

Nature VS Nurture

A brief discussion about galaxy quenching

Qinglin Ma, Xiaohan Wang, Wenshuo Xu, Zhixing Li

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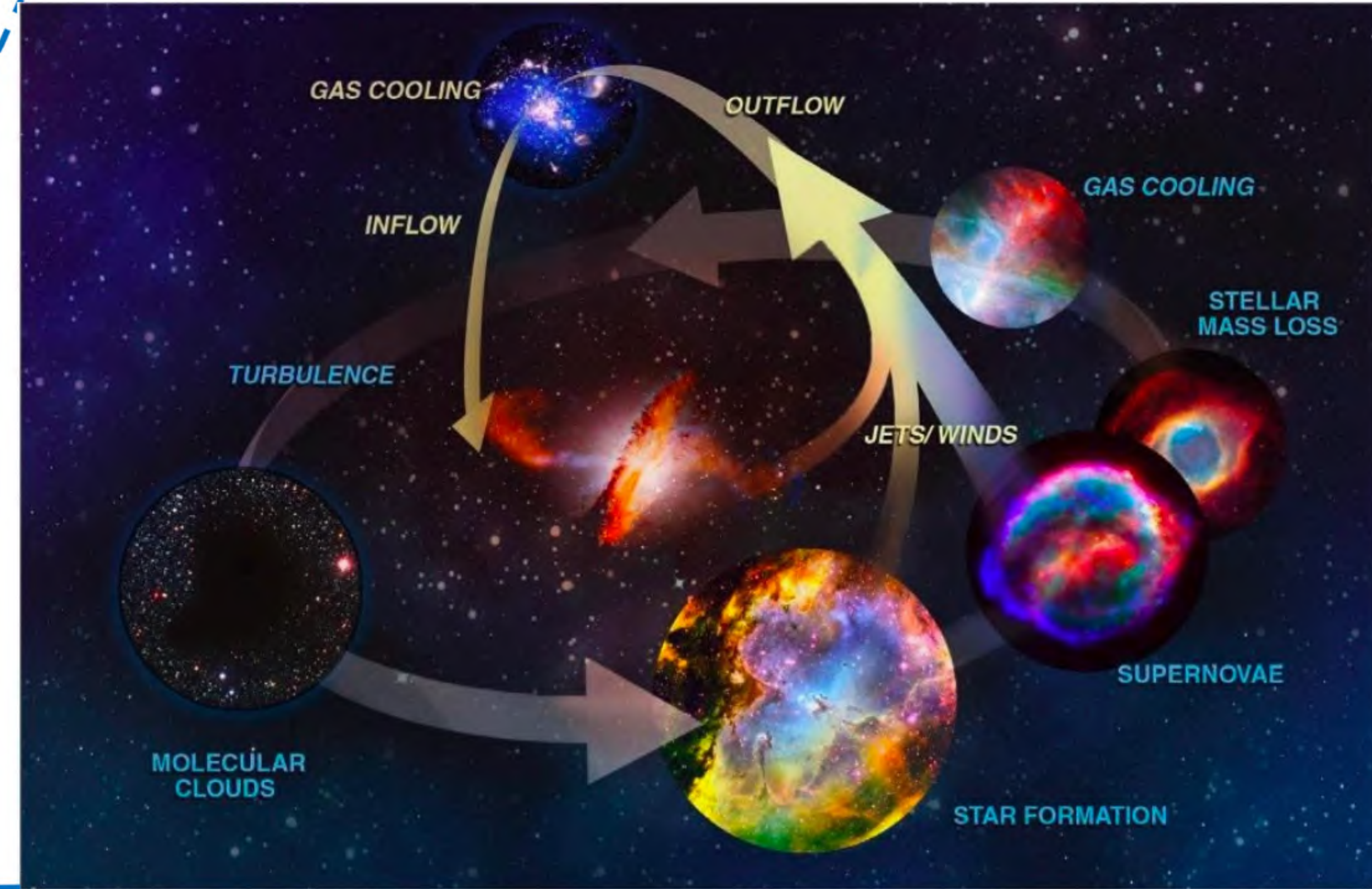
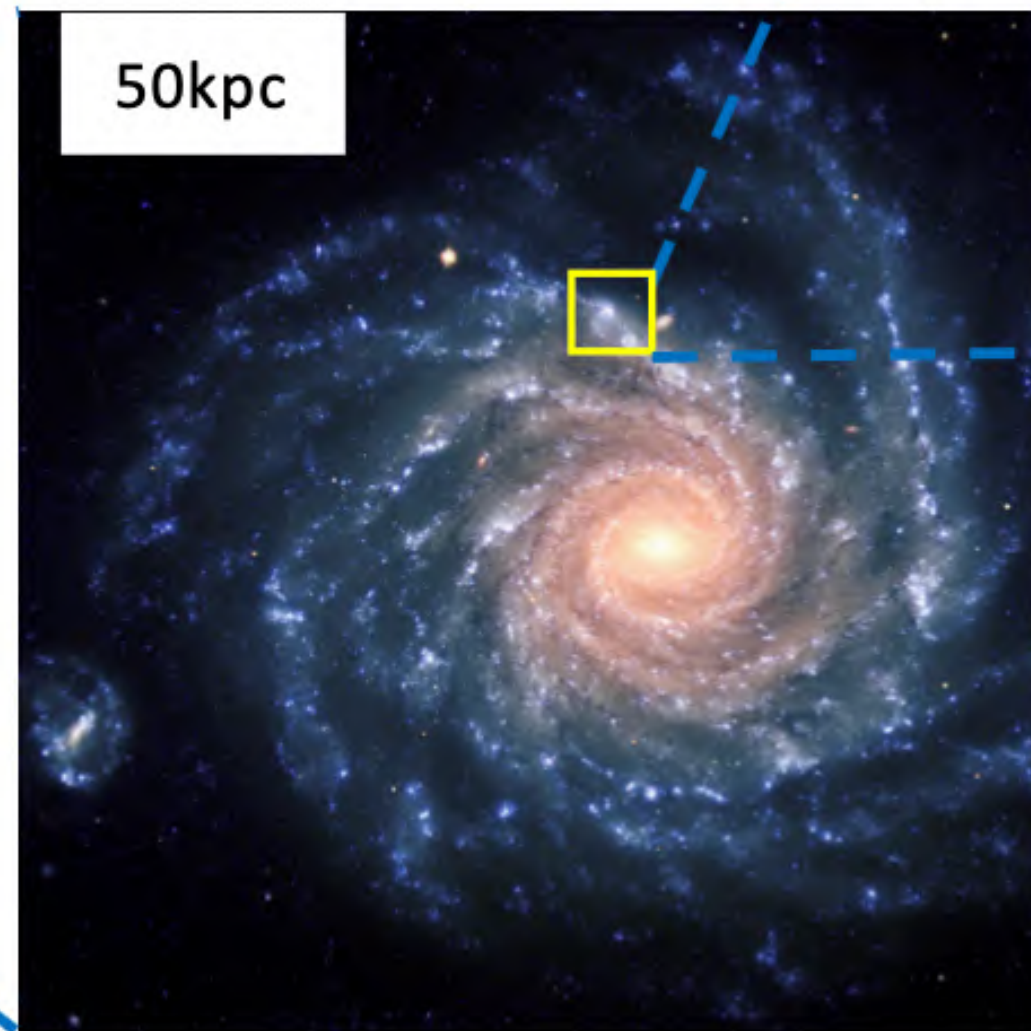
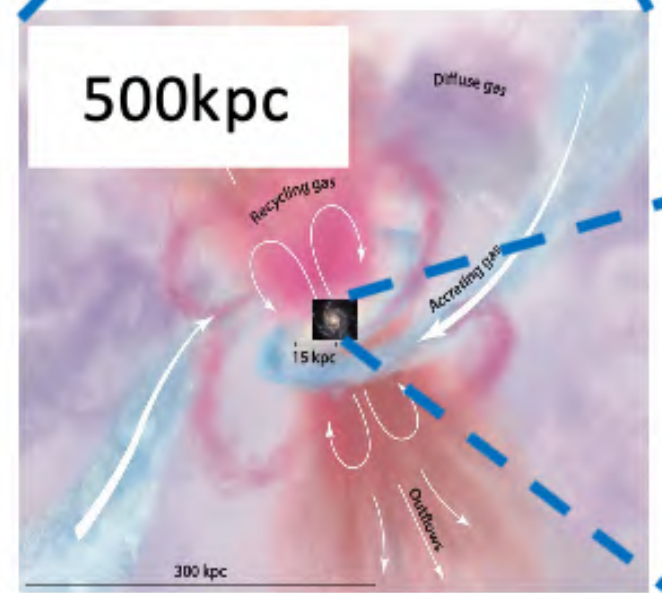
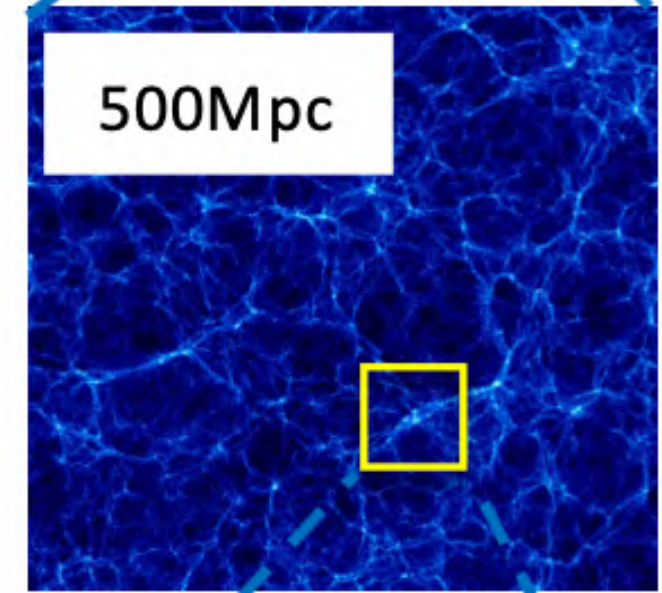
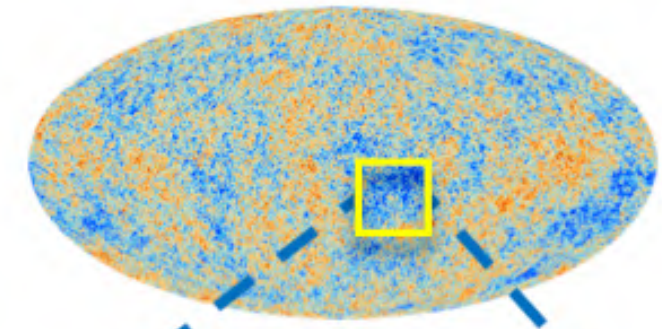
Outline

1. **Background**
2. Physical quenching **mechanisms**
3. **Entanglement** between nature and nurture quenching
4. A newly proposed mechanism: **angular momentum quenching**

Background

Qinglin Ma

A galaxy is a “cosmic ecosystem”

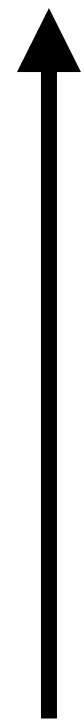


(see Astro2020)

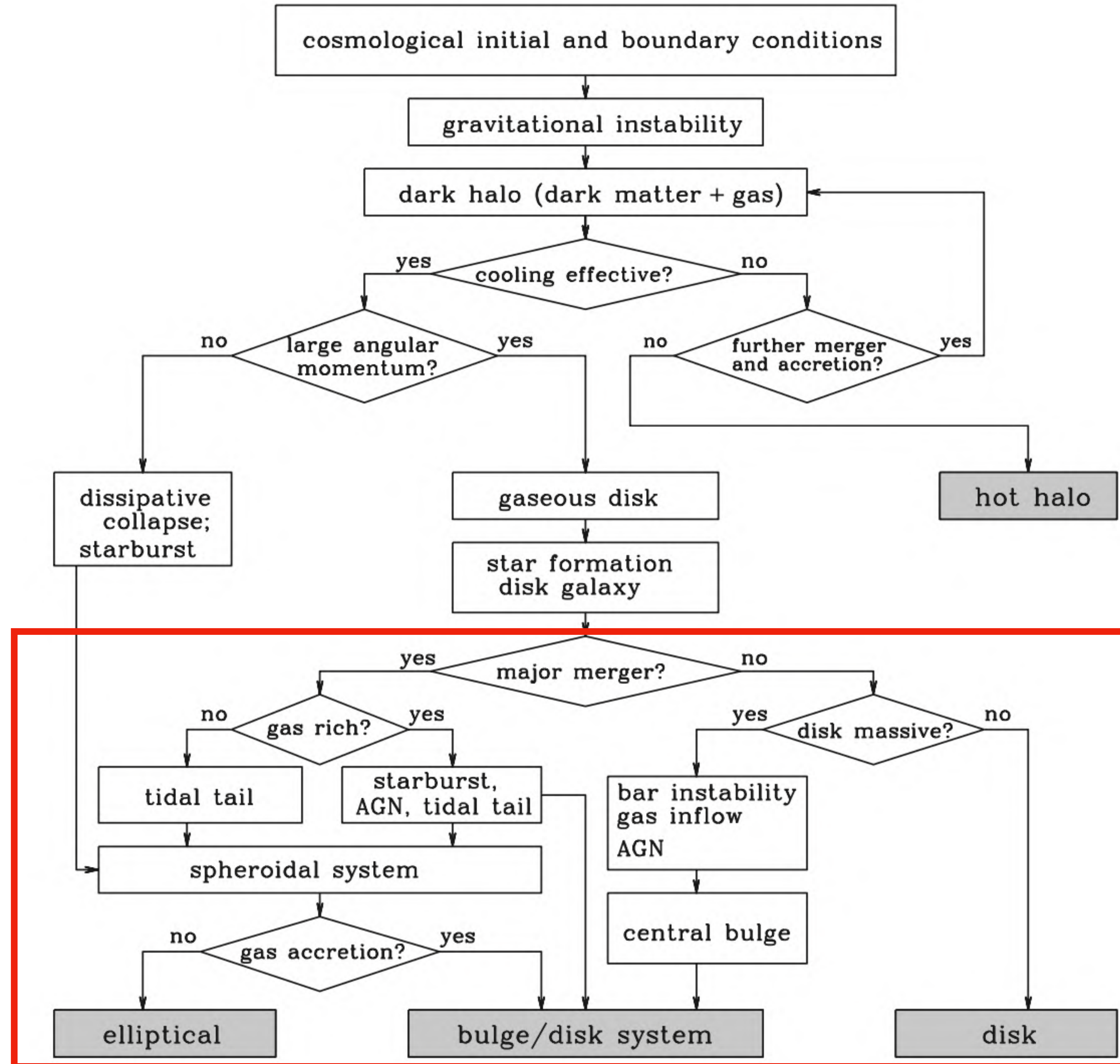
How will the galaxy form and evolve?

Mo et.al 2010

Quenching is one of the most important factors for the galaxy evolution!



Quenching or star-forming? ←



Quenching & star-forming

These features are often linked with each other.

	Star-forming galaxy	Quiescent galaxy
Morphology	Disc	Elliptical
Color	Blue	Red
Dynamics	Round	Radial
SFR	Star-forming	Quenched
Environment	Field	Cluster

