A Simple Model for Galaxy Evolution

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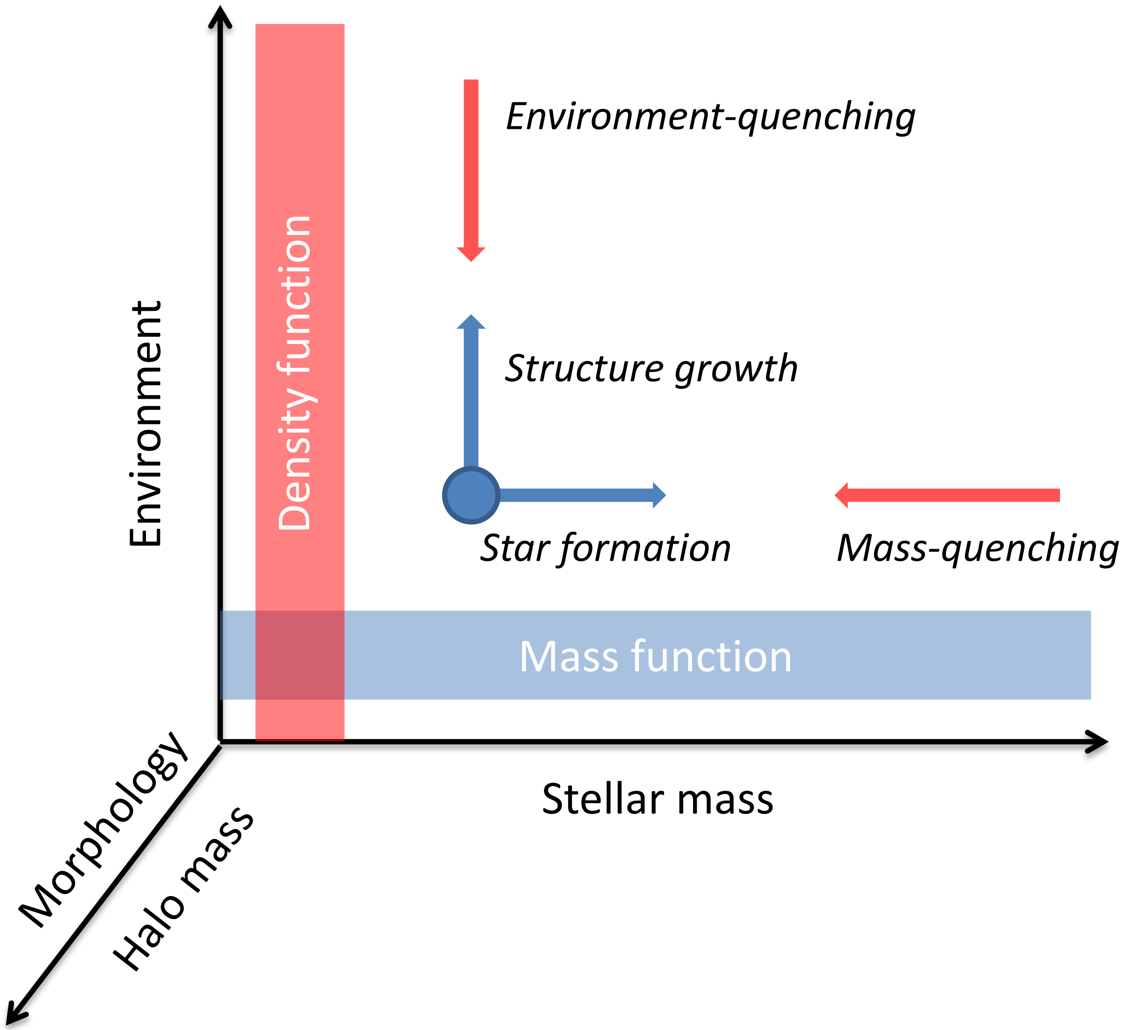
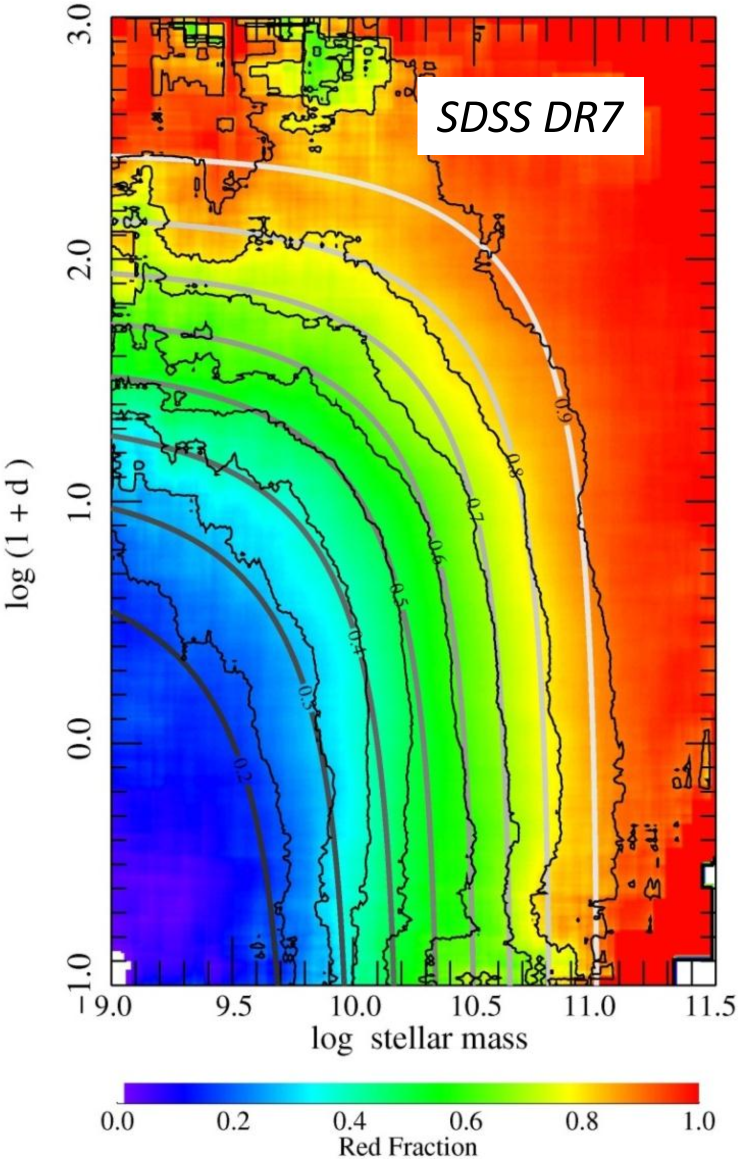
Yingjie Peng, Simon J. Lilly, et al. 2010, ApJ, 721, 193
Yingjie Peng, Simon J. Lilly, Alvio Renzini, Marcella Carollo, 2011, arXiv:1106.2546

Galaxy Evolution as a Dynamic Process

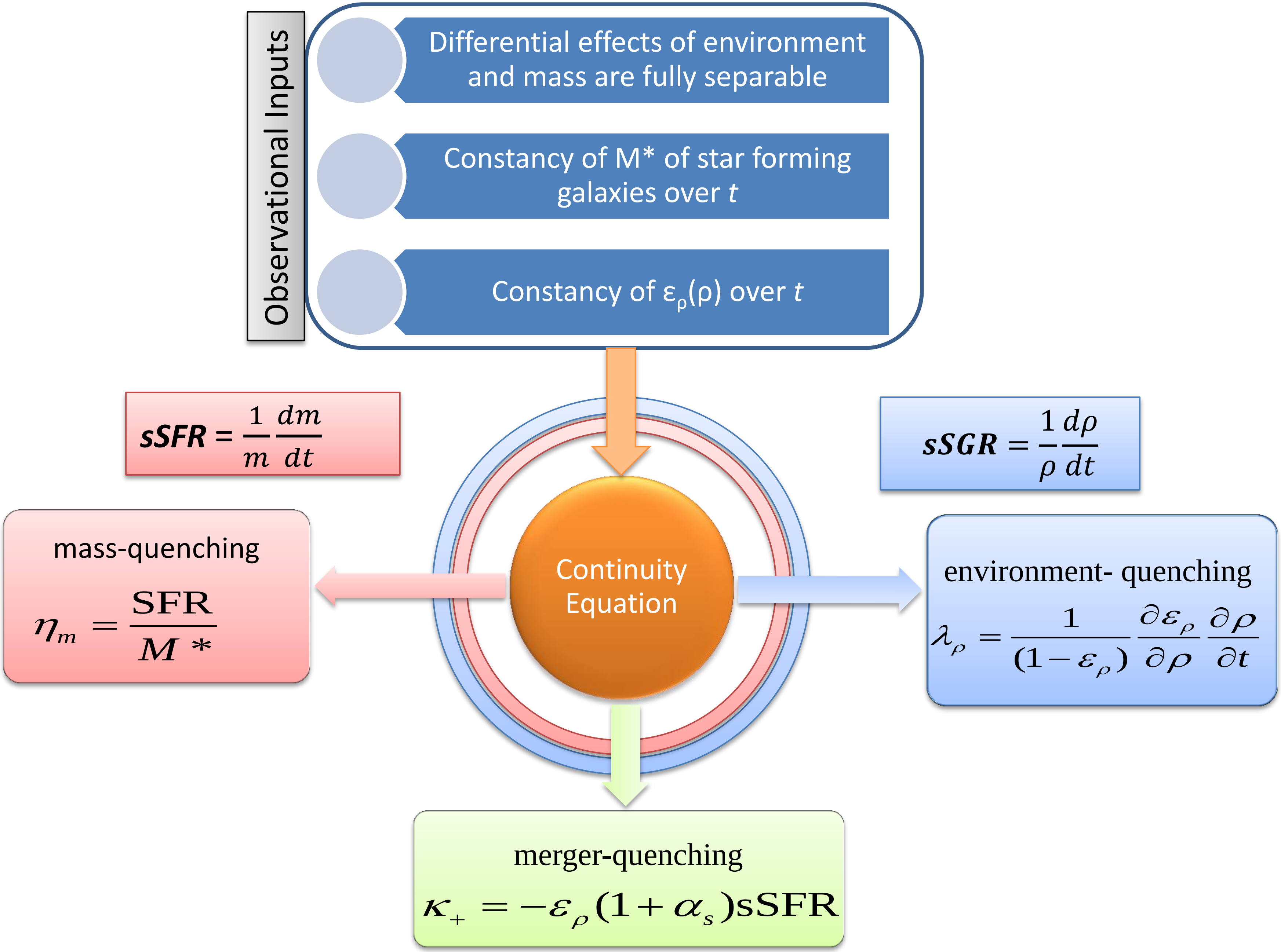




Continuity Equation:

$$\frac{\partial \phi_b(m,\rho)}{\partial t} + \left(\frac{\partial}{\partial \log M}\hat{m} + \frac{\partial}{\partial \log \rho}\hat{\rho}\right)\cdot\left[\phi_b(m,\rho)\left(\frac{\partial}{\partial \log M}\hat{m} + \frac{\partial}{\partial \log \rho}\hat{\rho}\right)\right] = -(\eta_m + \eta_\rho)\phi_b(m,\rho)$$

