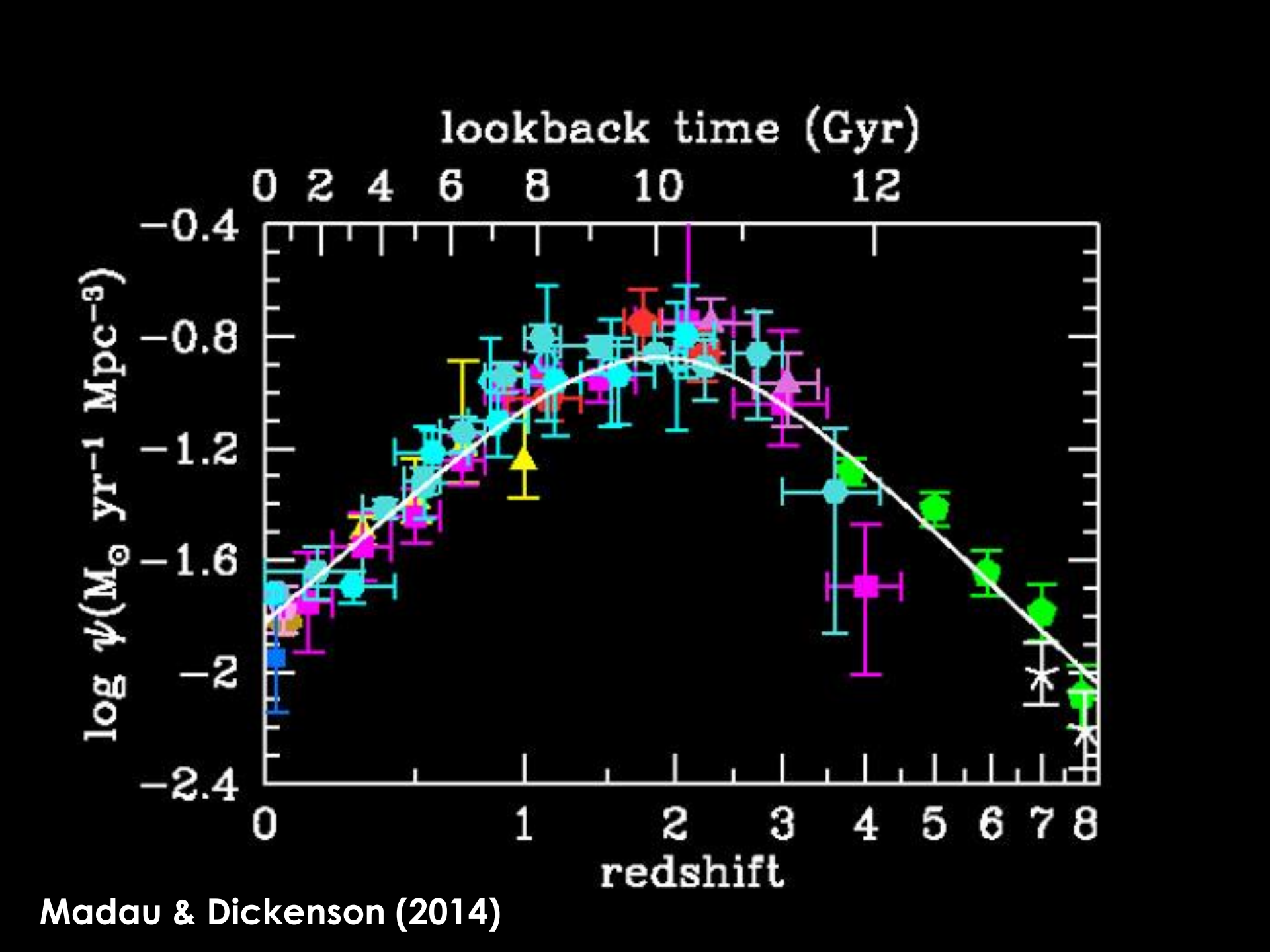
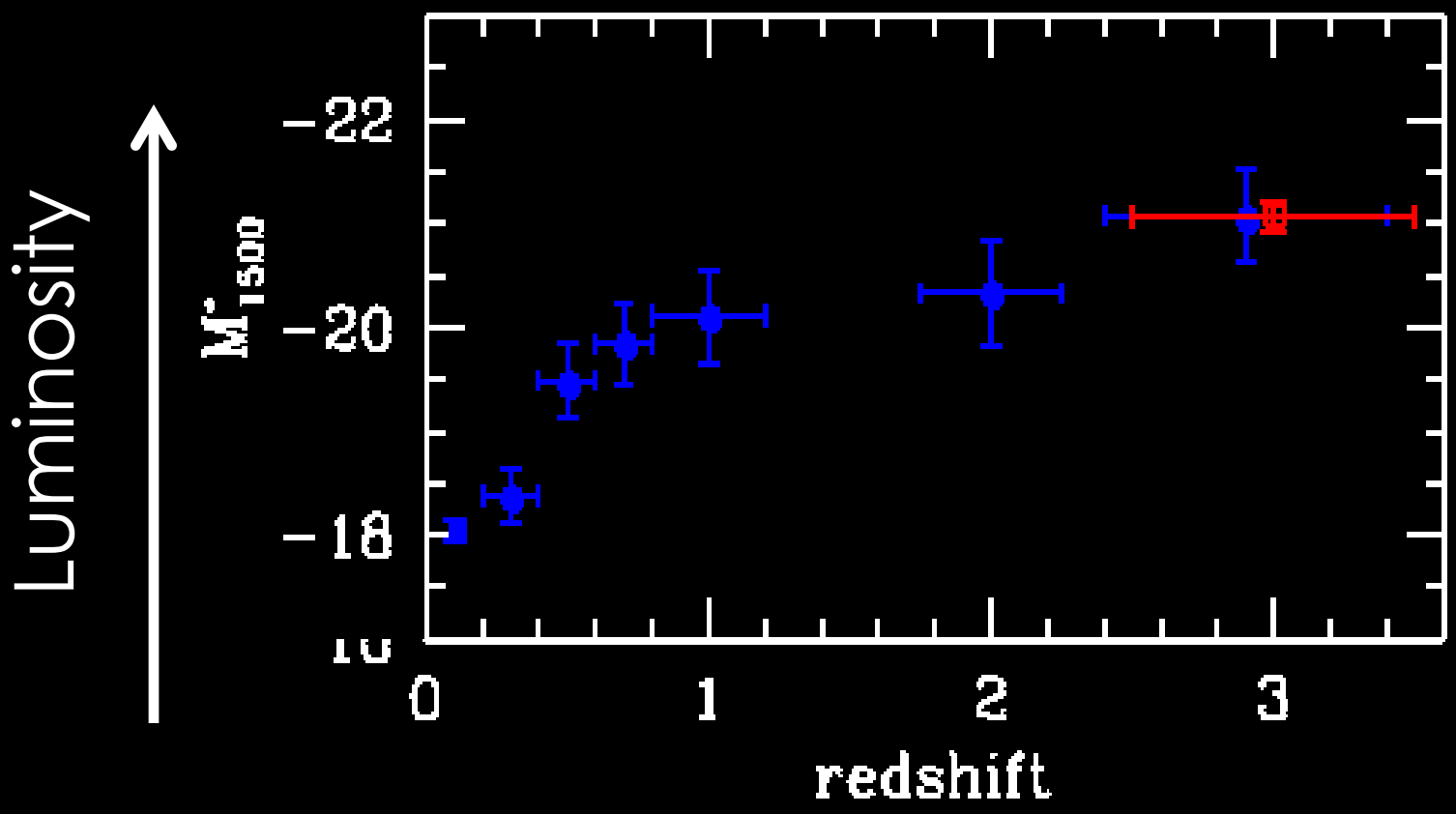
Constraining AGN Feedback

Evan Scannapieco
Arizona State University



Madau & Dickenson (2014)

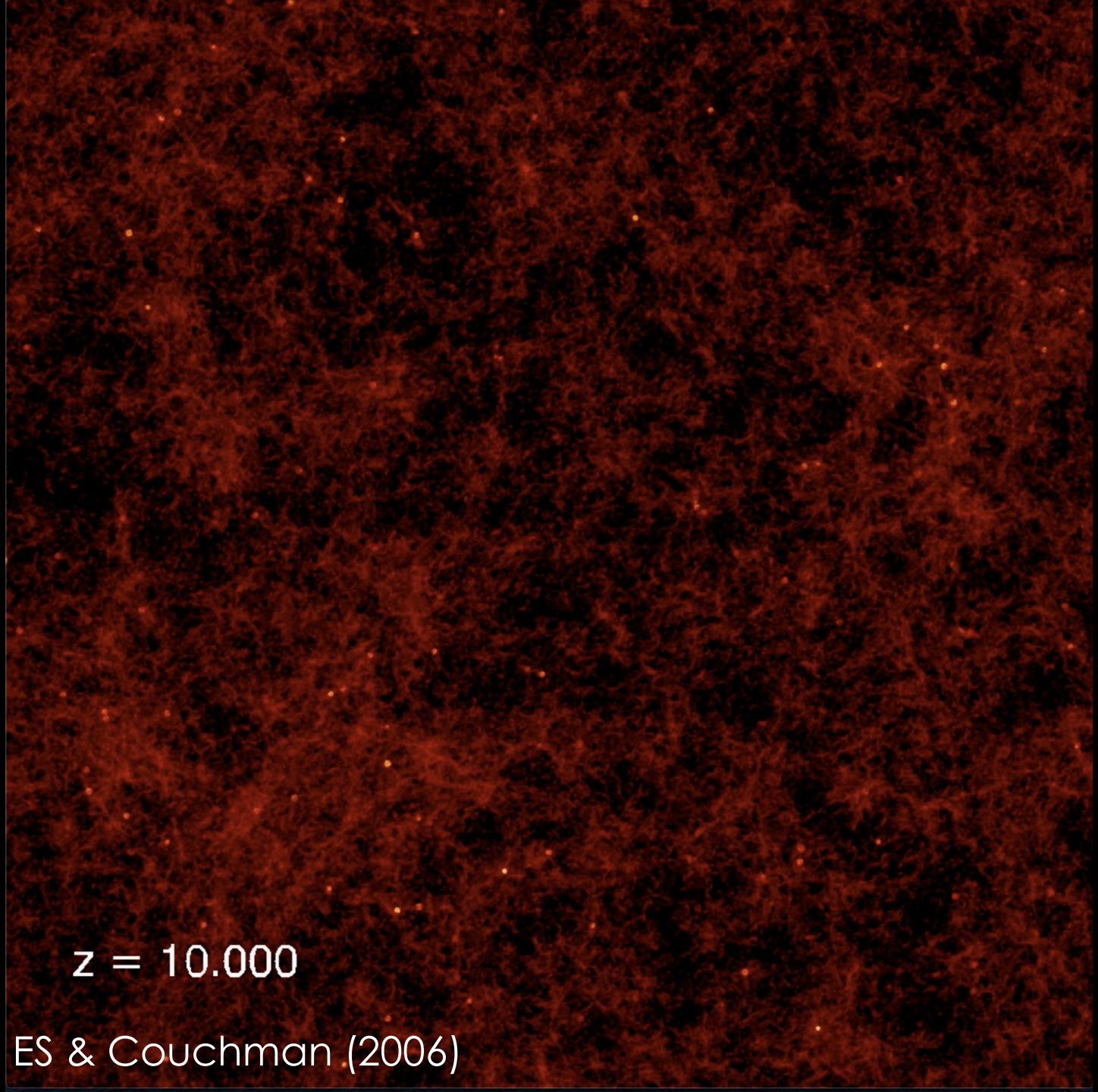
Antihierarchical Evolution-“Downsizing”



Arnouts etal (2005)