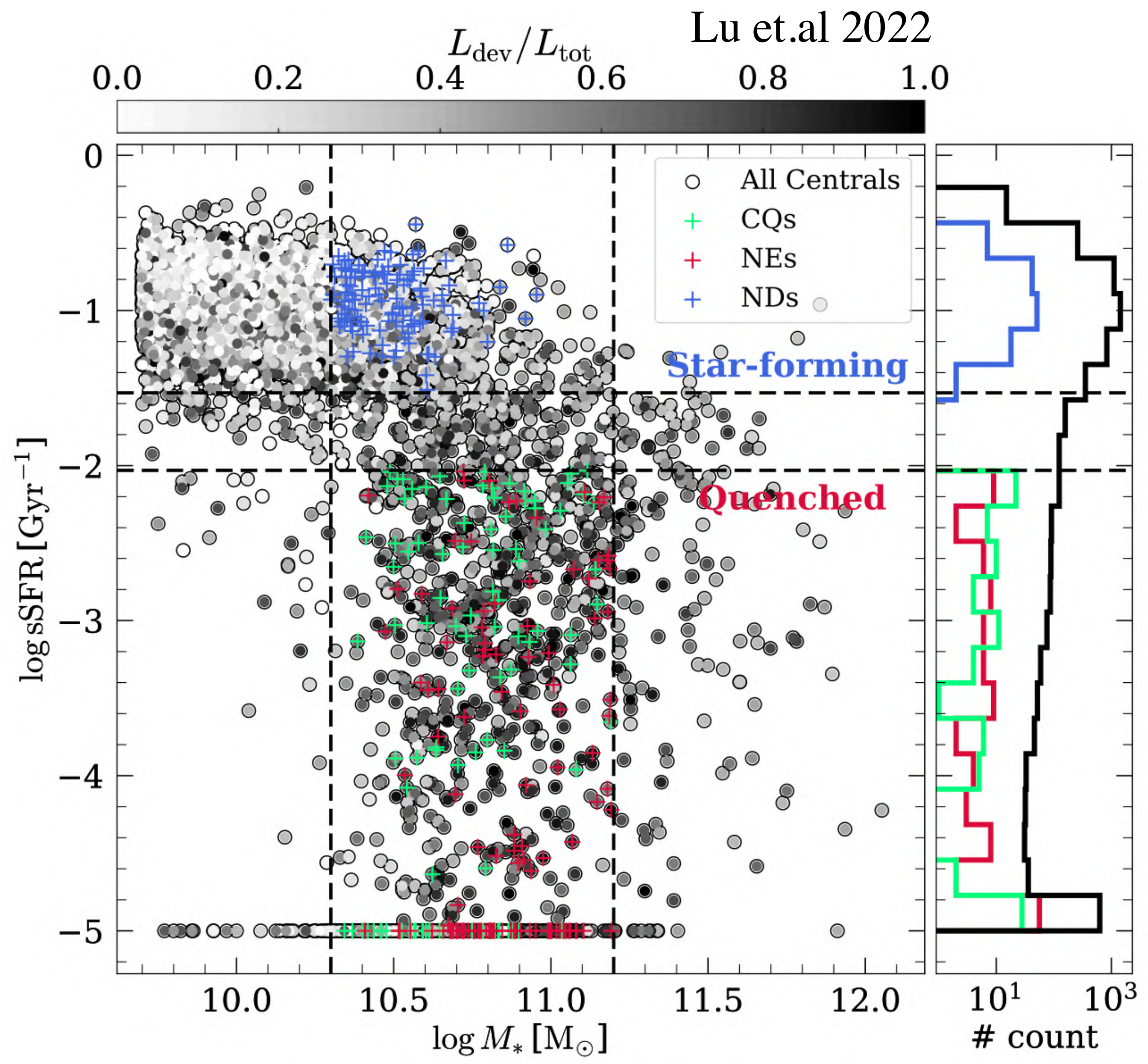
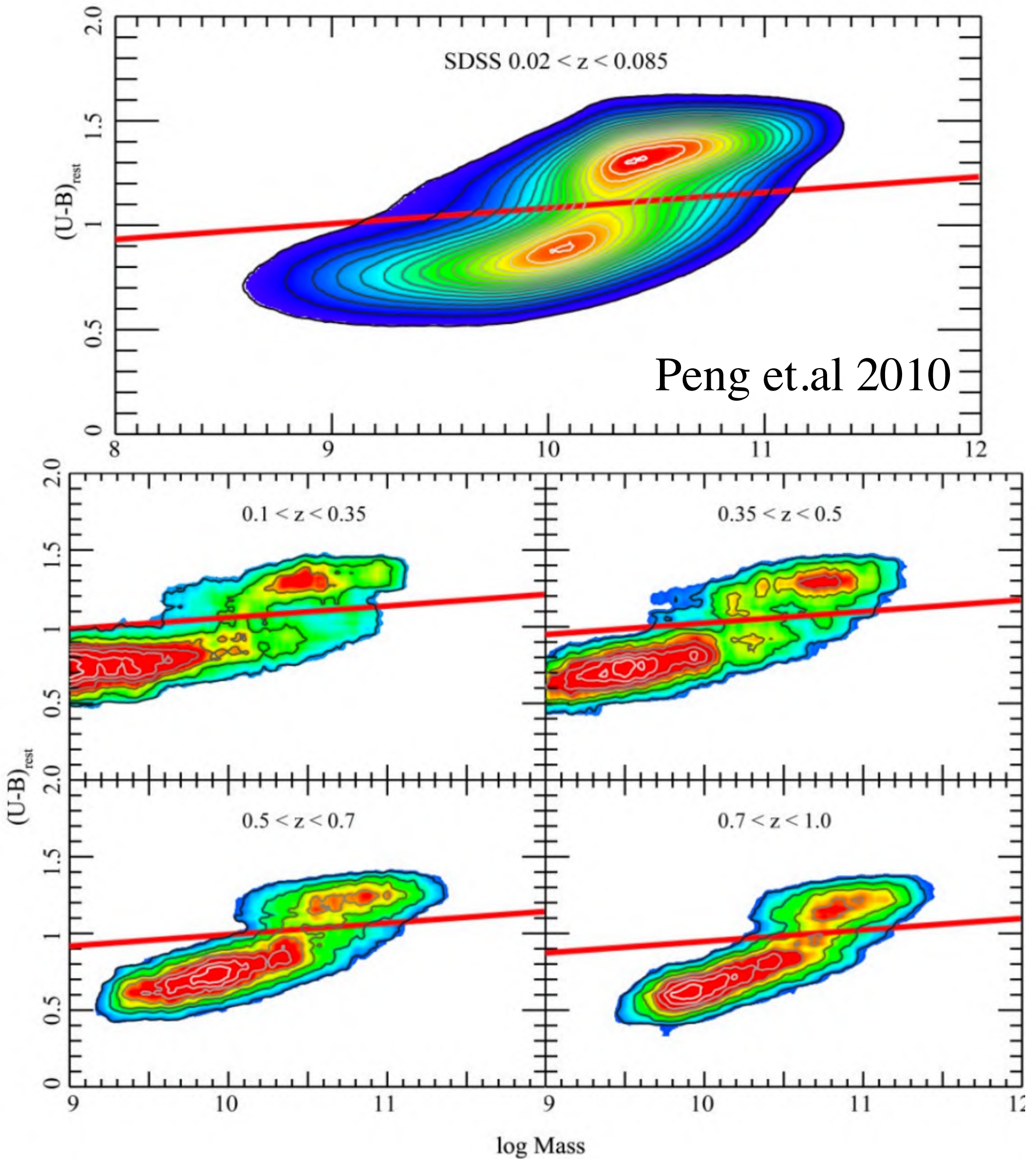
M51



NGC 4472



Quenching & star-forming



Exceptions



Blue Elliptical & Red Spiral

Nature & Nurture?



Nature: refers to those conditions that are set around the **formation time** of a galaxy and its dark matter halo.

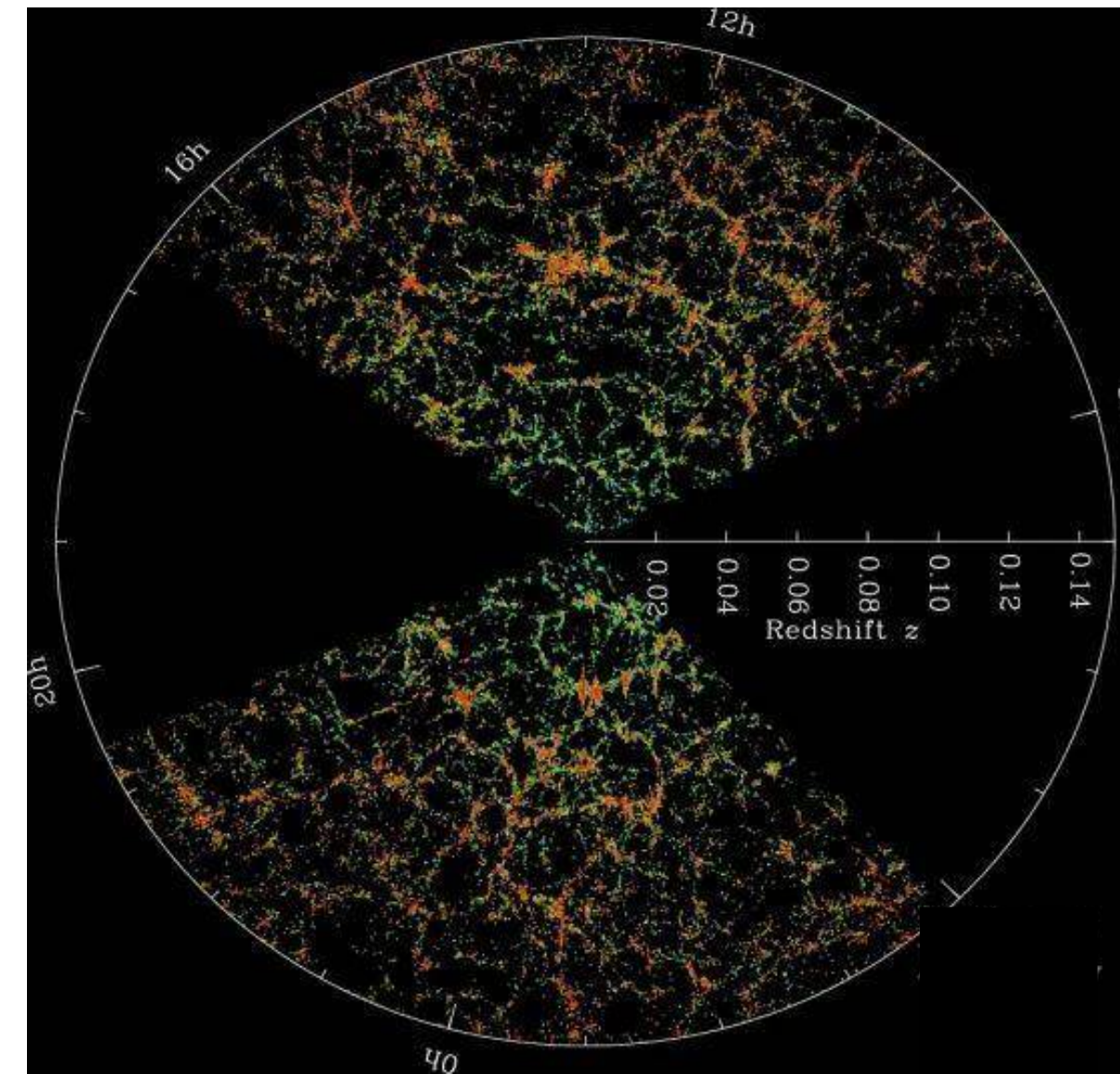
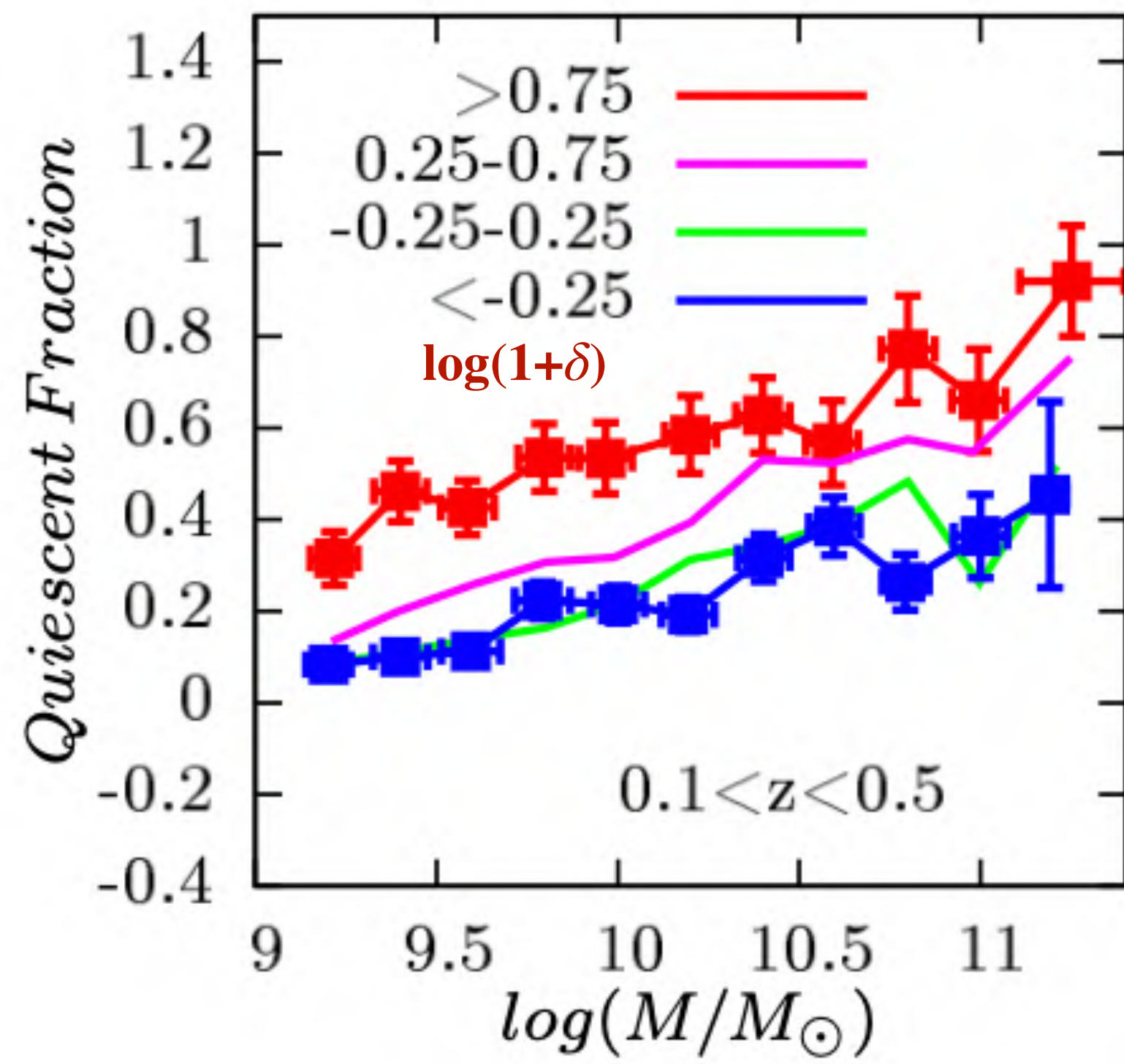


Nurture: those conditions that lead to **changes** of a galaxy's original status

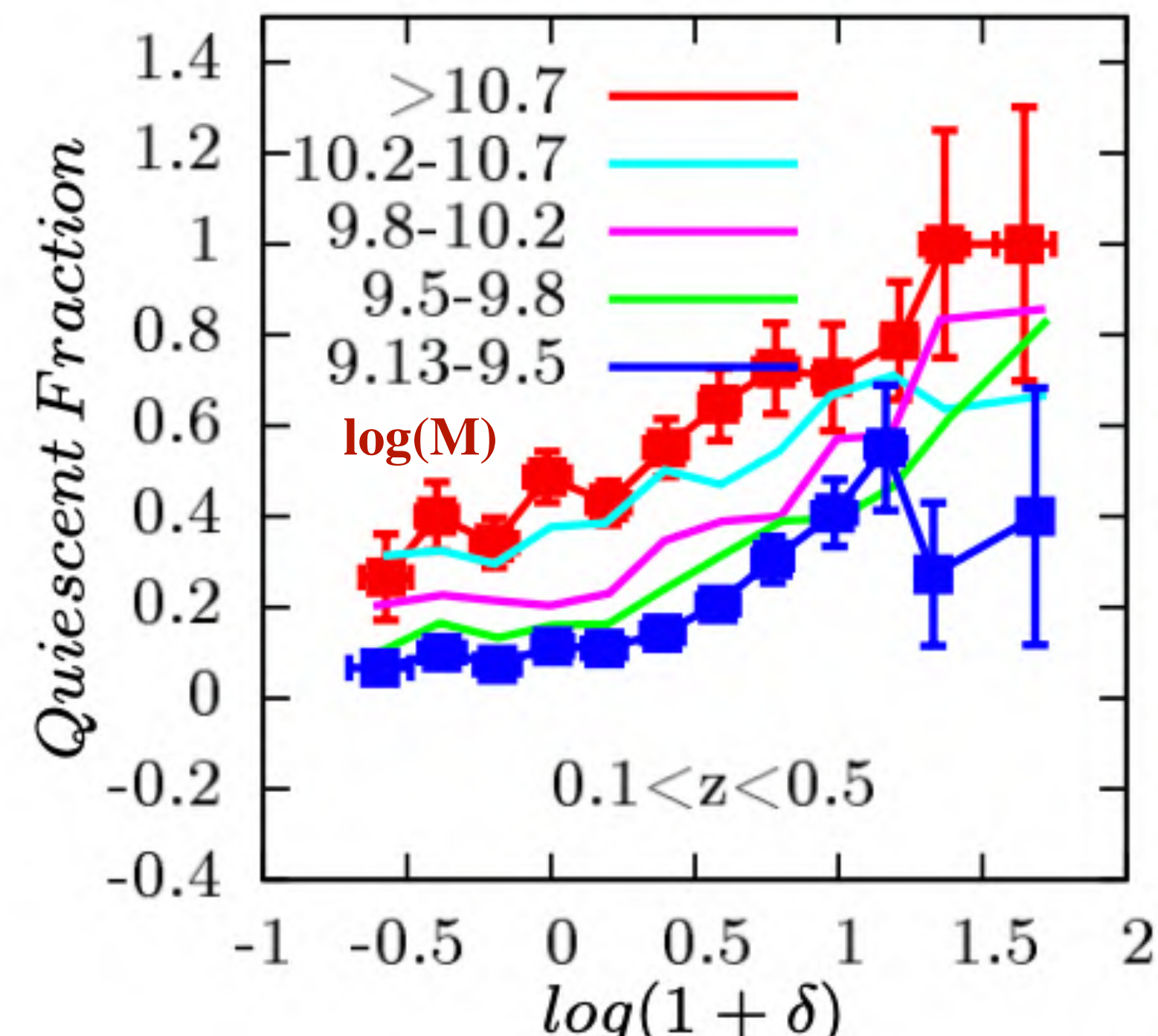
Mass quenching & Environmental quenching



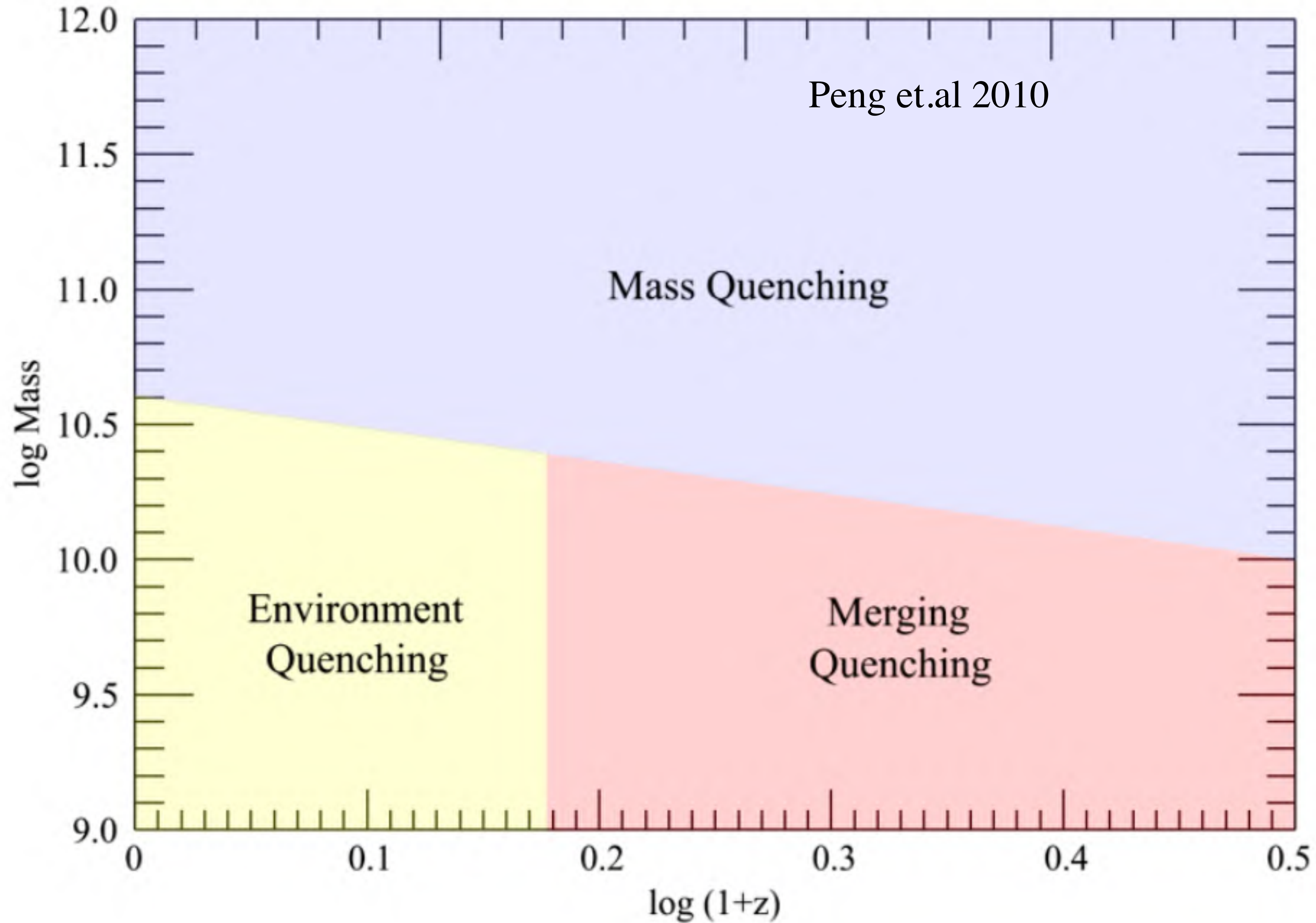
Nature ->
mass
quenching



Nurture ->
environmental
quenching



Mass quenching & Environmental quenching



Outline

1. **Background**
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Nature vs Nurture

Quenching Mechanisms

Xiaohan Wang

How to quench a galaxy?

