Constraining CGM Physics with using CAMELS

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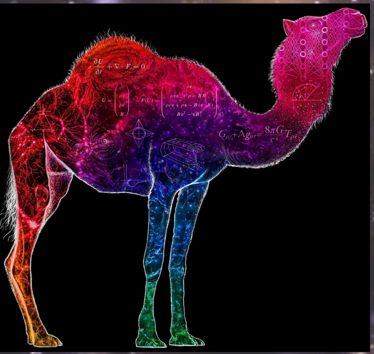

Lau et al 2025, ApJ 984, 190, arXiv:2412.04559

Cosmic Ecosystems
Perimeter Institute
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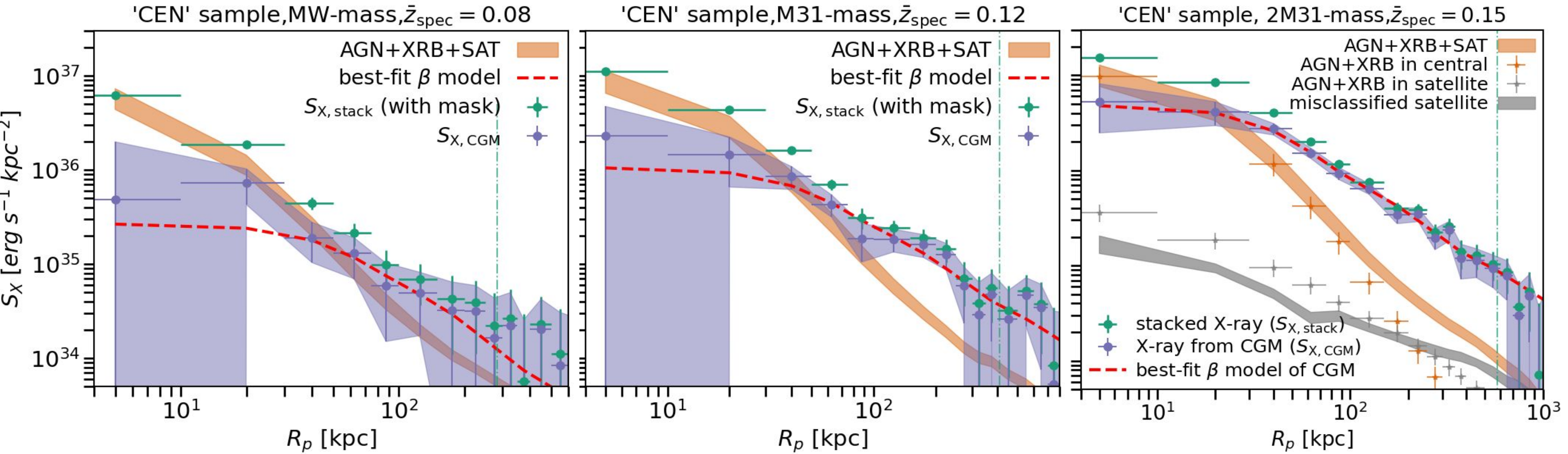
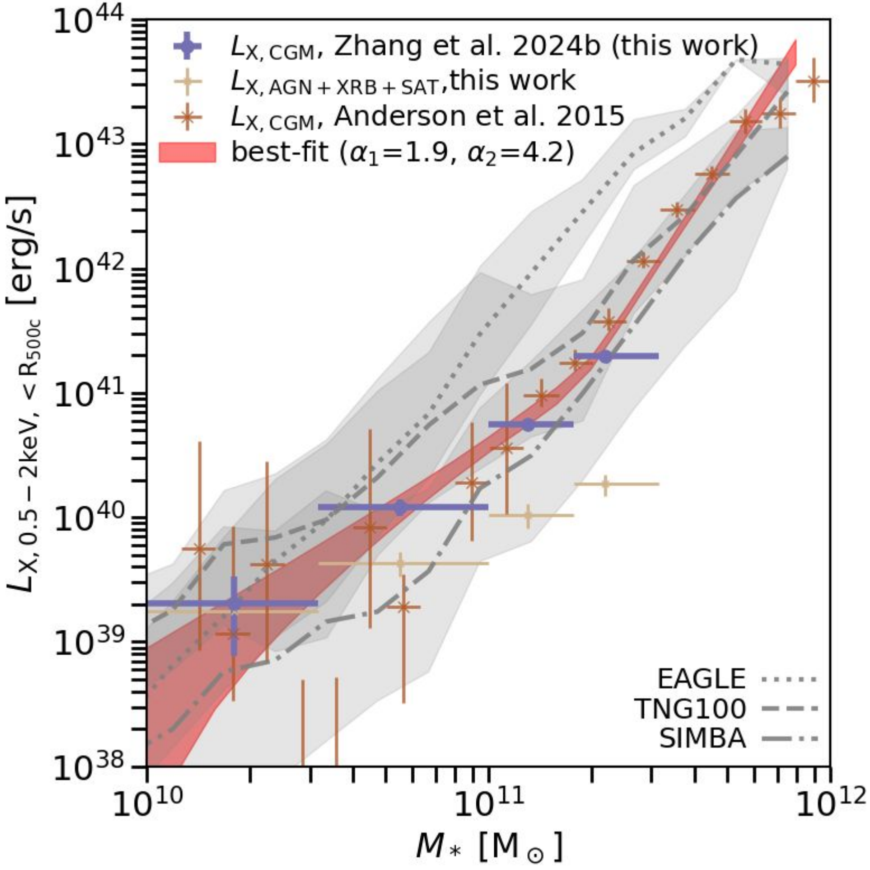
eROSITA All Sky Survey (eRASS) 4: Stacked XSB profiles from Central Galaxies from SDSS Main Galaxy Sample (Zhang+24)



- Stacked CGM measurements with eRASS4 (4 half-sky scans) on spectroscopic SDSS MGS galaxies (Zhang+24a).
- 3 stellar mass bins: 'MW', 'M31', '2M31'.
- Point sources and satellite galaxies are modeled.

$\log_{10}(M_*/M_\odot)$		$M_{*,med}/M_\odot$	redshift			$FULL_{spec}$	CEN	SAT
min	max		min	max	med	N_g	N_g	N_g
10.0	10.5	1.8×10^{10}	0.01	0.06	0.05	11922	7956	3966
10.5	11.0	5.5×10^{10}	0.02	0.10	0.08	45248	30825	14423
11.0	11.25	1.3×10^{11}	0.02	0.15	0.12	34046	26099	7947
11.25	11.5	2.2×10^{11}	0.03	0.19	0.15	24098	20342	3756

“Tensions” between eRASS and Simulations

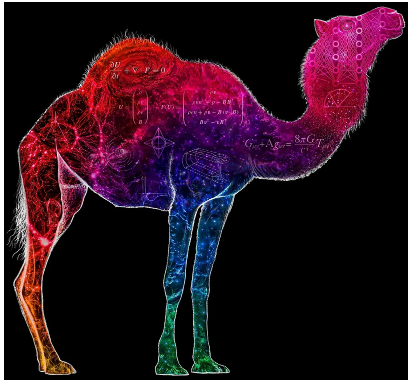


eRASS4 provides the stacked X-ray data on CGM (Zhang+24a,b) on SDSS spectroscopic galaxies.

