SEMI-ANALYTIC CATALOG FOR NEXT-GENERATION SURVEYS

Speaker: Wenxiang Pei （裴文祥）
Supervisor: Qi Guo （郭琦）

The 2nd Shanghai Assembly on Cosmology and Structure Formation @ Shanghai

Next-Generation Surveys

- DESI/CSST/Eucild/Roman/LSST
  - Large coverage, more obejects, high redshift, faint objects

Telescope	Orbit/ Site	Aperture	Time	FoV (deg^2)	$R_{EE80}('')$	Sky Coverage (deg^2)	Bandpass (nm)	Photometric Bands
CSST	LEO	2m	~2024	~1.1	<0.15	17500	255~1000	7
Euclid	L2	1.2m	2023	0.56 0.55	0.23 0.63	15000	550~900 920~2000	1 3
Roman	L2	2.4m	2026	0.28	0.24	2000	927~2000	4
LSST	Chile	8.4m	2024	9.6	0.54	18000	320~1050	6

Zhan 2021

Next-Generation Surveys

Large box, high resolution simulations

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Zhan 2021

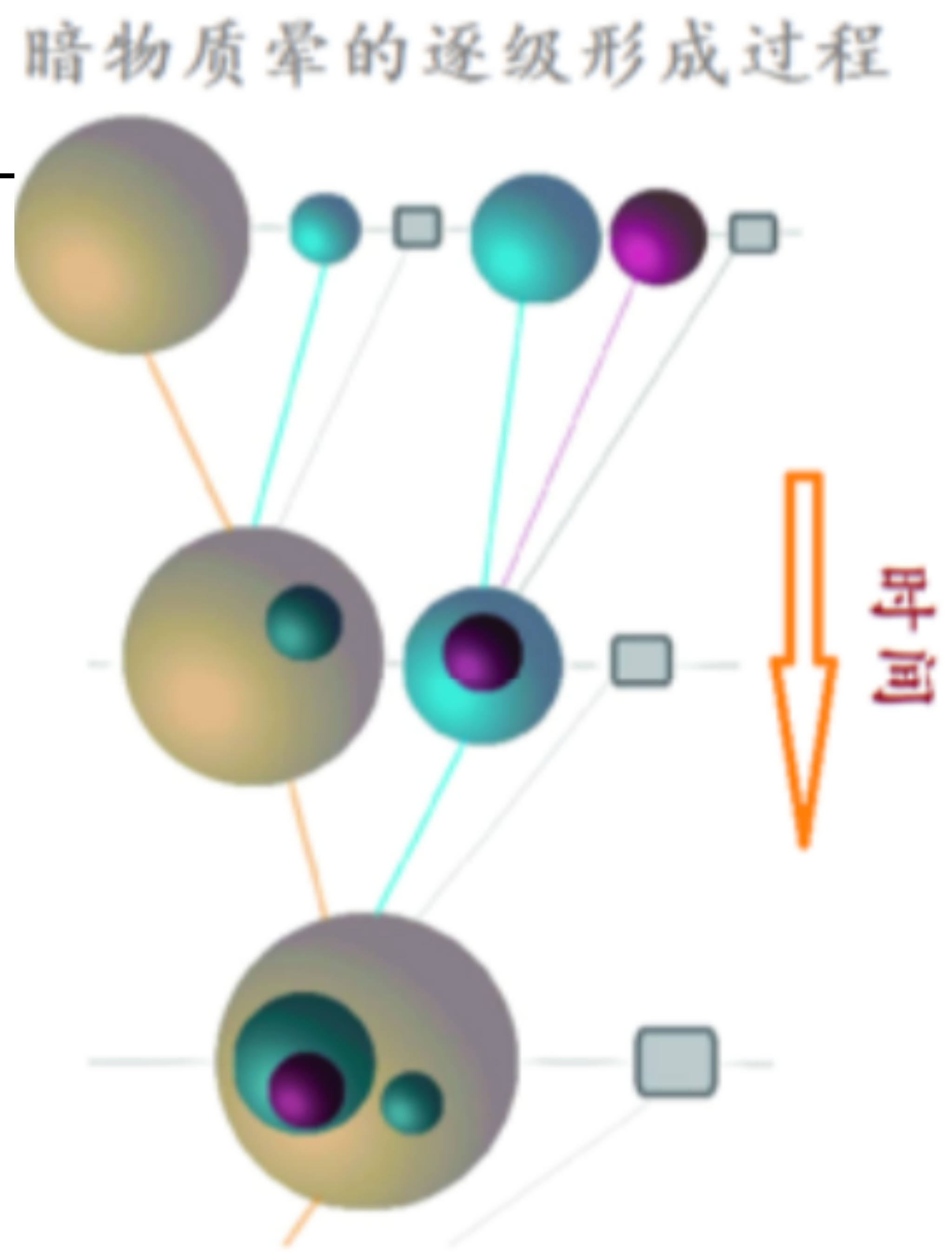
Next-Generation Surveys

- Simulations are crucial for modern cosmology
  - To understand complex physical processes related to various cosmic probs (BAO、RSD、Weak lensing and etc.)
  - To meet the requirement of accurate Cosmology(1%)
    selection effects, systematic uncertainties, statistic uncertainties

Semi-Analytic Model

- Lambda CDM
    - Dark matter - N-Body simulations
        - Collisionless Dark Matter Particles
        - Gravitation Only
        - FOF / Subfind / Merger Trees
    - Baryonic progress - Semi-Analytic Model / Hydrodynamical Simulation
        - Sub-grid Physics

Semi-Analytic Model



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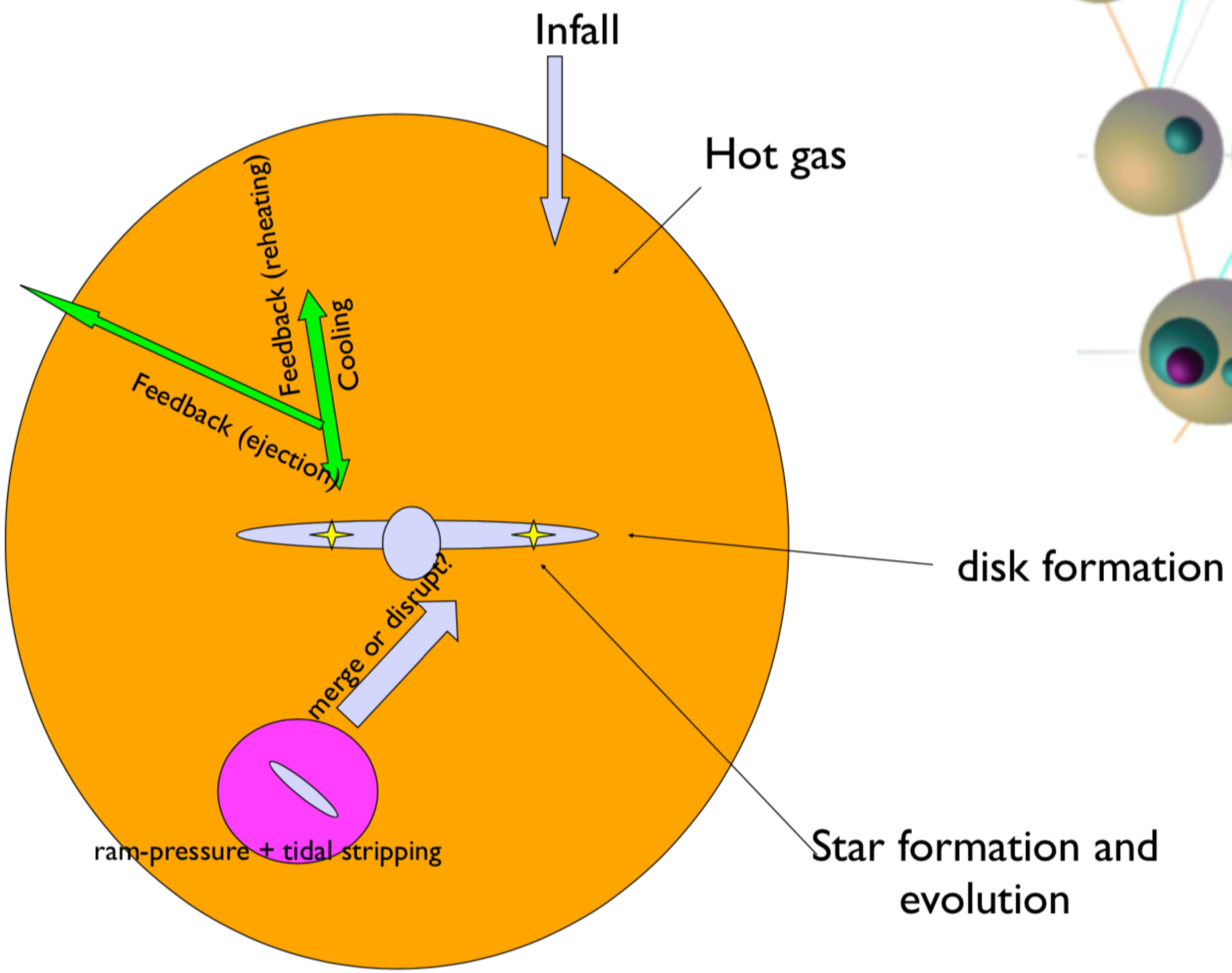

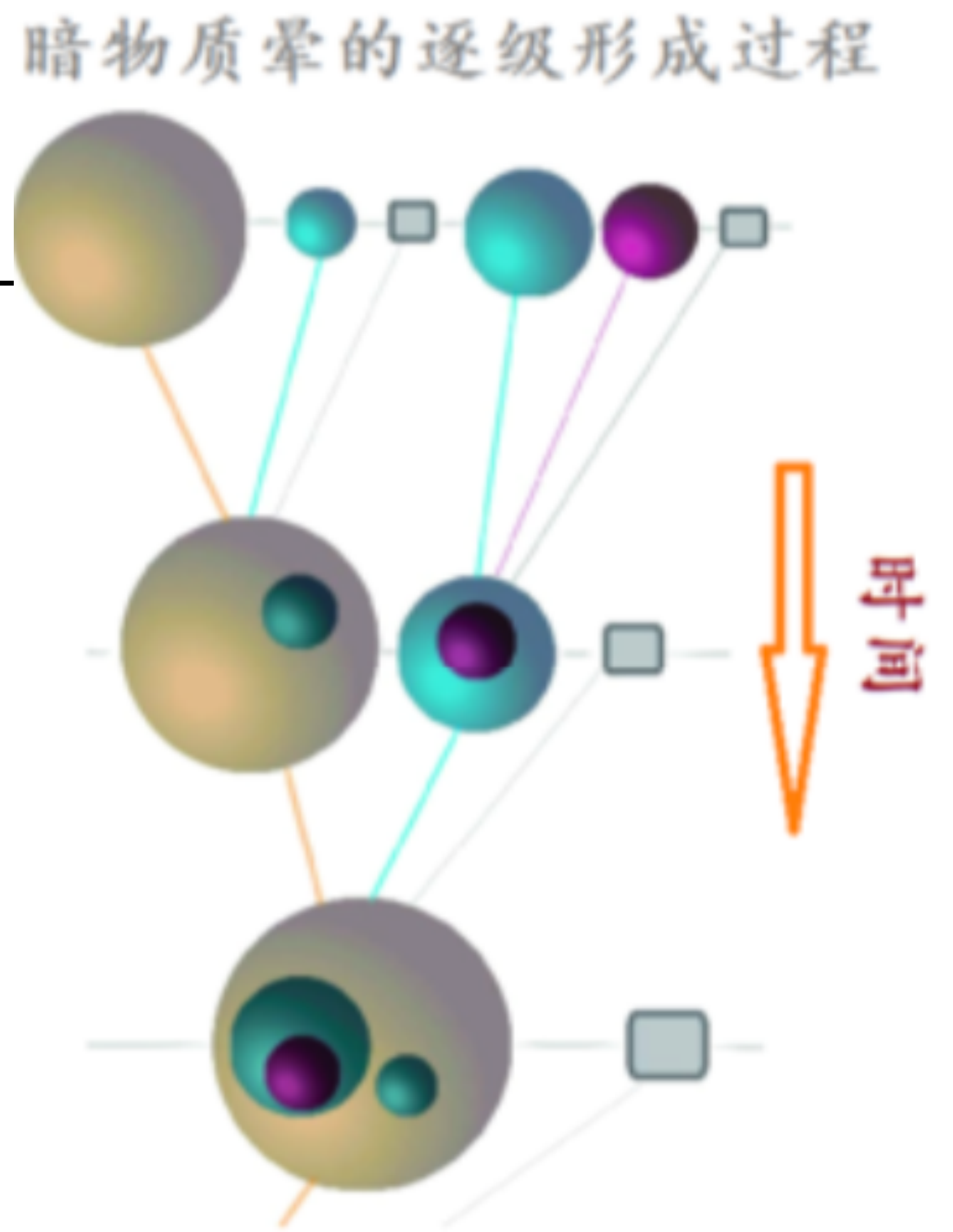

Semi-Analytic Model

- LGalaxies 2015 - Carlibrated on MR / MRII
    - 32 / 64 / 128 / 256 snapshots from a same test N-Body simulation (125Mpc/h)
    - Same halo properties at z~0.0 and similar tree structure

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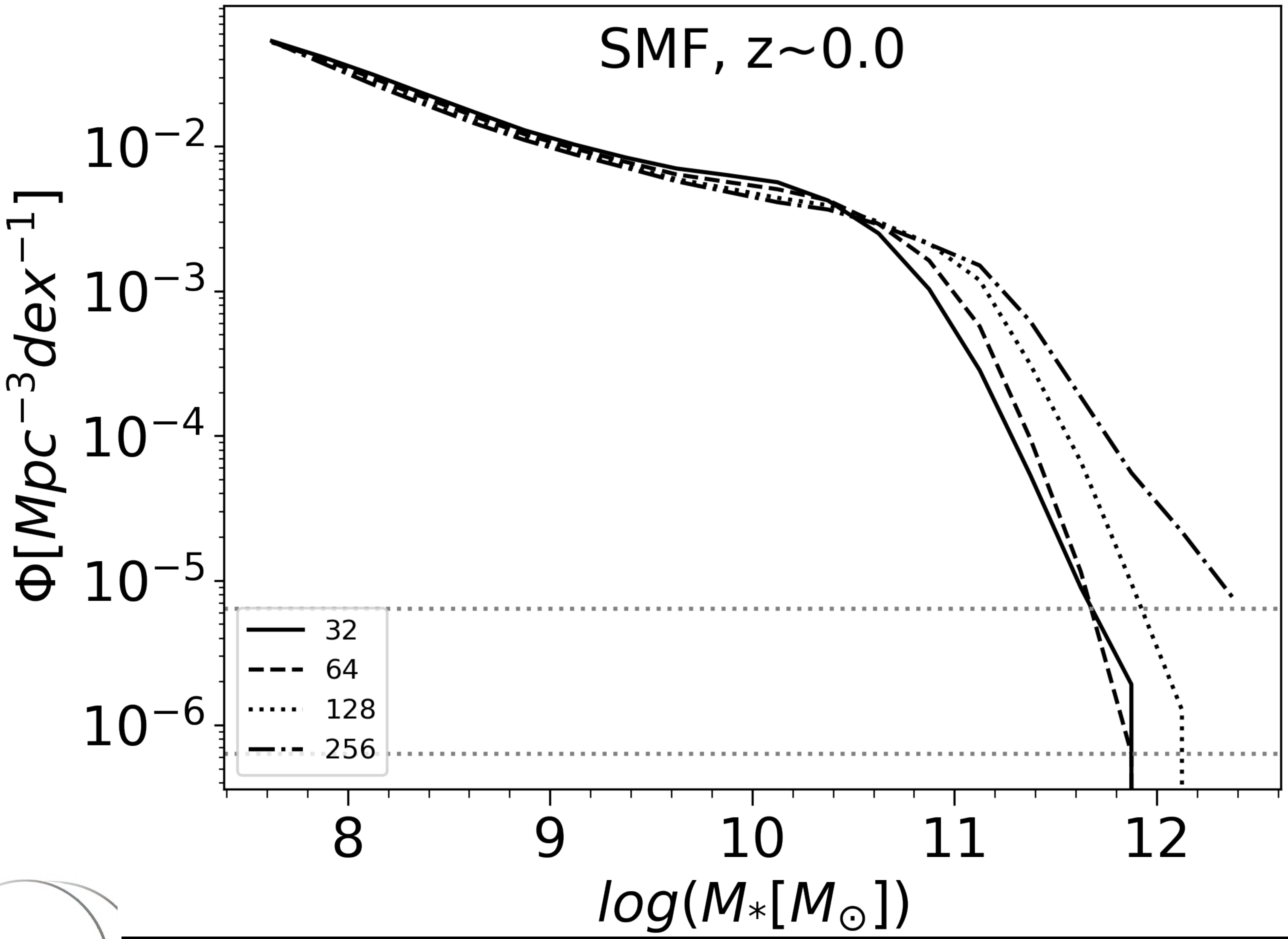

