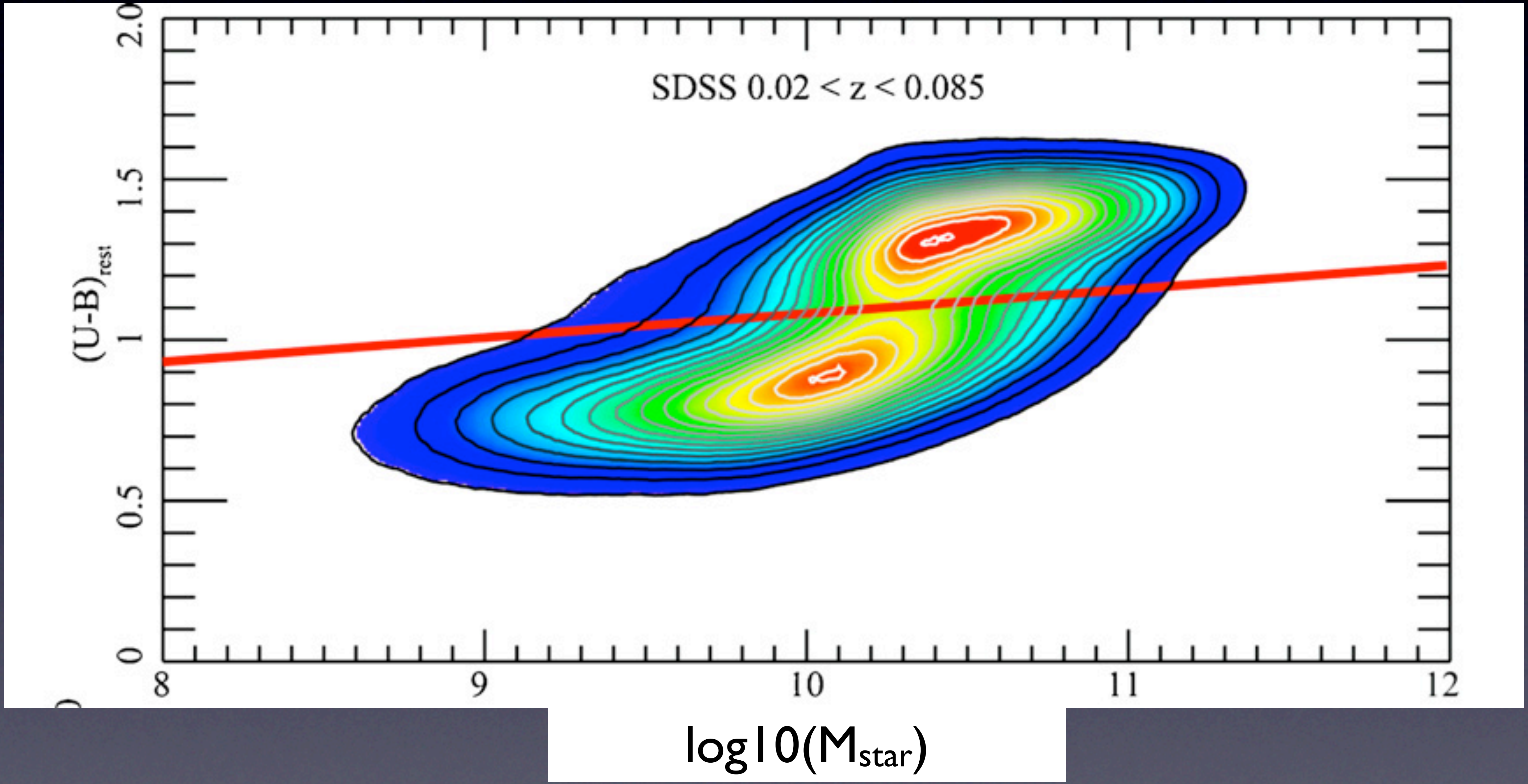
What turns galaxies off? - Revealing the links between galaxy color, structure and dark matter halo properties

David Wake
(University of Wisconsin-Madison)

Wake, van Dokkum and Franx 2012

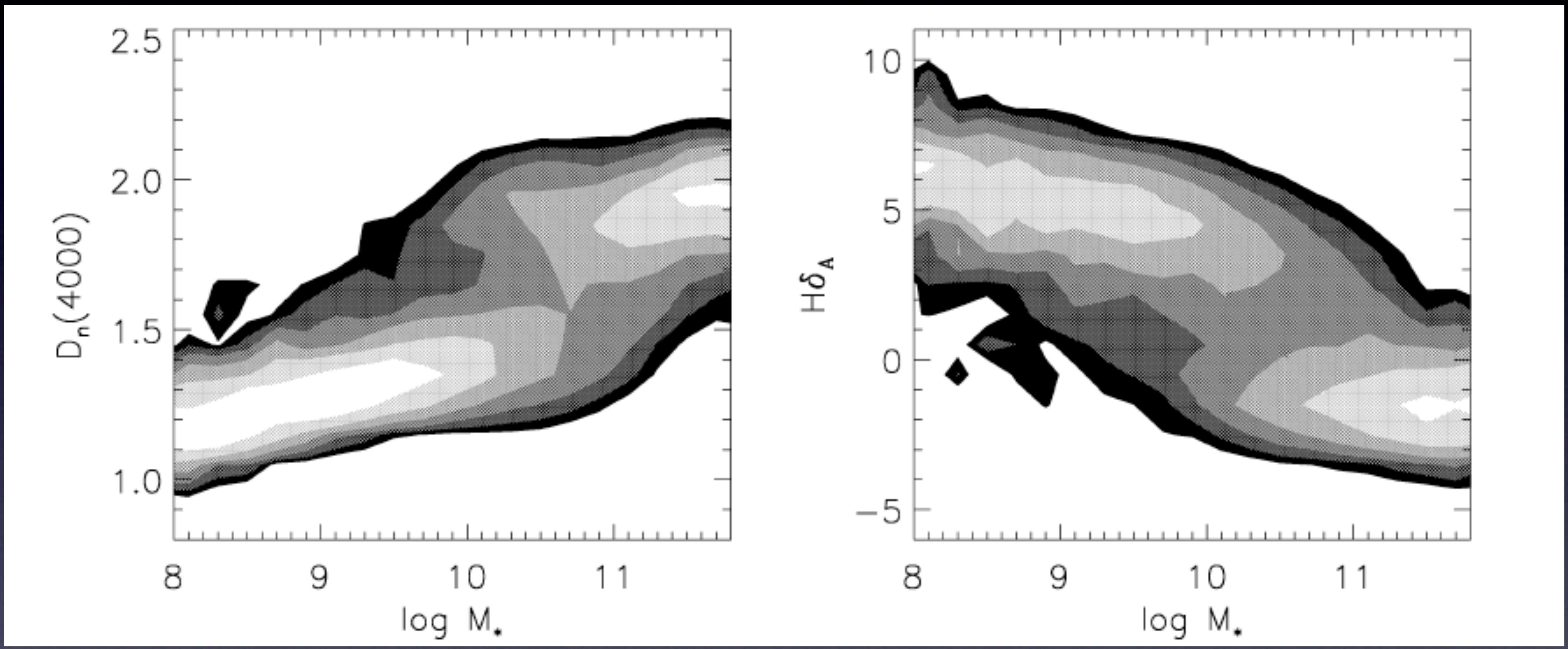
Wake, Franx and van Dokkum 2012

Galaxy bi-modality



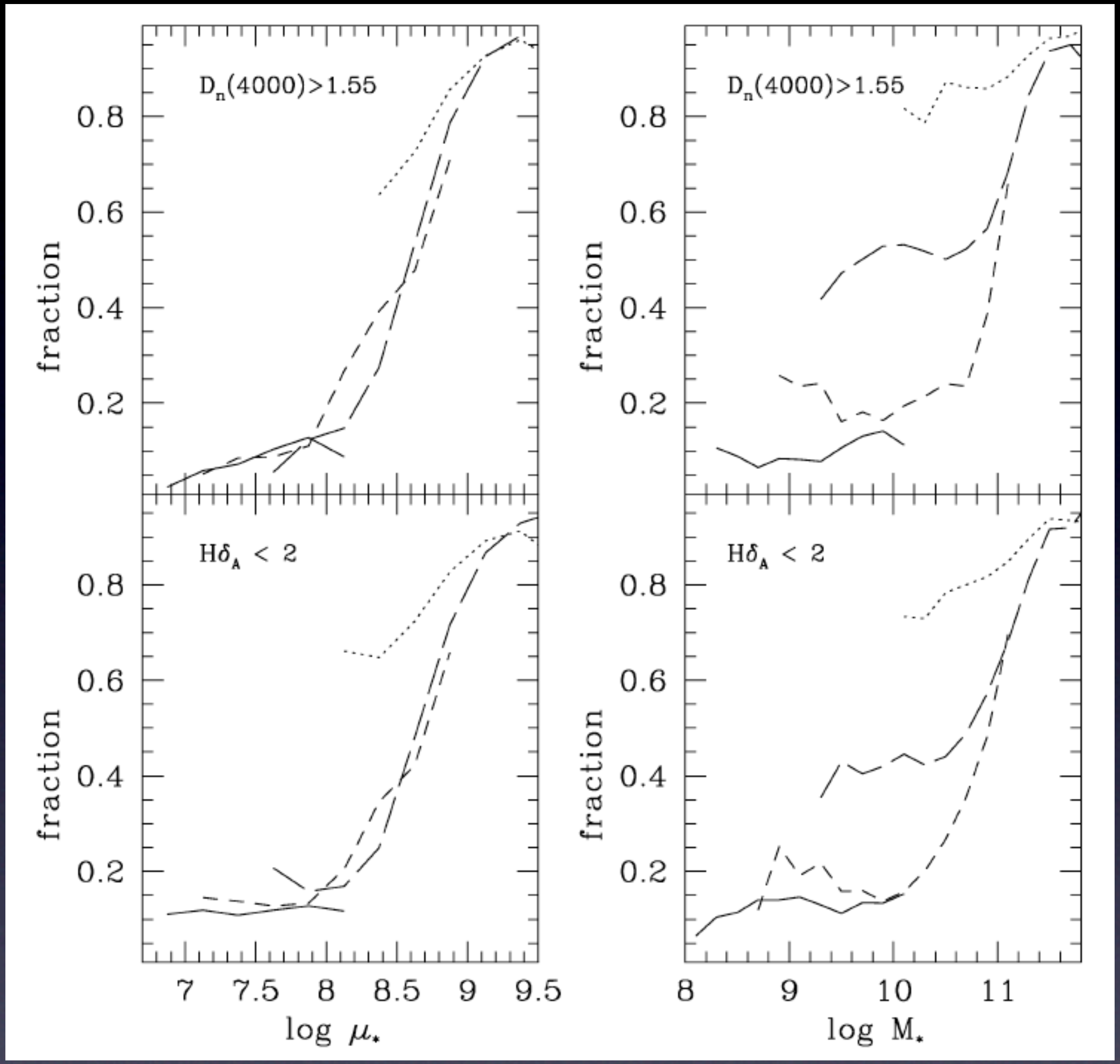
Peng et al. (2010)

Galaxy bi-modality



Kauffmann et al. (2003)

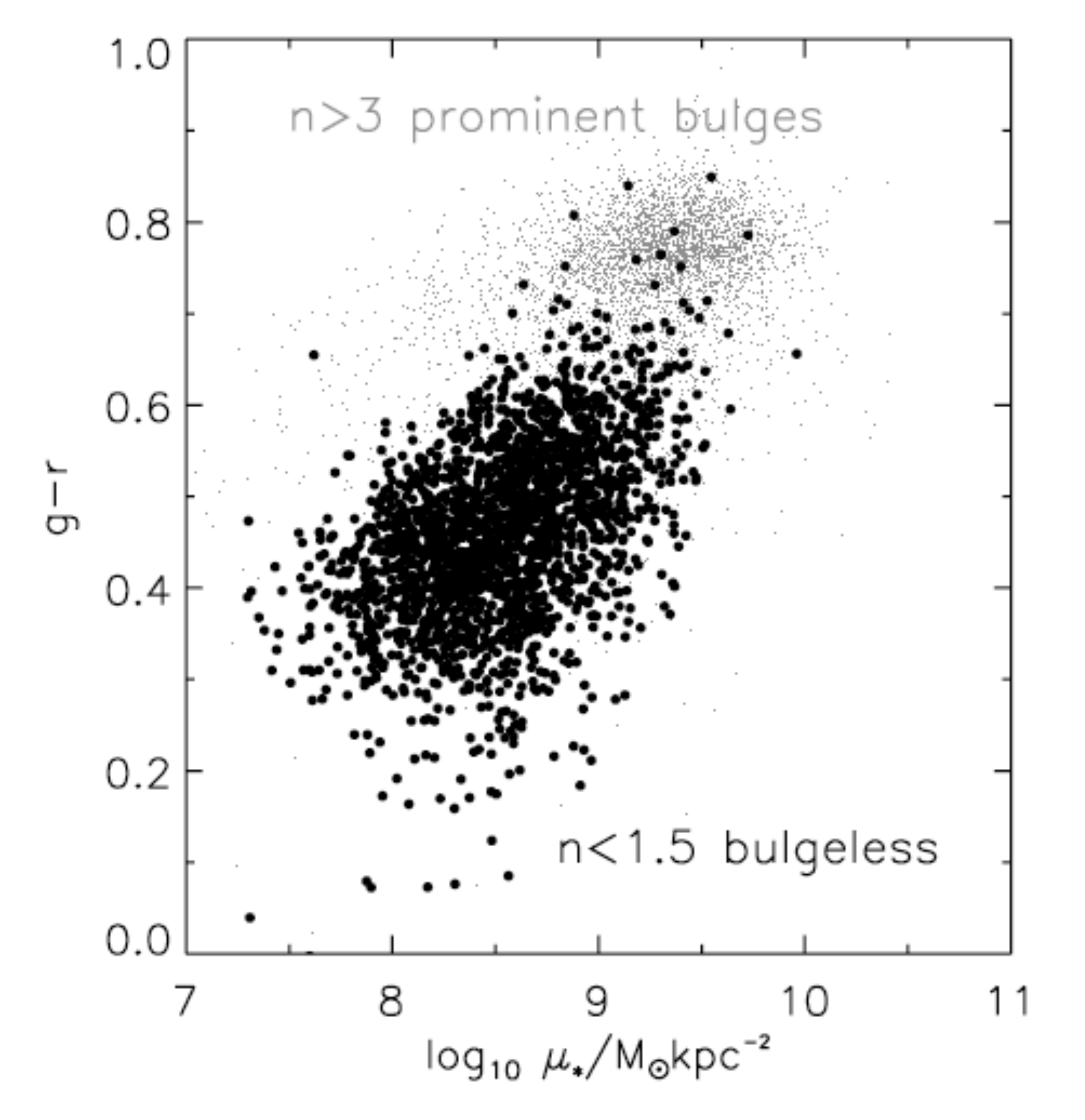
What drives the bi-modality?



Kauffmann et al. (2003, 2006) - Surface Stellar Mass Density ($\Sigma_* = M/R_e^2$) provides the best correlation.

Franx et al. (2008) - Inferred velocity dispersion (M/R_e) may be better than Σ_*.

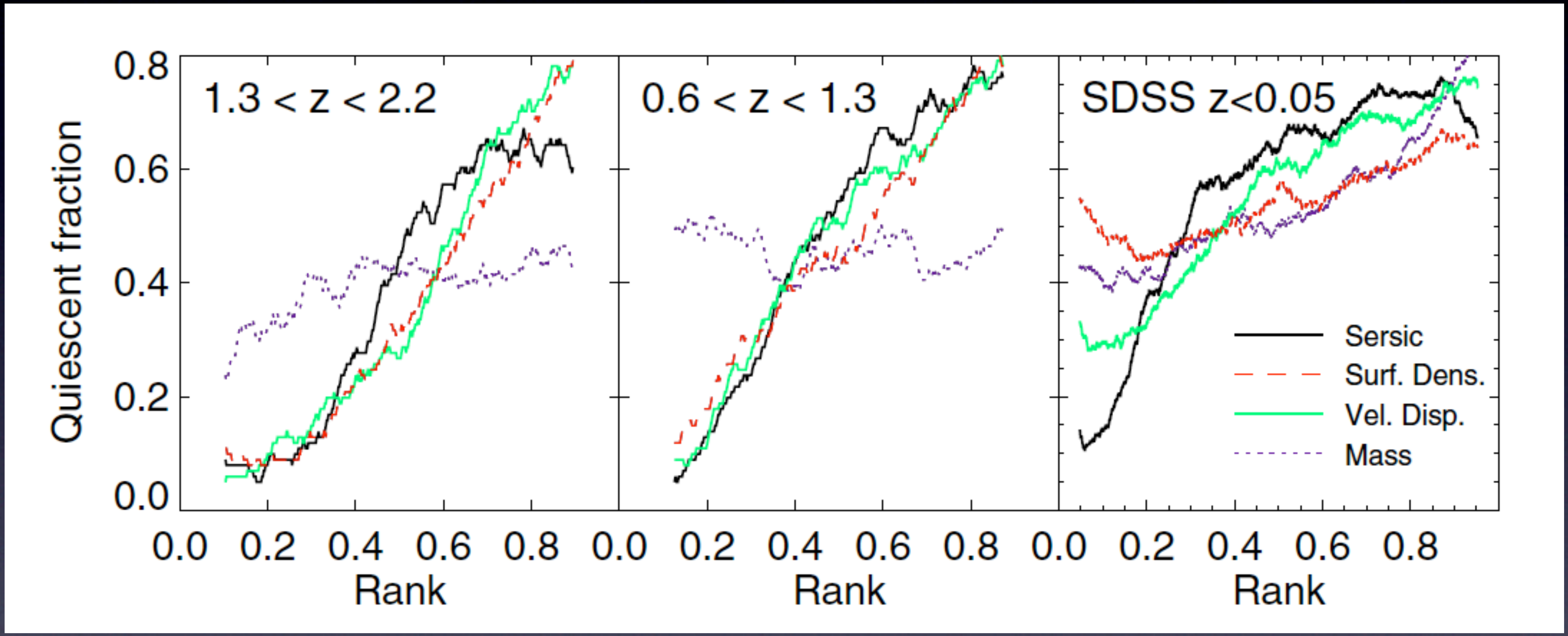
What drives the bi-modality?



Bell 2008 - Sersic index (n) may be better than Σ_{*}.

Surface brightness $\propto \exp(\text{radius}^n)$

What drives the bi-modality?



Bell et al. (2012) - n is even better than inferred velocity dispersion.

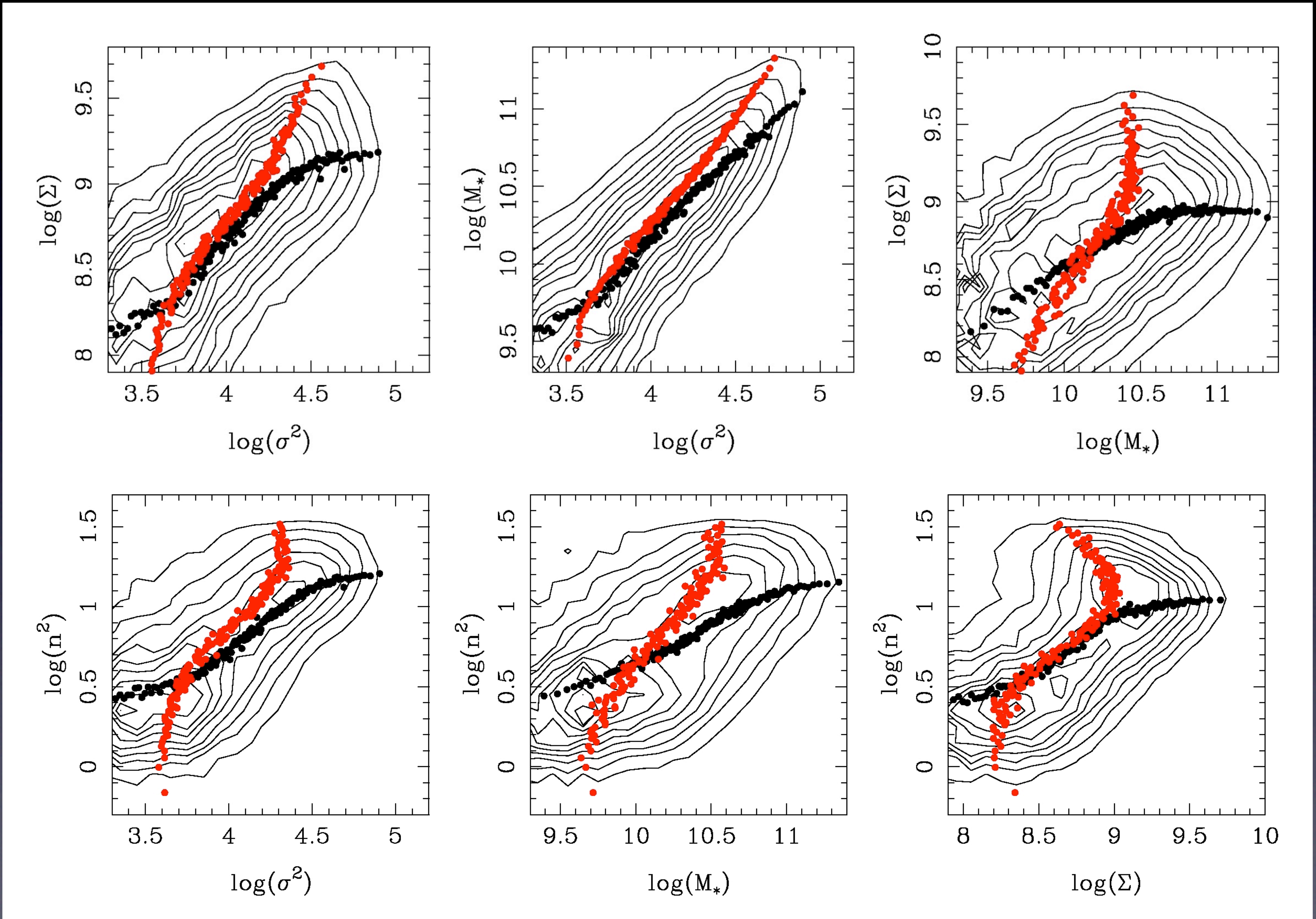
Which of these properties is the best indicator of a galaxy's color?

- SDSS data is large enough to make a precise test.
- Spectroscopic data provides measured velocity dispersion (σ).
- Fix each parameter in turn and see how the mean color depends on the others.
- If color only depended on say mass, when the mass is fixed their will be no trend with the other parameters.

