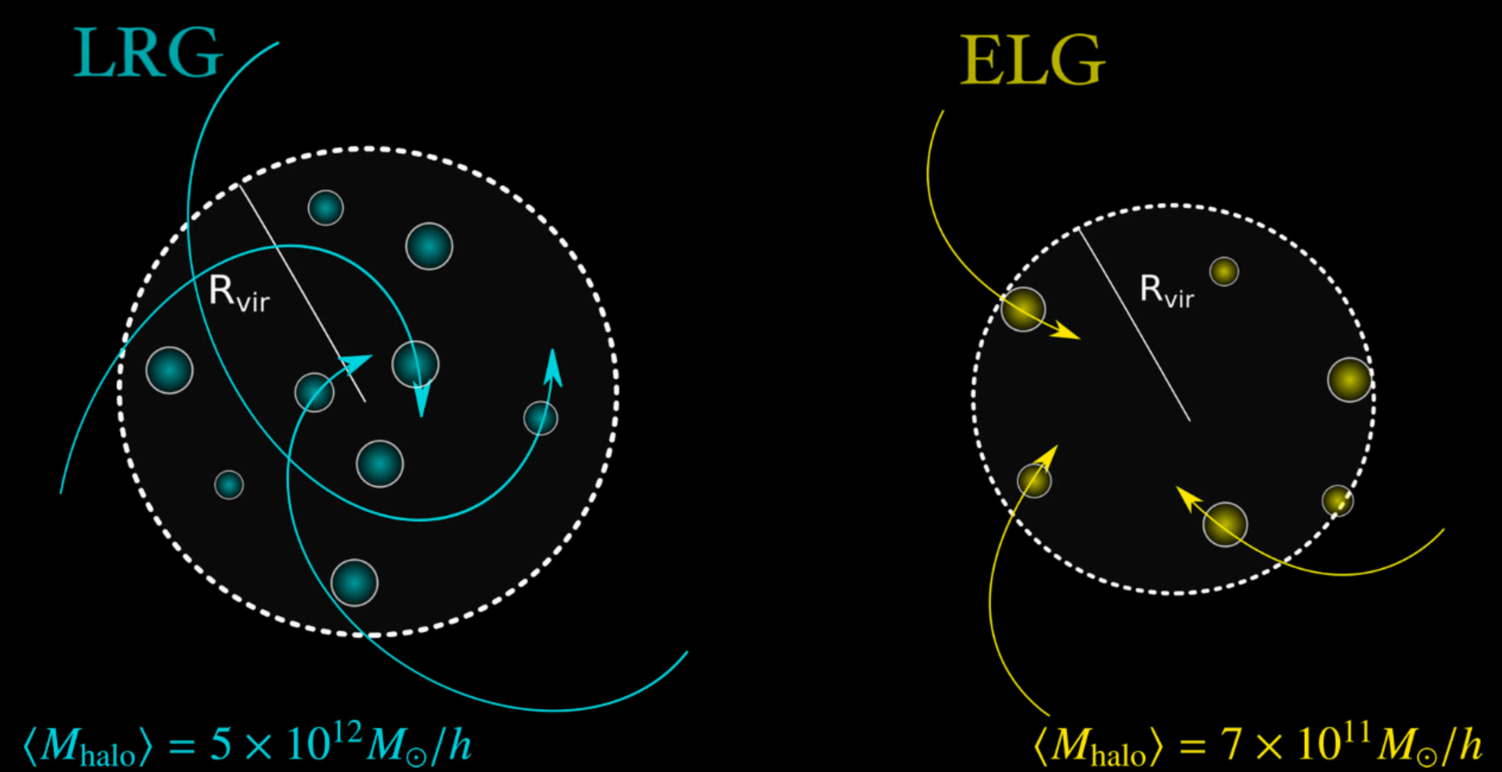




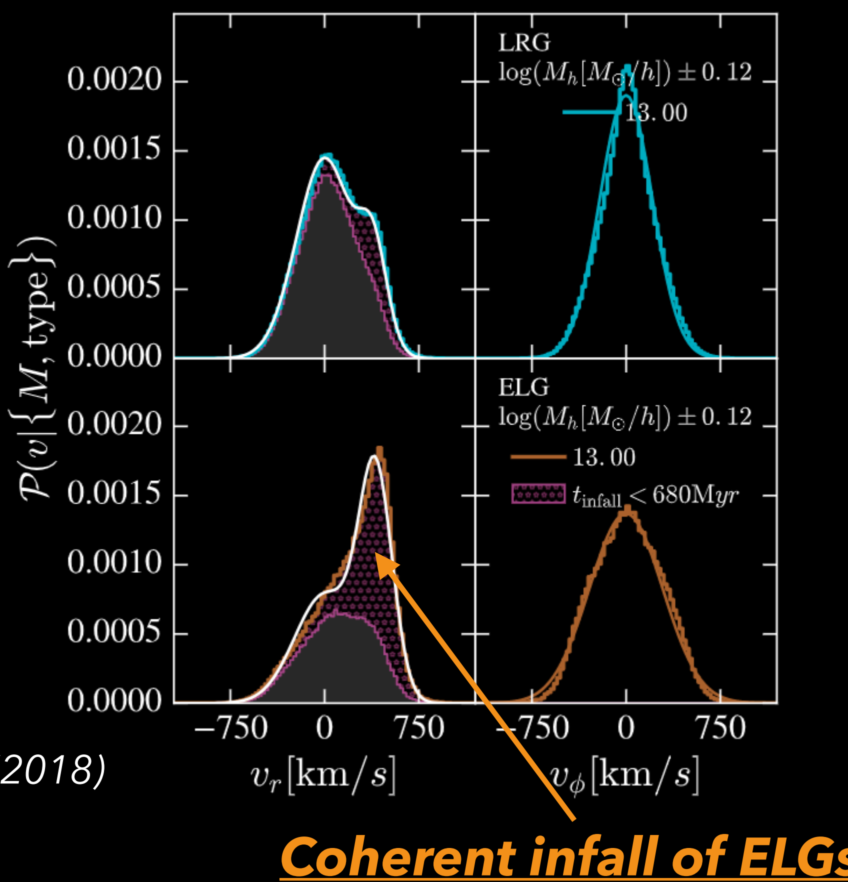
- ***PFS*** (in 2024) *Richard Ellis' talk*
  coverage: 1,200 deg^2
  [O II] ELGs ($0.6 < z < 2.4$)
- ***Euclid*** (in 2023?) *Sylvain de la Torre's talk*
  coverage: 15,000 deg^2
  Hα ELGs ($0.89 < z < 1.82$)

LRG vs ELG

✦ ***Luminous red galaxies (LRGs)***, which are widely used in cosmological context, are populations complementary to ELGs.



