Title: Constraining AGN Feedback with Multiwavelength Measurements

Speakers: Evan Scannapieco

Collection/Series: Cosmic Ecosystems

Subject: Cosmology

Date: July 28, 2025 - 2:40 PM

URL: https://pirsa.org/25070010

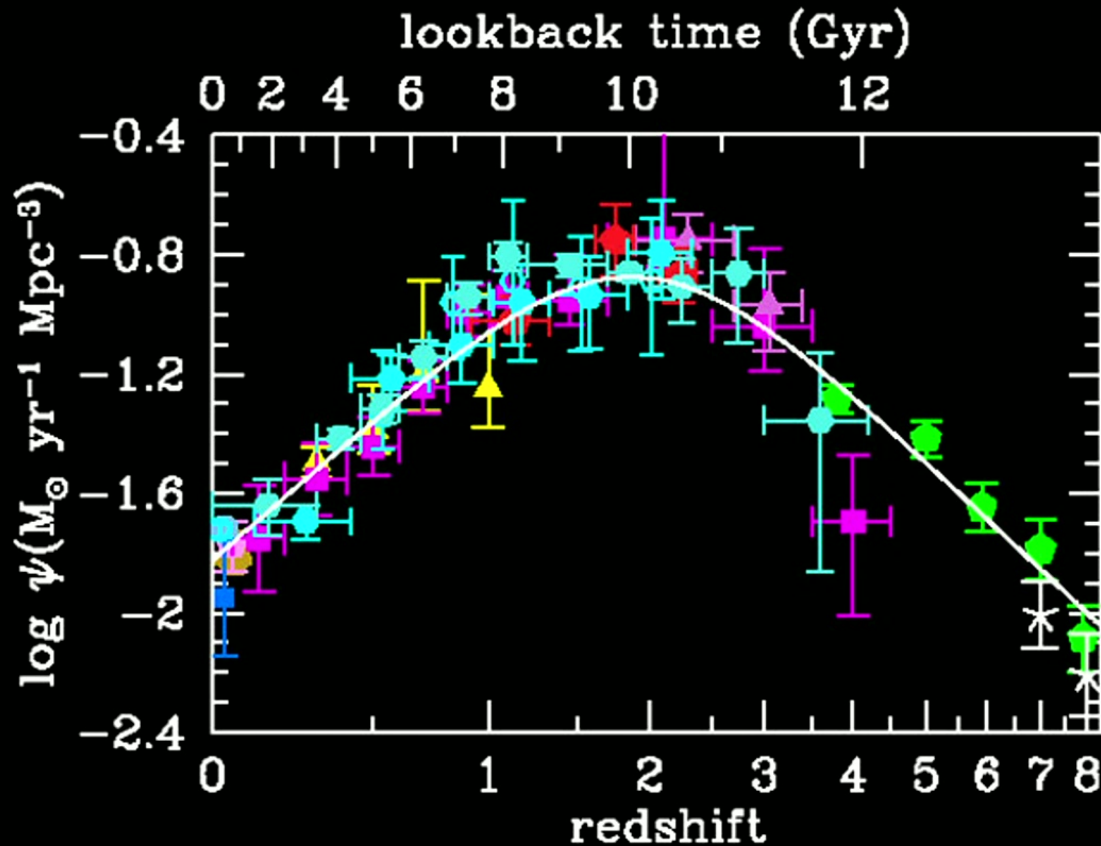
Abstract:

Feedback from active galactic nuclei (AGN) plays an essential role in current models of galaxy formation, yet the details of this process remain highly uncertain. I will describe our work combining numerical simulations with microwave, X-ray, and large-scale structure (LSS) survey data to better constrain this process. Our team has conducted a series of simulations spanning a broad range of feedback properties, enabling us to investigate their effects on the circumgalactic medium (CGM). At microwave wavelengths, we use these simulations to predict the thermal and kinetic Sunyaev-Zel'dovich (SZ) effects. We compare these predictions with stacked data from the Atacama Cosmology Telescope (ACT) and the South Pole Telescope (SPT) to derive constraints on AGN feedback. Additionally, we outline plans to improve these constraints with the TolTEC camera on the Large Millimeter Telescope (LMT).

At X-ray wavelengths, we apply these simulations to predict soft X-ray emission, which we compare with stacked eROSITA observations. A persistent challenge in interpreting these comparisons is the influence of halo mass. I will discuss how weak gravitational lensing can help resolve this issue, offering new insights into the co-evolution of galaxies and their AGN.

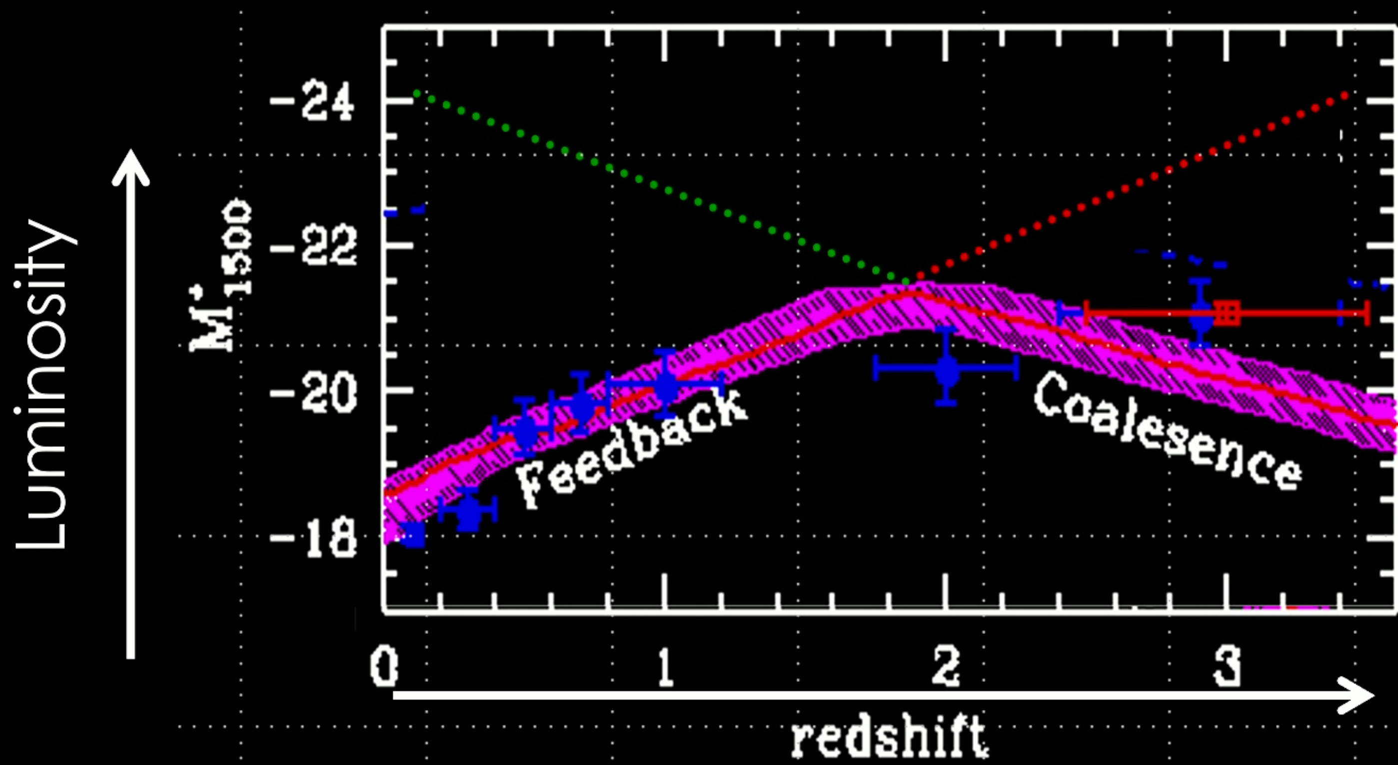
Constraining AGN Feedback with Multiwavelength Measurements

