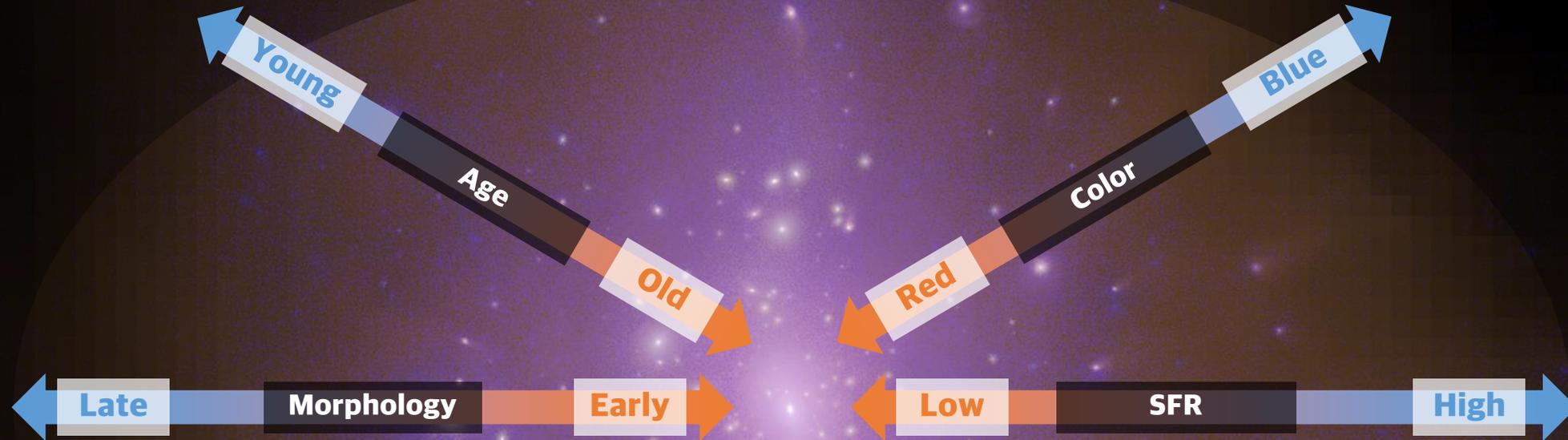


The Star Formation Quenching and the Transition Epoch of the Horizon-AGN Galaxies

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¹Yonsei University

Galaxy cluster environments are unusual



Cluster galaxies are $\left(\begin{array}{l} \text{Earlier type} \\ \text{More quenched} \\ \text{Older} \\ \text{Redder} \end{array} \right)$ than field galaxies

Which galaxies are quenched?

For NOW, Cluster galaxies are more quenched than field galaxies

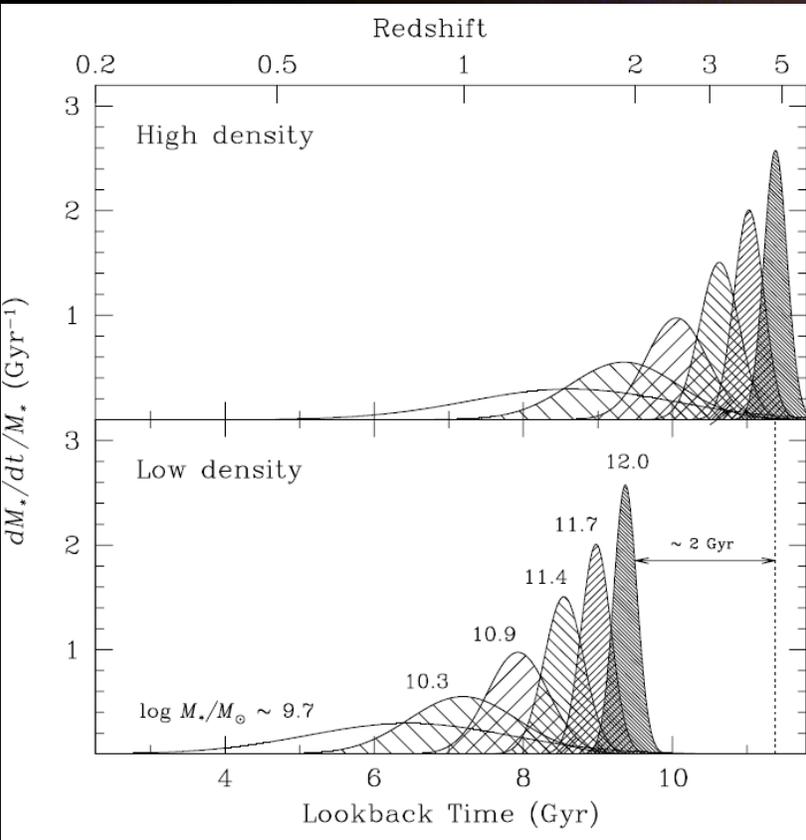
→ Always?

GOAL

Calculate the quenching timescale using the parametrized star formation history

Determine how quenching timescale varies with environments

Examine when cluster galaxies became less star-forming compared to field galaxies



Scenario of Thomas+05

Horizon-AGN

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

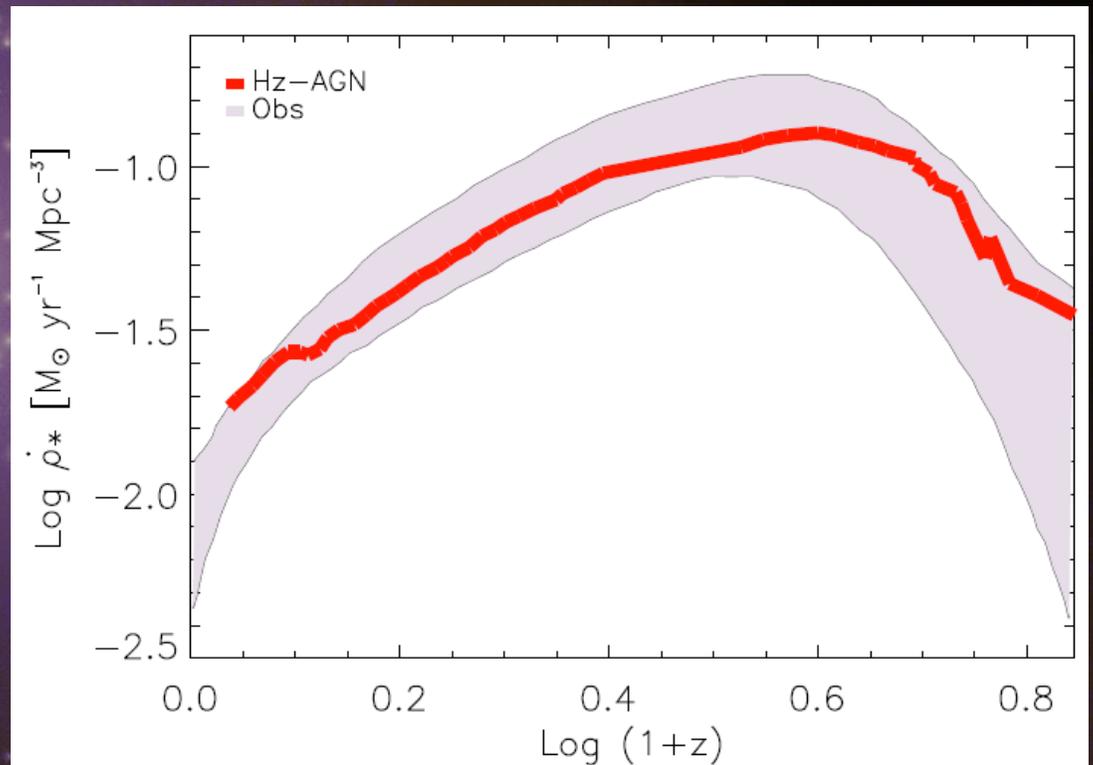
- Gas cooling & Heating
- Star formation & Stellar feedback
- AGN feedback

*More detail in Dubois+14

Yohan Dubois

Good agreement with observations

(e.g. cosmic SFH, LF, CMD, ...)



Kaviraj+17

Data Sample

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)

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

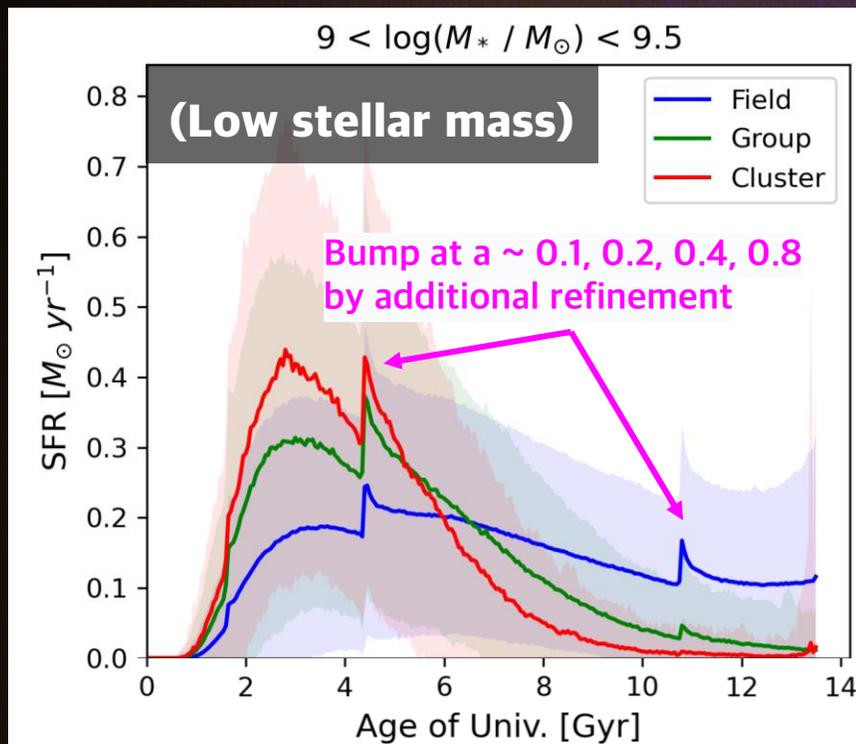
Field galaxy

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

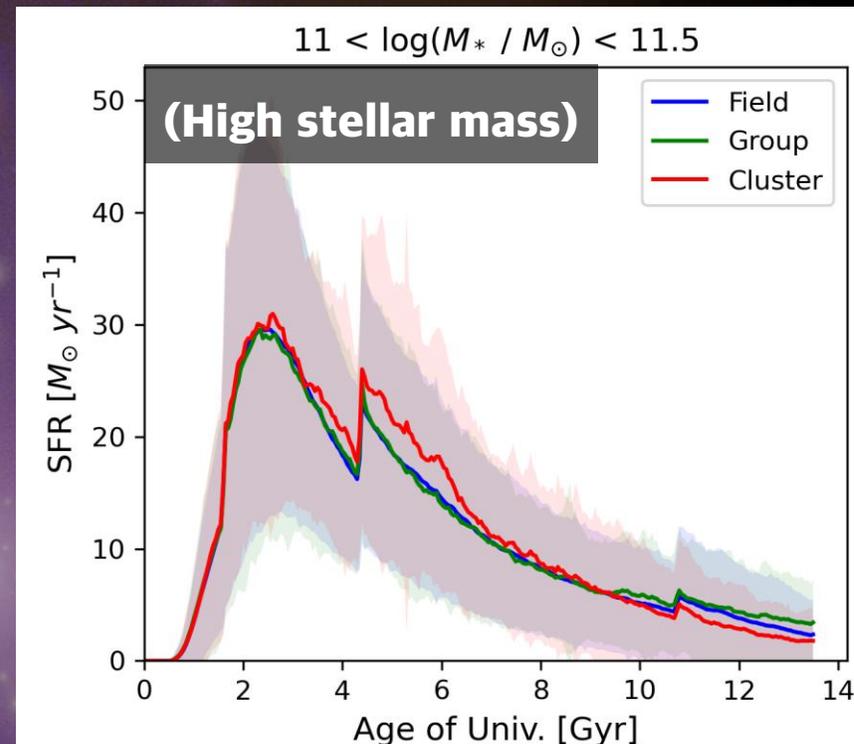
(Halo)	Cluster	Group
	16	412

(Galaxy)	Cluster	Group	Field	Total
All Mass	4431	16714	98372	119517
$> 10^9 M_\odot$	2888	10746	67566	81200

