Feedback Cycle in CAMELS

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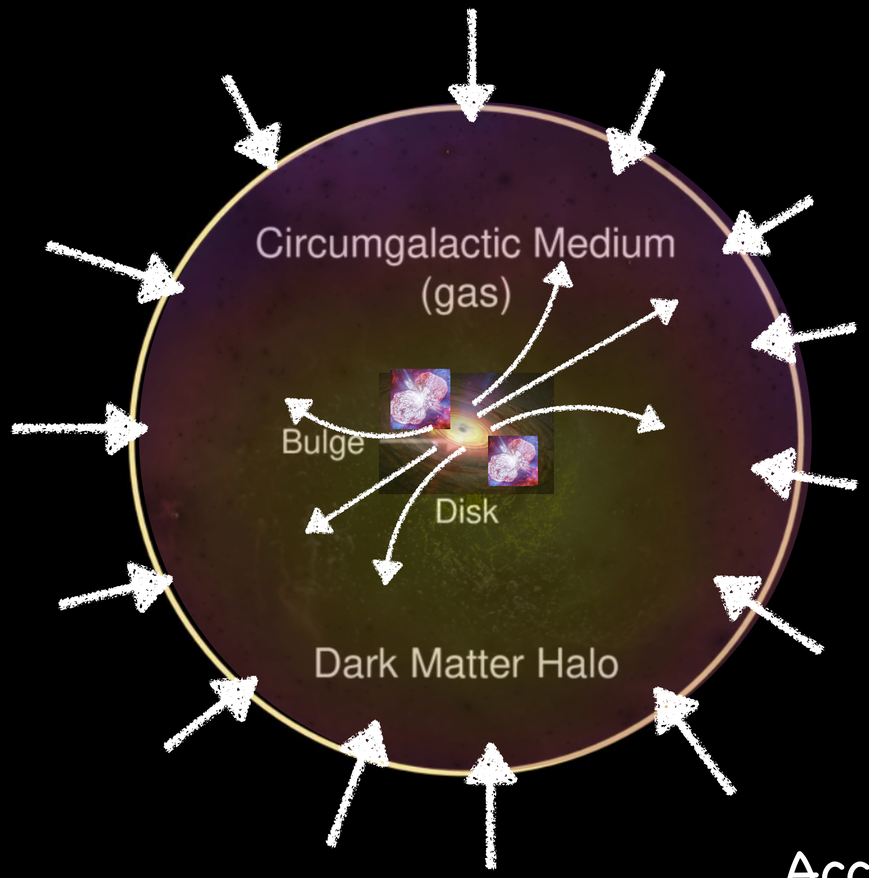
In collaboration with Ben Oppenheimer, Daisuke Nagai, Erwin Lau & Noam Scully

EAGLE-CGM Simulation visualization produced by Fiske Planetarium Productions
Credit: B. D. Oppenheimer

Feedback cycle in Galaxies

Circum-galactic medium (CGM) bears the imprint of a variety of physical processes

Active Galactic Nuclei (AGN) Feedback



Supernovae feedback

Accretion

Feedback cycle in CAMELS

Cosmology & Astrophysics with MachinE Learning Simulations

- Set of 6,325 simulations.
- **Different input physics** (1P set varying one parameter at a time) & cosmology.
- Ideal for CGM analysis in L* and massive galaxies ($M_h \sim 10^{11.5} - 10^{13} M_\odot$).

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A leap in observational datasets (sample size and resolution)

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★ Bregman et al. 2022: Stacked tSZ resolved profiles from L* galaxies (Planck+WMAP).

★ Chadayammuri et al. 2022: X-ray emission profiles from eFEDS (EAGLE & Illustris simulations unable to reproduce).

★ Amodeo et al. 2021: Detection of stacked tSZ/kSZ resolved profiles from massive galaxies & groups (ACT+BOSS).

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$$f_{CGM} \equiv M_{CGM}/M_h$$

