SEMI-ANALYTIC CATALOG FOR CSST WITH EMISSION LINES

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Supervisor: Qi Guo （郭琦）

Collaboration Workshop on Cosmology and Galaxy Formation @ Shanghai

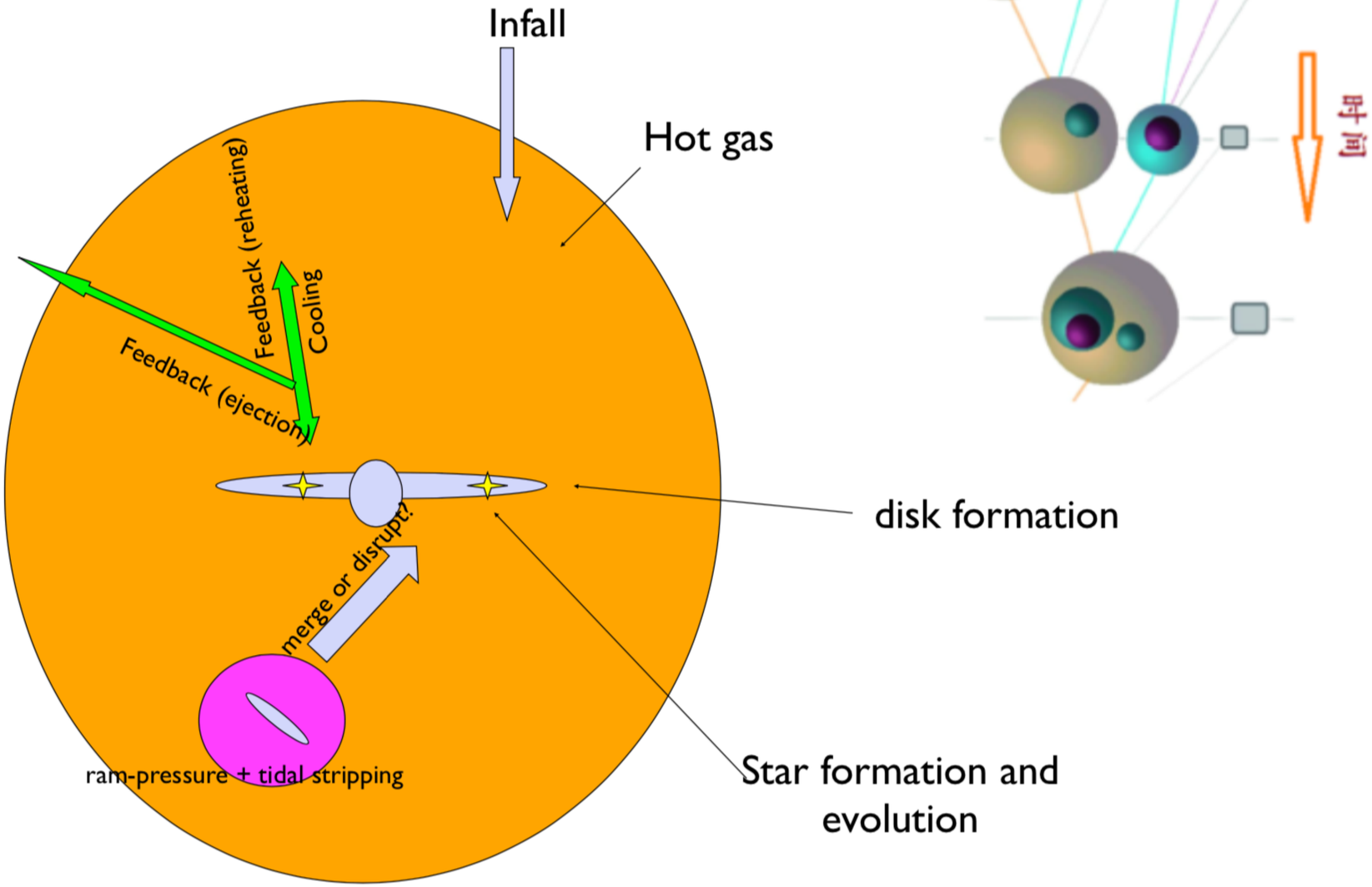
Outlines

- JiuTian Dark Matter Simulations
  - 300M/1Gpc/2Gpc
- Semi-Analytic Catalog
  - Modified H15 with CSST filters
  - Galaxy emission lines
  - AGN luminosity
  - Light-cones

JiuTian-1G Dark Matter Simulations

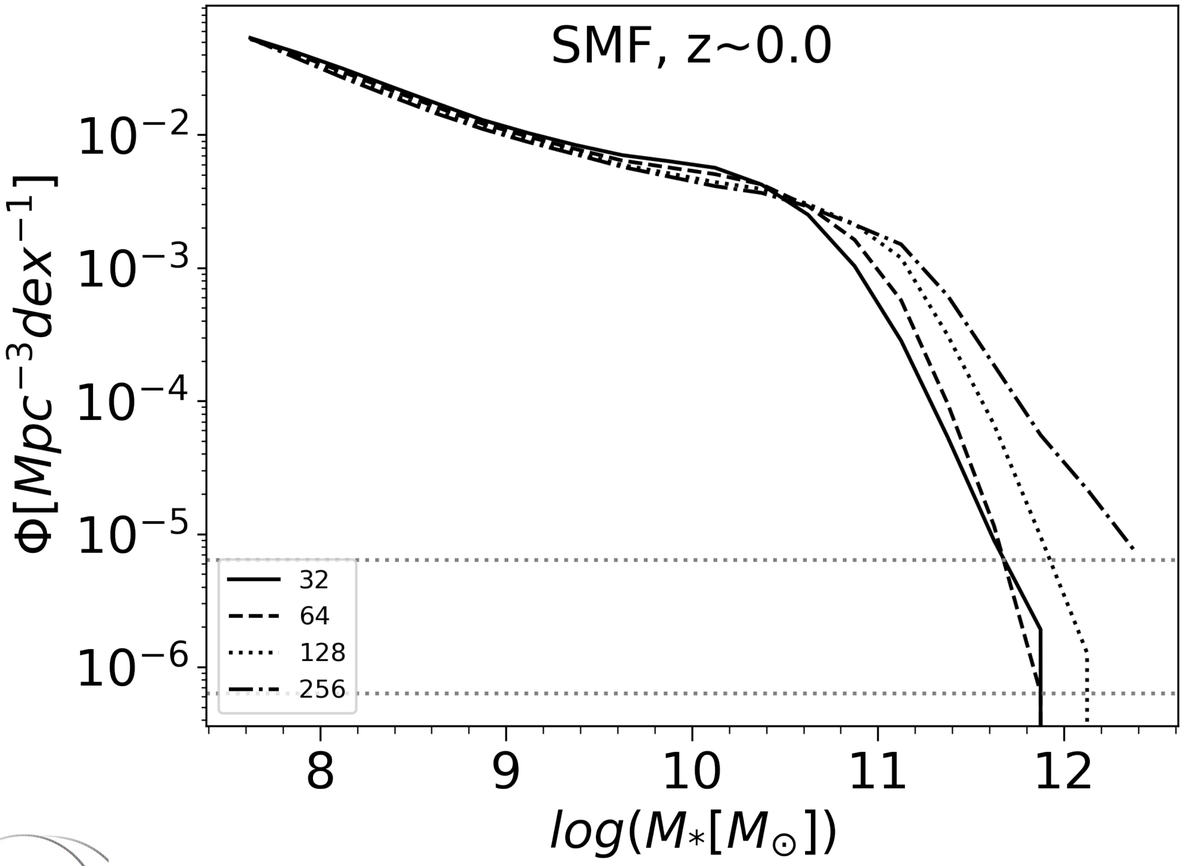
- Code: L-Gadget3
- Boxsize: 1Gpc/h
- Dark matter particle mass: $3.72295 \times 10^8 M_\odot/h$
- Dark matter particle number: 6144^3
- Snapshots: 128
- Cosmology: Planck 2018
  $\Omega_m = 0.3111$, $\Omega_\Lambda = 0.6889$, $\Omega_{baryon} = 0.0490$, $h = 0.6766$, $\sigma_8 = 0.8102$

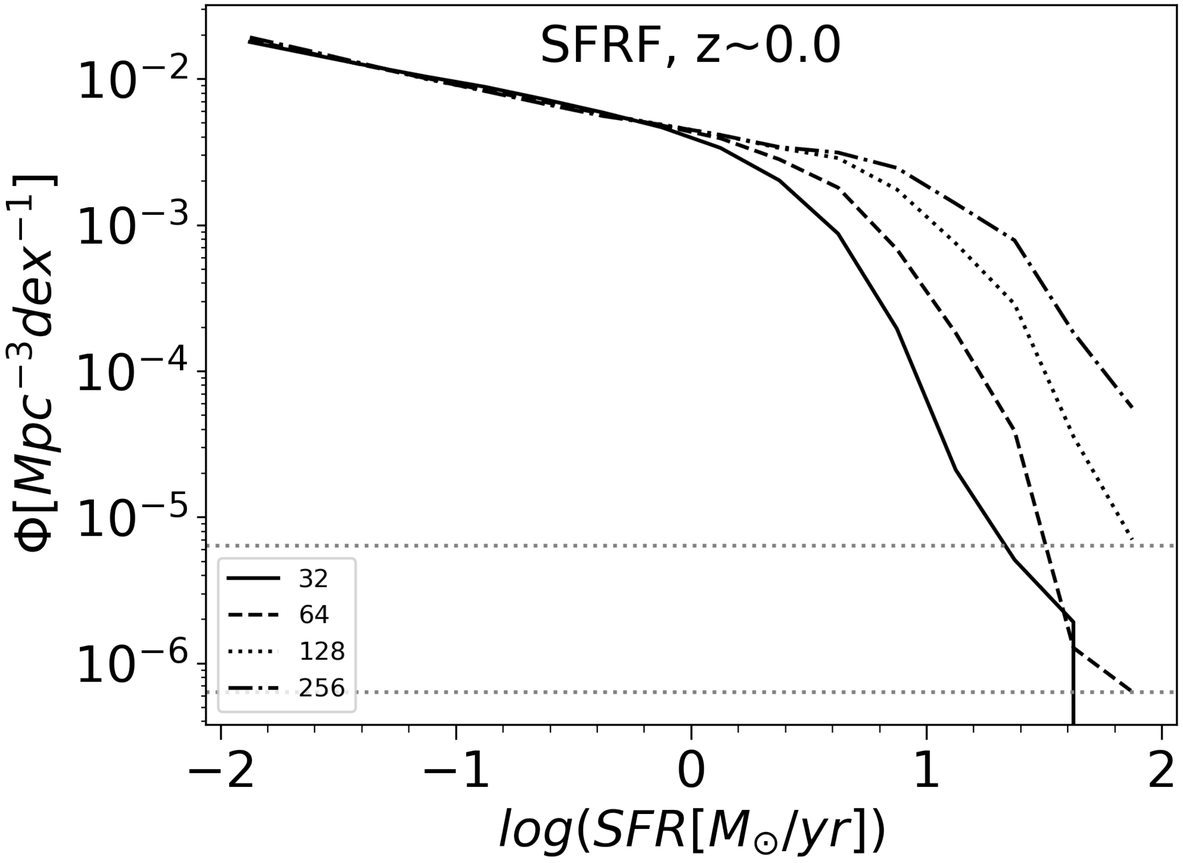
Semi-Analytic Model



Semi-Analytic Model

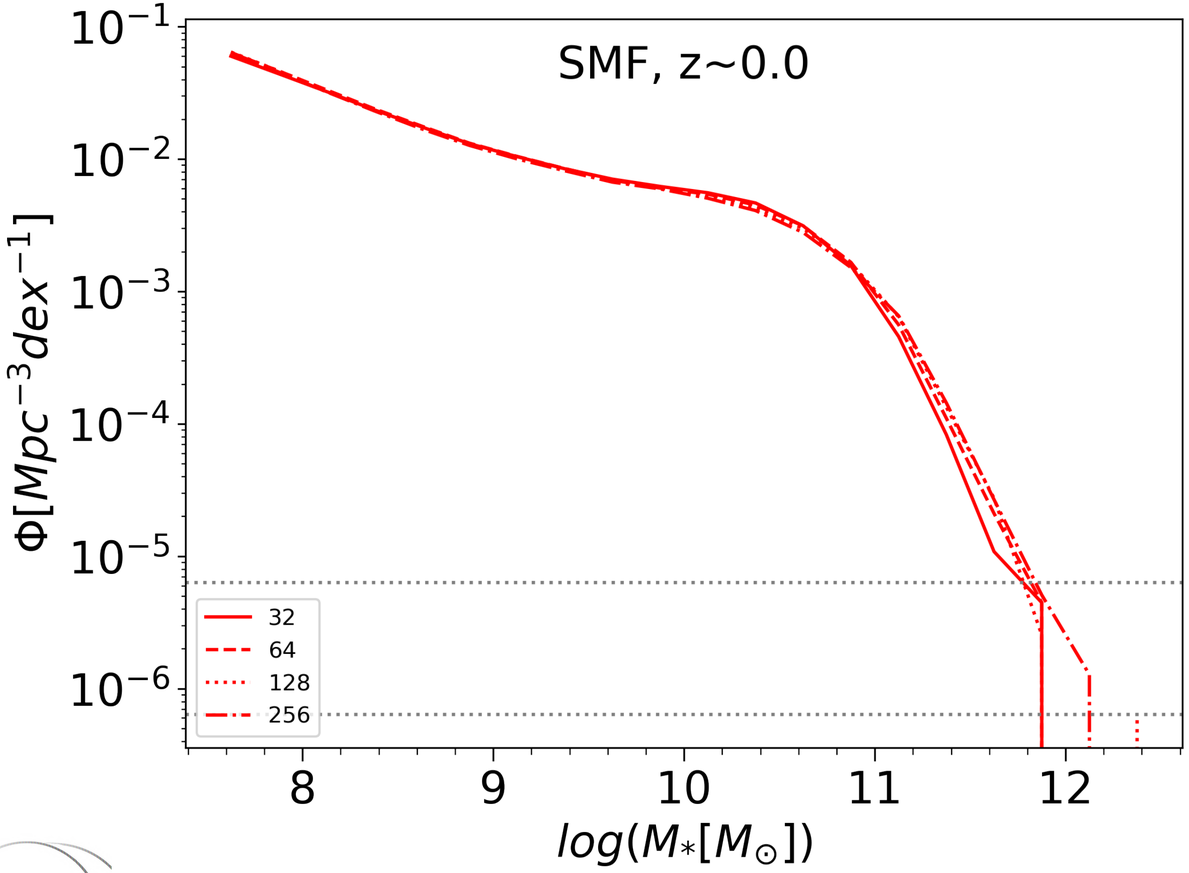
- LGalaxies 2015 + new disruption model + new parameters
  - Time convergence problem - Similar dark matter but different galaxies