Star Formation History



Clear environment dependency



No difference & Rapid quenching



Part I. Quenching Timescale

Part II. Transition Epoch

I. Star Formation History Modeling

Delayed Tau Model (Carnall+19)

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

$\tau \uparrow$: Extended SF

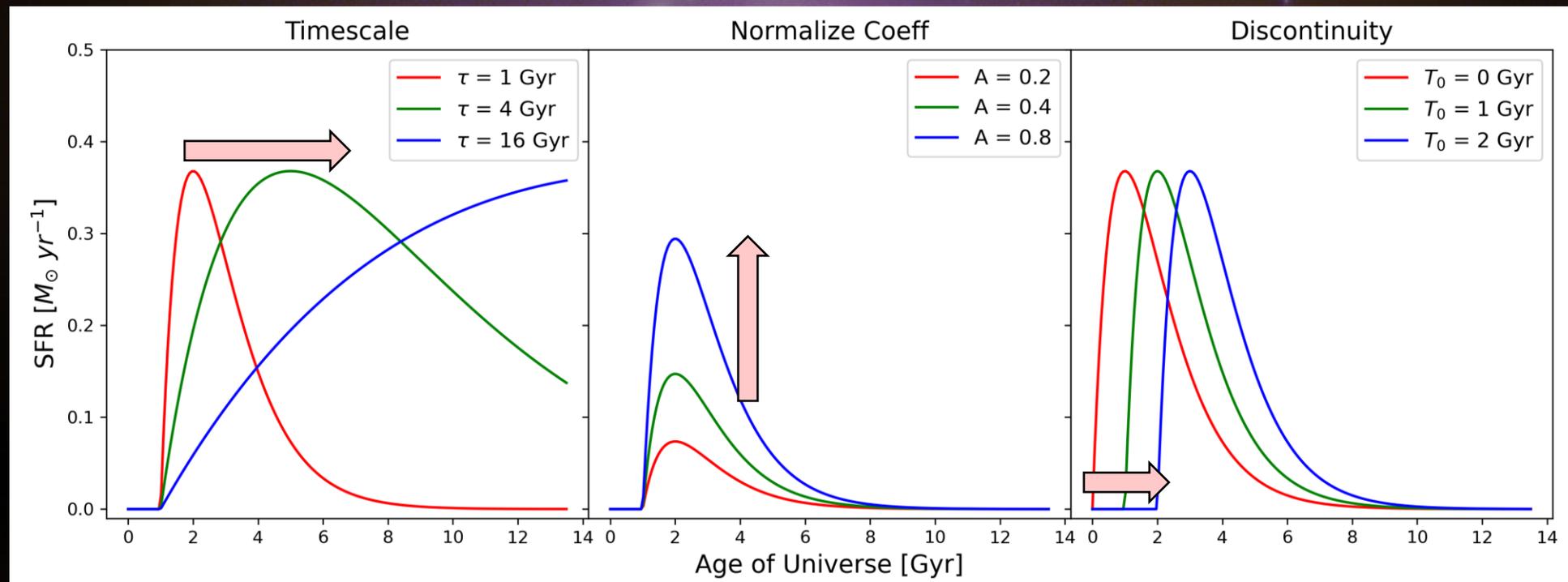
$A \uparrow$: Higher SF

$T_0 \uparrow$: Late start

$\tau \downarrow$: Rapid quenching

$A \downarrow$: Lower SF

$T_0 \downarrow$: Early start



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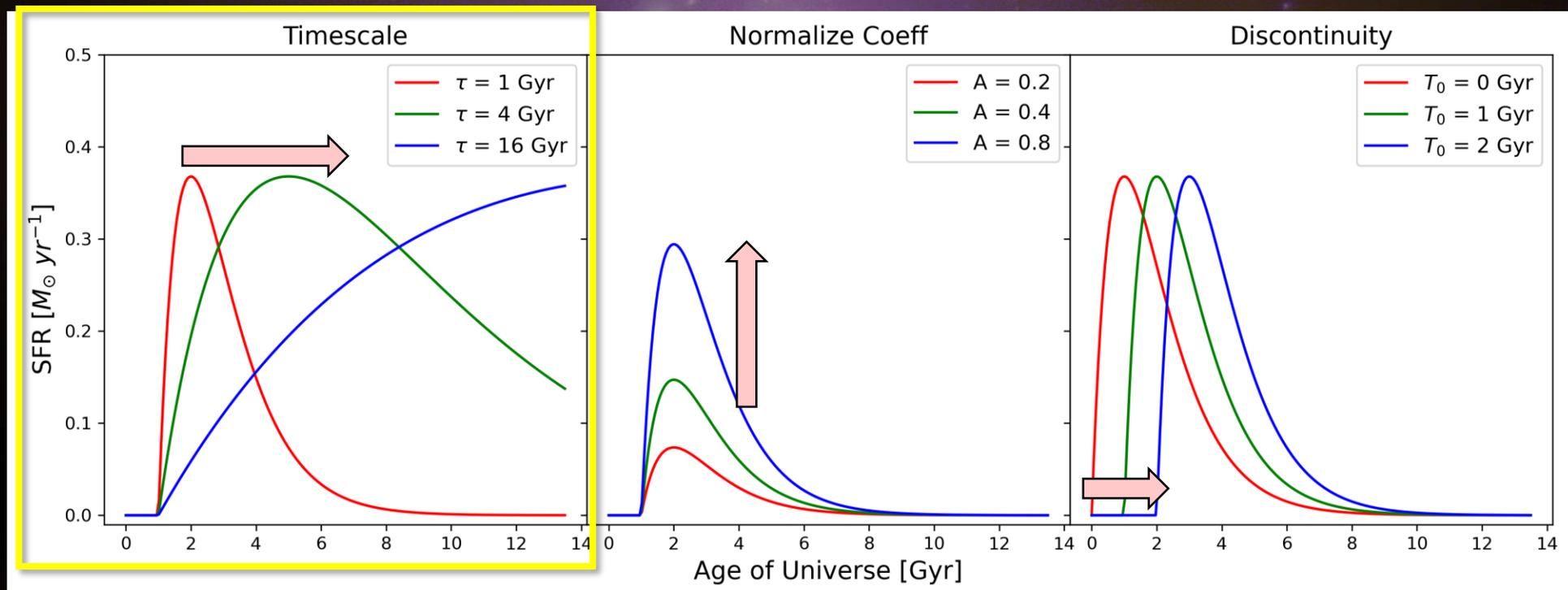