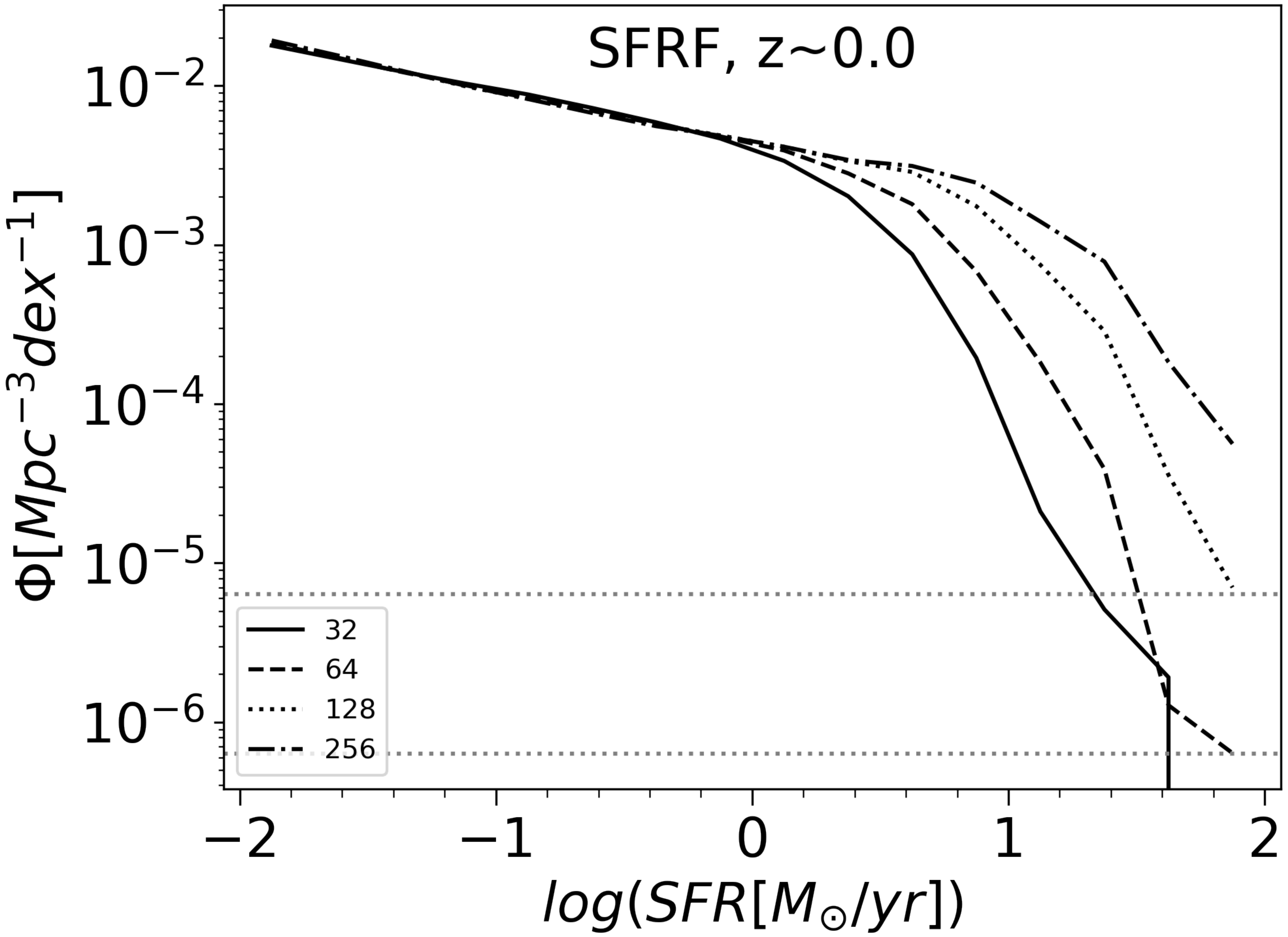

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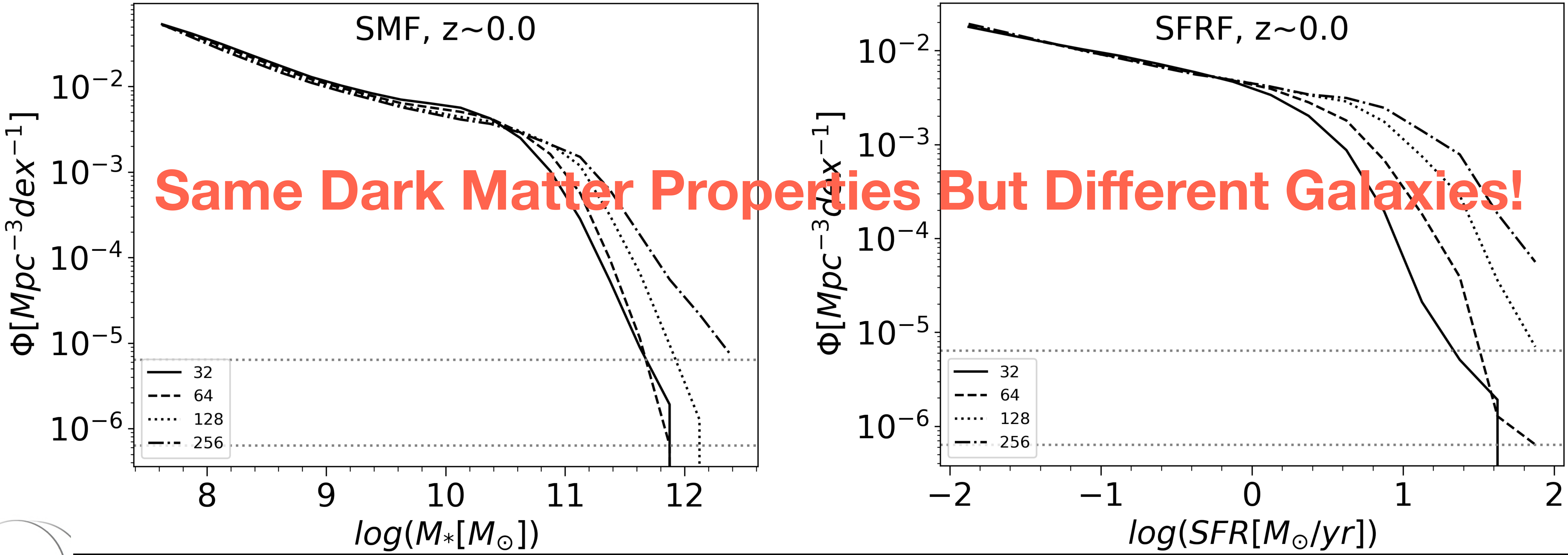


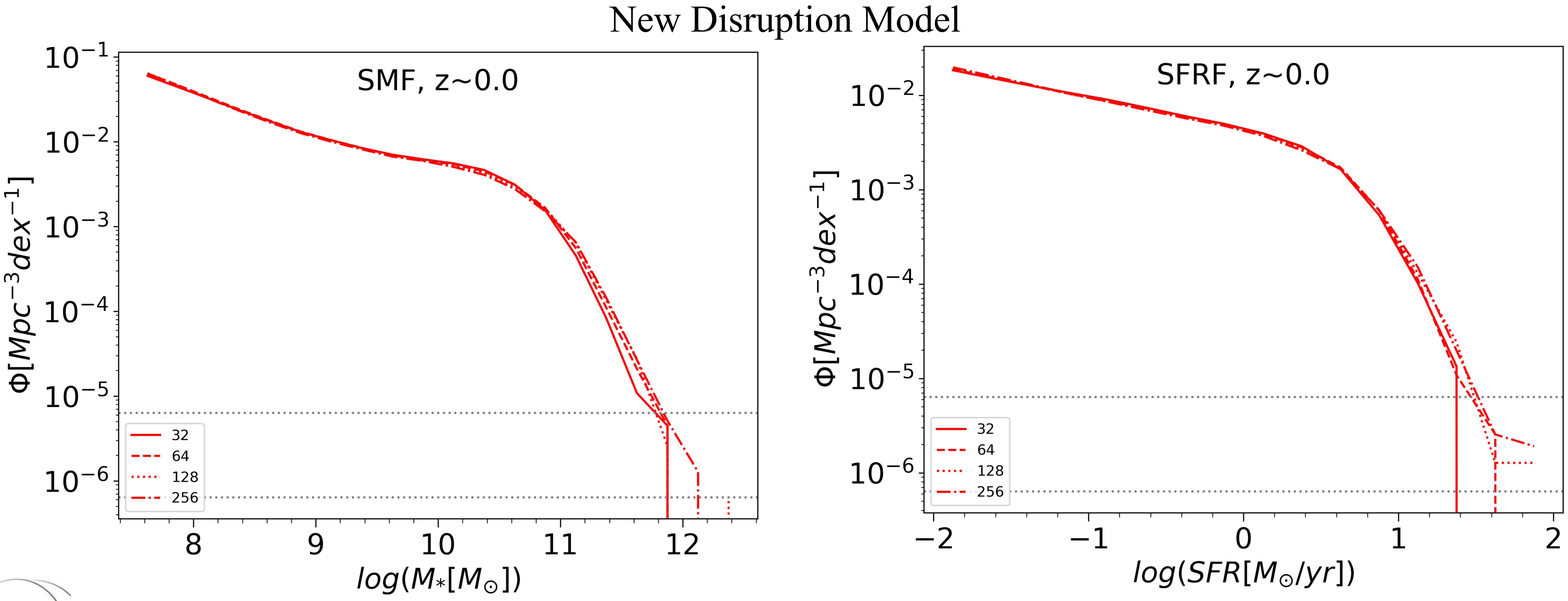
Semi-Analytic Model

smaller time gap $\Rightarrow$ more disruption less merger $\Rightarrow$ smaller BH $\Rightarrow$ larger SFR/M_*

New Disruption Model

Semi-Analytic Model

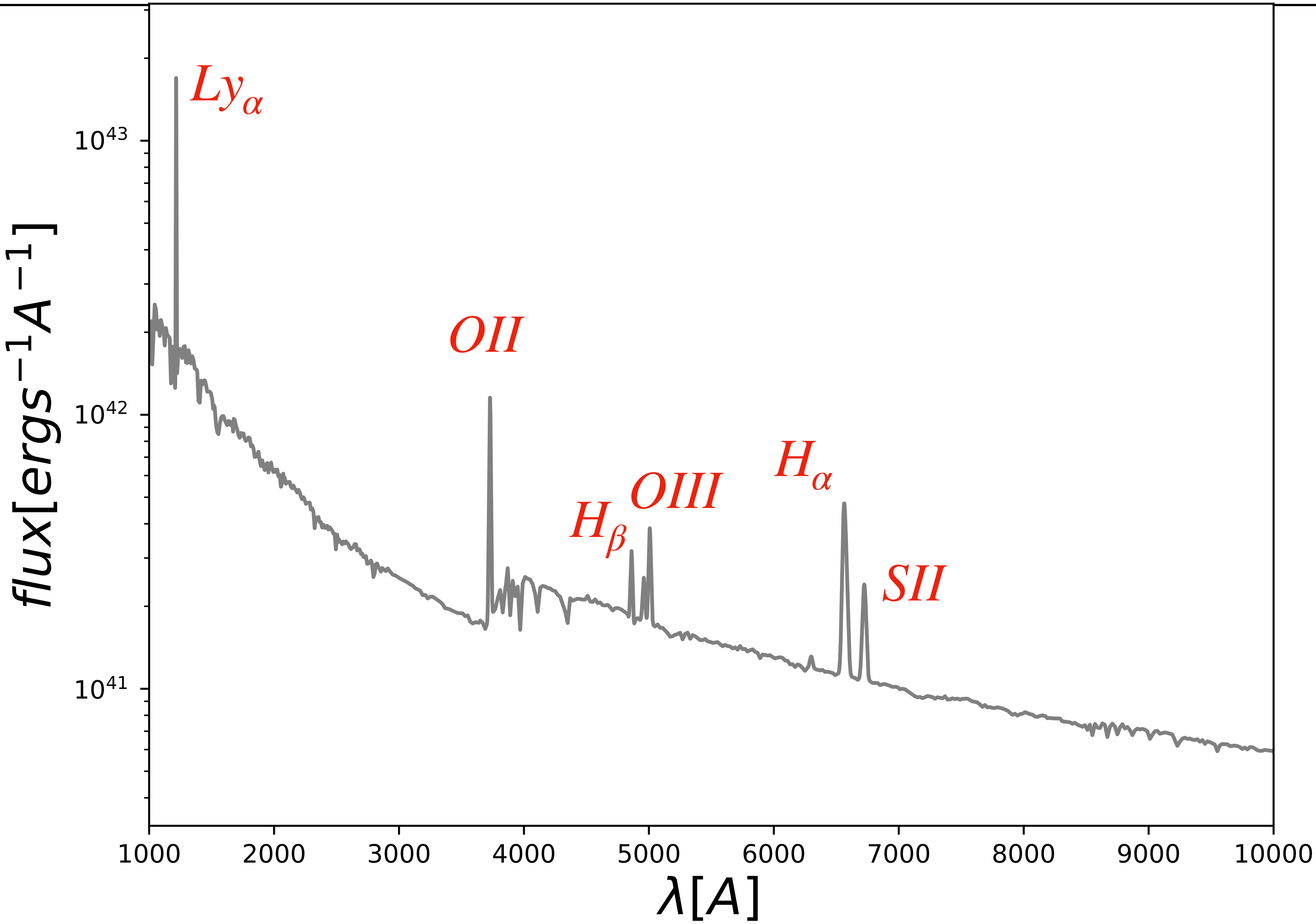
smaller time gap ⇒ **more disruption less merger** ⇒ **smaller BH** ⇒ **larger SFR/M_***