Evan Scannapieco
Arizona State University



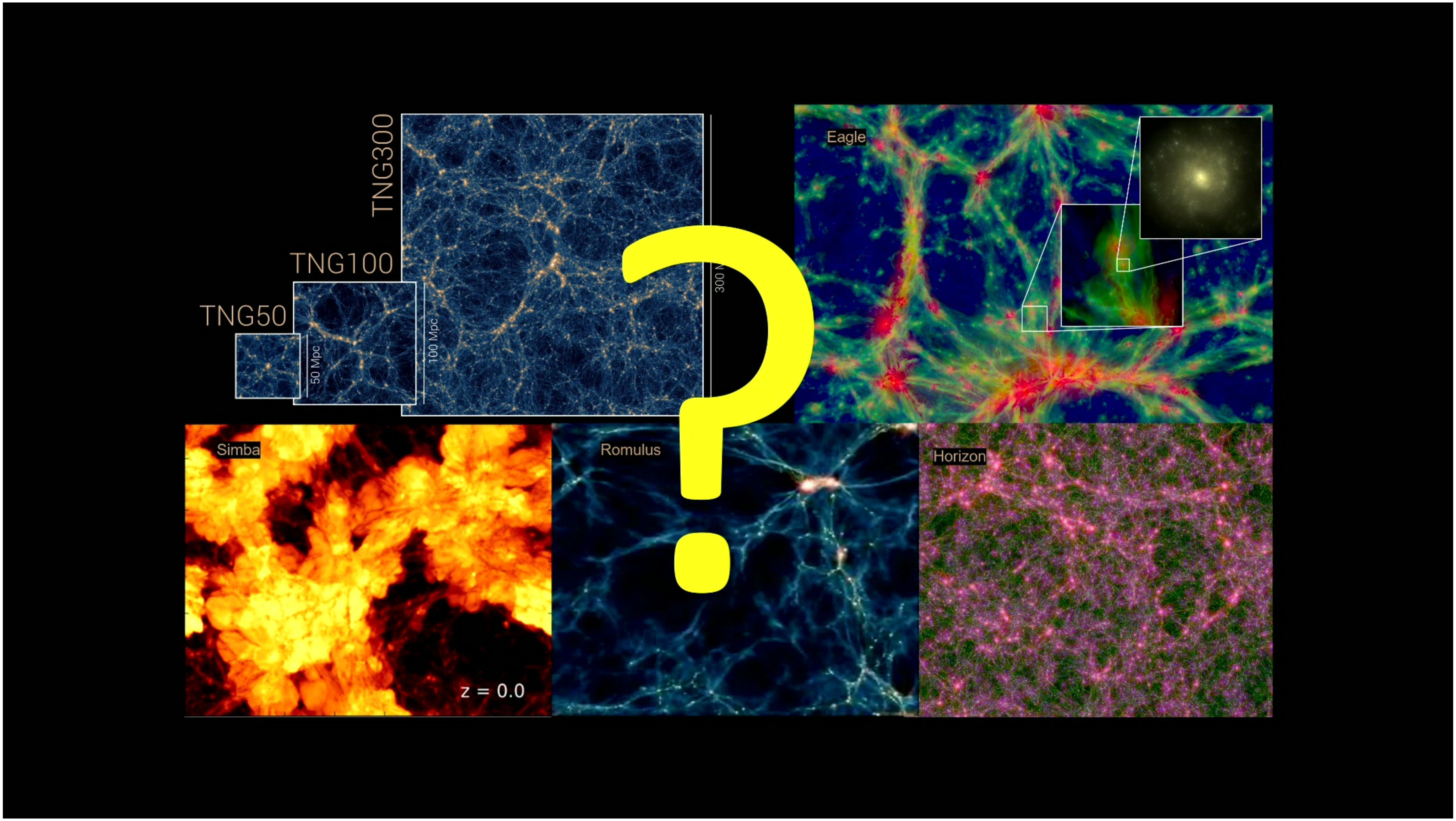
Madau & Dickenson (2014)

Downsizing



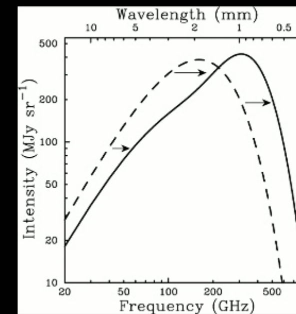
ES & Oh (2004)

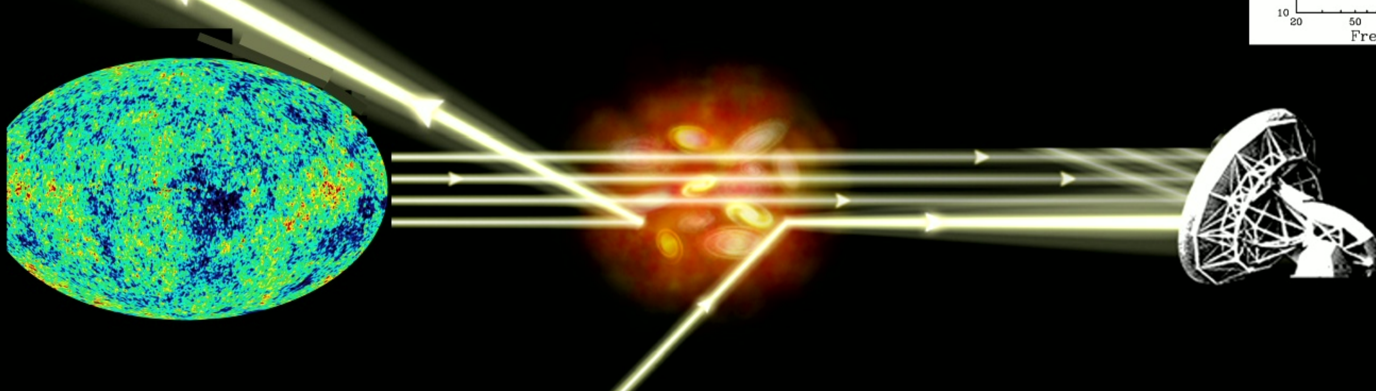
ES, Silk, & Bouwens (2005)


TNG300
TNG100
TNG50
50 Mpc
100 Mpc
Eagle
Simba
z = 0.0
Romulus
Horizon
?