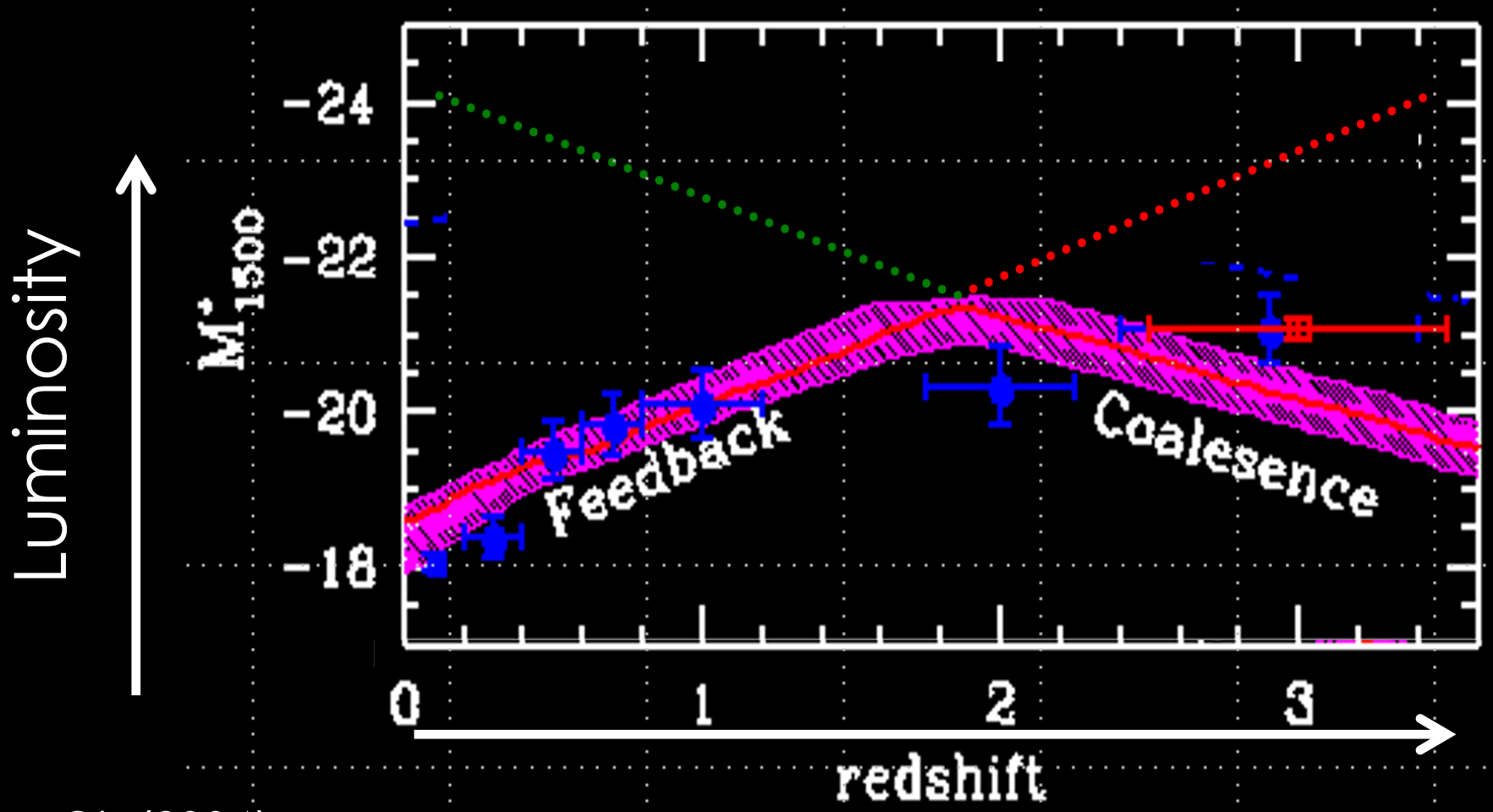
ES & Oh (2004) model

- Assume some small fraction, ε_k=0.05 of an active black hole's luminosity is converted to mechanical input
- Energy deposited as heat into surrounding medium
- Clustering between halos from Scannapieco & Barkana (2002) extension of Kaiser (1984), Bond et al. (1991), Lacey & Cole (1993), Mo & White (1996), etc..



Thacker, ES & Couchman (2006)

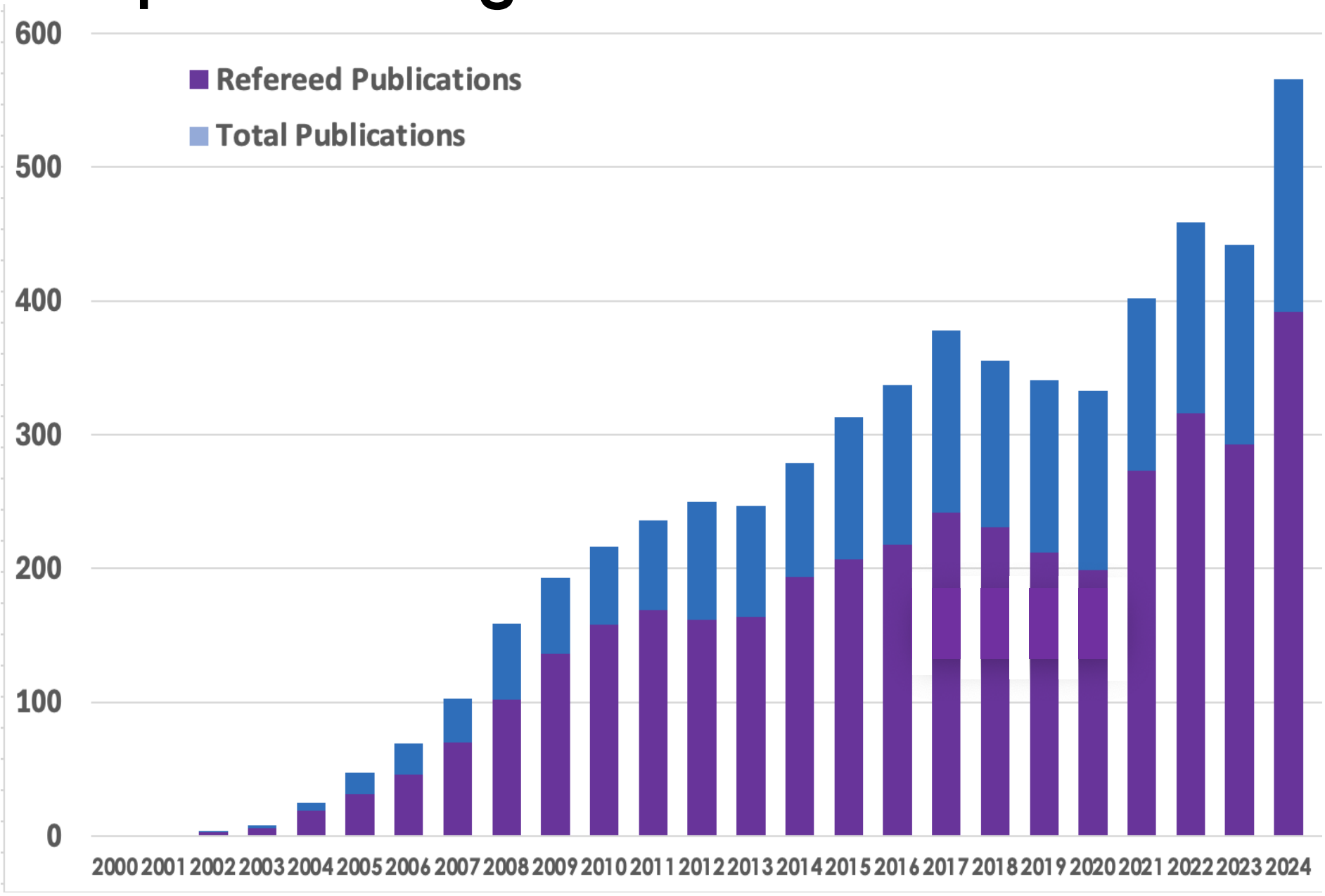
Downsizing



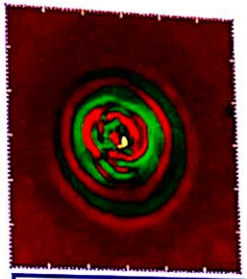
ES & Oh (2004)

ES, Silk, & Bouwens (2005)

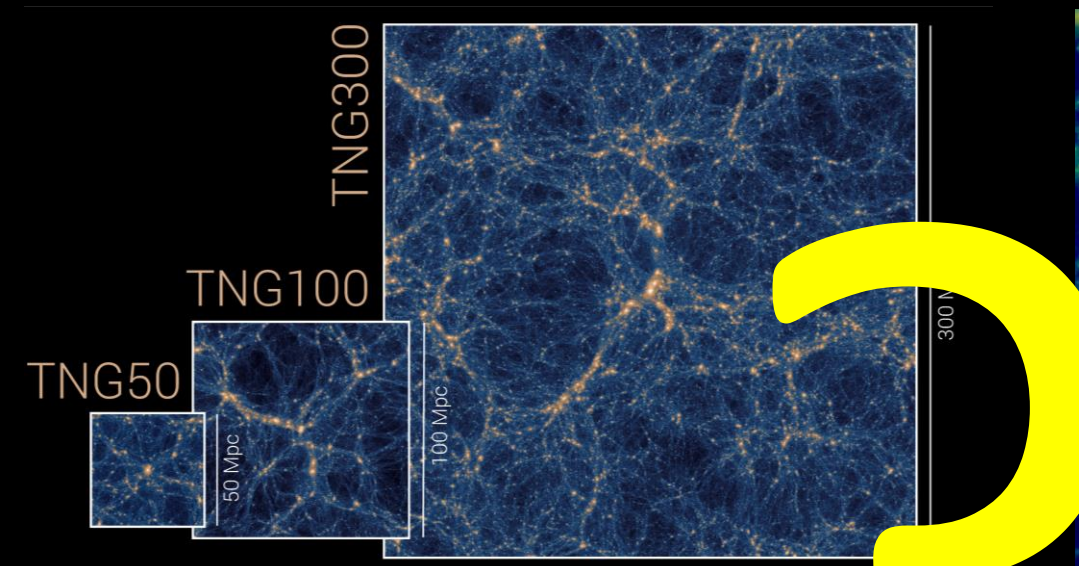
Papers referring to AGN or AGN Feedback

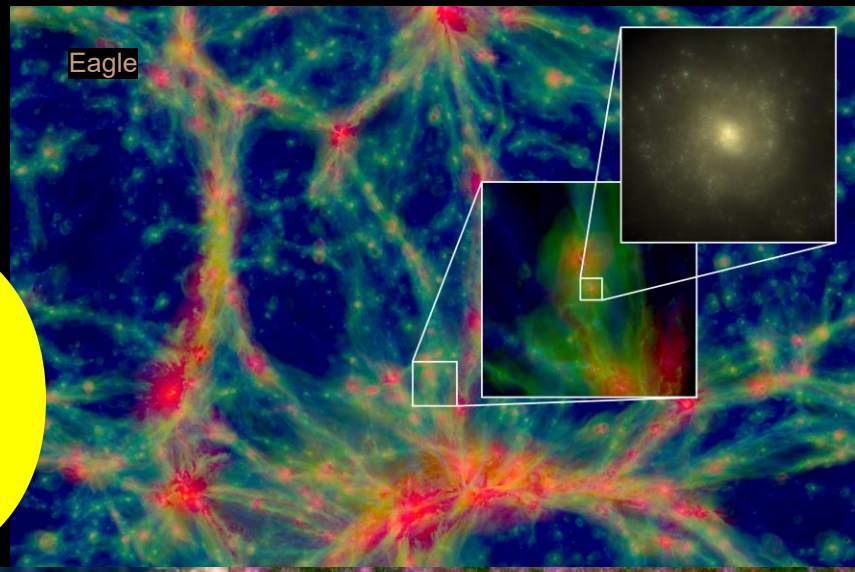


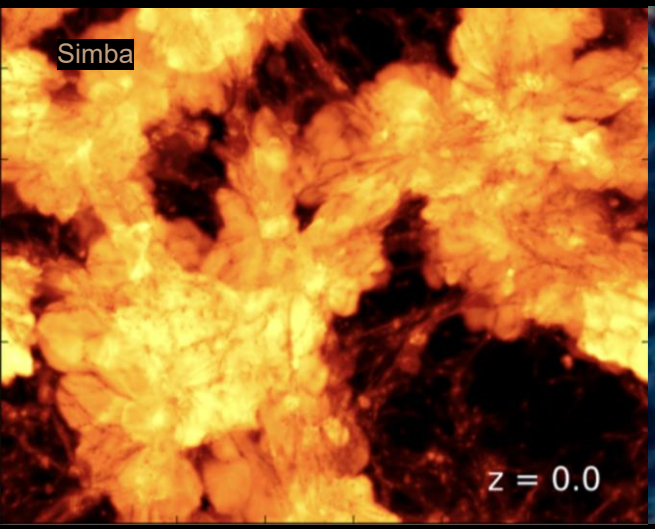
The 'Subgrid Model' Family Tree

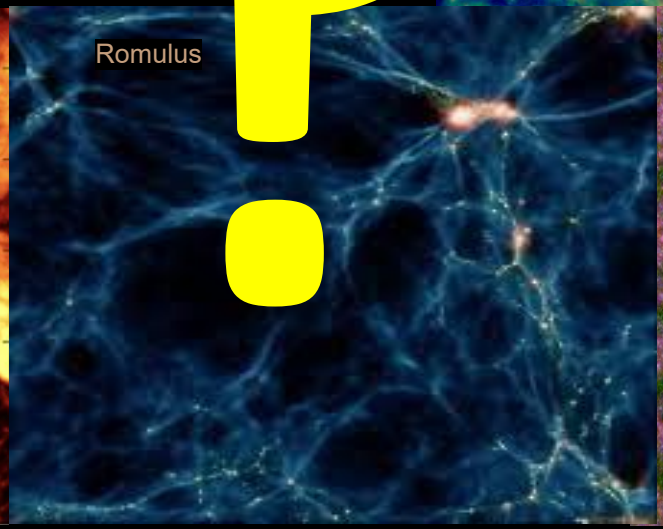


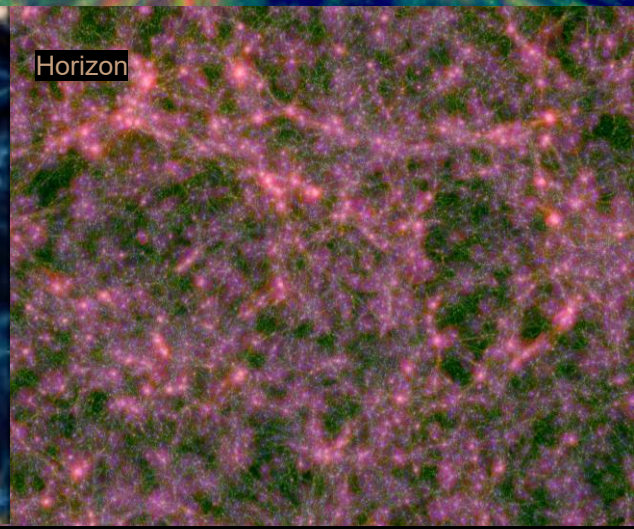
THERMAL
2005 Springel et al, di Matteo et al.
2008 Okamoto et al.
ROMULUS 2017 Tremmel et al. Short cooling 'shut-off'
Feng+15 BLUETIDES
ASTRID
Schaye+10 OWLS
2009 Booth & Schaye Mitigate overcooling
2011 Teyssier et al. -> RAMSES
Schaye+15 EAGLE
Bird+21
Schaye+23 FLAMINGO
Henden+18 FABLE
Vogelsberger+14 Illustris
TNG Pillepich+18
MAKE BUBBLES
2007 Sijacki et al.
Dubois+16 HorizonAGN
Dubois+21 NewHorizon
KINETIC
2010 Debuhr et al. Radiation pressure
Dubois et al. Jets
2012 Choi et al. BAL winds
2014 Barai et al. Numerical study
2016 Hopkins et al. BAL winds
2017 Weinberger et al. Low-accretion mode
Davé+19 SIMBA
2020 Torrey et al. BAL winds


