Title: X-raying CAMELS: Constraining Feedback Physics in Hot Halo Gas with CAMELS and eRASS

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Collection/Series: Cosmic Ecosystems

Subject: Cosmology

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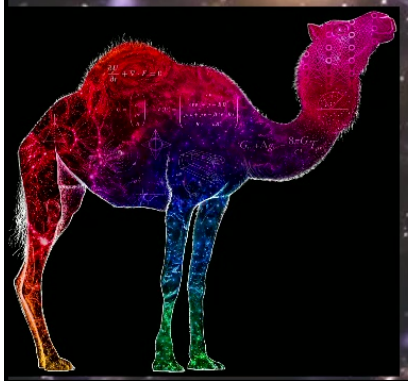
Abstract:

The circumgalactic medium (CGM) around massive galaxies plays a crucial role in regulating star formation and feedback. Using the CAMELS cosmological simulation suites, we develop emulators for the X-ray surface brightness profile and the X-ray luminosity–stellar mass scaling relation to investigate how stellar and AGN feedback shape the X-ray properties of the hot CGM. Our analysis shows that stellar feedback more significantly impacts the X-ray properties than AGN feedback within the parameters studied. Comparing the emulators to recent eROSITA All-Sky Survey observations, we found stronger feedback is needed than those currently implemented in the IllustrisTNG, SIMBA, and Astrid simulations, in order to match observed CGM properties. However, adopting these enhanced feedback parameters leads to deviations in the observed stellar-mass-halo-mass relations below the group mass scale. This tension suggests possible unaccounted systematics in X-ray CGM observations or inadequacies in the feedback models of cosmological simulations. Finally, I will also highlight upcoming X-ray constraints of feedback in the group and cluster scales with new CAMELS simulations and compare with those obtained at the CGM scale.

Constraining CGM Physics with using CAMELS

Erwin T. Lau

with Daisuke Nagai, Ákos Bogdán, Isabel Medlock, Ben Oppenheimer, Nick Battaglia, Daniel Anglés-Alcázar, Shy Genel, Yueying Ni, Francisco Villaescusa-Navarro



Lau et al 2025, ApJ 984, 190, arXiv:2412.04559

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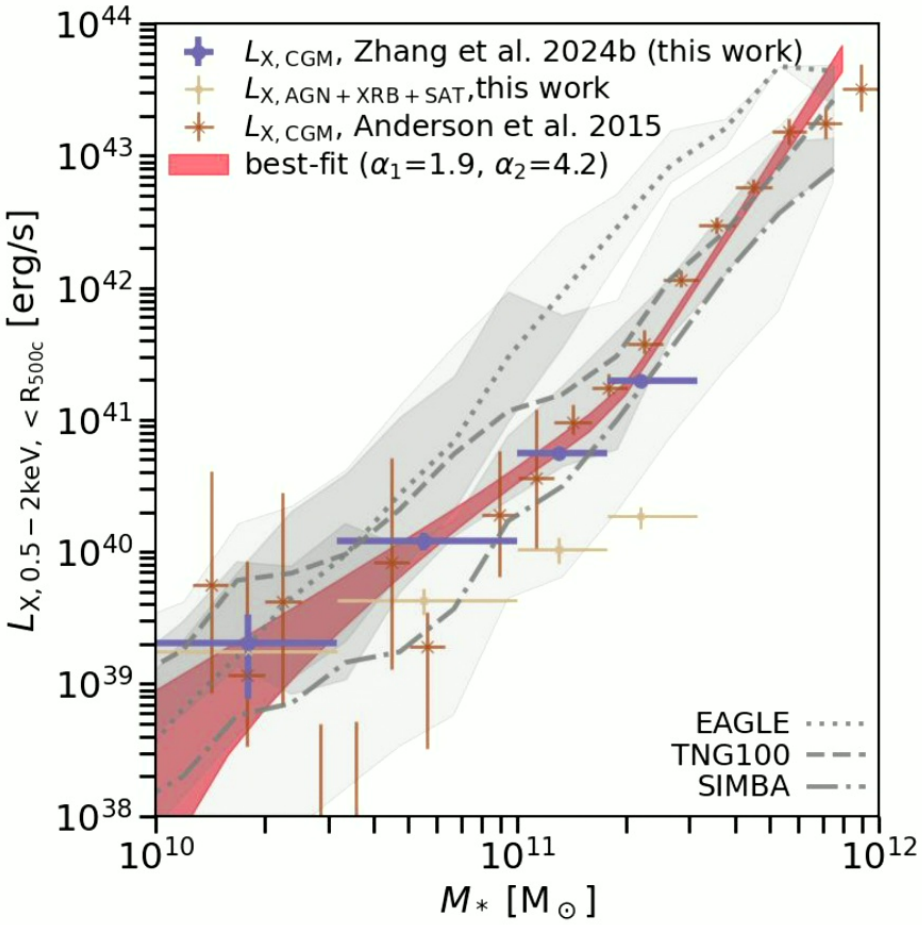
“Tensions” between eRASS and Simulations

