Emergence of the relations between galaxy morphology and environment : Cluster environment

<Co-evolution of the Cosmic Web and Galaxies across Cosmic Time> 2023. 2. 8
Kavli Institute for Theoretical Physics @ UC Santa Barbara

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& the HR5 collaboration

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KITP, UC Santa Barbara   Feb. 8, 2023

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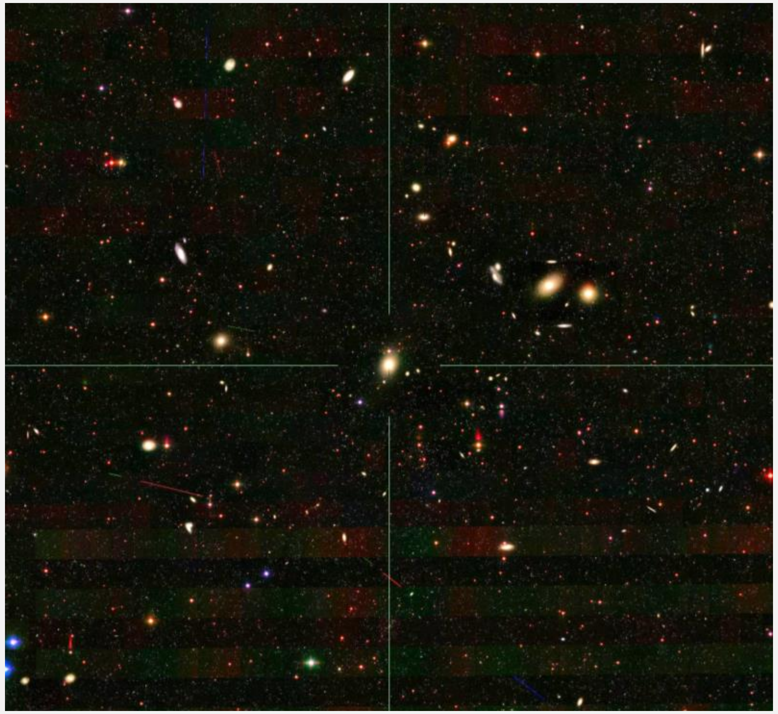
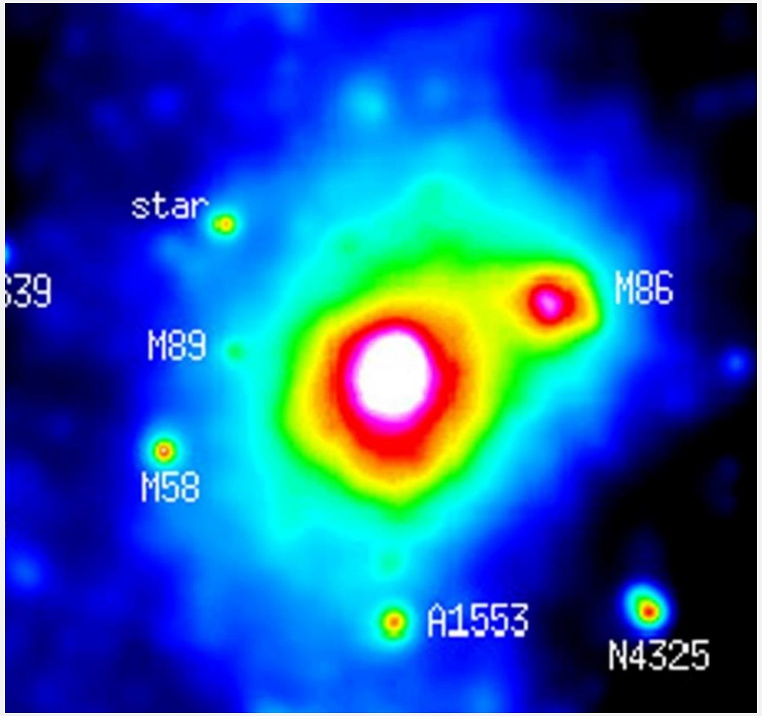
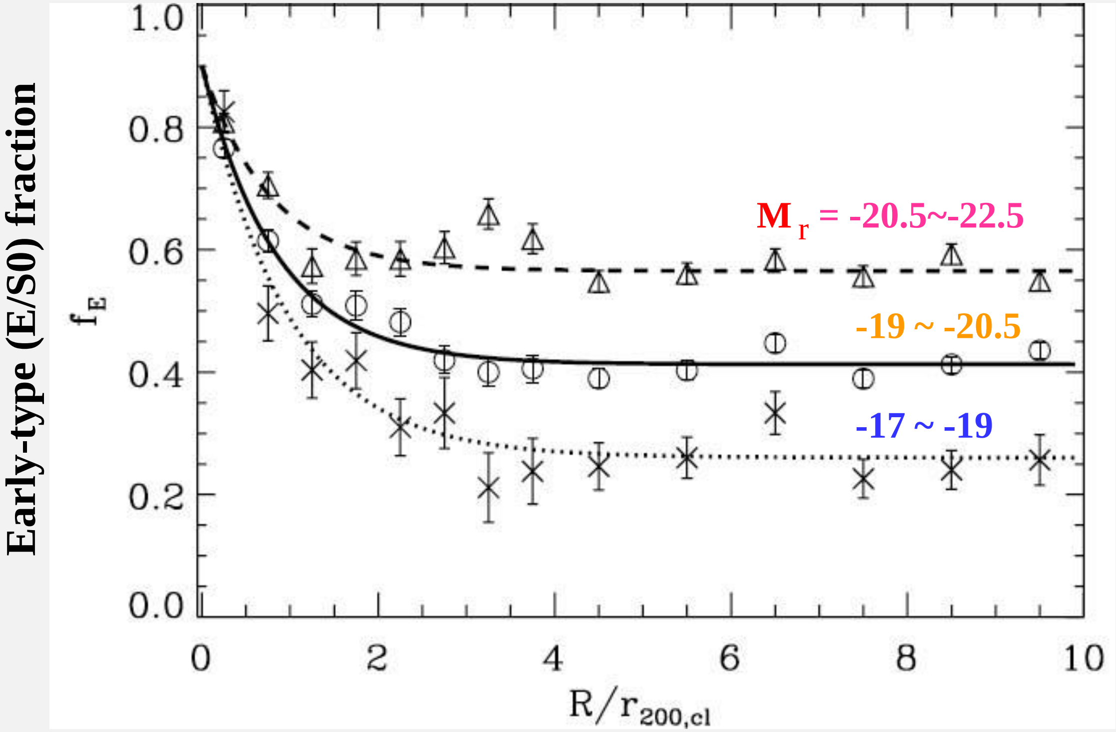




