"Simulating" Emission-Line Galaxies for Ongoing and Future BAO Surveys

Shun Saito

Missouri S&T, USA

Nov 7th 2019

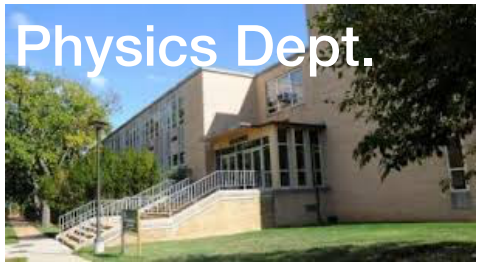
"The first Shanghai Assembly on Cosmology and Galaxy Formation"

Shanghai, China

MISSOURI S&T

New Astrophysics Group at Missouri S&T

In ***Rolla***, Missouri (100 mile from St. Louis)



Marco Cavaglia

- Gravitational Wave
- LIGO

Shun Saito (me)

- cosmology, LSS
- **HETDEX**, **PFS**

Missouri S&T joins dark energy experiment to solve accelerating cosmos mystery

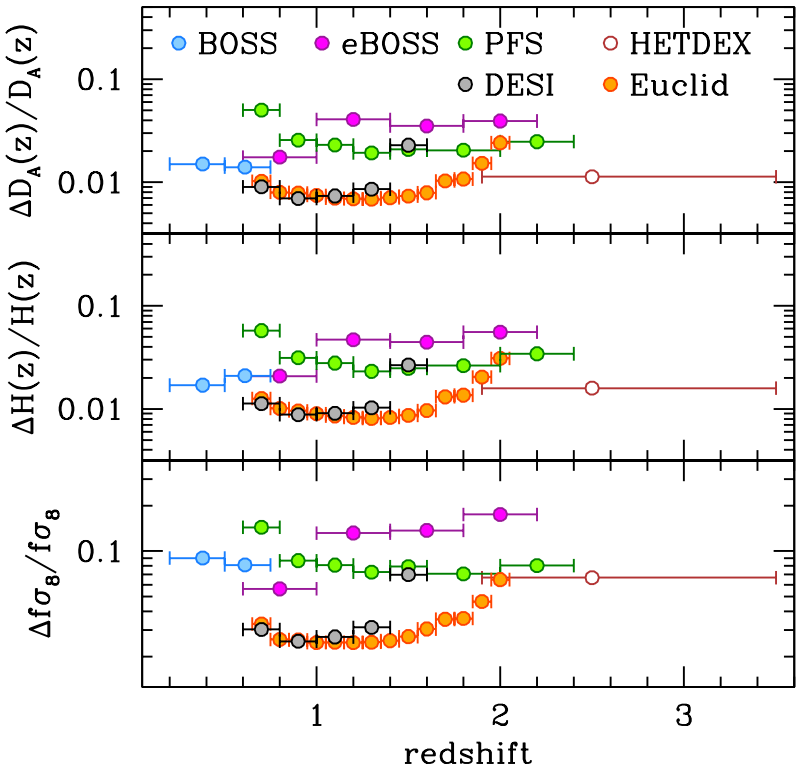
Posted by Delia Croessmann

On September 26, 2019

- "***Institute for Multi-messenger Astrophysics & Cosmology*** (***iMAC***)"
- Keep your eyes on future faculty hiring (+5 in principle…)

Introduction

©Ariel Sanchez (MPE)



c.f., also Angulo's talk

- All ongoing & future BAO galaxy surveys aims at **Emission Line Galaxies** at $z > 1$.

- Essential to construct a **realistic Mock Catalog** for ELGs.
  Does the **H**alo **O**ccupation **D**istribution method work well?

- Observed ELGs are "**special** populations".
  - eBOSS, PFS, DESI: [OII] after (mag, color) selection.
  - Euclid, WFIRST: Hα with flux threthold.

- Understanding interplay ISM physics in galaxy formation.
  e.g., Hirschmann+(2017)

Outline

Physical ⟷ *Empirical*

Hydro Sim.
- limited by sub-grid physics.

Semi-Analytical Model
- require calibration

Empirical Model
- HOD
- ***Abundance Matching***

Volume: *Small* → *Sufficiently large*

---

1) How to model Emission Line fluxes?

- find an empirical relation b/w F_{EL}(M*, SFR, …) in COSMOS.

SS, de la Torre, Ilbert+, *to appear on arXiv this month*.

2) How to paint ELGs in *N*-body simulations?

- embed our COSMOS model into the UniverseMachine.

SS, Hearin, Samushia+, *in prep*.

Preliminary

Empirical Approach to Model EL fluxes

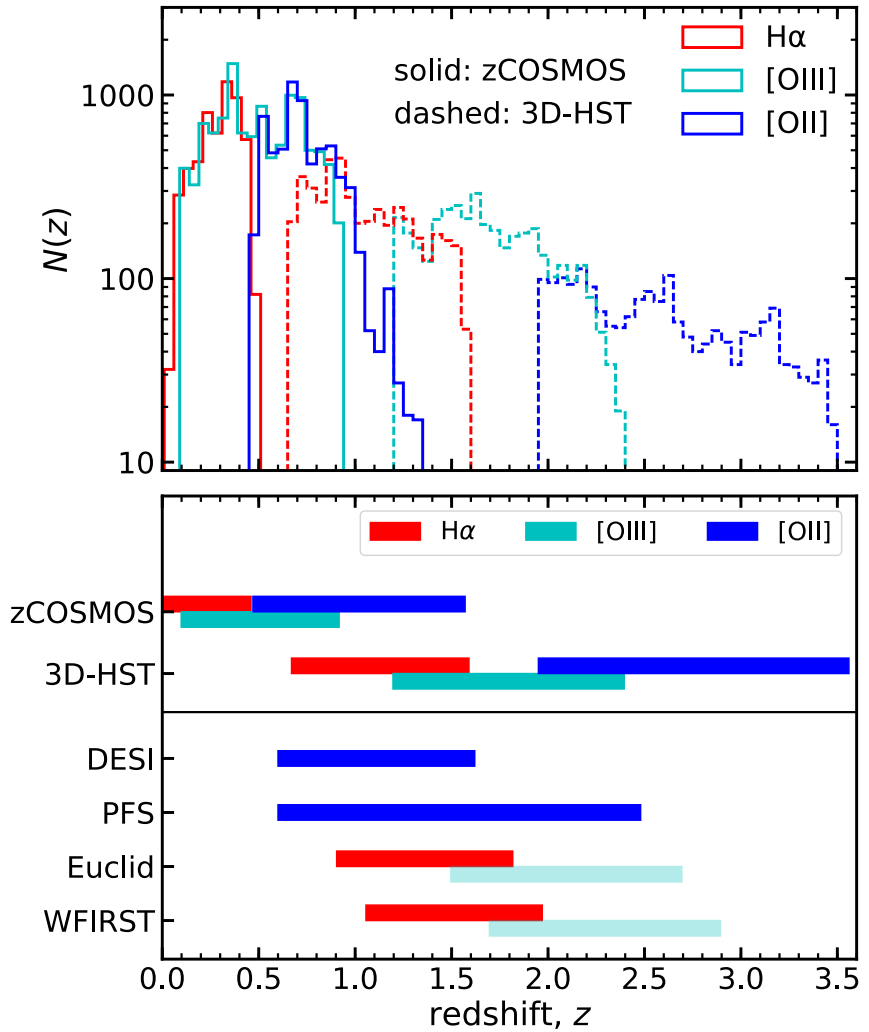
- Attempt to find an empirical mapping from continuum to ELs.

- 0.5M galaxies w/ 31 bands (UV-NIR) to K<24.7 over 1.38deg^2
  in COSMOS2015 (Laigle+2016)

- calibrate our model only with available spectrum dataset.