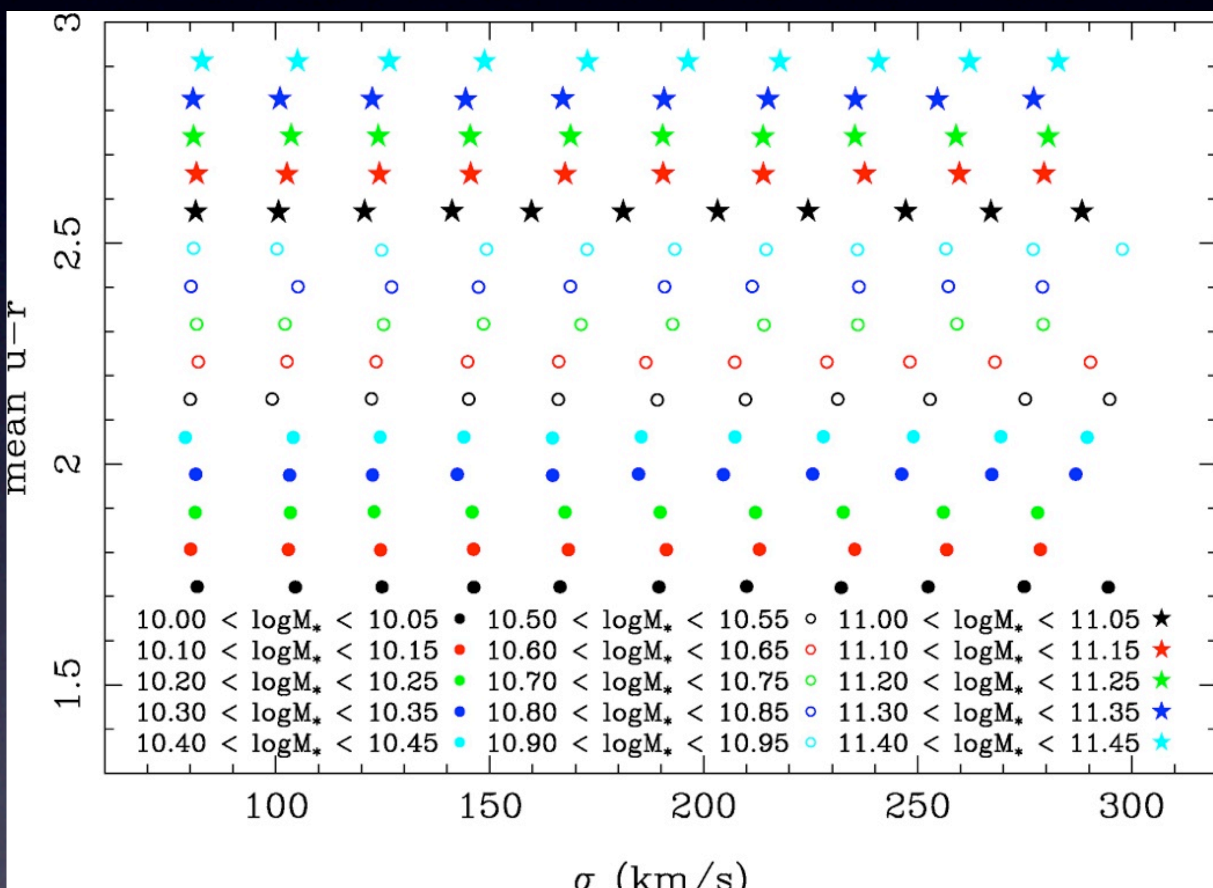
The data

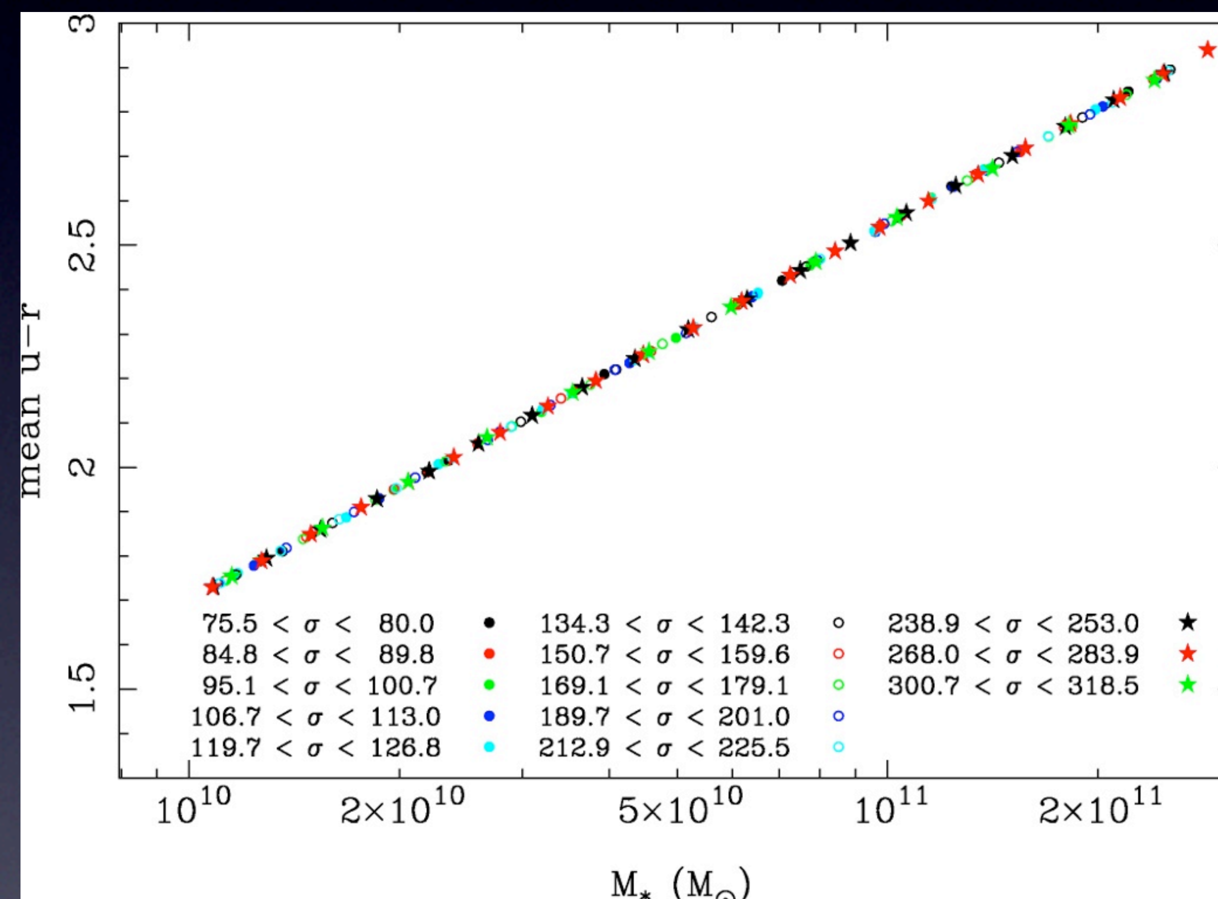
- SDSS DR7 MAIN galaxies selected from the NYU VAGC (Blanton et al. 2003).
- NYU VAGC provides k-corrected colors, Sersic fits to give n and R_e.
- Stellar mass-to-light ratios from the MPA-JHU group (Kauffmann et al. 2003).
- Fiber velocity dispersions are transformed to central dispersions within $R_e/8$ (Cappellari et al. 2008).
- Morphological classifications come from Galaxy Zoo (Linetott et al. 2011).
- Restrict the sample to $0.02 < z < 0.1$, $M_{star} > 10^{10}\ M_\odot$, $\sigma > 65$ km/s and no edge on galaxies ($P_{edge} < 0.3$).
- This leaves a sample of 111,966 galaxies.

The Structural Parameters

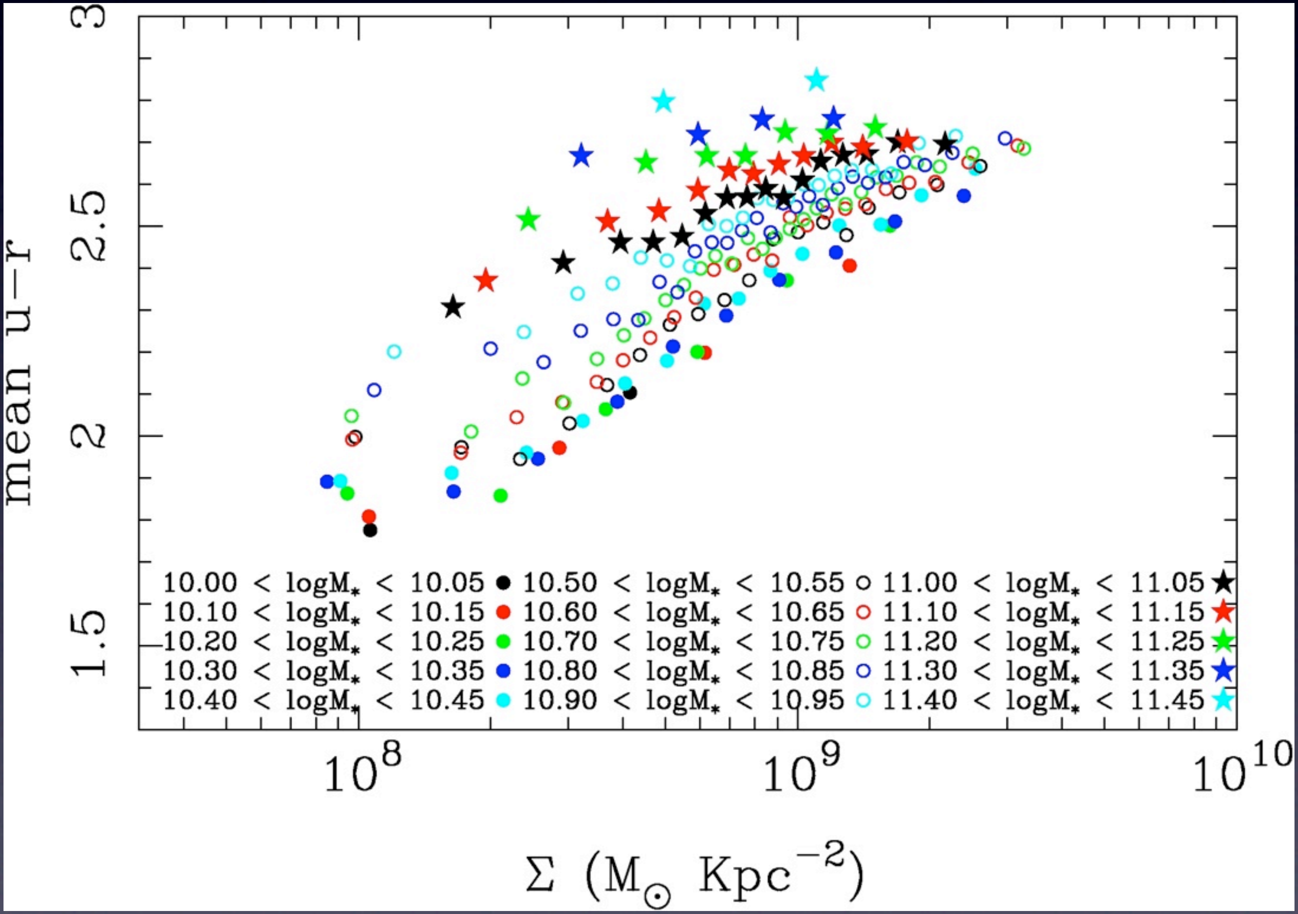


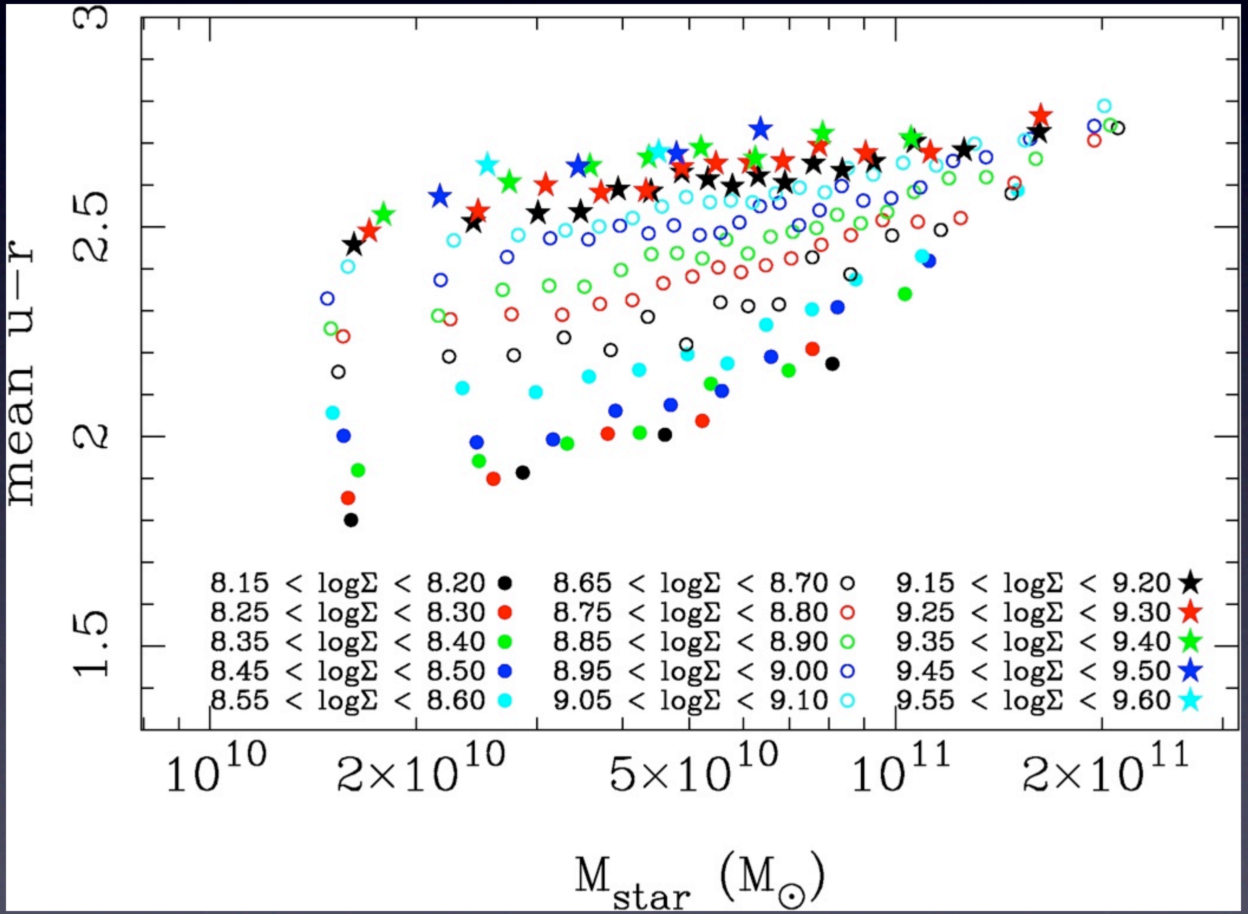
Isolating the dominant correlation.



