



Circumgalactic Medium : How to probe?

I. What is Circumgalactic Medium (CGM)?

- Diffuse gas surrounding a galaxy.
- Reservoir of matter & energy with complex dynamics.
- Multiphase (hot & cold) ionization structure¹.

It fuels **star formation** & **regulates** feedback in galaxy.

II. How to probe CGM?

- We focused on hot ($T \geq 10^6$ K) gas of the CGM surrounding low-redshift ($z = 0, 0.1$ and 0.2) galaxies.
- Multiwavelength observation is crucial for this purpose.

We characterized the X-ray signature of hot CGM using a cosmological simulation.

III. How to get galaxy in the IllustrisTNG 100-2 simulation

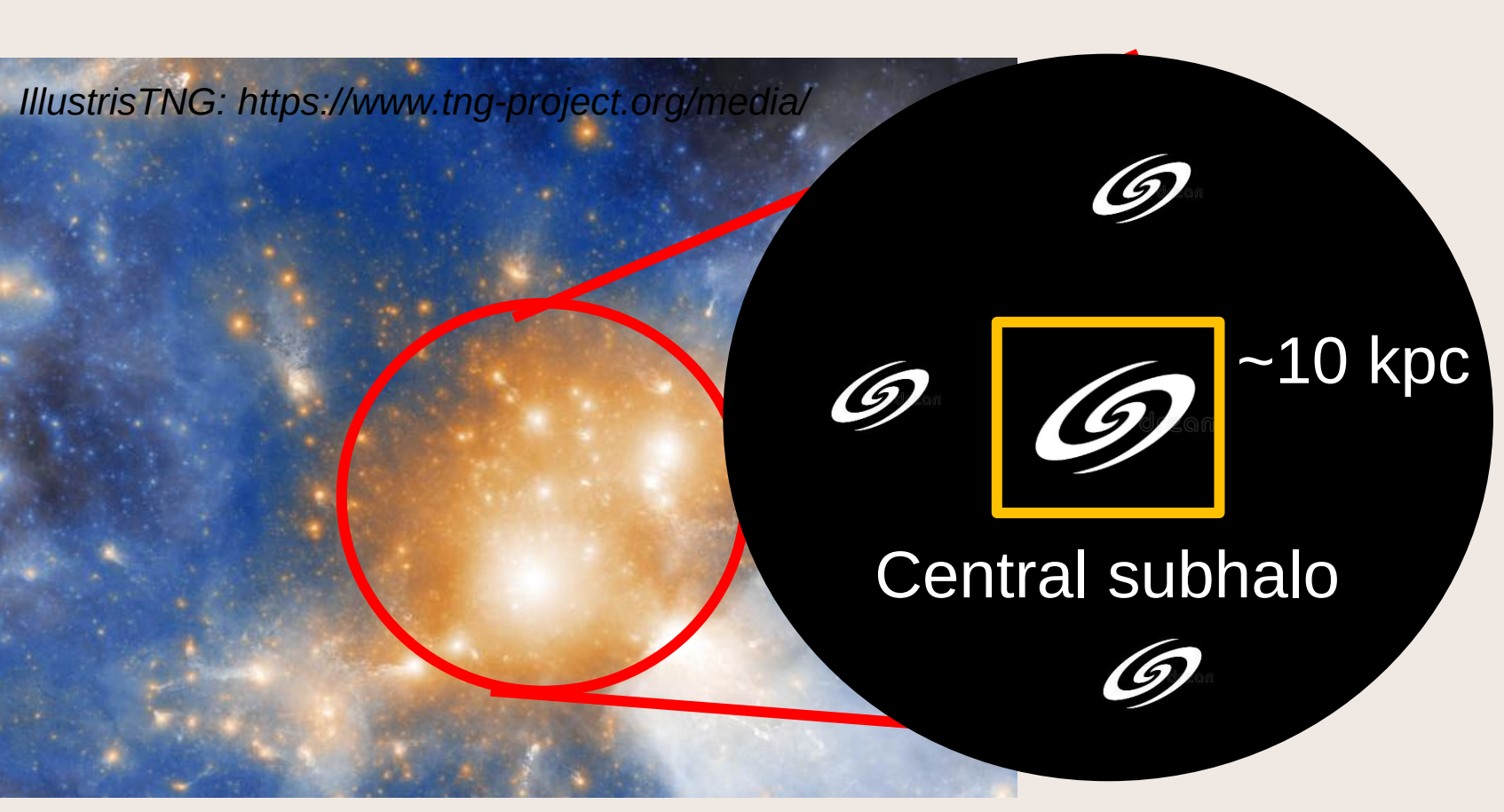


Fig 2. Visualizing dark matter halos (orange) within massive galaxy groups(left) and dark matter halo (Right)

IllustrisTNG²⁻⁶ is a sophisticated cosmological hydrodynamical simulation.