Luminosity – Morphology – SFR – Clustercentric Radius relation

Coma cluster © Justin Ng



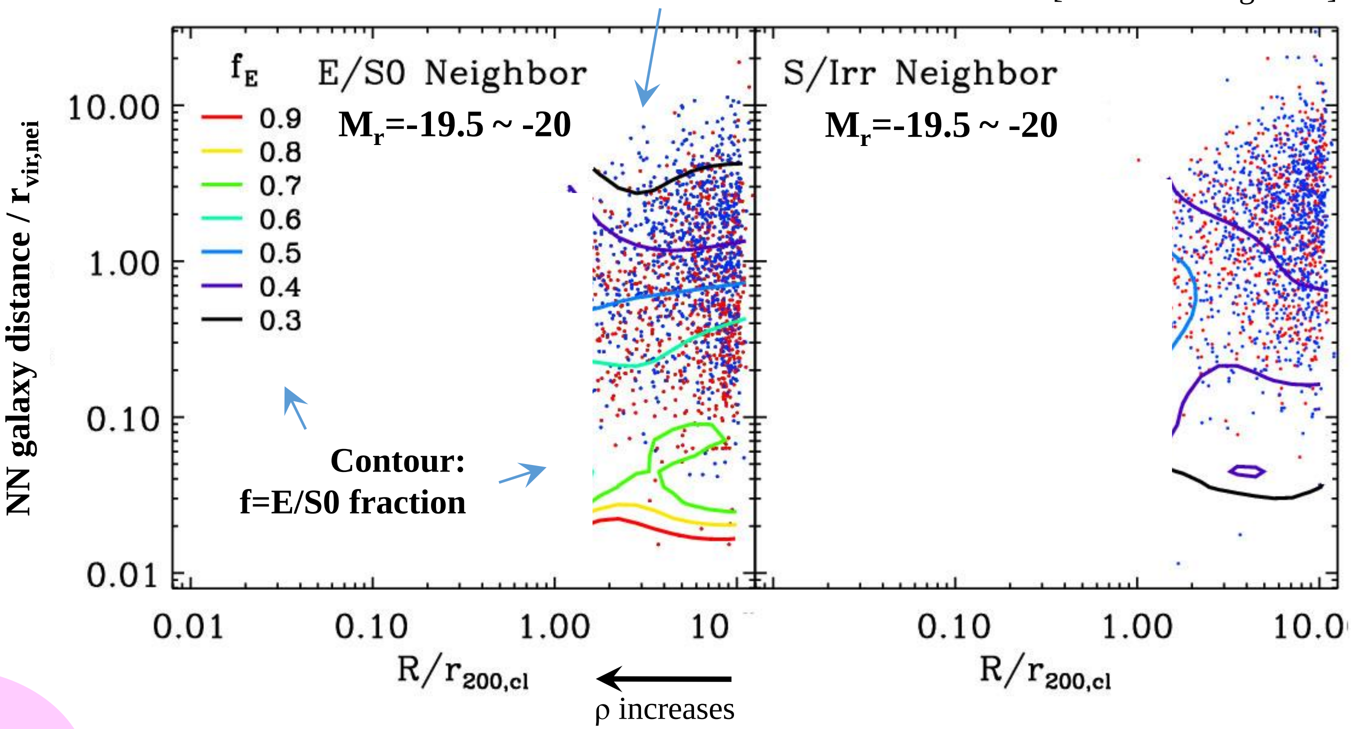
Clustercentric radius

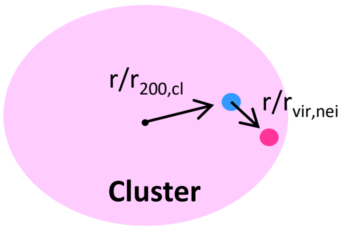
: Galaxies in & around 93 relaxed Abell clusters [Park & Hwang 2009]

Morphology – Environment relation

Red:E/S0 Blue:S/Irr

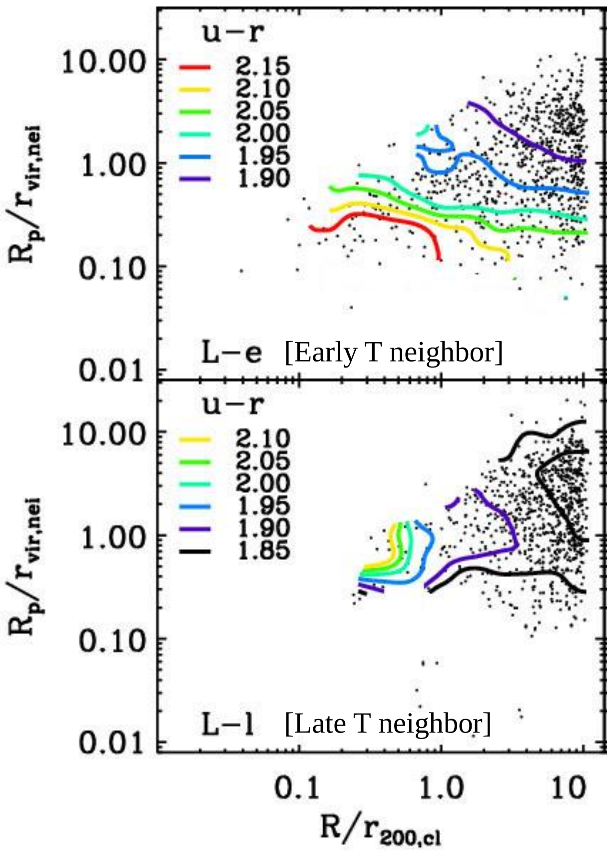
[Park & Hwang 2009]





∴ No morphology-'density' relation

SFR – Environment relation



∴ Interaction with neighbors gives big impact on SFA of cluster galaxies

(Cluster hot gas is not the main cause for SF quenching) [Park & Hwang 2009]

