Env22 Workshop

22nd - 23rd Feb 2022

Jeon et al. (in prep)

The star formation quenching and transition epoch of the Horizon-AGN galaxies

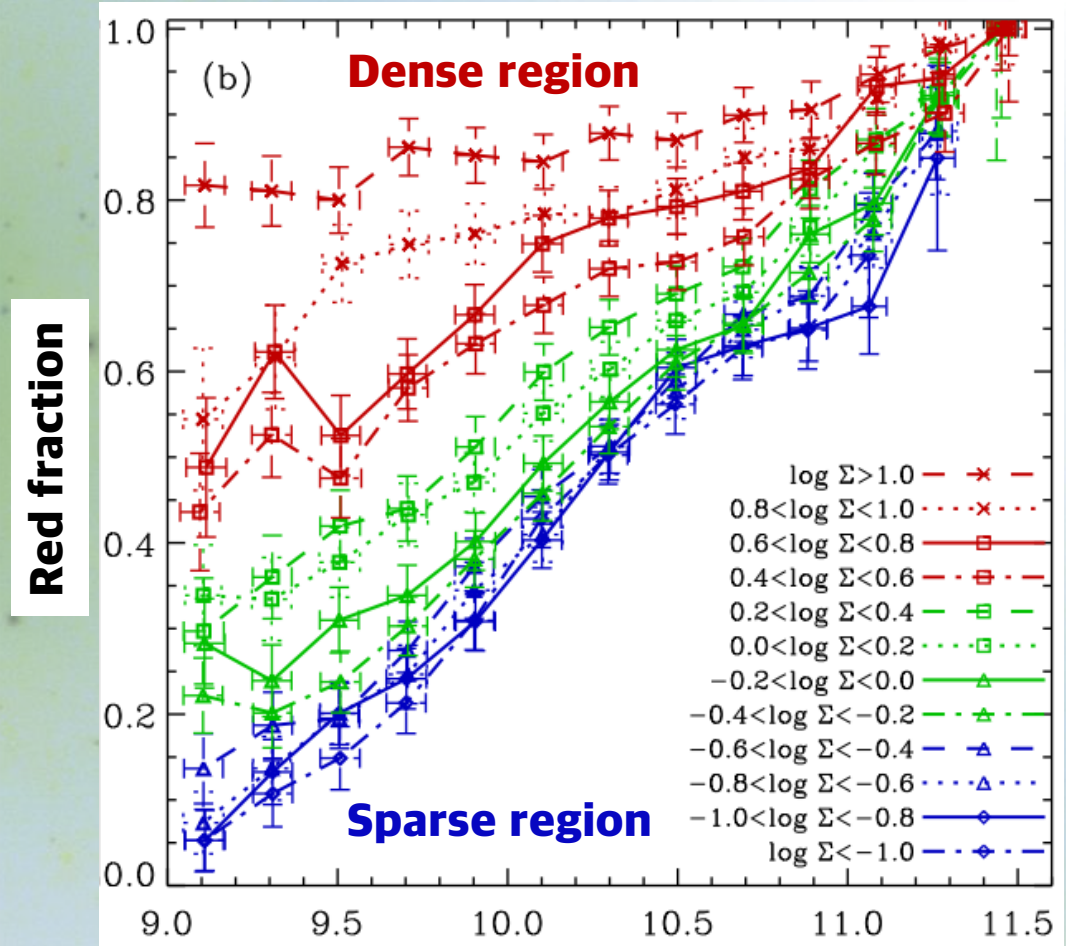
Seyoung Jeon (syj3514@yonsei.ac.kr)

Quiescent Cluster Galaxies

Galaxies $\left(\begin{array}{c}\text{in dense region}\\ \text{with high stellar mass}\end{array}\right)$ tend to be more quenched

Internal quenching
&
External quenching

Baldry+06



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Star Formation History (SFH)

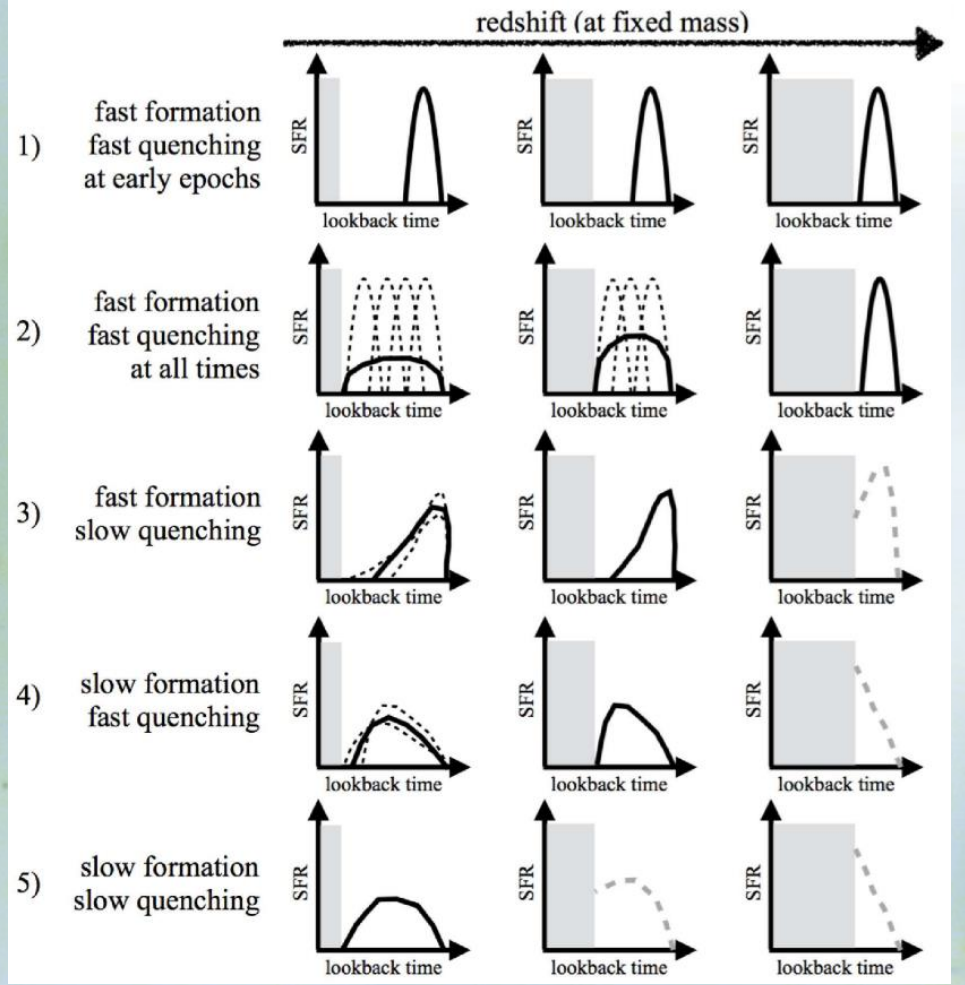
For now, cluster galaxies are more quenched than field galaxies

→ Always?

GOAL:

- Check whether the quenched fractions of Horizon-AGN galaxies corresponds to the observation
- Measure the quenching timescale using the parametrized SFH
- Determine how quenching timescale varies with environments
- Examine the "transition epoch" when cluster galaxies became less star-forming than field galaxies

Pacifici+16



Numerical Simulation

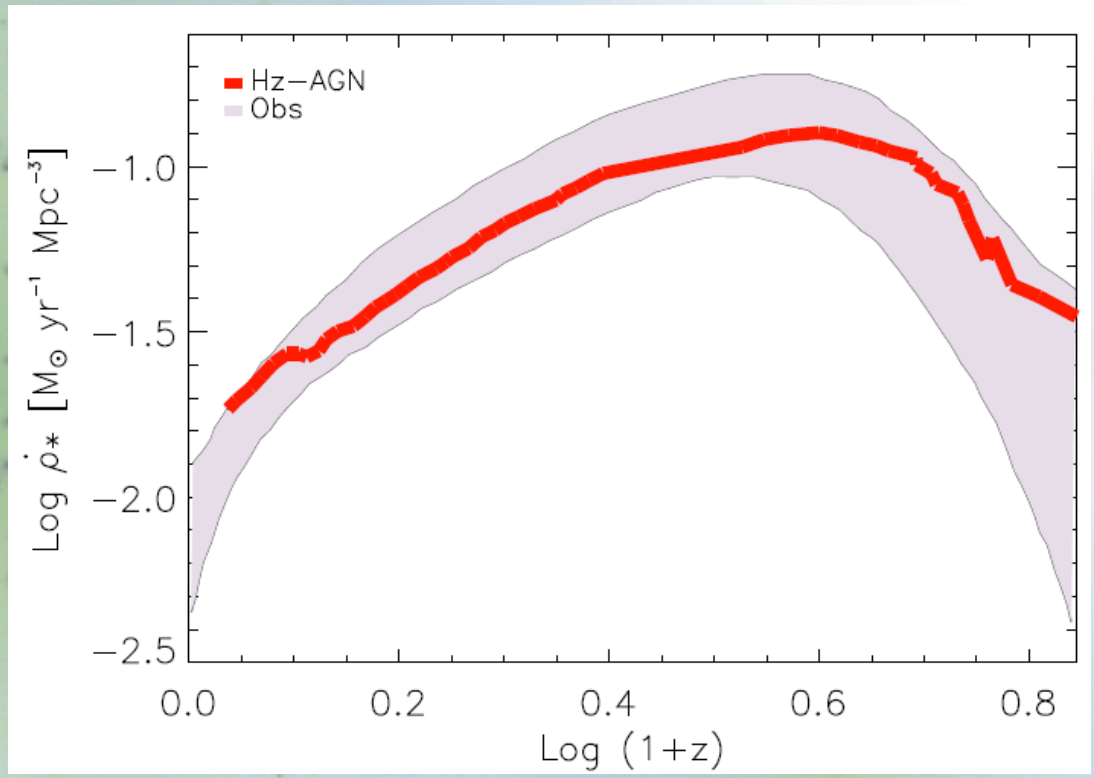
Horizon-AGN

- Hydrodynamic using RAMSES AMR code
- WMAP7 Cosmology
- Boxsize: 100 $h^{-1}\ cMpc$
- 1024^3 DM particles
- M_{DM} resolution ~ $8 \times 10^7\ M_\odot$
- M_* resolution ~ $2 \times 10^6\ M_\odot$
- Spatial resolution ~ 0.76 $h^{-1}\ ckpc$

- Gas cooling & Heating
- Star formation & Stellar feedback
- AGN feedback

*More detail in Dubois+14

Kaviraj+17



Good agreement with observations

(e.g., cosmic SFH, LF, CMD, ⋯)

Data Sample

(Halo)	Cluster	Group	**HALOFINDER** code: AdaptaHOP algorithm
	16	412	

(Galaxy)	Cluster	Group	Field	Total
All Mass	4,106	15,587	96,337	116,030
$> 10^9 M_\odot$	2,678	10,034	66,137	78,849

Stellar mass cut

: $\log(M_*/M_\odot) > 9$

Host halo

- Cluster halo: $\log(M_{halo}/M_\odot) > 14$
- Group halo: $13 < \log(M_{halo}/M_\odot) < 14$

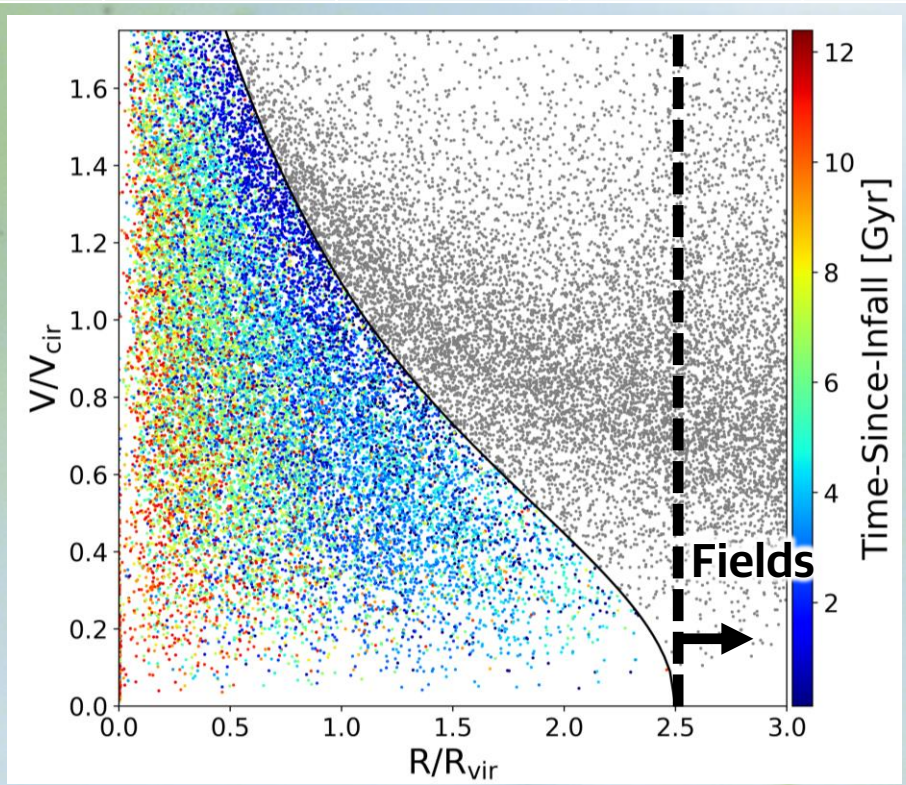
Satellite Membership

: Potential criterion (Han+18)

$$\frac{v^2}{2} + \Phi(r) < \Phi(2.5R_{vir})$$

Field galaxy

: Out of 2.5 R_{vir} of cluster (or group) halo



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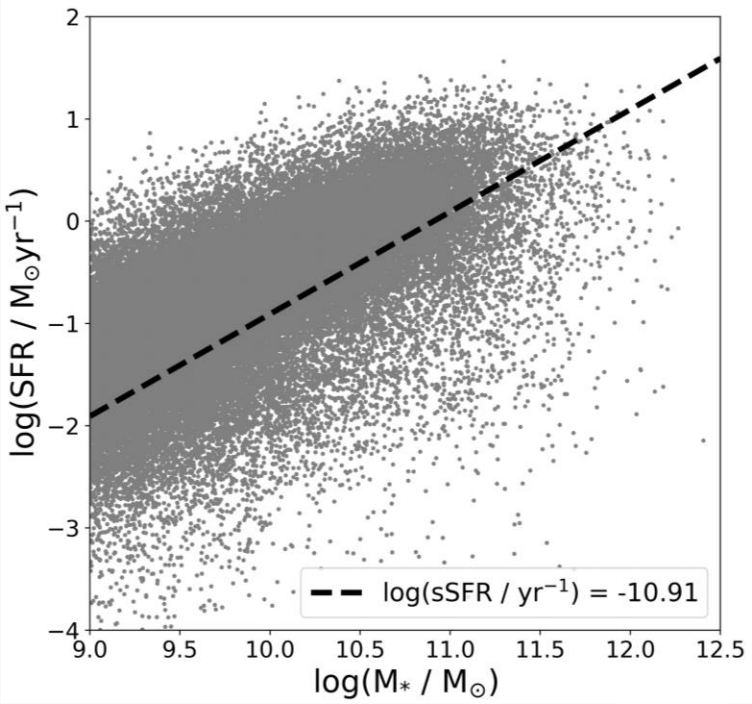
Quenched Fraction