Galaxy Emission Lines

- Emission lines
  - Line ratios - CLOUDY17
    - geometry
    - chemical content
    - ionizing spectrum
    - metallicity (Z)
    - ionizing parameter (U)
    - Hydrogen density (n_H)

star forming galaxy at z~0



Galaxy Emission Lines

- Emission lines
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    - geometry
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    - ionizing spectrum
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    - ionizing parameter (U)
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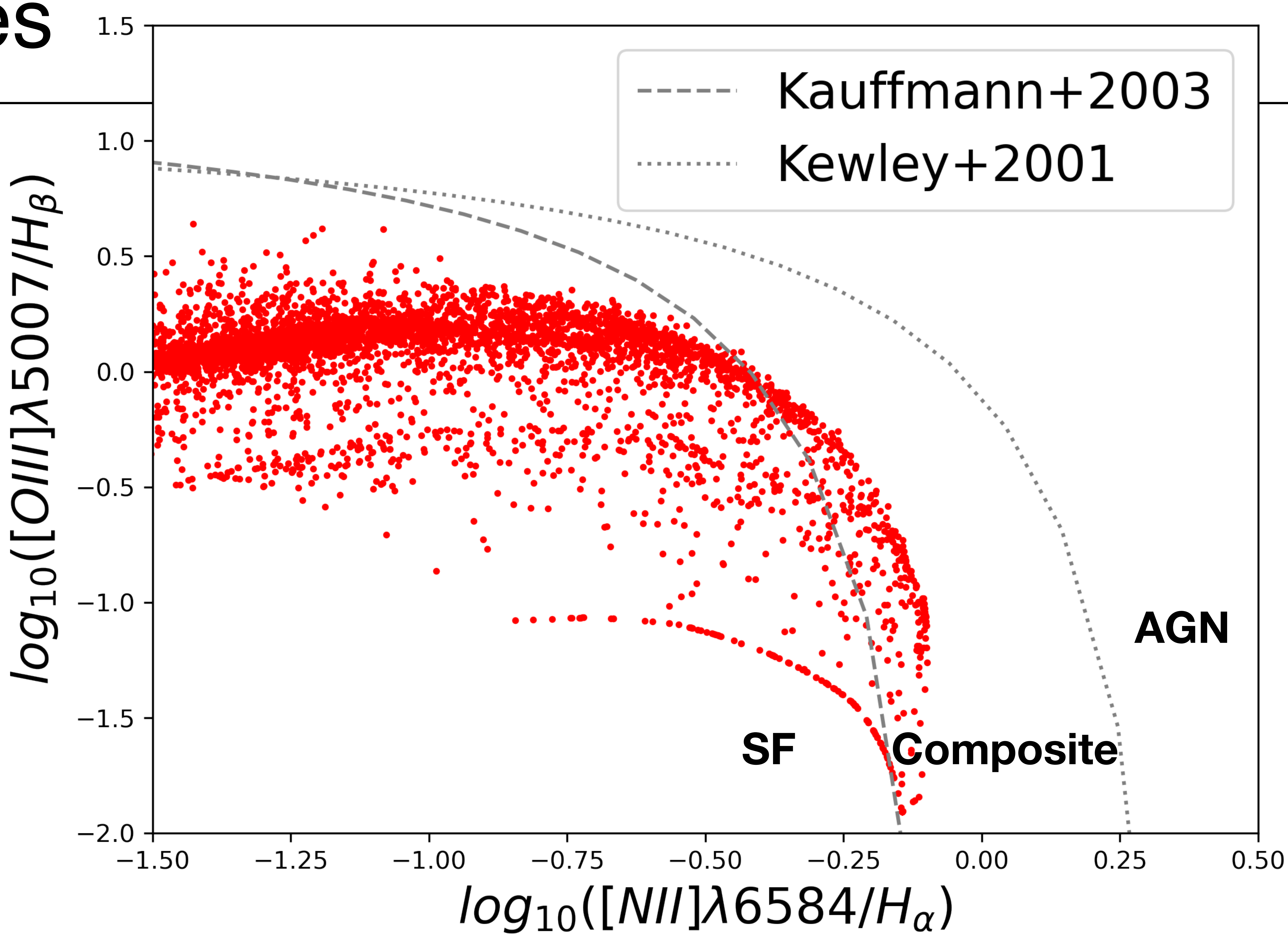
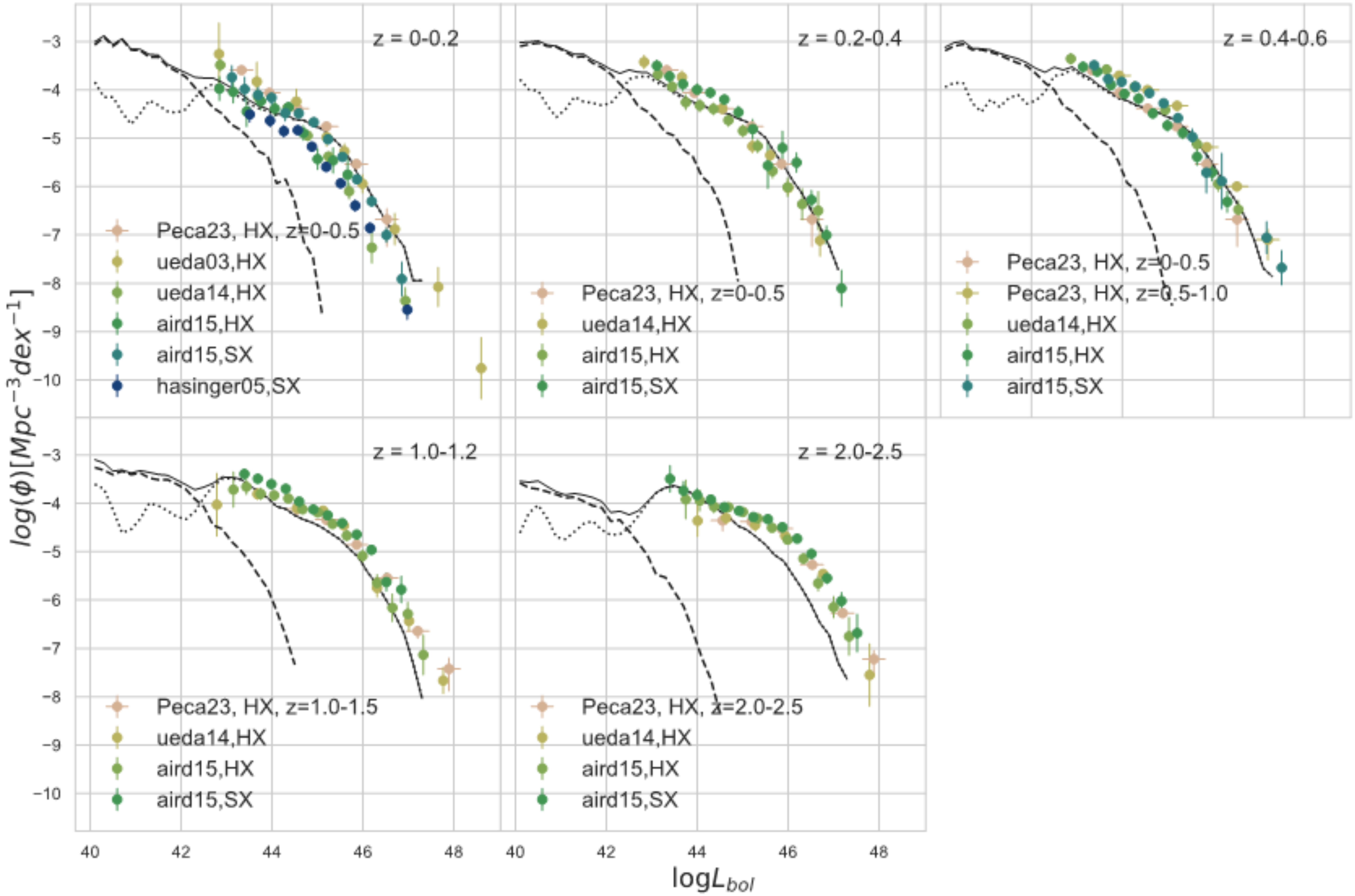


AGN Luminosities

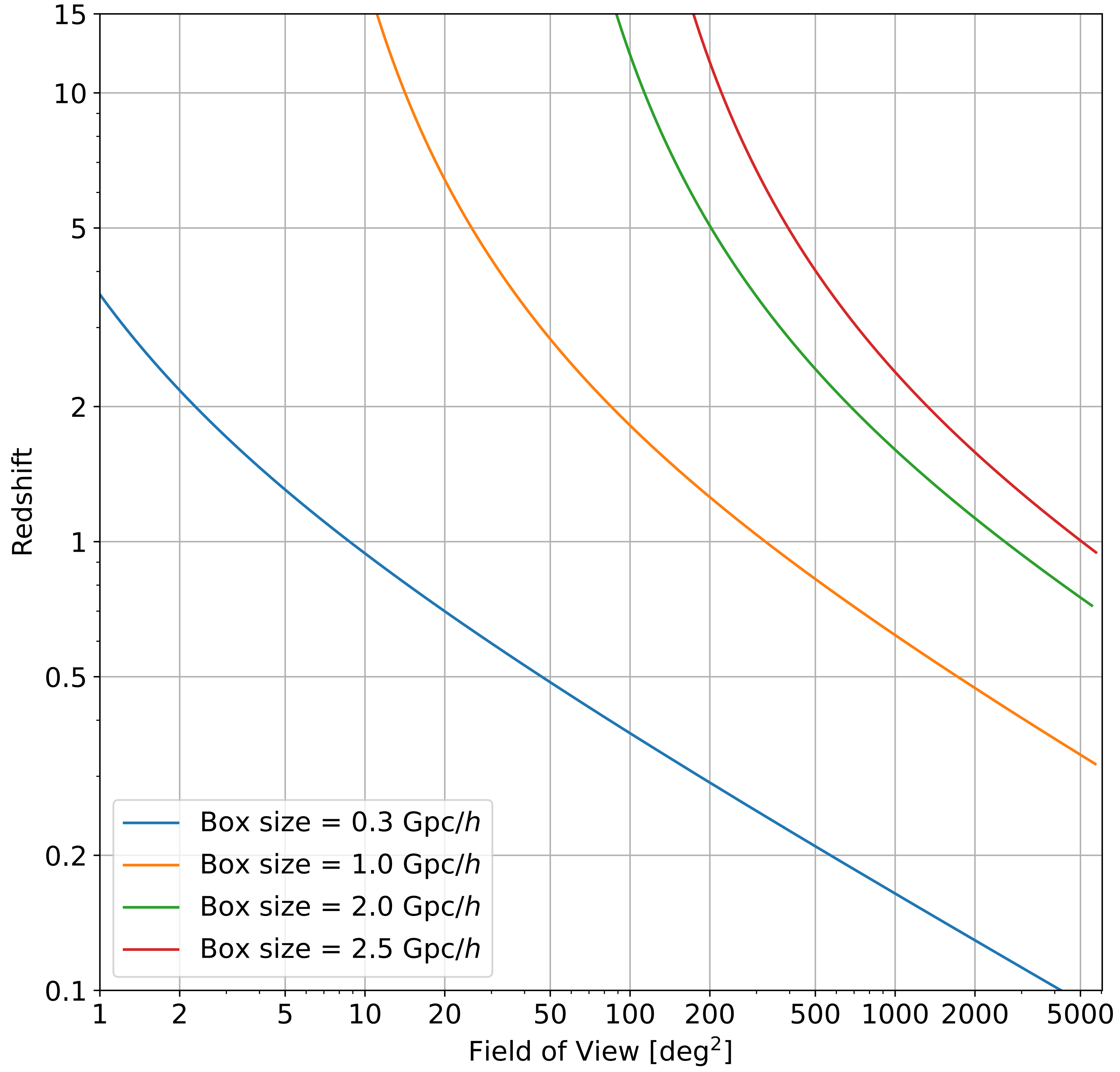


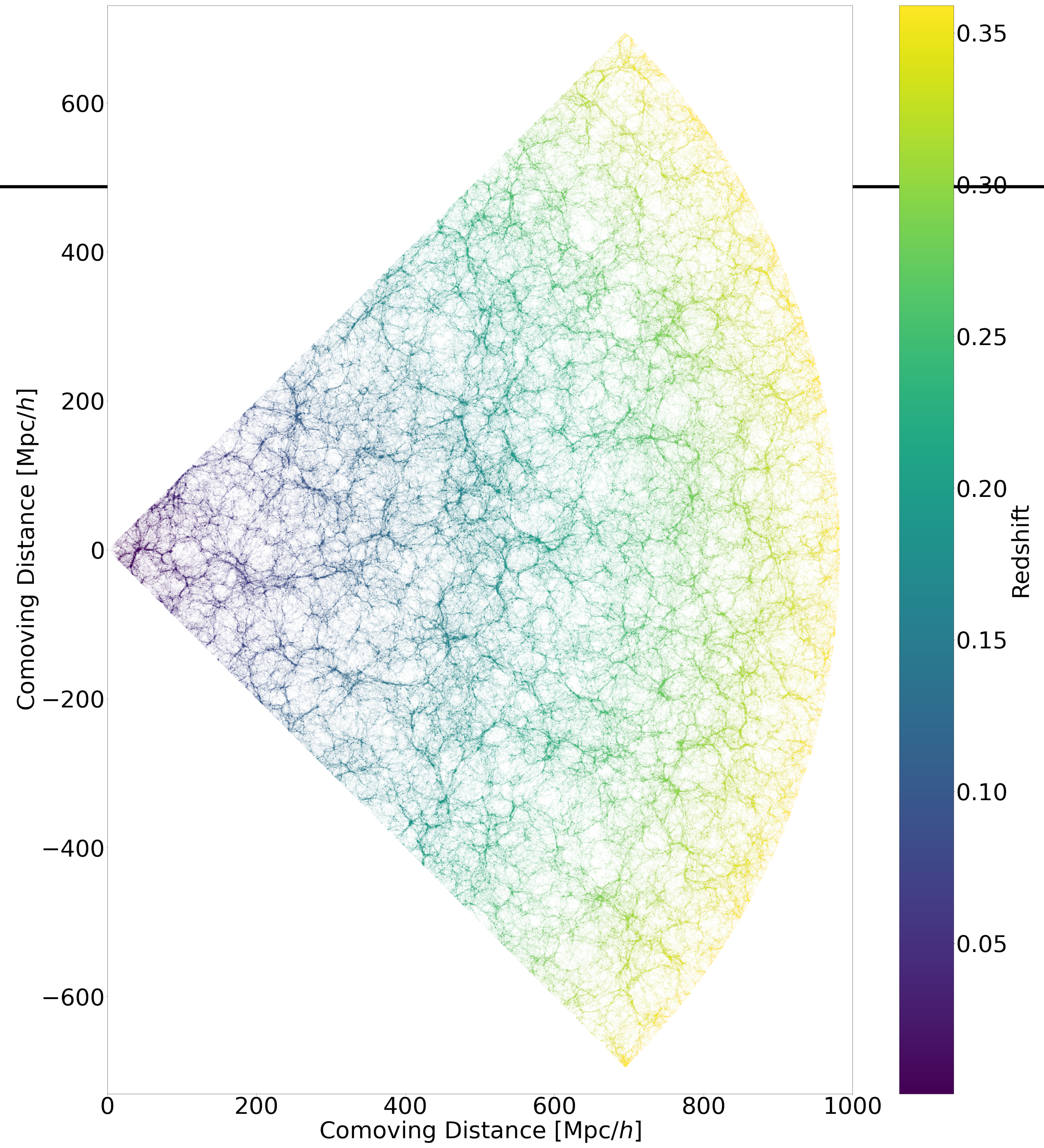
Tong Su (苏童)

See her talk on Thursday!

Light-cones

Redshift - FOV



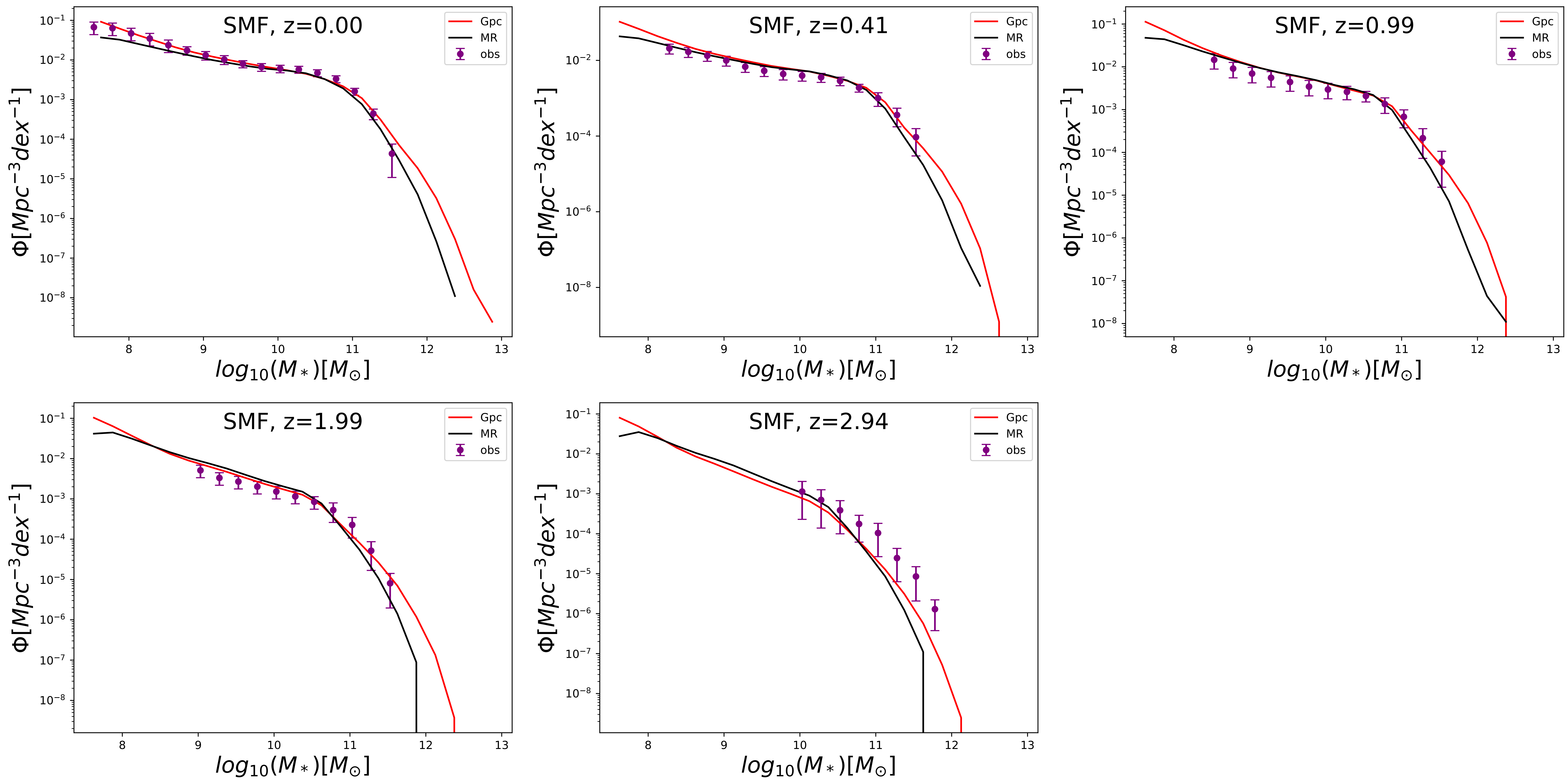


Yun Liu (刘赟)