Questions

1. When did the “L - Morphology - Environment relation” appear in galaxy clusters?

2. When did the SF characteristics of cluster galaxies appear?

3. What are the physical processes that resulted in those relations?

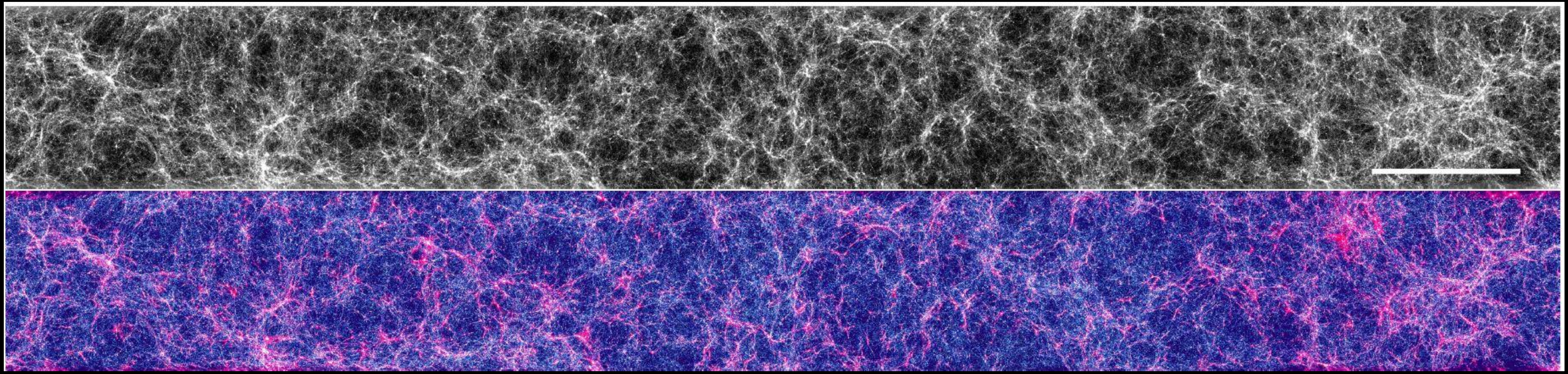
(4. When and how the physical parameters, L – morph – SFR – v/σ, of galaxies got correlated?)

Horizon Run 5 Cosmological Simulation [JH Lee 2021; C Park+ 2022]

Simulation code: Hybrid MPI-OpenMP RAMSES
Initial conditions: generated by the MUSIC package
using the second-order Lagrangian perturbation theory
Cosmological parameters: Ω_m=0.3, Ω_Λ=0.7, Ω_b=0.047, h_o=0.684
(flat ΛCDM)

Simulation box size: (1049 Mpc)^3
Zoomed-in regior (1049x119x127) Mpc^3
Resolution of the initial conditions: 128 kpc
Highest simulation resolution: 1 kpc

[dark matter]



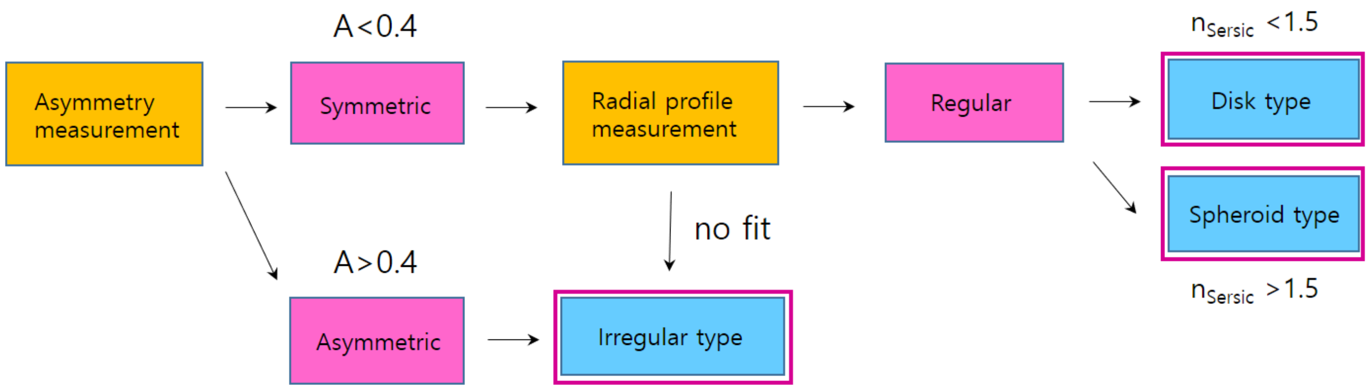
baryon

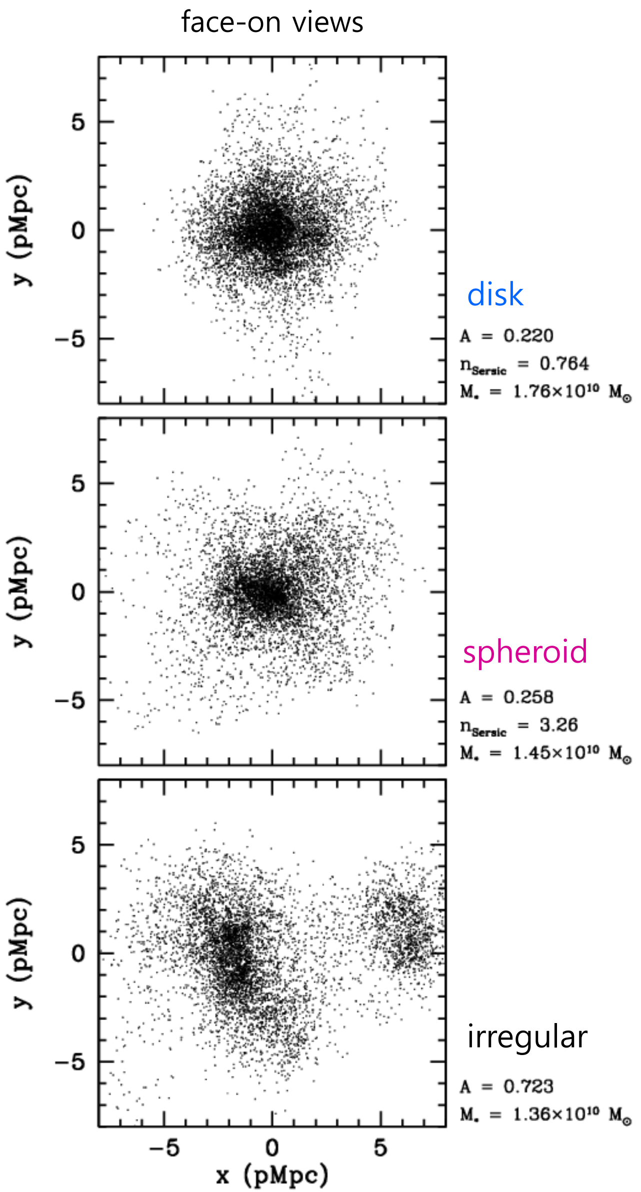
grey: stellar mass. red: gas temperature. blue: gas density