"Quenched": (Tacchella+19)

$$sSFR\ /\ yr^{-1} < \frac{1}{6\ t_H}$$



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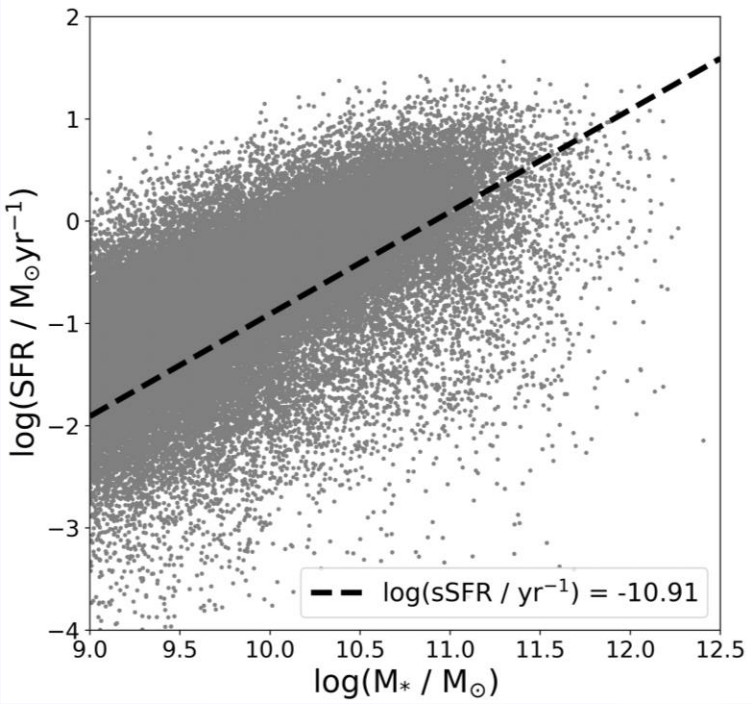

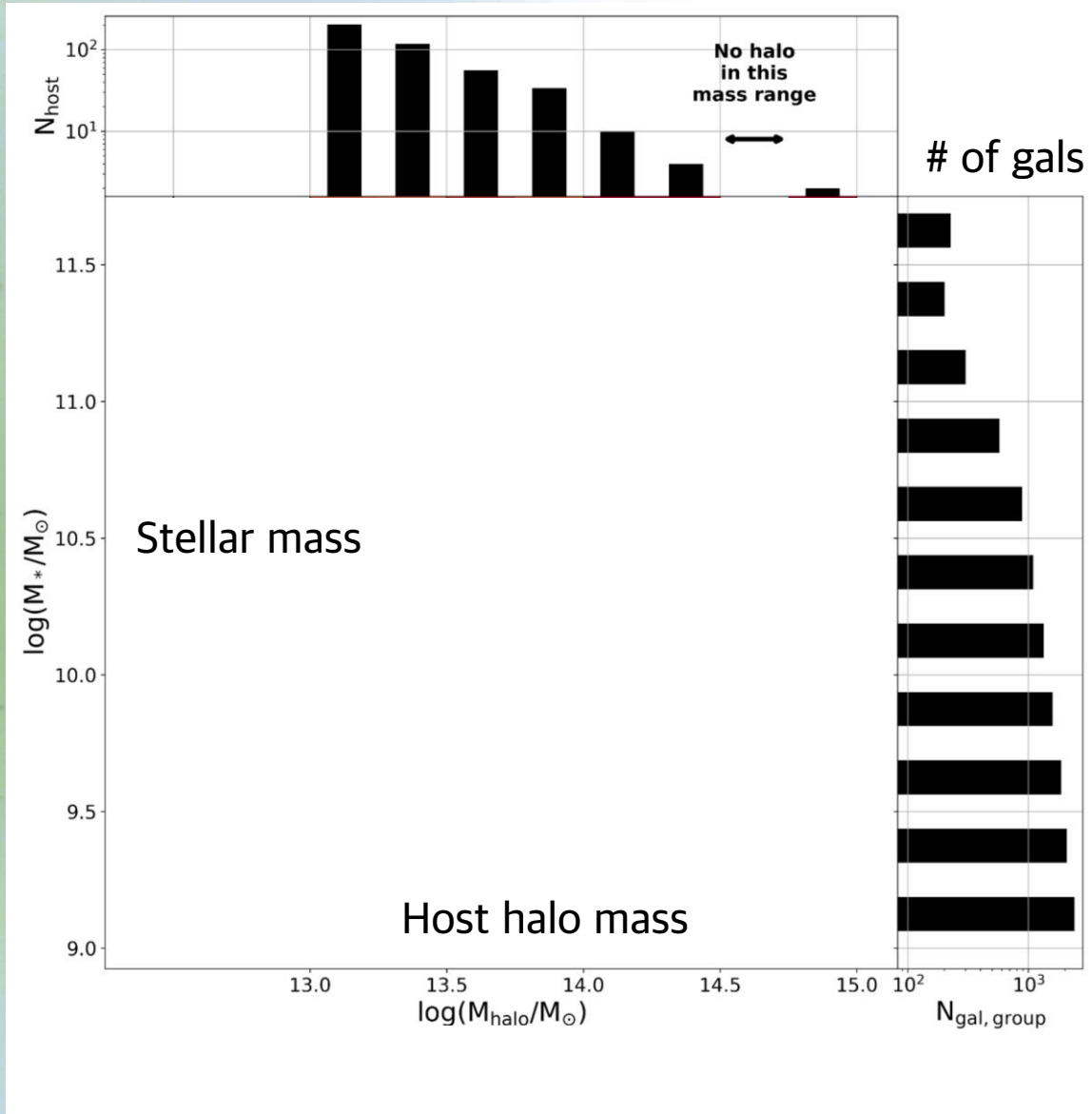

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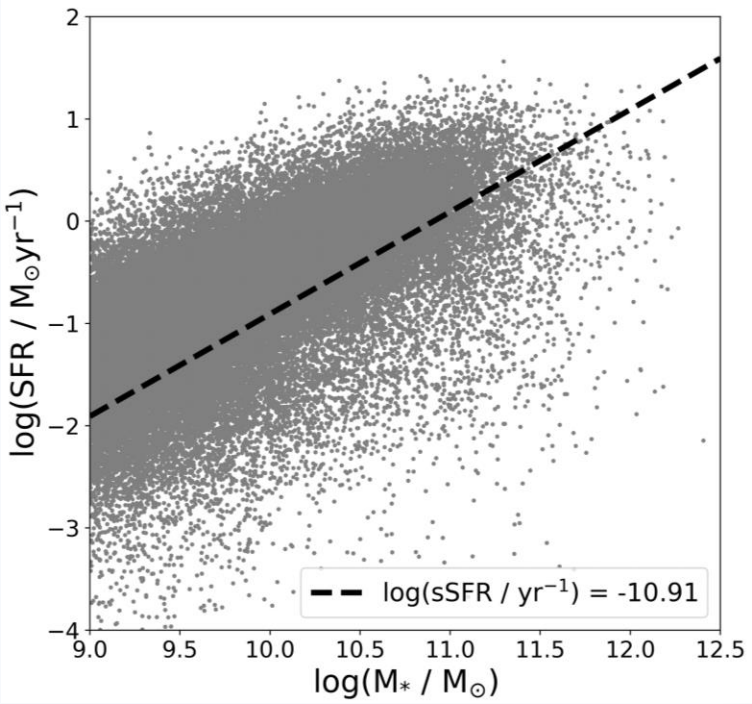

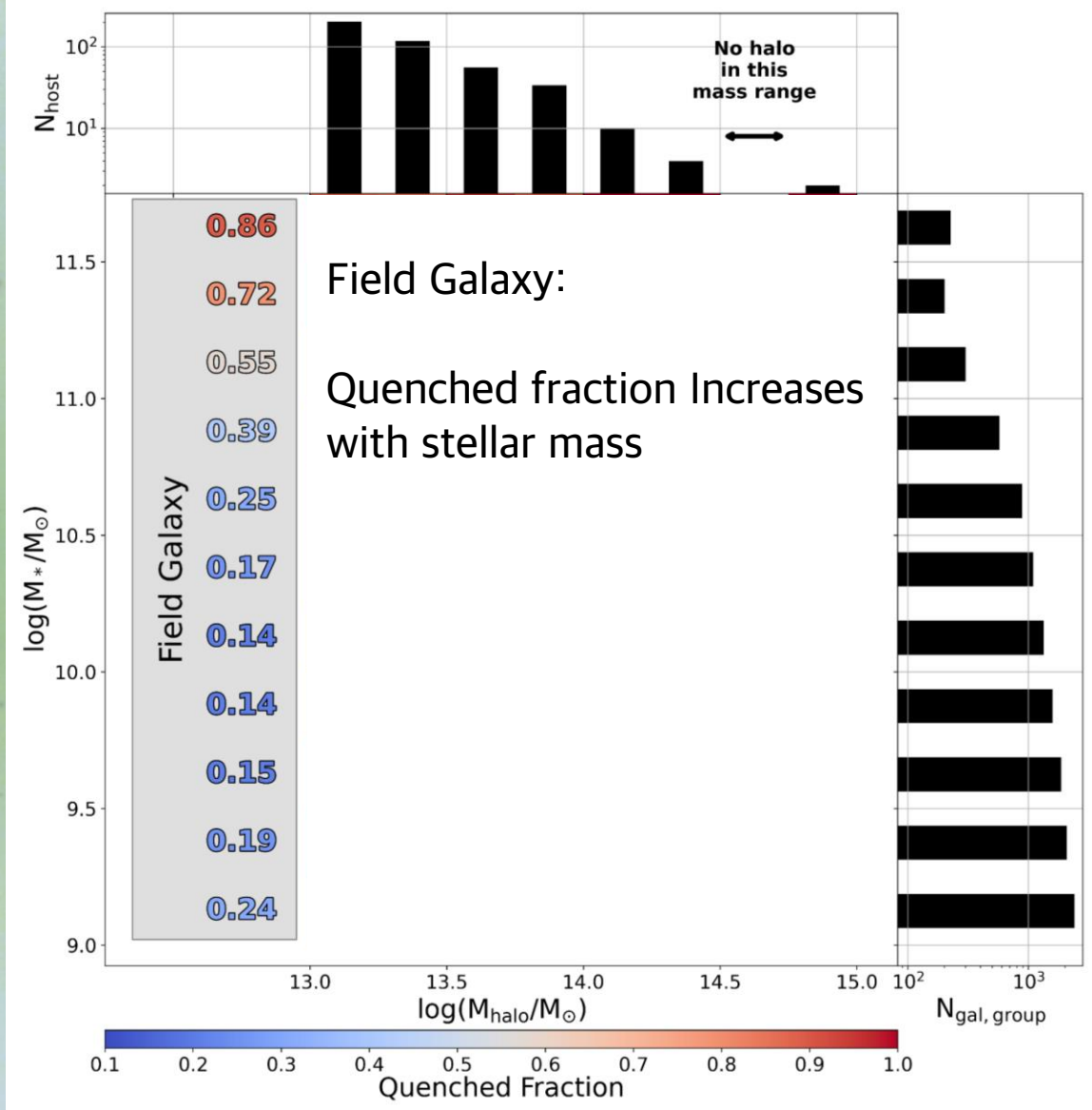

Field Galaxy:

Quenched fraction Increases with stellar mass

Quenched Fraction

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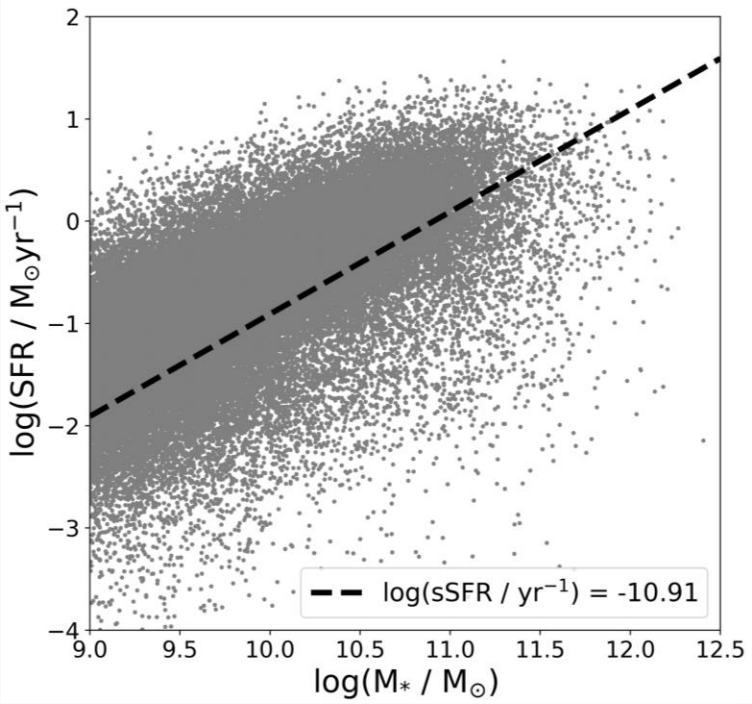
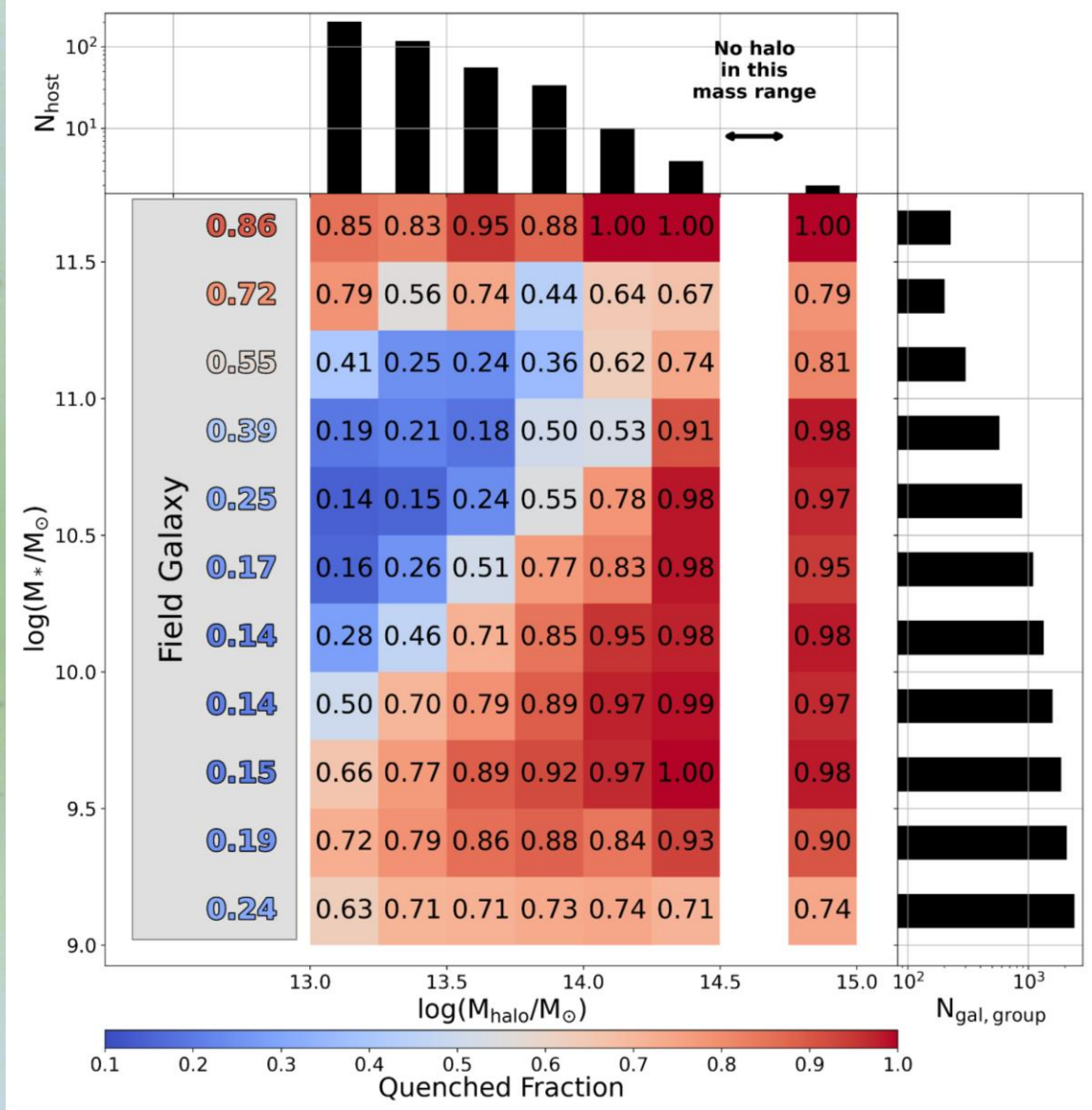
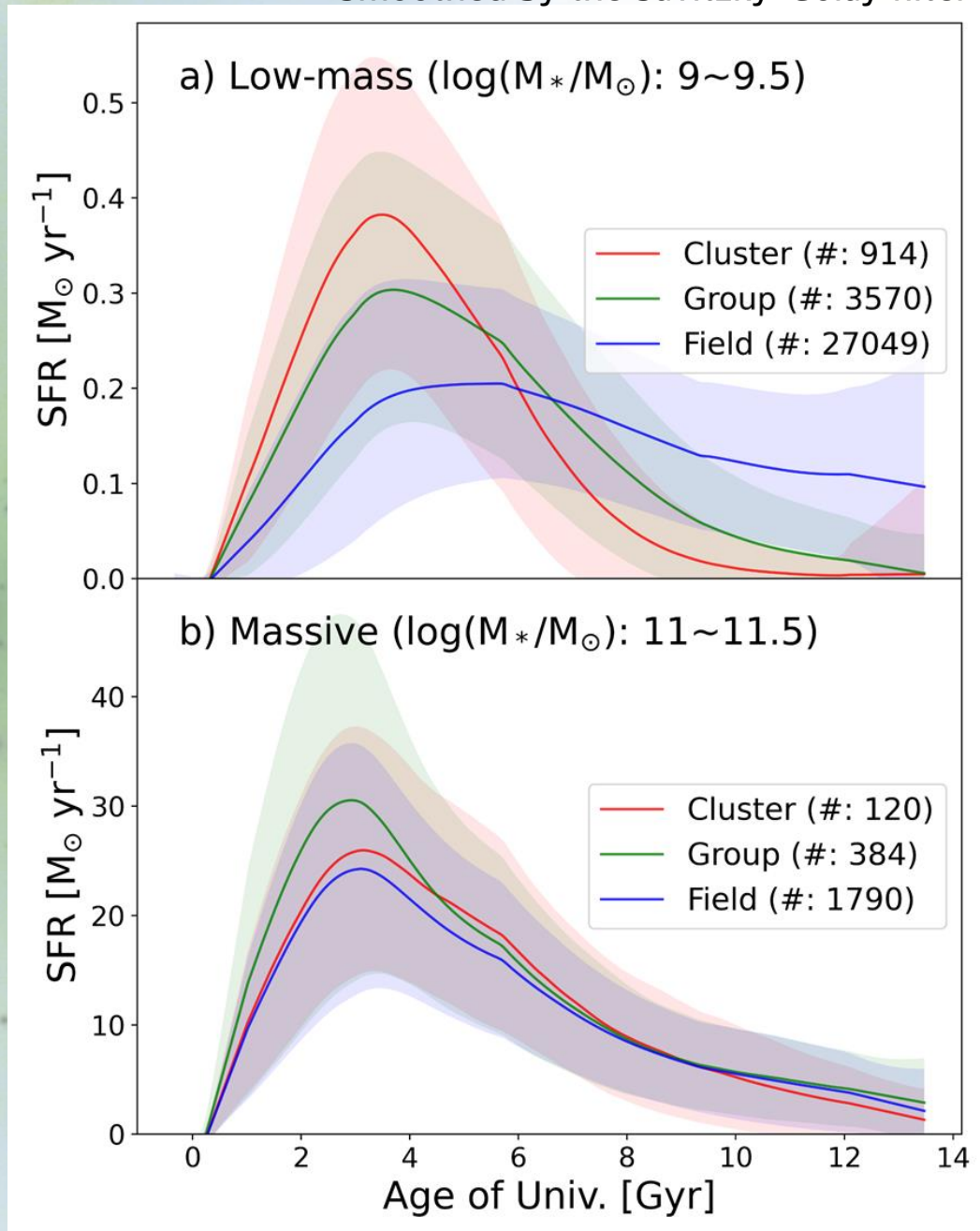




