Probing Hot Gas Components of the Circumgalactic Medium through X-ray Signatures

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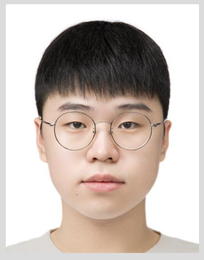
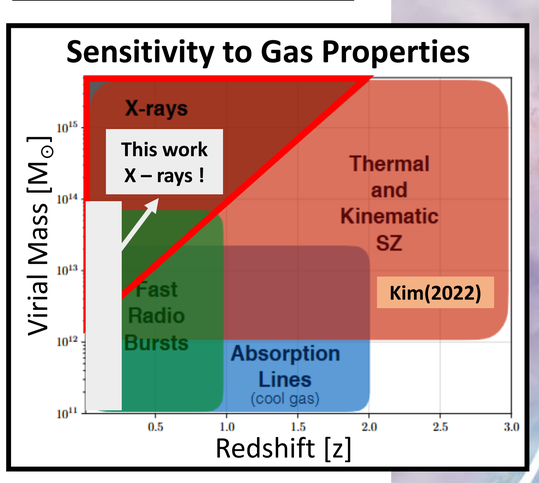


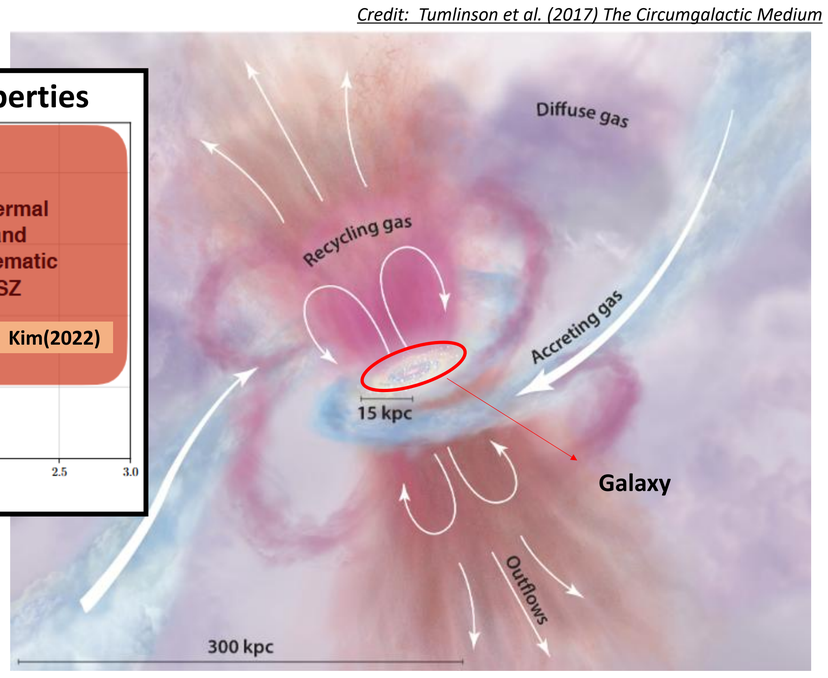
Introduction

Credit: Battaglia et al. (2019) Probes of the CGM and ICM over the next decade



How to Probe ?