✦Velocity distribution



Orsi+ (2018)

- LRGs are located close to the centre and their kinematics is virialized. On the other hand, ELGs are undergoing infall from outskirts.

➡ This coherent motion directly affects cosmological statistics, e.g., redshift space power spectrum.

Construction of Mock ELG Catalogue

IllustrisTNG **(Nelson+, 2019):**

Run by moving-mesh code AREPO (Springel, 2010)

L = 205 Mpc/h, N = 2 x 2500^3

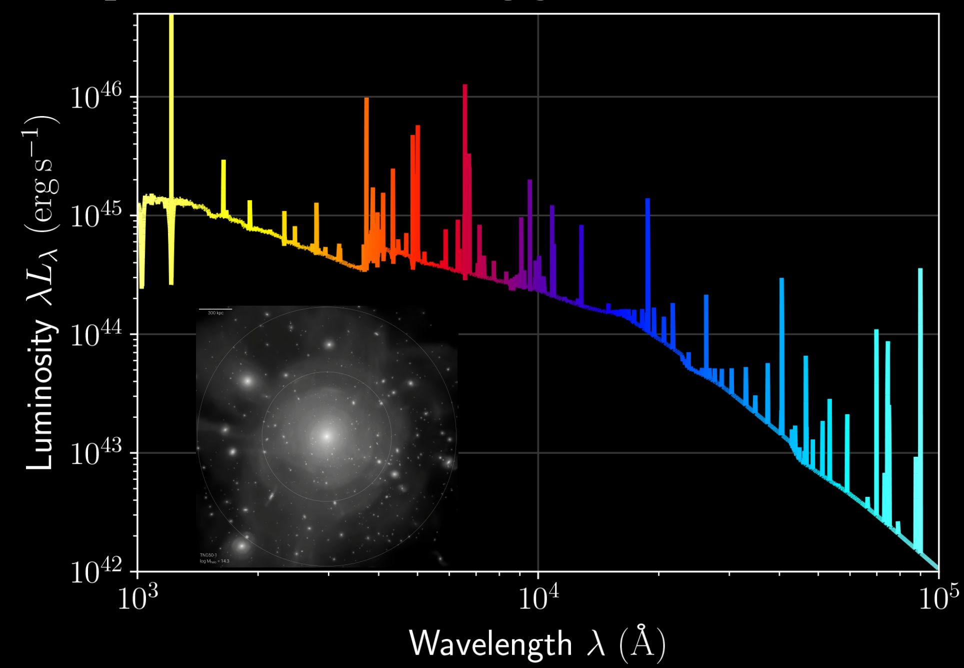
Various baryonic processes implemented:

Radiative cooling, star formation, stellar wind,
stellar feedback, BH formation/evolution, AGN feedback,
MHD, …

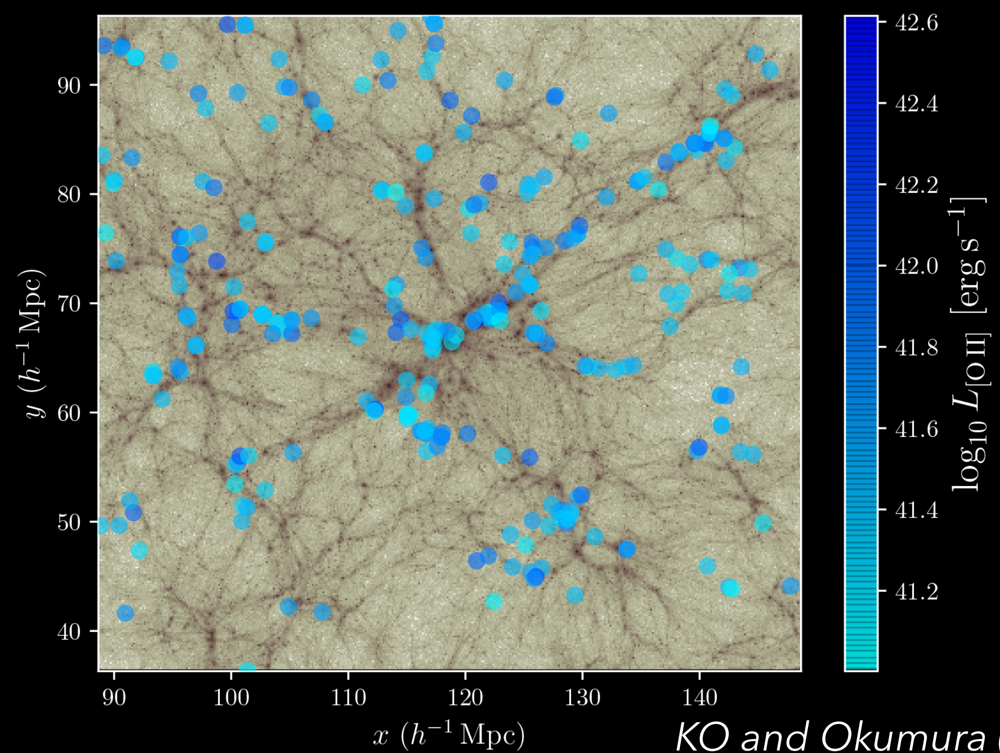
Stellar population synthesis:

For each star particle, we compute SED based on its metallicity and age with PÉGASE.3 (Fioc+, 2019) code coupled with photo-ionization code CLOUDY (Ferland+, 2017).

Spectral energy distribution

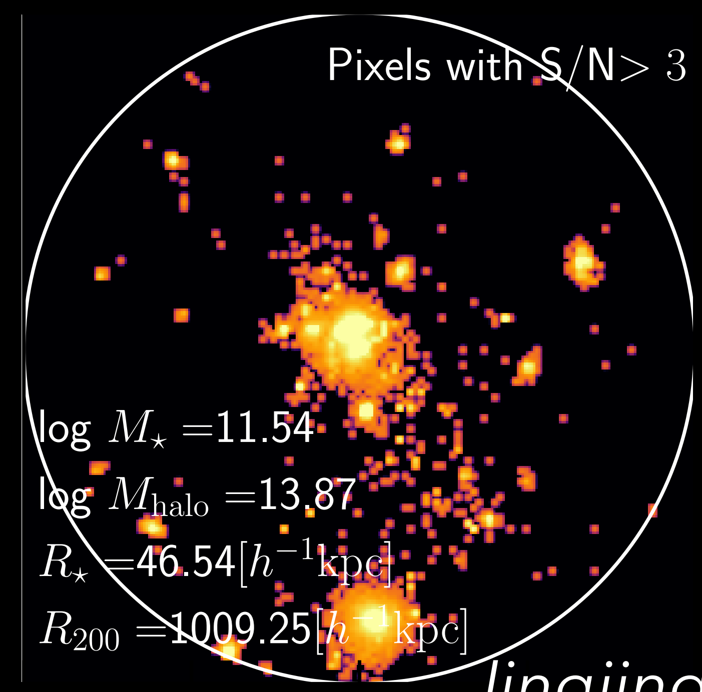


[O II] ELG distribution



KO and Okumura (2022)