There are no non-observational parameters in the model

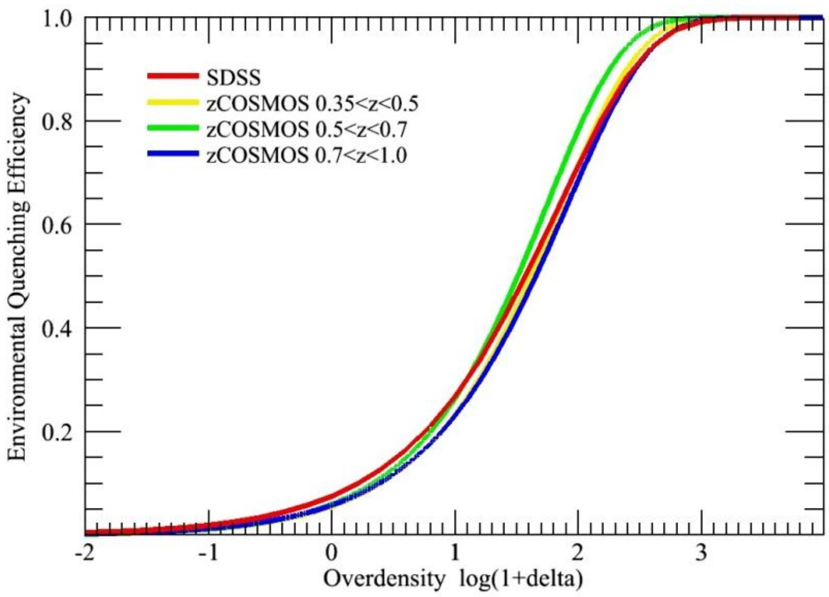


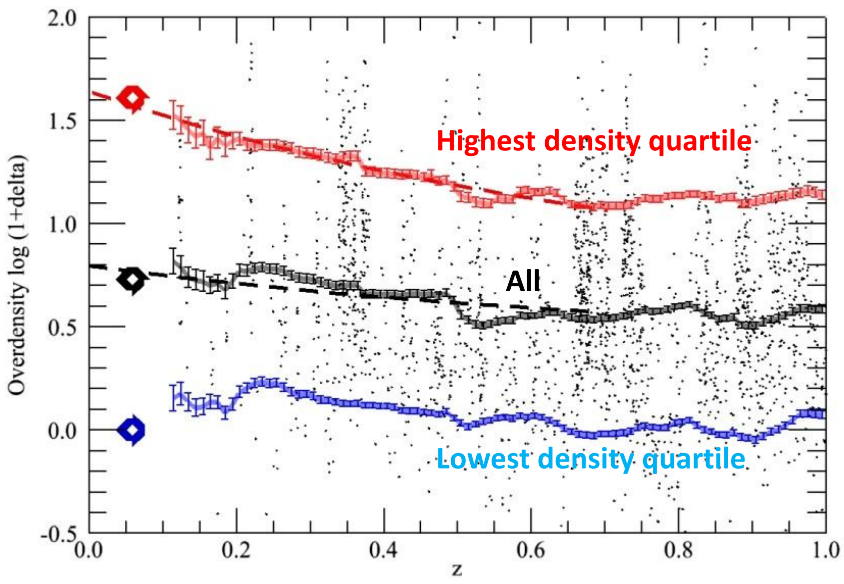
Model Constrains and Predicts

- Schechter function of star-forming galaxies
- Double-Schechter function of passive galaxies and all galaxies
- f_{red} (mass, environment, time)
- evolutionary histories of today's passive galaxies
- the "anti-hierarchical" run of mean age with mass for passive galaxies
- satellites-quenching
- the role of halo mass
- mass- function evolution, star formation history and stellar mass assembly history
- the amount of "dry merging"
- major merger rate
- Mass-function of the transient galaxies (e.g. AGN mass function)
- An inevitable evolution of the mass function

κ quenching as the merger-quenching

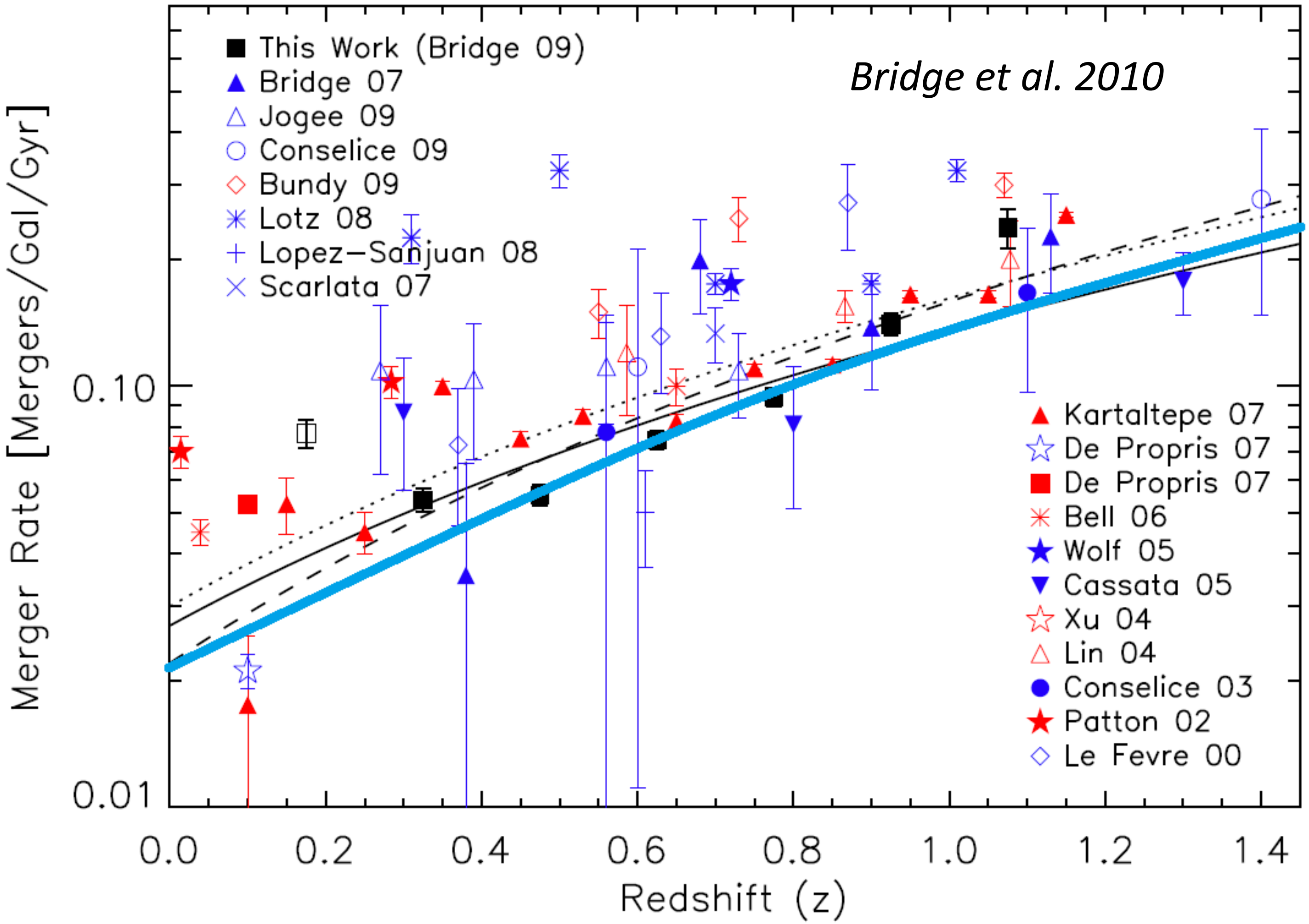
$$\kappa_{-} \sim \varepsilon_{\rho} \text{sSFR}$$