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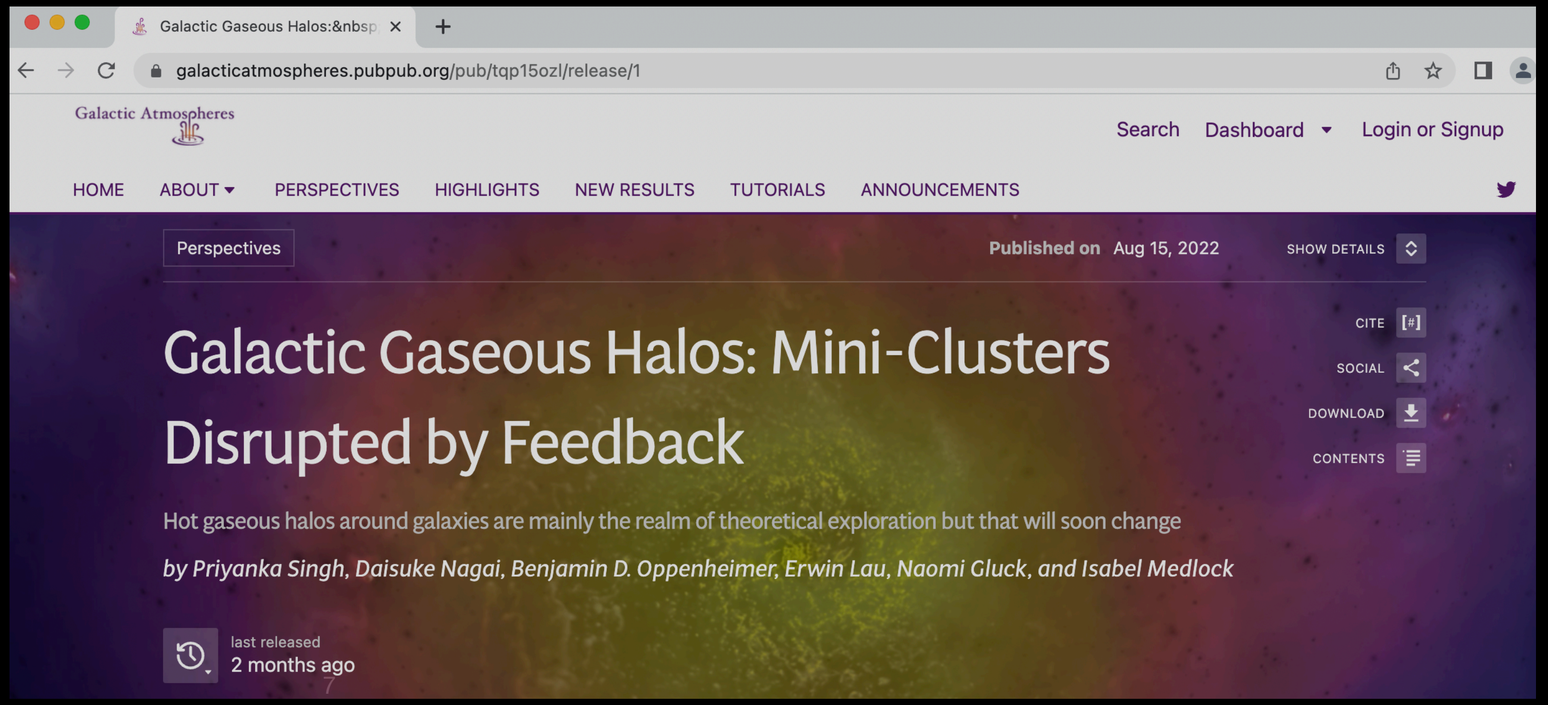
Simultaneous effort from simulations & improved analytical models to prepare ourselves for observational advances in the coming decade.



Feedback cycle in CAMELS

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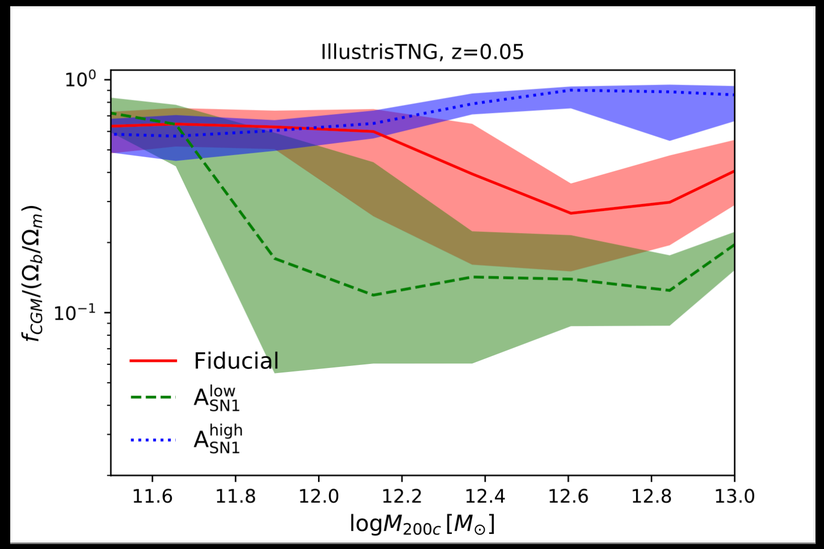
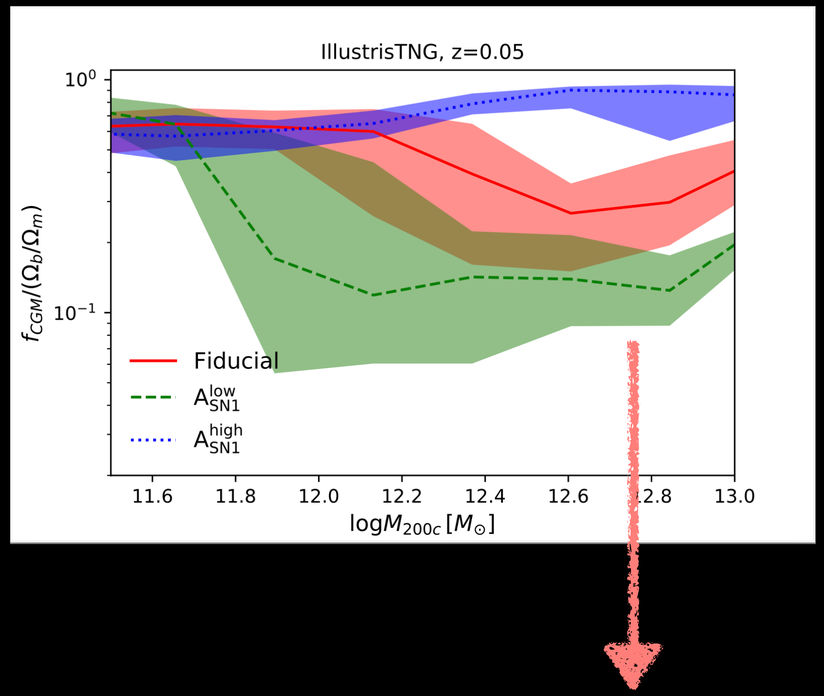
Feedback energy budget: A fundamental quantity controlling CGM budget (f_{CGM}) across simulations?

