上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Precision studies of galaxy formation and cosmology

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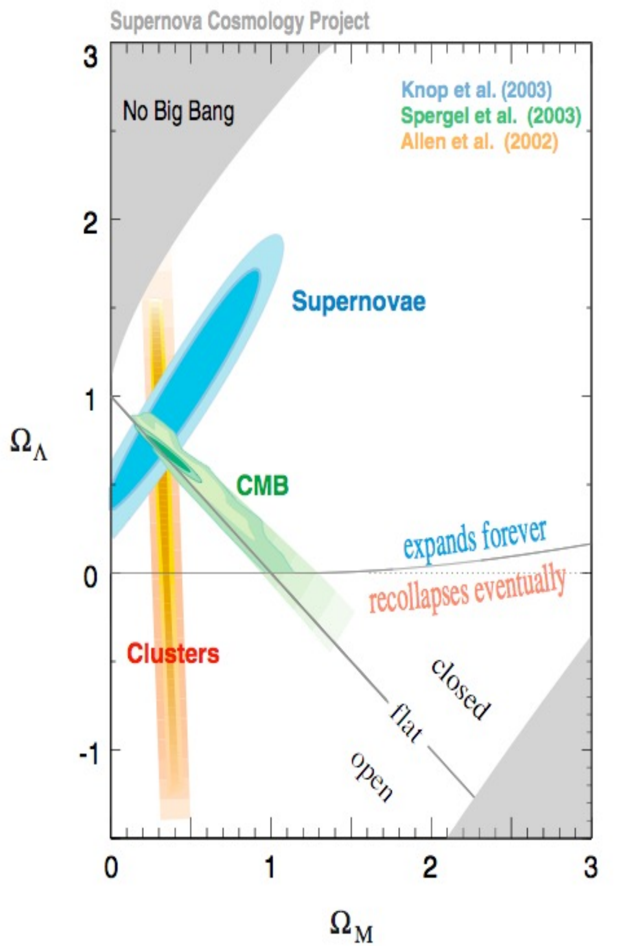
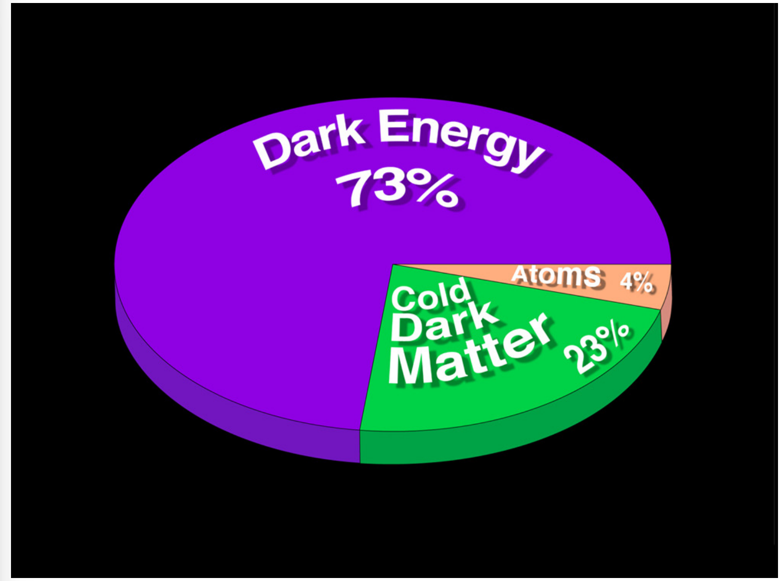
Standard Cosmological Model





Six Model Parameters only：

Ordinary Matter Density Ω_b

Cold Dark Matter Density Ω_{dm}

Dark (Vacuum) Energy Density Ω_Λ

Hubble Constant h

Primordial Fluctuation Power Spectrum（n_s， σ_8）

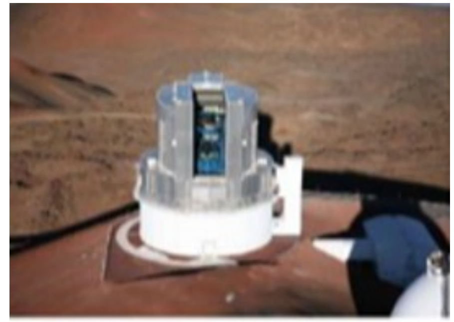
Still many key questions

- Dark Energy: cosmological constant Λ? GR not valid on cosmological scales?
- Dark Matter: what particles?
- Neutrinos: mass and sequence of the three flavors?
- S_8 Tension (i.e. Fluctuation Tension): real or not?
- Hubble Tension: real or not?

New generation of Galaxy Surveys

Ground

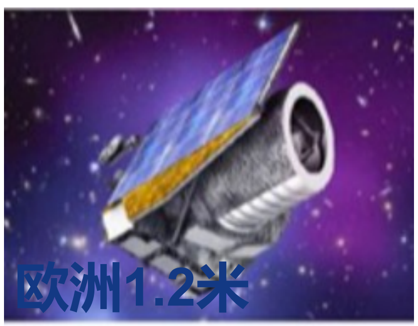
DESI
Spectroscopic
Ongoing (from 2021)



PFS
Spectroscopic
Starting from 2025

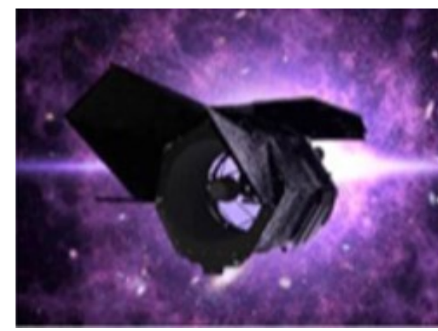
LSST
Imaging
Starting from 2024

Space



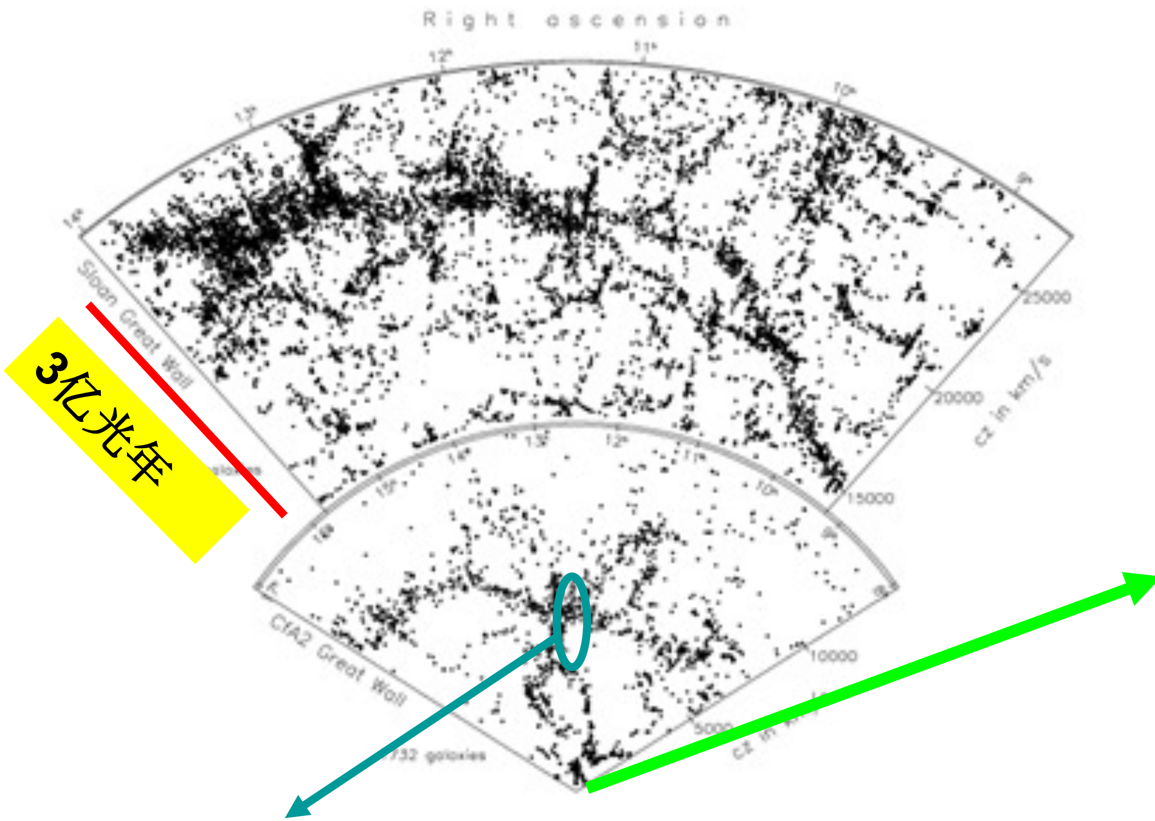
Euclid
Imaging & spectroscopic
Ongoing (from 2023)

CSST
Imaging & spectroscopic
Starting from 2026

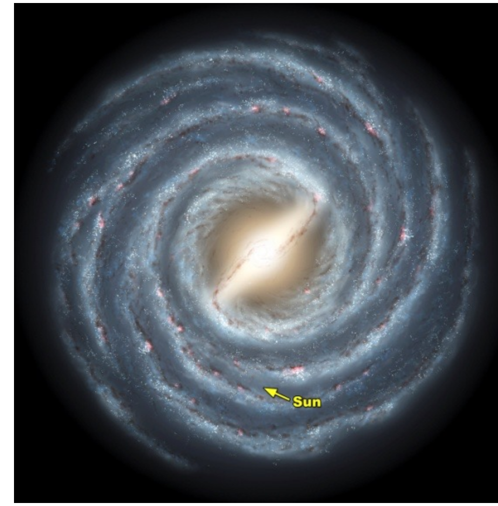


Roman
Imaging & spectroscopic
Starting from 2027

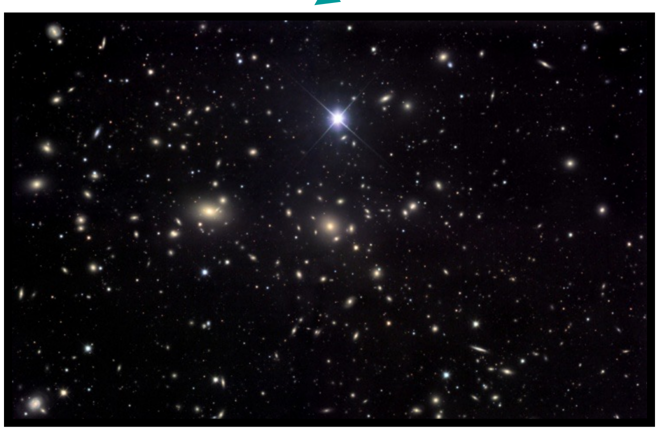
Sloan Digital Sky Survey



Milky Way



银河系：
10**12 太阳质量
（一万亿太阳质量）
太小：10 万光年



Coma Cluster：

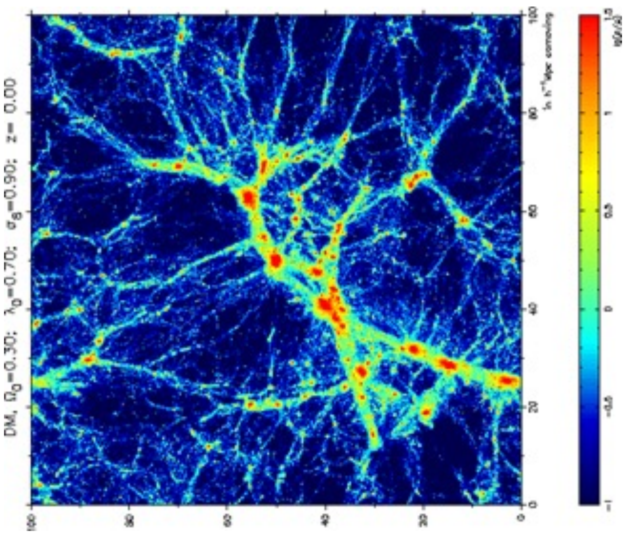
10**（14---15）太阳质量（一百万亿至一千万亿太阳质量）

1千万光年（直径）

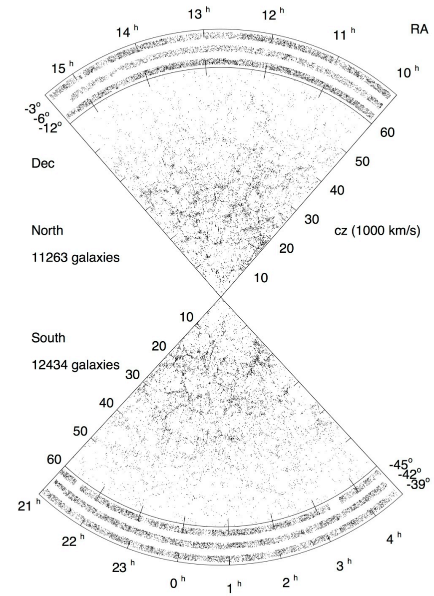
Still many key questions

- Dark Energy: cosmological constant Λ? GR not valid on cosmological scales?
- Dark Matter: what particles?
- Neutrinos: mass and sequence of the three flavors?
- S_8 Tension (i.e. Fluctuation Tension): real or not?
- Hubble Tension (i.e. H_0 tension): real or not?
- How galaxies are formed in the cosmic webs?

