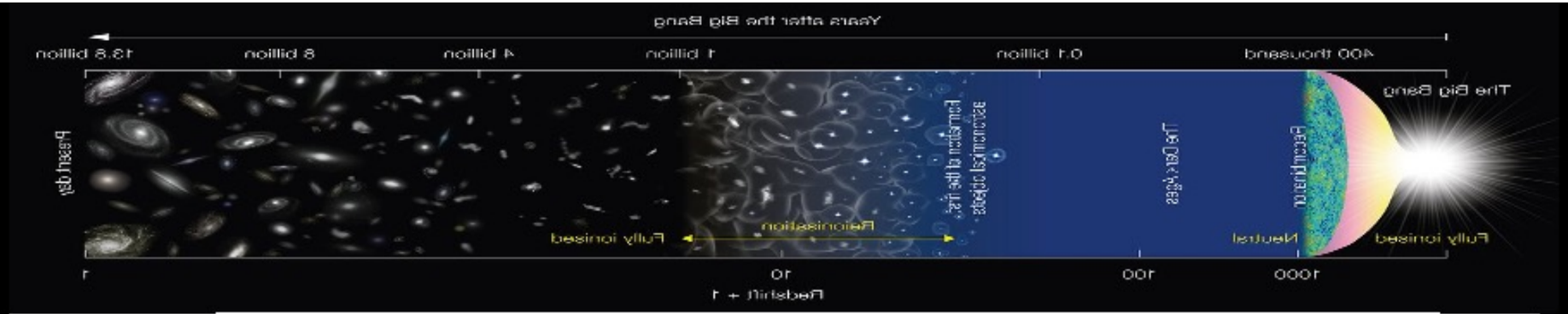
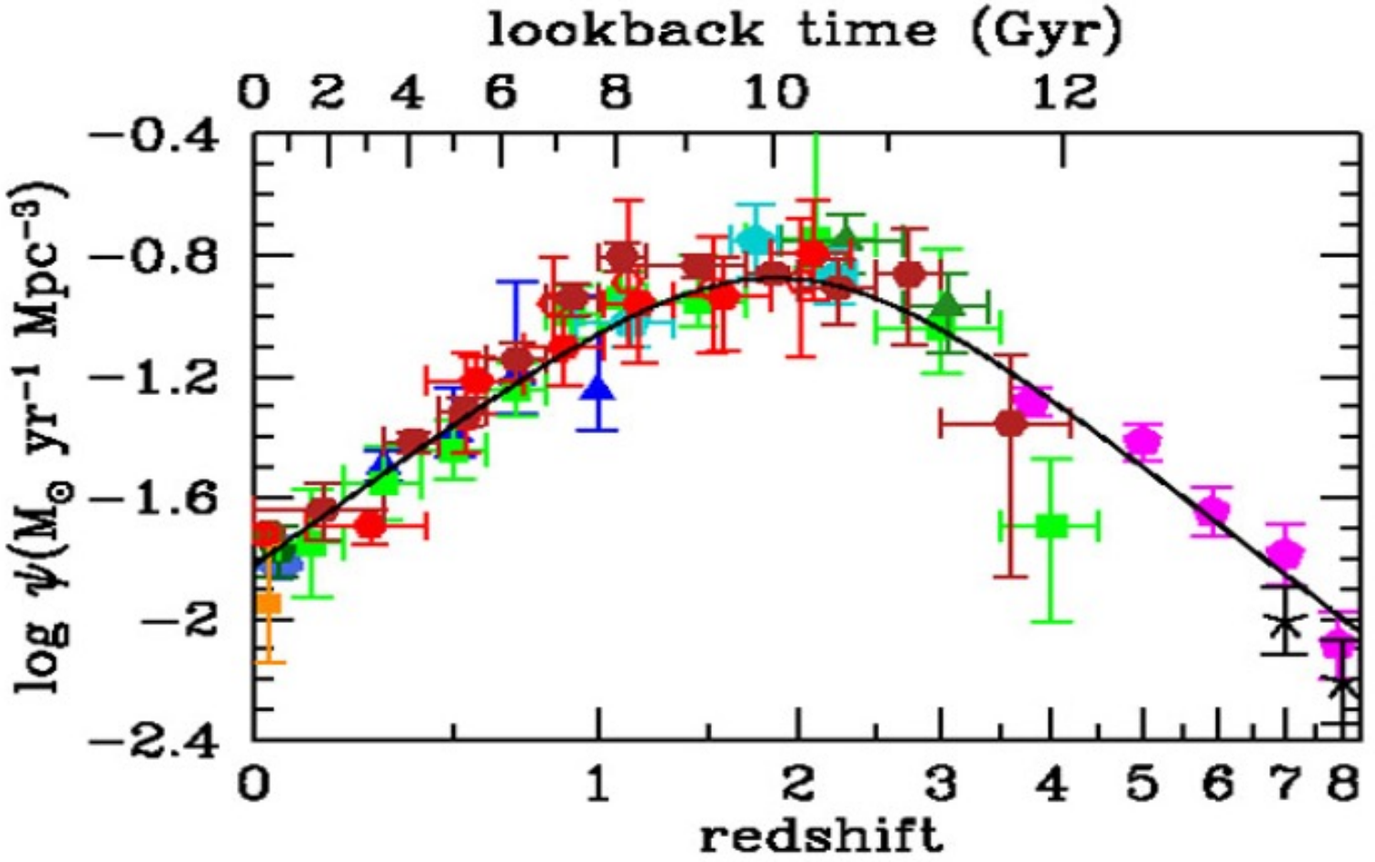
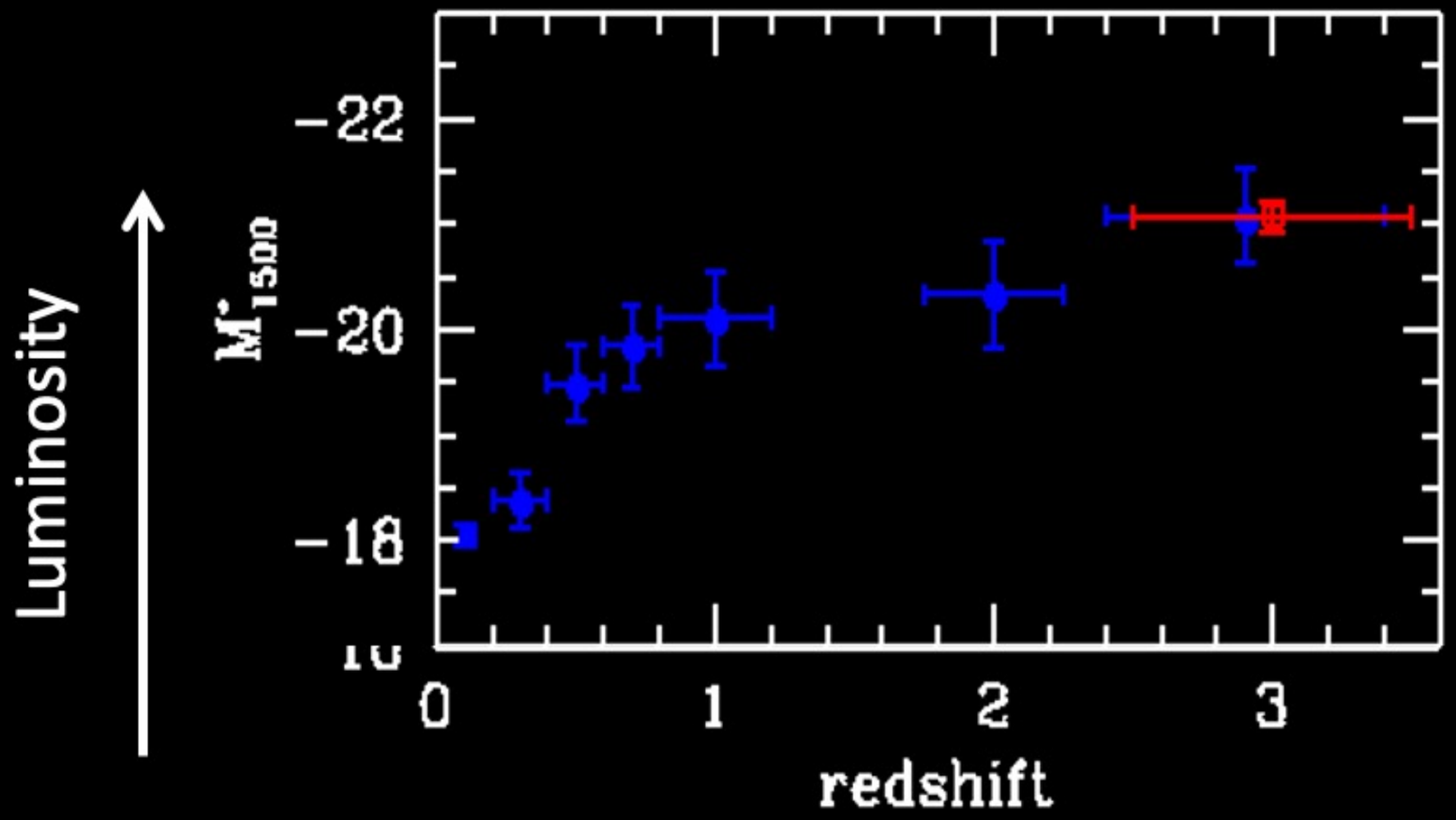
# Constraining The Thermal History of Groups and Clusters with the Sunyaev-Zel'dovich Effect



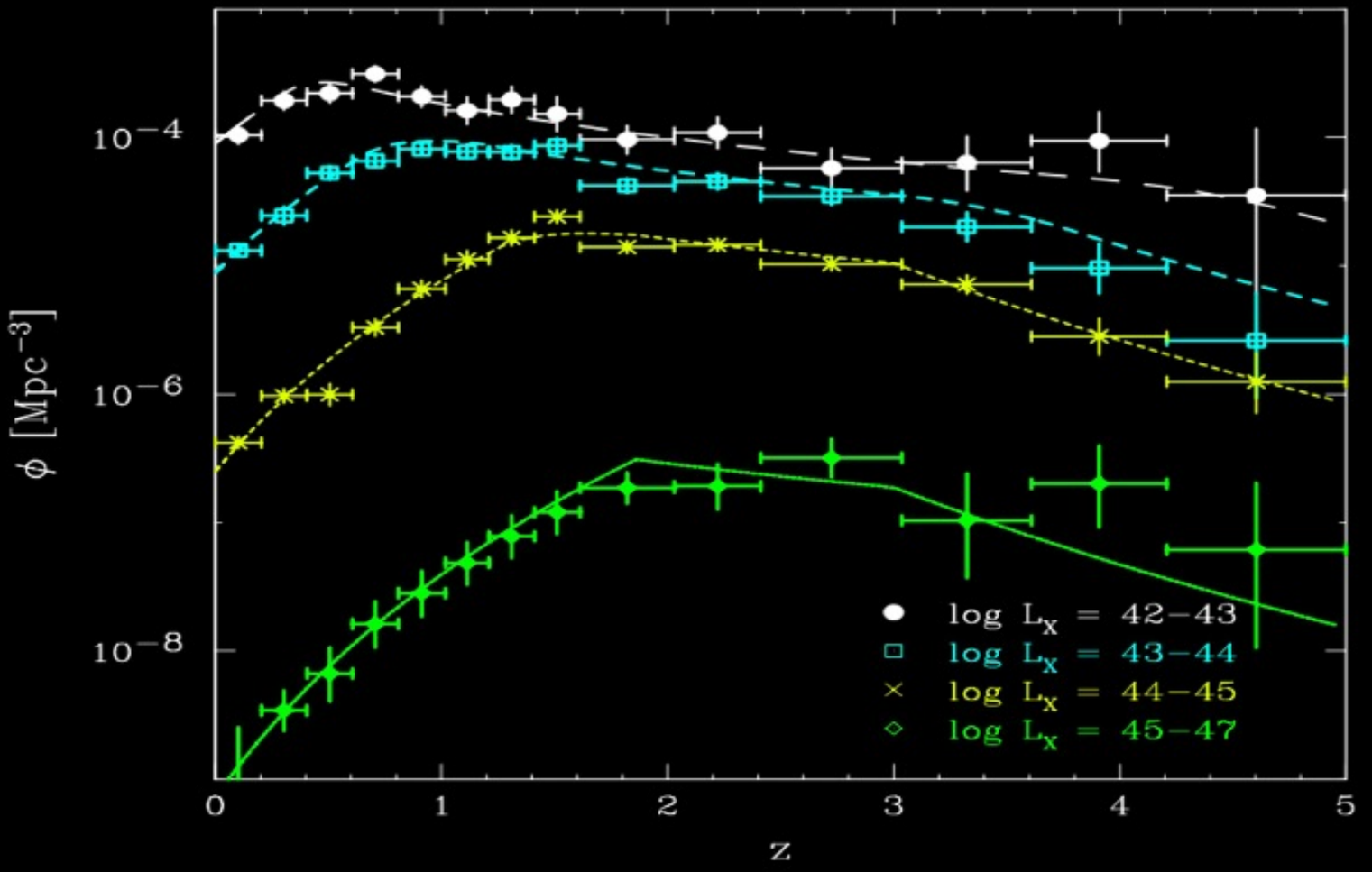

Madau & Dickenson (2014)