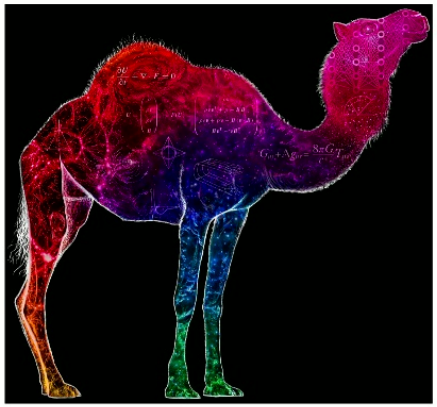


eRASS4 provides the stacked X-ray data on CGM (Zhang+24a,b) on SDSS spectroscopic galaxies.

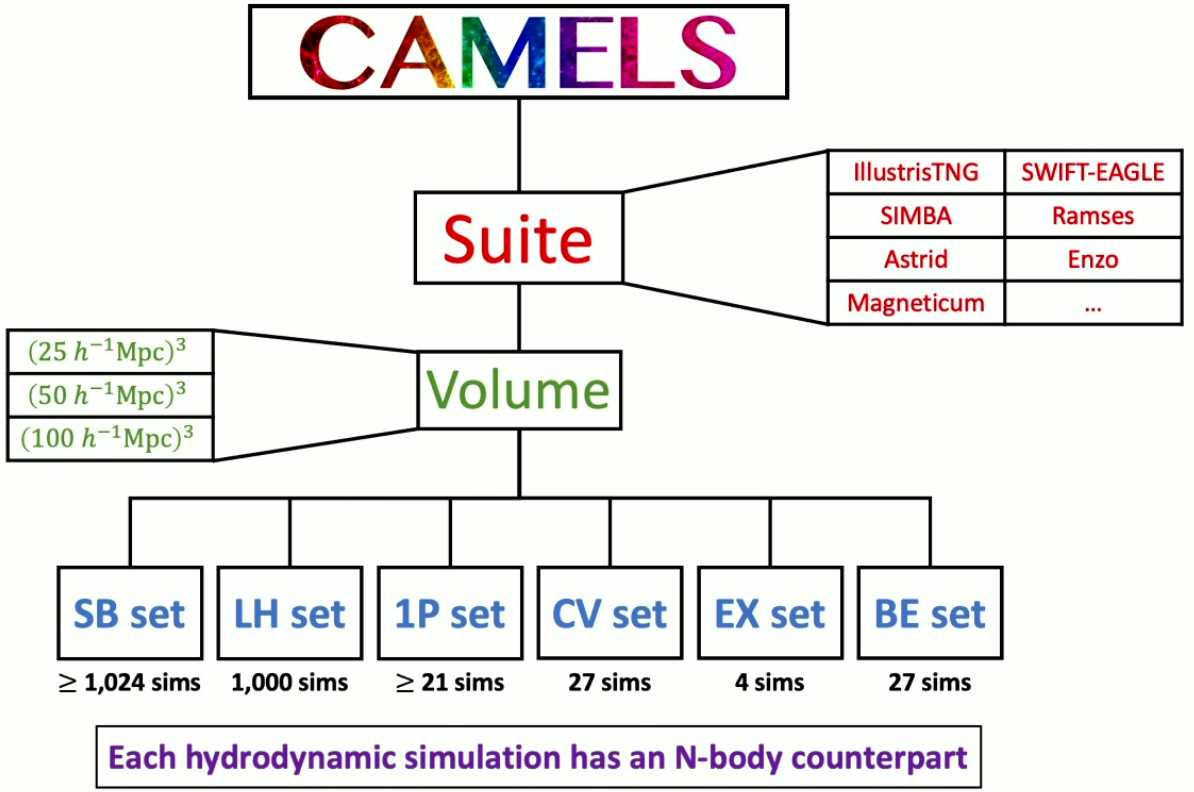
***Challenge**:* Differences between modern cosmological simulations (EAGLE, TNG100, SIMBA) with eRASS observations.