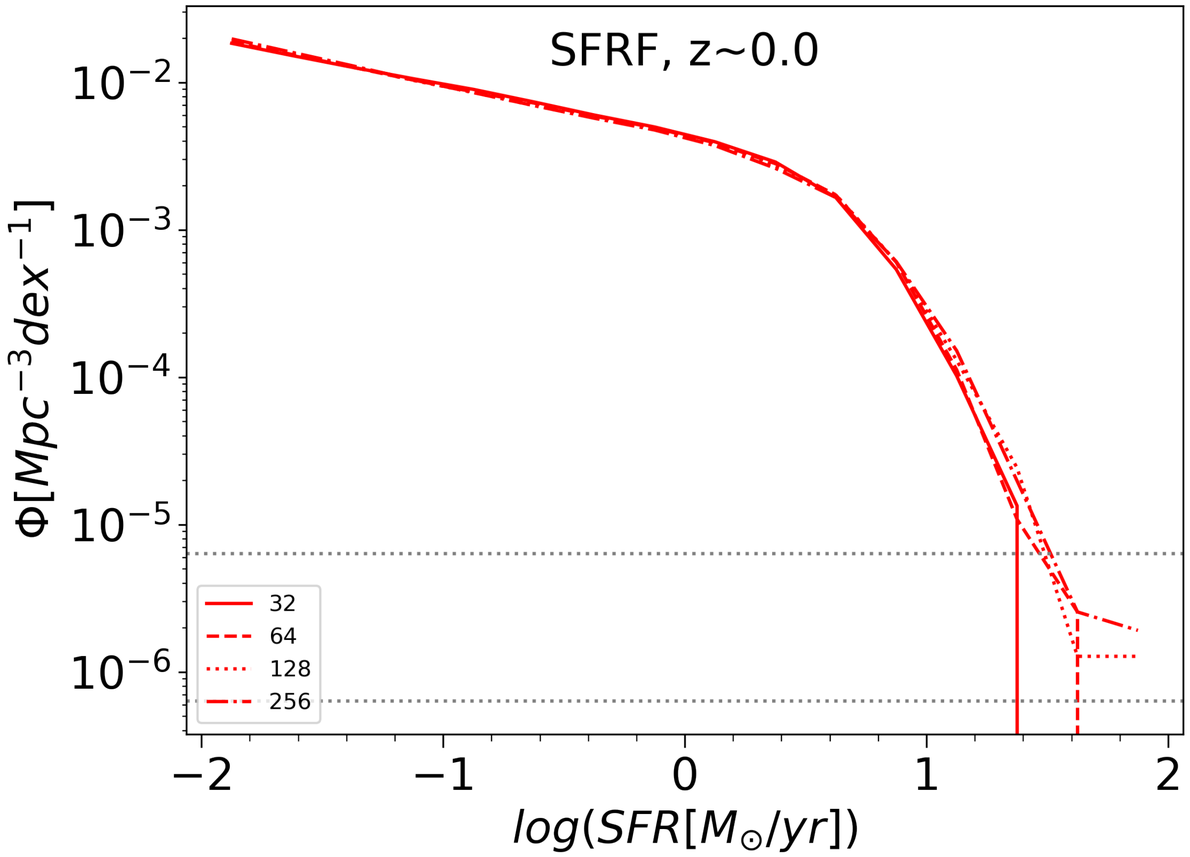




Time Convergence

- New disruption models
- Overall good agreement

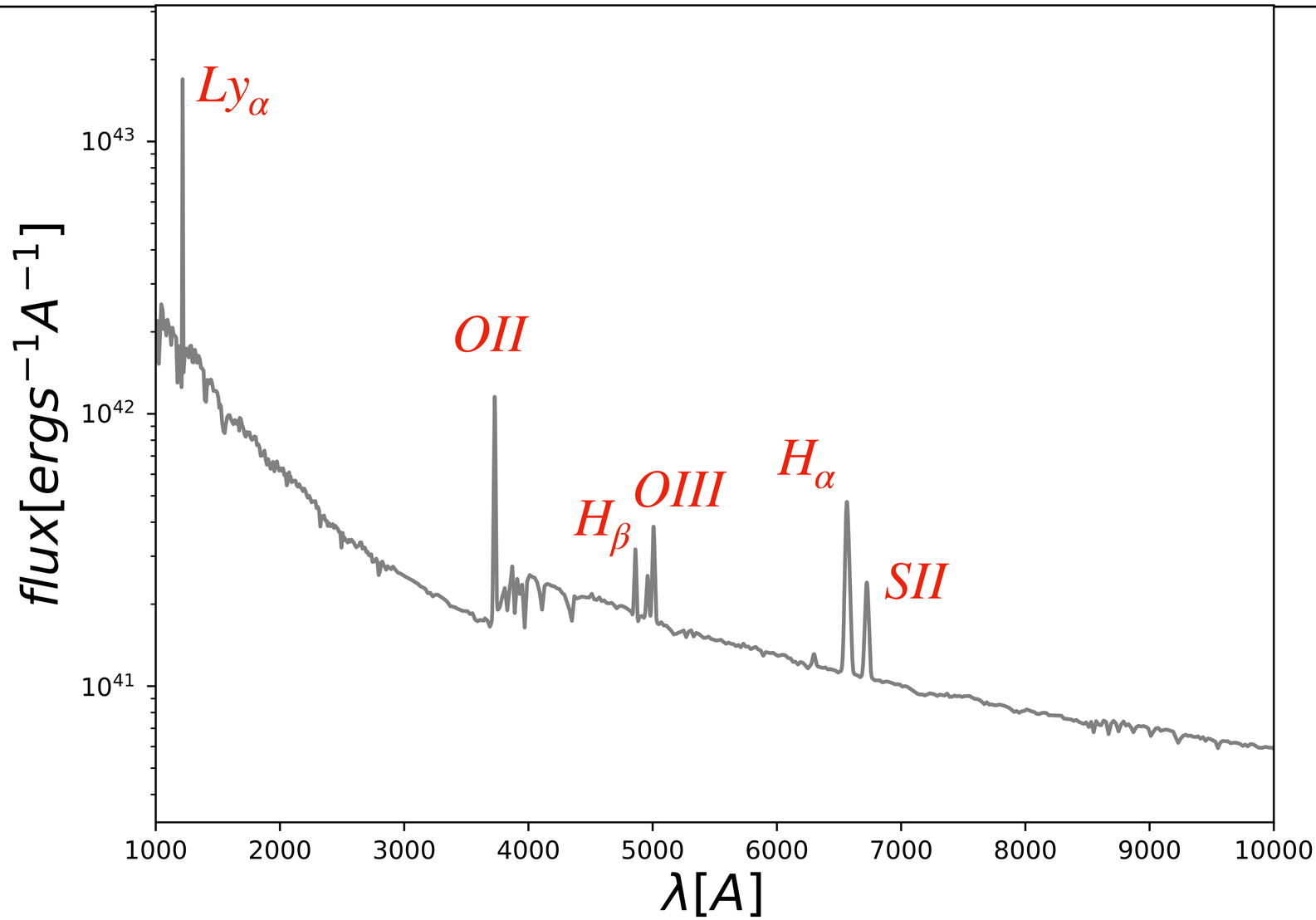




Galaxy Emission Lines

star forming galaxies at z~0

- Emission lines
  - Line ratios - CLOUDY13.03
    - geometry
    - chemical content
    - ionizing spectrum
    - metallicity (Z)
    - ionizing parameter (U)
    - Hydrogen density (n_H)



Galaxy Emission Lines

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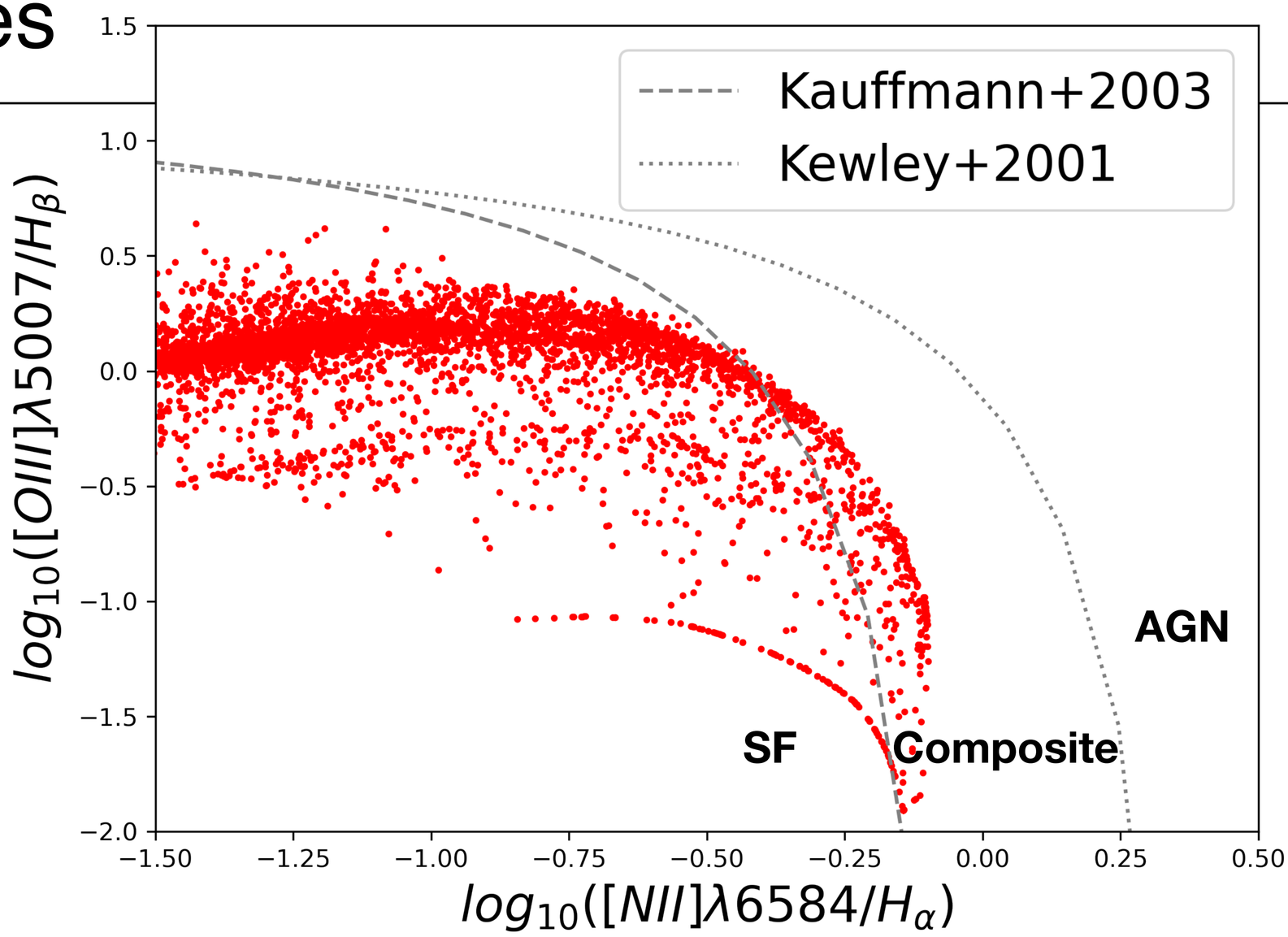
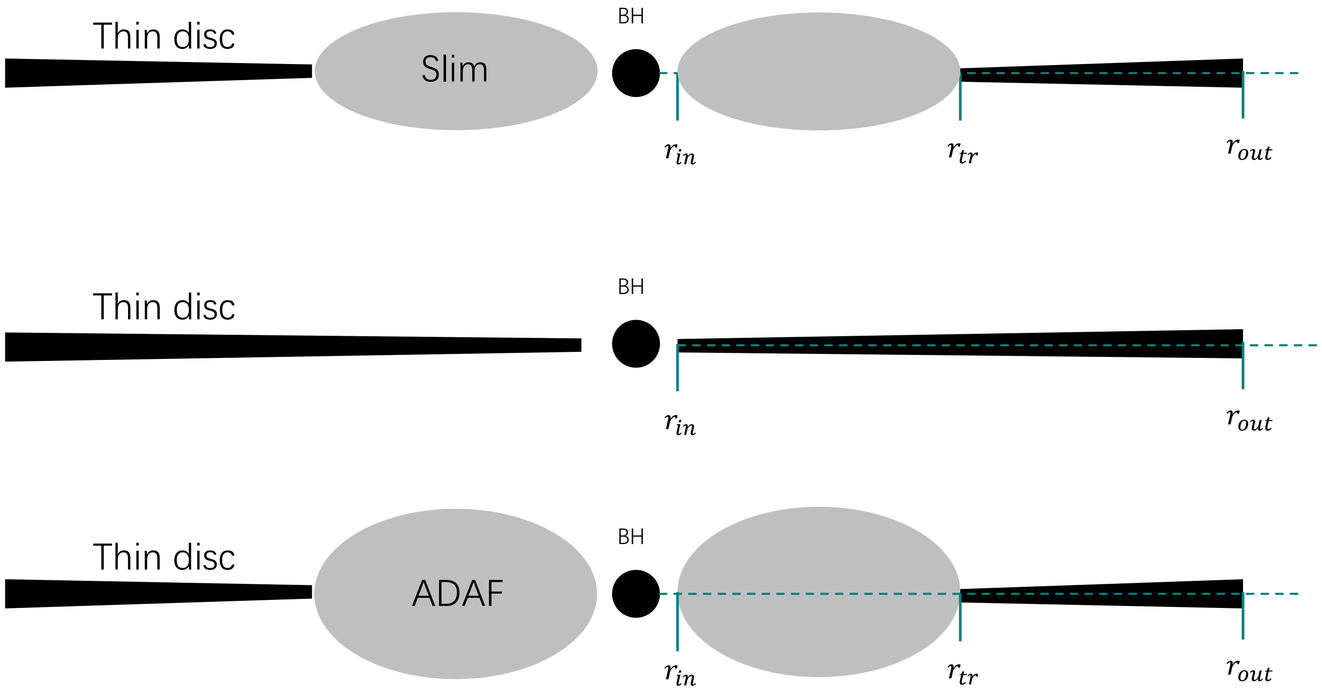