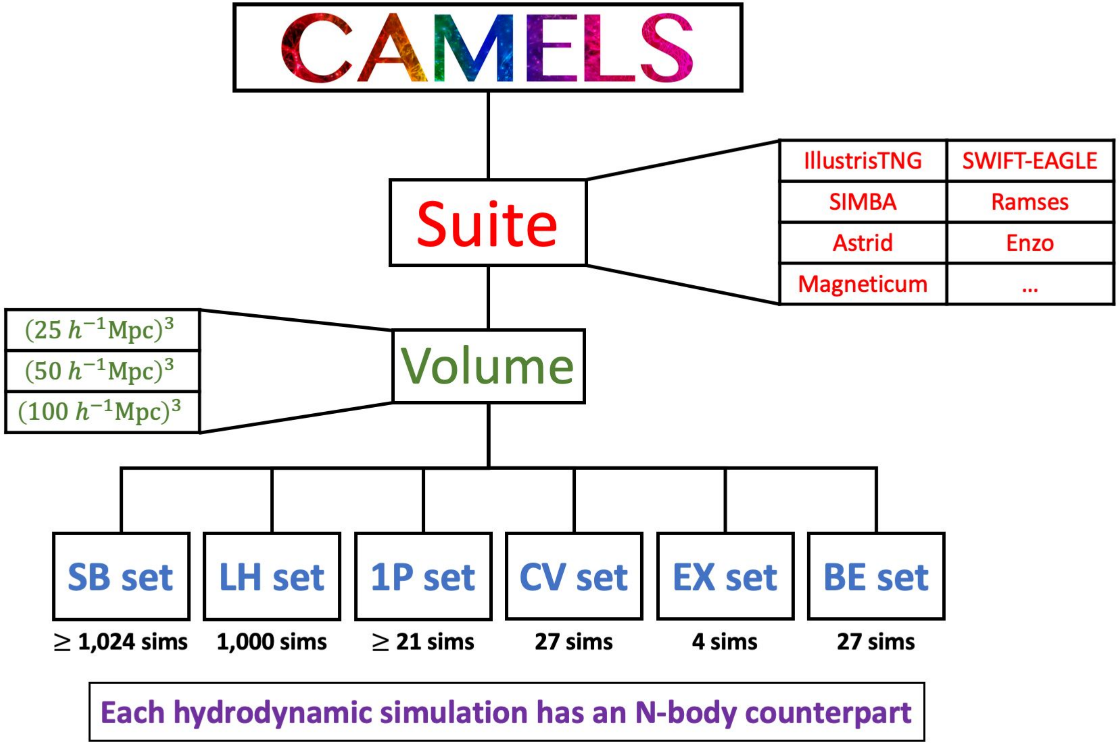
***Challenge**:* Differences between modern cosmological simulations (EAGLE, TNG100, SIMBA) with eRASS observations.

Question: How can we reconcile simulations with observations?

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

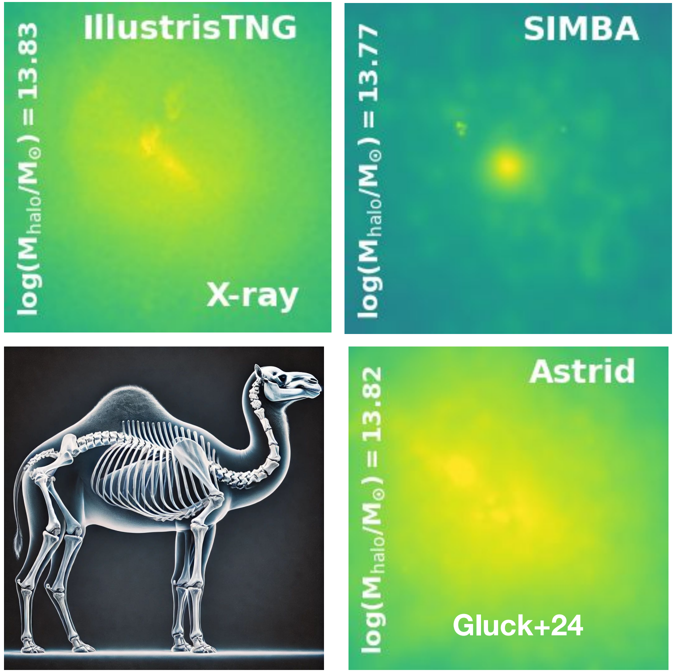


Villaescusa-Navarro et al. (2021, 2022), Ni et al (2023)



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

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

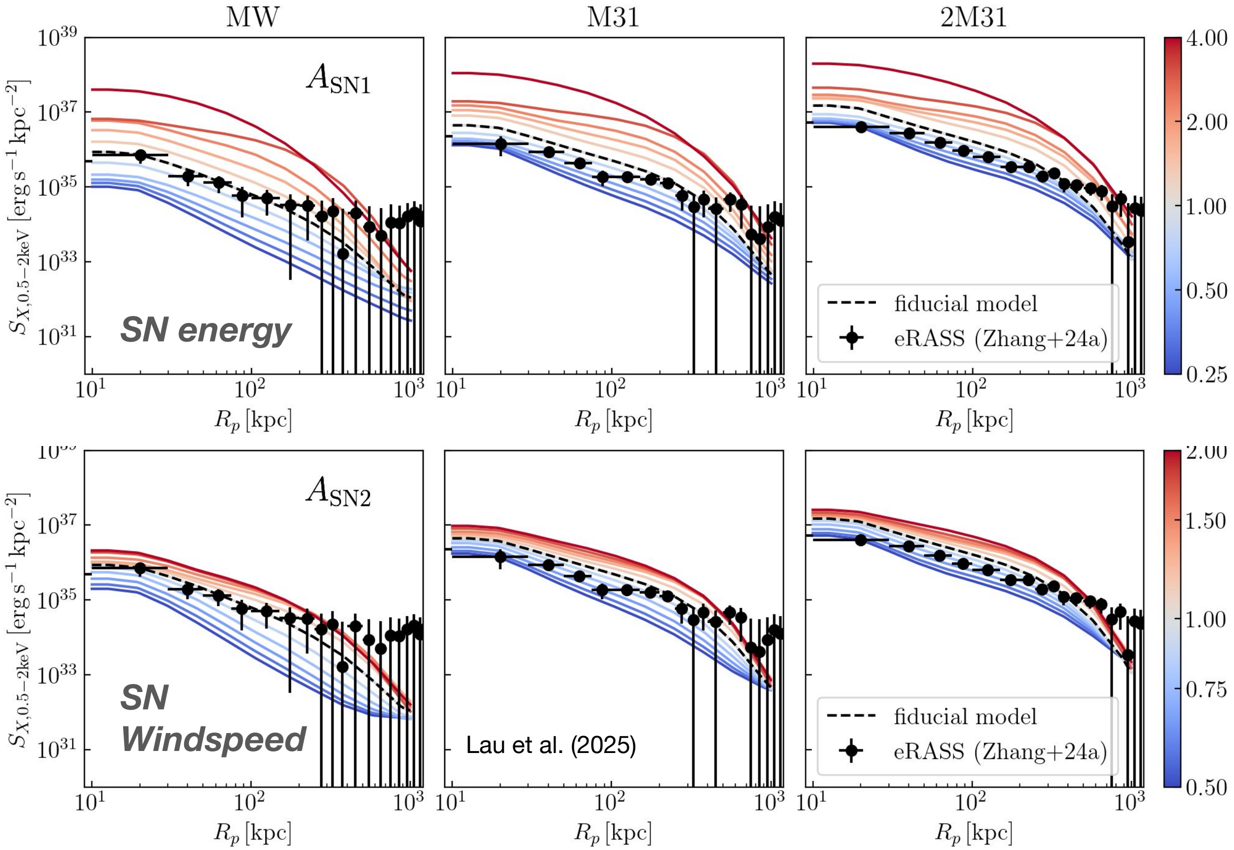


We create emulators for XSB profile and Lx-Mstar relation from the simulations.

