DEEP-Theory Meeting 10 March 2017

Constraining the Galaxy Halo Connection: Star Formation Histories, Galaxy Mergers, and Structural Properties, by Aldo Rodriguez-Puebla, Joel, Vladimir Avila-Reese, and Sandy submitted to MNRAS. Paper is posted at http://physics.ucsc.edu/~joel/Rodriguez-Puebla,Primack,Avilla-Reese,Faber-GalaxyHaloConnection-MNRAS%20submitted.pdf and the slides from my Feb 27 Cosmoclub presentation about this are at http://physics.ucsc.edu/~joel/GalaxyHaloConnectionPaper-Cosmoclub-27Feb2017.pdf . All the data in the paper can be downloaded from https://132.248.1.39/galaxy/galaxy_halo.html

Abundance Matching is Independent of Cosmic Environment Density, based on Radu Dragomir's UCSC senior thesis, advised by Aldo and Joel (we're drafting this now — I can show a new figure)

DM halo properties vs. density paper is now published in MNRAS; **halo mass loss** and **halo radial profile** papers being drafted (with Christoph Lee, Doug Hellinger). Christoph has prepared a summary.

Galaxy R_{eff} predicted by (spin parameter)(halo radius) = λR_{halo} paper led by Rachel Somerville — correcting h^{-1} error, the offset between $R_{3D}/(\lambda R_{halo})$ has mostly disappeared.

Recent results by Tze Goh showing **halo properties like concentration, accretion history, and spin are mainly determined by environmental density rather than by location within the cosmic web**. But now Tze has found small but consistent **differences between void halos** and halos in other locations at the same environmental density (with Tze Goh, Christoph Lee, Peter Behroozi, Doug Hellinger, Miguel Aragon Calvo).

Analysis of VELA Gen3 simulations is ongoing as inputs into Deep Learning by Christoph Lee and Sean Larkin, along with Avishai's student Tomer Nussbaum. Christoph is also learning how to use the DL code. Meanwhile, Hassen Yesuf is working with X Prochaska to look at evidence for **outflows in galaxies at $z \sim 0.5$** and compare with our ART simulations. We are giving Hassen access to output at $z = 0.5$ from Daniel Ceverino's simulation of a 2×10^{11} $M_\odot$ galaxy and also several more massive galaxies at $z \sim 0.8$.

Constraining the Galaxy-Halo Connection Over The Last 13.3 Gyrs: Star Formation Histories, Galaxy Mergers and Structural Properties

Aldo Rodríguez-Puebla[1,2⋆], Joel R. Primack[3], Vladimir Avila-Reese[2], and S. M. Faber[4]

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[2] *Instituto de Astronomía, Universidad Nacional Autónoma de México, A. P. 70-264, 04510, México, D.F., México*
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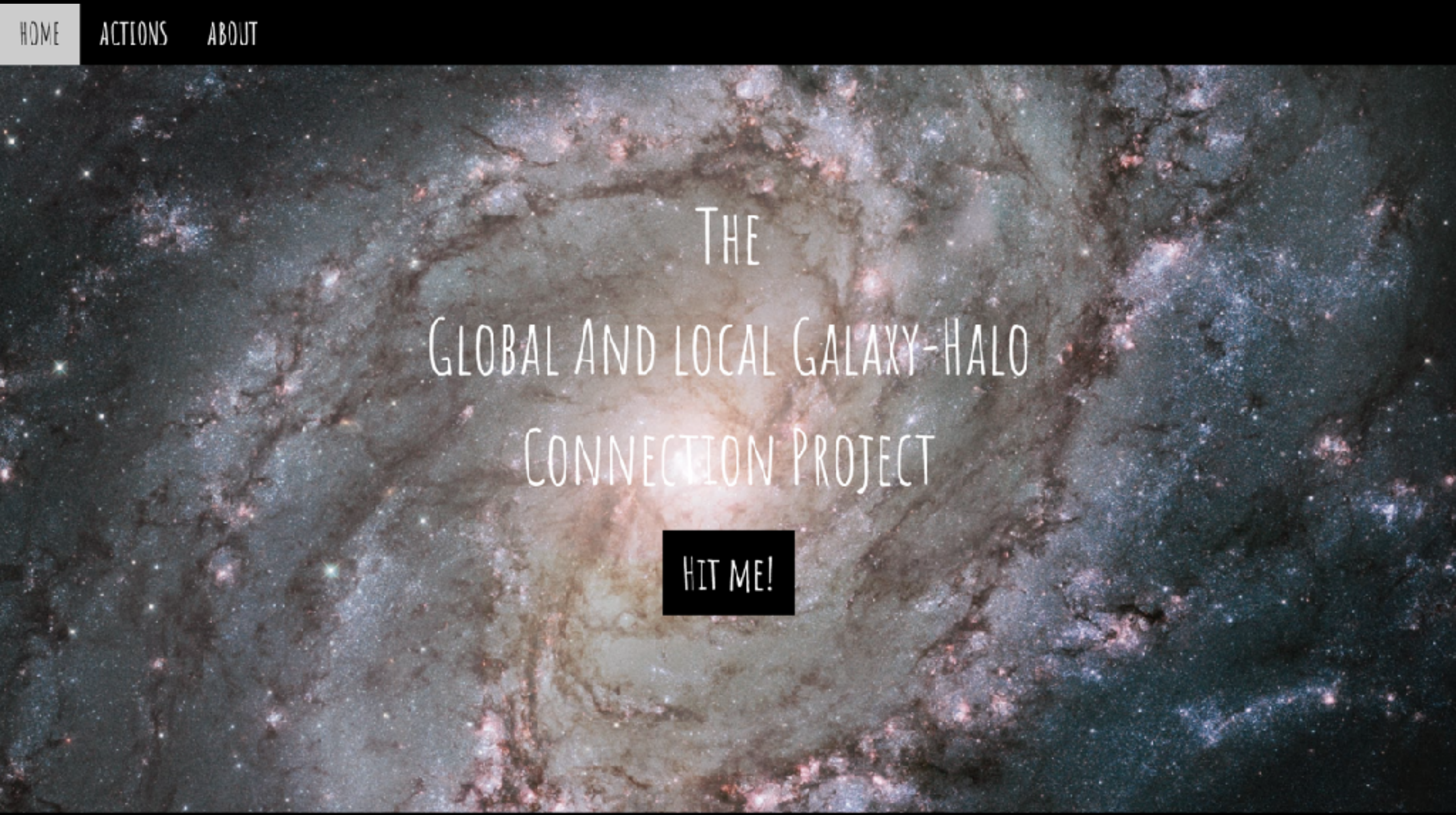
Submitted to MNRAS, on arXiv soon

ABSTRACT

We present new determinations of the stellar-to-halo mass relation (SHMR) at $z = 0 - 10$ that match the evolution of the galaxy stellar mass function, the $\mathrm{SFR} - M_*$ relation, and the cosmic star formation rate. We utilize a compilation of 40 observational studies from the literature and correct them for potential biases. Using our robust determinations of halo mass assembly and the SHMR, we infer star formation histories, merger rates, and structural properties for average galaxies, combining star-forming and quenched galaxies. Our main findings: (1) The halo mass M_{50} above which 50% of galaxies are quenched coincides with sSFR/sMAR ~ 1, where sMAR is the specific halo mass accretion rate. (2) M_{50} increases with redshift, presumably due to cold streams being more efficient at high redshift while virial shocks and AGN feedback become more relevant at lower redshifts. (3) The ratio sSFR/sMAR has a peak value, which occurs around $M_{\rm vir} \sim 2 \times 10^{11}\mathrm{M}_\odot$. (4) The stellar mass density within 1 kpc, Σ_1, is a good indicator of the galactic global sSFR. (5) Galaxies are statistically quenched after they reach a maximum in Σ_1, consistent with theoretical expectations of the gas compaction model; this maximum depends on redshift. (6) In-situ star formation is responsible for most galactic stellar mass growth, especially for lower-mass galaxies. (7) Galaxies grow inside out. The marked change in the slope of the size–mass relation when galaxies became quenched, from $d \log R_{\rm eff}/d \log M_* \sim 0.35$ to ~ 2.5, could be the result of dry minor mergers.

https://132.248.1.39/galaxy/galaxy_halo.html



Constraining the Galaxy Halo Connection: Star Formation Histories, Galaxy Mergers, and Structural Properties, by Aldo Rodriguez-Puebla, Joel Primack, Vladimir Avila-Reese, and Sandra Faber

We use results from the Bolshoi-Planck simulation (Aldo Rodriguez-Puebla, Peter Behroozi, Joel Primack, Anatoly Klypin, Christoph Lee, Doug Hellinger, MNRAS 462, 893 (2016), including halo and subhalo abundance as a function of redshift (Fig B1 at right), median halo mass growth for halos of given M_{vir} at z = 0 (Fig B2). Our semi-empirical approach uses SubHalo Abundance Matching (SHAM), which matches the cumulative galaxy stellar mass function (GSMF) to the cumulative stellar mass function to correlate galaxy stellar mass with (sub)halo mass.