Feedback cycle in CAMELS



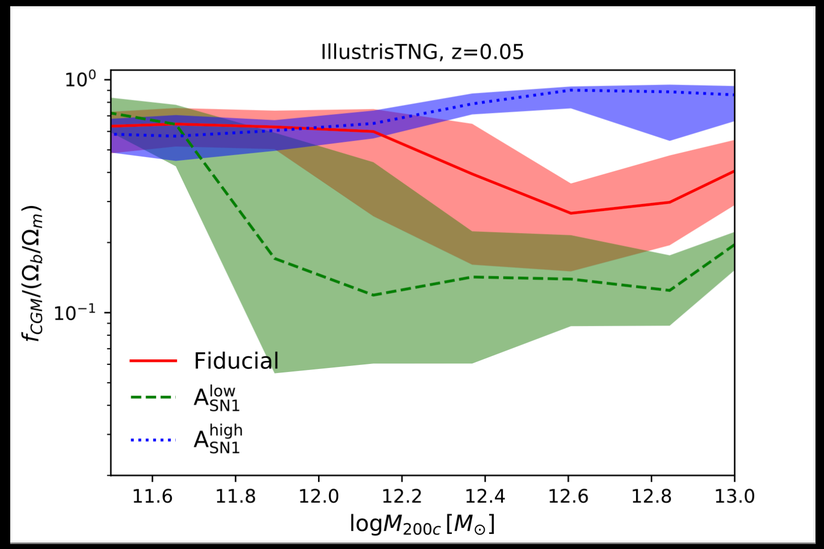
- Solid, dashed & dotted lines: median for a given mass bin.
- Shaded regions: 16th-84th percentile range.

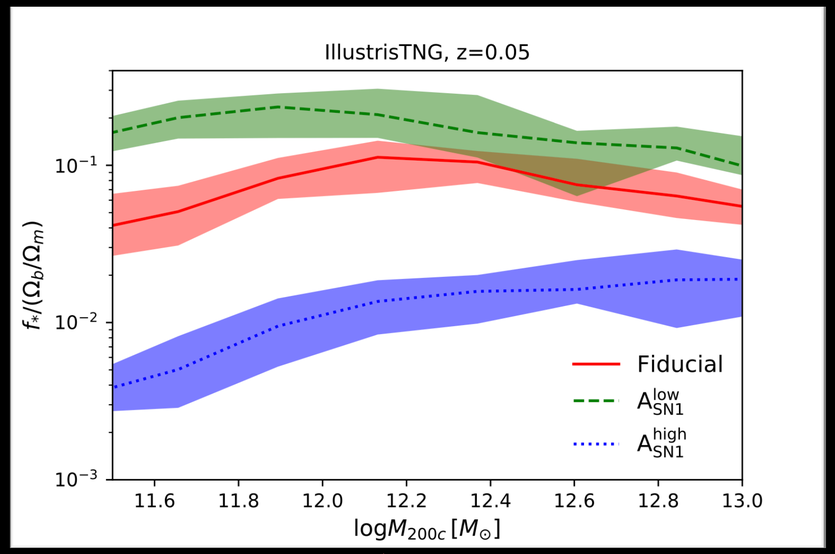
Feedback cycle in CAMELS



Increasing ASN1 (feedback energy per unit star-formation) increases CGM mass fraction for massive galaxies!