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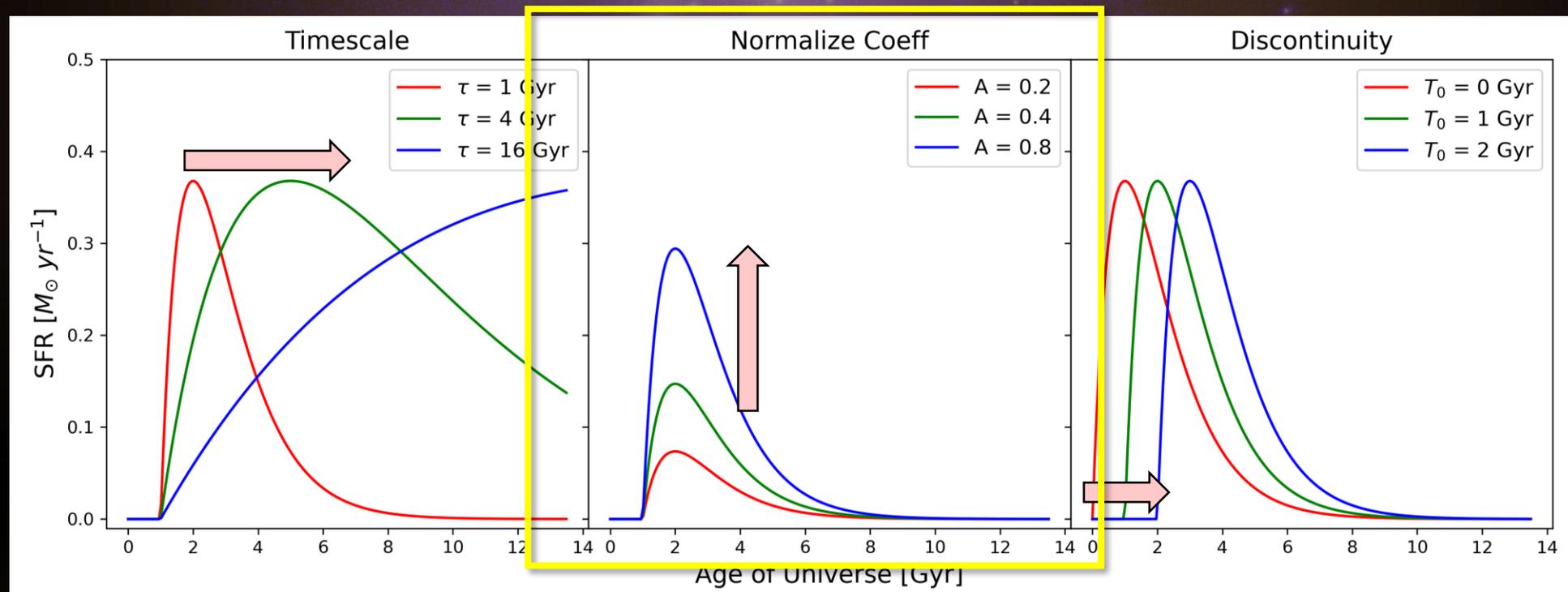
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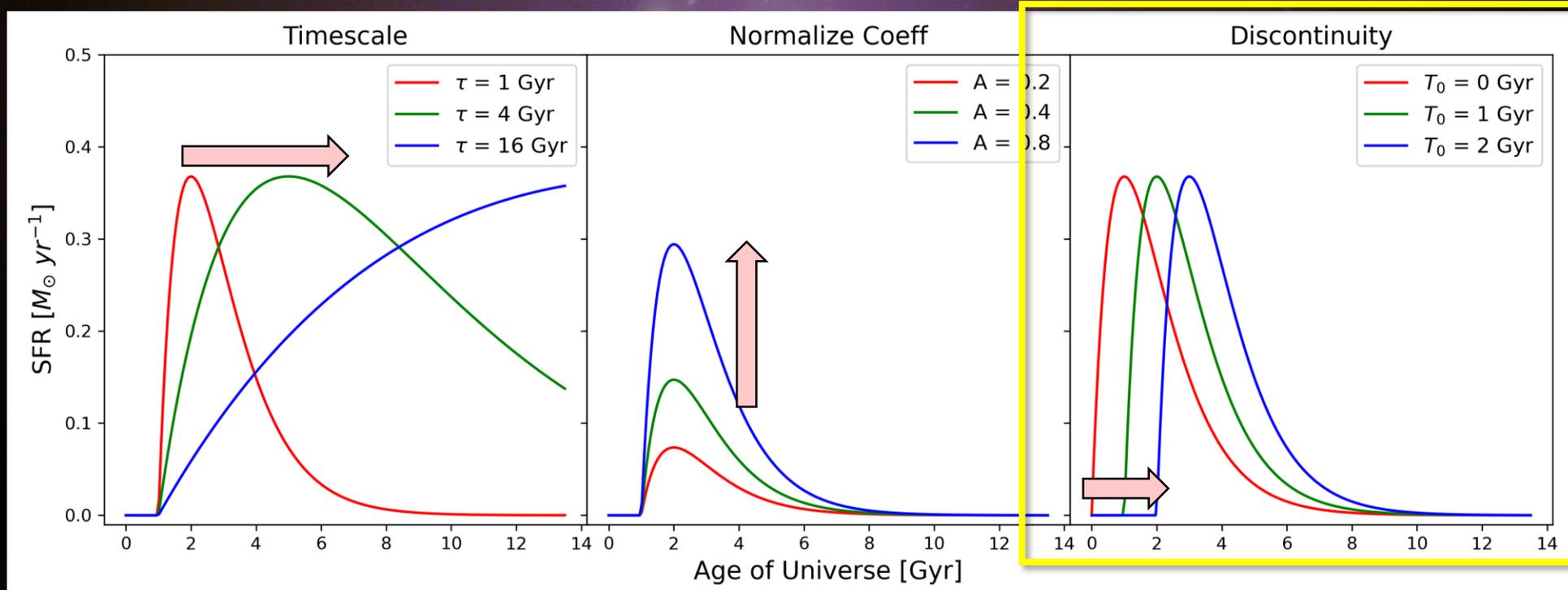
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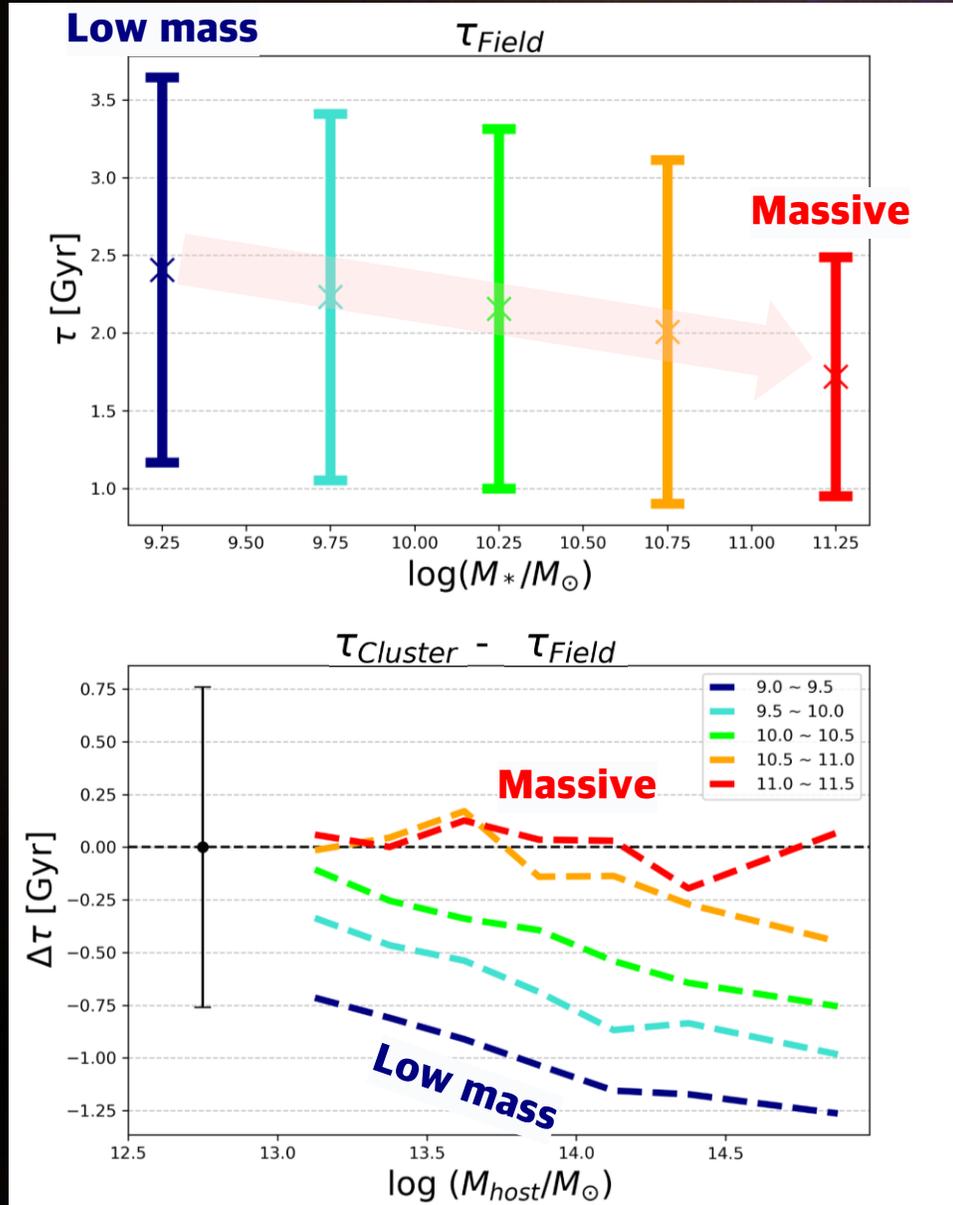
$A \downarrow$: Lower SF

$T_0 \uparrow$: Late start

$T_0 \downarrow$: Early start



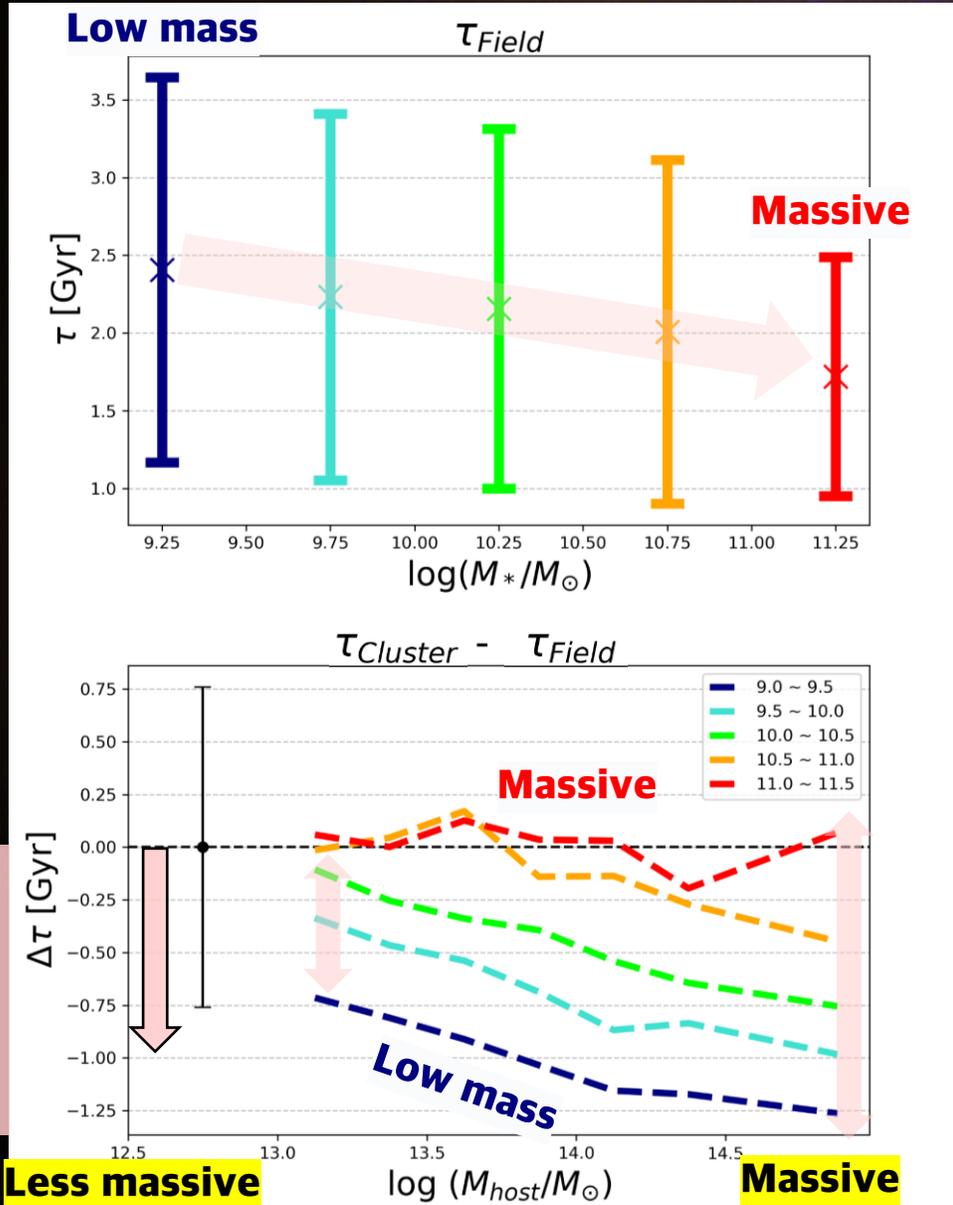
I. Quenching Timescale : $M_{host} - M_*$



Field Galaxy

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

I. Quenching Timescale : $M_{host} - M_*$



Field Galaxy

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Member Galaxy (Satellite)

- Low-mass ()