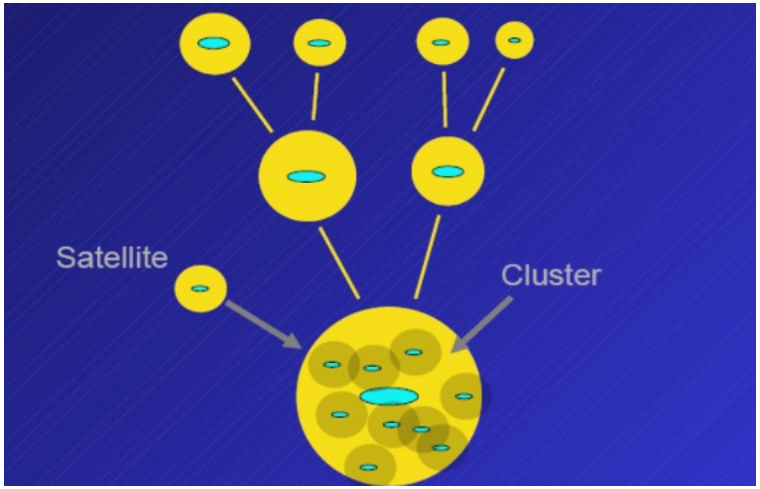
Large Scale Structures in the Universe



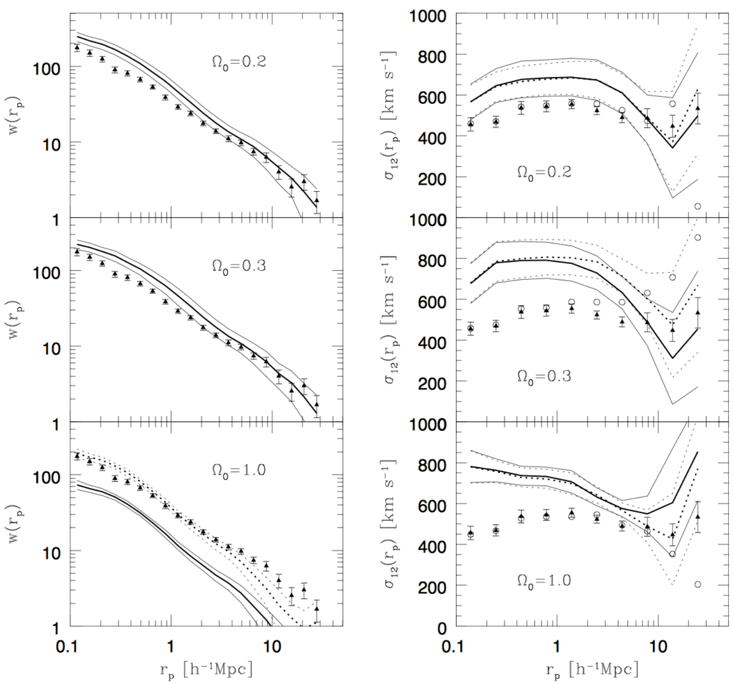
Simulation



Las Campanas Redshift Survey



The First HOD study using Las Campanas RS



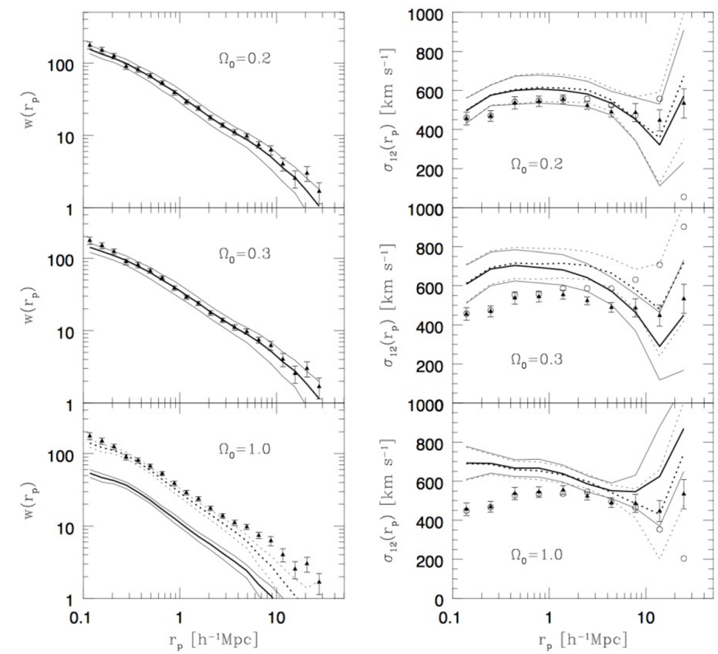


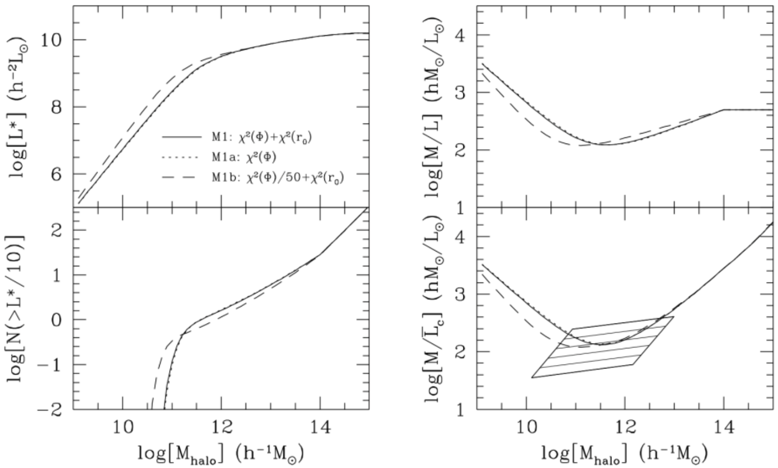
FIG. 4.—The predictions of the three CDM models incorporating a simple bias model (see text). The lines and symbols have the same meaning as in Fig. 3. The dashed lines in the lower left-hand panel are obtained by shifting the solid lines upward by an amount of $1/\sigma_8^2$.

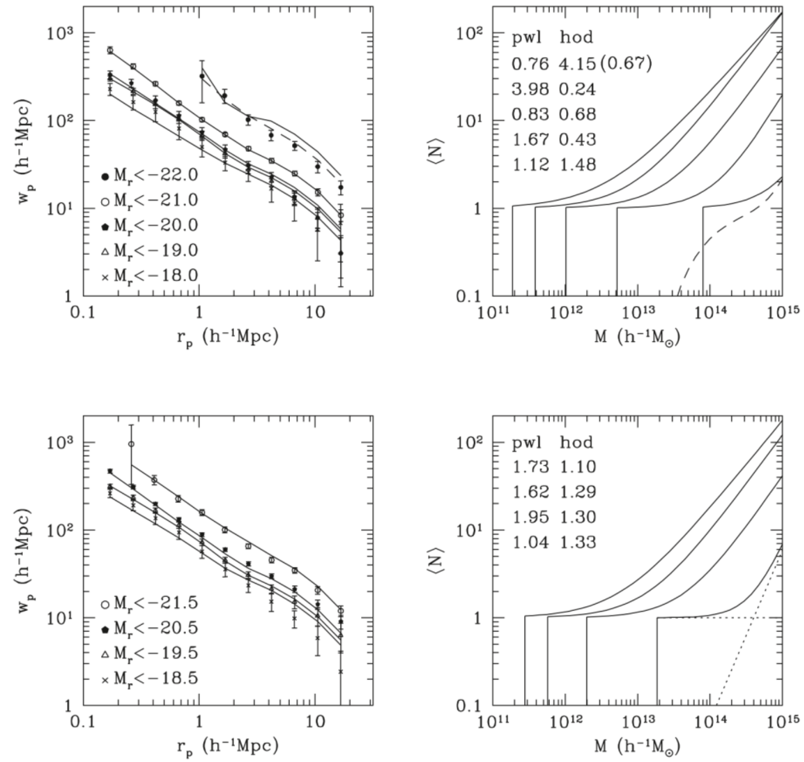
Obs vs DM **Obs vs HOD**

1. The first 2-pcf and PVD measurement for fiber redshift surveys, correcting for the fiber collisions
2. The first HOD modeling for observations, good agreement
3. PVD requires $S_8 = \sigma_8 \left(\frac{\Omega_m}{0.3}\right)^{0.5}$ ~ 0.8 with 10% error

Jing,Mo,Boerner 1998 ApJ

Galaxies in Halos (HOD)



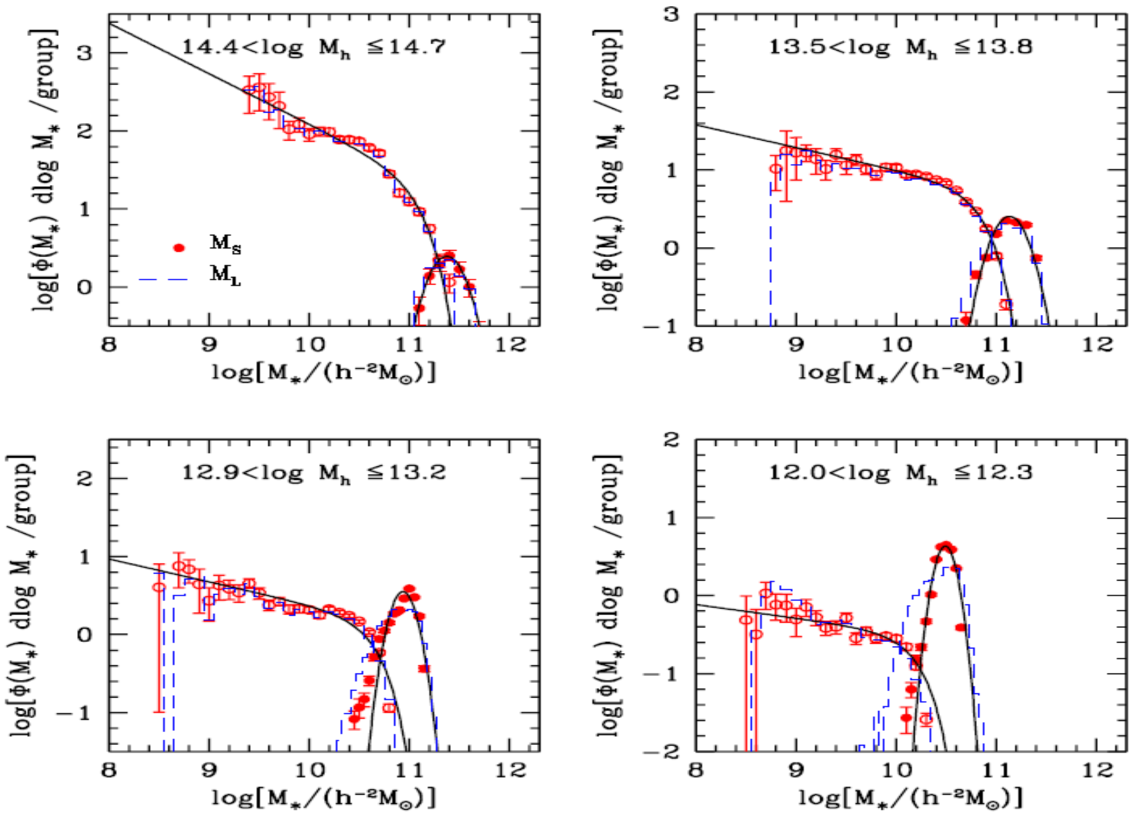


CLF HOD
Star formation most efficient in halos at the MW halo mass

Yang,X.H. （杨小虎） et al. 2003; with 2dF

Zehavi et al. 2005; HOD with SDSS

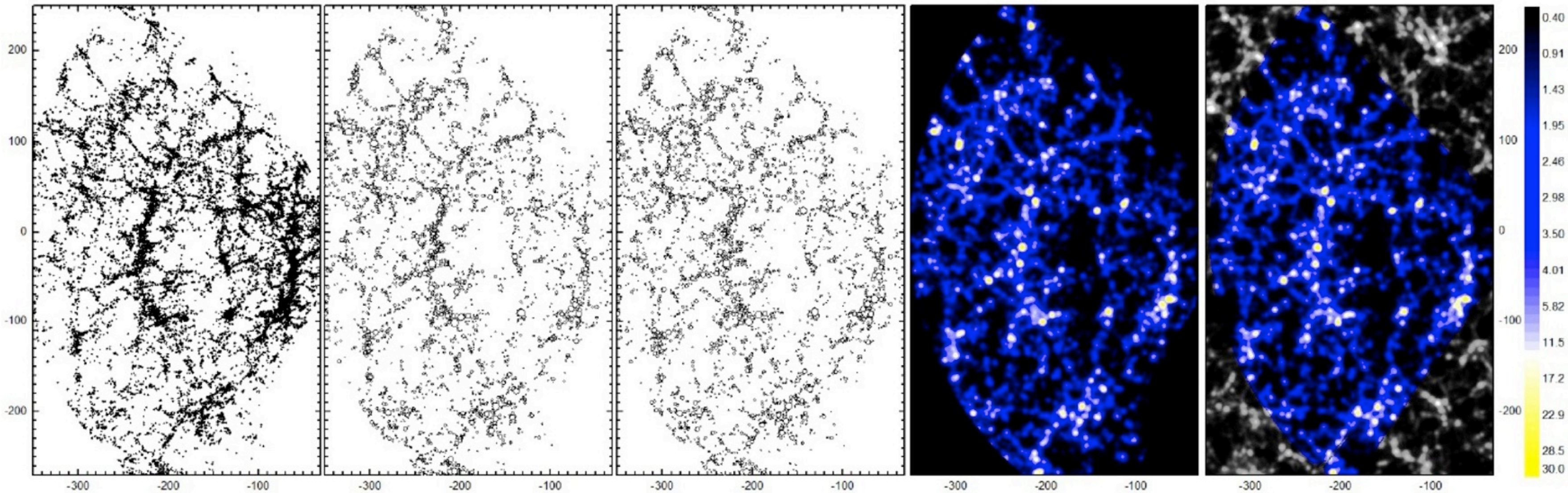
Direct HOD measurement from halo based groups



Yang,X.H. et al. 2008-2009 (HODs by mass or luminosity)

Yang,X.H. et al. 2004 (the halo based group finder)

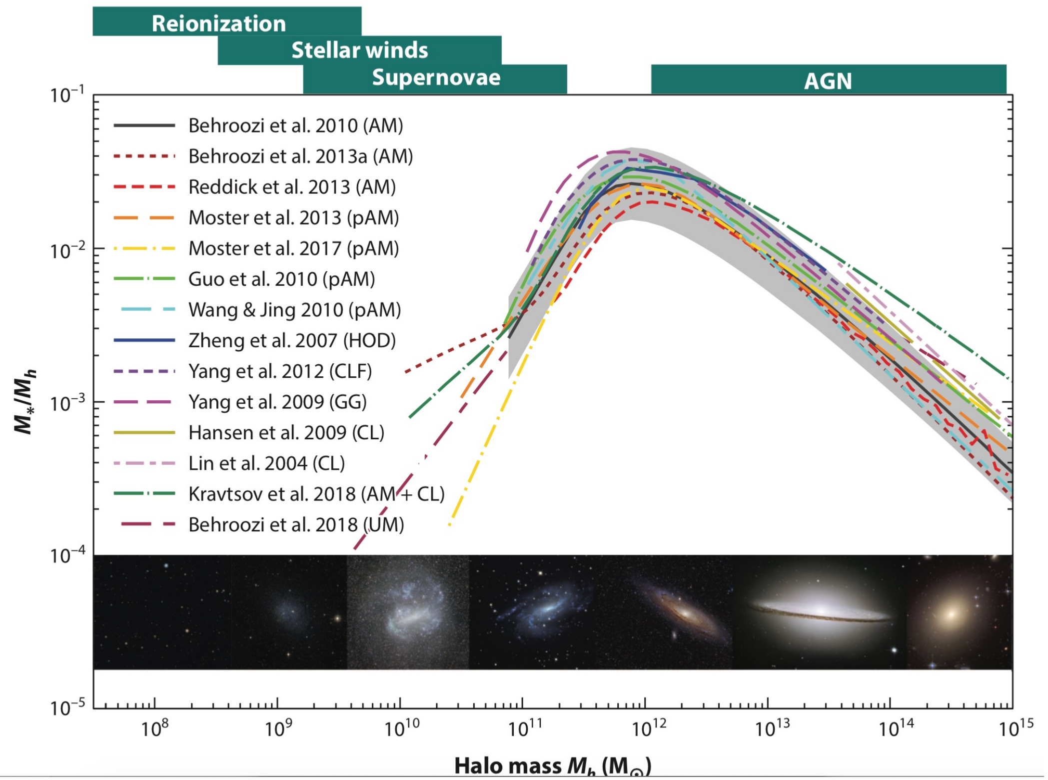
Reconstructing the evolution history of halos around galaxies in real Universe