Star Formation History

Smoothed by the Savitzky-Golay filter



Low-mass:

Clear environmental dependence

- Cluster gals: rapid formation & quenching at early time
- Field gals: extended star formation

High-mass:

Little difference & Rapid quenching

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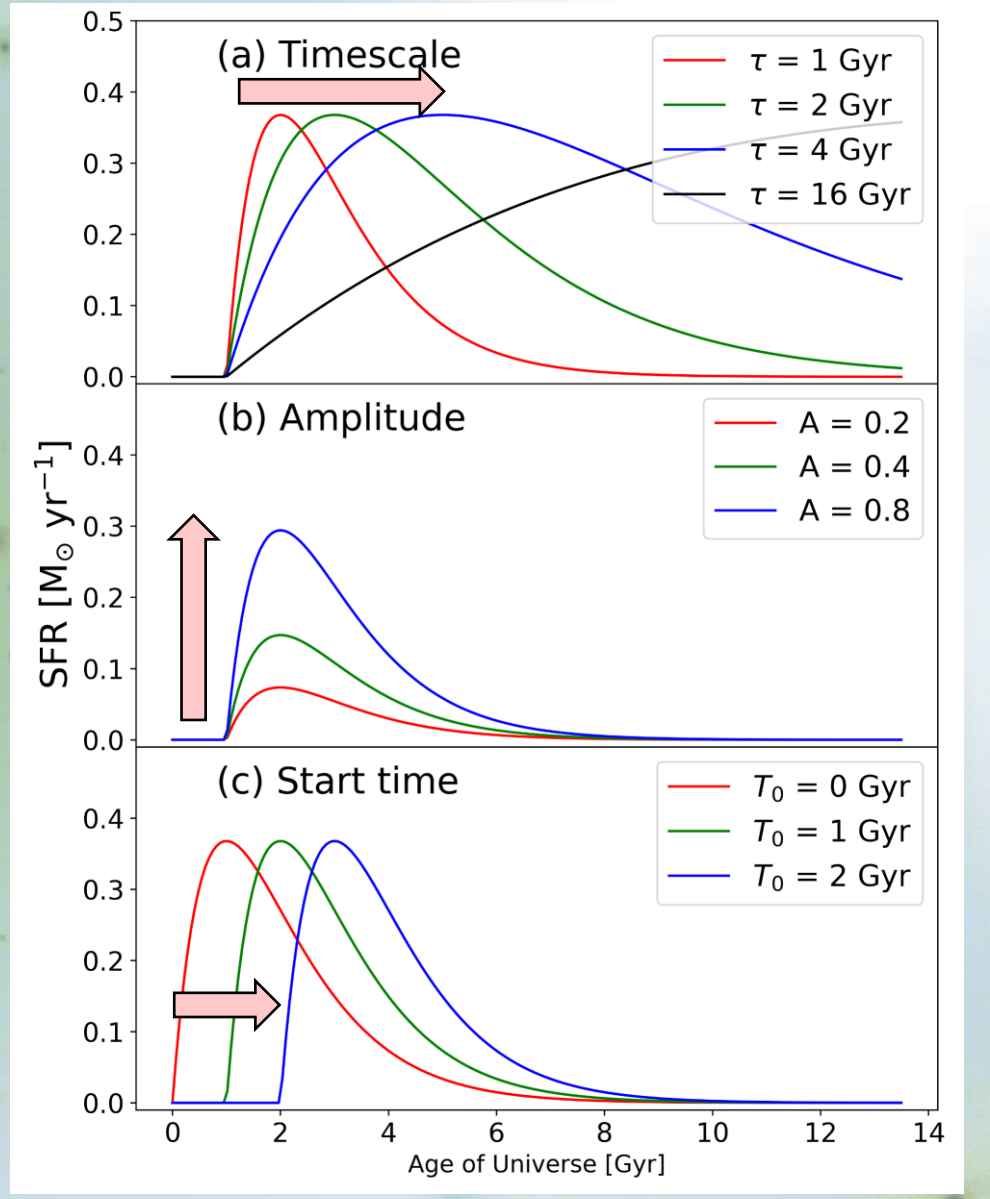
Star Formation History

Delayed Tau Model (Carnall+19)

$$SFR = \begin{cases} A(t - T_0)\exp\left(-\dfrac{t - T_0}{\tau}\right), & t > T_0 \\ 0, & t < T_0 \end{cases}$$

τ ↑: Extended SF	τ ↓: Rapid quenching
A ↑: Higher SF	A ↓: Lower SF
T_0 ↑: Late start	T_0 ↓: Early start



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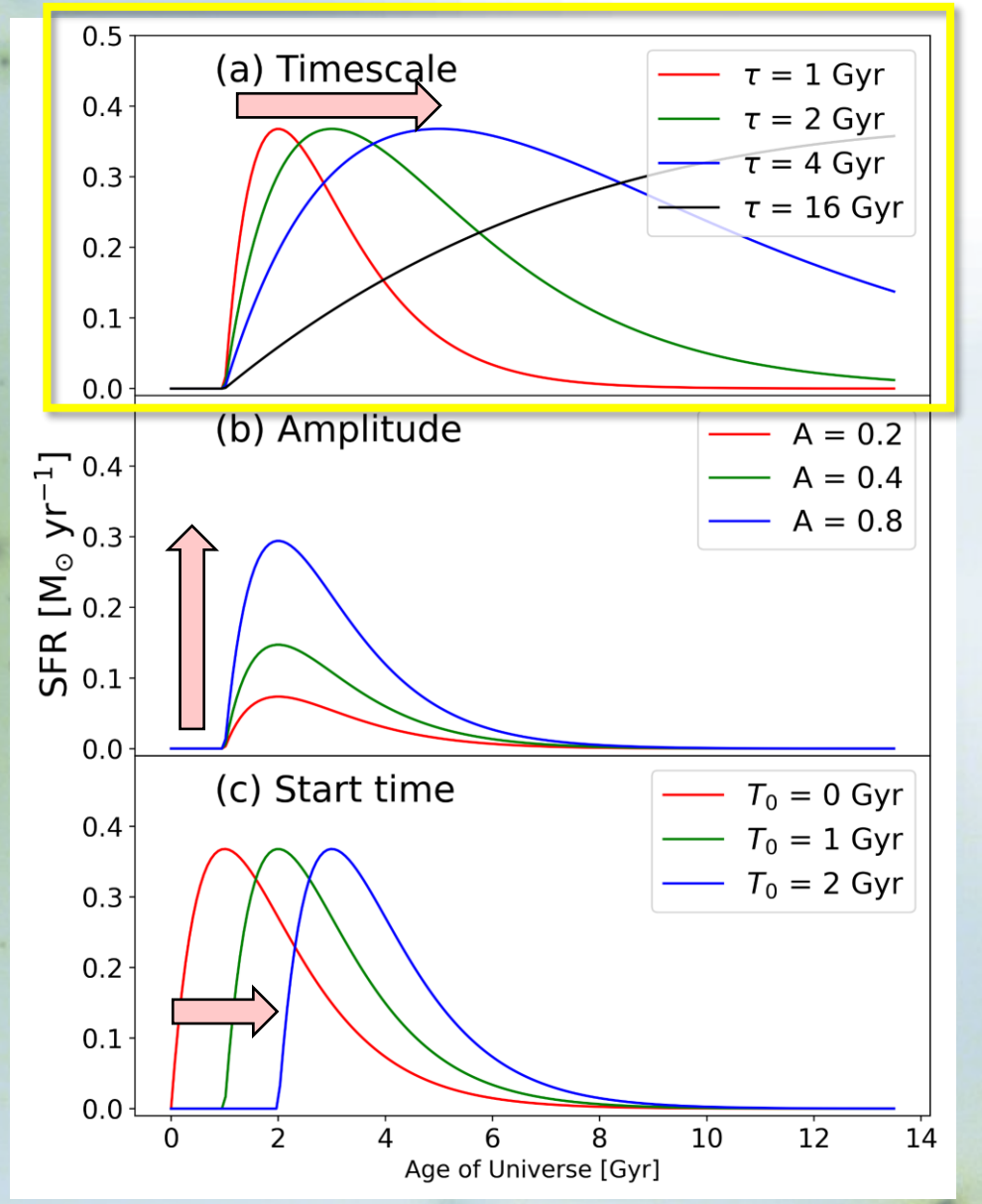
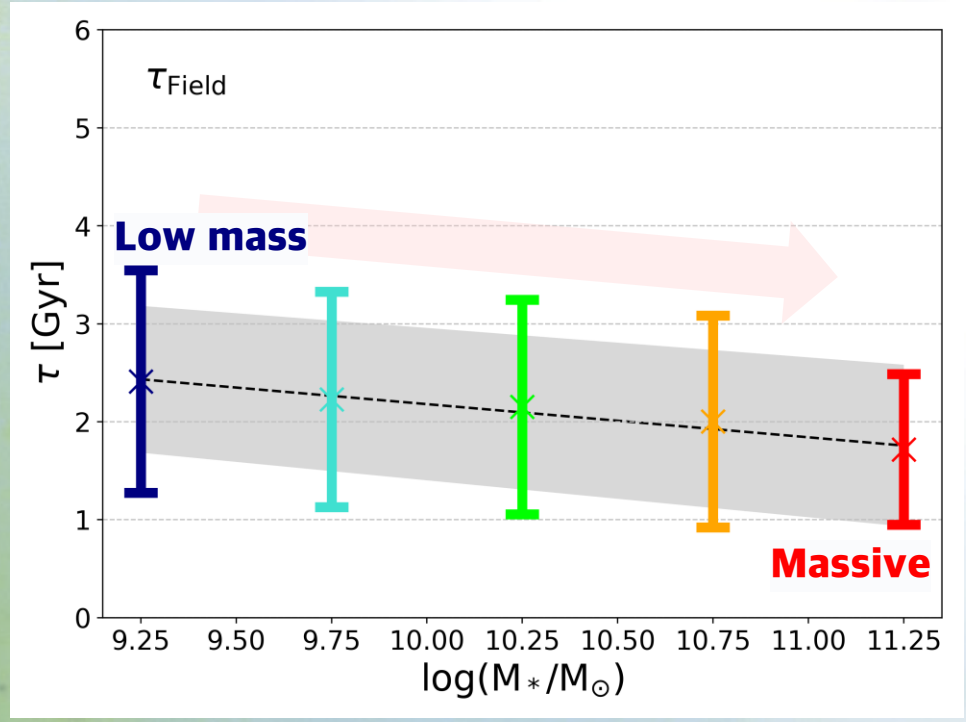