Sunyaev Zel'dovich Effect

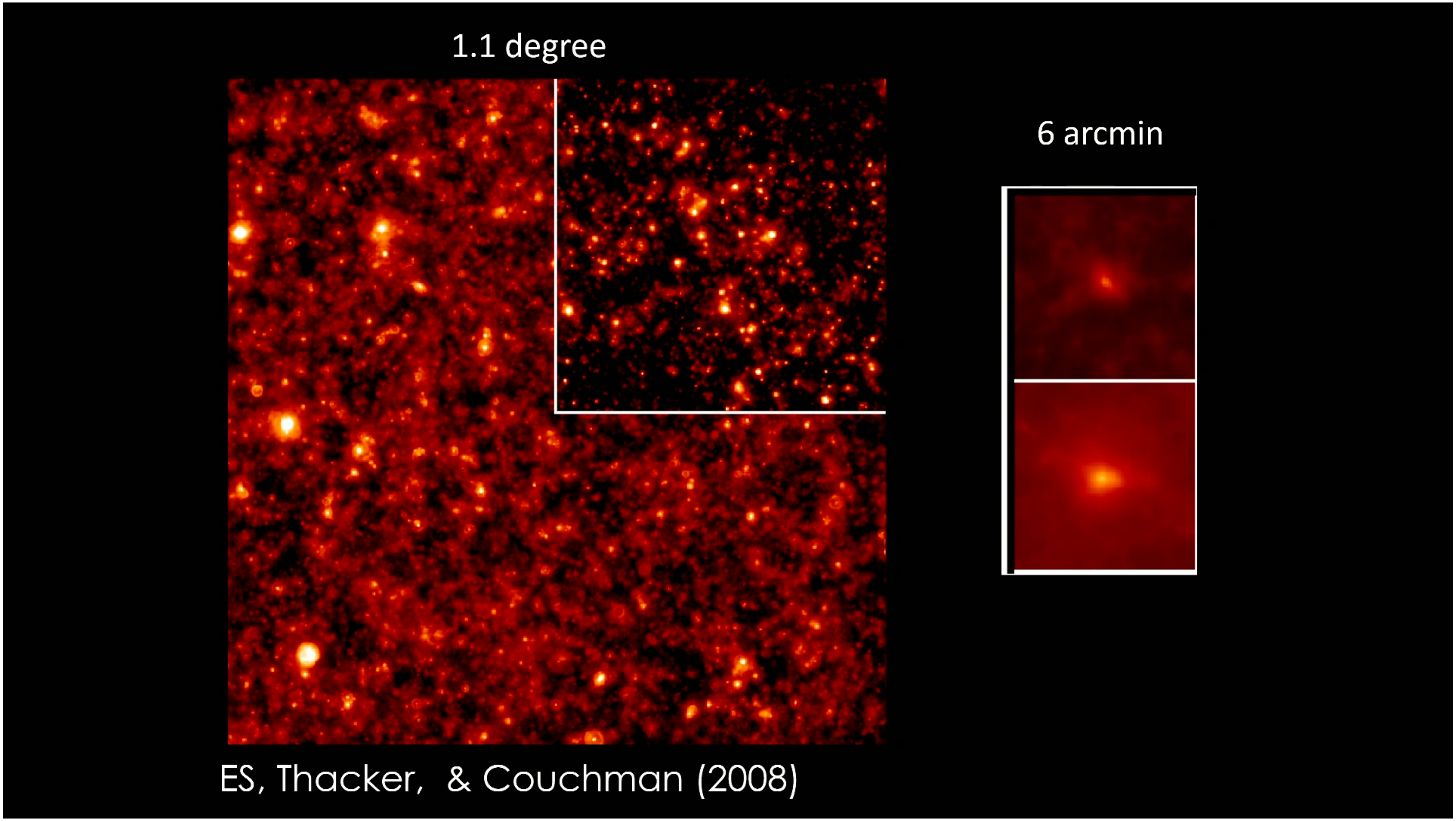
Signal α Gas Density Along Sightline
× Temperature Along Sightline
`` = Pressure Along Sightline





$$E_{\rm th} = 2.9 \times 10^{60} {\rm erg} \left(\frac{D_{\rm a}}{\rm Gpc}\right)^2 \frac{\rm Y}{10^{-6}\,{\rm arcmin}^2} \qquad {\rm Y} \equiv \int y(\theta)\, d\theta$$

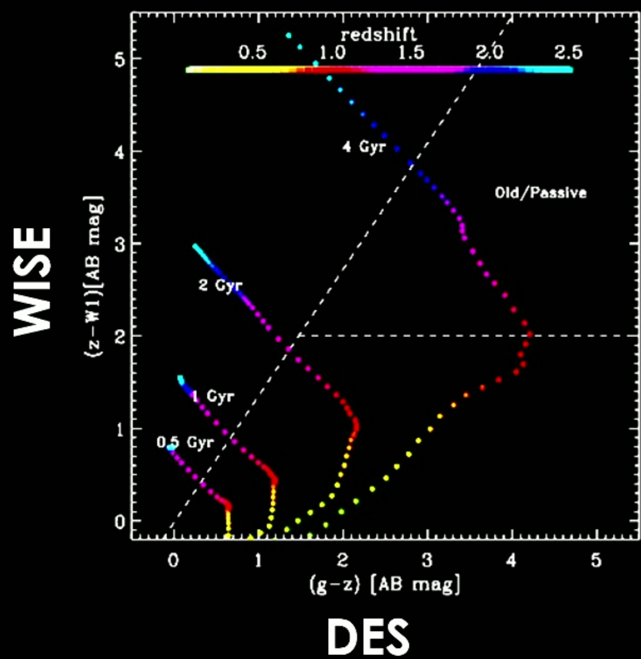
CR fans: note there is a correction for relativistic particles

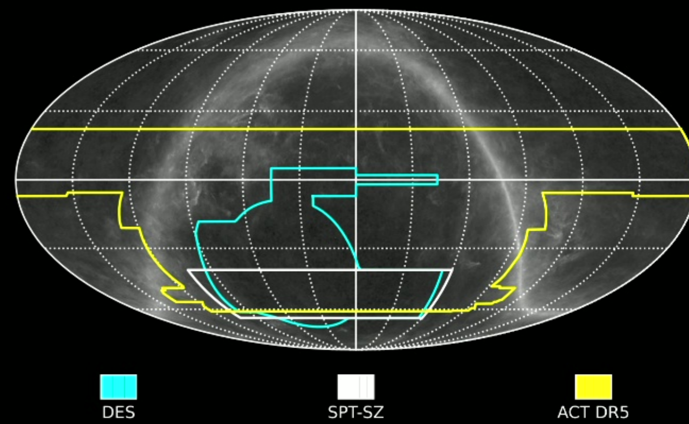

1.1 degree
6 arcmin
ES, Thacker, & Couchman (2008)