$$\kappa_{-} \sim 0.2 \text{ sSFR} \qquad 0<z<1$$

κ quenching as the merger-quenching



$\kappa_{-} \sim 0.2$ sSFR 0<z<1

The origin of the Schechter function

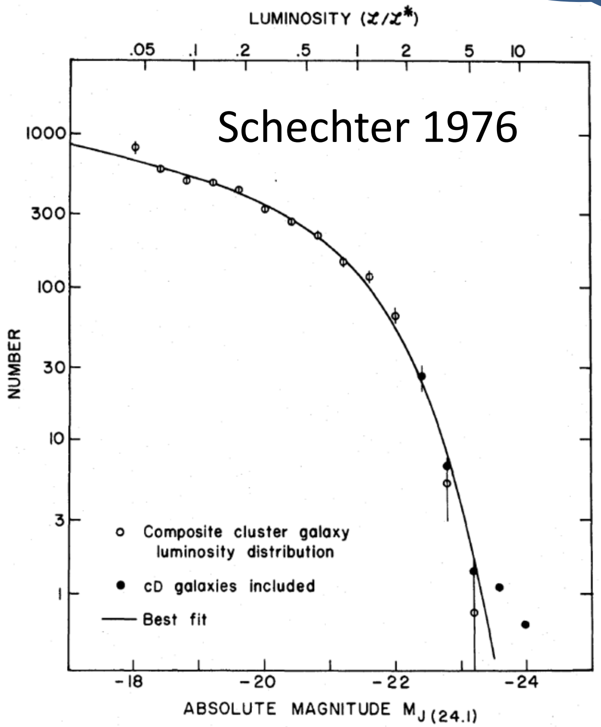
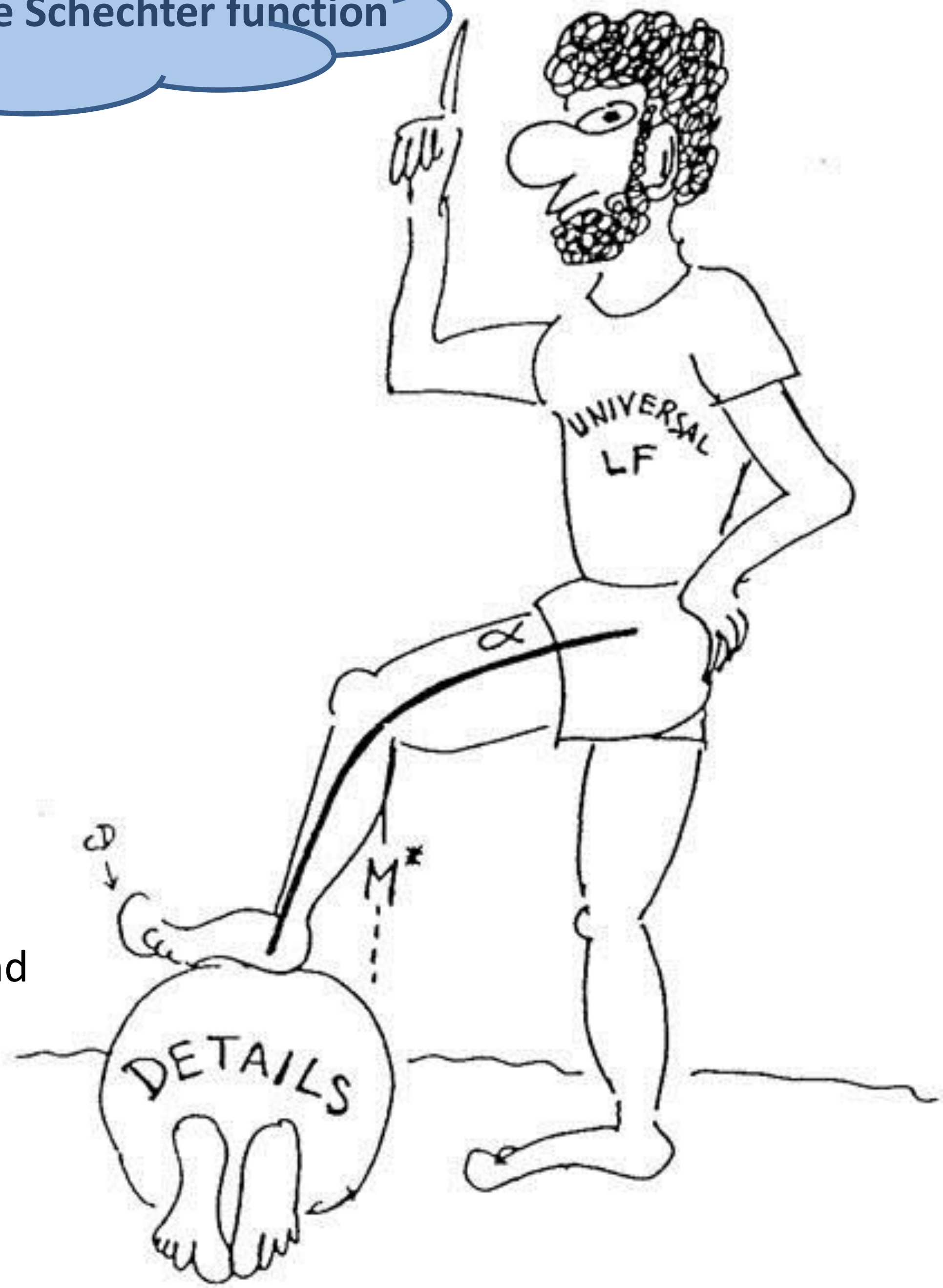


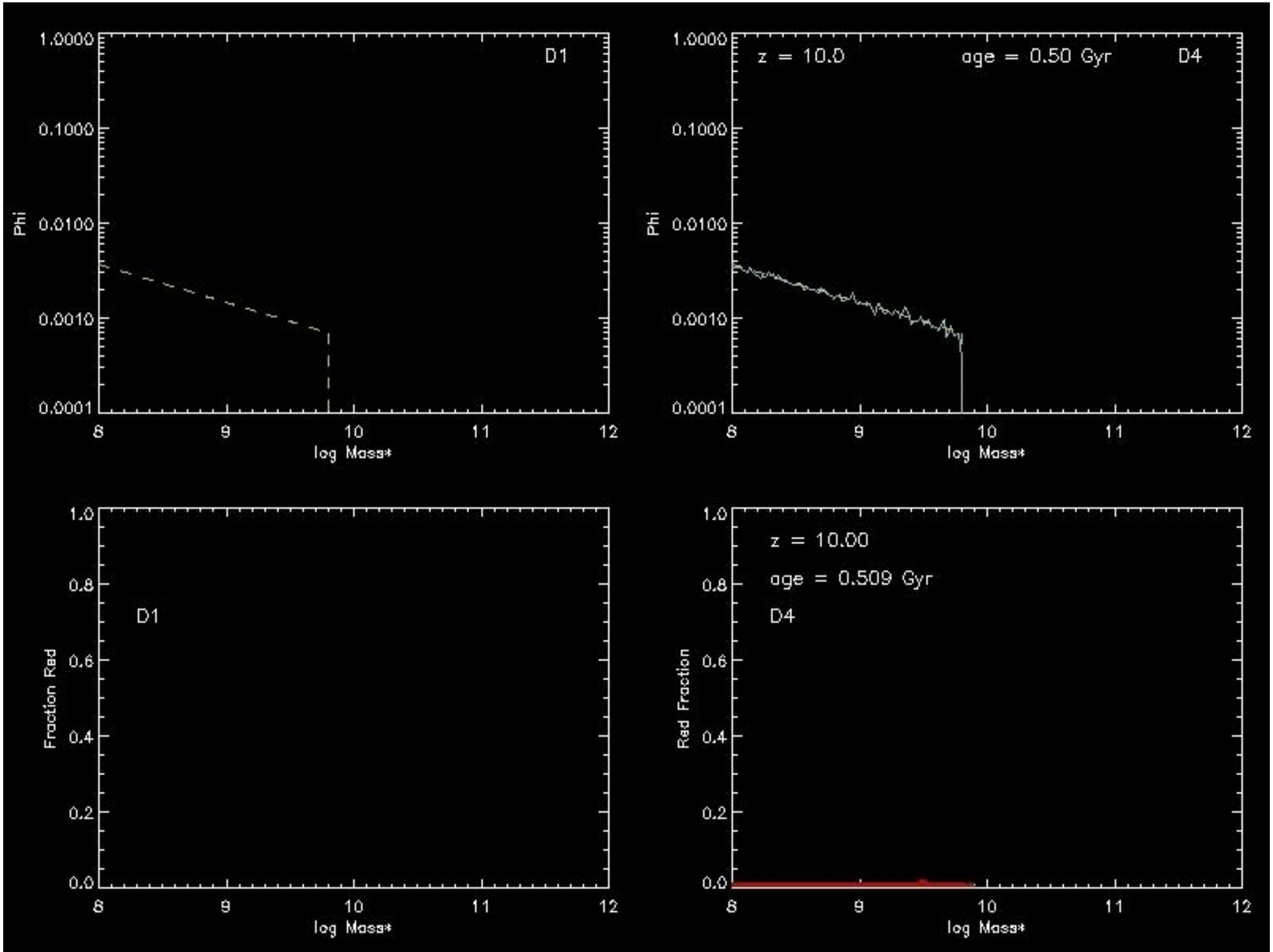
FIG. 2.—Best fit of analytic expression to observed composite cluster galaxy luminosity distribution. Filled circles show the effect of including cD galaxies in composite.



Binggeli's (1987) cartoon of Paul Schechter and his function. Quite why it has this form buries ***details*** under foot.

