Environmental Effects on the Star Formation History of Galaxies

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Background and Purpose

Lots of observations and theories have led to a so-called "inside-out quenching process" for galaxies, in which a galaxy evolves from "blue" galaxies (star-forming, with no/little bulge) into "red" galaxies (little star formation, perhaps with a dense bulge) with star formation extinguishment expanding from galaxy center to the edge.

However, the underlying physical process is uncertain yet. There're various channels causing star formation quench like halo quenching, morphology quenching and so on. In particular, the halo quenching process is quite different for central and satellite galaxies. Therefore, central/satellite division becomes crucial when we're discussing quenching process. The same logic applies to other environmental parameters, so we'll need to examine their influence on galaxy quenching. And this helps to understand the "natural" or "mature" scenario of galaxy evolution.

Data and Method

MaNGA data:

The MaNGA MPL-6 datacube provides us with spatially resolved spectrum in wavelength 3600 to 10000 Å for 4621 individual galaxies. Then spectral fitting with PPXF method (Cappellari & Emsellem, 2004; Cappellari, 2017) is applied to every spaxel to obtain a 2D distribution of the star formation indicators we need.

Indicators from MPL-6:

$D_{4000}(cen/Re)$

4000 Å break at galaxy center and Re (effective raidus) (Balogh et al. 1999)

$\alpha(D_{4000}) \equiv D_{4000}(cen) - D_{4000}(Re)$

$f_Q(1.5Re)$: (mass-weighted) fraction of quenched spaxel within 1.5Re

$$f_Q(1.5Re) = \frac{\sum_{r<1.5Re} m_{*,i} \times f_i(D_n(4000),\ EW(H_\alpha))}{\sum_{r<1.5Re} m_{*,i}}$$

$$f_i(D_n(4000),\ EW(H_\alpha)) = \begin{cases} 1, & D_n(4000)_i > 1.6 \ and \ EW(H_\alpha)_i < 2.0 \\ 0, & Otherwise \end{cases}$$

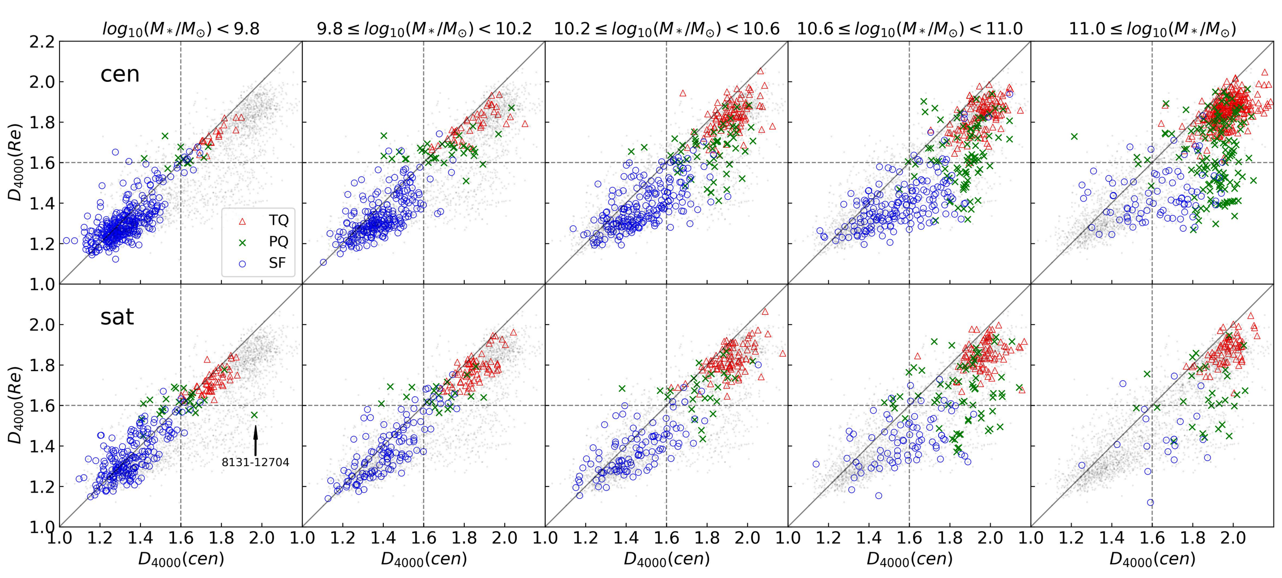
Environmental Parameters:

A halo-based group catalog for SDSS DR13 (Lim, S. H., et al. 2017, Mon Not R Astron Soc, 470, 2982) → Halo mass M_h; Virial radius R_{200}; Central/Satellite division

ELUCID applied to SDSS DR7 (Wang, H., et al. 2014, Astrophys J, 794) → local density $\log_{10}\delta$ (within 1 Mpc); large scale structure (LSS) type

Results and Analysis

1) Cen/Sat division



Red, Totally Quenched, TQ - $f_Q(1.5Re) > 0.9$;
Green, Partially Quenched, PQ - $0.1 < f_Q(1.5Re) \le 0.9$;
Blue, Star Forming, SF - $f_Q(1.5Re) \le 0.1$;
(Wang et al. 2018)

Fig. 1 - $D_{4000}(Re)$-$D_{4000}(cen)$, different mass, cen/sat galaxies

In Fig. 1, The distribution of galaxy on the $D_{4000}(Re)$-$D_{4000}(cen)$ plot strongly depends on mass, which is discussed in detail in Wang, E., et al. 2018, Astrophys J, 856, 137. In the same mass range, cen/sat division won't influence their position on the subplot.

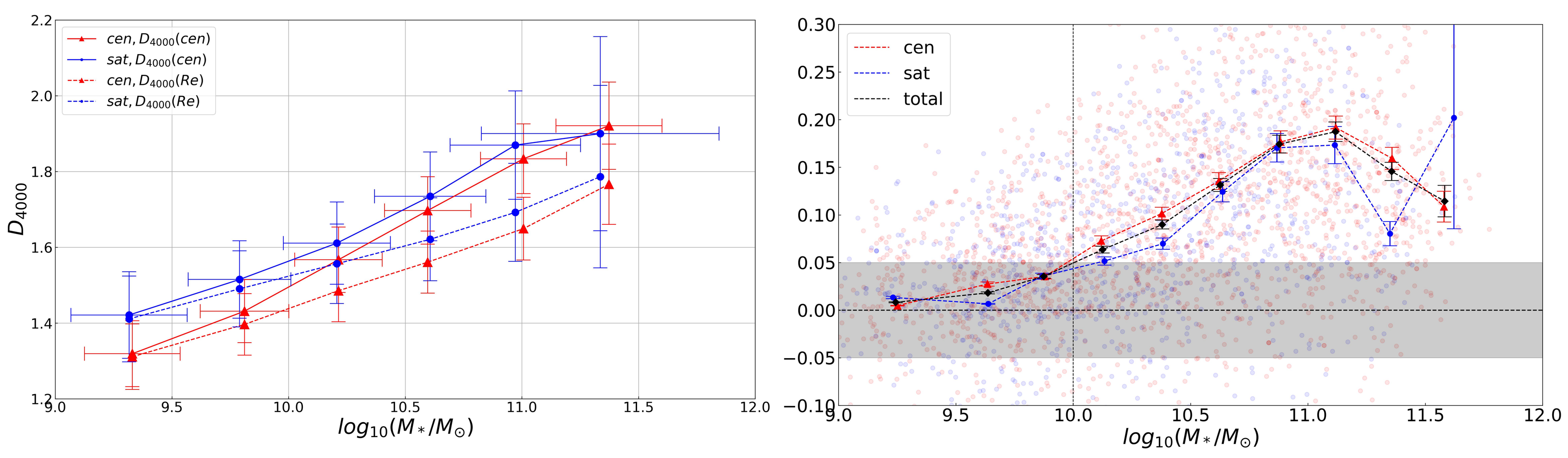


Fig. 2 - Average $D_{4000}(cen/Re)/\alpha(D_{4000})$-$\log_{10} M_*/M_\odot$, cen/sat galaxies

In Fig. 2, when stellar mass is low, average D4000 is higher for satellite than central galaxies. But when mass goes up, the difference between central and satellite galaxy become vague, both d4000 at center or Re.

What about $\alpha(D_{4000})$, which stands for the "gradiant" of D_{4000}? In the right panel of Fig. 2, we can find $\alpha(D_{4000})$ have nothing to do with cen/sat division !
So we claim:

① Cen/sat division will influence the development of "inside-out quenching" for individual galaxies: low mass satellites tend to evolve further into TQs

② However, galaxies of the same mass have same "quenching route": cen/sat division will NOT affect galaxies' deviation from 1:1 relation on the $D_{4000}(Re)$-$D_{4000}(cen)$ plot.

