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The Effects of AGN Feedback on Cold Gas Depletion and Quenching of Central Galaxies

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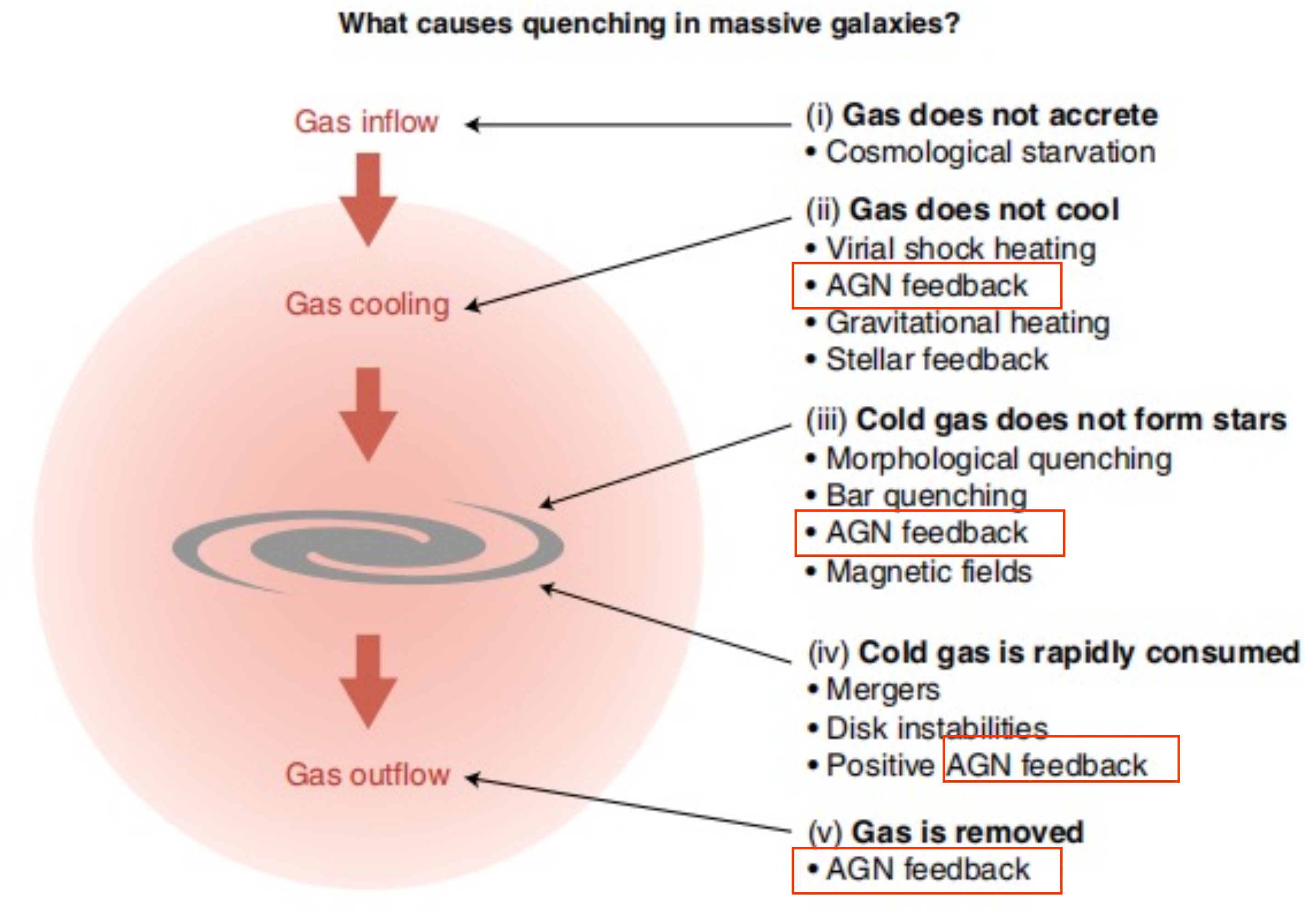
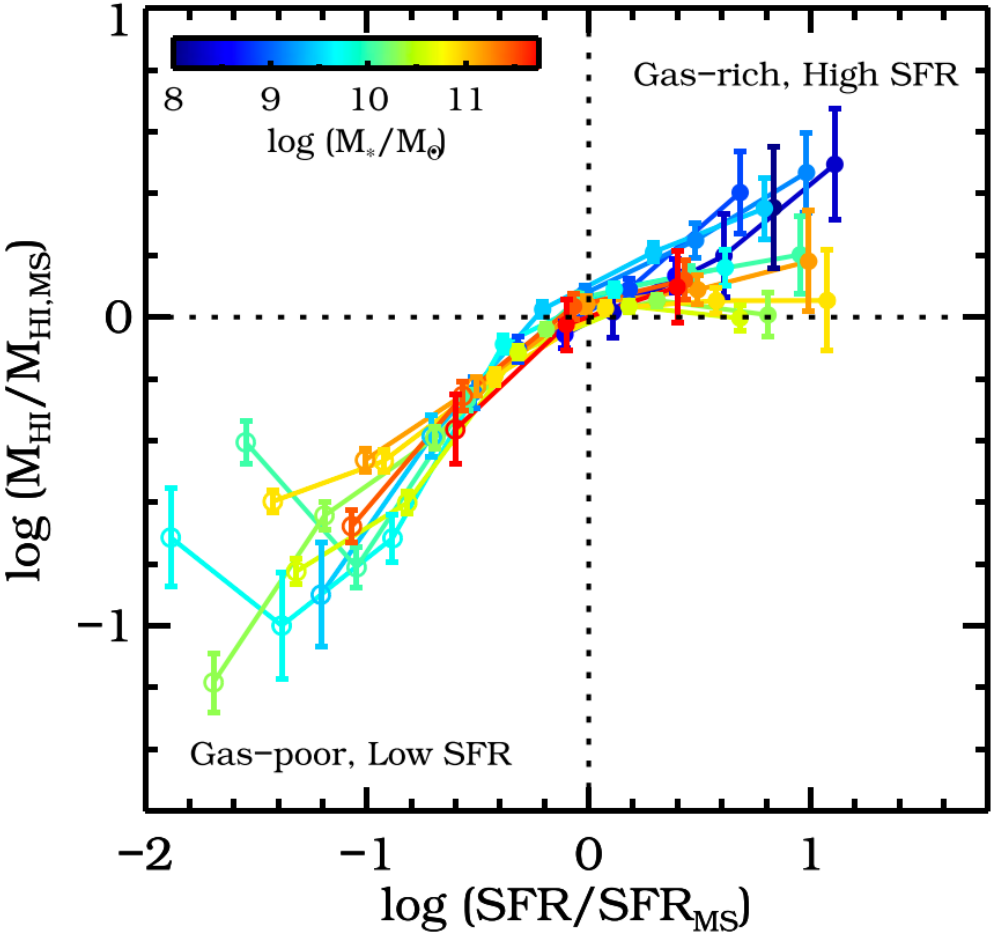
I. Background and Goal



Man, A., & Belli, S. 2018

AGN feedback is thought to be one of the most effective quenching scenarios.

I. Background and Goal

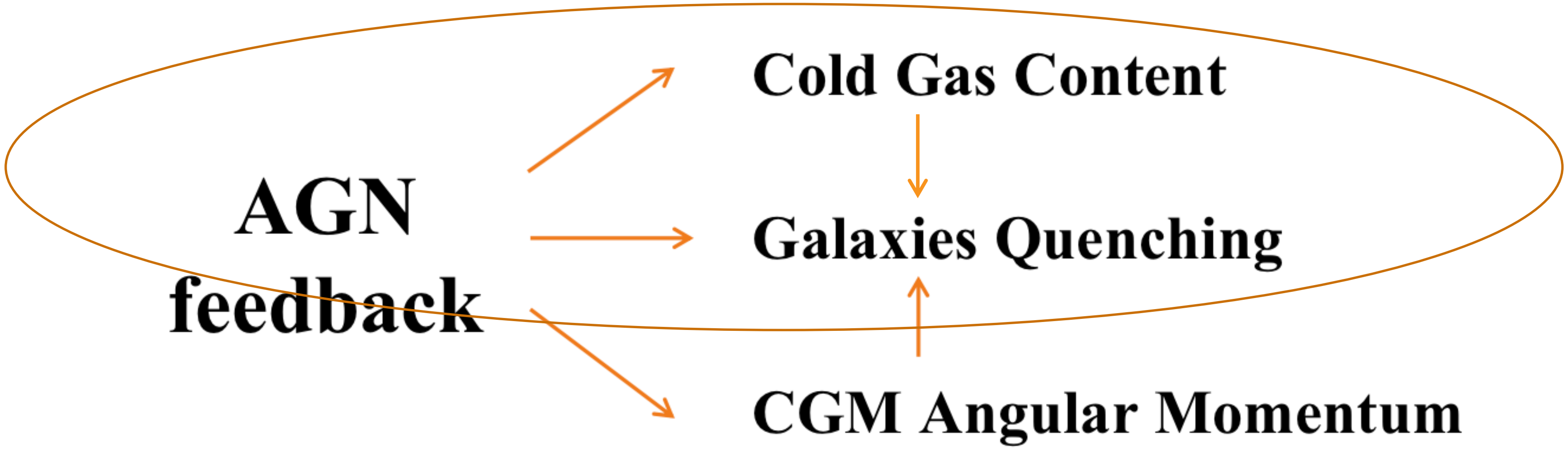


Guo et al. 2021

SDSS & ALFALFA

The HI masses are decreased with SFR, concluding that the cold gas depletion is the main reason of quenching.