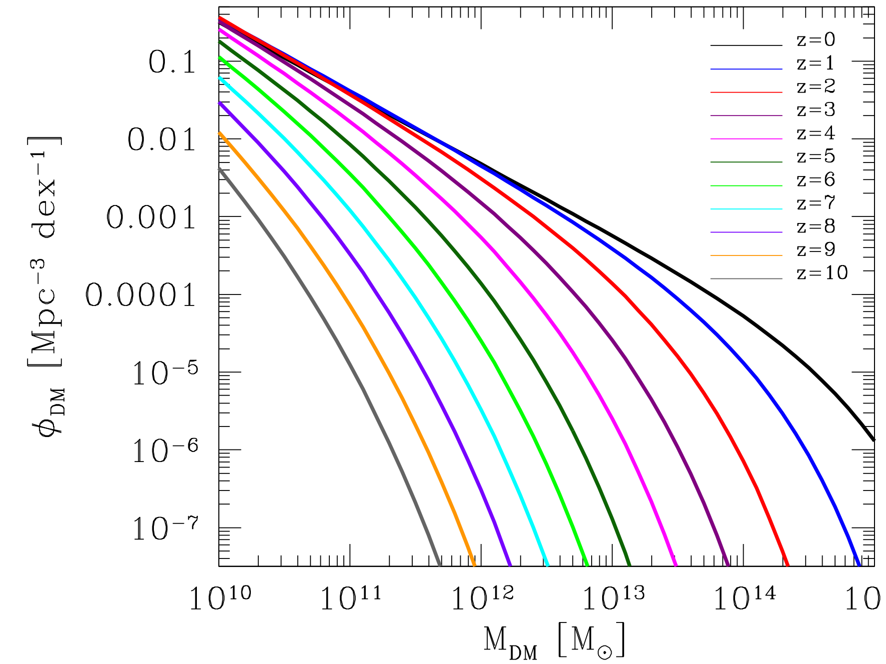
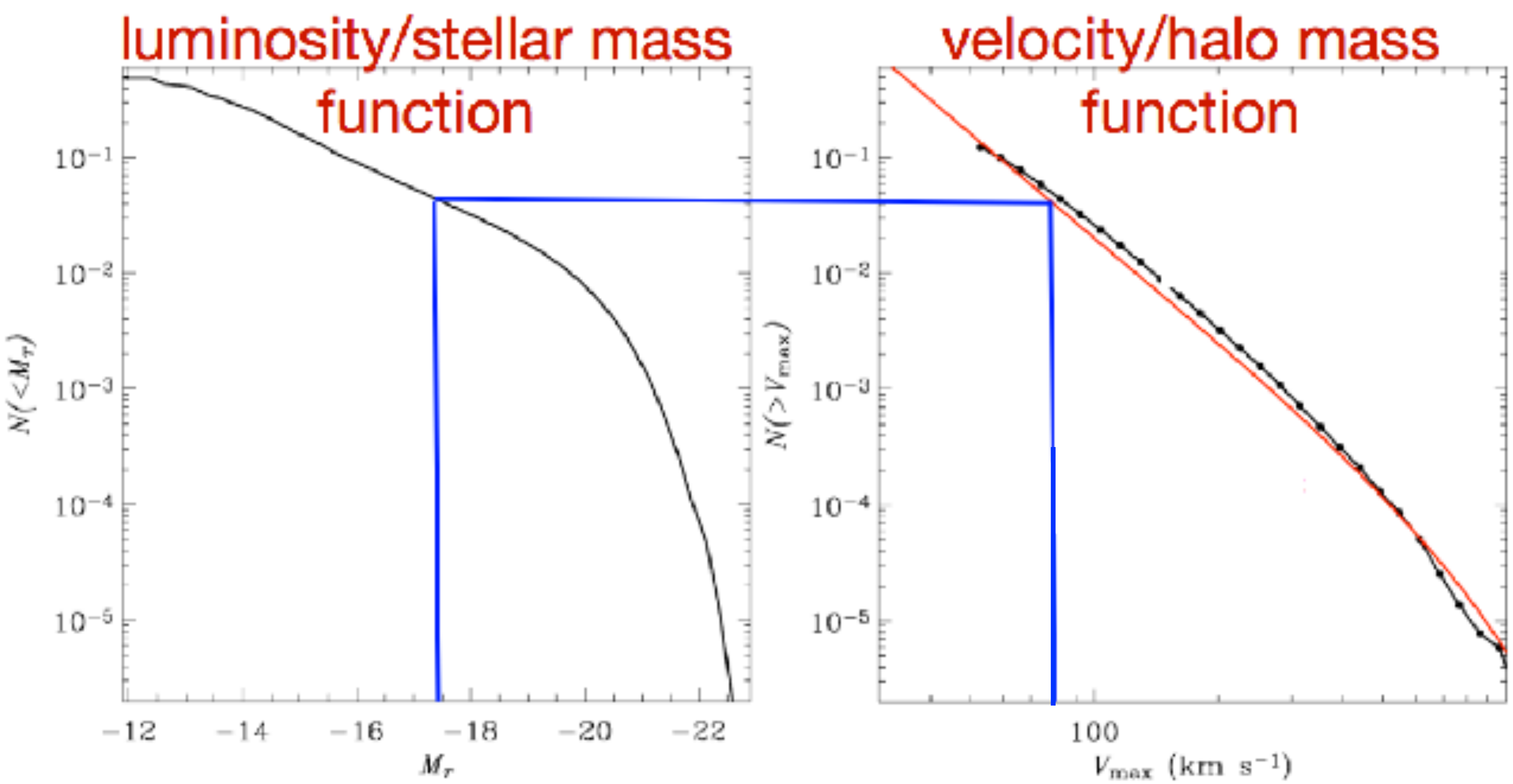


Figure B1. Total number density of halos and subhalos, $\phi_{\rm halo}(M_{\rm halo})dM_{\rm halo}$, from $z = 0$ to $z = 10$. $M_{\rm halo}$ should be interpreted as the virial mass, $M_{\rm vir}$, for distinct halos and $M_{\rm peak}$ for subhalos.. For central halos we are using the Tinker et al. (2008) model with the parameters updated in Rodríguez-Puebla et al. (2016a) based on large Bolshoi-Planck and MultiDark-Planck cosmological simulations using the cosmological parameters from the Planck mission. For subhalos we use the maximum mass reached along the main progenitor assembly, denoted as $M_{\rm peak}$.



Assumptions: every halo hosts a galaxy, mass growth of galaxies is associated with that of halos, blue star-forming galaxies are Sersic n = 1 (i.e., exponential) and red quenched galaxies are n = 4 (de Vaucouleurs).

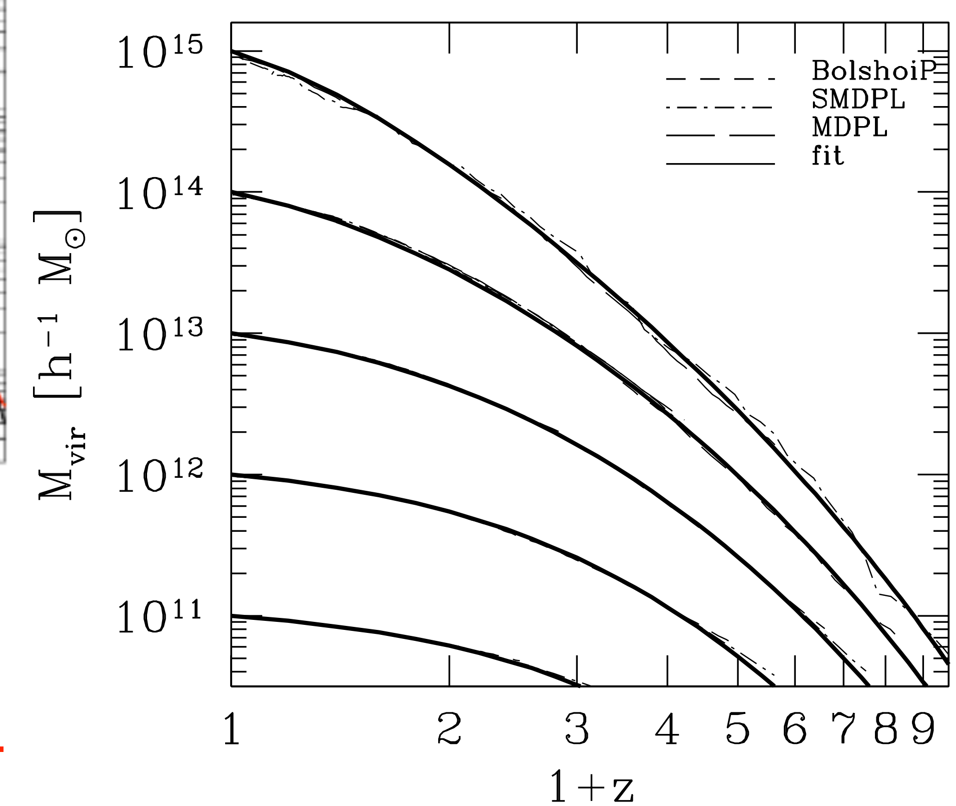


Figure B2. Median halo mass growth for progenitors $z = 0$ with masses of $M_{\rm vir} = 10^{11}, 10^{12}, 10^{13}$, 10^{14} and $10^{15} h^{-1} M_\odot$, solid lines. Fits to simulations are shown with the dotted lines.

Unlike the halo occupation distribution (HOD) or conditional stellar mass function approaches, we do not attempt to match the galaxy two-point correlation function or galaxy group catalogs.