HSC i-band luminosity



Jingjing Shi's talk

Shi, KO, Kurita and Takada (2021)

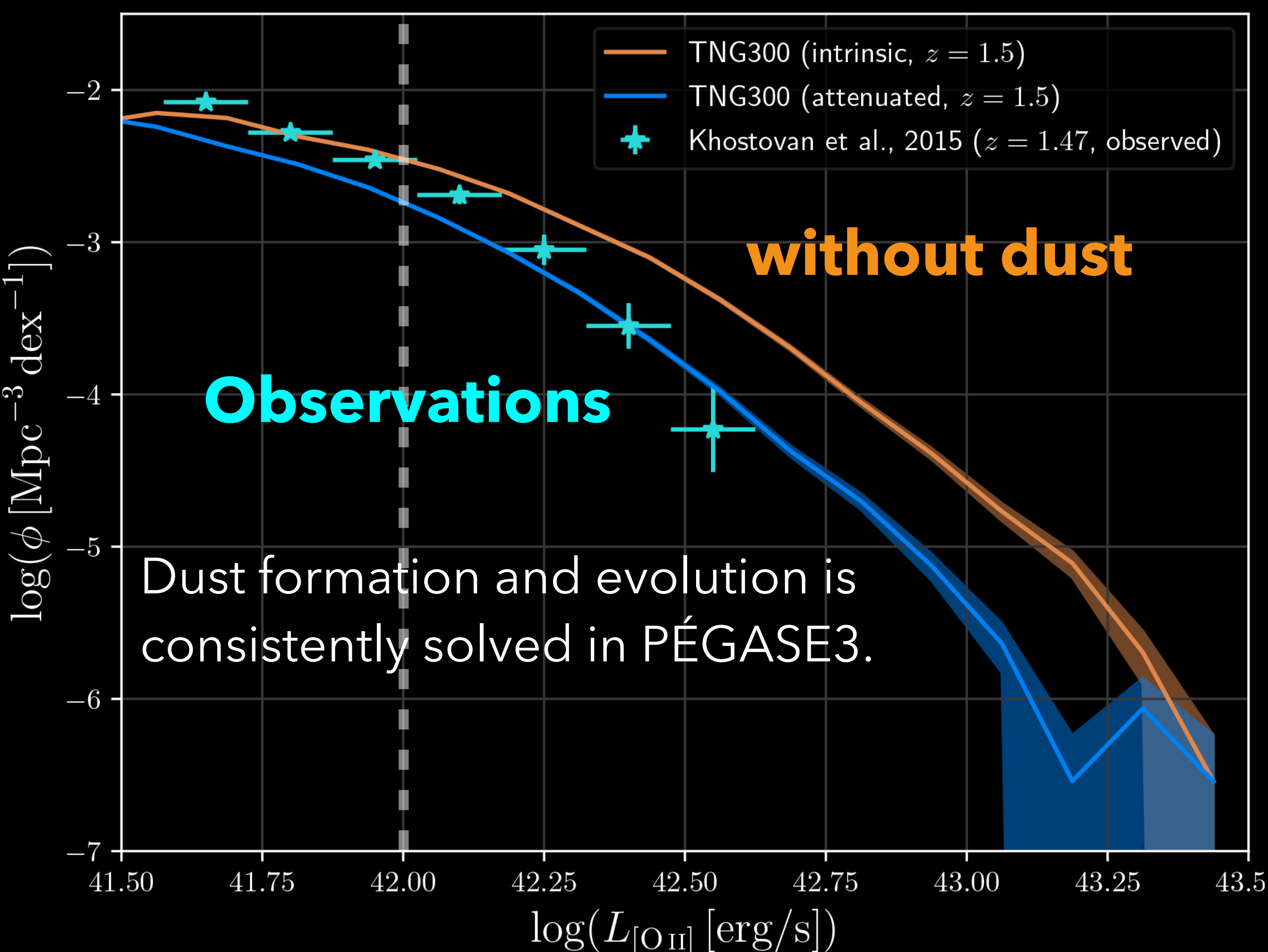
Luminosity Function of Hα and [O II] ELGs

✦ As validation of our mock ELG catalogues, luminosity functions of Hα and [O II] ELGs are compared with observations.

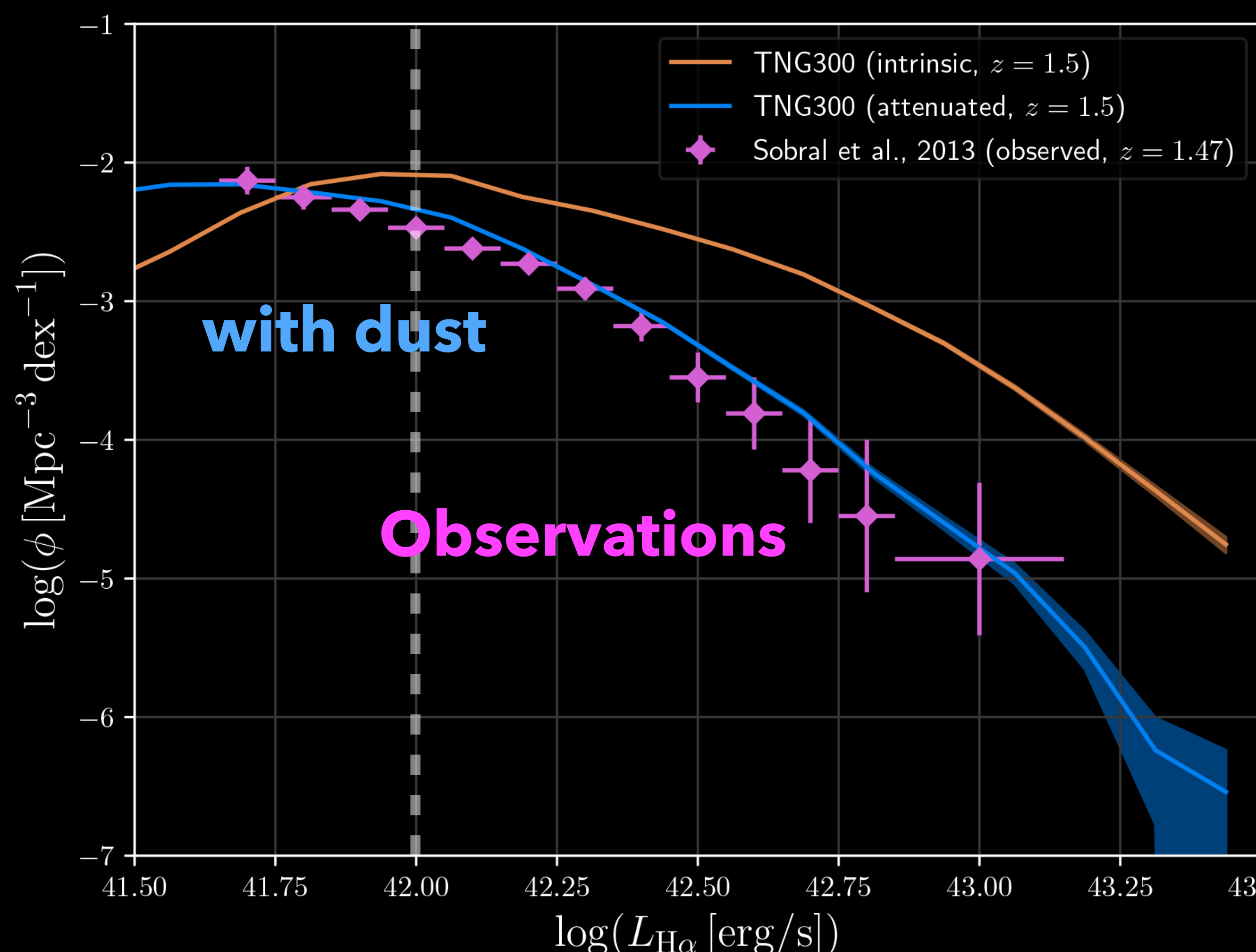
➡ When dust attenuation is taken into account, the results are consistent ***without tuning parameters***.