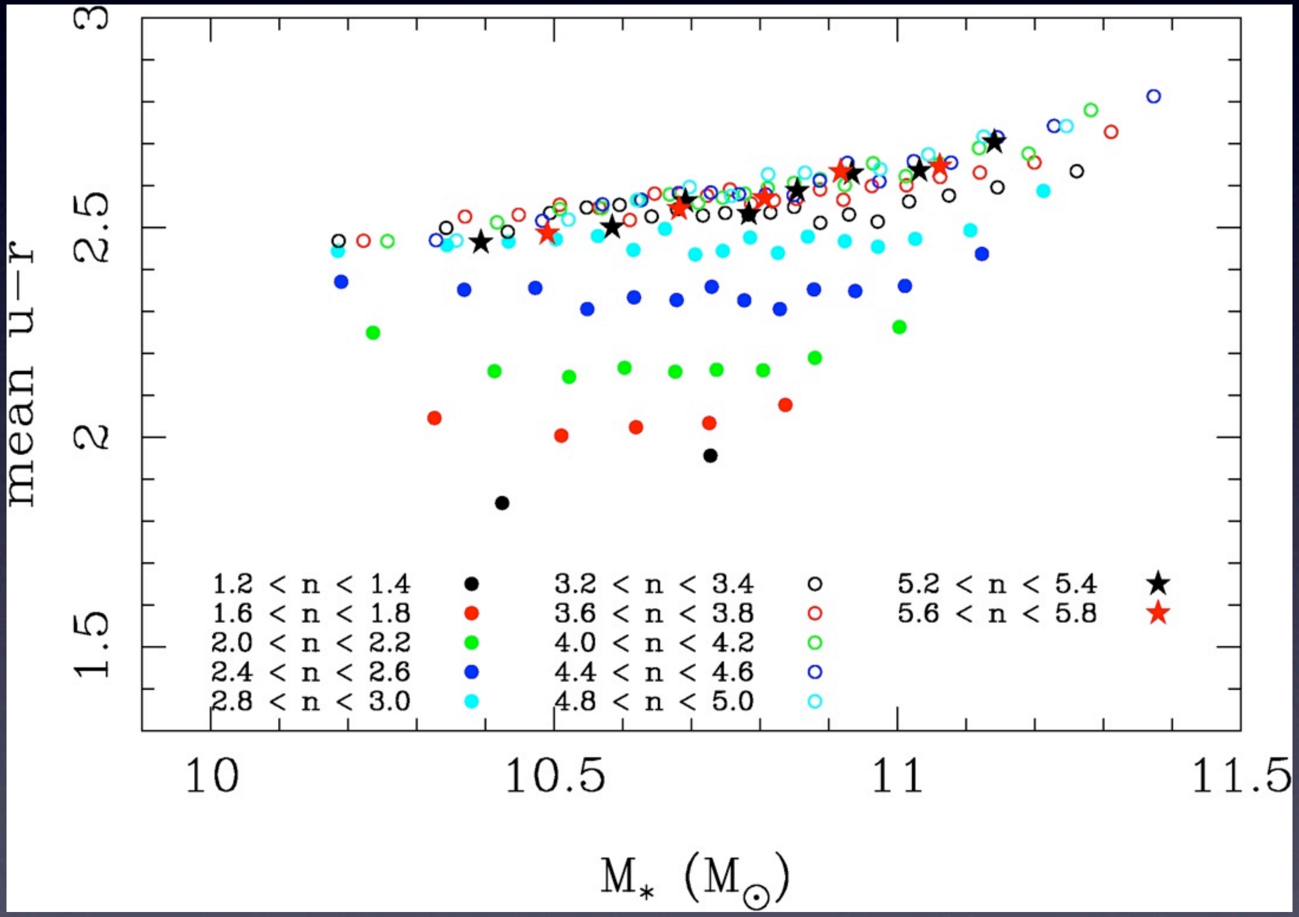


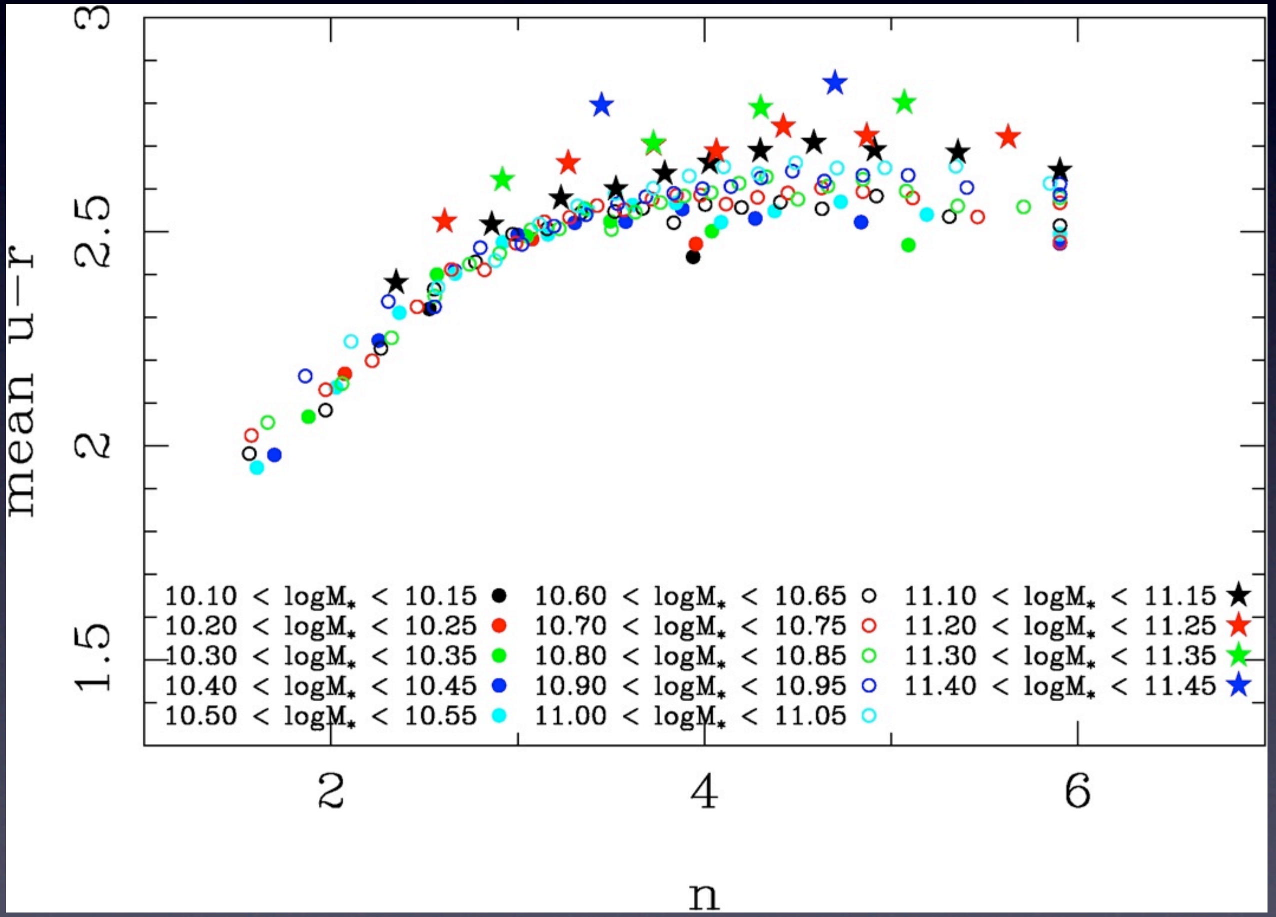
Surface Mass Density vs Stellar Mass



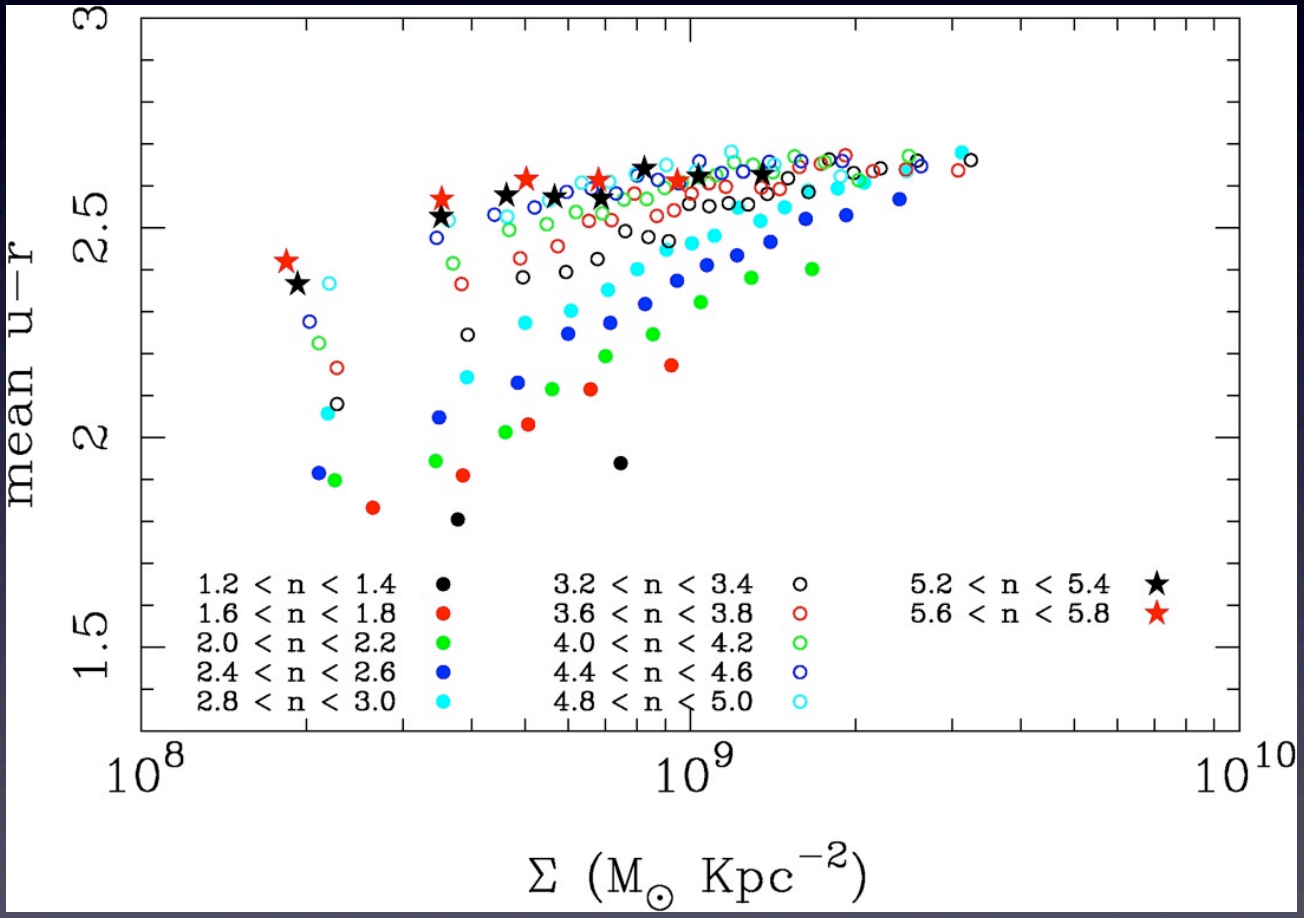


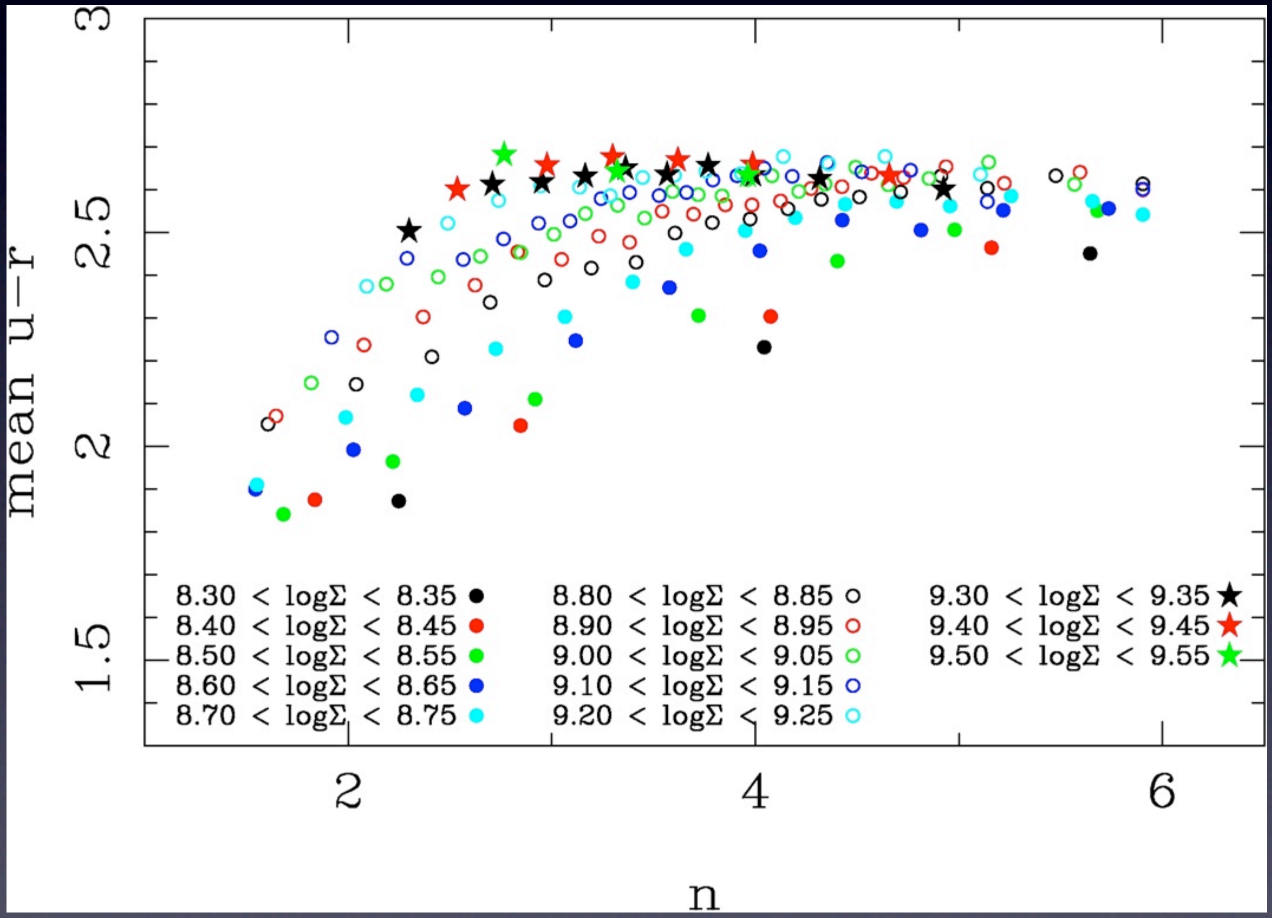
Stellar Mass vs Sersic Index



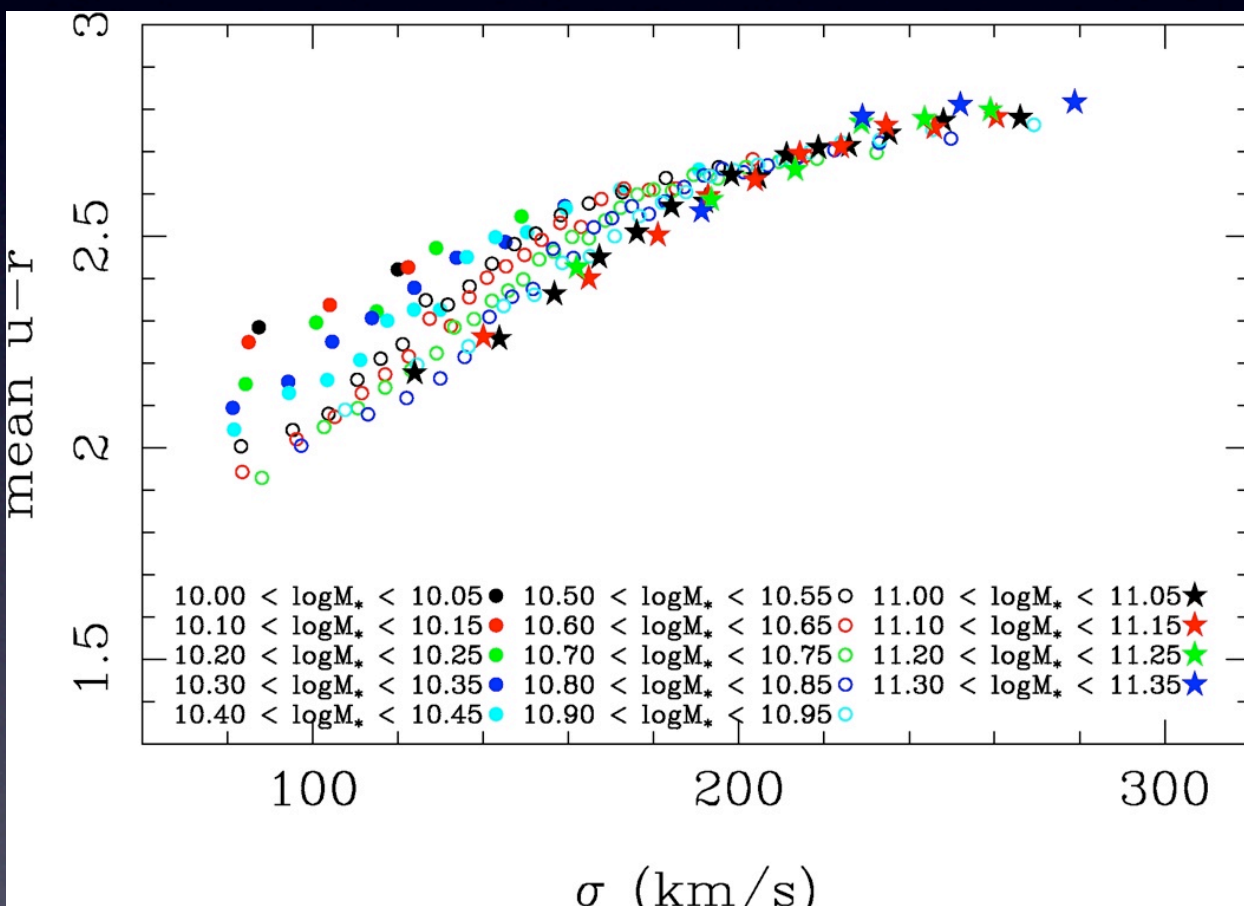


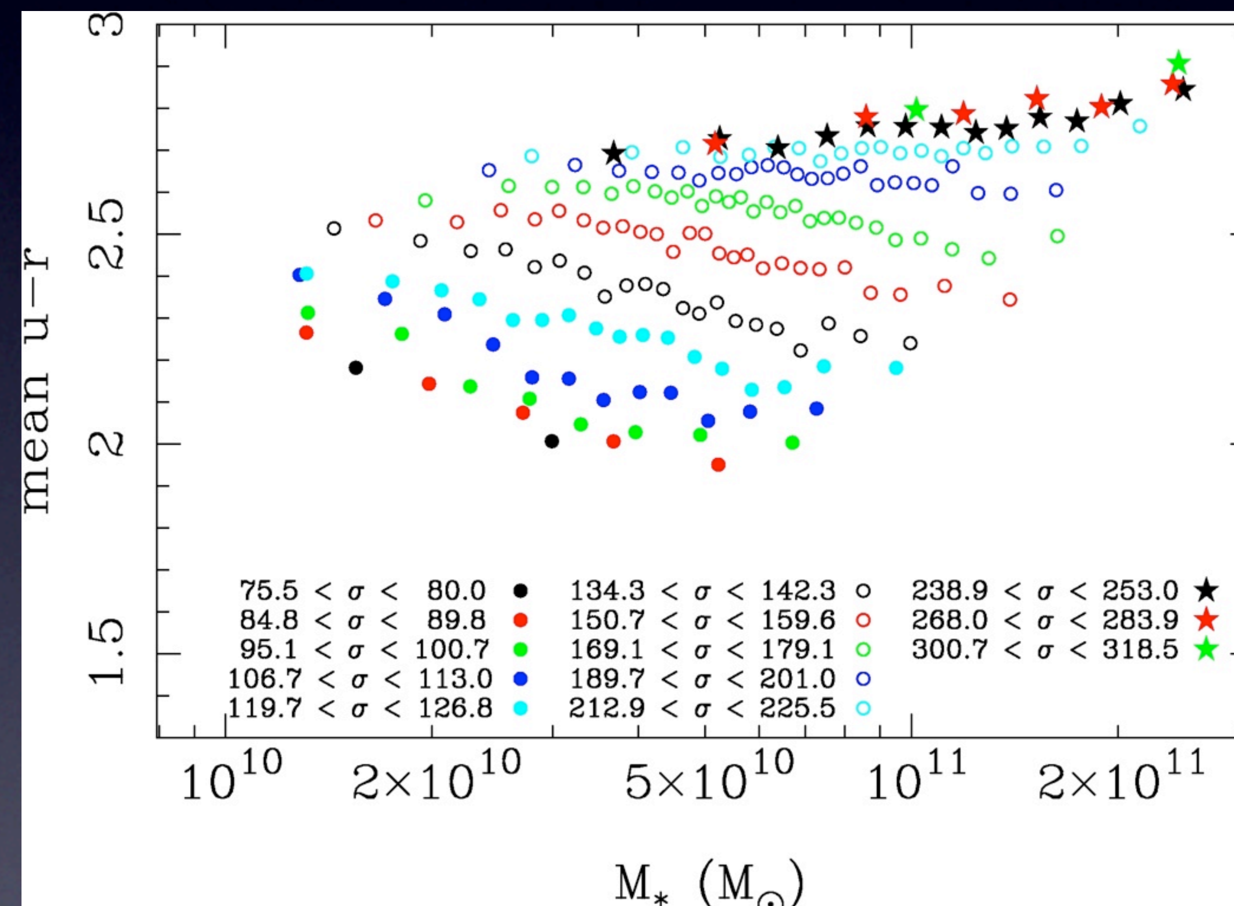
Surface Mass Density vs Sersic Index



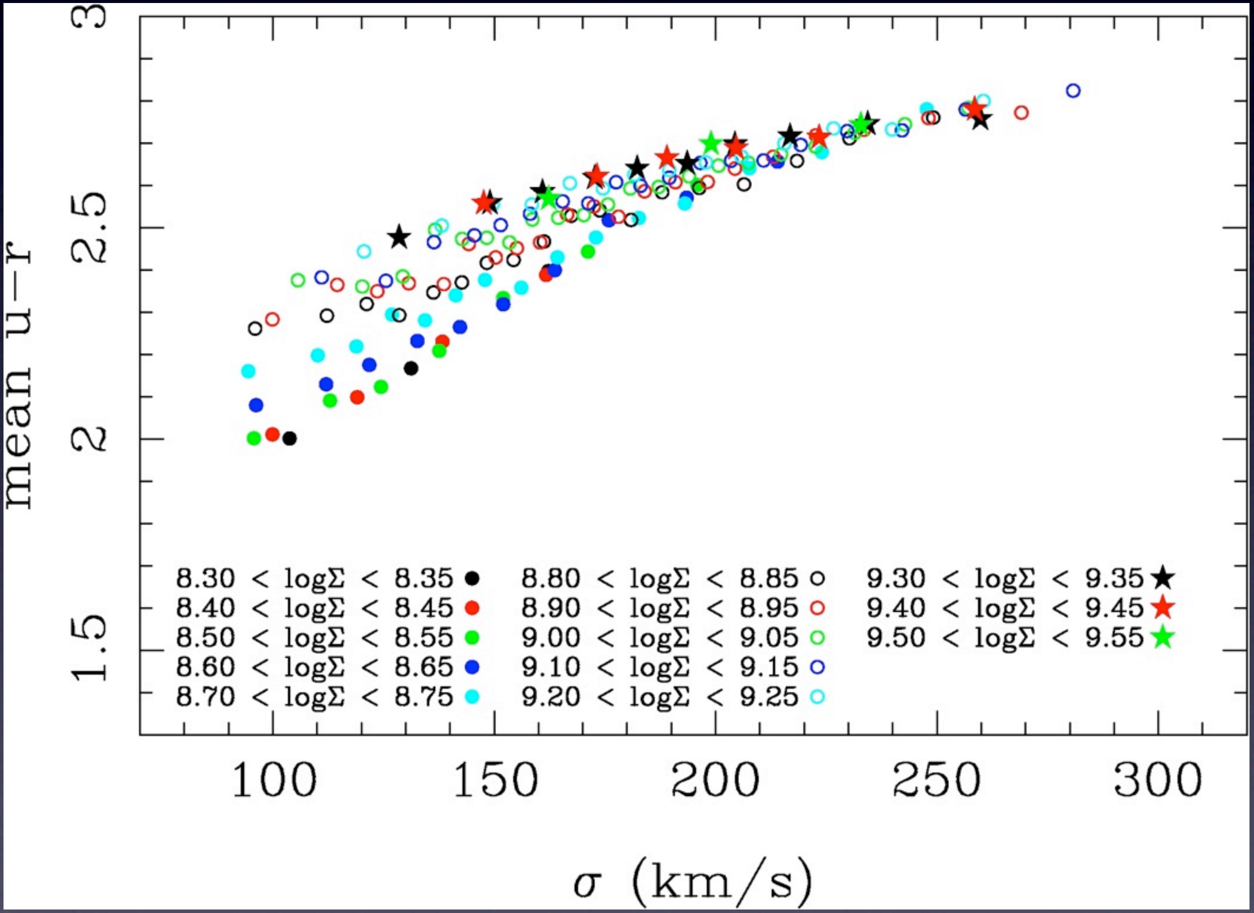


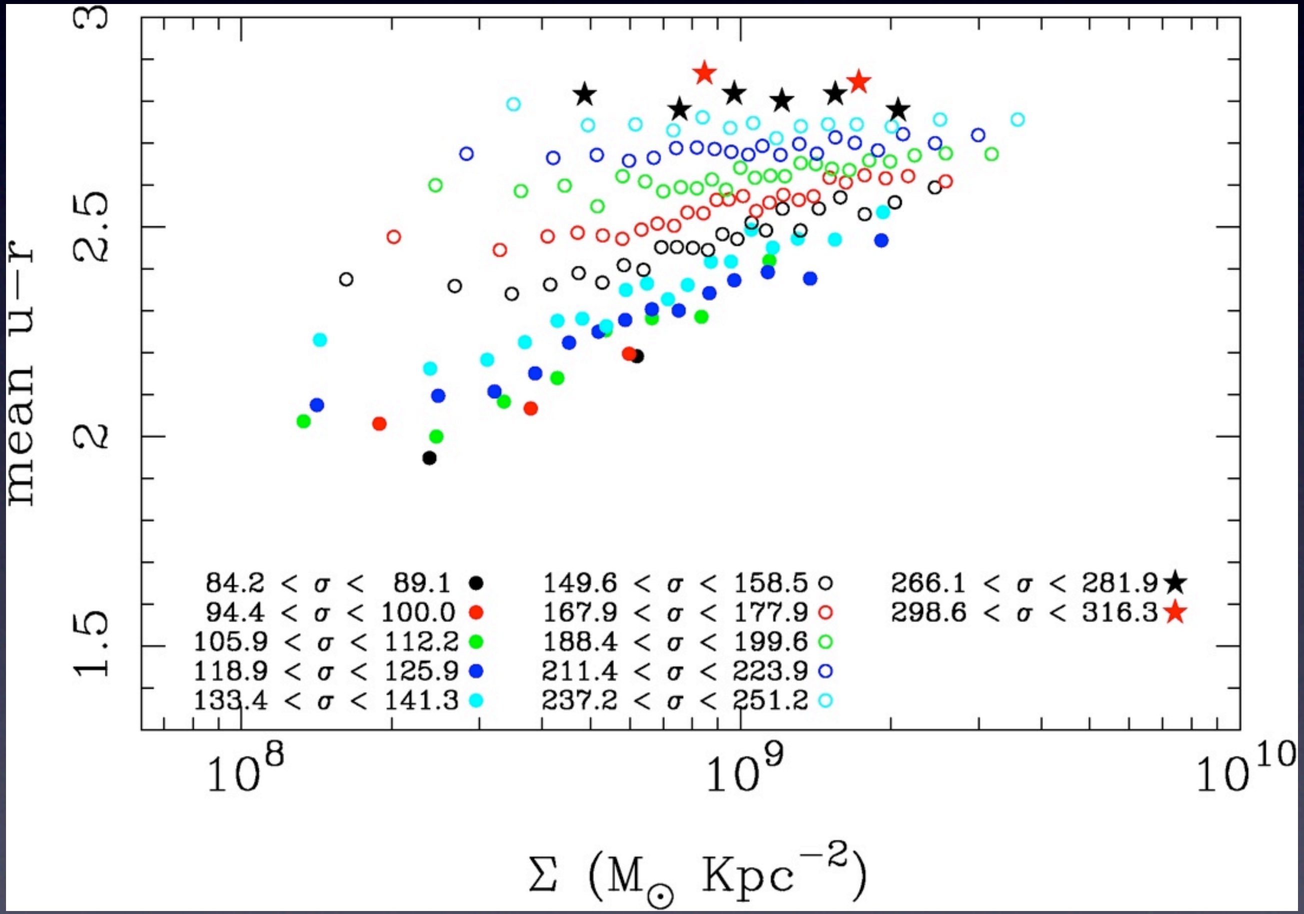
Velocity Dispersion vs Stellar Mass



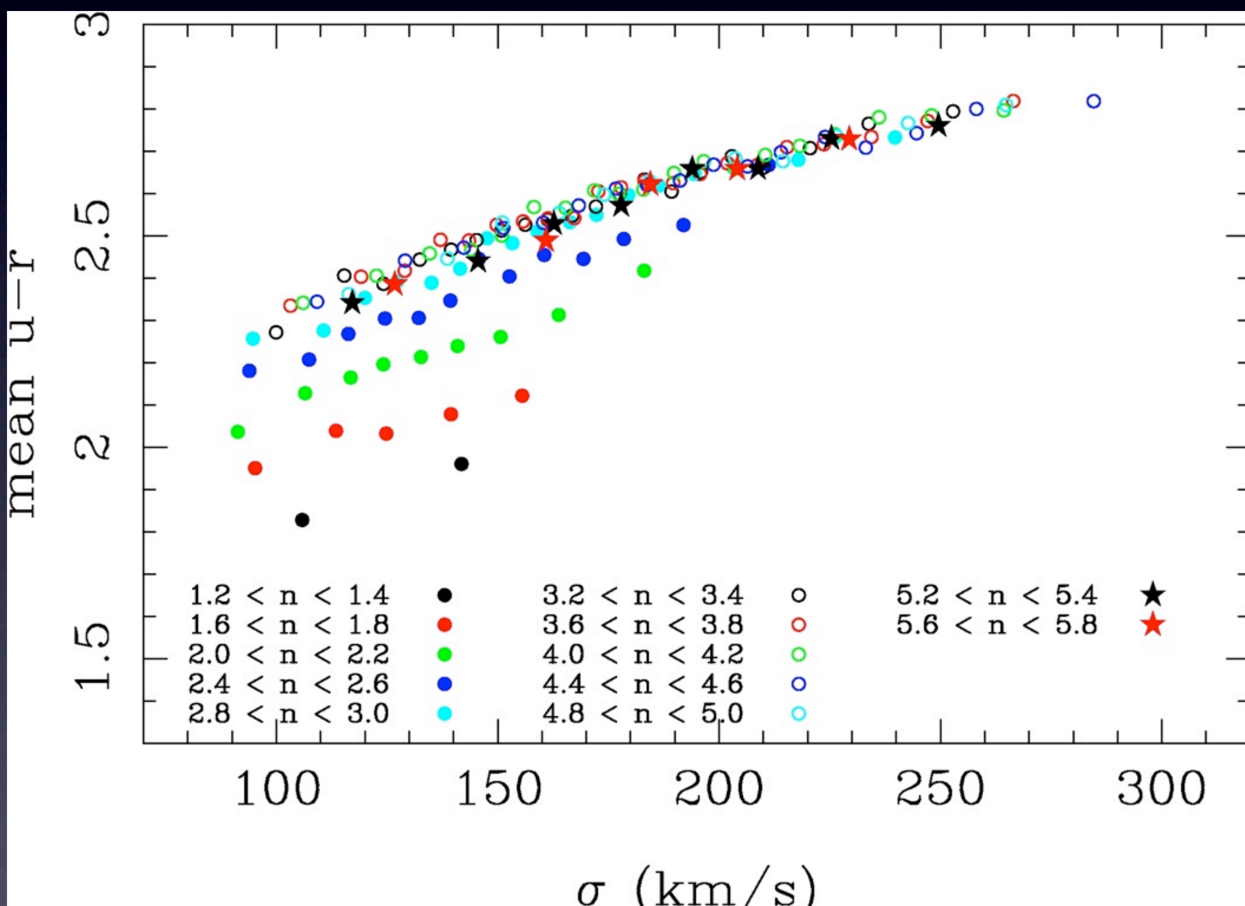