AGN Luminosities

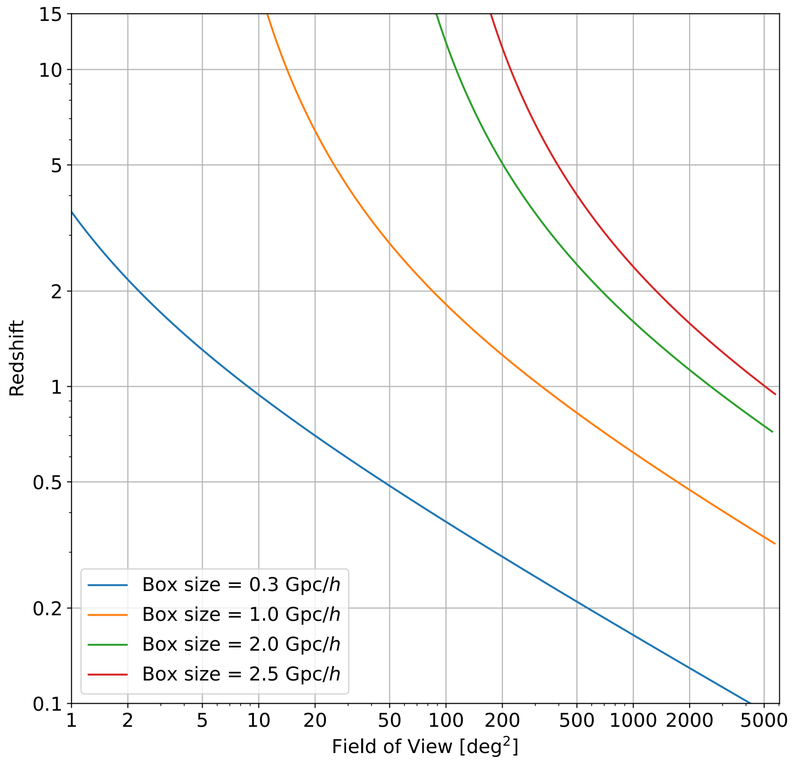


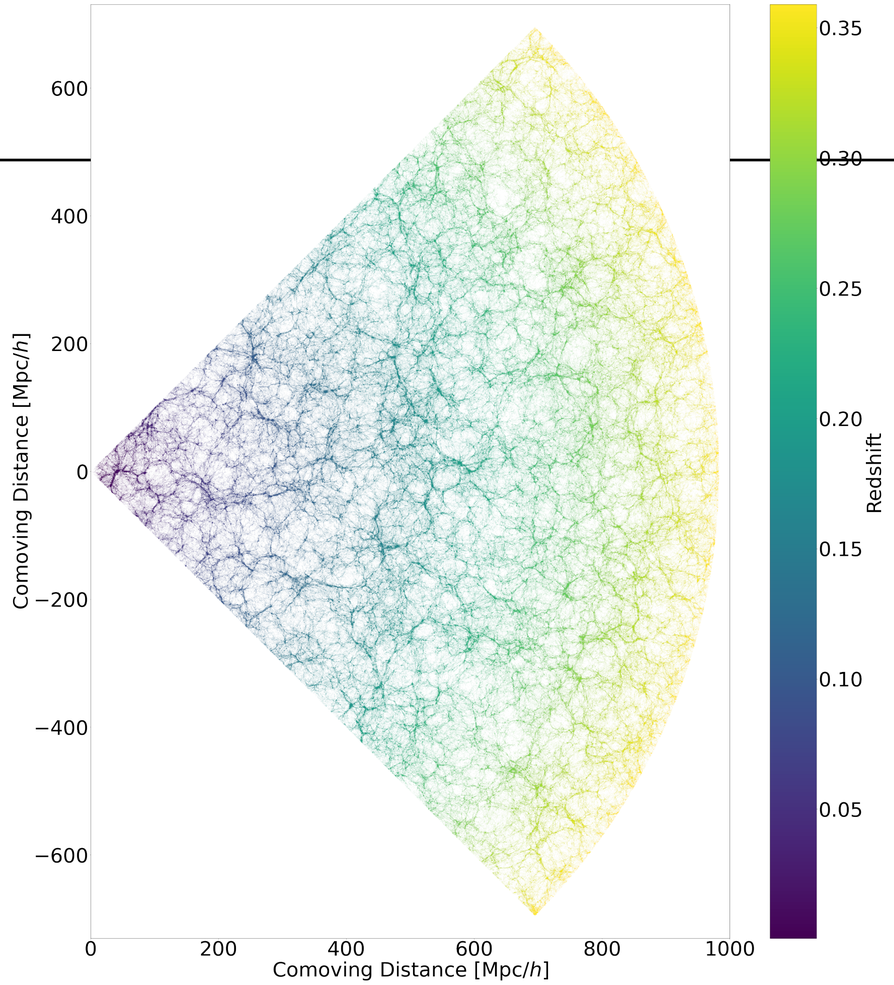
Tong Su (苏童)

	geometry	Optical depth	temperature	Radiation	luminosity	Accretion rate
Slim disk	Thick	thick	Hot	Blackbody	$\propto \ln \dot{M}$	$\dot{m} > 0.1$
Thin disk	Thin	Thick	Cool	Blackbody	$\propto \dot{M}$	$0.01 < \dot{m} \leq 0.1$
ADAF	thick	Thin	Hot, two temperature	Synchrotron, bremsstrahlung, inverse-compton	$\propto \dot{M}^2$	$\dot{m} \leq 0.01$

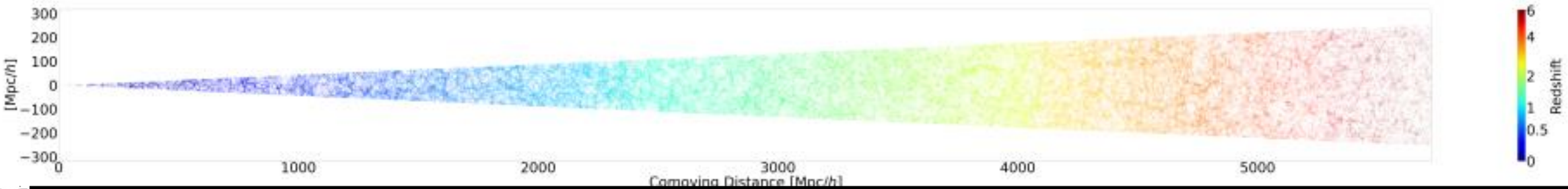
Light-cones

Redshift - FOV





Yun Liu (刘赟)



Tables

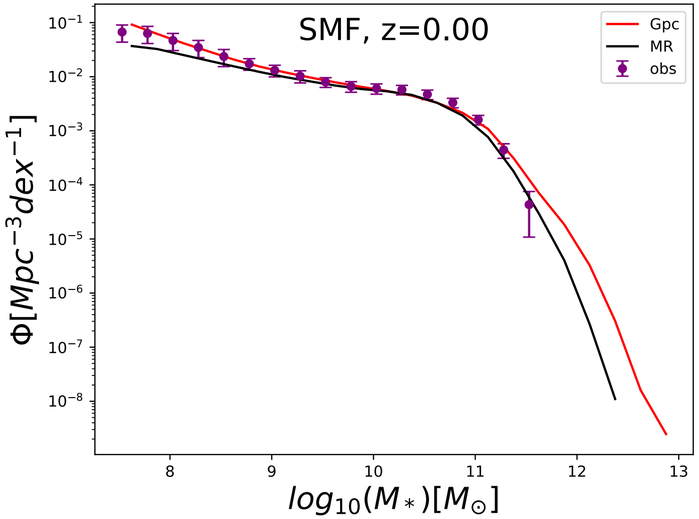
Galaxy data ~ 50T
total galaxies ~ 4.6e10

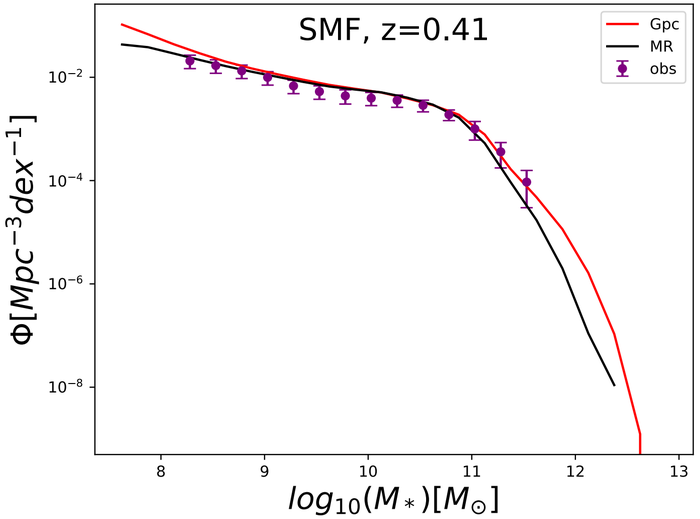
- x,y,z (RA, DEC)
- Vx,vy,vz
- Redshift
- CSST photometry, Emission line, AGN SED
- Other survey photometry (SDSS,COSMOS,JPAS…)
- Metallicity
- Age
- Bulge/Disk Size/Mass
- HI mass, rotation velocity
- Physical properties (Stellar Mass, Cold Gas Mass, Black Hole Mass, BH Accretion Rate…)

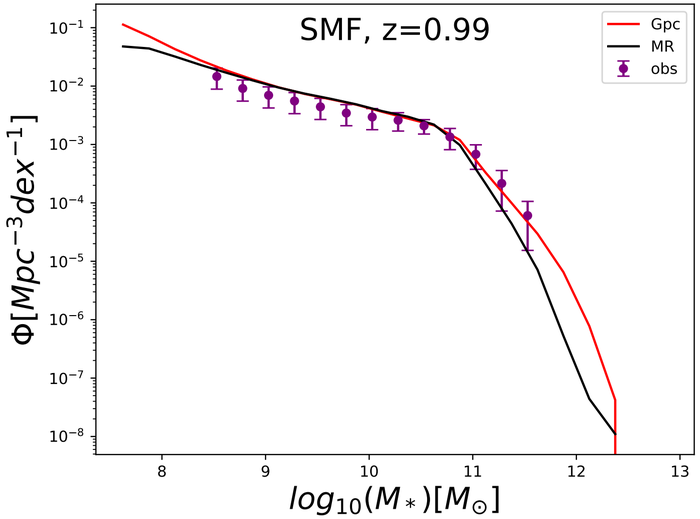
Emission lines ~ 700G/line

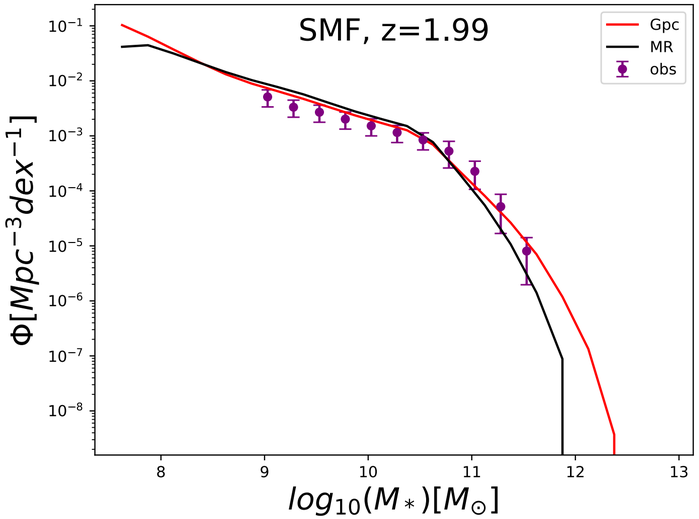
Lyalpha	1216.0
Hbeta	4861.0
Halpha	6563.0
OII_3727	3727.0
OII_3729	3729.0
OIII_5007	5007.0
OIII_4959	4959.0
OI_6300	6300.0
NII_6548	6548.0
NII_6584	6584.0
SII_6717	6717.0
SII_6731	6731.0
NeIII_3870	3870.0