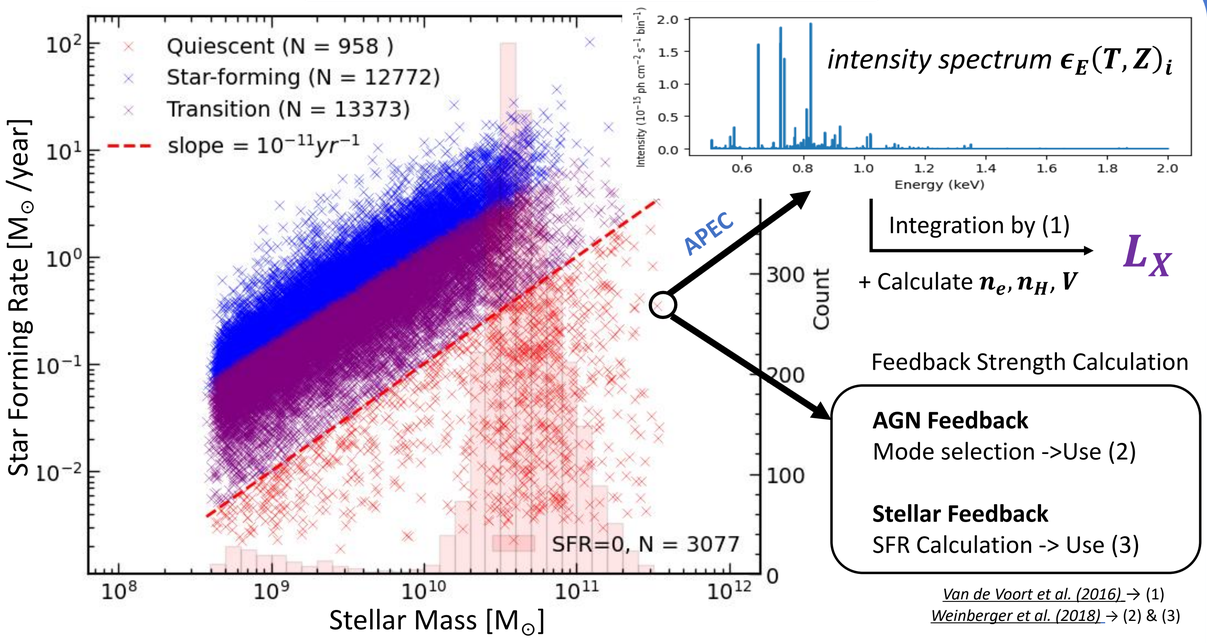
Credit: Tumlinson et al. (2017) The Circumgalactic Medium



- **Circumgalactic Medium (CGM)** fuels *star formation* and interacts with (AGN & Stellar) *feedback processes* in galaxies.
- Multi-wavelength observations of the CGM are crucial for understanding **galaxy evolution** and addressing the **missing baryon problem**.

I investigated soft ***X-ray luminosity (L_X)*** of the **hot gas components of CGM** ($T > 10^6$K) to identify the key physical drivers of L_X using ***cosmological simulation***

Data & Methods



$$L_X = \sum_i n_e n_H \epsilon_E(T,Z)_i \Delta E_i V \quad (1)$$

Feedback Strength Formula

$$\begin{cases} \dot{E_{AGN}} = k\dot{M}c^2, (k_{therm} = 0.2, k_{kinetic} = \varepsilon_{f,kin}) & (2) \\ \dot{E_{SFR}} = A \times SFR \times f(Z) & (3) \end{cases}$$

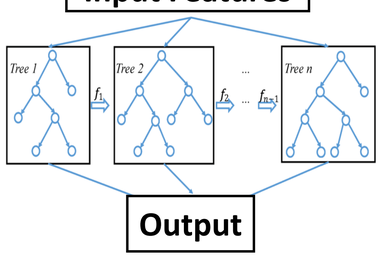
With **IllustrisTNG** & **PyAtomDB**, I Computed X-ray emission & Feedback strength.

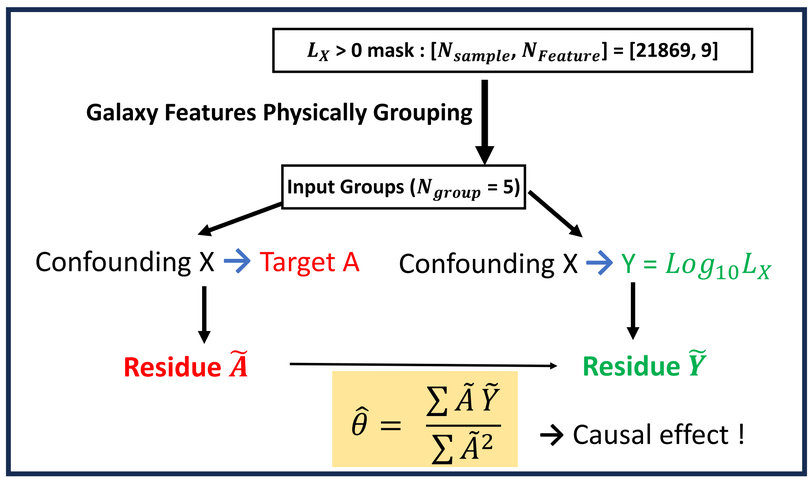
Classification	**Star Formation Rate (SFR)** → **Quiescent (QU)**, **Star-forming (SF)**, **Transition**
Region of interest	Hot gas within [0.15, 1] R_{500} sphere R_{500}: Virial Radius Proxy
Emission model	**APEC** (Collisional Ionized Equilibrium, assuming optically thin condition)
Energy band	Soft X-ray regime [0.5, 2] keV
Redshifts	$z = 0, 0.1, 0.2$ (Snapshots of the simulation)
Goal	Understanding the relation between L_X and key **physical properties** of galaxies

Then, How can I identify the key physical drivers?