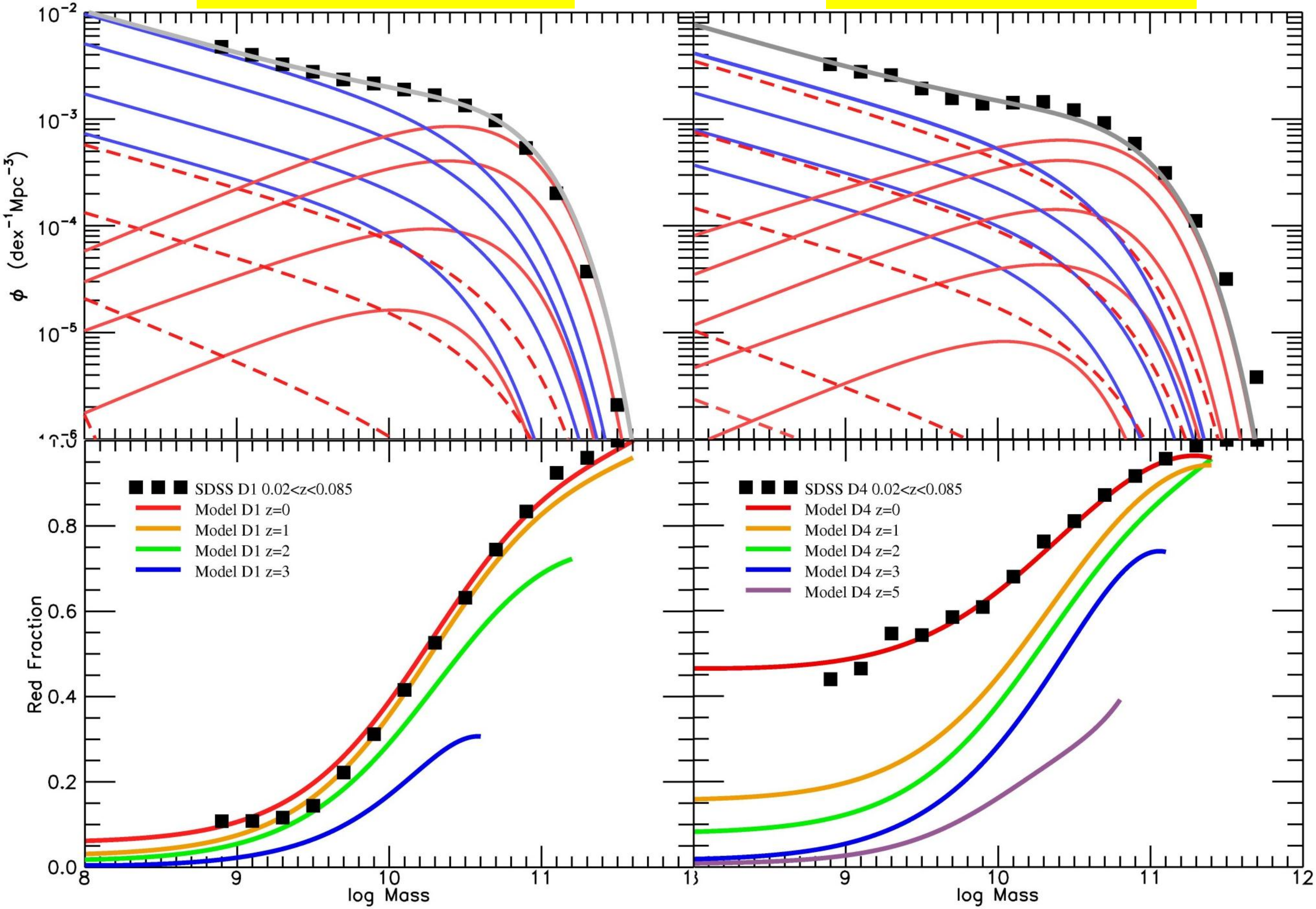
A Simple Model

For each of the two density quartiles D1 and D4, we generate a sample of 6 million star-forming galaxies at z = 10, following a primordial logarithmic mass function and taking the combined quenching rate at all times and for all galaxies.

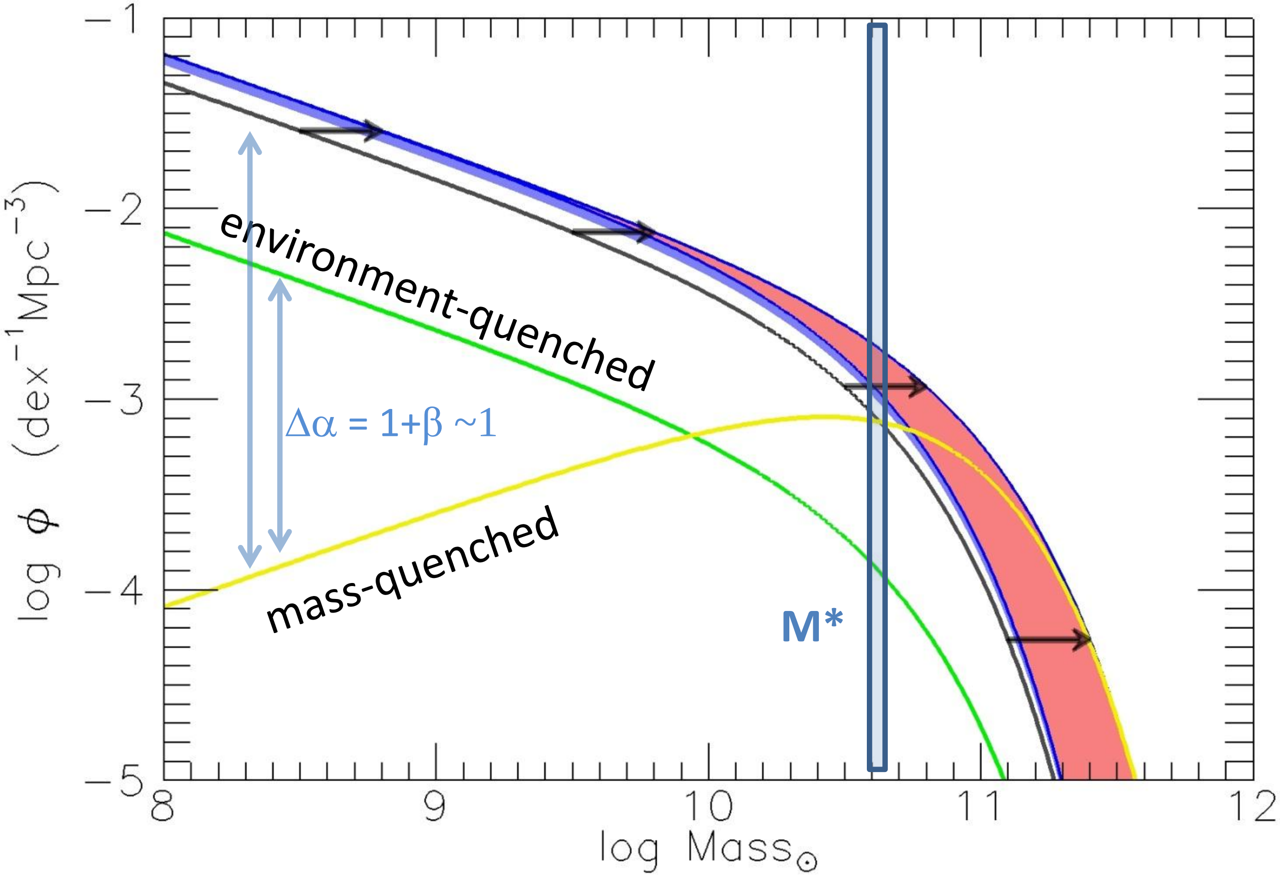


Predicted mass functions (top) and red fractions (bottom)

Lowest density quartile *highest density quartile*



The origin of the Schechter function



MF of Star-forming galaxies

Mass increase due to SF

Constant M* and α (z<~2)

mass-quenching

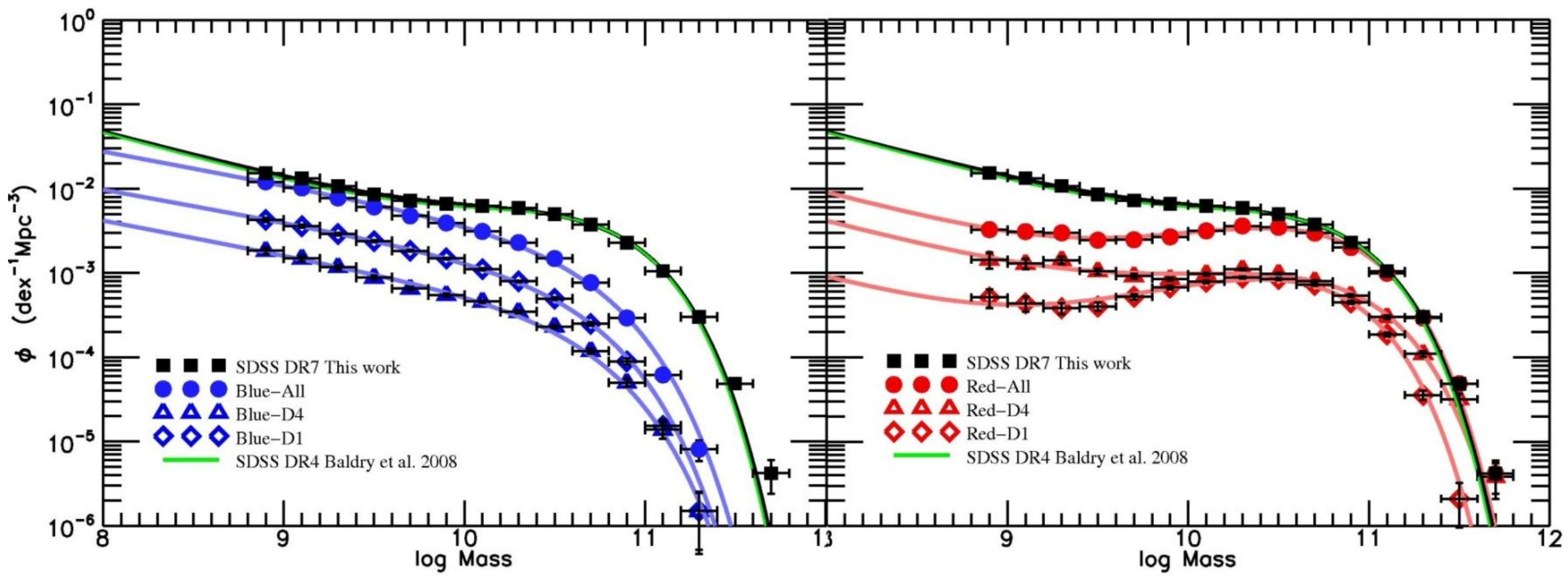
environment-quenching

post-quenching merging

increases the M* of the

passive galaxies

Observational Tests with SDSS



	$\log(M^*/M_\odot)$	$\phi_1^*/10^{-3}\mathrm{Mpc}^{-3}$	α_1	$\phi_2^*/10^{-3}\mathrm{Mpc}^{-3}$	α_2
Global	10.67 ± 0.01	4.032 ± 0.12	-0.52 ± 0.04	0.655 ± 0.09	-1.56 ± 0.12
Blue-all	10.63 ± 0.01	...	...	1.068 ± 0.03	-1.40 ± 0.01
Blue-D1	10.60 ± 0.01	...	...	0.417 ± 0.02	-1.39 ± 0.02
Blue-D4	10.64 ± 0.02	...	...	0.151 ± 0.01	-1.41 ± 0.04
Red-all	10.68 ± 0.01	3.410 ± 0.07	-0.39 ± 0.03	0.126 ± 0.02	(-1.56)
Red-D1	10.61 ± 0.01	0.893 ± 0.03	-0.36 ± 0.05	0.014 ± 0.01	(-1.56)
Red-D4	10.76 ± 0.02	0.814 ± 0.03	-0.55 ± 0.06	0.052 ± 0.01	(-1.56)