Quenching Timescale

Field Galaxy

: $M_* \uparrow \rightarrow \tau \downarrow \rightarrow$ Rapid quenching



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Quenching Timescale

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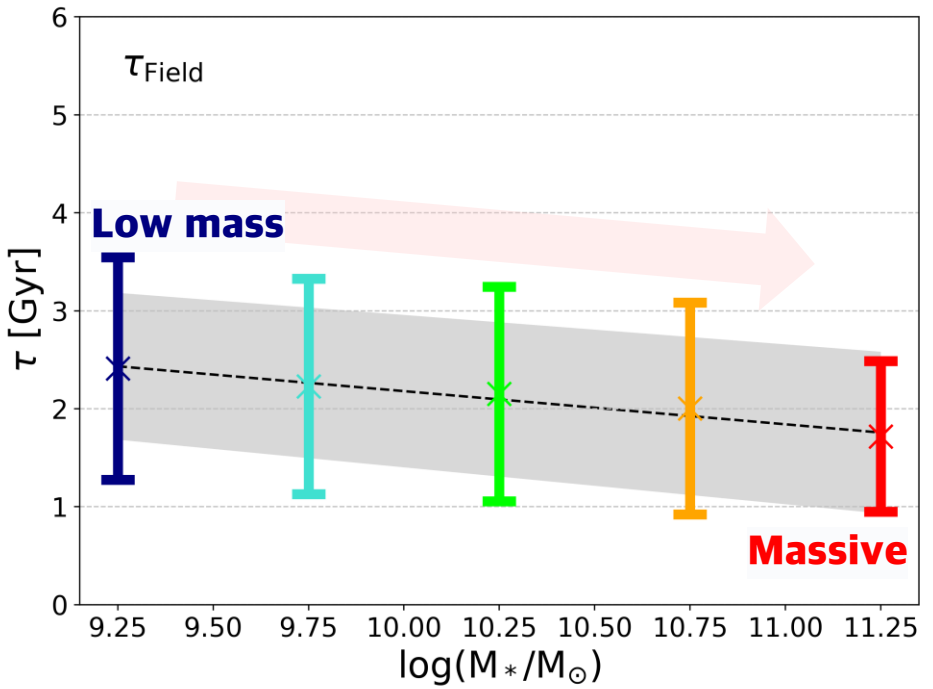
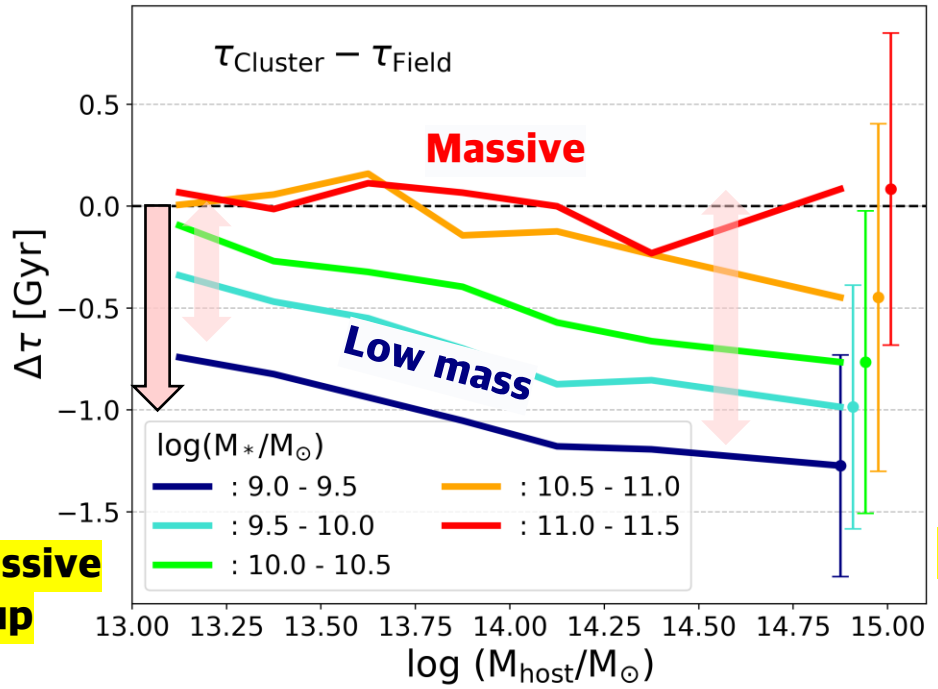
Member Galaxy (Satellite)





$\Delta\tau < 0$

: Rapid quenching than field gals

Less massive Group

Massive Cluster

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Quenching Timescale

Field Galaxy

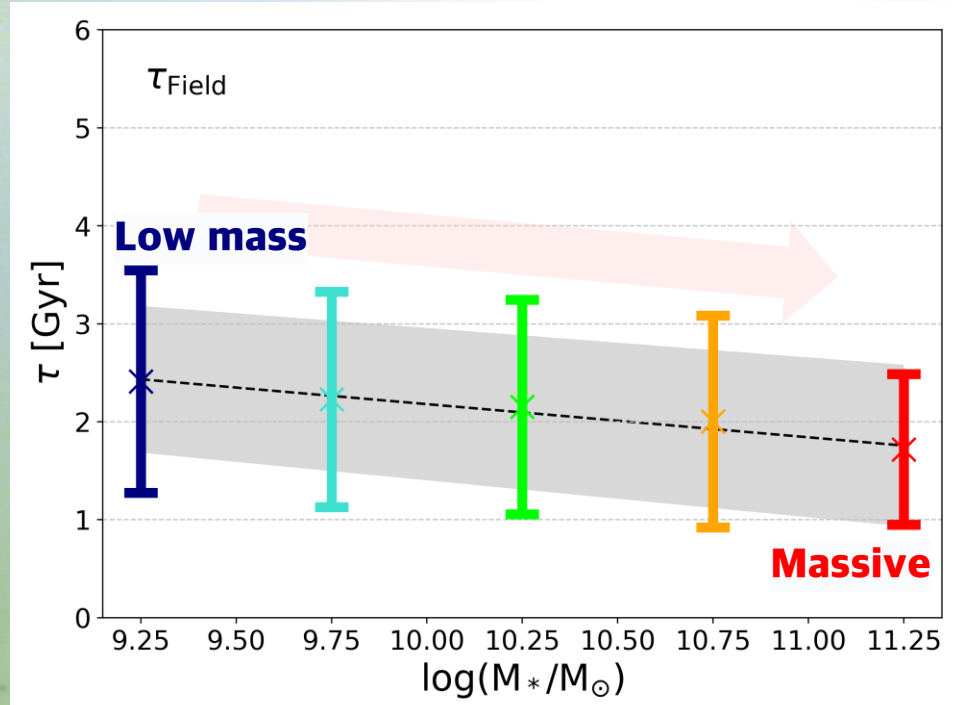
: $M_* \uparrow \rightarrow \tau \downarrow \rightarrow$ Rapid quenching

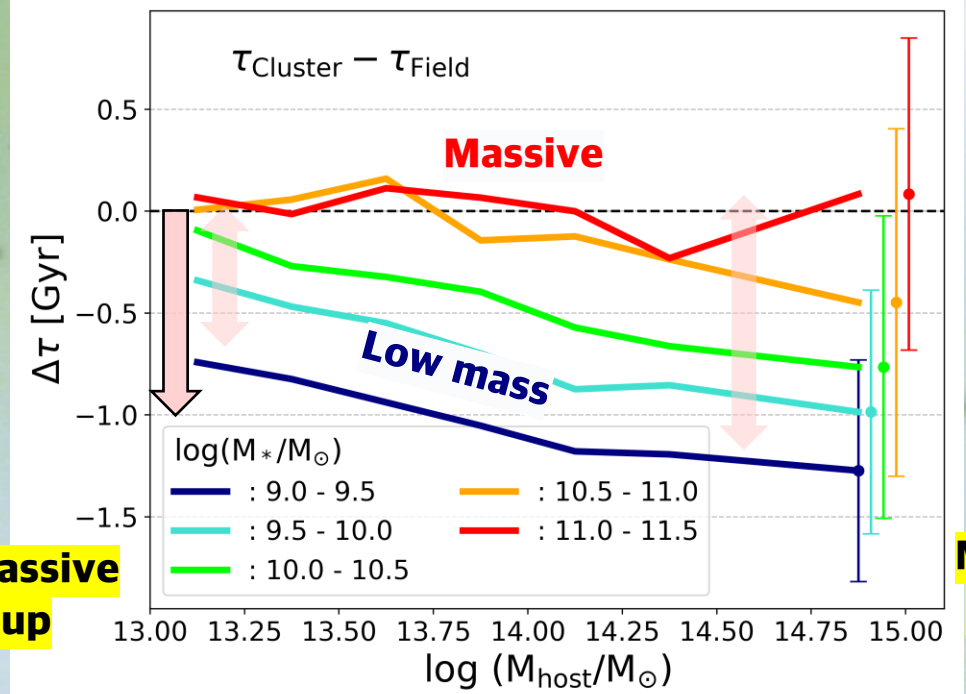
Member Galaxy (Satellite)

- Low-mass (**---**)

  : $\tau_{Field} > \tau_{Group} > \tau_{Cluster}$

  → Strong environmental quenching





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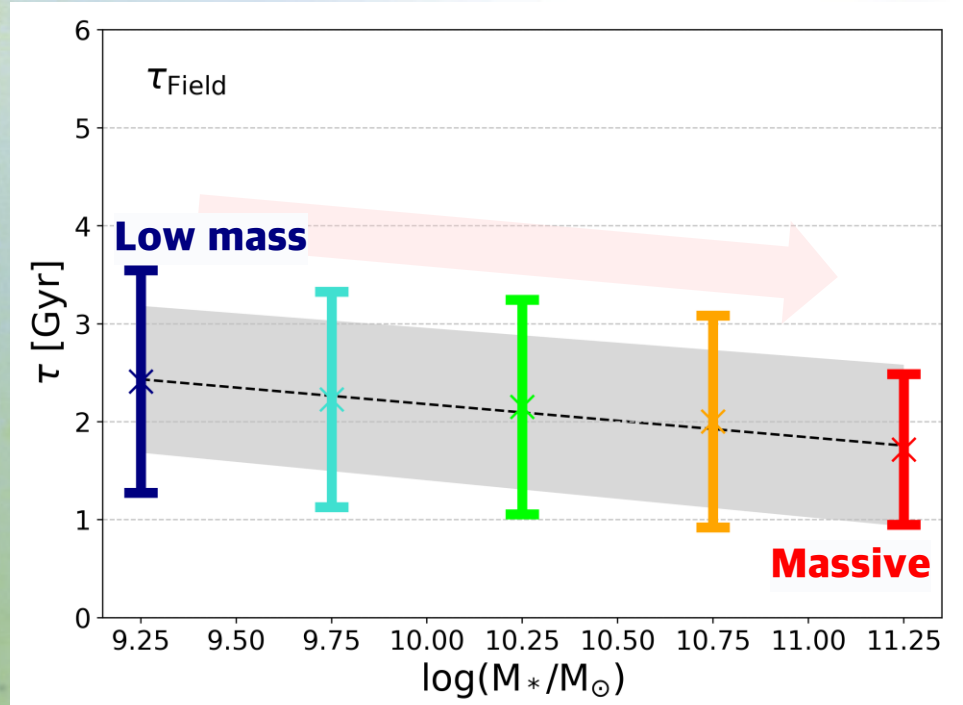
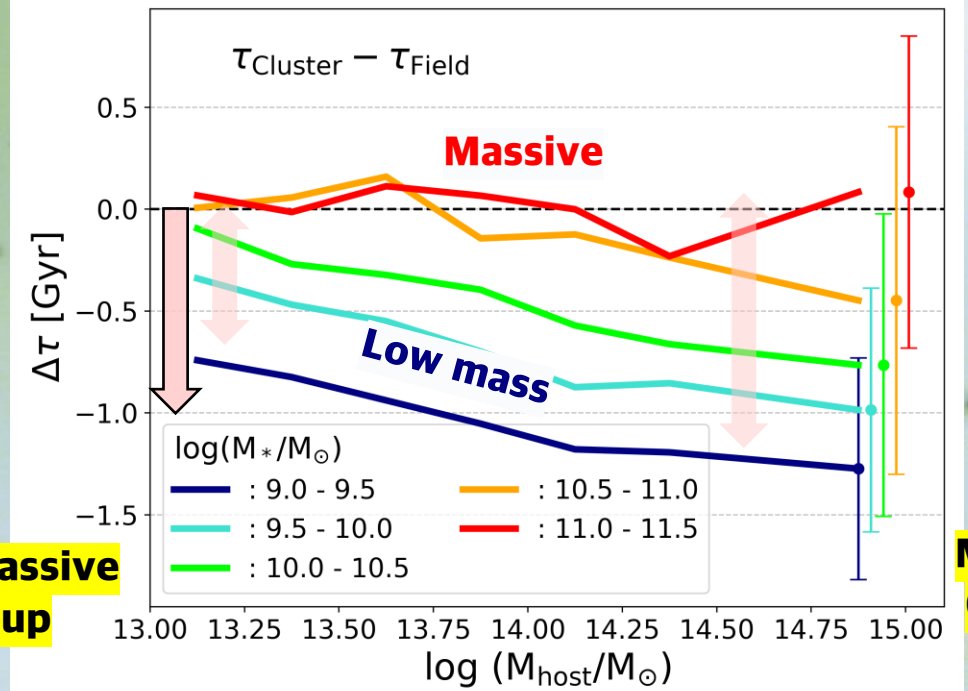
  → Strong environmental quenching

- $\frac{M_*}{M_{host}} \uparrow$

  : τ approaches to τ_{Field}

  → Resistance to environmental quenching





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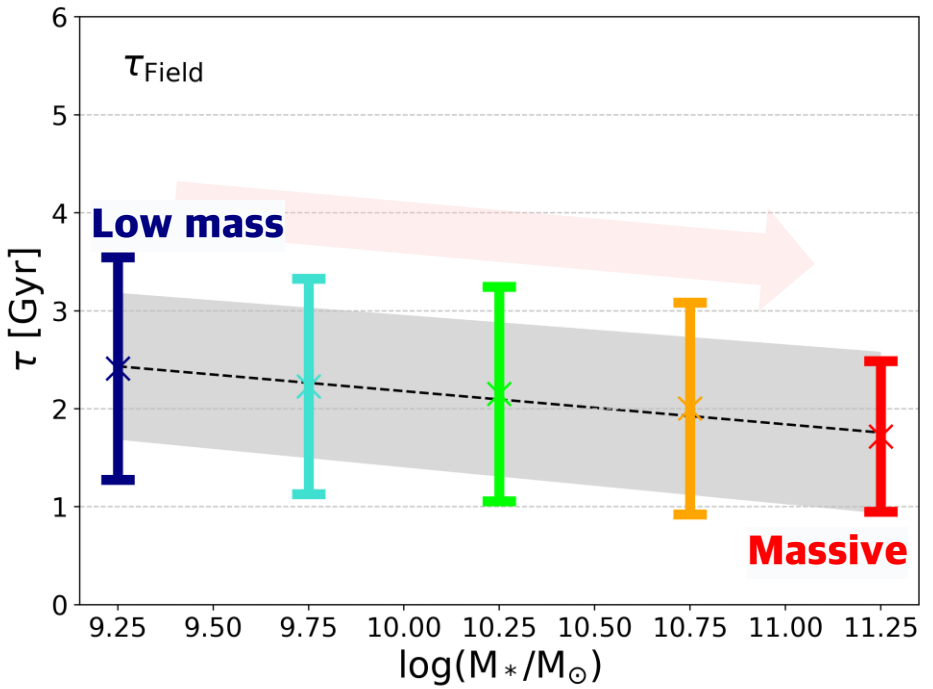
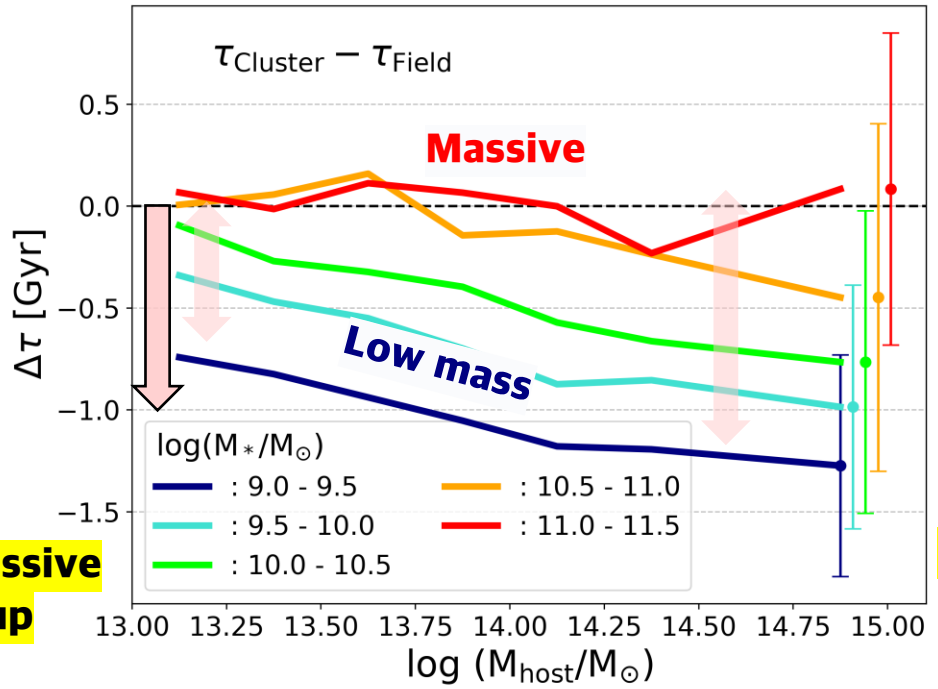
- Massive enough (**---**)