z = 1.5

Hα ELGs



[O II] ELGs



KO and Okumura (2022)

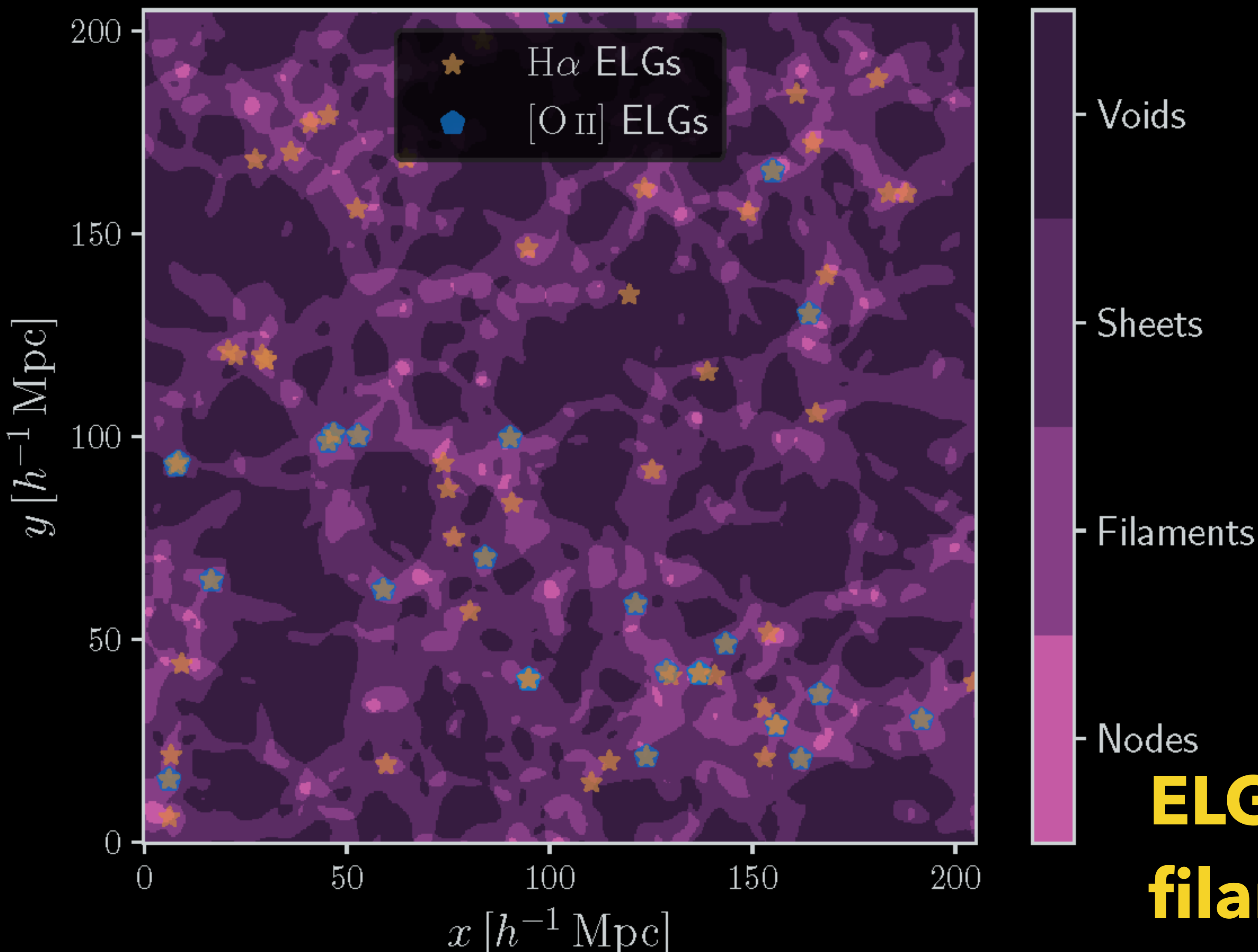
Environments: Cosmic Web

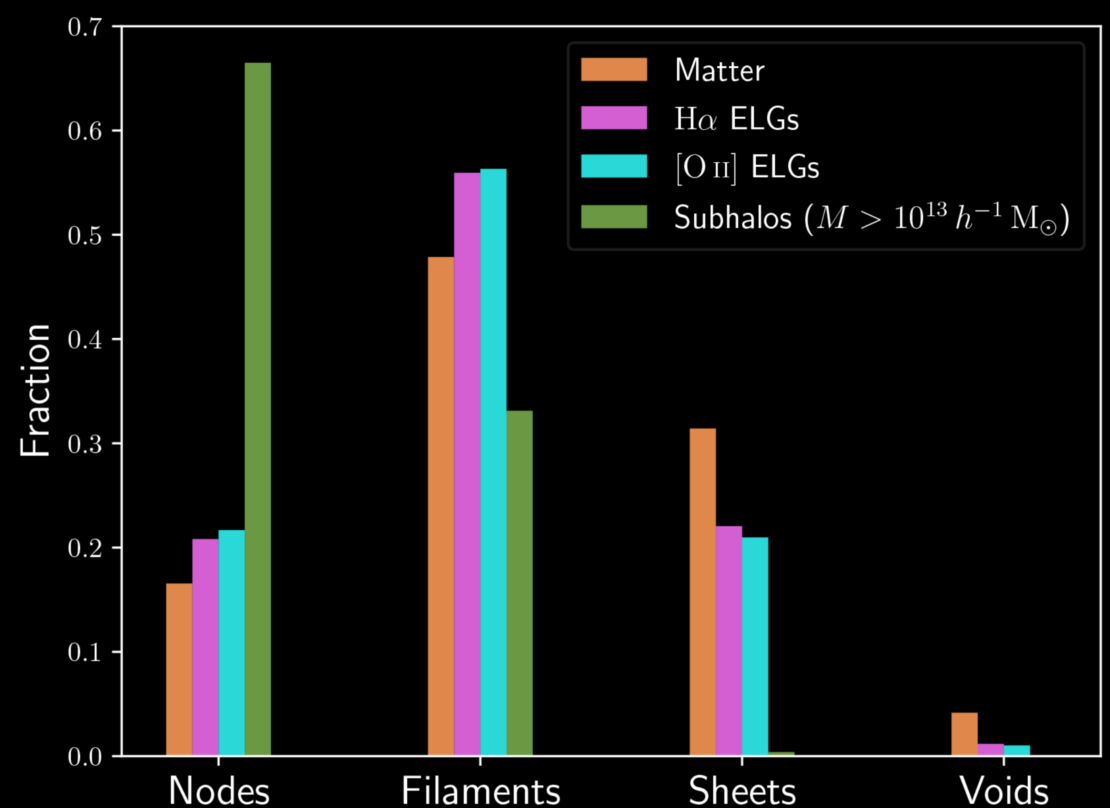
✦ *Where are ELGs in cosmic web structures?*

➡ Classification based on the tidal tensor (Hahn+ 2007, Libeskind+, 2018).

$$T_{ij} \equiv \frac{\partial^2 \phi}{\partial x_i \partial x_j}$$ ϕ : (scaled) gravitational potential

Each region is classified according to eigenvalues of the tidal tensor.





ELGs are more likely to be found in filaments.

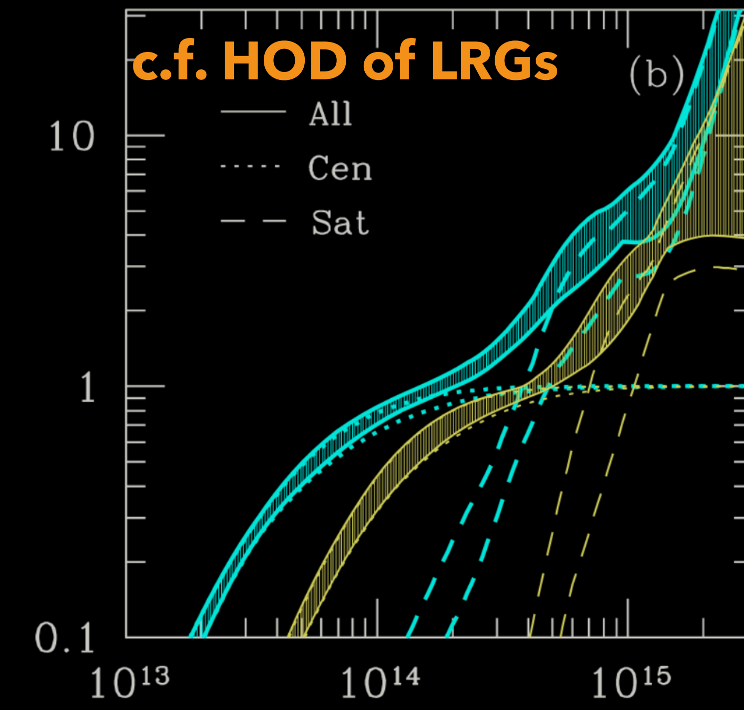
KO and Okumura (2022)

Halo Occupation Distribution

✦ ***Halo Occupation Distribution (HOD)***:
The mean number of galaxies as a function of halo mass. The most common way to relate galaxies with halo.

- **Central** = gradually growing step-like function
- **Satellite** = power-law function