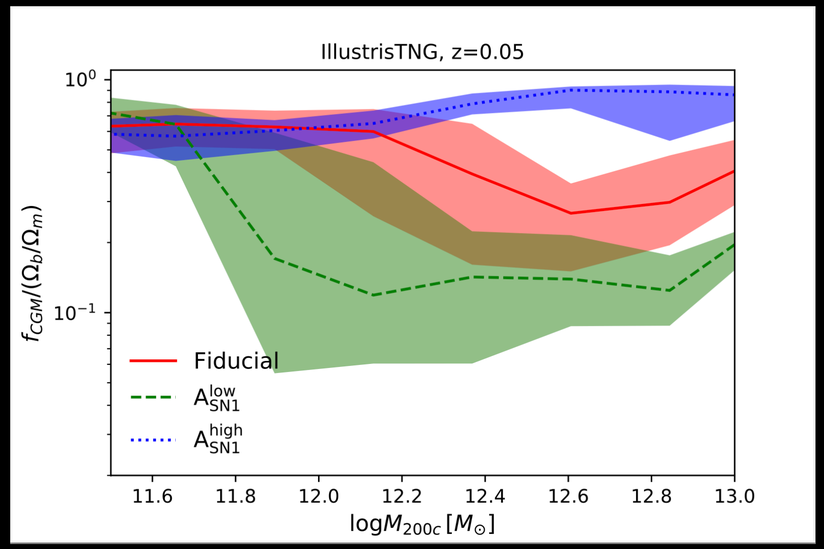
Feedback cycle in CAMELS

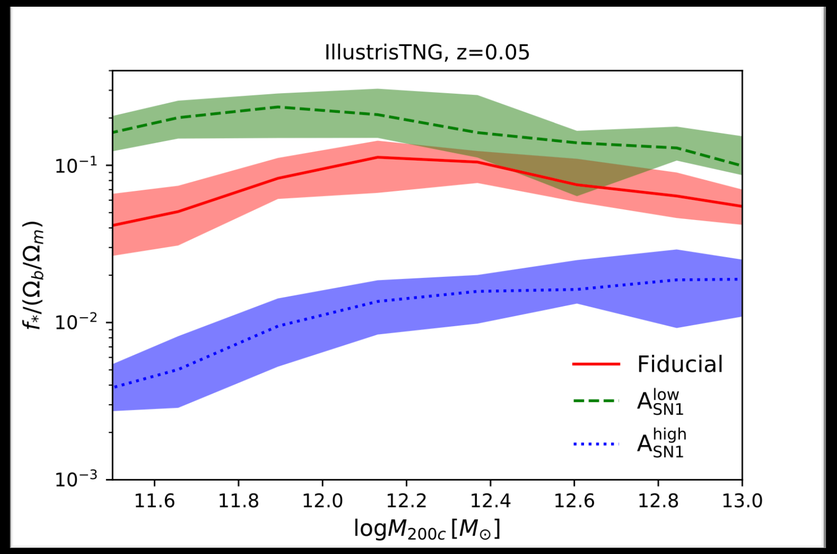


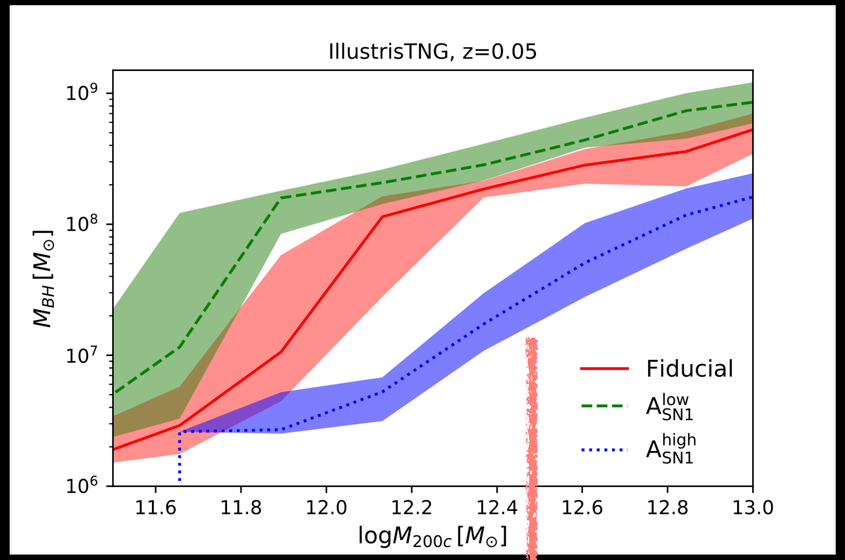


Increasing ASN1 (feedback energy per unit star-formation) decreases stellar mass fraction and hence the overall SNe feedback energy.