  ⟹ LF is our prediction. c.f., Izquierdo-Villalba+(2019)

  c.f. Jouvel+(2009), Valentino+(2017), Merson+(2017)…



Simple Model to Galaxy SED “stellar continuum”

✦ Redo the SED fitting to the COSMOS2015 photometry Laigle+(2016)

- stellar continuum
  * SPS model templates Bruzual & Charlot (2003)
  * Star Formation History (declining or delayed) & Age
  * Metallicity, $0.5Z_{sun}$ or Z_{sun}
  * dust reddening (two templates) Calzetti (2000), Arnout+(2003)

$$10^{-k(\lambda)E_{\rm star}(B-V)}$$

- photo-z: fixed with the values in Laigle+(2016)

$$12\ (\mathrm{BC03\ templates}) \times 43\,(\mathrm{ages}) \times 12\ (\mathrm{SFH\ and\ metallicities}) \times 2 \times 8\ (\mathrm{dust\ extinction})$$
$$= 99,072\ \mathrm{templates}$$

Simple Model to Galaxy SED "Emission Line"

✦ SED fitting to the COSMOS2015 photometry

- Emission Lines from star-forming nebulae

* compute LyC photons from HI, HeI and HeII by integrating BC03

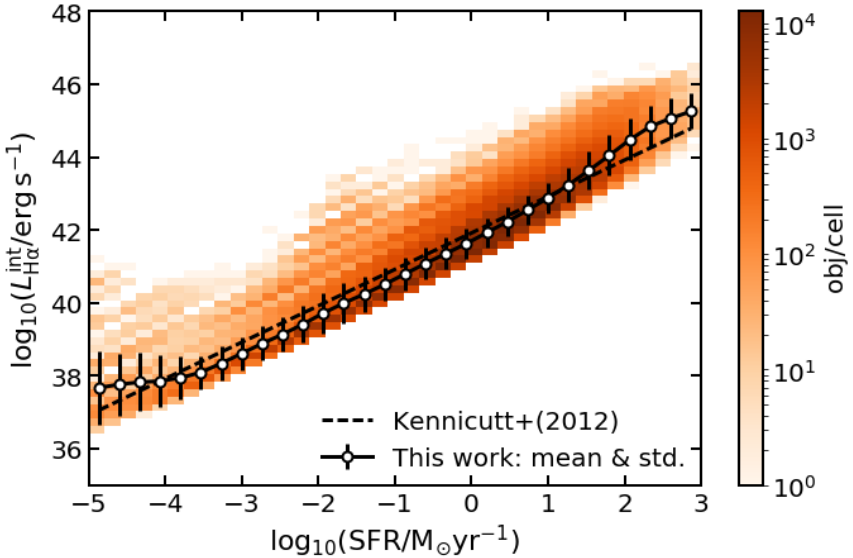
$$L_\lambda = \frac{hc}{\lambda}\frac{\alpha_\lambda(T_e)}{\alpha_B(T_e)}\, f_\gamma\, Q_{\rm LyC} \qquad T_e = 10^4\,{\rm K}\ \&\ n_e = 100\,{\rm cm}^{-3}$$

Schaerer & Vacca (1998)

* specifically derive Hβ luminosity

$$L_{\rm H\beta} = 4.78\times10^{-13}\, f_\gamma\, Q_{\rm LyC}$$

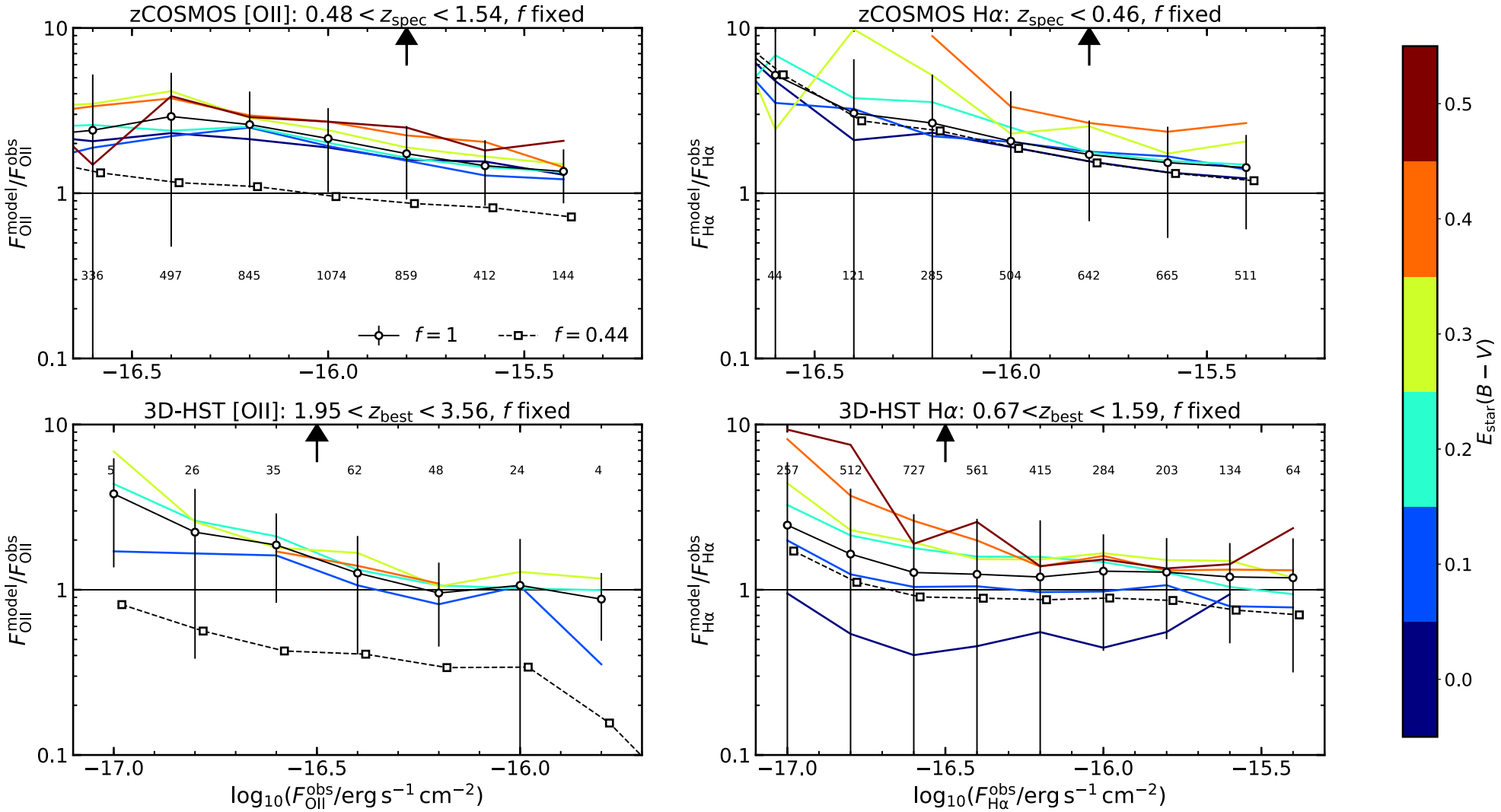
Consistent w/ the Kennicutt calibration



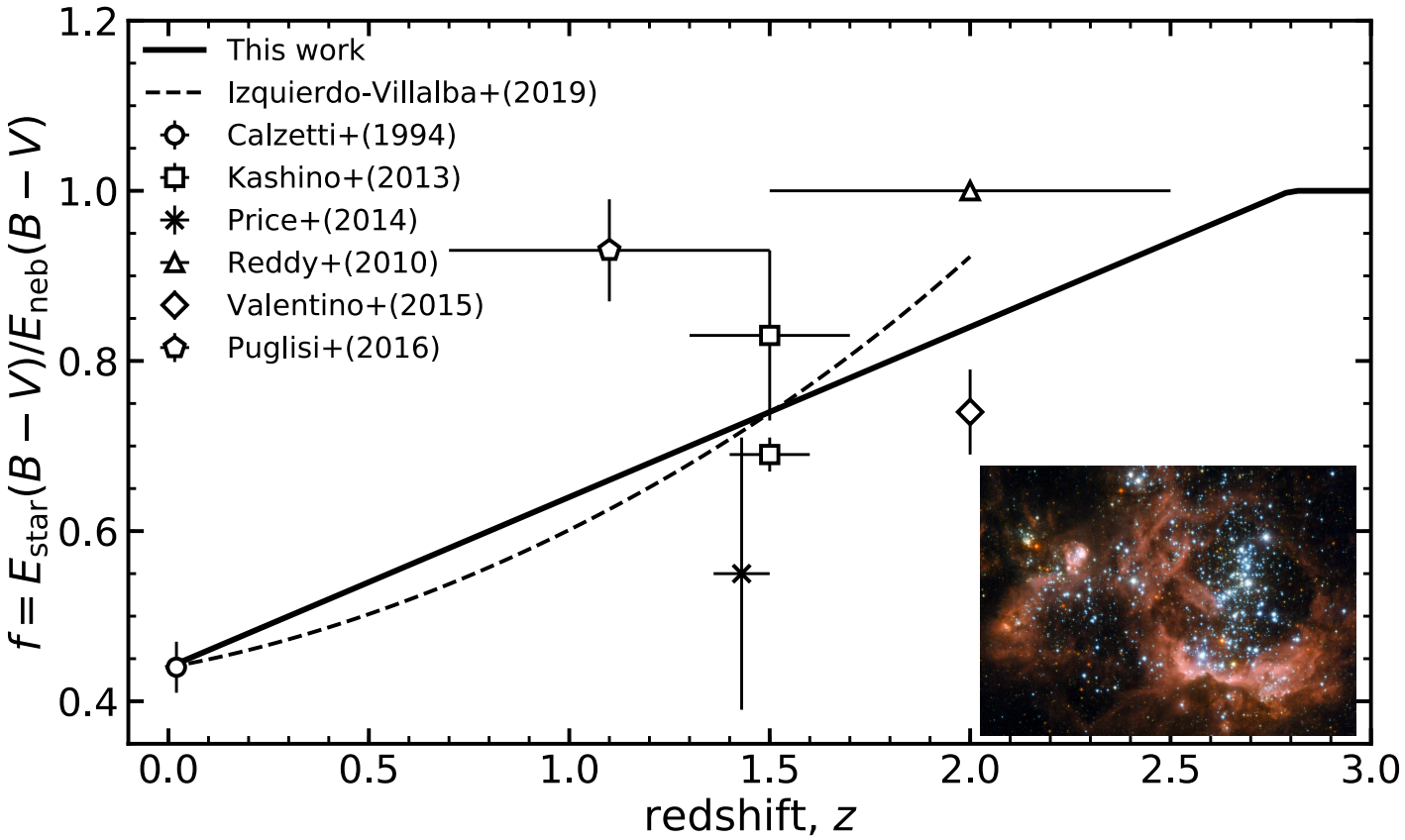
* fix the line ratio to convert to [OII]/Hβ=3, Hα/Hβ=2.9
  or exceptionally make it free for [OIII]