TNG300
TNG100
TNG50
50 Mpc
100 Mpc


Eagle

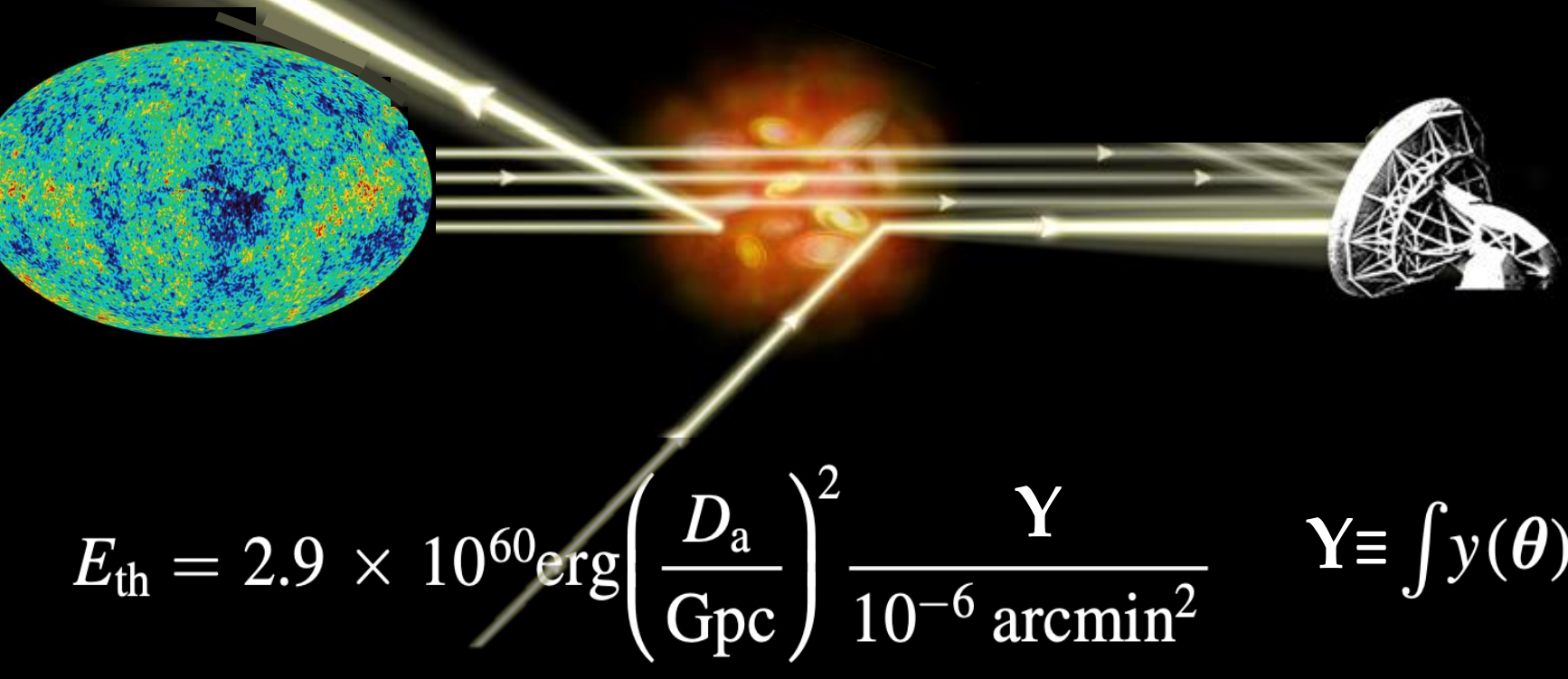

Simba
z = 0.0


Romulus


Horizon

Sunyaev Zel'dovich Effect

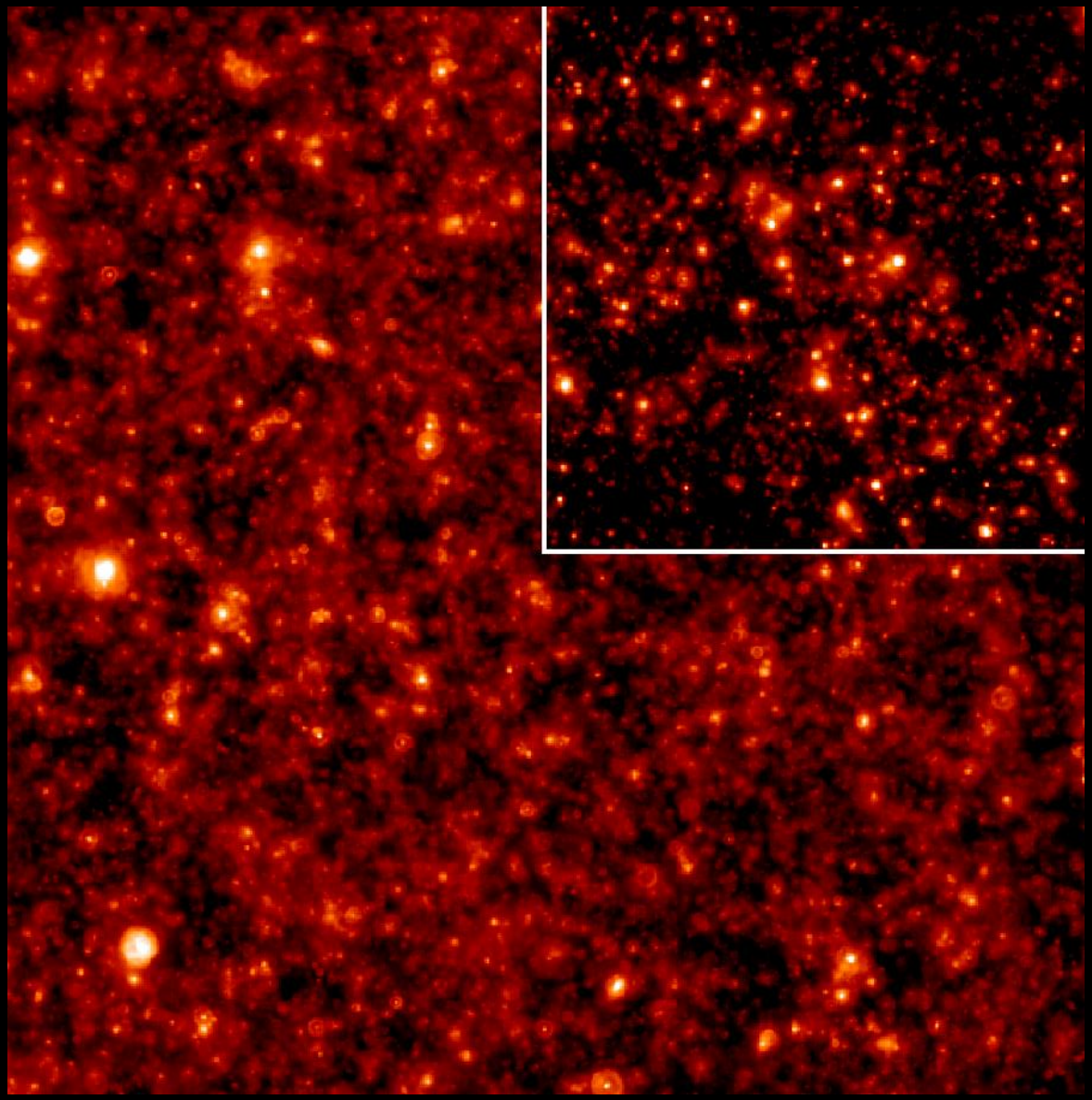
Signal α Gas Density Along Sightline
× Temperature Along Sightline
= Pressure Along Sightline



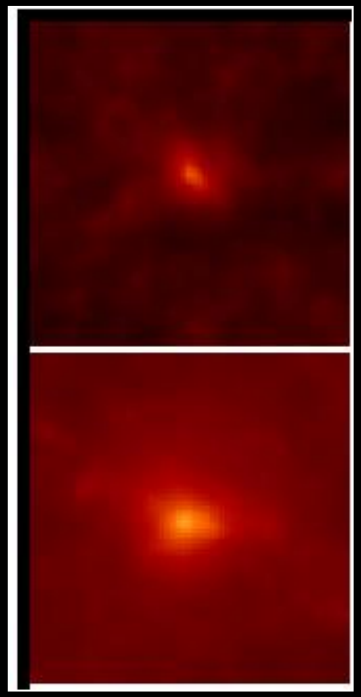
$$E_{\rm th} = 2.9 \times 10^{60} {\rm erg} \left(\frac{D_{\rm a}}{\rm Gpc} \right)^2 \frac{\rm Y}{10^{-6}\ {\rm arcmin}^2} \qquad {\rm Y} \equiv \int y(\theta)\, d\theta$$

CR fans: note there is a correction for relativistic particles

1.1 degree



6 arcmin



ES, Thacker, & Couchman (2008)