Single and Double Schechter functions for SF and passive? Double for total? ✔

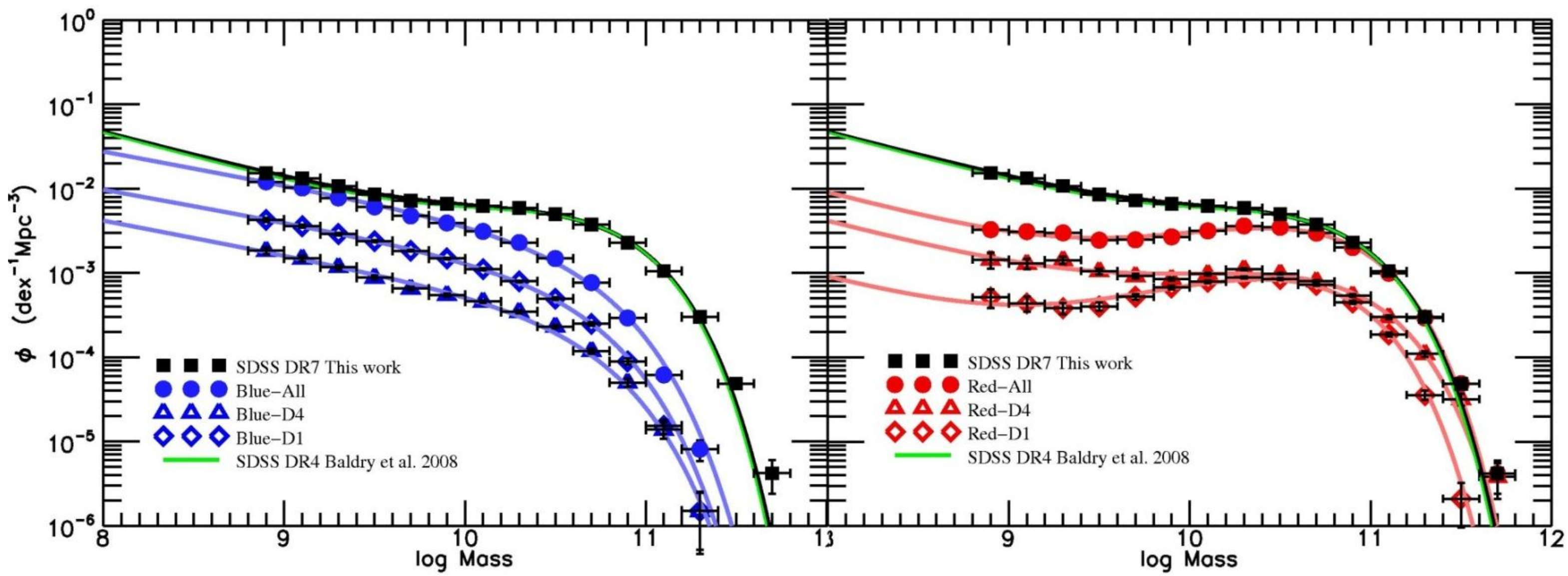
M* and α the same for SF in D1 and D4? ✔

M* the same for SF and passive in D1, α differs by $\Delta\alpha = 1$ (for $\beta = 0$)? ✔

φ* for secondary passive population higher in D4 than D1? ✔

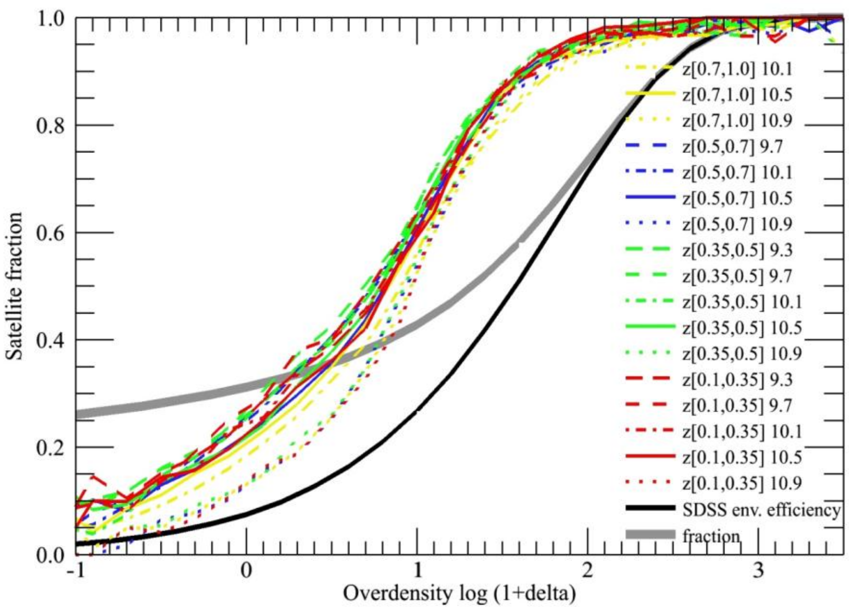
Post-quenching merging modifies M* and α for passives in D4? ✔

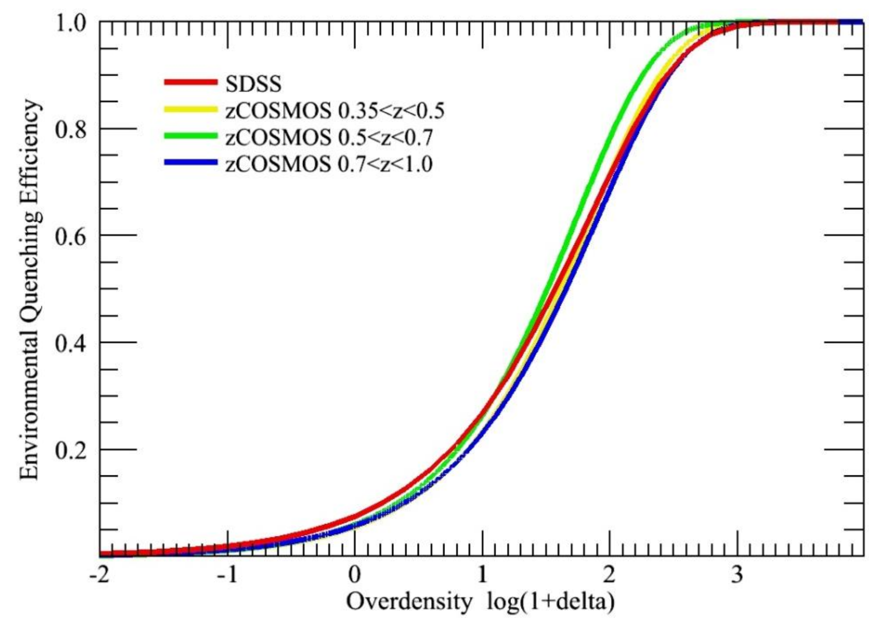
Observational Tests with SDSS



SDSS data	Prediction from model (without mergers)
$\left.\frac{\phi_{red}}{\phi_{blue}}\right\rvert_{M^*,\rho} = \frac{\phi^*_{red,1}+\phi^*_{red,2}}{\phi^*_{blue}} = \begin{cases} 2.26 & \text{D1} \\ 6.54 & \text{D4} \end{cases}$	$\left.\frac{\phi_{red}}{\phi_{blue}}\right\rvert_{M^*,\rho} = \frac{\phi^*_{red,1}+\phi^*_{red,2}}{\phi^*_{blue}} = \frac{\varepsilon_\rho + H^*}{1-\varepsilon_\rho} = \begin{cases} 2.80 & \text{D1} \\ 6.78 & \text{D4} \end{cases}$
$\frac{\phi^*_{red,1}}{\phi^*_{blue}} = \begin{cases} 2.2 & \text{D1} \\ 5.8 & \text{D4} \end{cases}$	$\frac{\phi^*_{red,1}}{\phi^*_{blue}} = -\frac{1}{(1-\varepsilon_\rho)(1+\alpha_s)} = \begin{cases} 2.71 & \text{D1} \\ 5.56 & \text{D4} \end{cases}$
$\frac{\phi^*_{red,2}}{\phi^*_{blue}} = \begin{cases} 0.06 & \text{D1} \\ 0.75 & \text{D4} \end{cases}$	$\frac{\phi^*_{red,2}}{\phi^*_{blue}} = \frac{\varepsilon_\rho}{1-\varepsilon_\rho} = \begin{cases} 0.087 & \text{D1} \\ 1.22 & \text{D4} \end{cases}$
$\frac{\phi^*_{red,1}}{\phi^*_{red,2}} = \begin{cases} 35.3 & \text{D1} \\ 7.78 & \text{D4} \end{cases}$	$\frac{\phi^*_{red,1}}{\phi^*_{red,2}} = -\frac{1}{\varepsilon_\rho(1+\alpha_s)} = \begin{cases} 31.3 & \text{D1} \\ 4.55 & \text{D4} \end{cases}$

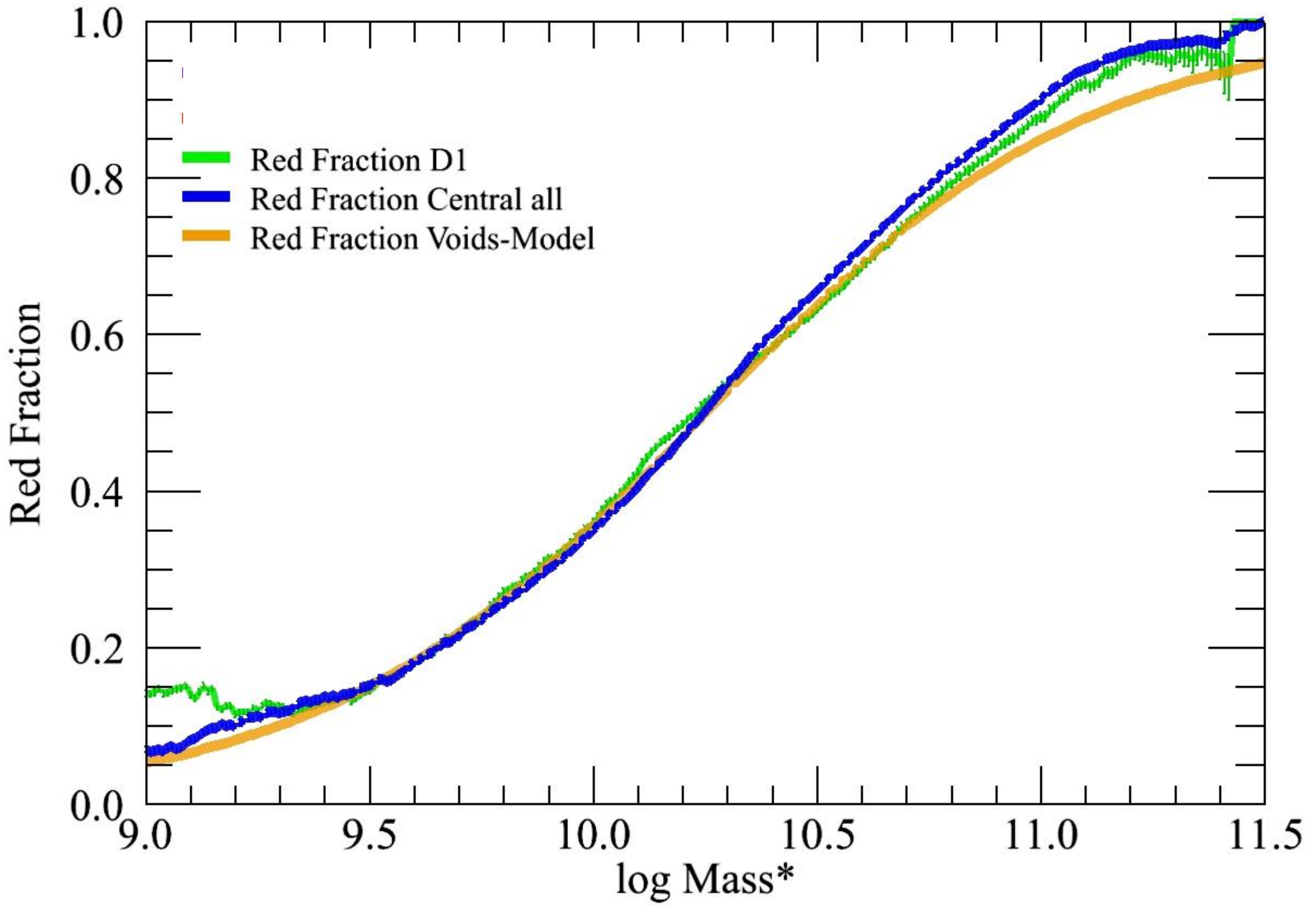
Satellite fraction averaged from 24 Millennium Run mocks (Kitzbichler & White 2007) also depends on <u>environment</u> but not on <u>mass</u> ($M < 10^{10.9}\,M_\odot$) or <u>epoch</u> ($z < 1$)