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

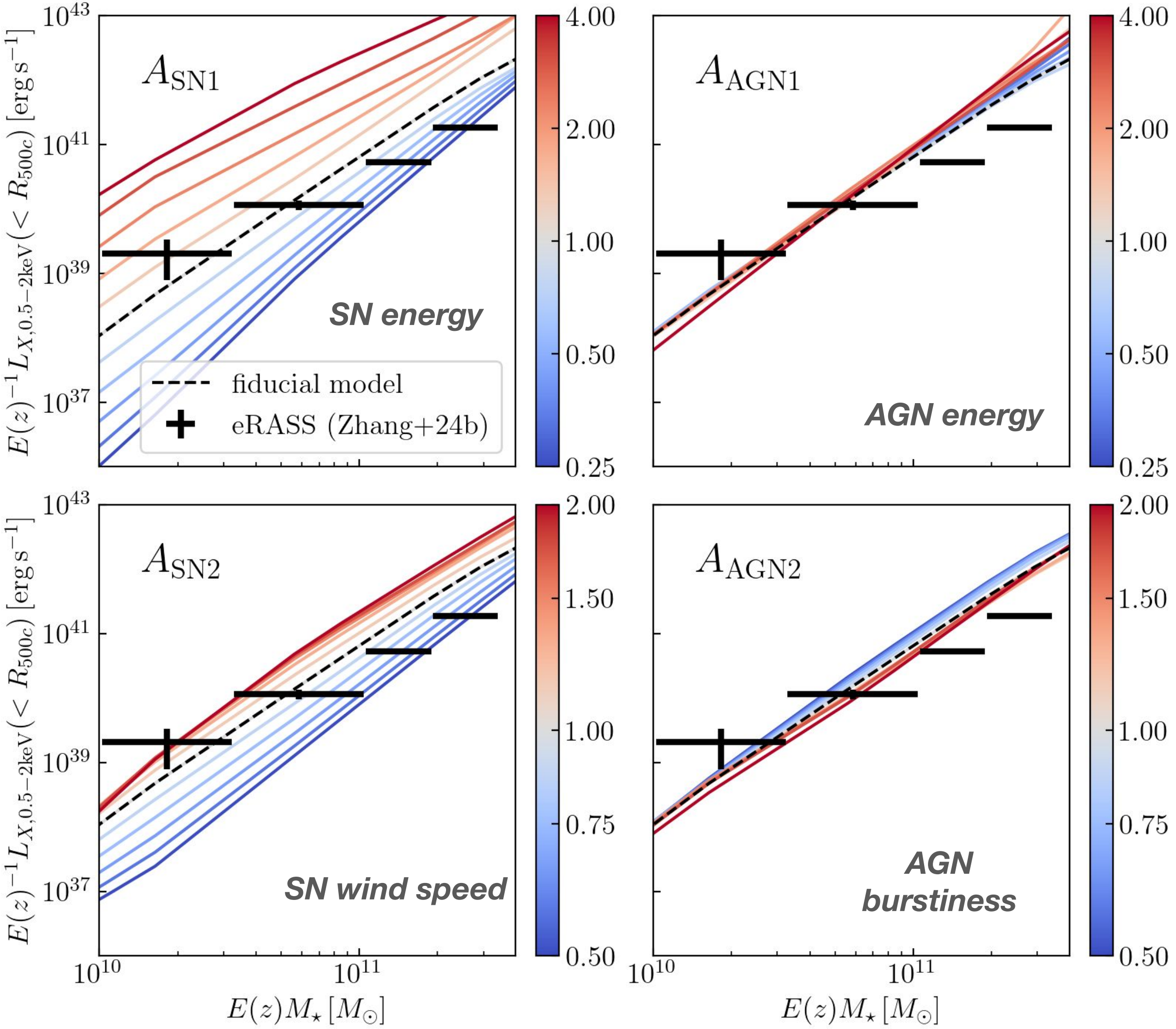
Feedback	*Value Range*	*Physical interpretation*
SN1	[0.25, 4.0]	SN energy output per SFR (IllustrisTNG, Astrid) Mass loading factor (SIMBA)
SN2	[0.5, 2.0]	SN wind speed
AGN1	[0.25, 4.0]	kinetic AGN feedback energy (IllustrisTNG, Astrid) AGN jet momentum flux (SIMBA)
AGN2	[0.5, 2.0] [0.25, 4.0] (Astrid)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