Constraining the Galaxy Halo Connection: Star Formation Histories, Galaxy Mergers, and Structural Properties, by Aldo Rodriguez-Puebla, Joel Primack, Vladimir Avila-Reese, and Sandra Faber

Table 1. Observational data on the galaxy stellar mass function

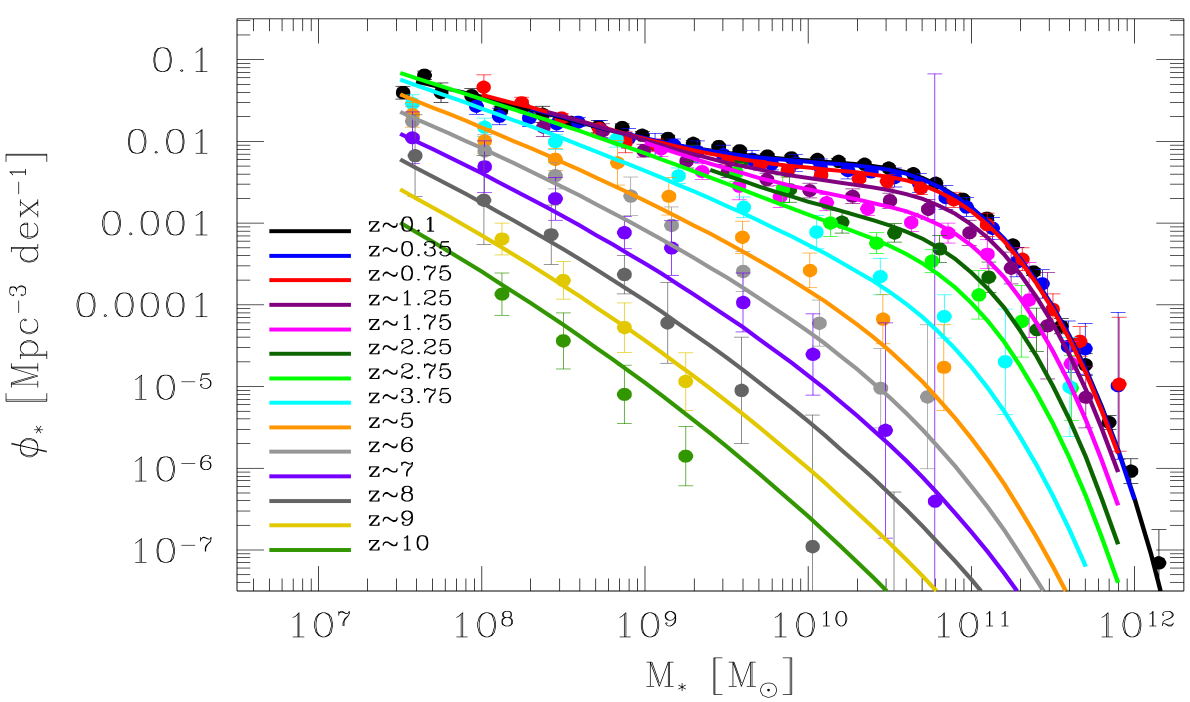
Author	Redshift[a]	Ω [deg^2]	Corrections
Bell et al. (2003)	$z \sim 0.1$	462	I+SP+C
Yang, Mo & van den Bosch (2009a)	$z \sim 0.1$	4681	I+SP+C
Li & White (2009)	$z \sim 0.1$	6437	I+P+C
Bernardi et al. (2010)	$z \sim 0.1$	4681	I+SP+C
Bernardi et al. (2013)	$z \sim 0.1$	7748	I+SP+C
Rodriguez-Puebla et al. in prep	$z \sim 0.1$	7748	S
Drory et al. (2009)	$0 < z < 1$	1.73	SP+C
Moustakas et al. (2013)	$0 < z < 1$	9	SP+D+C
Pérez-González et al. (2008)	$0.2 < z < 2.5$	0.184	I+SP+D+C
Tomczak et al. (2014)	$0.2 < z < 3$	0.0878	C
Ilbert et al. (2013)	$0.2 < z < 4$	2	C
Muzzin et al. (2013)	$0.2 < z < 4$	1.62	I+C
Santini et al. (2012)	$0.6 < z < 4.5$	0.0319	I+C
Mortlock et al. (2011)	$1 < z < 3.5$	0.0125	I+C
Marchesini et al. (2009)	$1.3 < z < 4$	0.142	I+C
Stark et al. (2009)	$z \sim 6$	0.089	I
Lee et al. (2012)	$3 < z < 7$	0.089	I+SP+C
González et al. (2011)	$4 < z < 7$	0.0778	I+C
Duncan et al. (2014)	$4 < z < 7$	0.0778	C
Song et al. (2015)	$4 < z < 8$	0.0778	I
This paper, Appendix D	$4 < z < 10$	0.0778	–

I=IMF; P= photometry corrections; S=Surface Brightness correction; D=Dust model; NE= Nebular Emissions: SP = SPS Model: C = Cosmology

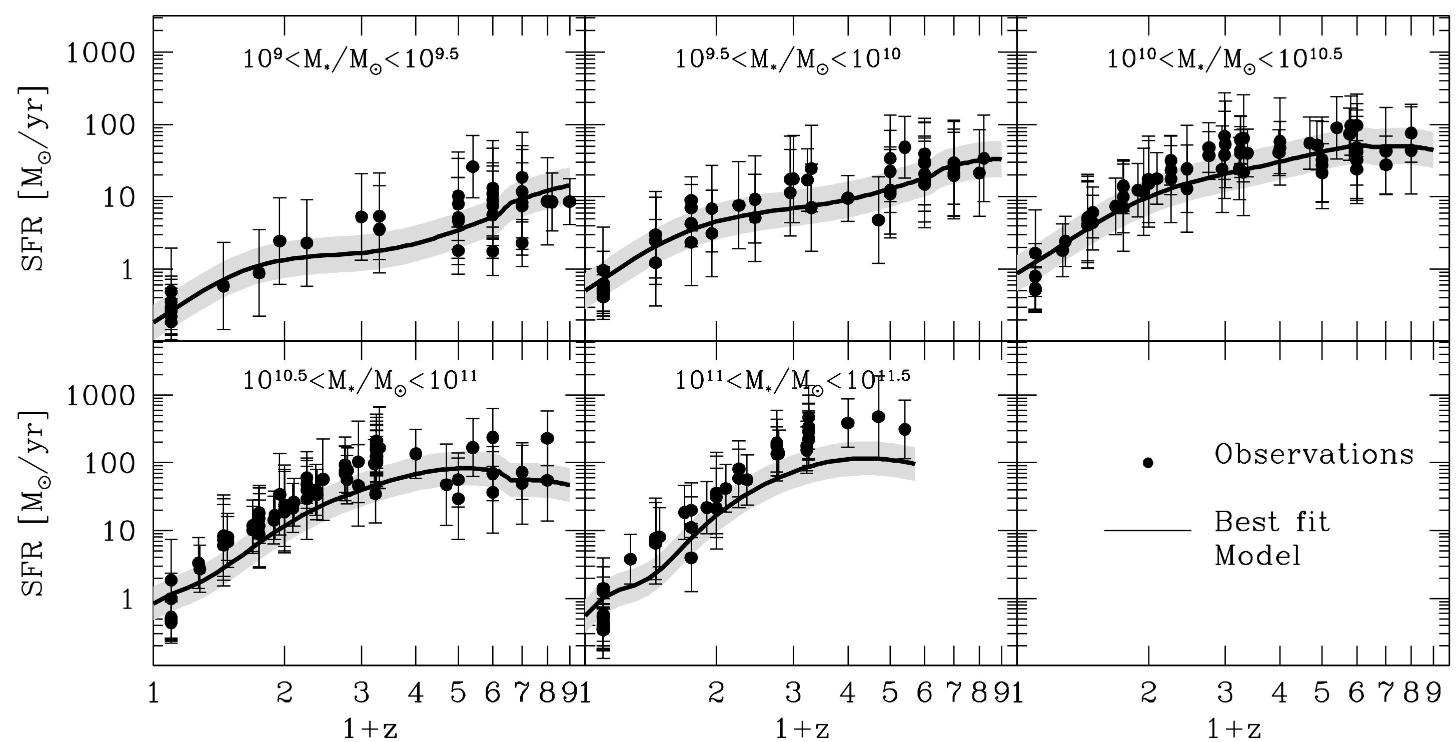
Table 2. Observational data on the star formation rates

Author	Redshift[a]	SFR Estimator	Corrections	Type
Chen et al. (2009)	$z \sim 0.1$	H_α/H_β	S	All
Salim et al. (2007)	$z \sim 0.1$	UV SED	S	All
Noeske et al. (2007)	$0.2 < z < 1.1$	UV+IR	S	All
Karim et al. (2011)	$0.2 < z < 3$	1.4 GHz	I+S+E	All
Dunne et al. (2009)	$0.45 < z < 2$	1.4 GHz	I+S+E	All
Kajisawa et al. (2010)	$0.5 < z < 3.5$	UV+IR	I	All
Whitaker et al. (2014)	$0.5 < z < 3$	UV+IR	I+S	All
Sobral et al. (2014)	$z \sim 2.23$	H_α	I+S+SP	SF
Reddy et al. (2012)	$2.3 < z < 3.7$	UV+IR	I+S+SP	SF
Magdis et al. (2010)	$z \sim 3$	FUV	I+S+SP	SF
Lee et al. (2011)	$3.3 < z < 4.3$	FUV	I+SP	SF
Lee et al. (2012)	$3.9 < z < 5$	FUV	I+SP	SF
González et al. (2012)	$4 < z < 6$	UV+IR	I+NE	SF
Salmon et al. (2015)	$4 < z < 6$	UV SED	I+NE+E	SF
Bouwens et al. (2011)	$4 < z < 7.2$	FUV	I+S	SF
Duncan et al. (2014)	$4 < z < 7$	UV SED	I+NE	SF
Shim et al. (2011)	$z \sim 4.4$	H_α	I+S+SP	SF
Steinhardt et al. (2014)	$z \sim 5$	UV SED	I+S	SF
González et al. (2010)	$z = 7.2$	UV+IR	I+NE	SF
This paper, Appendix D	$4 < z < 8$	FUV	I+E+NE	SF

I=IMF; S=Star formation calibration; E=Extinction; NE= Nebular Emissions; SP=SPS Model



Redshift evolution from z ~ 0.1 to z ~ 10 of the galaxy stellar mass function (GSMF) derived by using 20 observational samples from the literature and represented with the filled circles with error bars. The various GSMFs have been homogenized and corrected for potential systematics that could affect our results, see the text for details. Solid lines are the best fit model from a set of 3×10^5 MCMC trials.