JiuTian-1G Dark Matter Simulations

- Code: L-Gadget3
- Boxsize: 1Gpc/h
- Dark matter particle mass: $3.72295 \times 10^8 M_\odot/h$
- Dark matter particle number: 6144^3
- Snapshots: 128
- Cosmology: Planck 2018
  $\Omega_m = 0.3111,\ \Omega_\Lambda = 0.6889,\ \Omega_{baryon} = 0.0490,\ h = 0.6766,\ \sigma_8 = 0.8102$

Stellar Mass Function



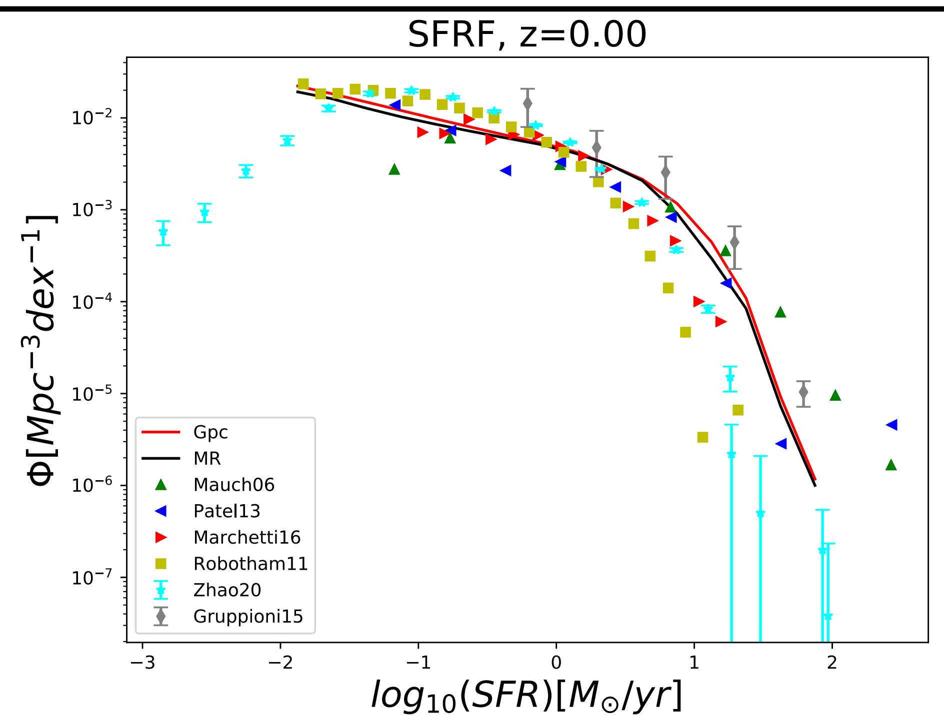
General Galaxy Properties

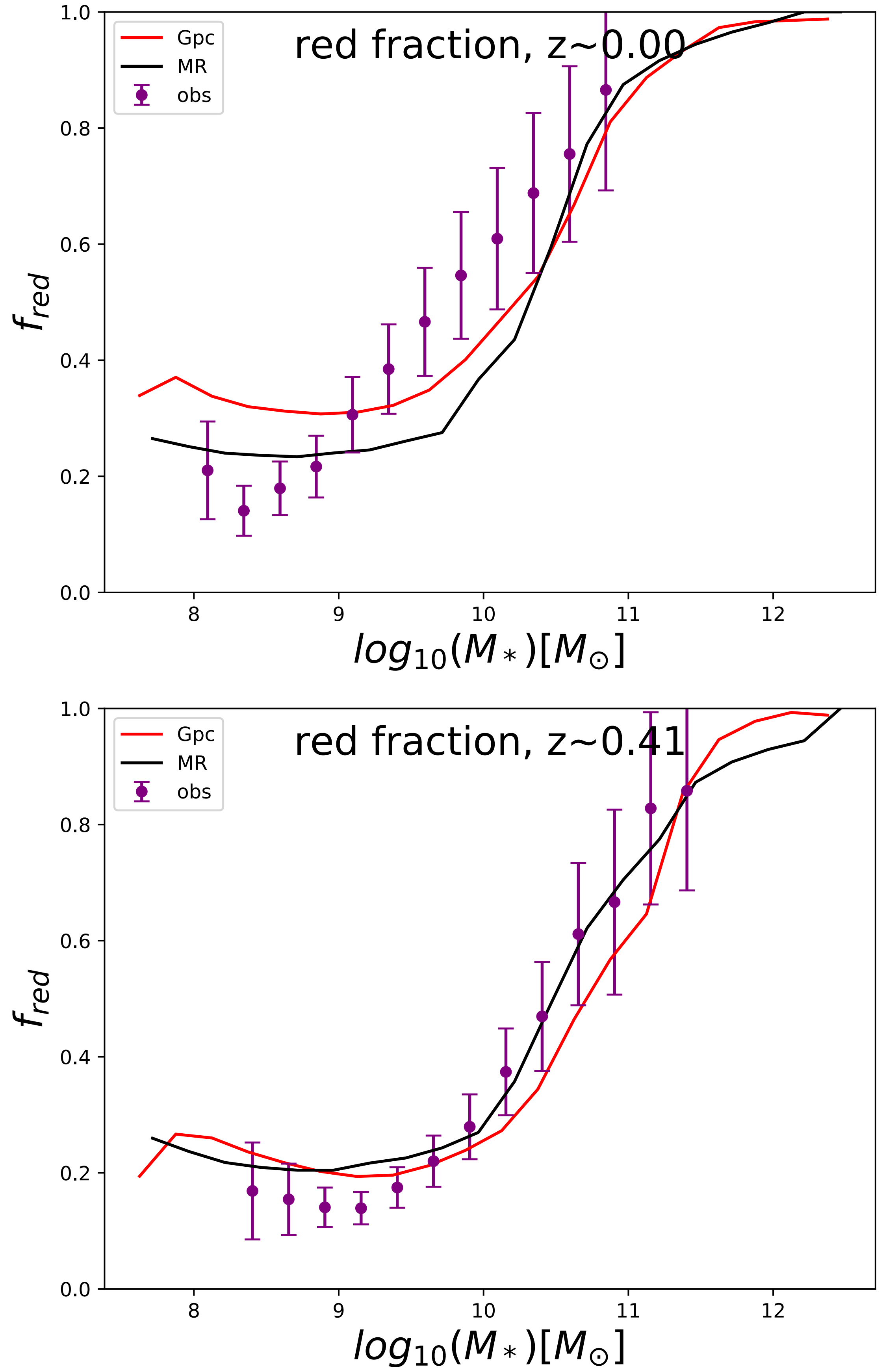
Red Fraction

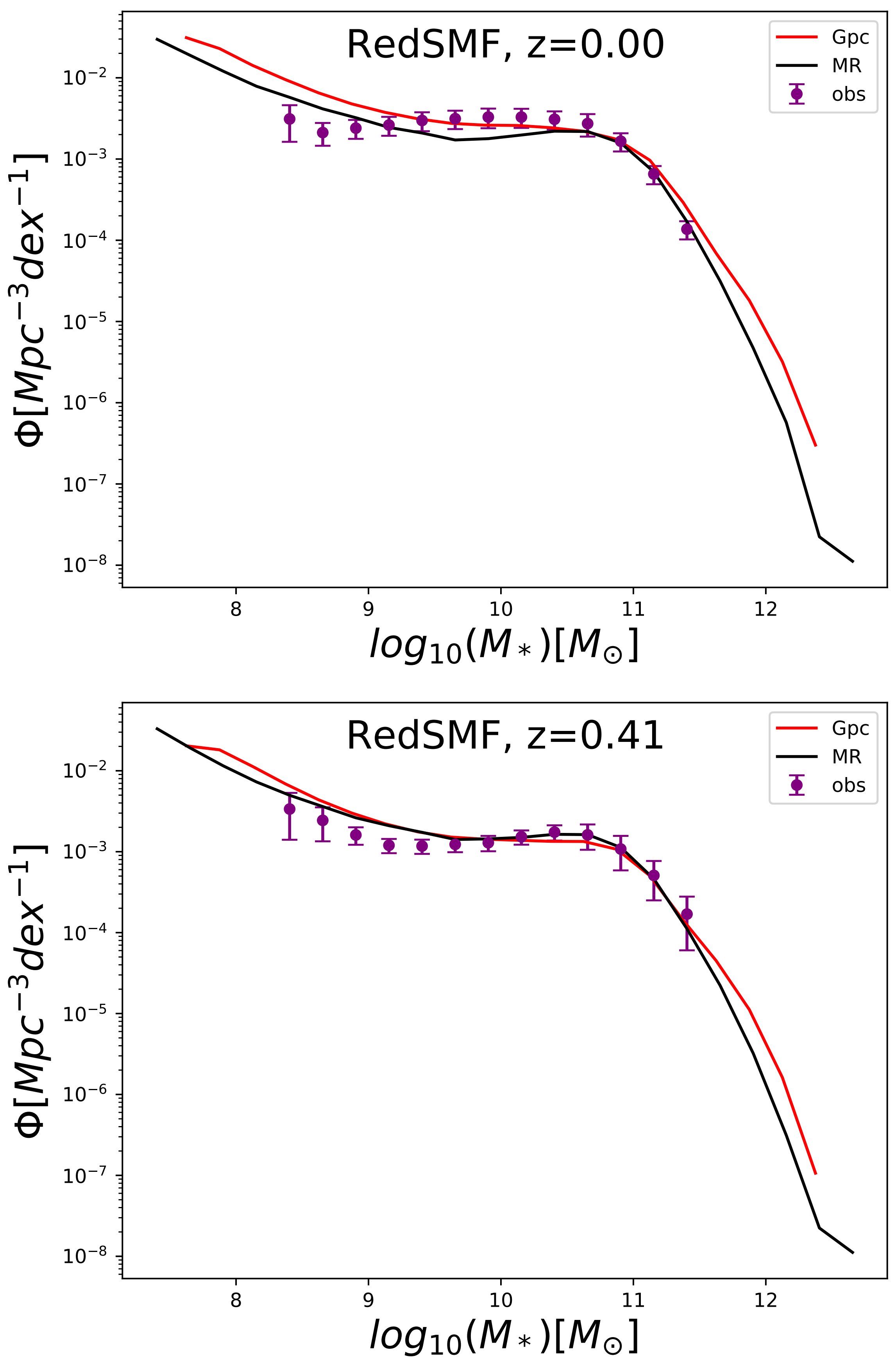
Red SMF

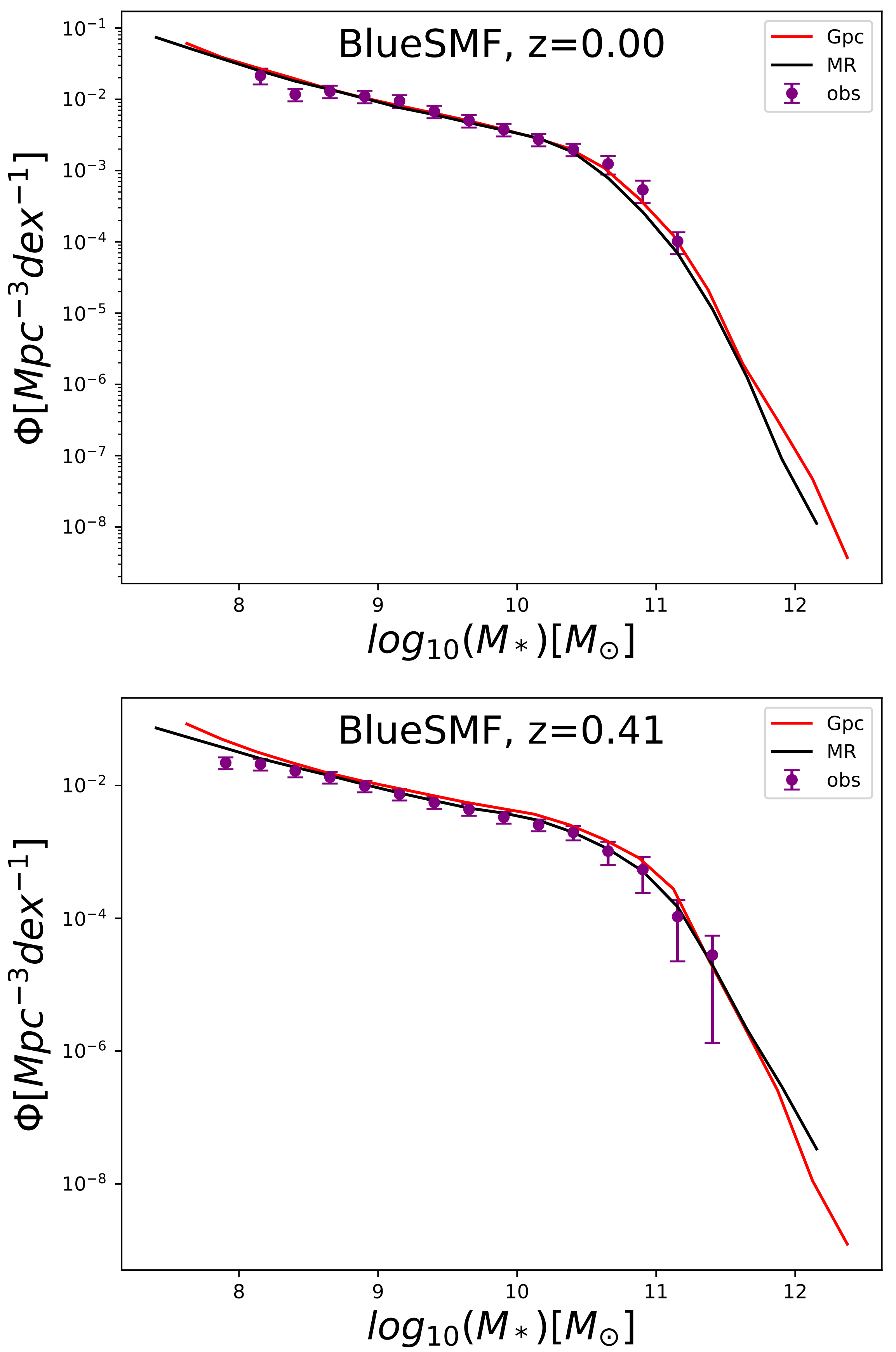
Blue SMF

SFRF

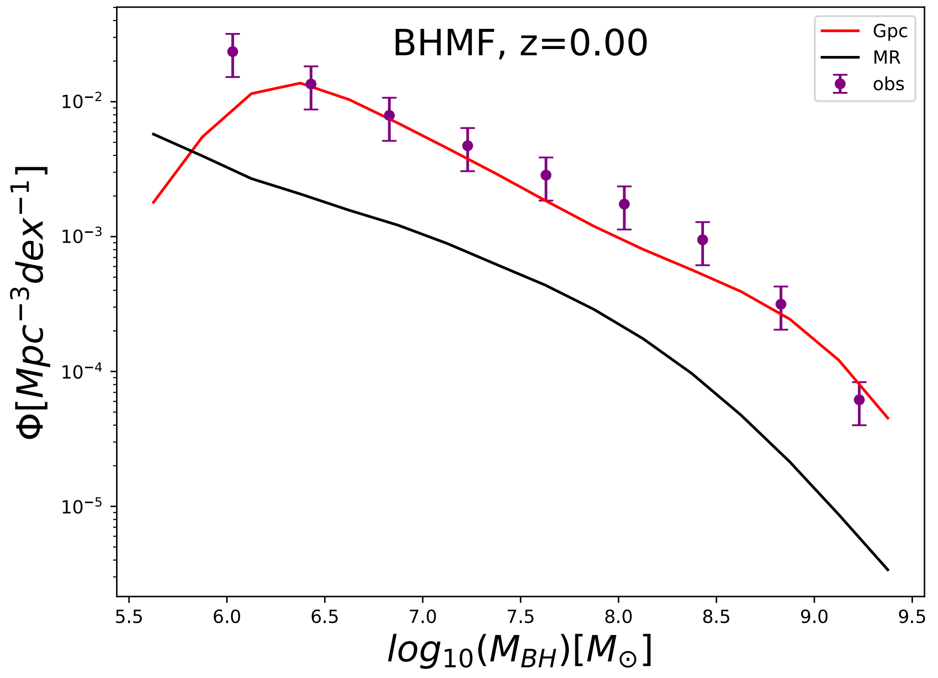




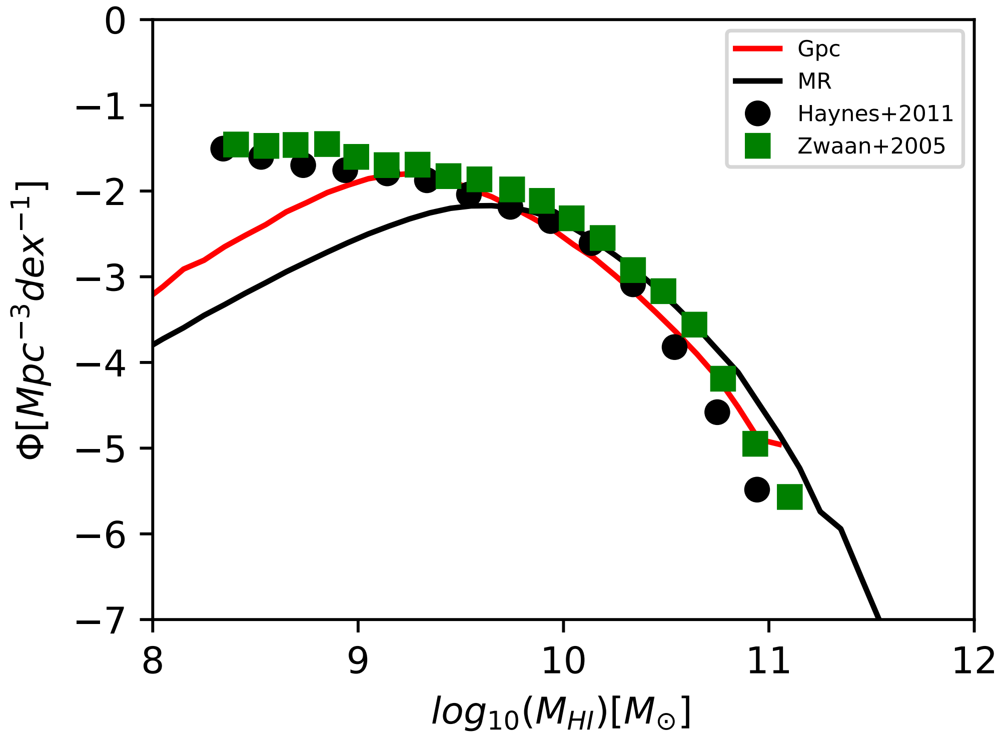




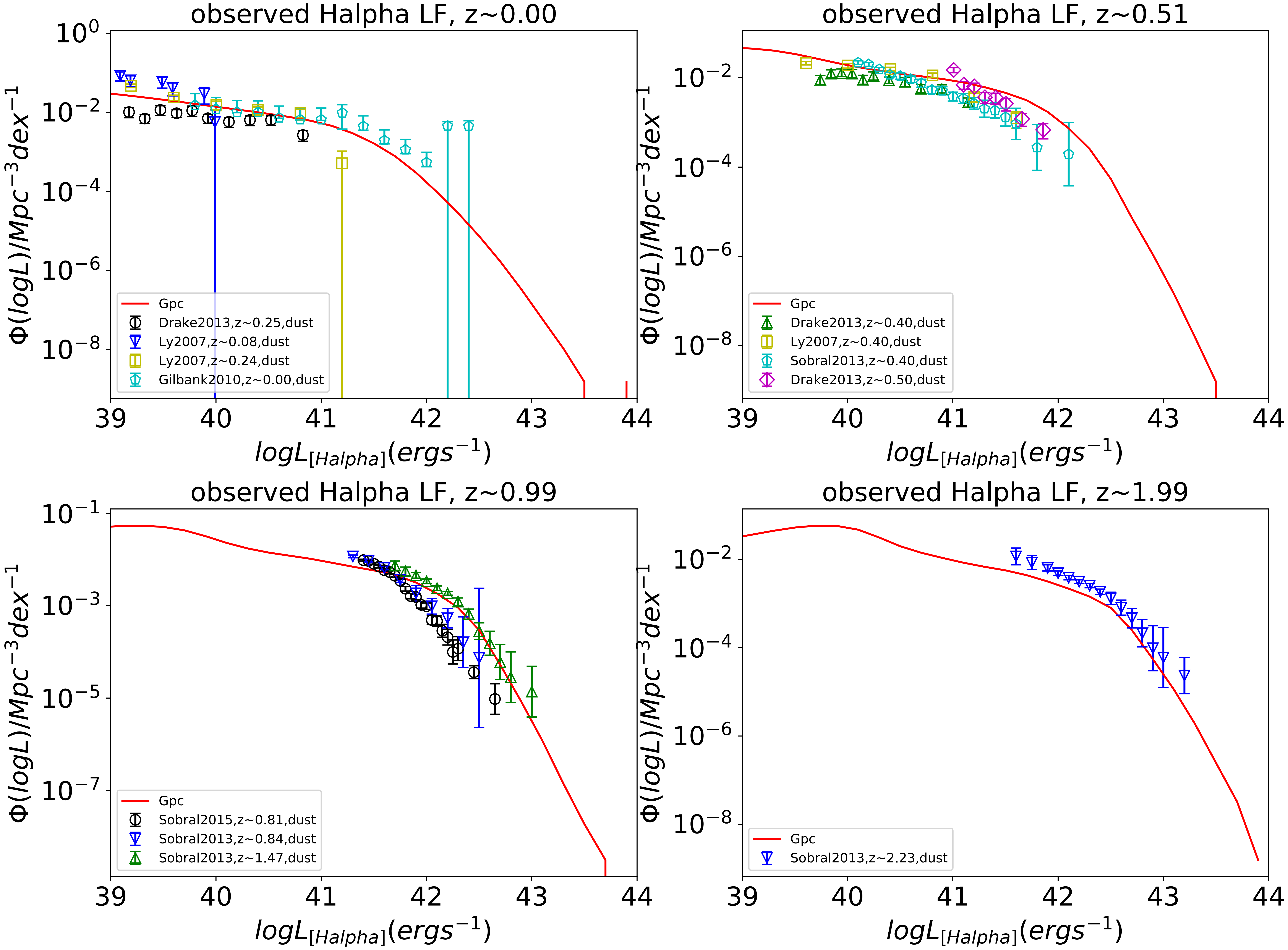
BHMF



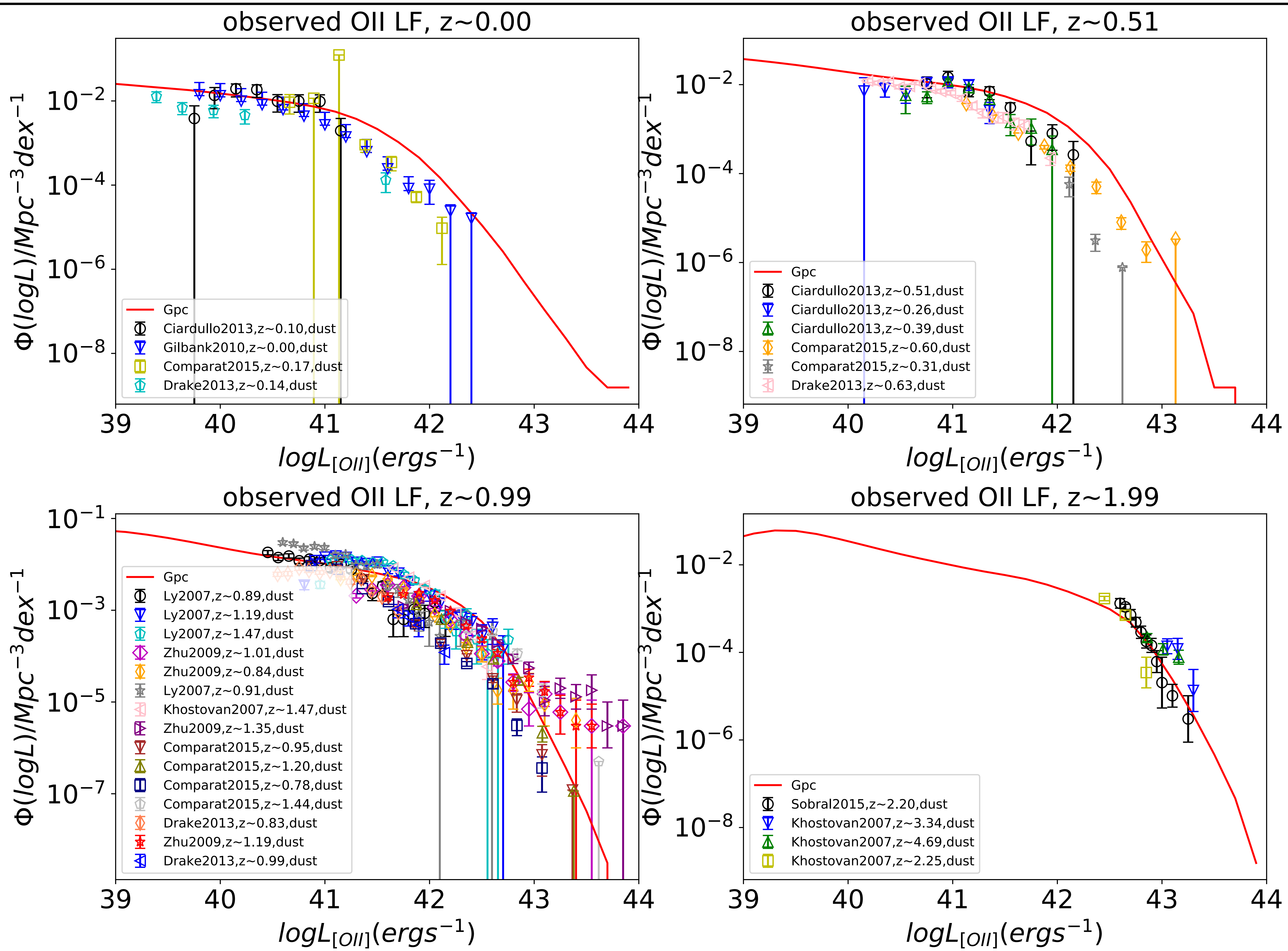