Fuel for star formation: cool molecular gas



Gravitationally unstable cool gas clumps



Star forms in high density of gas

How to quench a galaxy?

Fuel for star formation: cool molecular gas



- Stripping
- Consumption



Gravitationally unstable cool gas clumps



- Heating
- Stabilizing



Star forms in high density of gas

What processes quench galaxies?

Possible mechanisms

Gravity & instability



Morphological quenching
Halo quenching

Feedback

Active galactic nuclei
Supernova

Environment & interaction

Ram pressure stripping
Thermal evaporation
Strangulation/starvation

Galaxy interactions
merger

Environment-driven gas depletion

Get rid of your gas!

- Ram pressure stripping (Gunn & Gott 1972)
- Thermal evaporation (Cowie & Songaila 1977)
- Strangulation/starvation (Larson 1980)
- Interactions (harassment) (Moore 1996)

Gravitational
perturbation

Hydrodynamic
interactions

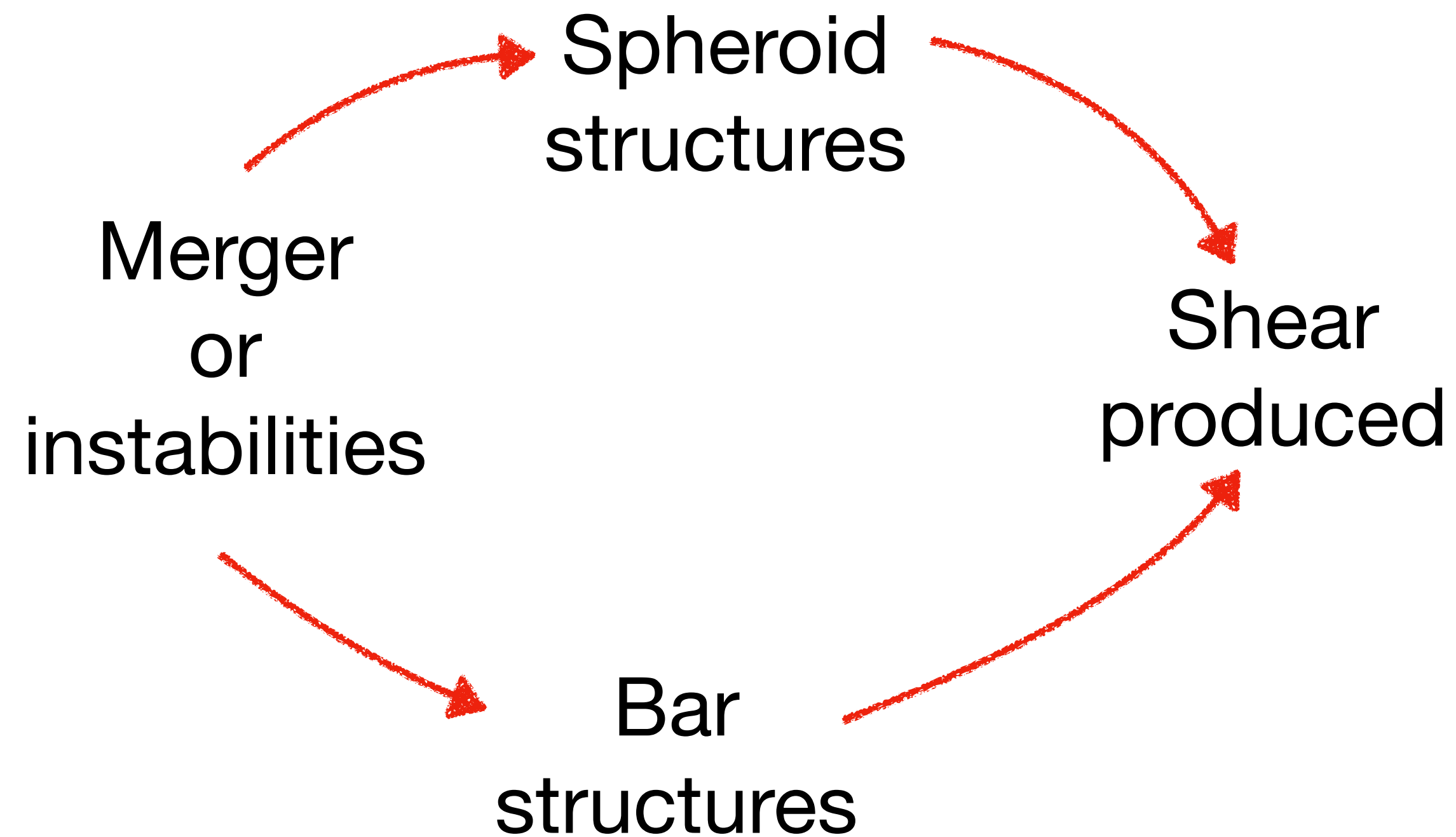


ESO 137-001, HST image

Gravity & Dynamics

No more clumps

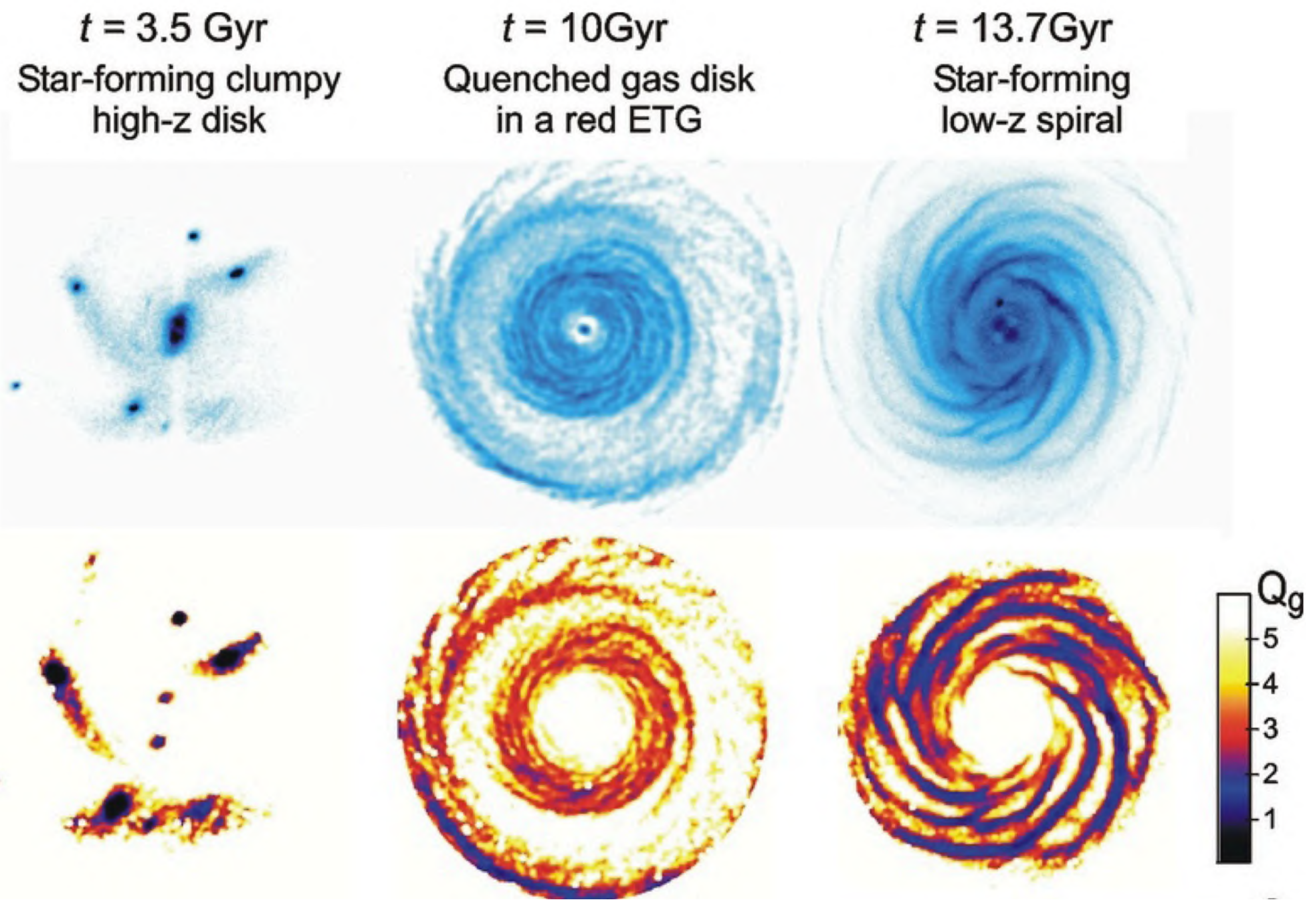
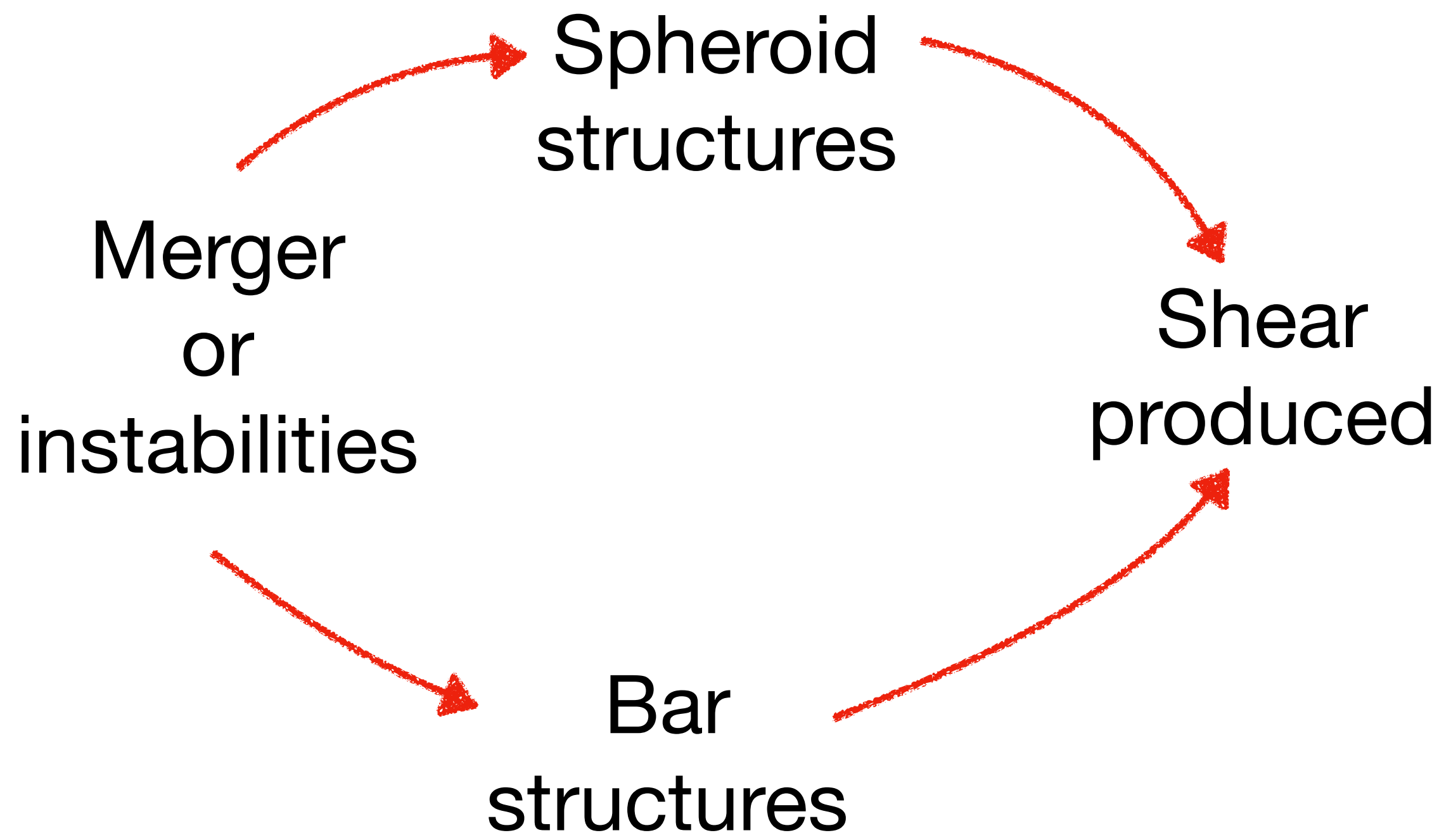
- morphological quenching (Martig 2009)
- Bar quenching (Khoperskov 2018)