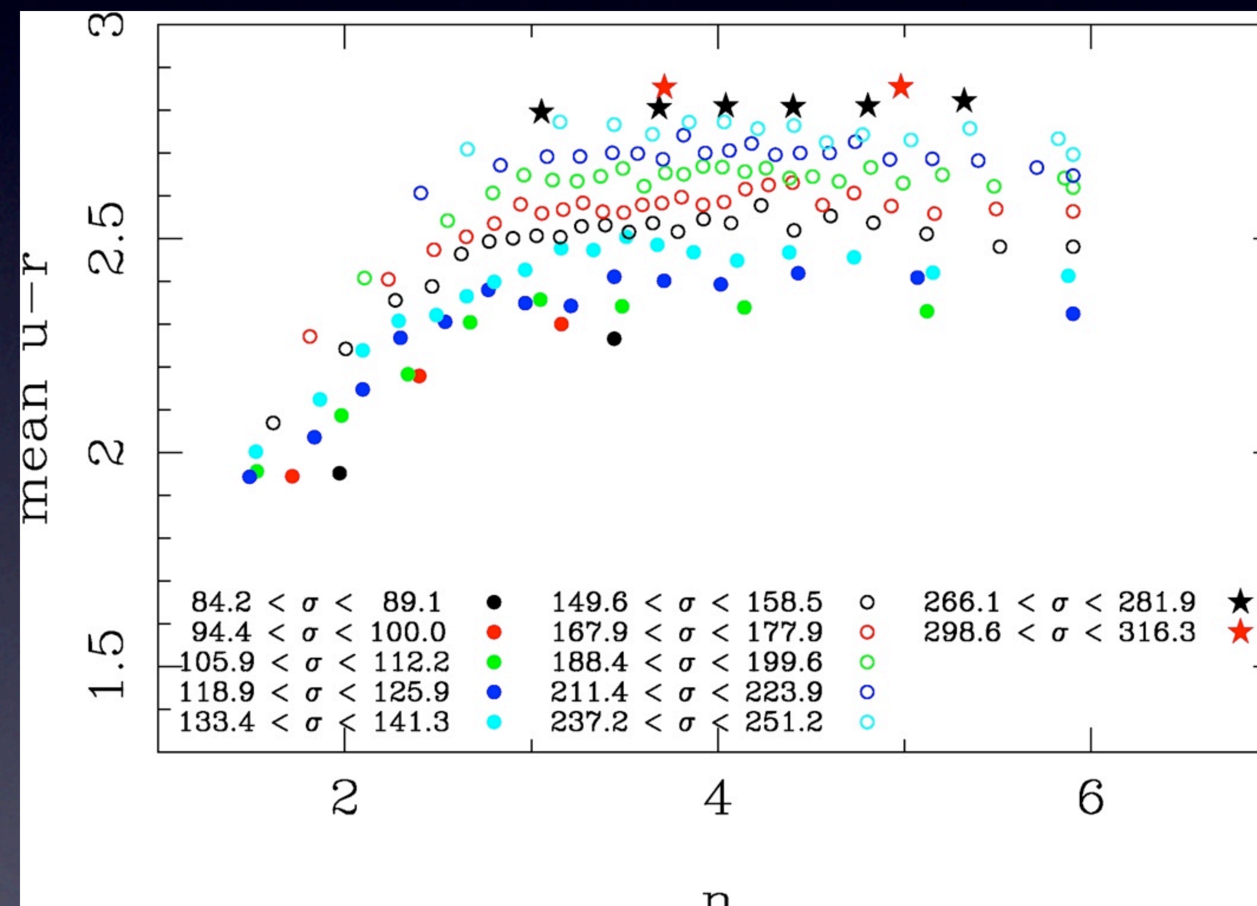
Velocity Dispersion vs Surface Mass Density

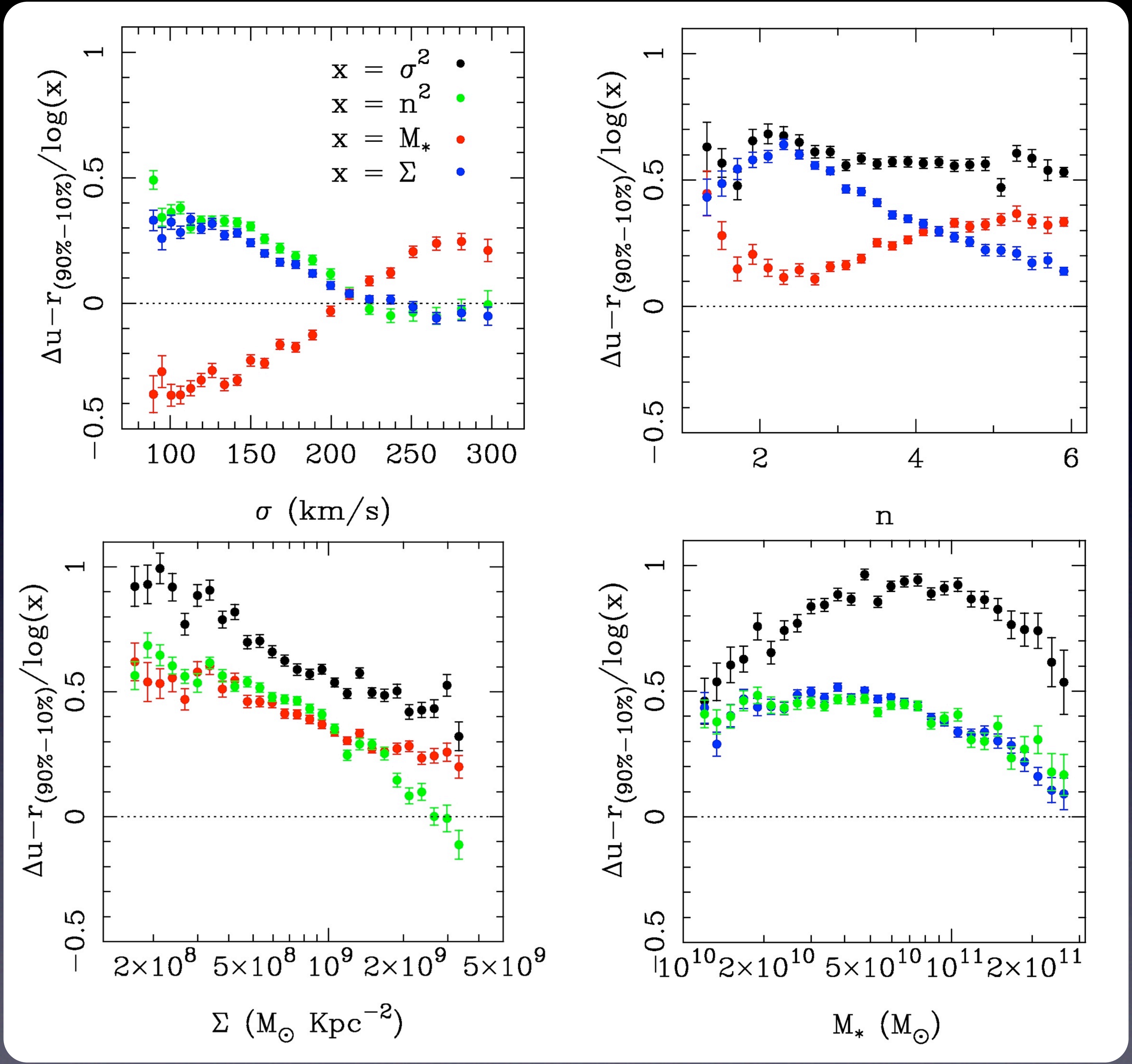




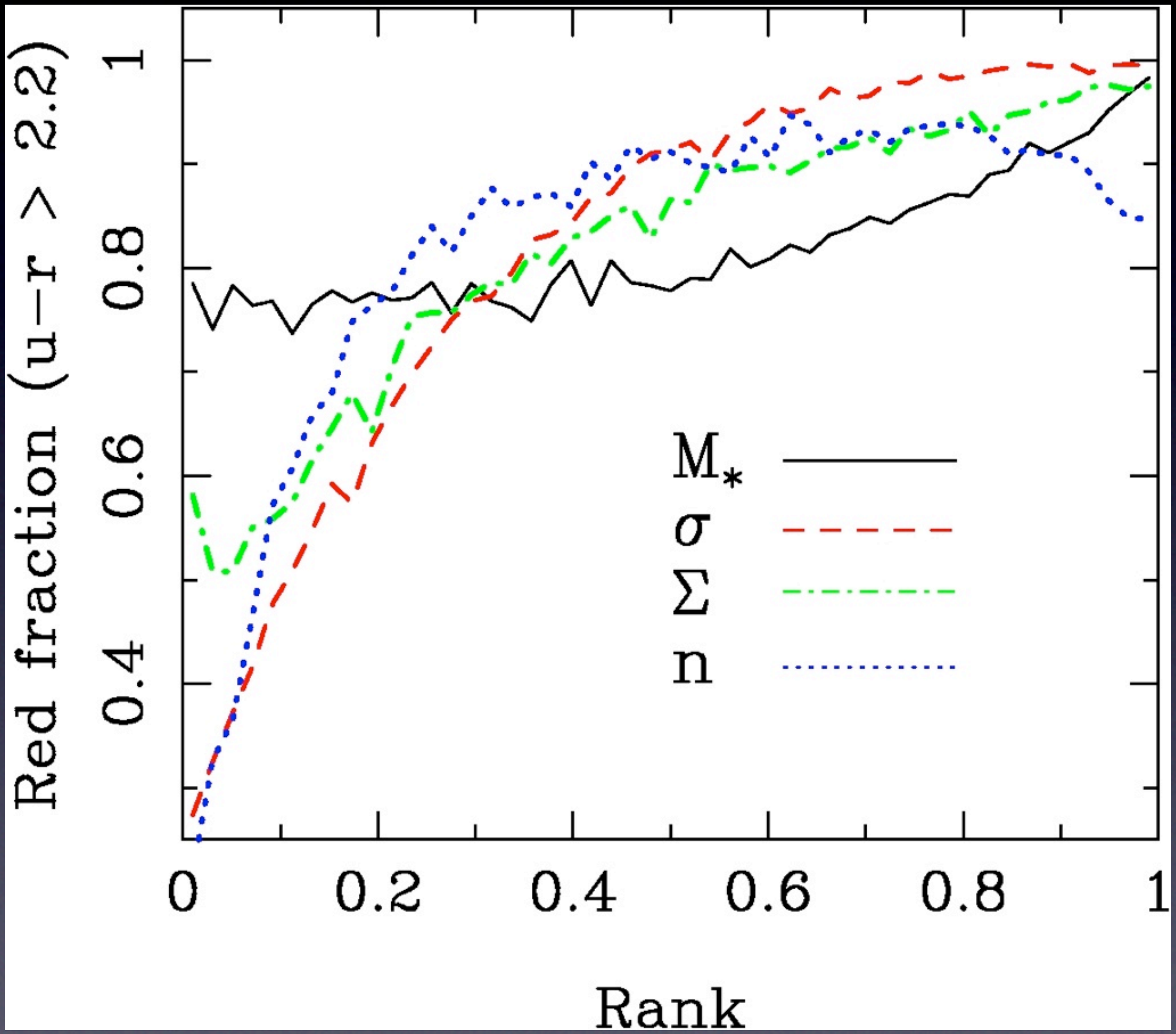
Velocity Dispersion vs Sersic Index

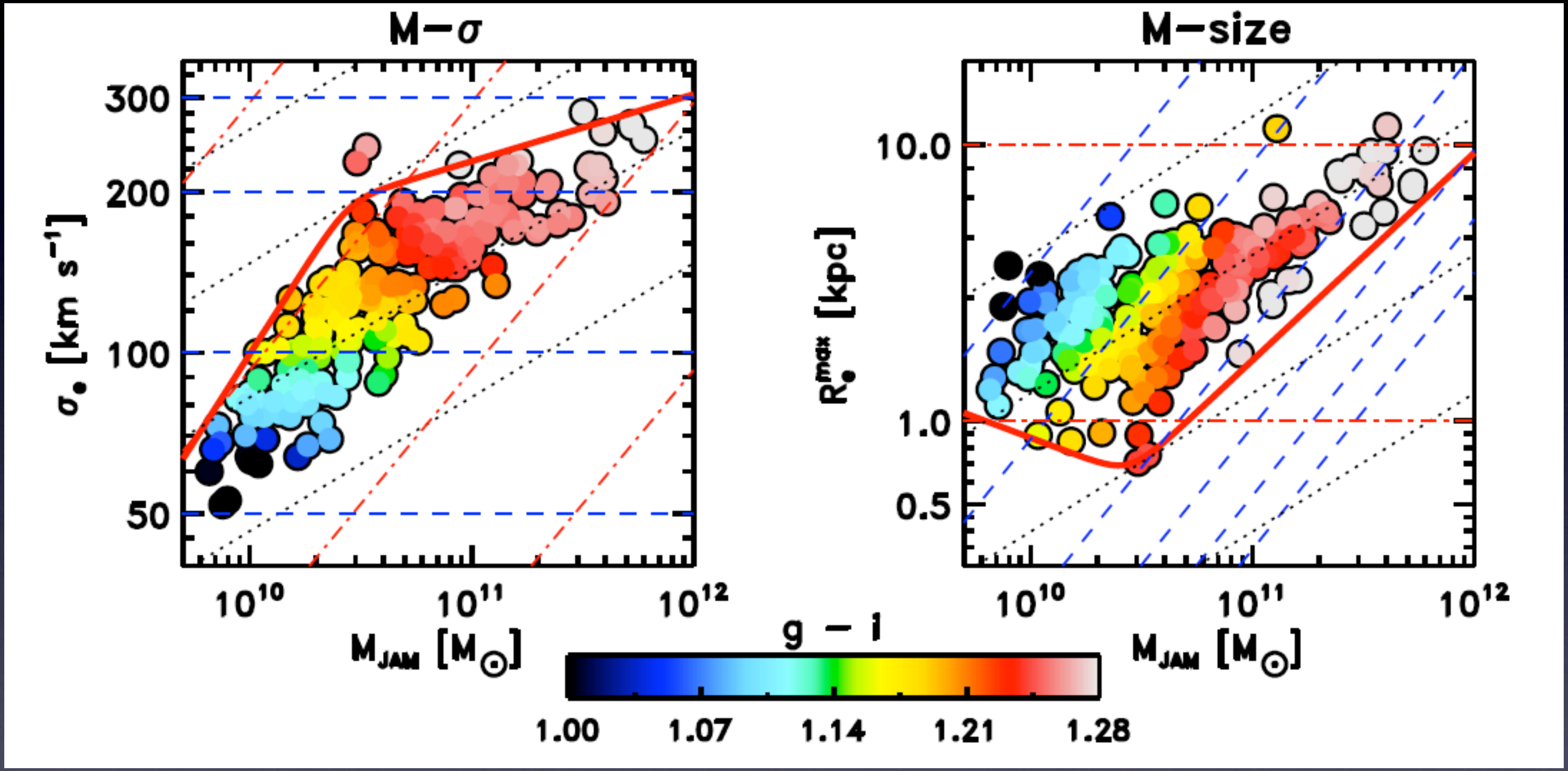




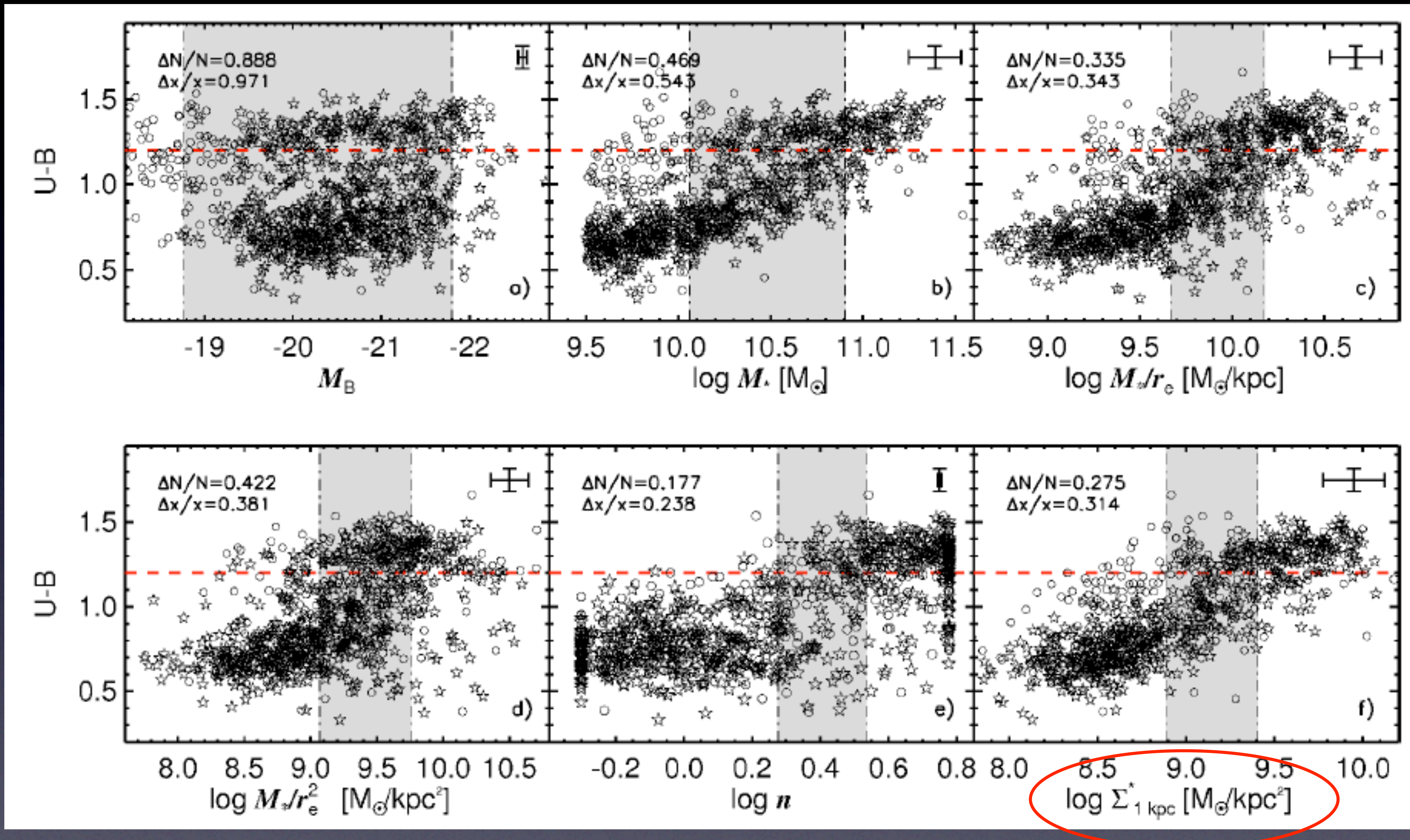


x = σ²
x = n²
x = M*
x = Σ
Δu−r(90%−10%)/log(x)
σ (km/s)
n
Σ (M⊙ Kpc⁻²)
M* (M⊙)


Red fraction (u−r > 2.2)
0.4
0.6
0.8
1
0
0.2
0.4
0.6
0.8
1
Rank
M_*
σ
Σ
n



ATLAS^{3D} Cappellari et al. (2012)