I. Background and Goal



AGN feedback

Cold Gas Content

Galaxies Quenching

CGM Angular Momentum

- Simulations vs Observations (Guo 2021)

II. Simulations and Data

- Data we use: TNG100 & SIMBA100

- Illustris-TNG:

  thermal mode: heat and ionize cold gas

  ↓ $\log M_{BH}/M_{sun} > 8.2$

  kinetic mode: random wind

- SIMBA:

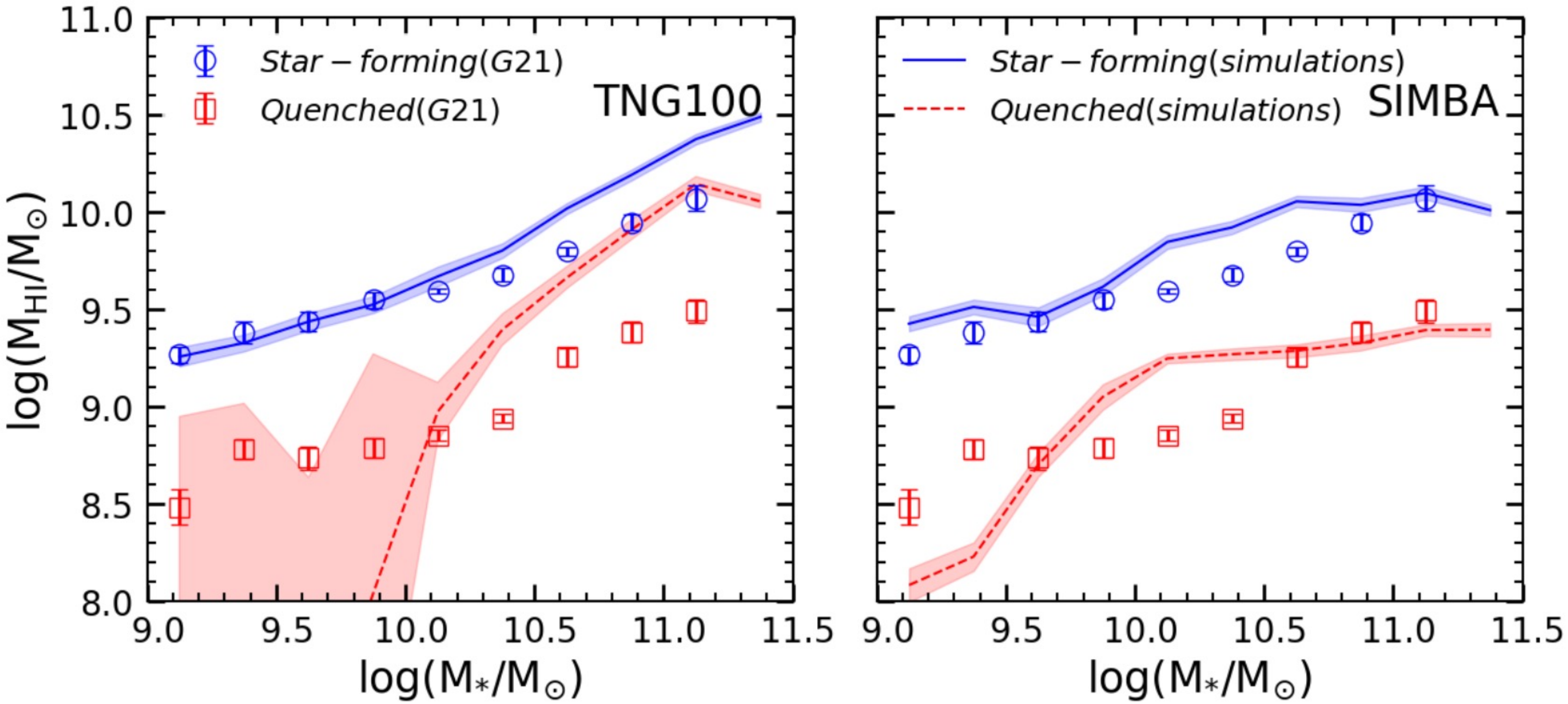
  quasar mode: outflow with low velocity

  ↓ $\log M_{BH}/M_{sun} > 7.5 \ \& \ f_{edd} < 0.2$

  jet mode: bioplar jet

III. HI--Stellar Mass Relation

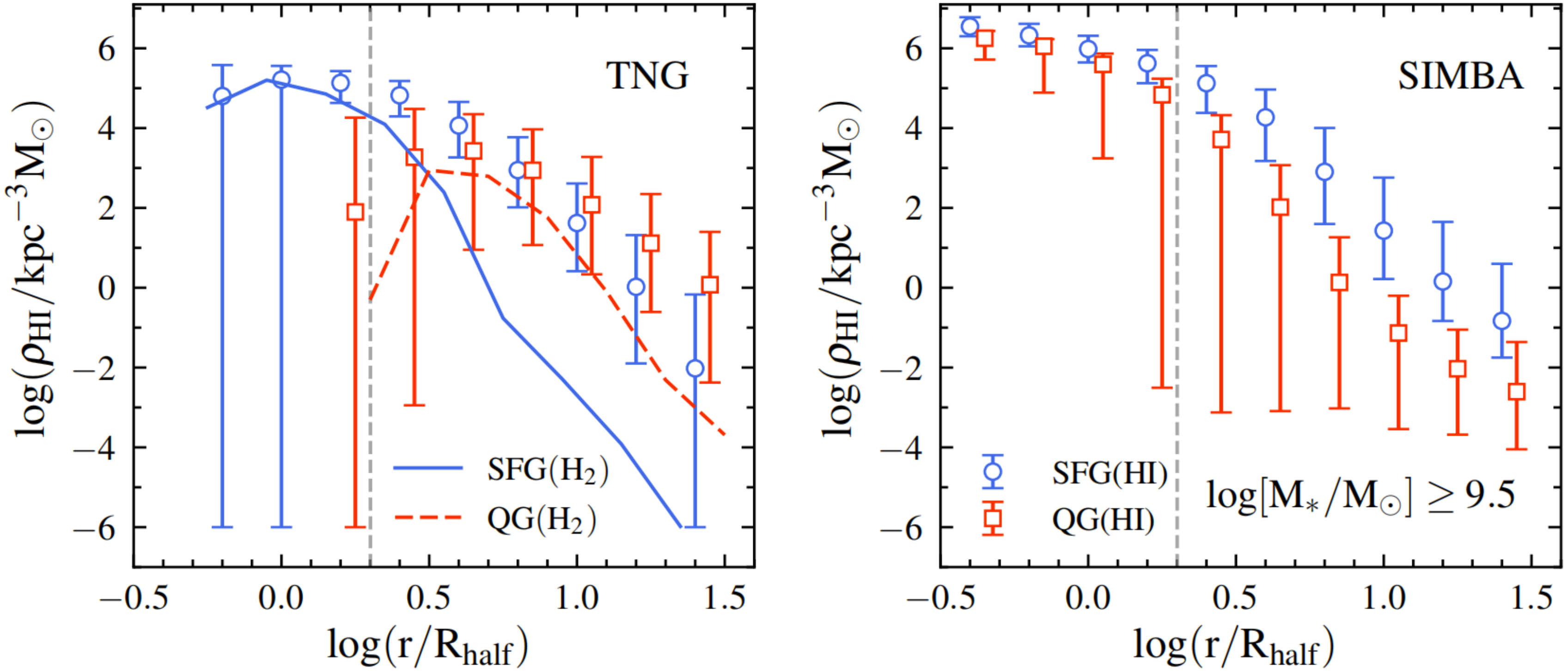
Ma et al. 2022



- TNG agrees with the HI observations in small SFGs, but over-predicts MHI for massive galaxies.
- SIMBA shows the better agreement.

III. Cold Gas Density Profile

Ma et al. 2022



SIMBA: quenched galaxies have lower HI mass density than the star-forming galaxies.

TNG: quenched galaxies have lower mass densities in the inner, but much higher in the outer.

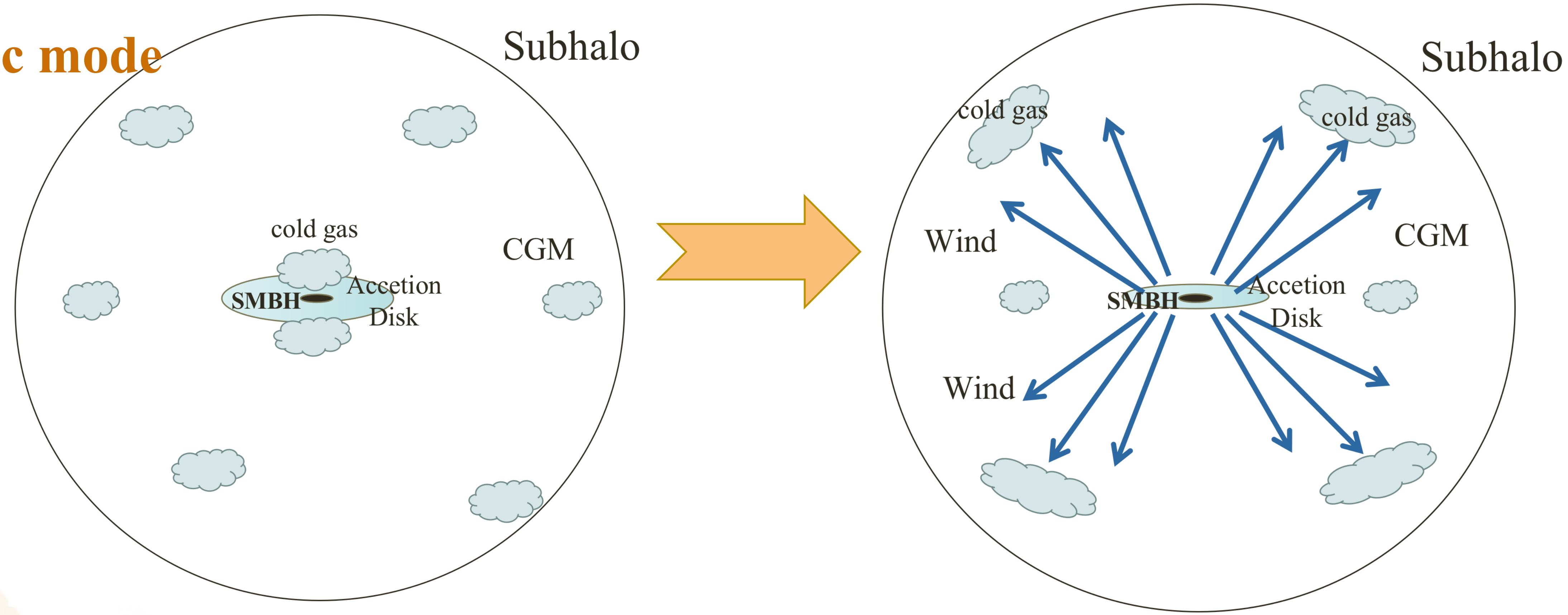
These differences are caused by AGN feedback scenarios.