* additional dust attenuation $E_{\rm neb}(B-V) = \dfrac{E_{\rm star}(B-V)}{f}$

Dust Attenuation is Key

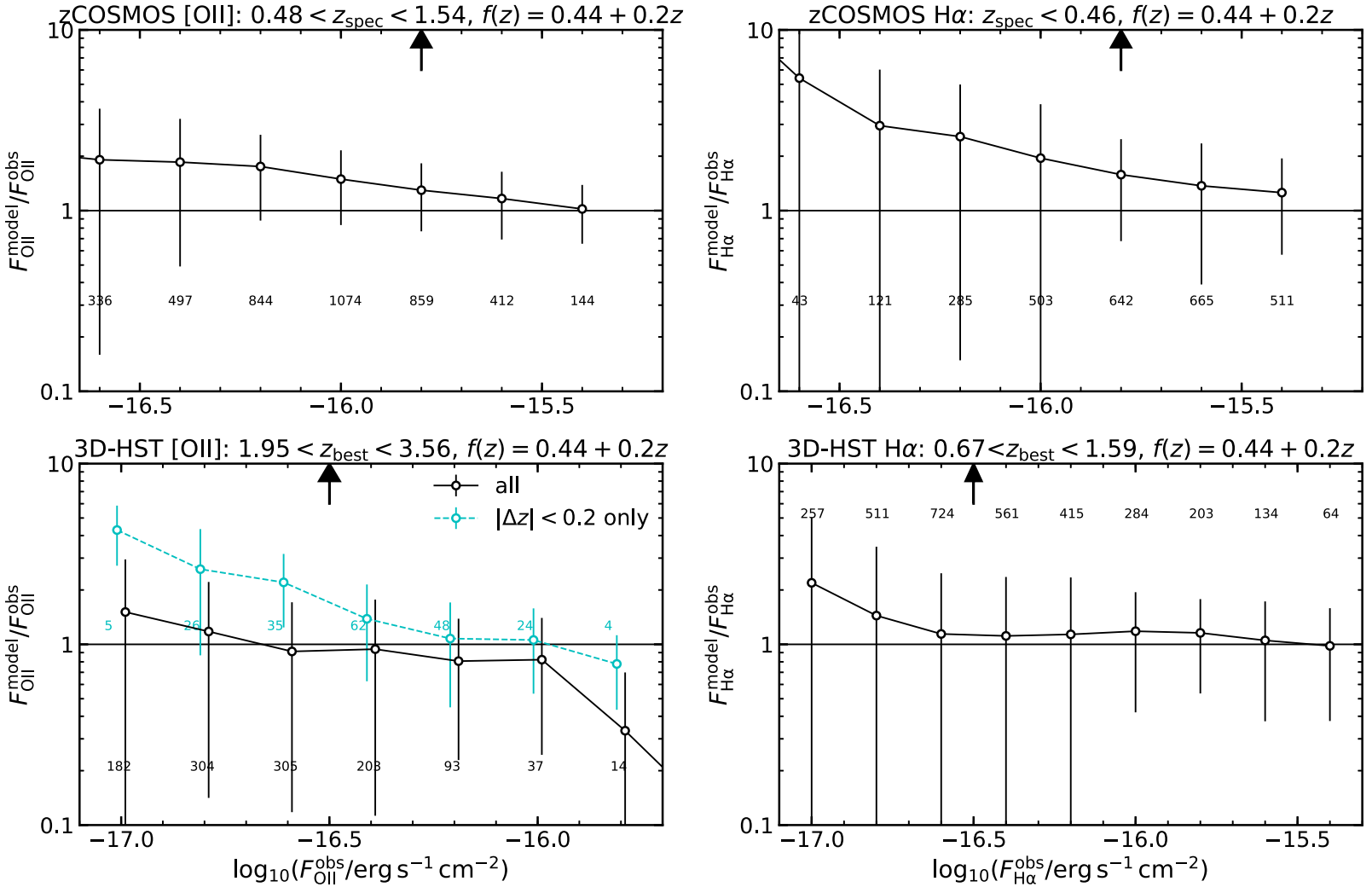


Dust Attenuation is Key

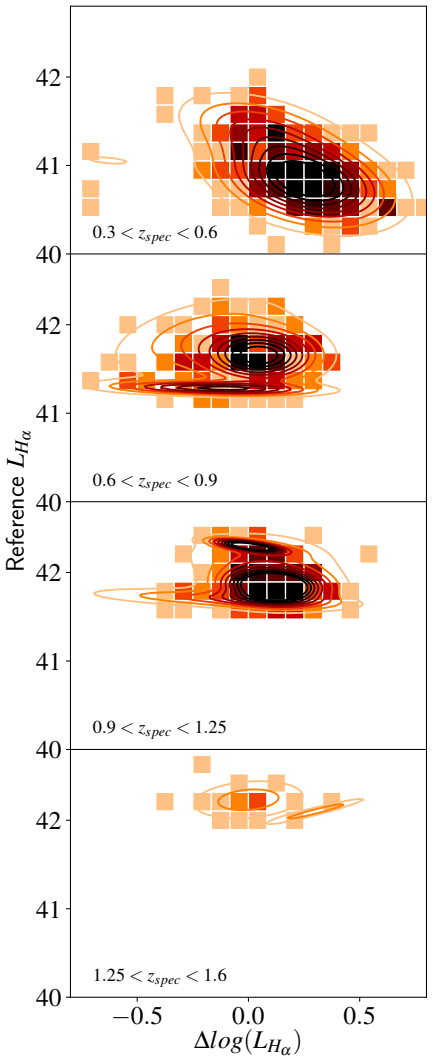


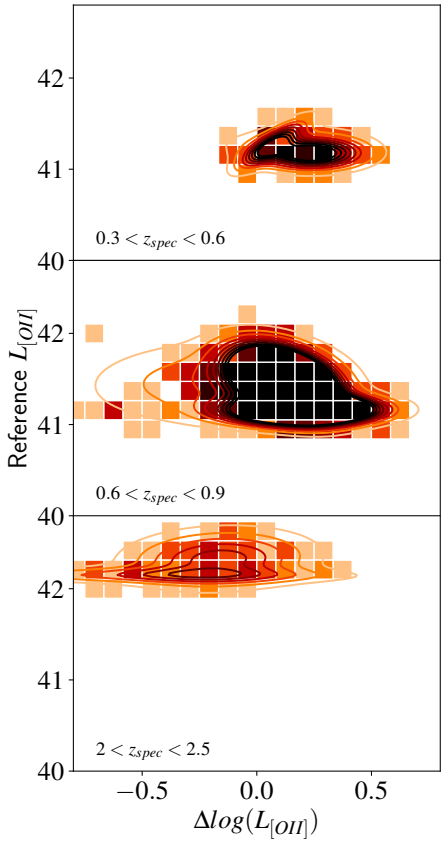
$$f(z) = 0.44 + 0.2z$$

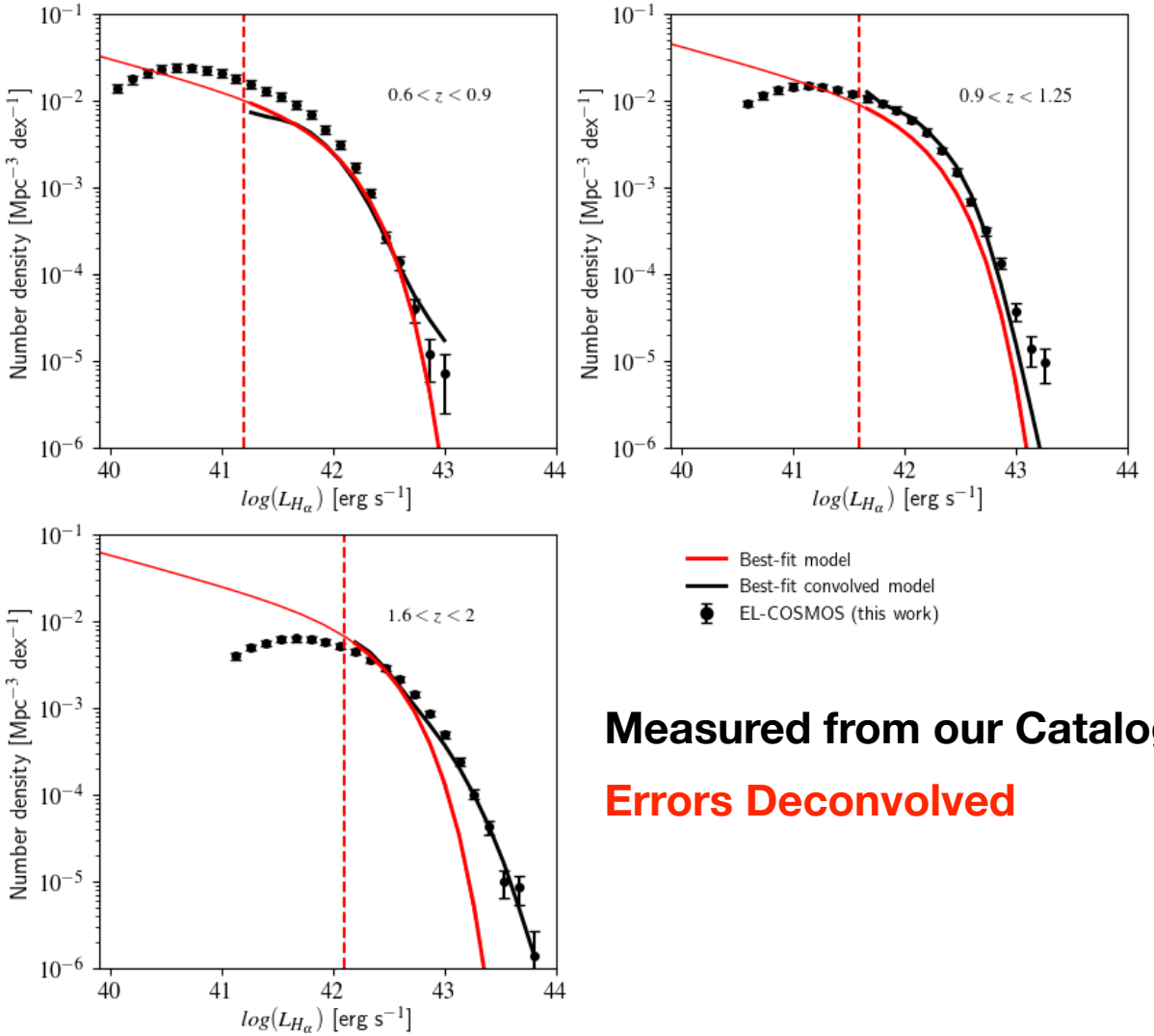