# “Downsizing”



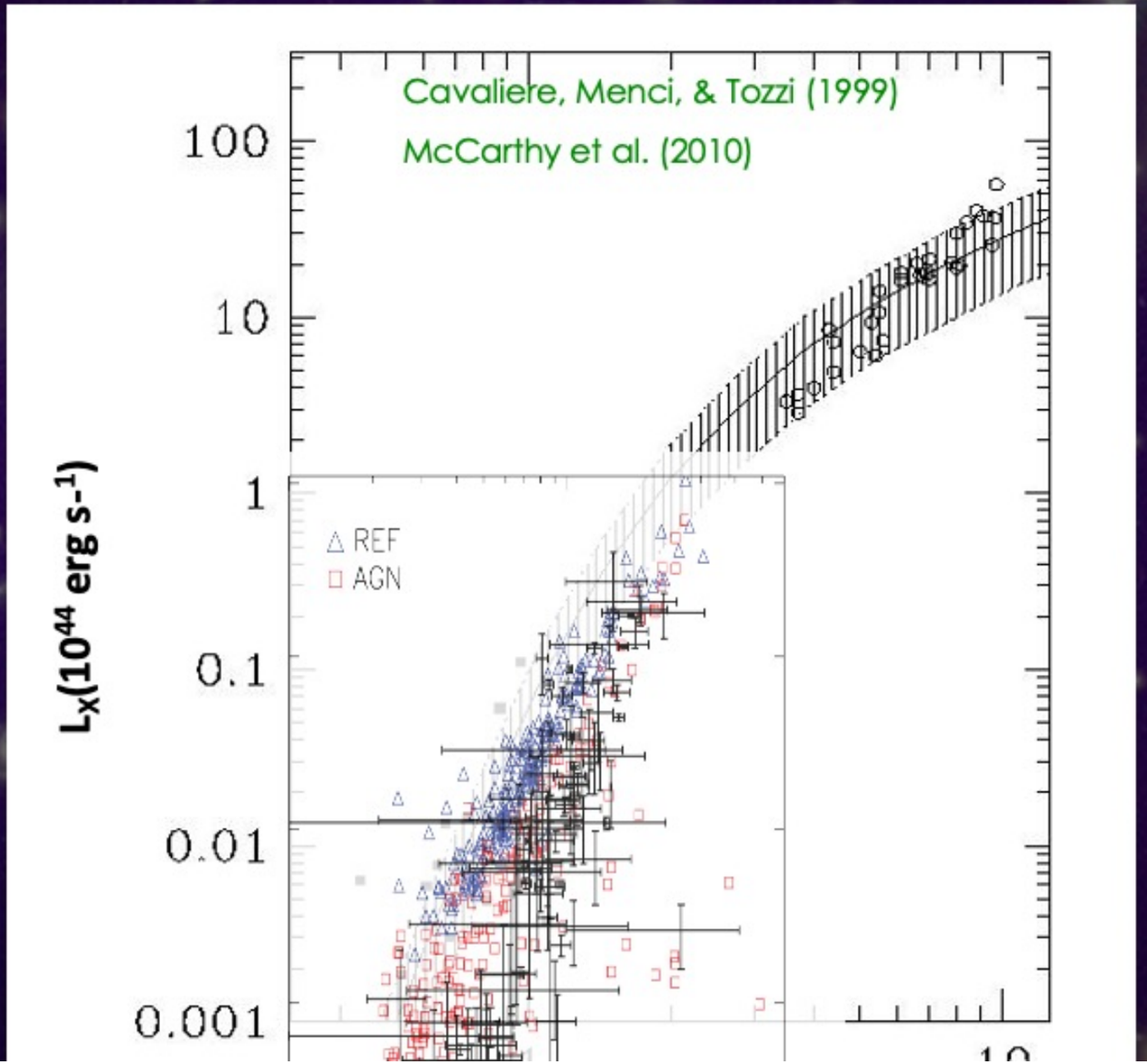

Arnouts etal (2005)

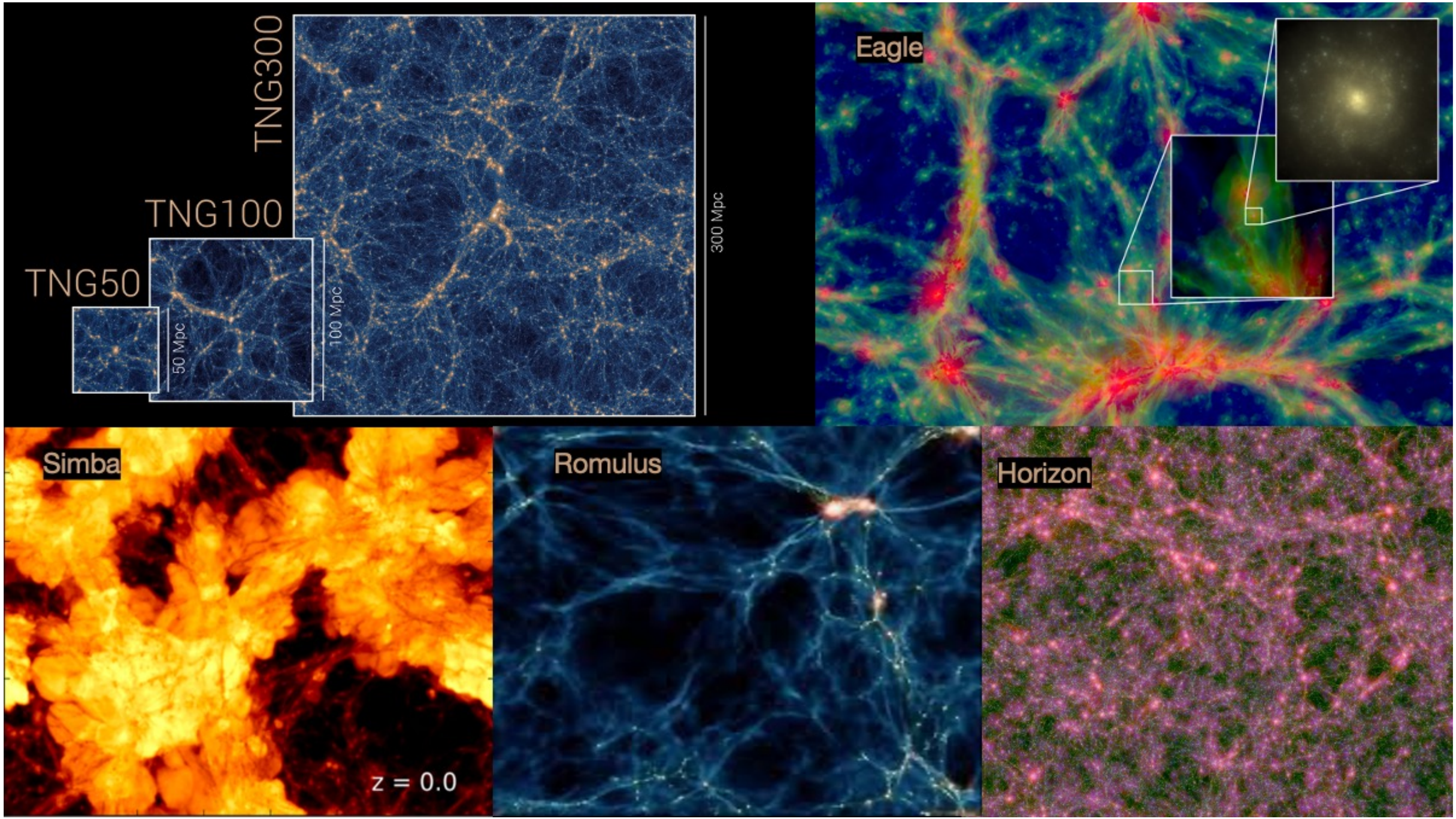
# Active Black Hole Evolution Over Time

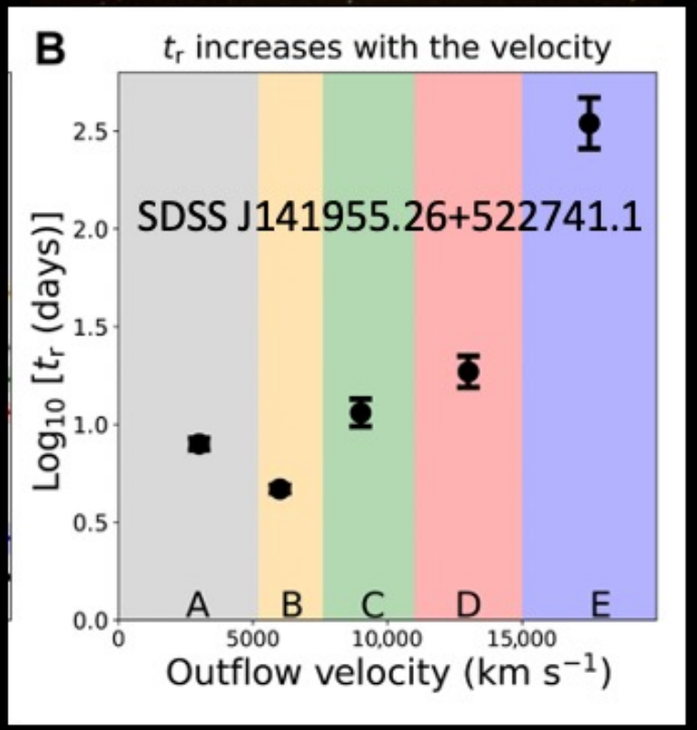



Ueda et al (2014)