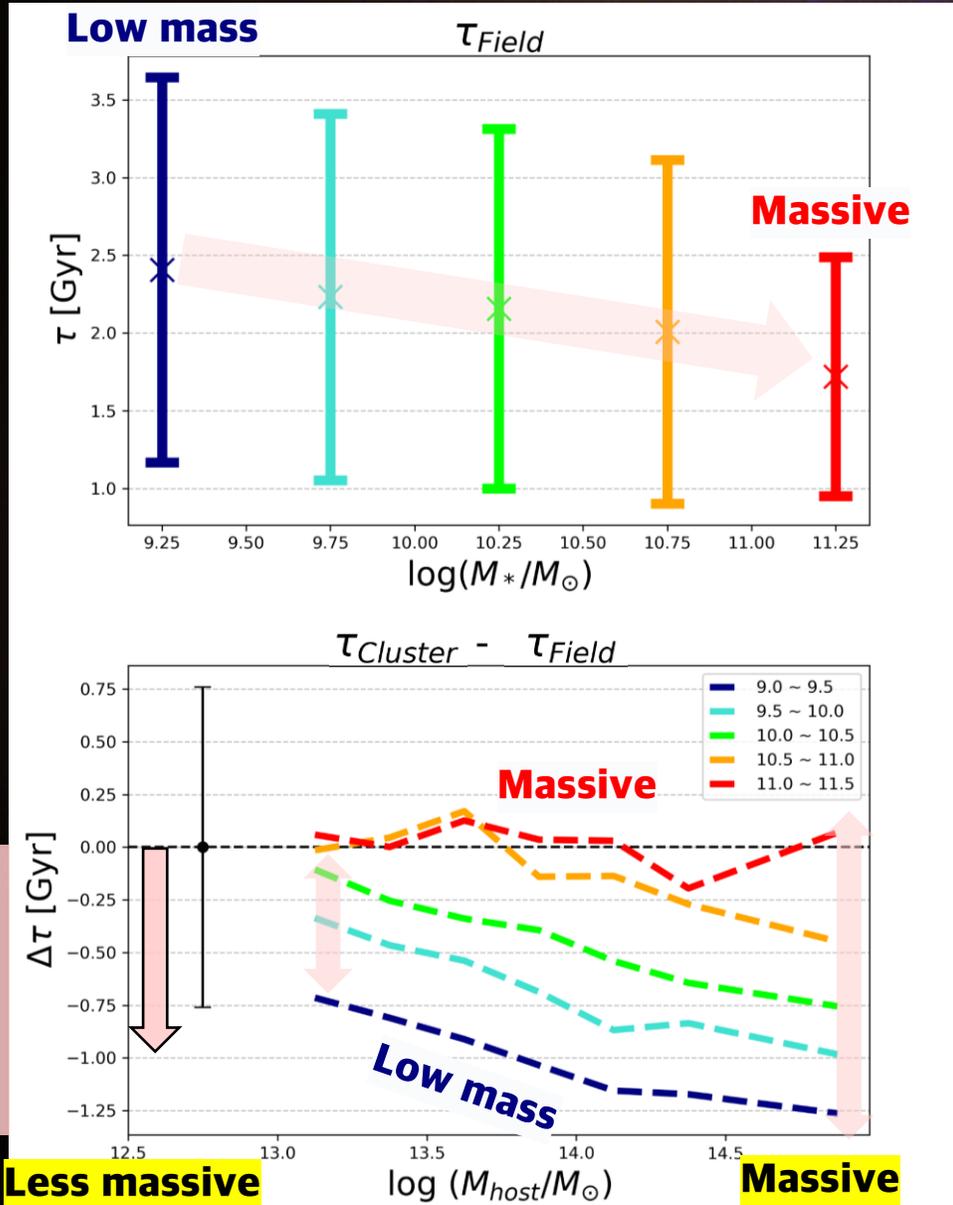
: $\tau_{Field} > \tau_{Group} > \tau_{Cluster}$

\rightarrow Strong environmental quenching

$\Delta\tau < 0$

: Rapid quenching
than field gals

I. Quenching Timescale : $M_{host} - M_*$



Field Galaxy

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

Member Galaxy (Satellite)

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\rightarrow Strong environmental quenching

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

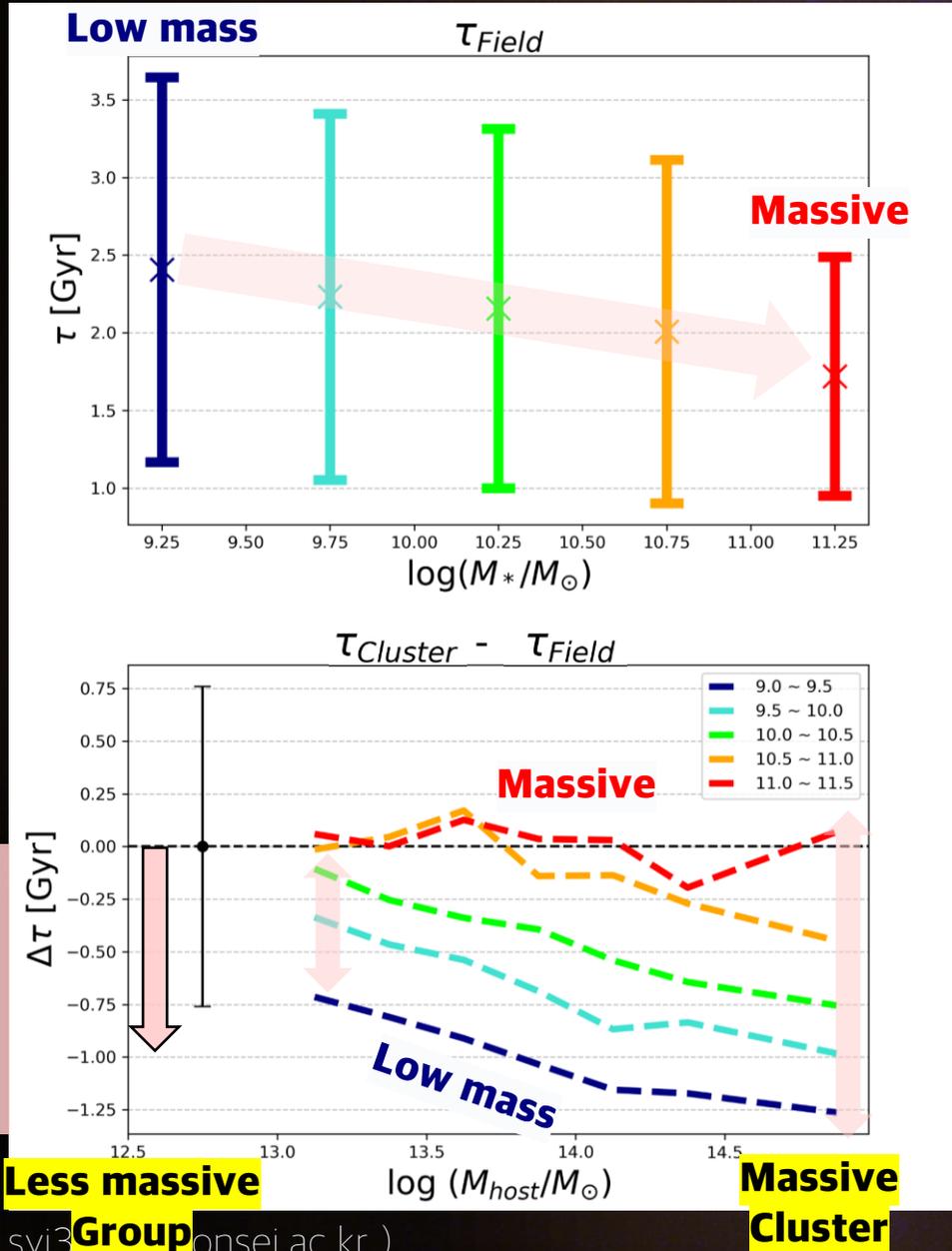
: τ approaches to τ_{Field}

\rightarrow Resistance to environmental quenching

$\Delta\tau < 0$

: Rapid quenching
than field gals

I. Quenching Timescale : $M_{host} - M_*$



Field Galaxy

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

Member Galaxy (Satellite)