Galaxy morphology classification

using *physical* (rather than *observable*) properties,
i.e. using stellar mass density distribution (Trayford+19; Park+2022)

1. Asymmetry parameter &
2. Sersic index of the radial profile of projected stellar mass density



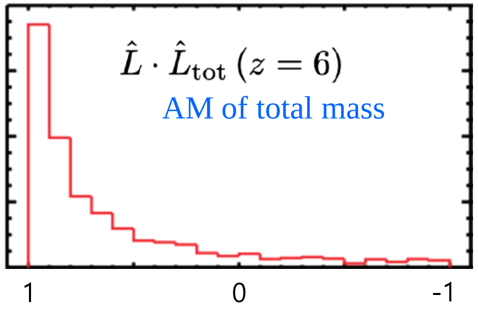


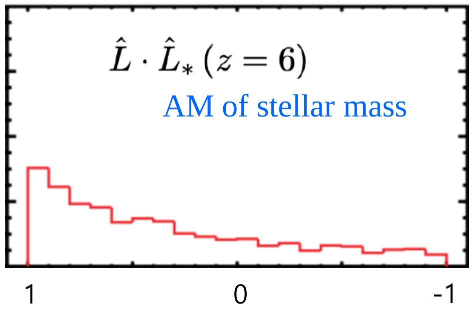
Morphology of the first galaxies in the cosmic morning [C. Park+ 2022]

Majority of galaxies are Disk types!!

Disks : Spheroids : Irregulars = **2/3 : 1/6 : 1/6** @ z = 4~8

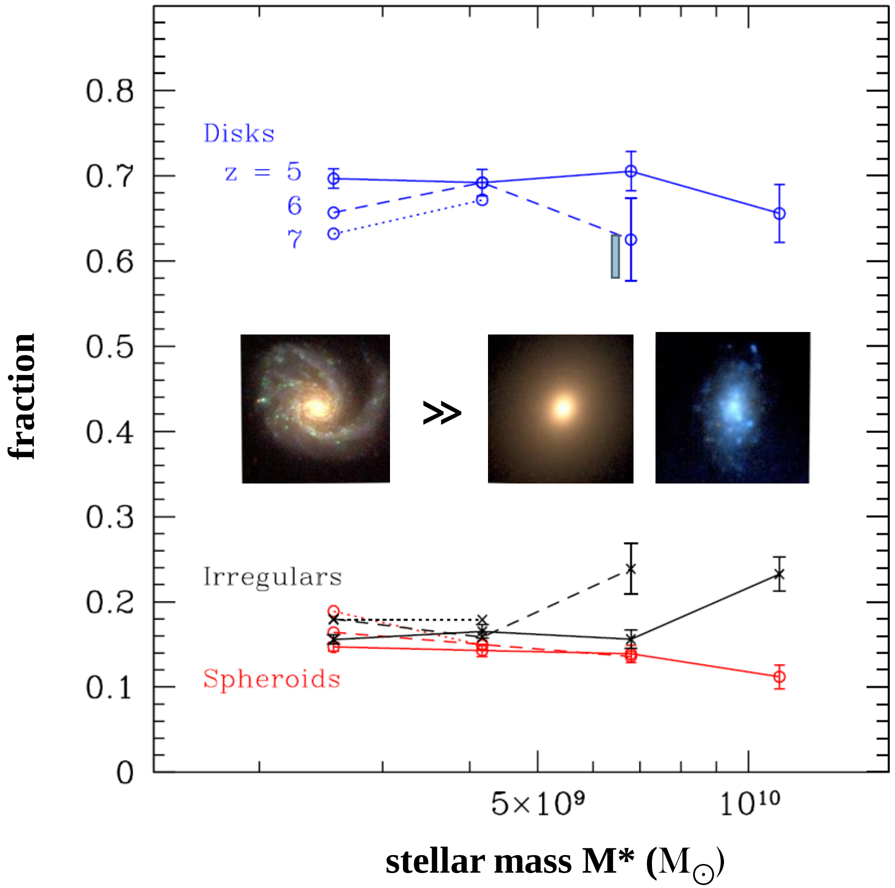
- Alignment between L (initial AM) and galaxy L_{tot} & L_*