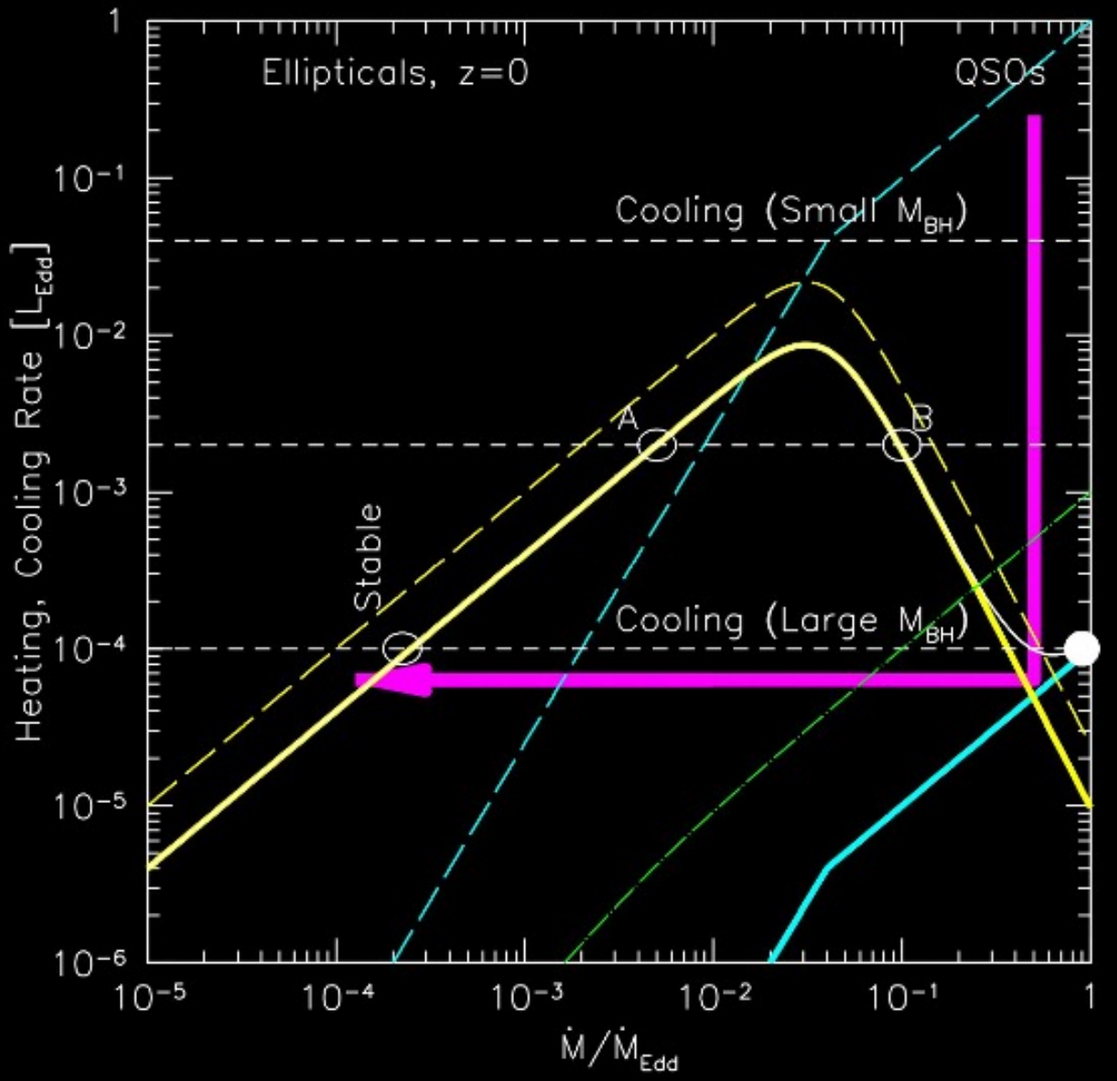
# Clusters


Cavaliere, Menci, & Tozzi (1999)
McCarthy et al. (2010)
100
10
1
0.1
0.01
0.001
△ REF
□ AGN
$L_X(10^{44}$ erg $s^{-1})$


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

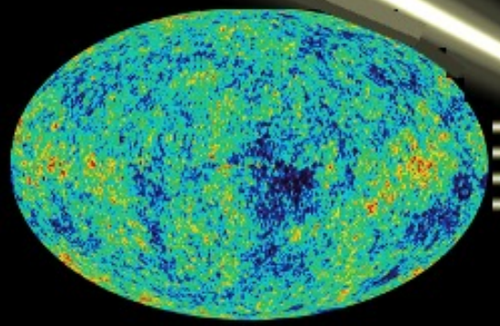



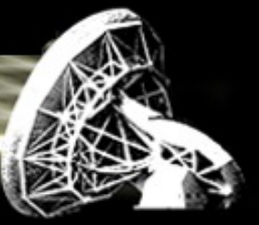

He et al (2021)



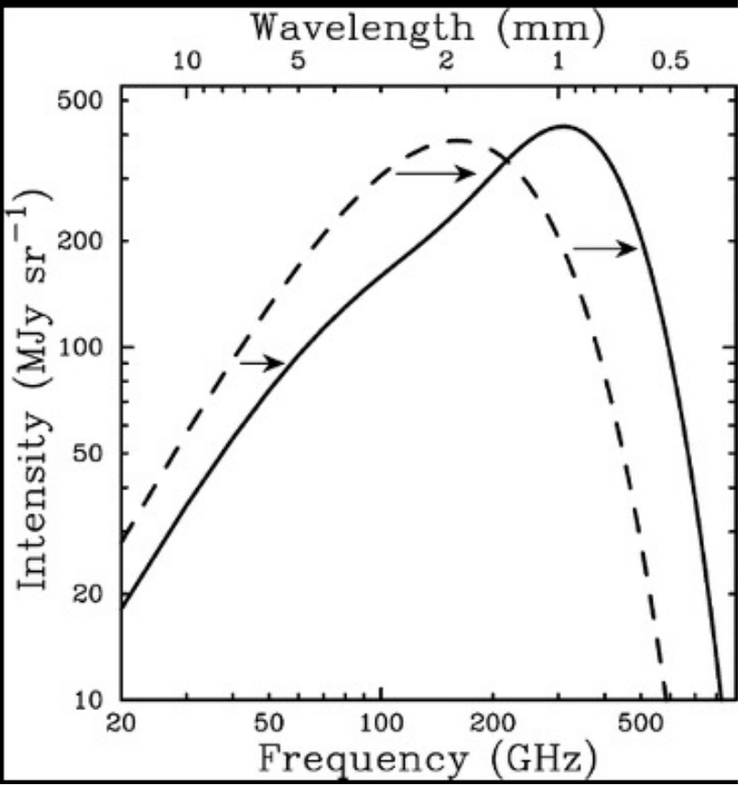

Werner, McNamara, Churzov,, ES (2019)

# Thermal Sunyaev-Zel'dovich Effect



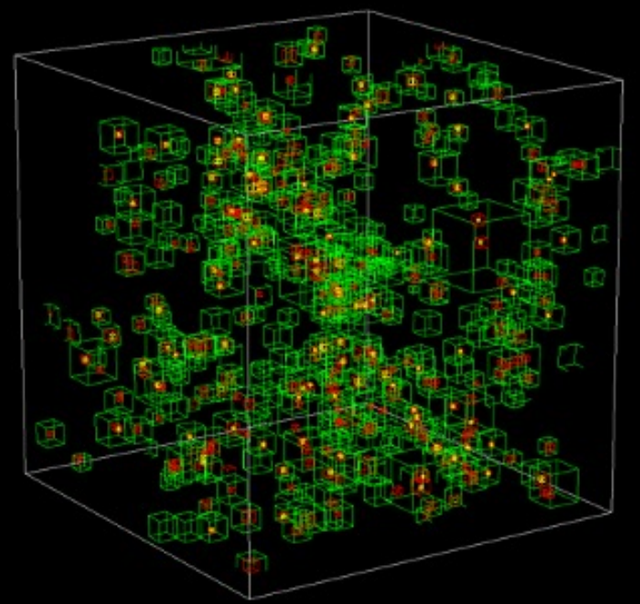


Signal $\alpha$ Gas Density Along Sightline
× Temperature Along Sightline
= Pressure Along Sightline