Question: How can we reconcile simulations with observations?

Cosmology and **A**strophysics with **M**achin**E** **L**earning **S**imulations

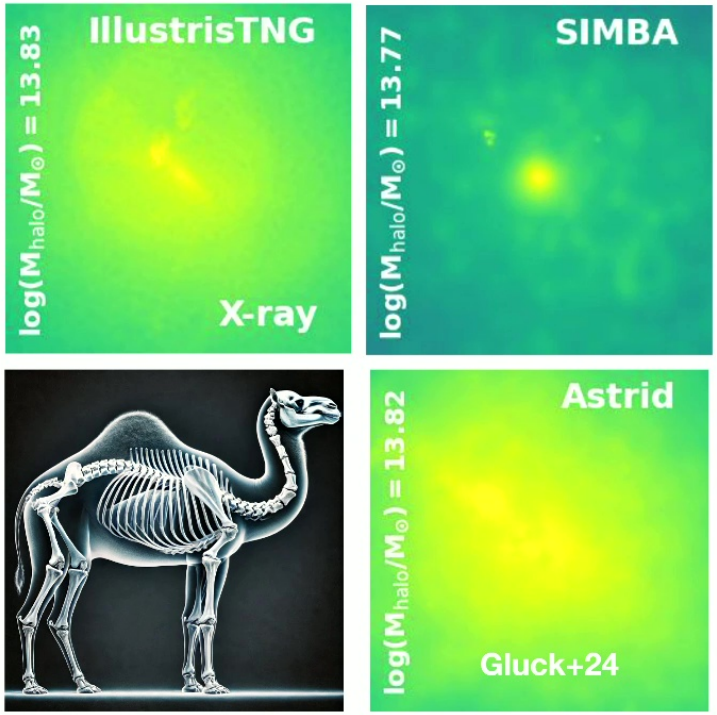


Villaescusa-Navarro et al. (2021, 2022), Ni et al (2023)



*C*osmology and *A*strophysics with *M*achin*E* *L*earning *S*imulations

Mock X-ray images of CAMELS CGM (Gluck+23)