THE DARK ENERGY SURVEY


WISE

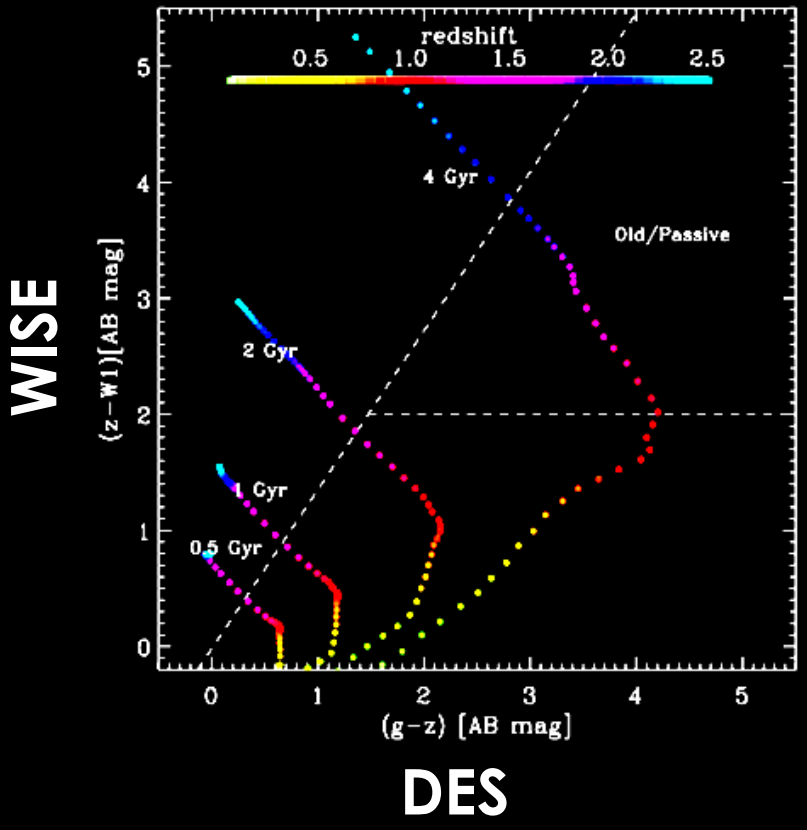

SOUTH
POLE
TELESCOPE
SPT

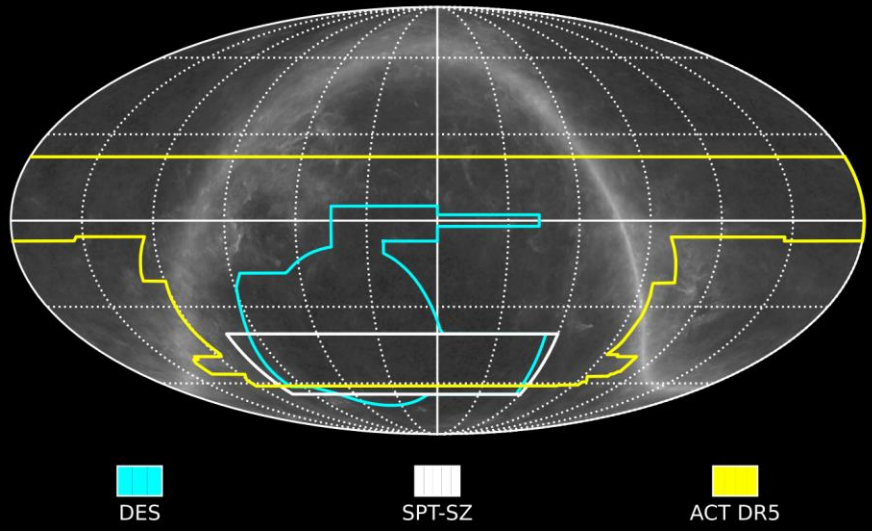

Atacama
Cosmology
Telescope

Seth Cohen

Selection and Sample

2,100 deg^2, 5,000 deg^2, 18,000 deg^2





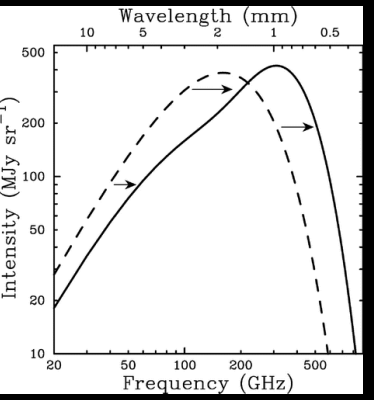
age > 1 Gyr , SSFR < 0.01 Gyr^{-1}

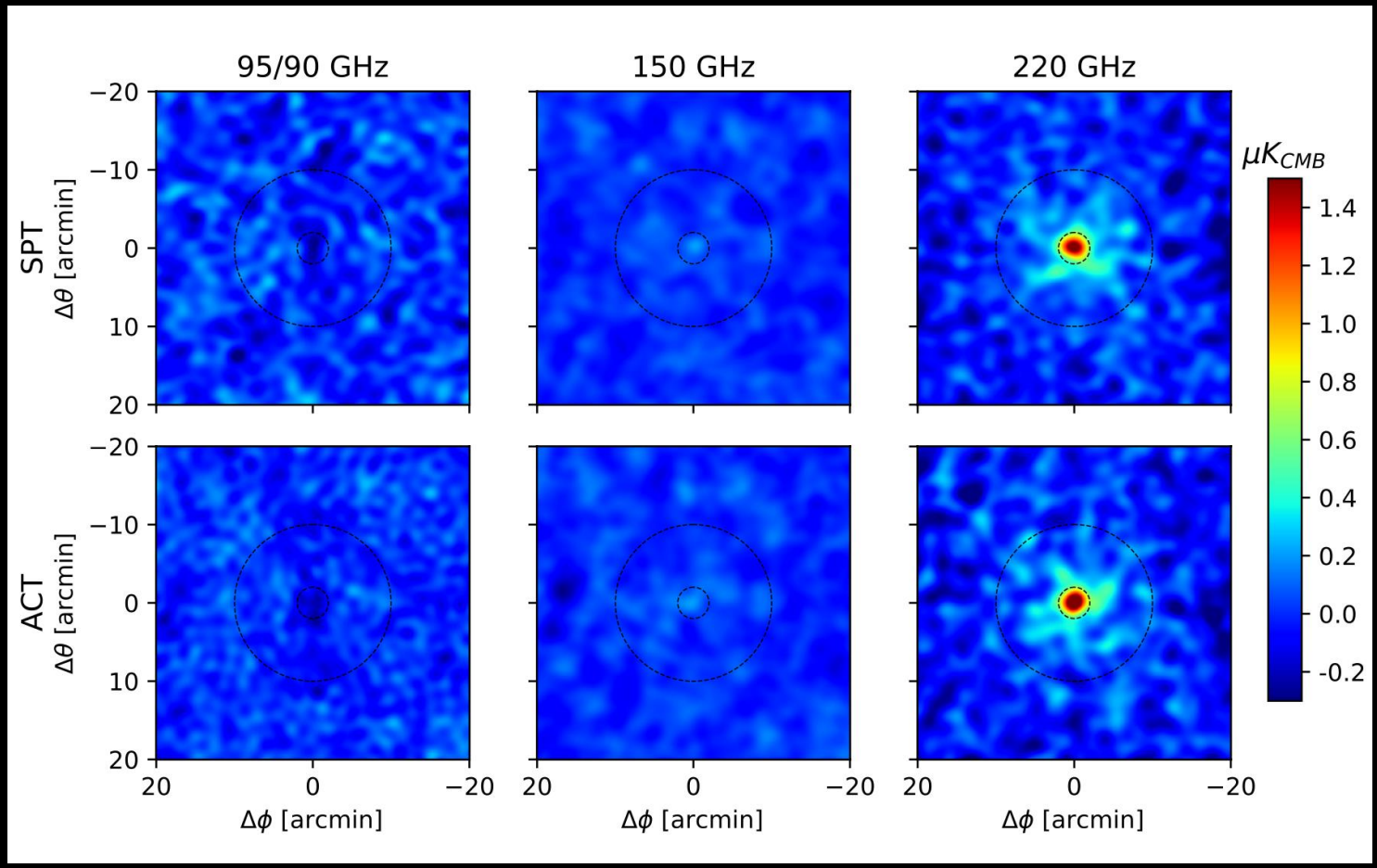
Catalog	N	z	$\log_{10}(\overline{M_\star}/M_\odot)$
SPT + ACT Overlap	94452	1.06	11.41
ACT Only	387627	1.07	11.44

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

Stacked Signals in the Overlap Region

Jeremey Meinke

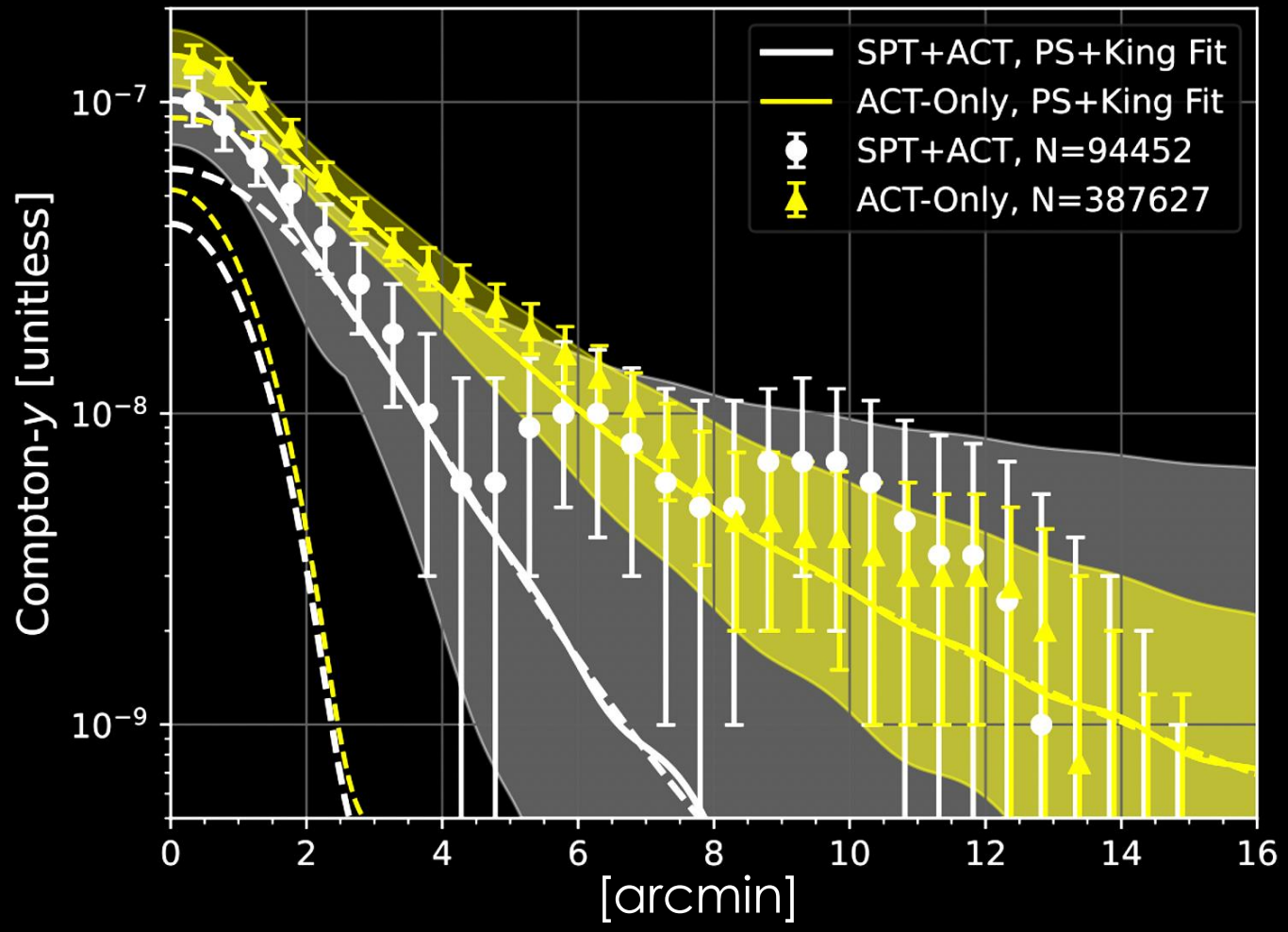




Meinke, Cohen, Moore, Böckman, Mauskopf, & ES (2023)