It is used to model the complex physics of gas and dark matter that shapes galaxies.

The central subhalo of each dark matter halo ($10^{11} < M_{500}/M_{\odot} < 10^{13.5}$) is our target.

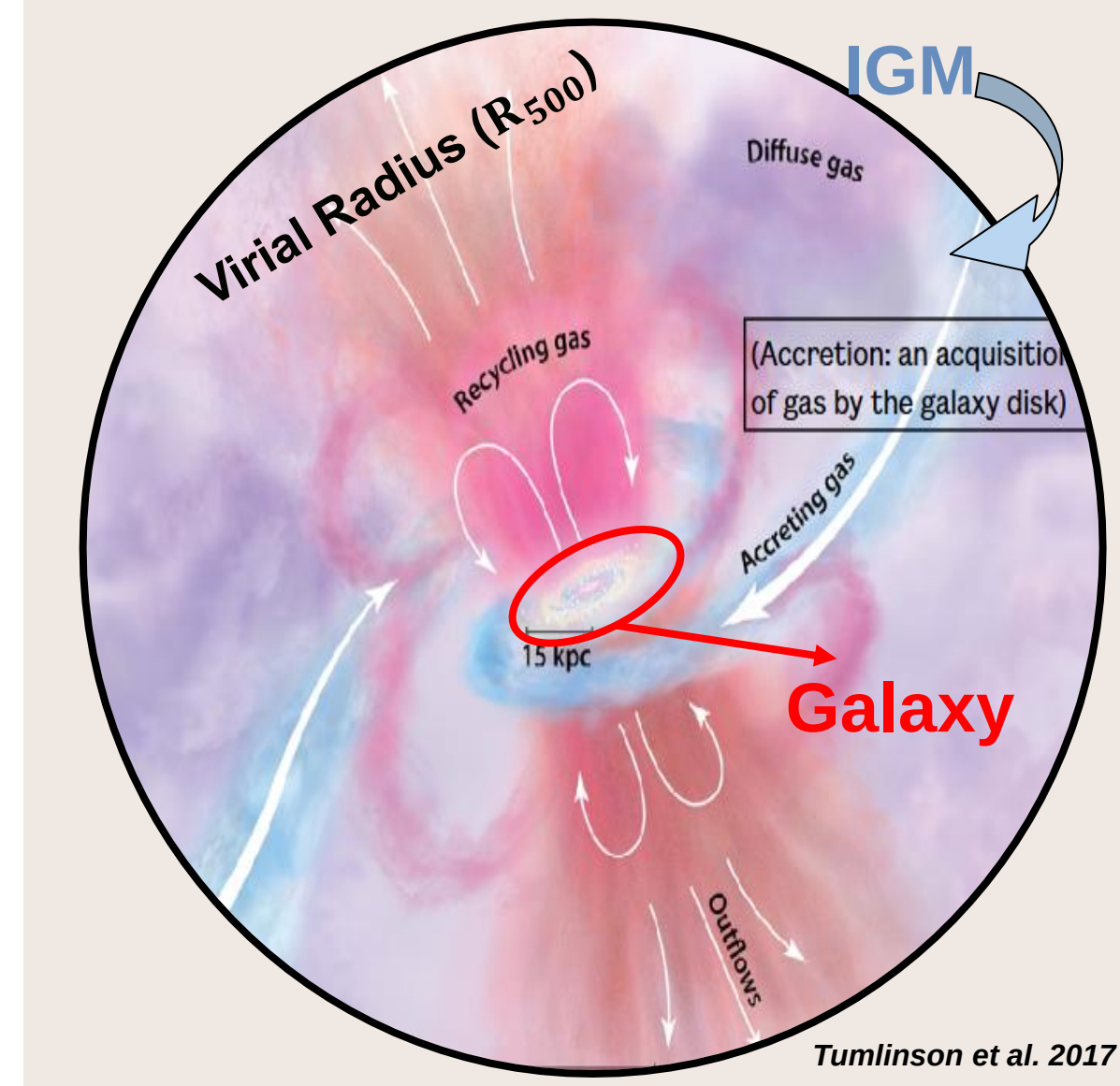


Fig1. Schematic of Circumgalactic Medium.