  : $\tau_{Field} \sim \tau_{Group} \sim \tau_{Cluster}$

  → Not affected by the host environment





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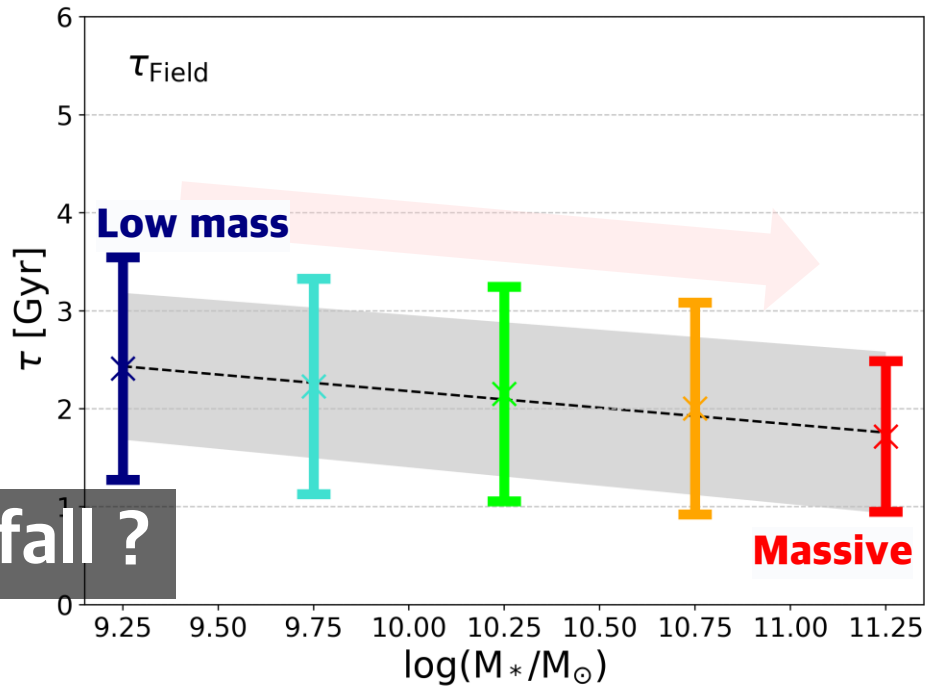
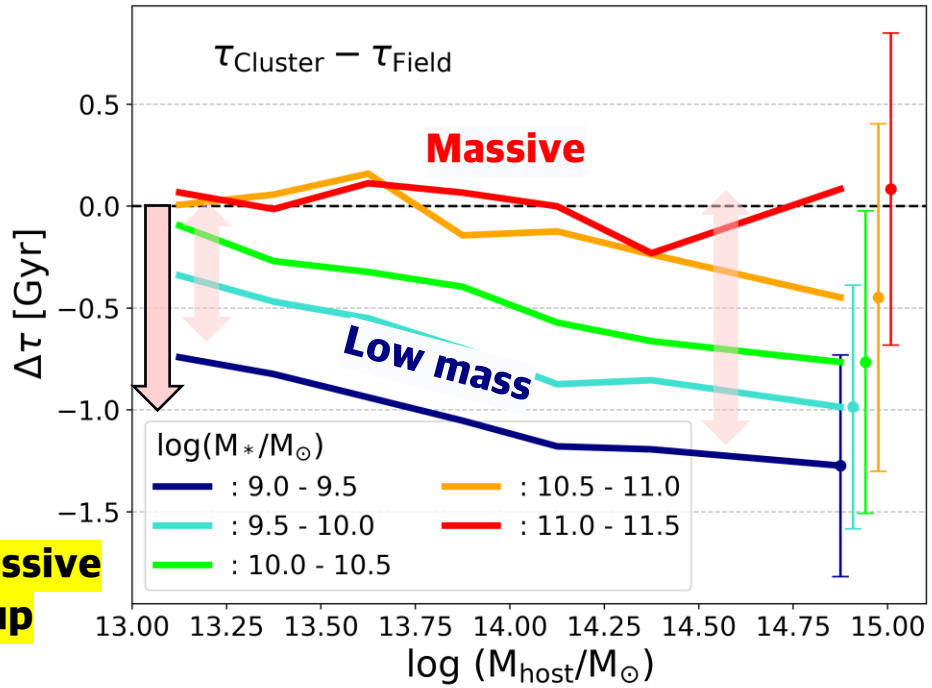
Time-Since-Infall ?





Less massive Group

Massive Cluster

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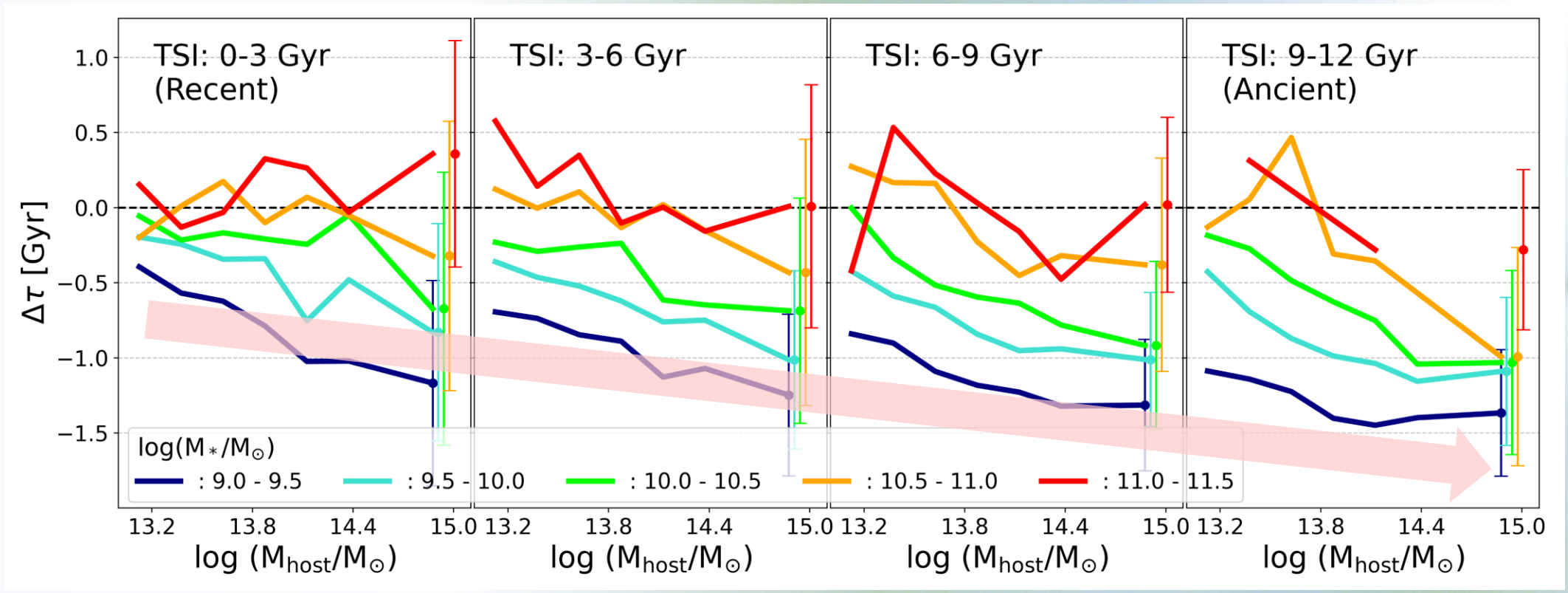
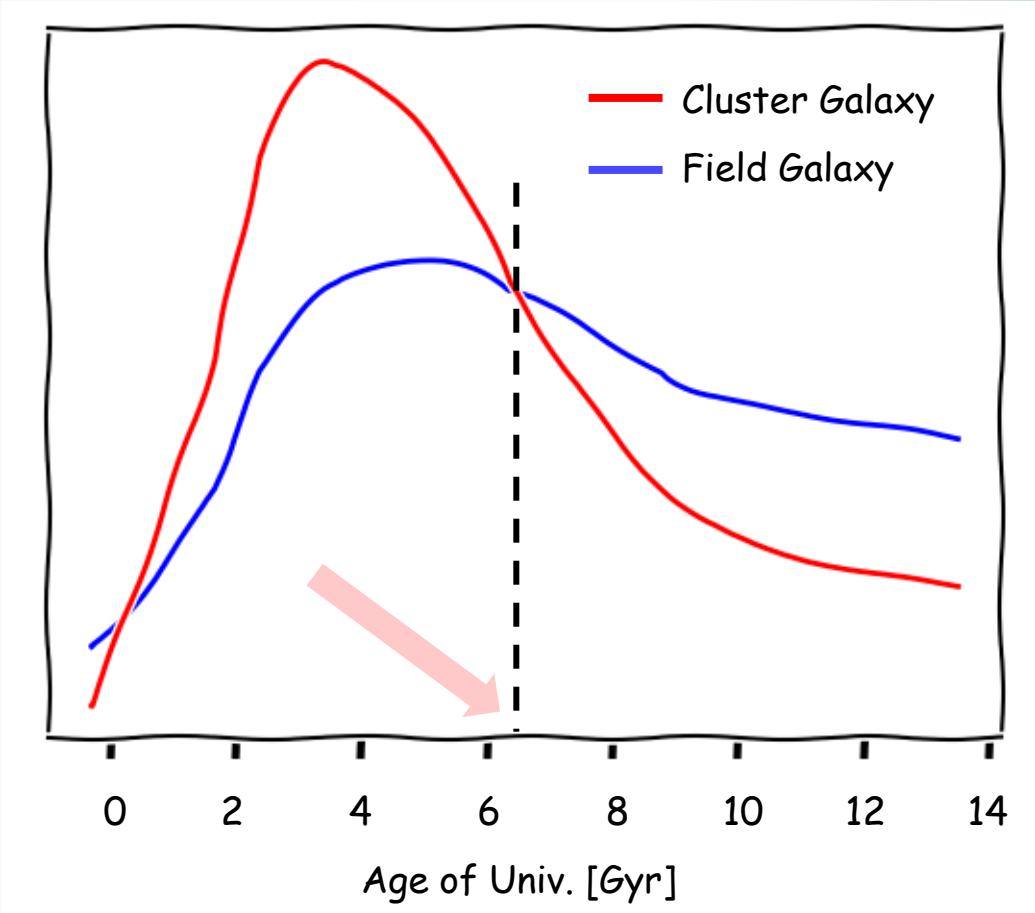
Quenching Timescale with Time-Since-Infall

Shorter residing time **Longer residing time**



Transition Epoch



Definition

: The epoch when cluster galaxies became less star-forming than field galaxies

Before transition

: Cluster galaxies are more star-forming

After transition

: Field galaxies are more star-forming

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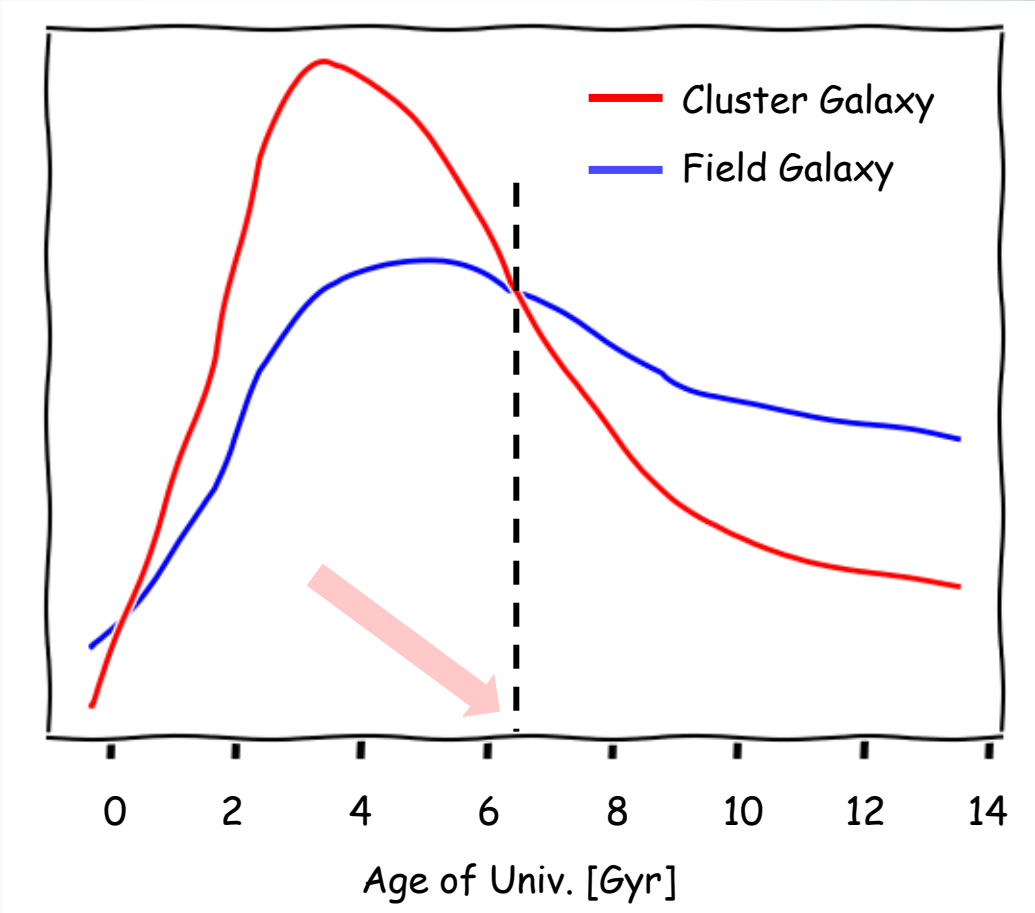
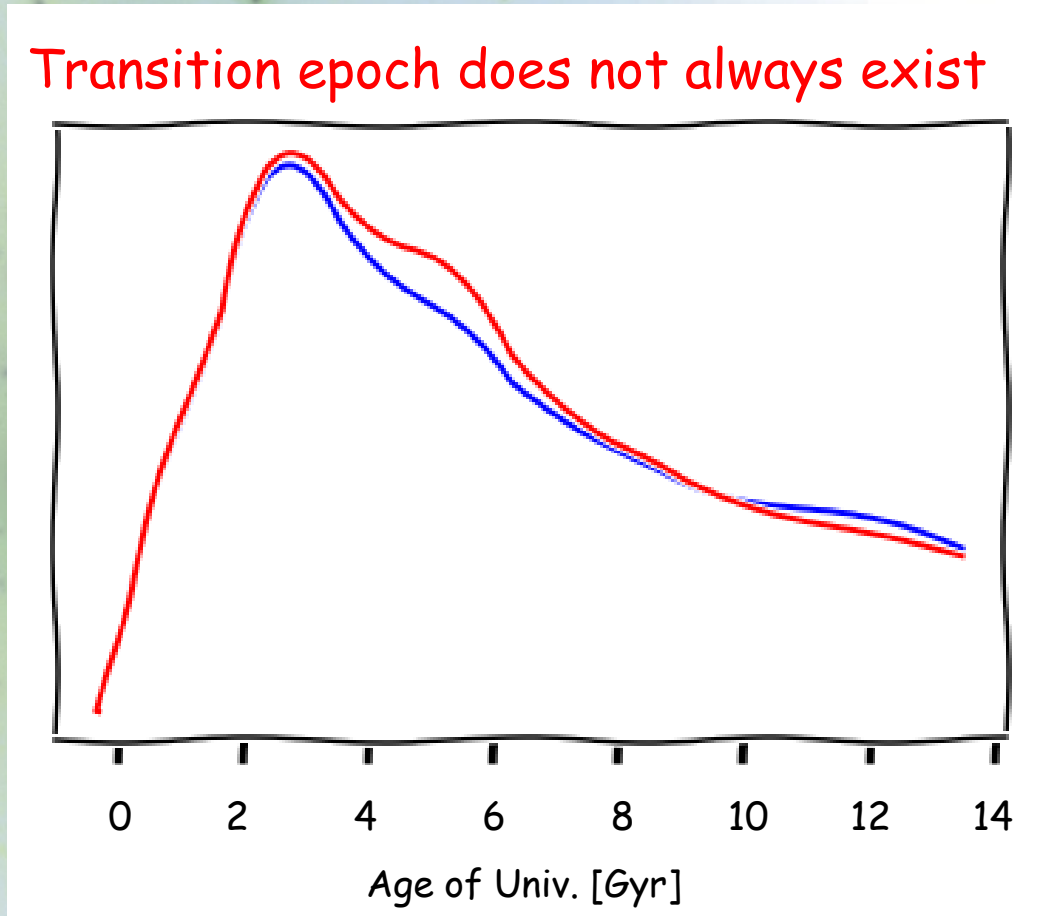
Transition Epoch