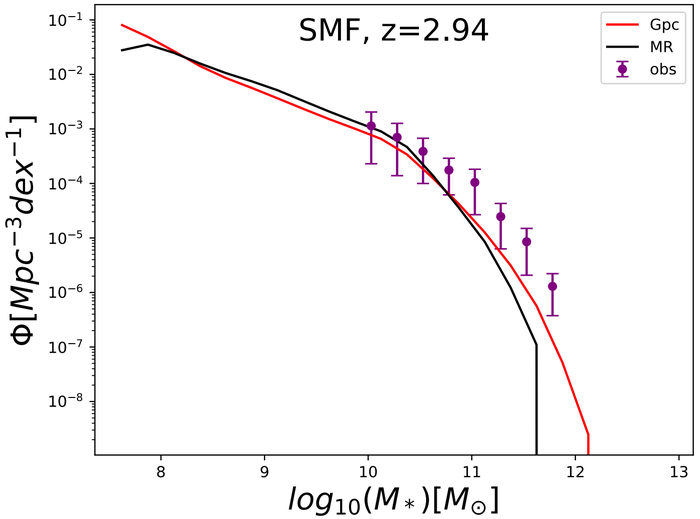
Stellar Mass Function





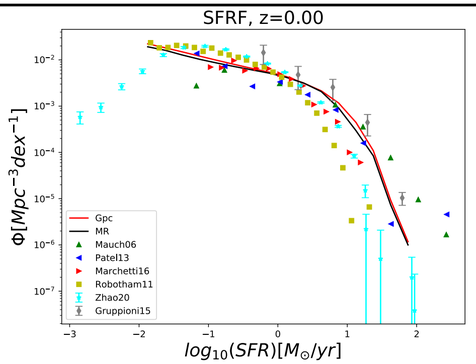




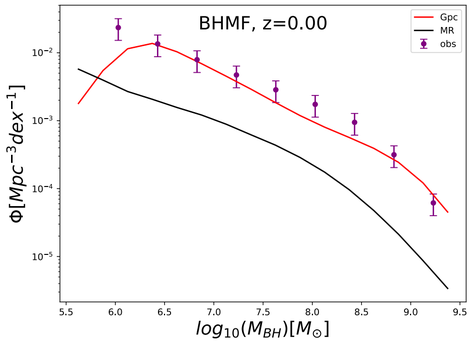


General Galaxy Properties

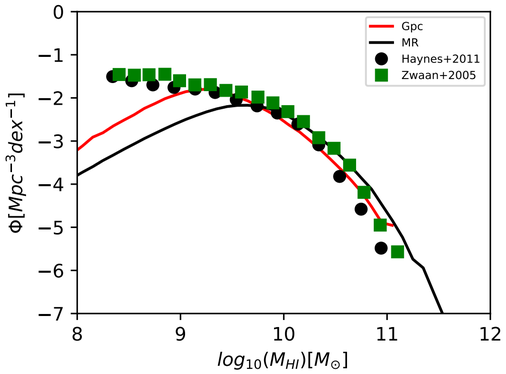
SFRF



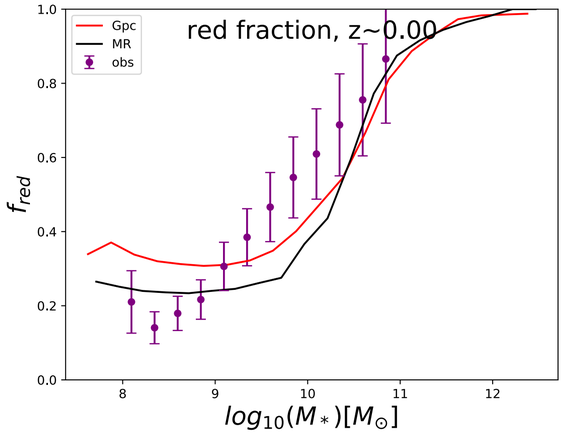
BHMF

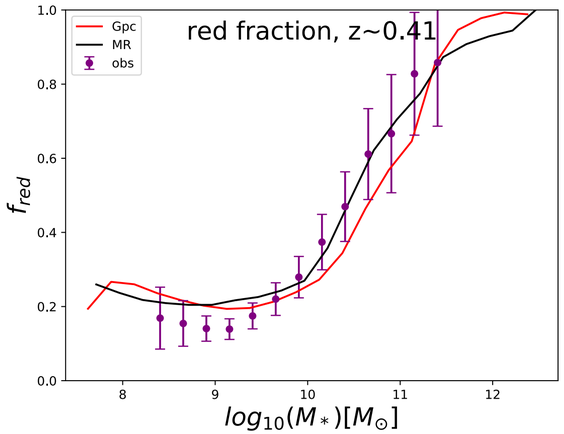


HIMF

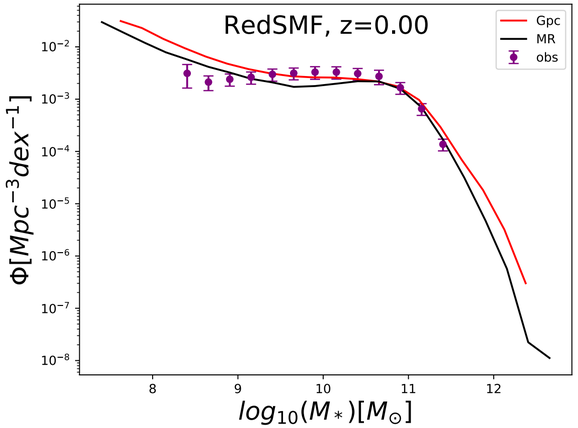


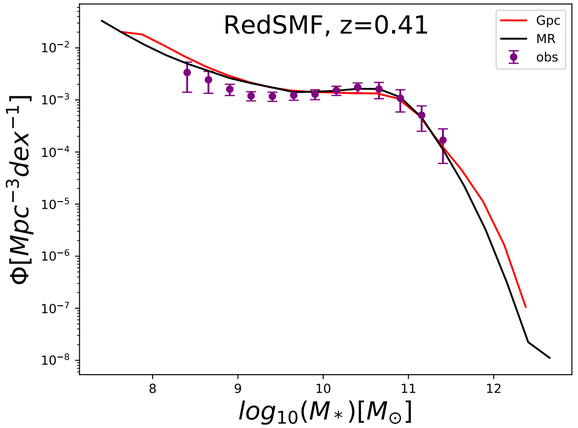
Red Fraction



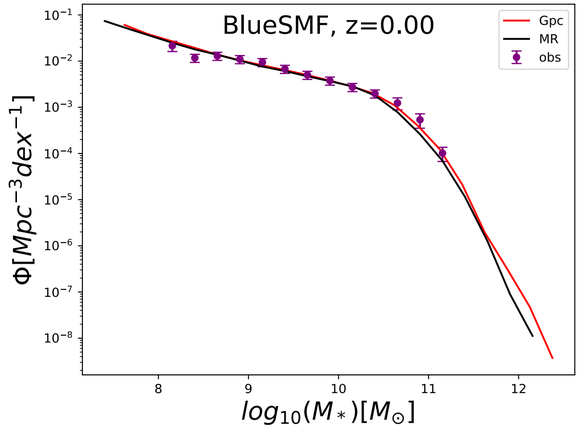


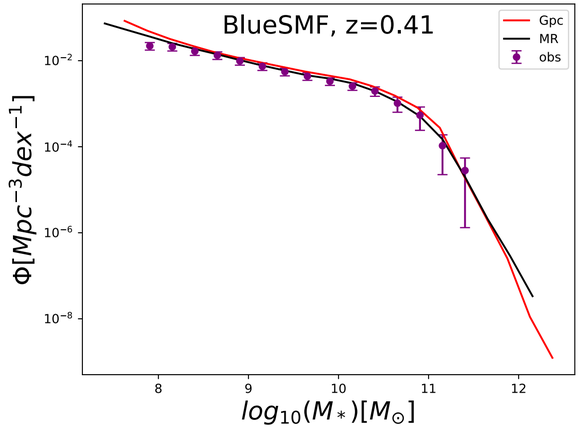
Red SMF



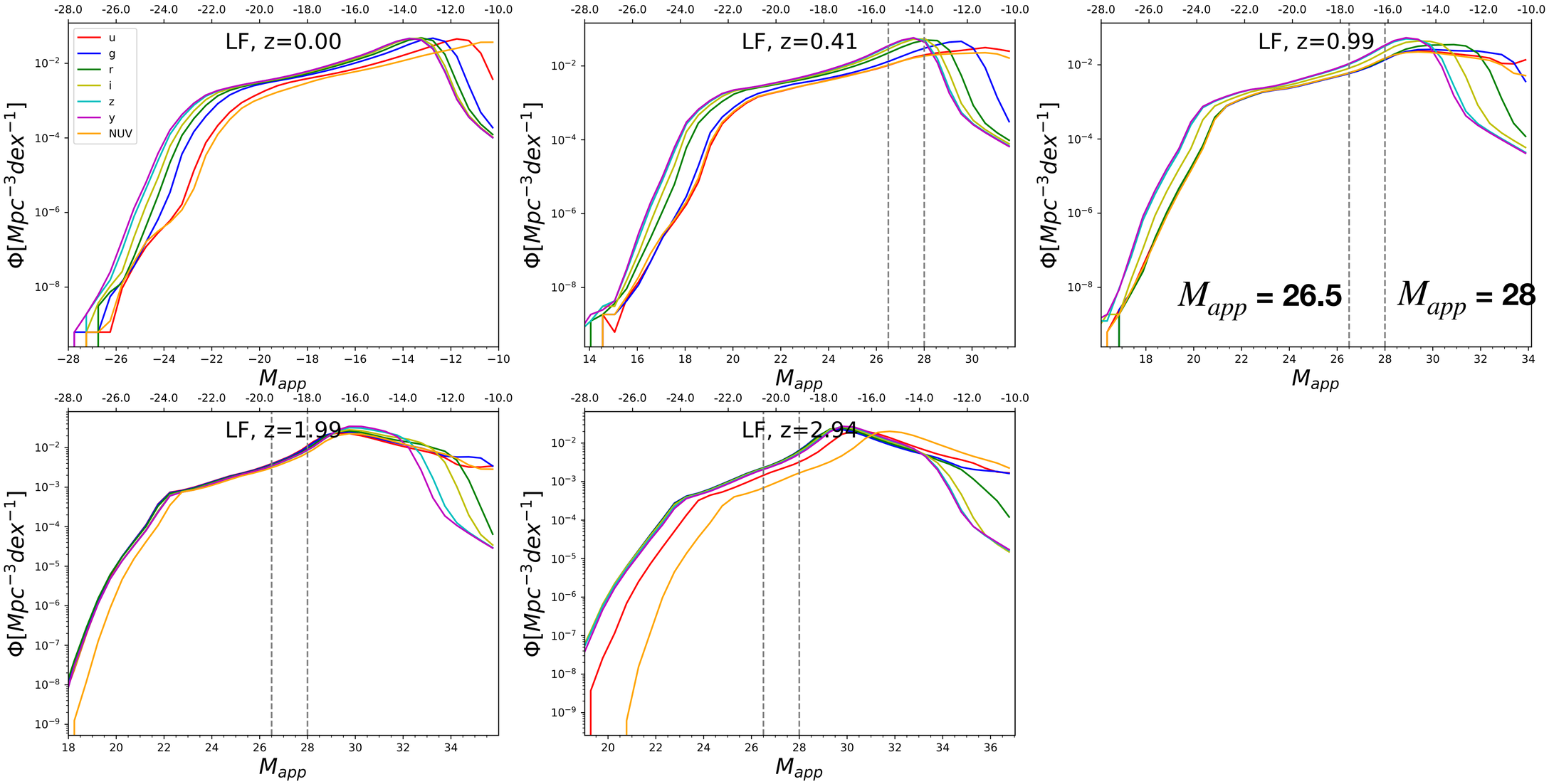