Performance of our Simple Model



“Eddington Bias” in our LF prediction







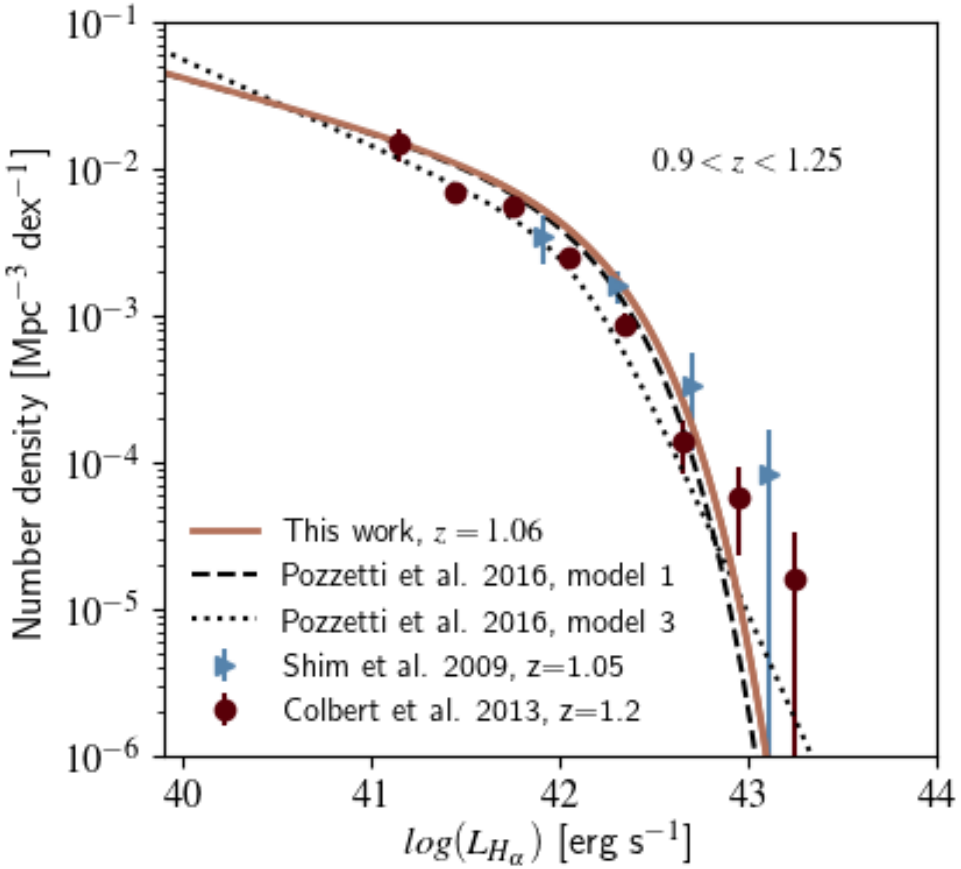
Measured from our Catalog

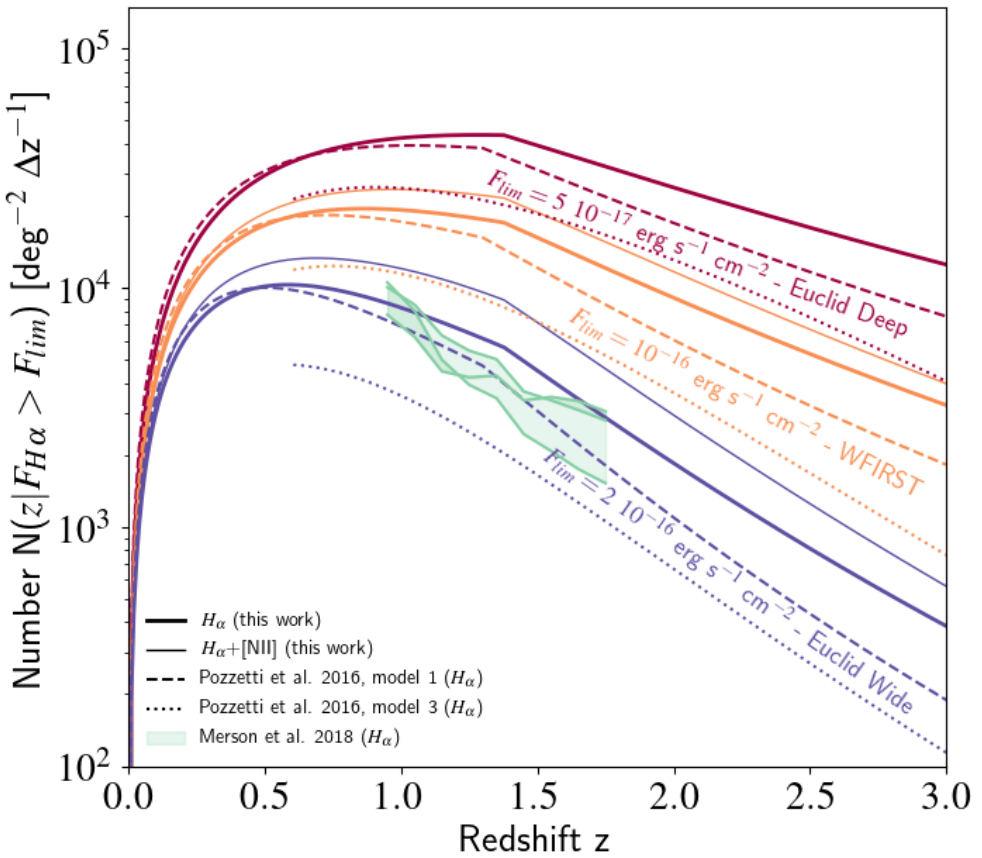
Errors Deconvolved

Predicted number density of ELGs

✦ Our LF predictions allow us to estimate the expected number density of ELGs.