Seth Cohen

Selection and Sample

2,100 deg², 5,000 deg², 18,000 deg²





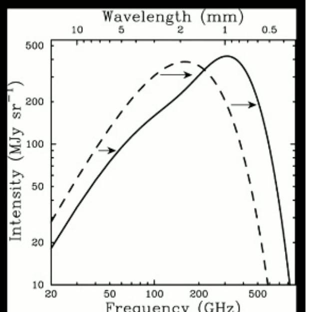
age > 1 Gyr , SSFR < 0.01 Gyr^{-1}

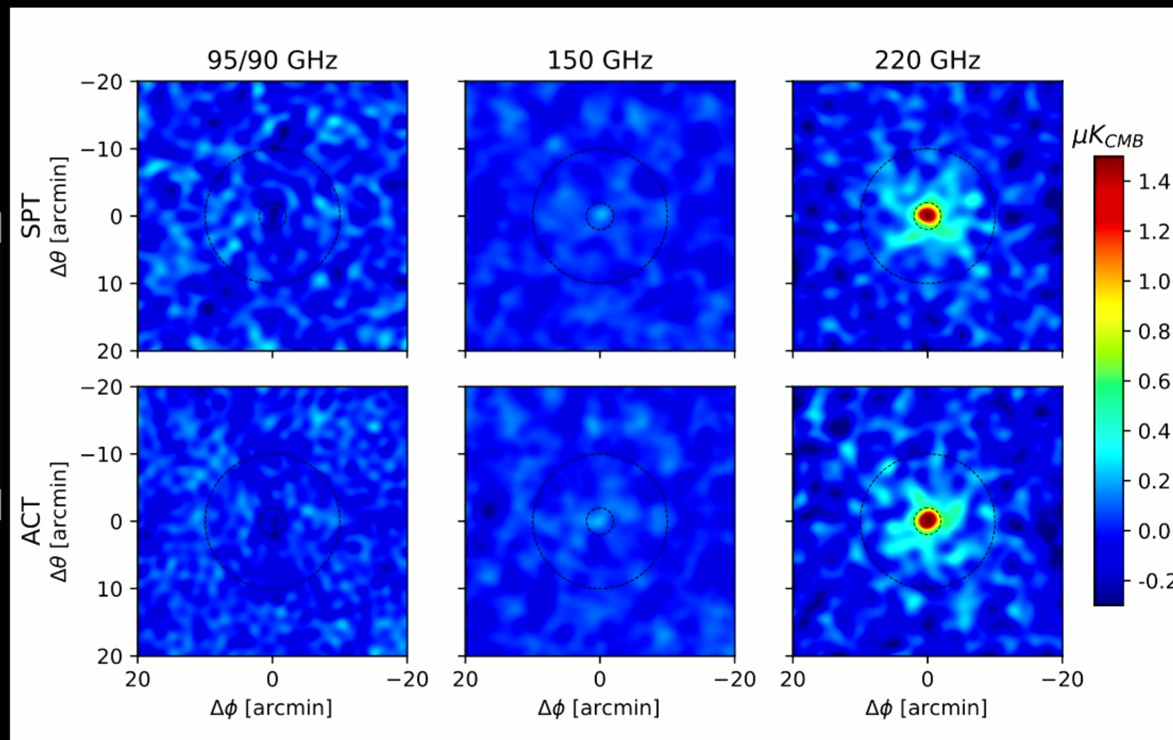
Catalog	N	z	$\log_{10}(\overline{M_\star}/M_\odot)$
SPT + ACT Overlap	94452	1.06	11.41
ACT Only	387627	1.07	11.44

Meinke, Cohen, Moore, Böckman, Mauskopf, & ES (2023)

Stacked Signals in the Overlap Region

Jeremey
Meinke



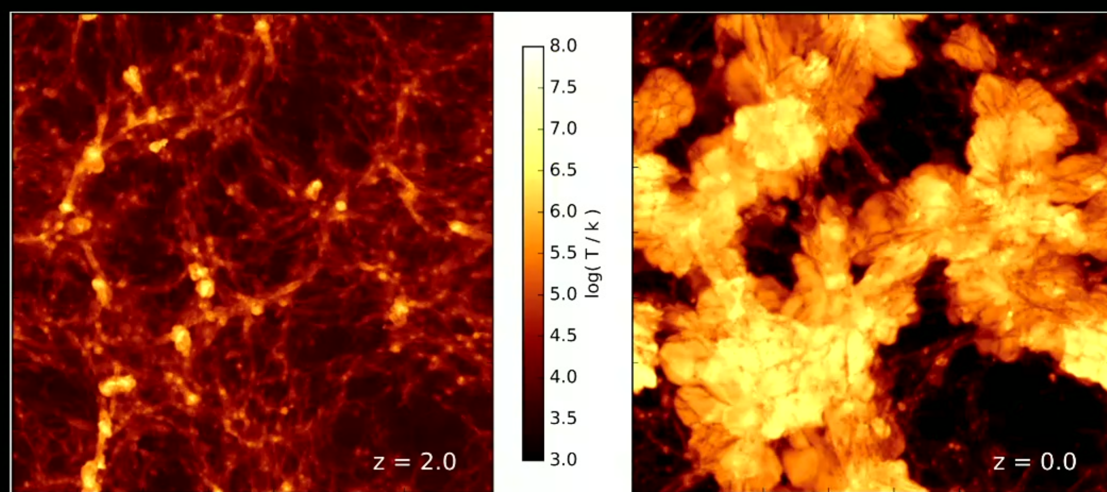


Meinke, Cohen, Moore, Böckman, Mauskopf, & ES (2023)

SIMBA

- MPI version of the GIZMO meshless code
- 100 cMpc/h box, 2 x1024^3 particles, to z=0 (2E7 Msun)
- Includes updates to Mufasa's sub-resolution star formation and feedback prescriptions.
- AGN are associated torque limited accretion (cold) / Bondi accretion (hot).
- 3-40% of energy in light goes into outflows depending L_{edd}

Davé et al (2019)