X-ray Surface Brightness Profiles: IllustrisTNG vs eRASS

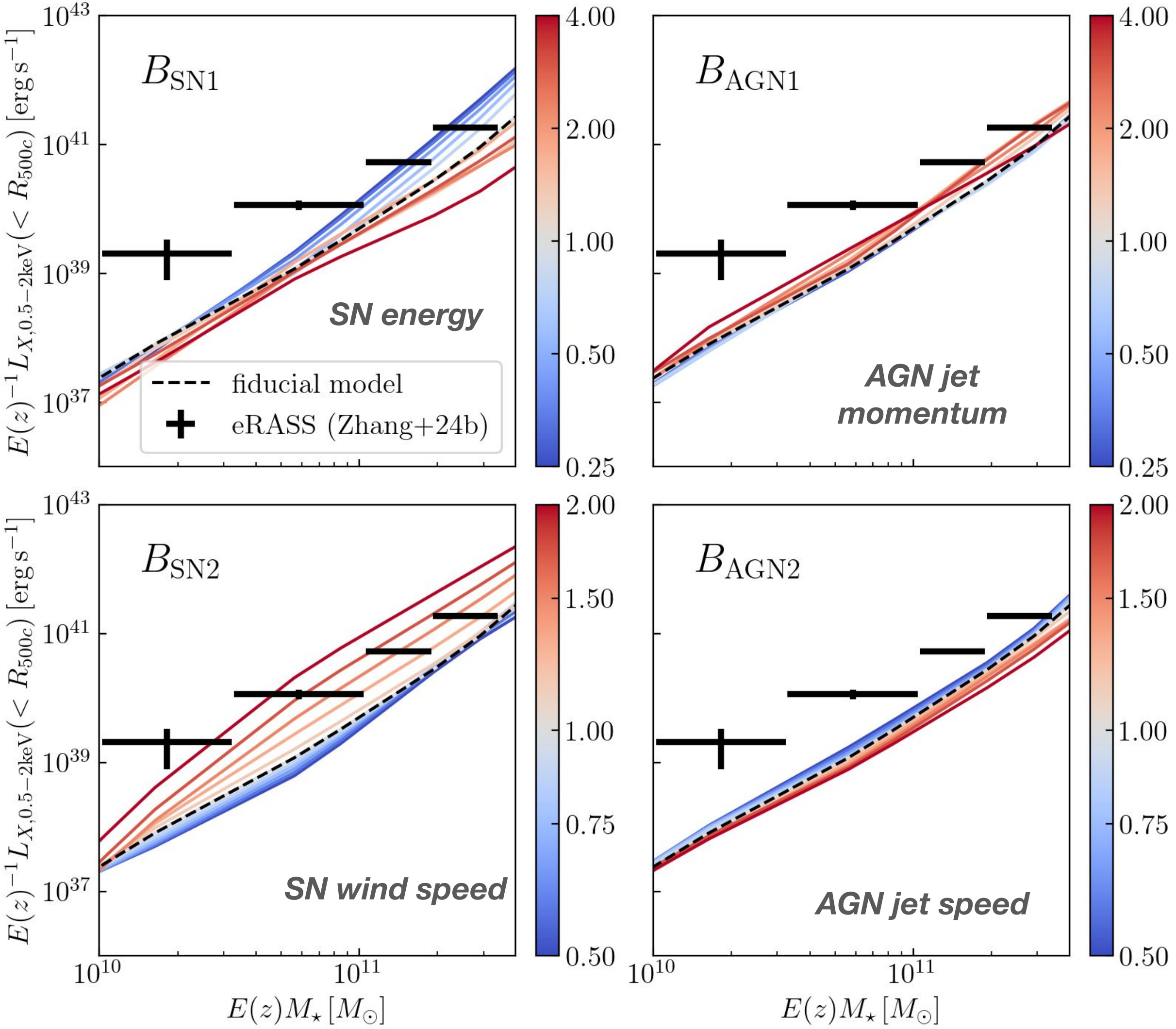


Increasing SN feedback increases gas density due to limiting accretion onto BH leading to higher X-ray surface brightness profiles.

Lx-Mstar: IllustrisTNG



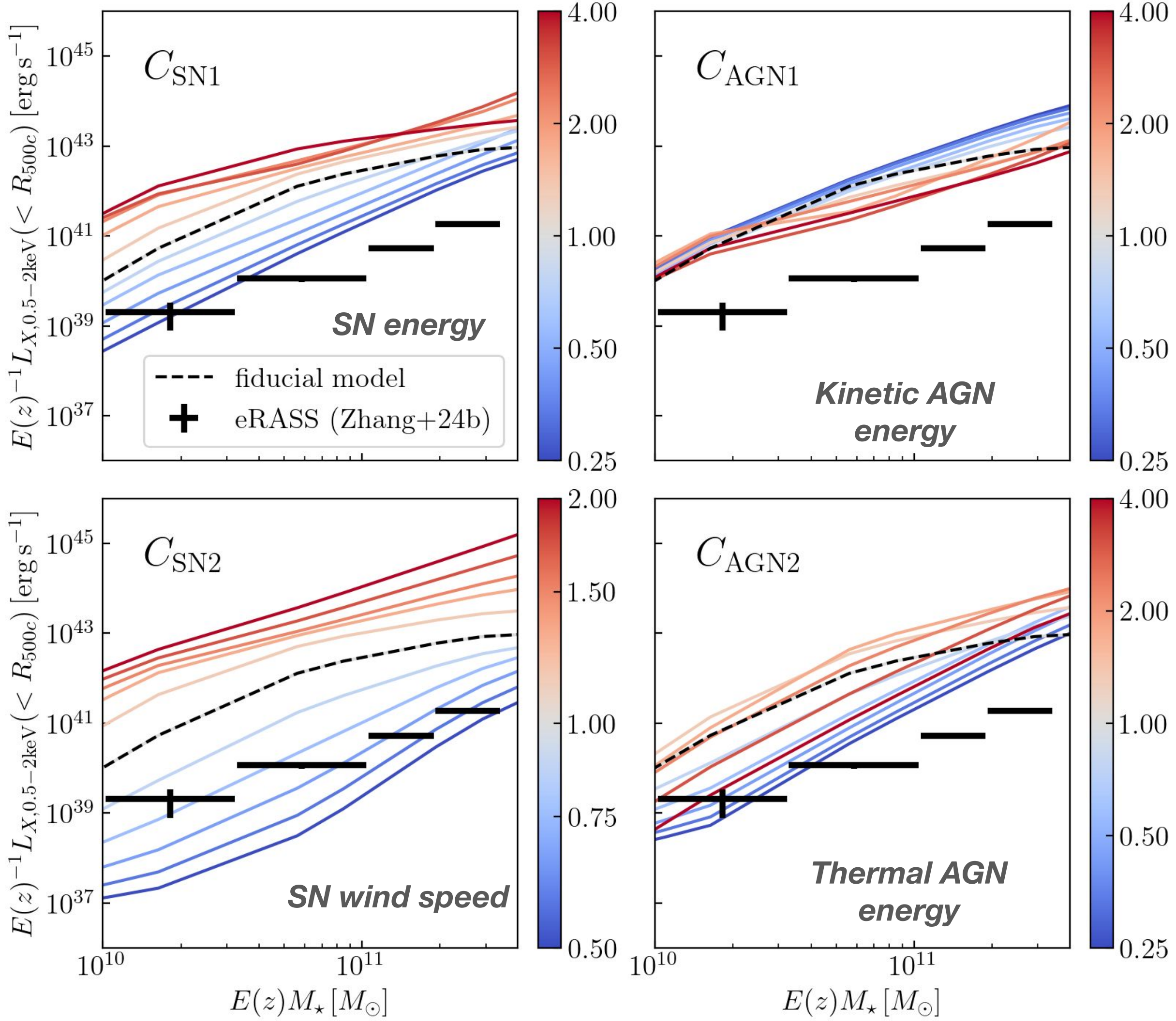
- Fiducial model overpredicts Lx at high stellar mass.
- More sensitive to SN feedback parameters than AGN feedback parameters.
- Relatively small number of massive halos due to small box size.



Lx-Mstar: SIMBA

- SIMBA generally underpredicts eRASS Lx-Mstar relation.
- More sensitive to SN wind speed, than SN mass loading.
- Weak dependence on AGN jet feedback.