Galaxy Classification & X-ray Emission Modeling

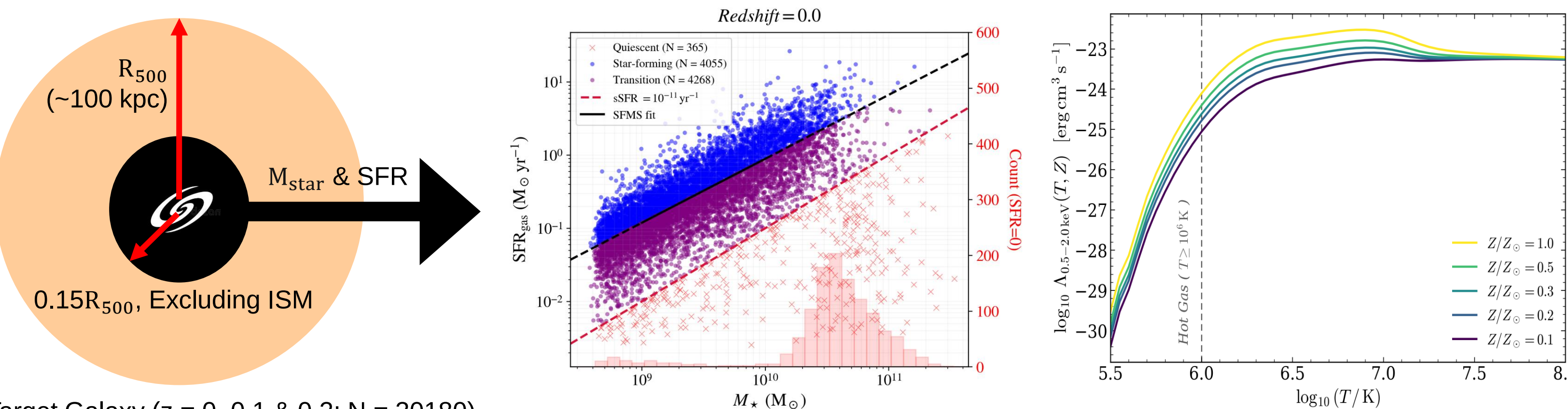


Fig 3. Schematic of CGM in our study(left), galaxy classification at $z = 0$ (middle) and CIE cooling function from APEC model (Right)

We defined CGM as gas cells within $0.15 < r/R_{500} < 1.0$ from the center.

- Galaxies are classified broadly following [7], into **quiescent** (QU; $sSFR < 10^{-11} M_{\odot} \text{yr}^{-1}$), **star-forming** (SF; above the SFMS fit) and **transitional** (TR; in between).
- Cooling function ($\Lambda_{\text{gas}}(T, Z)$; $0.5 - 2.0$ keV) is computed through the APEC model of PyAtomDB [8] by assuming collisional ionization equilibrium.
- X-ray luminosity (L_x) is estimated through gas cell-to-cell method: $L_x = n_e n_H \Lambda_{\text{gas}}(T, Z) V$