Blue SMF

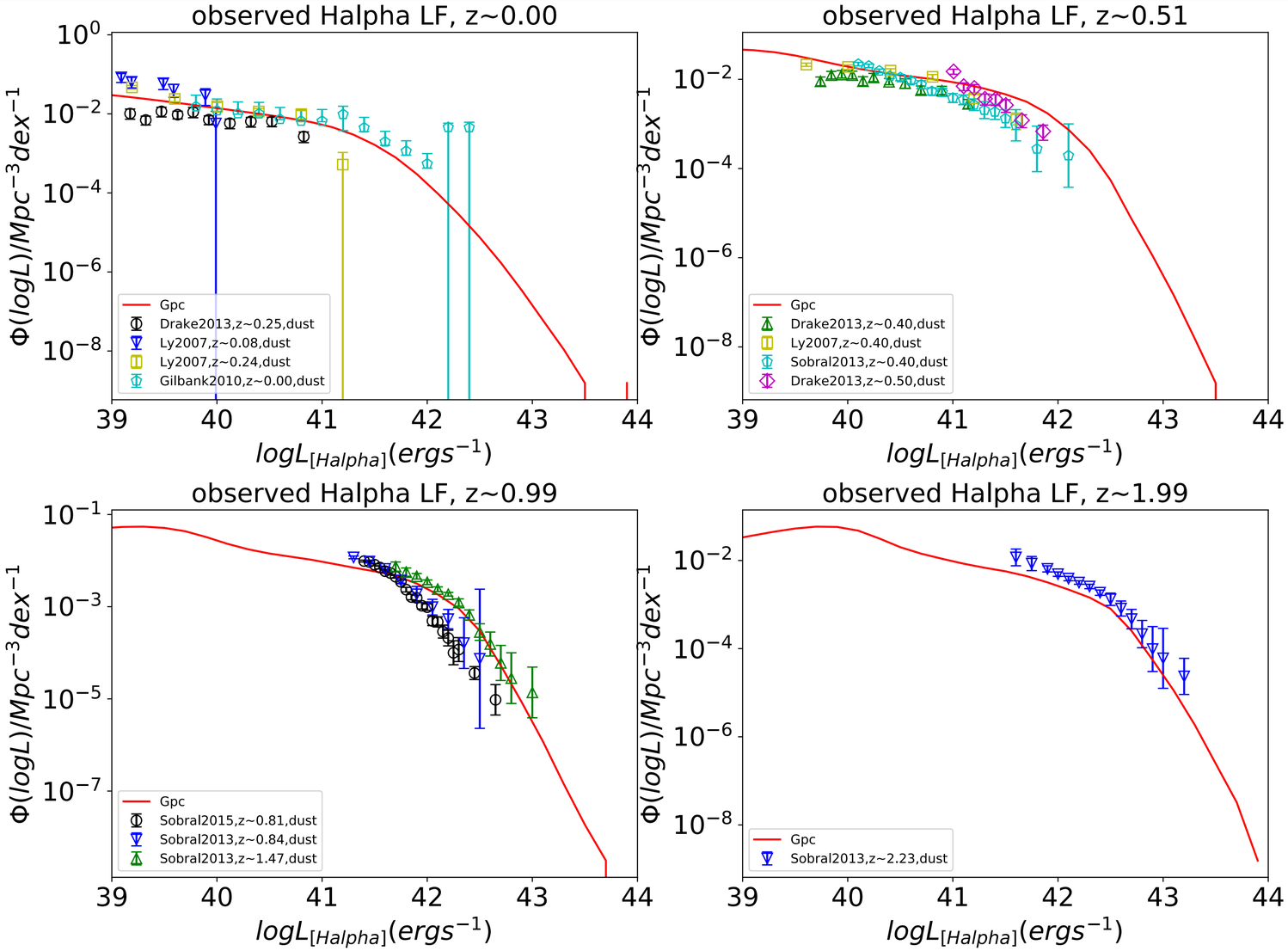




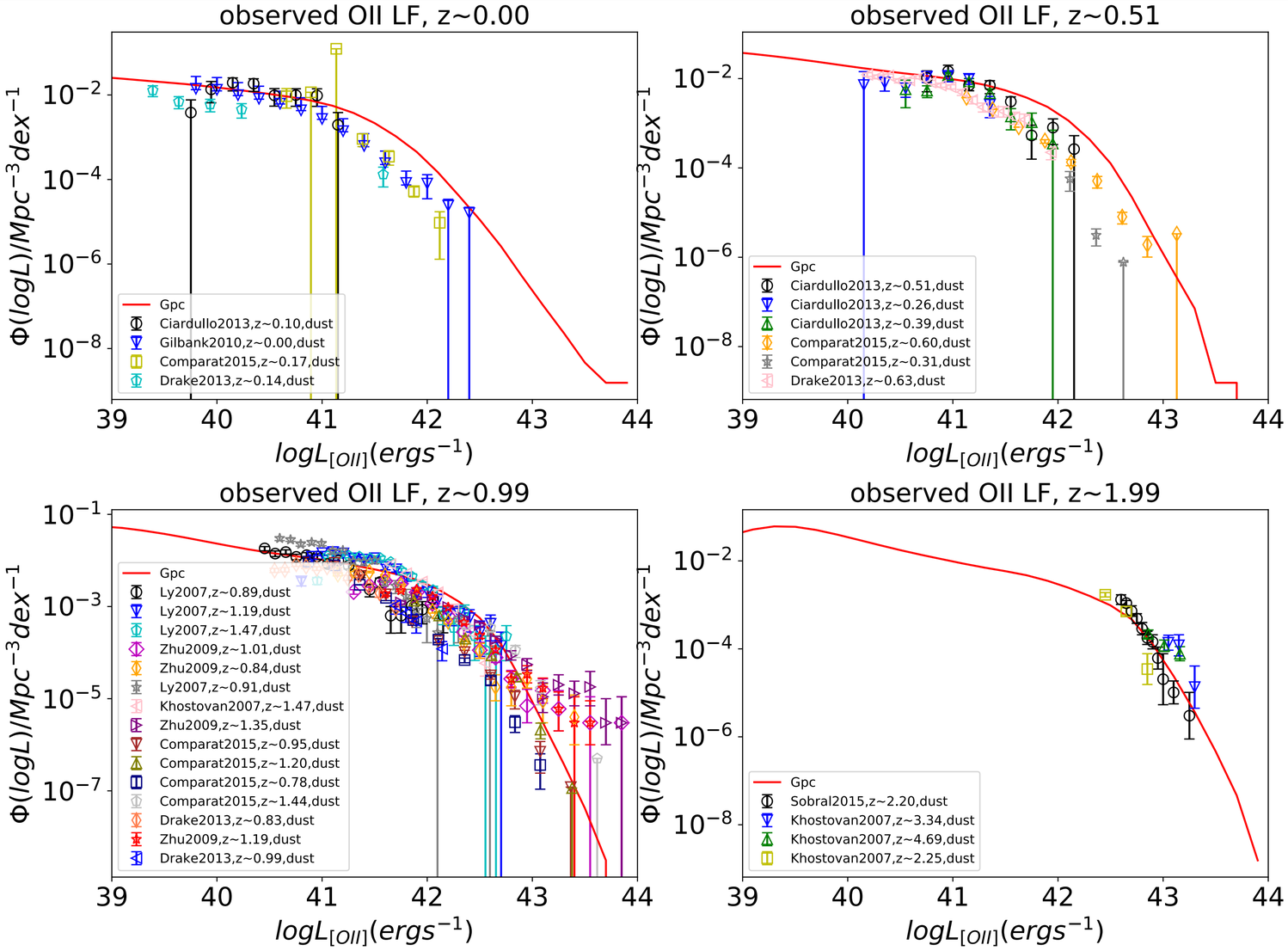
LF of CSST Filters



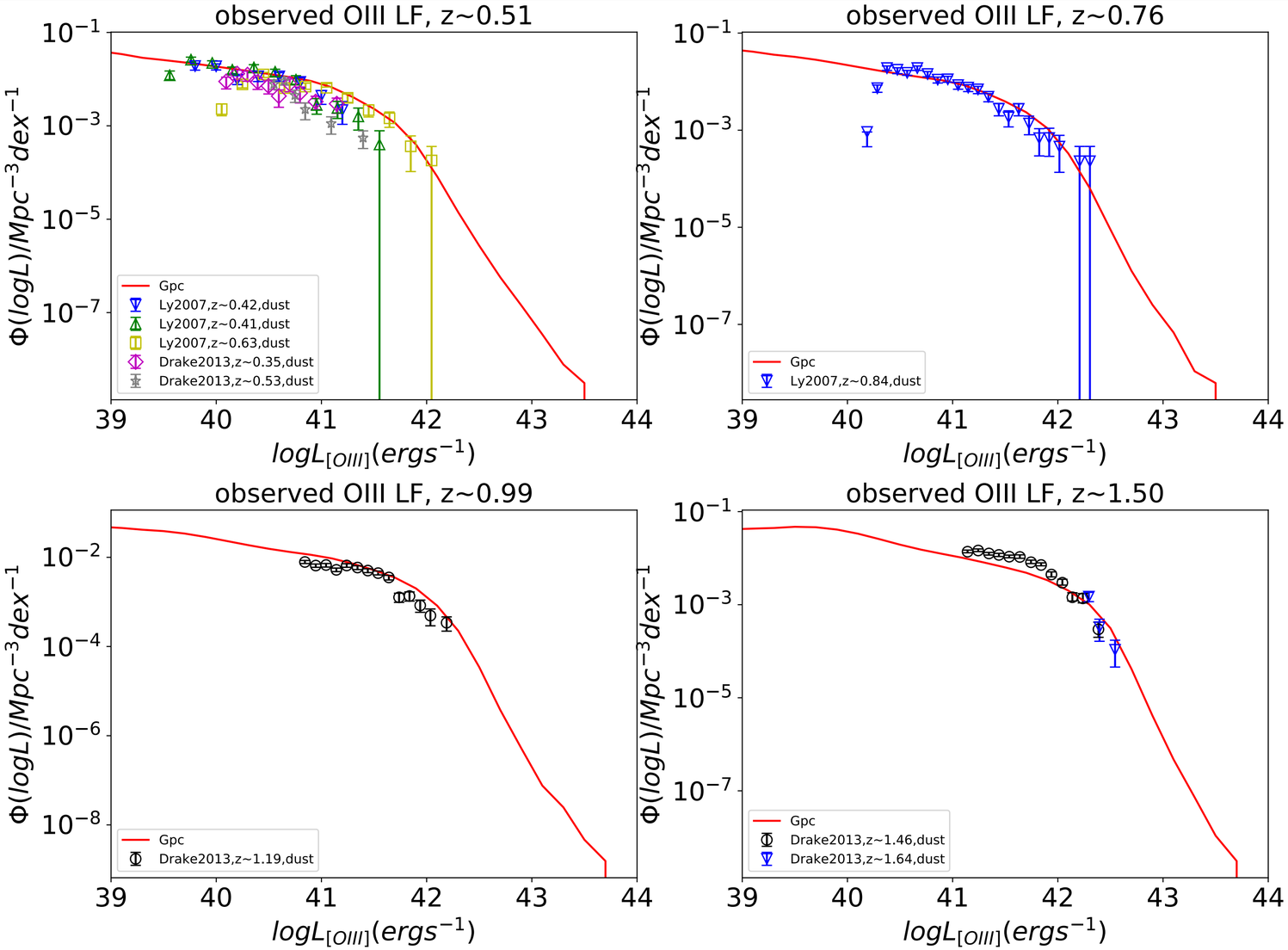
H_α Luminosity Function



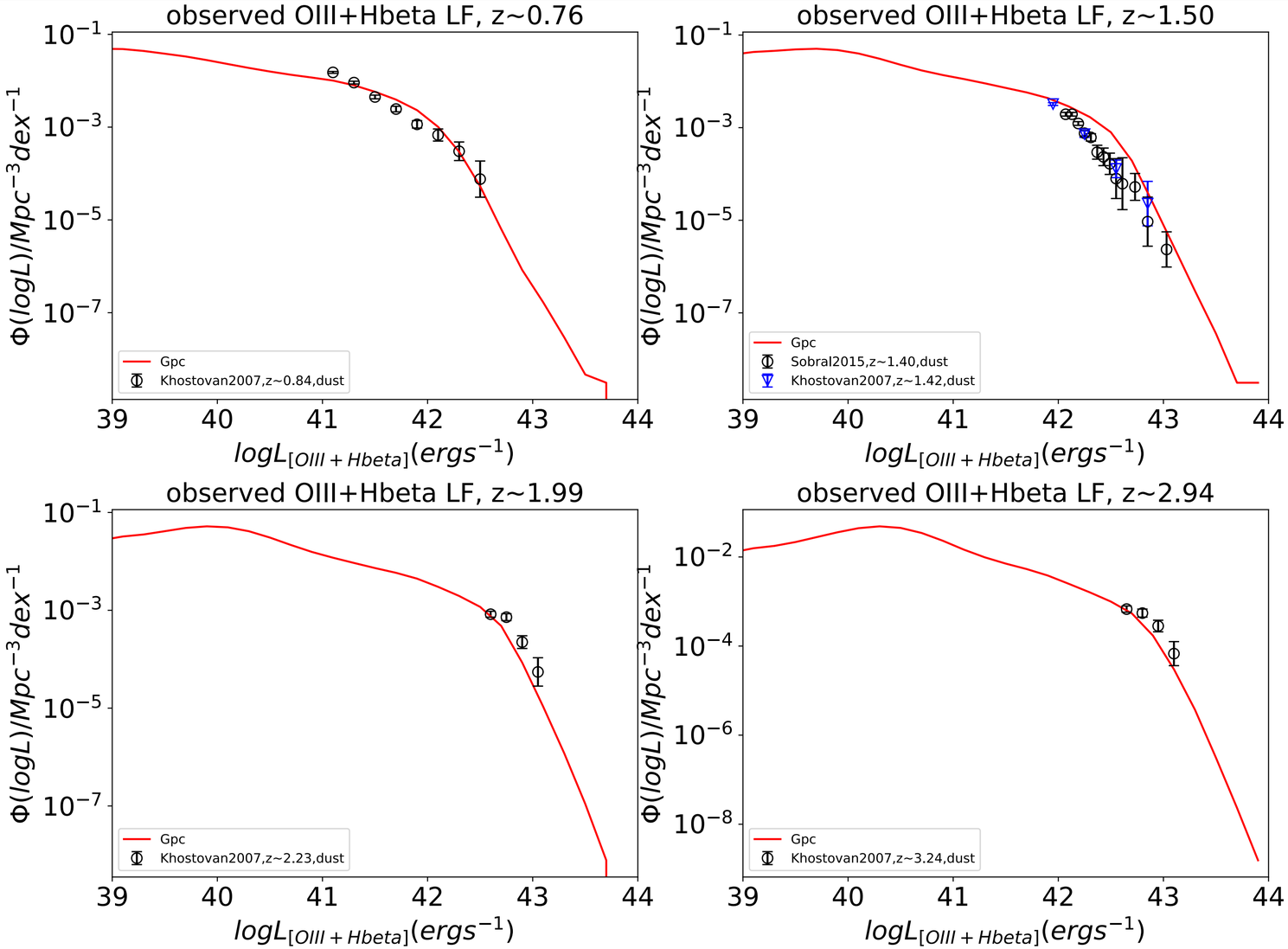
OII Luminosity Function



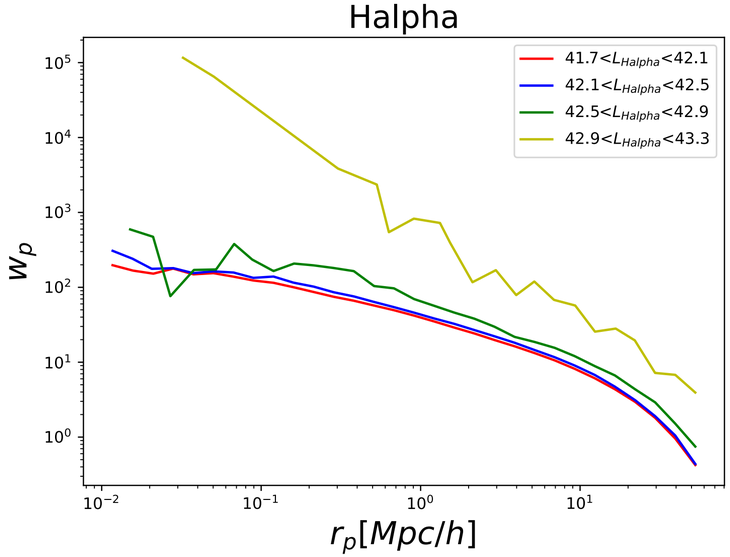
OIII Luminosity Function

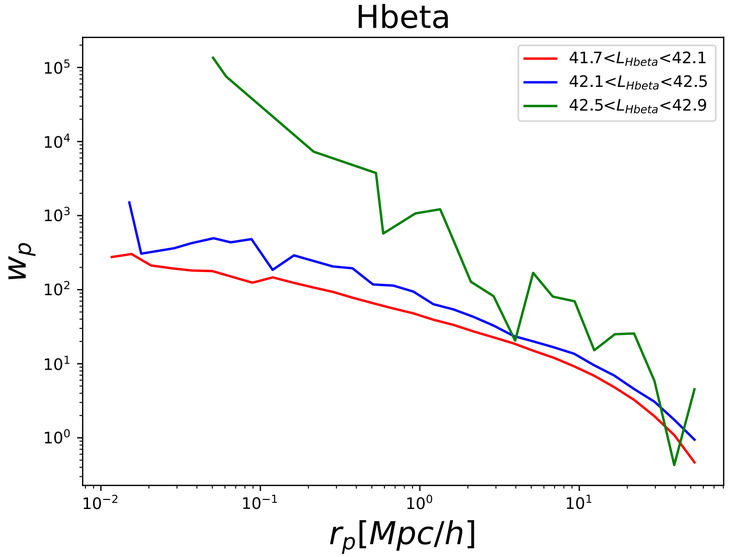


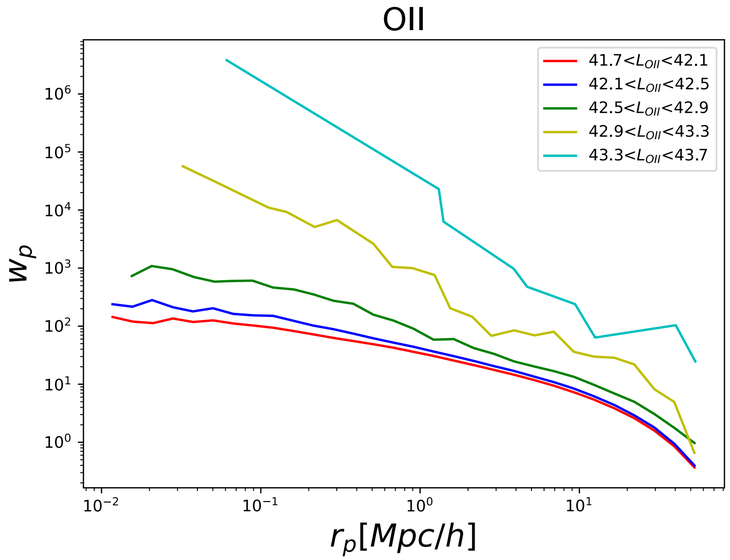
$OIII + H_\beta$ Luminosity Function

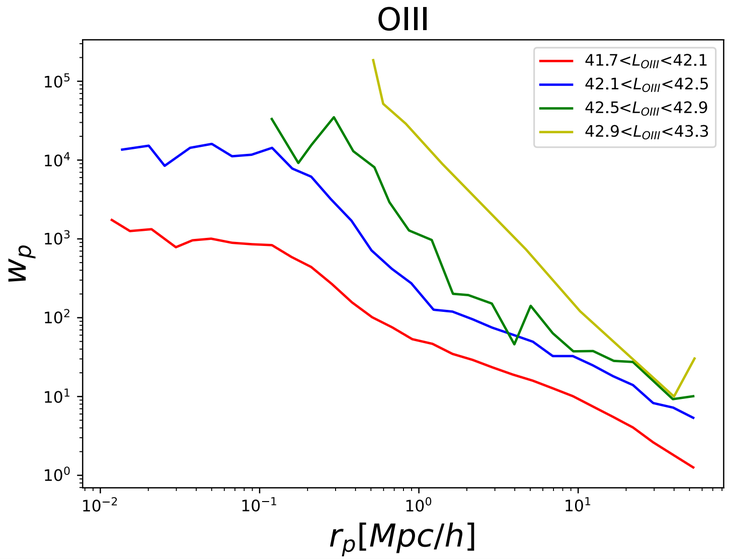


w_p of Luminosity-bin Samples