Stacked SZ Profiles

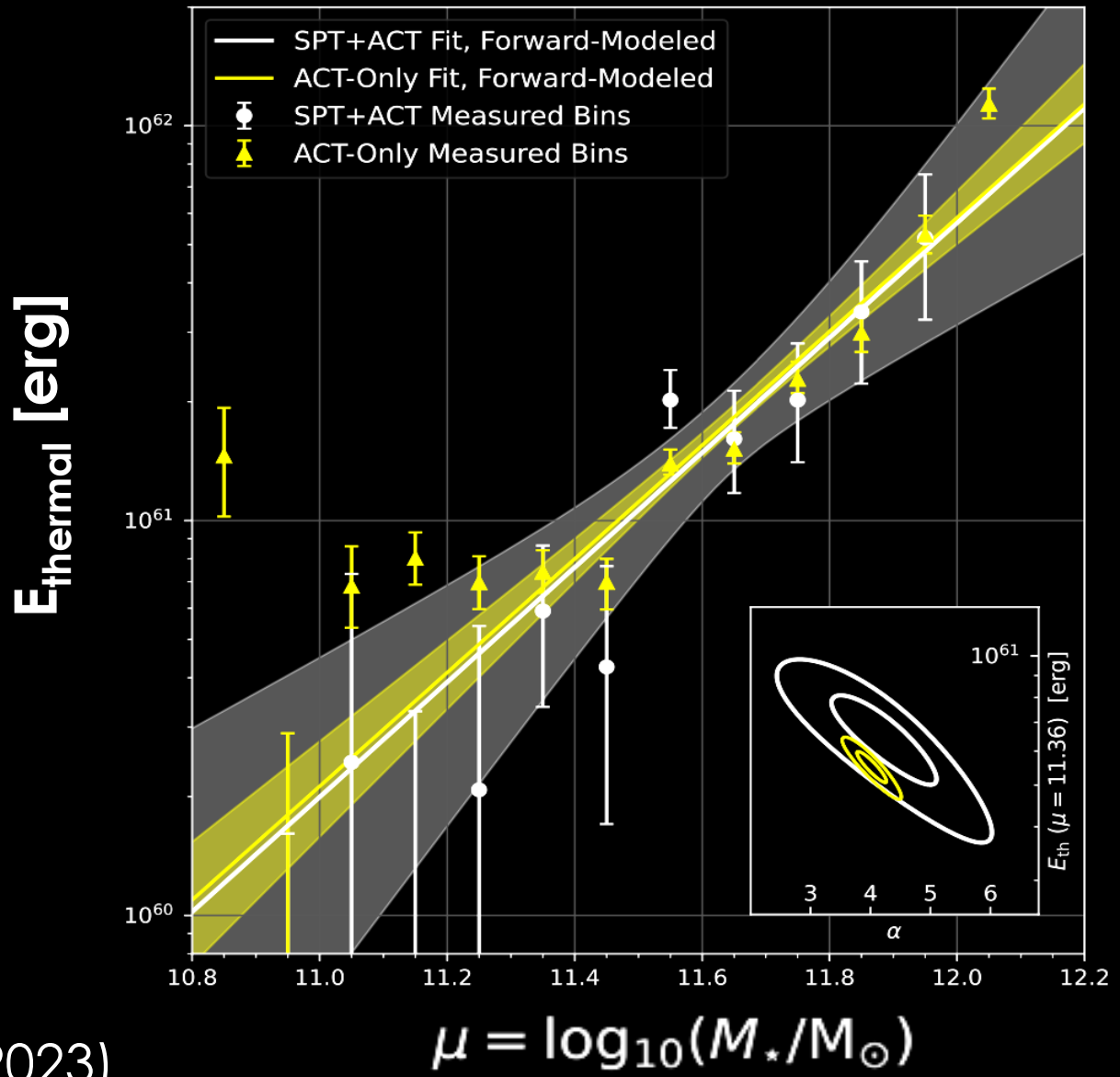
Jeremey Meinke



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

Jeremey Meinke

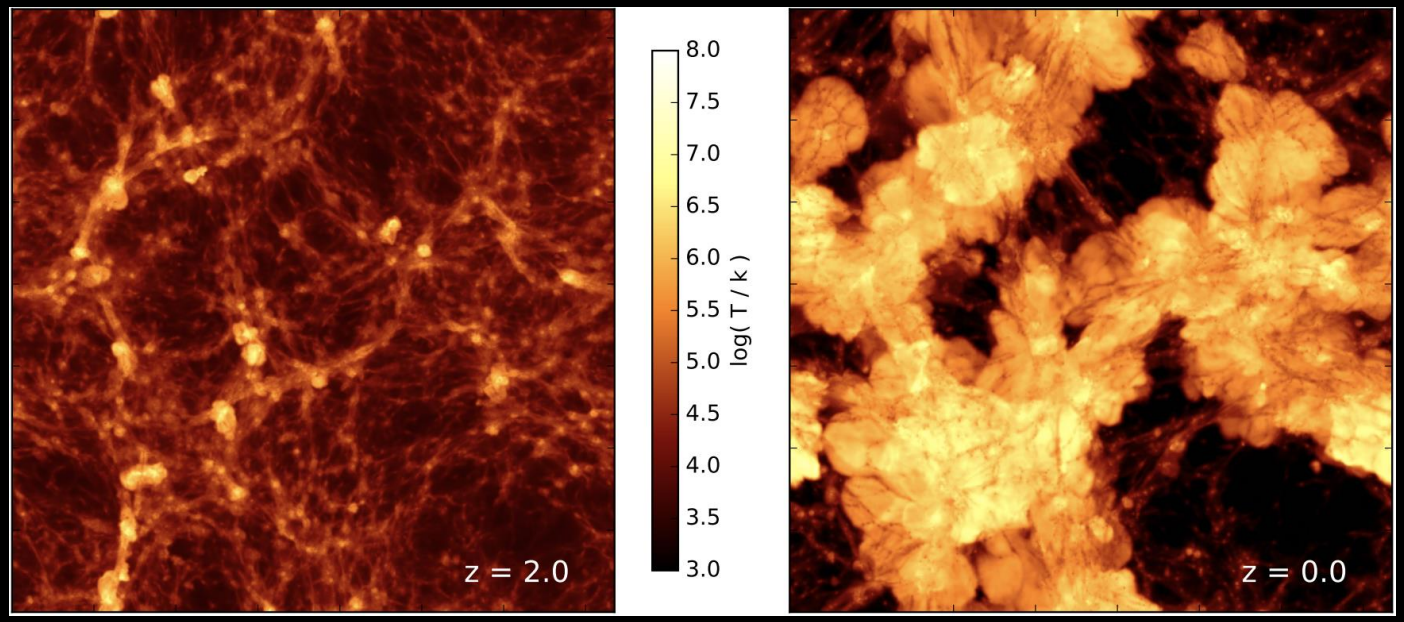
Total Thermal Energy (within R = 2.0′)



Meinke+ (2023)

SIMBA

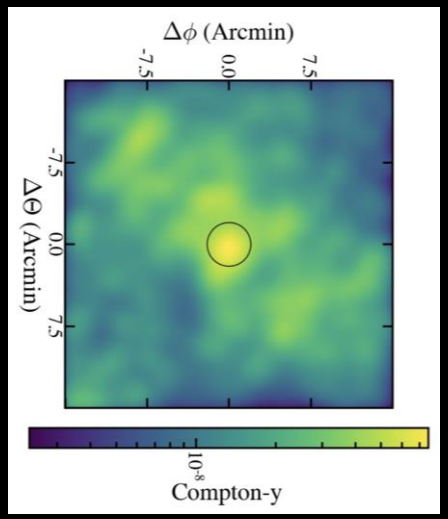
- MPI version of the GIZMO meshless code
- 100 cMpc/h box, 2 x1024^3 particles, to z=0 (2E7 Msun)
- Includes updates to Mufasa's sub-resolution star formation and feedback prescriptions.
- AGN are associated torque limited accretion (cold) / Bondi accretion (hot).
- 3-40% of energy in light goes into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

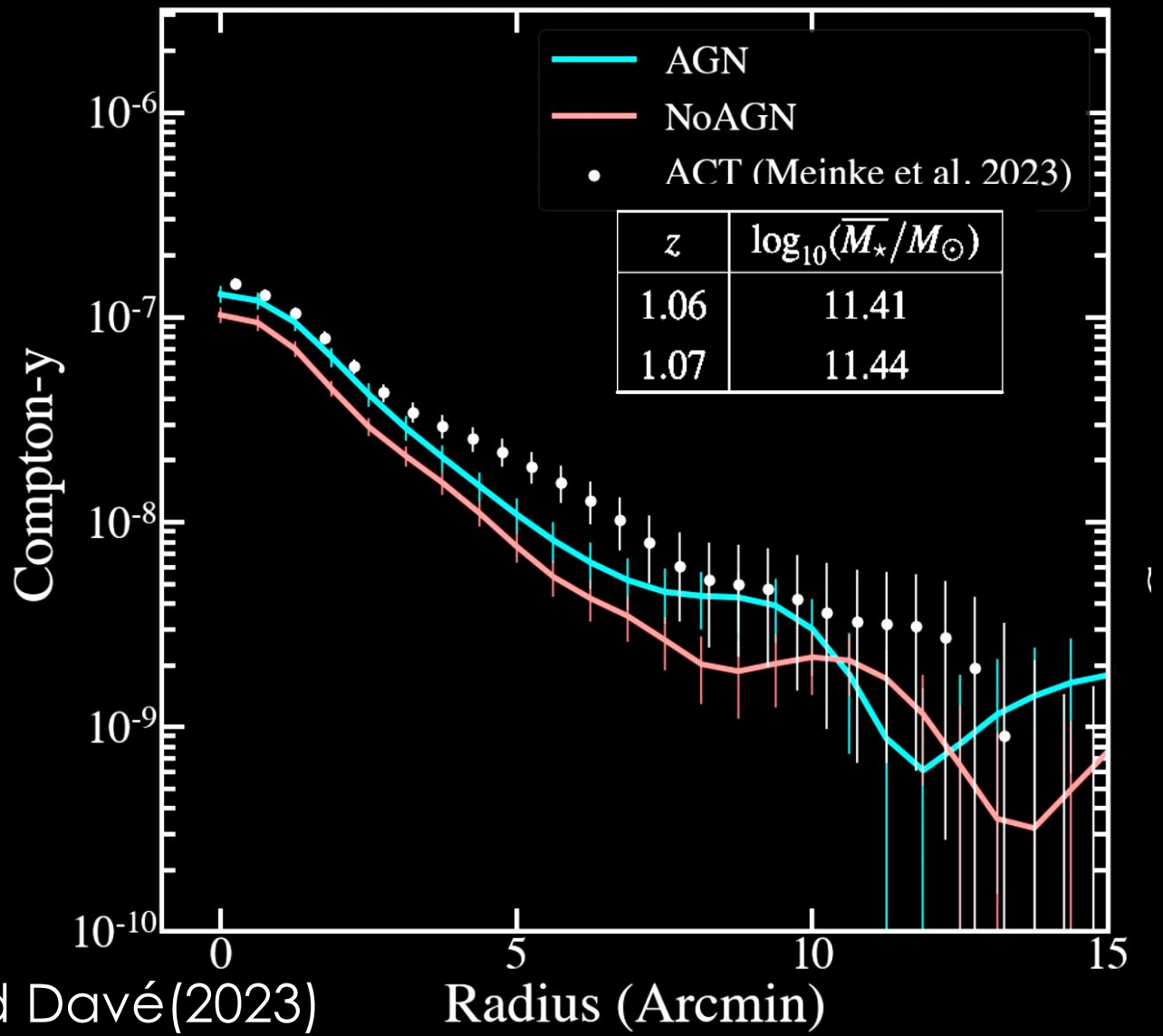


Davé et al (2019)

Skylar Grayson

z=1 Stacking SZ Data from SIMBA

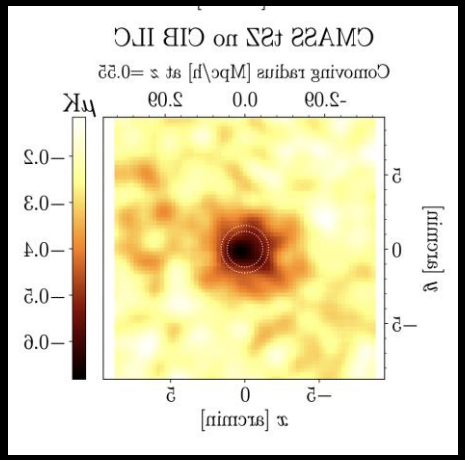


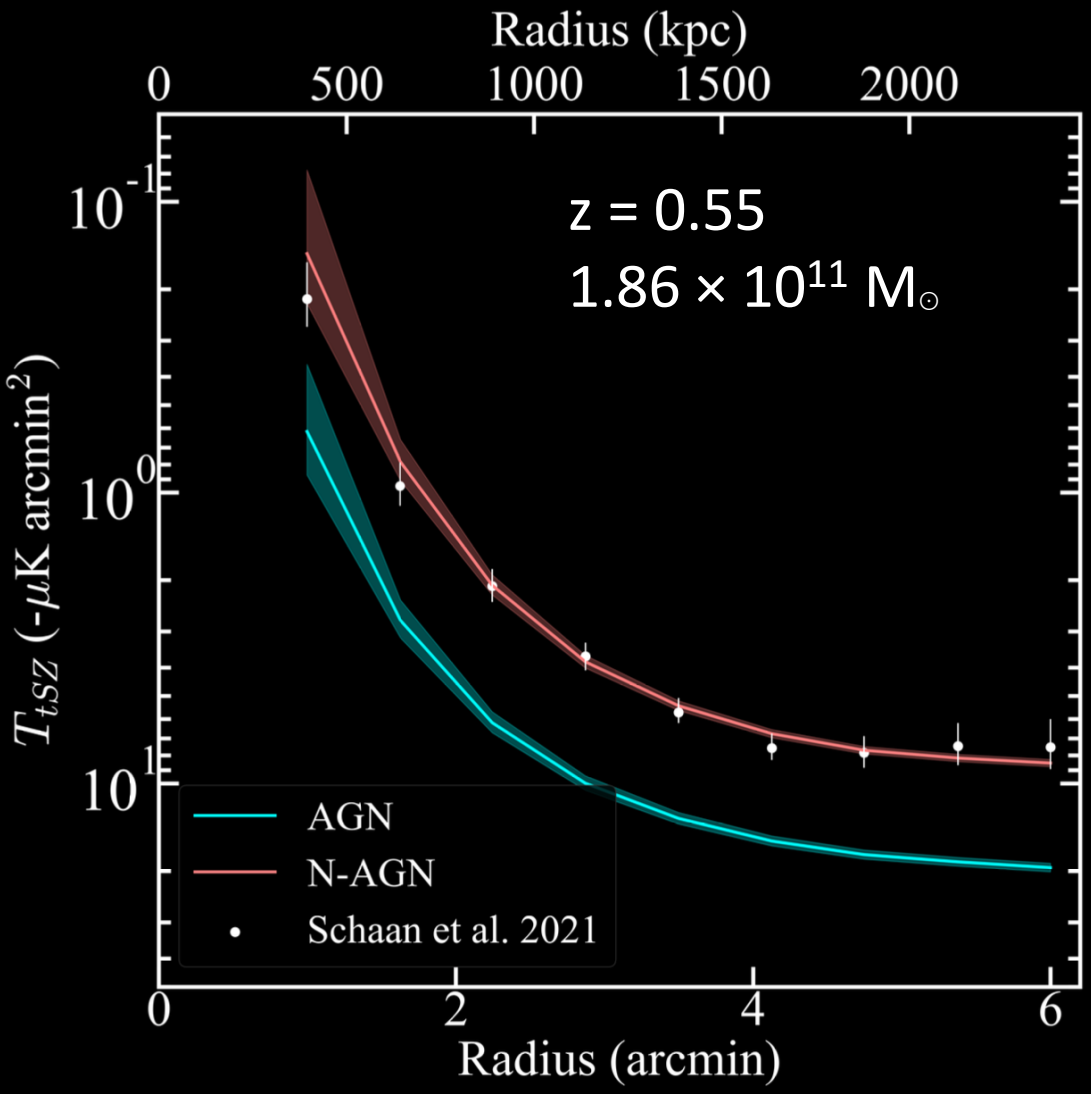


Grayson, ES, and Davé(2023)