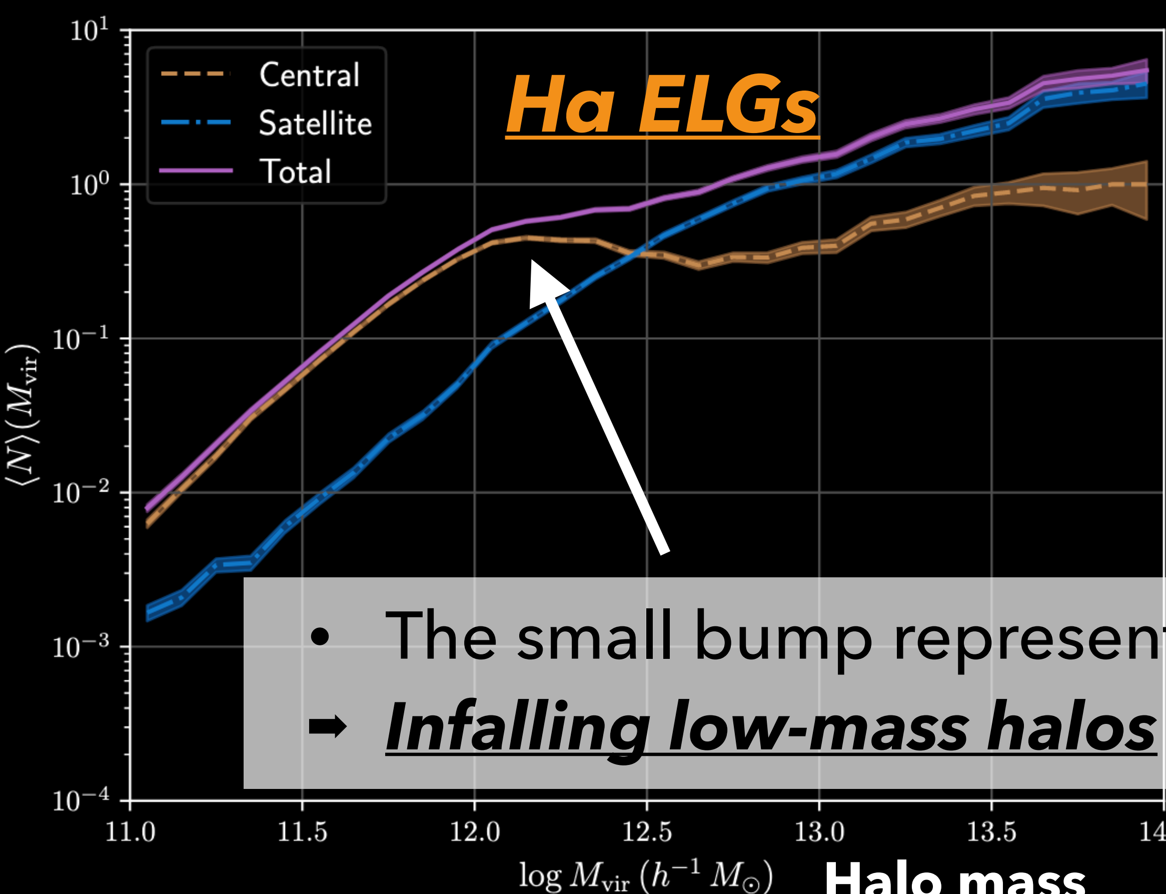
# of galaxies in halo

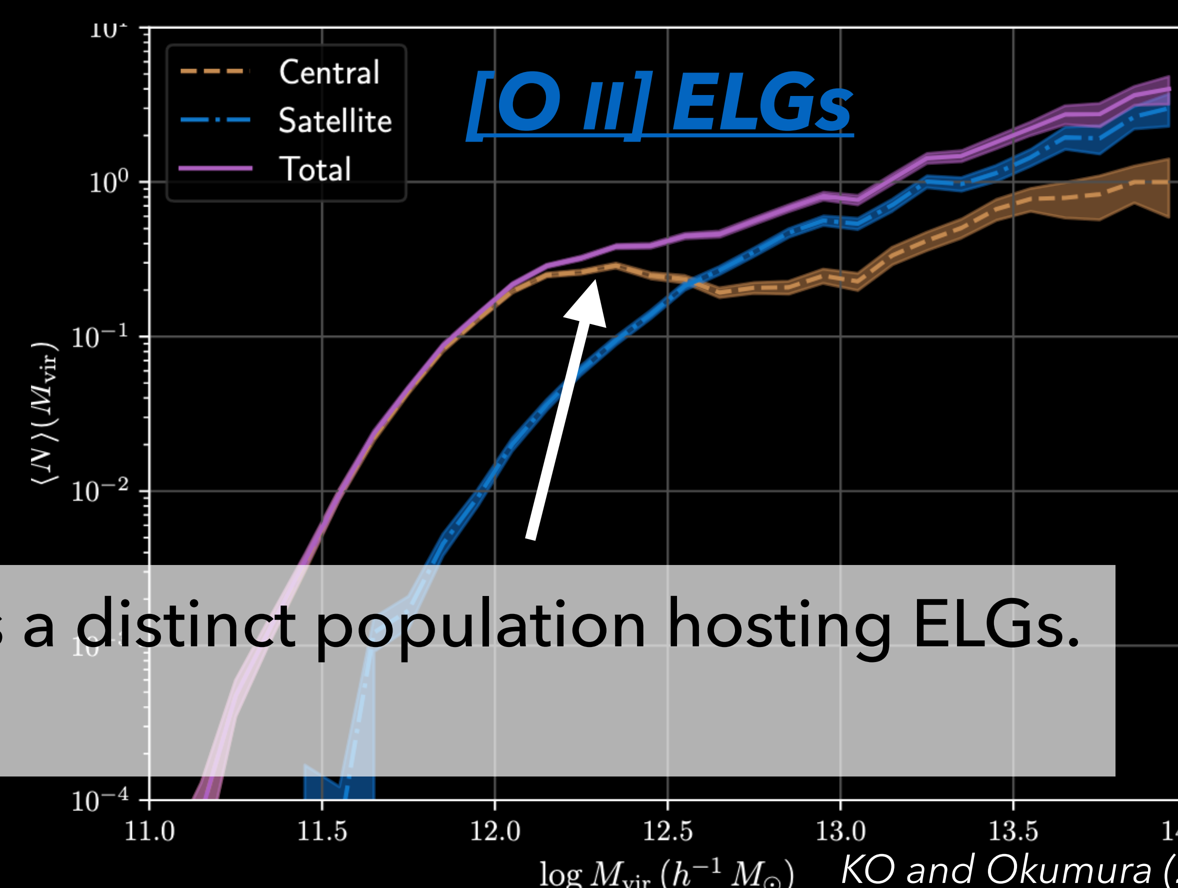


Halo mass

Zheng+ (2009)

# of galaxies





- The small bump represents a distinct population hosting ELGs.

➡ ***Infalling low-mass halos***