Star formation rates as a function of redshift z in five stellar mass bins. Black solid lines shows the resulting best fit model to the SFRs implied by our approach. The filled circles with error bars show the observed data.

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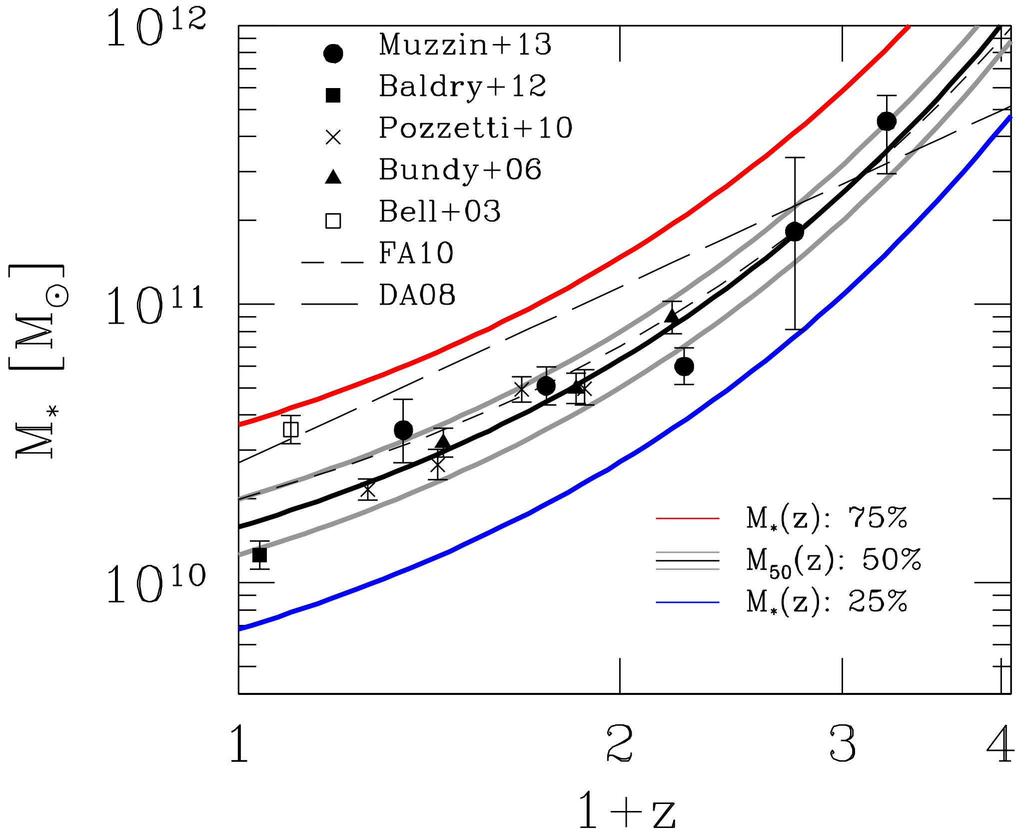


Figure 1. The stellar mass $M_{50}(z)$ at which the fractions of blue star-forming and red quenched galaxies are both 50%. The open square with error bars shows the transition mass for local galaxies as derived in Bell et al. (2003) based on the SDSS DR2 and using the $g-r$ color magnitude diagram, while the filled triangles show the transition mass derived in Bundy et al. (2006) based on the DEEP2 survey and using the $U-B$ color magnitude diagram. The long dashed line shows the results of Drory & Alvarez (2008) based on the FORS Deep Field survey using the SFR distribution. The x symbols show observations from Pozzetti et al. (2010) based on the COSMOS survey using the SFR distribution. A filled square shows observations from Baldry et al. (2012) based on the GAMA survey using the $g-r$ color magnitude diagram. Filled circles show observations from Muzzin et al. (2013) based on the COSMOS/ULTRAVISTA survey using the UVJ diagram. The short dashed line shows the empirical results based on abundance matching and using the SFR distribution by Firmani & Avila-Reese (2010). The solid black line shows the relation $\log(M_{50}(z)/M_{\odot}) = 10.2 + 0.6z$ employed in this paper, which is consistent with most of the above studies. The gray solid lines show the results when shifting $(M_{50}(z)/M_{\odot})$ 0.1 dex higher and lower. The red (blue) curves show the stellar mass vs. z where 75% (25%) of the galaxies are quenched.