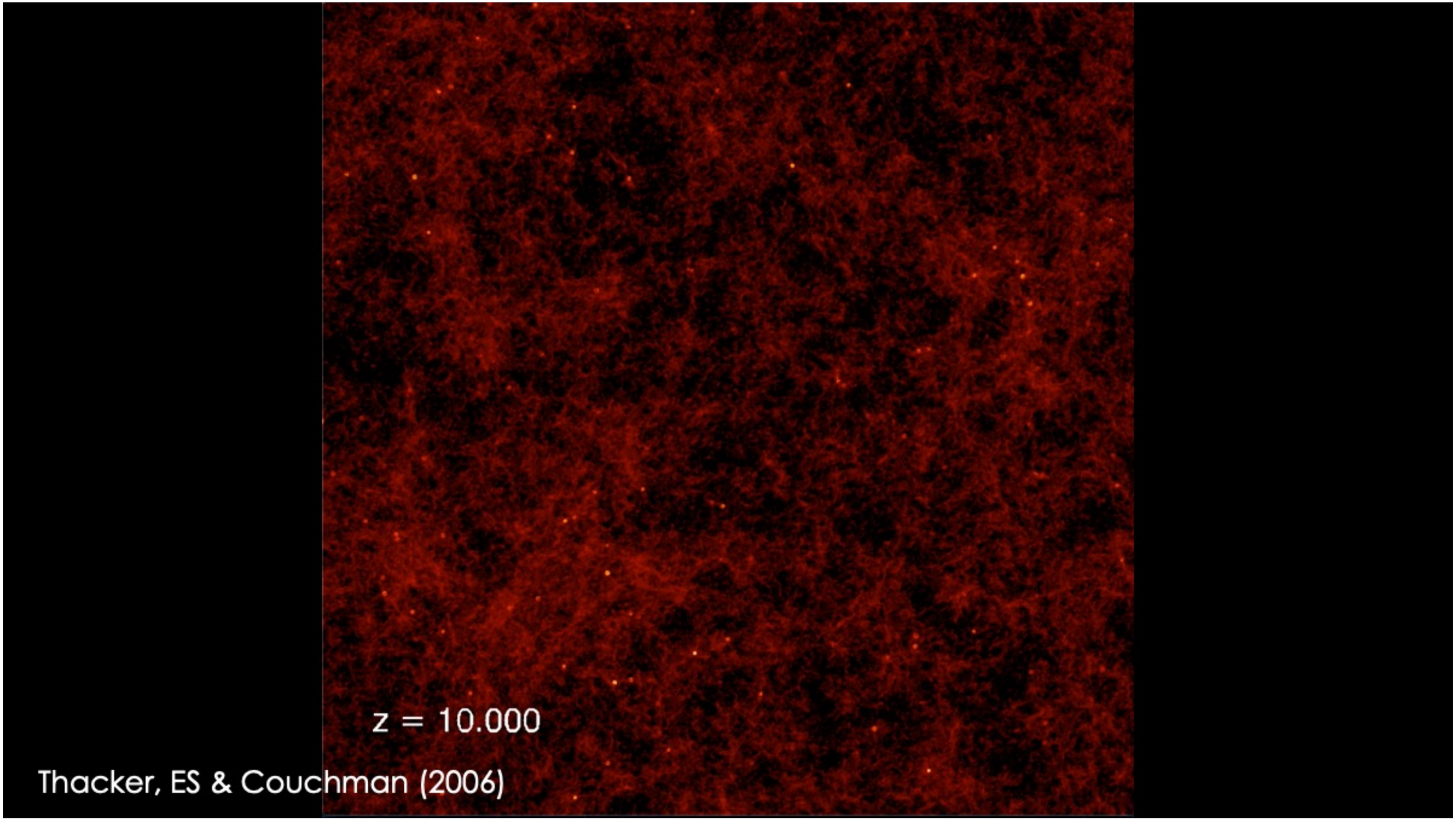
# Numerical Simulation

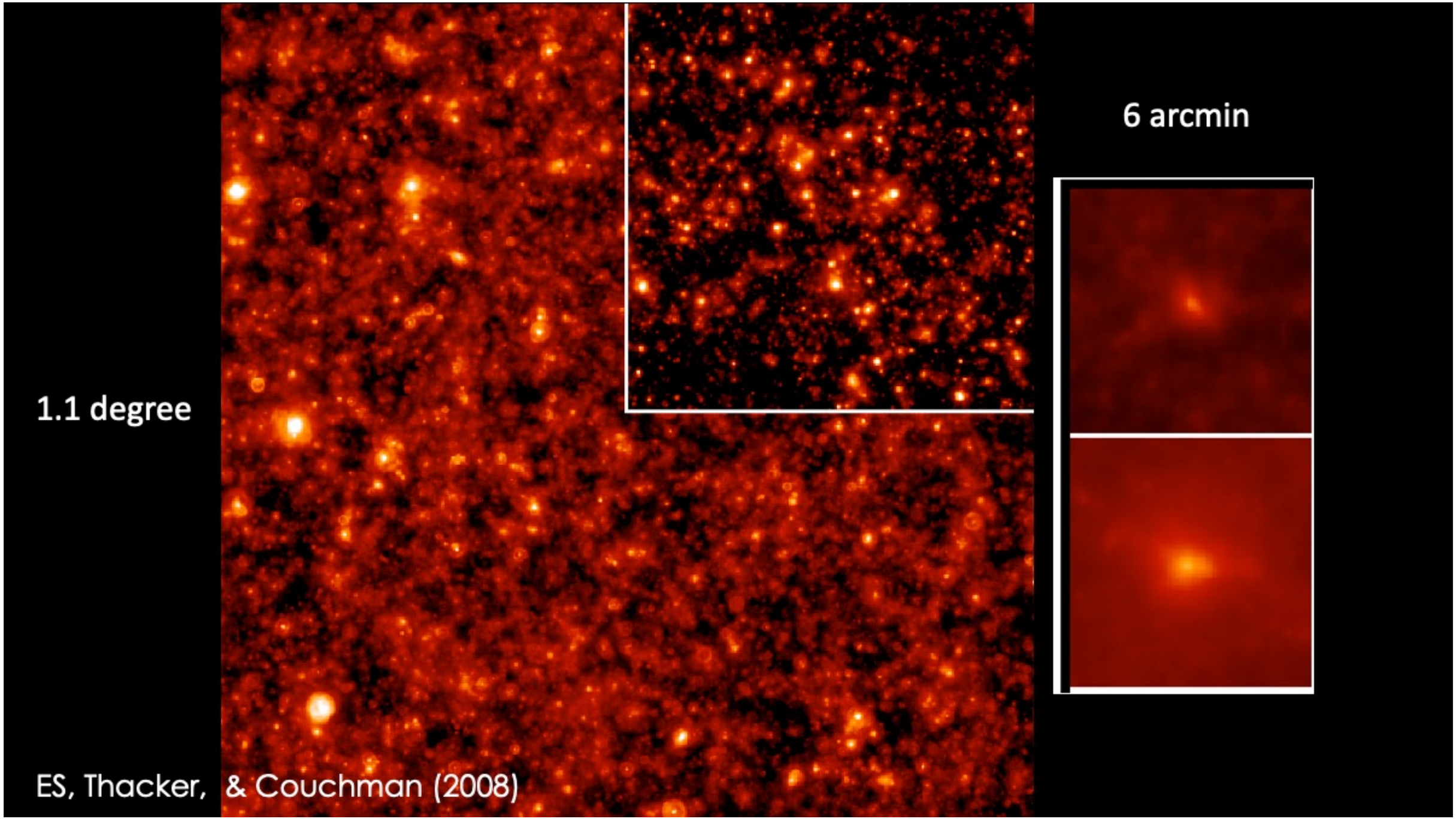
- OpenMP version of the 'Hydra' SPH code
- **146 cMpc/h box, 2x640$^3$ particles, to z=1.2**
- 2x 640$^3$ particles (half gas, half dark matter)
- Largest SPH simulation ever carried out at that time
- AGN are associated with mergers,
- ASSUME 5% of energy in light goes into
  **outflows** =>bursty, high energy input

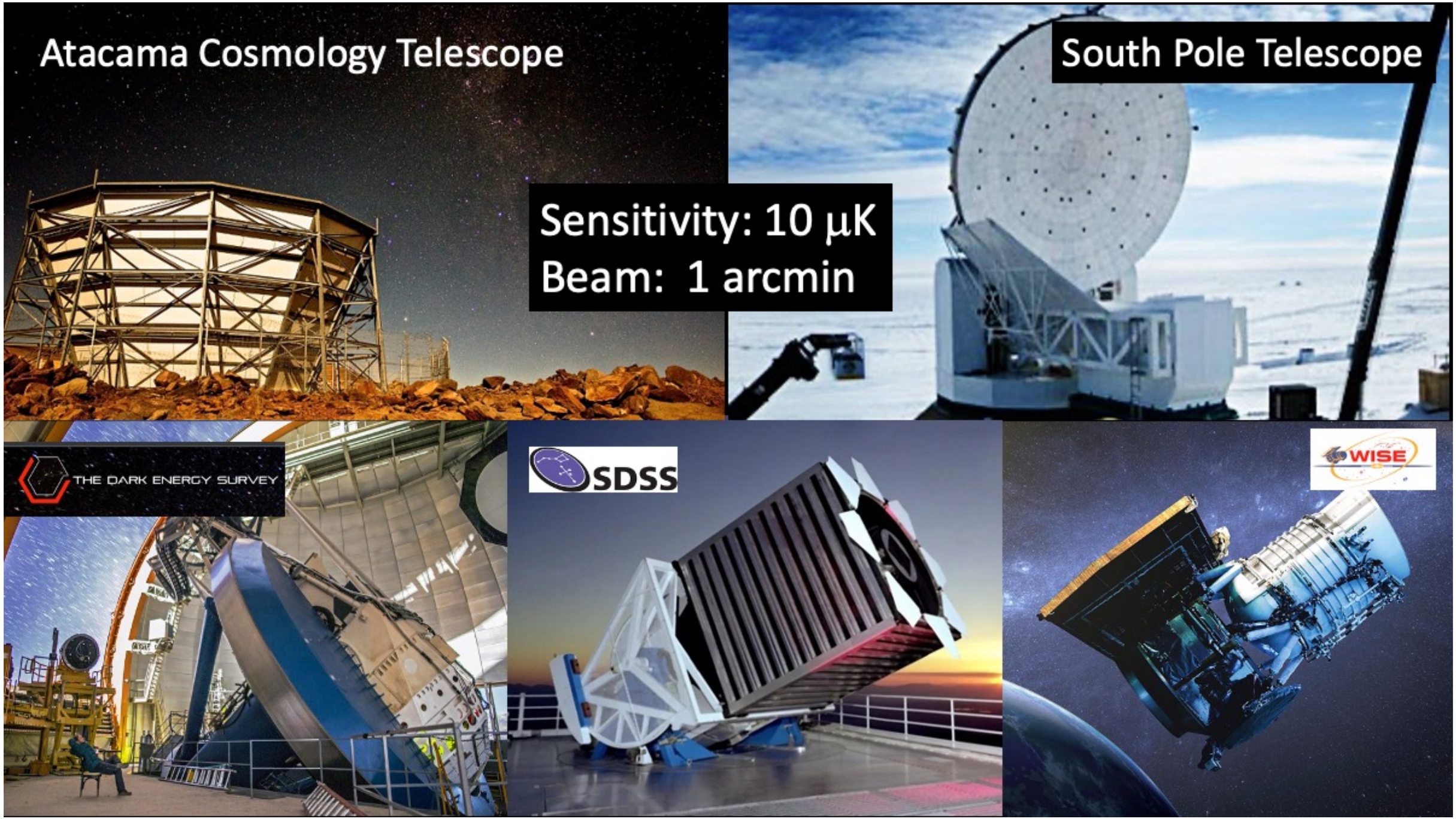


Thacker, ES & Couchman (2006)

ES & Oh (2004)

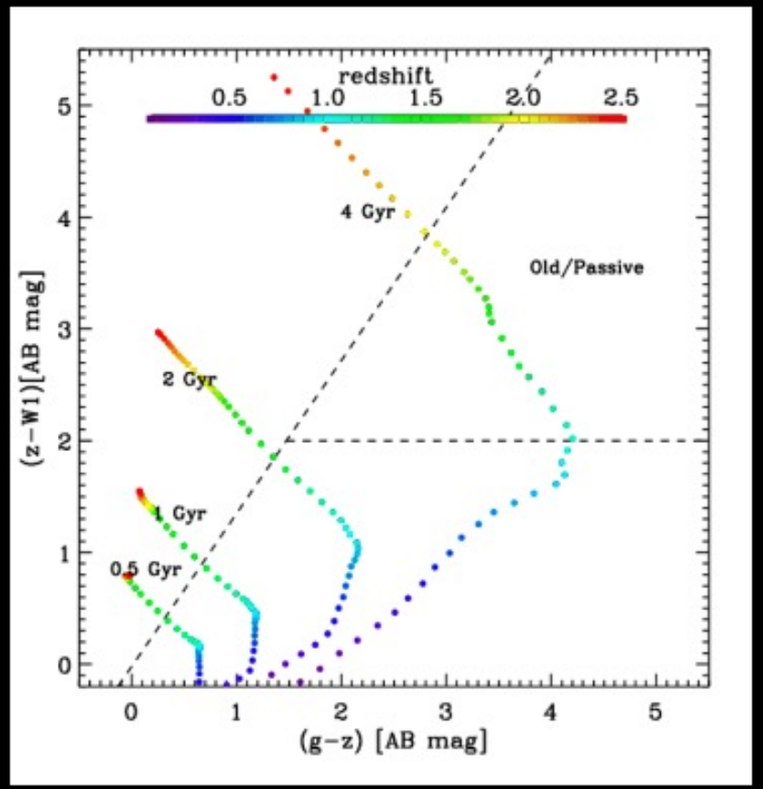

z = 10.000
Thacker, ES & Couchman (2006)

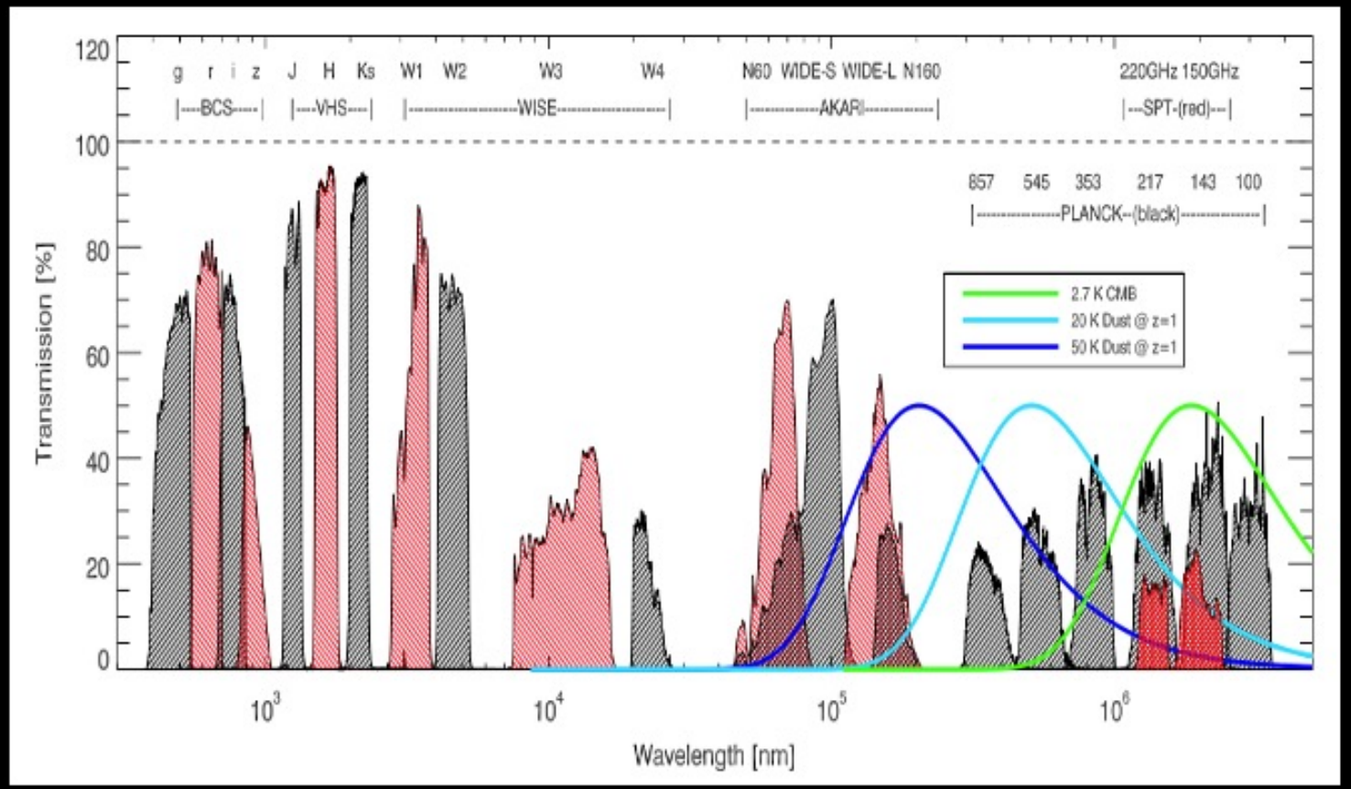

6 arcmin
1.1 degree
ES, Thacker, & Couchman (2008)