Skylar Grayson

z=0.55 Stacking SZ Data from SIMBA





Grayson, ES, and Davé(2023)

Better SZ Measurements

- **Large Millimeter Telescope (LMT)**
- 50-m diameter single dish telescope
- Located at 15,000 ft (4672 m)
  - Site on Sierra Negra in Puebla, MX
- Facility first light in 2011

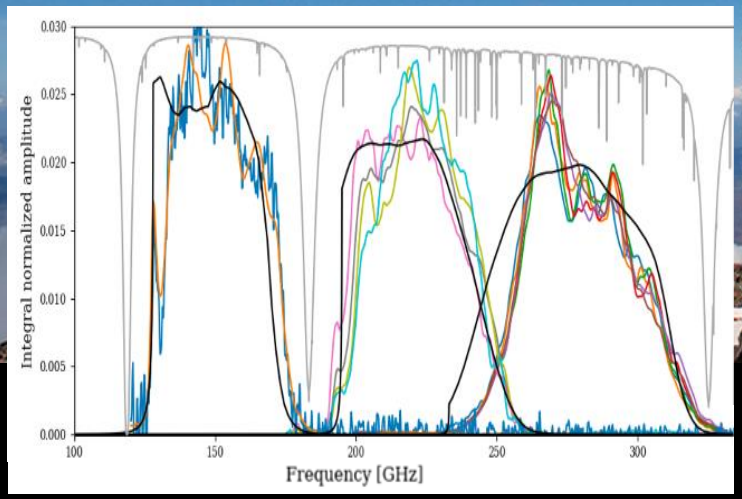
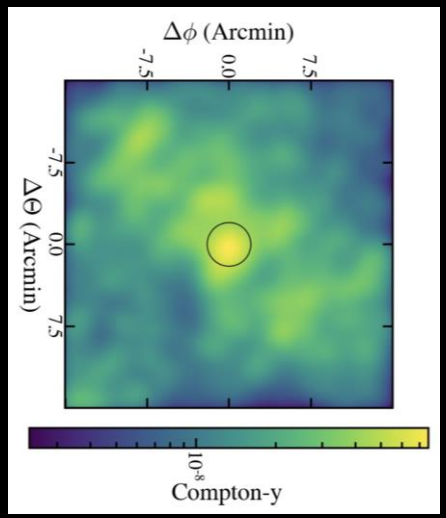
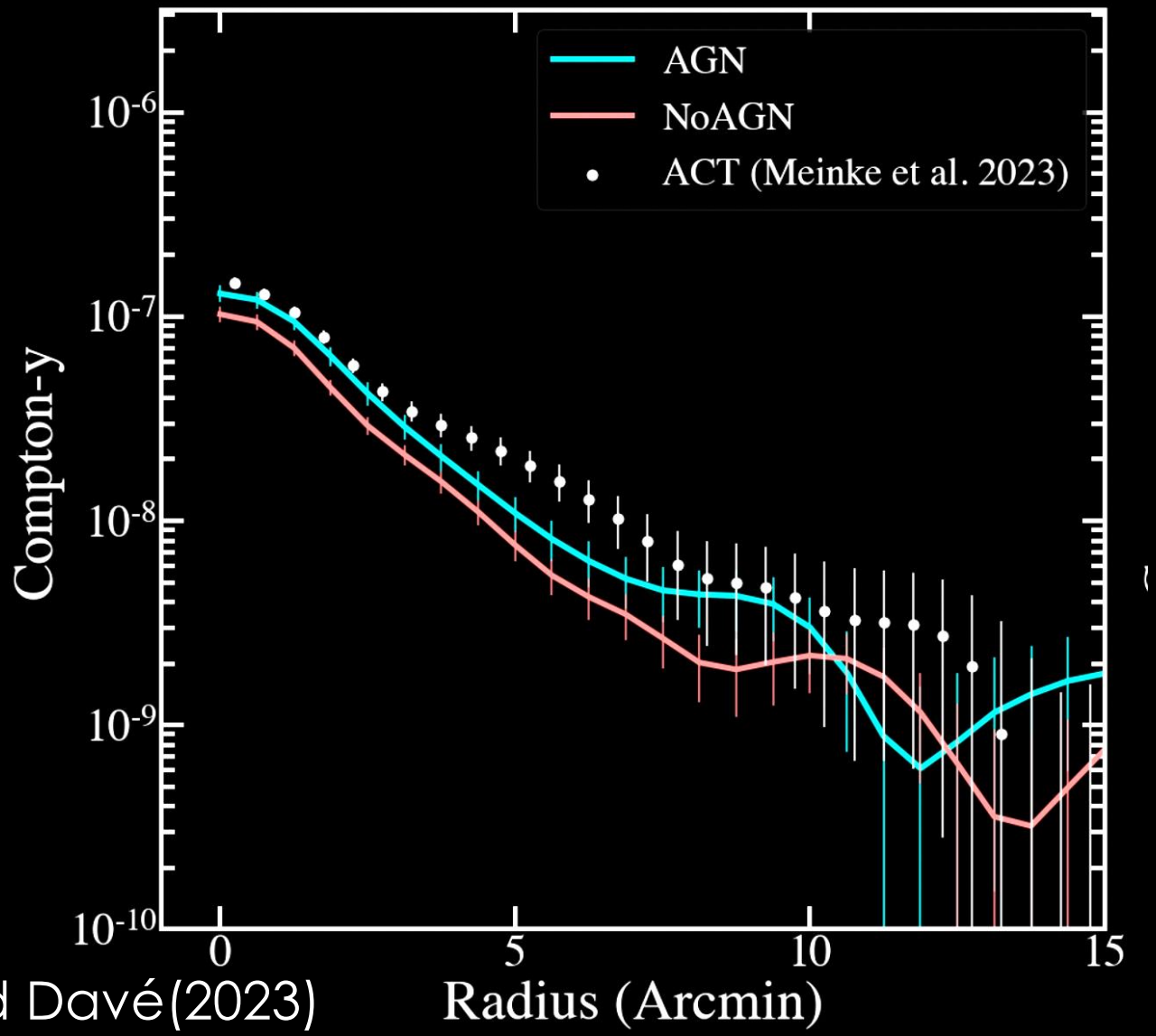


Image credit: Dario Lopez-Mills/AP PHOTO

Better SZ Measurements

Skylar Grayson

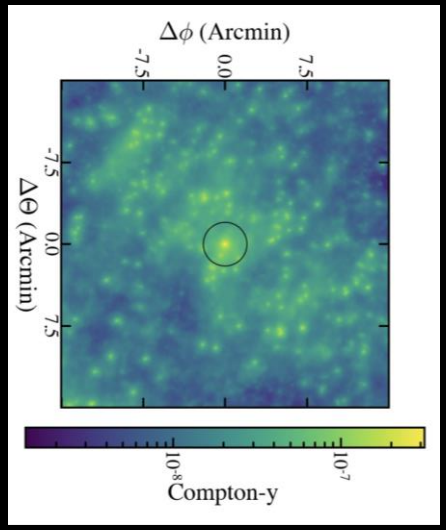


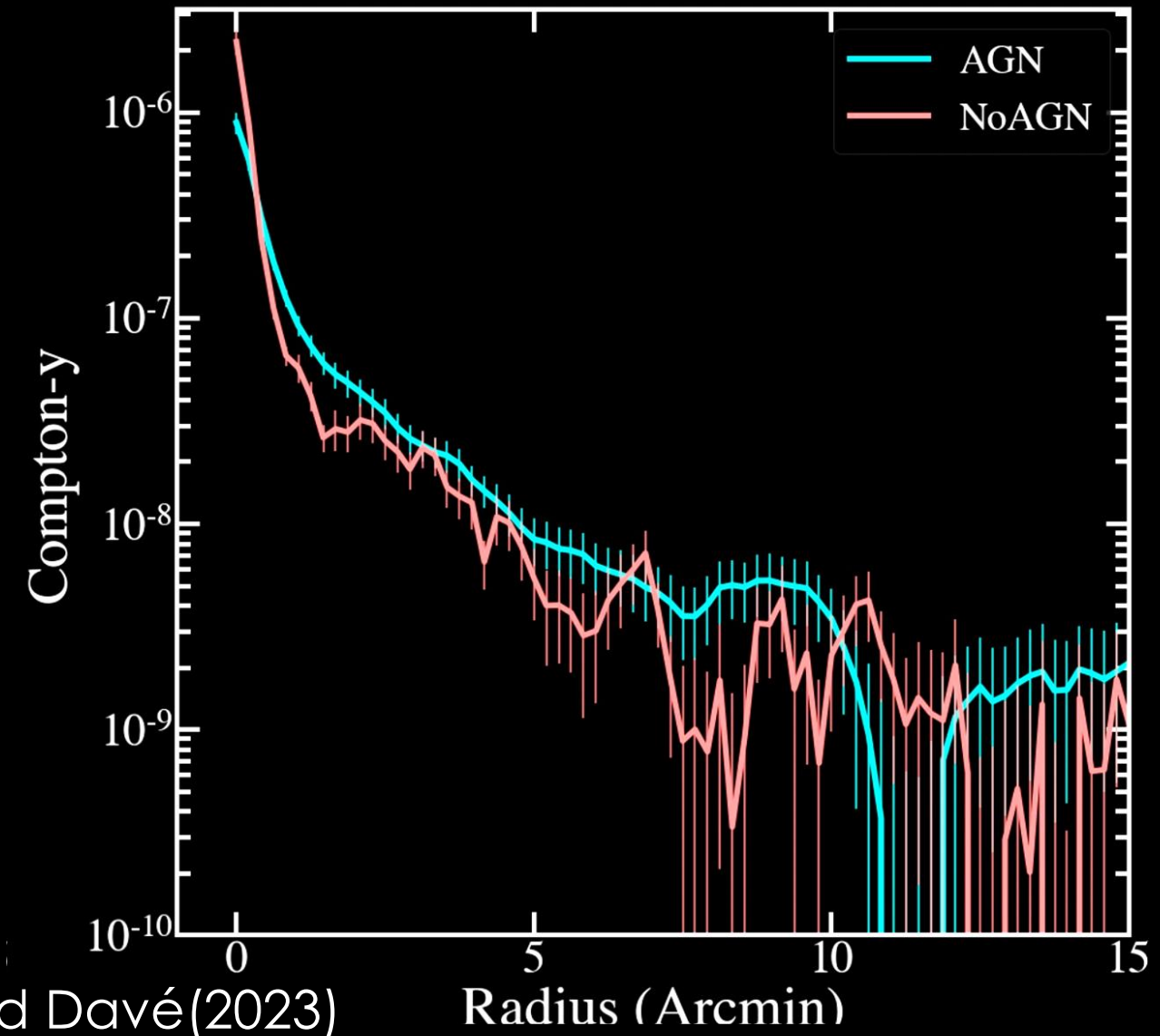


Grayson, ES, and Davé(2023)

Better SZ Measurements

Skylar Grayson





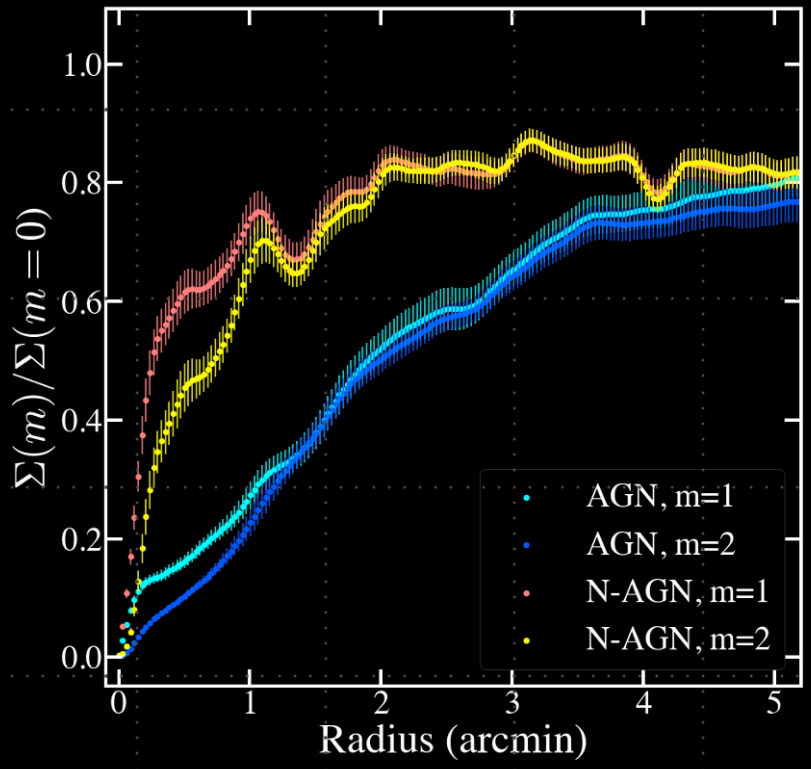
Grayson, ES, and Davé(2023)