III. Cold Gas Density Profile

These differences are caused by AGN feedback scenarios!

TNG

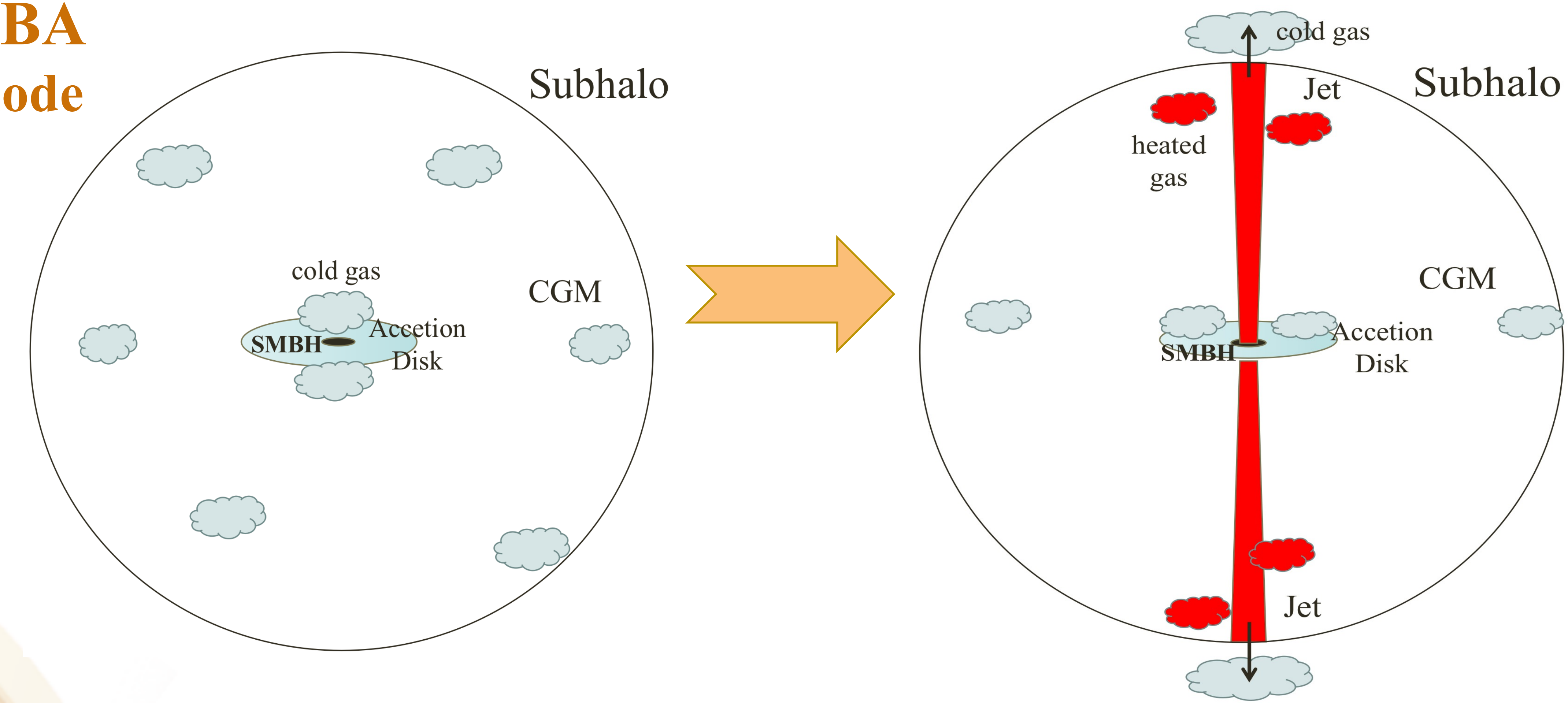
kinetic mode



III. Cold Gas Density Profile

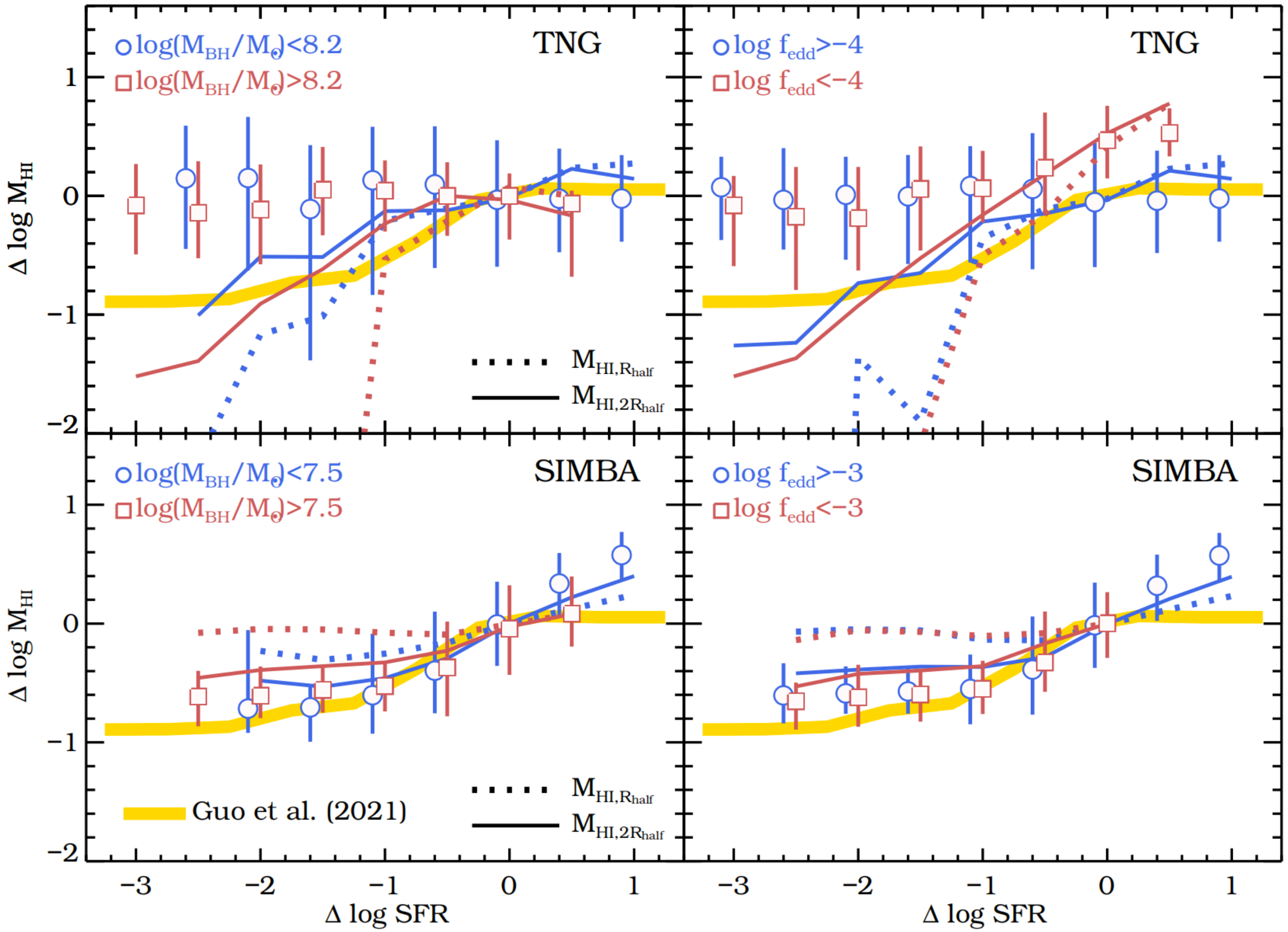
These differences are caused by AGN feedback scenarios!