Atacama Cosmology Telescope
South Pole Telescope
Sensitivity: 10 μK
Beam: 1 arcmin
THE DARK ENERGY SURVEY
SDSS
WISE

# Selection and Sample

WISE



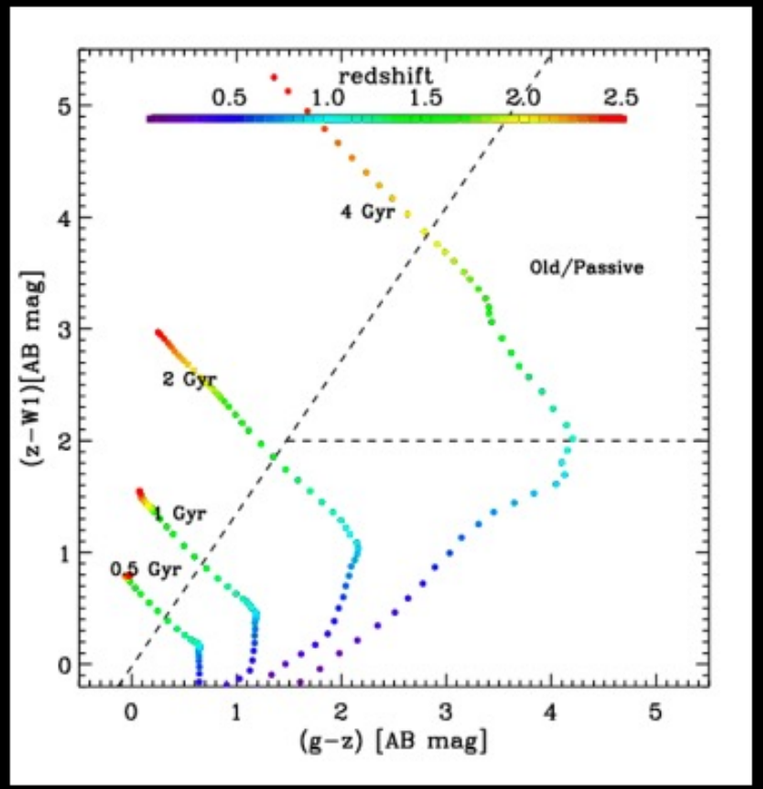




DES/SDSS

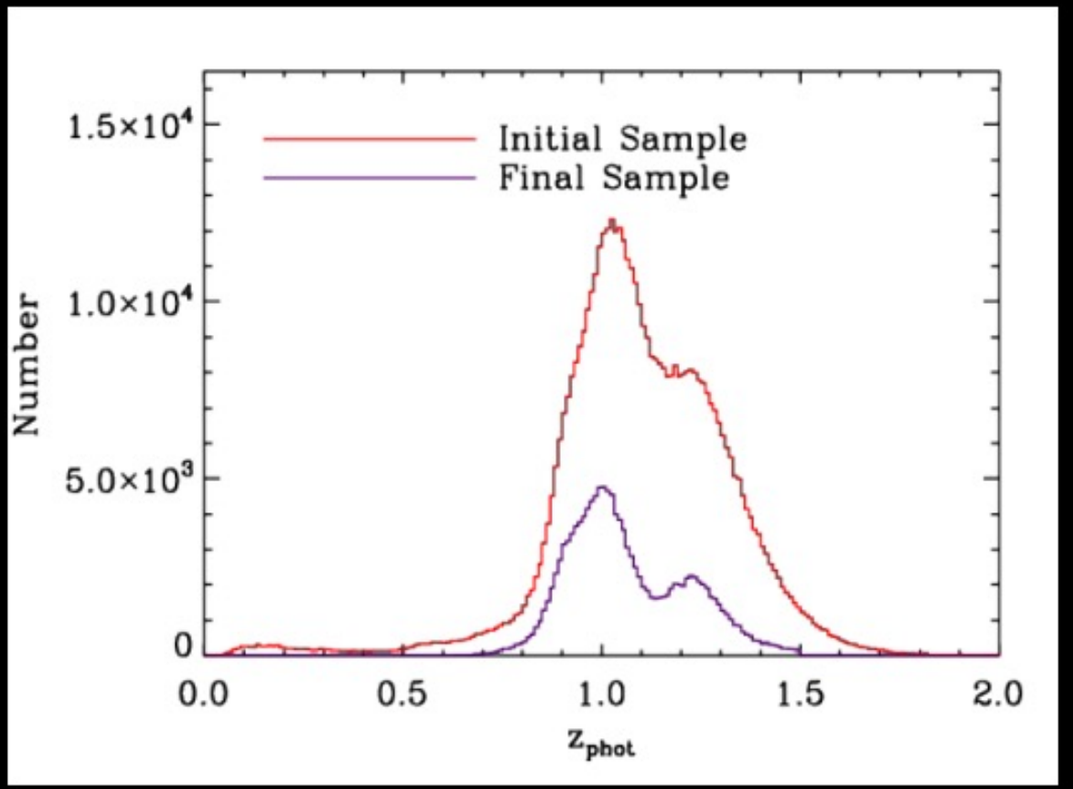
J. Meinke, et al. (2021)

# Selection and Sample

WISE




DES/SDSS




age > 1 Gyr

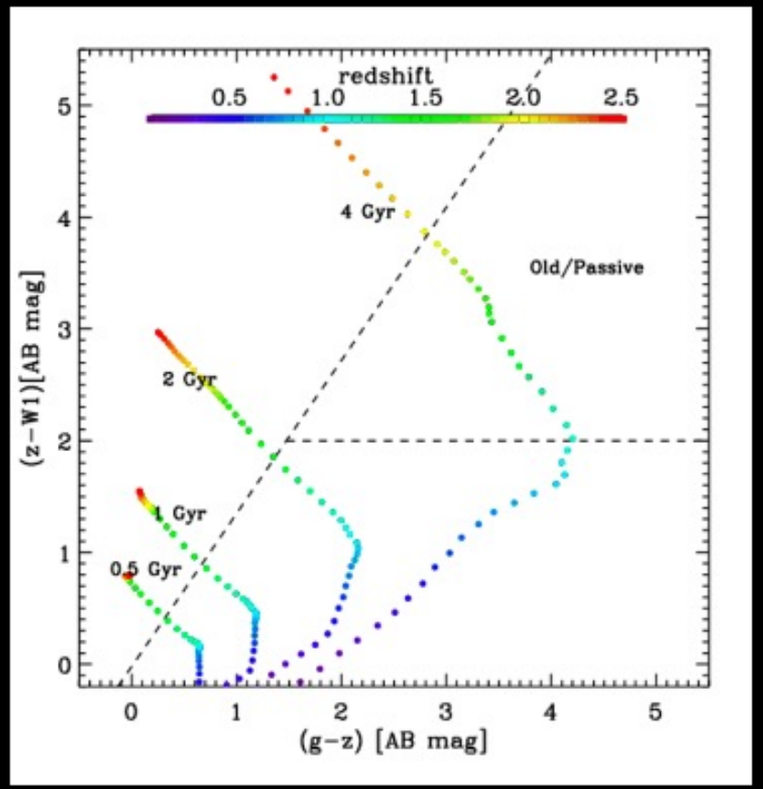
SSFR < 0.01 $Gyr^{-1}$

$0.5 < z_{phot} < 1.5$

J. Meinke, et al. (2021)

# Selection and Sample

WISE



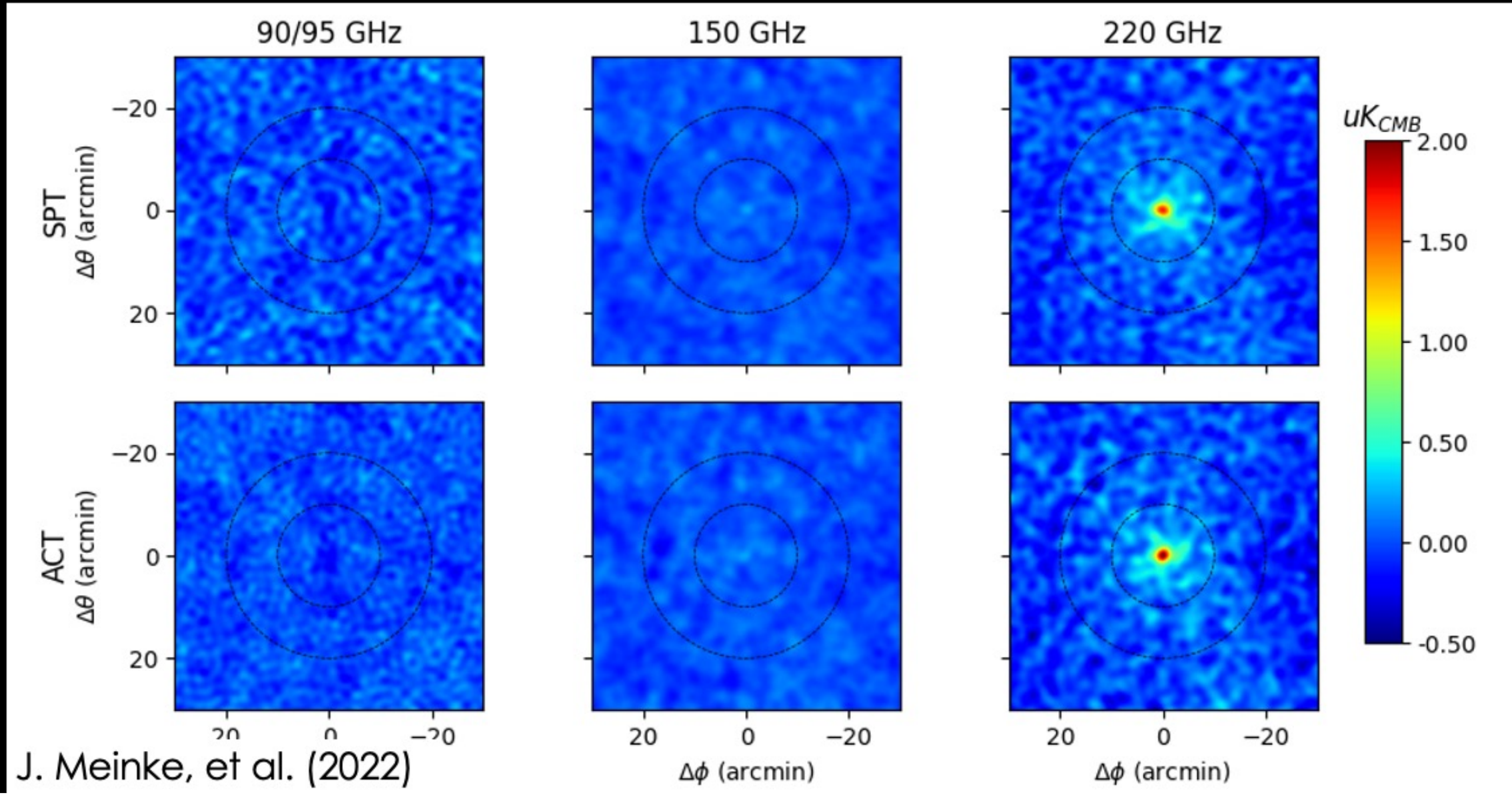

DES/SDSS

| 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 |
| ELG (ACT) | 465199 | 0.80 | – |