I. Scaling relation with mass (M_{500} , M_*)

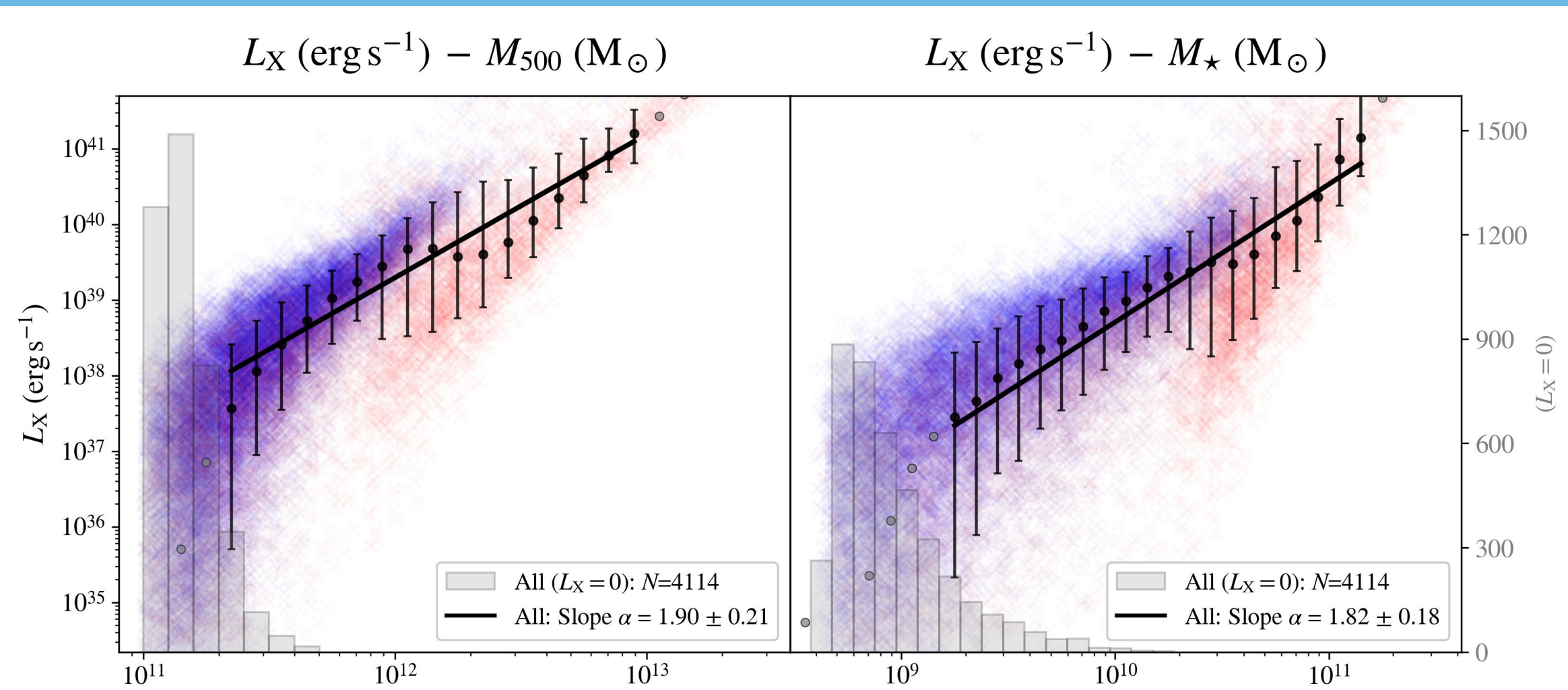


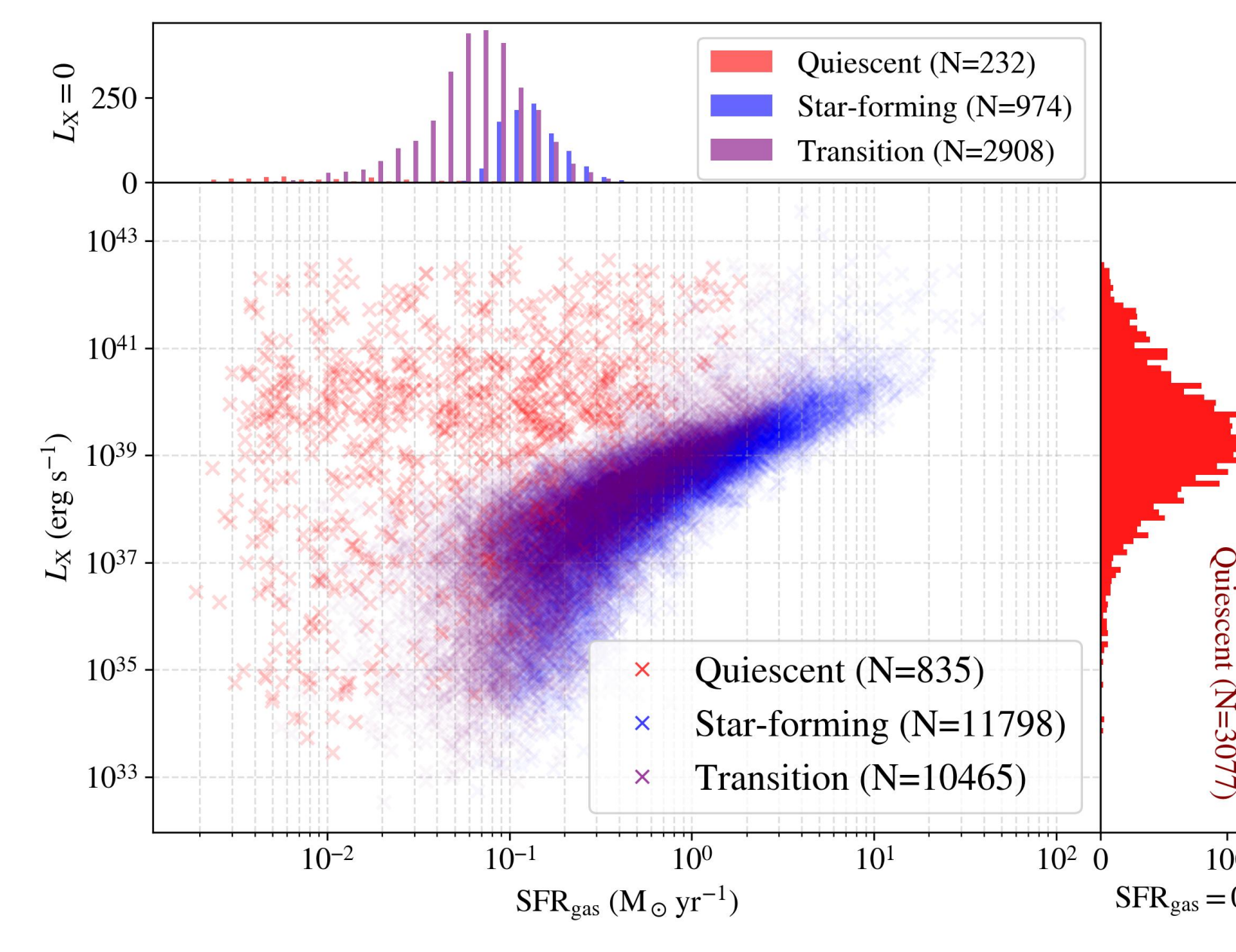
Fig 4. Scaling relation between L_x and M_{500} (left) and M_* (right), α is power law slope.

In each 0.1-dex mass bin, we take the median L_x (including $L_x=0$) & its 16th–84th range.

In MCMC fitting, we get the slope (α) & intercept (β).

- Combined sample: $\alpha = 1.90 \pm 0.21$ (M_{500}), 1.82 ± 0.18 (M_*).
- Comparison with self-similar prediction⁹ ($\alpha=1.5-1.6$): it is steeper by $1.3-1.9\sigma$, suggestive of non-gravitational heating by feedback.
- Each population is steeper still (SF 3.00 ± 0.55 , TR 3.69 ± 0.62 , QU 2.54 ± 0.48): SF and QU occupy offset loci in the $L_x - M_{500}$ plane, so the combined fit blends them.

II. Relation between the L_x and Star Formation Rate



	Star-forming	Transition	Quiescent
N	3,610	3,132	298
r	+0.81	+0.72	+0.37
Partial $r \mid M_{500}$	+0.43	+0.32	+0.01*
Partial $r \mid M_*$	+0.31	+0.28	-0.08*

Fig 5. Correlation between L_x & SFR at $z = 0, 0.1, 0.2$ (left) and its coefficients at $z = 0$ (right). * marks entries that are not significant

We find the clear trend between L_x & SFR especially for **star-forming** and **transition**, which cannot be explained through shared mass-dependence alone.

Star-forming and **transition** galaxies exhibit a strong correlation.

→ It remains significantly positive after controlling for halo mass or stellar mass.

Quiescent galaxies show a near-zero partial correlation.

→ Their weak raw correlation is attributable almost entirely to shared mass dependence.