Feedback cycle in CAMELS

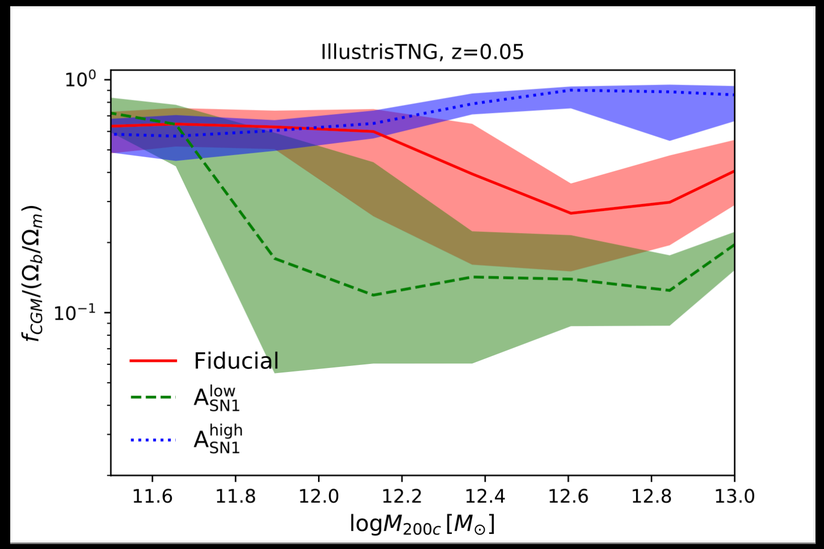


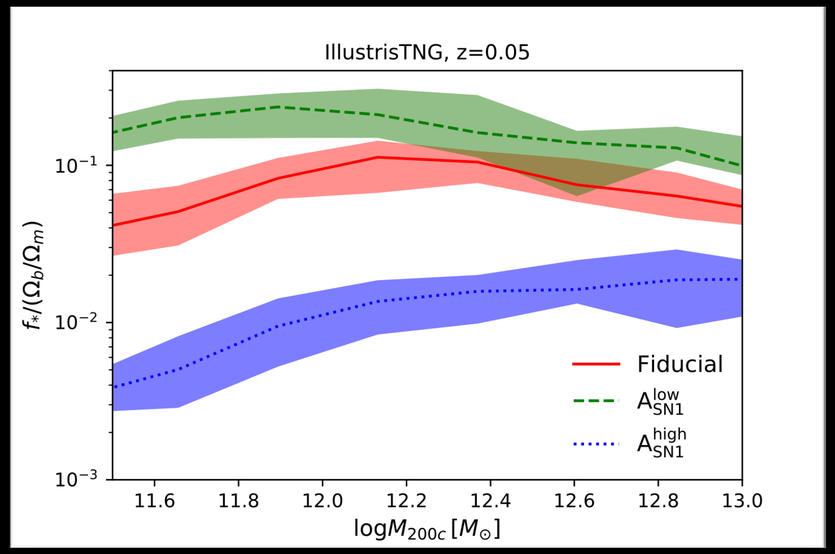


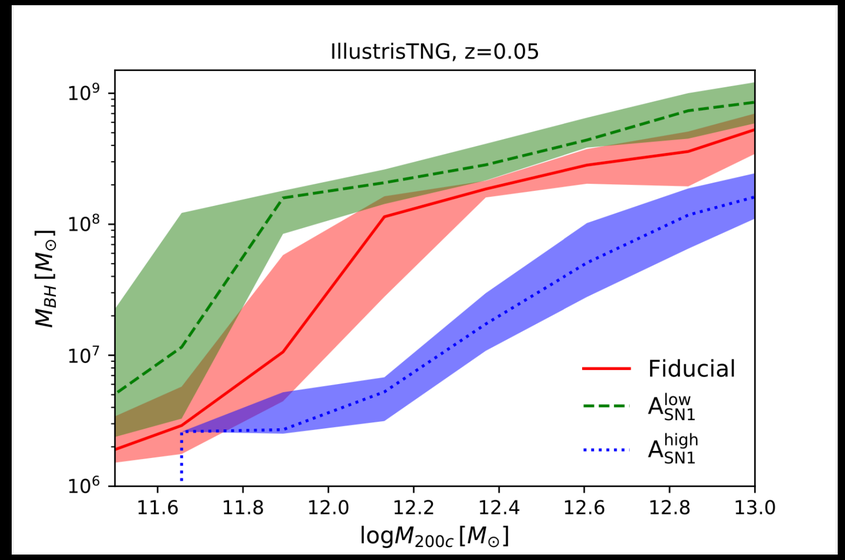


Increasing ASN1 (feedback energy per unit star-formation) decreases central supermassive black hole growth and hence the overall AGN feedback energy.