2600 deg$^2$
18,000 deg$^2$

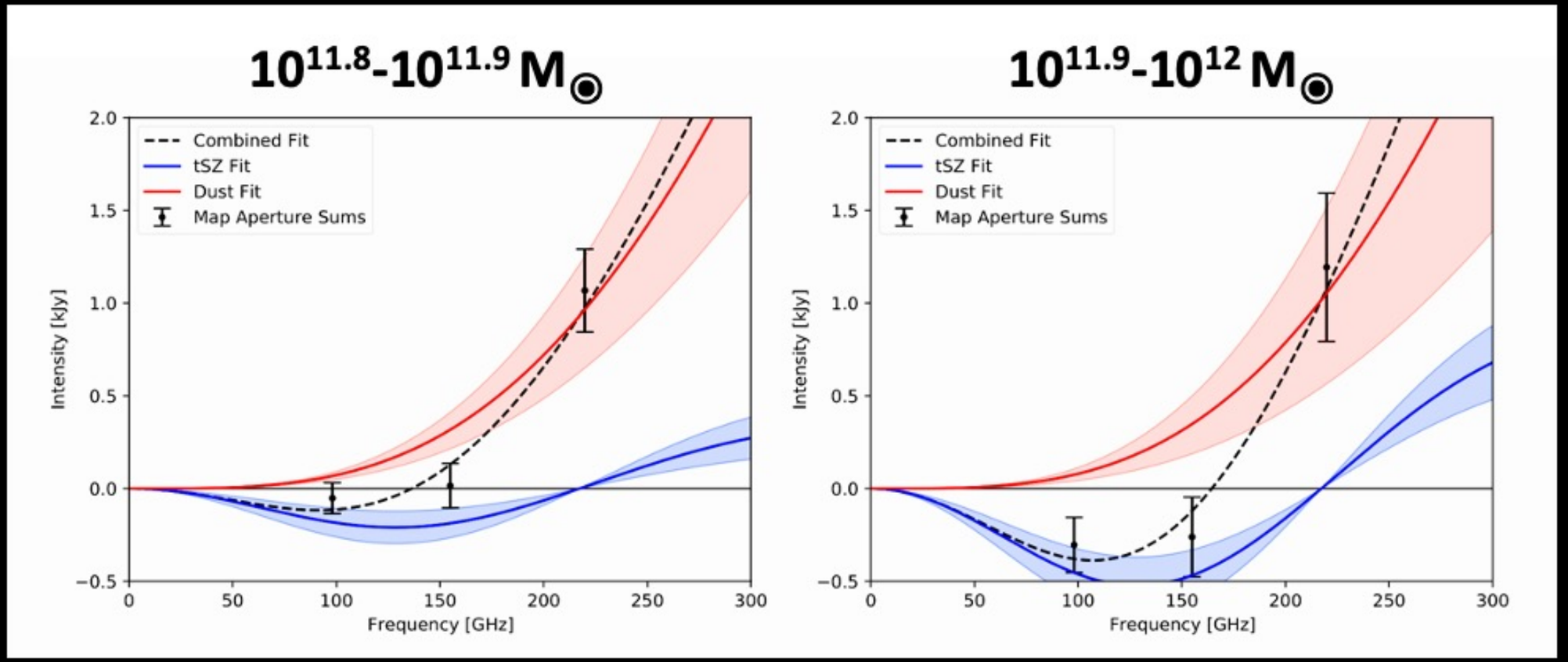
J. Meinke, et al. (2021)