III. Star Forming vs Quiescent Galaxies in Milky Way-Mass

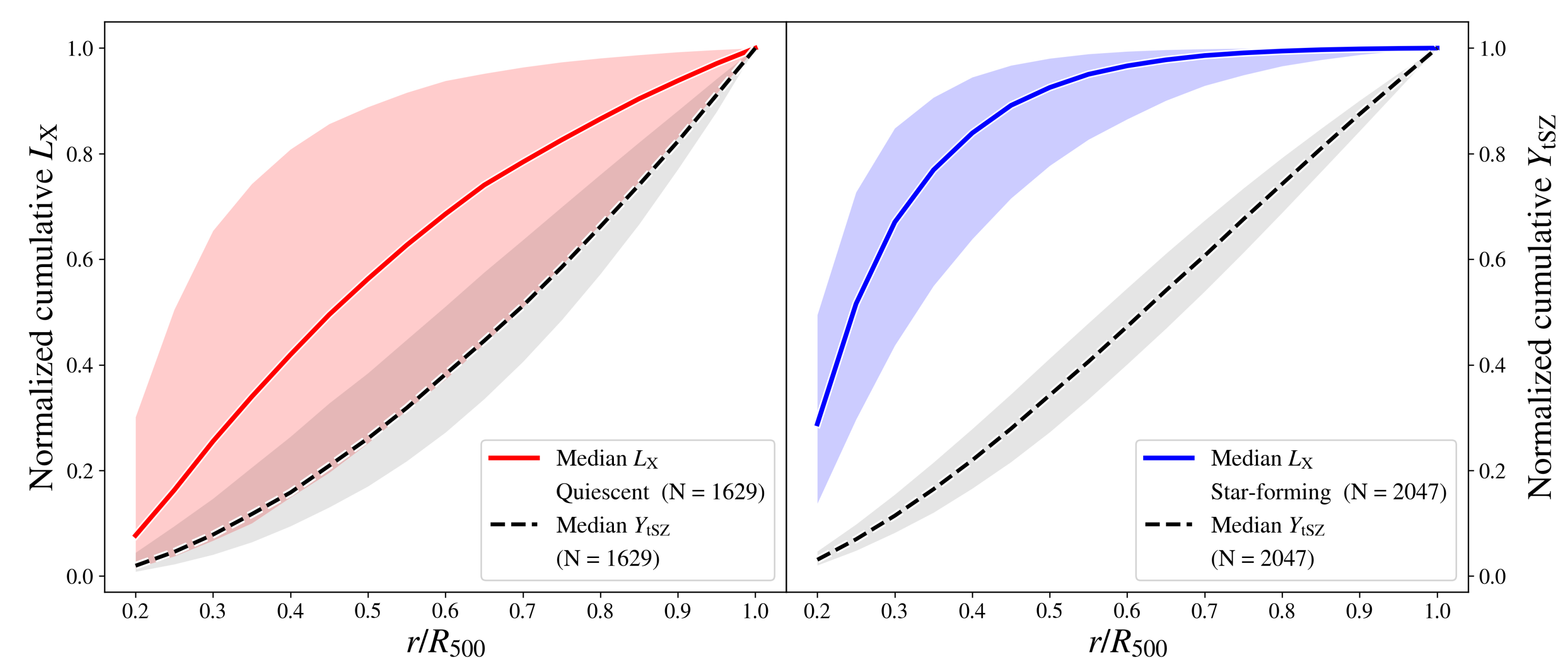


Fig 6. Normalized cumulative radial profiles of L_x (solid) and Y_{tsz} (dashed) for quiescent (left) and star-forming (right) galaxies. Lines show medians and shaded regions the 1 σ scatter.

Among Milky Way-mass galaxies ($10^{11.75} < M_{500}/M_{\odot} < 10^{12.25}$), L_x radial profiles are driven.

- Star-forming** galaxies show more centrally concentrated L_x profiles than **quiescent** systems.
- It is driven primarily up to an order-of-magnitude higher hot-gas density in the inner CGM.