Feedback cycle in CAMELS

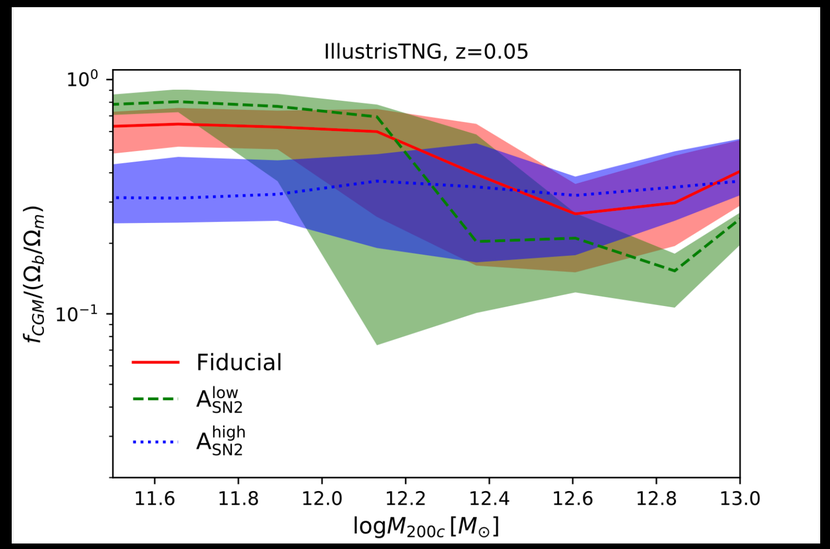


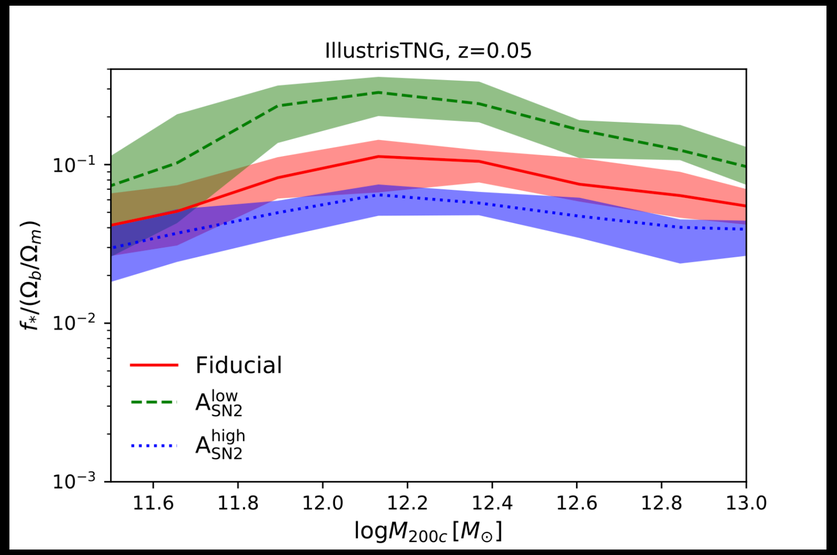


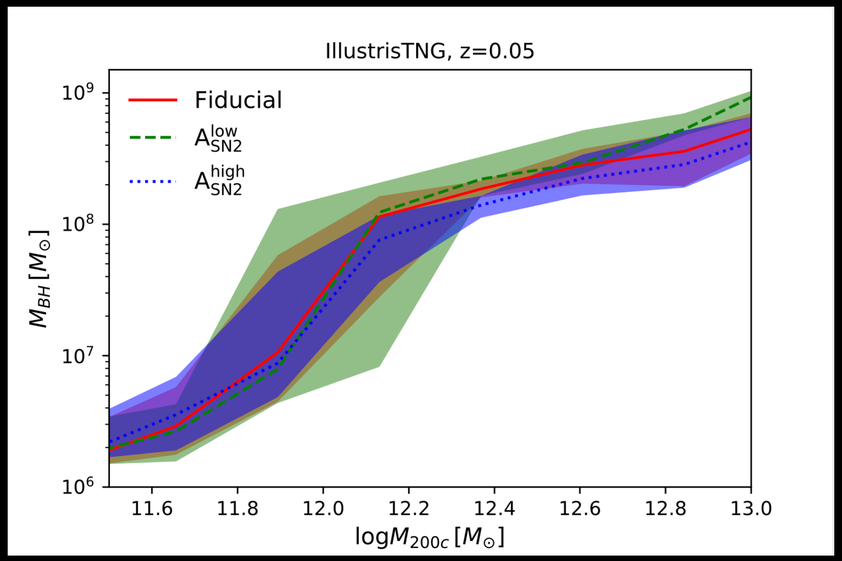


Feedback energy budget controls f_{CGM}: work in progress

Feedback cycle in CAMELS

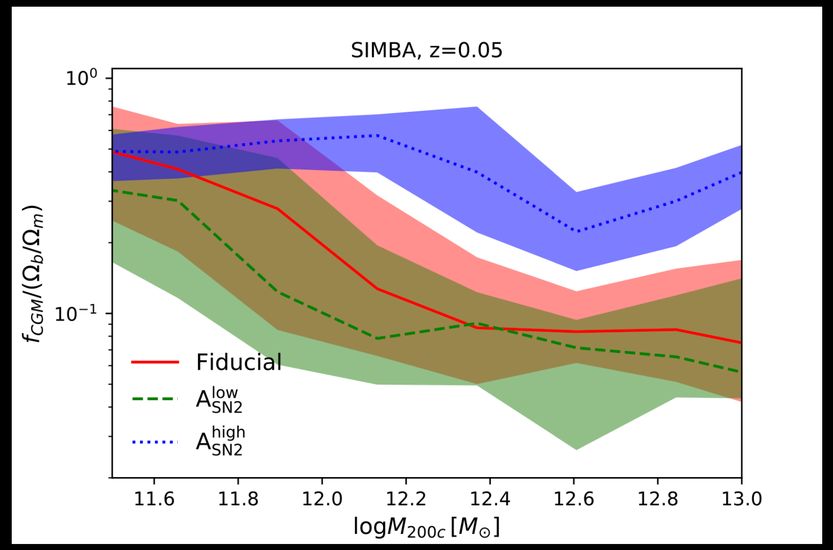


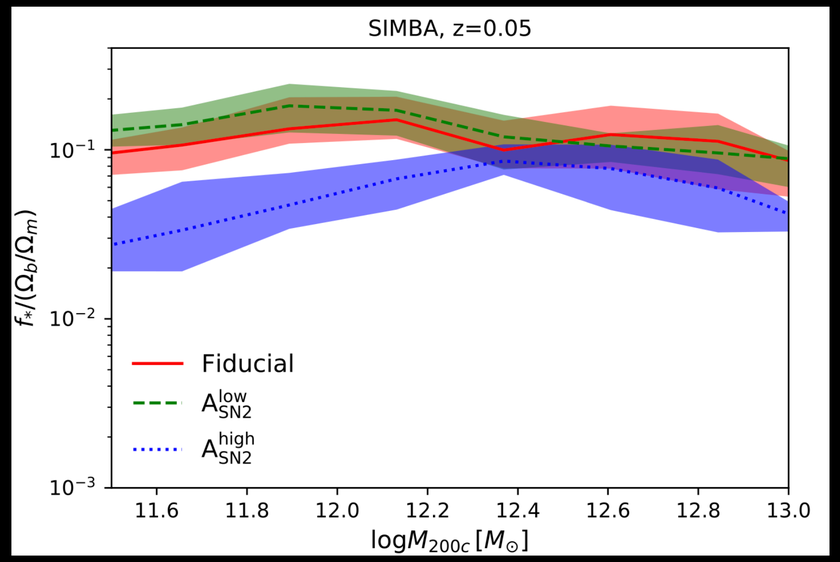


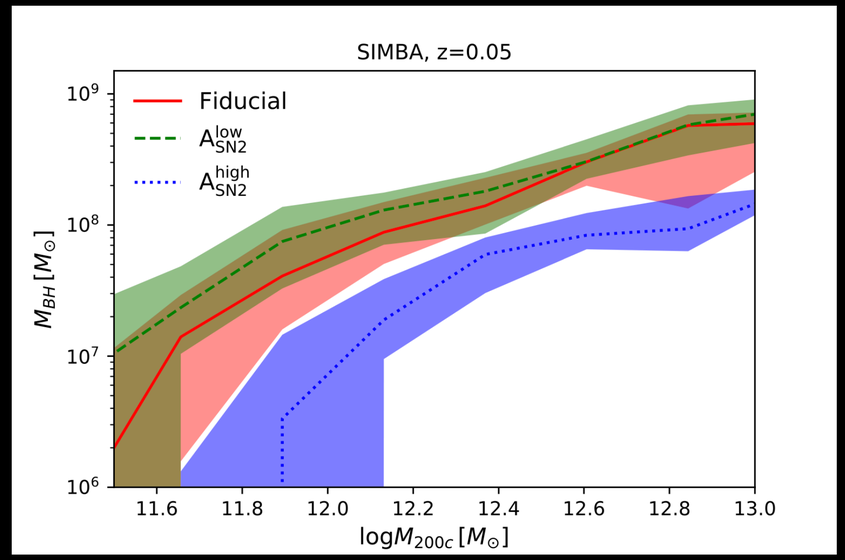


Less strong trends as a function of ASN2 (normalization factor for galactic wind speed)

Feedback cycle in CAMELS







Similar trends are evident in SIMBA as well with ASN2 (normalization factor for galactic wind speed)

Feedback energy budget controls f_{CGM} across subgrid models?

Summary