# Stacked Signals in the Overlap Region




J. Meinke, et al. (2022)

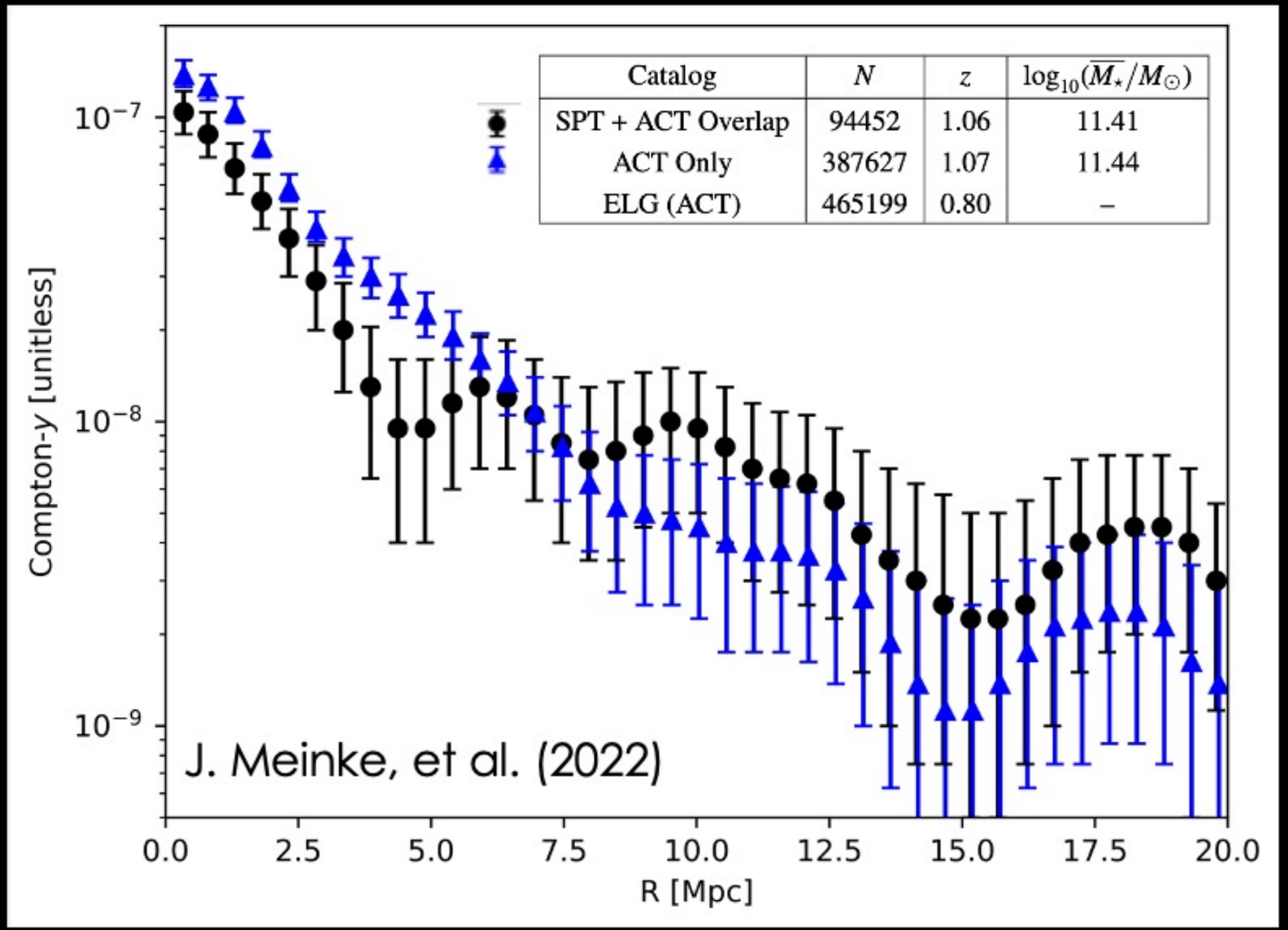
# Two Component Fitting to Dust and tSZ



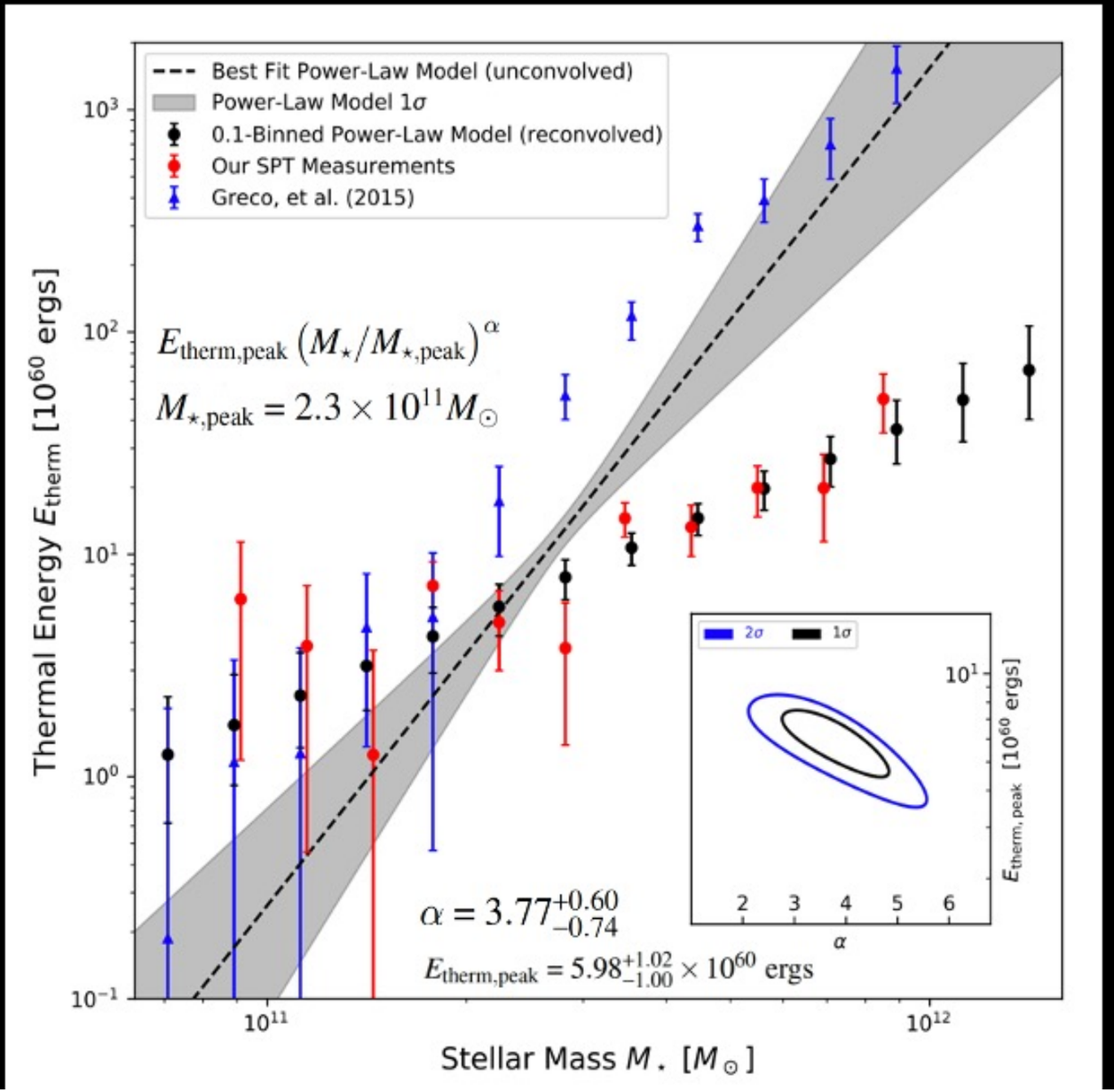

J. Meinke, et al. (2022)

$$\beta = 1.75 \pm 0.25 \text{ and } T_{\text{dust}} = 20 \pm 5\text{K}$$

# Stacked SZ Profiles

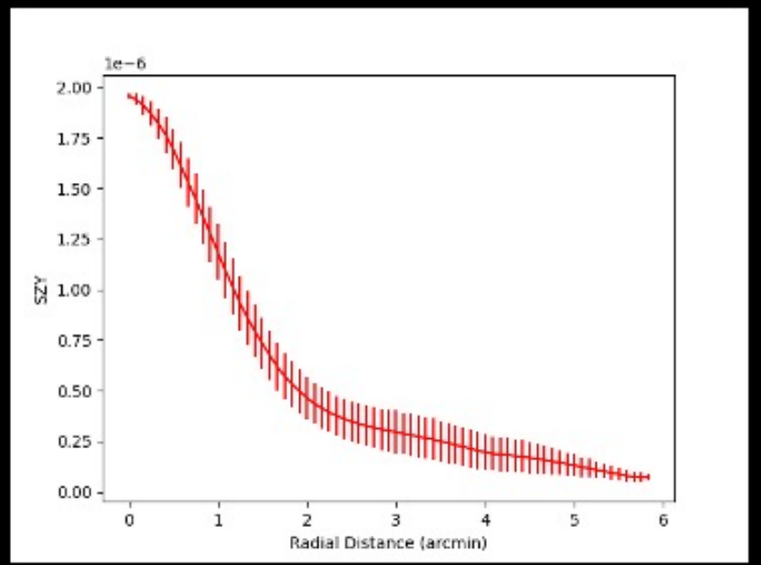


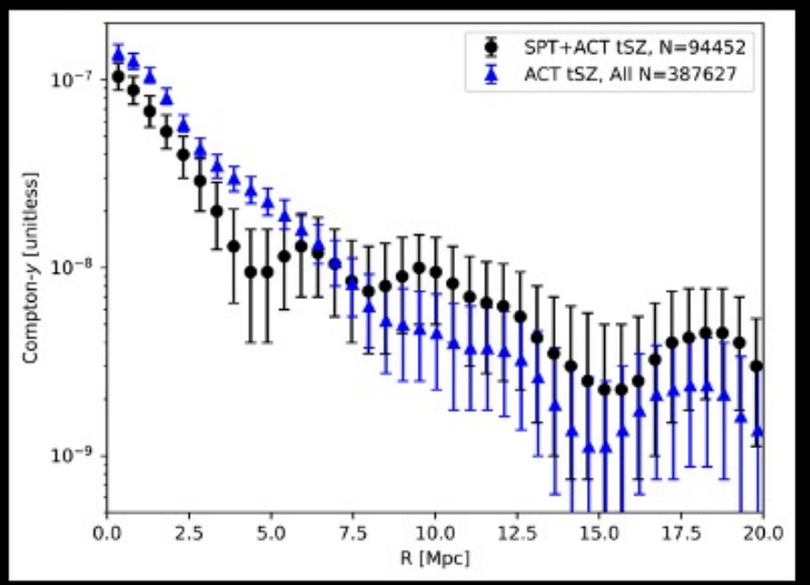
# Energy Per Stellar Mass

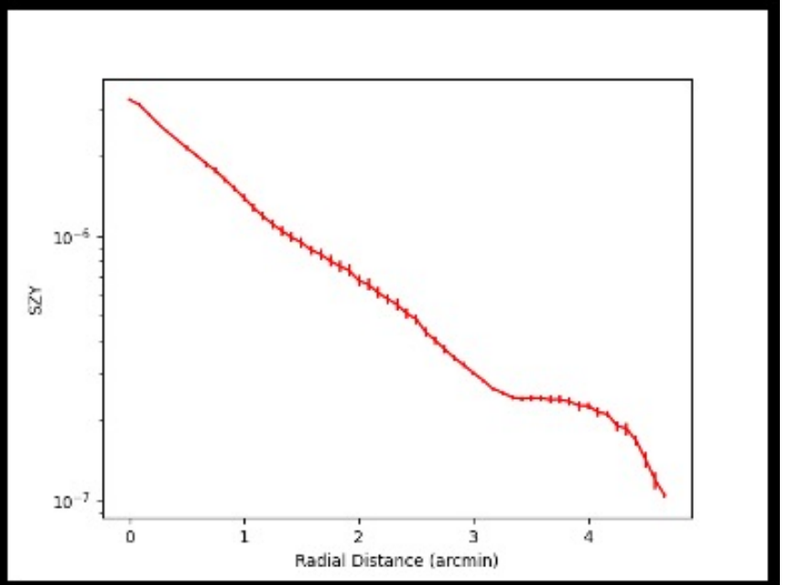



J. Meinke, et al. (2022)

# Preliminary Stacking SZ Data from SIMBA / 300

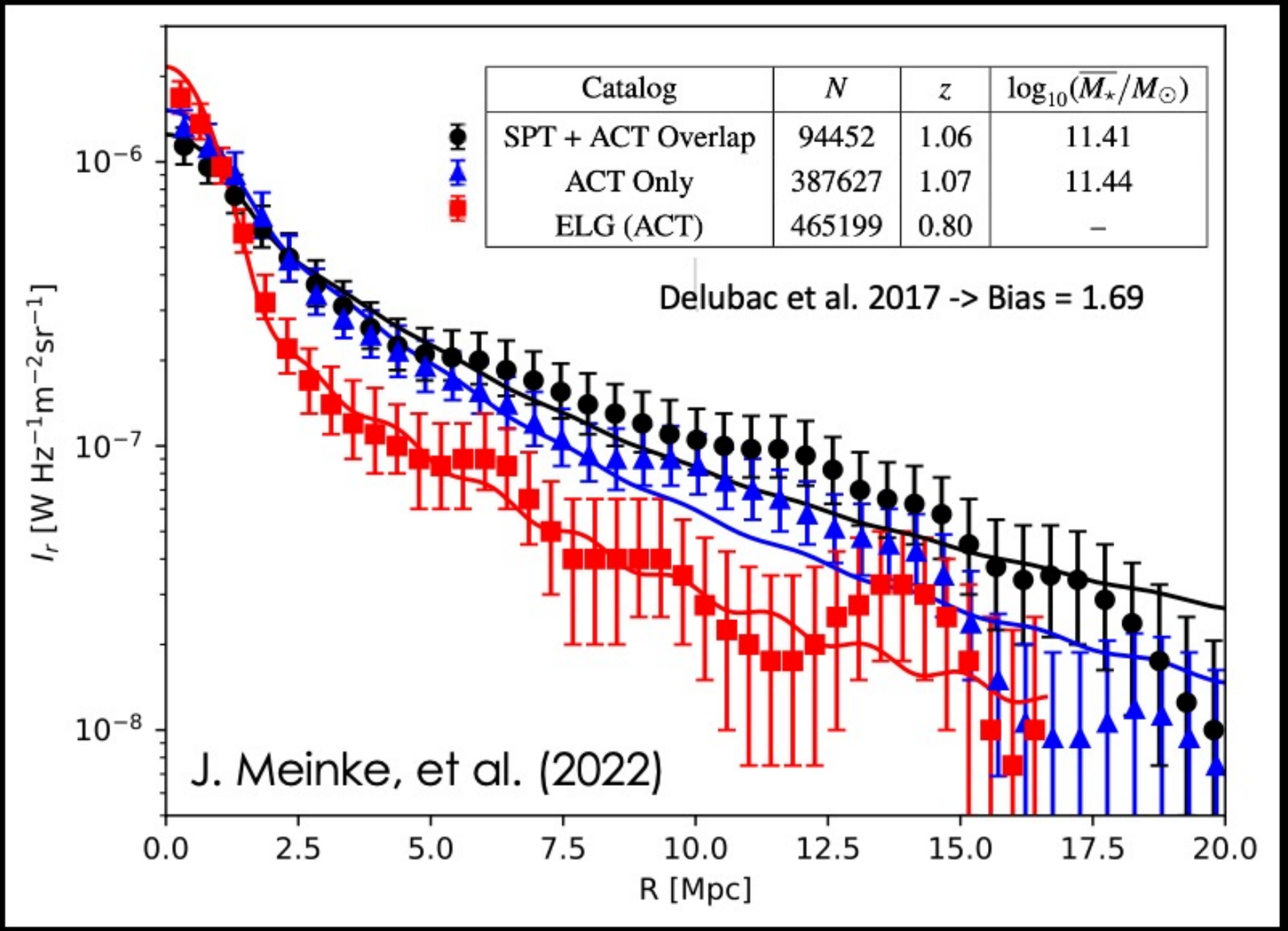


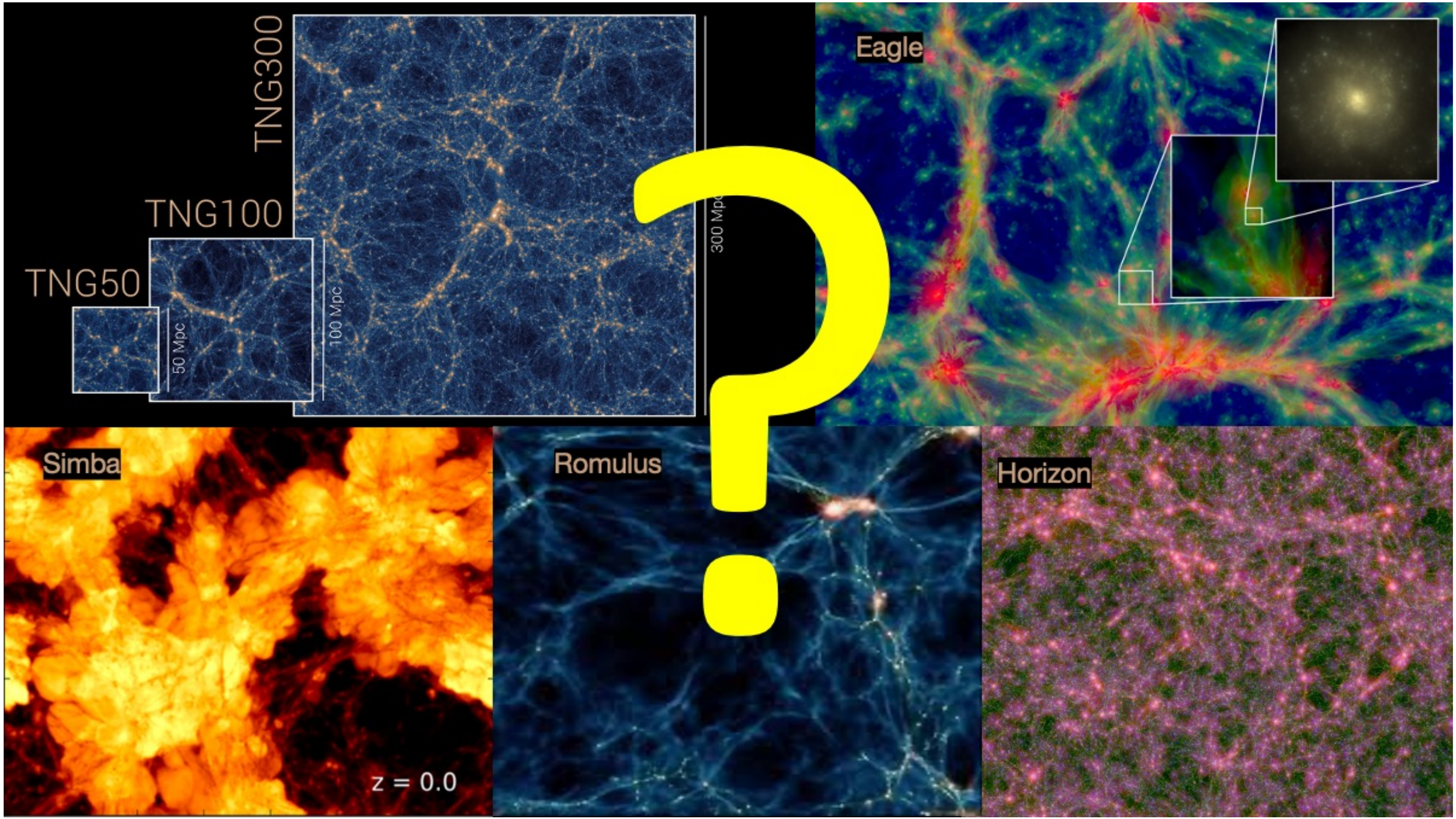




- SIMBA: Galaxy formation simulation
- Uses GIZMO with multiple other features including AGN jets, radiative winds, and X-ray feedback
- Initial data analysis done as described in Meinke et. al. 2021