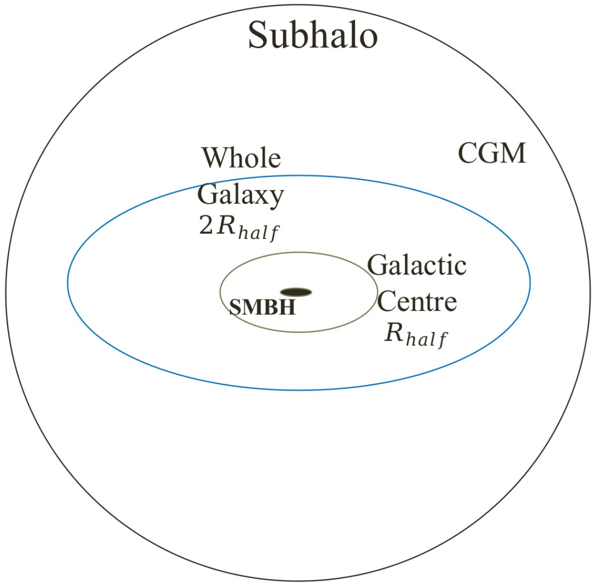
SIMBA
jet mode



III. Black Hole Accretion and AGN feedback

Ma et al. 2022





Galaxy quenching is generally achieved by the cumulative energy (M_{BH}) released from AGN rather than instantaneous feedback ($\dot{M}_{BH}$).

$$\Delta \log \mathrm{SFR} = \log \mathrm{SFR} - \log \mathrm{SFR}_{MS}$$

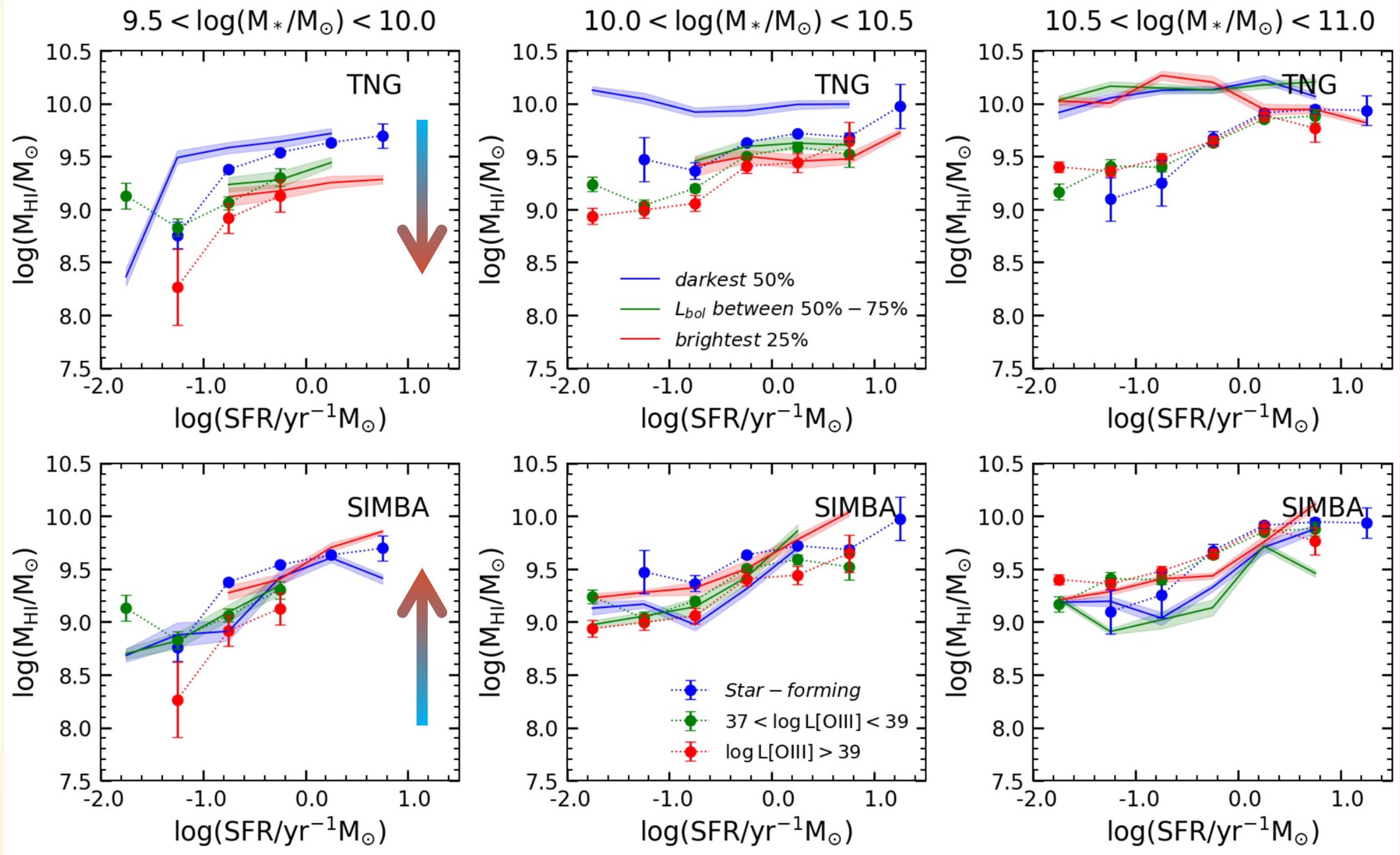
$$\Delta \log M_{HI} = \log M_{HI} - \log M_{HIMS}$$

quenched galaxies : $\Delta \log \mathrm{SFR} < -1$

star-forming galaxies : $\Delta \log \mathrm{SFR} > -1$

III. Black Hole Accretion and AGN feedback

Ma in prep



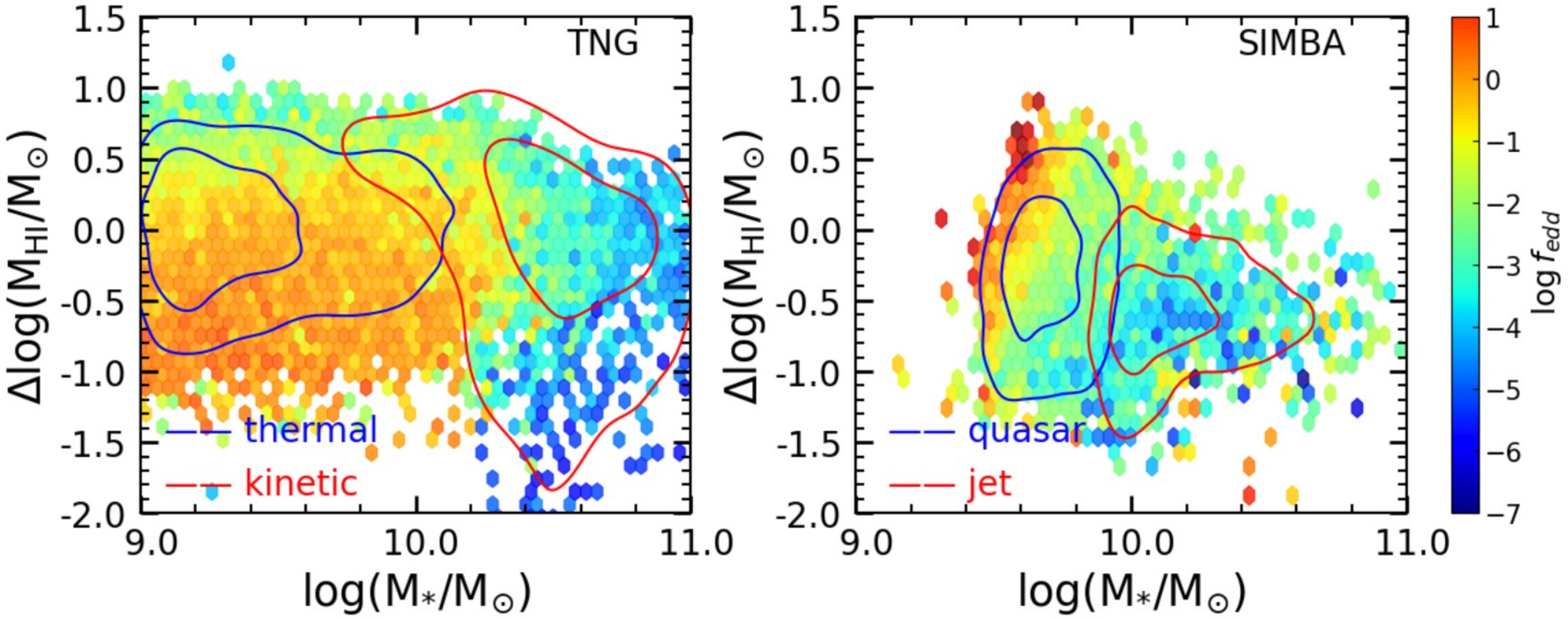
For small galaxies

- **TNG:** High L_{bol} may reduce HI, which agrees with observations.
- **SIMBA:** High L_{bol} prefers to retain more HI gas.

$$L_{\rm bol} = \epsilon_r \dot{M}_{\rm accr} c^2$$

III. Black Hole Accretion and AGN feedback

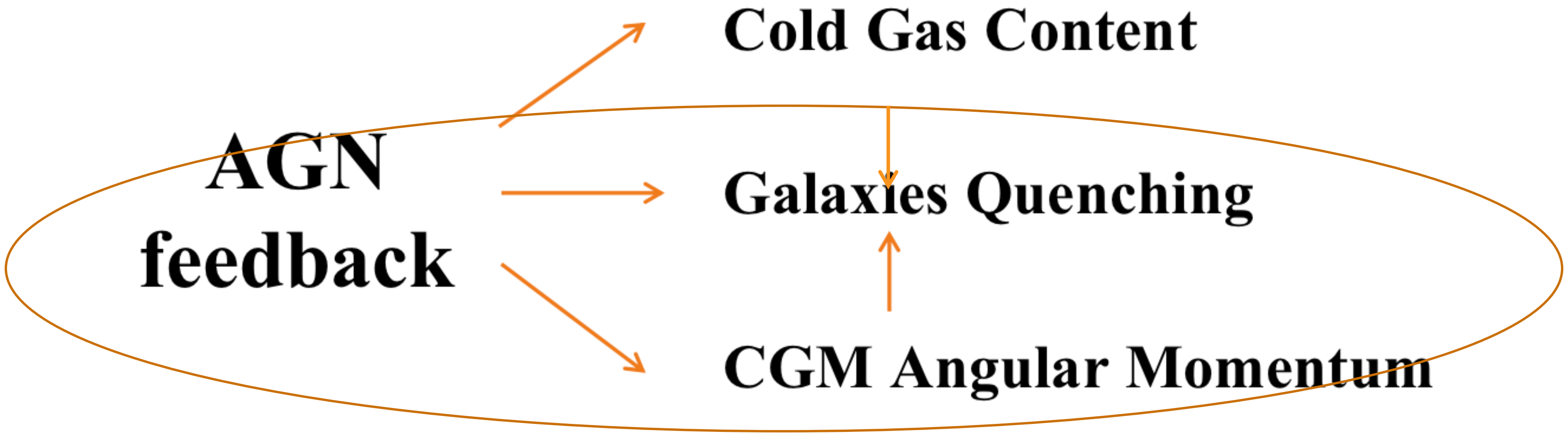
Ma in prep



- For small galaxies, thermal mode in TNG is more efficient to reduce HI gas.