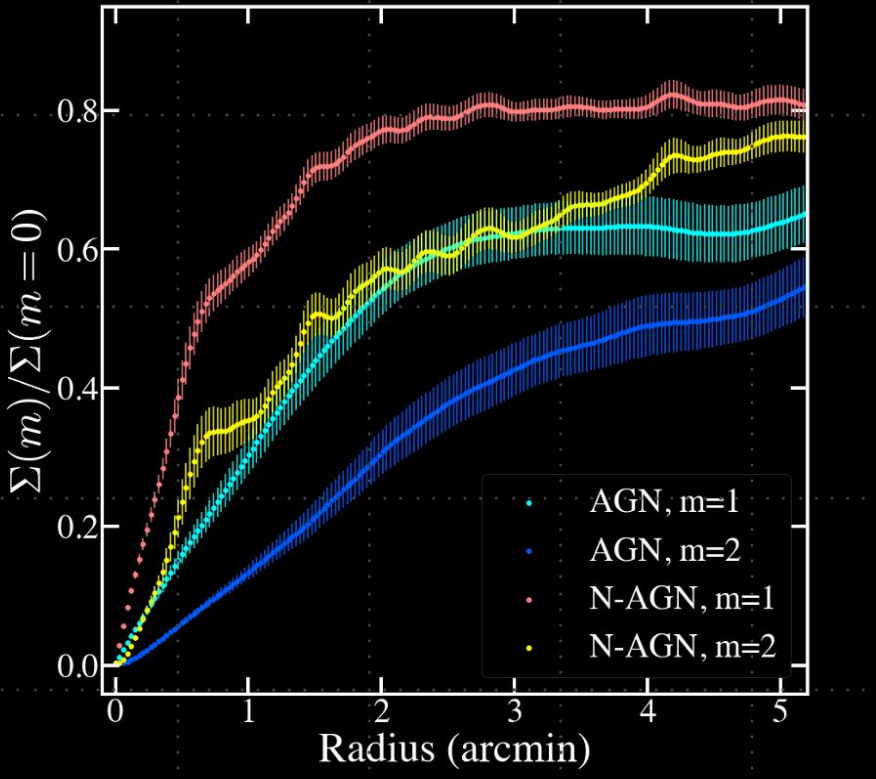
SZ Moments

z=1.0

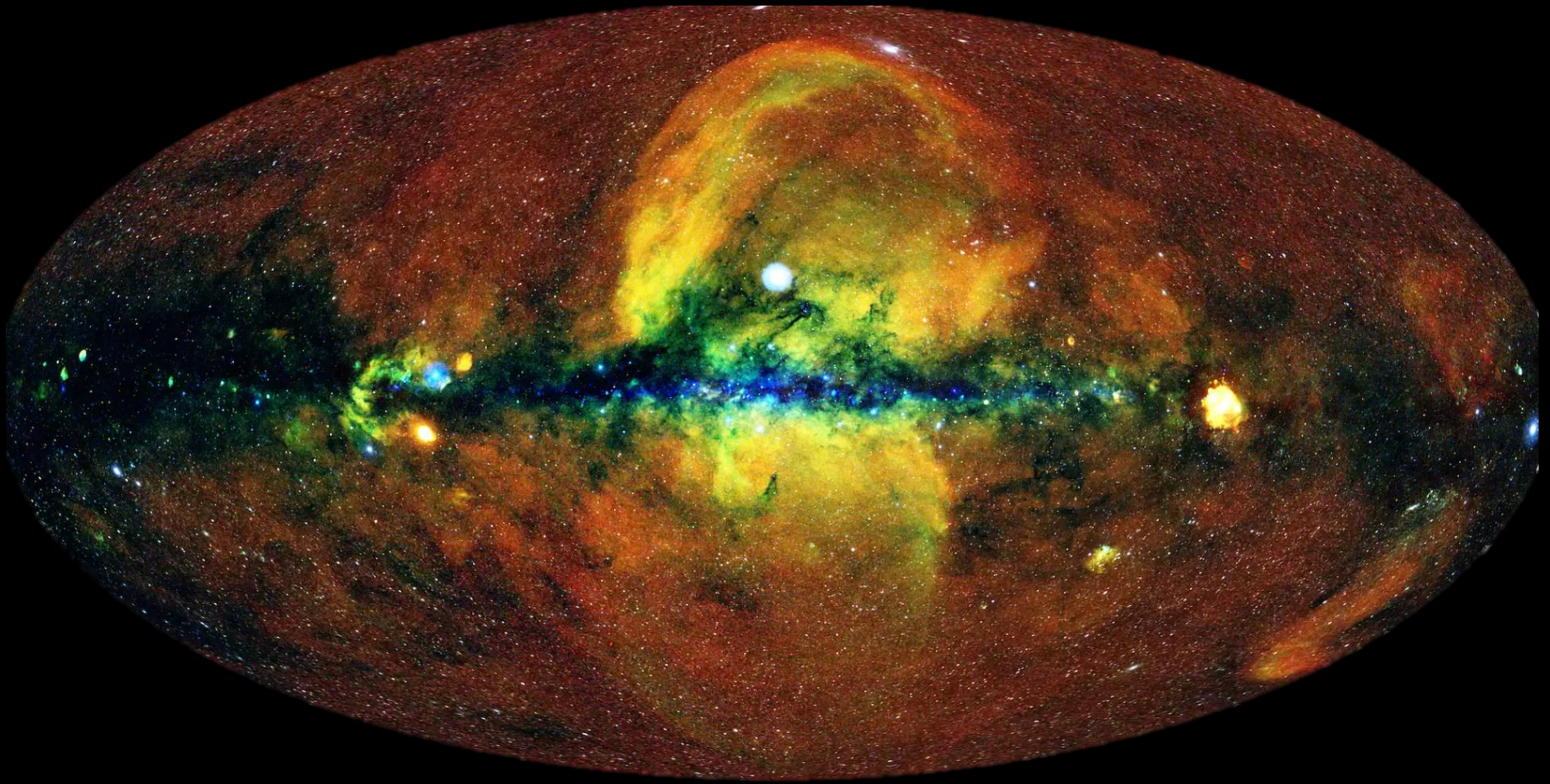
$$\Sigma(r,m) = \frac{1}{2\pi}\int_0^{2\pi} y(r,\theta)e^{im\theta}d\theta$$

z=0.5



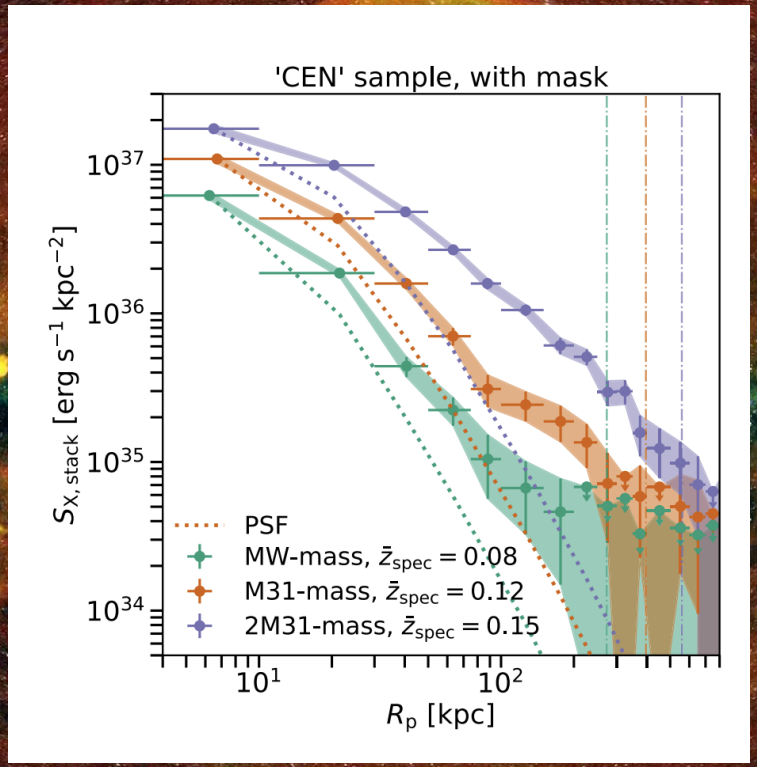


X-ray Emission



SRG/eROSITA All-sky Survey

X-ray Emission



SRG/eROSITA All-sky Survey

Simulated eROSITA Stacks

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

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

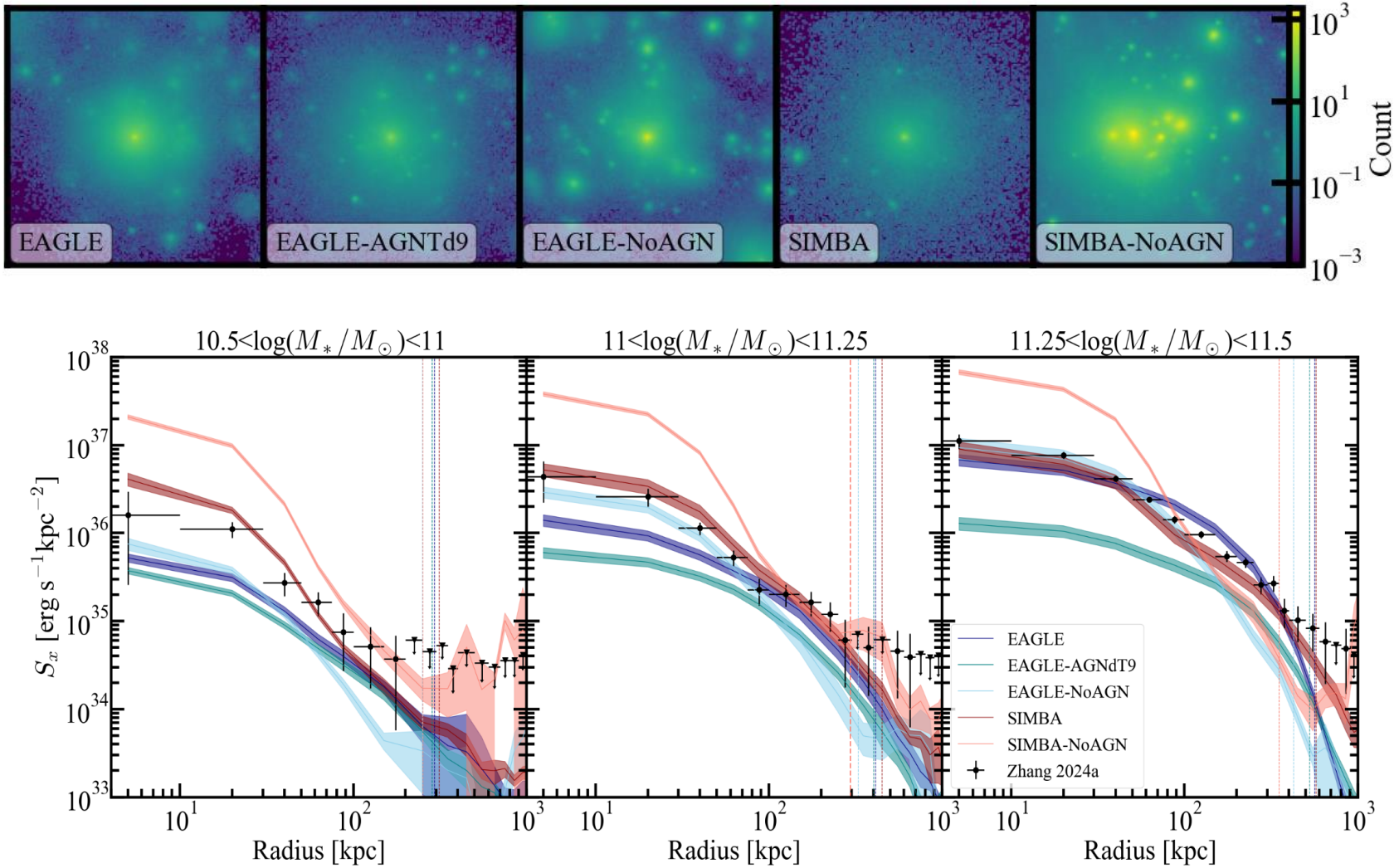
2. Project on the sky (via pyXSIM /APEC)