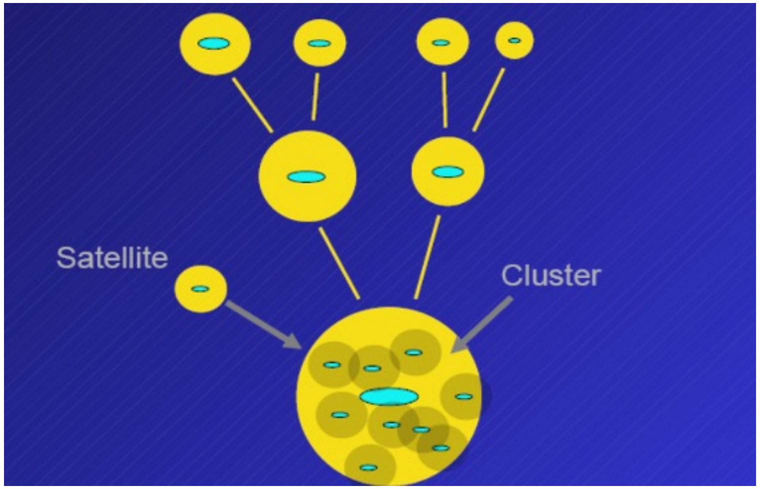


WANG, Huiyuan （王慧元） et al 2016; Elucid Project

Galaxy-Halo Connection

- Both for Galaxy formation and Cosmology
- Measure it from galaxy surveys



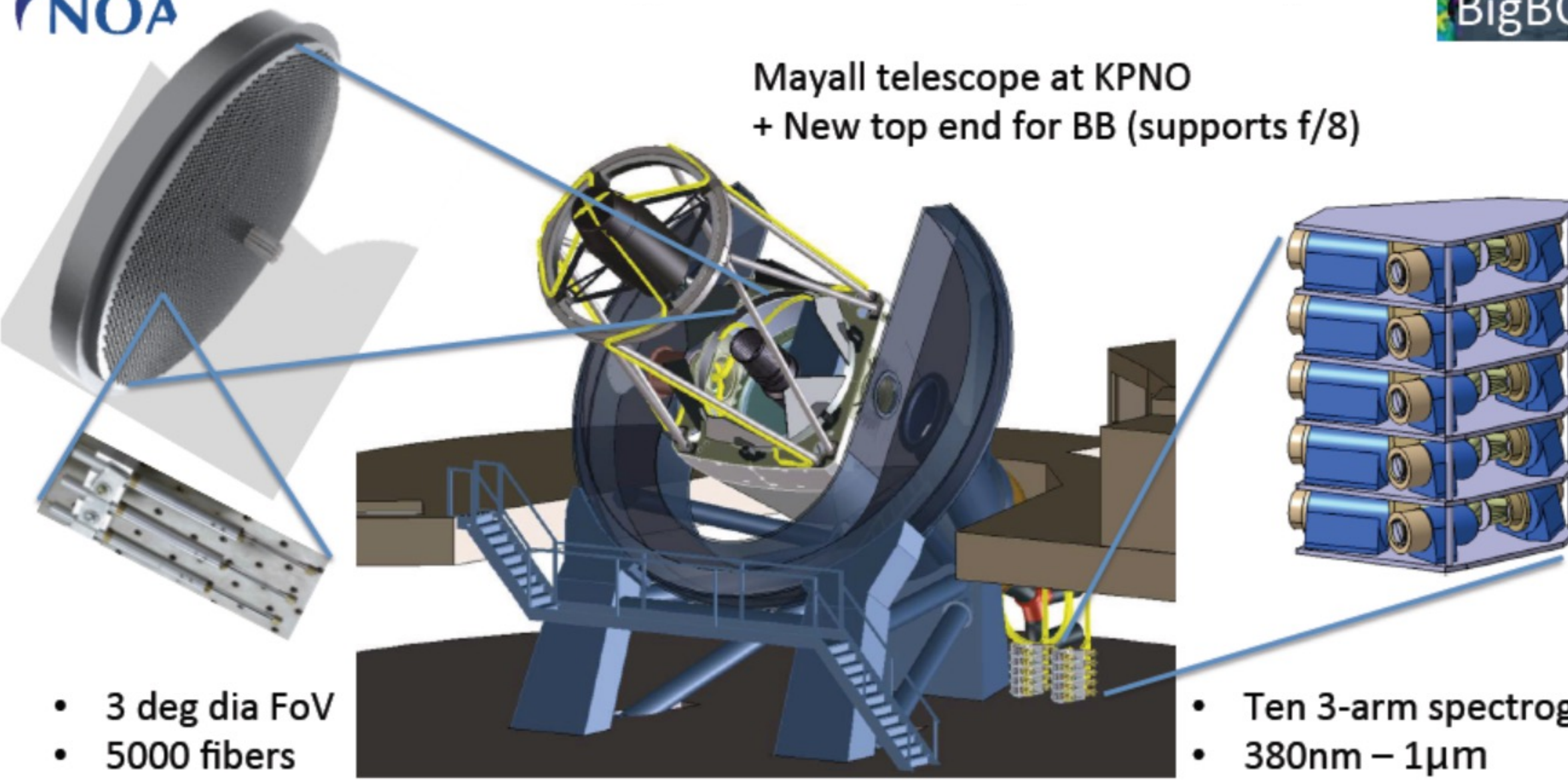


Current Status

- Quite well established for the local Universe ($z = 0.1$)
- But still much unexplored for faint galaxies (even at $z = 0$) or for higher redshift
- There is no faint enough wide-sky redshift survey that samples galaxies in a wide spectrum of stellar mass or luminosity

DESI--Dark Energy Spectroscopic Instrument

DESI Capability



- 3 deg dia FoV
- 5000 fibers

- Ten 3-arm spectrographs
- 380nm – 1μm

Nearly 40,000 spectra per night!!

See Natalie Roe's talk!

DESI spectroscopic samples

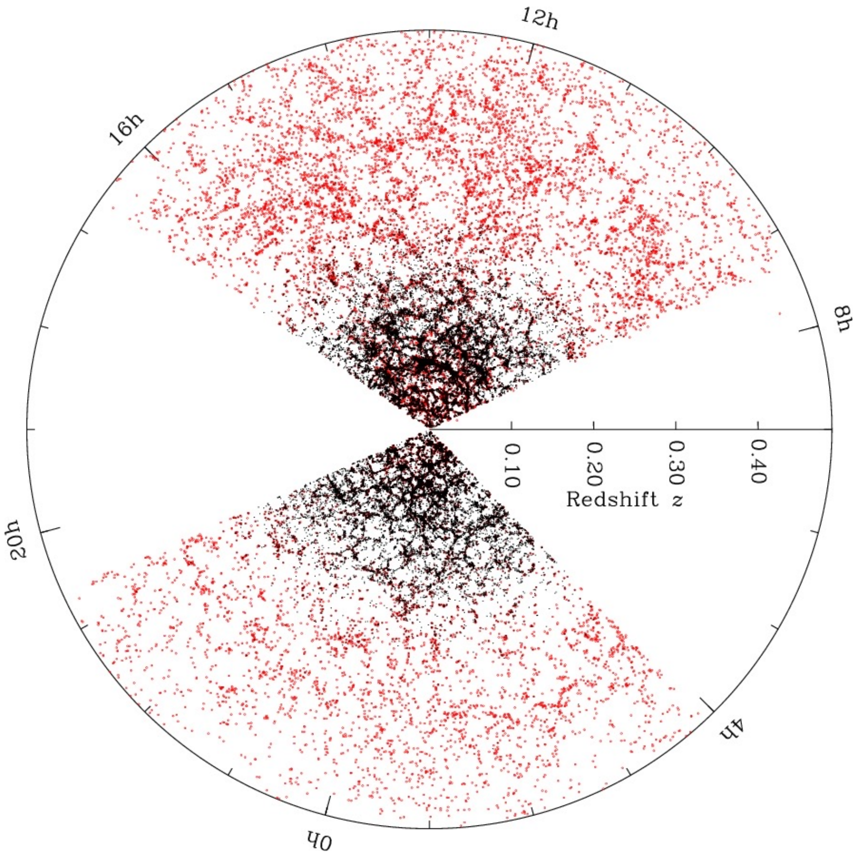
Summary: A new baseline

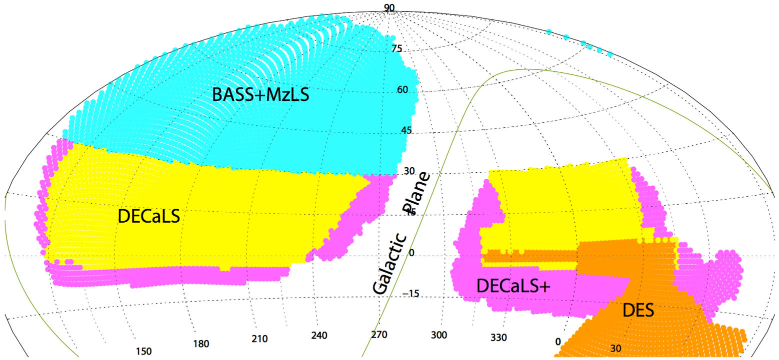
SV3 LRG	0.3–1.0	g,r,z,$W1$	600	565	500	7.0 M
SV3 ELG	0.6–1.6	g,r,z	1950	1420	910	12.7 M
SV3 QSO (tracers)	< 2.1	g,r,z,$W1$,$W2$	210	210	140	1.96 M
SV3 QSO (Ly-α)	> 2.1	g,r,z,$W1$,$W2$	100	295	60	0.84 M
Total in dark time			**2860**	**2490**	**1619**	**22.5 M**
SV3 BGS	0.05–0.4	r (Gaia G)	860	688	678	9.5 M
SV3 BGS–Faint	0.05–0.4	r (Gaia G)	540	324	317	4.4 M
SV3 MWS	0.0	g,r (Gaia μ)	800+	720	720	10.1 M
Total in bright time			**2200+**	**1732**	**1715**	**24.0 M**

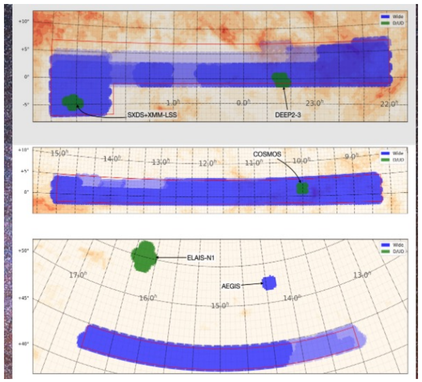
Huge redshift samples： 20M+ LRGs, ELGs, QSOs
But they are highly selective, and biased

How they are related to underlying Dark Matter Halos?

Galaxy surveys



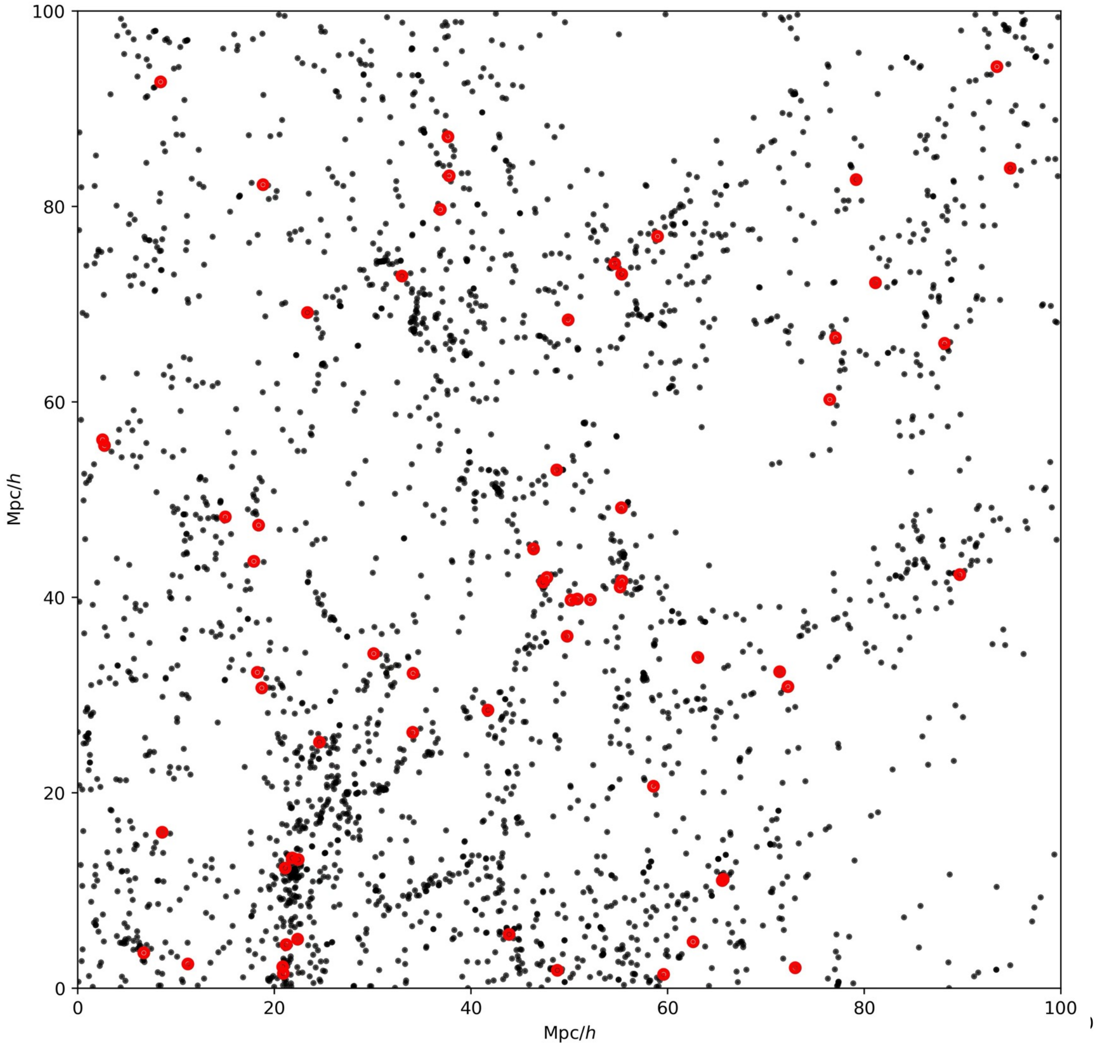




Redshift surveys: 3d but brighter, biased

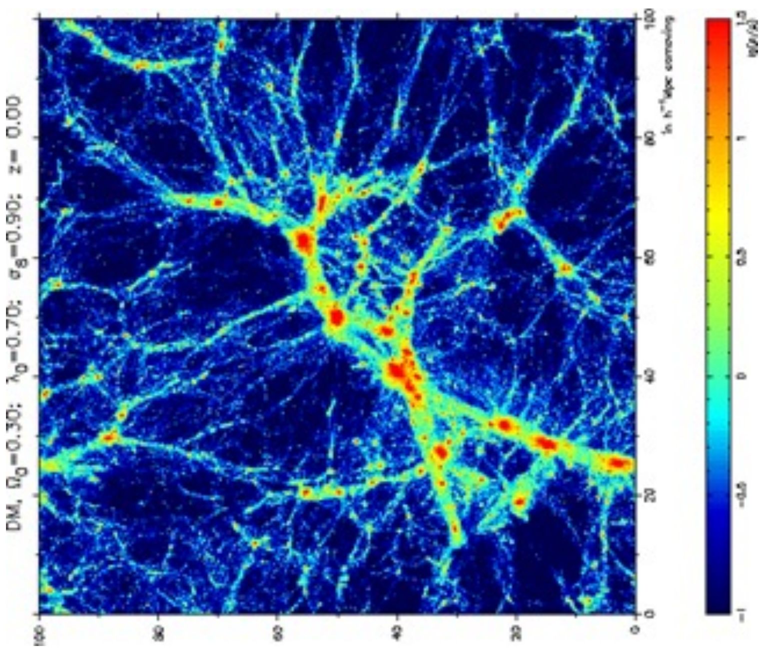
Photometric surveys: 2d but much fainter, complete