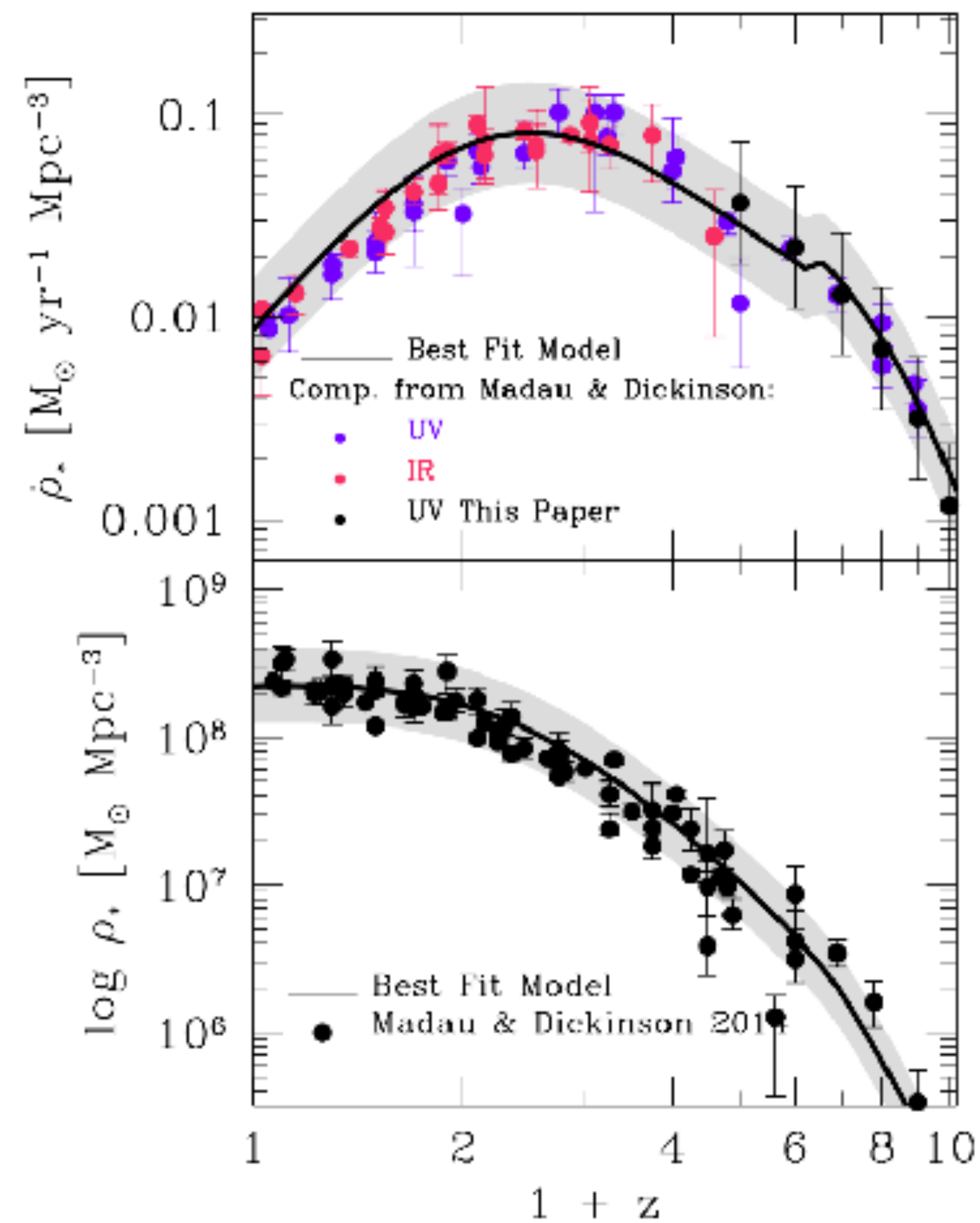
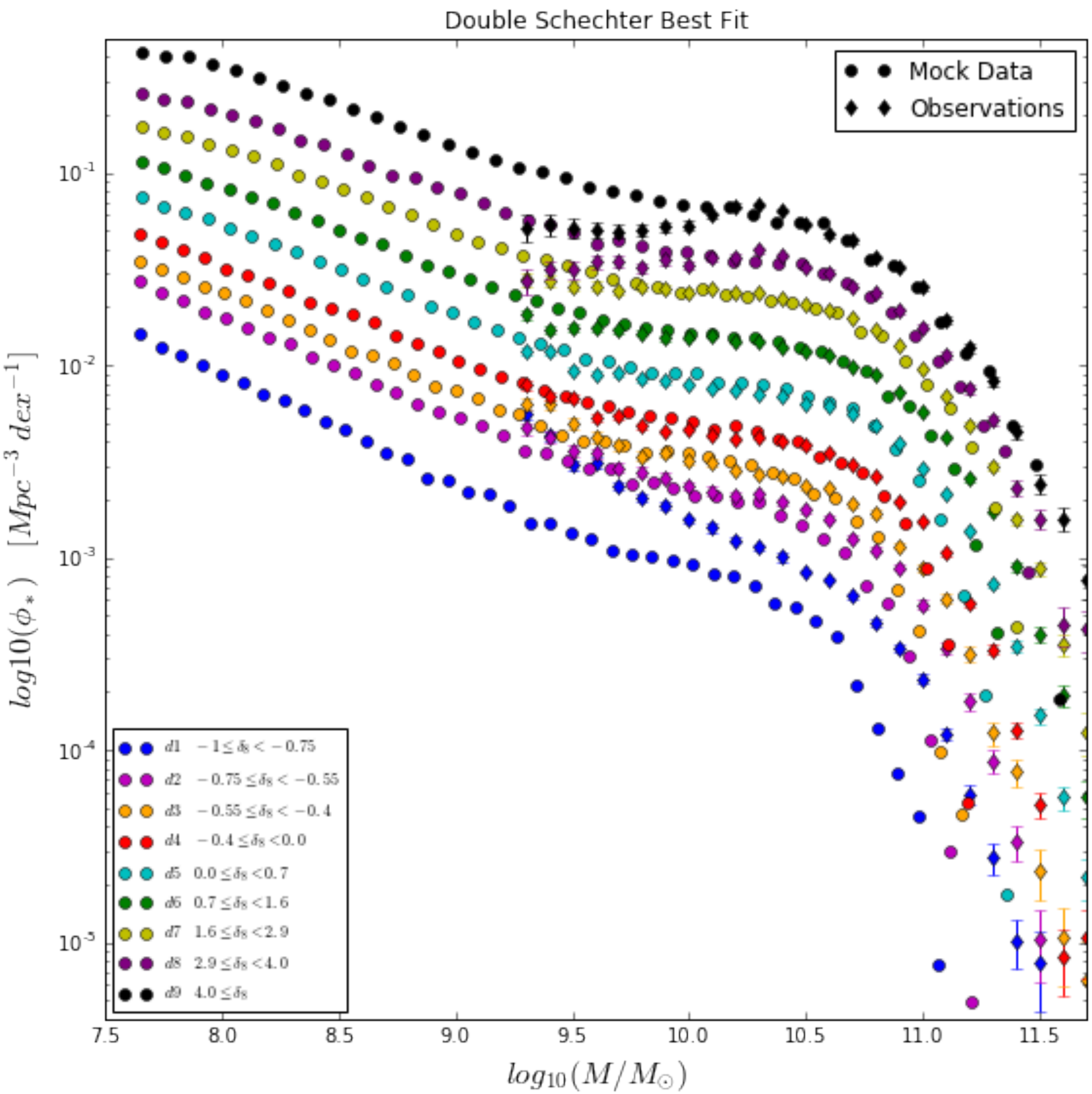


Figure 5. Upper Panel: Cosmic star formation rate, CSFR. The solid black line shows the resulting best fit model to the CSFR as described in Section 2.4. Filled red and violet circles show a set of compiled observations by Madau & Dickinson (2014) from FUV+IR rest frame luminosities. UV luminosities are dust-corrected. Black solid circles show the results from the UV dust-corrected luminosity functions described in Appendix D. **Lower Panel:** Cosmic stellar mass density. The solid black line shows the predictions for our best fit model. Filled black circles show the data points compiled in Madau & Dickinson (2014). All data was adjusted to the IMF of Chabrier (2003). In both panels, the light grey shaded area shows the systematic assumed to be of 0.25 dex.

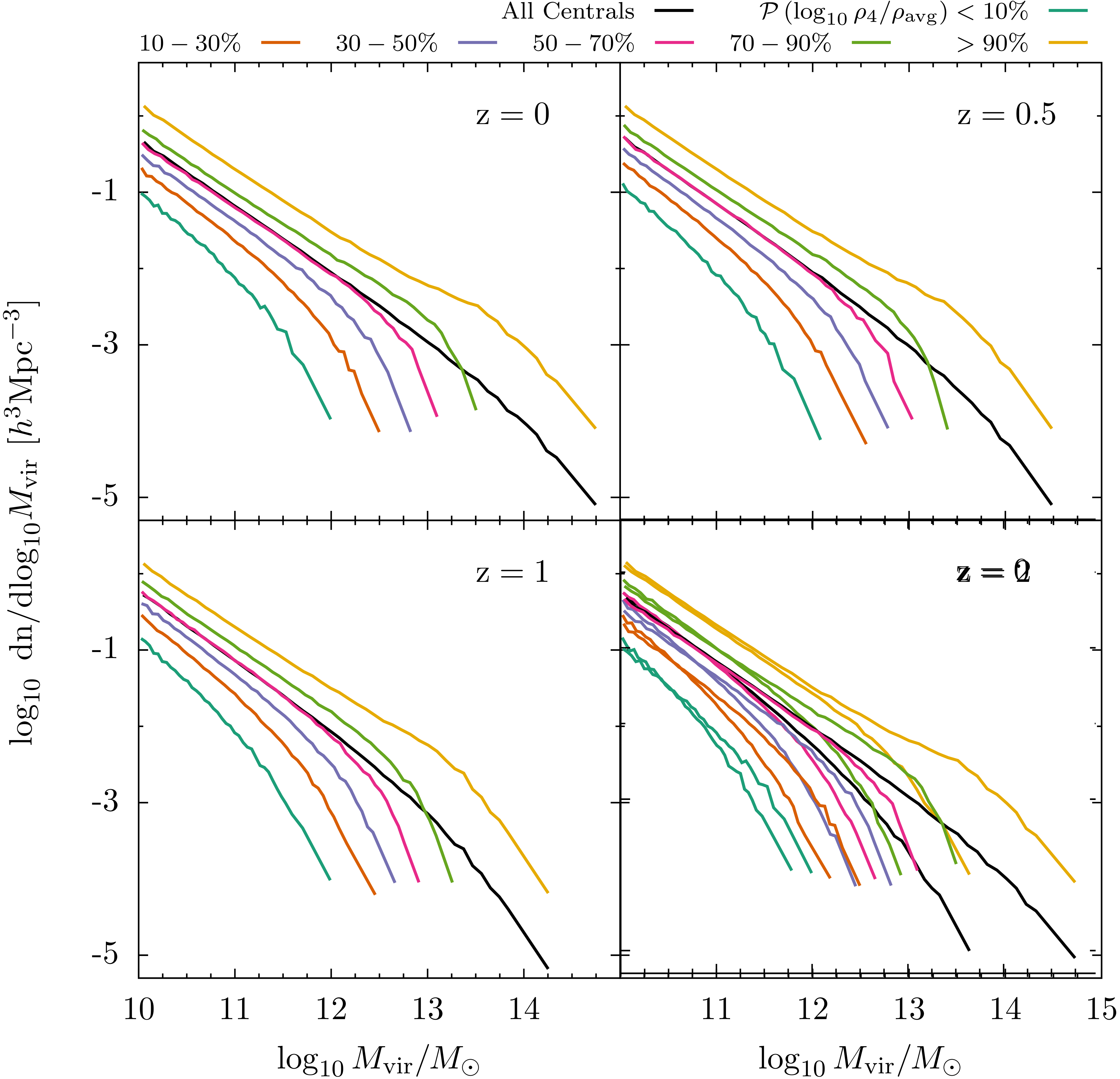
Abundance Matching is Independent of Cosmic Environment Density, based on Radu Dragomir's UCSC senior thesis, advised by Aldo and Joel. We're drafting this now — here's a new figure, showing that the mock mass function agrees very well with the SDSS data at all but the lowest densities:



This expands on Radu Dragomir's UCSC senior thesis, which showed that the r-band luminosity function at different environmental densities is correctly predicted by abundance matching with no dependence on density.

We want to explore the separation between centrals vs satellites. To my knowledge there is not such a work in the field and we could do the comparison between simulation and observations very quickly through the Yang et al. galaxy group catalog.

We should also use improved density determinations for galaxies at the lower densities.