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

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

: τ approaches to τ_{Field}

\rightarrow Resistance to environmental quenching

- Massive enough

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

\rightarrow Not affected by the host environment

$\Delta\tau < 0$

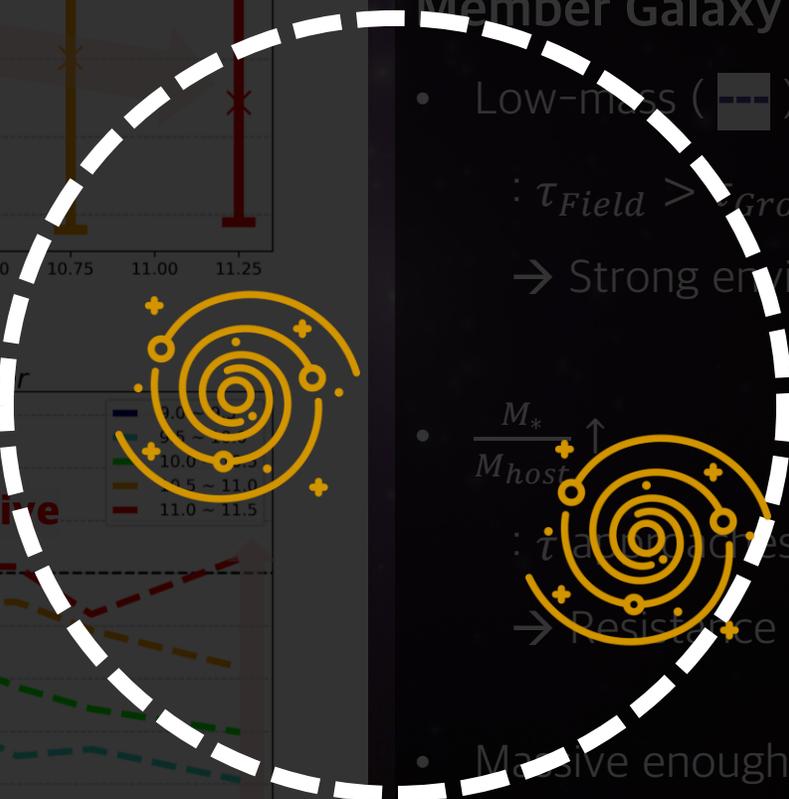
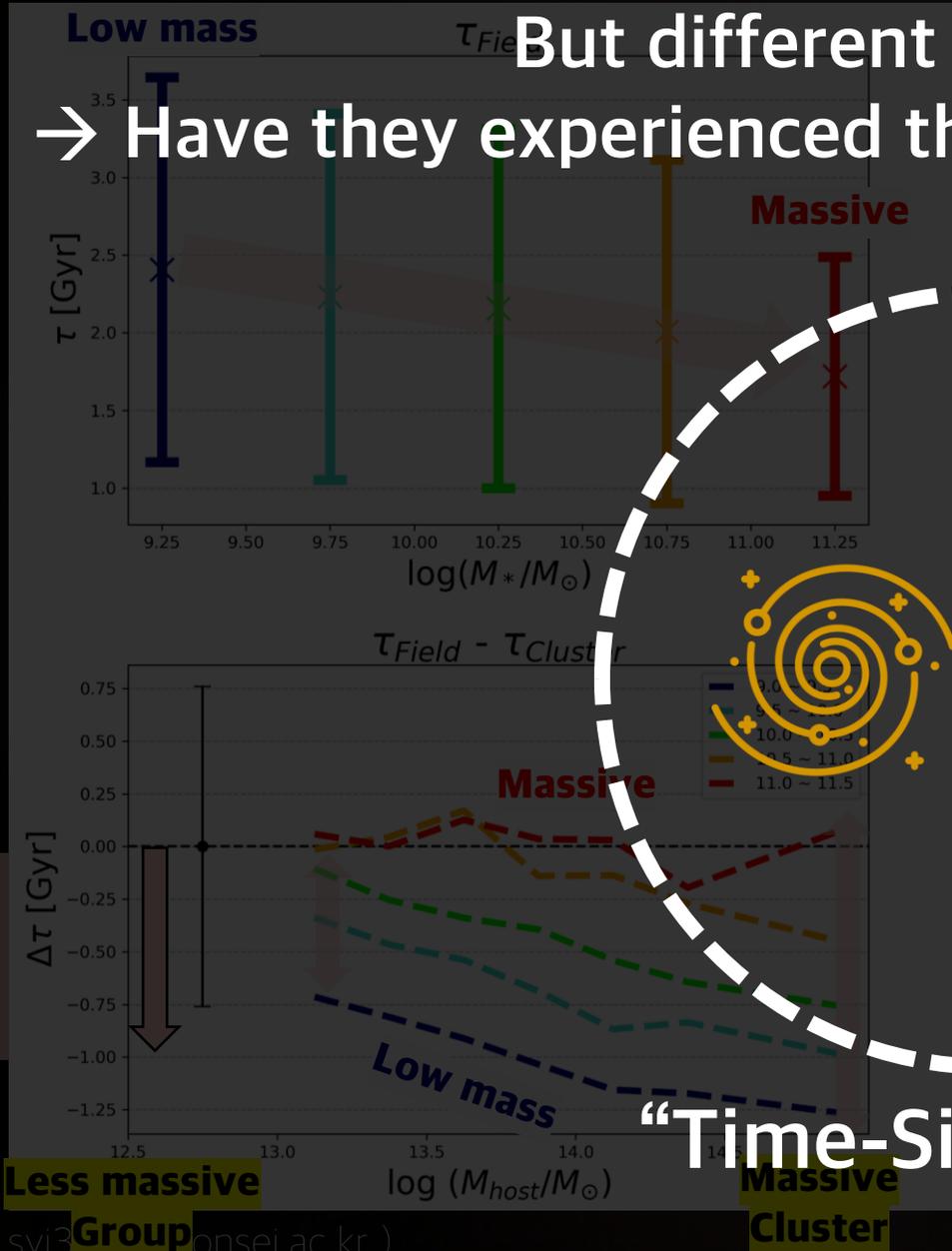
: Rapid quenching
than field gals

I. Quenching Timescale

Same stellar mass & same host mass

But different infalling epoch

→ Have they experienced the same environmental effect?



Member Galaxy (Satellite)

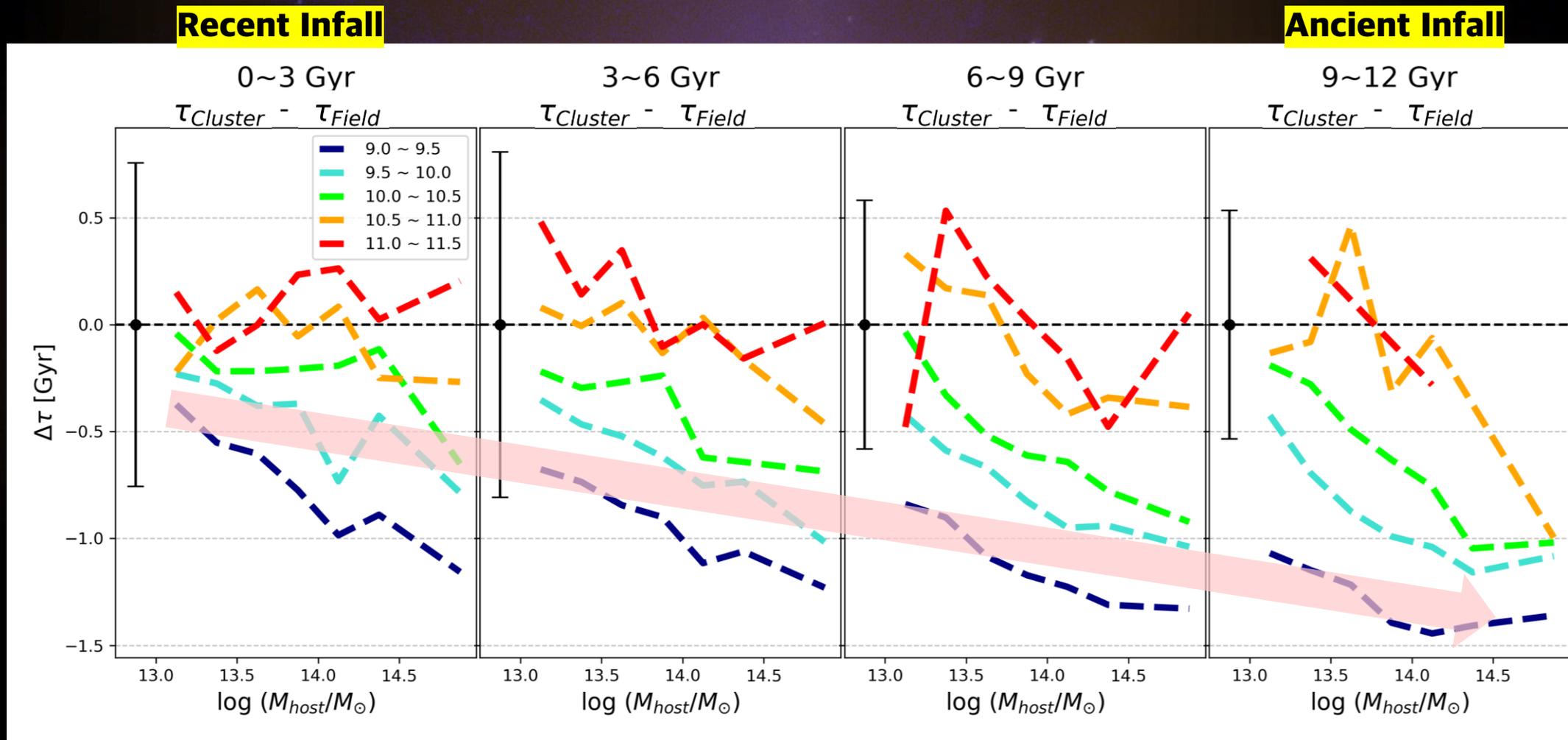
- Low-mass ($\frac{M_*}{M_{host}} \downarrow$)
 - : $\tau_{Field} > \tau_{Group} > \tau_{Cluster}$
 - Strong environmental quenching
- Massive enough ($\frac{M_*}{M_{host}} \uparrow$)
 - : τ_{Field} approaches to τ_{Field}
 - Resistance to environmental quenching
- Massive enough ($\frac{M_*}{M_{host}} \uparrow$)
 - : $\tau_{Field} \sim \tau_{Group} \sim \tau_{Cluster}$
 - Not affected by host environment

$\Delta\tau < 0$

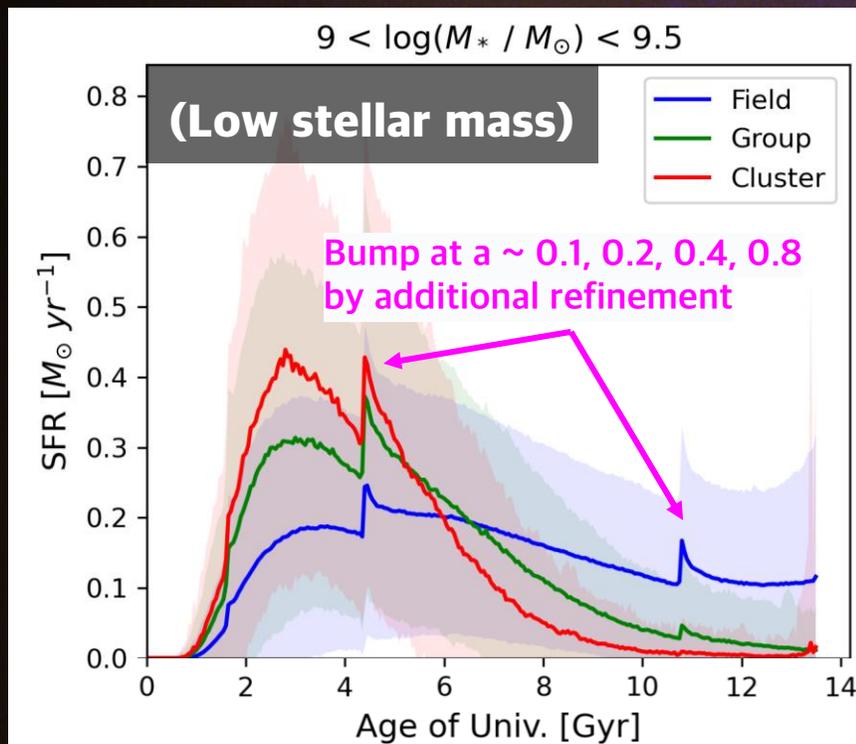
: Rapid quenching than field gals

I. Quenching Timescale : $M_{host} - M_* - TSI$

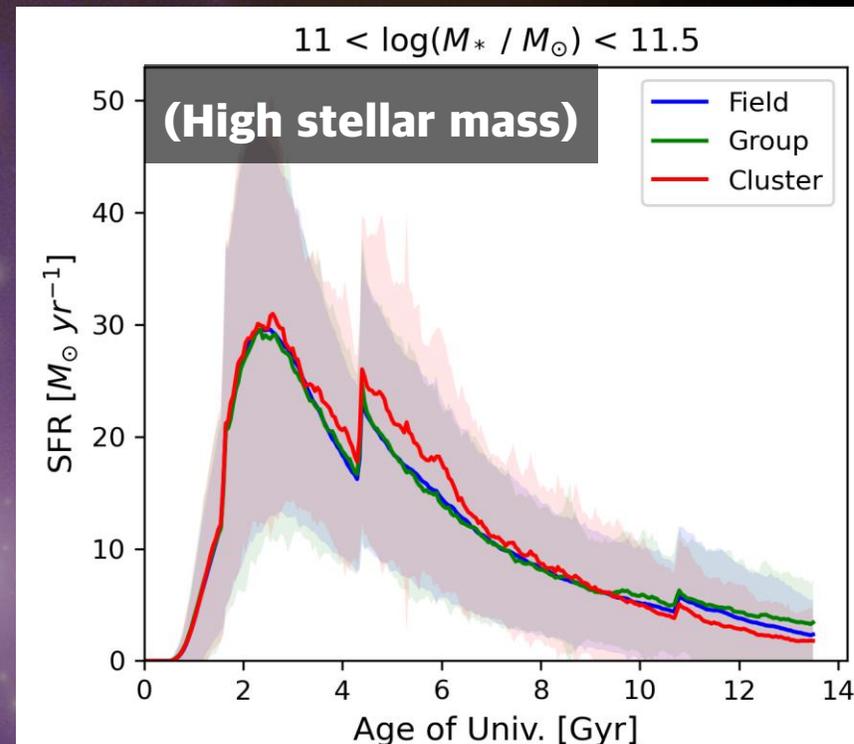
Time Since Infall (TSI)