IV. Summary

- Galaxy quenching is generally achieved by the cumulative energy released from AGN feedback.
- AGN feedback models in two simulations have different impacts on galaxies cold gas content and distribution.



AGN feedback

Cold Gas Content

Galaxies Quenching

CGM Angular Momentum

SIMBA: The Effect of CGM Angular Momentum on Galaxy Quenching

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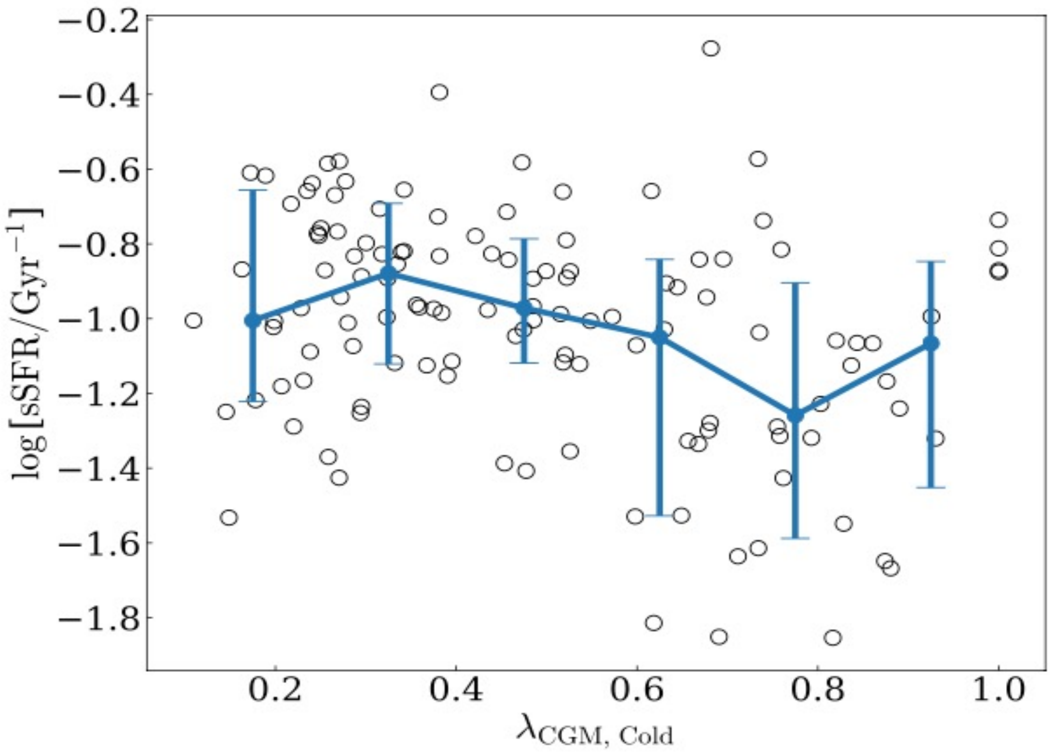
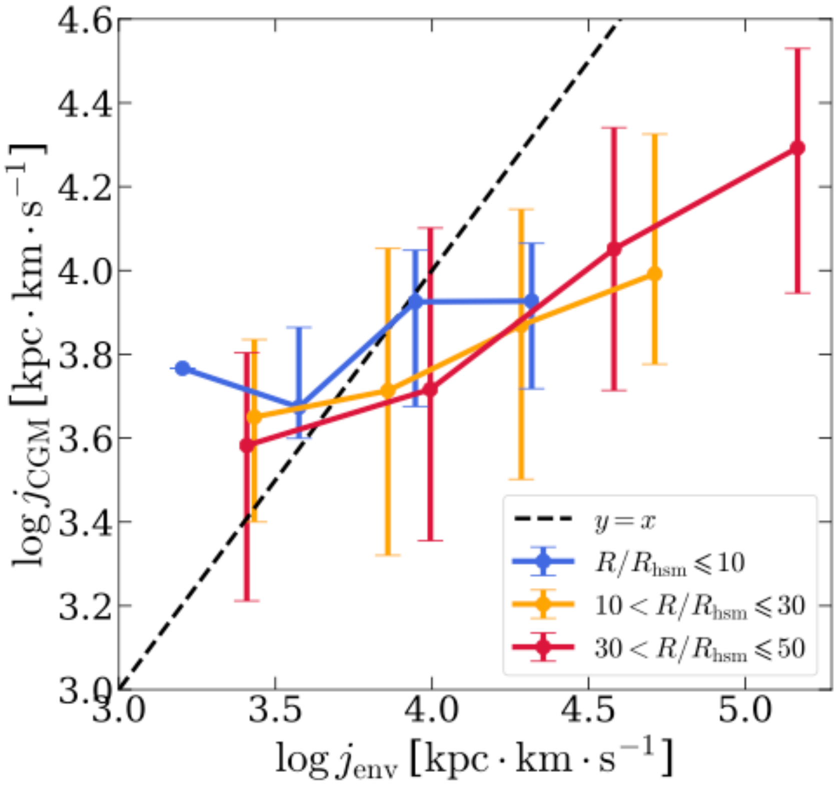
I. Background and Goal

Large-scale environments affect galaxy star formation via Circum-galactic Medium (CGM)





sSFR--- λ_{CGM} anti-correlation,

"**Angular Momentum Quenching** "

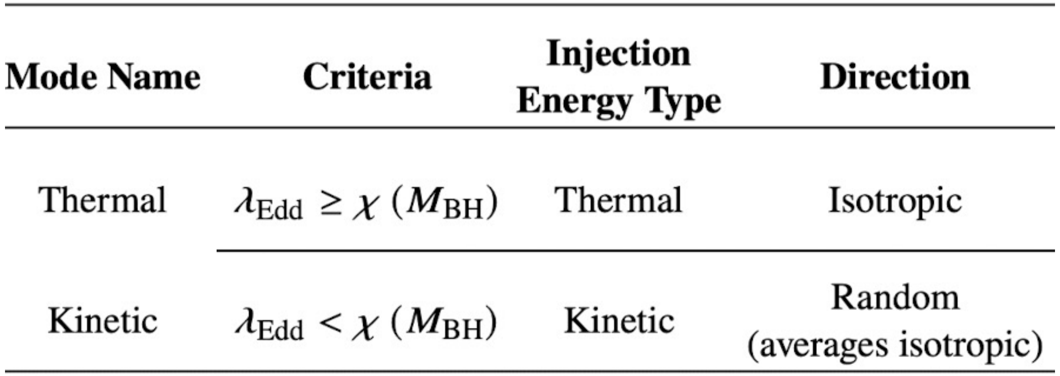
(Xu et al.2021)

j_{CGM}---j_{env} positive correlation, **large scale environments modulate angular momentum of CGM.**

(Wang et al.2022)

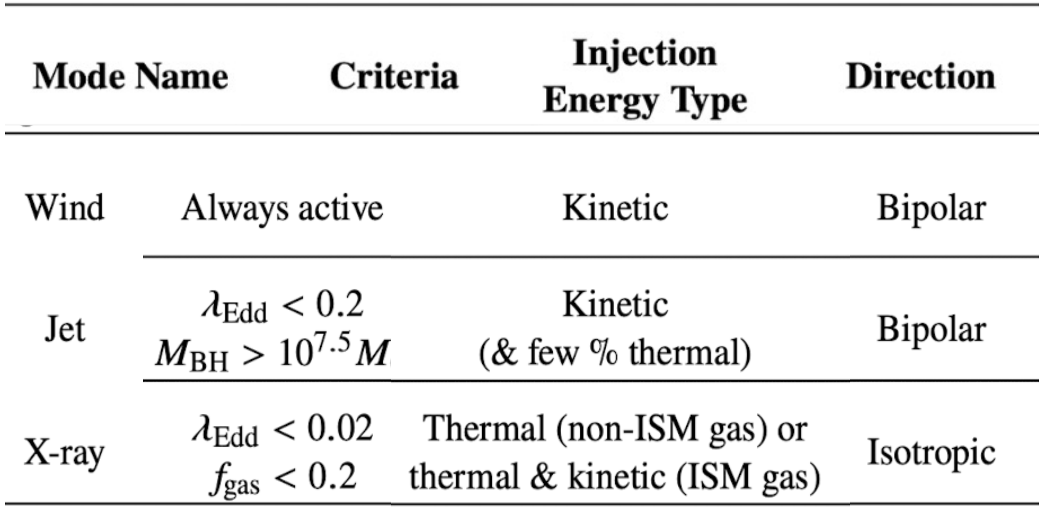
II. Simulations

TNG:

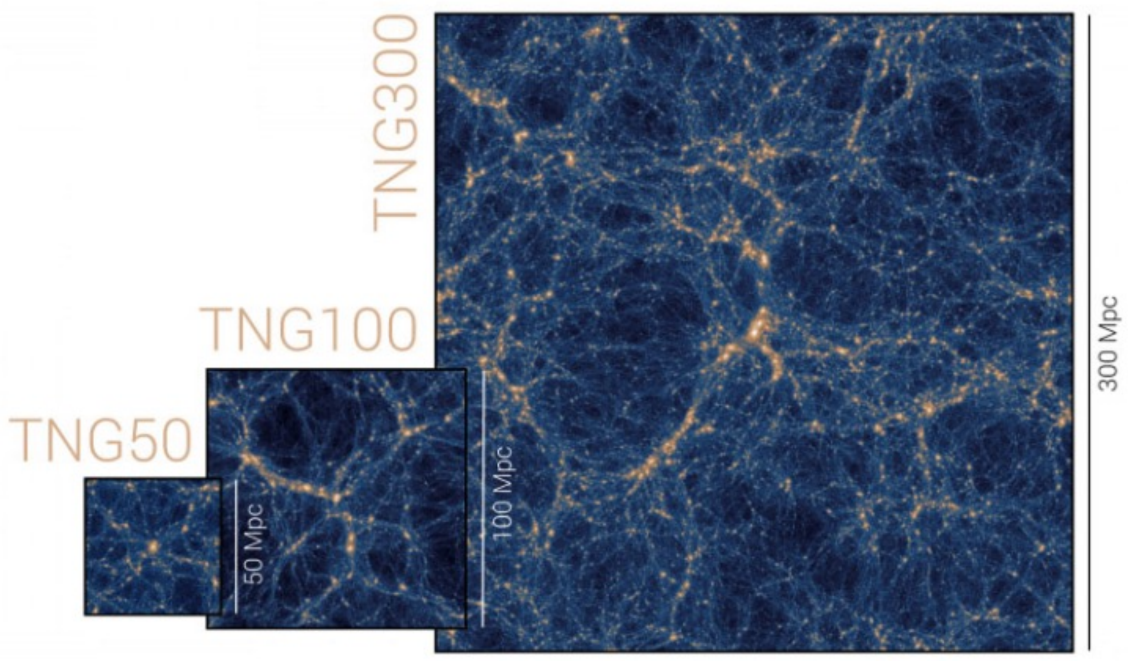


Mode Name	Criteria	Injection Energy Type	Direction
Thermal	$\lambda_{\mathrm{Edd}} \geq \chi\,(M_{\mathrm{BH}})$	Thermal	Isotropic
Kinetic	$\lambda_{\mathrm{Edd}} < \chi\,(M_{\mathrm{BH}})$	Kinetic	Random (averages isotropic)

SIMBA:



Mode Name	Criteria	Injection Energy Type	Direction
Wind	Always active	Kinetic	Bipolar
Jet	$\lambda_{\mathrm{Edd}} < 0.2$ $M_{\mathrm{BH}} > 10^{7.5} M$	Kinetic (& few % thermal)	Bipolar
X-ray	$\lambda_{\mathrm{Edd}} < 0.02$ $f_{\mathrm{gas}} < 0.2$	Thermal (non-ISM gas) or thermal & kinetic (ISM gas)	Isotropic



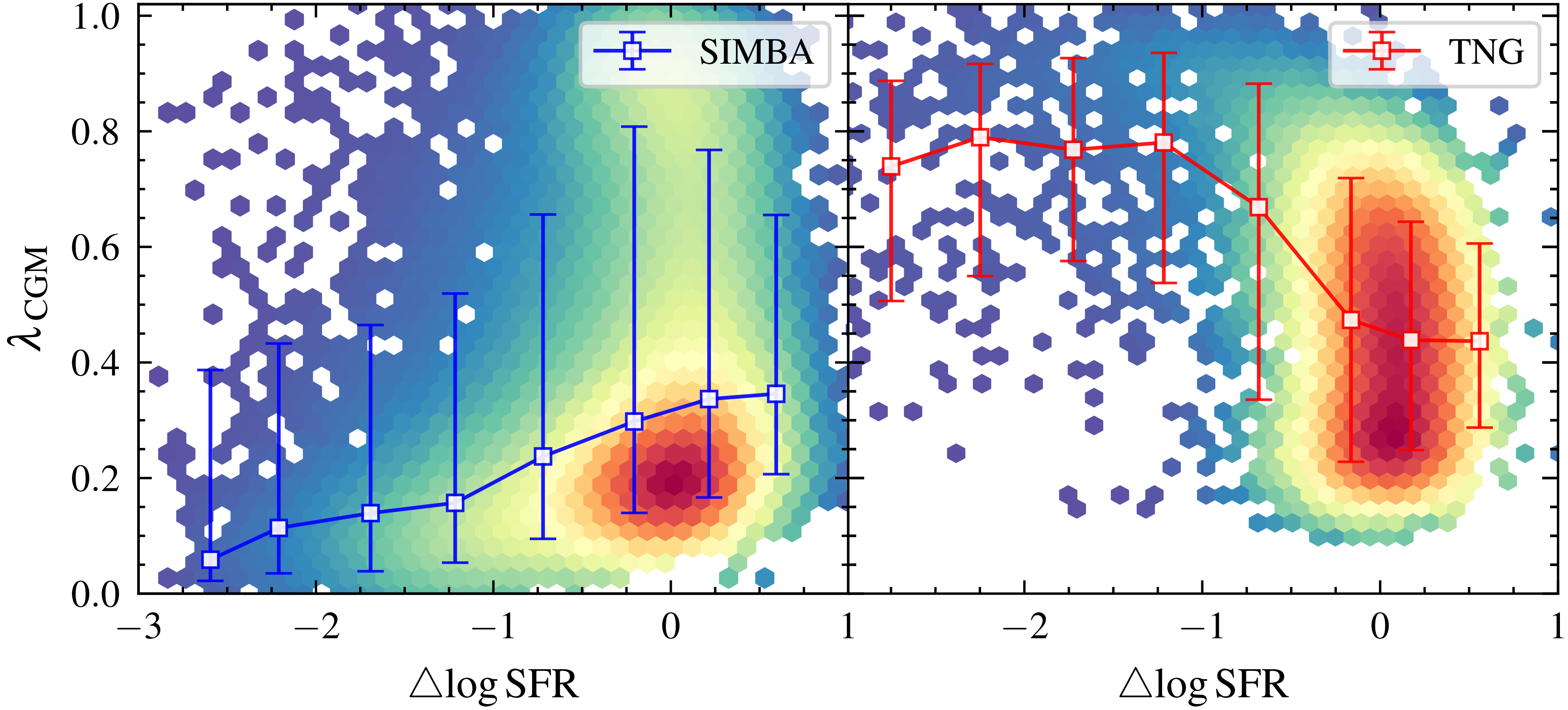
-The TNG Collaboration

Figure: The Next Generation Illustris Simulations (TNG)
(tng-project.org)

Table: S. R. Ward et al. 2022

III. λ_{CGM} vs. ΔSFR

$$\lambda_{CGM} = \frac{\Sigma_i\, m_i\, v_{t,i}^2/[GM(\leq r_i)/r_i]}{\Sigma_i\, m_i}$$



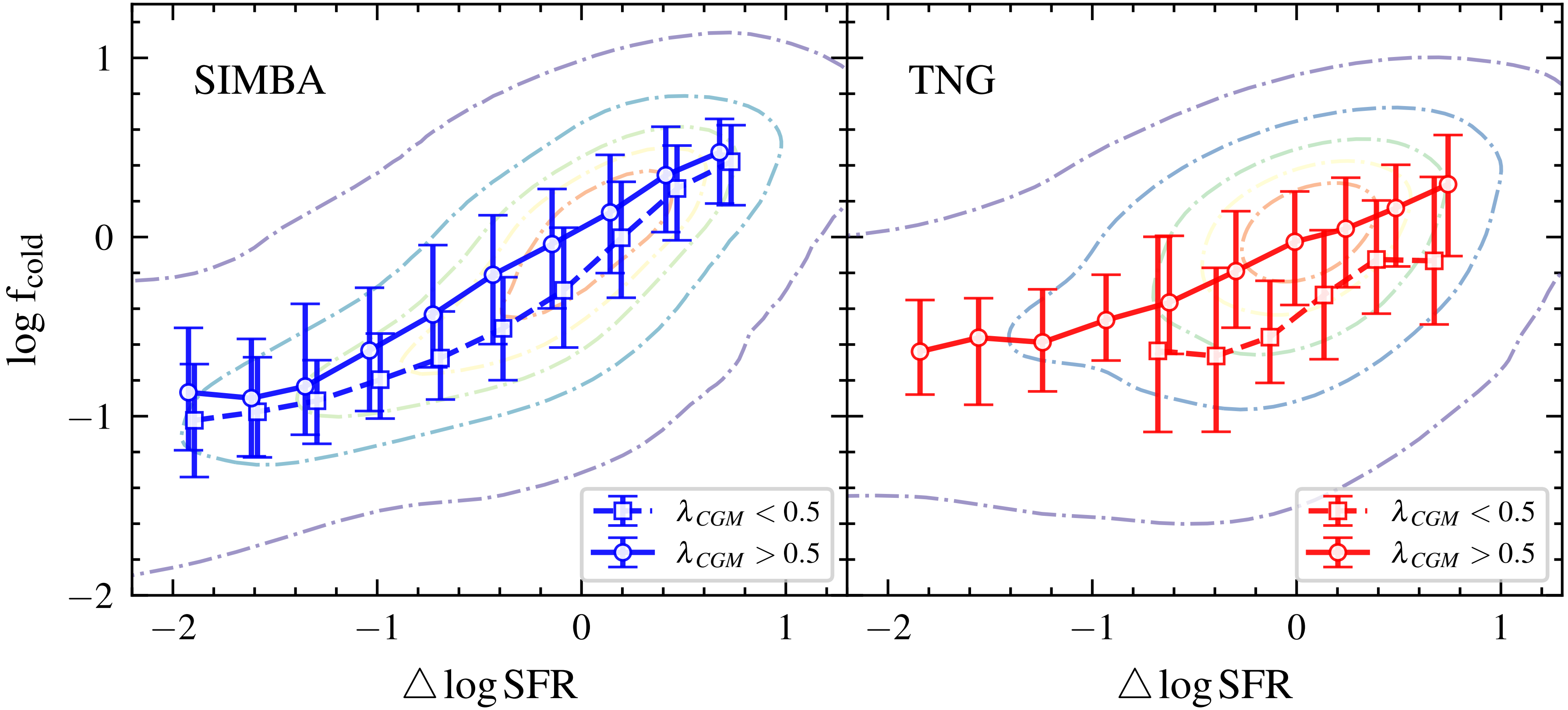
- **ΔSFR**: SFR offset from SFMS at fixed stellar masses.
- Circum-galactic medium (CGM):