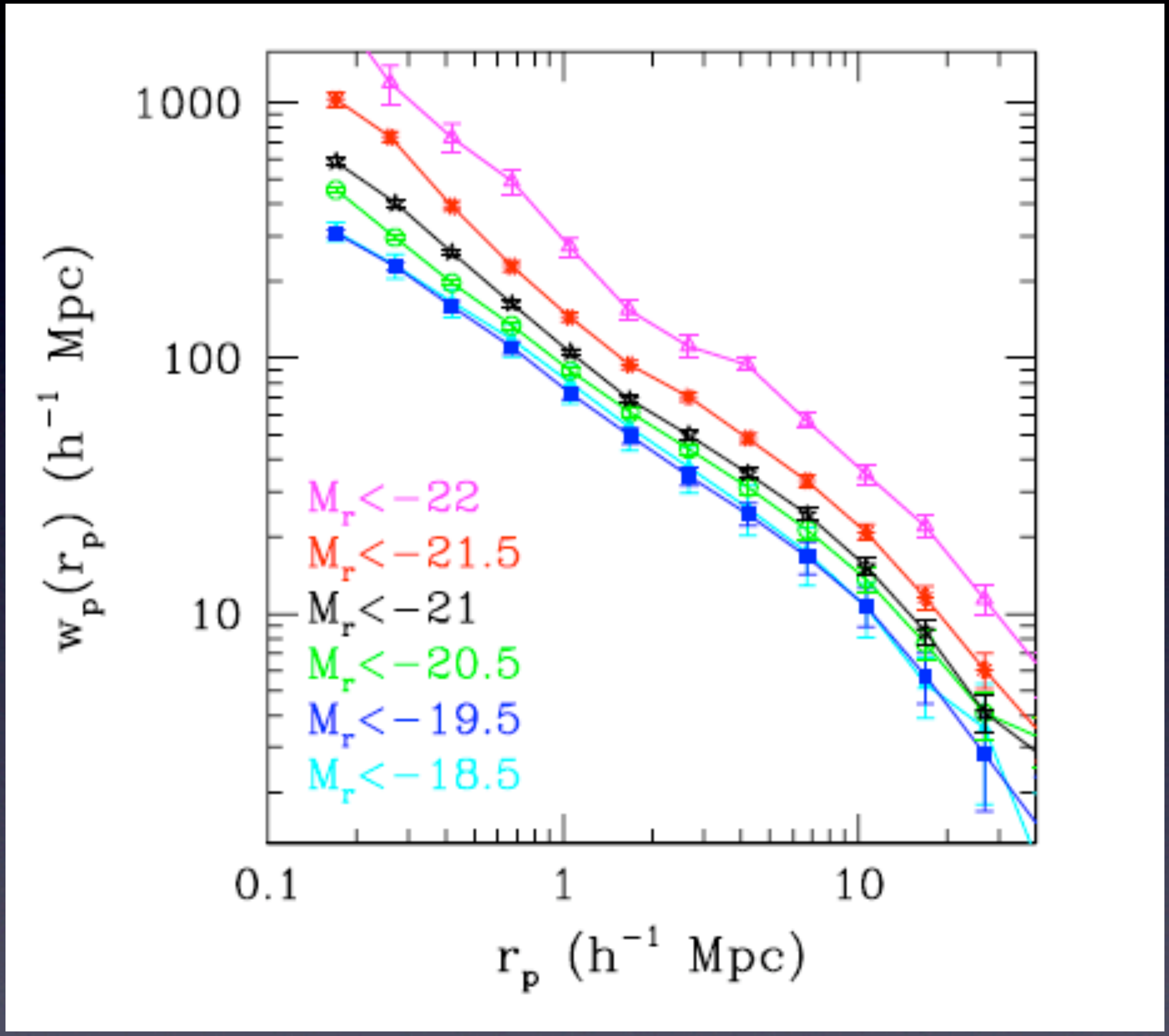


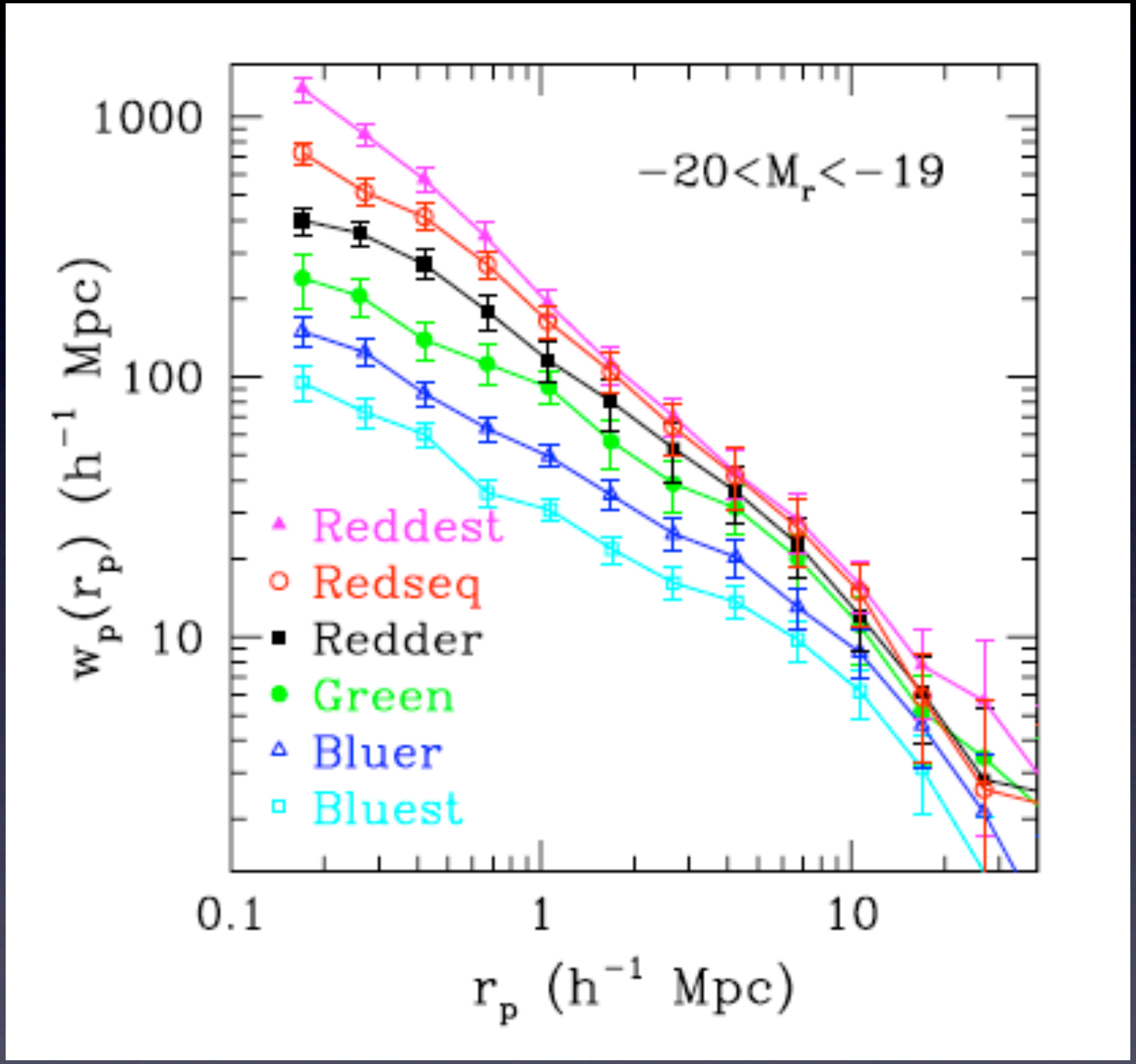
DEEP2/AEGIS - Cheung et al. (2012)

What causes the observed correlations?

- Best indicator is σ (or Σ_{1kpc}), followed by n, Σ (or M/ R_e) and finally mass.
- This implies that the formation of a dominant bulge is contributing to the shut off of SF (Major merger, gas exhaustion/removal, AGN feedback e.g. Hopkins et al. 2009).
- Something is keeping these galaxies shut off - high mass halos have shock heated gas and continuing 'radio mode' feedback (e.g. Croton et al. 2006, Dekel & Birnboim 2006)
- Could σ be telling us about the halo (more so than M_{star})?

Using clustering to relate galaxies to dark matter halos



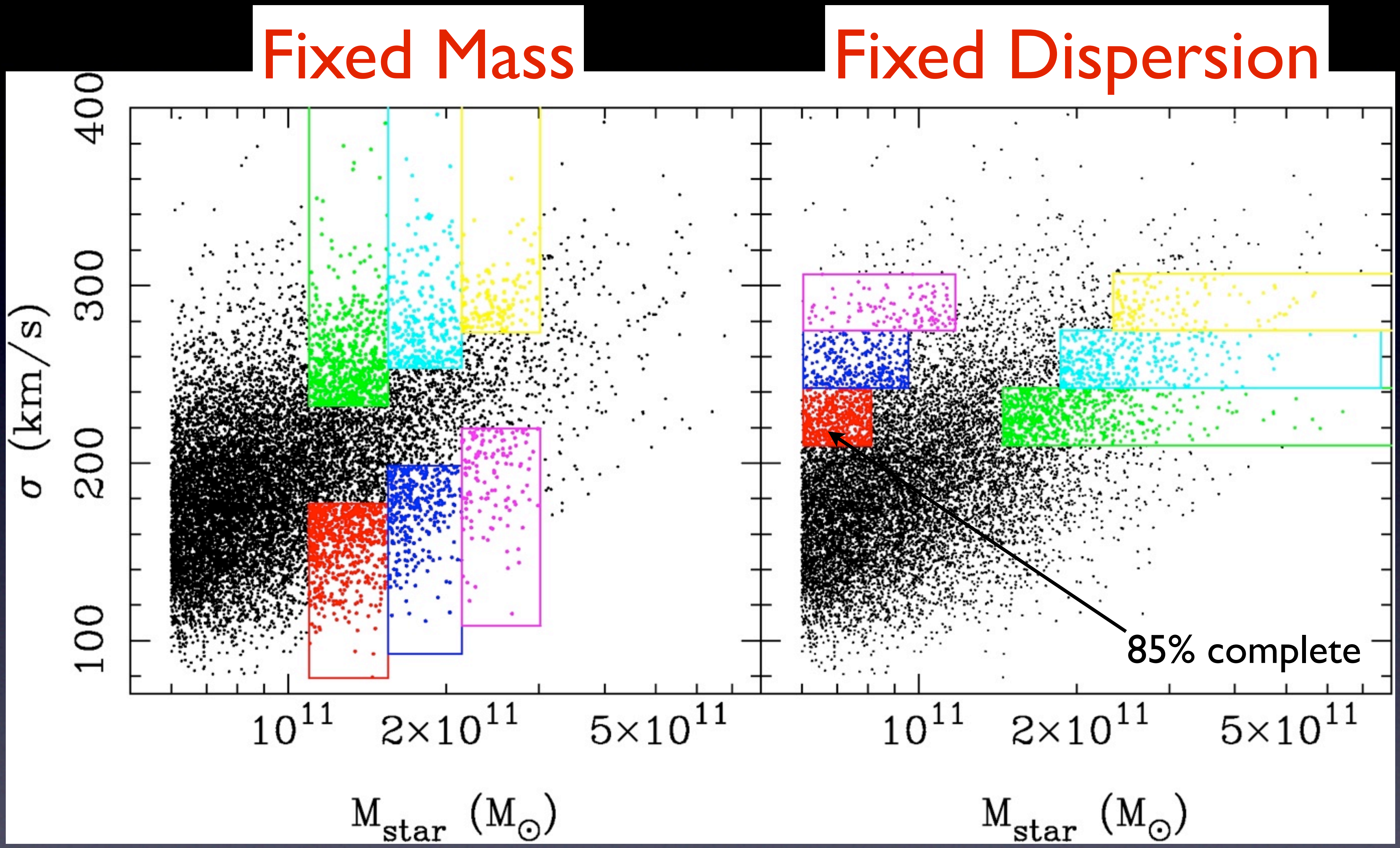


Zehavi et al. (2011)

- Dependence of clustering on luminosity, stellar mass, color, SFR and morphology have all be investigated.
- For central galaxies M_{star} is thought to be tightly correlated with M_{halo}.
- No one has investigated how clustering depends on σ or Σ even though they are strongly correlated with galaxy properties.

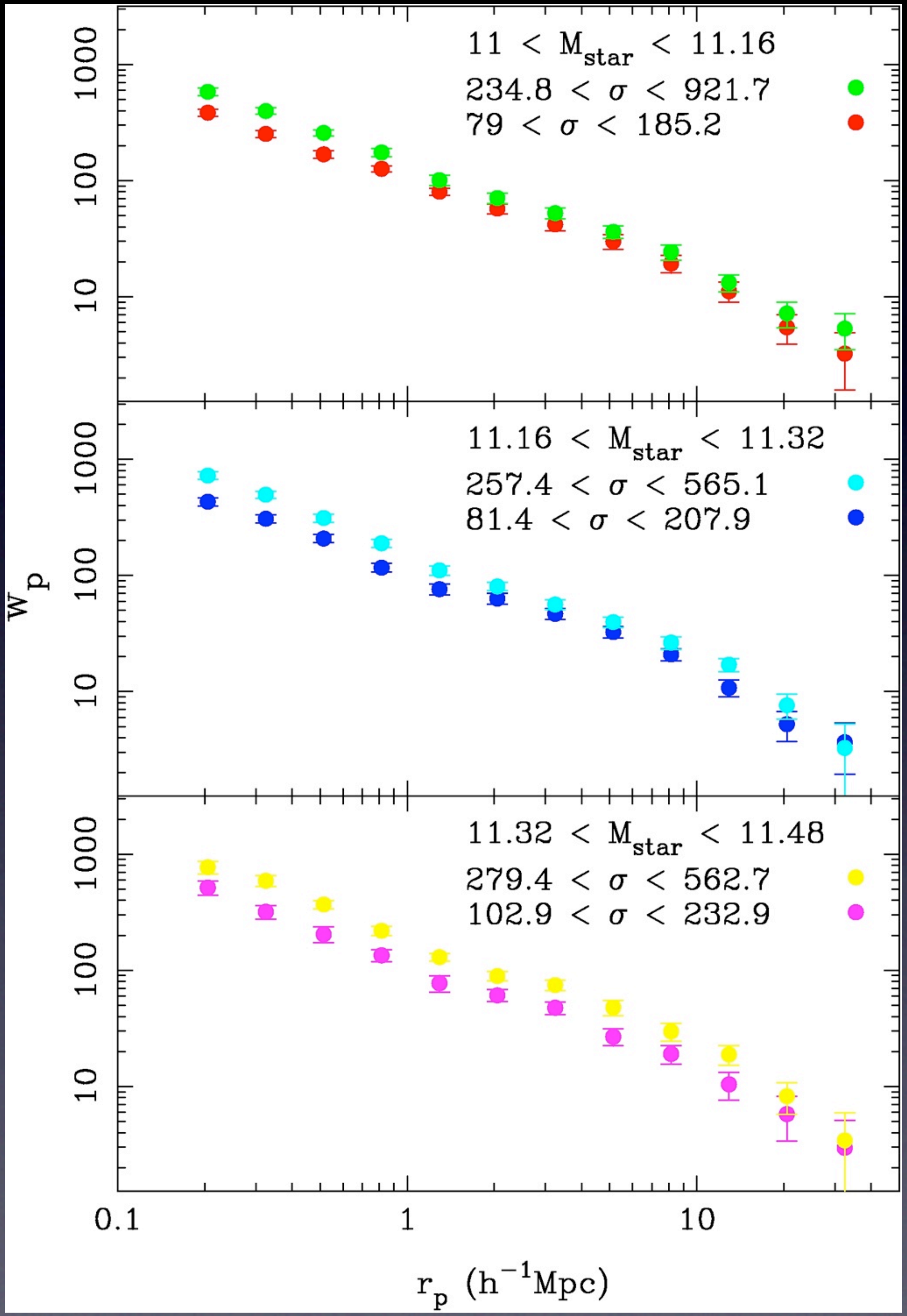
Which of stellar mass, surface mass density or velocity dispersion is the best indicator of clustering amplitude?

- Fix one parameter whilst varying the other and see how the clustering amplitude changes.
- Large volume limited sample of galaxies, complete in both mass and velocity dispersion.
- Parent sample with $0.04 < z < 0.15$ and $M_{star} > 6 \times 10^{10}\ M_{\odot}$.