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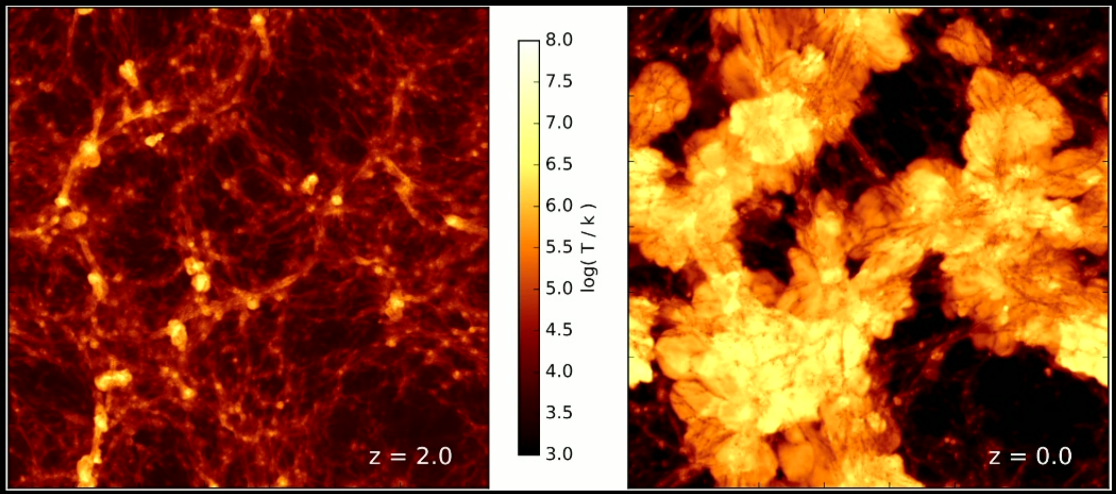
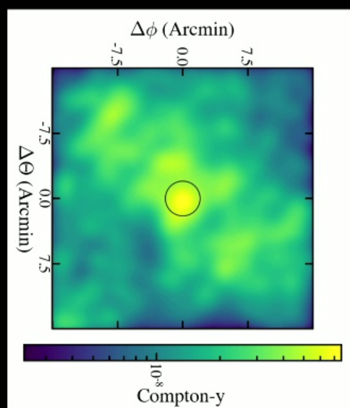
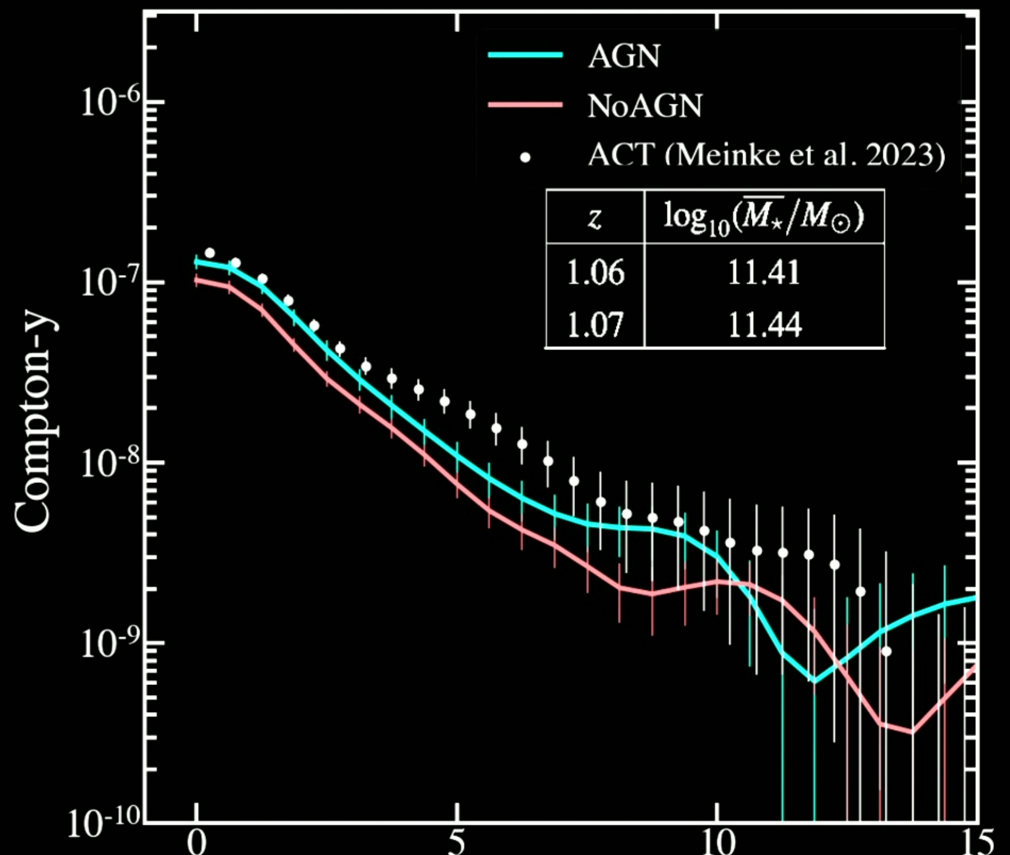


z=1 Stacking SZ Data from SIMBA

Skylar Grayson

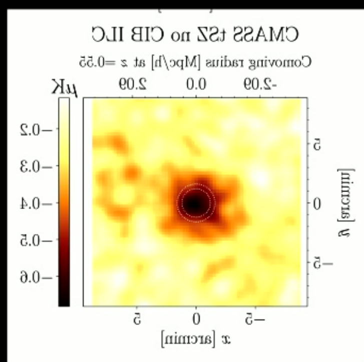


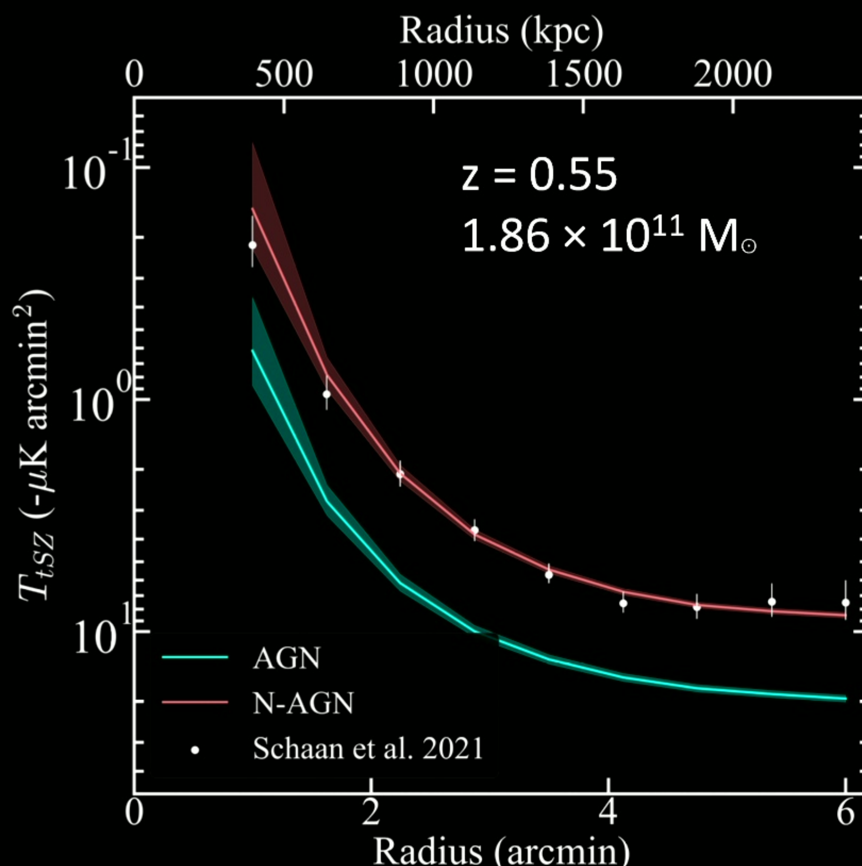


Grayson, ES, and Davé(2023)

z=0.55 Stacking SZ Data from SIMBA

Skylar Grayson



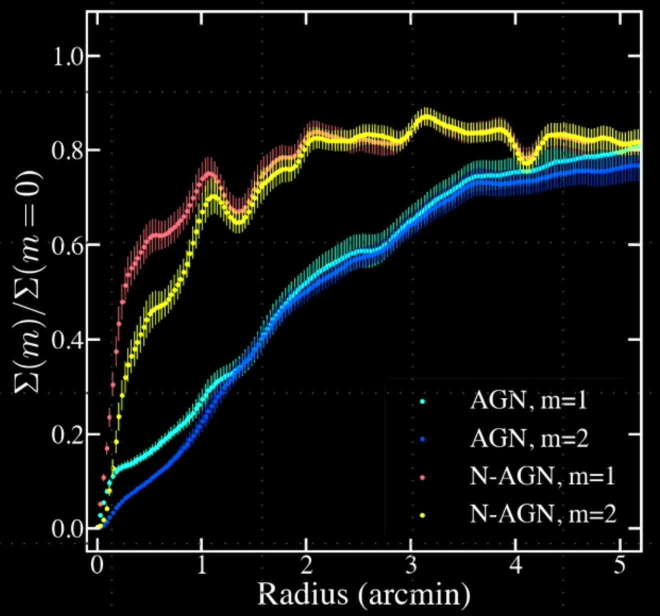


Grayson, ES, and Davé(2023)