Gravity & Dynamics

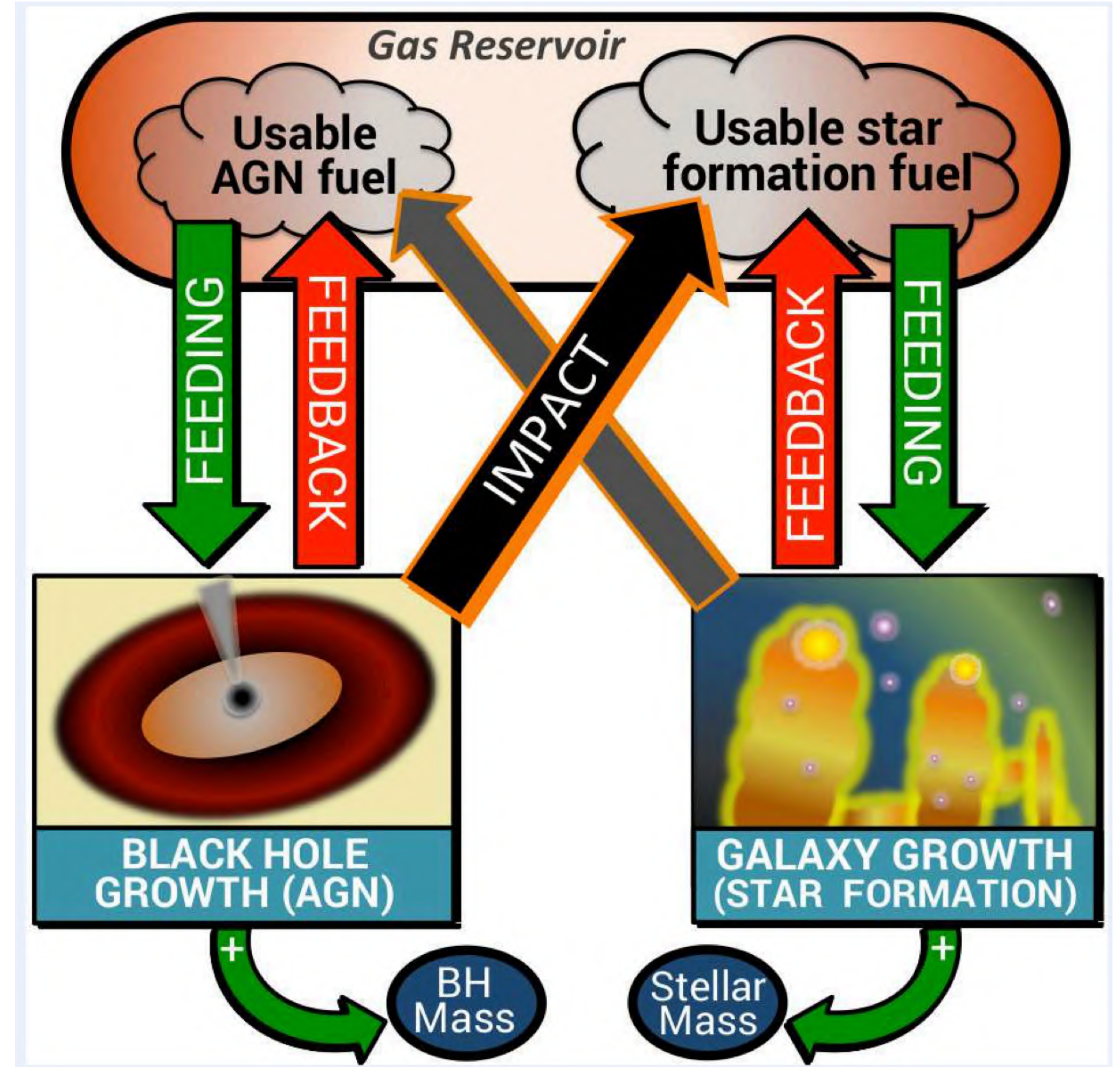
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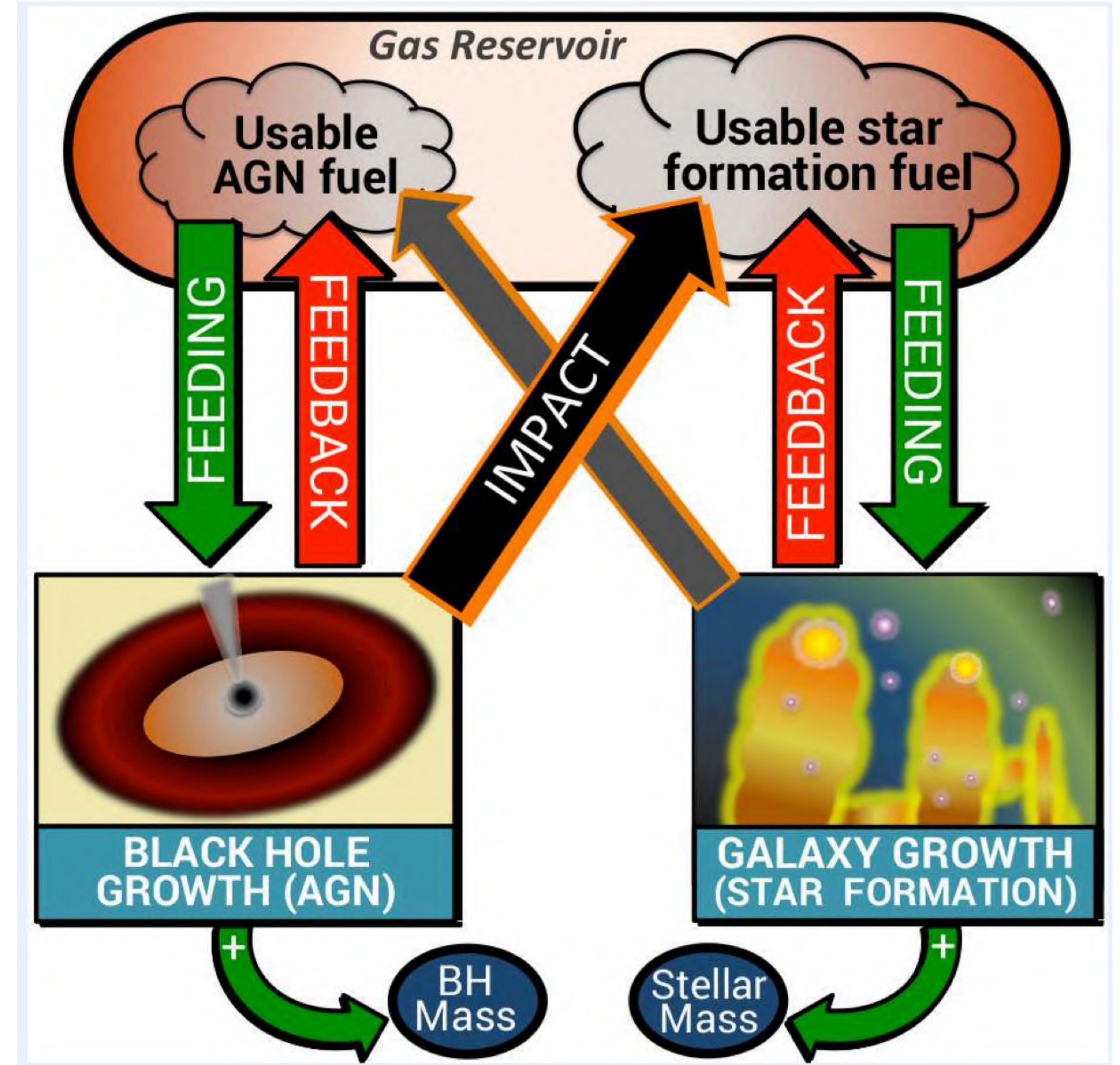
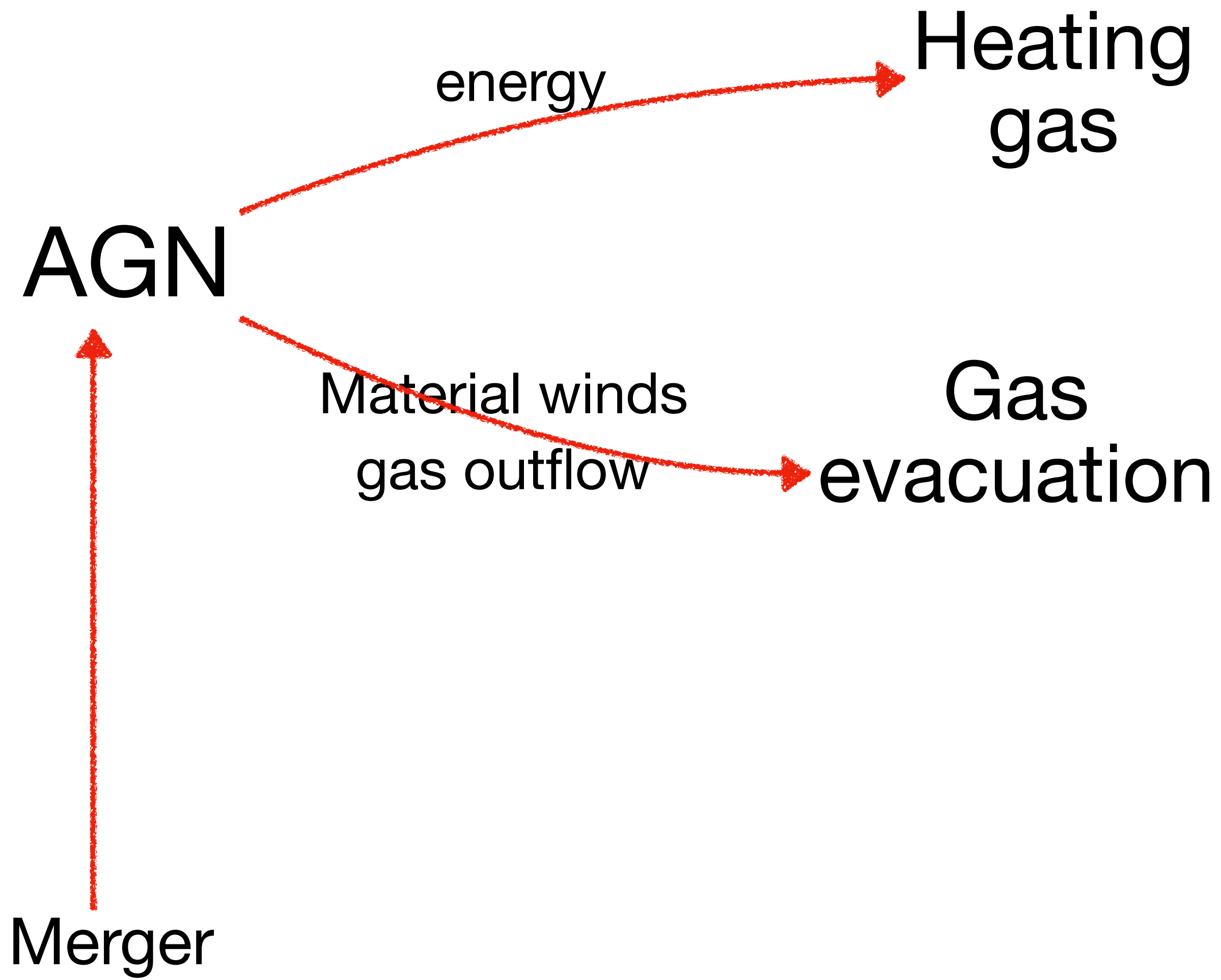
Martig 2009

AGN feedback



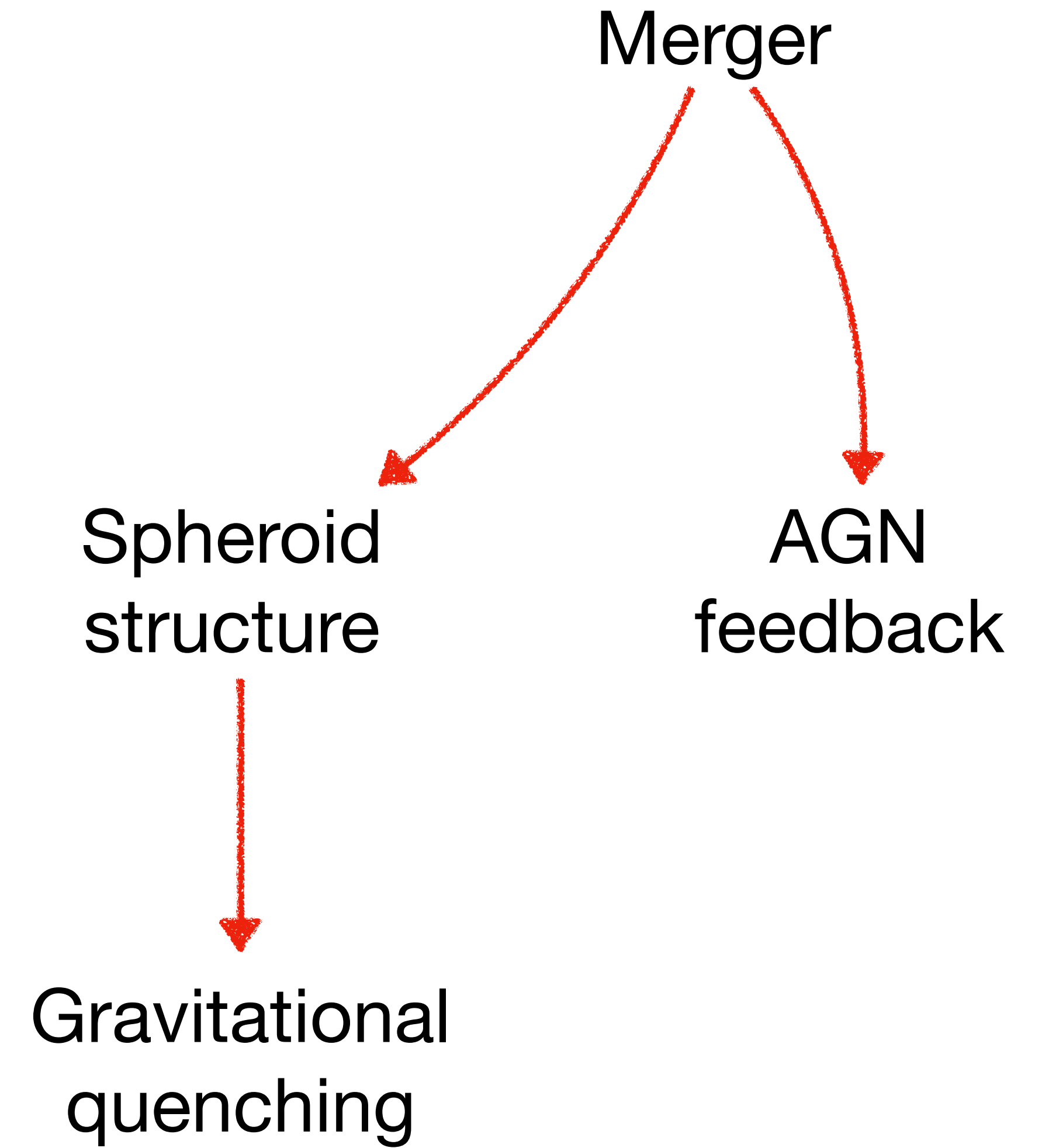
Harrison 2017

AGN feedback



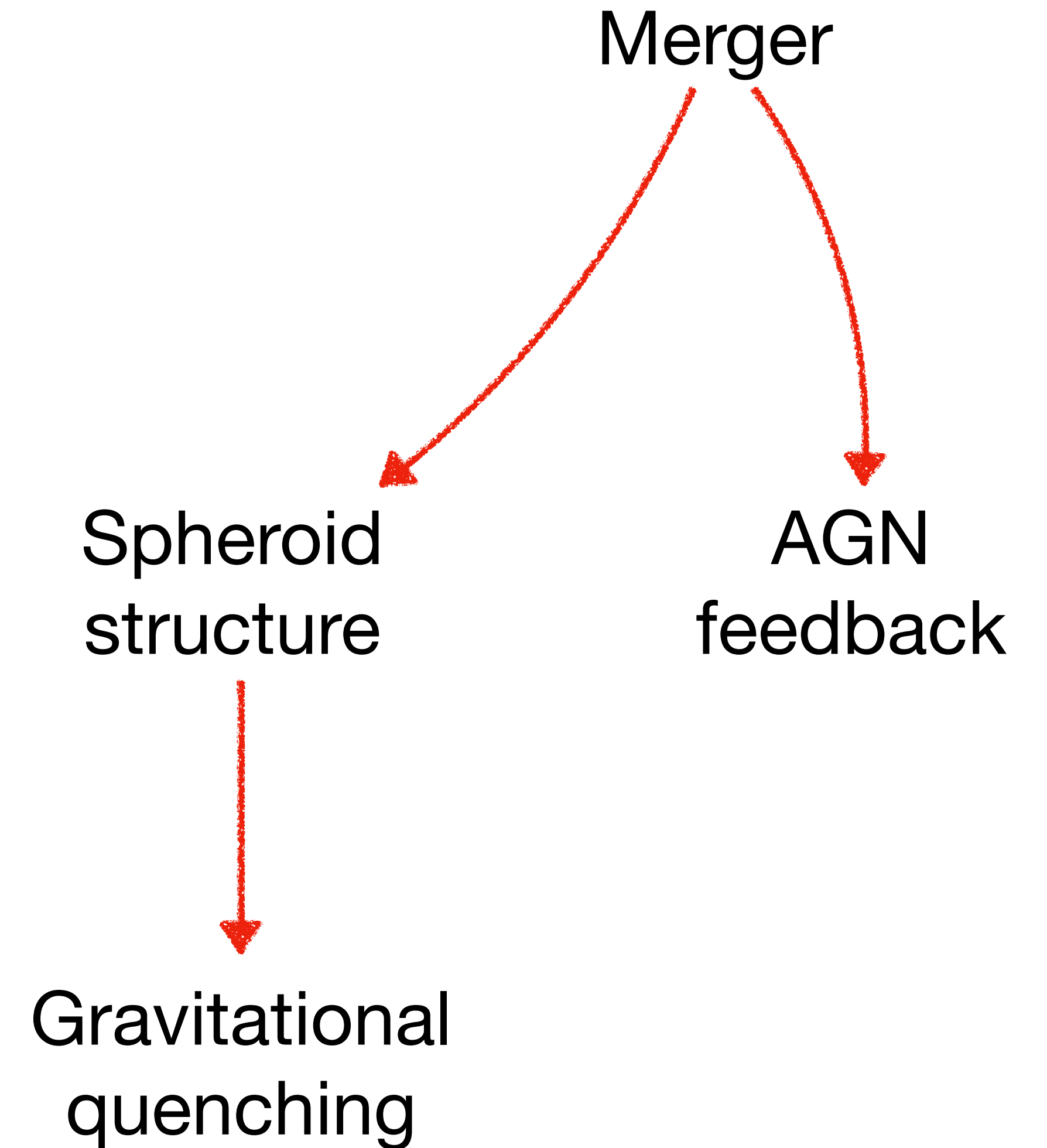
Harrison 2017

Mechanisms: complex and entangled



Mechanisms: complex and entangled

- Mass quenching can be triggered by mergers
- Galaxy can be star forming again
- Many mechanisms are happening simultaneously



Take home message

Quenching mechanisms

- To quench a galaxy, either gas is got rid of, or gas is heated or stabilized and prevented to form clumps.
- Environmental quenching includes gravitational and hydrodynamical perturbations and can get rid of gas.
- Spheroid and bar structures in galaxies can help stabilize gas and quench galaxy.
- AGN feedback is important and efficient in quenching, and can be triggered by merger.
- Quenching mechanisms are multiple and complex.