In P10, we speculate our "environment-quenching" is probably simply "satellite-quenching" with $30\% < f_{\mathrm{quench}} < 75\%$ for $\log(1+\delta) < 2$, independent of both mass and epoch.

Red fraction of Centrals/Satellites in Yang et al. SDSS Dr7 group catalogue



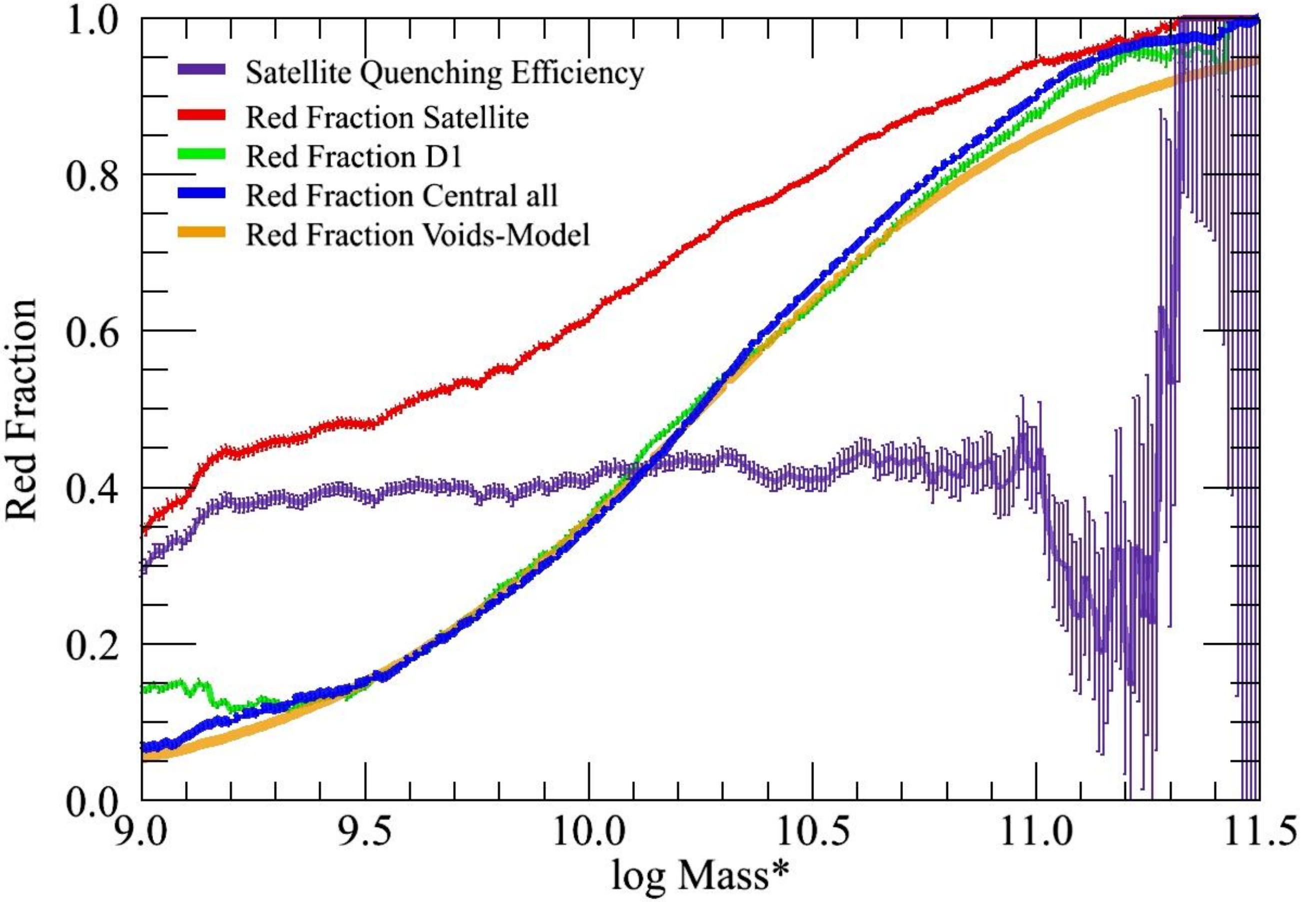
mass-quenching efficiency –
f_{red} in the most under dense regions

$$\varepsilon_m = f_{red}(m, \rho_0)$$
$$= \frac{1}{1-(1+\alpha_s)\frac{M^*}{m}}$$

log M* ~ 10.6

α_s ~ -1.4

Red fraction of Centrals/Satellites in Yang et al. SDSS Dr7 group catalogue

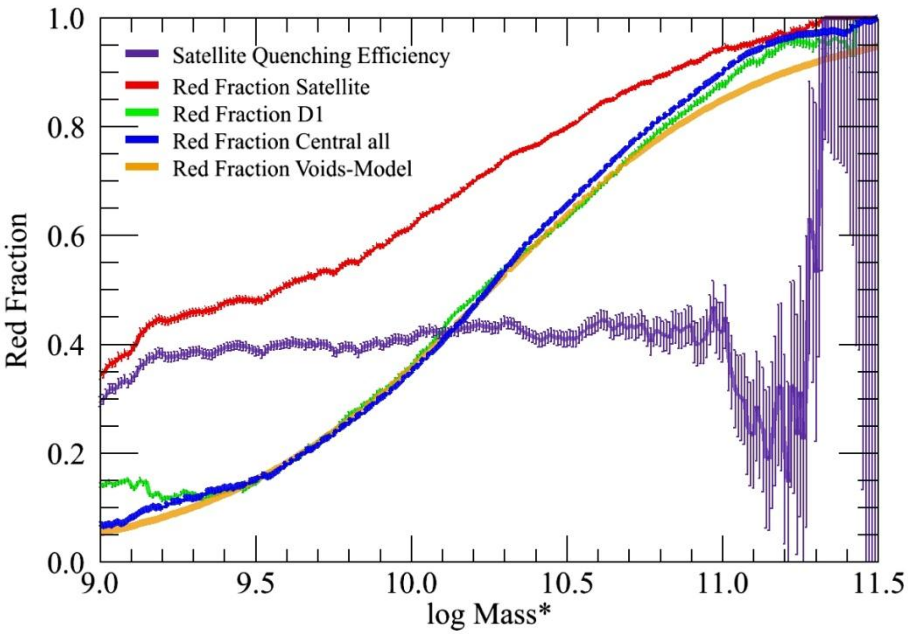


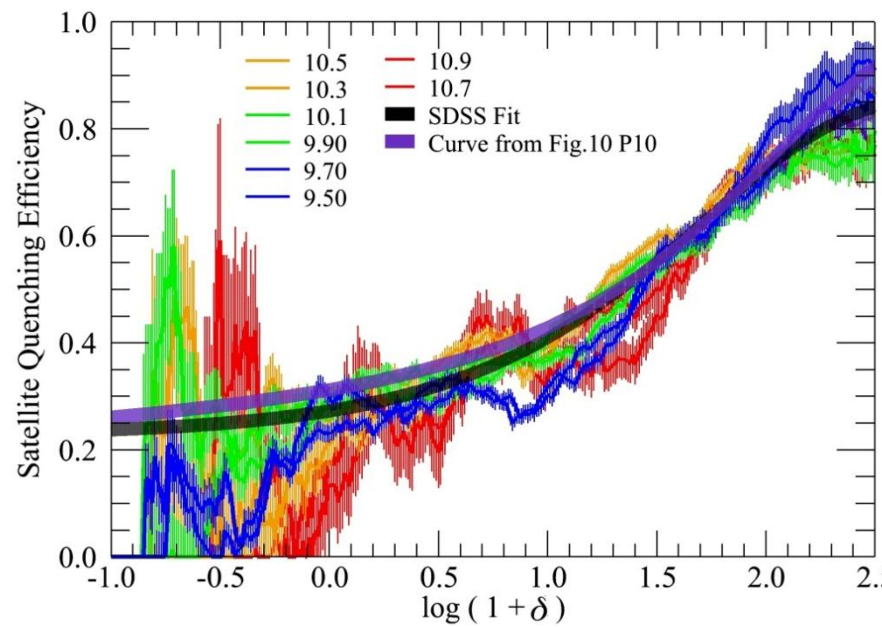
environment averaged satellite – quenching efficiency

$$\bar{\varepsilon}_{sat}(m) = \frac{\bar{f}_{sat,red}(m) - \bar{f}_{cen,red}(m)}{\bar{f}_{cen,blue}(m)}$$