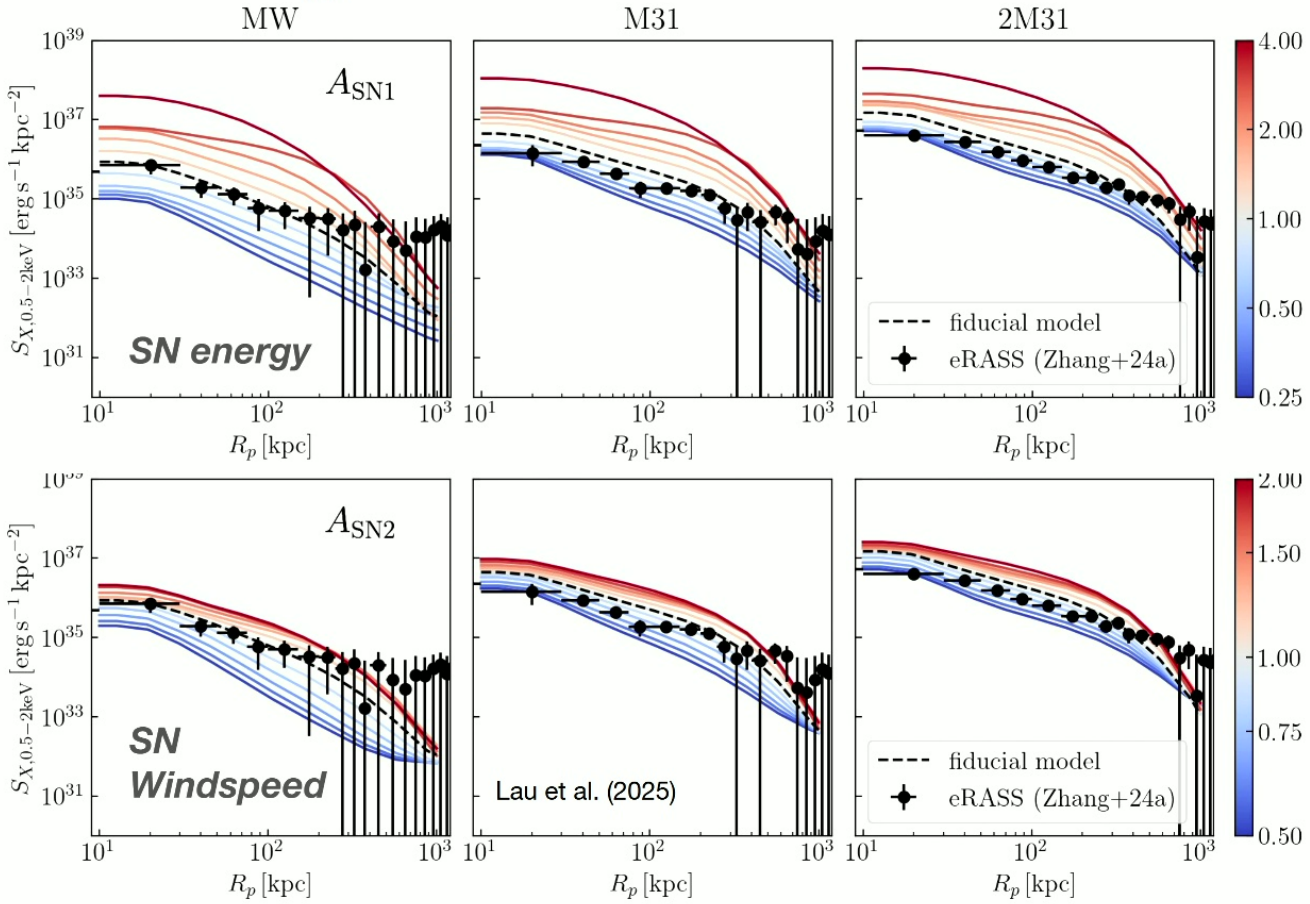


We create emulators for XSB profile and Lx-Mstar relation from the simulations.