Spectroscopic (red) vs Photometric (black) objects



Why helpful

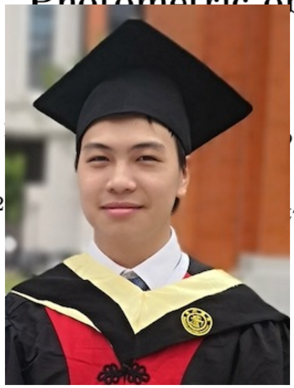
- Redshift Surveys delineate or represent cosmic webs
- With deep photometric sample, find how the photo galaxies (down to the faint limit) are distributed in the cosmic webs
- In turn, know better how sparse redshift tracers are related to DM halos



Both are important for galaxy formation and cosmology

No photo-z is used

Photometric objects Around Cosmic webs (PAC) delineated in a spectroscopic survey. I. Methods



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Submitted to ApJ

ABSTRACT

We provide a method for estimating the projected density distribution $\bar{n}_2 w_p(r_p)$ of photometric objects around spectroscopic objects in a spectroscopic survey. This quantity describes the distribution of Photometric sources with certain physical properties (e.g., luminosity, mass, color etc). Around

central galaxies of different mass. The PAC method has many potential applications for studying the

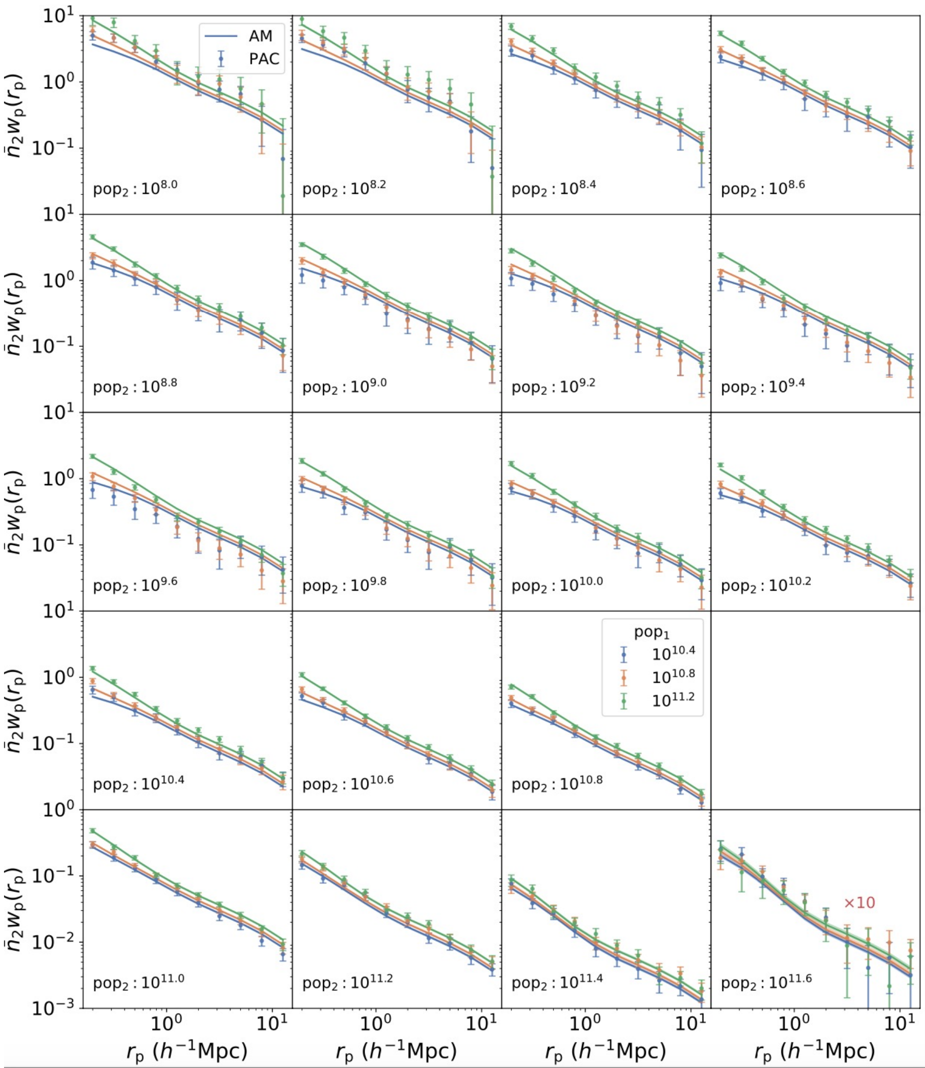
$\bar{n}_2 w_p(r_p)$ is the excess of neighbors of certain properties in photometric catalog around a spectroscopic object, where $\bar{n}_2$ is the mean number density of the photo galaxies specified, $w_p(r_p)$ is the cross correlation function between the photo and spectroscopic objects

2021arXiv210911738 ApJ 2022(Paper I)

Why is $n_2\omega_{12}(r_p)$ so useful?

- It measures the number excess of neighbors with certain properties, i.e. Environments of z-objects
- It provides information n_2 and $\omega_{12}(r_p)$, i.e. one-point function (LF, SMF, etc) and two-point functions (density profiles of clusters, clustering)
- One can go much deeper with photometric catalog, without using photometric redshift
- The method does not suffer from target selection, fiber collisions or stellar contamination, complementary to studies based on spectroscopic samples

Examples of $n_2 w_{12}(r_p)$ measurement

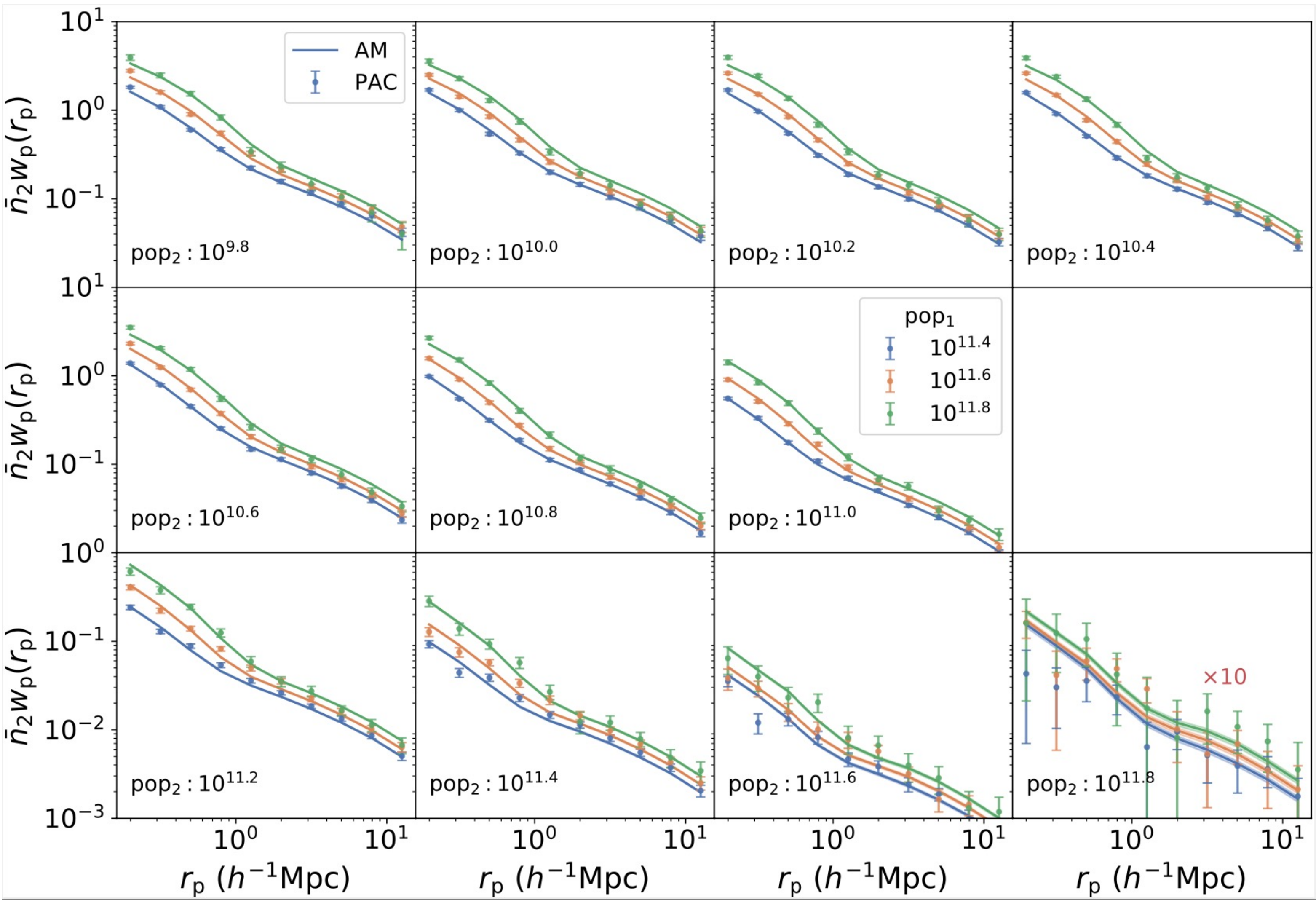


SDSS Main + DESI image

1. $z_s < 0.2$ spectroscopic objs of $M_* = 10^{10.4}$ *(blue)*, $10^{10.8}$ *(red)*, $10^{11.2}$ *(green)* $M_\odot$;
Photo objs with mass $\{10^8, 10^{11.6}\}$ $M_\odot$, *i.e. whole mass spectrum*
2. *data (dots) vs BP13 fitting (lines)*
3. *Behroozi et al. (2013) form* ***fits very well***

Xu,YPJ et al. 2023 ApJ (Paper IV)

At $z_s = 0.6$, both BP13 and DP work well

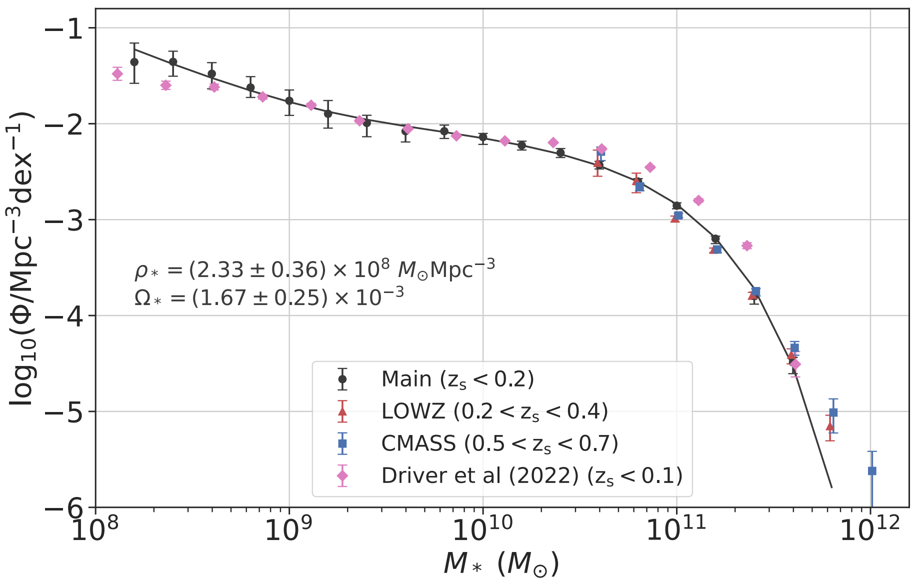


BOSS CMASS +DESI image

1. Accurate measurement of the galaxy stellar mass function to $z_s = 0.6$

- *Use SDSS Main, LOWZ, CMASS redshift samples + DESI photometric catalog (DR9)*
- *Use SED fitting to get stellar mass for galaxies in both type of catalogs (photo-z not used)*
- *Use PAC, calculate $n_2 w_{12}(r_p)$ for spectroscopic sample (massive galaxies) and photometric sample (all galaxies down to very small ones)*
- *Calculate $w_{12}(r_p)$ from the spectro sample*
- *Dividing the two quantities to get n_2 in a stellar mass bin, i.e. the galaxy stellar mass function*

Galaxy Stellar Mass Functions (GSMFs $z_s < 0.6$)



- ***GSMF measured very accurately down to $M_* = 10^{8.2} M_\odot$ for $z_s < 0.2$ and down to $M_* = 10^{10.6} M_\odot$ for $0.2 < z_s < 0.6$***
- ***No evolution for $M_* > 10^{10.6} M_\odot$***
- ***Clear up-turn at $M_* \approx 10^{9.5} M_\odot$ at $z_s < 0.2$, and the double Schechter function fits well***

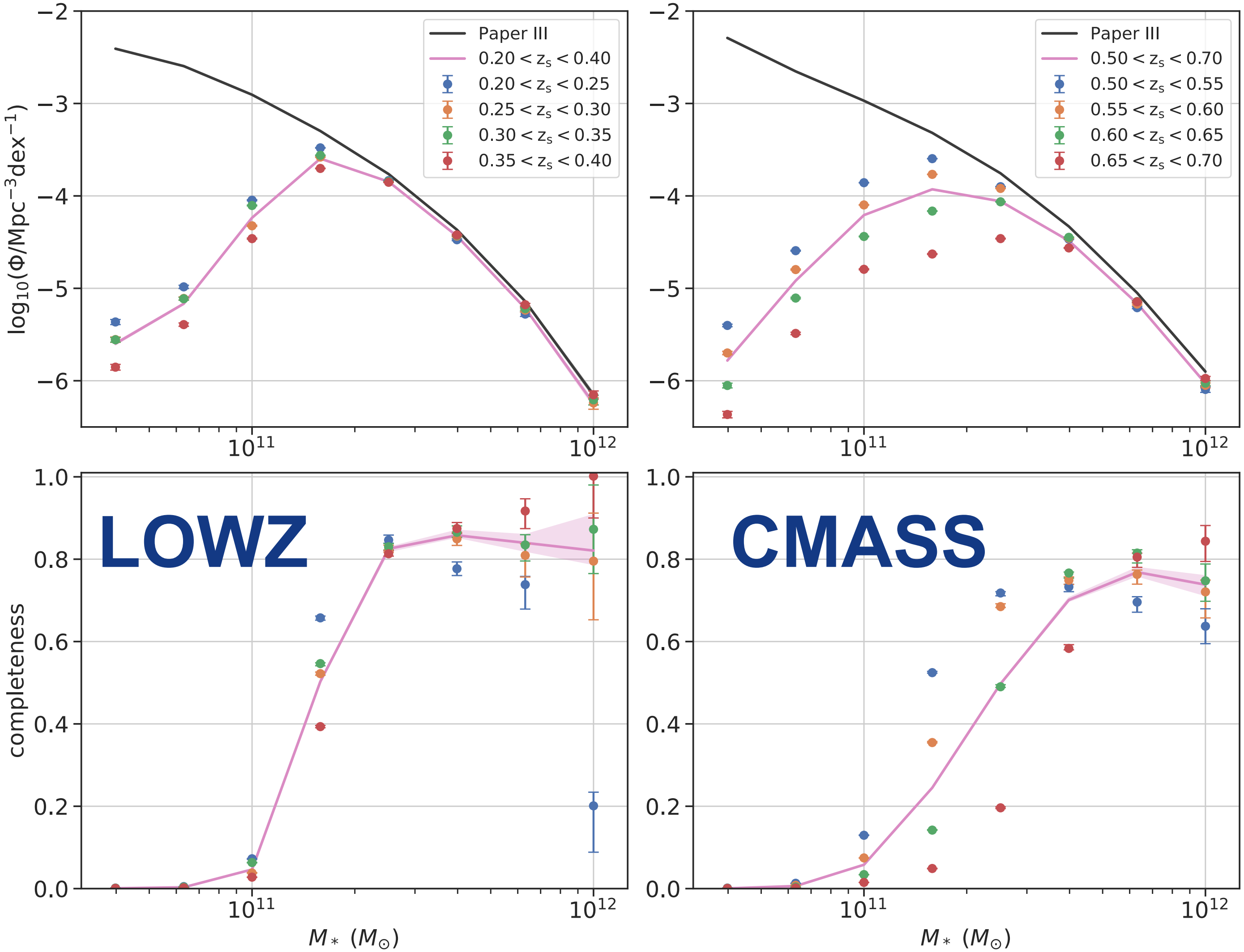
Table 2. Parameters of the double Schechter function for the GSMF from the Main sample ($z_s < 0.2$).