- Predicts larger number of Hα in Euclid than Pozetti+(2016).





UniverseMachine Model

- Provides an empirical relation of

  (M*,sSFR) ⇔ N-body subhalos (merger histories)

- *N*-body simulation

  BolshoiP

  L_{box} = 250Mpc/h, M_p=1.5 x 10^8 M_{sun}/h

  MDPL2

  L_{box} = 1Gpc/h, M_p=1.5 x 10^9 M_{sun}/h

  Lightcone is available (0<z<8, 1600deg²)

  ***OuterRim** available soon

  L_{box} = 3Gpc/h, M_p=1.85 x 10^9 M_{sun}/h

=> Combine with (M*,sSFR) ⇔ (F_{EL}) in our COSMOS.

Behroozi+(2019)

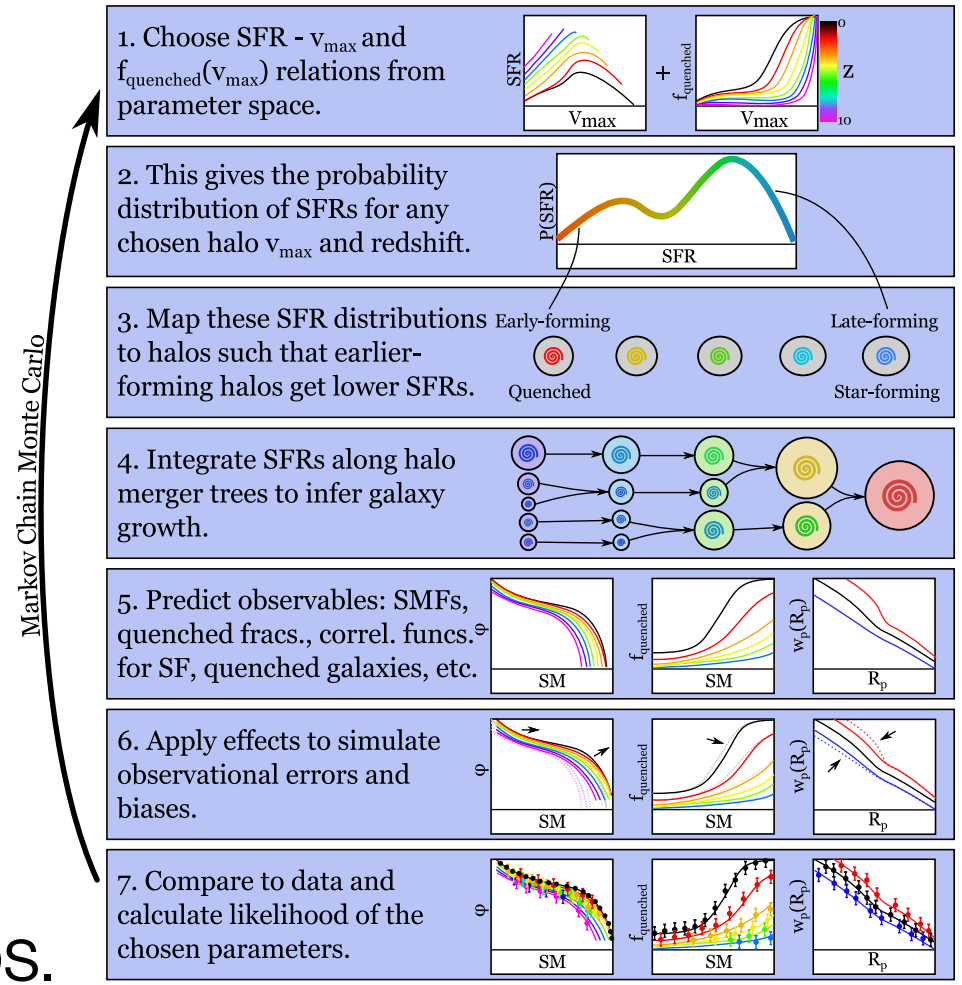


Figure 1. Visual summary of the method for linking galaxy growth to halo growth (§3).

Preliminary Investigation

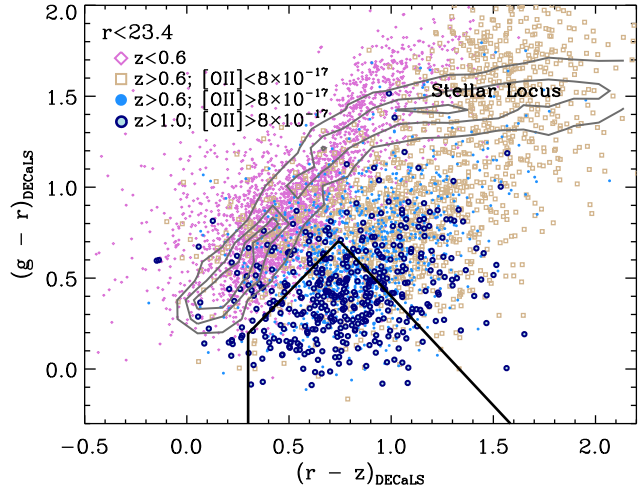
- As an example, mimic the selection in DESI [OII] ELGs.

$$20 < g < 23.5 \qquad 0.3 < r - z < 1.6$$

$$g - r < 1.15(r - z) \qquad g - r < -1.2(r - z) + 1.6$$

& $F_{[\mathrm{OII}]} > 2 \times 10^{-16}\,\mathrm{erg/s/cm^2}$ $\quad n_{\mathrm{g}} \sim 5 \times 10^{-4}\,[(h/\mathrm{Mpc})^3]$

DESI collab.+(2016)



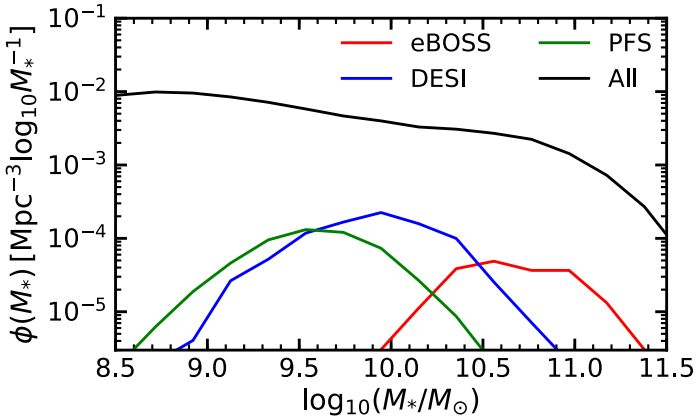
- In principle, we can do a similar investigation for **eBOSS & PFS**.

- Two simple questions

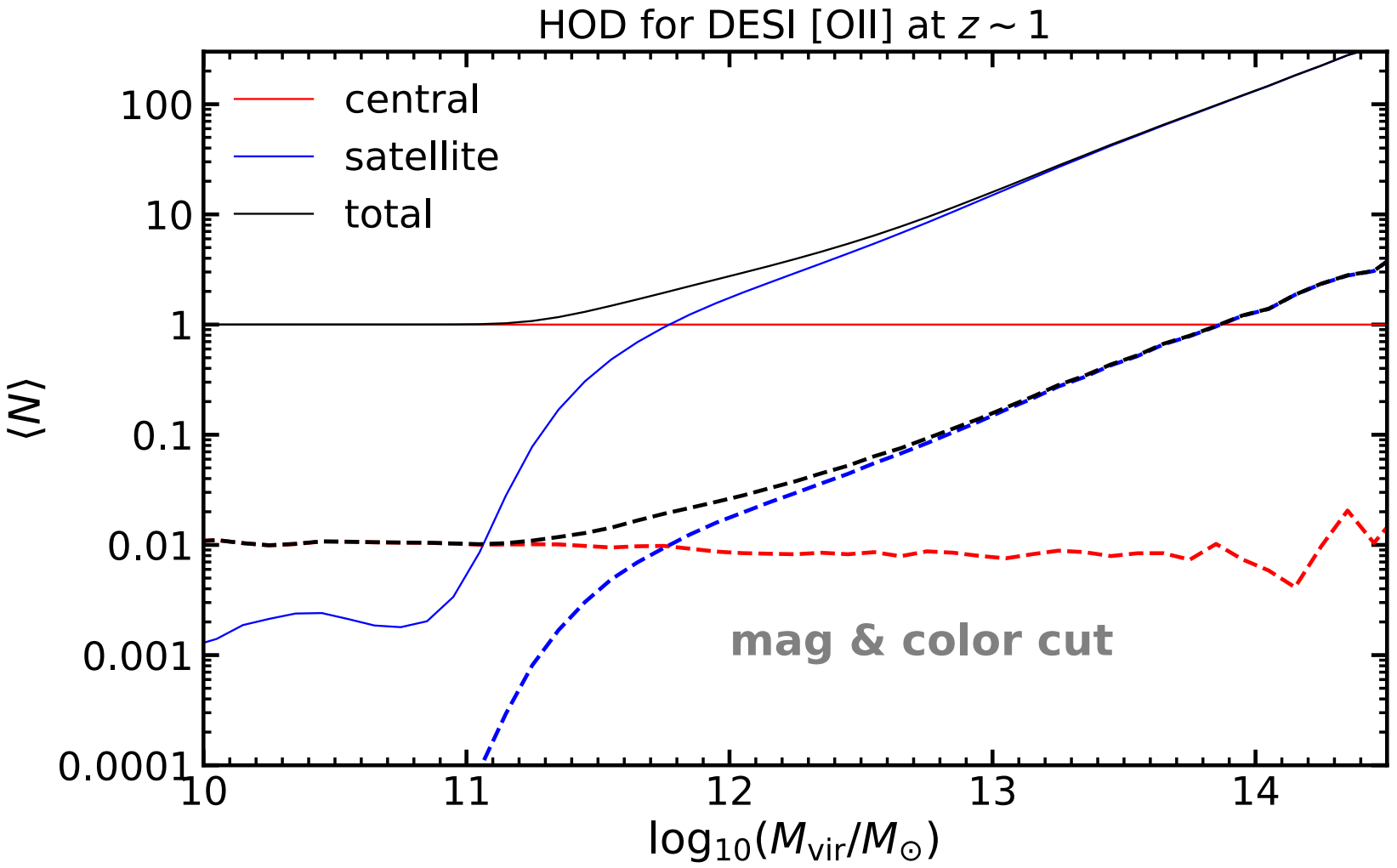
  1) Understand the selection in terms of HOD.