Star Formation History

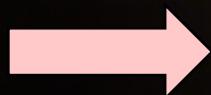


Clear environment dependency



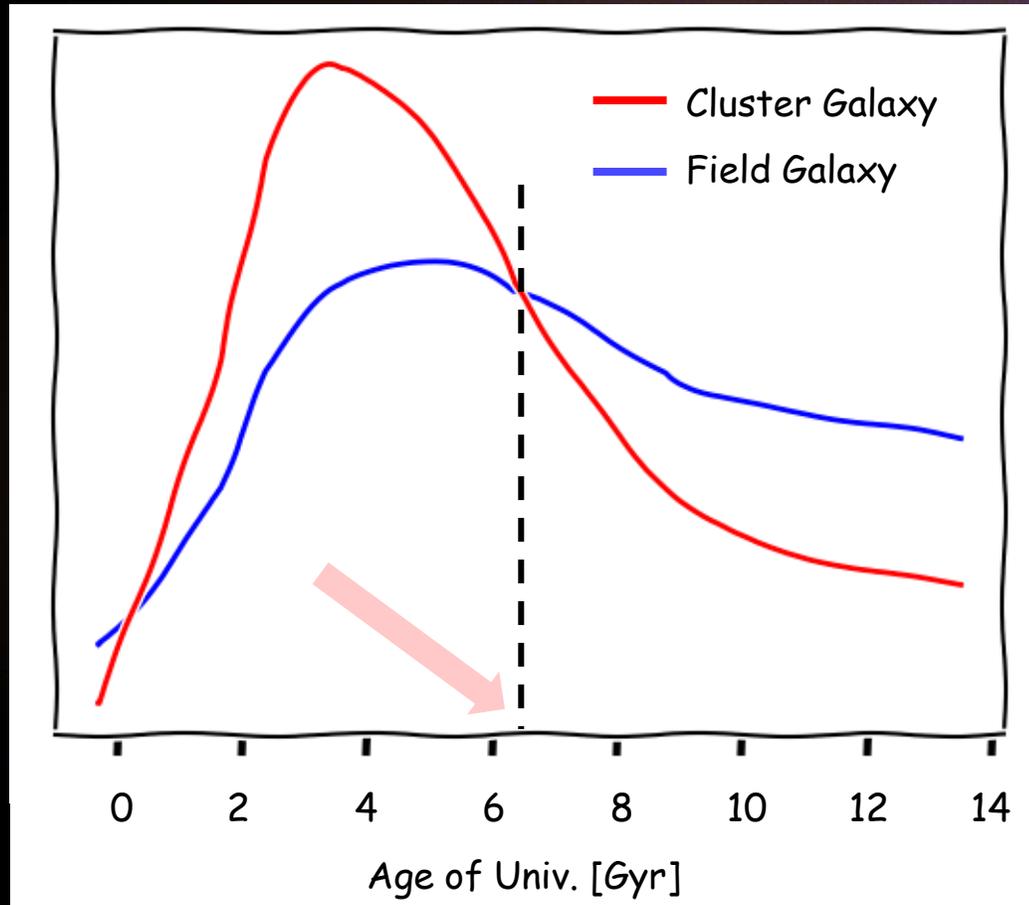
No difference & Rapid quenching

Part I. Quenching Timescale



Part II. Transition Epoch

II. Transition Epoch



Definition

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

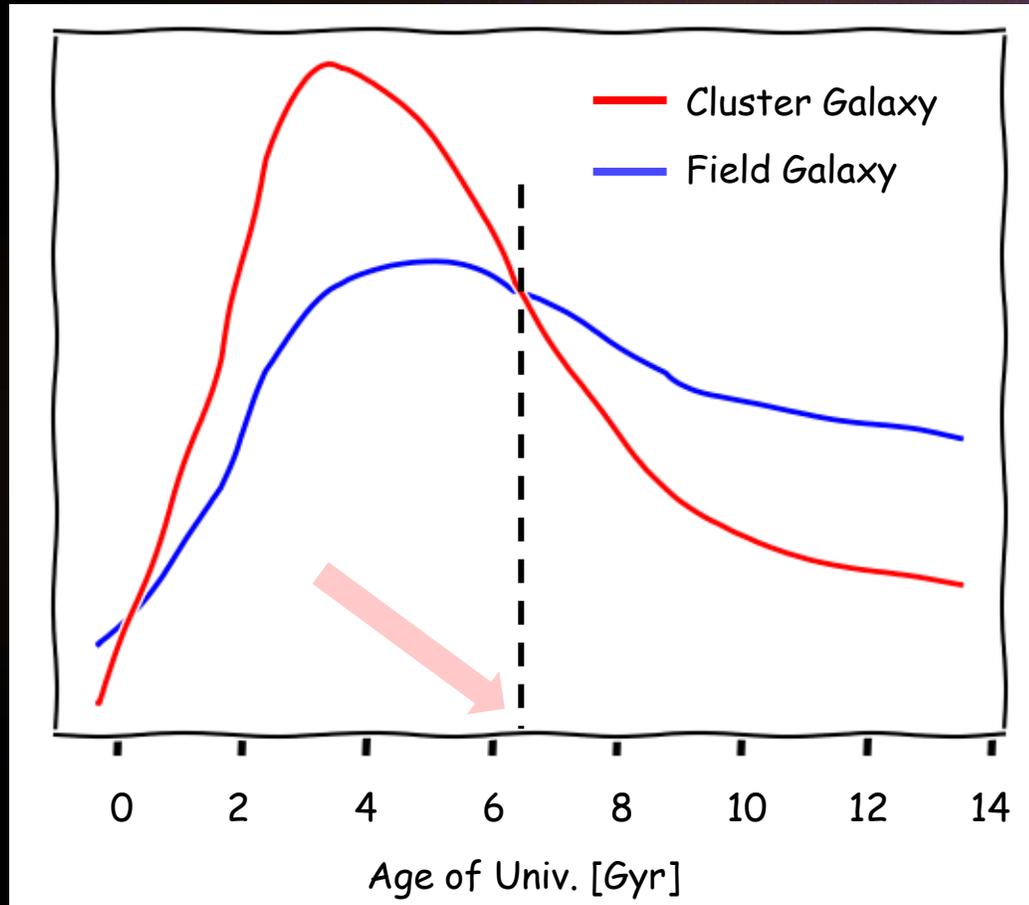
Before transition