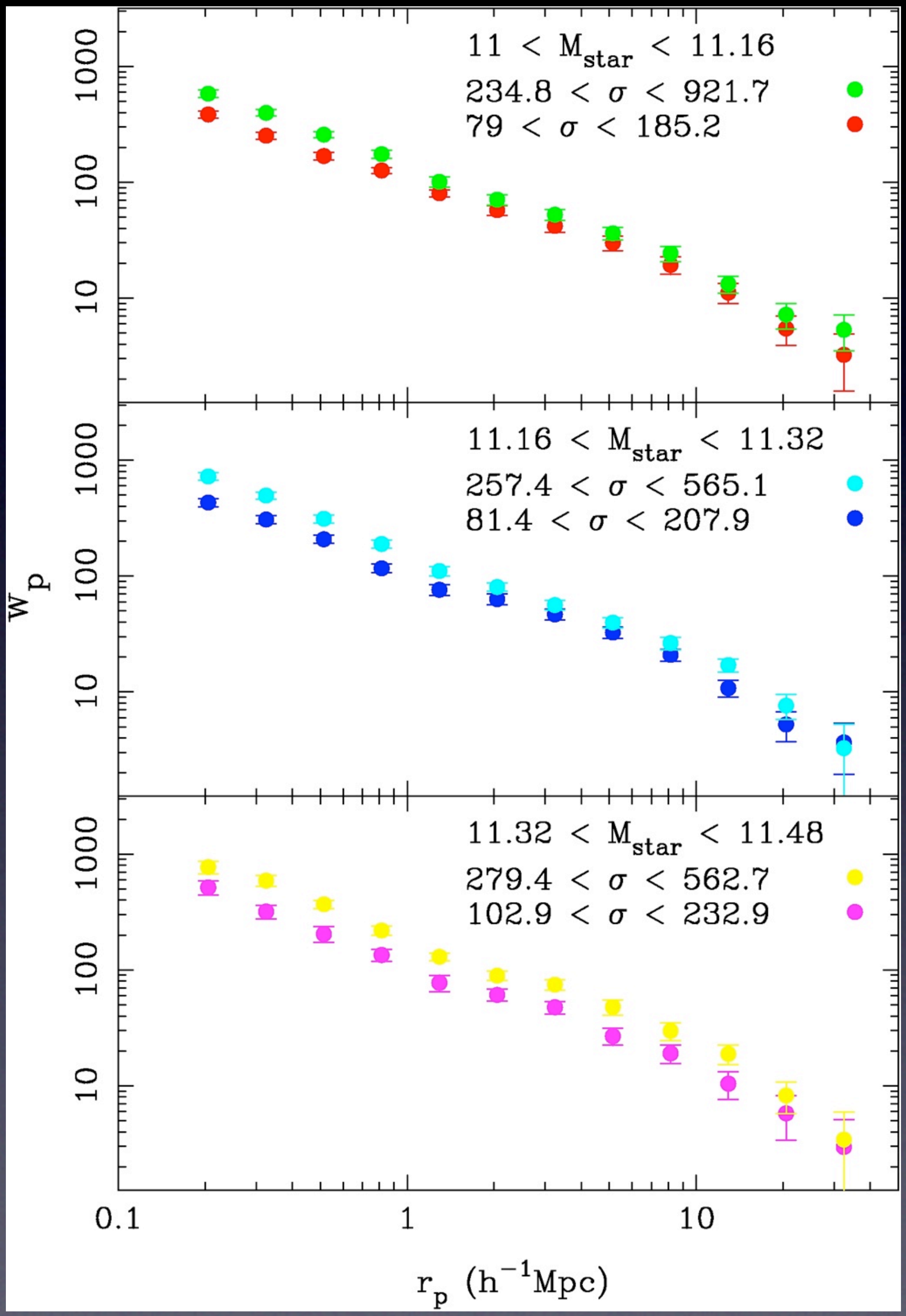


Samples are matched by rank in either σ or M_{star}

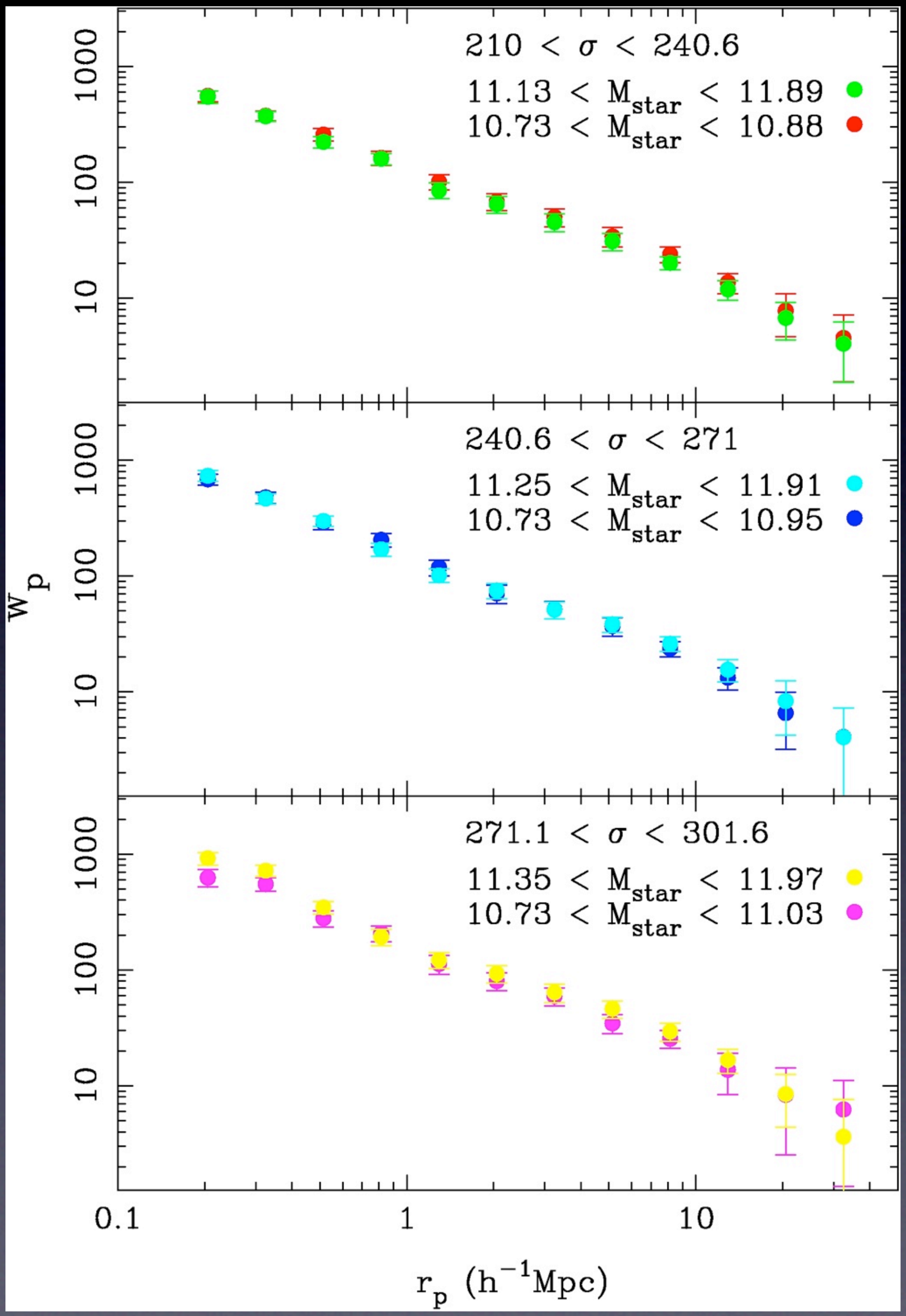
Varying σ at fixed M_{star}



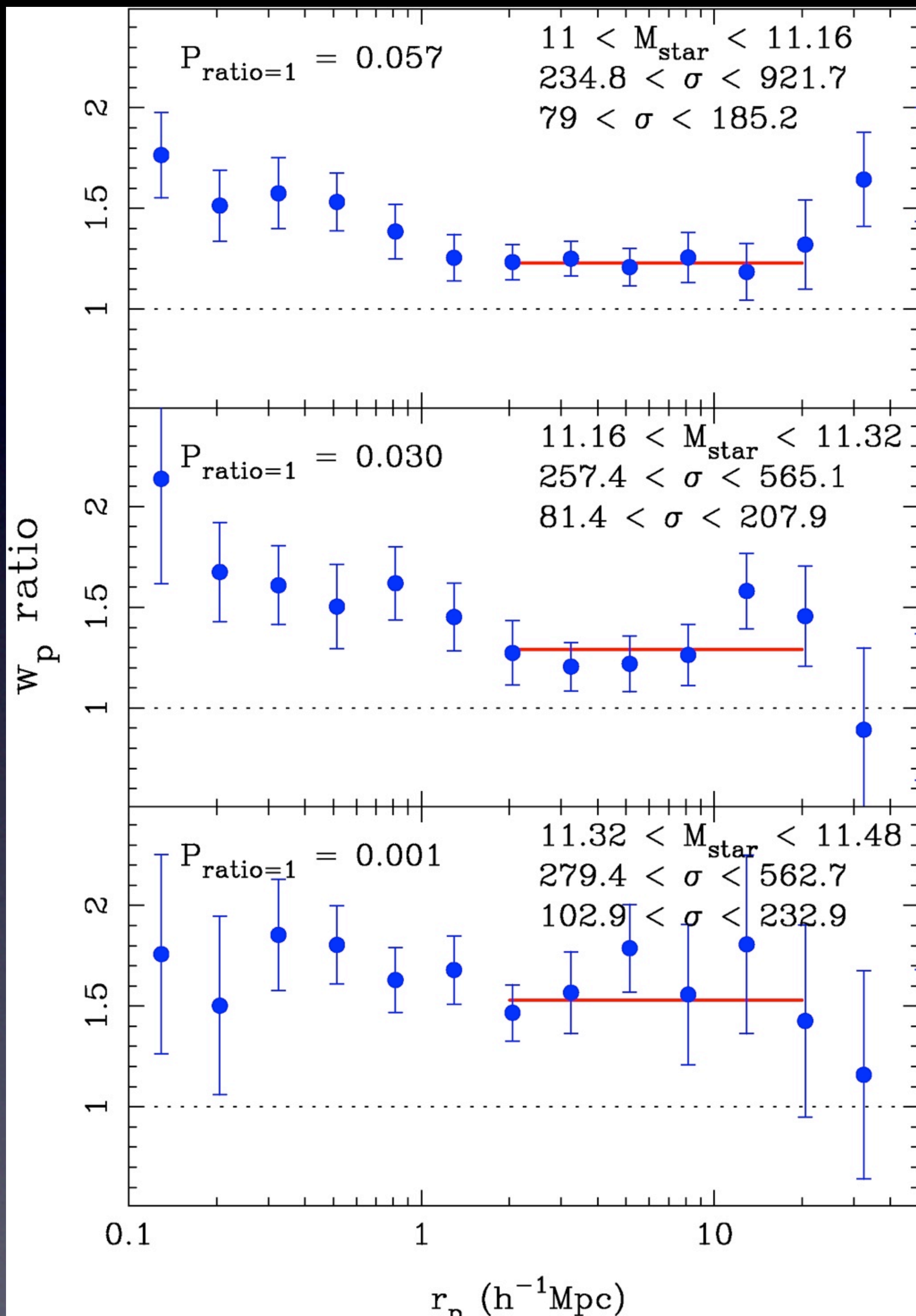
Varying σ at fixed M_{star}



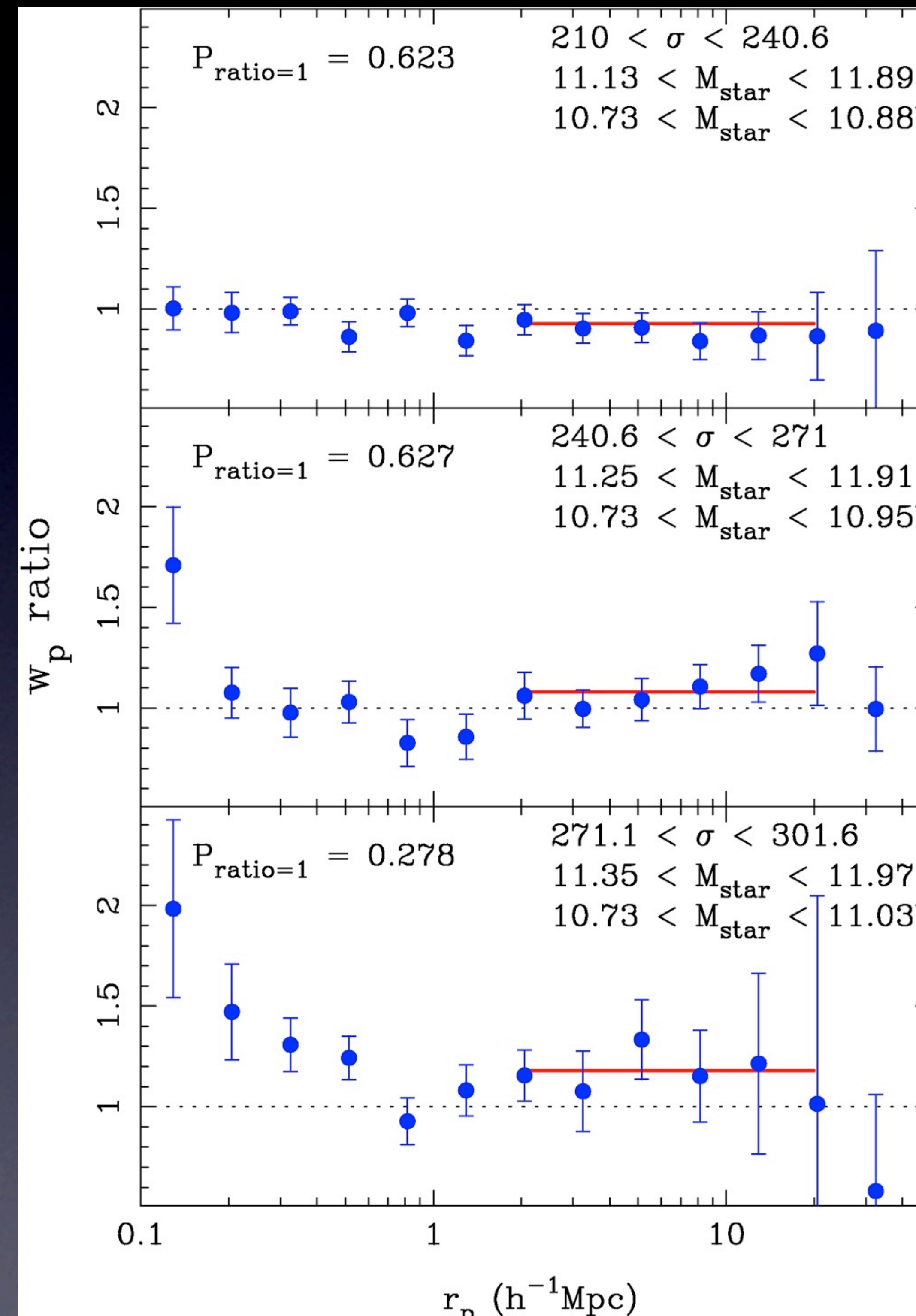
Varying M_{star} at fixed σ



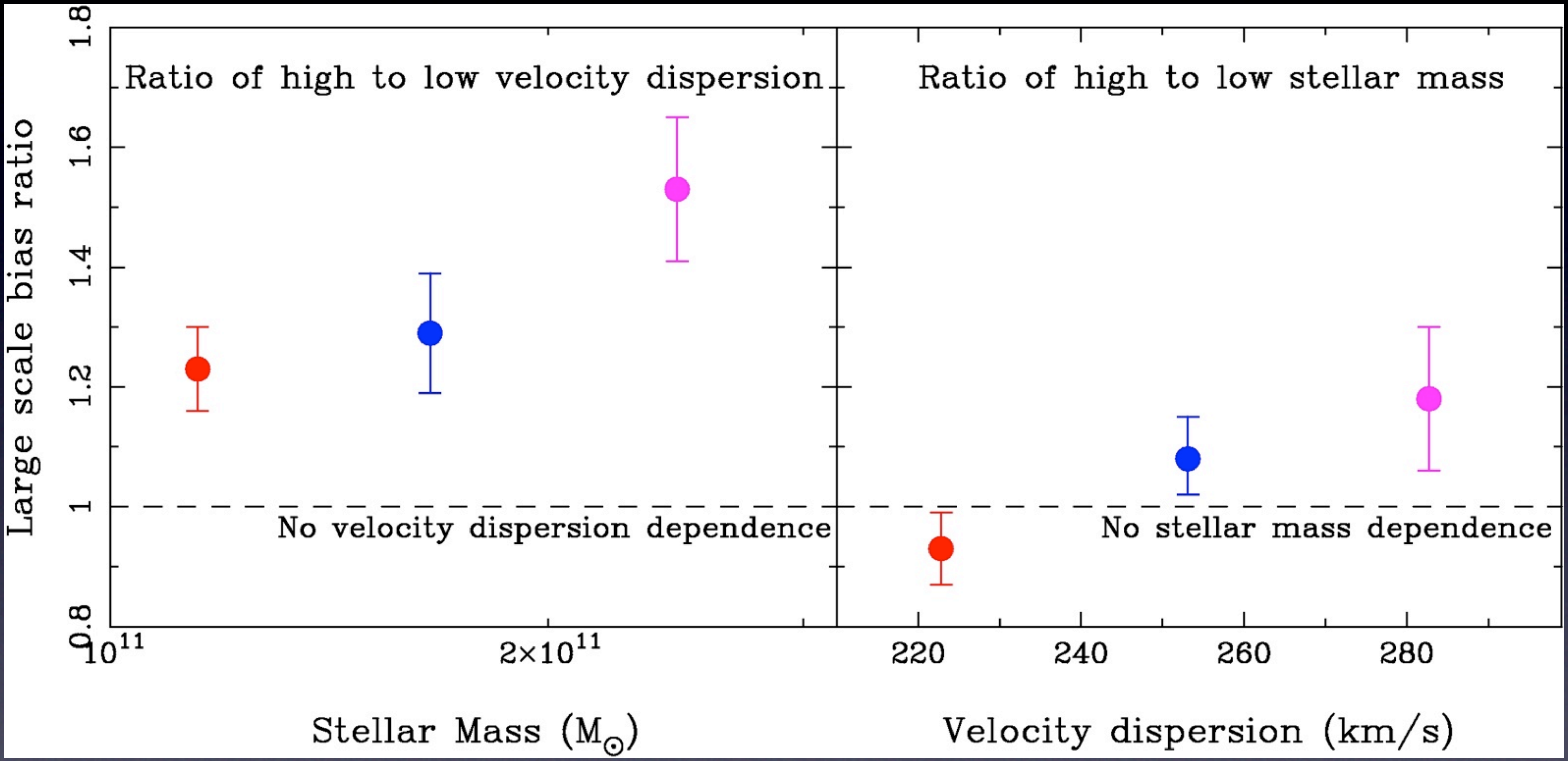
Varying σ at fixed M_{star} | Varying M_{star} at fixed σ



Combined $P_{ratio=1}$ = 0.00009



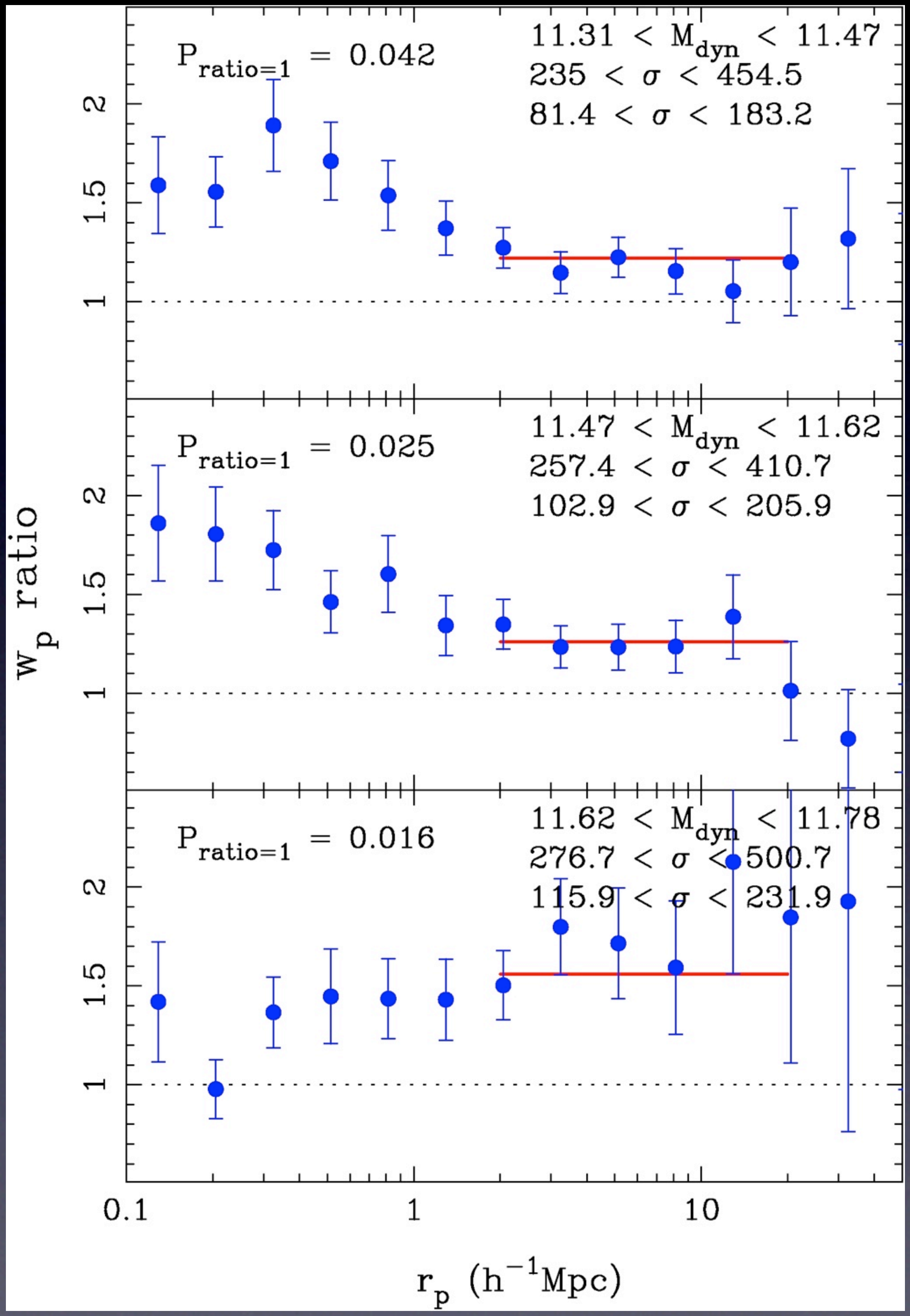
Combined $P_{ratio=1}$ = 0.58


Ratio of high to low velocity dispersion
Ratio of high to low stellar mass
Large scale bias ratio
1.8
1.6
1.4
1.2
1
0.8
No velocity dispersion dependence
No stellar mass dependence
10^{11}
2×10^{11}
220
240
260
280
Stellar Mass ($M_\odot$)
Velocity dispersion (km/s)

Potential systematic errors?

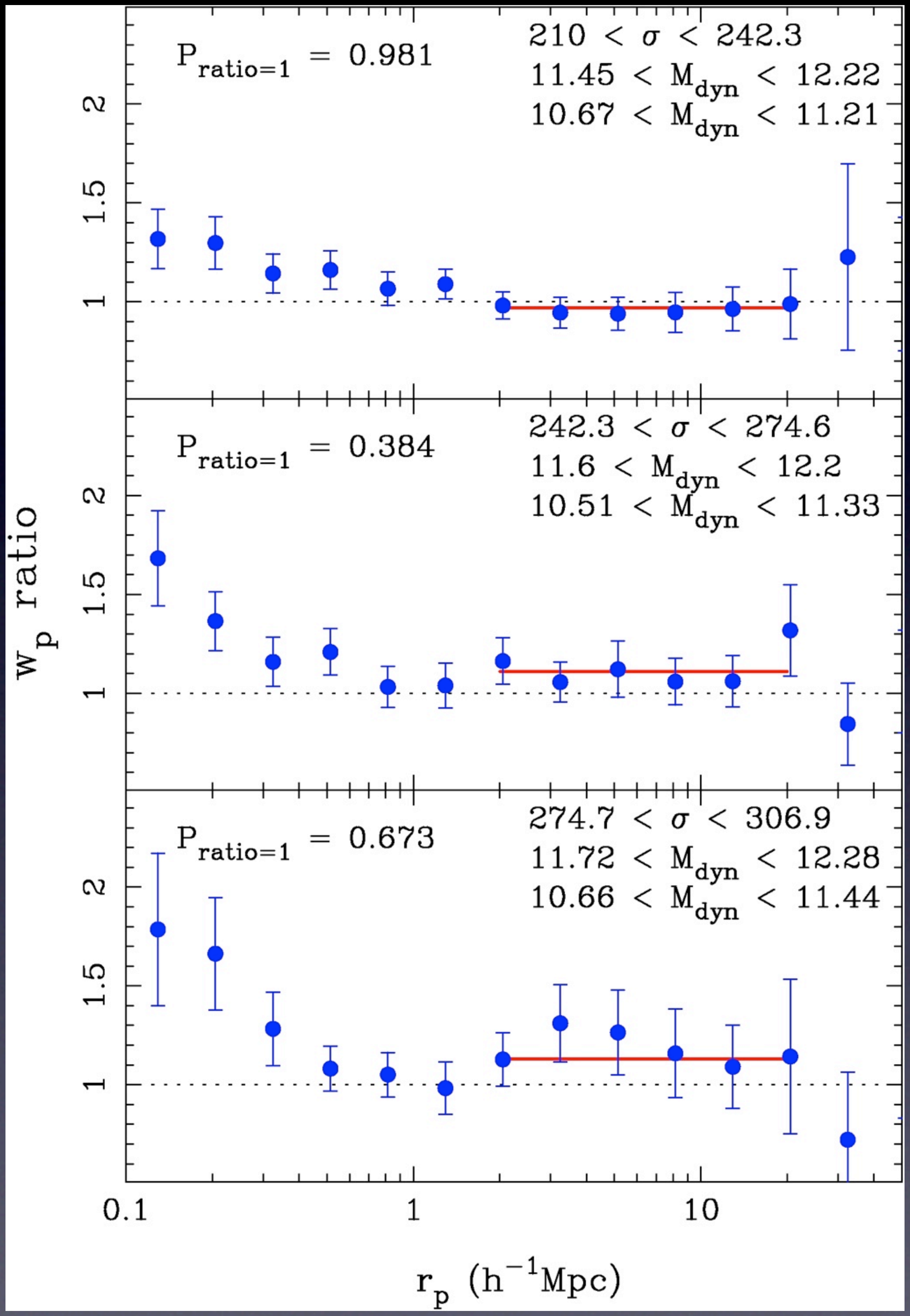
- Errors on M_{star} are much larger than those on σ.
- Replace M_{star} with dynamical mass ($M_{dyn} \propto \sigma/R_e$)
- Replace σ with surface mass density ($\Sigma = M_{star}/R_e^2$).