$2R_{hsm}$ --- 100 kpc

No declining trend in SIMBA

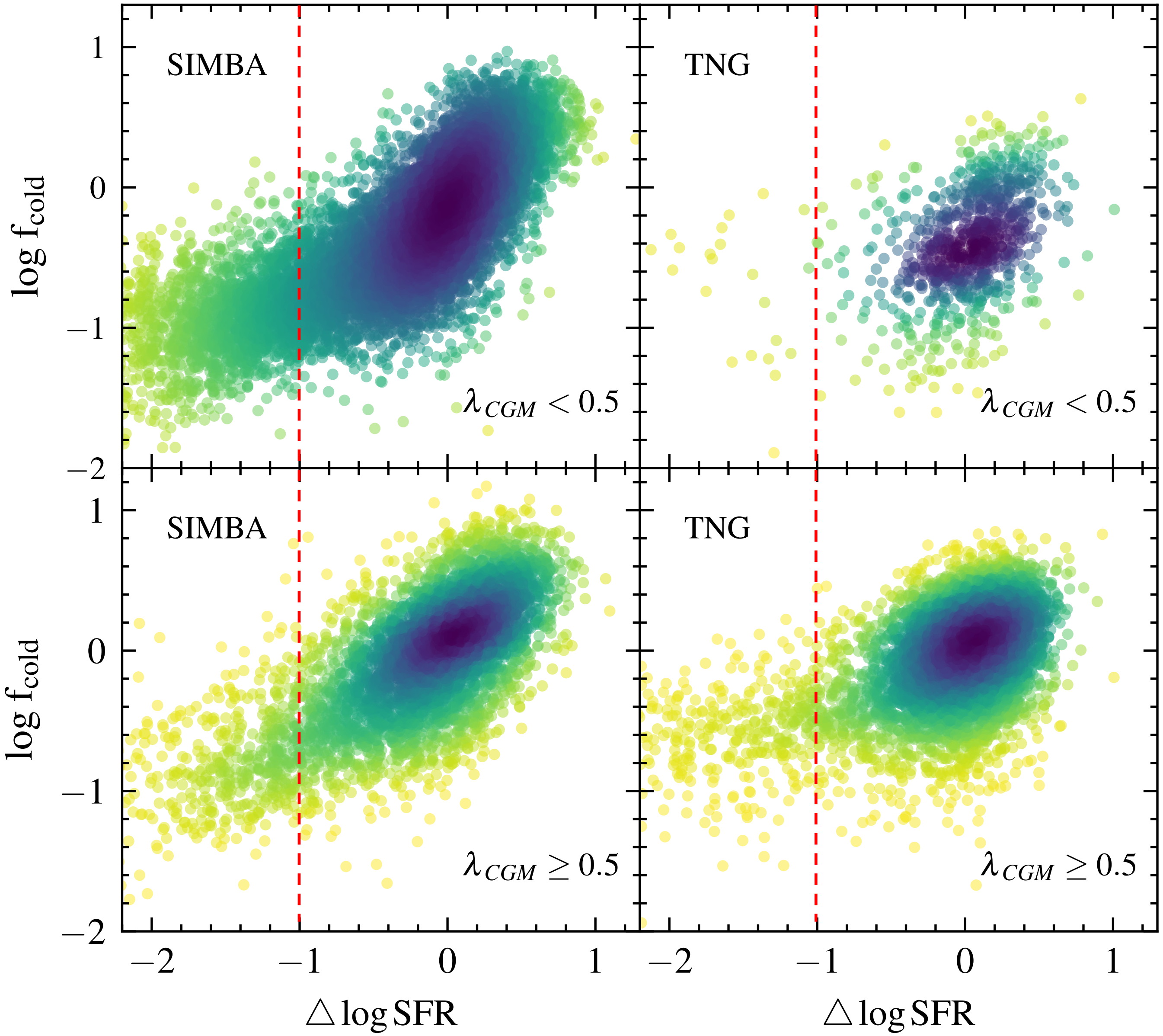
III. Cold Gas Fraction vs. ΔSFR

Cold phase: $10^4K < T < 2\times10^4K$



- In the same cold gas level, high CGM angular momentum is accompanied with relatively low SFR, which is obvious in TNG but slight in SIMBA.

III. Number Density Distribution in f_{cold}---ΔSFR

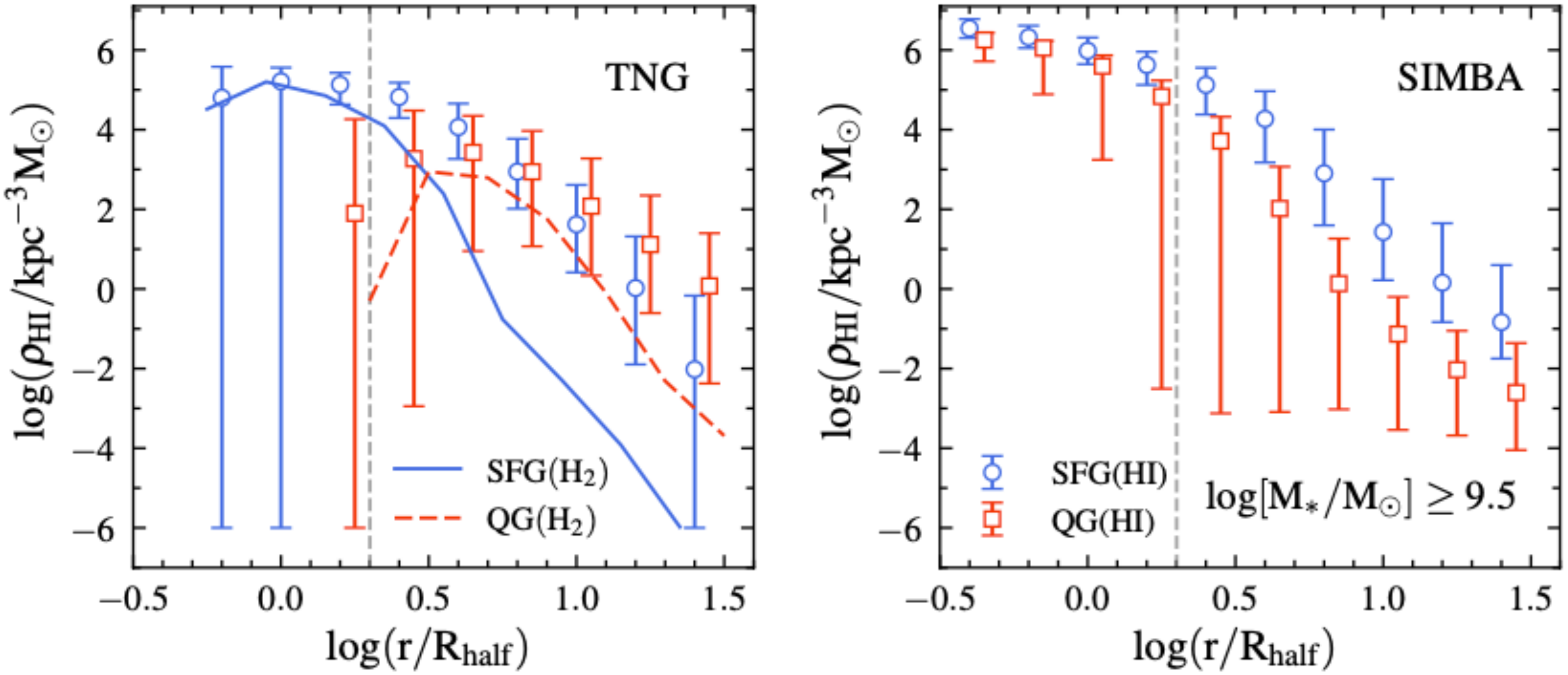


Distribution of quenched galaxies

- SIMBA: High spin less than low spin, high spin indicates gas rich.
- TNG: High spin more than low spin

CQs: Quenched but dynamically cold galaxies. (Lu et al. 2021)