$\log_{10}\phi_0$ (Mpc^{-3})	$\log_{10} M_1$ ($M_\odot$)	$\log_{10} M_2$ ($M_\odot$)	α_1	α_2
$-13.58^{+0.24}_{-0.31}$	$10.92^{+0.11}_{-0.09}$	$9.18^{+0.57}_{-0.57}$	$-1.22^{+0.15}_{-0.15}$	$-1.97^{+0.90}_{-0.87}$

$$\phi(M_*)dM_* = \phi_0 \left[\left(\frac{M_*}{M_1}\right)^{\alpha_1} \exp\left(-\frac{M_*}{M_1}\right) + \left(\frac{M_1}{M_2}\right) \left(\frac{M_*}{M_2}\right)^{\alpha_2} \exp\left(-\frac{M_*}{M_2}\right) \right] dM_* \, ,$$

Xu, YPJ et al. 2022, ApJ 939,104; arXiv:2207.12423 (Paper III)

Incompleteness of LOWZ and CMASS



2. Accurate Stellar Halo Mass Relation (SHMR) to $z_s = 0.6$

- *Use high resolution simulation CosmicGrowth (Jing 2019) to model the observed $n_2 w_{12}(r_p)$*
- *Halos and subhalos identified with HBT(Han et al 2012)*
- *Assuming a lognormal distribution for M_* of scatter σ, use Abundance Matching (AM) method with two forms,*
  - *Double Power law (DP):*
    - *five parameters*

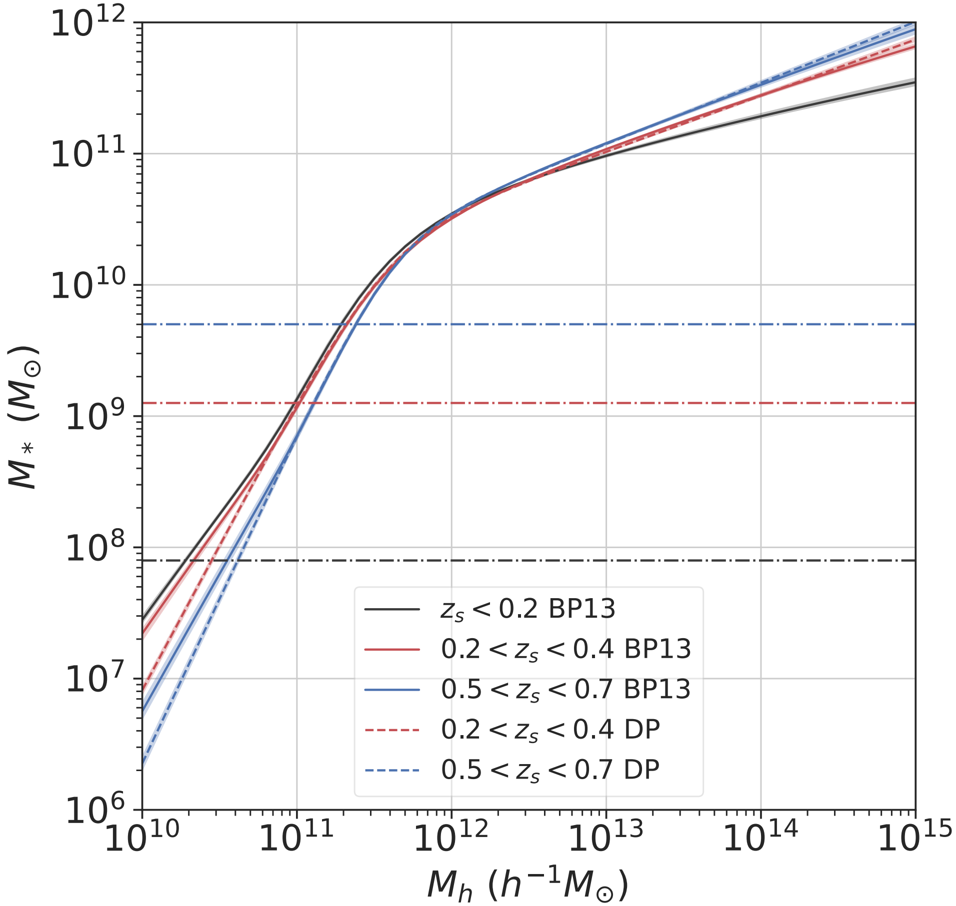
$$M_* = \left[\frac{2k}{(M_{acc}/M_0)^{-\alpha} + (M_{acc}/M_0)^{-\beta}}\right]$$

  - *Behroozi et al. (2013) (BP13):*
    - *Six parameters*

$$\log_{10}(M_*) = \log_{10}(\epsilon M_0) + f\left(\log_{10}\left(\frac{M_{acc}}{M_0}\right)\right) - f(0) \qquad (9)$$

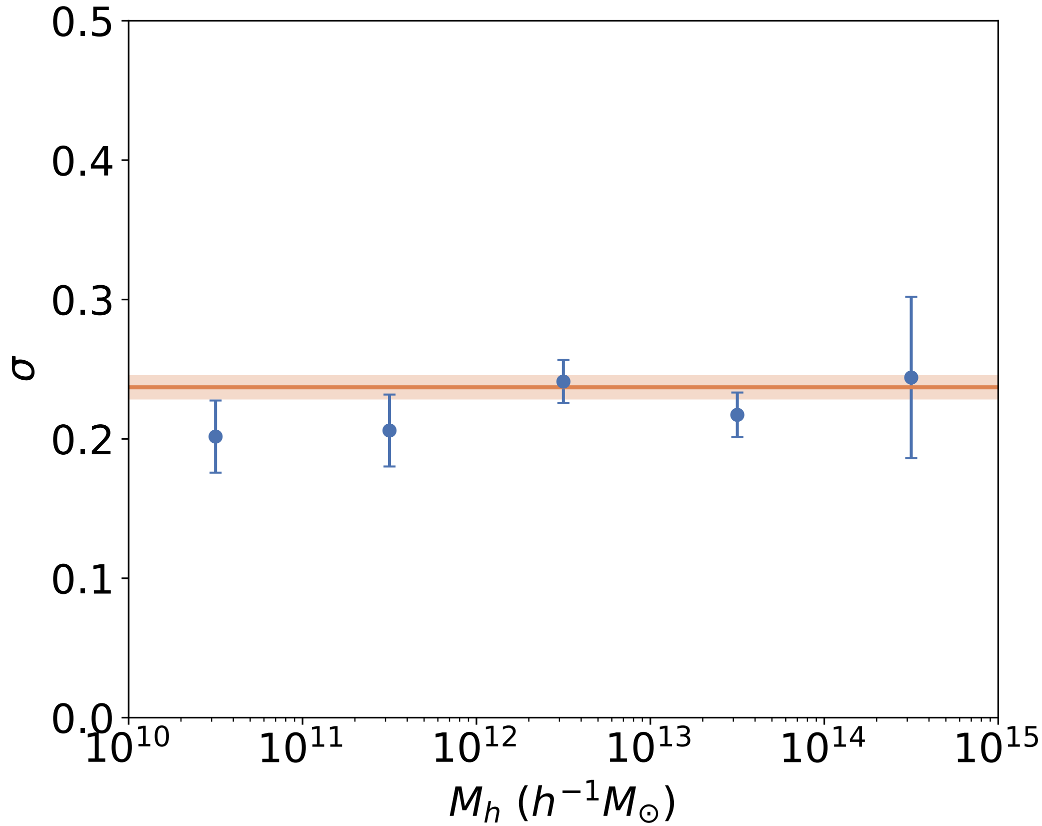
$$f(x) = -\log_{10}(10^{-\beta x} + 1) + \delta\frac{(\log_{10}(1+\exp(x)))^{\alpha}}{1+\exp(10^{-x})},$$

Very Accurate SHMR $z_s < 0.6$



1. *very accurate SHMR for halo mass: $M_h > 10^{11.4}\ h^{-1}M_\odot$ at $z_s = 0.6$; $M_h > 10^{11.1}\ h^{-1}M_\odot$ at $z_s = 0.3$; $M_h > 10^{10.3} h^{-1}M_\odot$ at $z_s = 0.1$*
2. *For large halos, M_* in a halo of fixed M_h is larger at higher z (SF quenched; downsizing)*
3. *For small halos, the opposite is true (SF has been going on)*

Scatter σ of SHMR: no dependence on halo mass



Dots: $\sigma(M_h)$ ***for 5 halo mass bins (5 para)***

Line: global σ for all halos (one para)

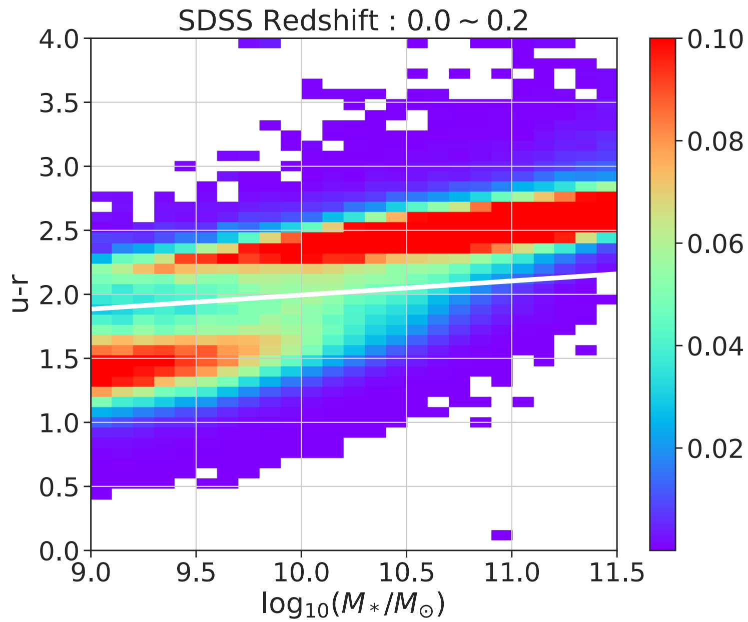
Well agree!

With the accurate determination of $n_2 w_{12}(r_p)$***, we are able to prove the scatter σ is constant with a high precision***

Applications

- What are the roles of mass and environment in quenching galaxies?
- Resolve S8 tension?

1. Bimodal color distribution in SDSS



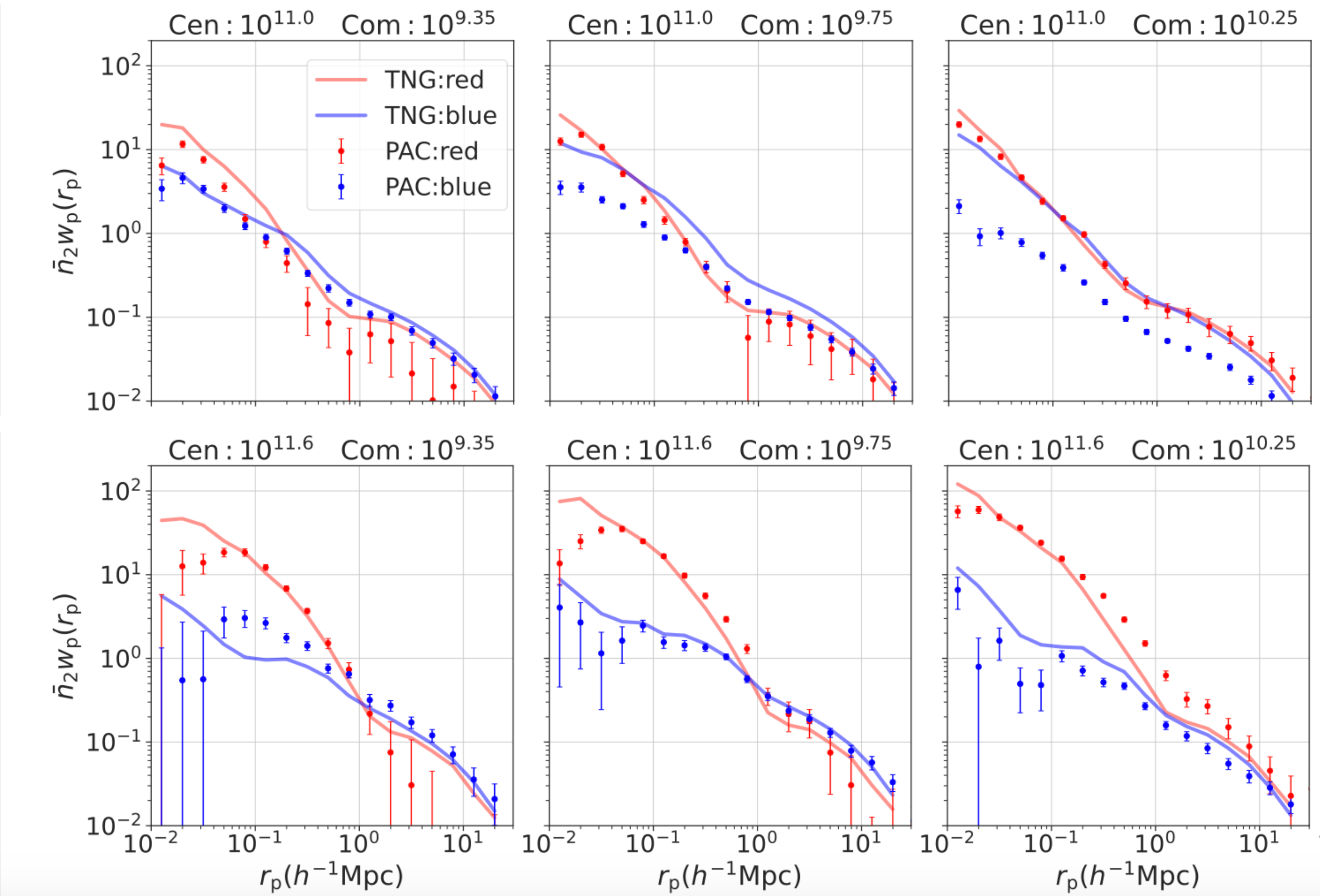
- What are the roles of mass and environment
- Use