: Cluster galaxies are more star-forming

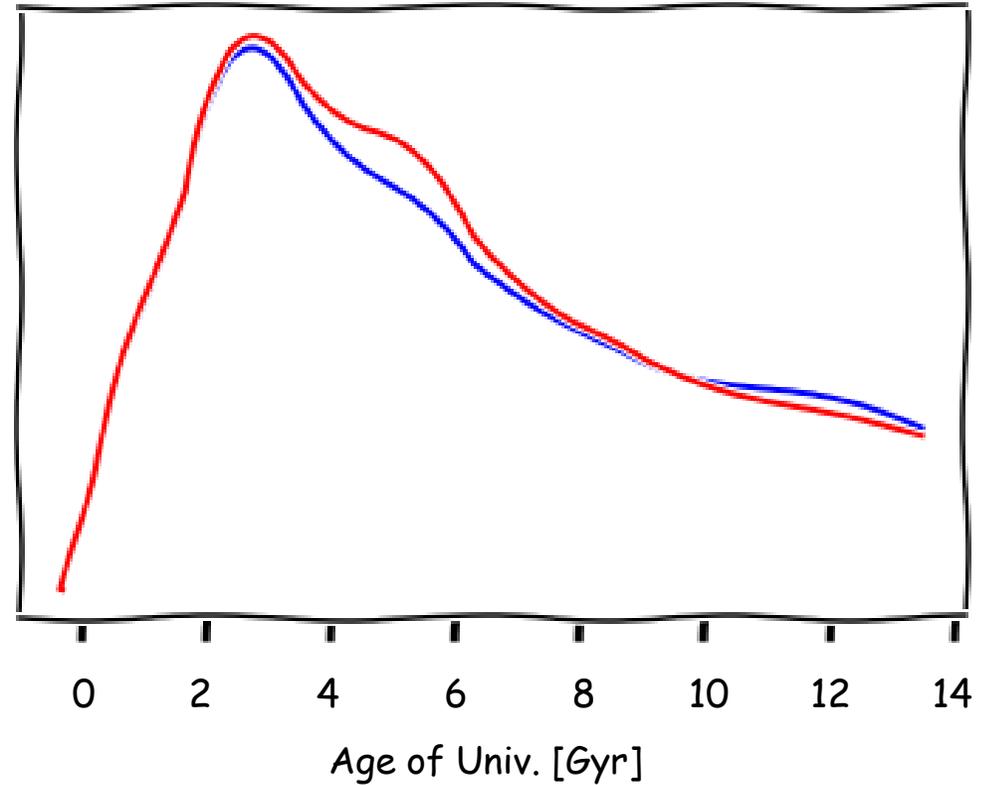
After transition

: Field galaxies are more star-forming

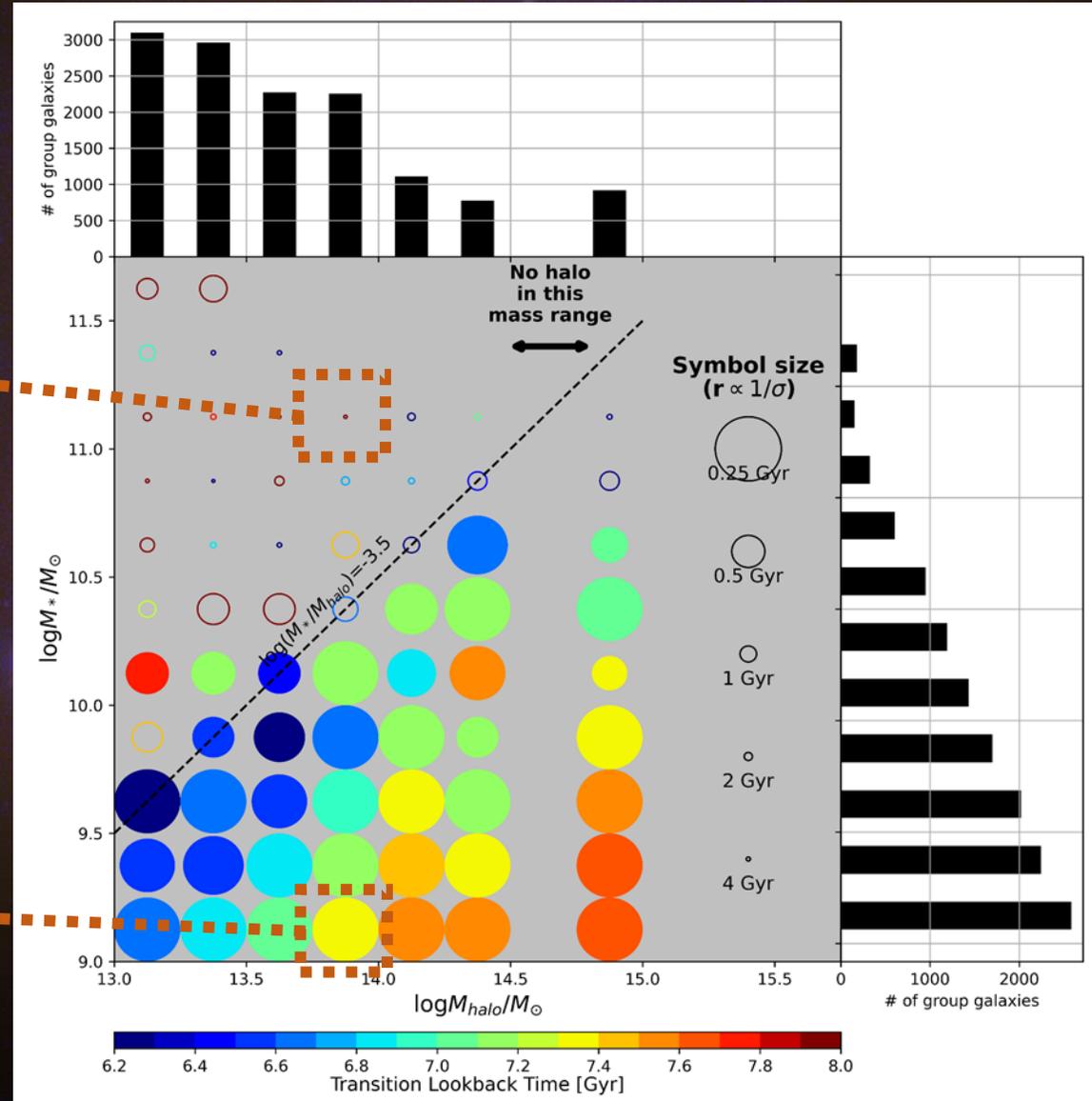
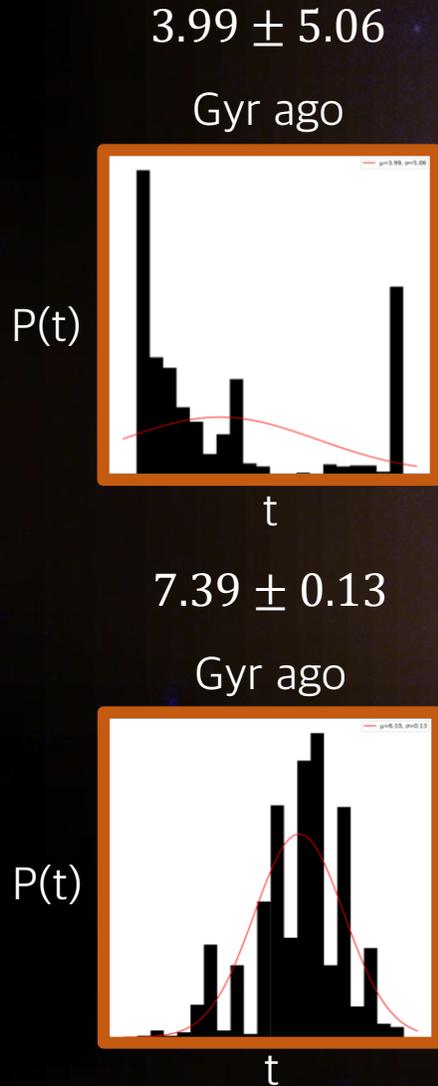
II. Transition Epoch



Transition epoch does not always exist

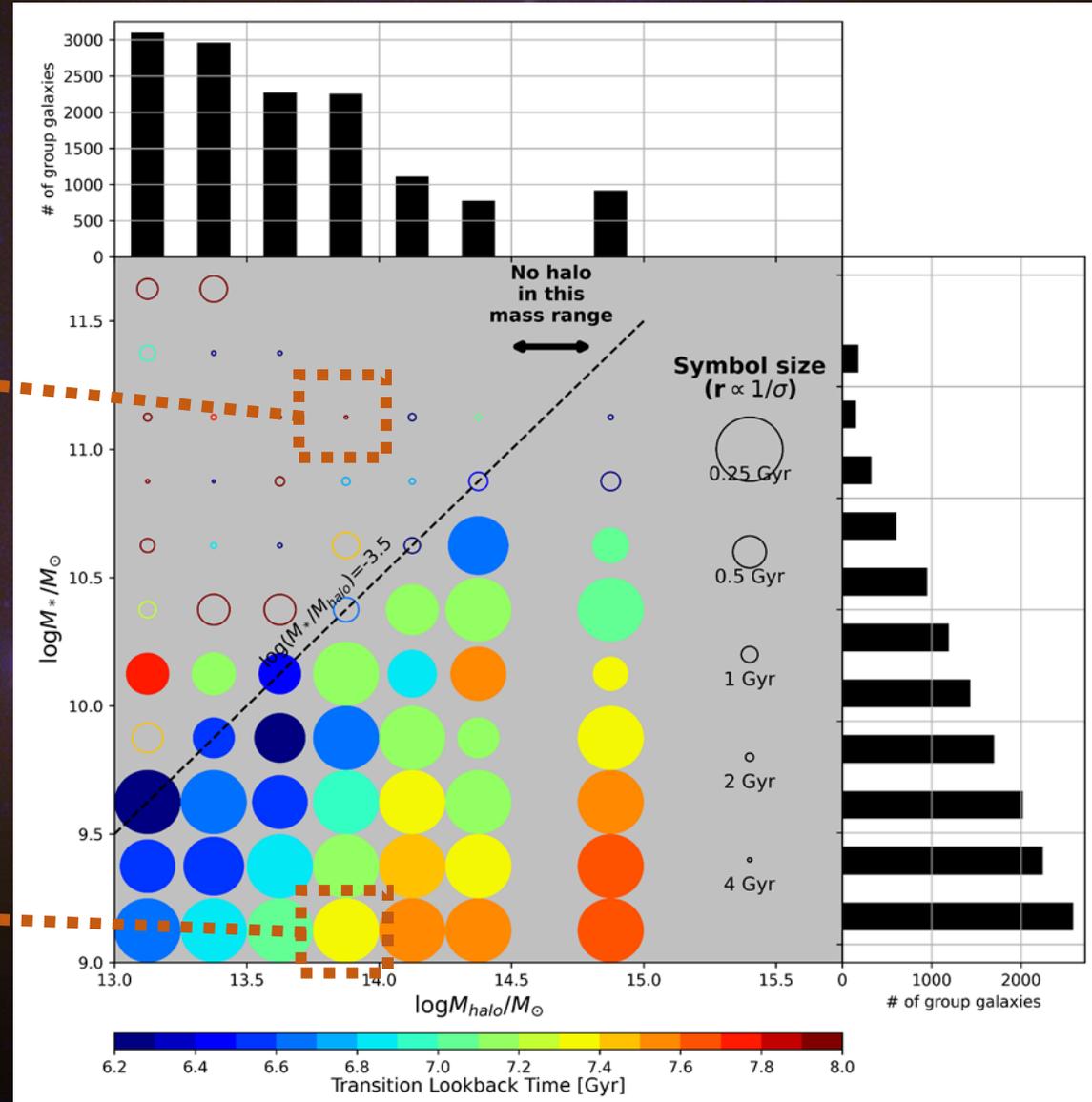
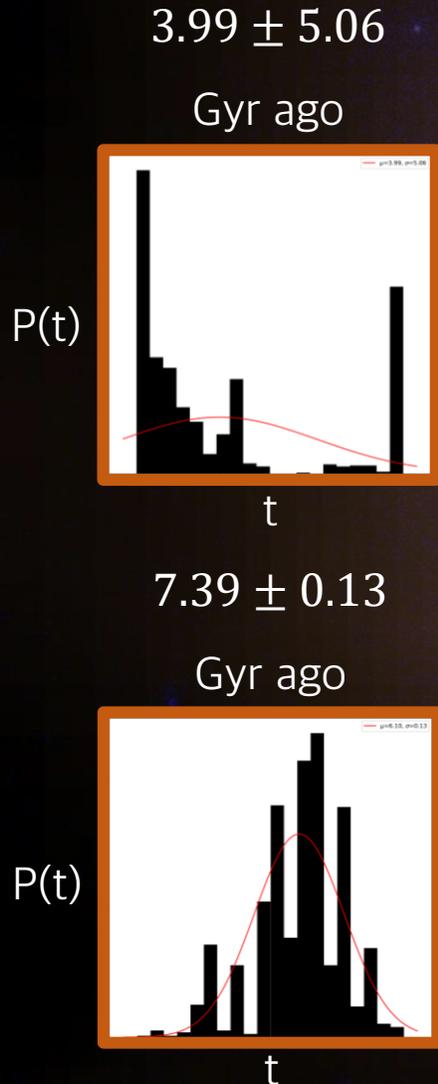