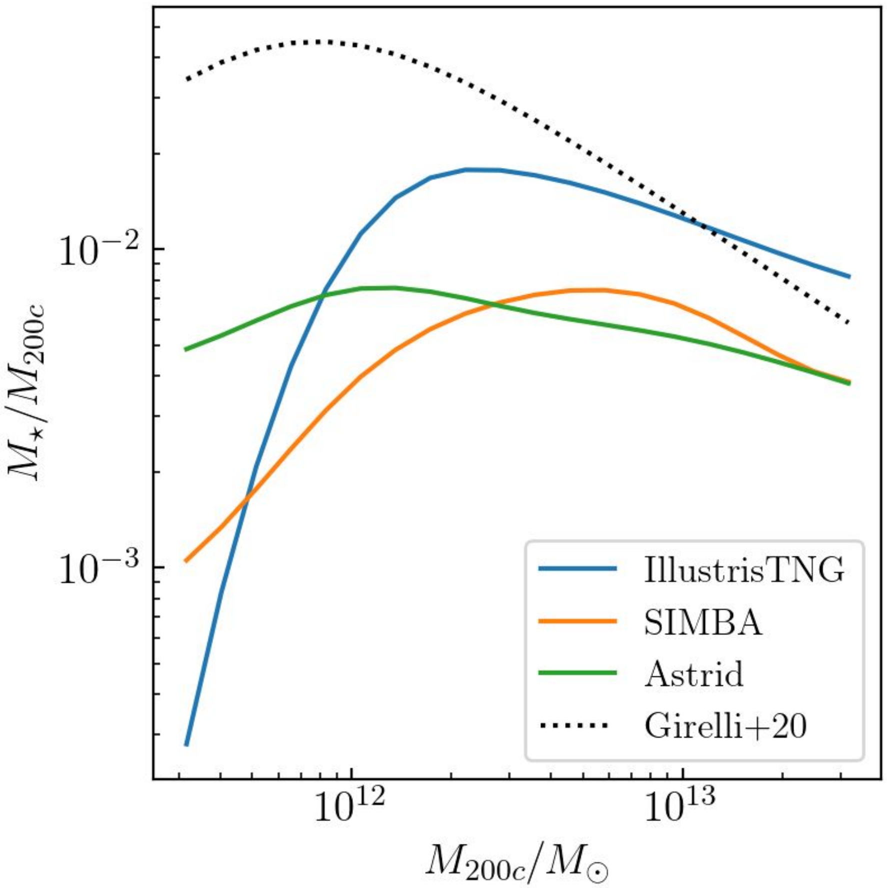
Lx-Mstar: Astrid



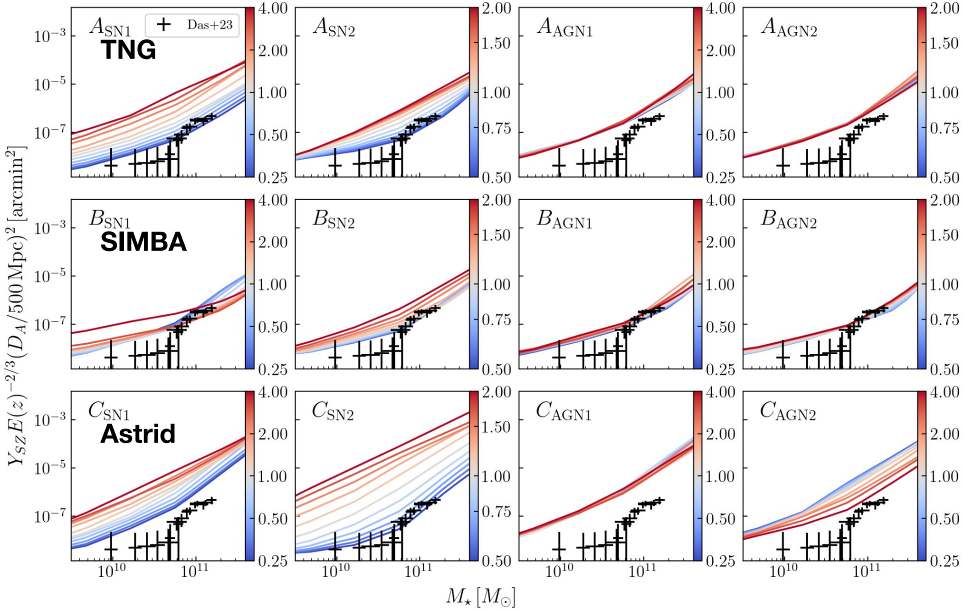
- Fiducial model overpredicts Lx by ~100.
- Very sensitive to SN and thermal AGN feedback.
- Non-monotonic behaviour with thermal AGN feedback.
- Strong thermal AGN feedback pushes out hot gas.

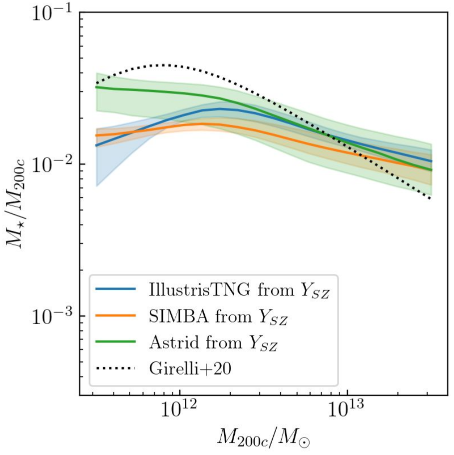
Tension: Stellar Mass-Halo Mass Relation

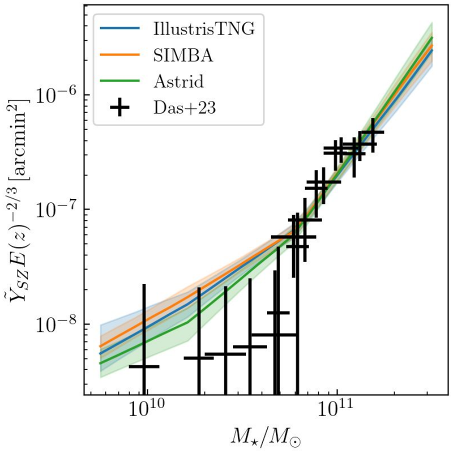
- Best-fit feedback parameters lead to Mstar-M relation that is different from observations.
- Stronger feedback leads to suppression of stellar mass at low halo masses, inconsistent with observations.
- Caveat: reducing potential contamination from X-ray binaries and background can alleviate the tension.



Preliminary: Constraining Feedback with thermal SZ

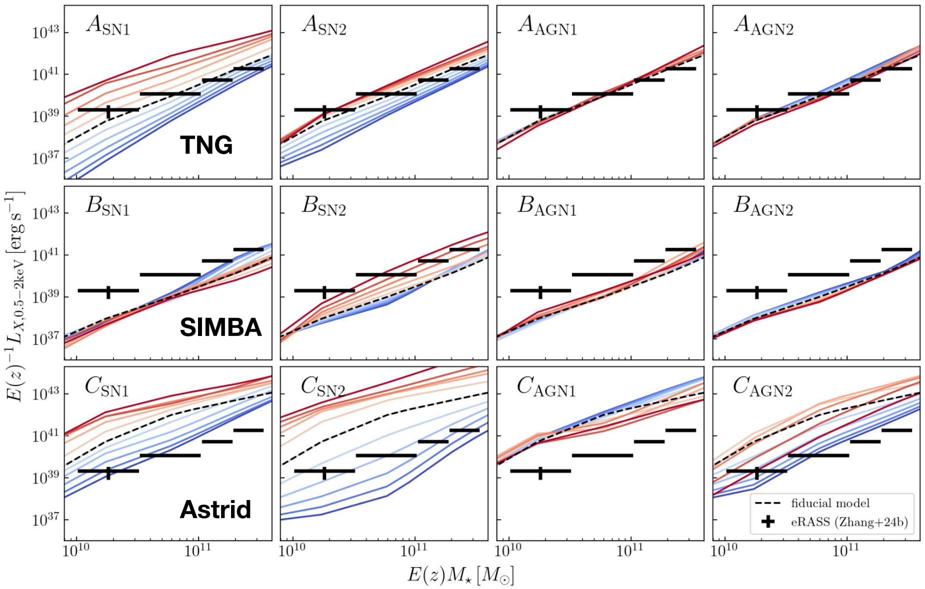




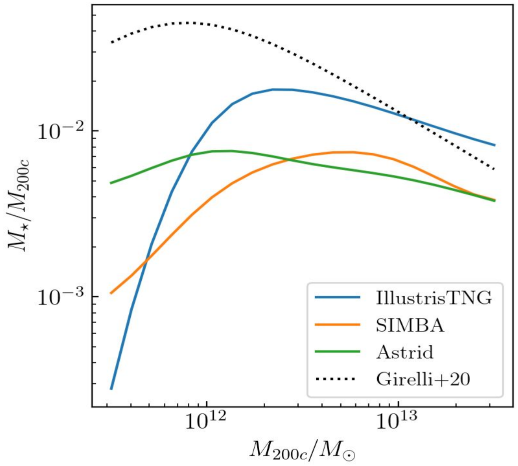


- **Comparison with CAMELS simulations:** Lower stellar feedback matches observations for all models (TNG, SIMBA, Astrid).