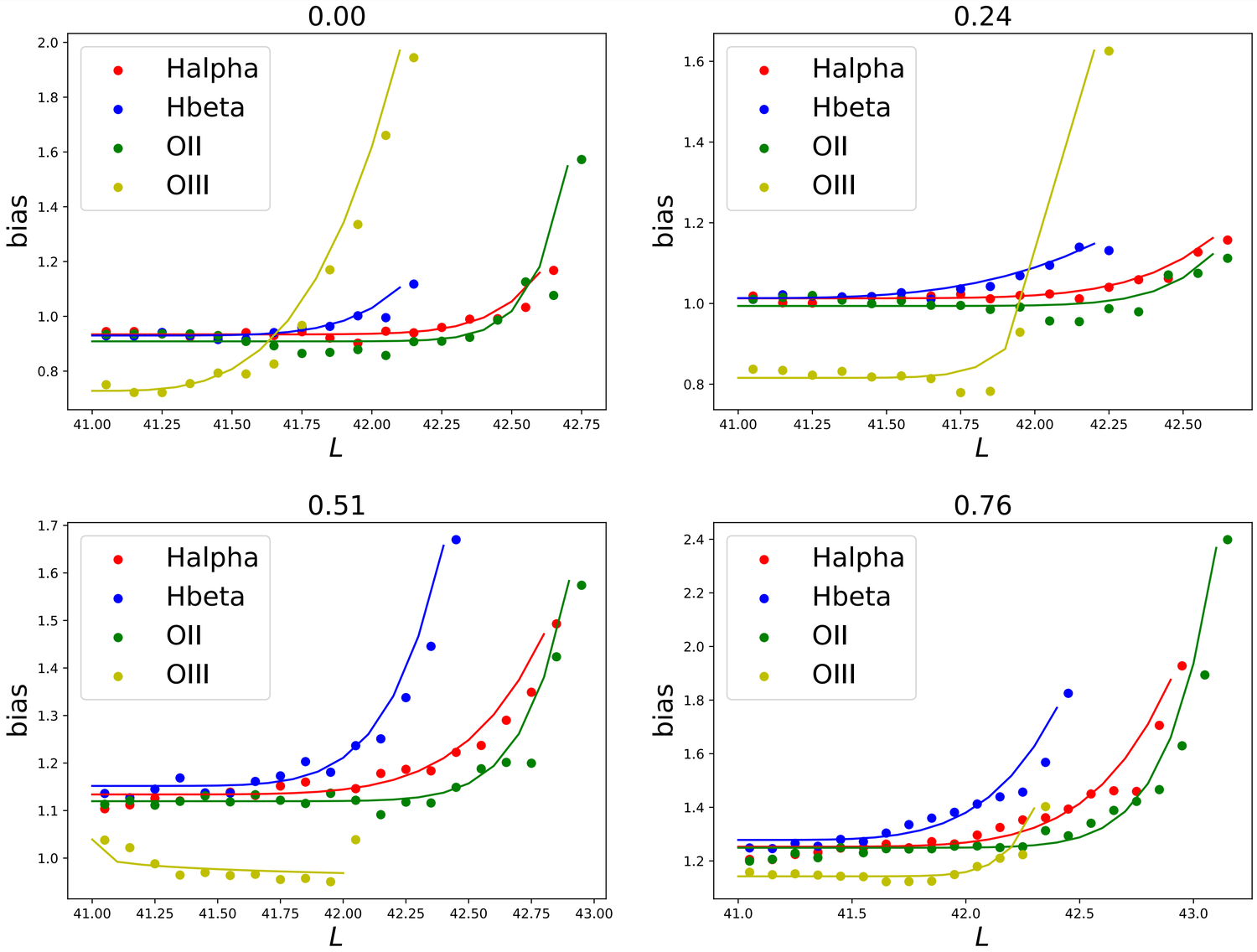






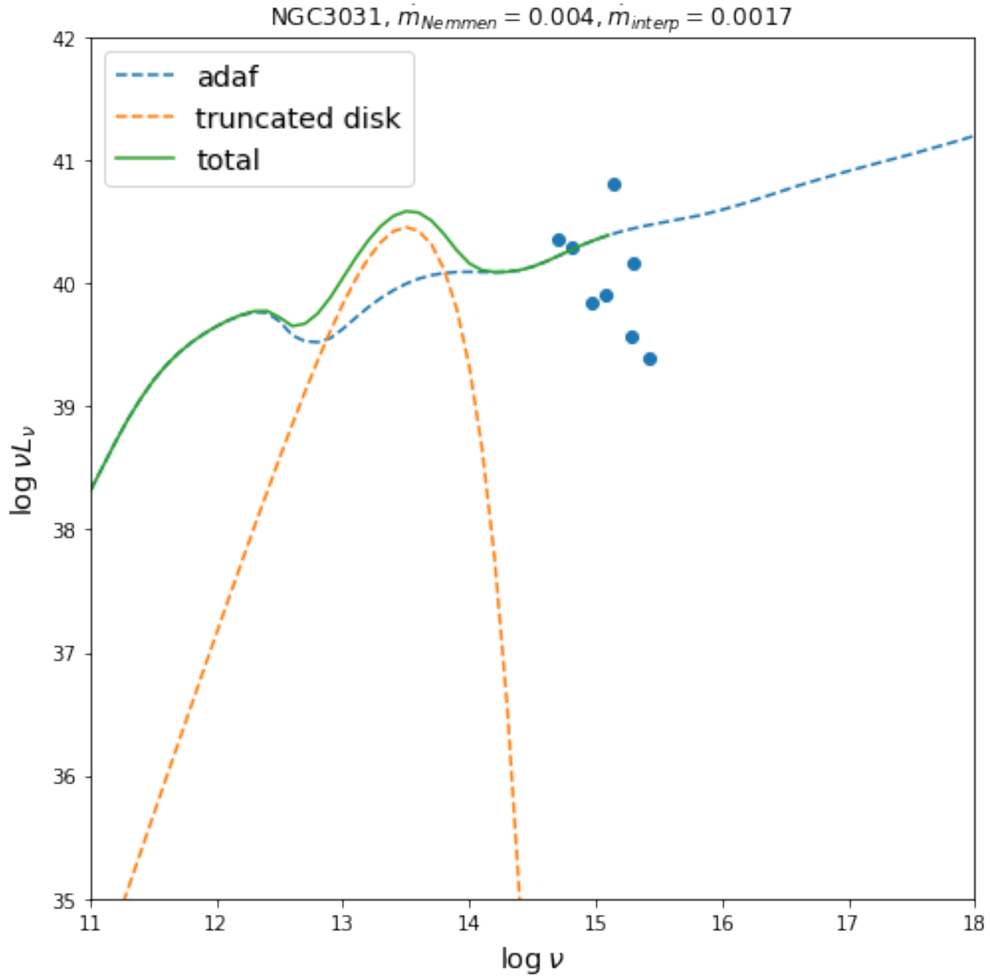


Bias Tracers

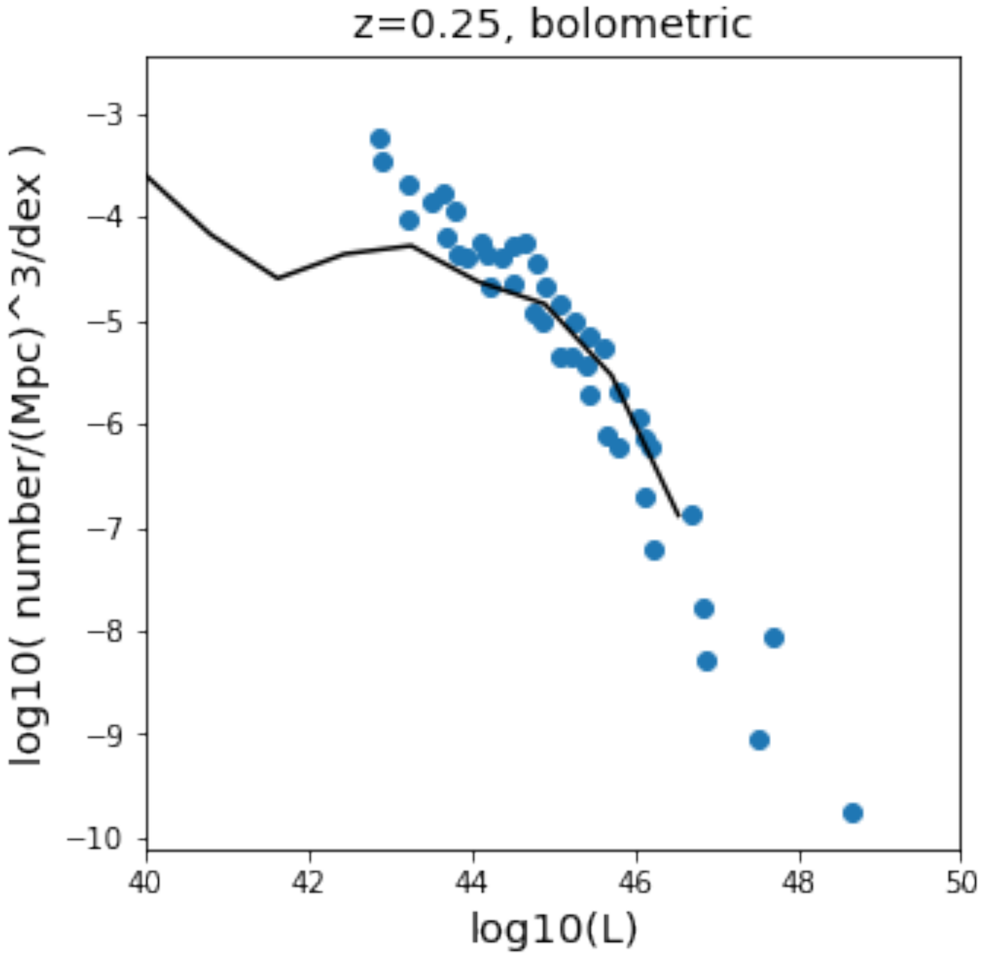


AGN Luminosities

NGC3031

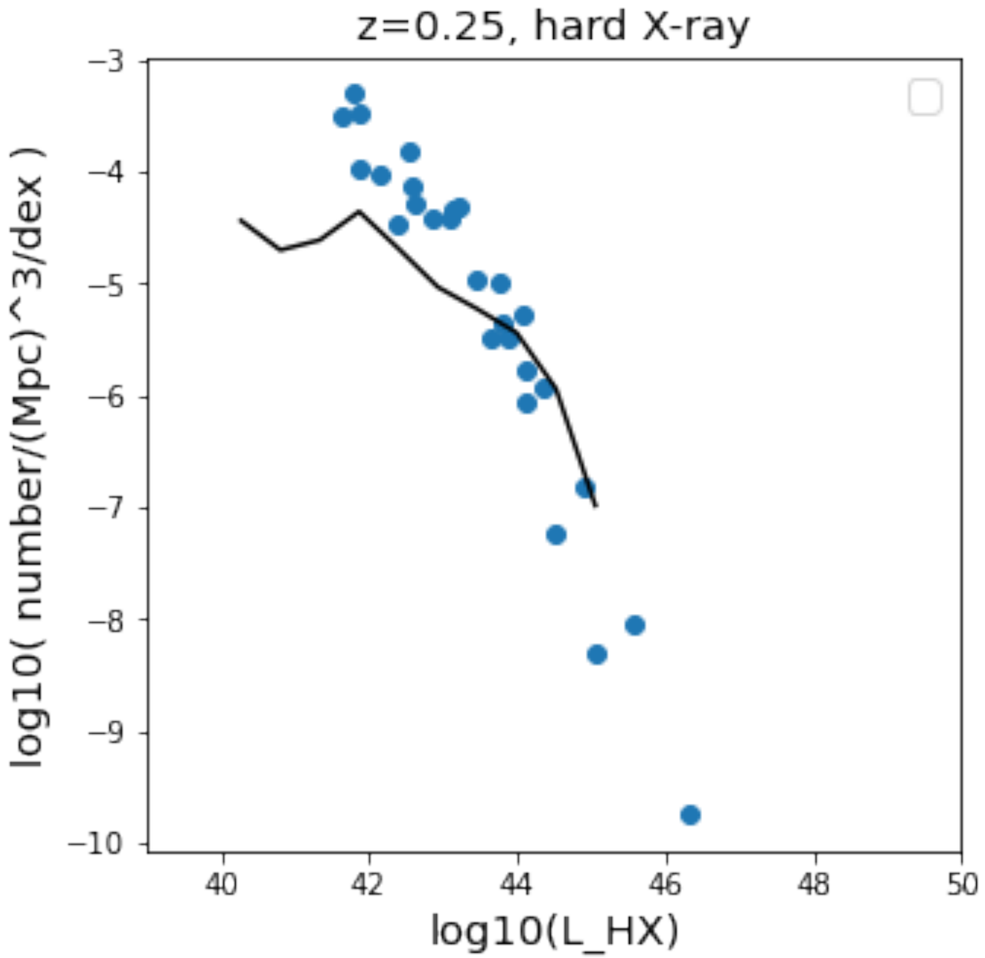


Bolometric Luminosity Function

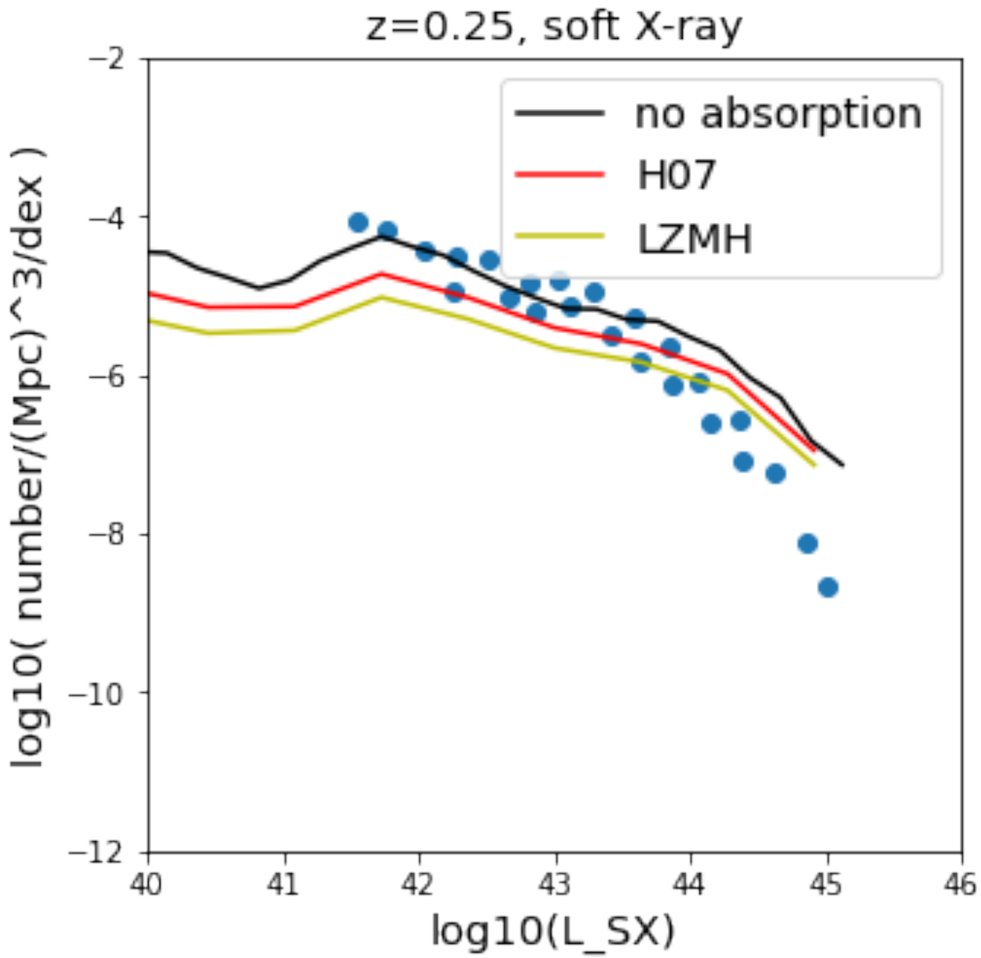


AGN Luminosities

Hard X-ray



Soft X-ray



Summary

- Semi-analytic catalog based on JiuTian-1G dark matter simulation
- 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

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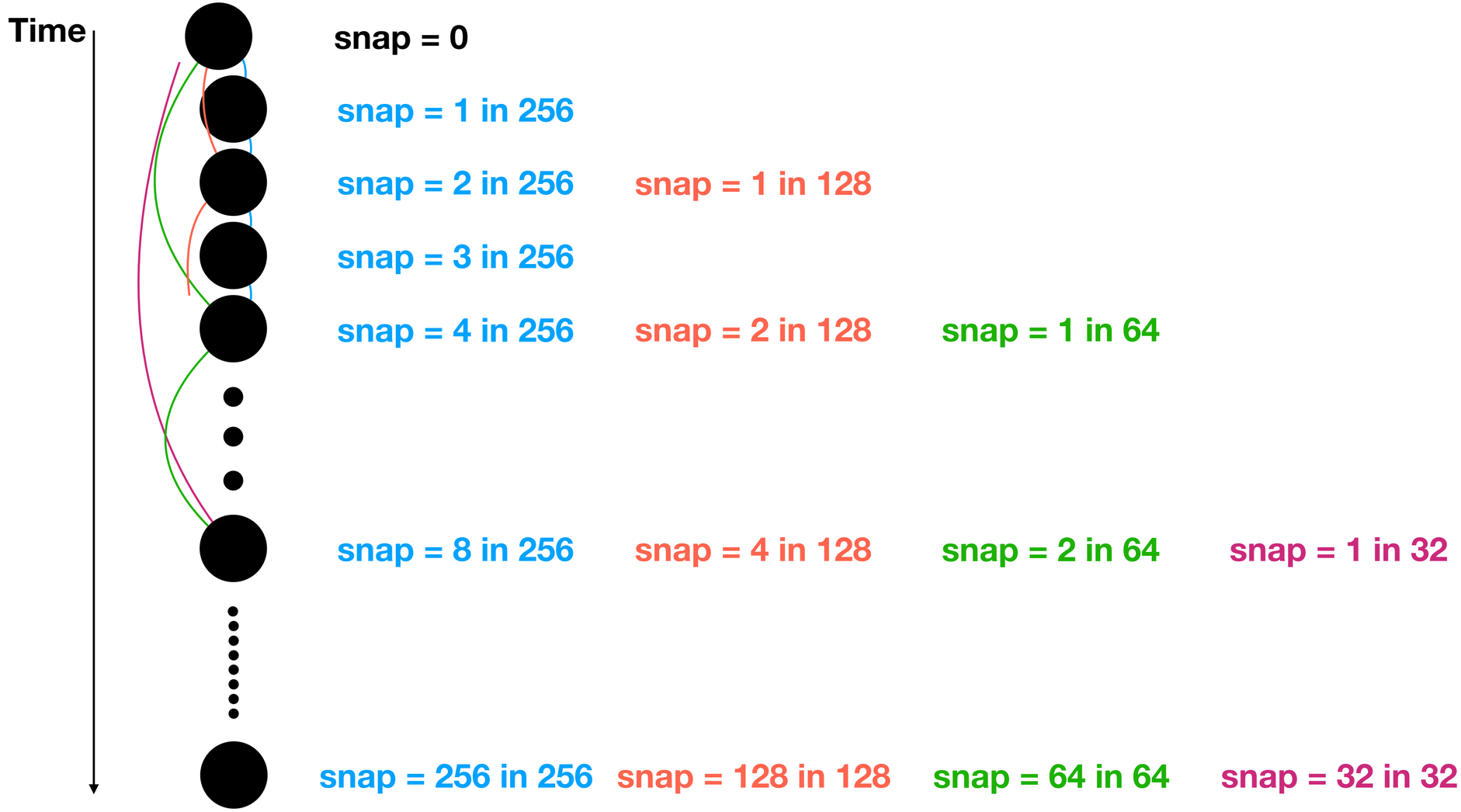
TNANKS!