HIMF



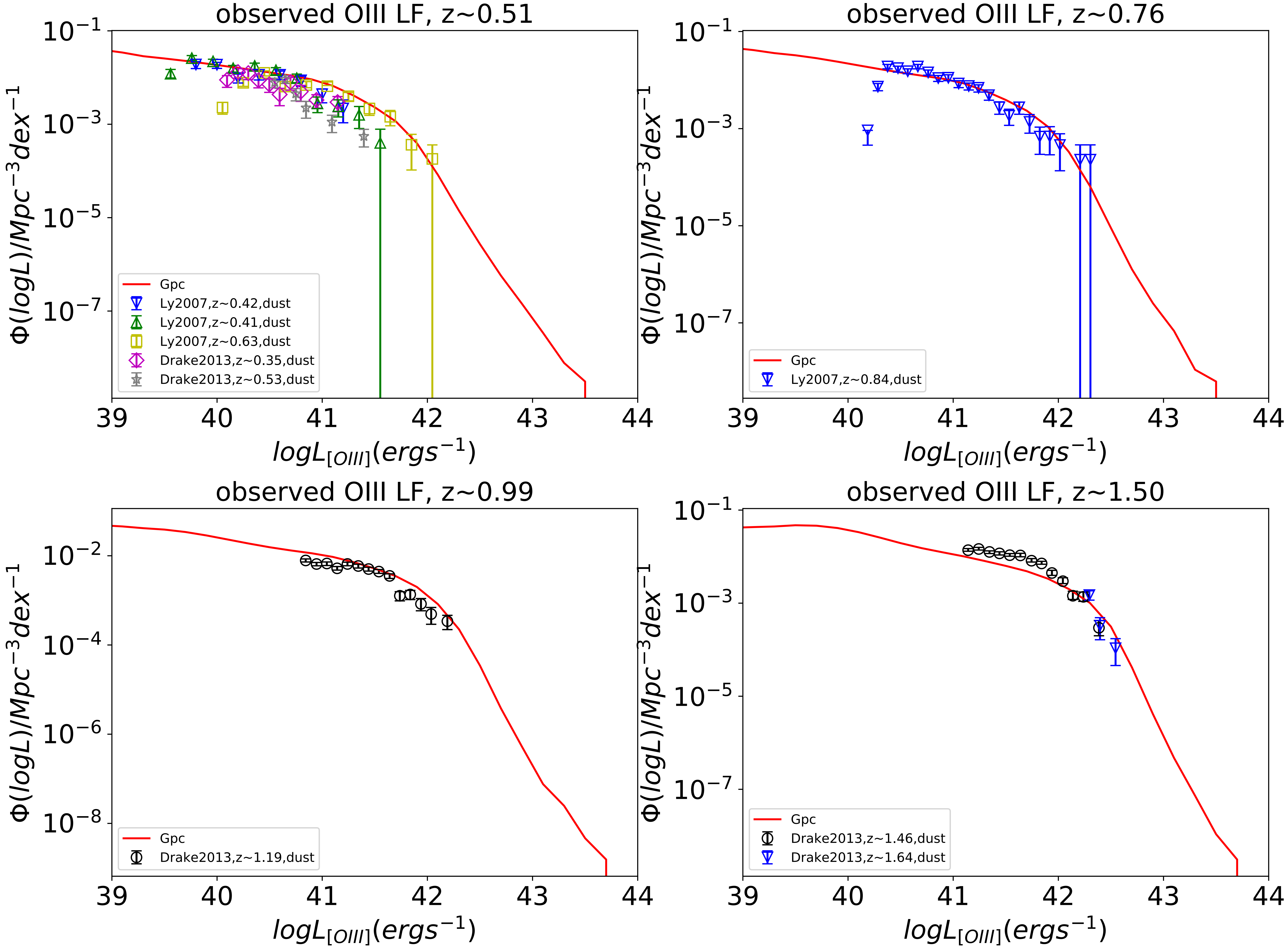
H_α Luminosity Function



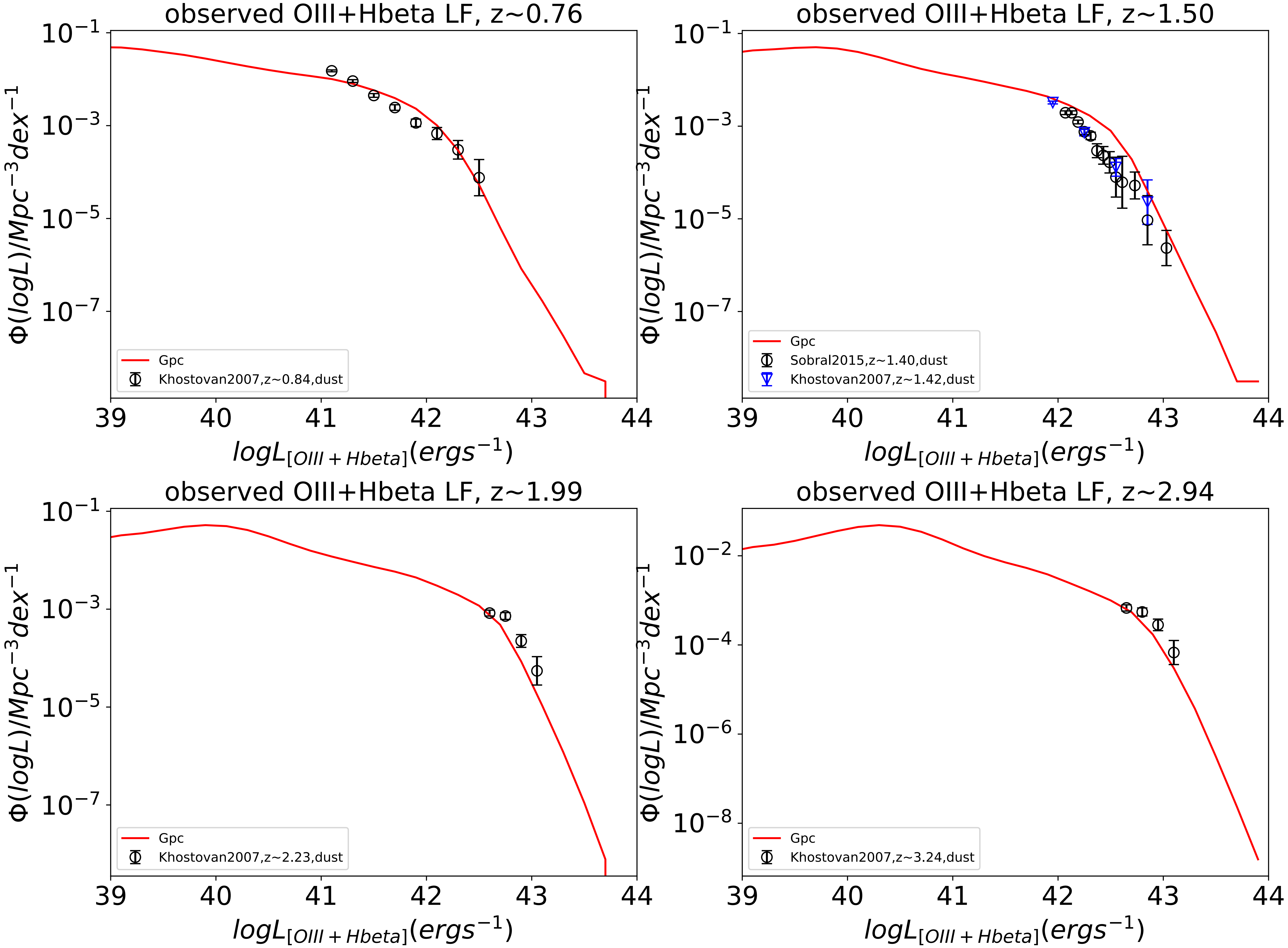
OII Luminosity Function



OIII Luminosity Function



$OIII + H_\beta$ Luminosity Function



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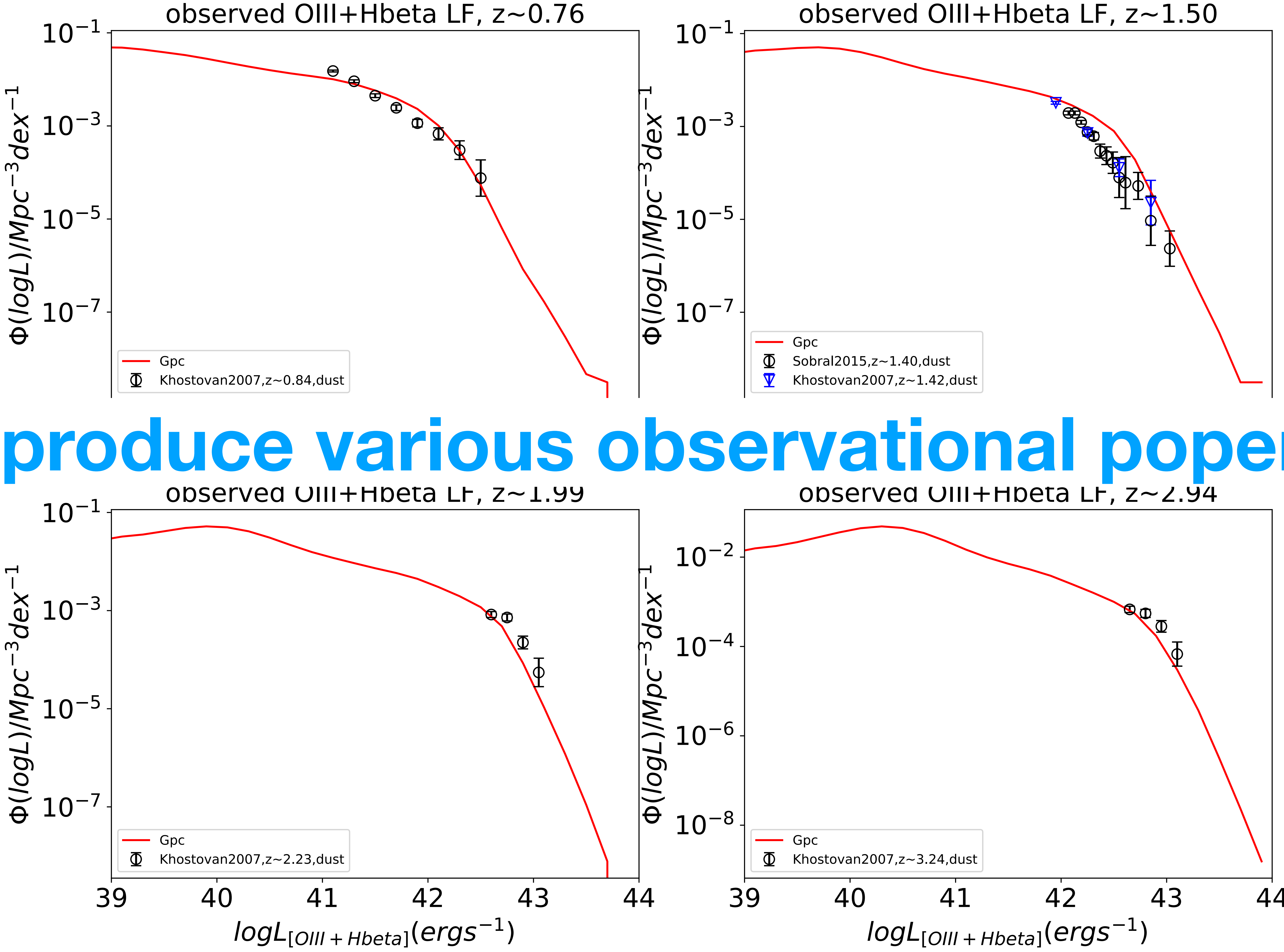

Reproduce various observational poperties

SAM Catalog

Galaxies Properties, SFH, photometry & SED, emission lines, AGN SED, HI, light-cones…

x,y,z (RA, DEC)
Vx,vy,vz
Redshift
CSST photometry, Emission line, AGN SED
Other survey photometry (SDSS,COSMOS,JPAS…)
Metallicity
Age
Bulge/Disk Size/Mass
HI mass, rotation velocity
Physical properties (Stellar Mass, Cold Gas Mass, Black Hole Mass, BH Accretion Rate…)

Lyalpha	1216.0
Hbeta	4861.0
Halpha	6563.0