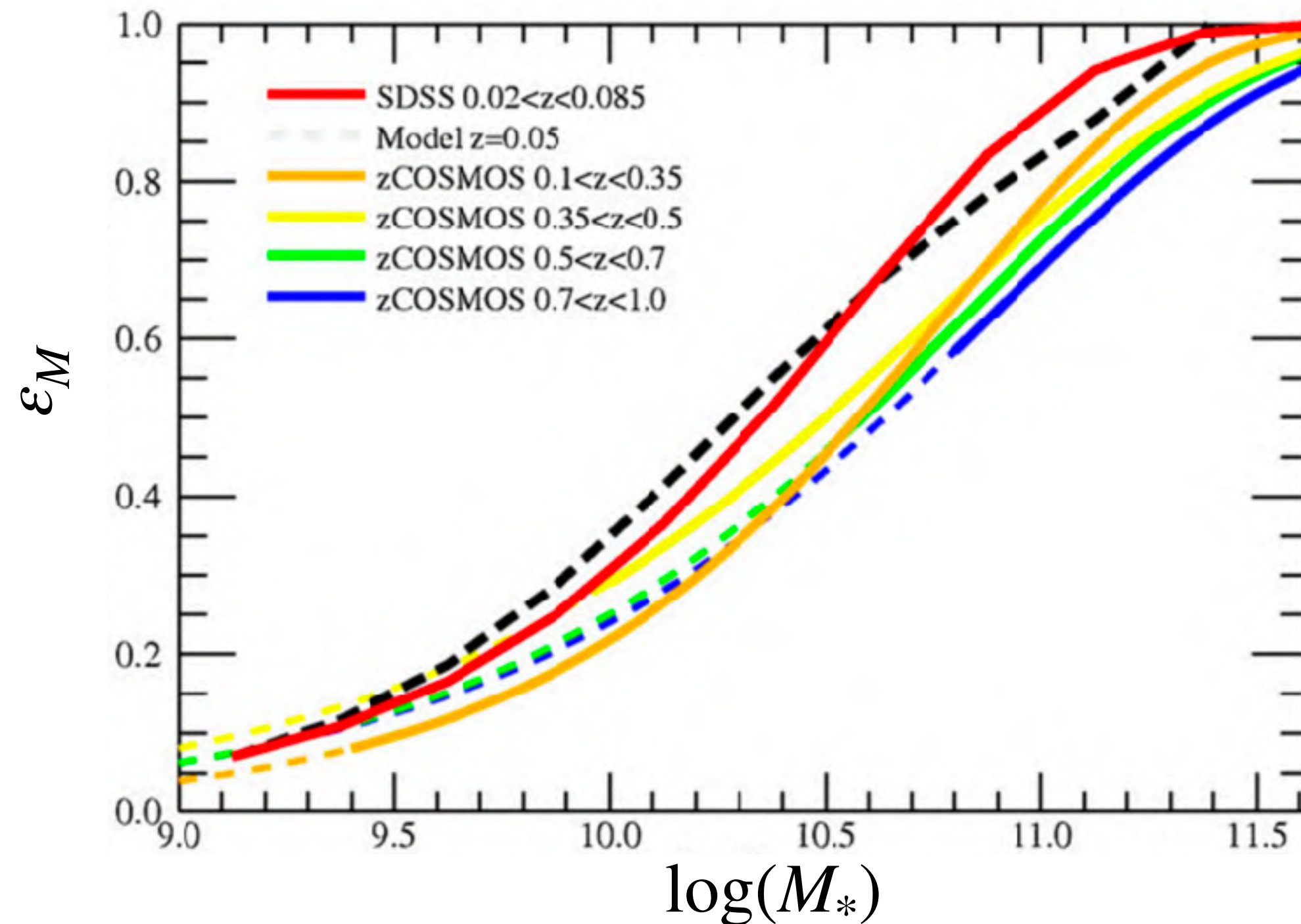
Possible Entanglement between
Mass(**nature**) and Environment(**nurture**)
for Galaxy Quenching

Wenshuo Xu

Quantitative descriptions of quenching: quenching efficiency

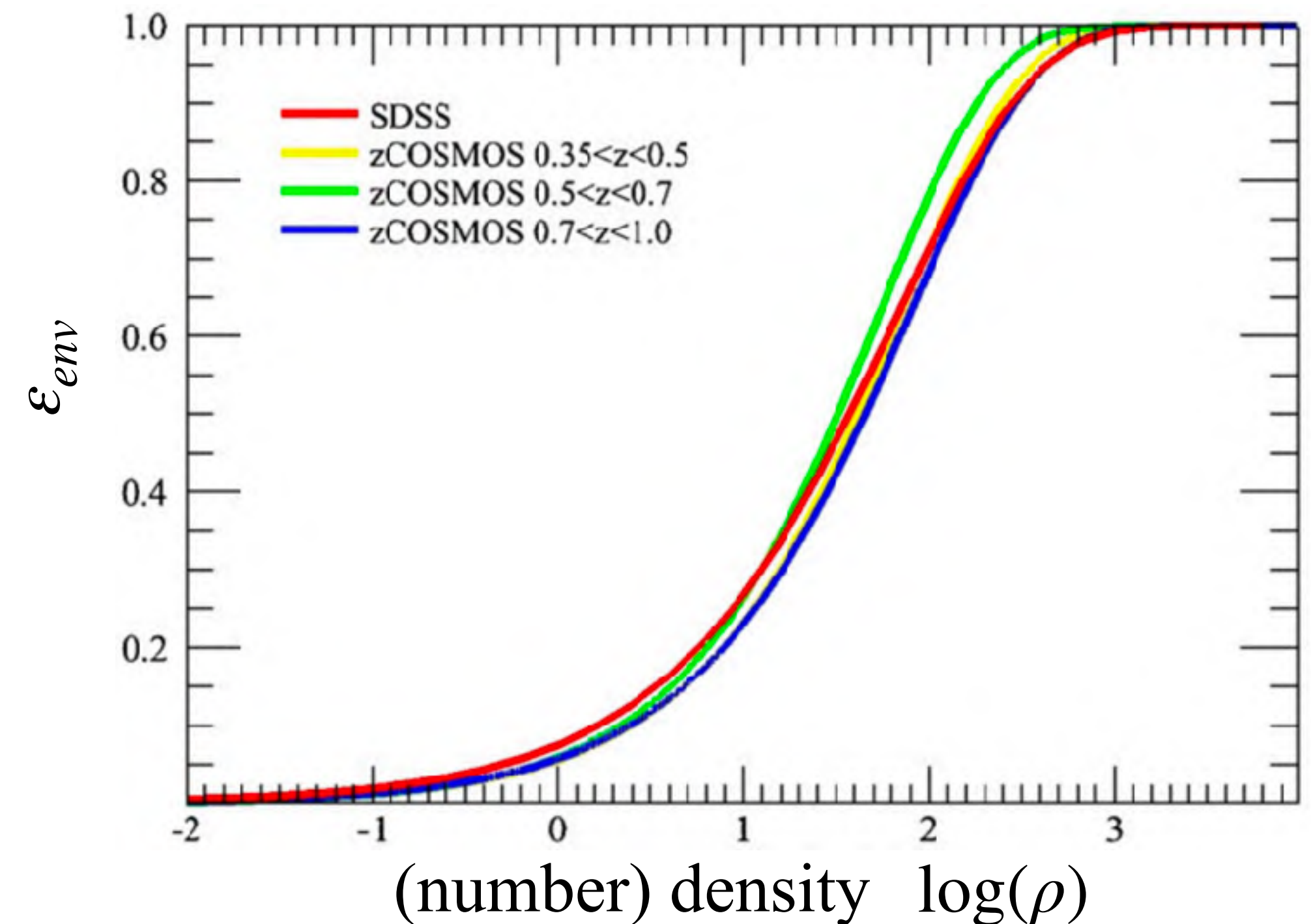
mass quenching

$$\varepsilon_M(M_*, M_{*,0}) = \frac{f_Q(M_*) - f_Q(M_{*,0})}{f_{SF}(M_{*,0})}$$



environmental quenching

$$\varepsilon_{env}(\rho, \rho_0) = \frac{f_Q(\rho) - f_Q(\rho_0)}{f_{SF}(\rho_0)}$$



(Peng et al. 2010)

Entanglement between mass and environment

* Entanglement in galaxy properties

e.g. Massive galaxies tend to live in denser environment, BCG

* Entanglement in quenching processes

e.g. $\varepsilon_{env}(\rho, \rho_0) \longrightarrow \varepsilon_{env}(\rho, M_*, \rho_0)$

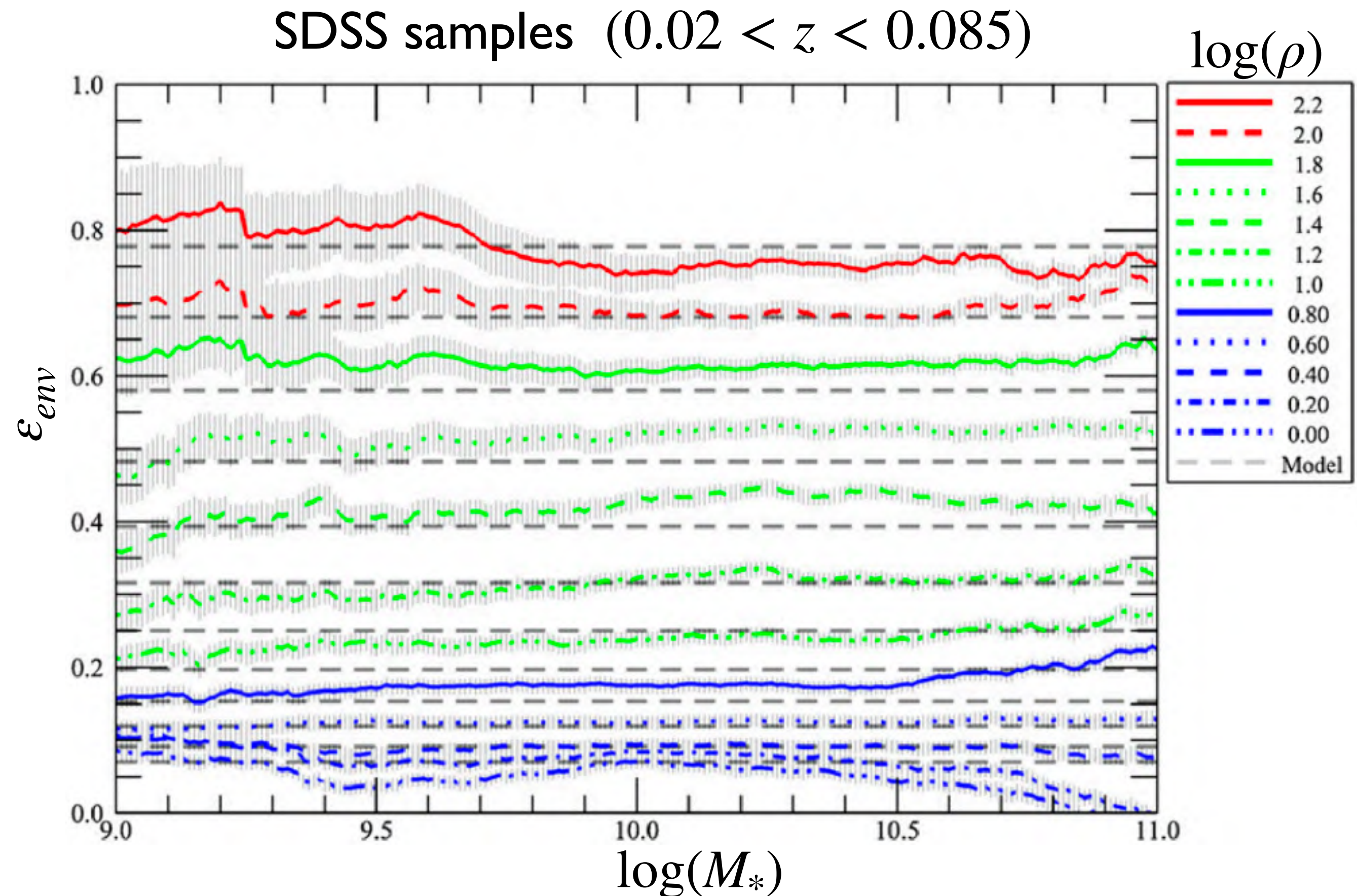
Mass and environmental quenching are separable

* Entanglement in quenching mechanisms

e.g. $\varepsilon_{env}(\rho, \rho_0) \longrightarrow \varepsilon_{env}(\rho, M_*, \rho_0)$

(Peng et al. 2010)

- * fix local density ρ , study the variations of ε_{env} with M_*
- * no obvious dependence on M_* in ε_{env} (same result for ε_M)
- * no entanglement in mass and environmental quenching mechanisms



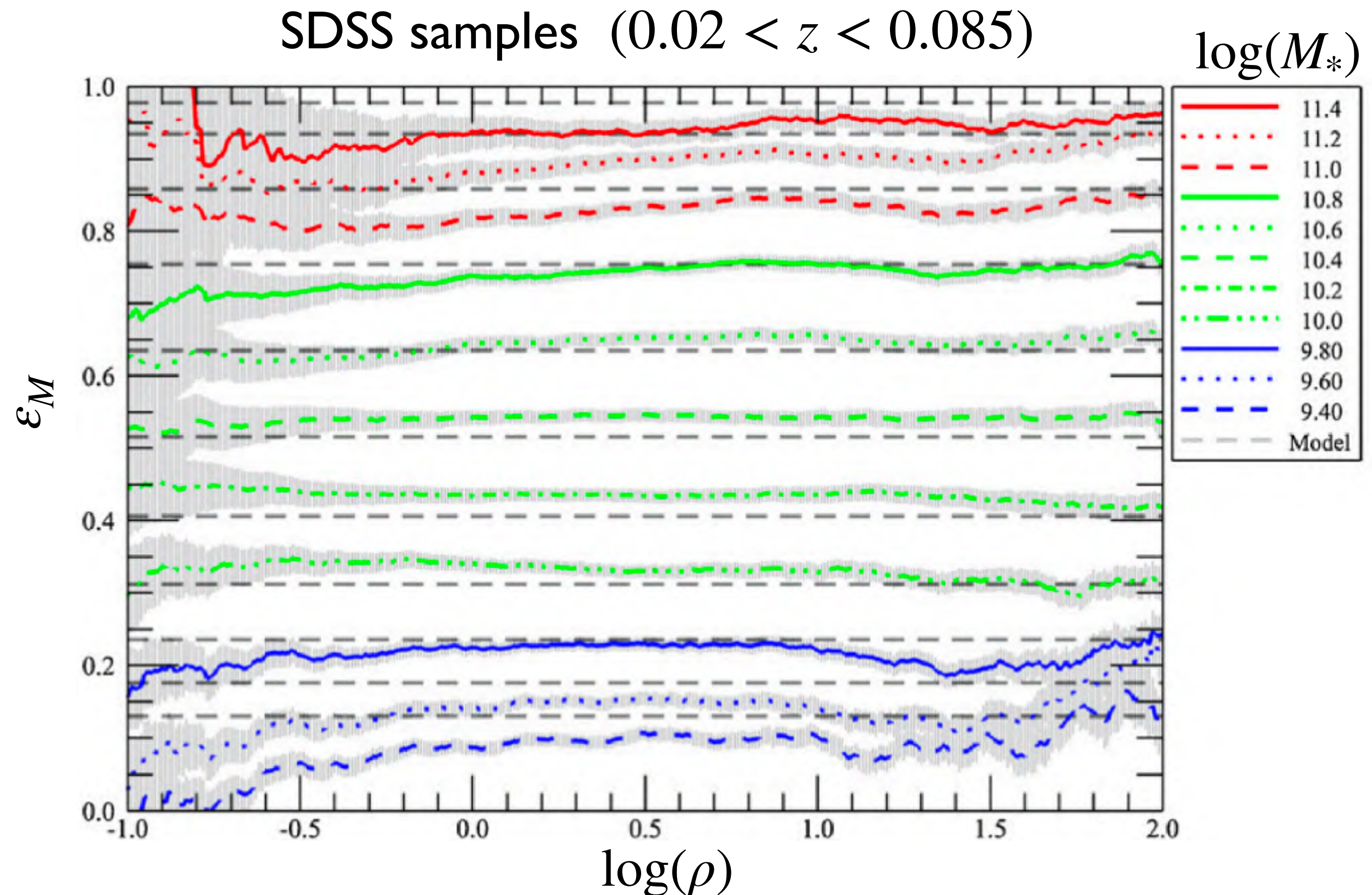
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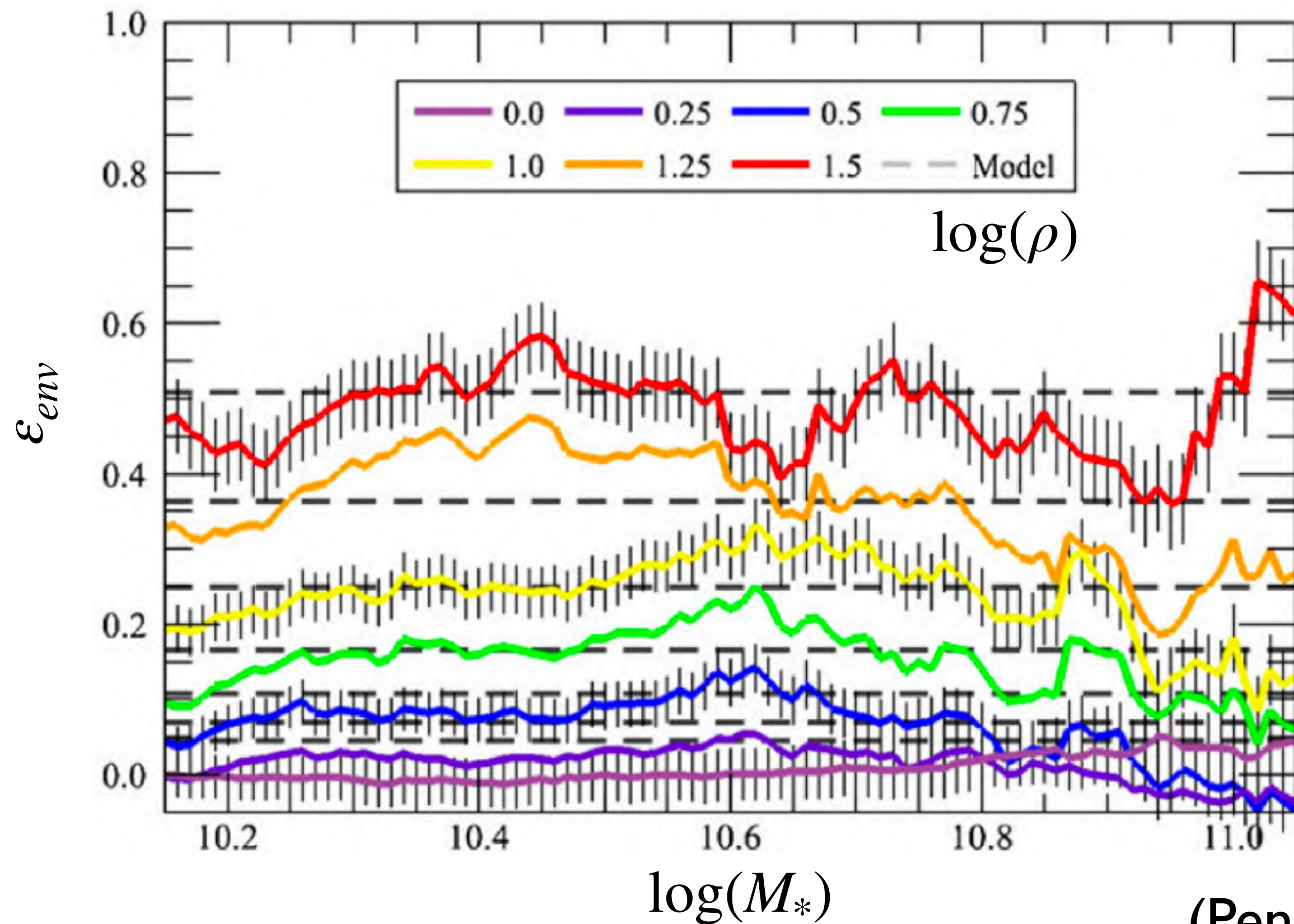