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

4. Select galaxies and stack to generate radial profiles

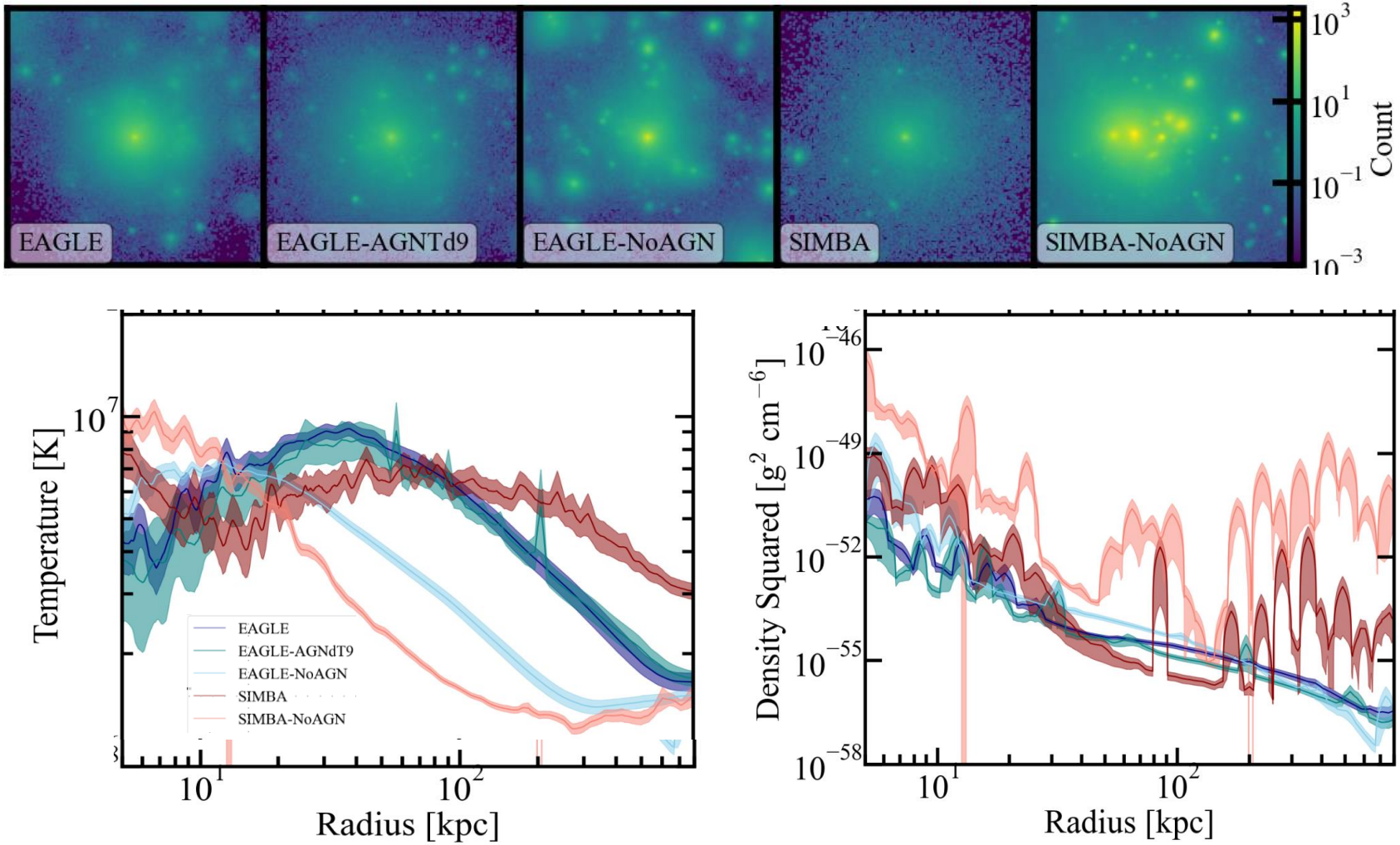
Grayson, ES, Comparat, ZuHone, Zhang, Sheeram, Brüggen, & Bulbul (2025 xarXiv:2506.09123)

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)

Building a Tool to Constrain AGN Feedback

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

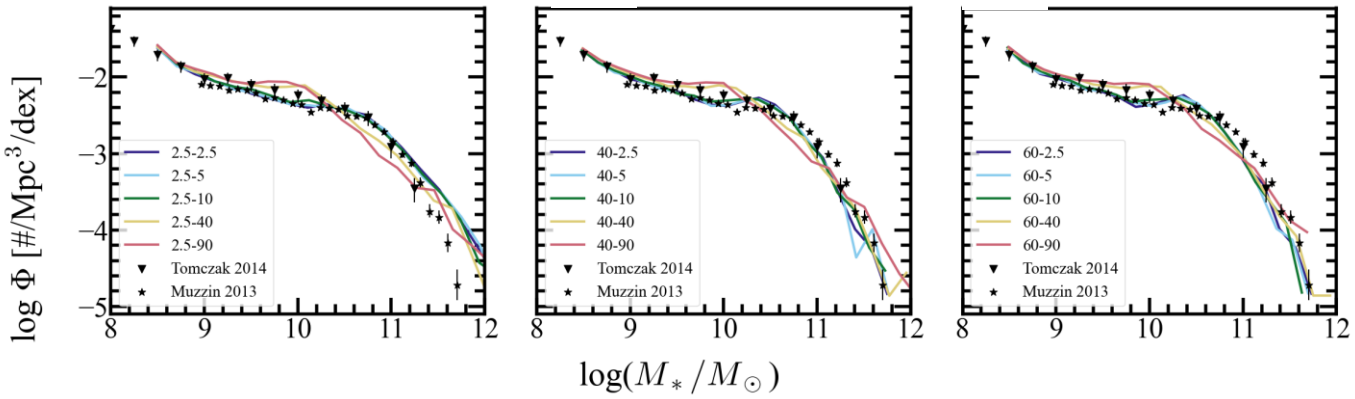
$$\eta = 0.1$$

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

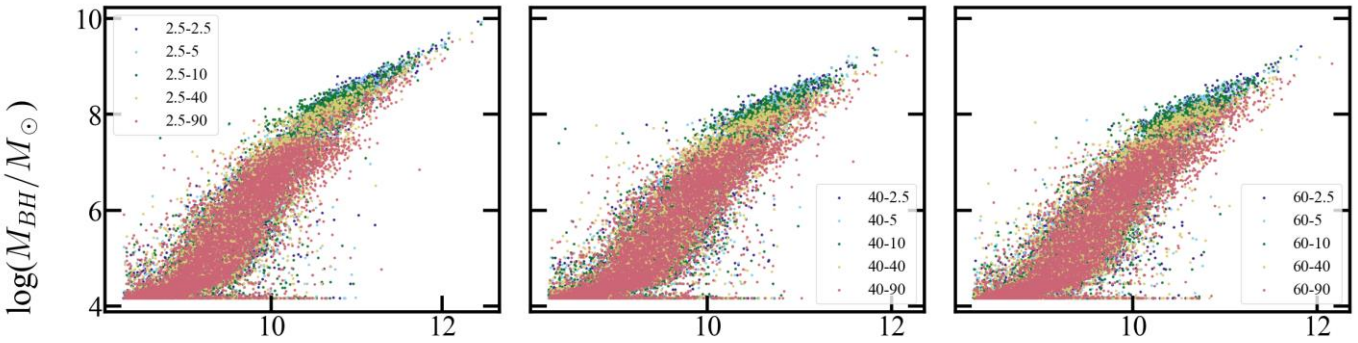
These are the parameters we change in the RAFIKI runs
Runs are labelled jet-wind, so 40-2.5 has ε_j =0.4 and ε_w = 0.025

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

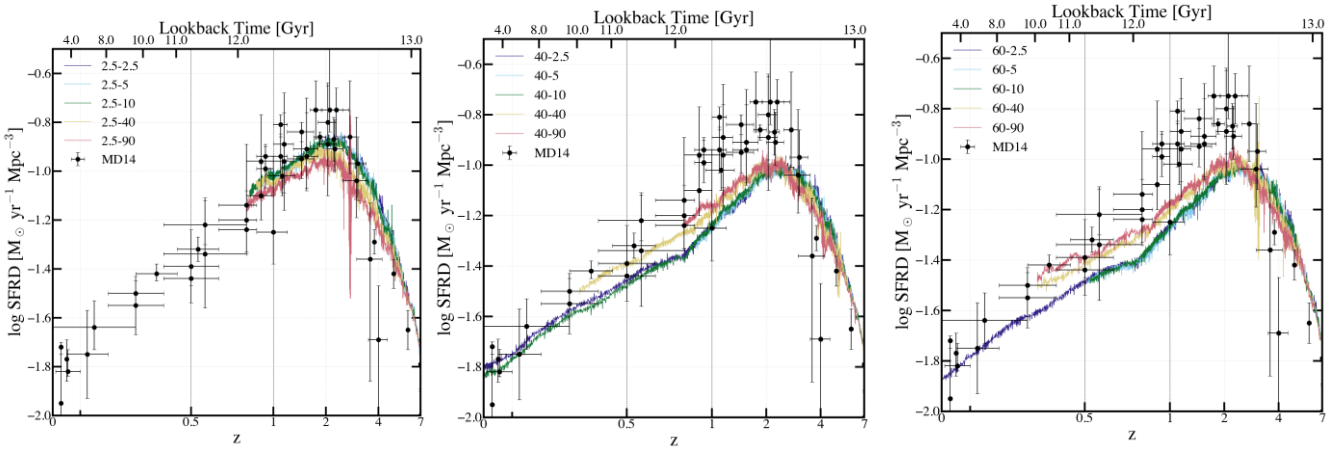
Z=1 Galaxy Stellar Mass Function



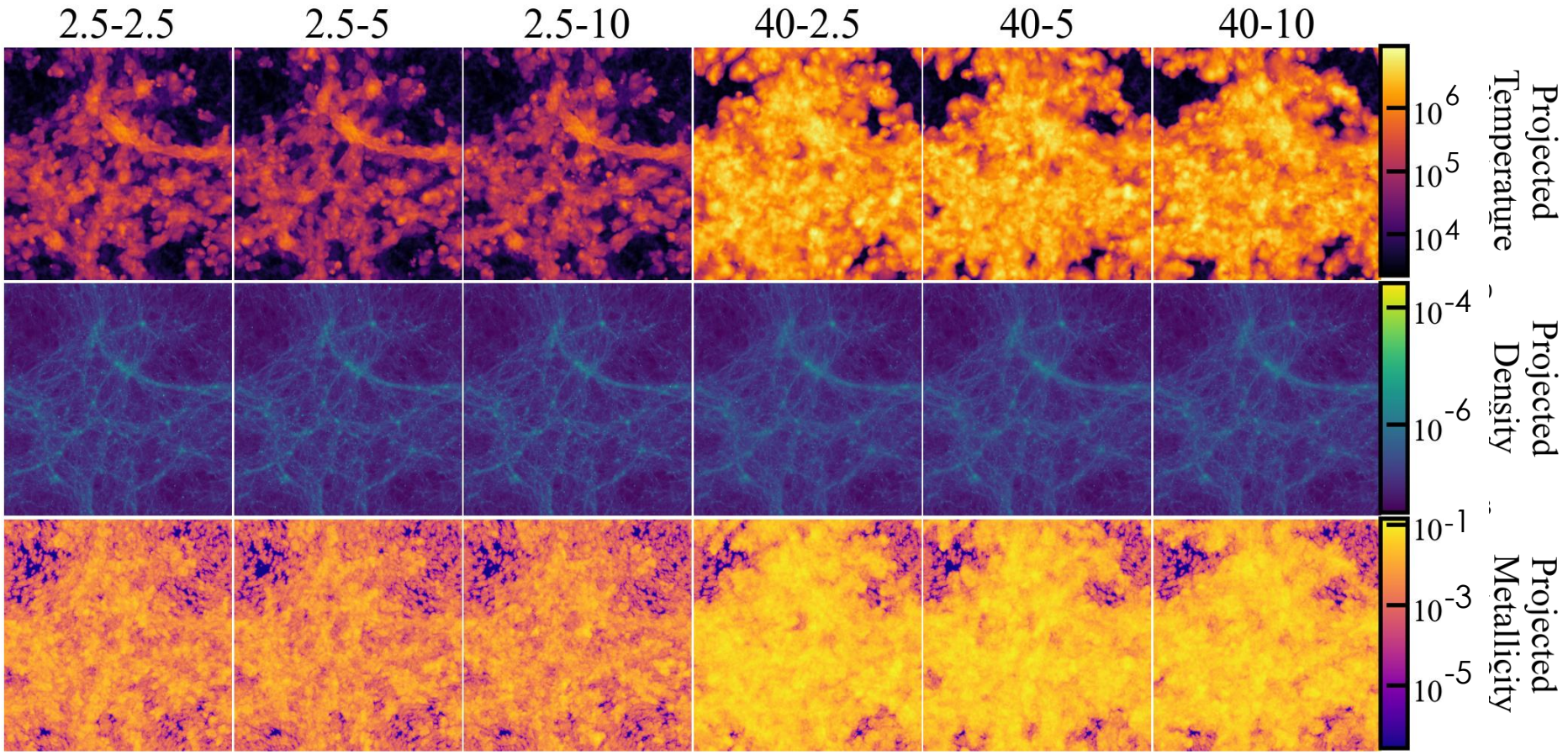
M_{BH} / M_*



SFRD



Coming soon


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

Conclusions