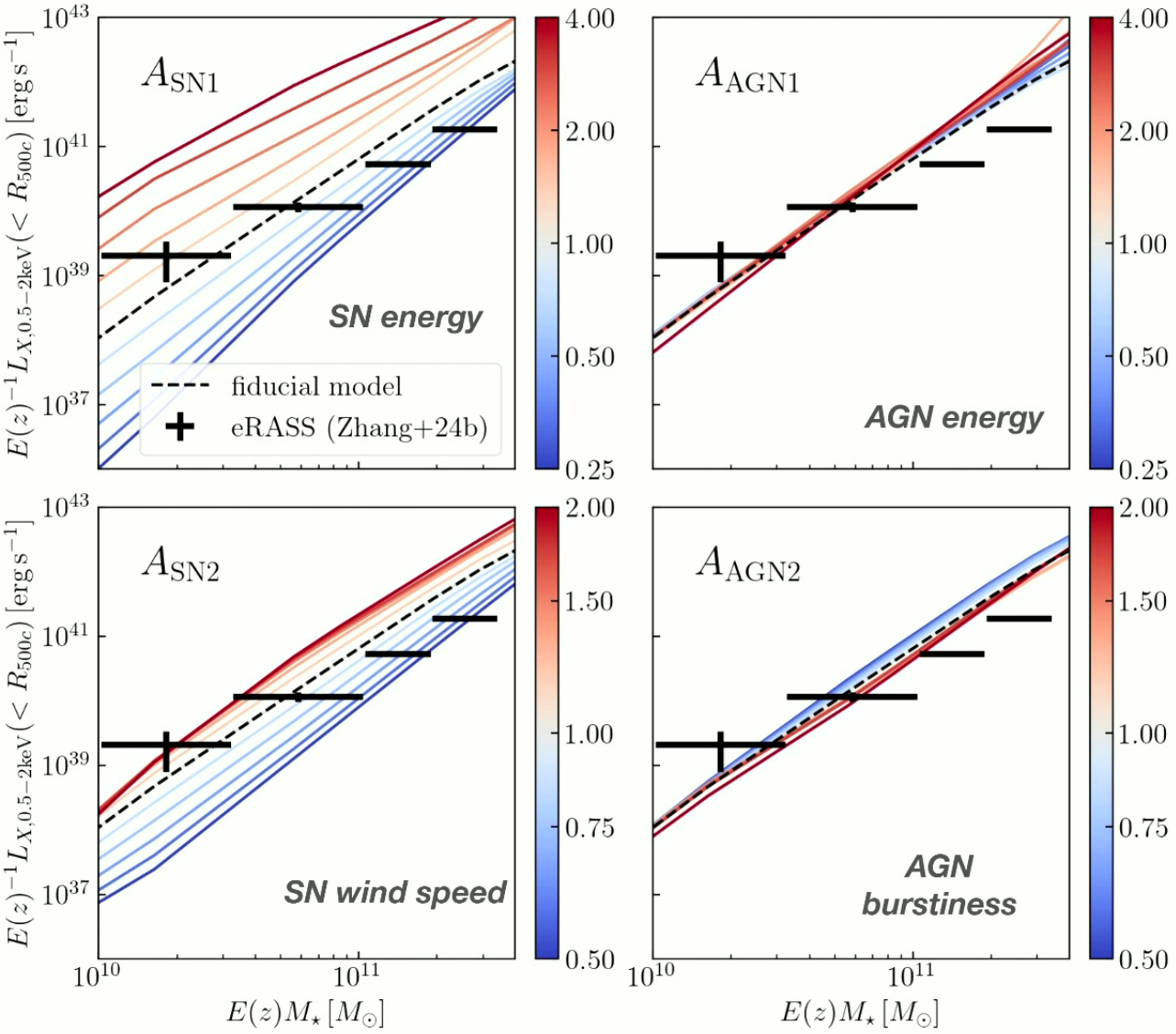
1000 runs with parameters sampled with Latin Hypercube
Box size = 25 Mpc/h; Resolution: 10^7 Msun; 2 kpc