All Centrals
$\mathcal{P}(\log_{10}\rho_4/\rho_{\rm avg}) < 10\%$
$10-30\%$
$30-50\%$
$50-70\%$
$70-90\%$
$> 90\%$
z = 0
z = 0.5
z = 1
z = 2
$\log_{10}\ {\rm dn/dlog_{10}}M_{\rm vir}\ [h^3{\rm Mpc}^{-3}]$
$\log_{10} M_{\rm vir}/M_\odot$
-1
-3
-5
10
11
12
13
14
15

Galaxy R_{eff} predicted by (spin parameter)(halo radius) = λR_{halo} paper led by Rachel Somerville — correcting h^{-1} error, the offset between $R_{3D}/(\lambda R_{halo})$ has mostly disappeared.

Begin forwarded message:
From: rachel somerville <somerville@physics.rutgers.edu>
Subject: re/rh comparison
Date: January 24, 2017 at 8:46:28 AM PST
To: Kuang-Han Huang <KUANGHAN@pha.jhu.edu>, Peter Behroozi <pbehroozi@gmail.com>, "Henry C. Ferguson" <ferguson@stsci.edu>

dear kuang & peter,

thank you for your sleuth work! indeed, peter was right -- there was a unit problem in my results.

because i had converted peter's original ascii lightcones for use by my SAMs, which do not use his recorded r_vir, i had correctly converted the halo masses from units of 1/h M_sun to M_sun, but NOT converted the virial radii from 1/h Mpc to Mpc.

when i correct this problem, many things make more sense. **my re/r_h in the lowest redshift bin of CANDELS now match up much better with the GAMA and kravtsov results. also the systematic offset between our results has gone away.**

BUT there is still something puzzling. in the attached plot, the black dots are my results with the units now fixed. the red triangles are from the latest catalog you sent me, using rvir_mvir_kpc_b13. the grey crosses are using the column r200c_kpc_t14. my understanding was that the rvir_mvir_kpc_b13 column should use the same halo definition and SMHM relation as my calculation, and the r200c_kpc_t14 column should reflect the results in your submitted paper. however, oddly, the gray crosses agree *better* with my calculation than the red triangles (i.e., we seem to get better agreement when using different halo mass definitions and SMHM relations) -- at least at large stellar masses.

i wanted to check with you to make sure i understood your catalog correctly. what do you think about this? maybe it is still worth doing the check of running your code on the mocks with scatter? i can send you a new mock, or you can just divide all the virial radii by h.

best

rachel

--
-+
dr. rachel somerville somerville@physics.rutgers.edu

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The Relationship between Galaxy and Dark Matter Halo Size from $z \sim 3$ to the present

Rachel S. Somerville[1,2], Peter Behroozi[3], Viraj Pandya[4], Avishai Dekel[5], S. M. Faber[4], H. C. Ferguson[6], Adriano Fontana[10], Kuang-Han Huang[7], Anton M. Koekemoer[6], David Koo[4], P. G. Pérez-González[8], Joel R. Primack[9], Paola Santini[10], Edward N. Taylor[11], Arjen van der Wel[12]

$$\mathrm{SHRH}\lambda \equiv R_{\mathrm{eff}}/(\lambda\, R_{\mathrm{halo}})$$

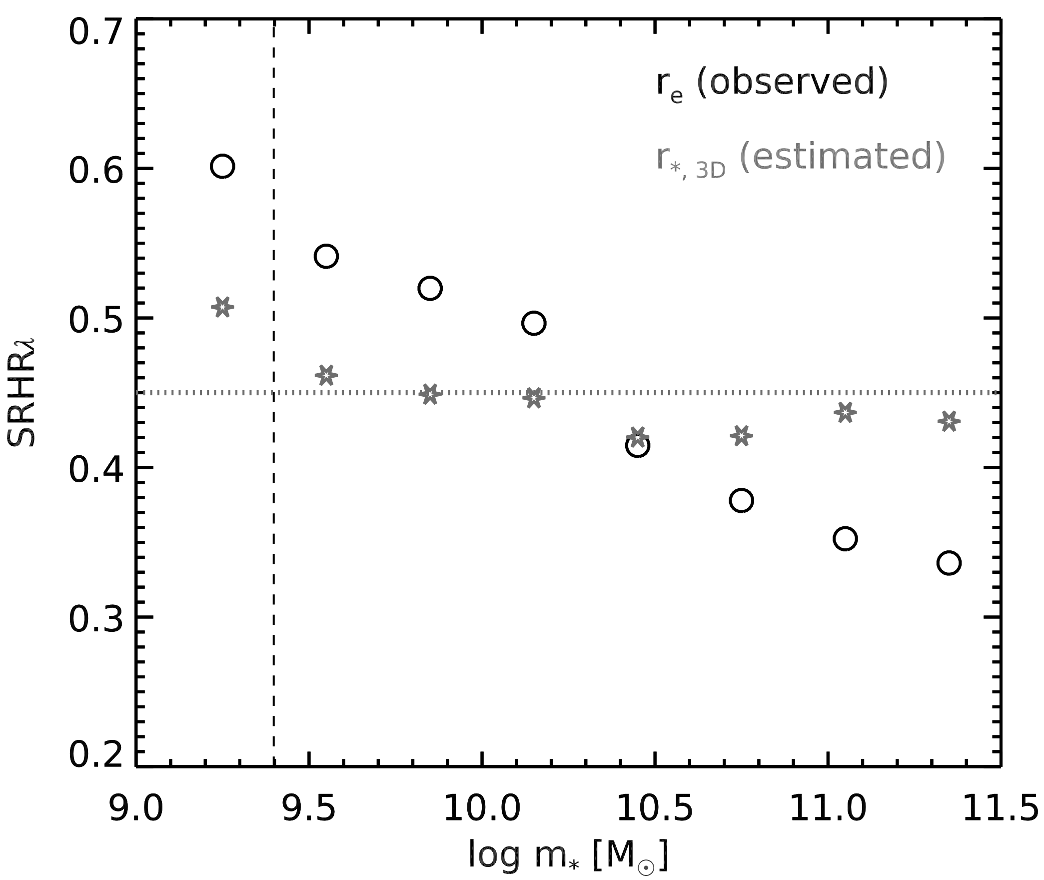


Figure 5. Median radius divided by the median value of the spin parameter times the halo virial radius, in bins of stellar mass, at $z \sim 0.1$. Open circles are based on the GAMA DR2 catalogs and are for the observed (projected) r-band half-light radius r_e. **The dashed vertical line shows the 97.7% stellar mass completeness limit for the GAMA sample.** Gray star symbols show the same quantity for the estimated 3D half-stellar mass radius ($r_{*,3D}$). It is striking that the ratio between galaxy size and halo size remains so nearly constant over a wide range in stellar mass.