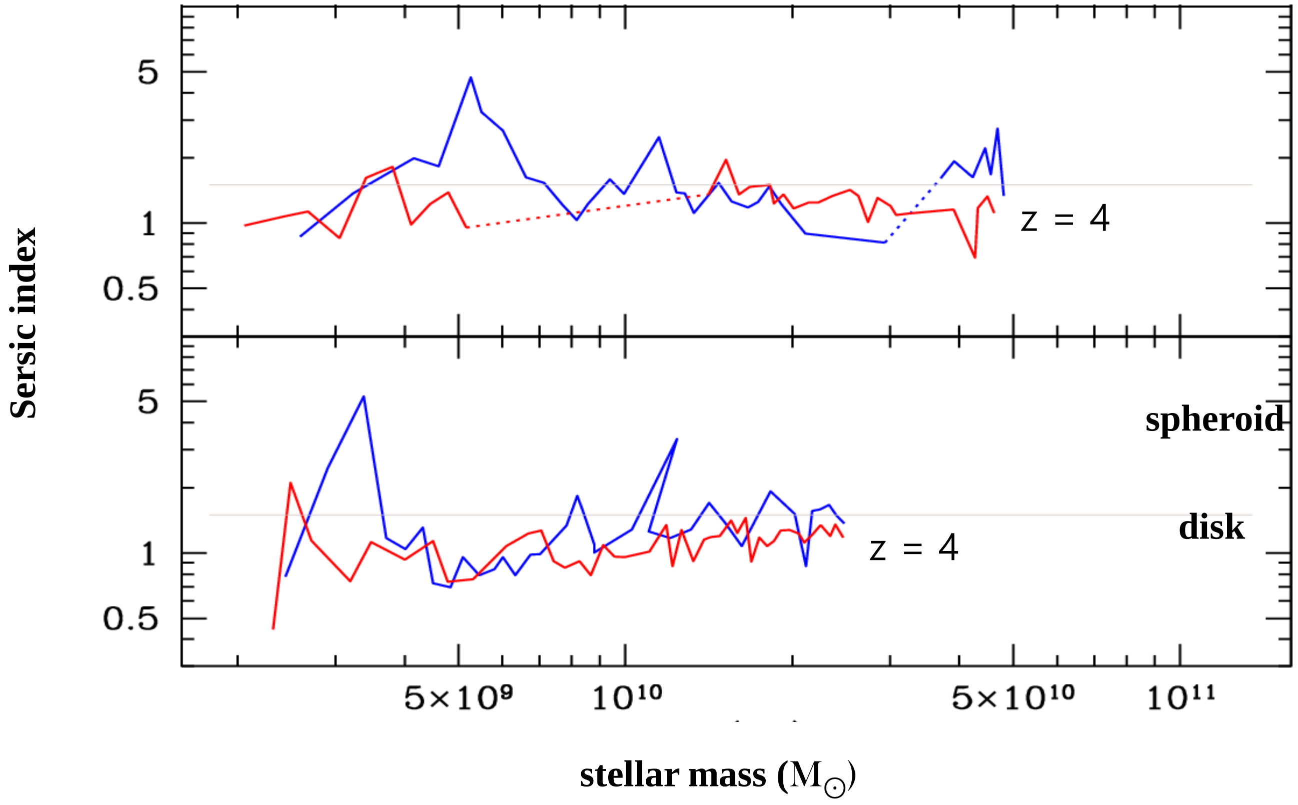
Angular momentum due to the tidal torque on proto-galactic regions $\propto$ $L_\alpha \equiv \epsilon_{\alpha\beta\gamma} \sum_\sigma I_{\beta\sigma} \partial_\sigma \partial_\gamma \Phi(\boldsymbol{q}_c)$

∴ **Large-scale tidal field/velocity field in the initial conditions responsible for dominance of disks and return to disk morphology!**



What determines the morphology of the first galaxies? : Spheroid & Irr

Irregular or spheroidal morphology is incidental and transient!



2 random galaxies reaching $M_* \sim 5x10^{10}\ M_\odot$ at z=4

2 random galaxies reaching $M_* \sim 2.5x10^{10}\ M_\odot$ at z=4

Development of Morphology – Cluster Environment relation

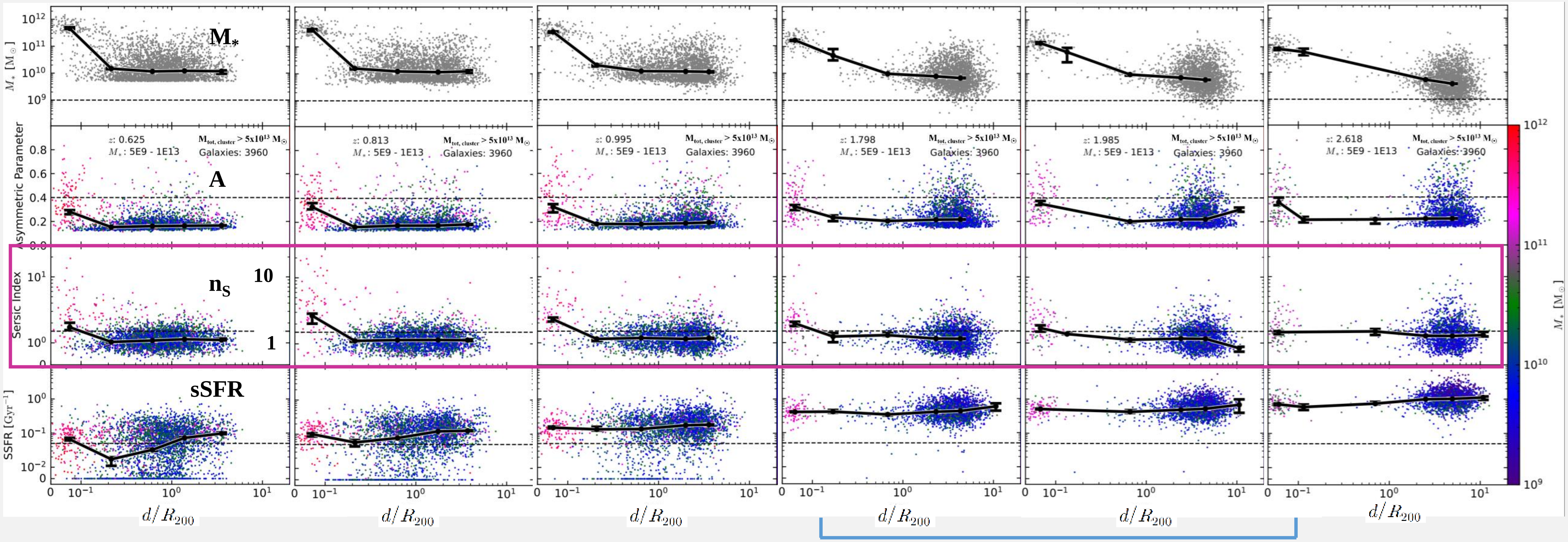
162 HR5 galaxy clusters with $M_{tot} > 5x10^{13}\ M_\odot$ at z=0.625