- **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

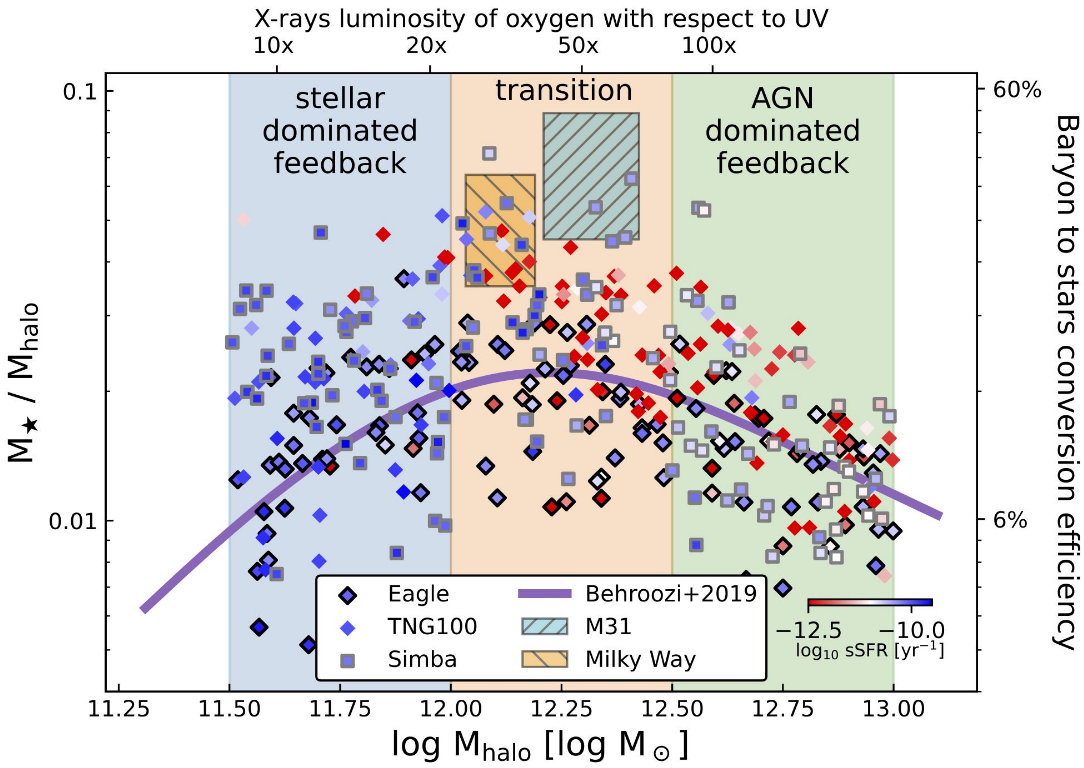


Takehome messages



- **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.
- **Bottom line**: Multiwavelength (X=ray+SZ+stars) observations required for understanding feedback and CGM properties.

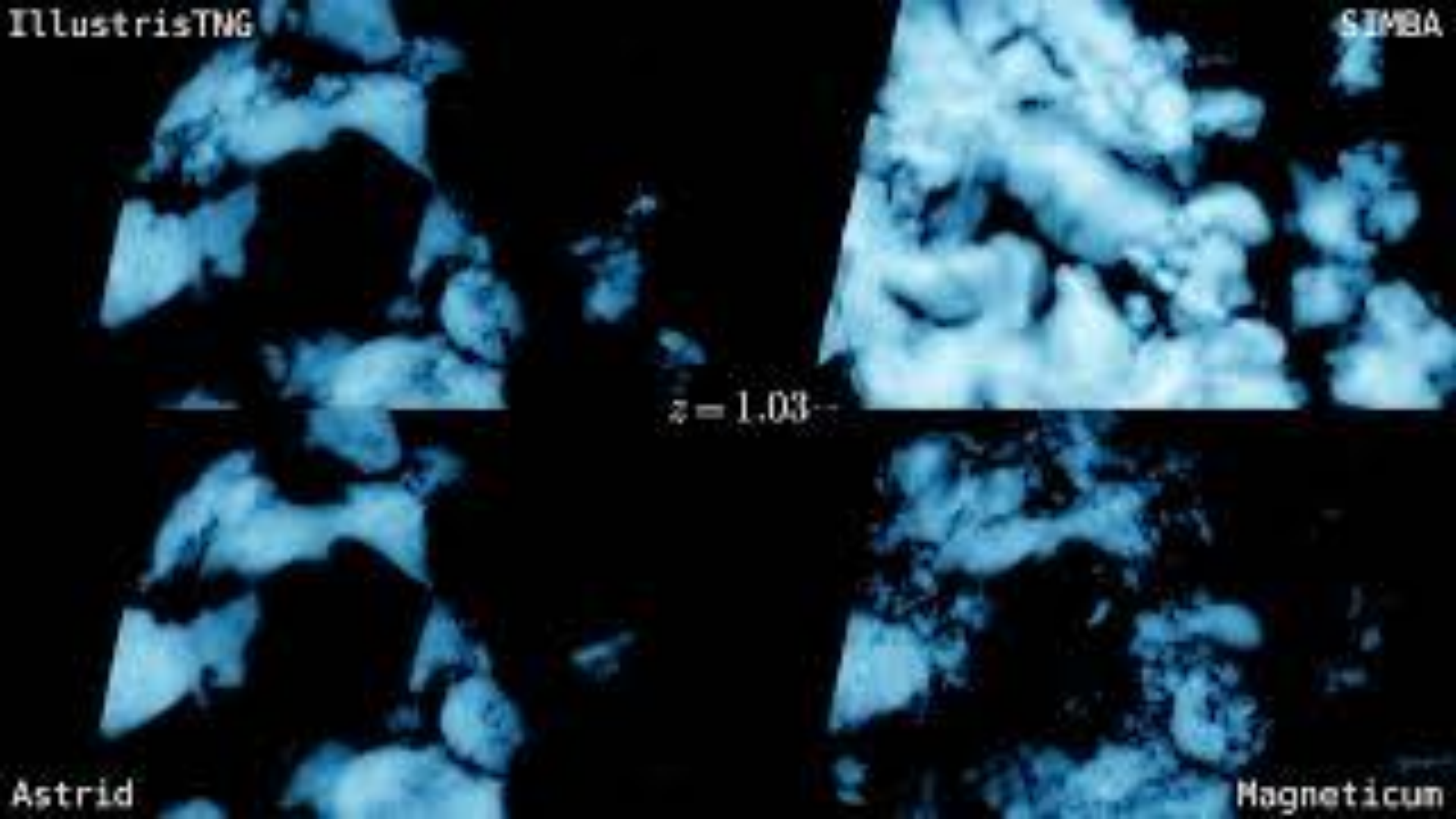
Circumgalactic Medium: Key Probe of Baryon Cycle



Schellenberger+23

The Circumgalactic Medium (CGM): gas surrounding massive galaxies can tell us about