Transition epoch does not always exist



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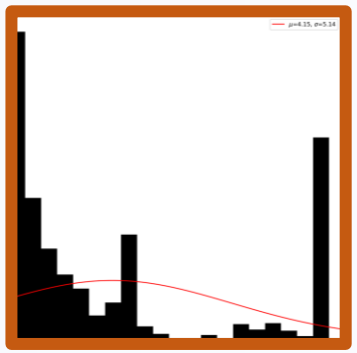
Transition Epoch

4.15 ± 5.14 Gyr



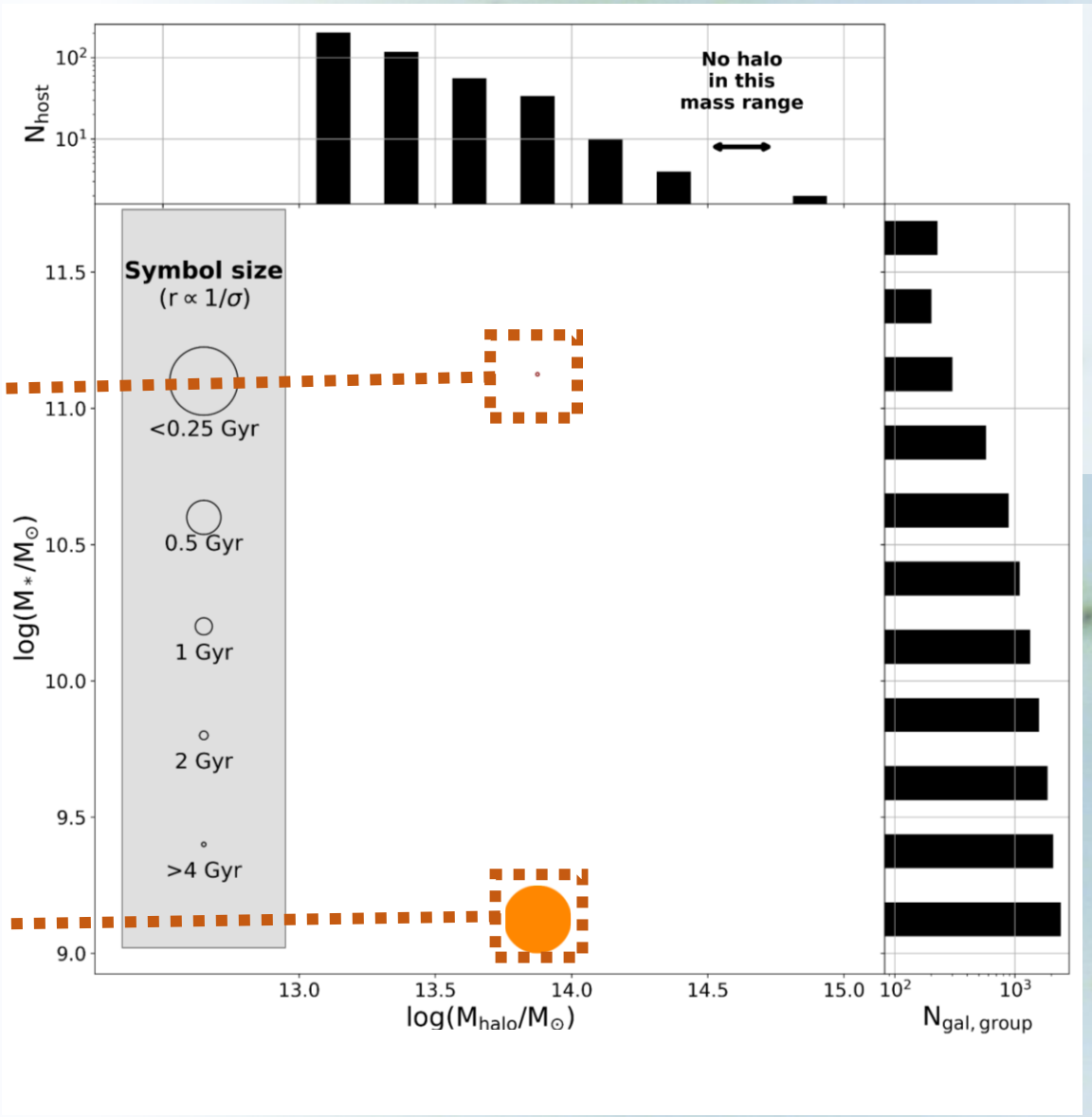
P(t)

t_{univ}

6.10 ± 0.12 Gyr

P(t)

t_{univ}



● : Transition exists

○ : No transition

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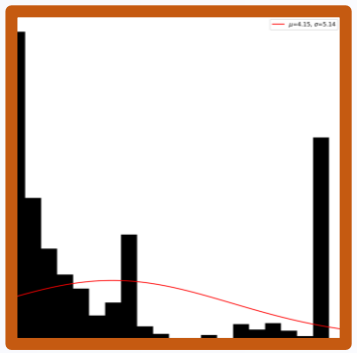

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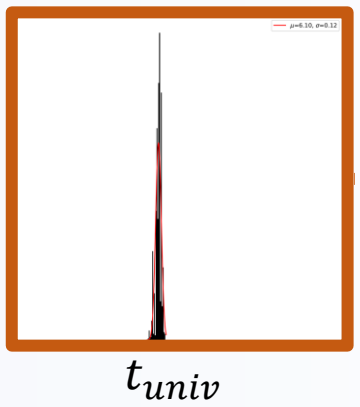

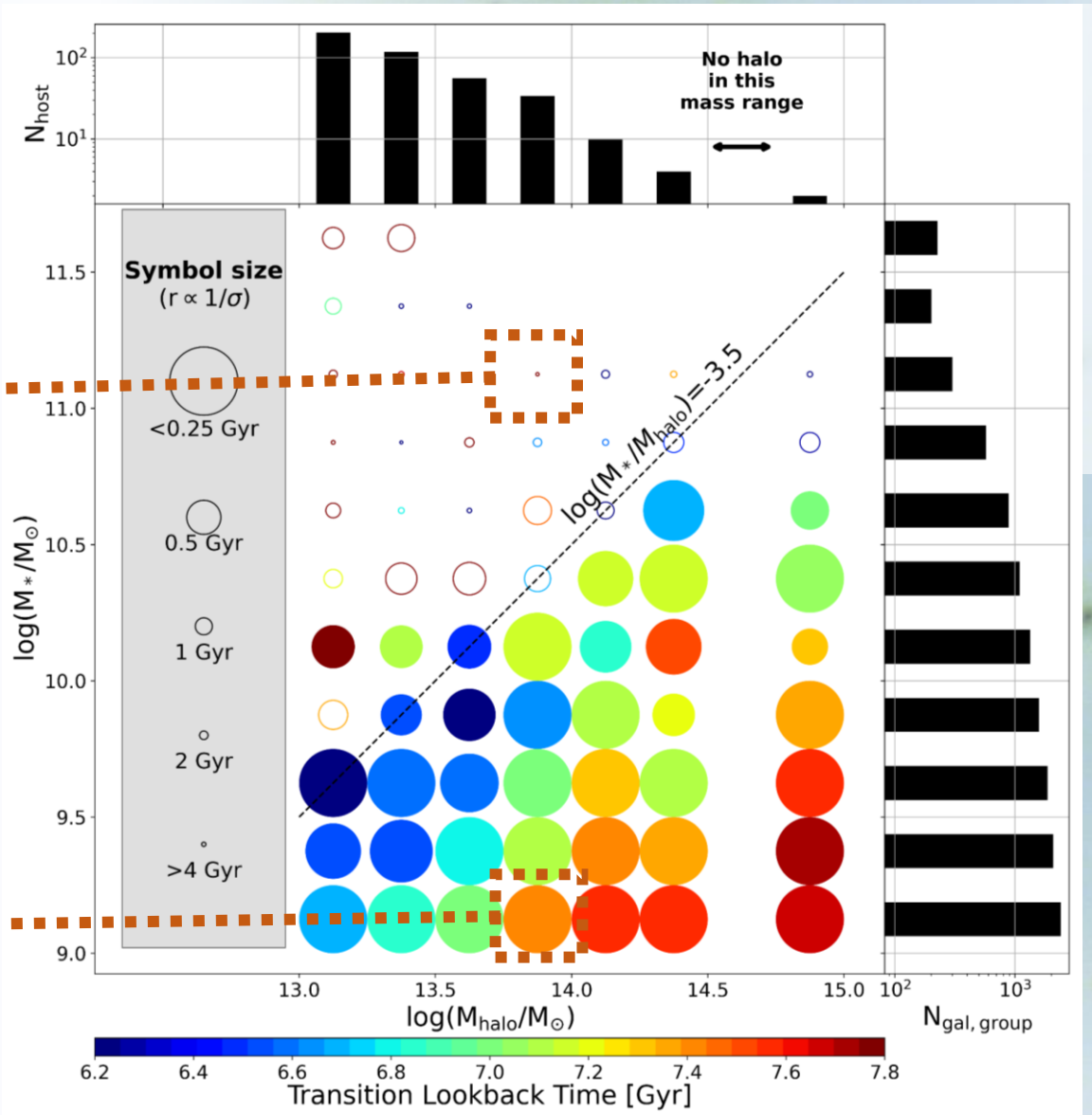

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○ : No transition

● : Earlier transition

● : Later transition

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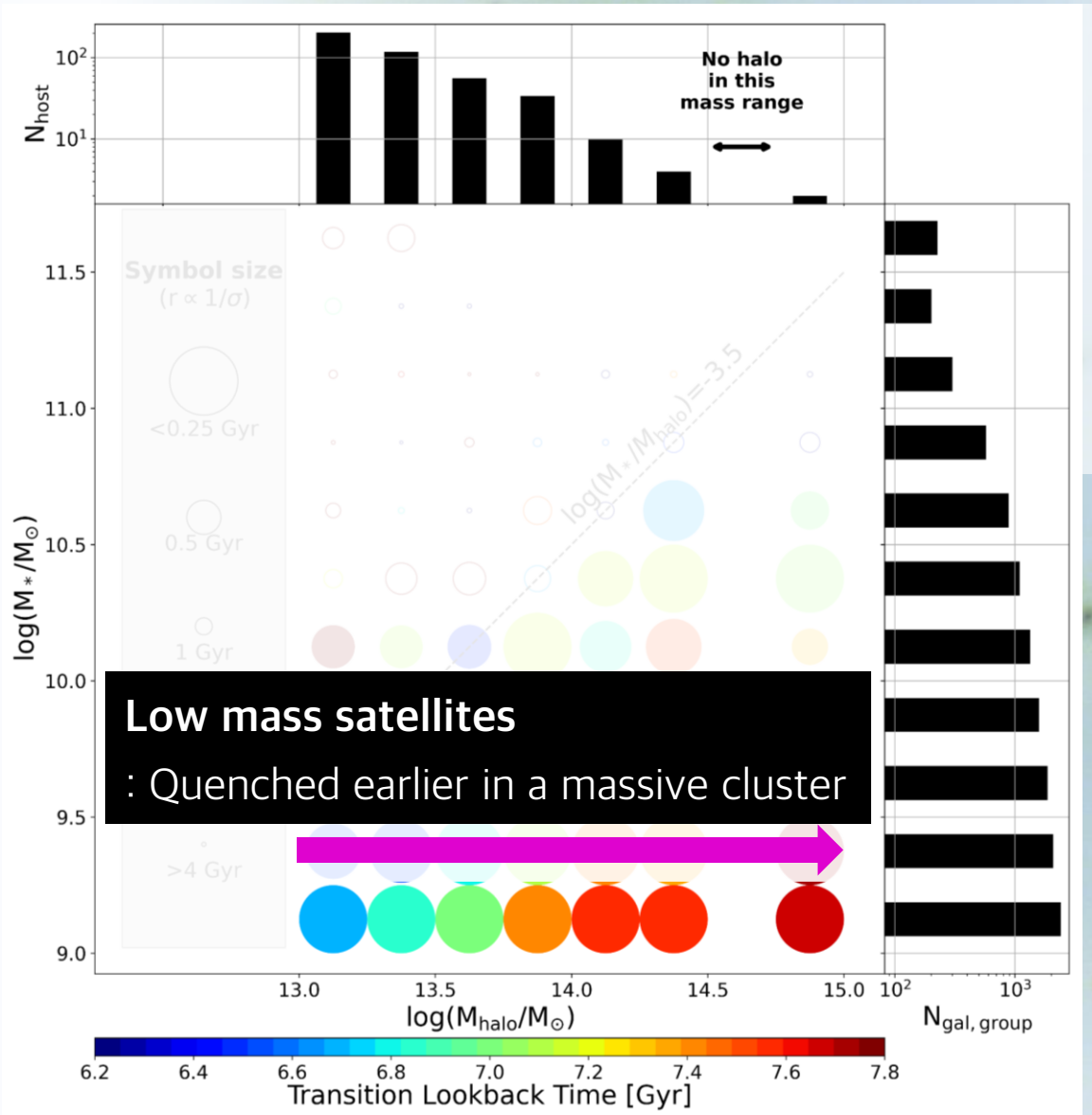
Transition Epoch