3960 cluster member galaxies with $M_* > 5x10^9\ M_\odot$ at z=0.625

Trace the main progenitor of each member galaxy

Mass(L) - Morphology – Clustercentric Radius relation

z = 0.625 | **0.8** | **1.0** | **1.8** | **2.0** | **2.6**

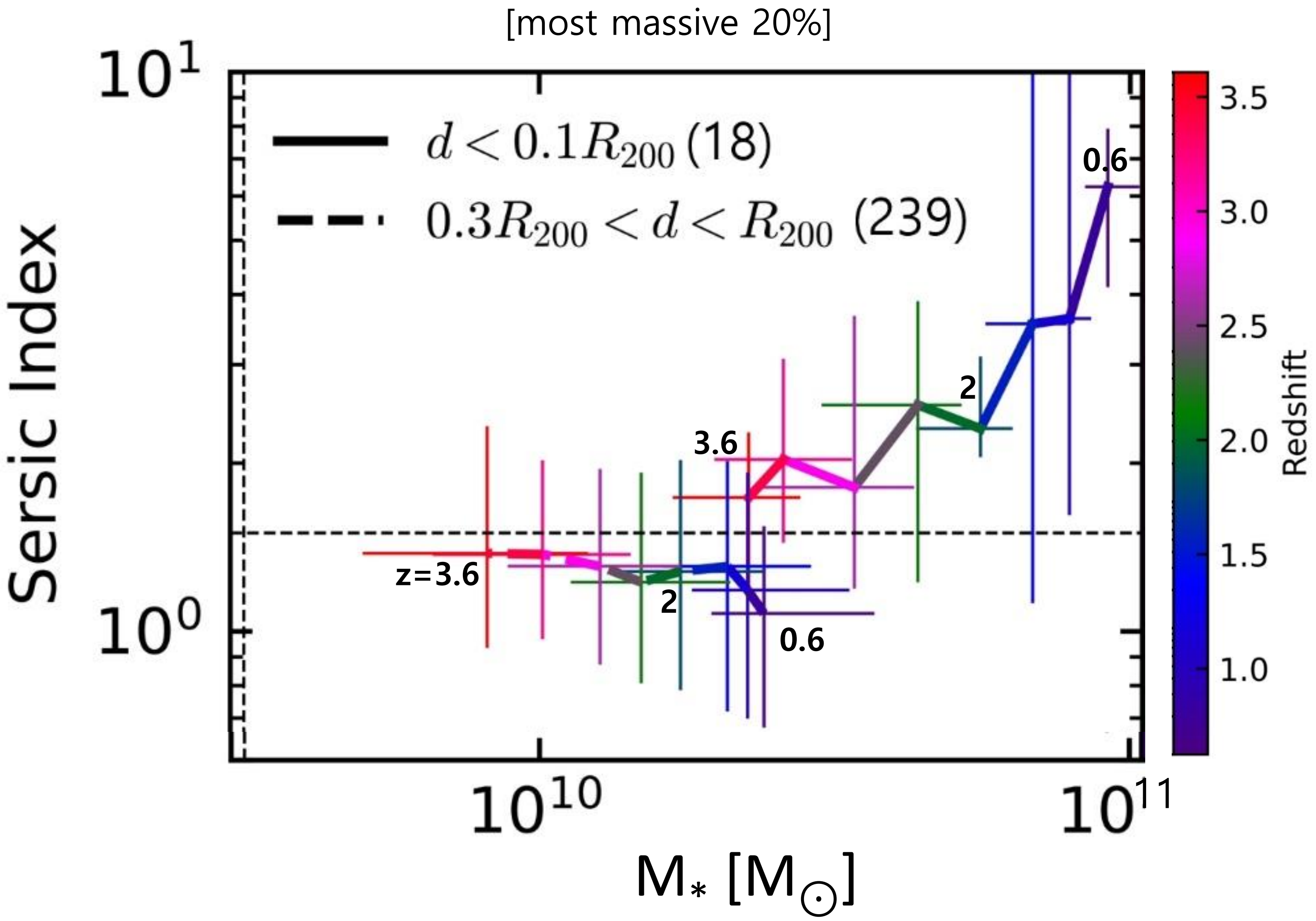


Passive disks join the central region

Morphology - r_{cl} relation well-established !

Morphology - r_{cl} relation emerges here !

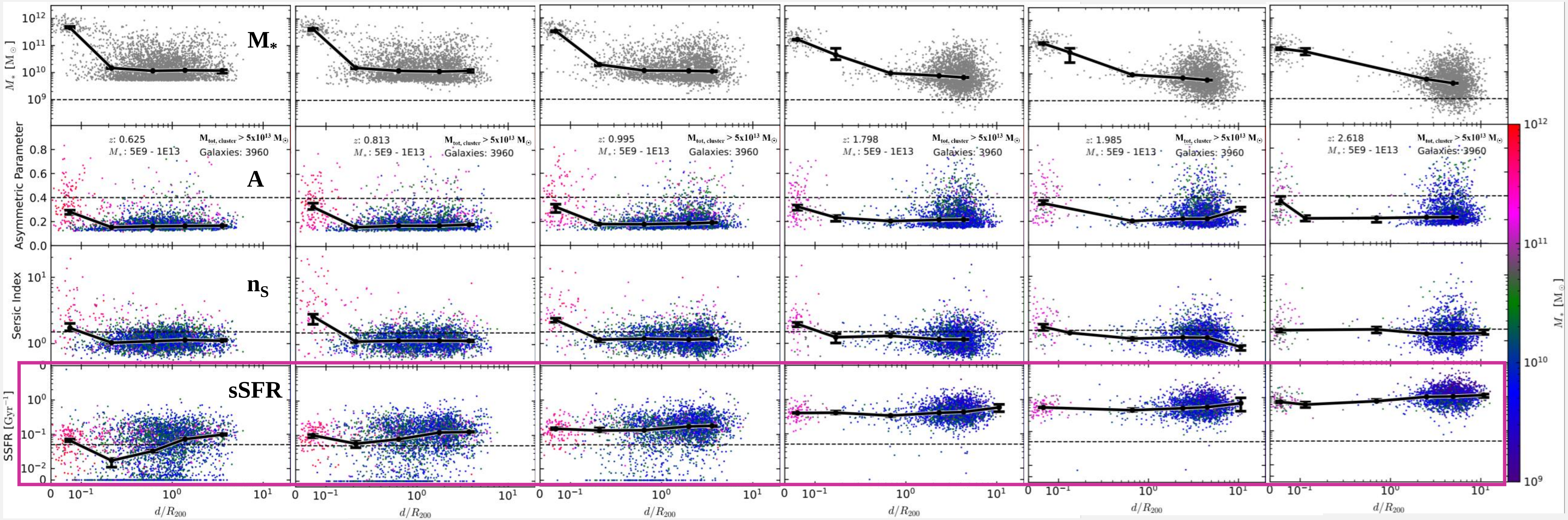
(central galaxy)



% Morphology depends not directly on mass, but on galaxy location in the cosmic web & how galaxy acquires its mass (+some cumulative effect)