$$\bar{\varepsilon}_{sat} \sim 40\%$$

Red fraction of Centrals/Satellites in Yang et al. SDSS Dr7 group catalogue





environment averaged satellite–quenching efficiency

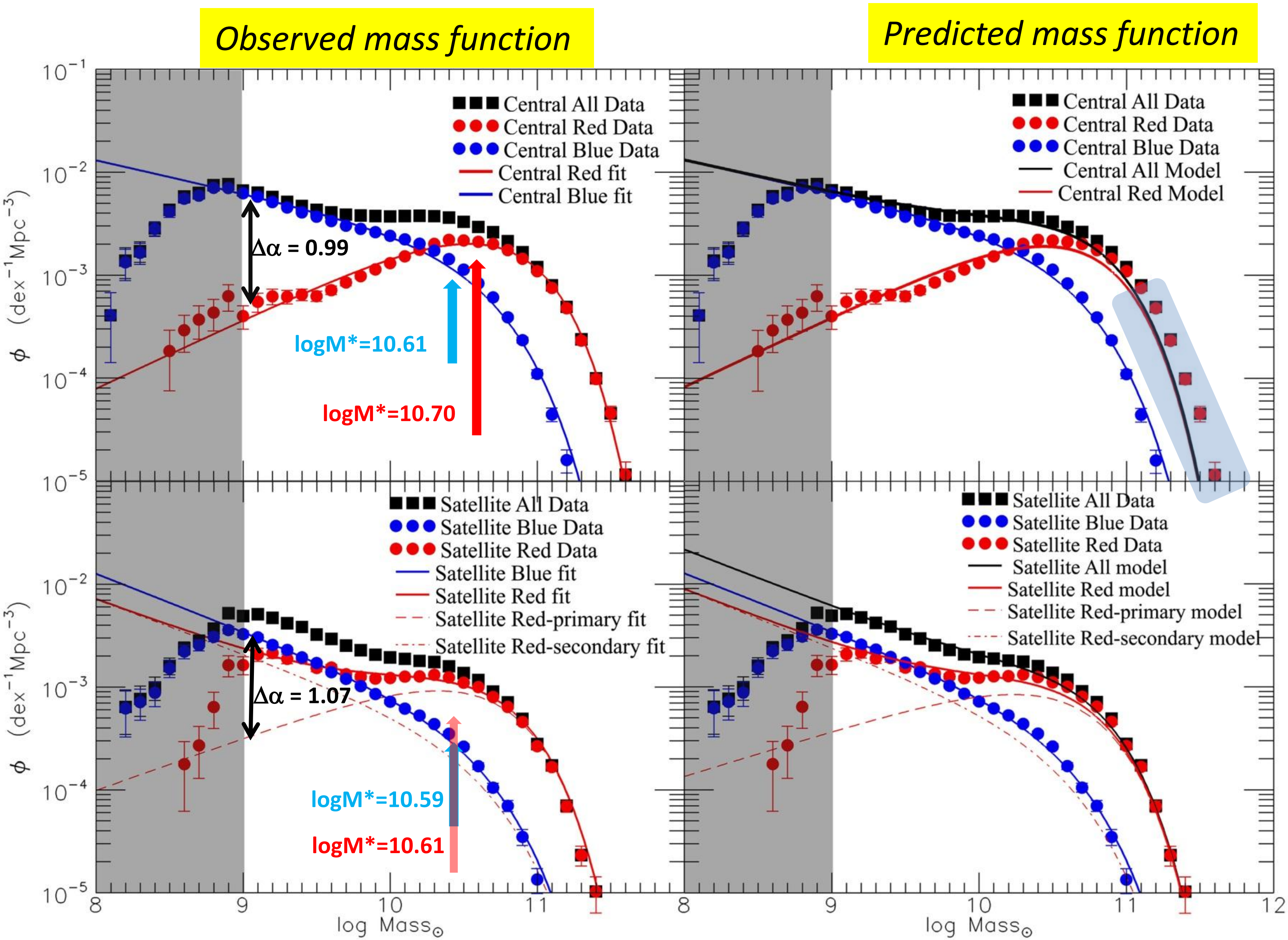
$$\bar{\varepsilon}_{sat} \sim 40\%$$

independent of mass

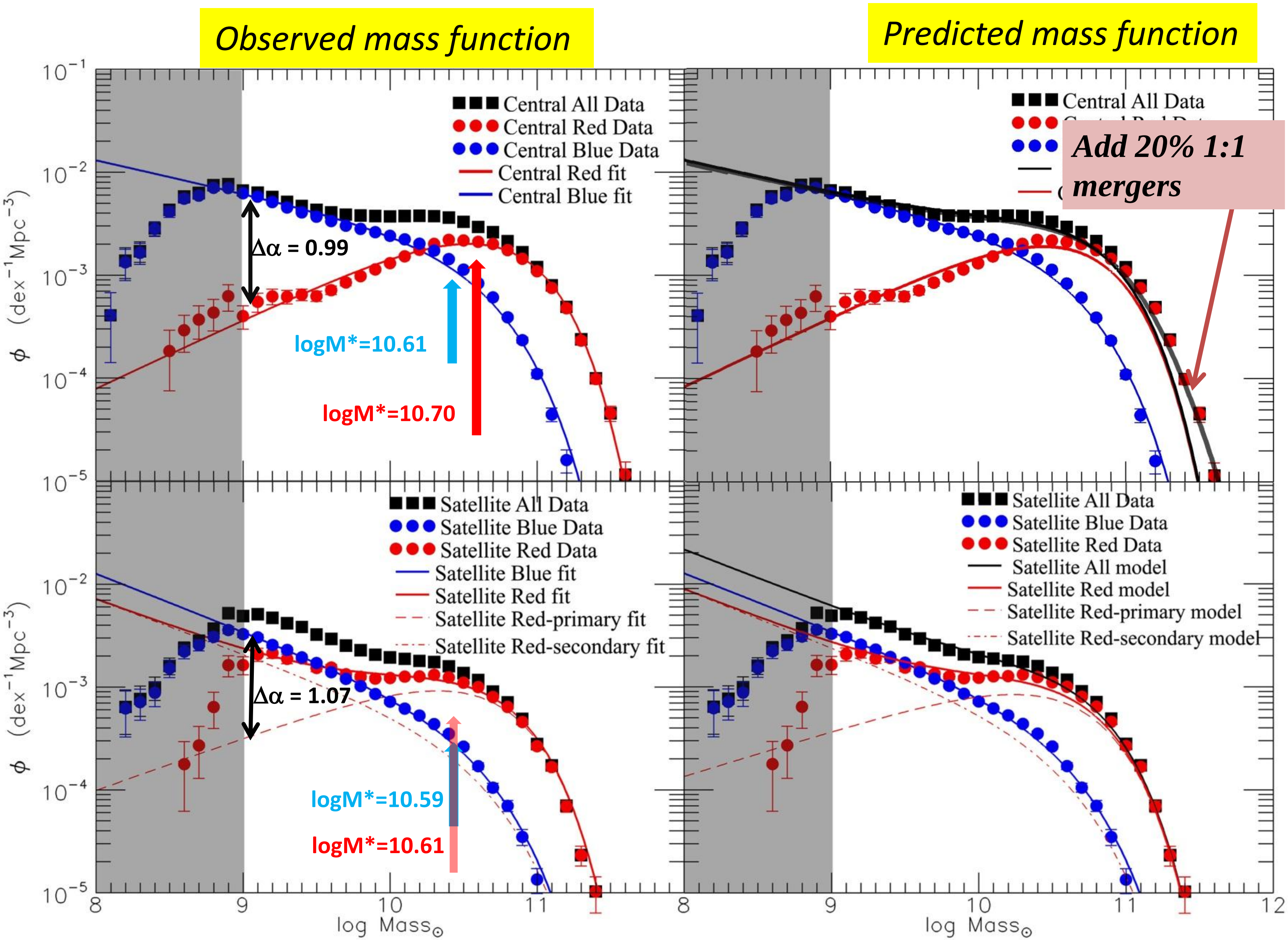
satellite–quenching efficiency

ε_{sat} strongly depends on environment, independent of mass

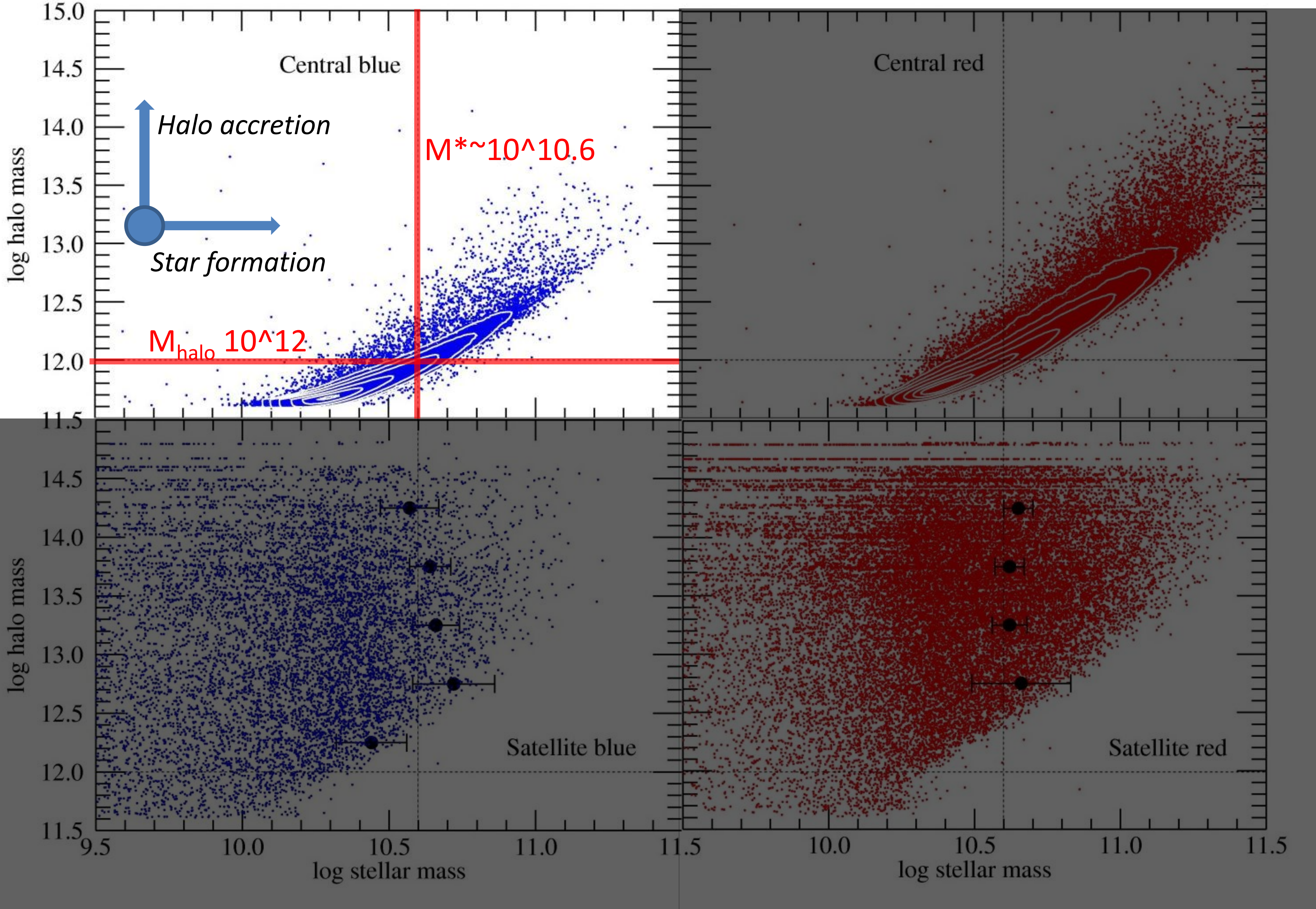
Stellar Mass Function of Centrals/Satellites