→ = XGBoost model

Input Features



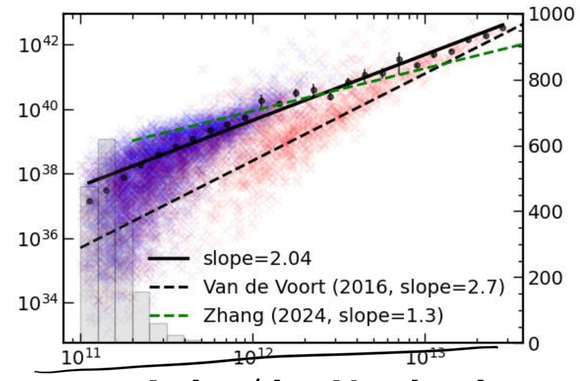


Double Machine Learning (DML) Approach !

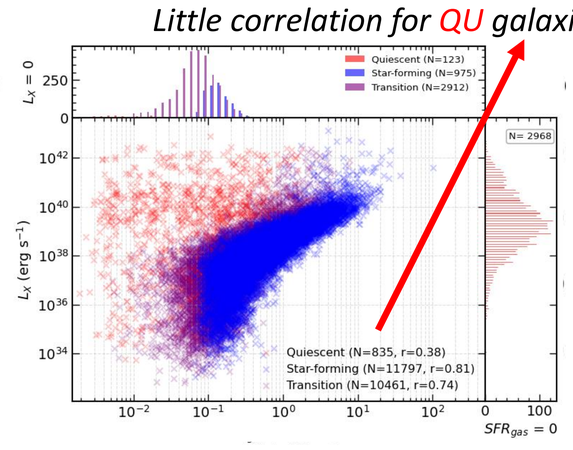
Results

1) Correlation check

Little correlation for QU galaxies



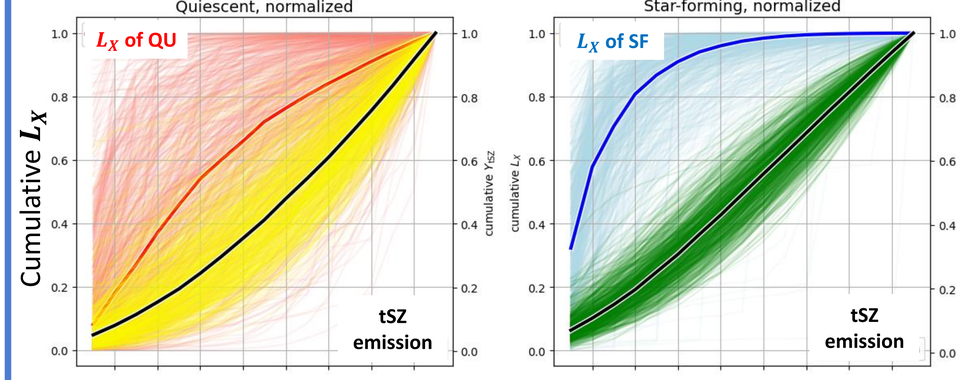
L_X [erg/s] vs M_{500} [$M_\odot$]



L_X [erg/s] vs Star Forming Rate [$M_\odot$ /year]

∴ The **higher** the sSFR of a galaxy, **the stronger** the correlation between SFR and L_X

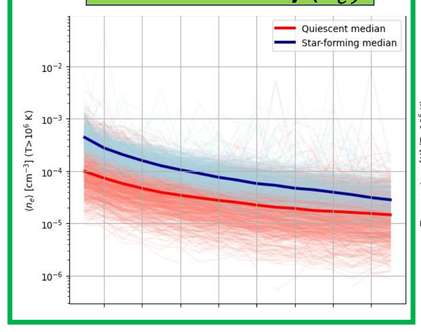
2) Radial Profile of L_X belonging to Milky-way mass galaxies