  2) What happens if we infer HOD from w_p?

SMF at z~1



1) Understand the selection in terms of HOD

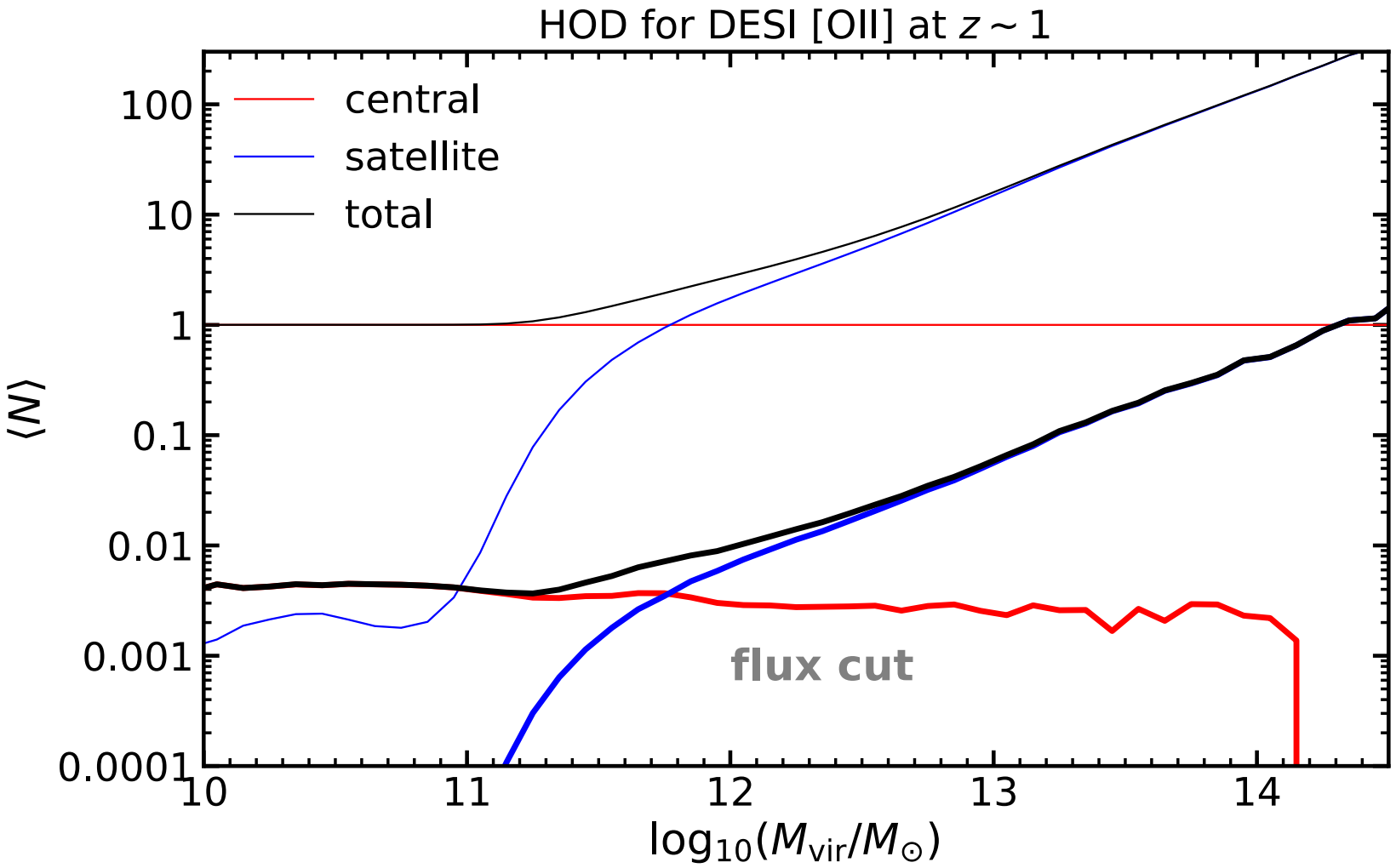


- satellite: **f_{sat}~36.2%**,

99.8% of satellites are

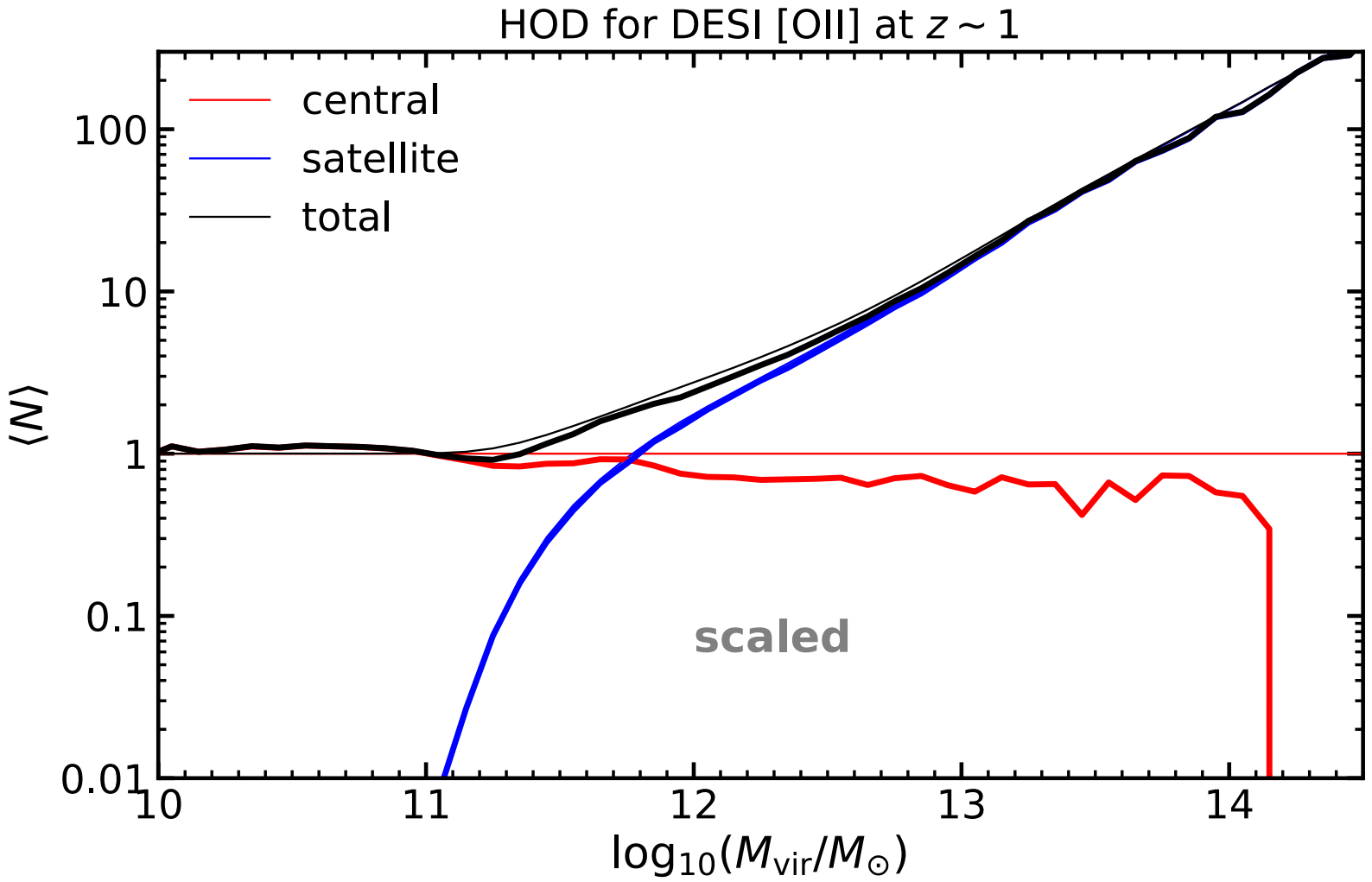
hosted by non-DESI cens.