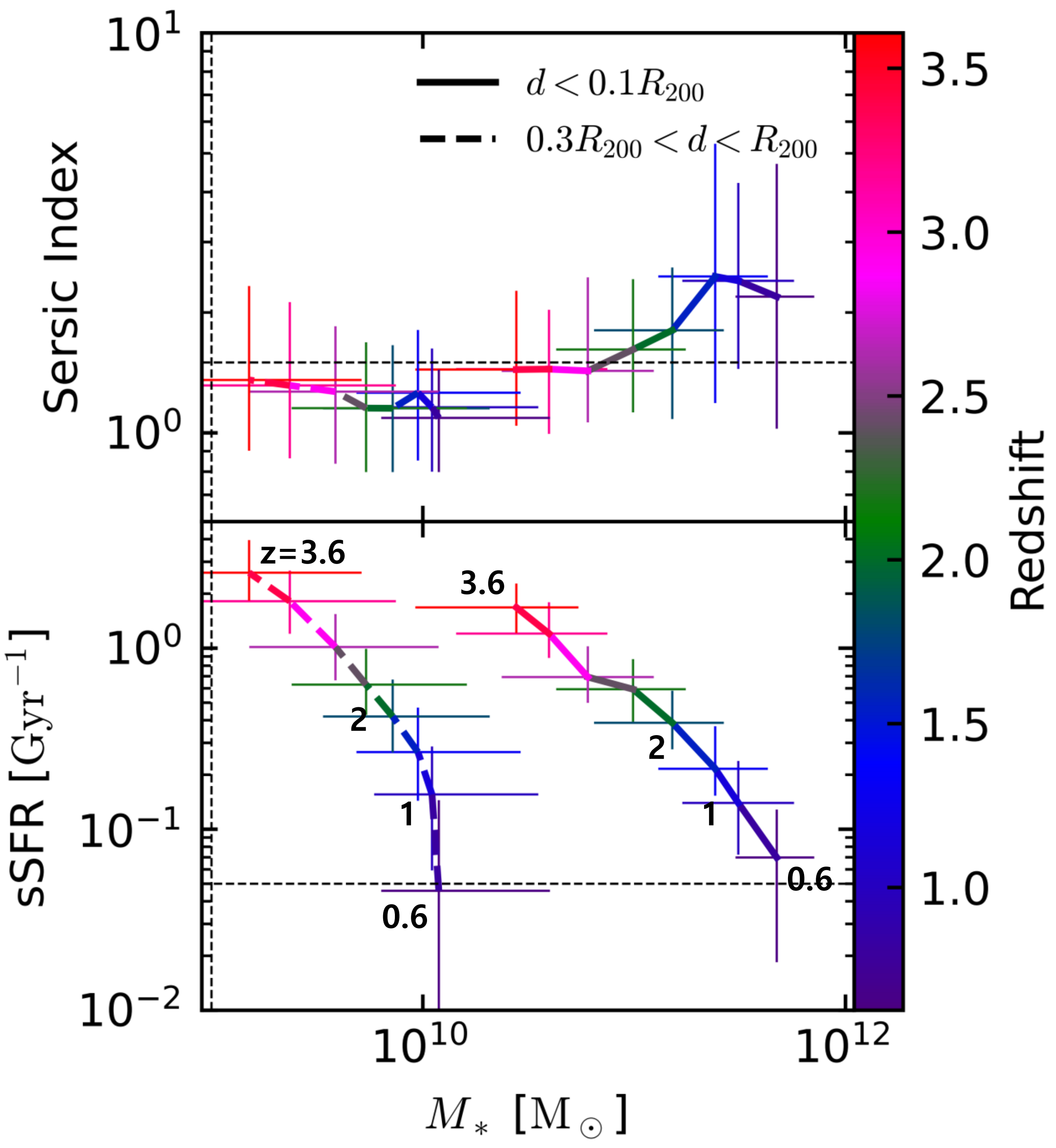
Mass(L) - sSFR – Clustercentric Radius relation