Mass and environmental quenching are separable

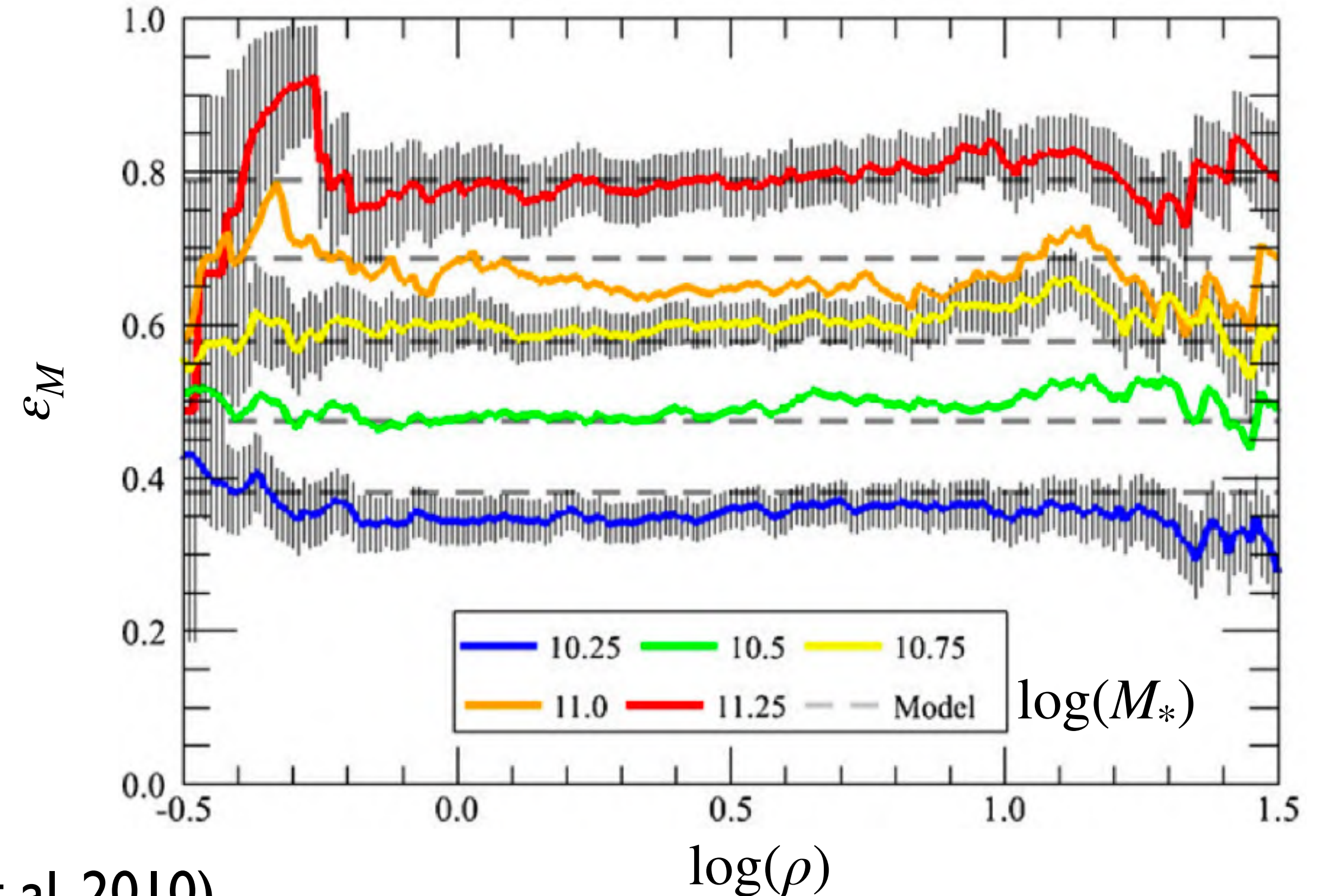
* Entanglement in quenching mechanisms

$$\text{e.g. } \varepsilon_{env}(\rho, \rho_0) \longrightarrow \varepsilon_{env}(\rho, M_*, \rho_0)$$

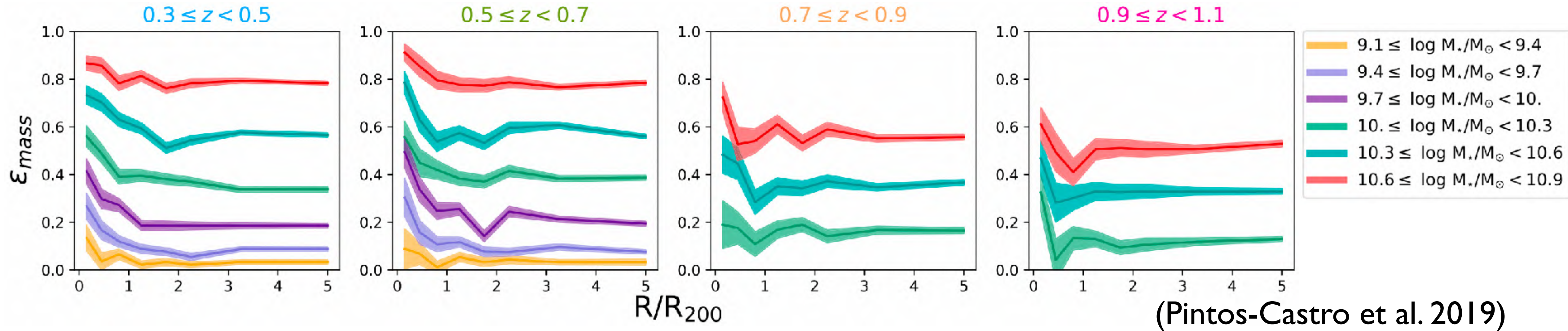
zCOSMOS samples ($0.3 < z < 0.6$)



(Peng et al. 2010)

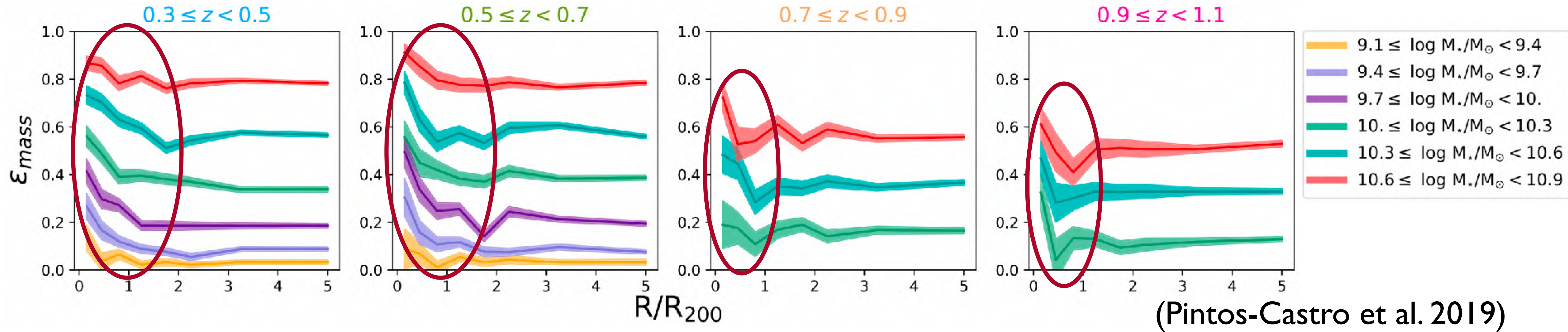


Mass and environmental quenching are inseparable



- * 209 galaxy cluster systems, compare galaxies in cluster and field environments
- * The distance to cluster center (R/R_{200}) is used to indicate environment. (different from previous studies)

Mass and environmental quenching are inseparable



- * Mass quenching efficiency depends on environment when approaching the center of cluster.
- * This region has **higher local density** than samples in Peng et al. 2010, which indicates entanglement appears in extremely dense regions.

Does mass quenching really depend on environment?

- * Galaxy samples at the center of cluster are biased

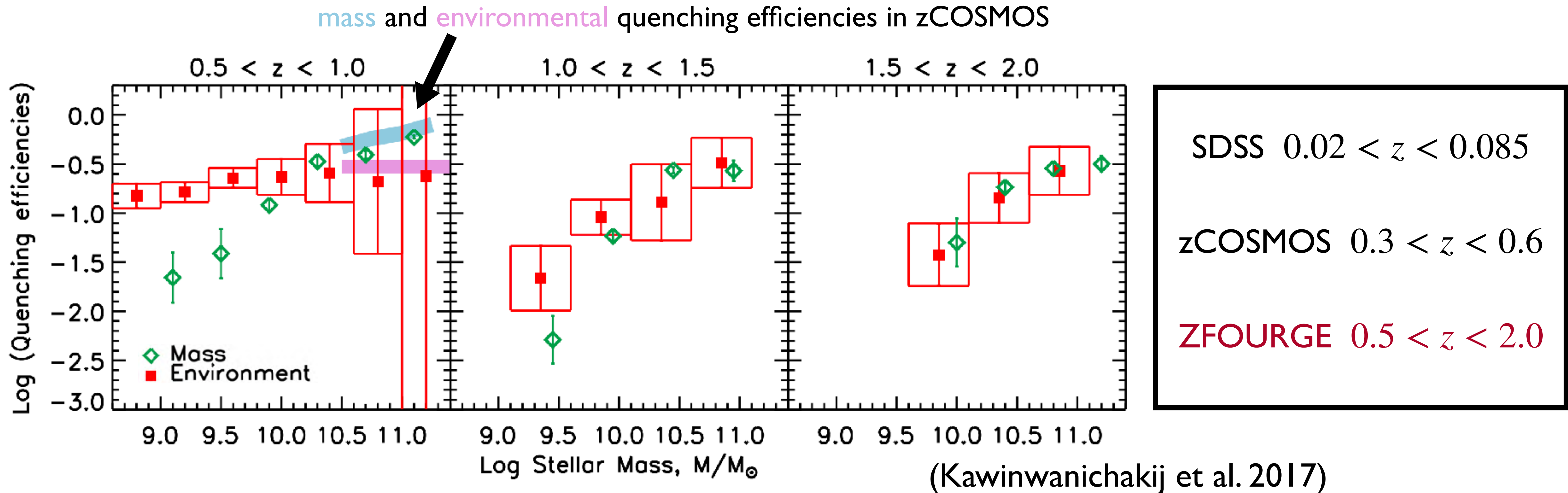
Galaxies forming **in situ** at the center of cluster can start their quenching process much earlier than other infalling galaxies.

- * Mass quenching **mechanisms** can be entangled with environment

The effect of environment does not influence **AGN activities** in blue/green galaxies, but is significant in red galaxies.
(Miraghaei 2021)

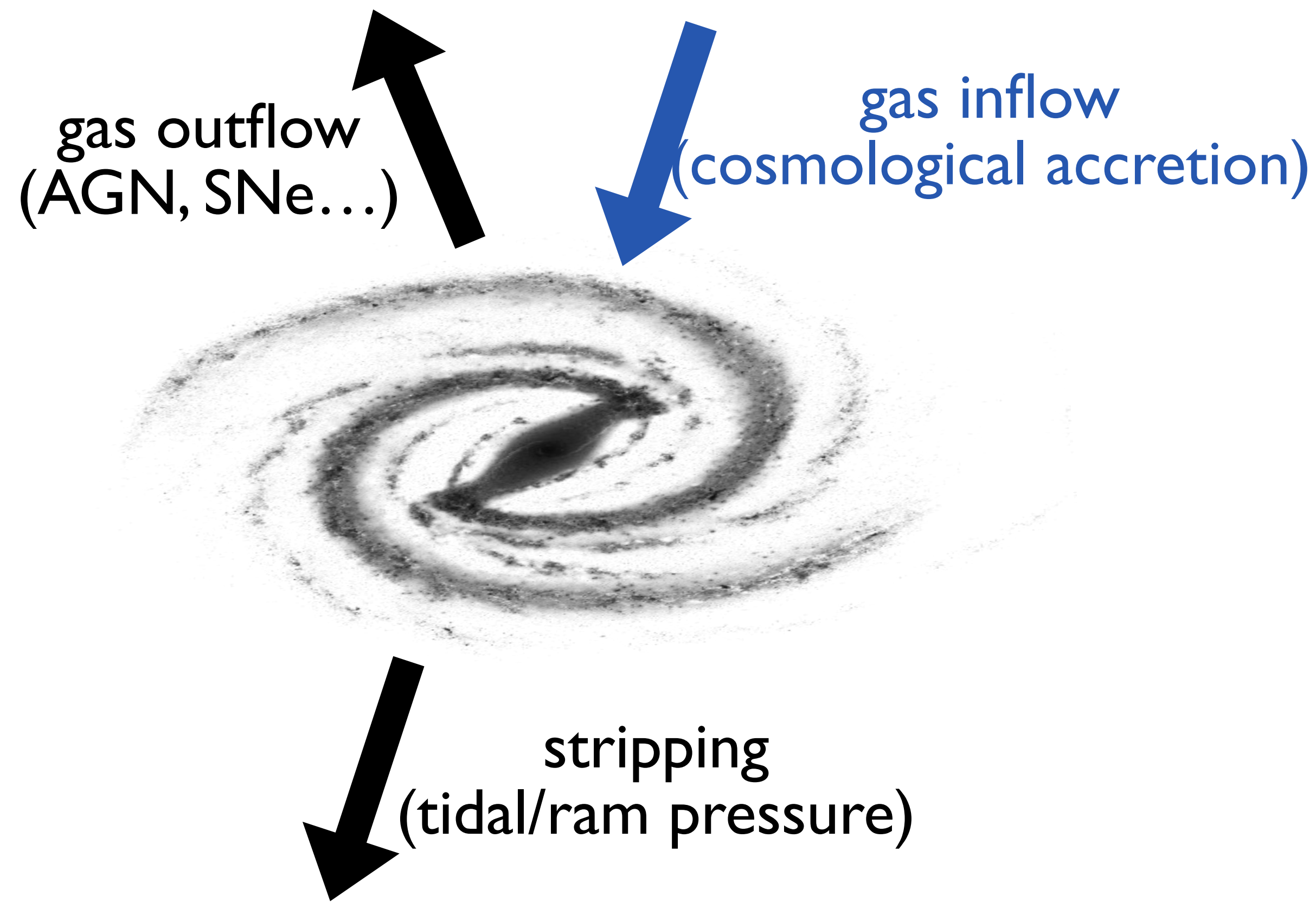
SN feedback can be related to the environment.
(e.g. Mcleod et al. 2021)

Mass and environmental quenching are inseparable

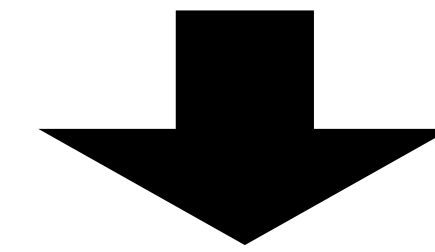


- * Environmental quenching efficiency depends on stellar mass at high redshift ($z > 1.0$)
- * Result favors the “overconsumption” model

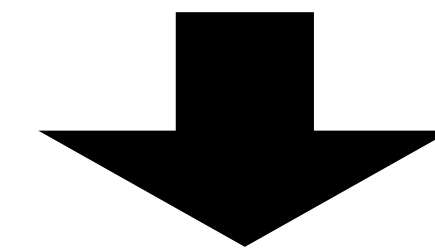
“Overconsumption” quenching model



Gas inflow is halted when galaxy falls into a denser region.



Galaxy starts to consume its inner gas reservoir for star formation



Massive galaxies consume gas more rapidly and then have a higher quenching efficiency

- * At **low redshift**, the SFR of galaxies declines, then the environmental quenching is dominated by **stripping**, which is less relevant to stellar mass.

Brief summary

- * The entanglement between mass and environmental quenching is an important but **controversial** question.
- * “Overconsumption” model well explains the observed environmental quenching efficiency and indicates the importance of **gas supply from outside environment** to galaxy star formation.
- * This entanglement adds an extra complication to “nature vs nurture” discussions. More attention should be paid to the underlying physical mechanisms for galaxy quenching.