1) Understand the selection in terms of HOD



- satellite: **f_{sat}~36.2%**, 99.8% of satellites are hosted by non-DESI cens.

1) Understand the selection in terms of HOD

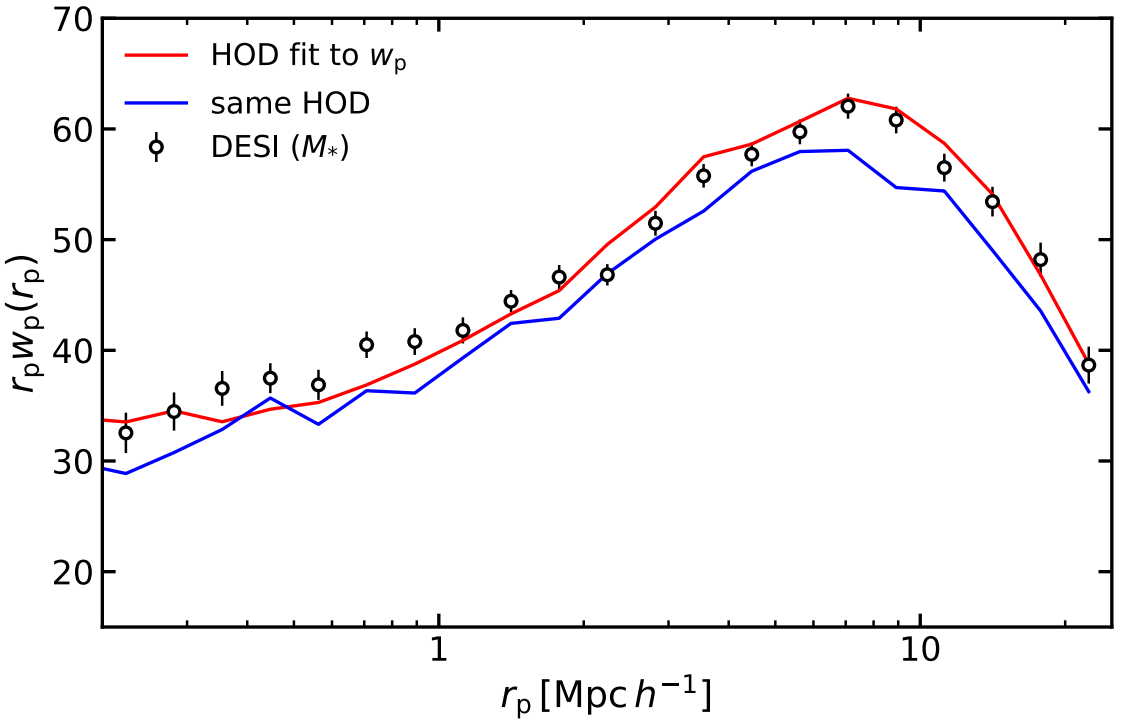


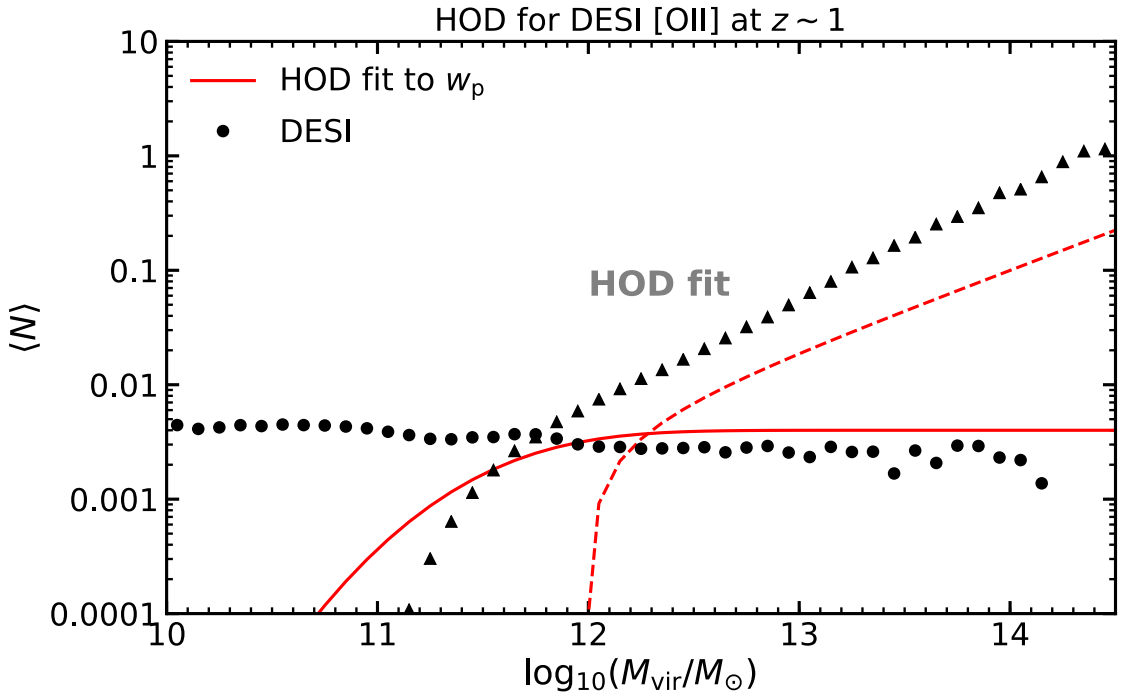
- satellite: **f_{sat}~36.2%**,

99.8% of satellites are

hosted by non-DESI cens.

2) What happens if we infer HOD from w_p?





- ✦ Simple 5-parameter HOD in Zheng+(2005) can fit to w_p but ***WRONG***!
- ✦ Exact HOD cannot fully explain the DESI w_p. Assembly bias? e.g., Zentner+(2013)