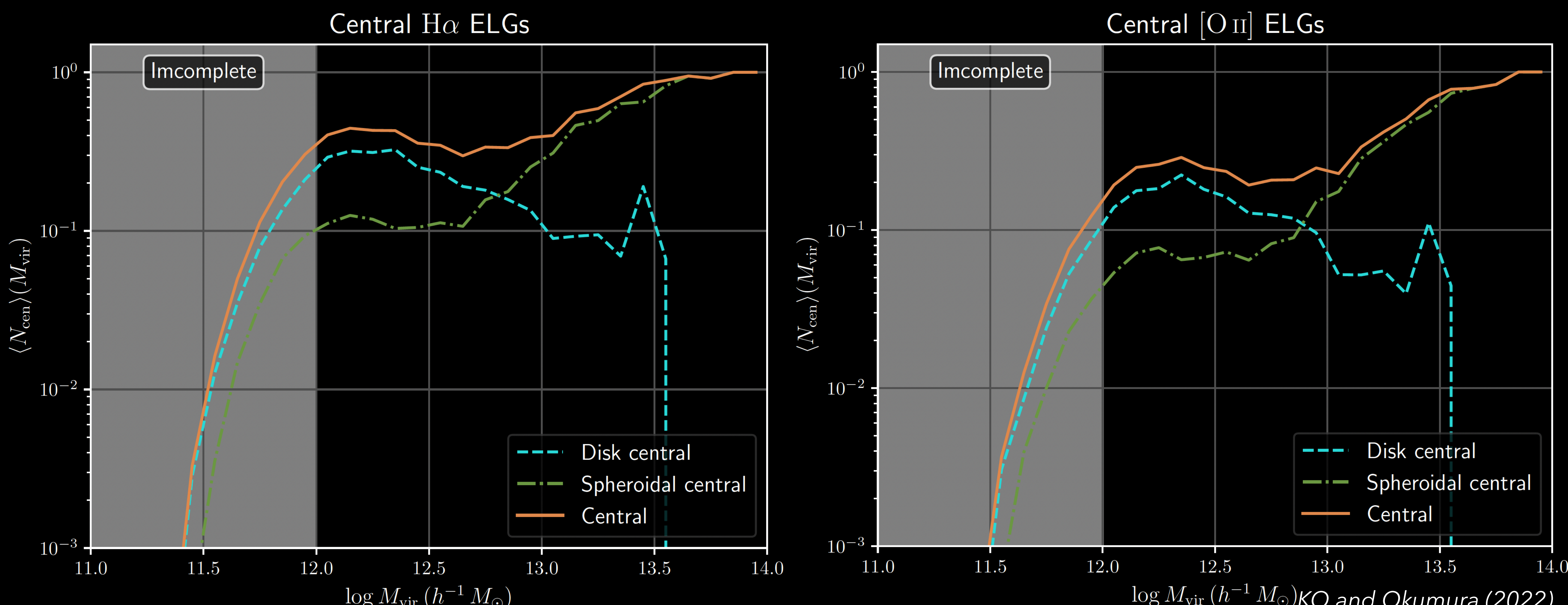
Halo mass

KO and Okumura (2022)

Halo Occupation Distribution

✦ ***Origin of peak around $10^{12.5}$ Msun/h of central HOD:***
Central ELGs are split into **disk centrals** and **spheroidal centrals** according to bulge-over-total-mass ratio.