2) Local Density / Halo Mass & LSS (large scale structure) type

Since local density and halo mass originally have very strong connection to each other, it's not surprising that they give almost the same conclusion. We've only displayed plots for local density here.

In Fig. 3, in the same line (mass range), $D_{4000}(cen)$ goes up with local density, especially for low mass galaxies, and this trend disappears in the high mass region.

What's more, for lines of the same mass, satellite galaxies react more intensively to local density increasement than central galaxies. This is consistent with our conclusion for cen/sat division.

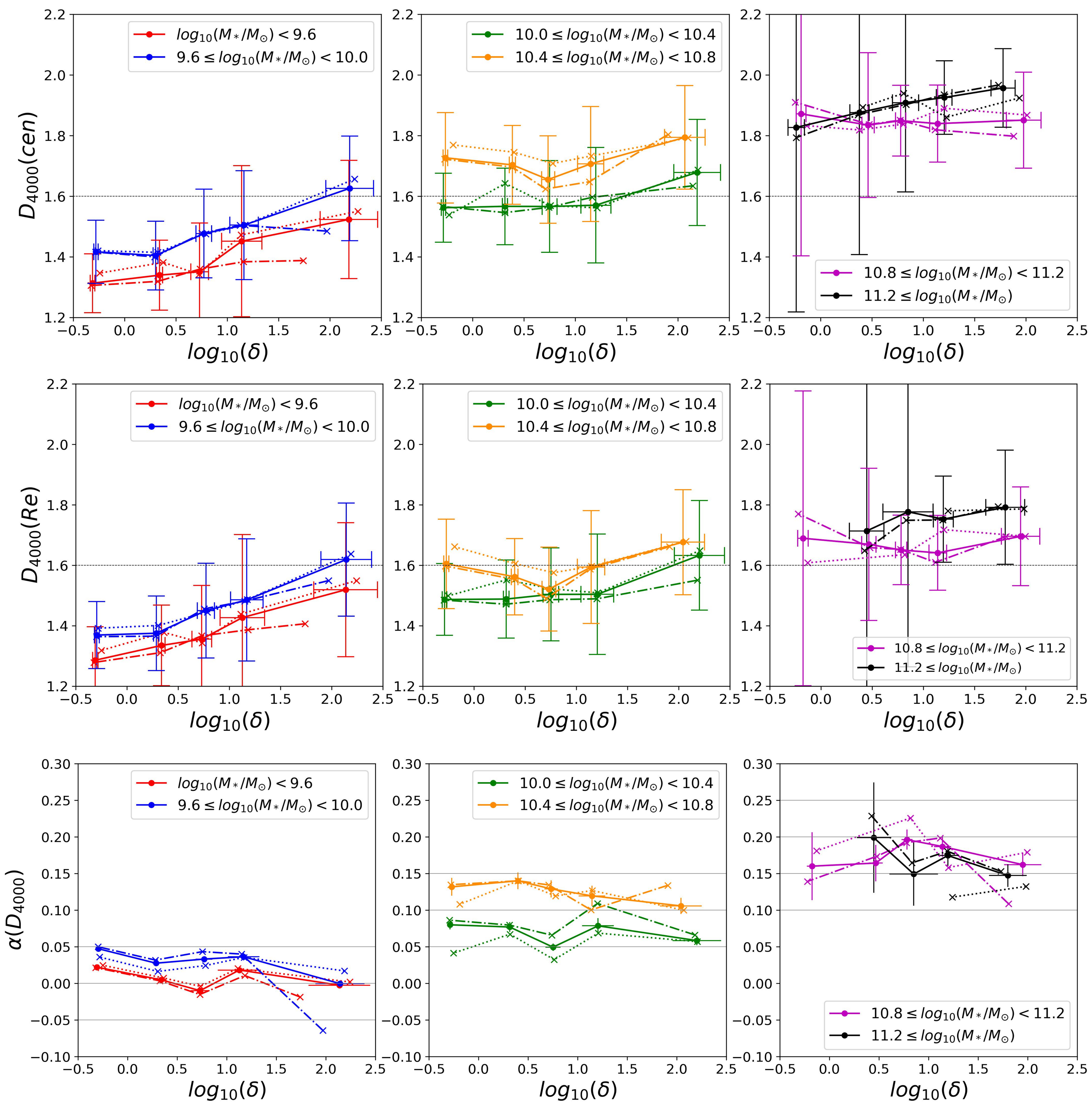


Fig. 3 - Average $D_{4000}(cen/Re)/\alpha(D_{4000})$-$\log_{10}(\delta)$, different mass
—— all the galaxies ; ··· satellite galaxies ; —·— central galaxies

The situation is exactly the same for $D_{4000}(Re)$. But alpha is still unaffected.