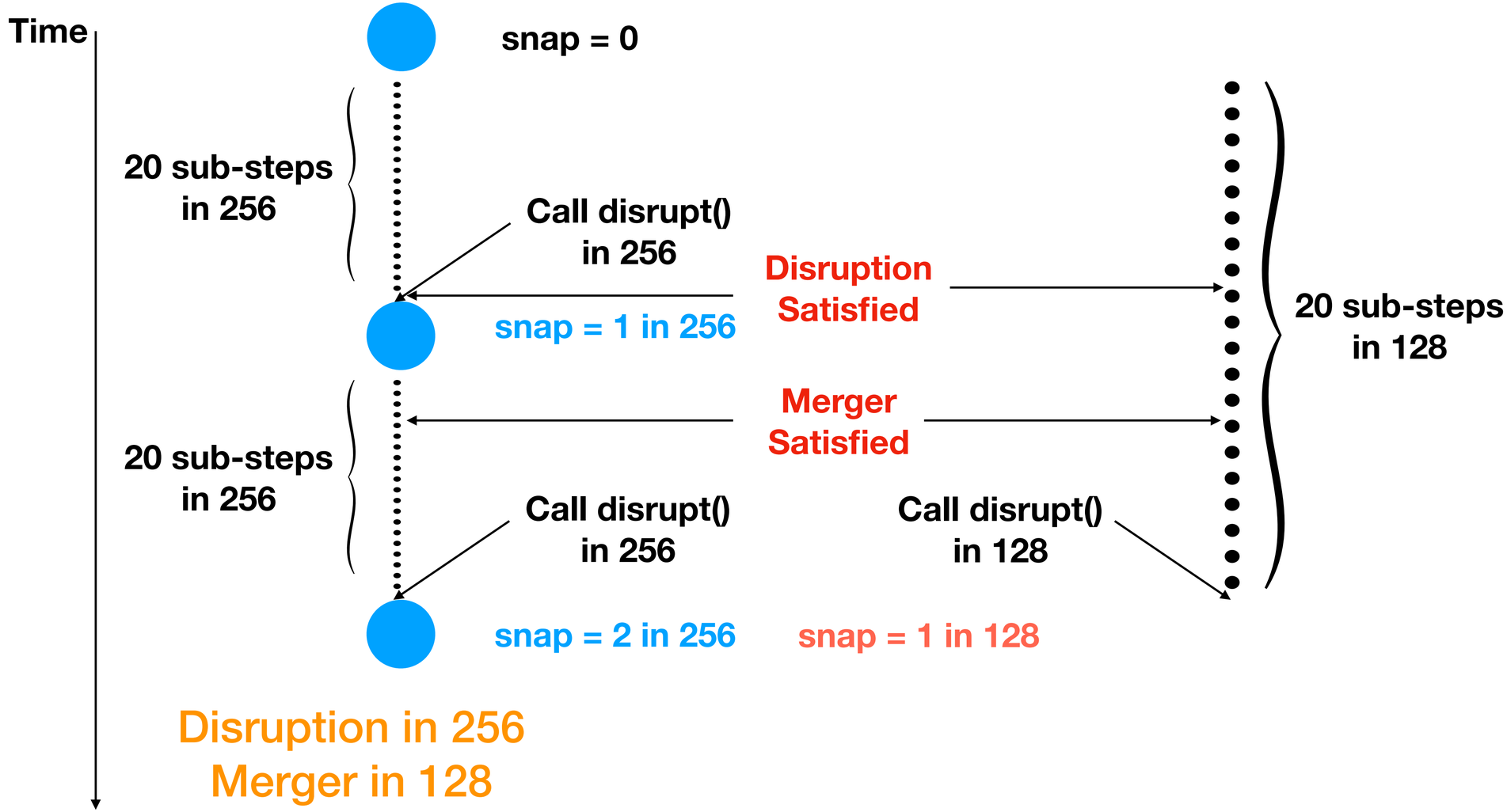
Appendix


Time
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
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_***

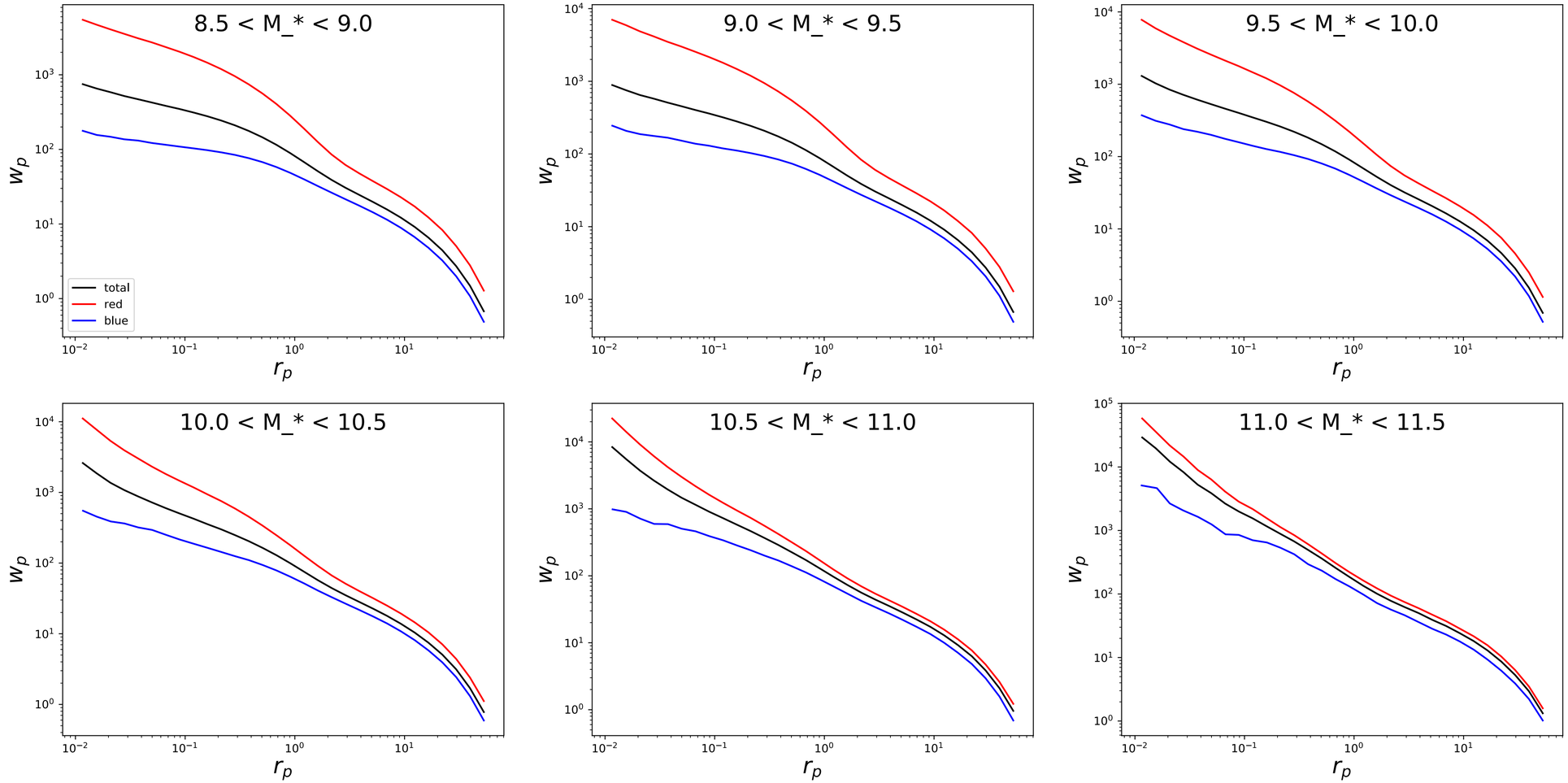
Appendix

- 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 $\rho_{sat,half}$

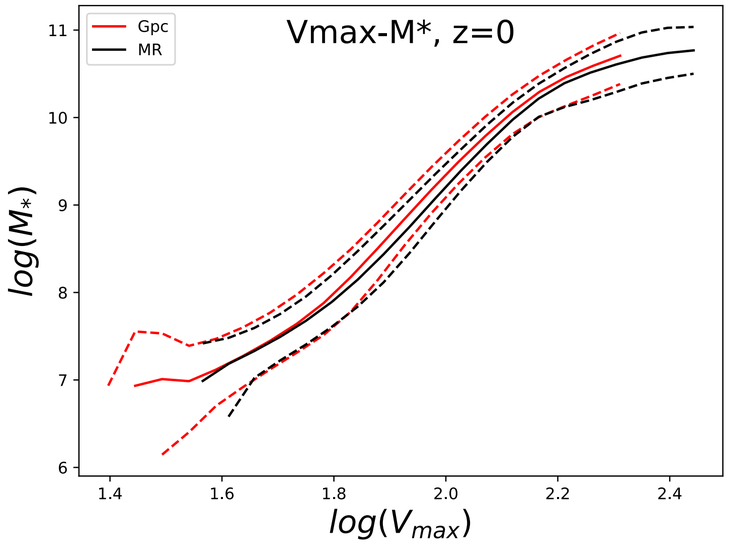
Appendix

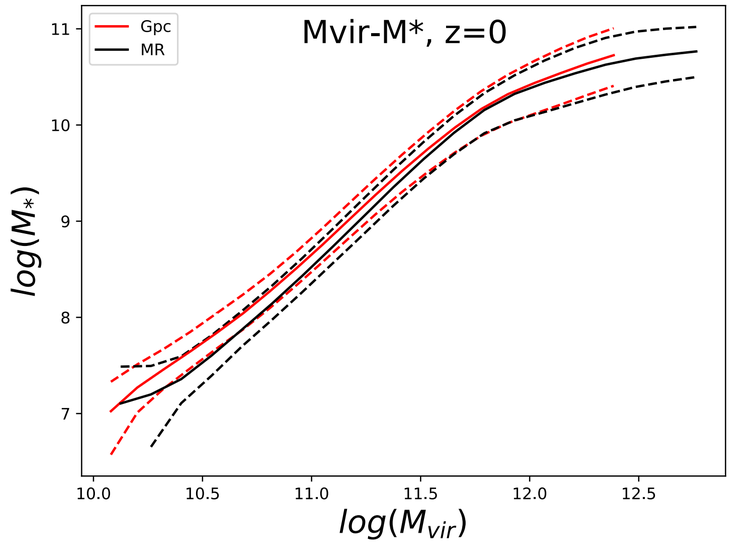
- Change disruption model
  - $R \propto \sqrt{1 - \Delta t / t_{friction}}$
  - Smaller time gap $\Rightarrow \Delta t \rightarrow t_{friction} \Rightarrow R \rightarrow 0 \Rightarrow \rho_{DM,halo} \rightarrow \infty$
  - All orphans will be disrupted!
  - A distance limit in disruption model to solve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

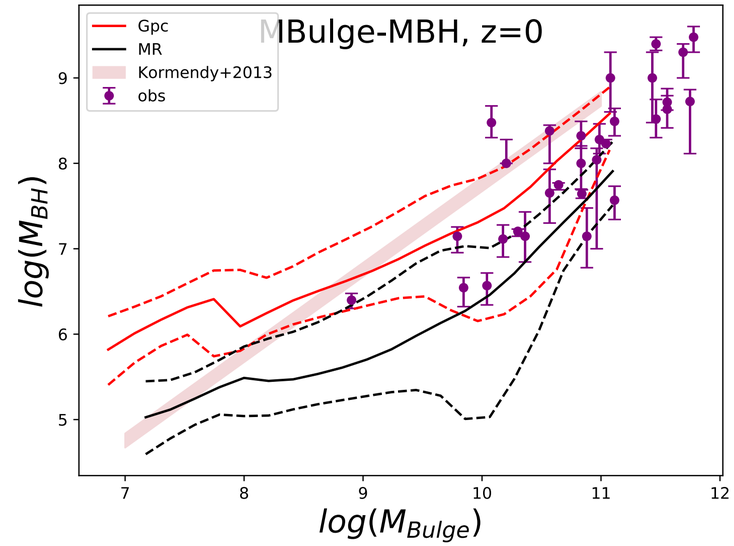
Appendix

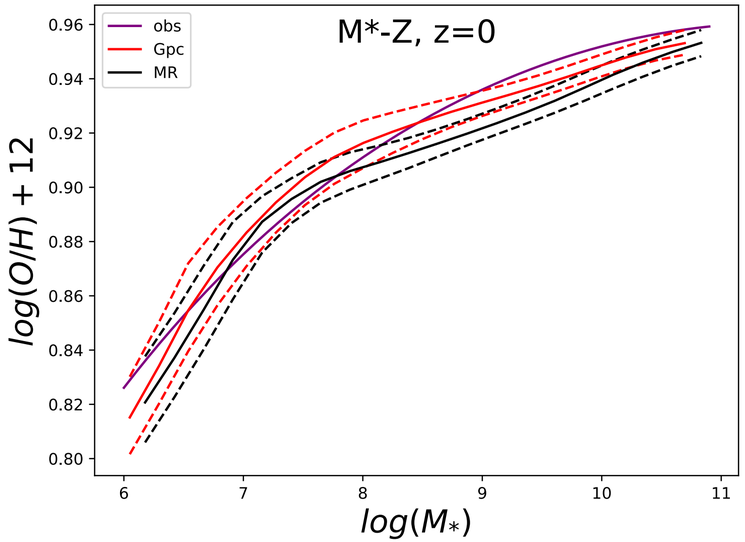

8.5 < M_* < 9.0
9.0 < M_* < 9.5
9.5 < M_* < 10.0
10.0 < M_* < 10.5
10.5 < M_* < 11.0
11.0 < M_* < 11.5
total
red
blue
w_p
r_p