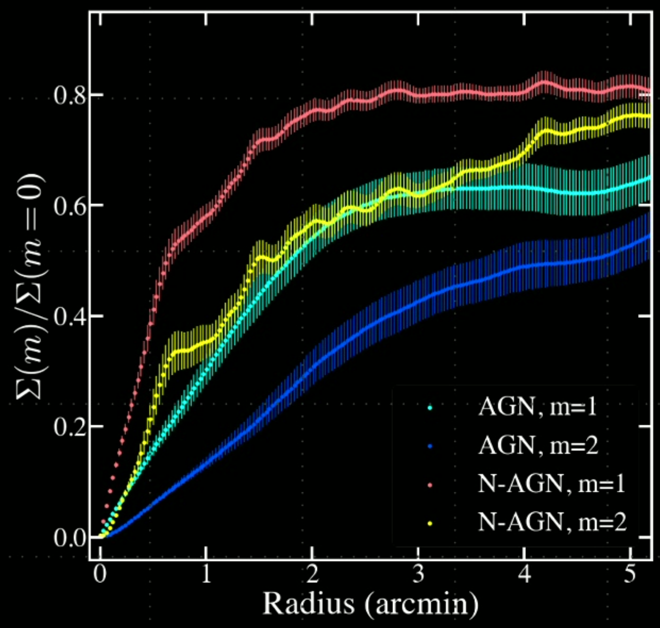
SZ Moments

$$\Sigma(r, m) = \frac{1}{2\pi}\int_0^{2\pi} y(r,\theta)e^{im\theta}d\theta$$

z=1.0



z=0.5



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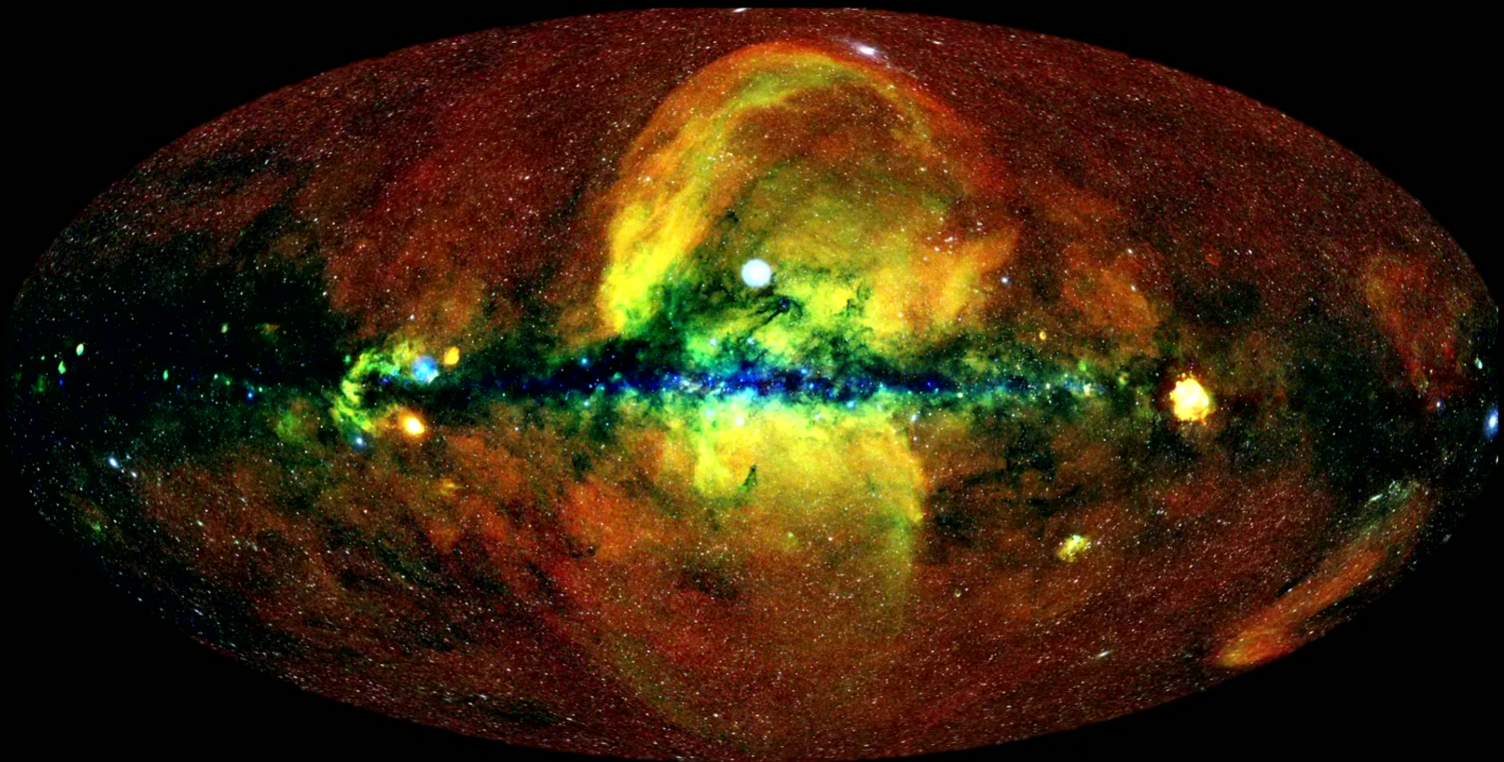
X-ray Emission



SRG/eROSITA All-sky Survey

Simulated eROSITA Stacks

Model Hot gas and LMXB + HMXB Contributions
SIMBA simulations EAGLE (bursty feedback put in thermally, ε_f=0.15)