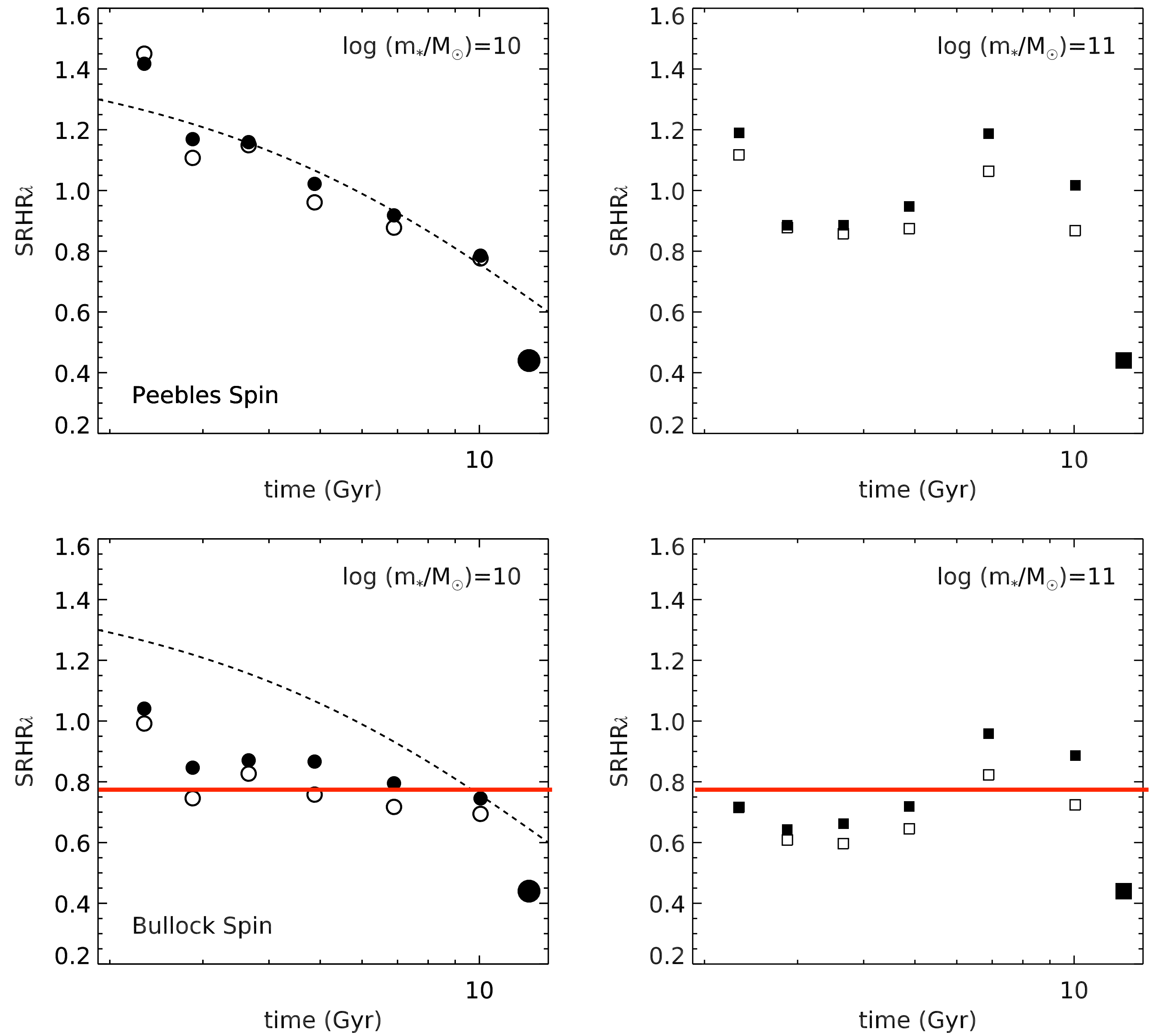
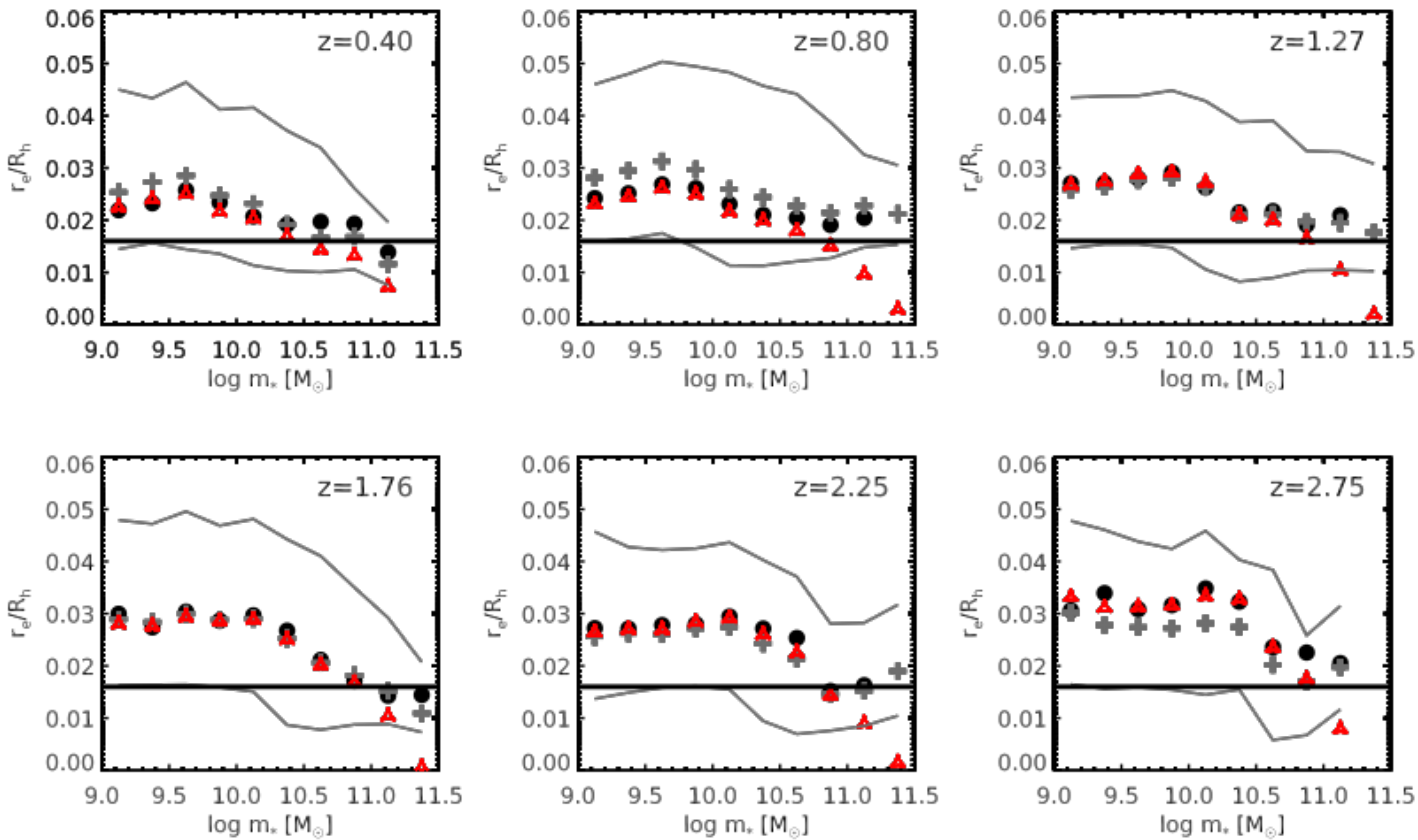


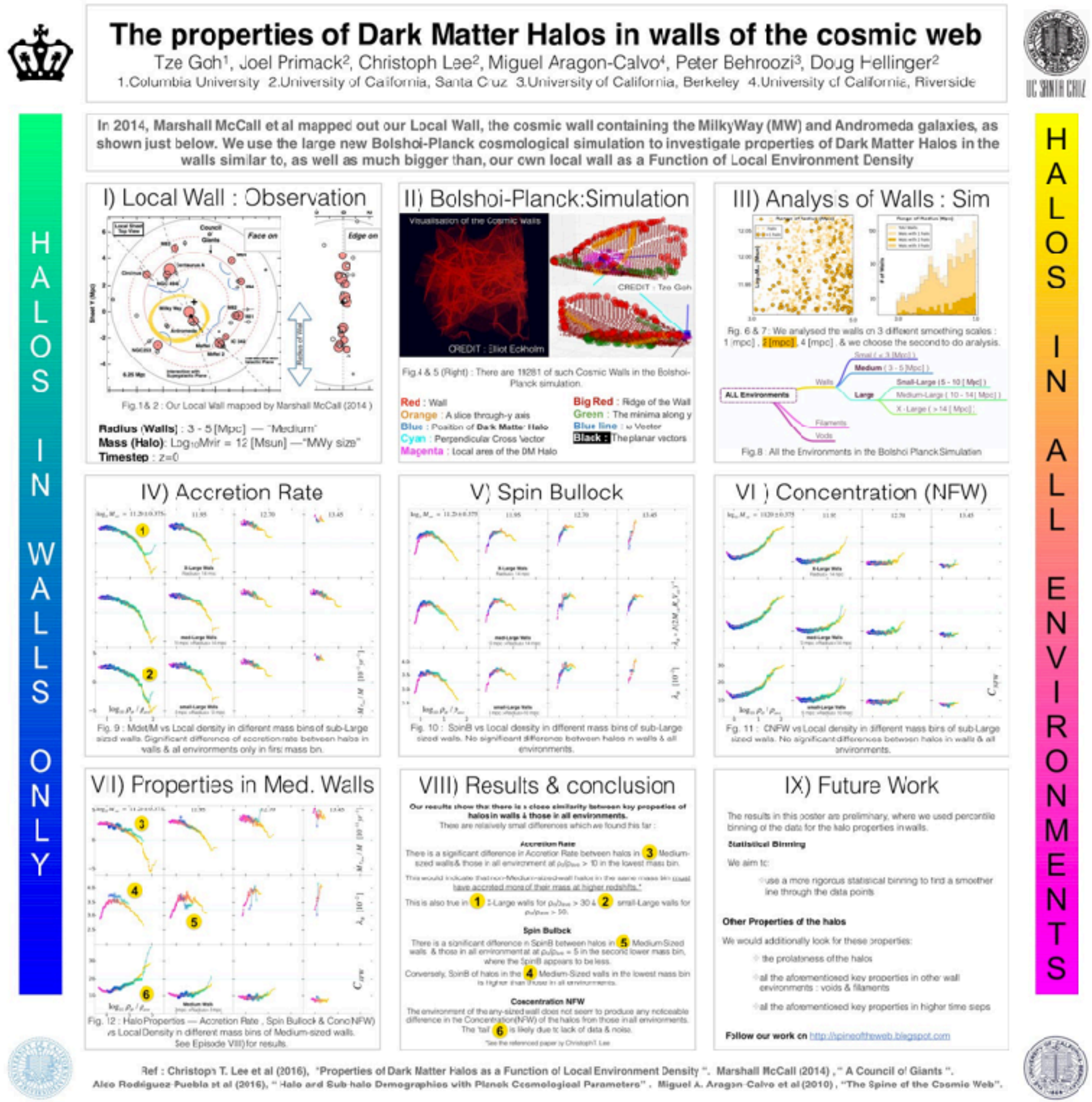
Figure 9. Time evolution of the ratio between median $r_{*,3D}$ and λR_h for two different stellar mass bins: $10^{9.75}\,\mathrm{M}_\odot < m_* < 10^{10.25}\,\mathrm{M}_\odot$ (left; filled) and $10^{10.75}\,\mathrm{M}_\odot < m_* < 10^{11.25}\,\mathrm{M}_\odot$ (right; filled). Top row: Peebles spin; Bottom row: Bullock spin. The result for the $z = 0.1$ GAMA sample is nearly identical for both mass bins, and is shown by the large symbol. The ratio of the mean quantities is shown by the open symbols — using means instead of medians results in slightly different values of SRHRλ, but does not change any of the trends. The time dependence of SRHRλ for the lower stellar mass bins (when using the Peebles spin) is fairly well fit by a declining exponential with a timescale of 15 Gyr (shown by the dashed line in both of the left panels). The value of SRHRλ for massive galaxies remains nearly constant, or increases slightly, with cosmic time within the CANDELS sample. The CANDELS values, however, seem systematically higher than those derived for GAMA.