Varying σ at fixed M_{dyn}



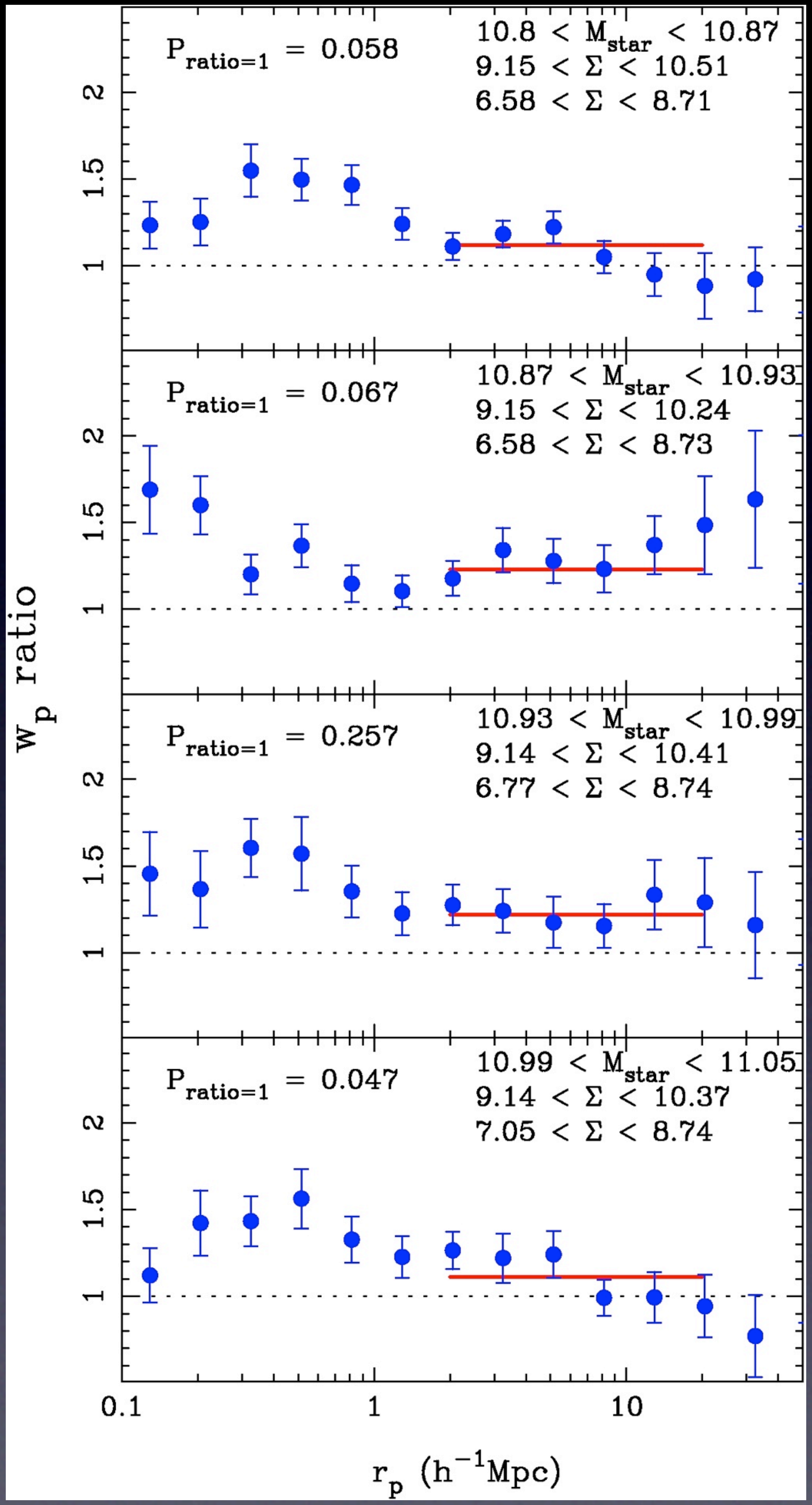
Combined $P_{ratio=1}$ = 0.00085

Varying M_{dyn} at fixed σ



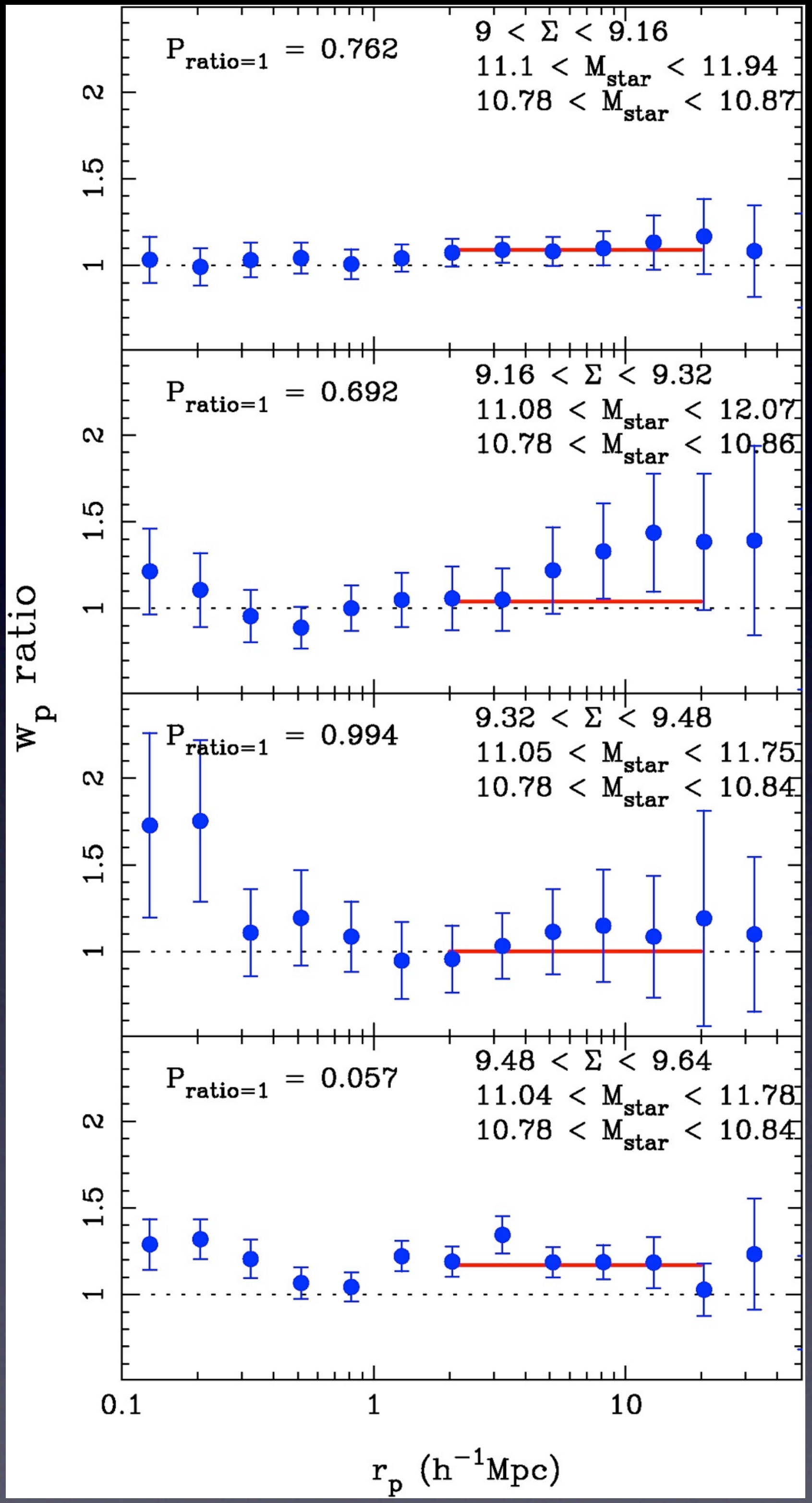
Combined $P_{ratio=1}$ = 0.87

Varying Σ at fixed M_{star}

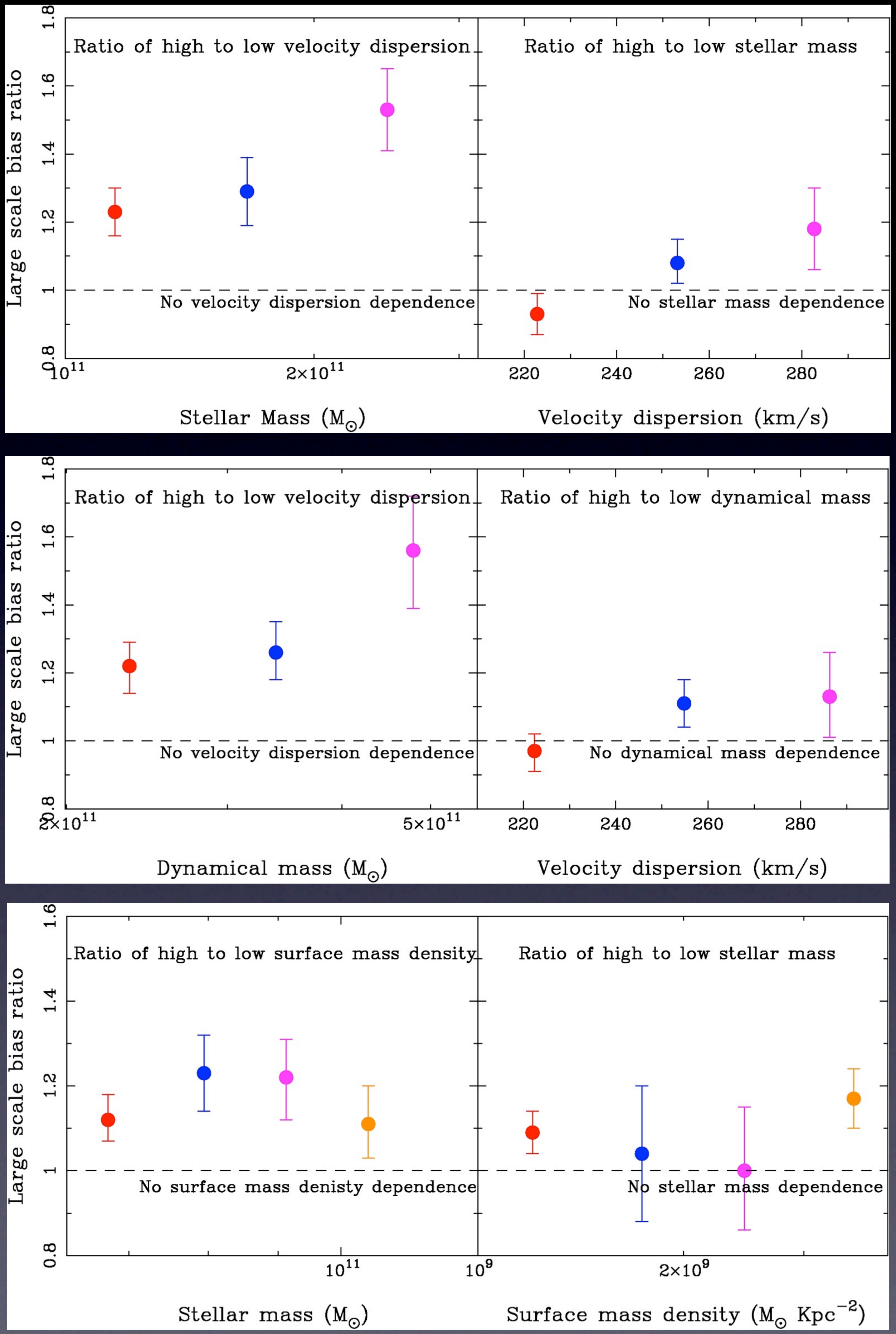


Combined $P_{ratio=1}$ = 0.0071

Varying M_{star} at fixed Σ



Combined $P_{ratio=1}$ = 0.66



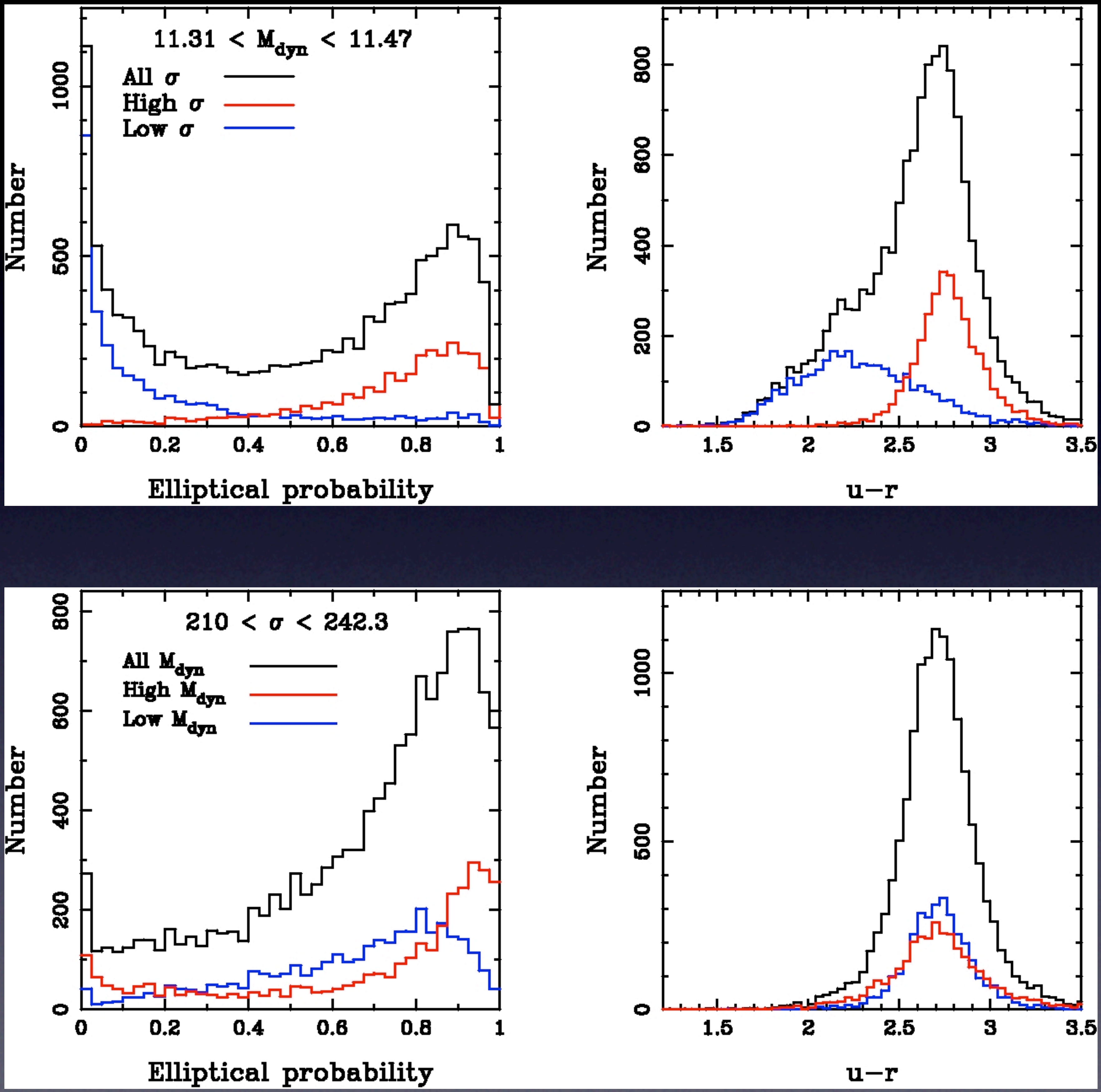
Ratio of high to low velocity dispersion
Ratio of high to low stellar mass
No velocity dispersion dependence
No stellar mass dependence
Large scale bias ratio
Stellar Mass ($M_\odot$)
Velocity dispersion (km/s)
Ratio of high to low velocity dispersion
Ratio of high to low dynamical mass
No velocity dispersion dependence
No dynamical mass dependence
Dynamical mass ($M_\odot$)
Velocity dispersion (km/s)
Ratio of high to low surface mass density
Ratio of high to low stellar mass
No surface mass denisty dependence
No stellar mass dependence
Stellar mass ($M_\odot$)
Surface mass density ($M_\odot$ Kpc^{-2})

Third variable?

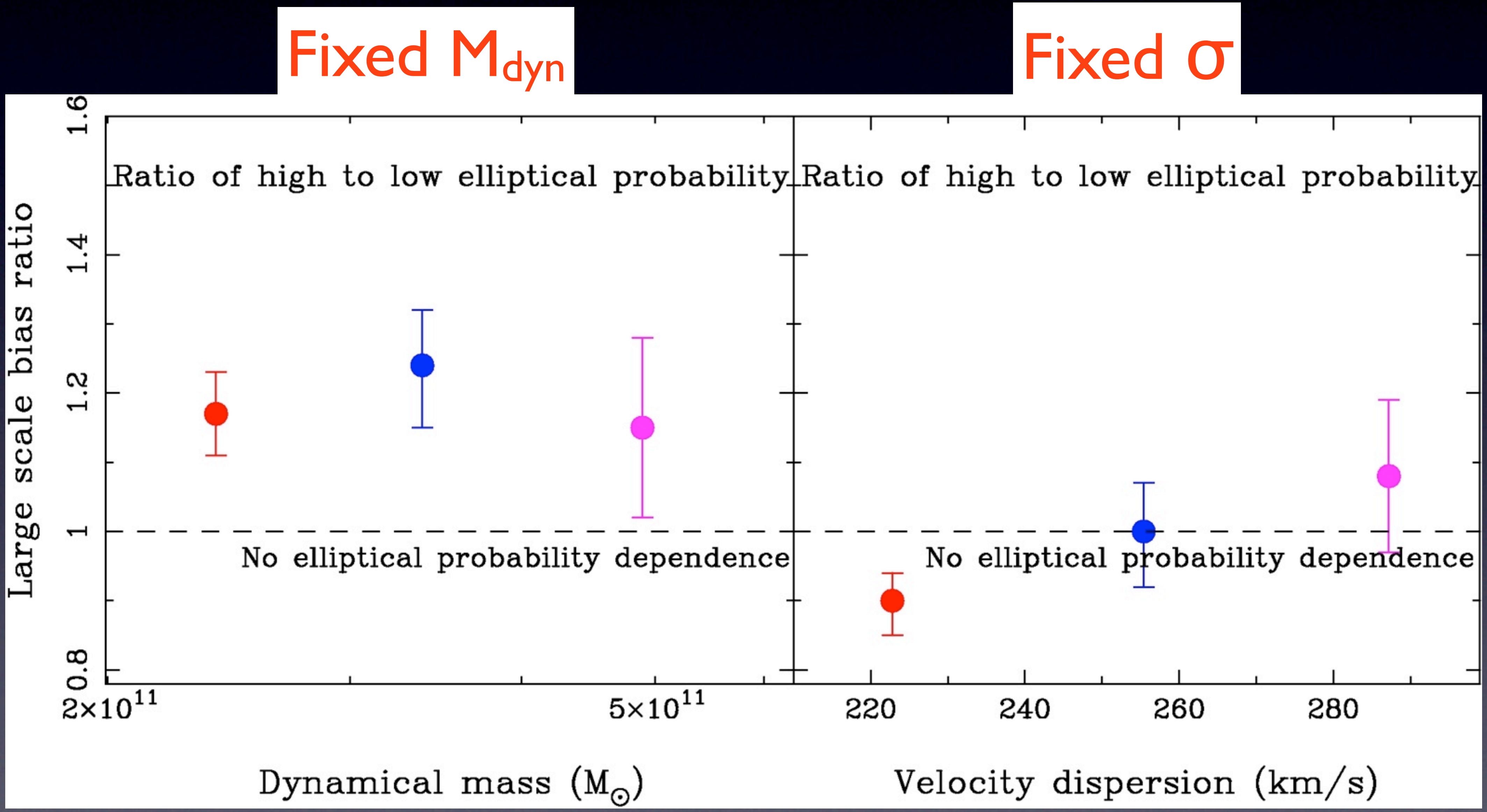
- Both σ and Σ are more strongly correlated than either M_{star} or M_{dyn} with clustering amplitude.
- What about color or morphology?

Fixed M_{dyn}

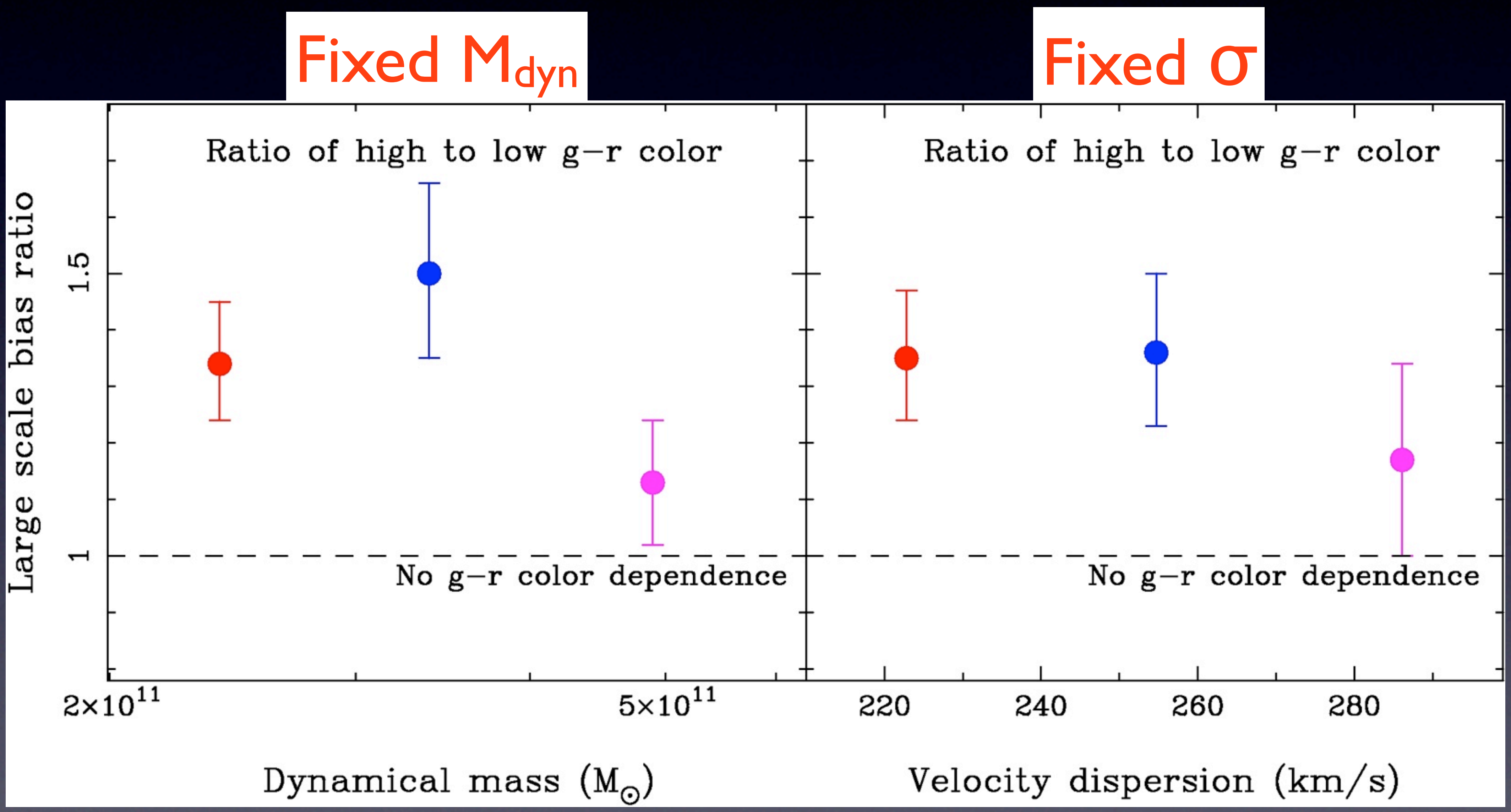
Fixed σ



Dependence of clustering amplitude on morphology



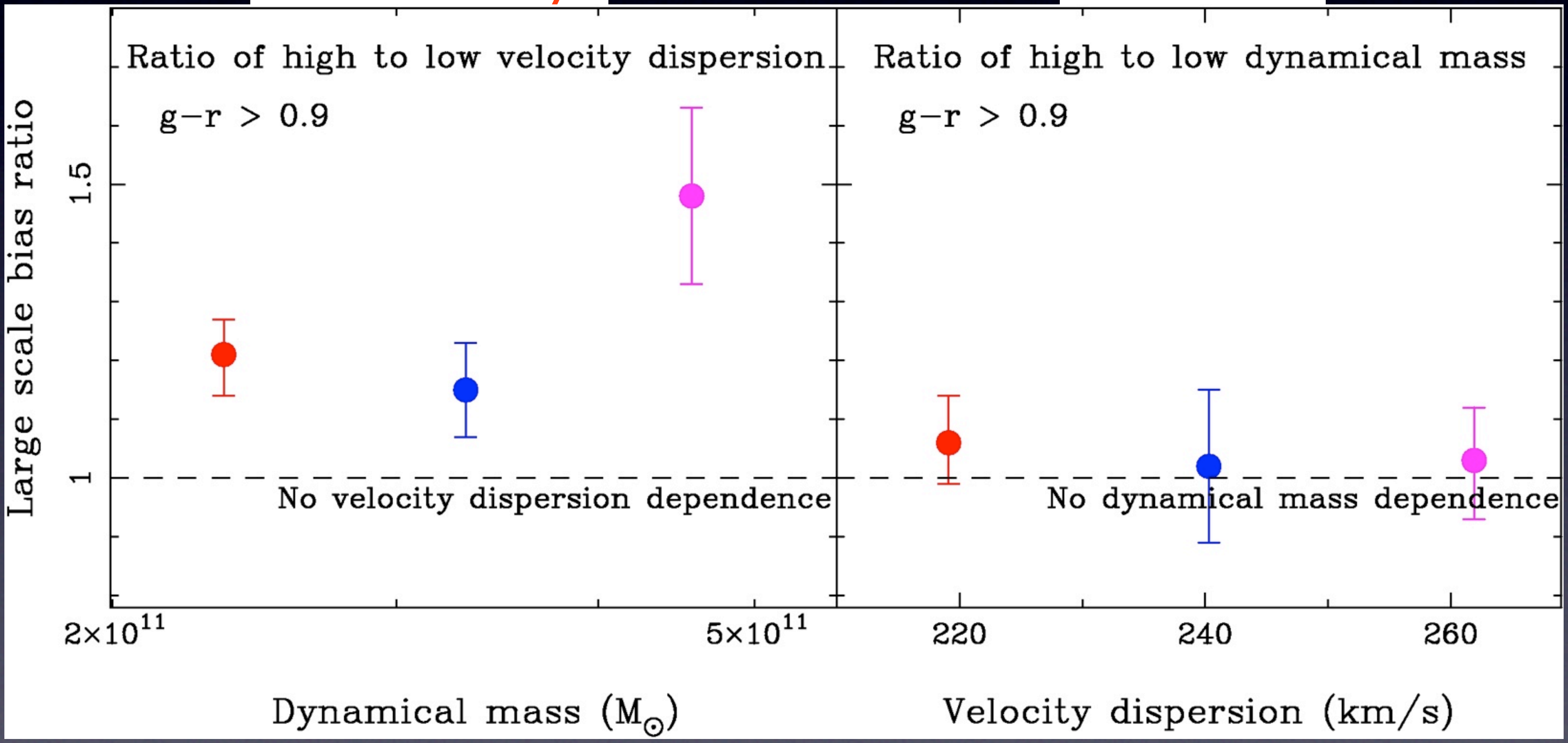
Dependence of clustering amplitude on color