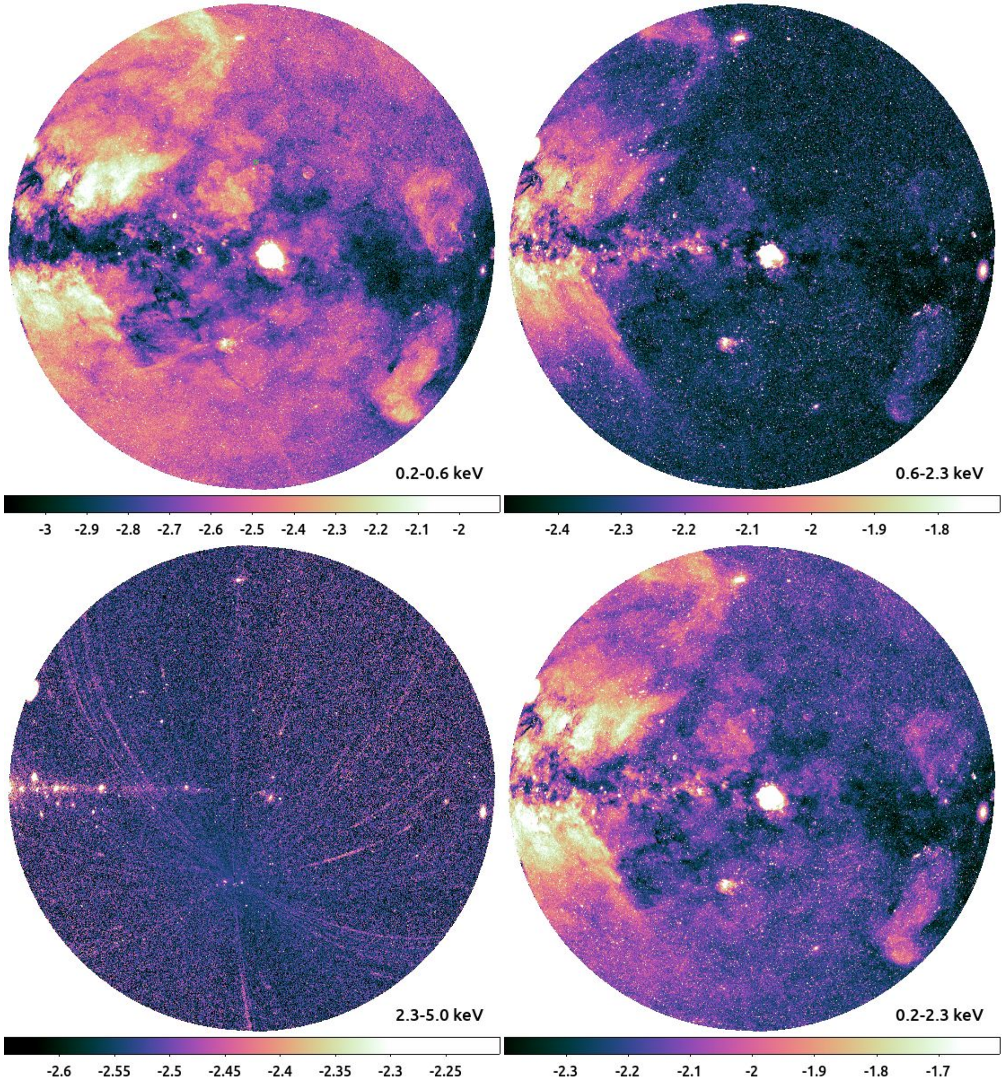
- Gas Inflow and Star Formation
- Feedback and Outflows
- Metal Enrichment and Chemical Evolution


IllustrisTNG
SIMBA
z = 1.03
Astrid
Magneticum

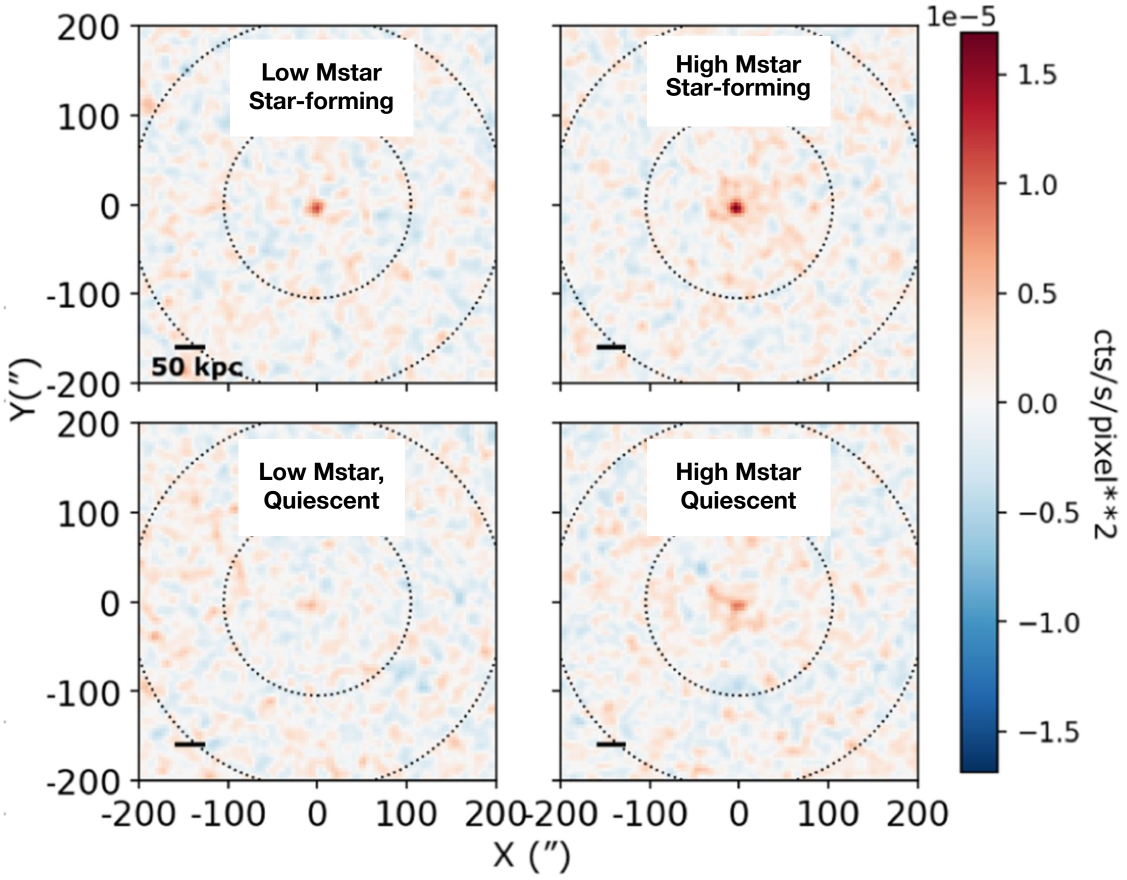
eROSITA All Sky Survey (eRASS)

- German-Russian X-ray mission.
- ~4 full-sky scans.
- Average few 100 seconds exposure.
- First Western Galactic half-sky scan released from the German side.
- Contains the largest number of X-ray sources detected so far.