z = 0.625 | 0.8 | 1.0 | 1.8 | 2.0 | 2.6

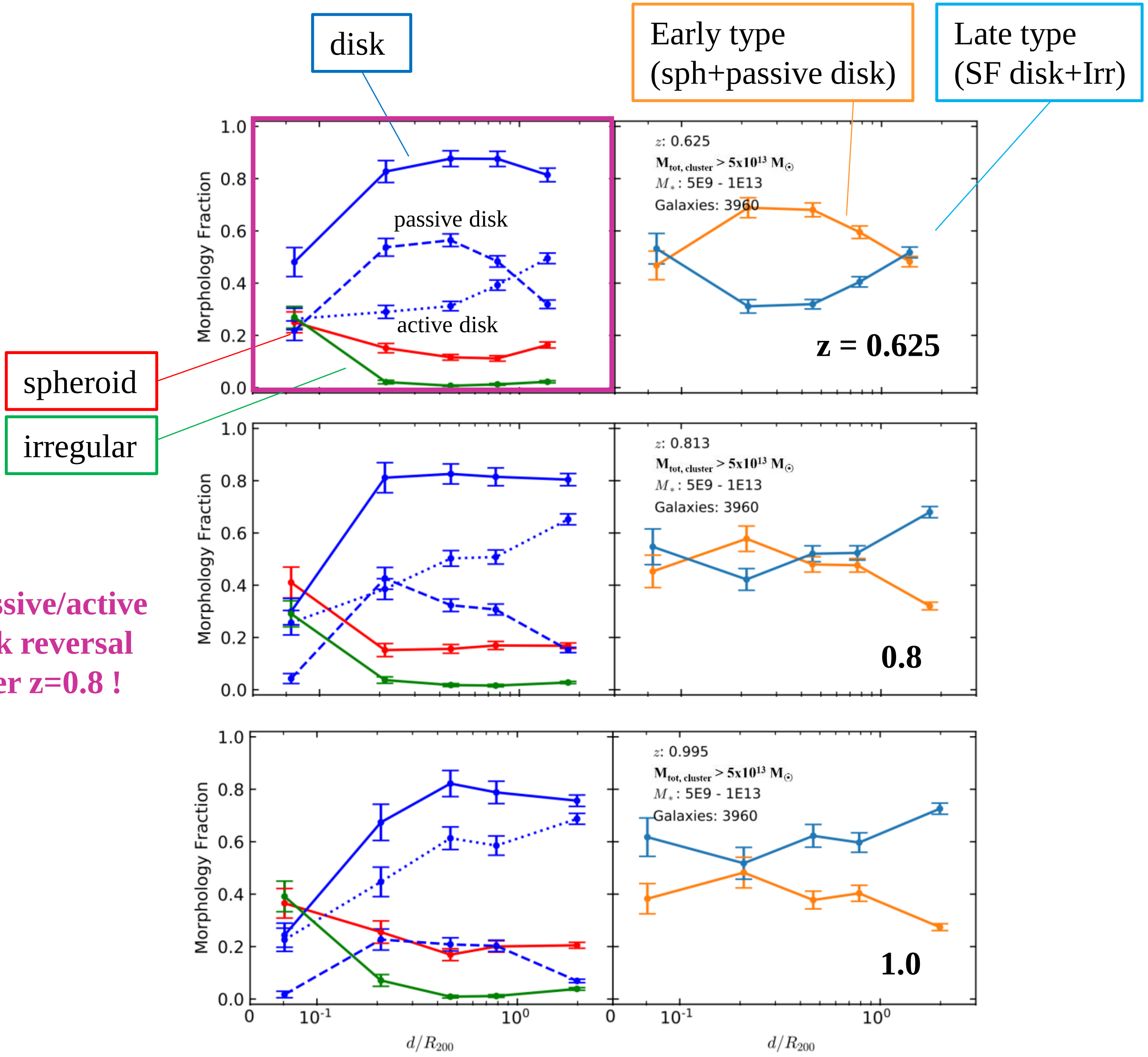


sSFR - r_{cl} relation emerges here !

Neighbor interaction at 0.1~1 r_{cl}/R_{200}

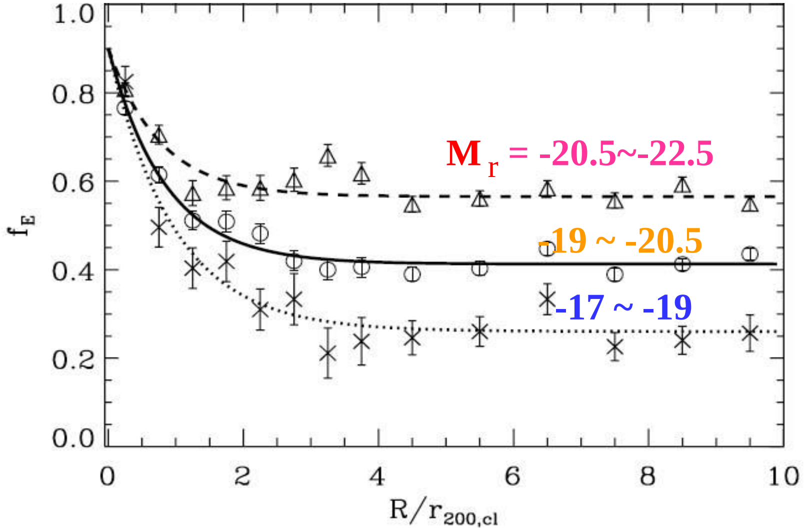


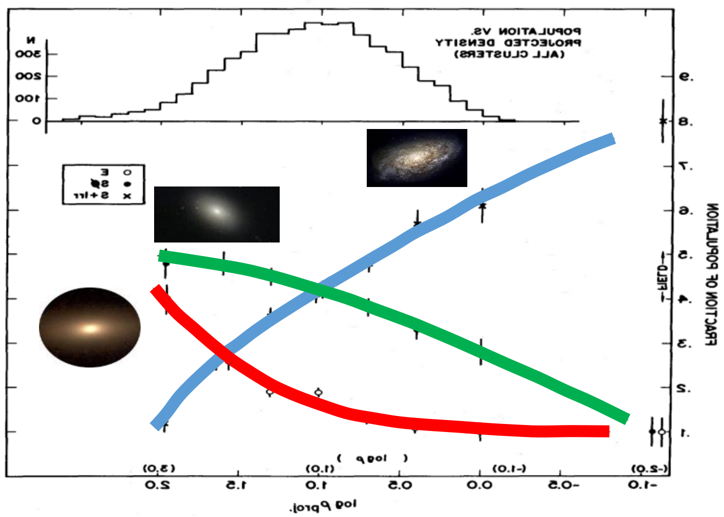
$d < 0.1R_{200}$
$0.3R_{200} < d < R_{200}$
Sersic Index
sSFR [Gyr^{-1}]
M_* [M$_\odot$]
Redshift
z=3.6
3.6
2
1
0.6
2
1
0.6



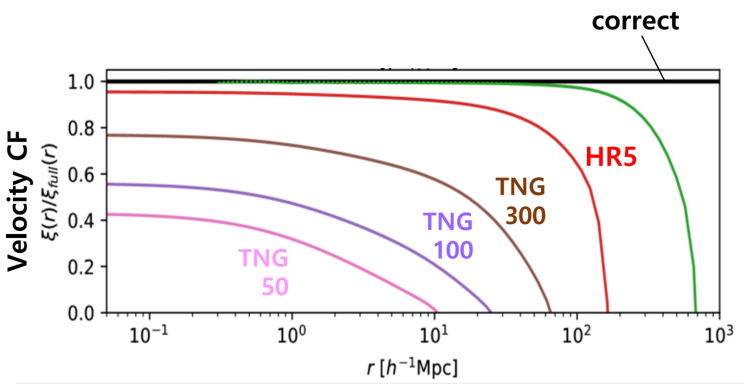
Clustercentric radius

Passive/active disk reversal after z=0.8 !





Summary



1. Horizon Run 5: Morphology of galaxy stellar mass density distribution
- 1cGpc box + 1pkpc resolution
- Coherence of $\mathbf{v}_{\mathbf{pec}}$ ~correctly represented on galaxy & cluster scales.

2. Galaxy morphology in the cosmic morning (z<4)
- Dominated by disk galaxies (fraction $\approx 2/3$)
- Disk morphology - the tidal torque imprinted in the initial conditions
- Spheroidal and irregular morphologies are incidental and transient.

3. Luminosity/Mass - morphology - $\mathbf{r_{cl}}$ relation
- Emerges at z = 2.5~2, and well established at z~1.5
- Strong interactions & high merger rate accompanied by mass growth at the center seems responsible (indicated by large Irr fraction at the center)

4. Luminosity/Mass - SFR - $\mathbf{r_{cl}}$ relation
- Emerges at z= ~1 (depends on SF history of simulation)
- Mostly due to passive disk domination at $r_{cl}/R_{200} < 1$ after z= ~1
- Impacts of mass growth stop, interaction with neighbors [on-going]