  $$u - r = 0.11\, logM\star + 0.895$$

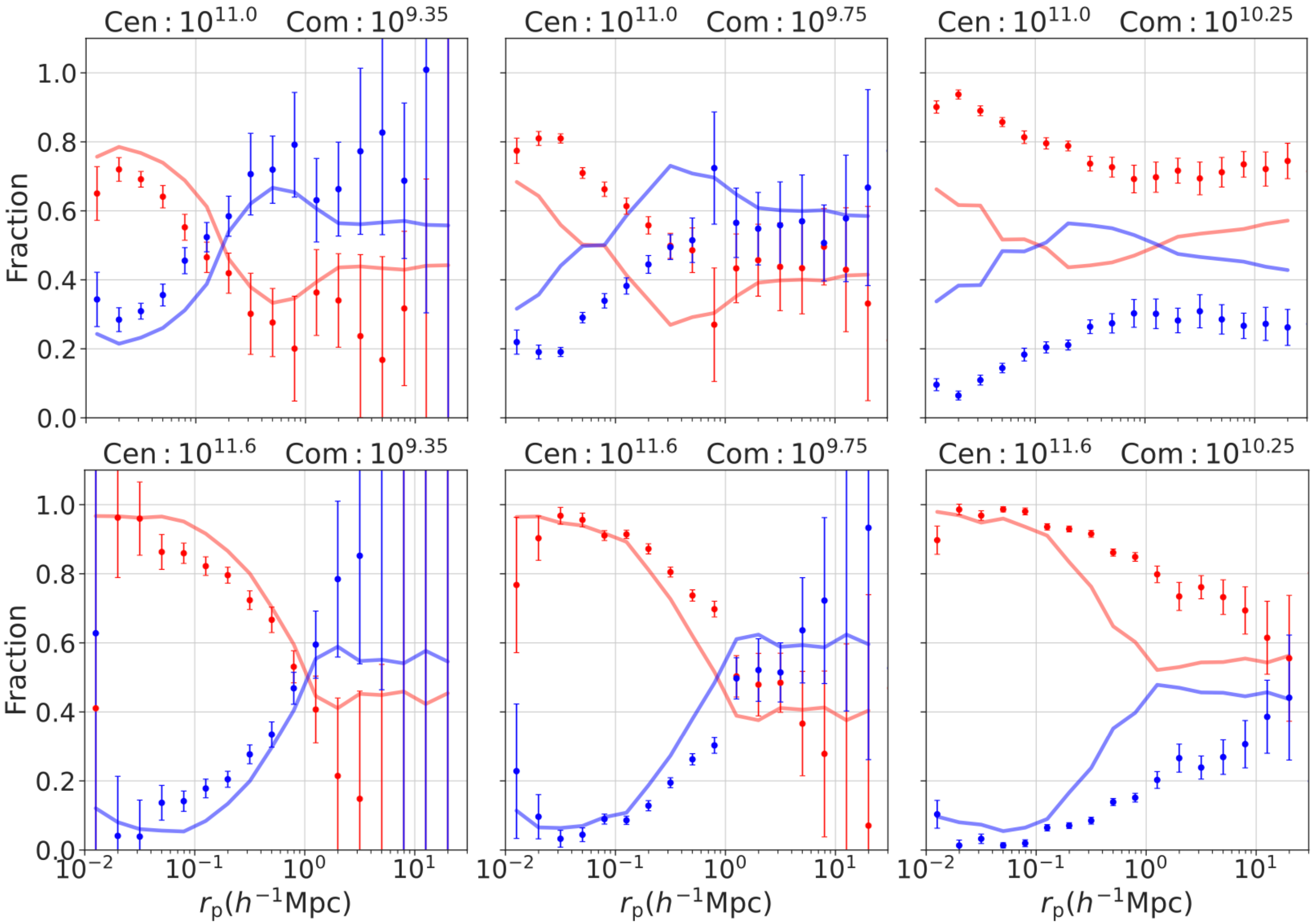
  to define the quenching
- Adopt that this quenching criterion does not change with redshift

Yun Zheng (郑赟）, Kun Xu, YPJ et al. 2024, astroph2401.11997 ApJ(in press)

Red and blue galaxies around central galaxies

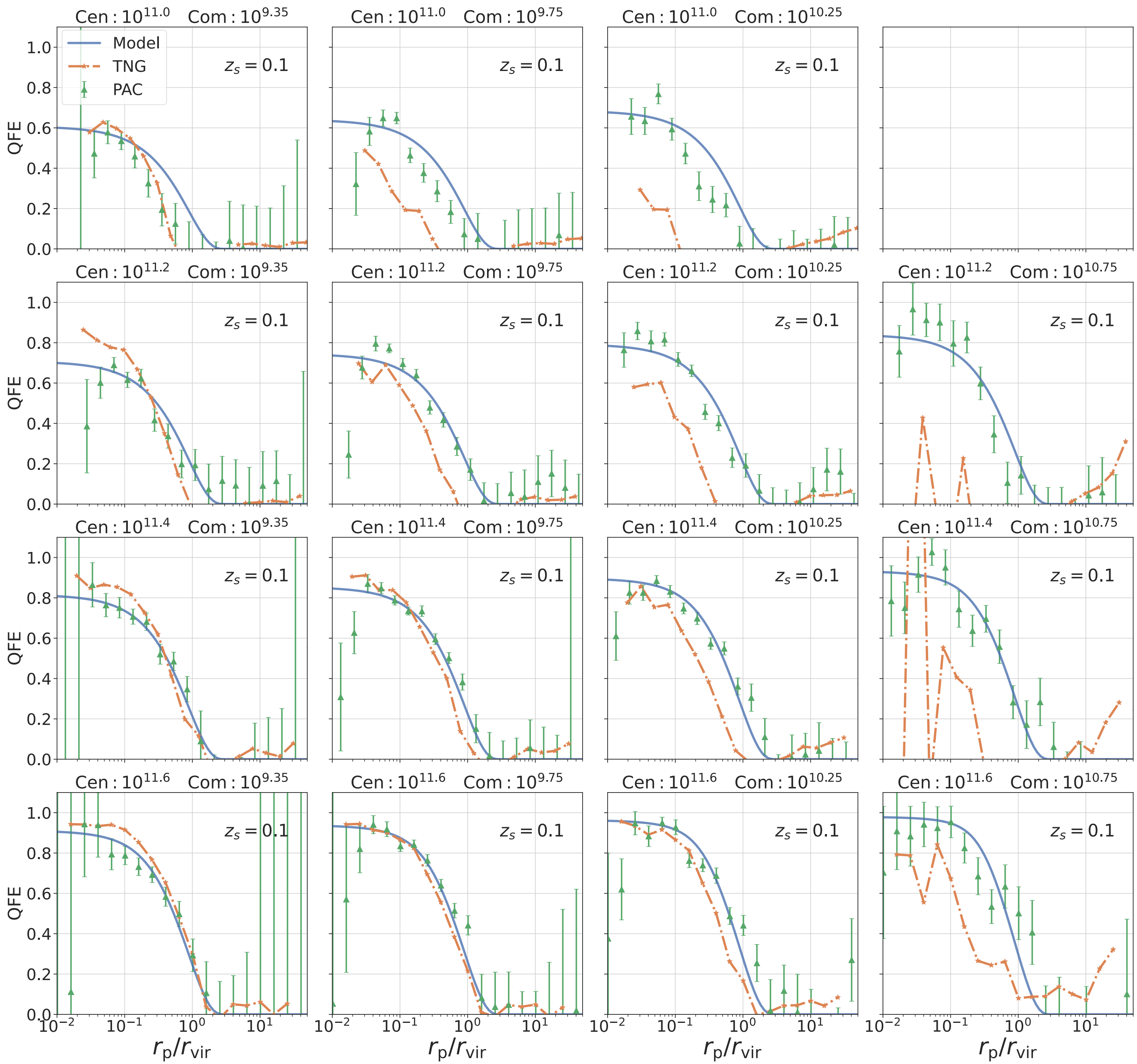


Red and blue fractions



Environment quenching

- ***The quenching fraction (red fraction) is a combined effect of mass and environment***
- ***Define Quenching Fraction due to Environment (QFE):***
- $$QFE = \frac{f_q - \overline{f_q}}{1 - \overline{f_q}} = \frac{f_q - \overline{f_q}}{\overline{f_{blue}}}$$



Cen : 10^11.0 Com : 10^9.35
Cen : 10^11.0 Com : 10^9.75
Cen : 10^11.0 Com : 10^10.25
Cen : 10^11.2 Com : 10^9.35
Cen : 10^11.2 Com : 10^9.75
Cen : 10^11.2 Com : 10^10.25
Cen : 10^11.2 Com : 10^10.75
Cen : 10^11.4 Com : 10^9.35
Cen : 10^11.4 Com : 10^9.75
Cen : 10^11.4 Com : 10^10.25
Cen : 10^11.4 Com : 10^10.75
Cen : 10^11.6 Com : 10^9.35
Cen : 10^11.6 Com : 10^9.75
Cen : 10^11.6 Com : 10^10.25
Cen : 10^11.6 Com : 10^10.75
Model
TNG
PAC
$z_s = 0.1$
QFE
r_p/r_{vir}

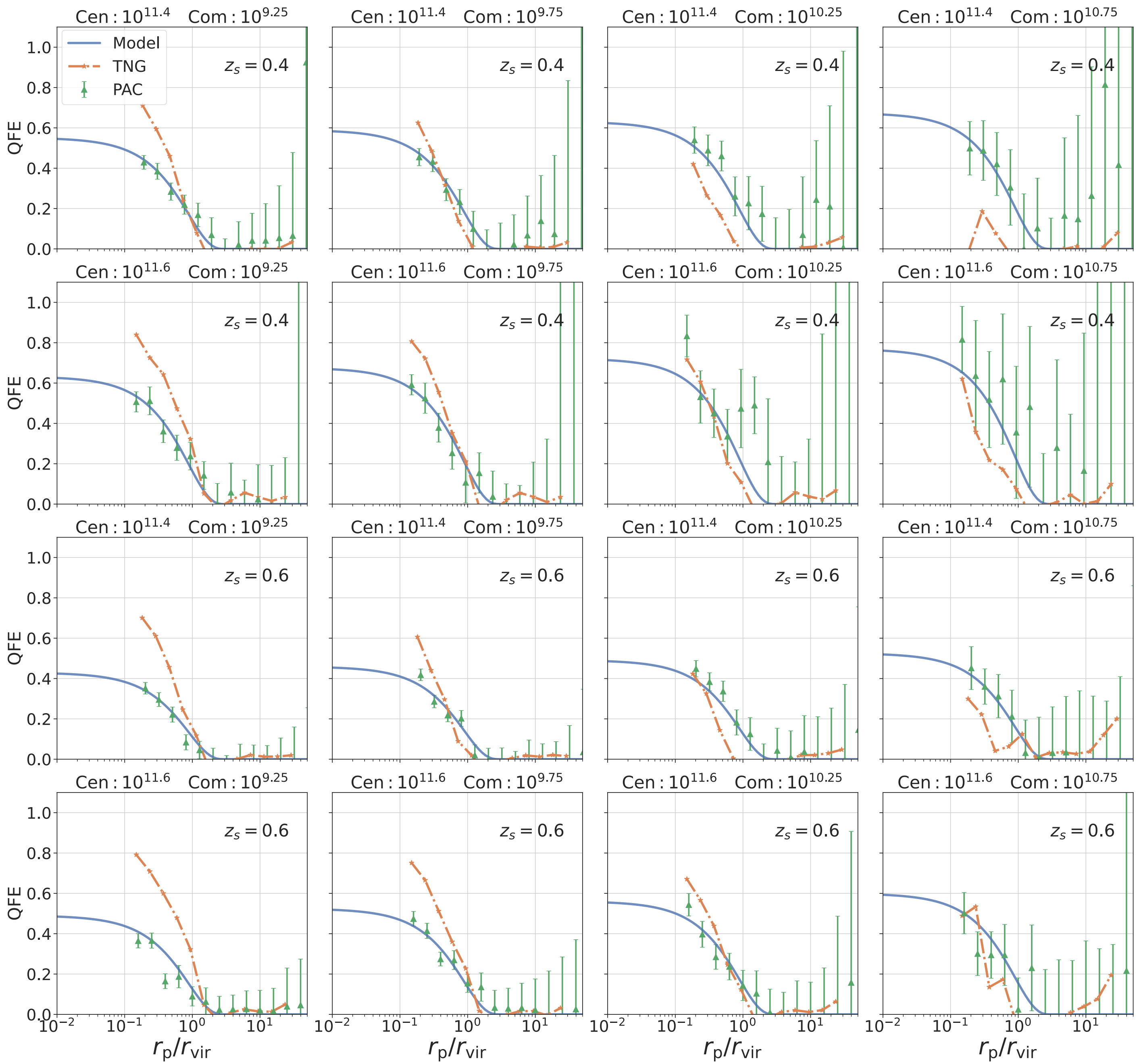
Environment quenching

- ***We find that QFE can be approximated as***

- $$QFE \propto \frac{1}{(1+z)^{1.5}} \left[\frac{M_{*,sat}}{M_{*,cen}}\right]^{0.06} r_{vir}^{0.66} \left[1 - \frac{r_p}{3r_{vir}}\right]^3$$

  (for $r_p < 3r_{vir}$; 0 for $r_p > 3r_{vir}$)

  - *Environment quenching up to the splash radius ($3r_{vir}$)*
  - *bigger halo quenches more efficiently*
  - *Depends on satellite mass very weakly*
  - *Lower at higher redshift*
  - *Applicable to halo model*

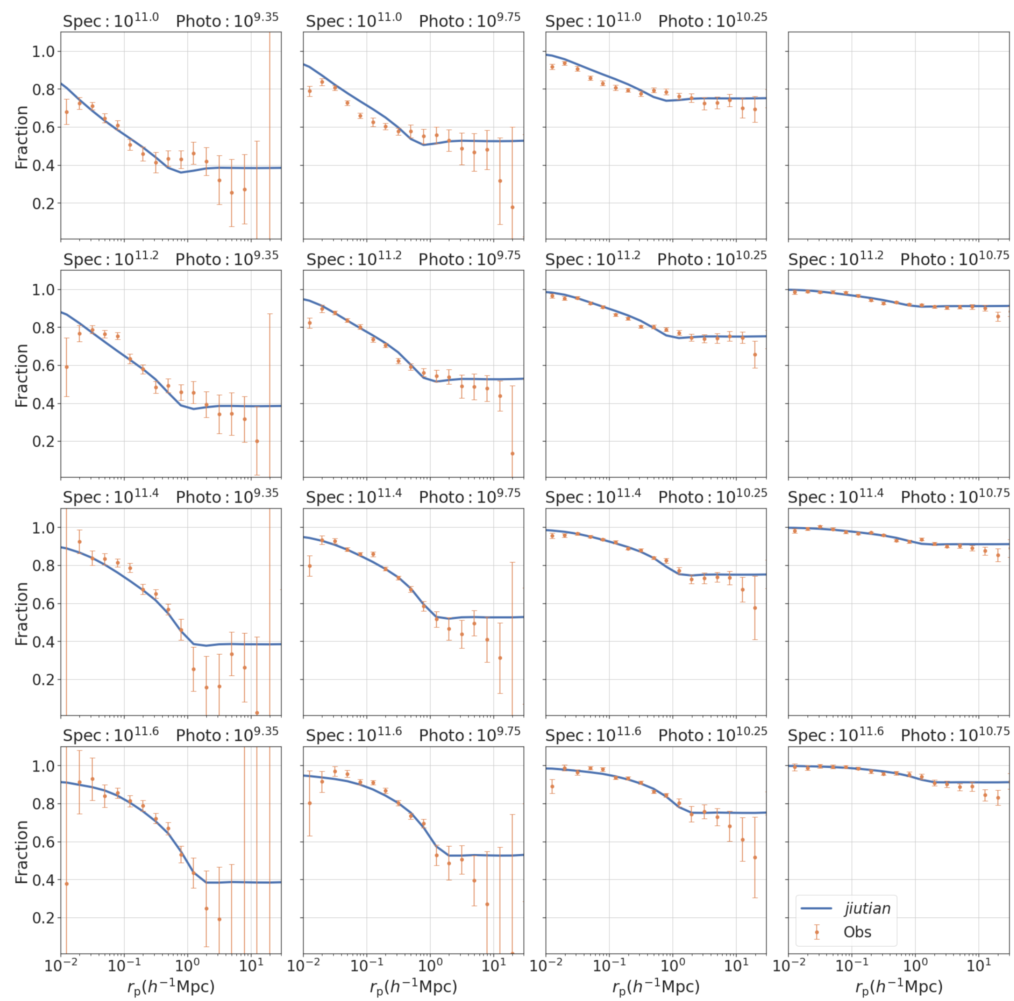


Cen : $10^{11.4}$ Com : $10^{9.25}$
Cen : $10^{11.4}$ Com : $10^{9.75}$
Cen : $10^{11.4}$ Com : $10^{10.25}$
Cen : $10^{11.4}$ Com : $10^{10.75}$
Cen : $10^{11.6}$ Com : $10^{9.25}$
Cen : $10^{11.6}$ Com : $10^{9.75}$
Cen : $10^{11.6}$ Com : $10^{10.25}$
Cen : $10^{11.6}$ Com : $10^{10.75}$
$z_s = 0.4$
$z_s = 0.6$
Model
TNG
PAC
QFE
r_p/r_{vir}