OII_3727	3727.0
OII_3729	3729.0
OIII_5007	5007.0
OIII_4959	4959.0
OI_6300	6300.0
NII_6548	6548.0
NII_6584	6584.0
SII_6717	6717.0
SII_6731	6731.0
NeIII_3870	3870.0

Hyper-Millennium Simulation

- Code: PhotoNs (Wang et al. 2021)
- Boxsize: 2.5Gpc/h
- Dark matter particle mass: $3.21 \times 10^8 M_\odot/h$
- Dark matter particle number: $16128^3 \sim 4.2 \times 10^{12}$
- Snapshots: 100
- Cosmology: Planck 2018
  $\Omega_m = 0.3111$, $\Omega_\Lambda = 0.6889$, $\Omega_{baryon} = 0.0490$, $h = 0.6766$, $\sigma_8 = 0.8102$

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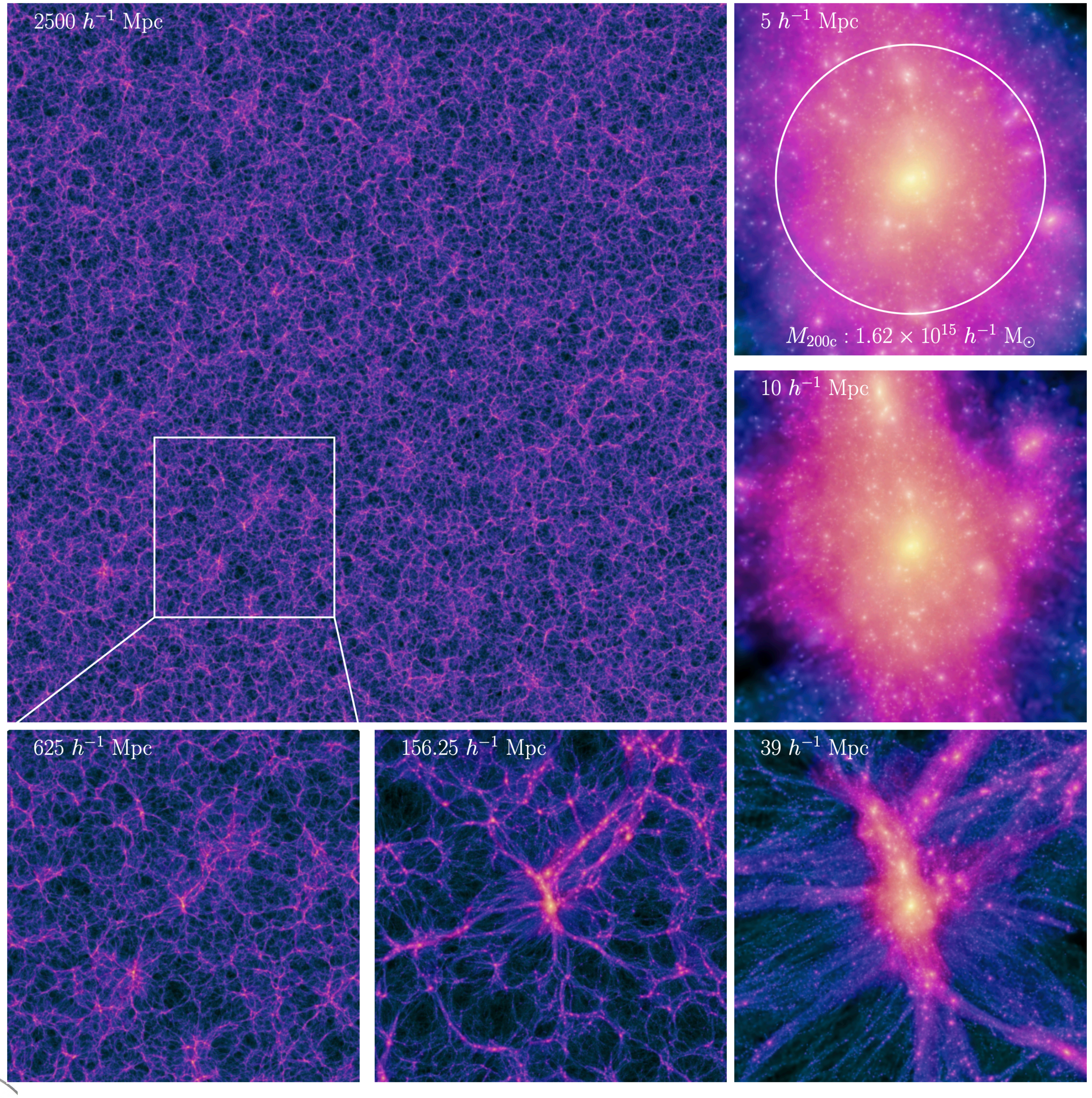

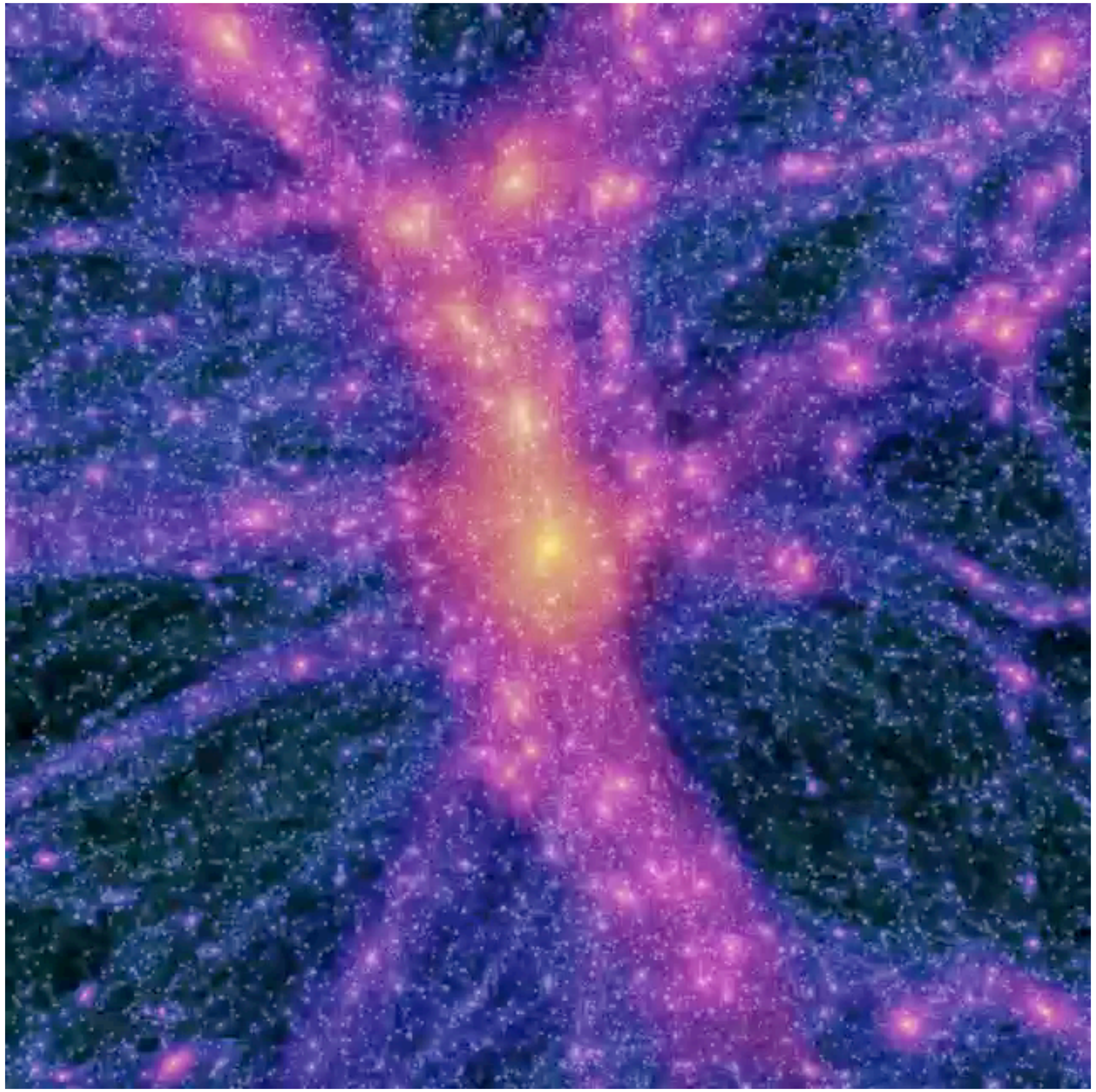

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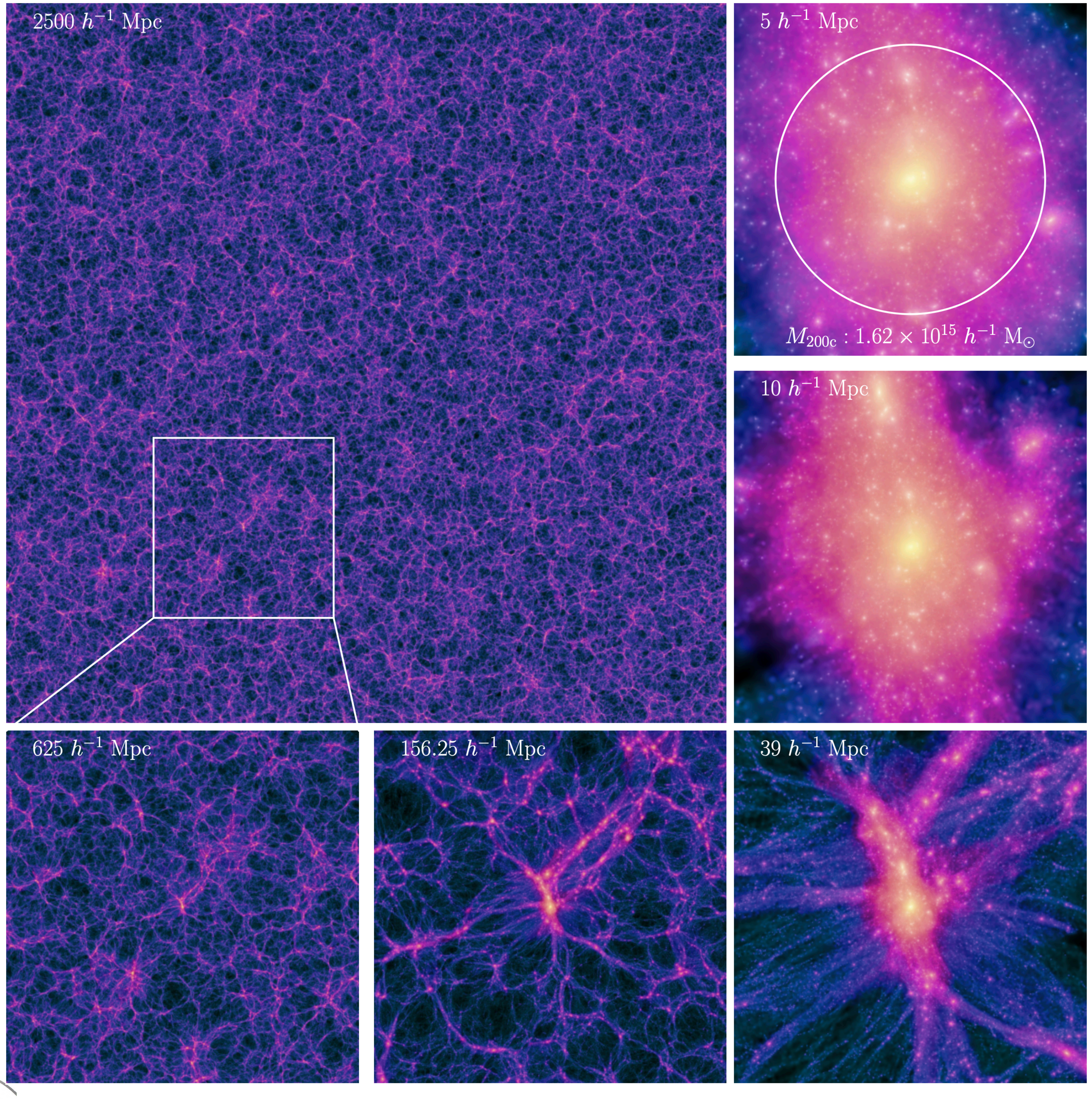