1. Generate photons from 5 different cosmological simulations using APEC CIE model

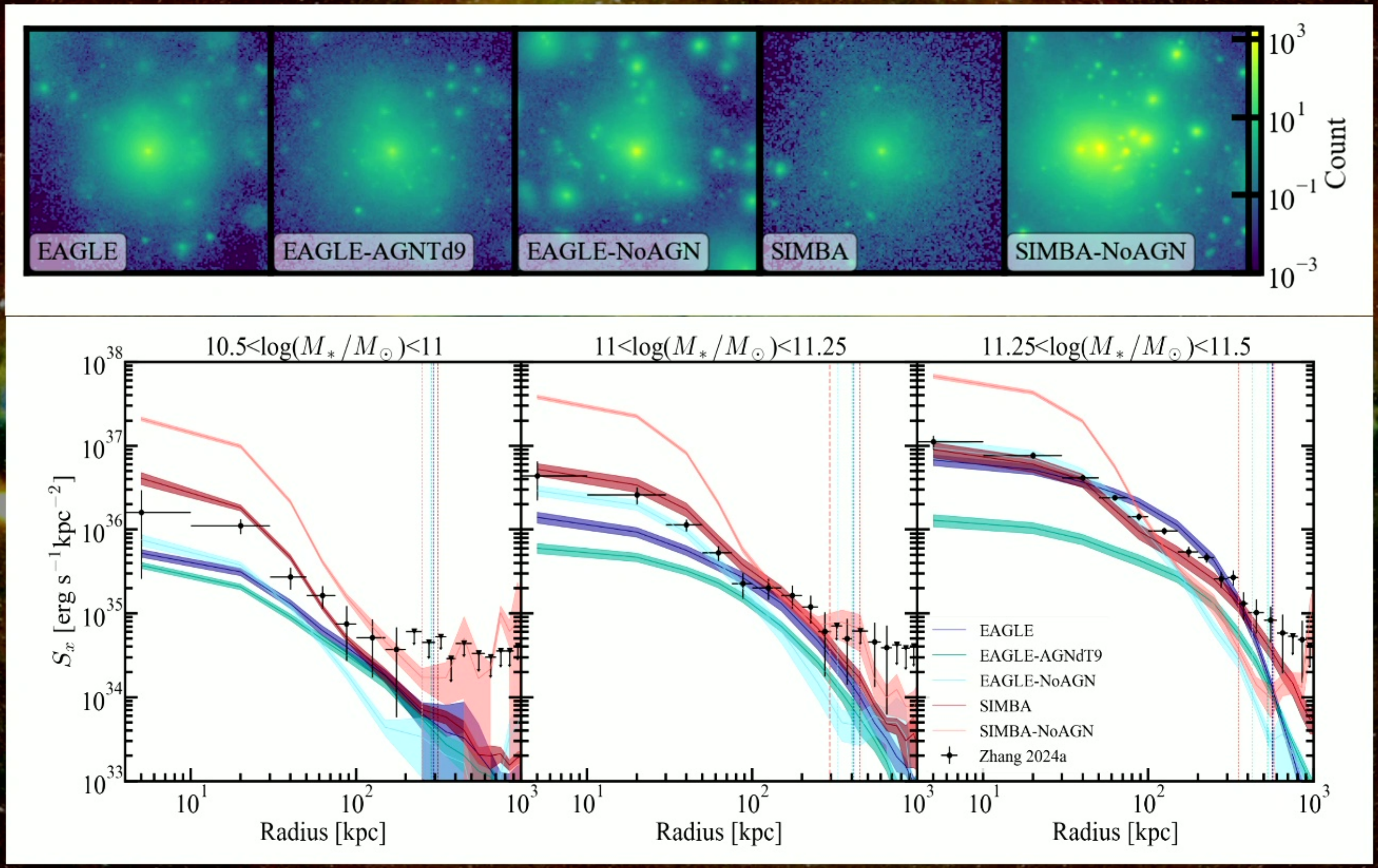
2. Project on the sky (via pyXSIM /APEC)

3. Simulate 1000ks observation with eROSITA using SOXS, including instrumental effects (PSF, ARF, RMF, backgrounds)

4. Select galaxies and stack to generate radial profiles

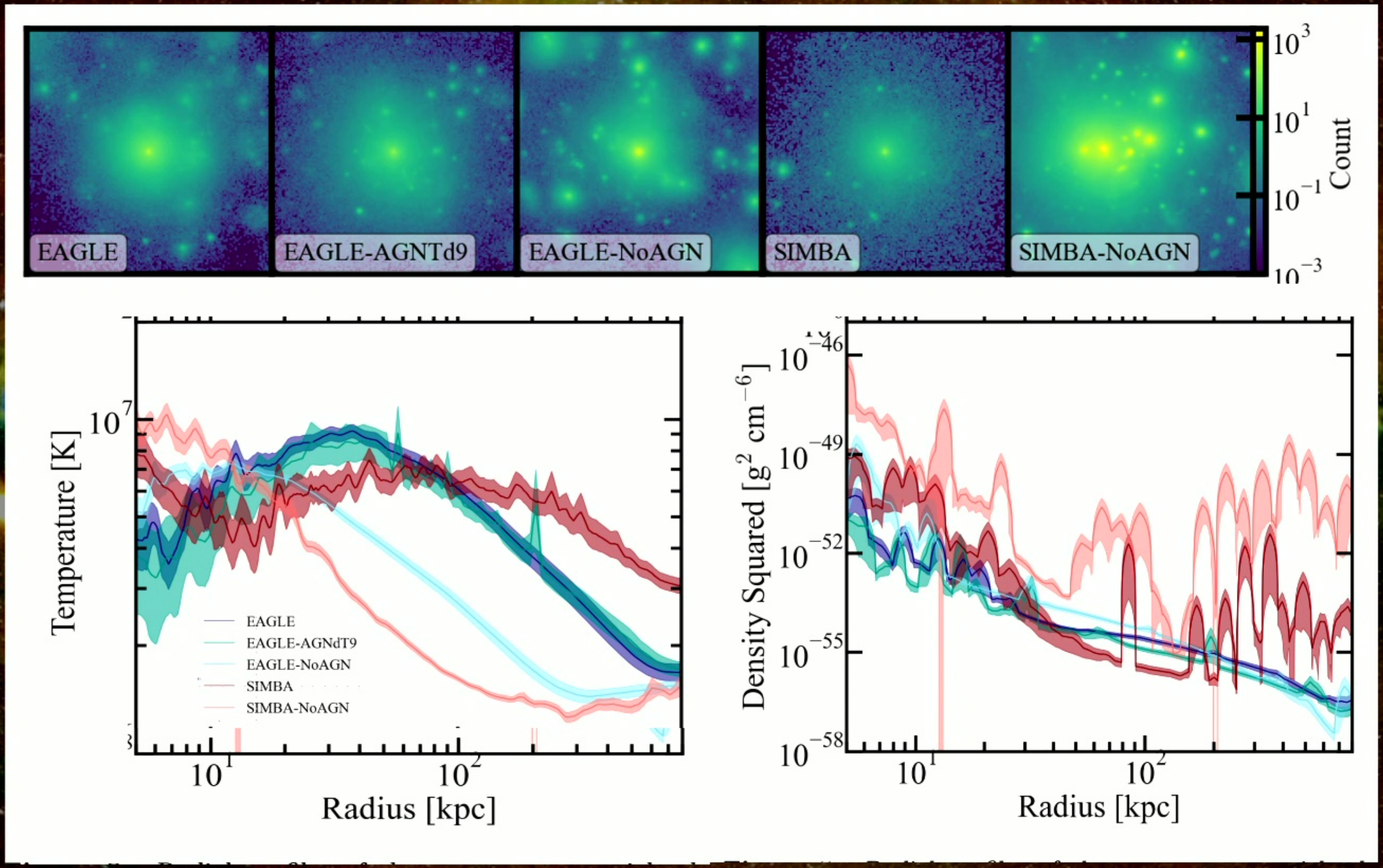
Grayson, ES, Comparat, ZuHone, Zhang, Sheeram, Brüggen, & Bulbul (2025 xarXiv:2506.09123)

X-ray Emission



Grayson, ES, Comparat, ZuHone, Zhang, Sheeram, Brüggen, & Bulbul (2025 xarXiv:2506.09123)

X-ray Emission



Grayson, ES, Comparat, ZuHone, Zhang, Sheeram, Brüggen, & Bulbul (2025 xarXiv:2506.09123)