- CGM mass fraction increases with increasing feedback in massive galaxies for IllustrisTNG.
  - ➡ Driven by a combination of reduced stellar and AGN feedback strength.
- Qualitatively similar trends in SIMBA.
- CGM viewed as own-scaled ICM disrupted by feedback: help decode forthcoming multi wavelength CGM observations.

Road Ahead

- How it impacts CGM in different temperature phases (& hence different observables)?
- A fundamental relation between CGM mass fraction and feedback energy budget (including LH set)+symbolic regression.

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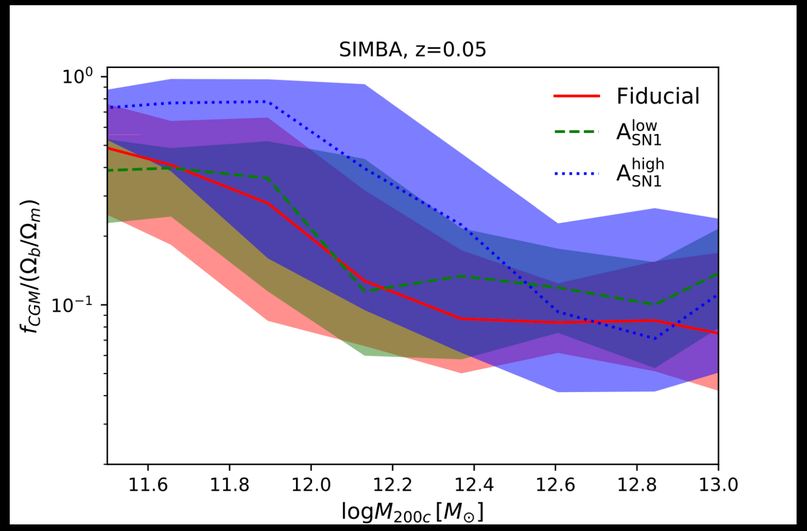
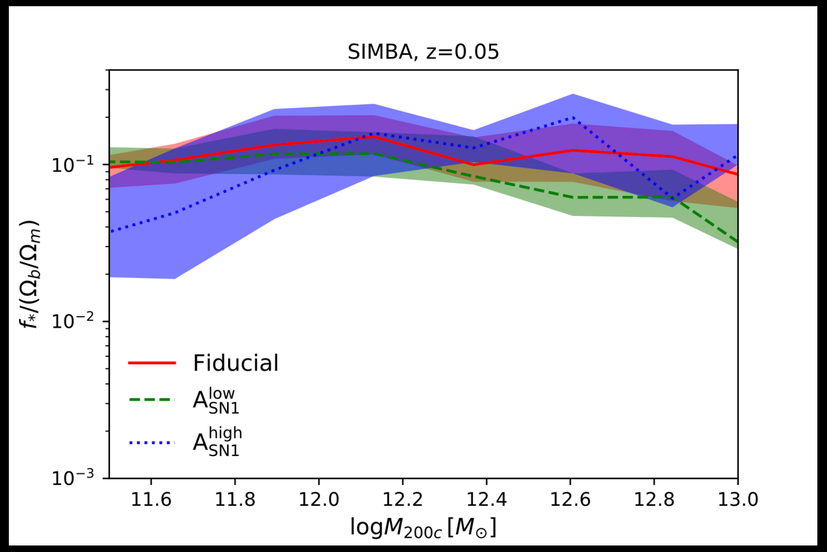
Thanks!