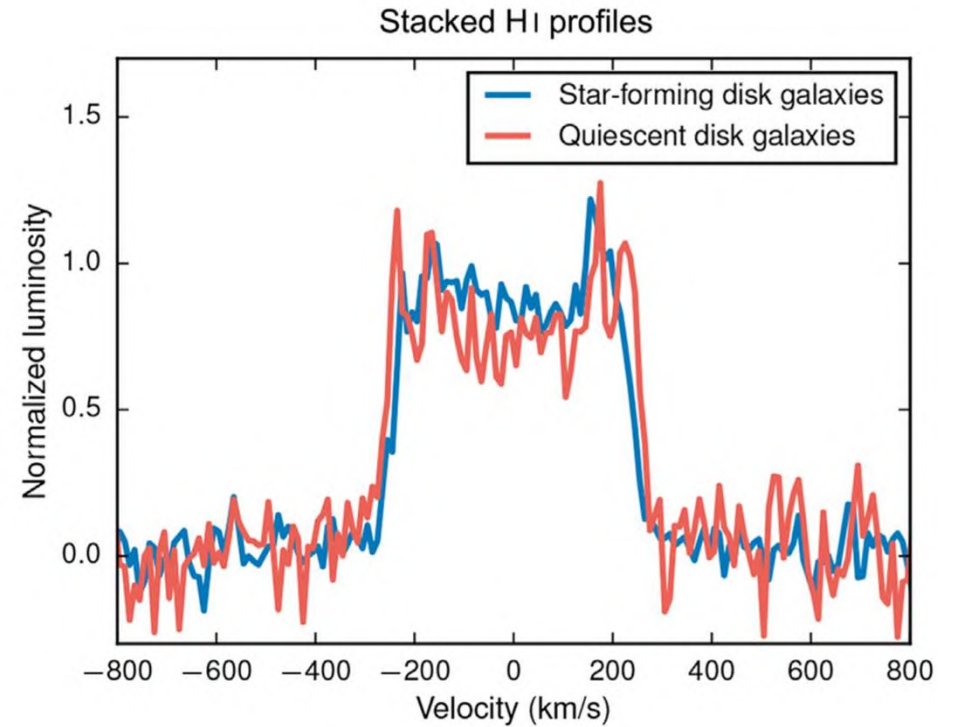
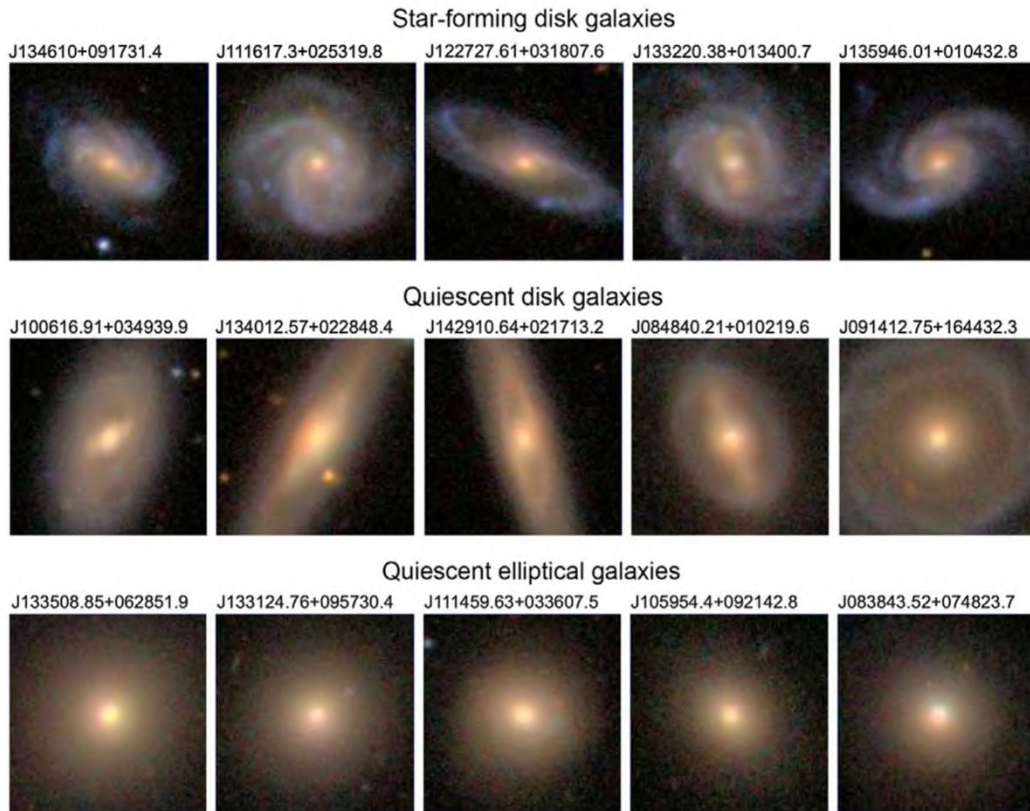
Angular-momentum Quenching

From large-scale environment to CGM angular momentum to star forming activities –
II: quenched galaxies (Lu et al. 2021)

Speaker: Zhixing Li

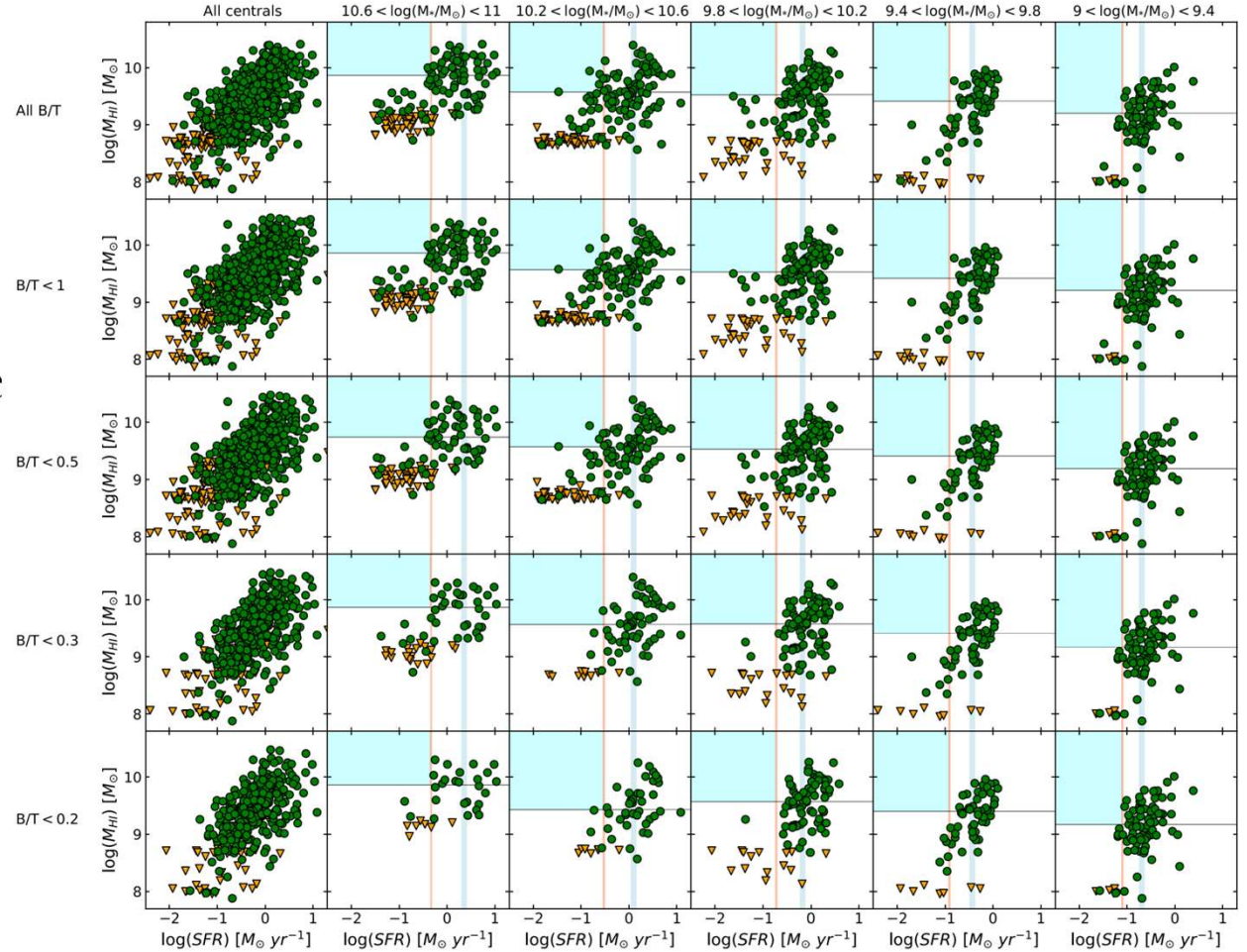
Background

- Some results from ALFALFA+SSDS+GASS show...



Background

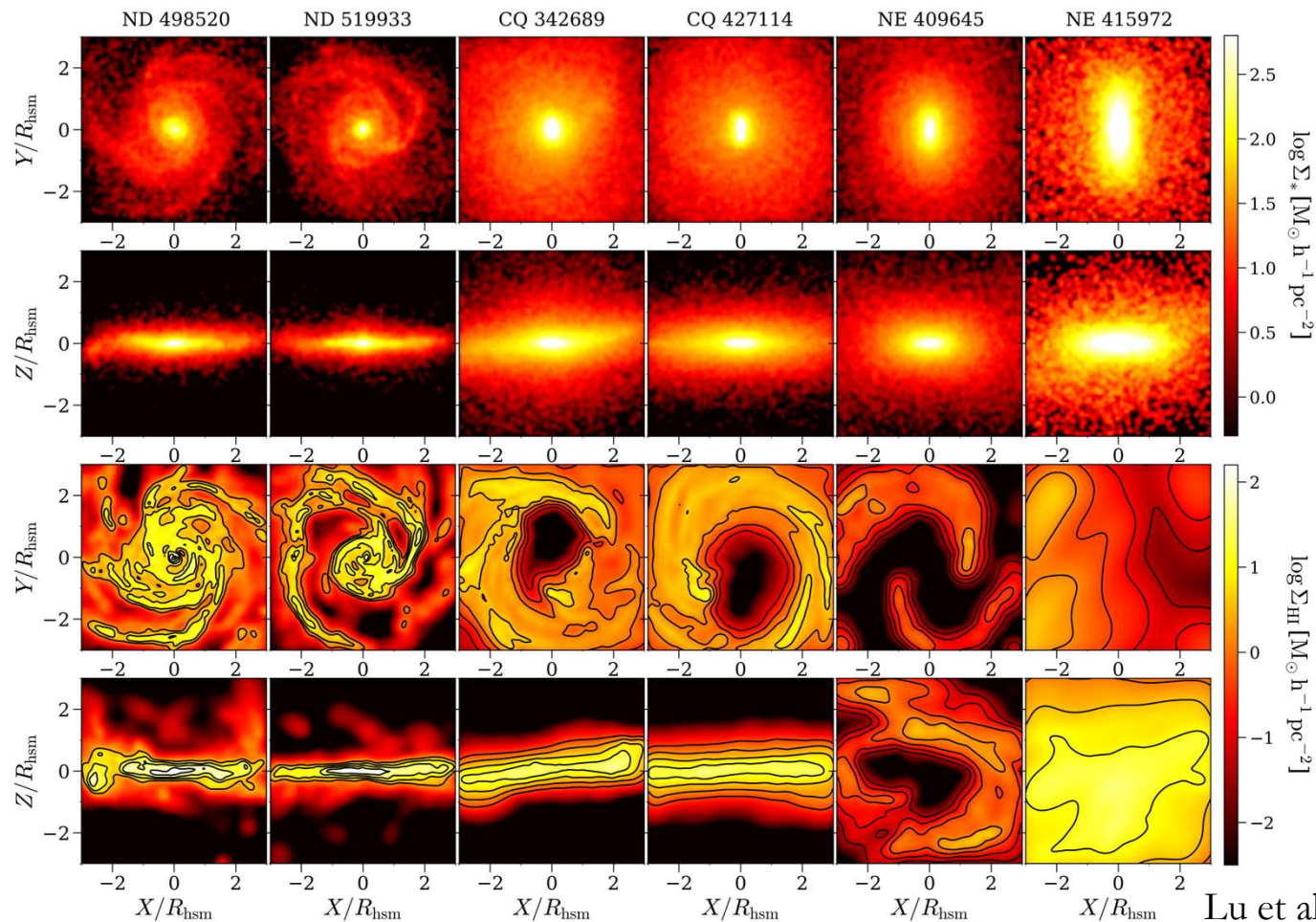
- Some Controversies...
- H I-rich passive central disc galaxies are the **exception rather than the norm** (Cortese et al. 2020)



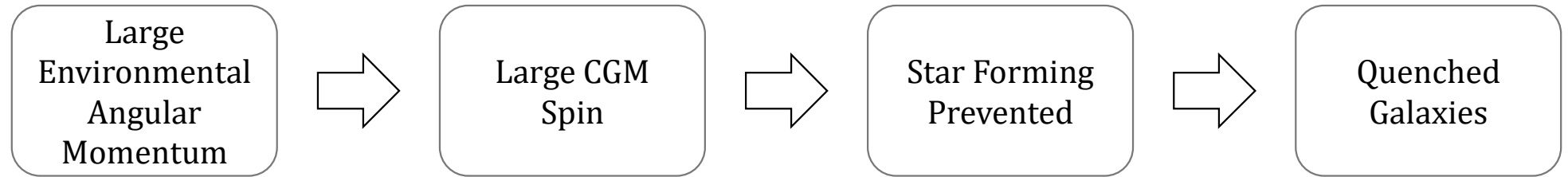
How to maintain a **disk galaxy**
quenched while it have a
Surprisingly large **Atomic Gas**
Reservoir?

Background

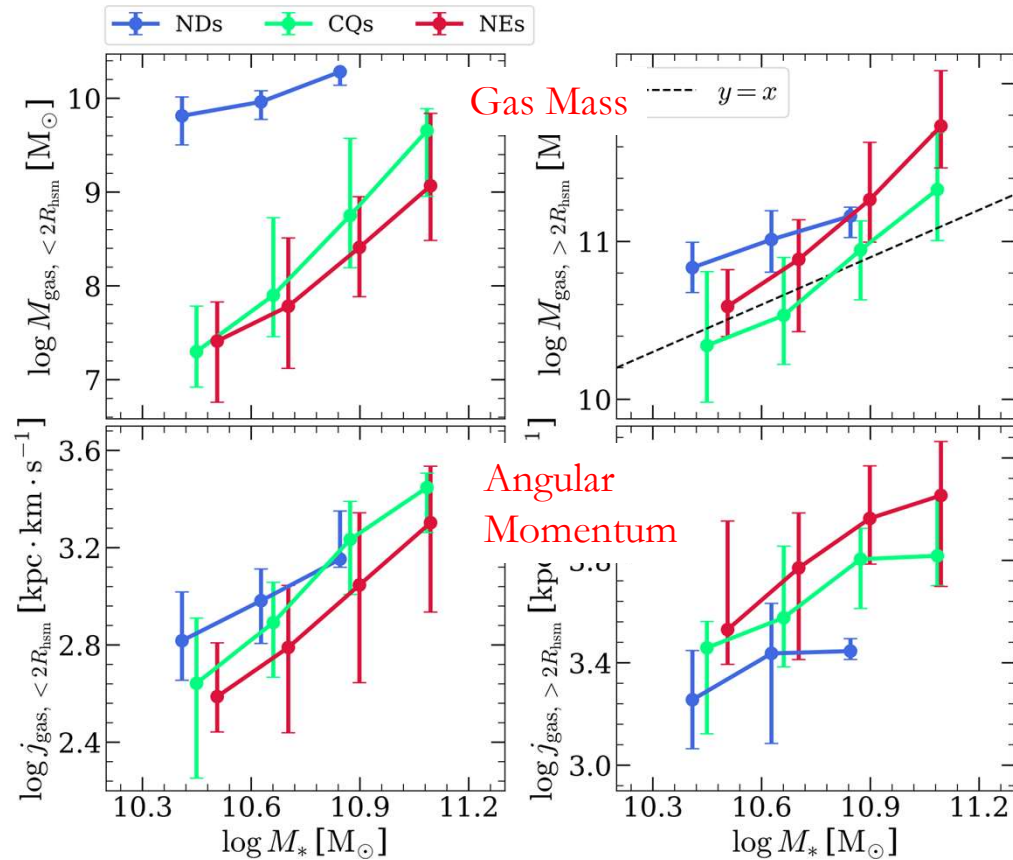
- Possible Solution:
 - gas accreted via streams are to come in with **high angular momentum** (Renzini et al. 2018)
 - Angular-momentum quenching (Peng et al. 2020)