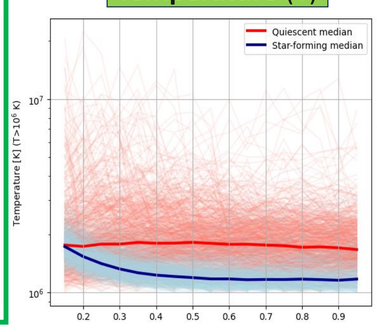
Different radial profile ! **Why?**

Analyze gas properties in eq (1)

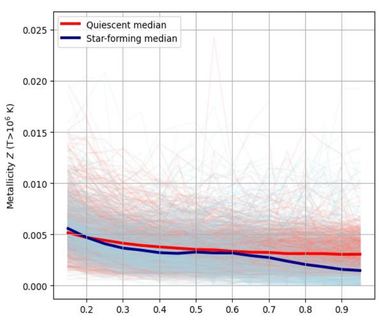
Electron Density (n_e)



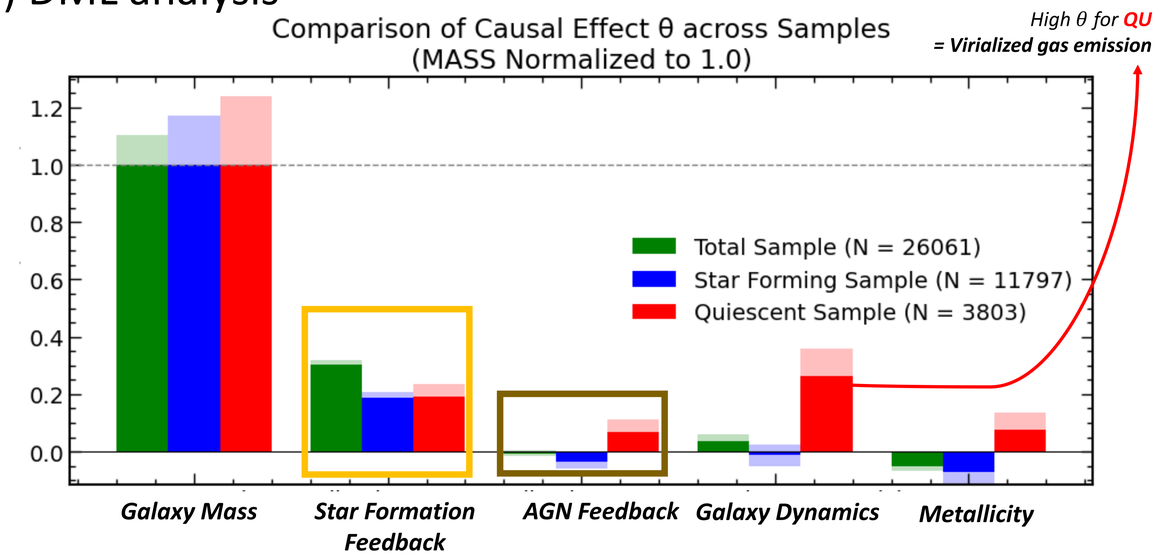
Temperature (T)



Metalicity (Z)



3) DML analysis



∴ While **Mass** is dominant, **star formation** plays a key role in regulating X-ray emission

Conclusions & Caveats : How to Overcome?

1. Correlation between L_X, mass (M_{500}) and SFR which showed high consistency with previous works.
2. Radial profile of L_X shows distinct difference in **QU** and **SF** galaxies. This is because of n_e (n_H) distribution, showing they are main gas properties dominating L_X.
3. Through DML, AGN has little contribution for L_X, while Star Formation shows meaningful causal effect. For **QU**, galaxy dynamic is highly impacting to L_X.

SF galaxies : higher, centrally concentrated L_X → stellar feedback

QU galaxies : lower, radially extended L_X → Virialized gas driven by galactic dynamics, but simultaneously influenced by stellar feedback

Contributions	Quantitatively demonstrates the importance of stellar feedback to L_X.
Caveats	Simulation dependency; possible bias from finite simulation resolution.
Solution	**Extend** to other simulations (e.g., **EAGLE**), and incorporate observation-based priors to reweight/regularize feature distributions (SFR floor) in the DML pipeline.

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