Color could be the third variable

Red galaxies only

Fixed M_{dyn} Fixed σ

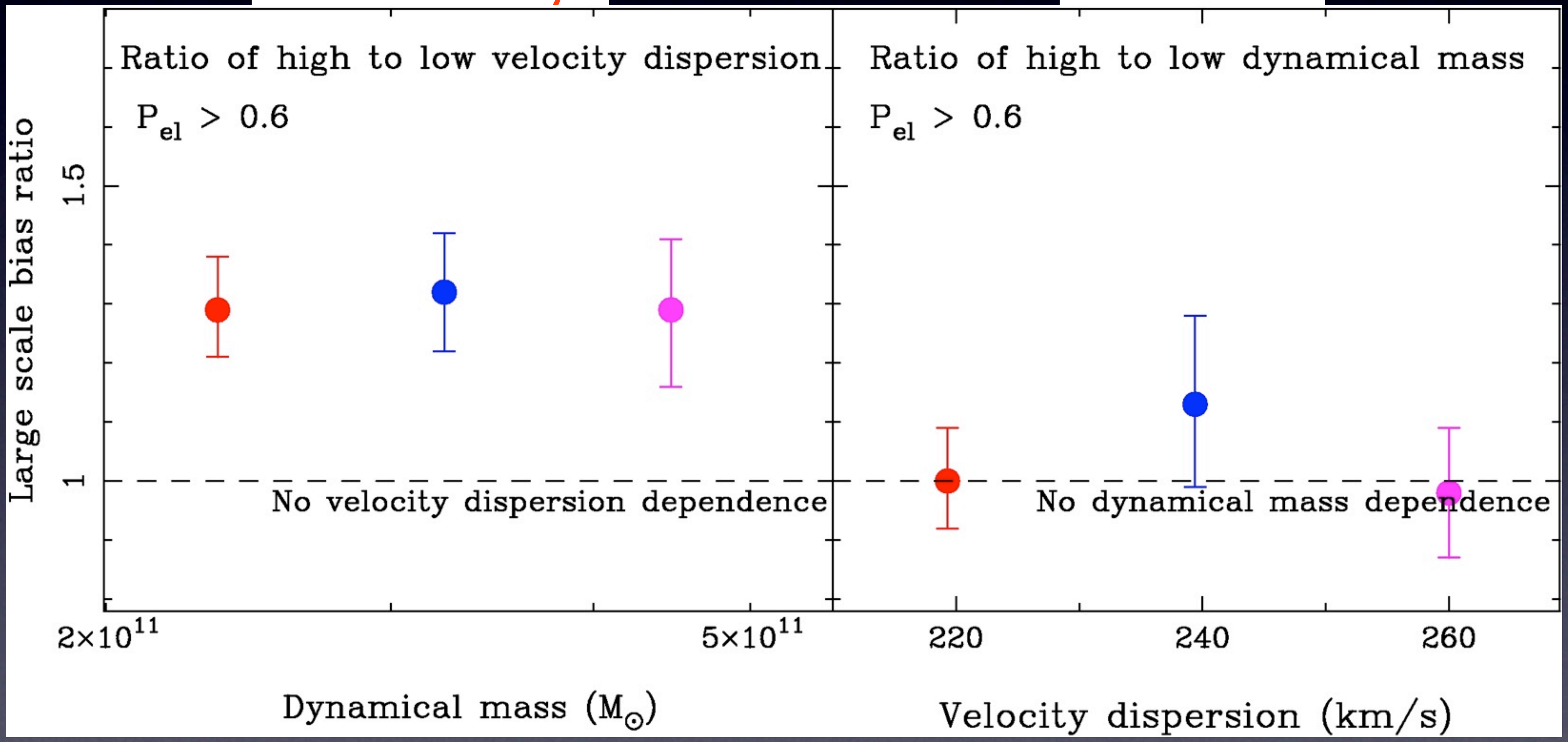


Combined $P_{ratio=1}$ = 0.027

Combined $P_{ratio=1}$ = 0.92

Elliptical galaxies only

Fixed M_{dyn} Fixed σ



Combined $P_{ratio=1}$ = 0.0043

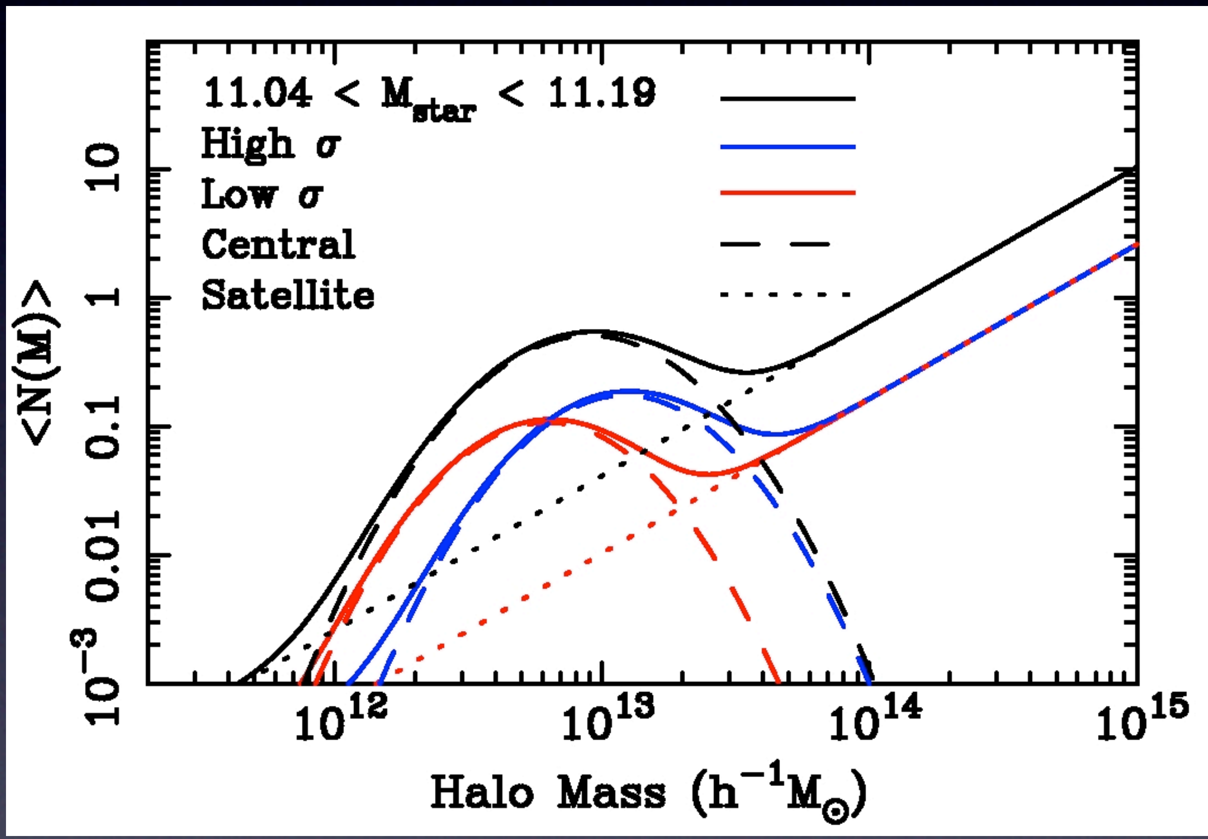
Combined $P_{ratio=1}$ = 0.77

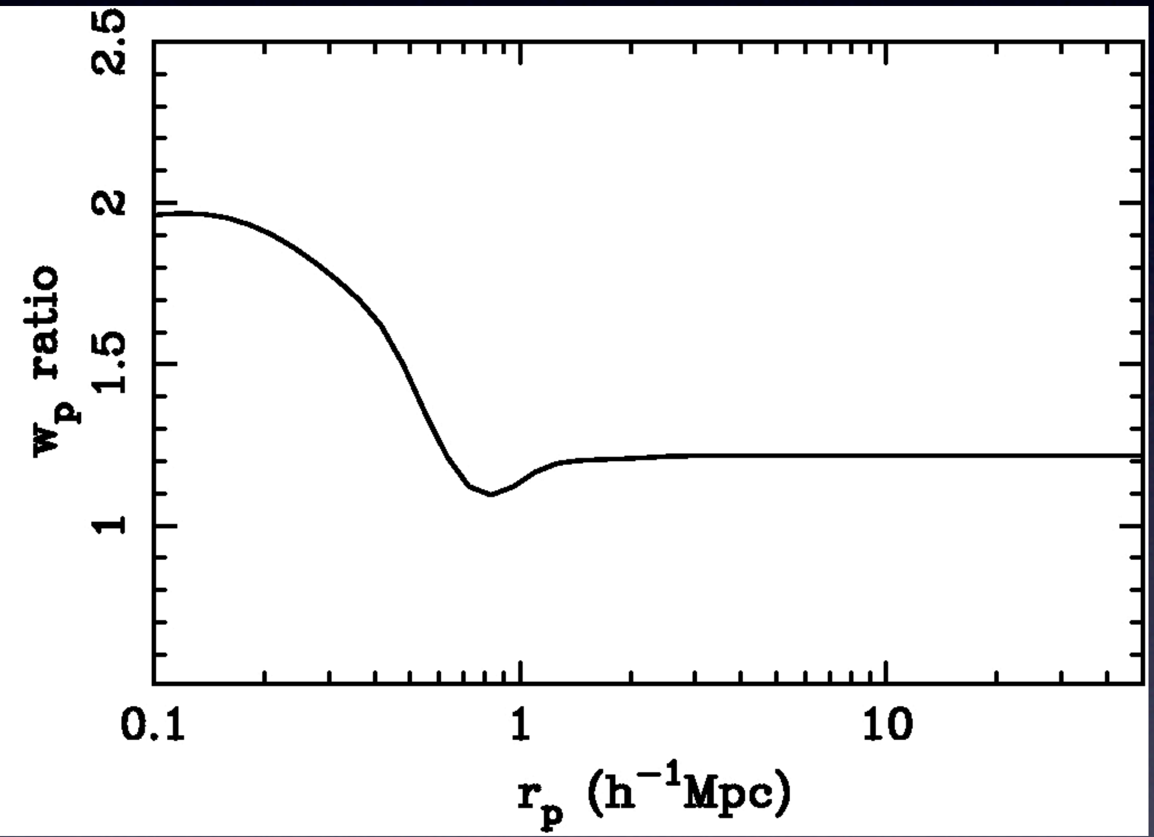
- Even at fixed color or morphology σ is the best indicator of clustering amplitude.

Relating clustering amplitude and halo properties.

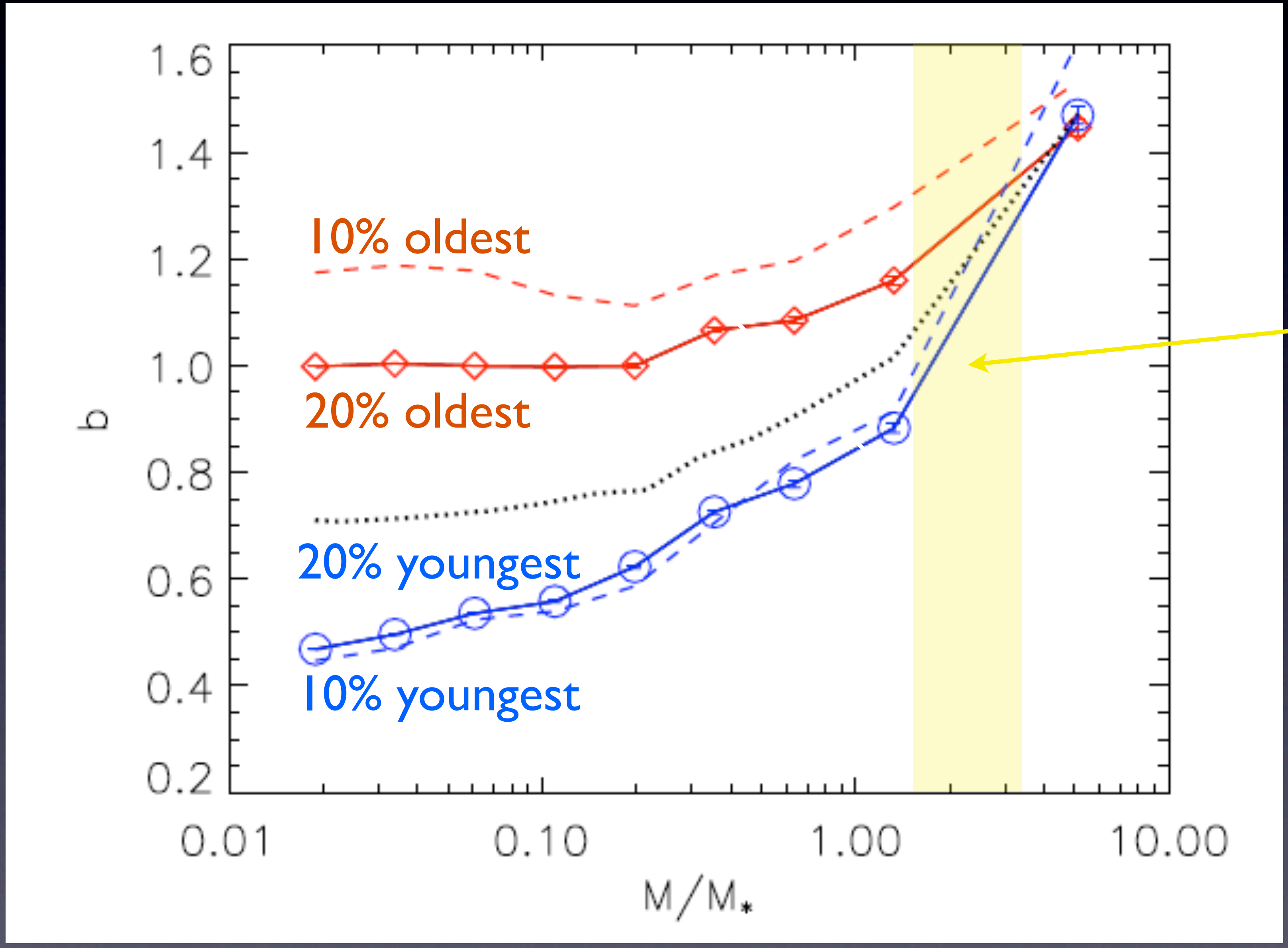
- Three possibilities:
  1. Tighter correlation between σ and M_{halo} than between M_{star} and M_{halo} for central galaxies.
  2. There is a correlation between σ and halo formation time for central galaxies.
  3. There is correlation between σ and M_{halo} for satellite galaxies.

σ and M_{halo} Centrals





σ and halo formation time

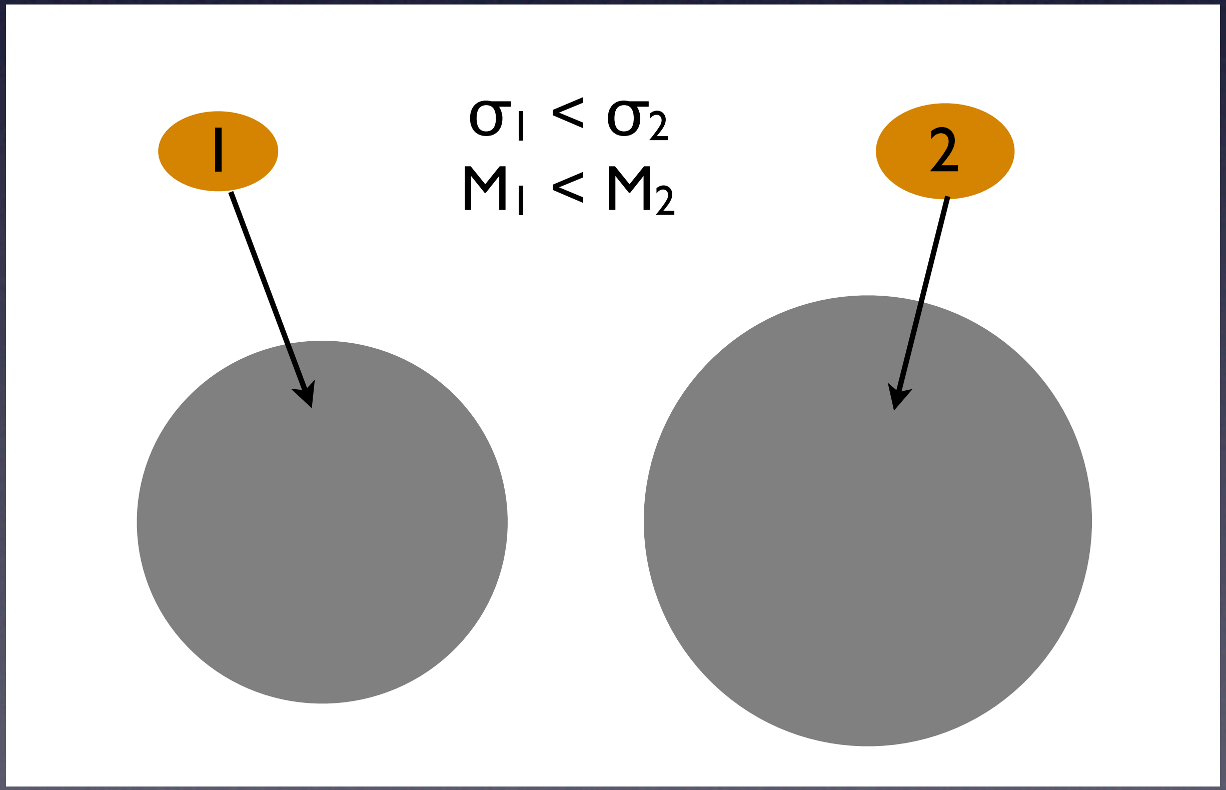


w_p ratios = 1.56 - 1.13

Gao et al. (2005)

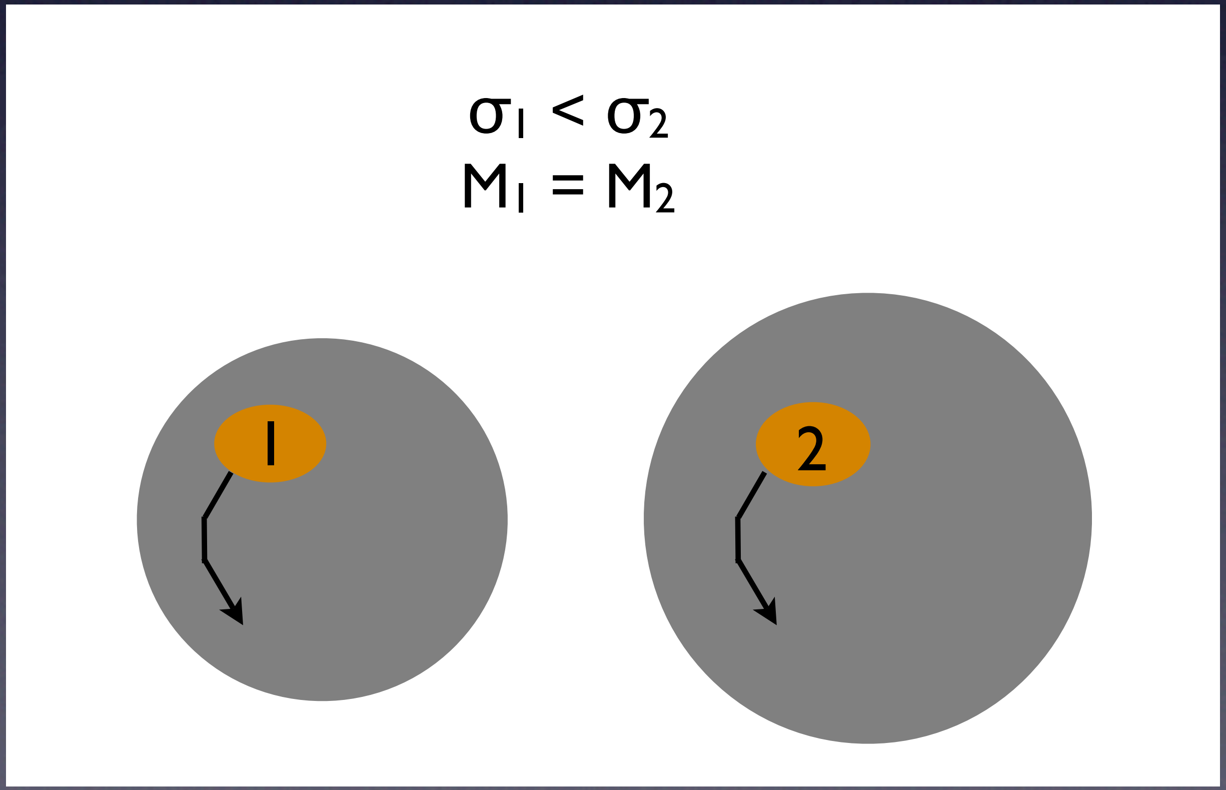
σ and M_{halo} Satellites

- Need satellite galaxies of a given mass to be in a higher mass halo if they have a higher σ.
- Tidal striping could cause this.



σ and M_{halo} Satellites

- Need satellite galaxies of a given mass to be in a higher mass halo if they have a higher σ.
- Tidal striping could cause this.



Back to color

- σ is the best indicator of a galaxy's color.
- High σ means their is a large bulge, which means a large black hole => truncation of SF.
- σ could also be better correlated with halo mass or halo age.
- High halo mass is required to maintain a low SFR (shock heated gas, radio mode feedback).
- Old halos should host galaxies with older stellar populations.

Next steps

- Which mechanism is responsible for the tight relationship between σ - clustering amplitude?
  - Lensing (CS82, CFHT-LS, HSC)
  - Satellite kinematics
  - Group catalogs
- Resolved spectroscopy - MaNGA.