Mechanism

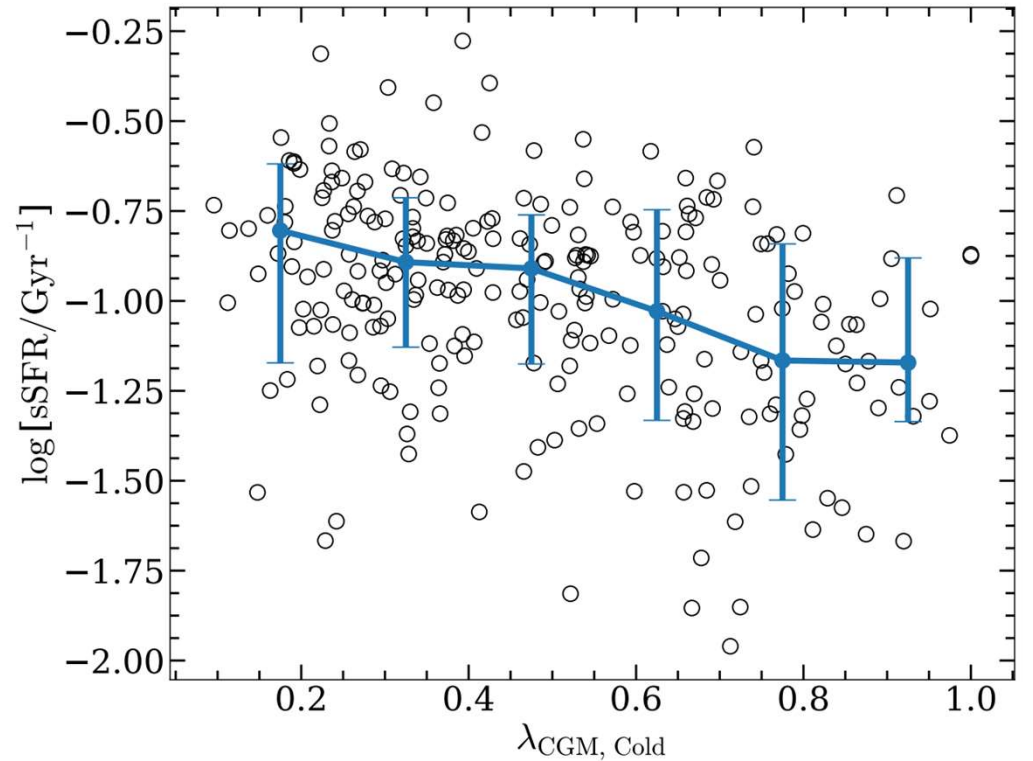


Statistical Results



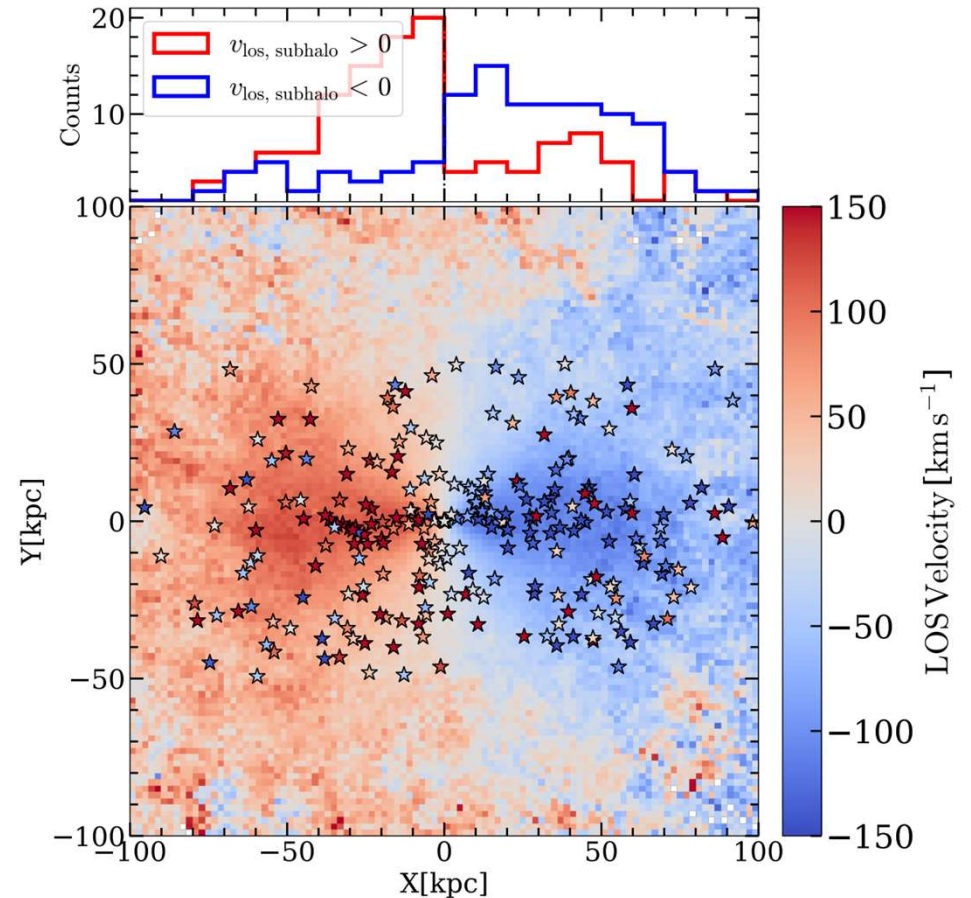
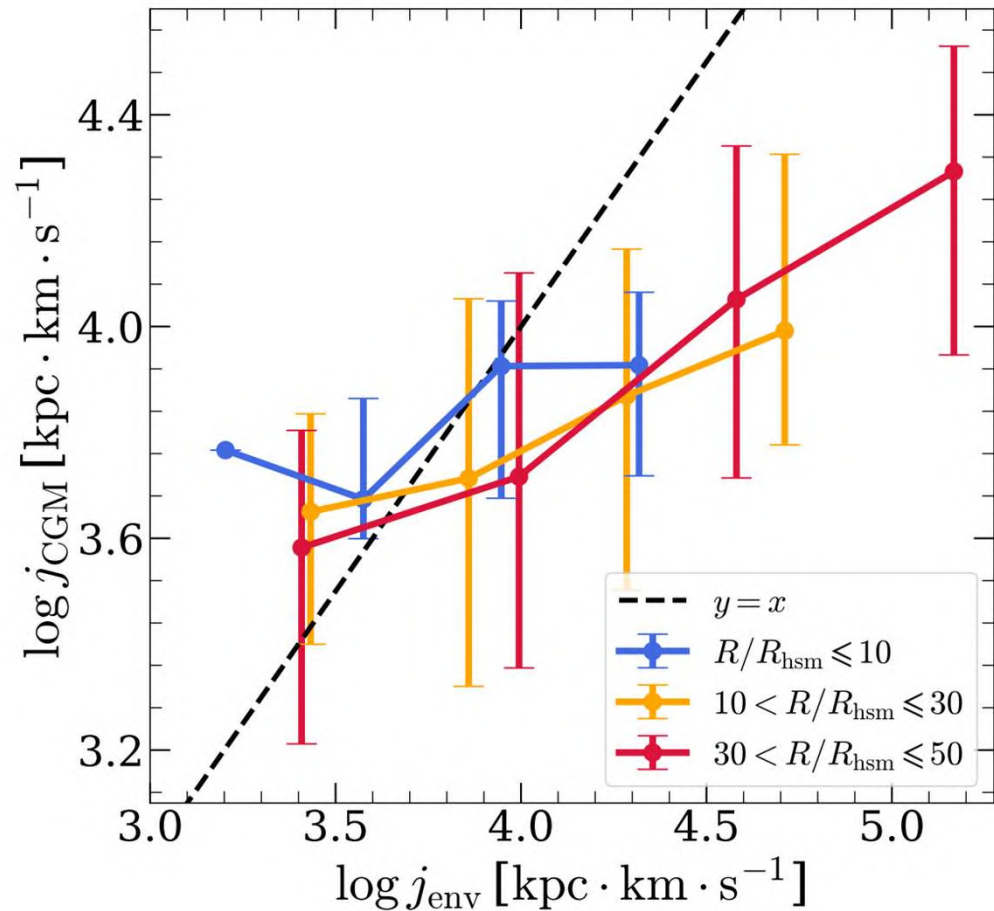
ISM Gas inside Galaxies

CGM Gas in Outskirt

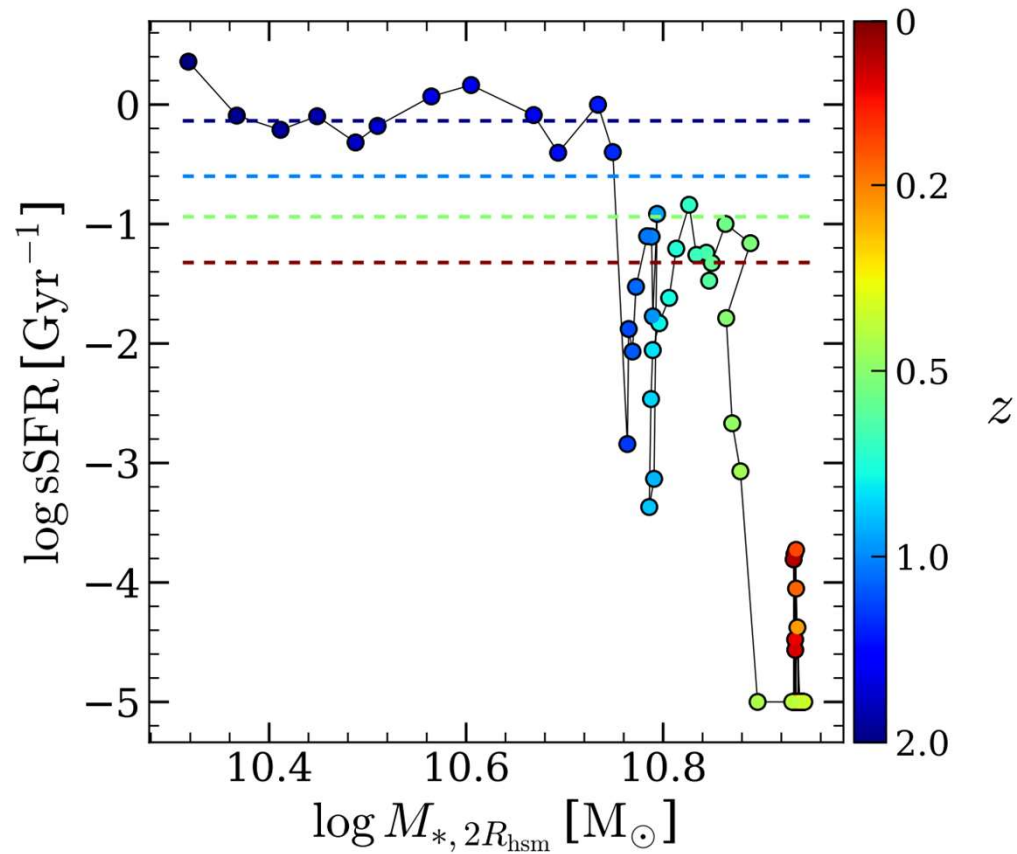


For Disk Galaxies, an anti-correlation between sSFR and λ_{CGM}

Statistical Results



Mechanism



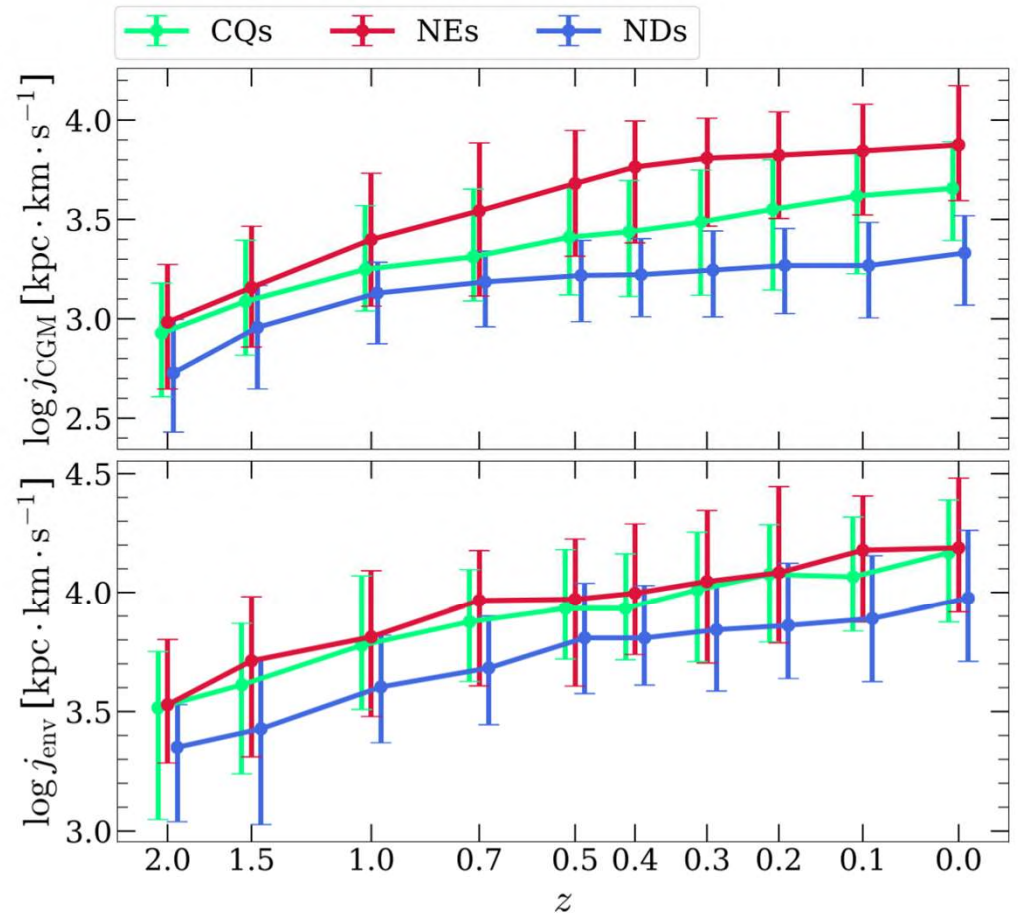
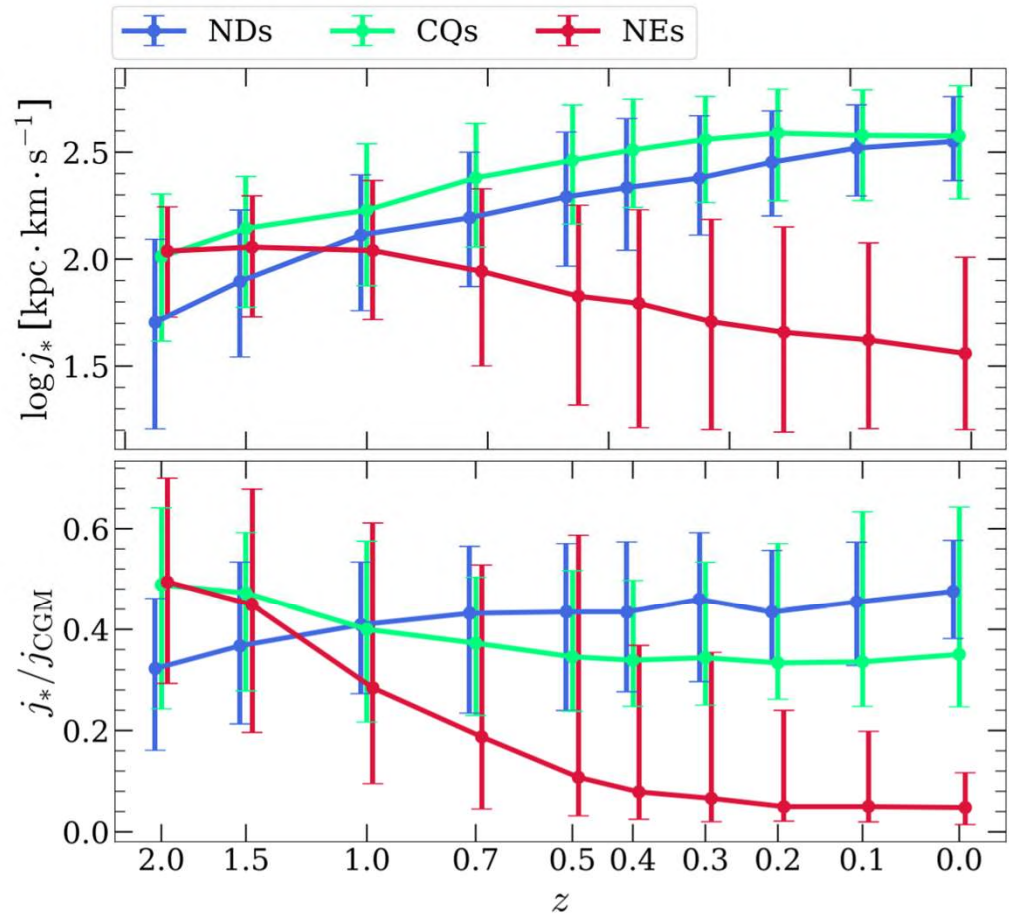
- High angular momenta can keep the disc quenched.

those conditions that lead to
changes of a galaxy's
original status

Nature or Nurture ?

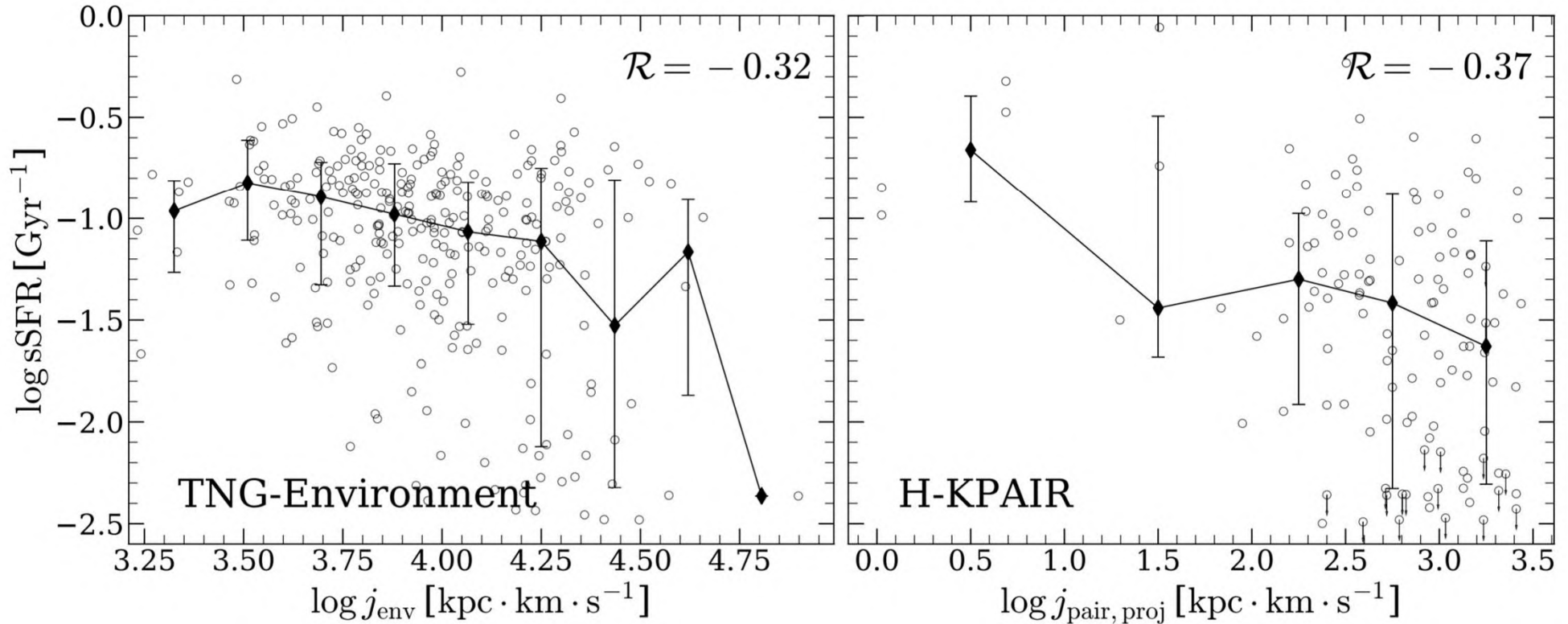
refers to those conditions that
are **set around the formation
time** of a
galaxy and its dark matter halo.

Nature vs Nurture?



Future Observations

- Anti-correlation between **galaxy star formation rates** and specific **environmental angular momenta**



Take-home Message

- According to TNGIllustris Simulation:
 - Quenched \neq gas-poor
 - CGM angular momenta $\uparrow \leftrightarrow$ star forming activity & feedback \downarrow
 - CGM angular momenta \leftrightarrow Environmental momenta
 - Different **fates** of galaxies may originate from **an early epoch**

 - Calling for **bigger samples** of galaxy pairs in order to provide further observational support for the proposed anti-correlation between **orbital angular momenta of satellite galaxies** and **central star formation activity**
-

Summary

- Galaxy quenching plays an important role in galaxy evolution and is the result of multiple mechanisms. Different mechanism dominates at different evolution era.
 - The entanglement between mass and environmental quenching adds extra complication into “nature versus nurture” discussions. “Overconsumption” model can be one possible underlying solution.
 - As a “nature” effect, angular momentum helps to maintain quenching condition for already quenched galaxies. A coherent rotation pattern exists across multiple distances in galaxy halo.
-