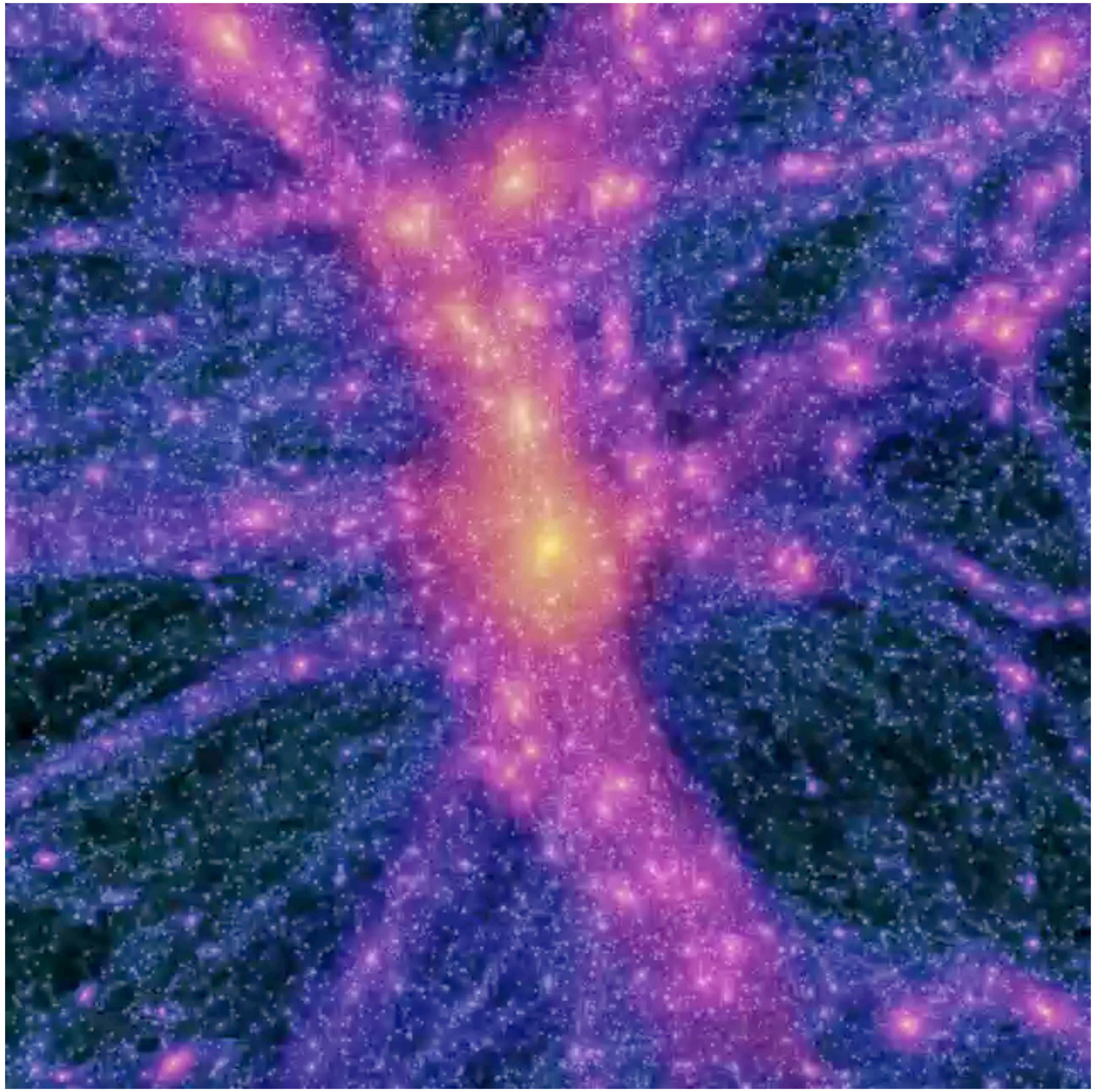

Summary

- Galaxy formation models
  - Improve semi-analytical models to solve convergence issue
  - Ionization model + radiation transfer (galaxy emission lines)
  - AGN luminosities
  - Light-cones on request
- Succeed in reproduce local and high redshift galaxy properties, especially including emission line luminosity functions of Halpha, Hbeta, OII, OIII, and AGN luminosities
- Our model could be applied to Hyper-Millennium - the **largest** N-Body cosmological simulation in the world

Volume $2.5^3[h^{-3}Gpc^3]$**, particle mass** $3.21 \times 10^8[M_\odot/h]$**, Particle number 4 trillion**

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TNANKS!

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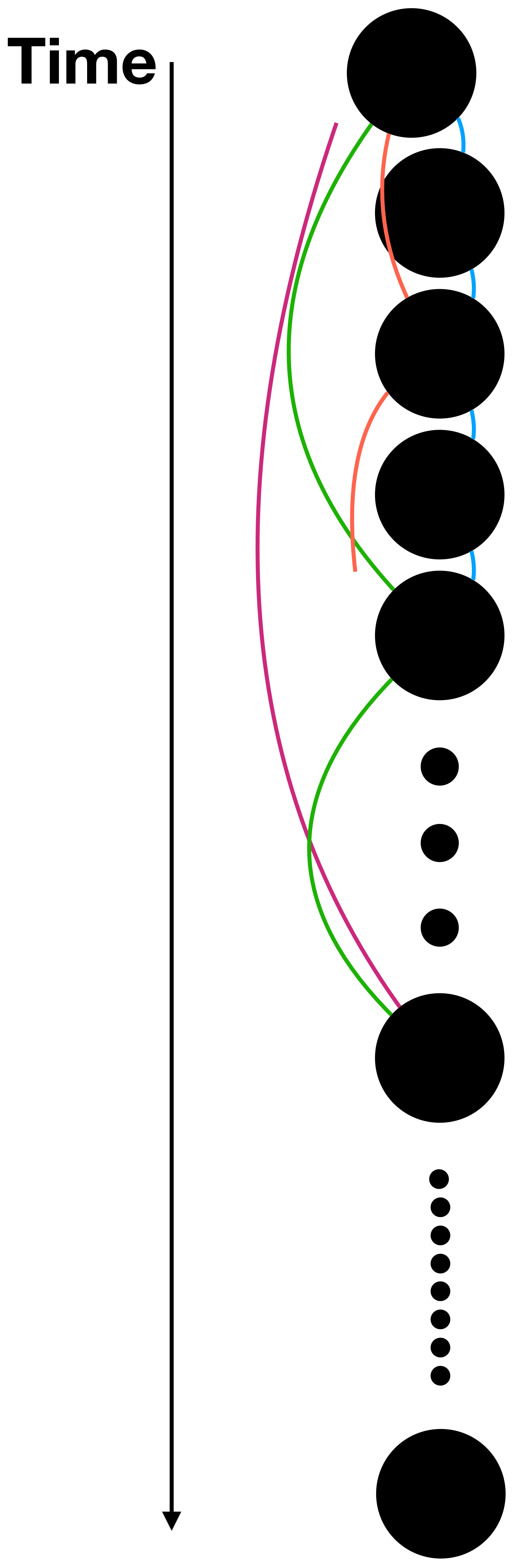


snap = 0

snap = 1 in 256

snap = 2 in 256 snap = 1 in 128

snap = 3 in 256

snap = 4 in 256 snap = 2 in 128 snap = 1 in 64

snap = 8 in 256 snap = 4 in 128 snap = 2 in 64 snap = 1 in 32

snap = 256 in 256 snap = 128 in 128 snap = 64 in 64 snap = 32 in 32

Appendix

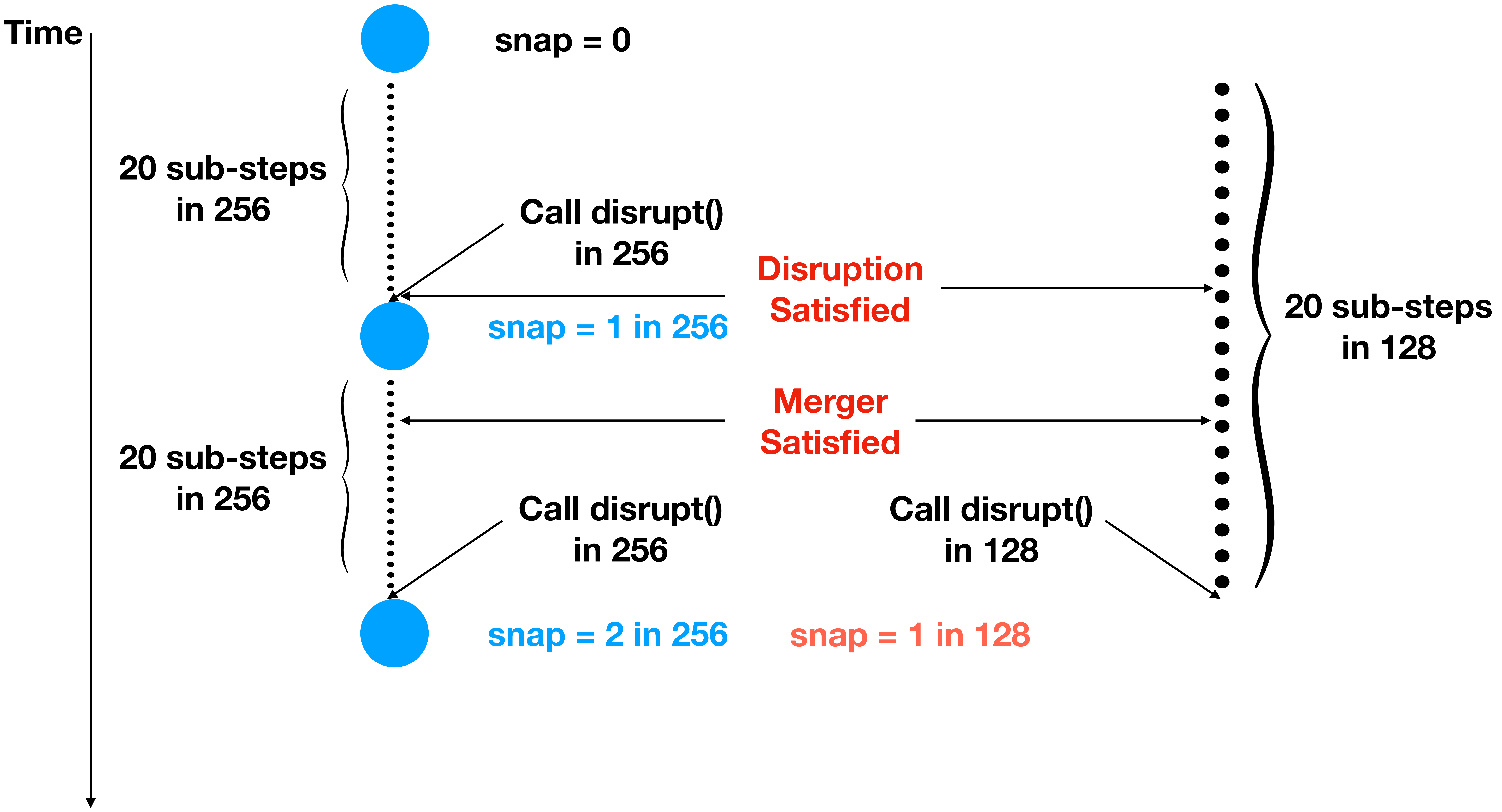
- Disruption model in H15

- $$\frac{M_{DM,halo}(R_{peri})}{R_{peri}^3} \equiv \rho_{DM,halo} > \rho_{sat} \equiv \frac{M_{sat}}{R_{sat,half}^3}$$

- $$(\frac{R}{R_{peri}})^2 = \frac{lnR/R_{peri} + \frac{1}{2}(V/V_{200c})^2}{\frac{1}{2}(V_t/V_{200c})^2}$$

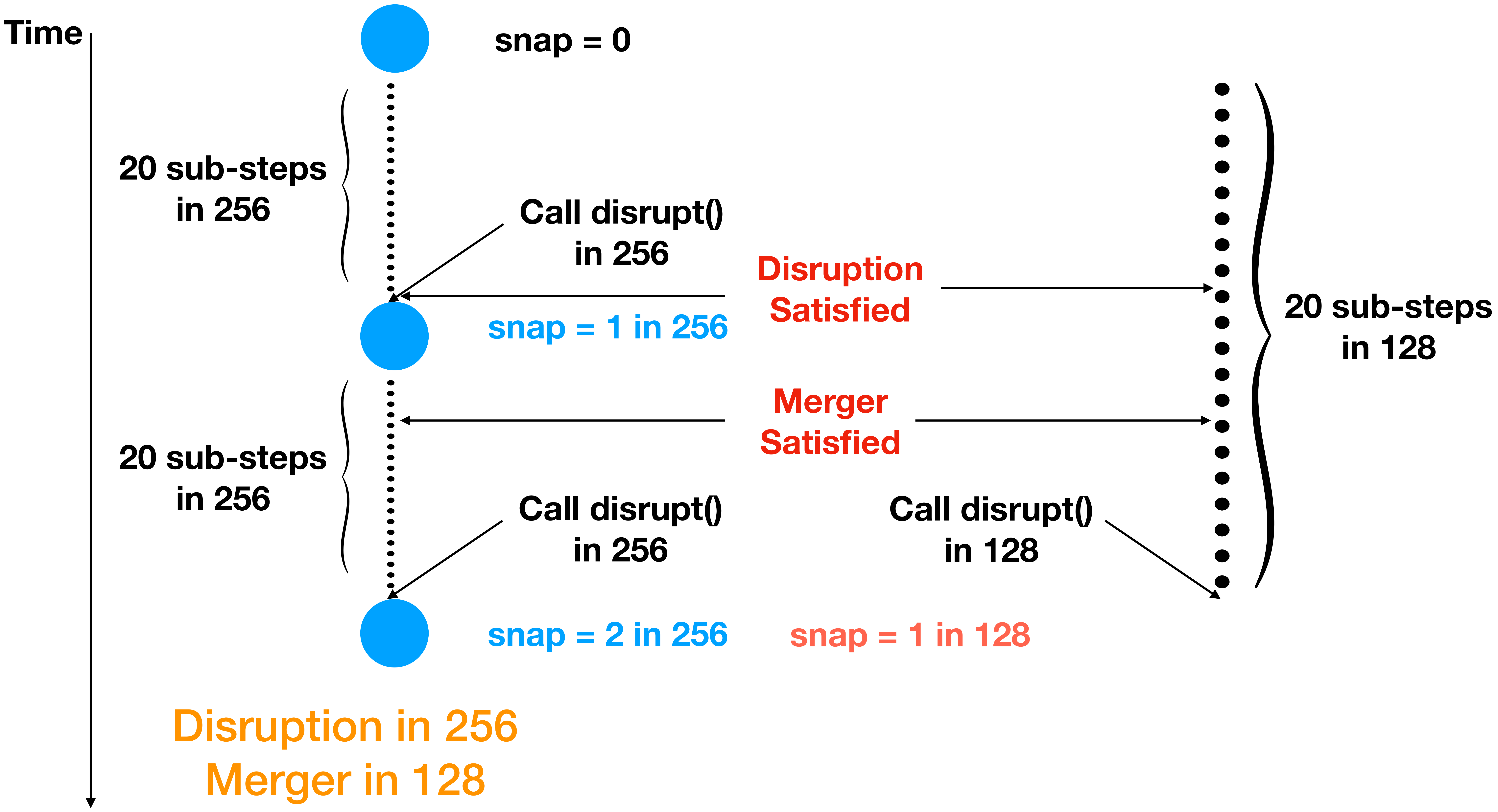
- H15 calls function "disrupt" only at the end of each snap, but calls "deal_with_galaxy_merger" in sub-steps whenever "MergerTime < 0".