➡ **The peak is dominated by disk centrals which correspond to infalling isolated halos.**



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Halo Occupation Distribution

- ***Zheng Model:***

Standard and conventional model

$$\langle N_{\rm cen}|M\rangle = \frac{1}{2}\left[1+{\rm erf}\left(\frac{\log(M/M_{\rm min})}{\sigma_{\log M}}\right)\right]$$

$$\langle N_{\rm sat}|M\rangle = \frac{1}{2}\left[1+{\rm erf}\left(\frac{\log(M/M_{\rm min})}{\sigma_{\log M}}\right)\right]\left(\frac{M-M_0}{M_1}\right)^{\alpha}$$

Zheng+ (2005)

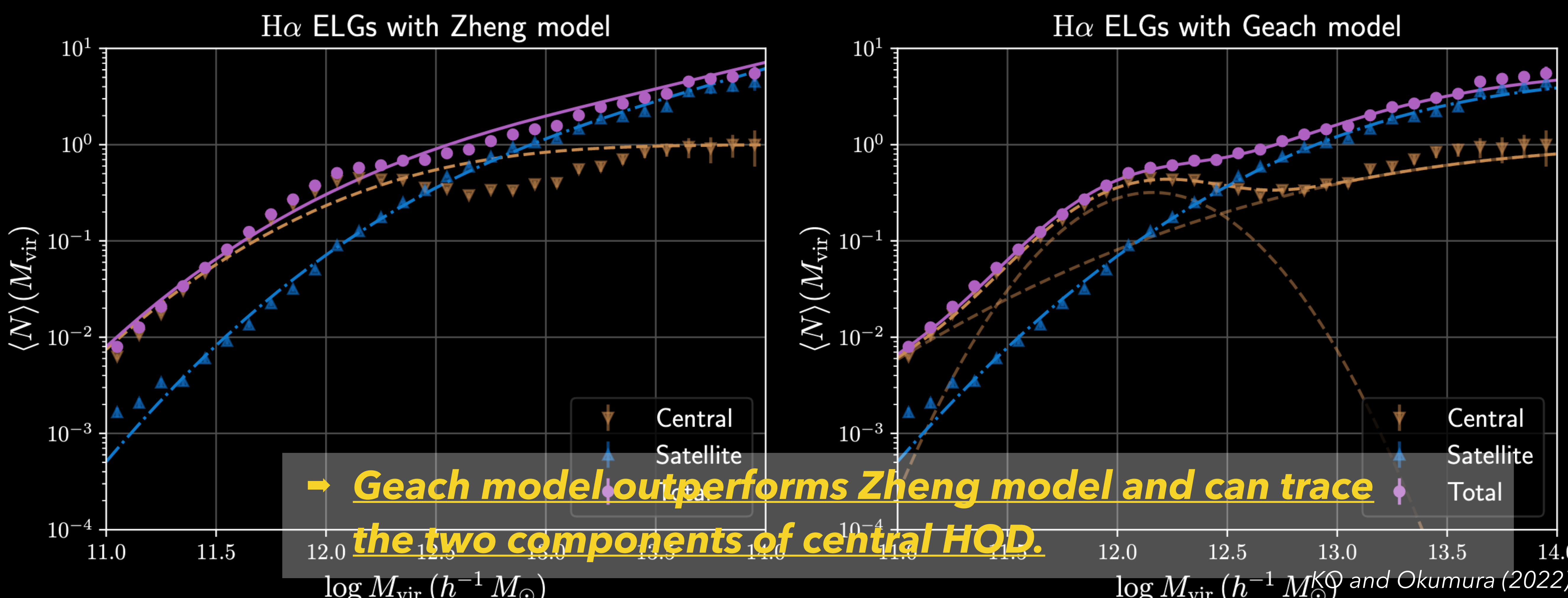
- ***(Modified) Geach Model:***

Central HOD is composed of step-like function and Gaussian

$$\langle N_{\rm cen}|M\rangle = F_c^B(1-F_c^A)\exp\left[-\frac{\log(M/M_c)^2}{2\sigma_{\log M}^2}\right] + F_c^A\frac{1}{2}\left[1+{\rm erf}\left(\frac{\log(M/M_{\rm min})}{\sigma_{\log M}}\right)\right]$$

$$\langle N_{\rm sat}|M\rangle = F_s\frac{1}{2}\left[1+{\rm erf}\left(\frac{\log(M/M_{\rm min})}{\delta_{\log M}}\right)\right]\left(\frac{M}{M_{\rm min}}\right)^{\alpha}$$

Geach+ (2012)