Feedback	*Value Range*	*Physical interpretation*
SN1	[0.25, 4.0]	SN energy output per SFR (IllustrisTNG, Astrid) Mass loading factor (SIMBA)
SN2	[0.5, 2.0]	SN wind speed
AGN1	[0.25, 4.0]	kinetic AGN feedback energy (IllustrisTNG, Astrid) AGN jet momentum flux (SIMBA)
AGN2	[0.5, 2.0] [0.25, 4.0] (Astrid)	AGN 'Burstiness' (IllustrisTNG) Jet speed (SIMBA) thermal AGN feedback energy (Astrid)

X-ray Surface Brightness Profiles: IllustrisTNG vs eRASS

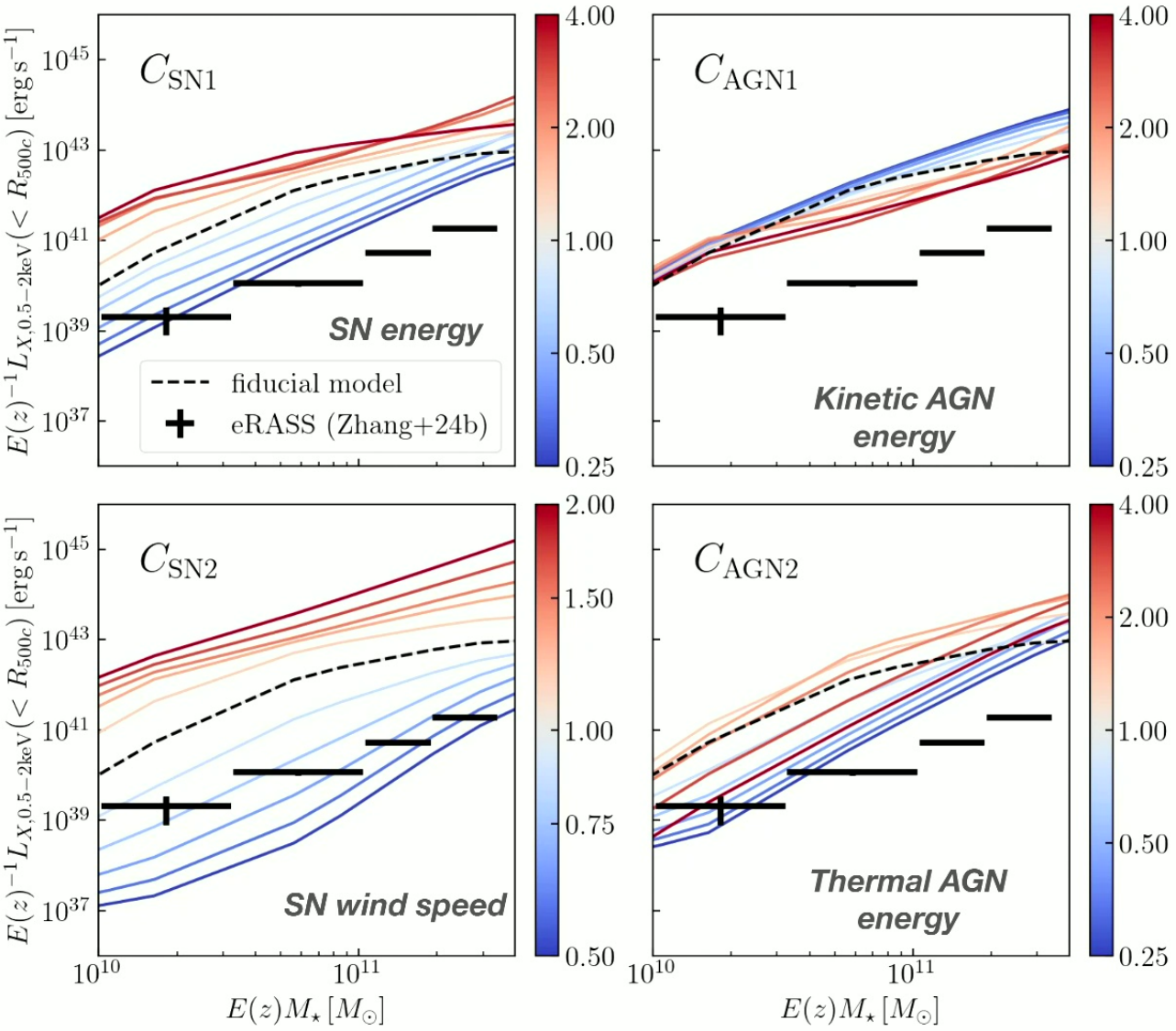


Increasing SN feedback increases gas density due to limiting accretion onto BH leading to higher X-ray surface brightness profiles.



Lx-Mstar: IllustrisTNG

- Fiducial model overpredicts Lx at high stellar mass.
- More sensitive to SN feedback parameters than AGN feedback parameters.
- Relatively small number of massive halos due to small box size.