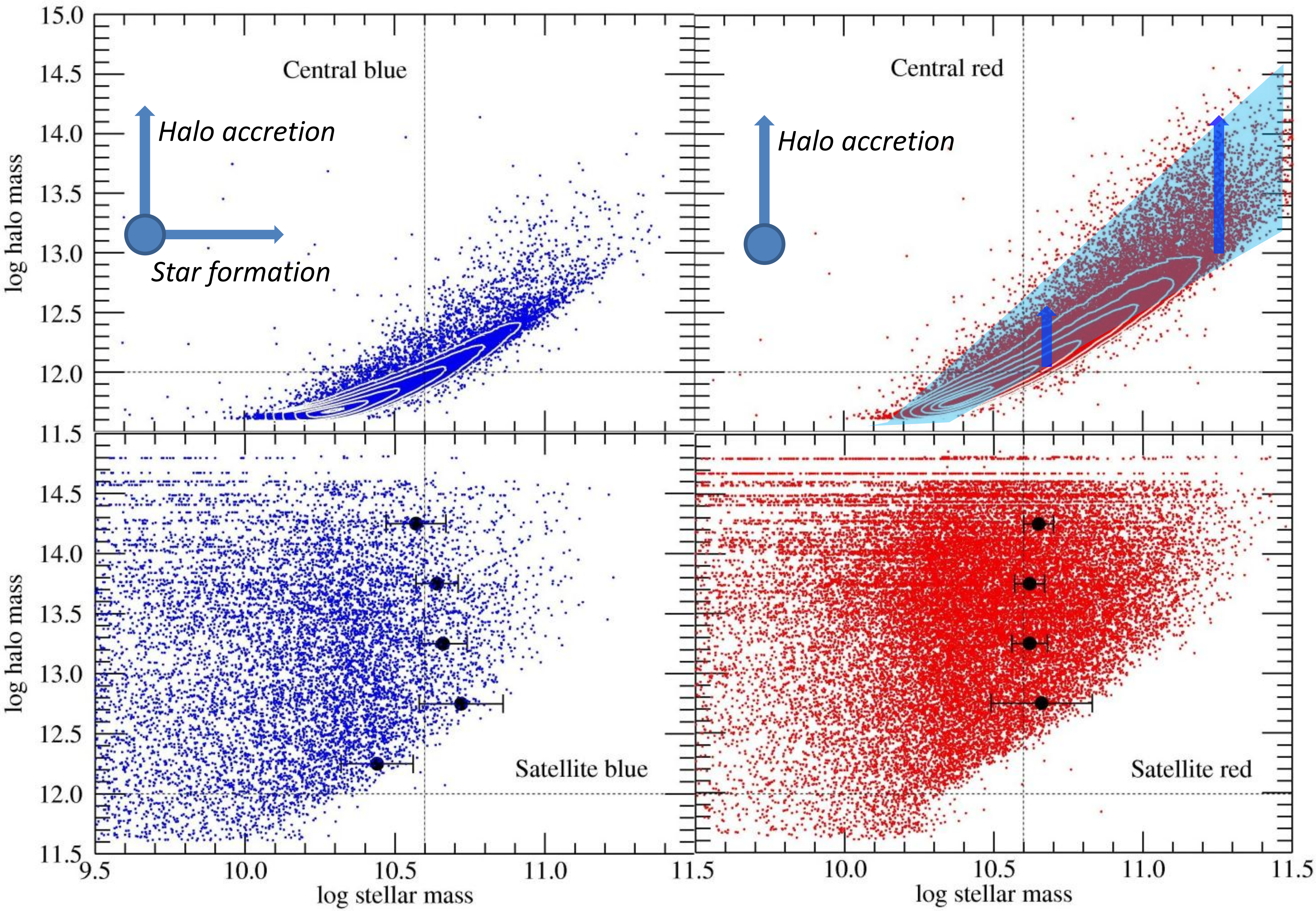
Stellar Mass Function of Centrals/Satellites

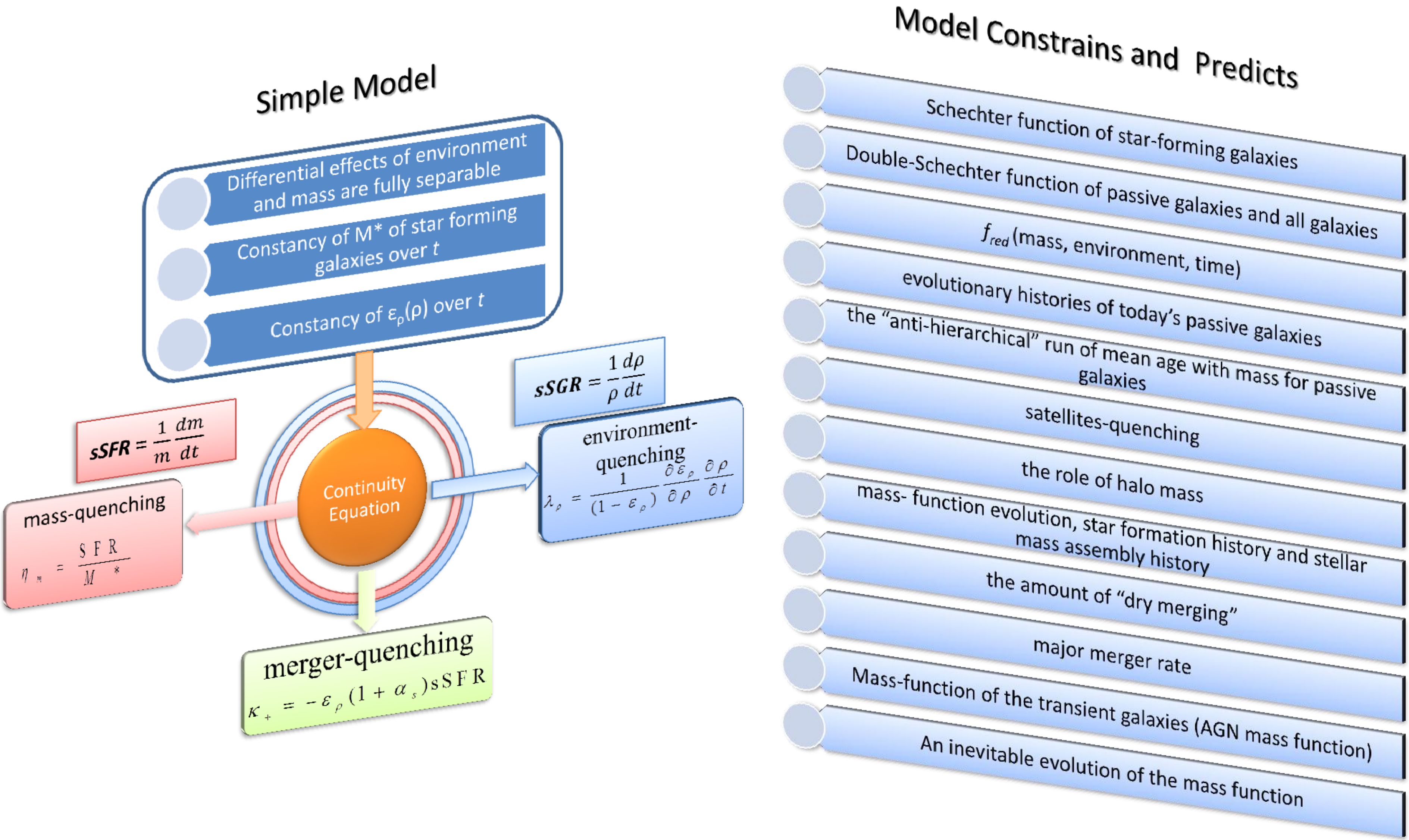


Stellar Mass vs. Halo mass (of parent group)



Stellar Mass vs. Halo mass (of parent group)




Simple Model
Differential effects of environment and mass are fully separable
Constancy of M* of star forming galaxies over t
Constancy of $\varepsilon_\rho(\rho)$ over t
Continuity Equation
$sSFR = \frac{1}{m}\frac{dm}{dt}$
mass-quenching
$\eta_m = \frac{SFR}{M^*}$
$sSGR = \frac{1}{\rho}\frac{d\rho}{dt}$
environment-quenching
$\lambda_\rho = \frac{1}{(1-\varepsilon_\rho)}\frac{\partial \varepsilon_\rho}{\partial \rho}\frac{\partial \rho}{\partial t}$
merger-quenching
$\kappa_+ = -\varepsilon_\rho(1+\alpha_s)sSFR$
Model Constrains and Predicts
Schechter function of star-forming galaxies
Double-Schechter function of passive galaxies and all galaxies
f_{red} (mass, environment, time)
evolutionary histories of today's passive galaxies
the "anti-hierarchical" run of mean age with mass for passive galaxies
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the role of halo mass
mass- function evolution, star formation history and stellar mass assembly history
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Mass-function of the transient galaxies (AGN mass function)
An inevitable evolution of the mass function