Appendix

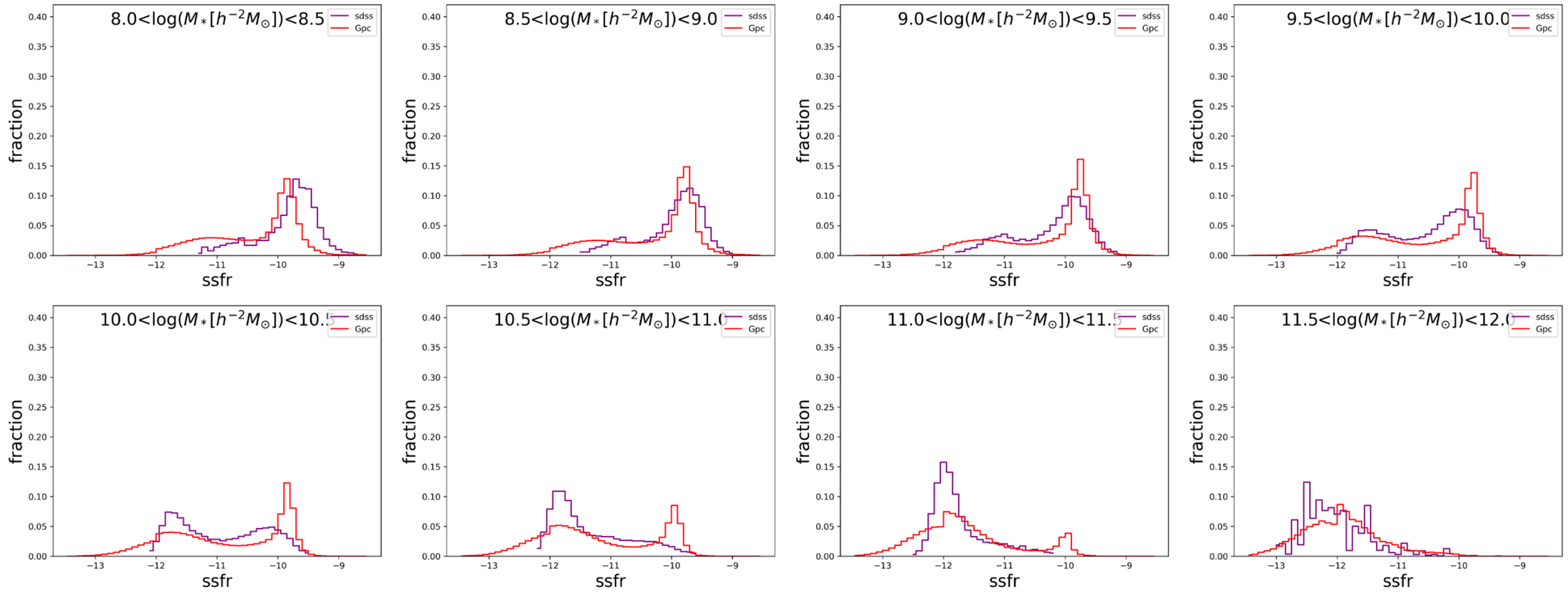

Vmax-M*, z=0
Gpc
MR
log(M*)
log(Vmax)


Mvir-M*, z=0
Gpc
MR
log(M*)
log(Mvir)


MBulge-MBH, z=0
Gpc
MR
Kormendy+2013
obs
log(MBH)
log(MBulge)


M*-Z, z=0
obs
Gpc
MR
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

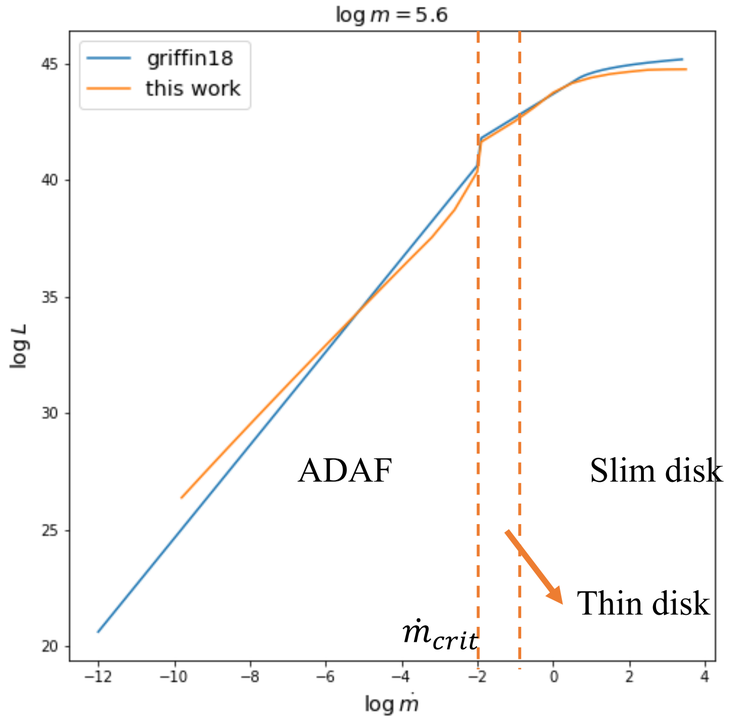
- Emission lines
  - Get U, Z_{cold}, and n_H for individual galaxies (Baugh et al. 2022)

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

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

Appendix

Accretion rate-luminosity relation

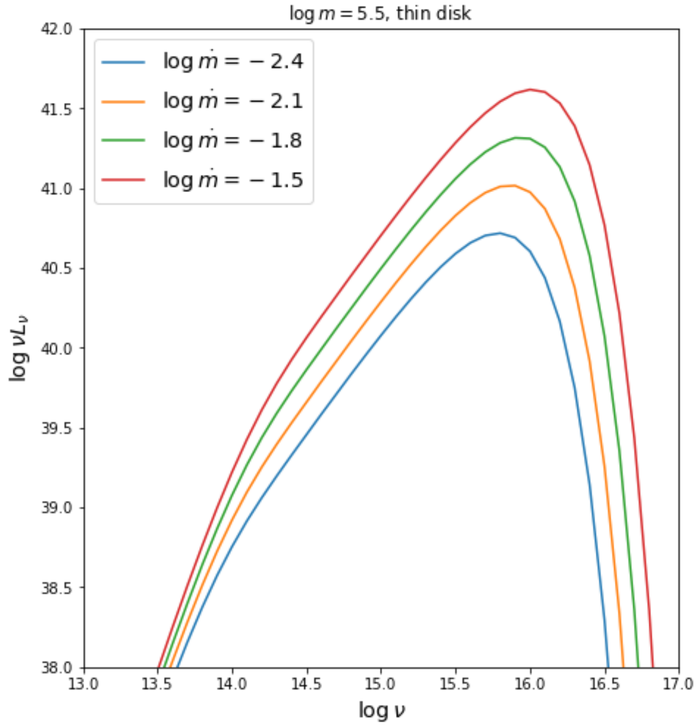


α	β	δ	s
0.3	0.95	0	0

$\dot{m}_{crit} \approx 0.183\alpha^{1.677}$ (Li&Qiao 2023)

Appendix

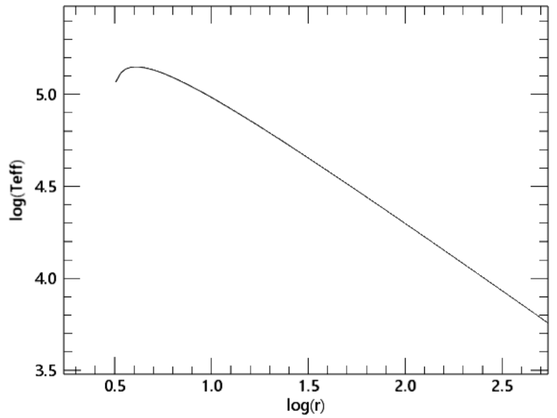
Thin disk



Energy equation: $q^{vis} = q^{rad}$

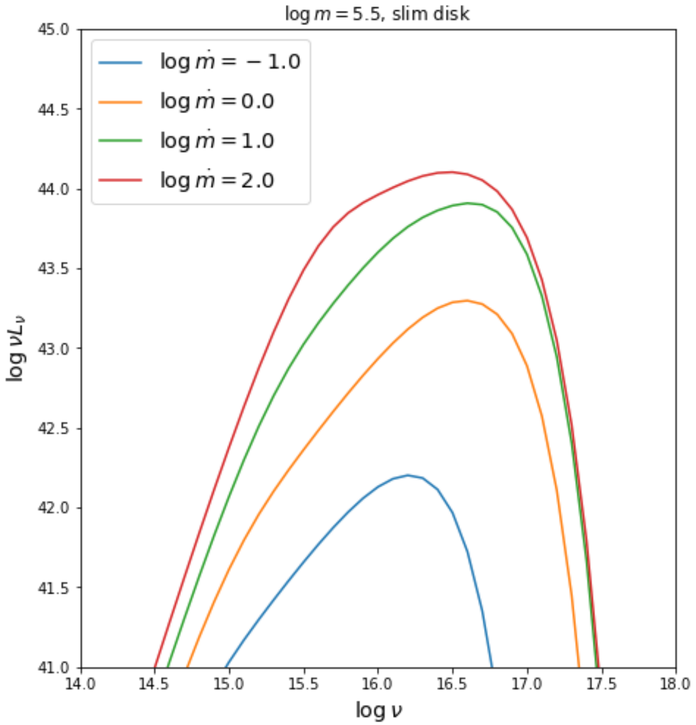
Temperature:

$$T_{eff}(R) = \left\{\frac{3GM\dot{M}}{8\pi R^3\sigma}\left[1-\left(\frac{R_*}{R}\right)^{1/2}\right]\right\}^{1/4}$$



Appendix

Slim disk



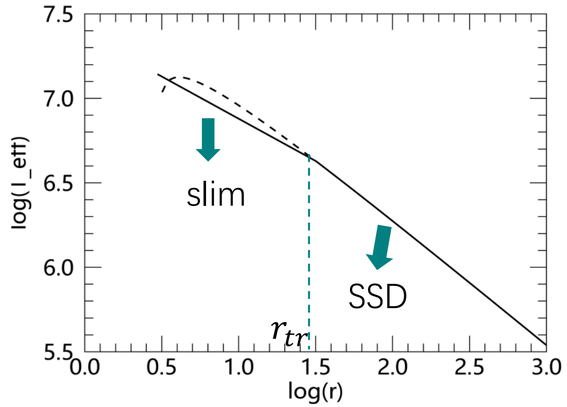
Energy equation: $q^{vis} = q^{rad} + q^{adv}$

Truncation radius:

$$R_{tr} = 51\left(\frac{\dot{m}}{10}\right) R_s \quad \text{(watarai 2006)}$$

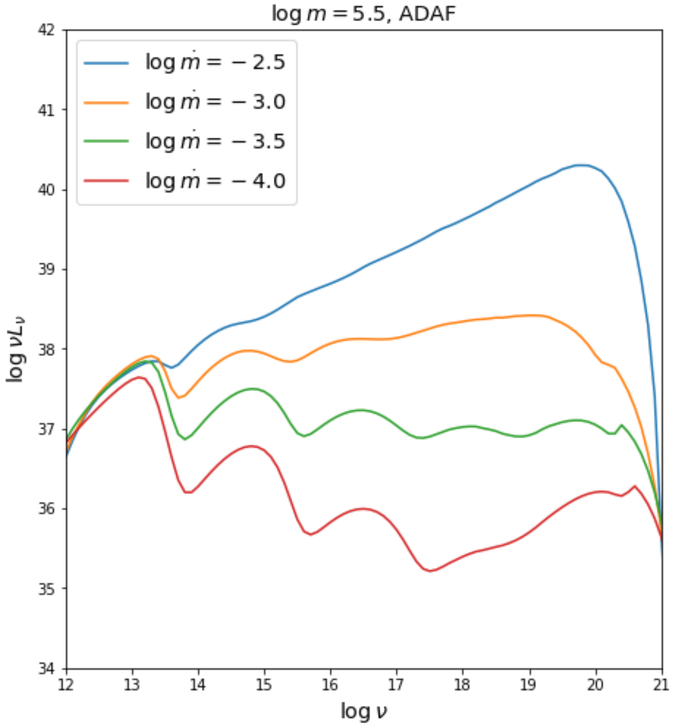
Temperature:

$$T_{eff} = 2.52 \times 10^7 f(\dot{m}, r)^{1/8} \left(\frac{m}{10}\right)^{-1/4} r^{-1/2}$$



Appendix

ADAF



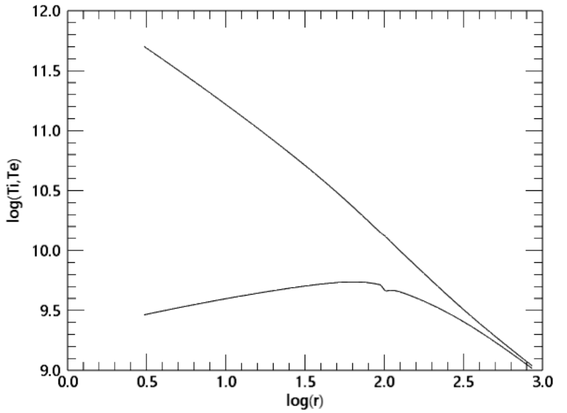
Energy equation:

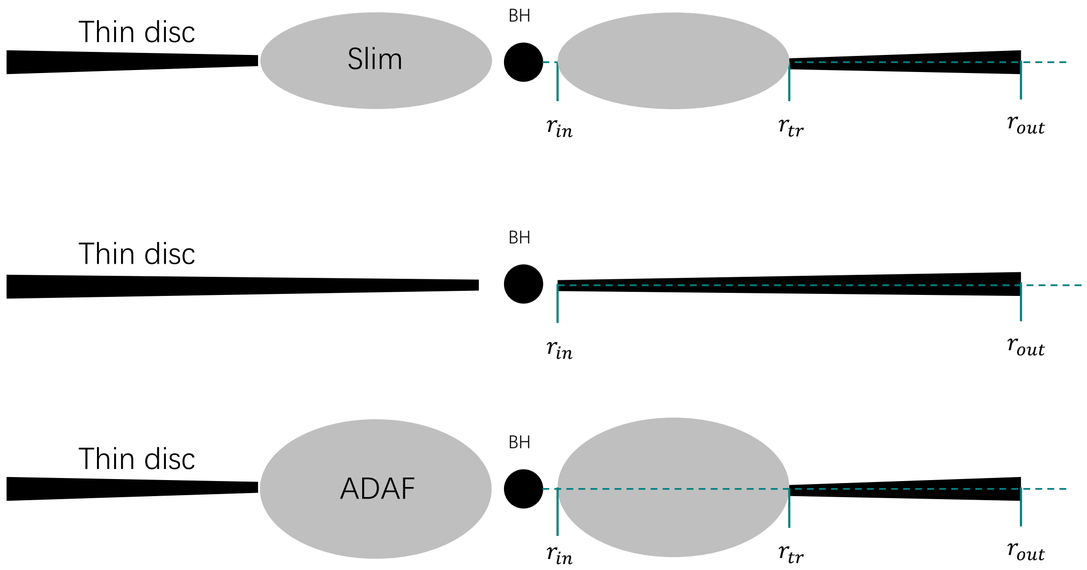
$$q^{vis} = q^{adv} + q^{ie}$$
$$q^{ie} = q^{rad}$$

Truncation radius:

$$R_{tr} = 17.3\,\dot{m}^{-0.886}\alpha^{0.07}\,\beta^{4.61}R_s$$ (Taam et al.2012)

Temperature:





	geometry	Optical depth	temperature	Radiation	luminosity	Accretion rate
Slim disk	Thick	thick	Hot	Blackbody	$\propto \ln \dot{M}$	$\dot{m} > 0.1$
Thin disk	Thin	Thick	Cool	Blackbody	$\propto \dot{M}$	$0.01 < \dot{m} \leq 0.1$
ADAF	thick	Thin	Hot, two temperature	Synchrotron, bremsstrahlung, inverse-compton	$\propto \dot{M}^2$	$\dot{m} \leq 0.01$