II. Transition Epoch



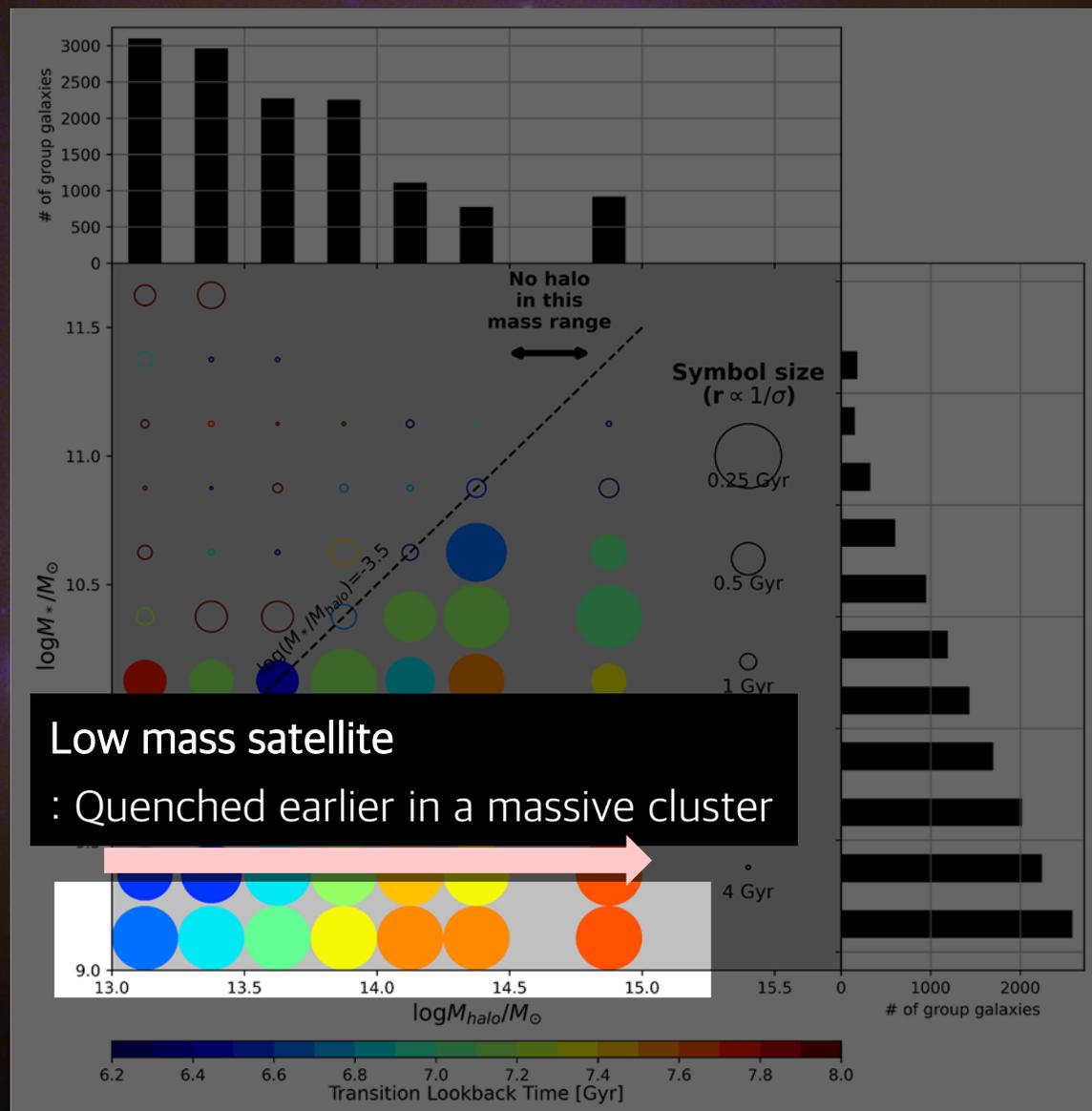
○ : Transition exists
○ : No transition

II. Transition Epoch



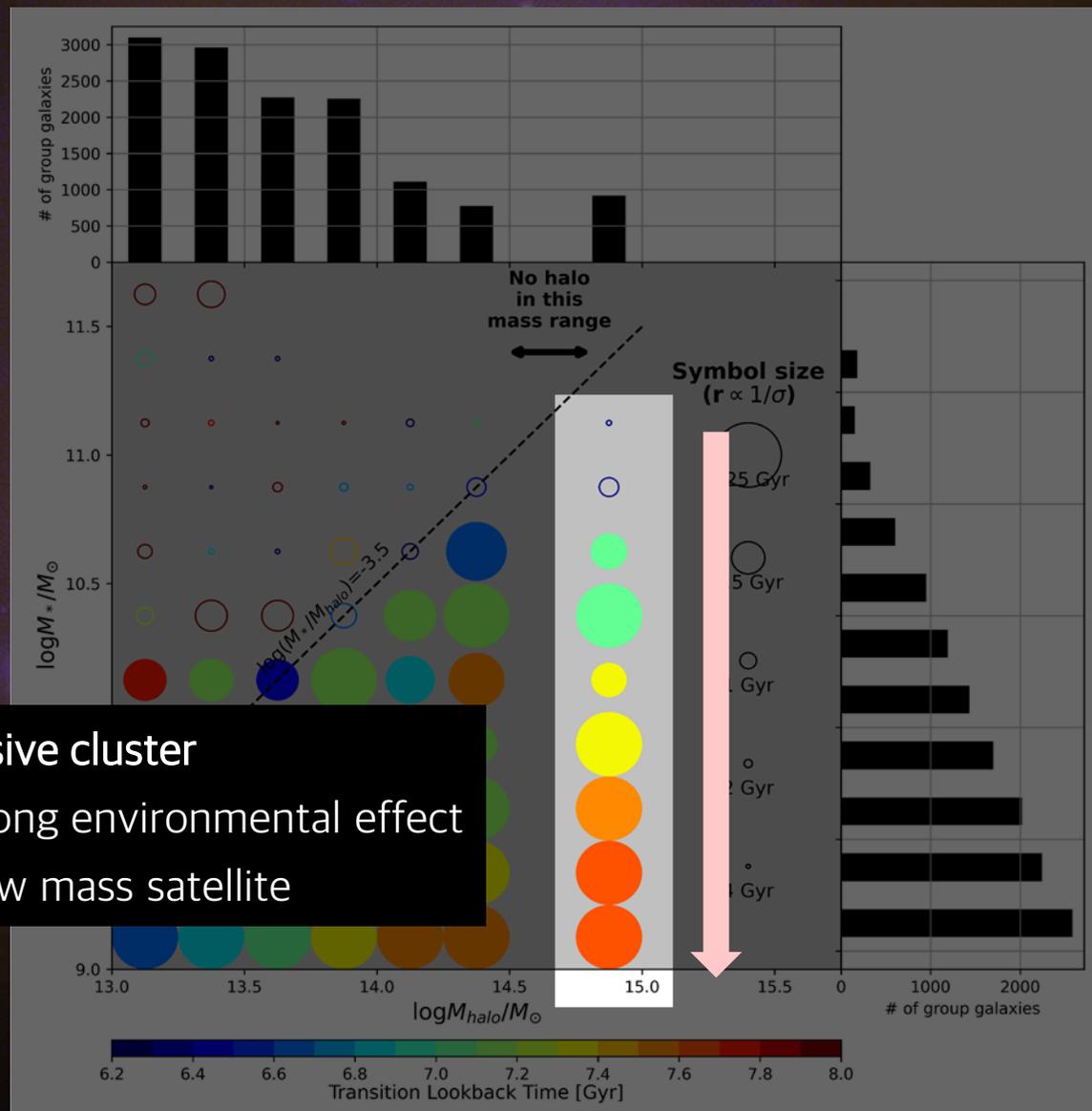
- : Transition exists
- : No transition
- : Earlier transition
- : Later transition

II. Transition Epoch



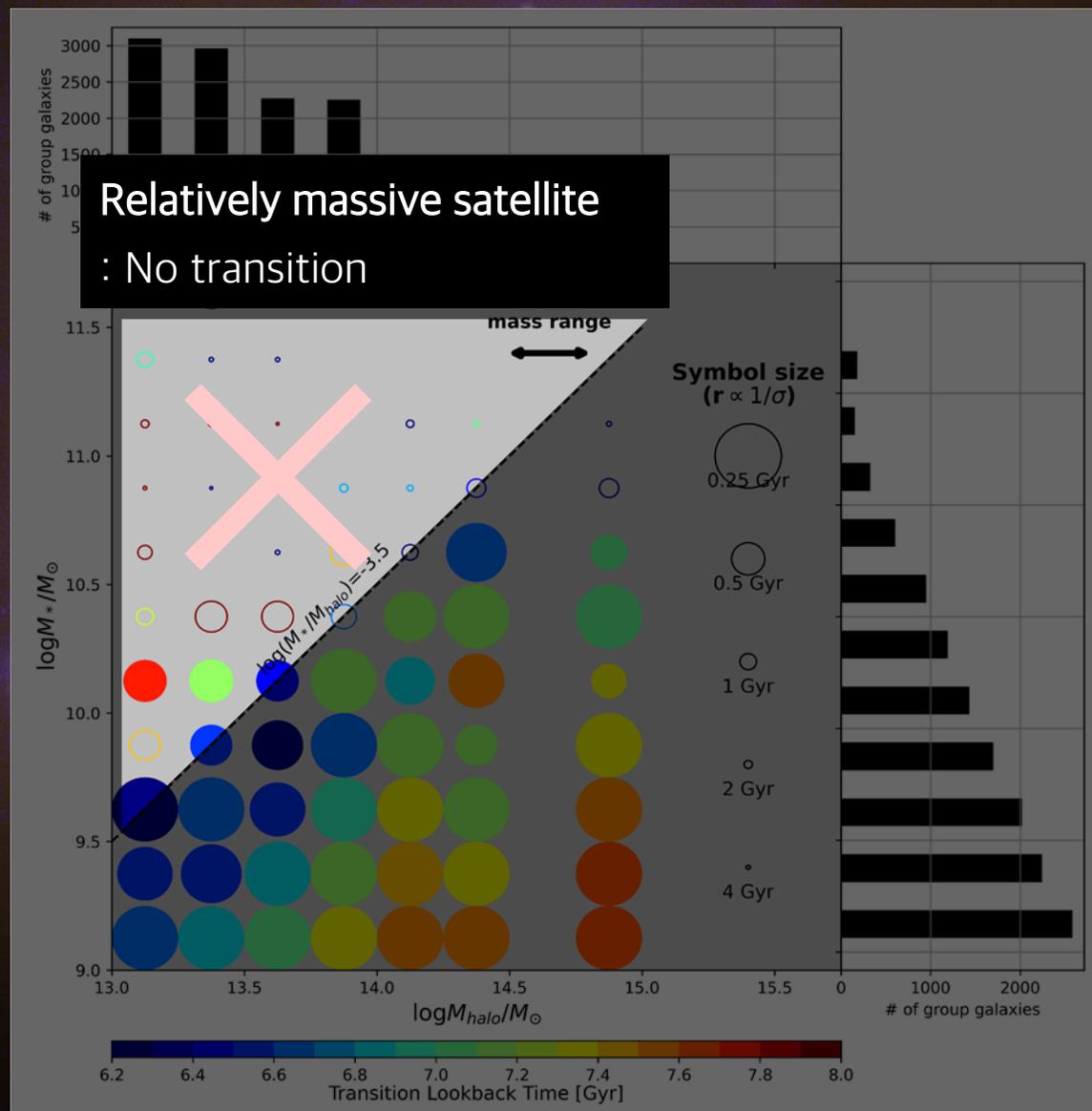
-  : Transition exists
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II. Transition Epoch



-  : Transition exists
-  : No transition
-  : Earlier transition
-  : Later transition

II. Transition Epoch



- : Transition exists
- : No transition
- : Earlier transition
- : Later transition

Summary

SFH: Cluster vs. Field in Horizon-AGN

I. Quenching Timescale

It is important not only “How dense environments” but also “How long live in dense environments”

- Rapid quenching for massive galaxies and massive host halos
- In cluster (or group) environments, τ is decreased additionally for relatively lower mass satellites
- Ancient infallers show more significant τ decrease than recent infallers

II. Transition epoch

Low mass satellites in massive clusters became quiescent first

- Low mass galaxies have earlier transition for increasing host halo mass
- Massive galaxies do not show a transition → no difference between field and cluster galaxies
- In cluster environments, low mass galaxies are quenched earlier than massive galaxies
- In group-size halos, relatively massive galaxies are not affected by environments