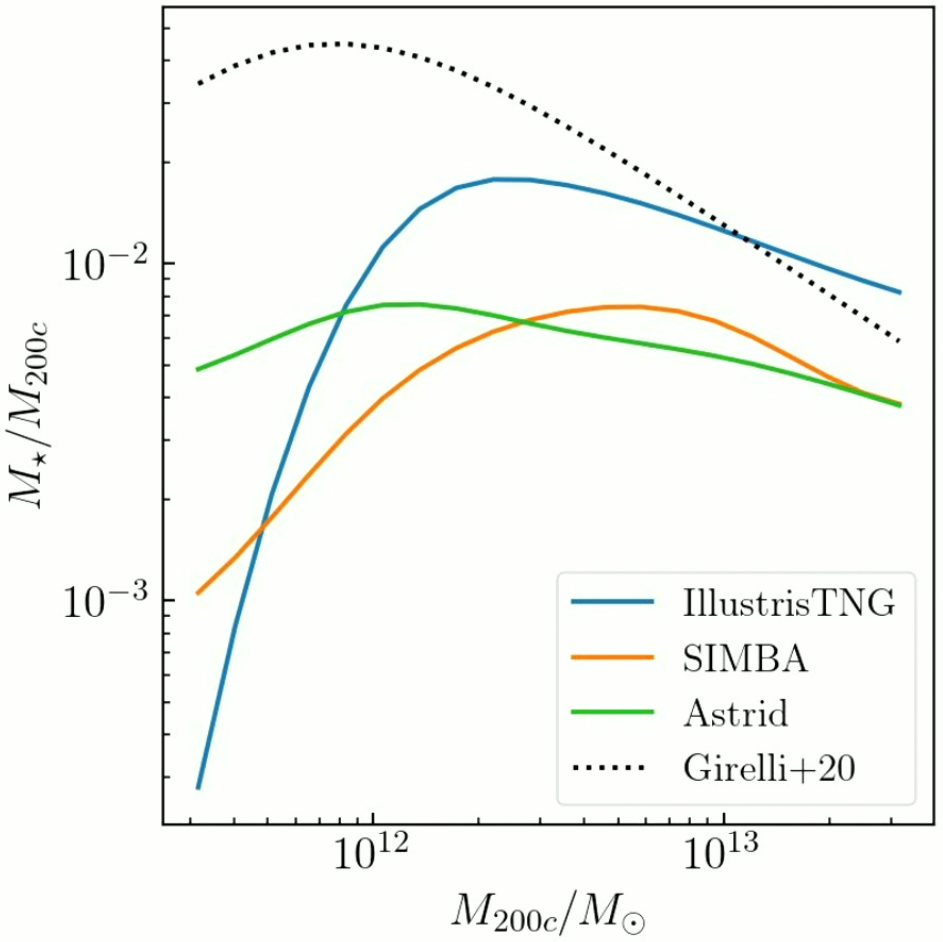


Lx-Mstar: Astrid

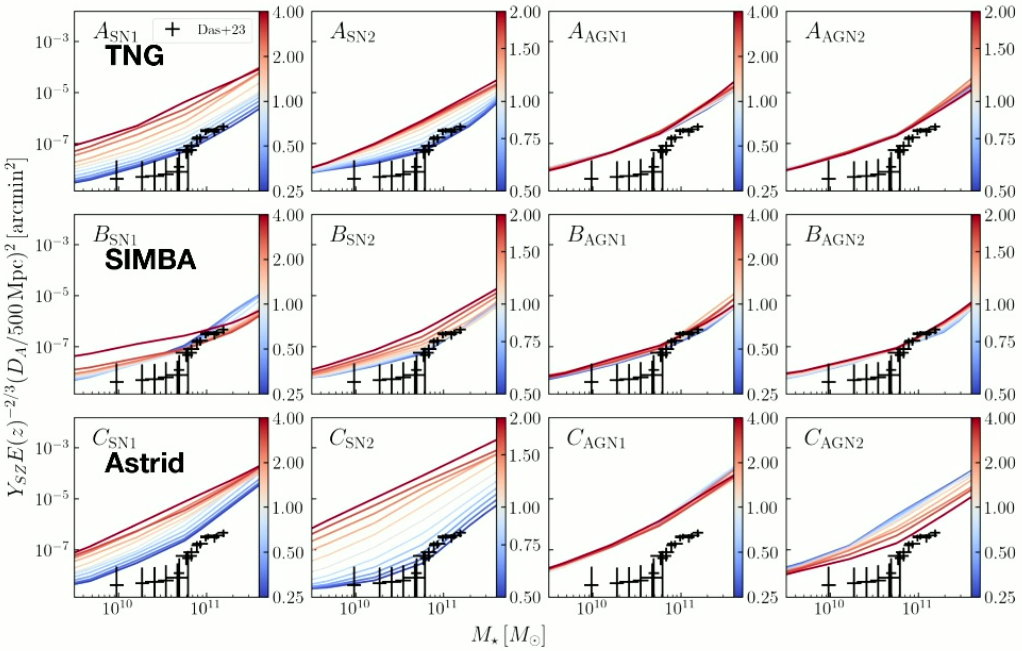
- Fiducial model overpredicts Lx by ~100.
- Very sensitive to SN and thermal AGN feedback.
- Non-monotonic behaviour with thermal AGN feedback.
- Strong thermal AGN feedback pushes out hot gas.

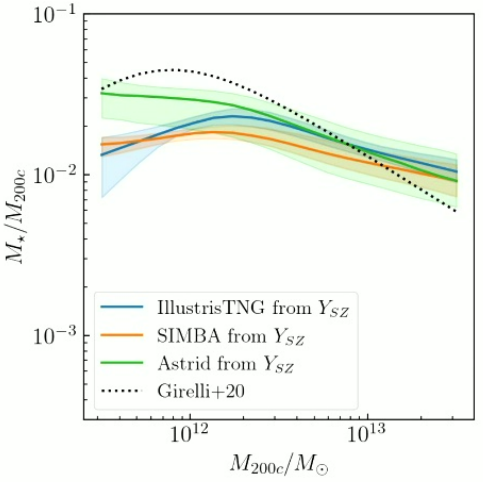
Tension: Stellar Mass-Halo Mass Relation

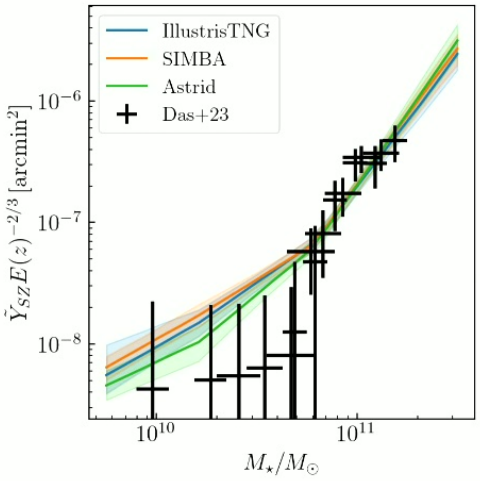
- Best-fit feedback parameters lead to Mstar-M relation that is different from observations.
- Stronger feedback leads to suppression of stellar mass at low halo masses, inconsistent with observations.
- Caveat: reducing potential contamination from X-ray binaries and background can alleviate the tension.