III. Cold Gas Density Profile

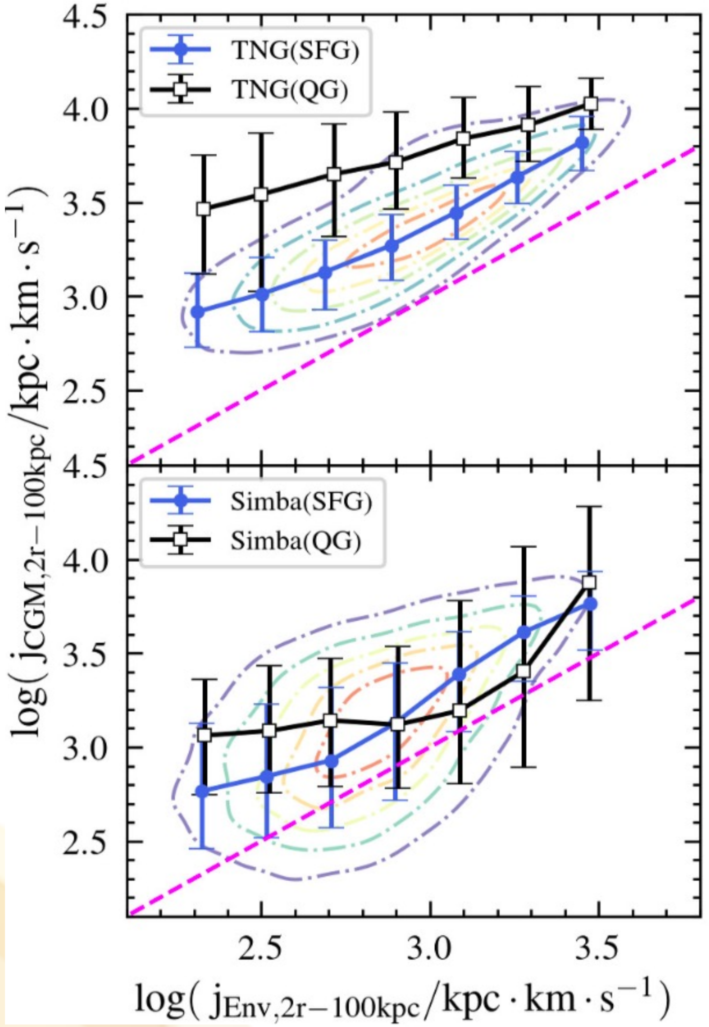


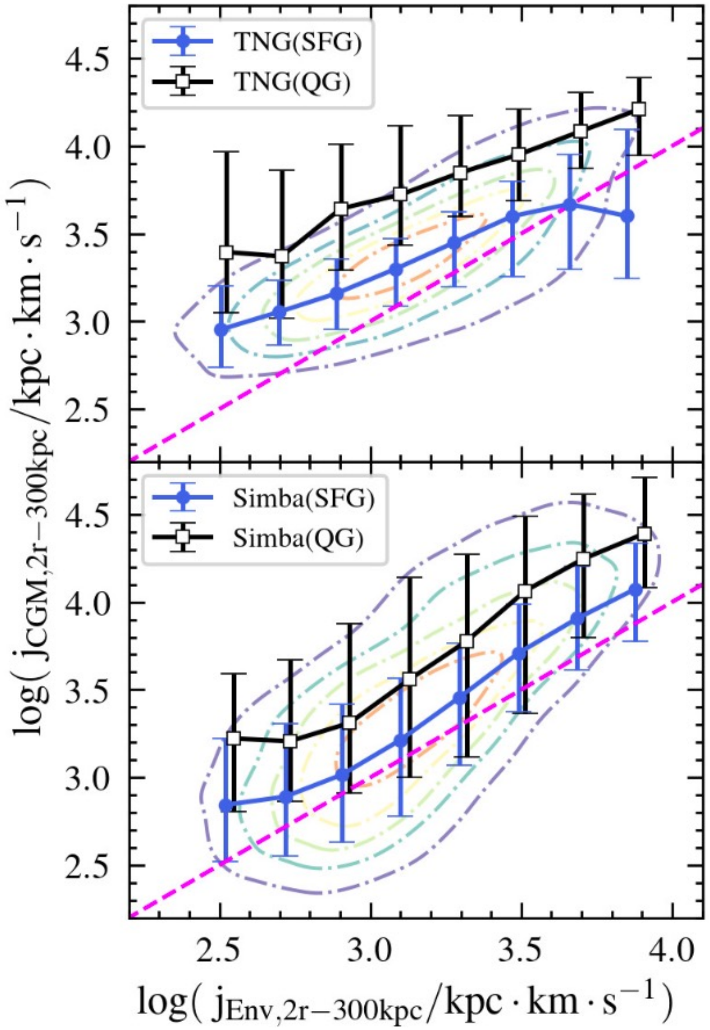
Cold gas density profile.

(Wenlin Ma, Kexin Liu et.al., 2022)

III. j_{CGM} vs. j_{env}

$$\mathbf{j_x} = \frac{\sum_\mathbf{i} \mathbf{m_i}\, \mathbf{r_i} \times \mathbf{v_i}}{\sum_\mathbf{i} \mathbf{m_i}}, \quad \mathbf{j}_\mathrm{env} = \frac{\sum_i M_{\mathrm{tot},\,i}\, \mathbf{r_i} \times \mathbf{v_i}}{\sum_i M_{\mathrm{tot},\,i}}$$

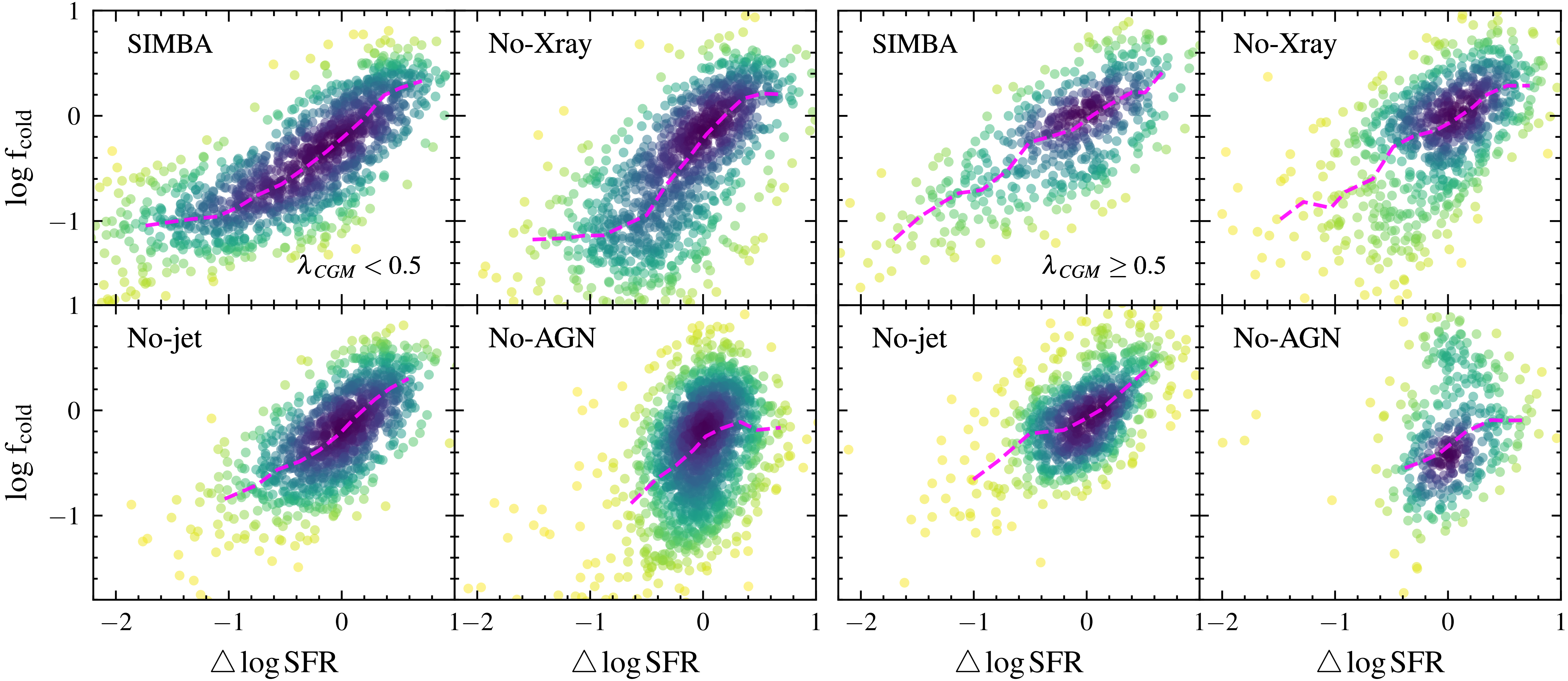




- Based on TNG, high environment angular momentum (j_{env}) brings higher angular momentum to CGM of QG than SFG, which in turn inhibits star formation.
- There is no obvious preference for the effects of large-scale environments on CGM when considering large errorbar in SIMBA.

IV. Results based on SIMBA50

No-Xray, No-jet, No-AGN



V. Summary

- SIMBA agrees observations better for $M_{HI} - M_*$ relation . TNG agrees with the observations for small SFGs, but overpredicts M_{HI} for all massive galaxies.
- Kinetic AGN feedback in TNG mainly redistributes the inner gas to the outer, while jet mode in SIMBA reduces over cold content. Because the different impacts of AGN feedback in simulations, we found TNG needs additional mechanism to make galaxy stay quenching ,but SIMBA doesn’t.
- In small galaxies, the effects of AGN feedback on HI gas are opposite. AGNs with higher luminosity will reduce HI efficiently in TNG, while they prefer to retain more HI in SIMBA.

THANKS！

Any questions and comments are highly welcome!