# Stacked Dust Emission Profiles




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

# 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

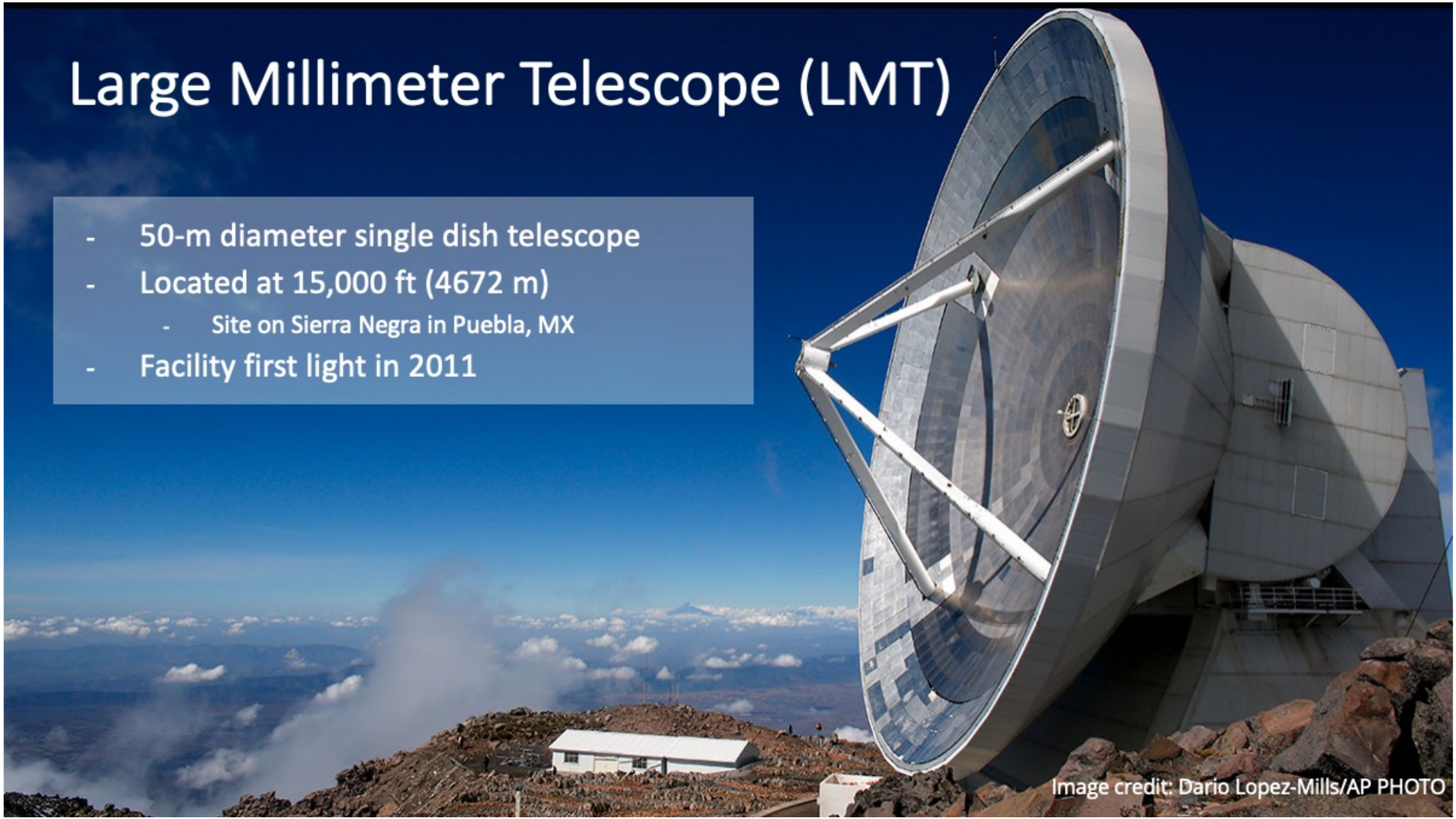
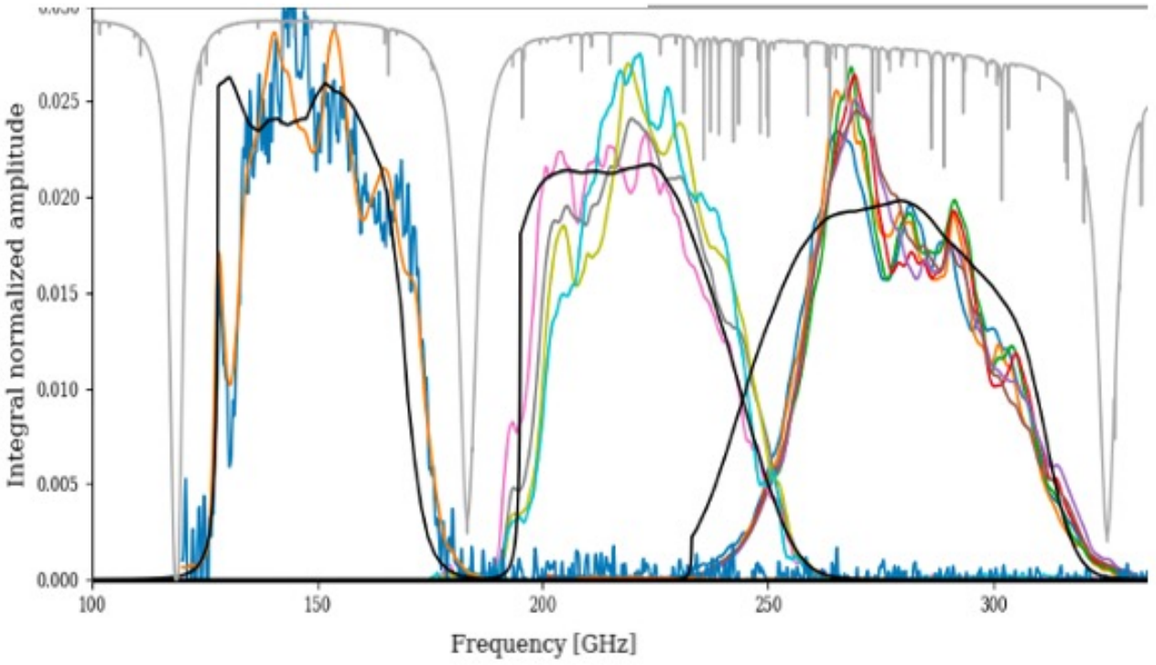
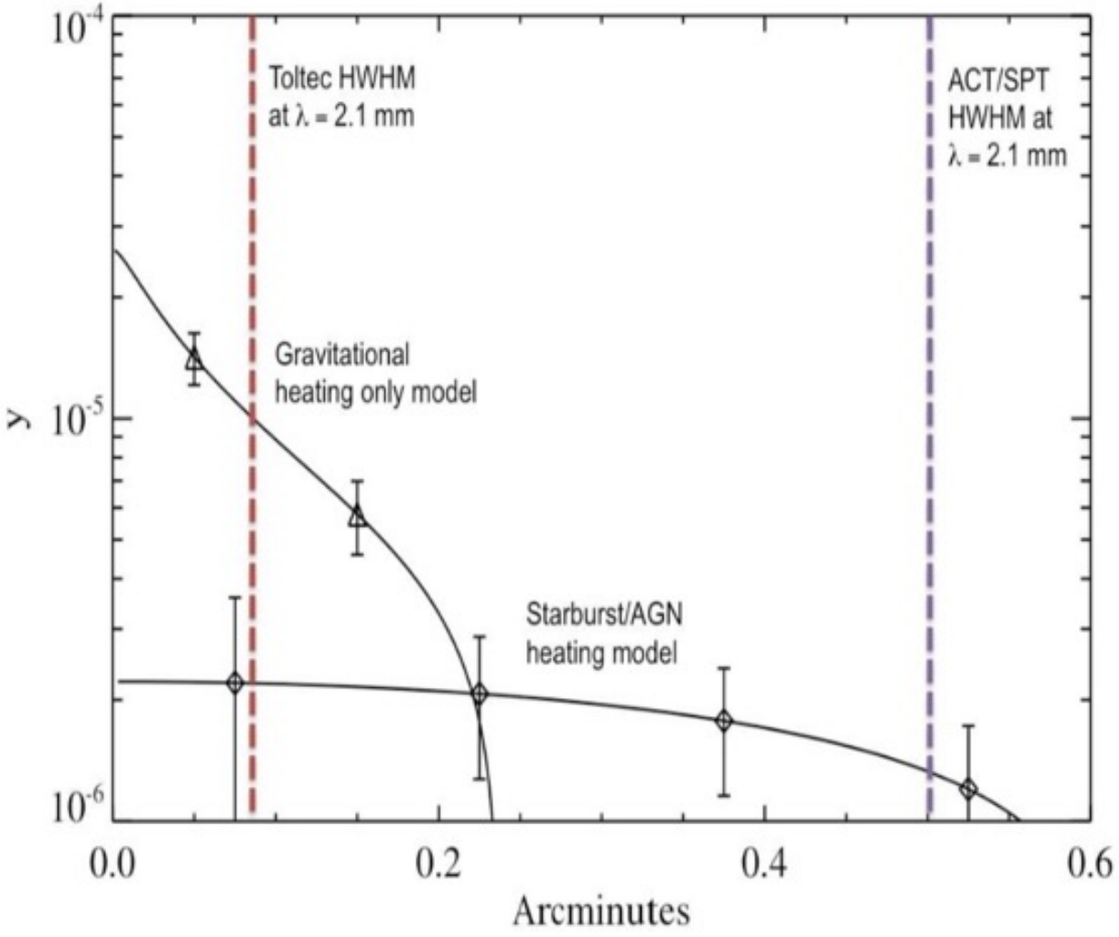


Image credit: Dario Lopez-Mills/AP PHOTO


TolTEC
ASU Cardiff INAOE Michigan NIST Northwestern UMass Wisconsin


Integral normalized amplitude
0.025
0.020
0.015
0.010
0.005
0.000
100
150
200
250
300
Frequency [GHz]


$10^{-4}$
$10^{-5}$
$10^{-6}$
y
Toltec HWHM
at λ = 2.1 mm
ACT/SPT
HWHM at
λ = 2.1 mm
Gravitational
heating only model
Starburst/AGN
heating model
0.0
0.2
0.4
0.6
Arcminutes

# Installing TolTEC

From: N. Denigris

# Installing TolTEC



Installation completed 12/2021
Observations start this fall

From: N. Denigris

# Conclusions