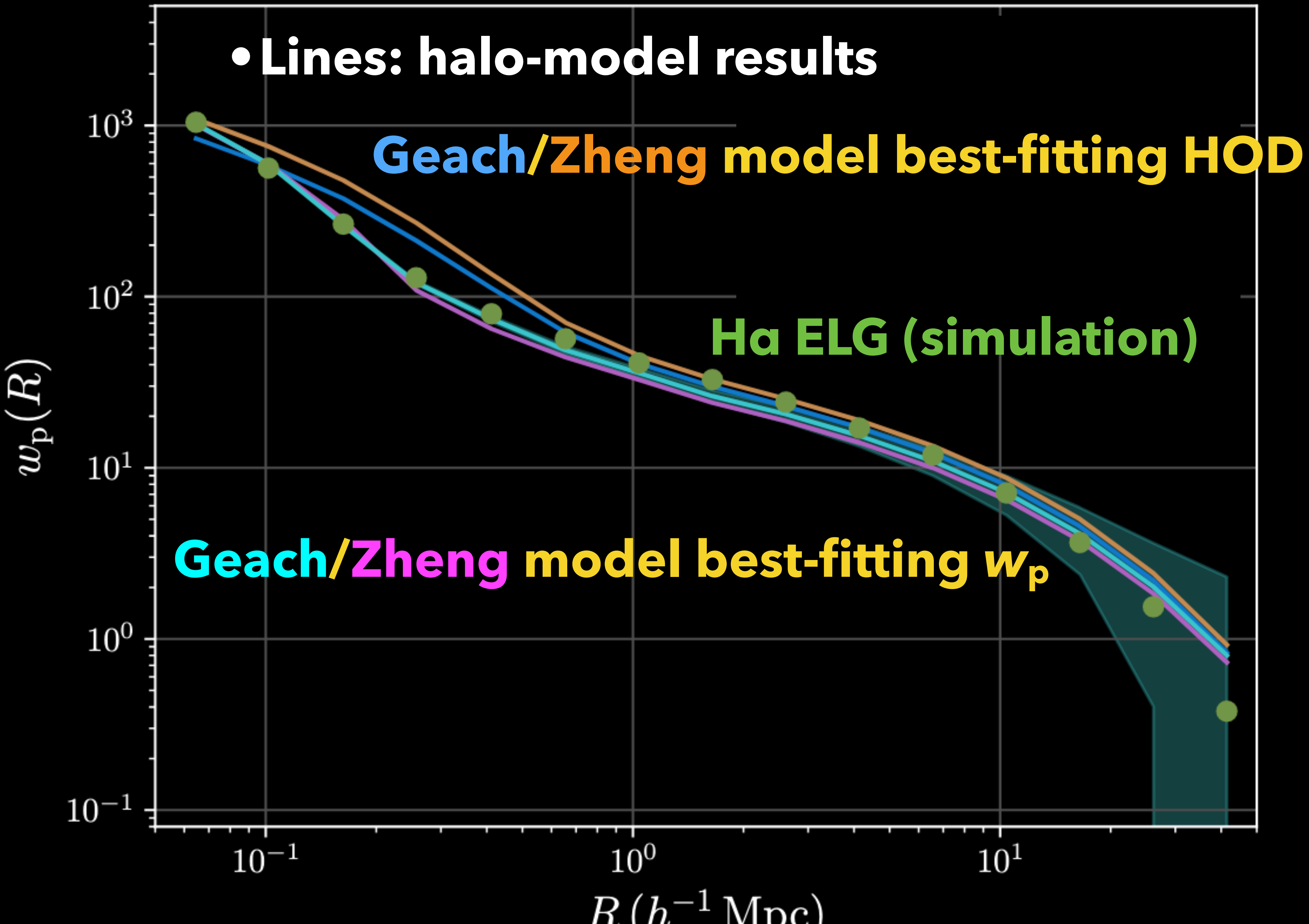
KO and Okumura (2022)

➡ ***Geach model outperforms Zheng model and can trace the two components of central HOD.***

Projected Correlation Functions

✦ ***Projected correlation functions***

➡ One of major statistics used in practical measurements.



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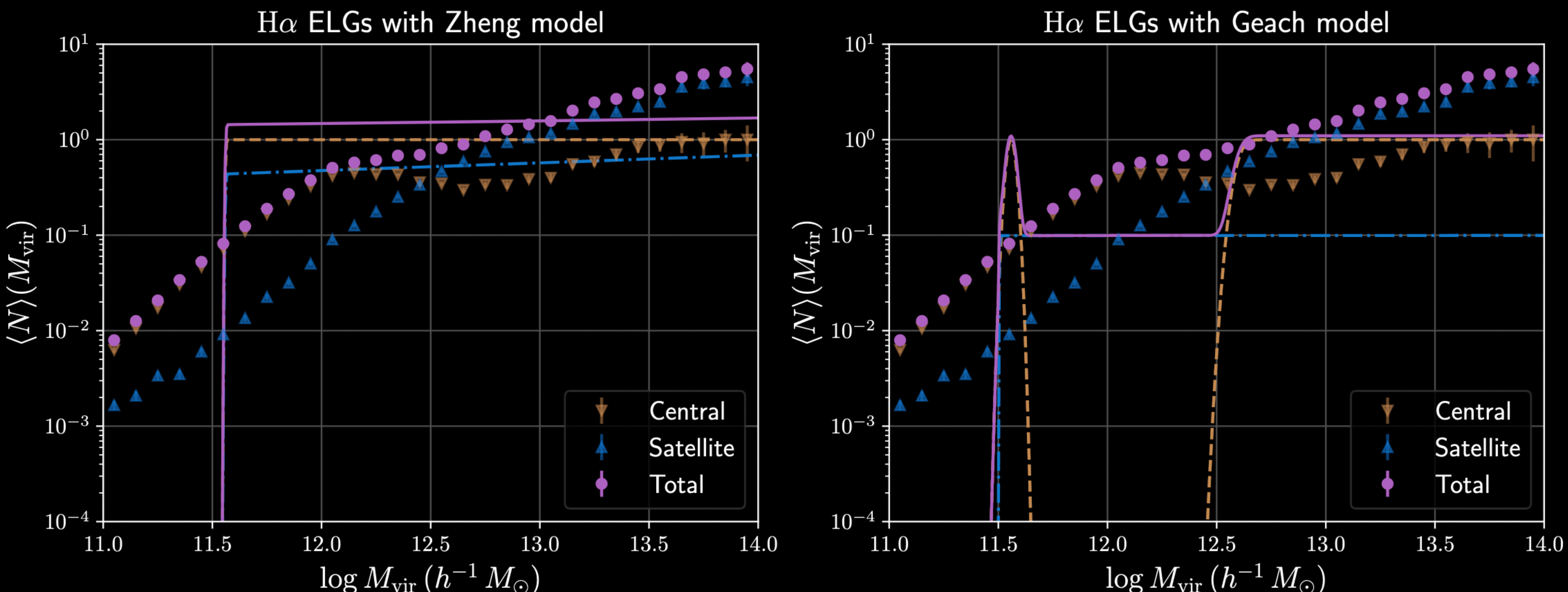
Projected Correlation Functions

✦ ***HOD which fits projected correlation functions the best***

- The HODs completely deviate from the HOD directly measured from simulations.

➡ The projected correlation functions are not enough to constrain HOD models.
Prior knowledge on HOD parameters or functional shape from simulations is important to robustly constrain the HOD.

Lines: Best-fitting HOD / Points: HOD measured from simulations



KO and Okumura (2022)

Summary

- Hydrodynamical simulations are the ideal tool to scrutinise the galaxy-matter relation to improve modelling of ELG clustering.
- We have generated realistic ELG mock catalogues, which are suitable to investigate ELG-halo connections.
- We directly measured HOD and projected correlation function of ELGs. **Geach HOD model can fit both better than Zheng HOD model.**
- HODs can be constrained with projected correlation functions. However, the inferred HODs are quite different from HODs measured from simulations. **Additional information, e.g., hydro sims, is essential to robustly determine the HOD.**