When i correct this problem, many things make more sense. **my re/r_h in the lowest redshift bin of CANDELS now match up much better with the GAMA and kravtsov results. also the systematic offset between our results has gone away.**

BUT there is still something puzzling. in the attached plot, the black dots are my results with the units now fixed. the red triangles are from the latest catalog you sent me, using rvir_mvir_kpc_b13. the grey crosses are using the column r200c_kpc_t14. my understanding was that the rvir_mvir_kpc_b13 column should use the same halo definition and SMHM relation as my calculation, and the r200c_kpc_t14 column should reflect the results in your submitted paper. however, oddly, the gray crosses agree *better* with my calculation than the red triangles (i.e., we seem to get better agreement when using different halo mass definitions and SMHM relations) -- at least at large stellar masses.



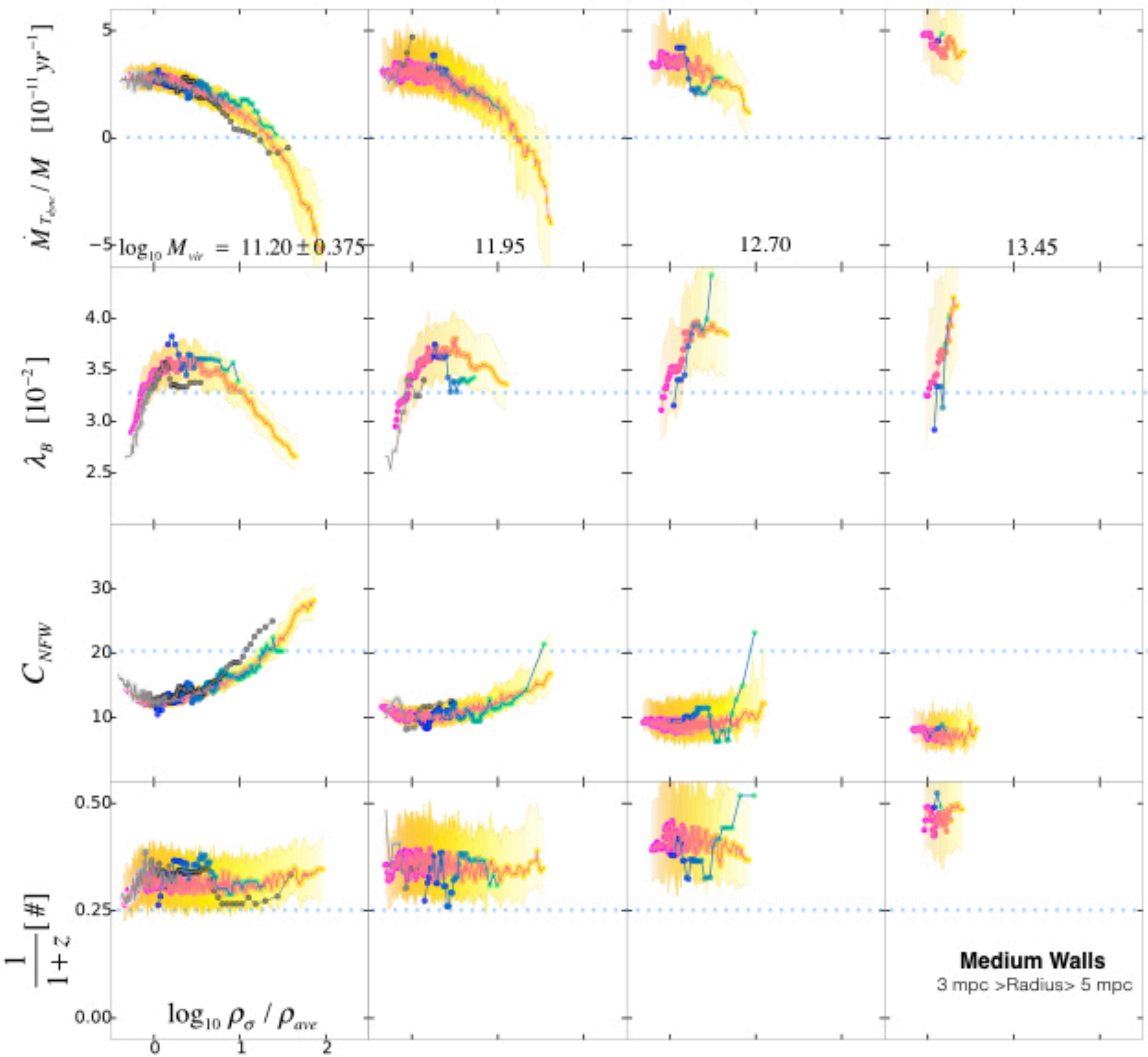
Jan 2017 **AAS Poster** by Tze Goh showing halo properties like concentration, accretion history, and spin are mainly determined by environmental density rather than by location within the cosmic web. Download the poster at http://spineoftheweb.blogspot.com/



Halo Properties in Med. Walls vs Density

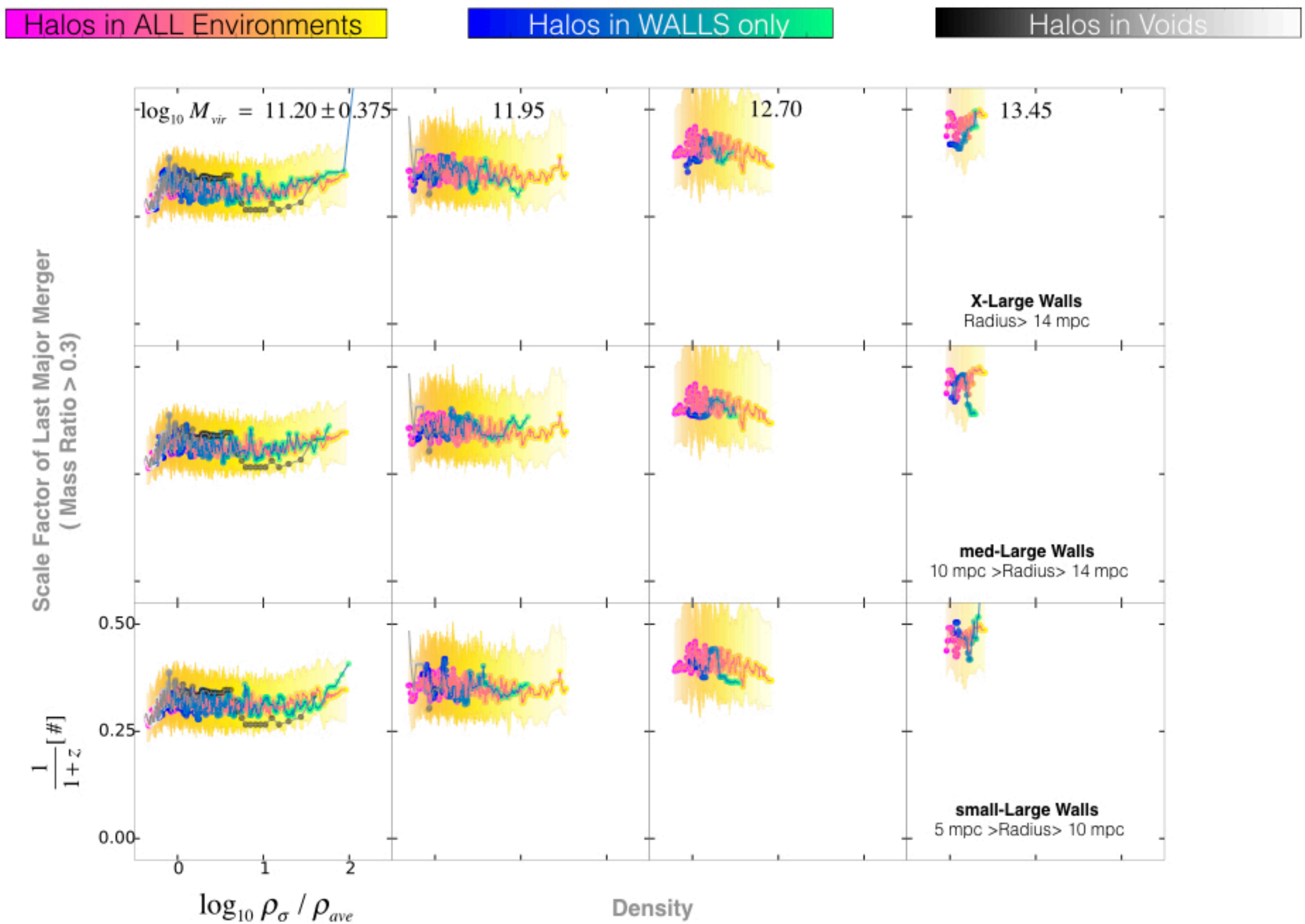
Accretion Rate, SpinB, CFNW, Scale factor of the last major merger is compared with density in different mass bins of medium sized walls only

Halos in ALL Environments | Halos in WALLS only | Halos in Voids



Scale Factor of Last MM vs Density

Scale Factor of last major merger compared with density in different mass bins of sub-Large sized walls only



Spin Bullock vs Density

SpinB is compared with density in different mass bins of sub-Large sized walls only