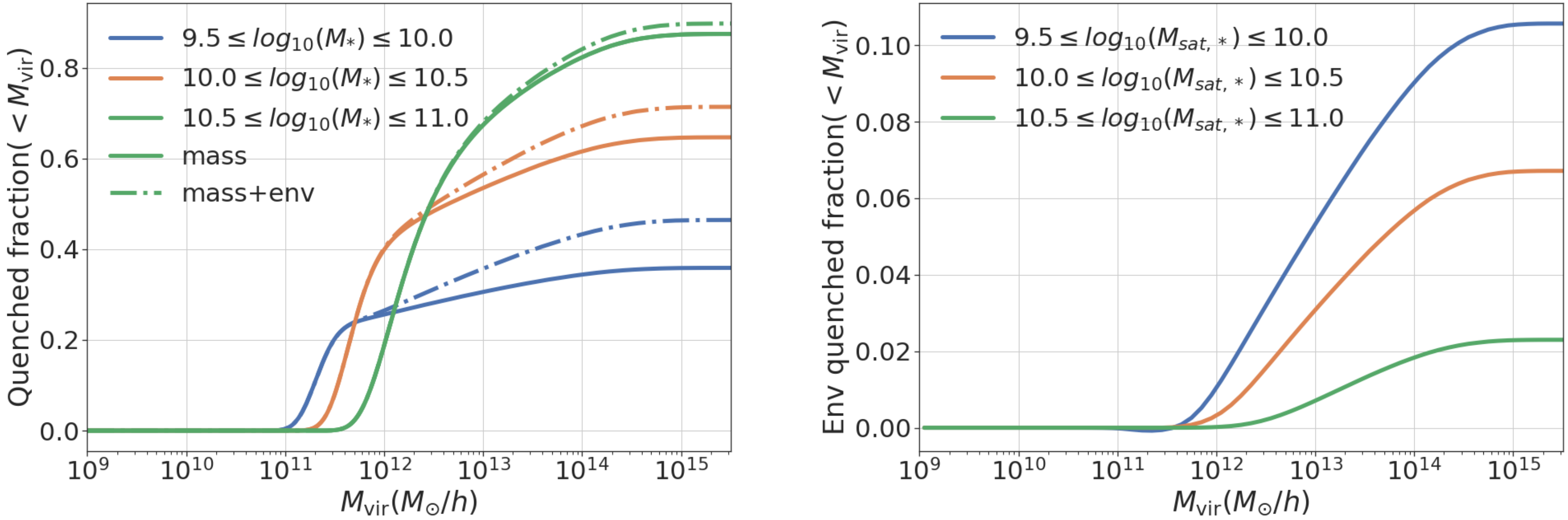
Fully separate Mass and Environment effects

Combining SHMR and quenched fractions(or QFE) measured, we are able to fully separate mass and environment quenching

Dots: observed; lines (simulation+SHMR)

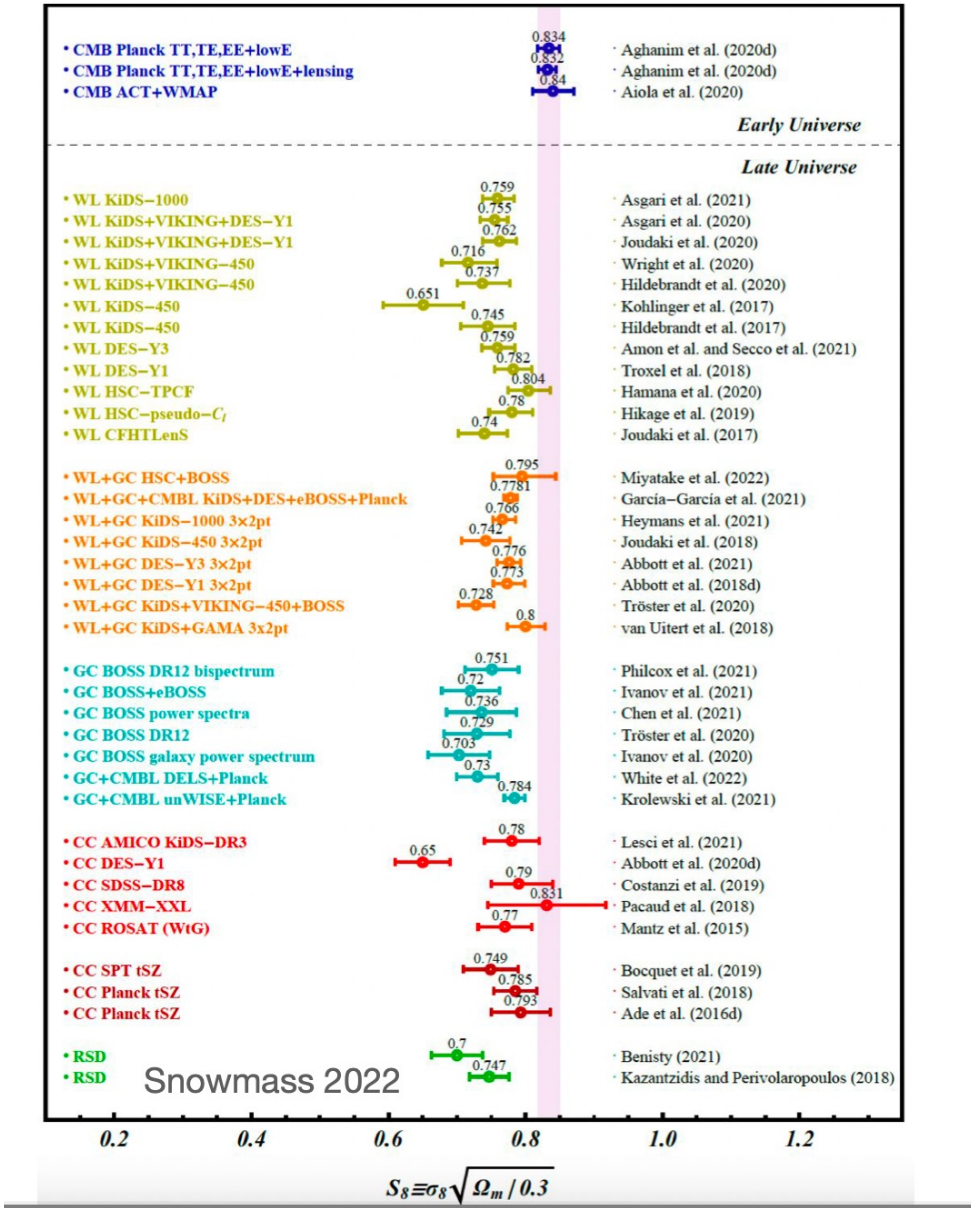


Quenching effects by mass and environment



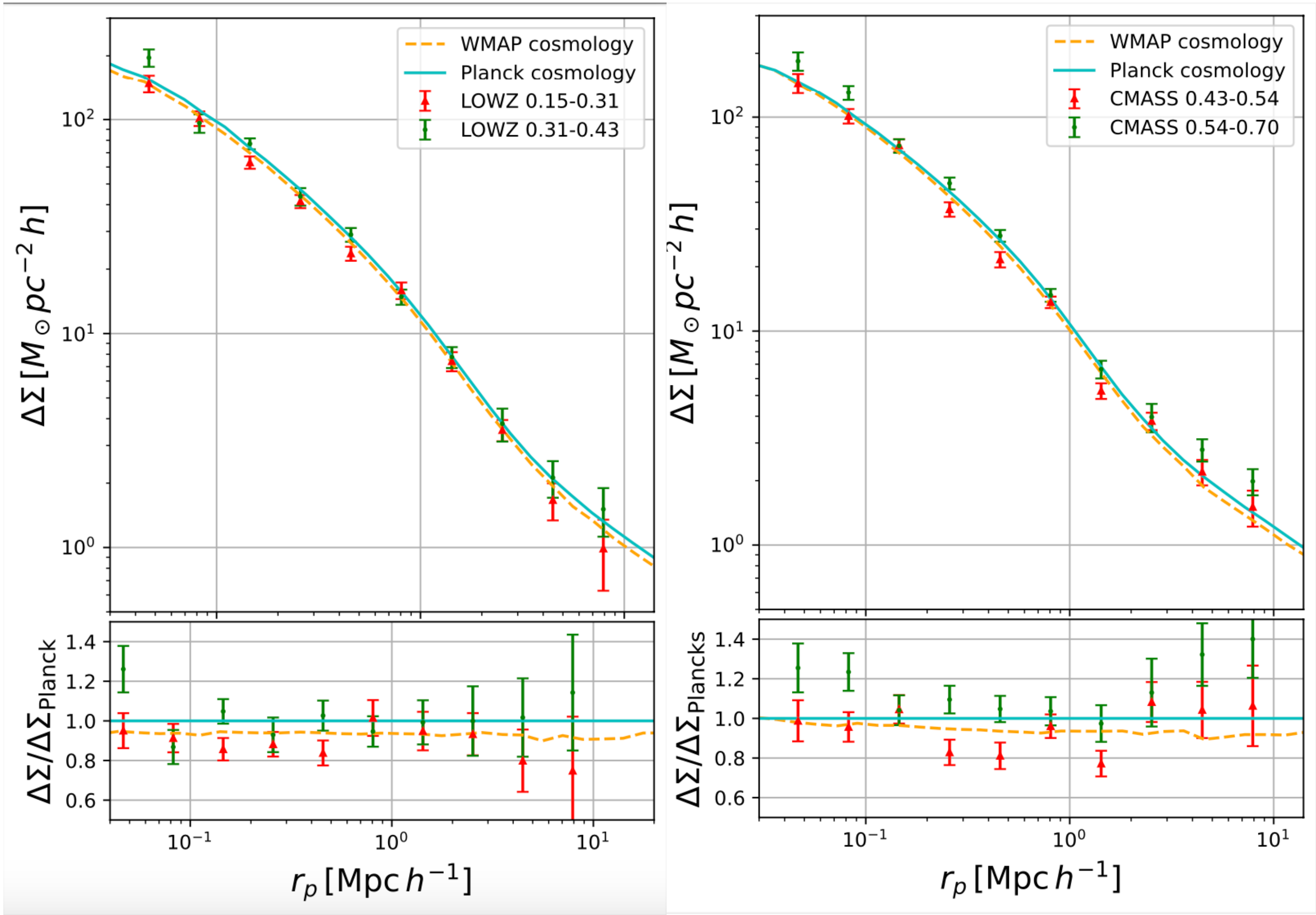
1. From most massive to small galaxies to $10^{9.5}$ $\mathrm{M}_\odot$, the quenched fraction changed from ~1 to 45%
2. quenching is **dominated always by mass**
3. To the total quenched fraction, the environment contribution is from about 3% for massive galaxies ($10^{10.75}$ $\mathrm{M}_\odot$) to 27% for small ones ($10^{9.75}$ $\mathrm{M}_\odot$)