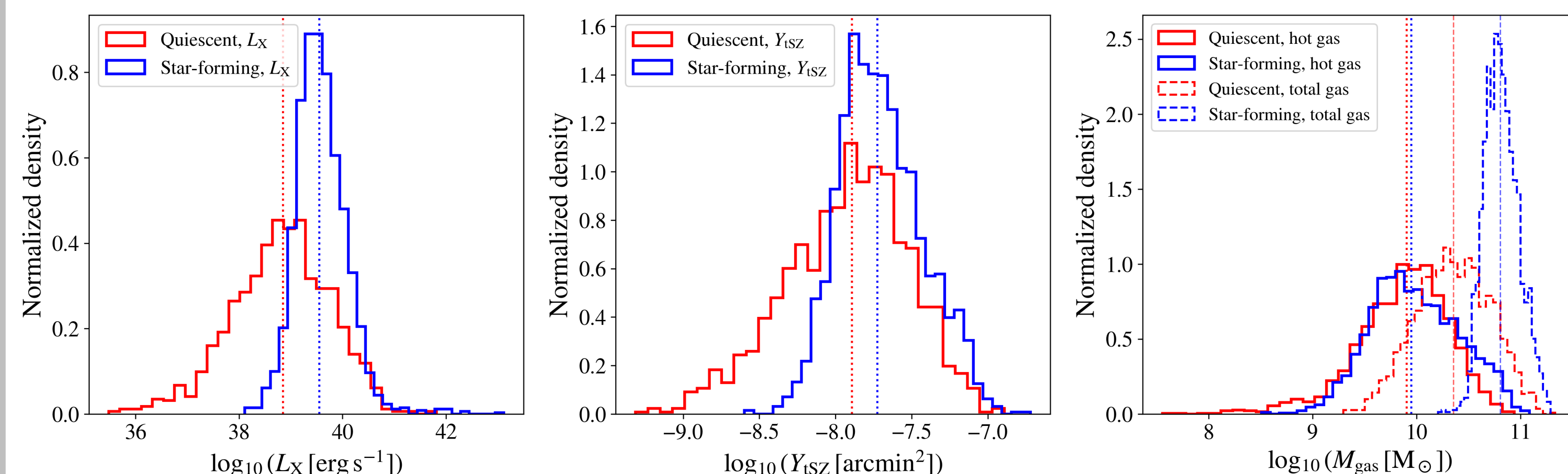


Fig 7. Distributions of L_x (left), Y_{tsz} (middle), and gas mass (right); solid: hot, dashed: total for quiescent (red) and star-forming (blue) galaxies. Dotted lines mark the medians.

We confirmed the **L_x dichotomy**: **Star-forming** galaxies are ~ 5 times luminous that **quiescent** galaxies in the soft X-ray.

- This matches the direction and order of magnitude reported by TNG-based studies^{10,11}.
- While we confirm that quiescent galaxies are depleted in total gas mass (0.45 dex), such depletion is not found in the hot phase specifically.
- Y_{tsz} profiles differ far more mildly. This confirms that the L_x dichotomy reflects the spatial redistribution of hot gas rather than a difference in total thermal energy.
- We propose that gas depletion occurs preferentially in cooler gas, while the hot phase is redistributed rather than removed.

References

[1] Tumlinson, J., et al. 2017, ARA&A, 55, 389 [2–6] Nelson, D., et al. 2018, MNRAS, 475, 624; Springel, V., et al. 2018, 475, 676; Pillepich, A., et al. 2018, 475, 648; Naiman, J. P., et al. 2018, 477, 1206; Marinacci, F., et al. 2018, 480, 5113 [7] Kim, J., et al. 2022, ApJ, 926, 179 [8] Foster, A. R., & Heuer, K. 2020, Atoms, 8, 49 [9] Lovisari, L., et al. 2021, Universe, 7, 139 [10] Truong, N., et al. 2020, MNRAS, 494, 549 [11] Oppenheimer, B. D., et al. 2020, ApJ, 893, L24

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Discussion

Two modes of hot CGM

- In **star-forming** galaxies, star formation (stellar feedback) is active and hot gas is denser in the inner CGM. This yields brighter, compact emission and L_x –SFR link that mass alone cannot explain.
- In **quiescent** galaxies, AGN kinetic feedback has likely pushed gas outward, leaving an extended, low-density hot atmosphere whose L_x follows halo mass rather than SFR.

Location of gas is significant: Hot-gas mass and Y_{tsz} are similar, yet L_x differs by ~ 5 times. $L_x \propto n_e^2$ traces how hot gas is distributed, $Y_{\text{tsz}} \propto n_e T$ traces its thermal energy.

Caveats: Intrinsic, unstacked 3D emission from a single model (TNG100-2) is sensitive to the subgrid feedback, and not directly comparable with stacked, projected eROSITA profiles.

Outlook: SF–QU contrast at fixed halo mass can be tested by stacking eROSITA survey data; resolved profiles of individual halos await NewAthena and proposed missions such as HUBS.