Appendix



Time
snap = 0
20 sub-steps
in 256
Call disrupt()
in 256
Disruption
Satisfied
snap = 1 in 256
20 sub-steps
in 128
Merger
Satisfied
20 sub-steps
in 256
Call disrupt()
in 256
Call disrupt()
in 128
snap = 2 in 256
snap = 1 in 128

Appendix


Time
snap = 0
20 sub-steps
in 256
Call disrupt()
in 256
Disruption
Satisfied
20 sub-steps
in 128
snap = 1 in 256
Merger
Satisfied
20 sub-steps
in 256
Call disrupt()
in 256
Call disrupt()
in 128
snap = 2 in 256
snap = 1 in 128
Disruption in 256
Merger in 128

Appendix

- Simulations with larger max snapshots tend to have more disruptions and less mergers.

- The main channel of BH growth is "quasar mode" during mergers, so more disruptions mean smaller BHs.

- Smaller BHs mean less efficient AGN feedback, result in larger SFR and M_*.

smaller time gap $\Rightarrow$ **more disruption less merger** $\Rightarrow$ **smaller BH** $\Rightarrow$ **larger SFR/M_***

Appendix

- Change disruption model
  - Deal with disruption in sub-steps
  - Calculate distance from orphan to central at sub-step by linear interpolation
    - $Pos_{substep,i} = Pos_{n,i} + (Pos_{n+1,i} - Pos_{n,i}) \times \frac{\delta t_{step}}{t_{n+1} - t_n}$
    - $R = \sqrt{\sum_{i=1}^{3} (Pos_{central,i} - Pos_{orphan,i})^2}$
  - Calculate $\rho_{DM,halo}$ at distance R instead of R_{peri} in H15
  - Compare $\rho_{DM,halo}$ to $\rho_{sat,half}$

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  - $R \propto \sqrt{1 - \Delta t / t_{friction}}$

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  - All orphans will be disrupted!

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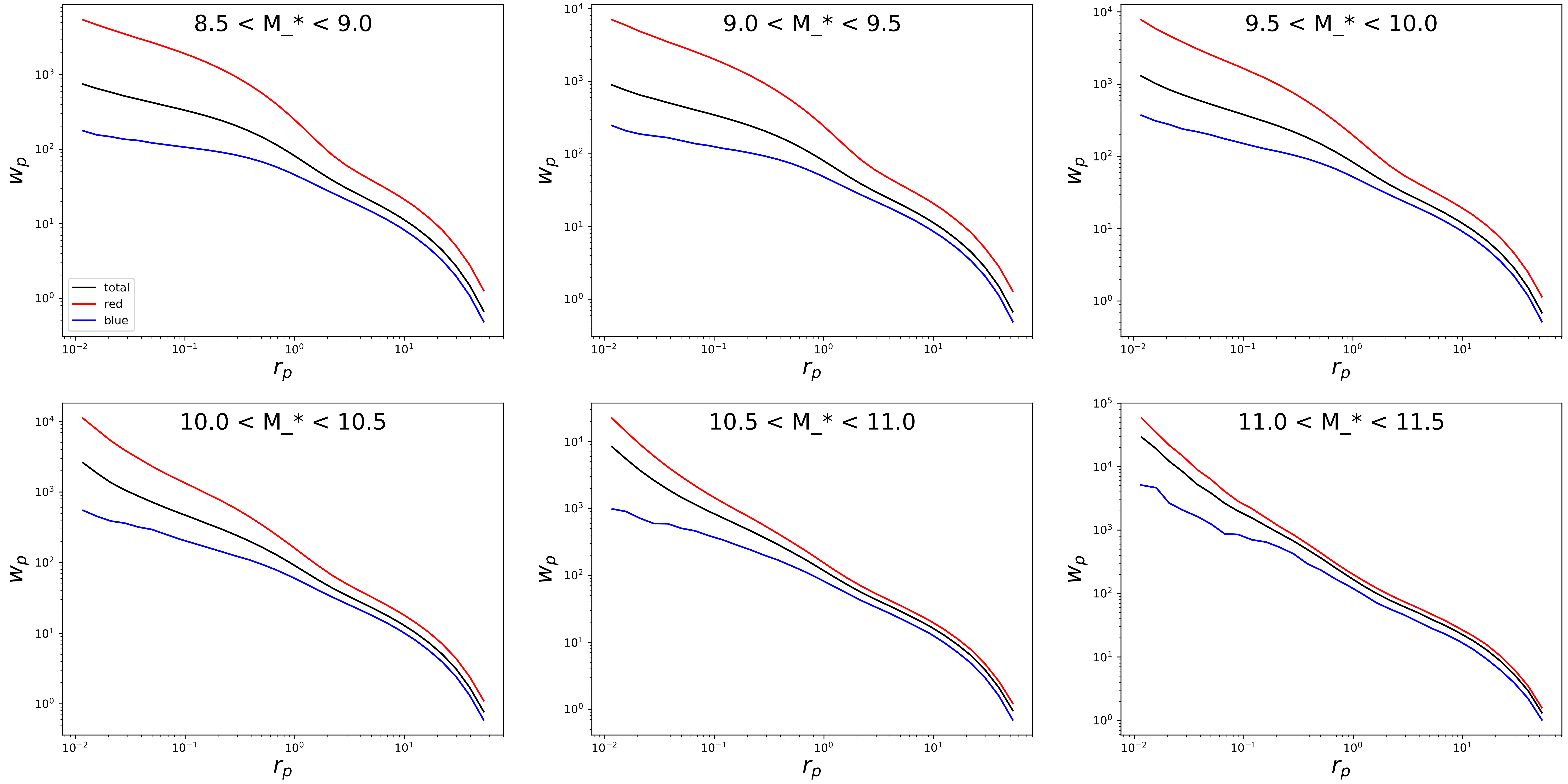
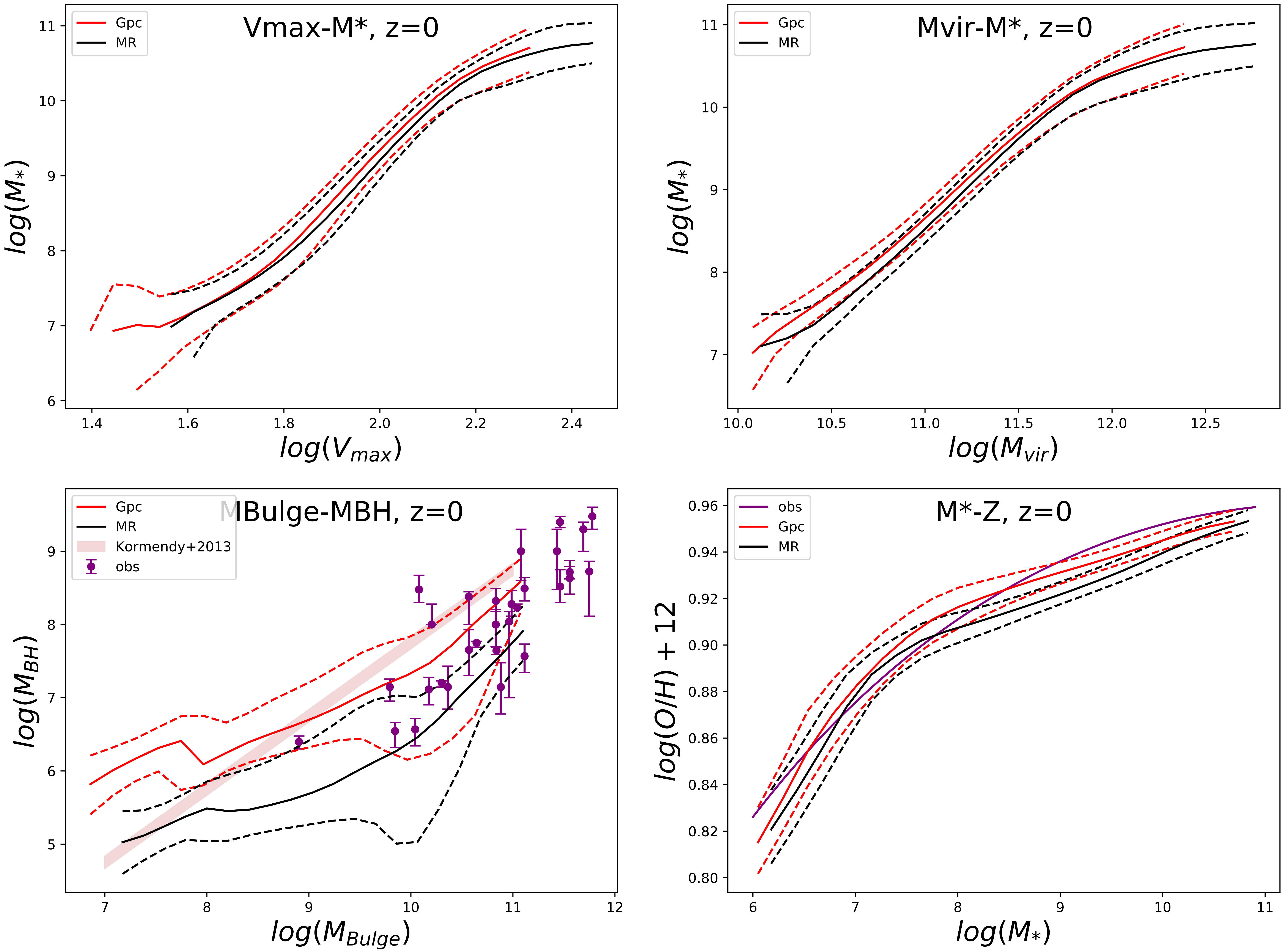
- Change disruption model
  - $R \propto \sqrt{1 - \Delta t / t_{friction}}$
  - Smaller time gap $\Rightarrow \Delta t \rightarrow t_{friction} \Rightarrow R \rightarrow 0 \Rightarrow \rho_{DM,halo} \rightarrow \infty$
  - All orphans will be disrupted!
  - A distance limit in disruption model to solve this problem:
    - $R > R_{central,disk}$
  - $R_{central,disk}$: the gas disk radius of central galaxies

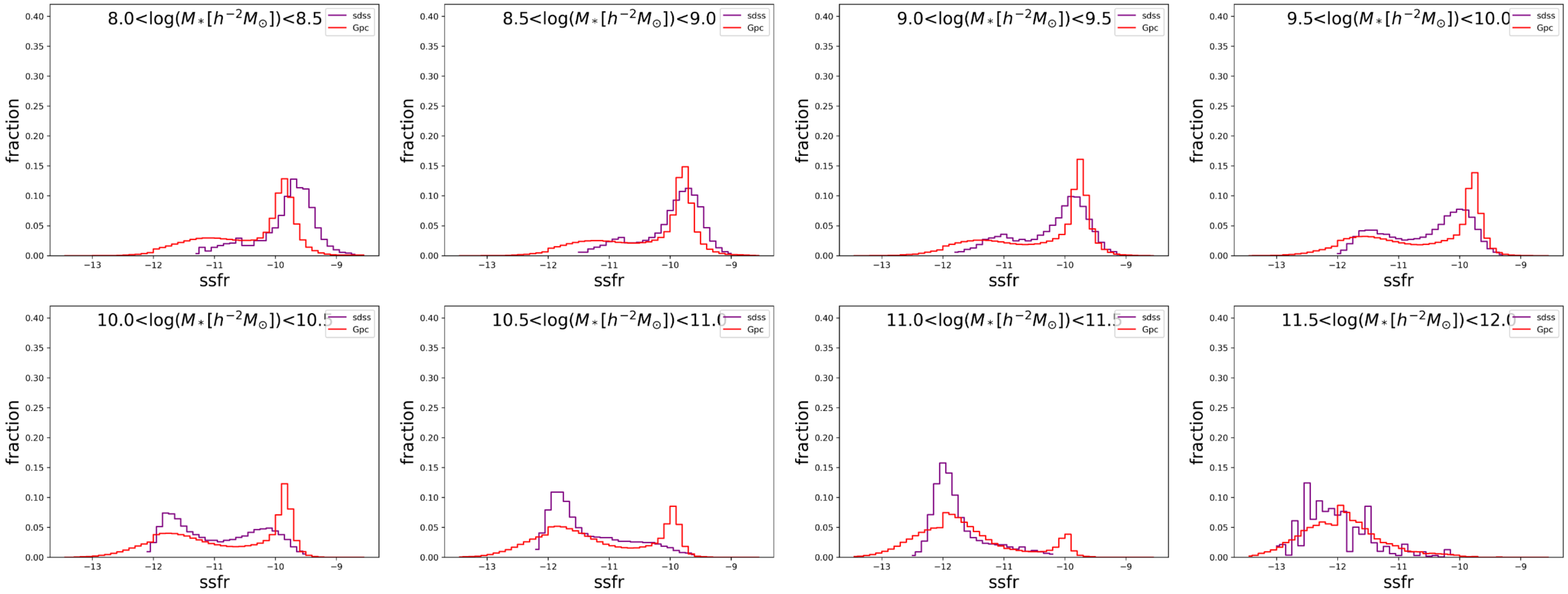
Appendix


8.5 < M_* < 9.0
9.0 < M_* < 9.5
9.5 < M_* < 10.0
10.0 < M_* < 10.5
10.5 < M_* < 11.0
11.0 < M_* < 11.5
total
red
blue
w_p
r_p

Appendix


Vmax-M*, z=0
Gpc
MR
log(M*)
log(Vmax)
Mvir-M*, z=0
log(Mvir)
MBulge-MBH, z=0
Kormendy+2013
obs
log(MBH)
log(MBulge)
M*-Z, z=0
log(O/H) + 12
log(M*)

Appendix


8.0<log($M_*[h^{-2}M_\odot]$)<8.5
8.5<log($M_*[h^{-2}M_\odot]$)<9.0
9.0<log($M_*[h^{-2}M_\odot]$)<9.5
9.5<log($M_*[h^{-2}M_\odot]$)<10.0
10.0<log($M_*[h^{-2}M_\odot]$)<10.5
10.5<log($M_*[h^{-2}M_\odot]$)<11.0
11.0<log($M_*[h^{-2}M_\odot]$)<11.5
11.5<log($M_*[h^{-2}M_\odot]$)<12.0
sdss
Gpc
fraction
ssfr

Appendix

- Emission lines

  - Get U, Z_{cold}, and n_H for individual galaxies (Baugh et al. 2022)

$$\log_{10} U = -2.316 - 0.36\left(0.69 + \log_{10}\left(Z_{\rm cold}/Z_{\odot}\right)\right)$$
$$-0.292\log_{10}\left(n_{\rm e}/{\rm cm}^{-3}\right)$$
$$+0.428\left(\log_{10}\left(sSFR'/{\rm yr}^{-1}\right) + 9\right)$$

$$\log_{10}\left[\frac{n_{\rm e}}{{\rm cm}^{-3}}\right] = 2.066 + 0.310\left(\log_{10}\left(M_{*}/M_{\odot}\right) - 10.0\right)$$
$$+0.492\left(\log_{10}\left(sSFR'/{\rm yr}^{-1}\right) + 9\right)$$