2. S_8 tension



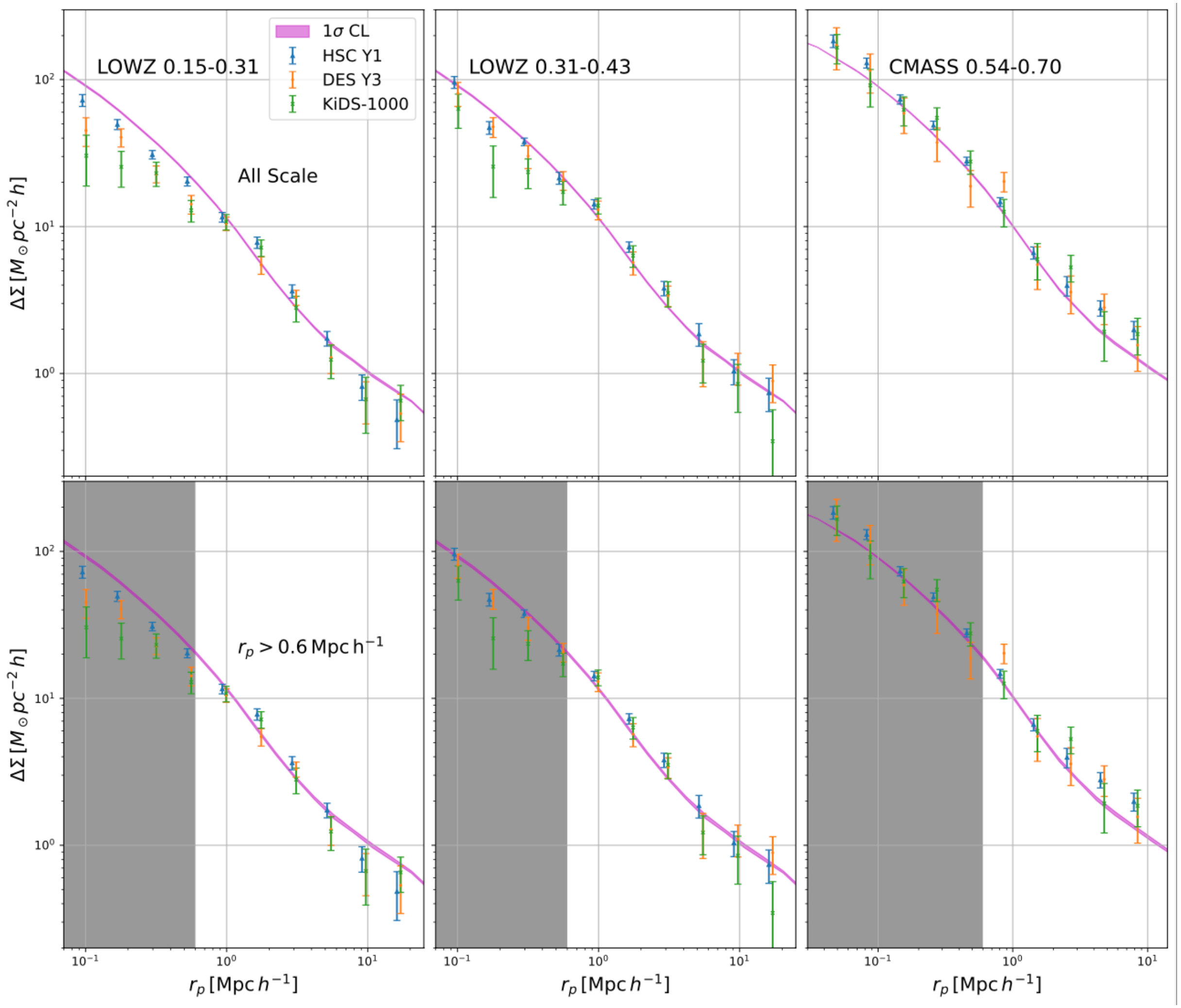
CMB Planck TT,TE,EE+lowE
CMB Planck TT,TE,EE+lowE+lensing
CMB ACT+WMAP
Early Universe
Late Universe
WL KiDS−1000
WL KiDS+VIKING+DES−Y1
WL KiDS+VIKING+DES−Y1
WL KiDS+VIKING−450
WL KiDS+VIKING−450
WL KiDS−450
WL KiDS−450
WL DES−Y3
WL DES−Y1
WL HSC−TPCF
WL HSC−pseudo−C_l
WL CFHTLenS
WL+GC HSC+BOSS
WL+GC+CMBL KiDS+DES+eBOSS+Planck
WL+GC KiDS−1000 3x2pt
WL+GC KiDS−450 3x2pt
WL+GC DES−Y3 3x2pt
WL+GC DES−Y1 3x2pt
WL+GC KiDS+VIKING−450+BOSS
WL+GC KiDS+GAMA 3x2pt
GC BOSS DR12 bispectrum
GC BOSS+eBOSS
GC BOSS power spectra
GC BOSS DR12
GC BOSS galaxy power spectrum
GC+CMBL DELS+Planck
GC+CMBL unWISE+Planck
CC AMICO KiDS−DR3
CC DES−Y1
CC SDSS−DR8
CC XMM−XXL
CC ROSAT (WtG)
CC SPT tSZ
CC Planck tSZ
CC Planck tSZ
RSD
RSD
Snowmass 2022
0.834
0.832
0.84
0.759
0.755
0.762
0.716
0.737
0.651
0.745
0.759
0.782
0.804
0.78
0.74
0.795
0.7781
0.766
0.742
0.776
0.773
0.728
0.8
0.751
0.72
0.736
0.729
0.703
0.73
0.784
0.78
0.65
0.79
0.831
0.77
0.749
0.785
0.793
0.7
0.747
Aghanim et al. (2020d)
Aghanim et al. (2020d)
Aiola et al. (2020)
Asgari et al. (2021)
Asgari et al. (2020)
Joudaki et al. (2020)
Wright et al. (2020)
Hildebrandt et al. (2020)
Kohlinger et al. (2017)
Hildebrandt et al. (2017)
Amon et al. and Secco et al. (2021)
Troxel et al. (2018)
Hamana et al. (2020)
Hikage et al. (2019)
Joudaki et al. (2017)
Miyatake et al. (2022)
García−García et al. (2021)
Heymans et al. (2021)
Joudaki et al. (2018)
Abbott et al. (2021)
Abbott et al. (2018d)
Tröster et al. (2020)
van Uitert et al. (2018)
Philcox et al. (2021)
Ivanov et al. (2021)
Chen et al. (2021)
Tröster et al. (2020)
Ivanov et al. (2020)
White et al. (2022)
Krolewski et al. (2021)
Lesci et al. (2021)
Abbott et al. (2020d)
Costanzi et al. (2019)
Pacaud et al. (2018)
Mantz et al. (2015)
Bocquet et al. (2019)
Salvati et al. (2018)
Ade et al. (2016d)
Benisty (2021)
Kazantzidis and Perivolaropoulos (2018)
0.2
0.4
0.6
0.8
1.0
1.2
$S_8 \equiv \sigma_8 \sqrt{\Omega_m / 0.3}$

No S_8-tension from BOSS-HSC GG-lensing



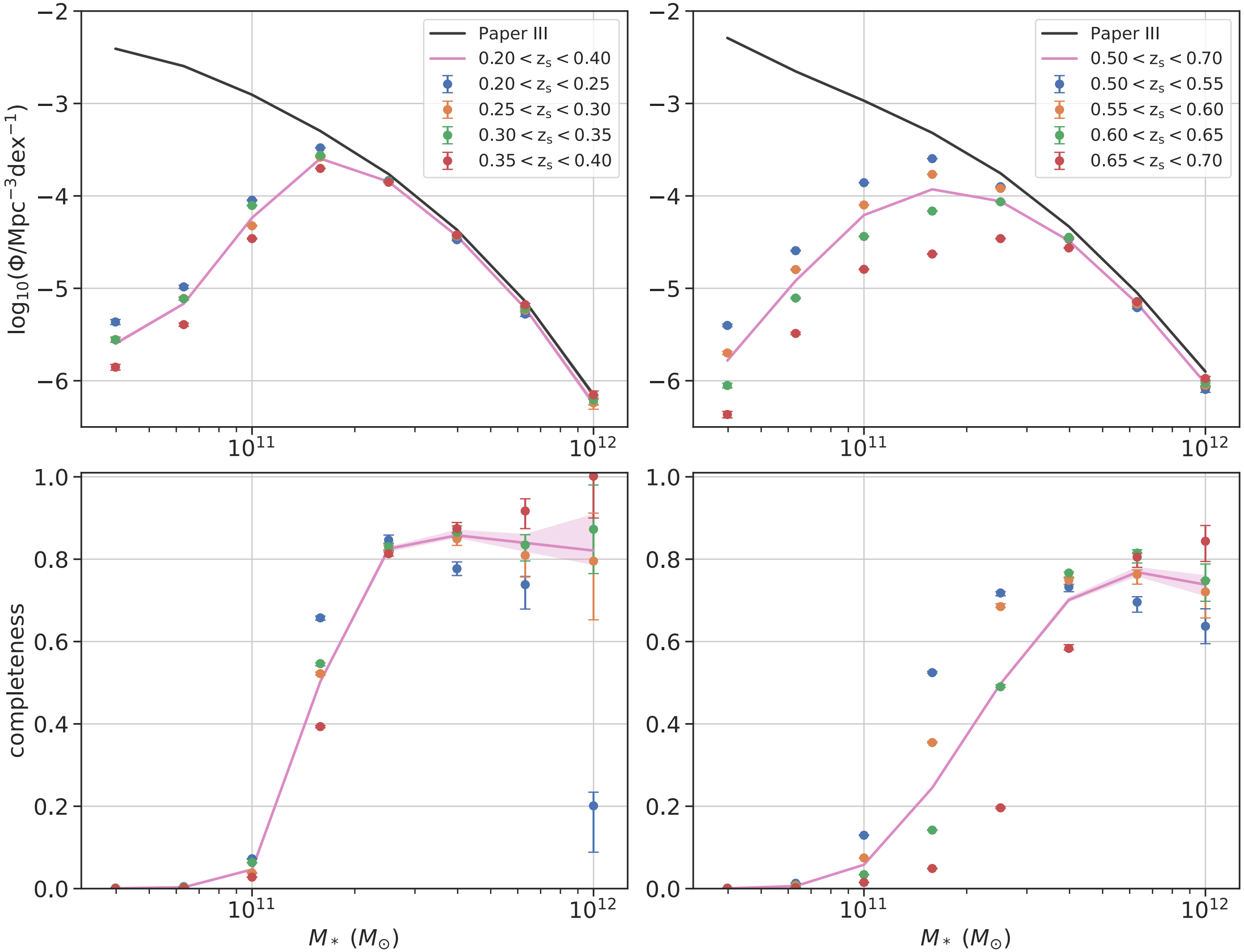
罗孝麟等, to be submitted

Planck consistent with KiDs and DES



No feedback suppression needed if small scale GG lensing in KiDs only not considered

Incompleteness properly accounted for



Magnification of CMASS galaxies

- Using Total Flux of background galaxies (using color cut for $z > 0.8$) in DESI image (DECaLS or Southern)
- Corrected for Dust Attenuation
- Perfect agreement with Planck S_8
- No need for strong feedback
- Even higher at $r_p < 0.07\, h^{-1}Mpc$
- SIDM or bottom heavy IMF?

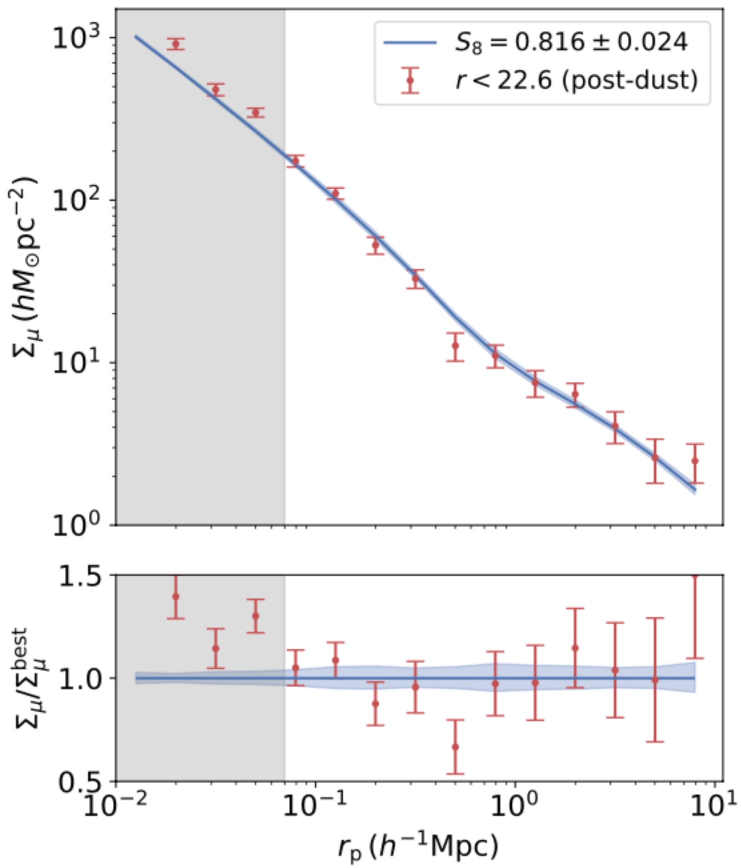


Figure 19. The best-fit Σ_μ and the 1σ confidence level for the measurements from the $r < 22.6$ source samples with $S_8 = 0.816 \pm 0.024$.

Kun, XU, YPJ et al 2024 to be submitted soon

The Astrophysical Journal, 758:50 (15pp), 2012 October 10 doi:10.1088/0004-637X/758/1/50

INTERNAL KINEMATICS OF GROUPS OF GALAXIES IN THE SLOAN DIGITAL SKY SURVEY DATA RELEASE 7

Cheng Li[1], Y. P. Jing[1], Shude Mao[2,3], Jiaxin Han[1], Qiuying Peng[1], Xiaohu Yang[1], H. J. Mo[4], and Frank van den Bosch[5]
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, China
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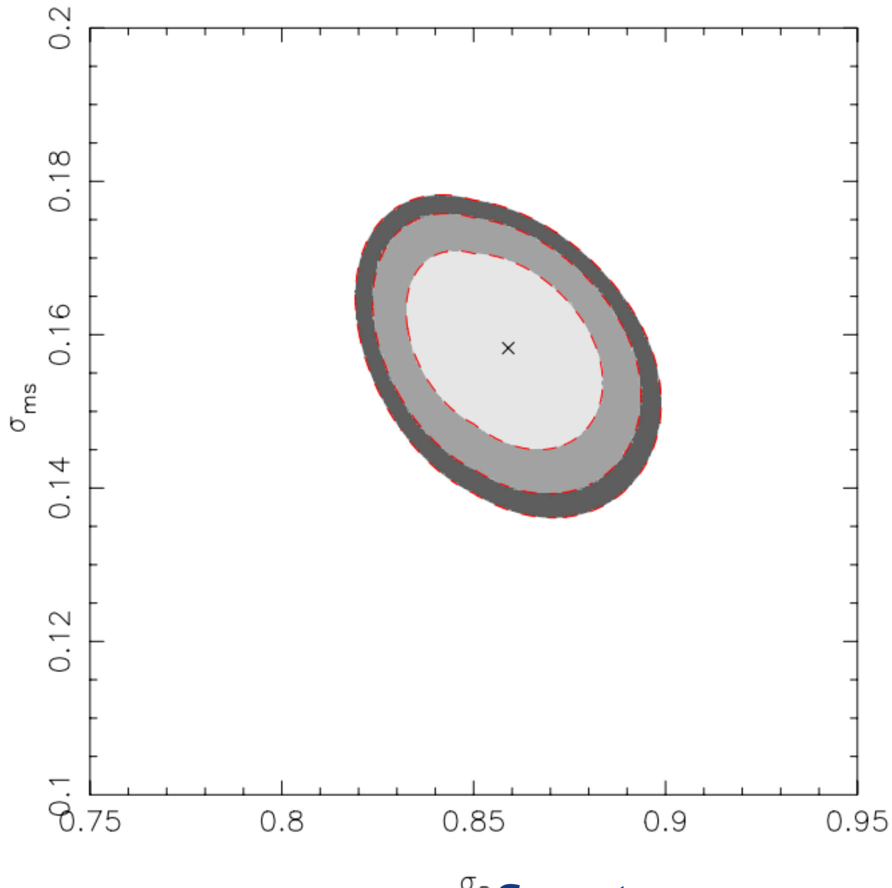
USA
01, USA



$S_8 = 0.826 \pm 0.020$ perfect agreement with Planck (Li et al. 2012)

Remarks on future

- ***DESI and PFS will yield huge redshift samples of LRGs,ELGs and QSO at z=1-3***
- ***New wide deep photometry surveys are coming, LSST, CSST, Euclid, WFIRST, etc***
- ***New opportunities for precision-studies on galaxy formation and cosmology***

Thank You!

6 Papers on PAC

Xu, K., Zheng, Y., & Jing, Y. 2022, ApJ, 925, 31; arXiv:2109.11738 (Methods; Paper I)
Xu, K. & Jing, Y. 2022, ApJ, 926, 130; arXiv:2110.05760 (color, morphology, size; Paper II)
Xu, K., Jing, Y.P., & Gao, H. 2022, ApJ 939,; arXiv:2207.12423 (GSMF; Paper III)
Xu, K., Jing, Y.P., Zheng,Y., & Gao, H. 2023, ApJ 944 ; arXiv: 2211.02665 (SMHR; Paper IV)
Zheng,Y.,Xu,K,Jing,Y.P.,Gao,H.,Zhao,D.H. 2024, ApJ, arXiv:2401.11997 (Quenching; Paper V)
Gui,S.Q., Xu,K, Jing,Y.P. et al. 2024, ApJ, arXiv:2401.00565 (High QSO satellite fraction; Paper VI)

see also Wang,W,Jing,Y.P. et al 2011, ApJ, 734,88