A Tool to Constrain AGN Feedback

$$L = \eta \dot{M}_{\rm BH} c^2$$

$$\eta = 0.1$$

$$\dot{P}_j = \boxed{\epsilon_j} L/v \quad \dot{P}_w = \boxed{\epsilon_w} L/v$$

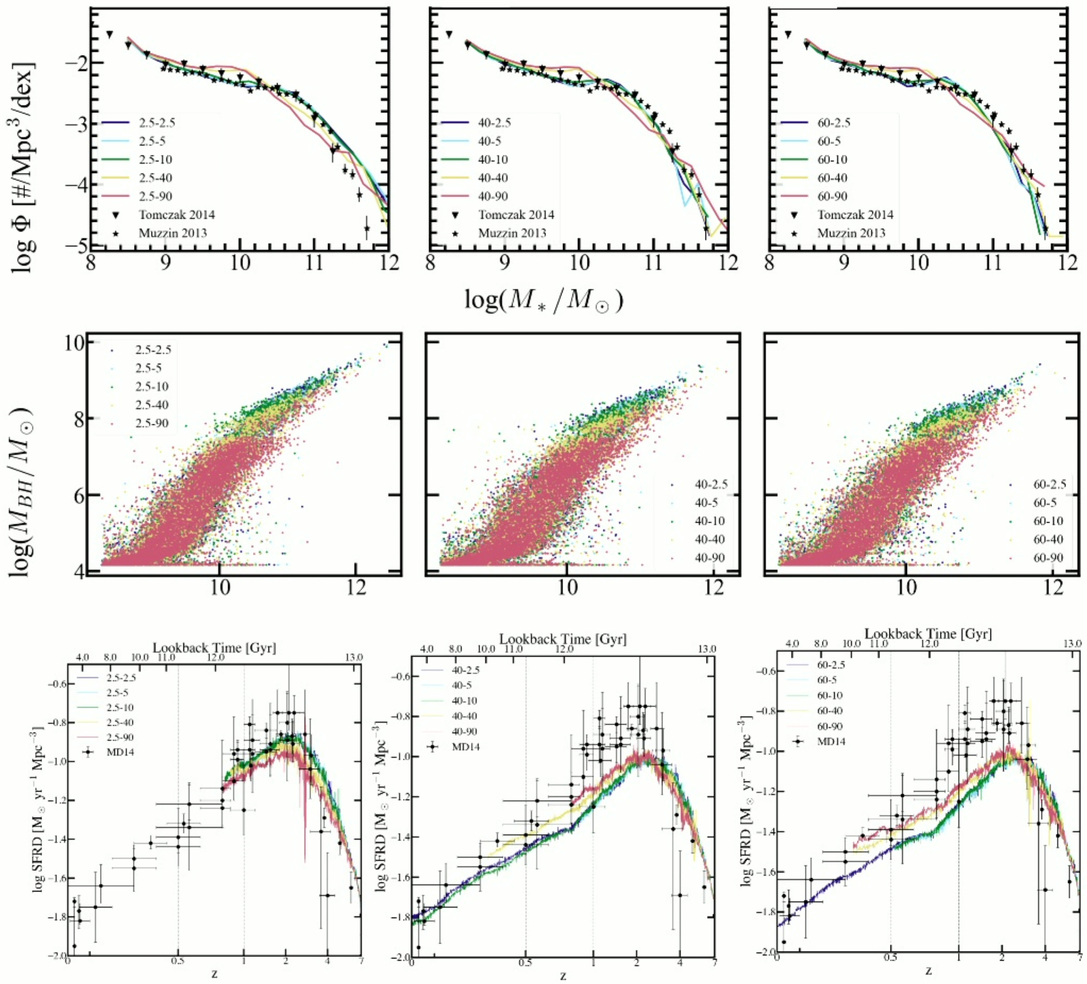
These are the parameters we change in the RAFIKI runs
Runs are labelled jet-wind, so 40-2.5 has ε_j =0.4 and ε_w = 0.025

$\epsilon_j = 0.025$ $\epsilon_j = 0.4$ $\epsilon_j = 0.6$

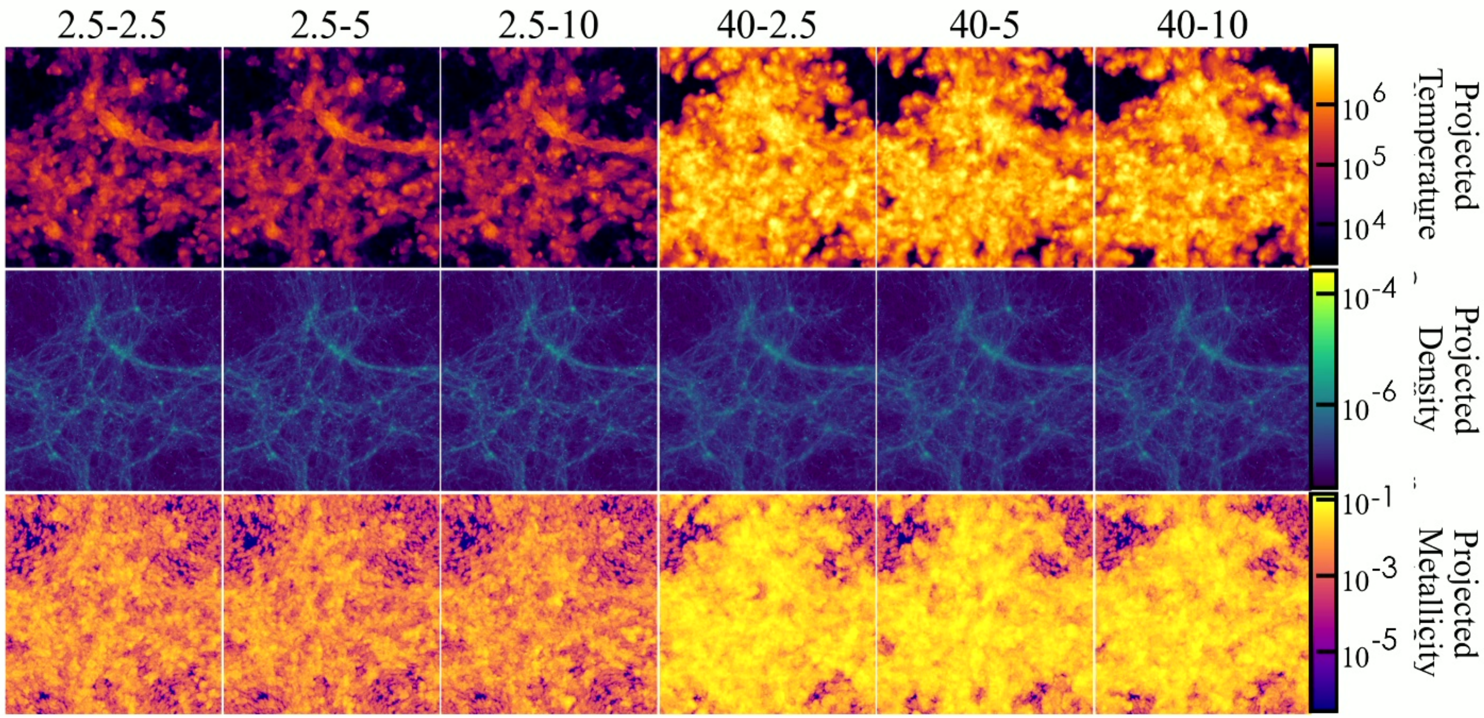
Z=1 Galaxy Stellar Mass Function

M_{BH} / M_*

SFRD



Coming soon



2.5-2.5
2.5-5
2.5-10
40-2.5
40-5
40-10
Projected Temperature
10^6
10^5
10^4
Projected Density
10^-4
10^-6
Projected Metallicity
10^-1
10^-3
10^-5

Conclusions