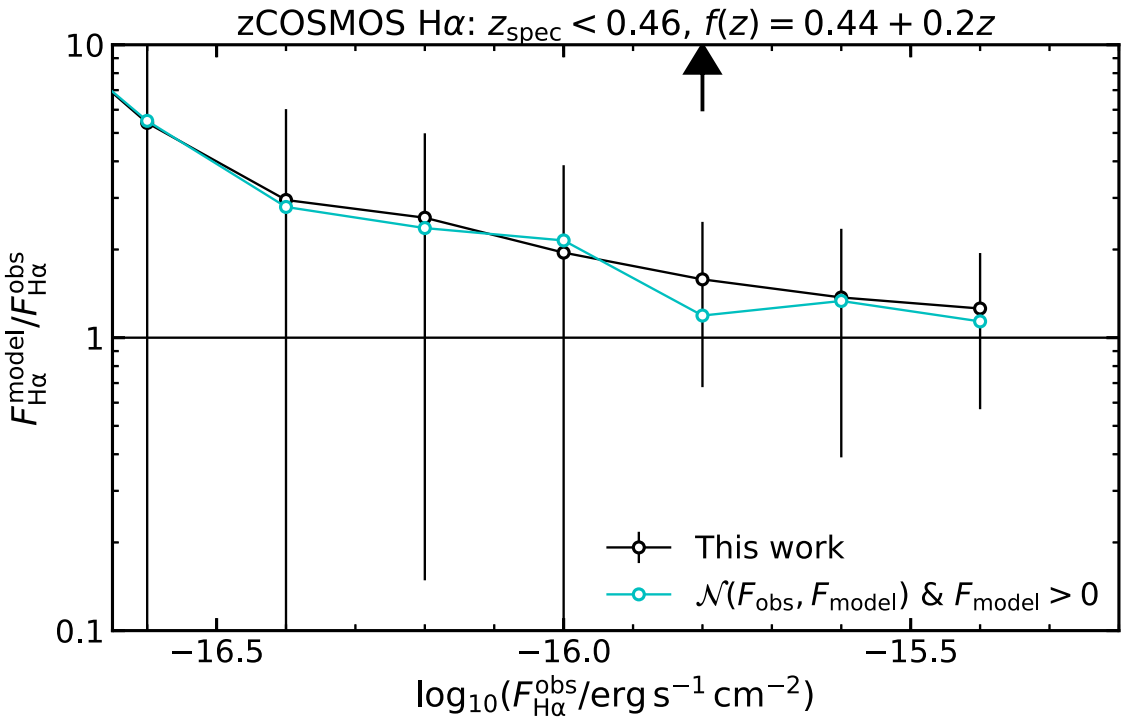
Summary

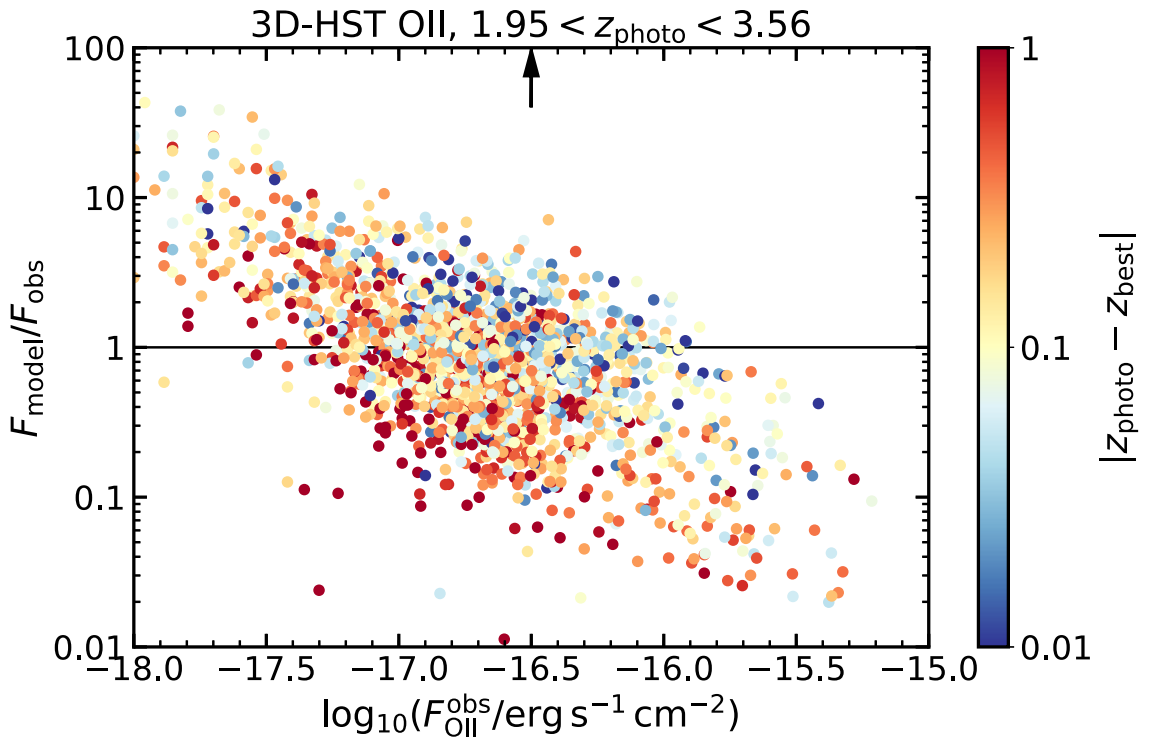
- ELG Mock Catalog shall play an essential role in forthcoming BAO surveys.

- Understand a galaxy selection in terms of galaxy properties:
  - Empirical relation b/w EL fluxes & galaxy properties in COSMOS2015.
  - Embed this to UniverseMachine which gives (M*,sSFR) ⇔ DM halo properties.

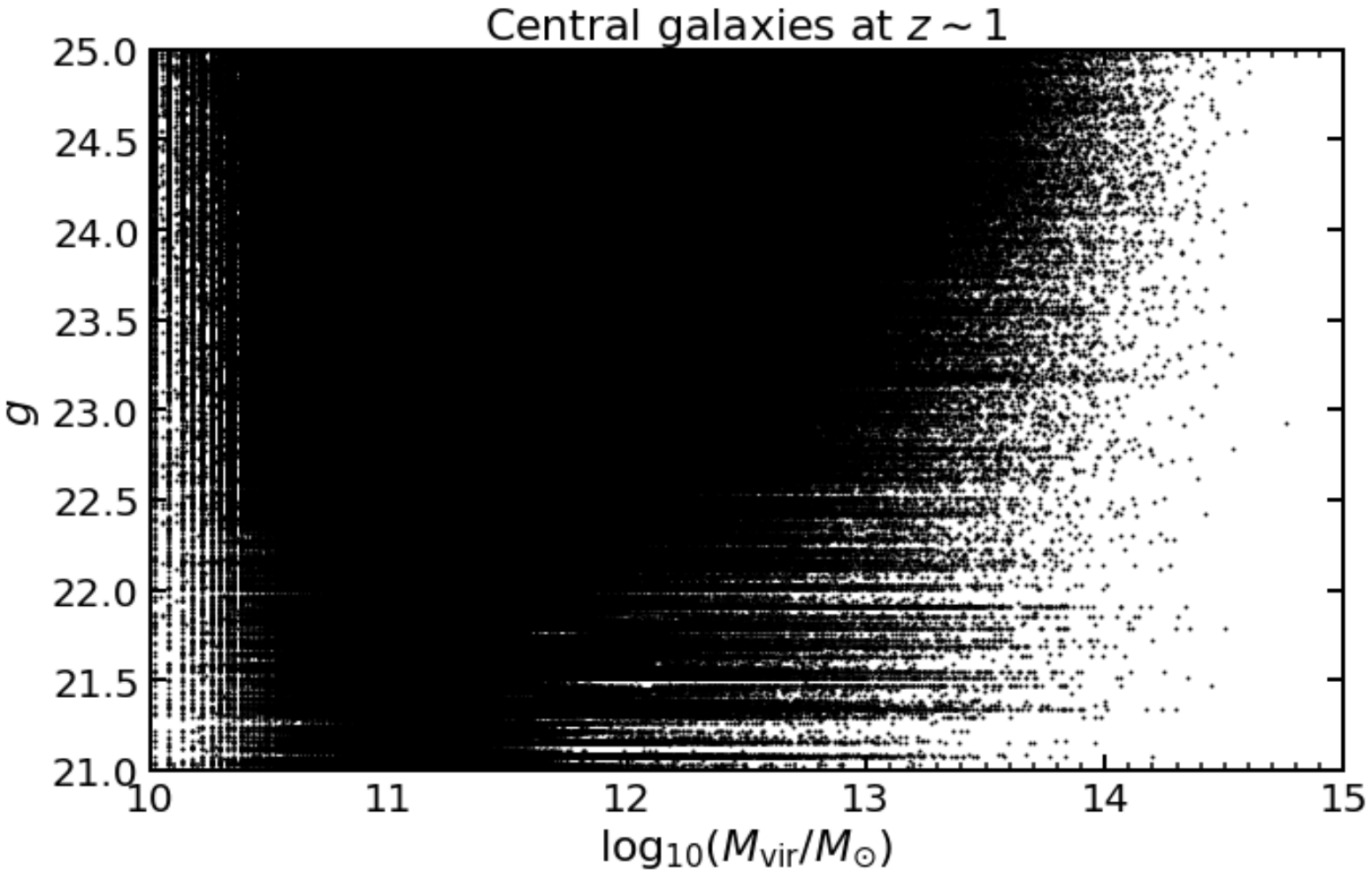
- Showed a preliminary investigation for DESI-like selection.
  - Constraining HOD from w_p is *NOT* a good idea for ELGs.
  - Can be validated with e.g., eBOSS ELGs. Guo+(2019), Alam+(2019)
  - We will investigate the best strategy with our UM-COSMOS ELG mock.

Appendix


zCOSMOS Hα: $z_{spec} < 0.46$, $f(z) = 0.44 + 0.2z$
10
1
0.1
−16.5
−16.0
−15.5
$F_{Hα}^{model}/F_{Hα}^{obs}$
$\log_{10}(F_{Hα}^{obs}/erg\,s^{-1}\,cm^{-2})$
This work
$\mathcal{N}(F_{obs}, F_{model})$ & $F_{model} > 0$


3D-HST OII, $1.95 < z_{photo} < 3.56$
100
10
1
0.1
0.01
−18.0
−17.5
−17.0
−16.5
−16.0
−15.5
−15.0
F_{model}/F_{obs}
$\log_{10}(F_{OII}^{obs}/erg\,s^{-1}\,cm^{-2})$
1
0.1
0.01
$|z_{photo} - z_{best}|$

Appendix


Central galaxies at $z \sim 1$
25.0
24.5
24.0
23.5
23.0
22.5
22.0
21.5
21.0
g
10
11
12
13
14
15
$\log_{10}(M_{\rm vir}/M_\odot)$