(Although there might be some slight trend in the low mass case, it's within the error range of D_{4000})

In Fig. 4 (Shortly speaking, the five bars of the same color in the same subplot add up to 1), the fraction of TQ galaxies becomes bigger than SF galaxies when local density increases. This phenomenon occurs in cluster galaxies.

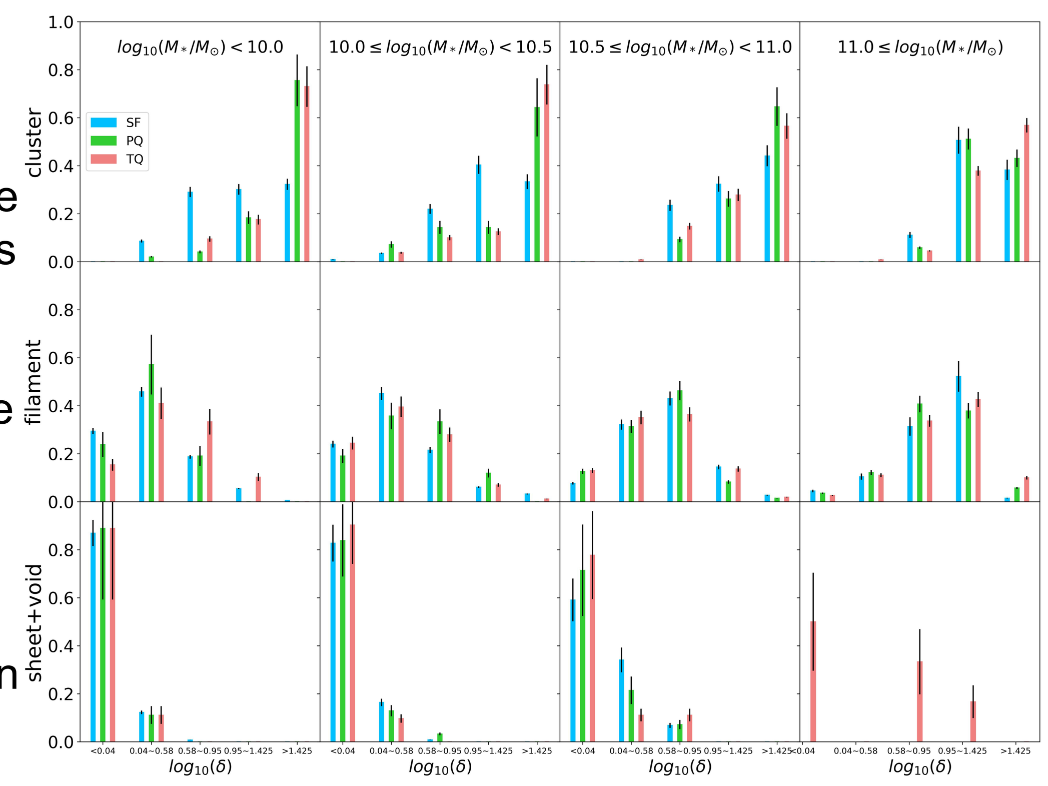


Fig. 4 - Fraction of #galaxies in different density bin, different mass & LSS type

3) d/r200: distance to center/virial radius of halo (for satellite galaxies only)

In Fig. 5, the parameters seem not influenced by distance. The reason could be various. It can be because the quenching process simply has nothing to do with the radius, or because we have too few satellite galaxies to make further division. Projection reason also counts. Any way, further investigation or discussion is needed.