Preliminary: Constraining Feedback with thermal SZ

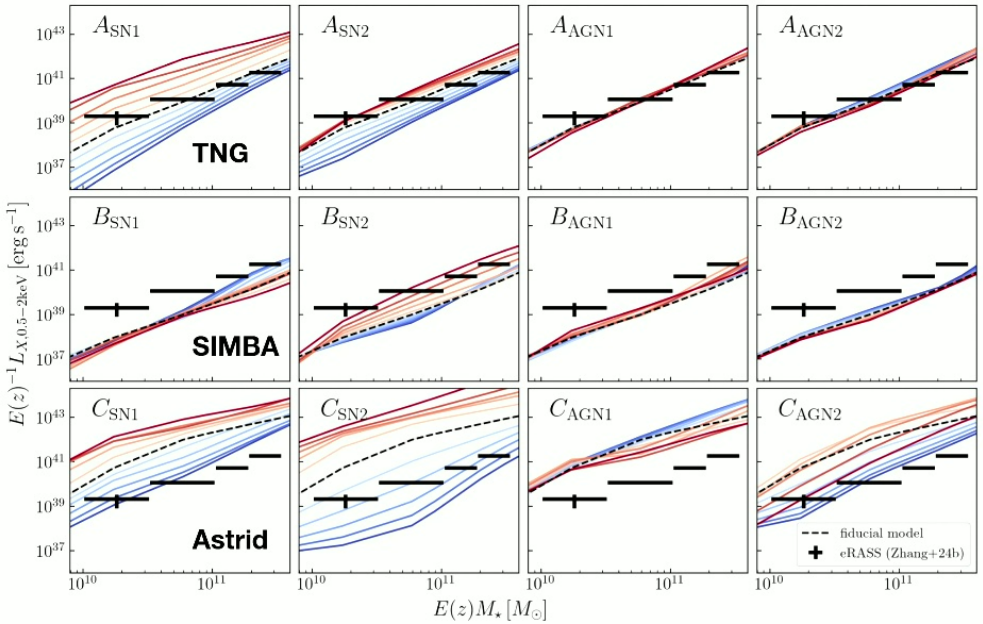




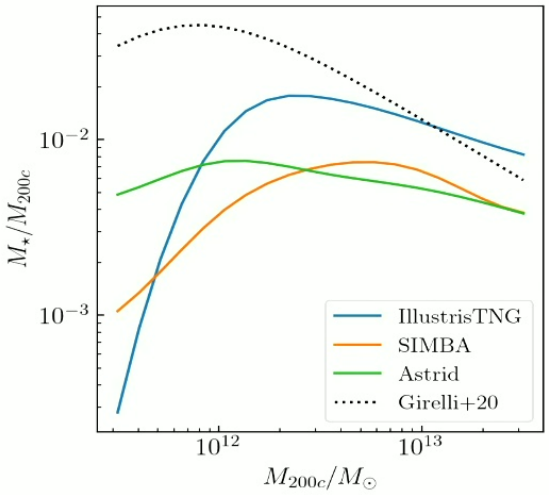


- **Comparison with CAMELS simulations:** Lower stellar feedback matches the lower stellar feedback to observations for all models (TNG, SIMBA, Astrid).

- **Little Tension:** Mstar-Mhalo relation with best-fit feedback with Ysz-Mstar is consistent with observations at higher stellar masses Mstar > 1e11 Msun
- **Uncertain:** Systematics due to stacking
- **Wishlist:**
  - Cross X-ray/SZ for the same sample
  - Lower mass scale measurements



Takehome messages



- **eRASS stacked CGM observation prefers stronger SN and AGN feedback energies** in modern cosmological simulations.
- **Tension:** the resulting stellar mass relation from eRASS doesn't match with observations.
- **Contaminations** (X-ray binaries, background emissions due to groups) may overestimate X-ray CGM. Accounting for them will alleviate the tension.
- **Future Work:** SZ and high-resolution X-ray Chandra/XMM observations will help with the tension.