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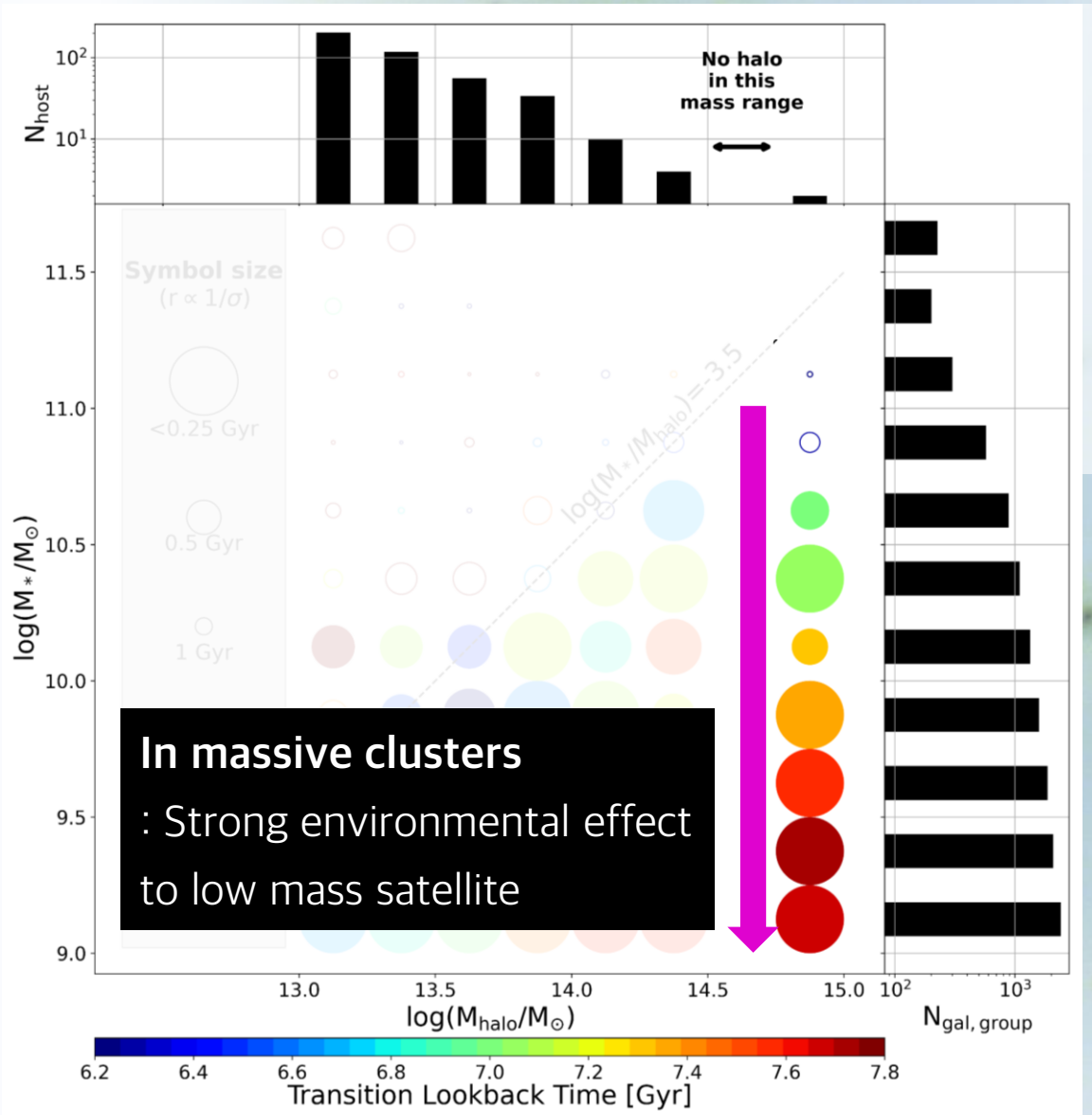

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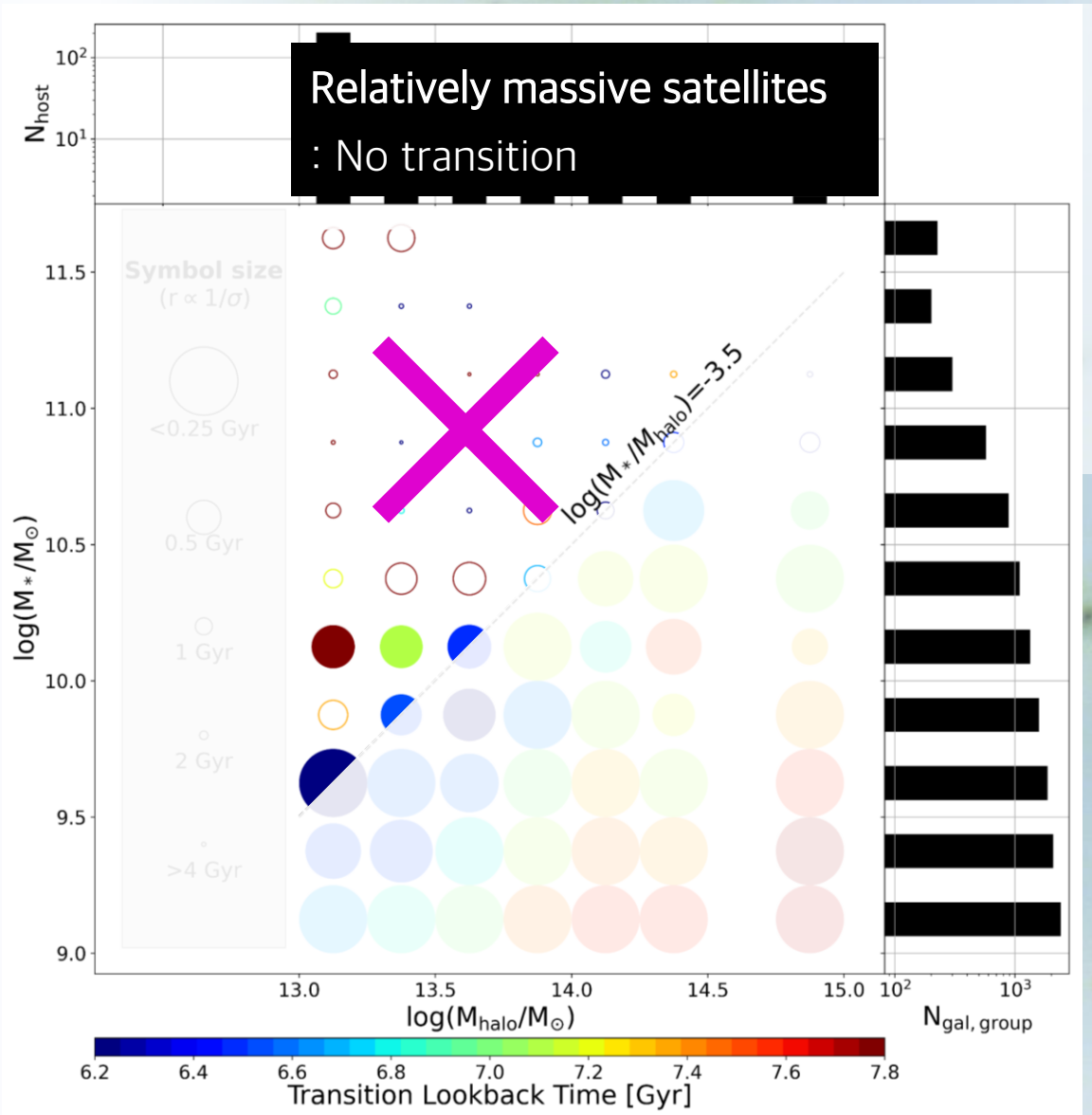

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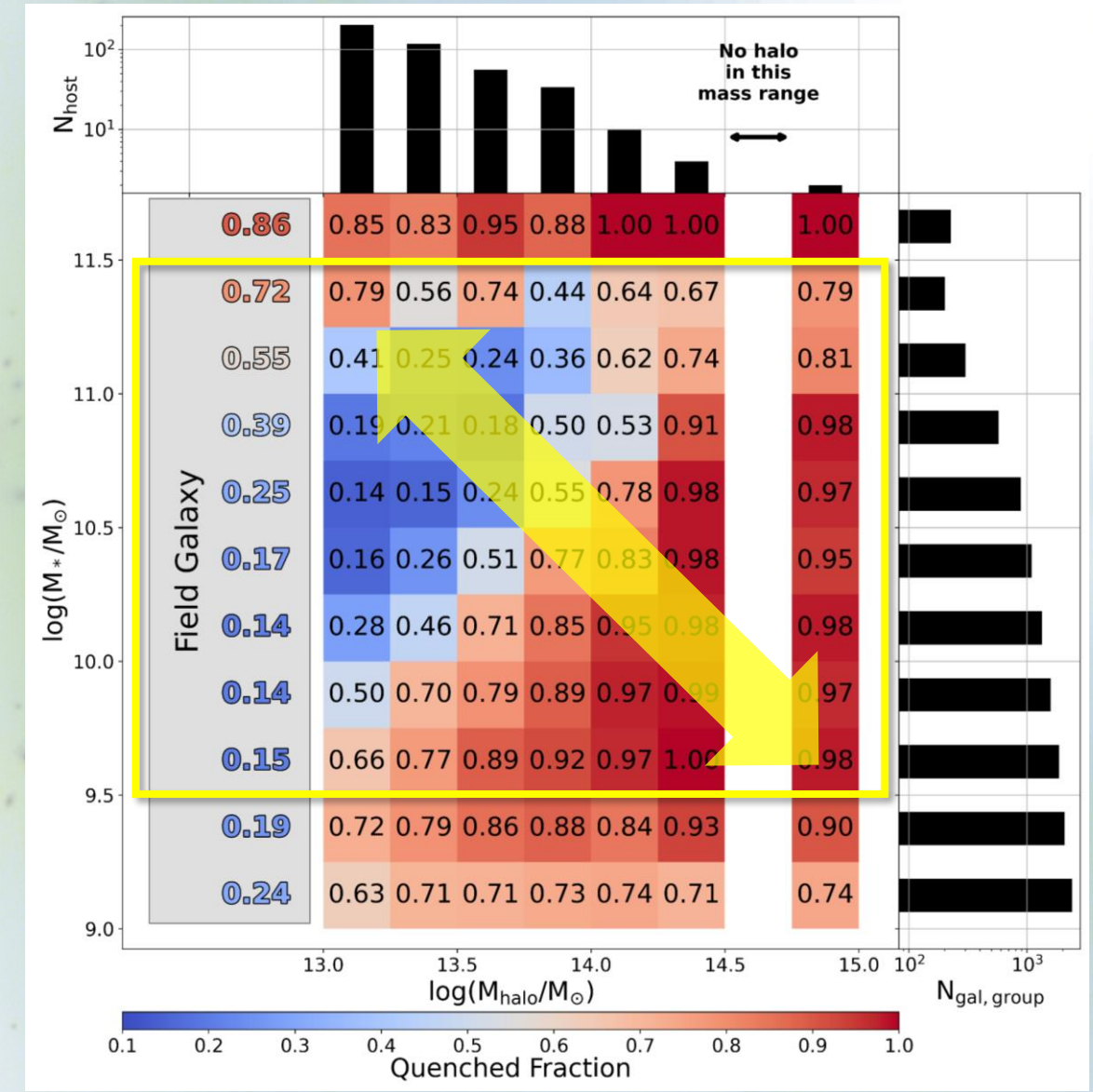
Halo-to-Stellar Mass Ratio

$M_* \downarrow$ & $M_{halo} \uparrow$: Redder

$M_* \uparrow$ & $M_{halo} \downarrow$: Bluer

→ Relation with Halo-to-stellar mass ratio?

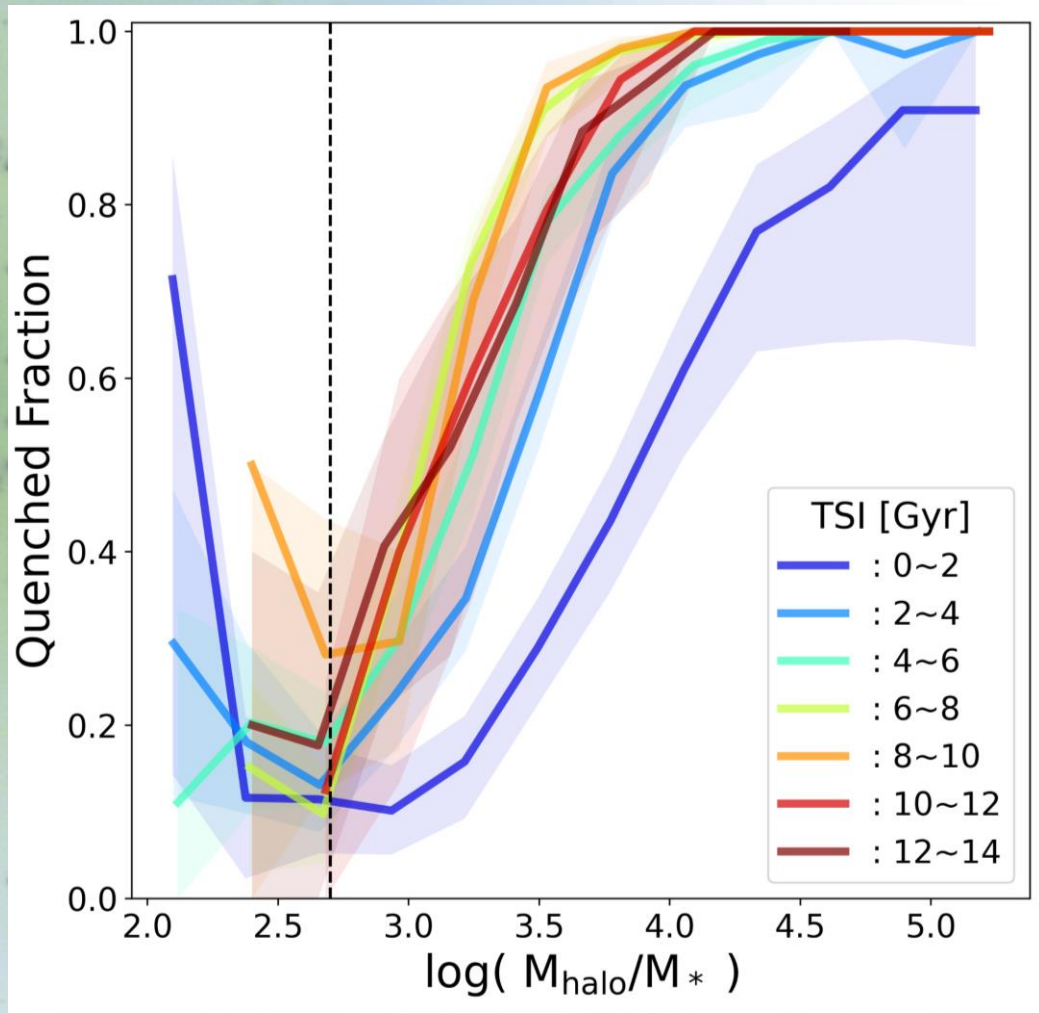
$$M_{halo}/M_*$$



Halo-to-Stellar Mass Ratio

$M_{halo}/M_* > 10^{2.7}$:

- Rapid increase of the quenched fraction with the mass ratio
- Overall quenched fractions increase with TSI mildly



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- Rapid increase of the quenched fraction with the mass ratio
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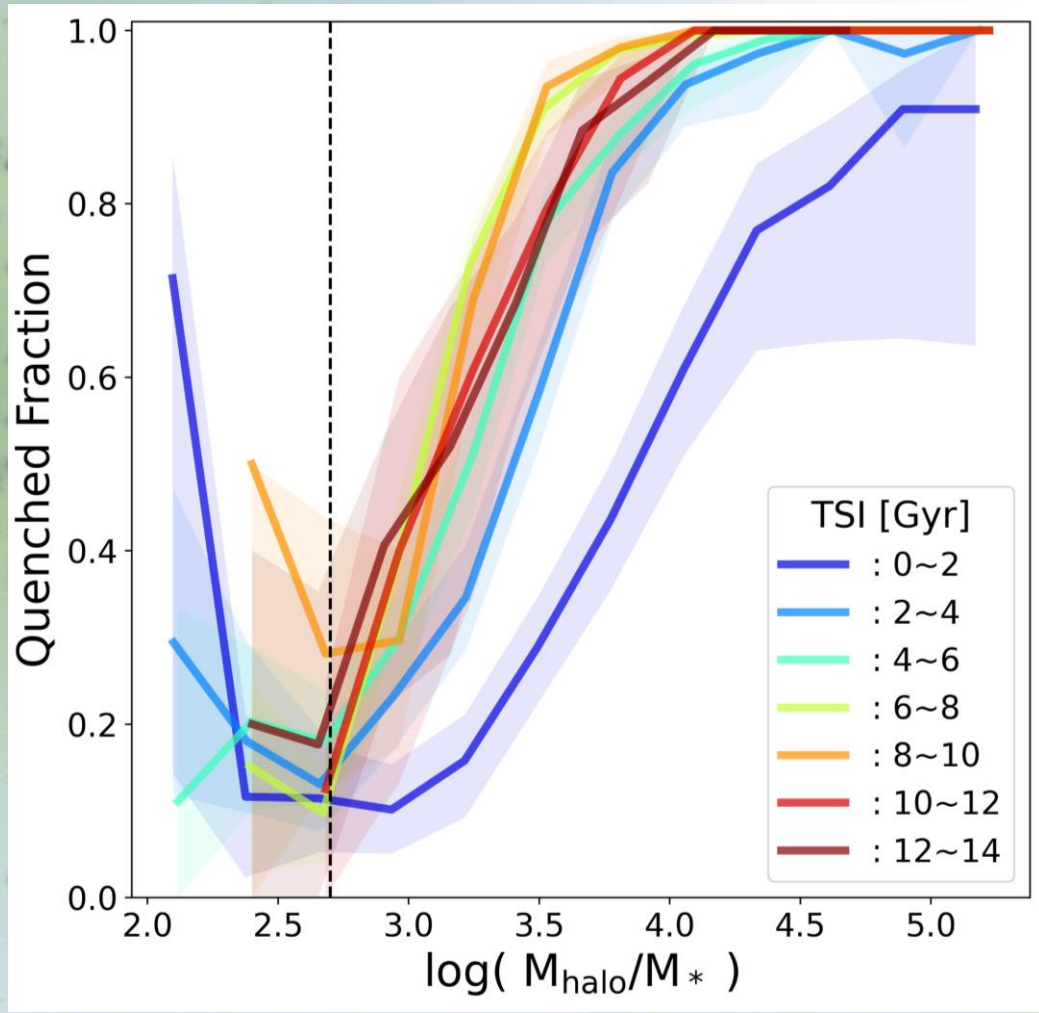
$M_{halo}/M_* < 10^{2.7}$:

- Reversed trends (higher QF for low mass ratio)
- Very massive galaxies compared to their host mass

  → Mass quenching dominated regime



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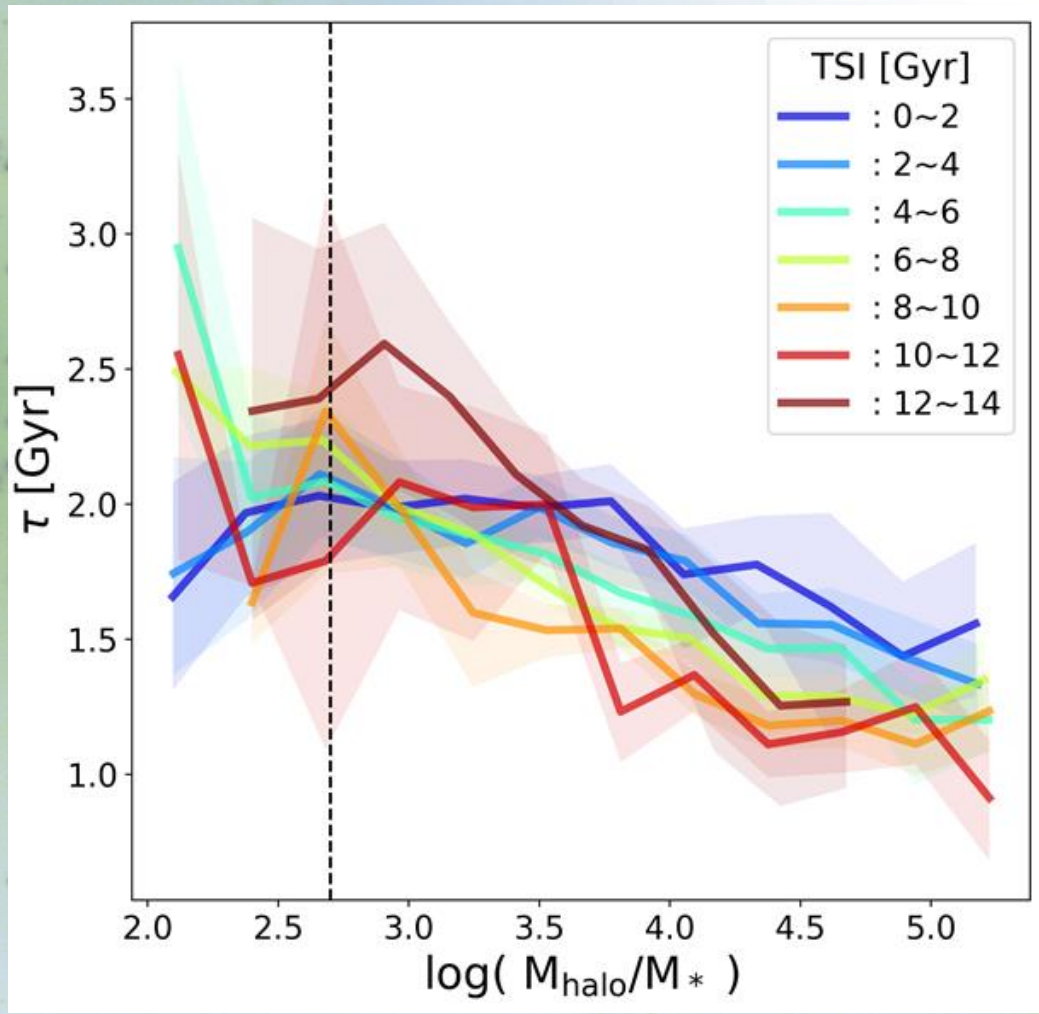
Halo-to-Stellar Mass Ratio

$M_{halo}/M_* > 10^{2.7}$:

- Quenching timescale (τ) decreases with the mass ratio
- Steeper slopes in galaxies with longer TSI



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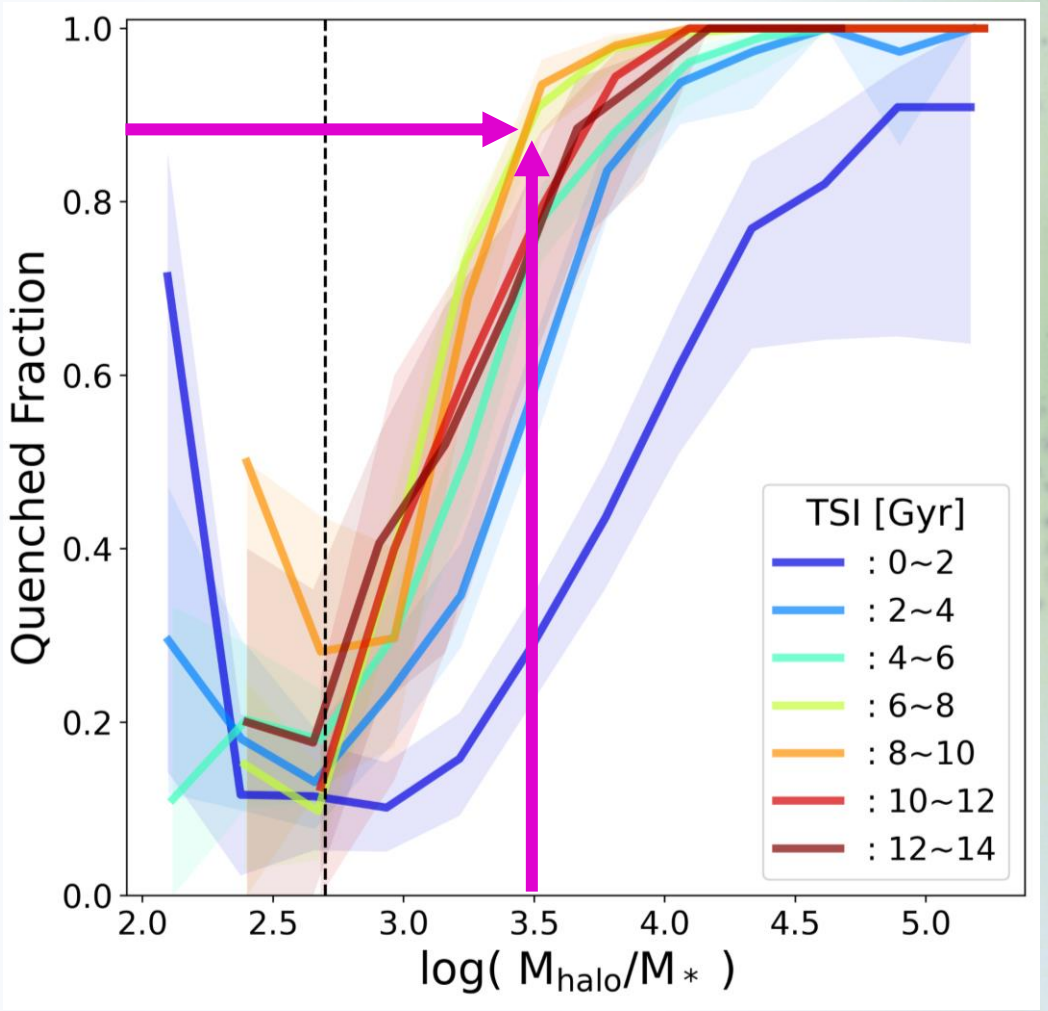
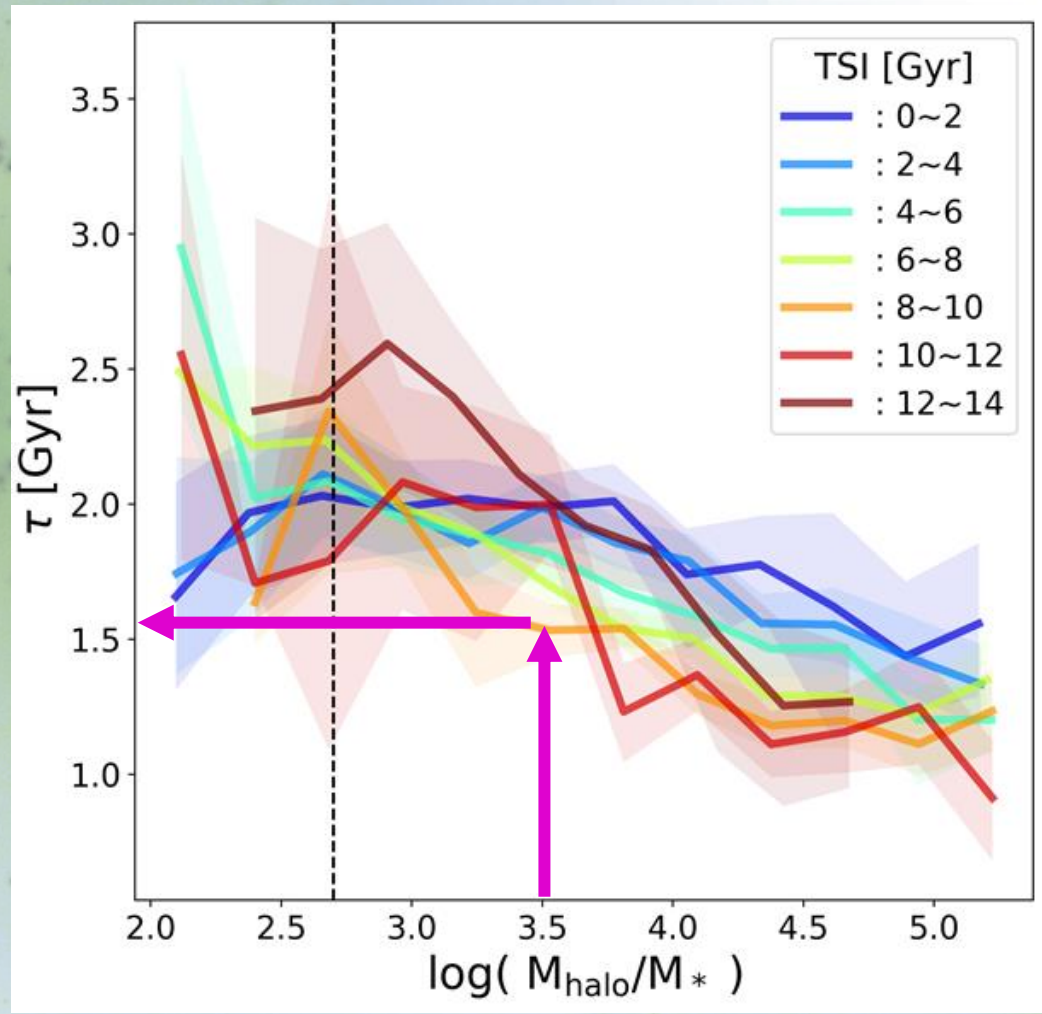
Halo-to-Stellar Mass Ratio

Could be used to infer the SFH?

1) Mass ratio + Quenched fraction → TSI
2) Mass ratio + TSI → τ





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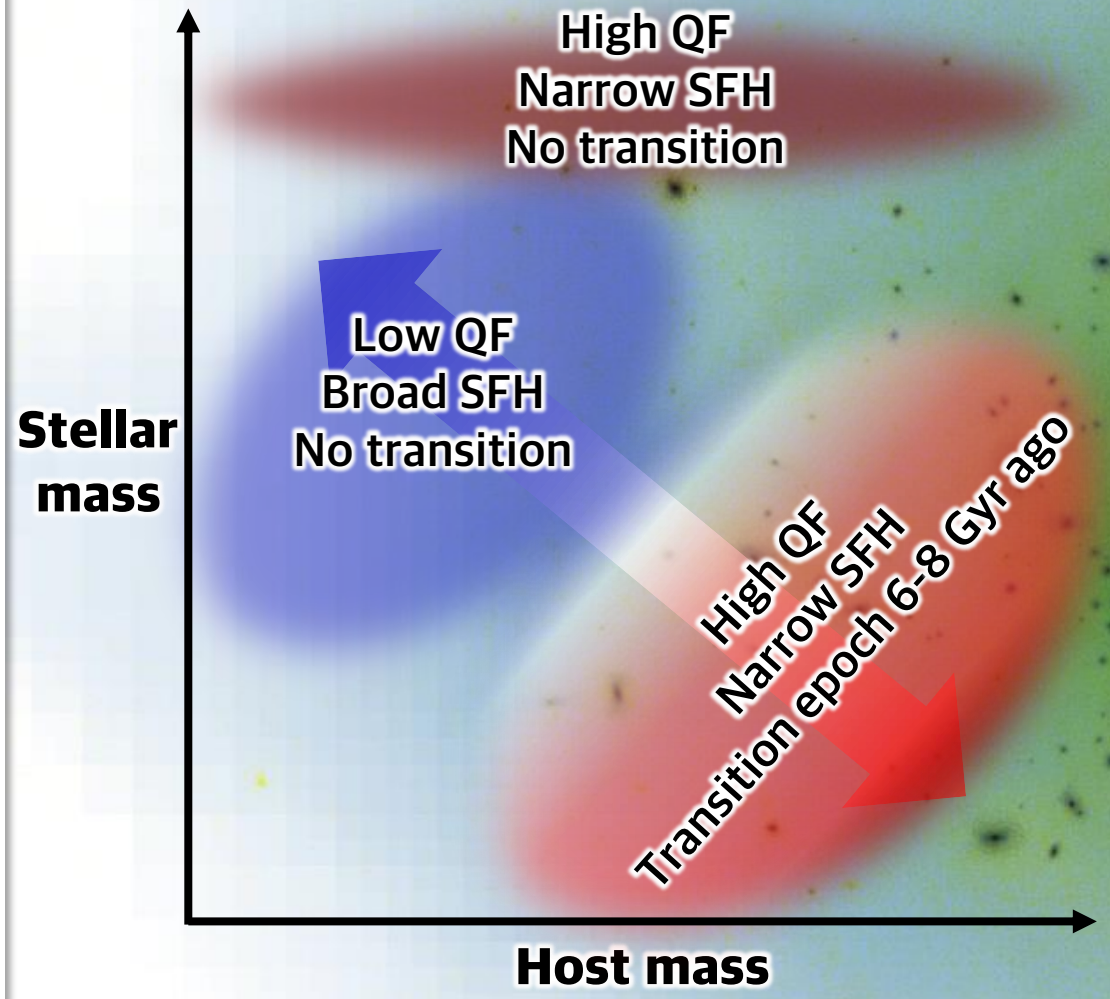
Summary



Internal properties (Stellar mass) + External properties (Host mass & TSI) → How are these related to star formation and quenching?

- **Quenched fraction** increase toward
  - higher stellar mass regime
  - lower stellar mass & higher host mass
  - Longer TSI
- **Quenching timescale (τ)** decreases toward
  - Higher stellar mass regime
  - Lower stellar mass & higher host mass
  - Longer TSI
- **Transition epoch** exists only for lower stellar mass & higher host mass from 6 to 8 Gyr ago
- **Halo-to-Stellar mass ratio** could be a good indicator to infer SFH and quenched status

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