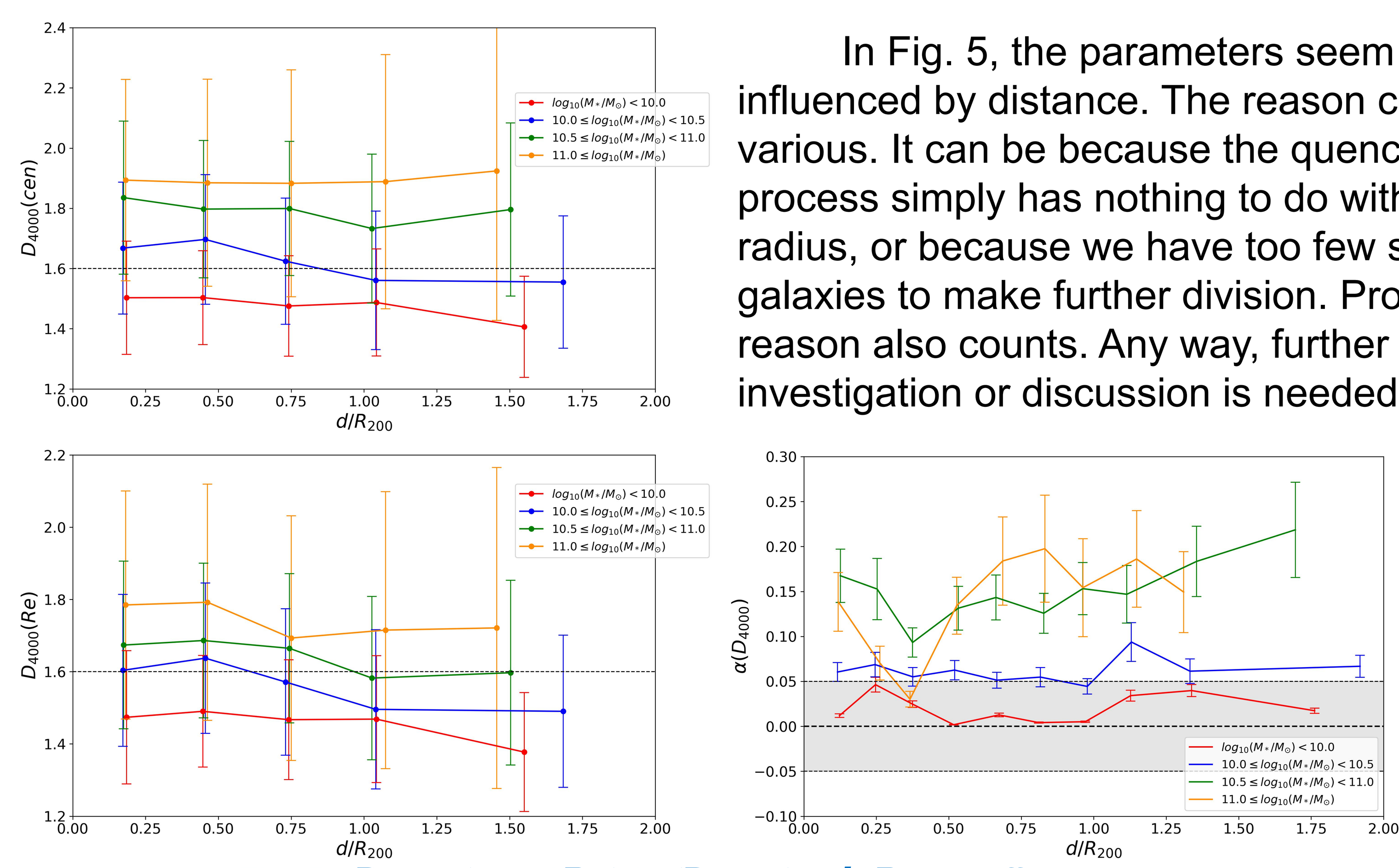


Fig. 5 - $D_{4000}(cen/Re)/\alpha(D_{4000})$ - d/R_{200}, different mass

Conclusion

1) $\alpha(D_{4000})$ in galaxies ONLY depends on stellar mass; all the environmental factors we mentioned above affect galaxy center and edge SYNCHRONOUSLY.
2) low-mass satellite galaxies can develop faster into TQ galaxies, compared with central galaxies in the same mass range; and this difference disappears when mass increases.
3) In environments with high local density/halo mass, fraction of TQ galaxies are higher for low-mass galaxies; this pattern is only seen in cluster galaxies.
4) We didn't find influence of r/R_{200} for satellite galaxies.