Merloni+24



Measuring the X-ray CGM with Stacking



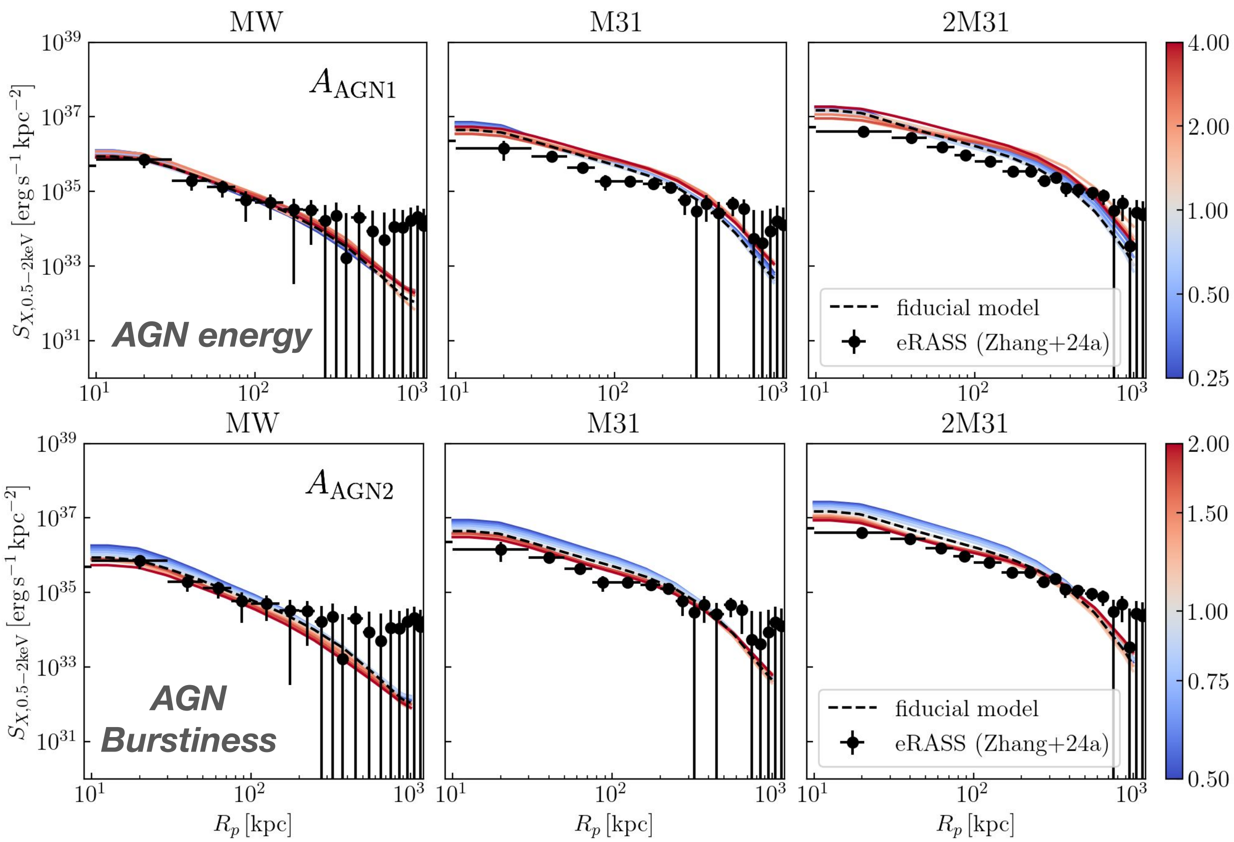
CGM of individual galaxies are dim. Stacking increase S/N.

Systematics:

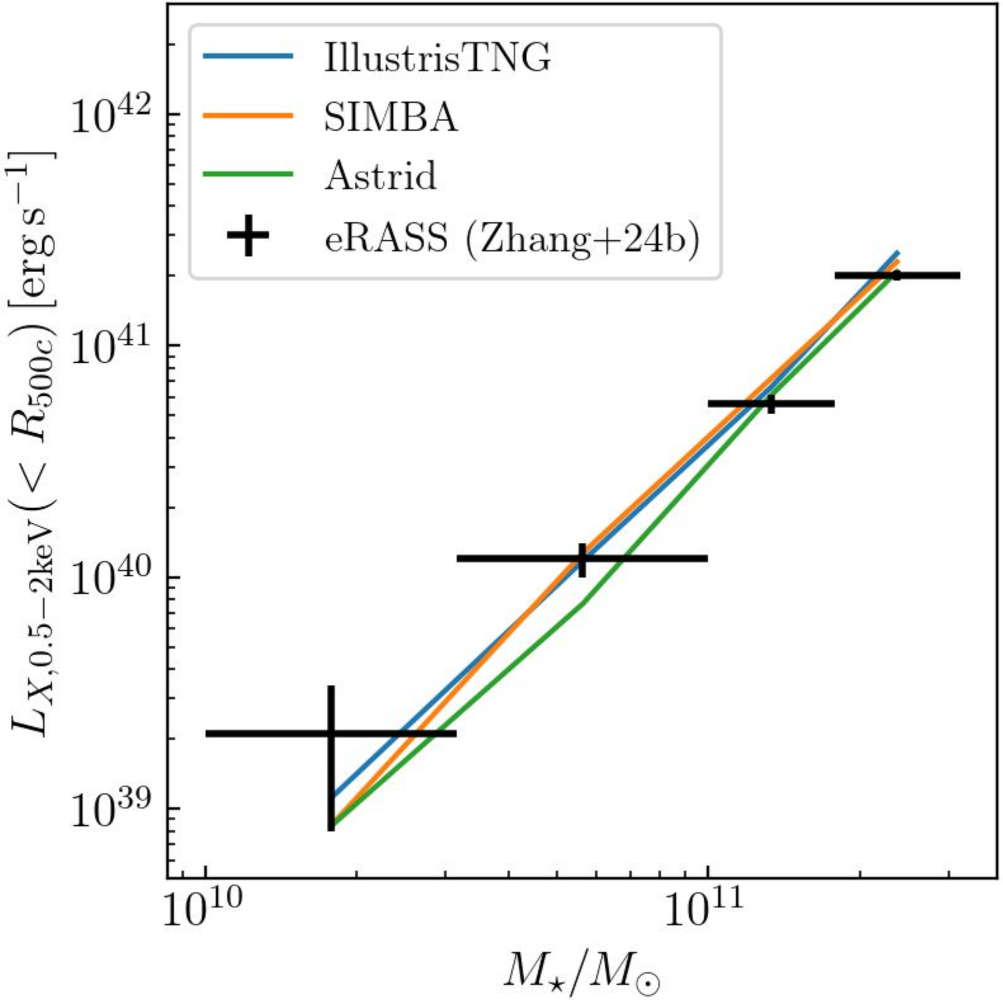
- Contaminants: X-ray binaries, AGN, emissions from galaxy groups.
- Biased due to few outliers.
- Instruments: eROSITA has large PSF (27”)

Chadayammuri+22, see also Comparat+22

X-ray Surface Brightness Profiles: IllustrisTNG vs eRASS



X-ray emission at CGM scales has weaker dependence on AGN feedback.



Constraints on feedback parameters

Small statistical errors in Lx in eRASS leads to tight constraints on feedback parameters.

Parameter	TNG	SIMBA	Astrid
SN1	$2.07^{+0.35}_{-0.34}$	$3.45^{+0.35}_{-0.38}$	$2.07^{+0.82}_{-1.00}$
SN2	$0.6^{+0.13}_{-0.07}$	$1.63^{+0.20}_{-0.05}$	$0.78^{+0.13}_{-0.13}$
AGN1	$2.18^{+1.56}_{-1.14}$	$1.79^{+0.55}_{-0.80}$	$2.42^{+0.84}_{-1.39}$
AGN2	$1.15^{+0.53}_{-0.54}$	$1.62^{+0.27}_{-0.53}$	$0.67^{0.65}_{-0.30}$