Back-up

SIMBA A_{SN1}


SIMBA, z=0.05
Fiducial
A_{SN1}^{low}
A_{SN1}^{high}
$f_{CGM}/(\Omega_b/\Omega_m)$
10^0
10^{-1}
11.6
11.8
12.0
12.2
12.4
12.6
12.8
13.0
$\log M_{200c}\,[M_\odot]$


SIMBA, z=0.05
Fiducial
A_{SN1}^{low}
A_{SN1}^{high}
$f_*/(\Omega_b/\Omega_m)$
10^{-1}
10^{-2}
10^{-3}
11.6
11.8
12.0
12.2
12.4
12.6
12.8
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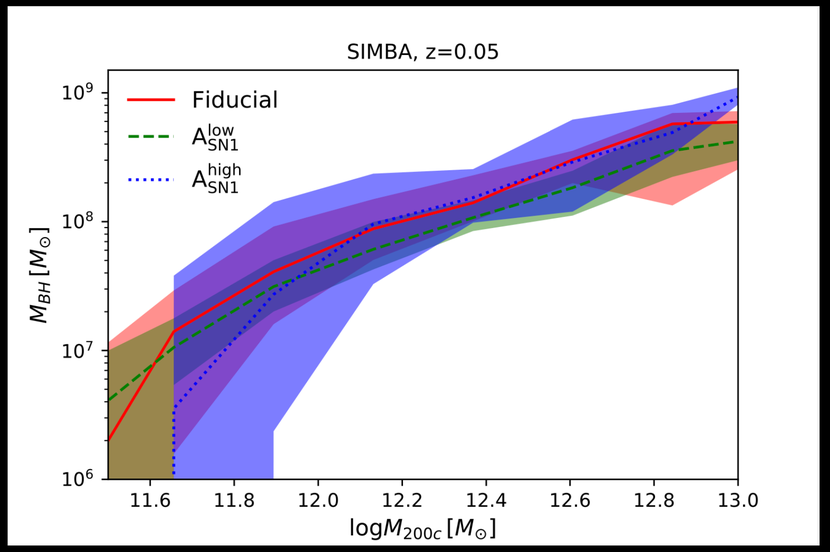
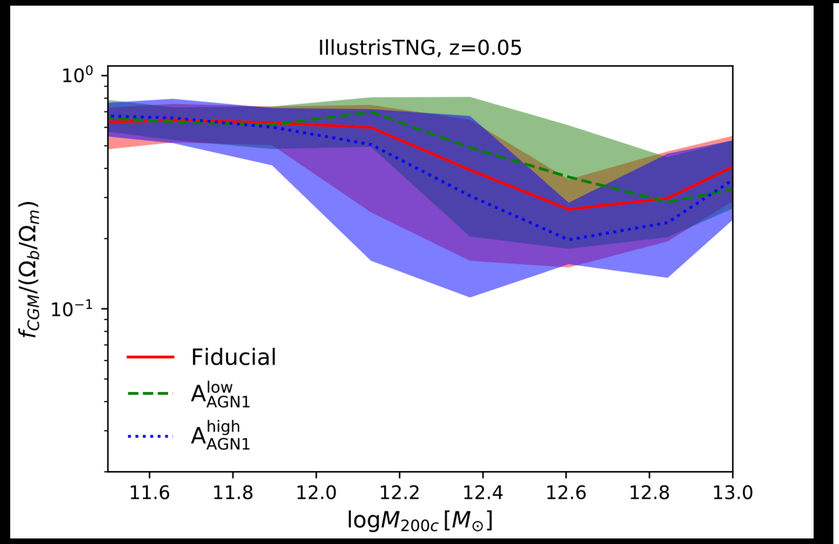
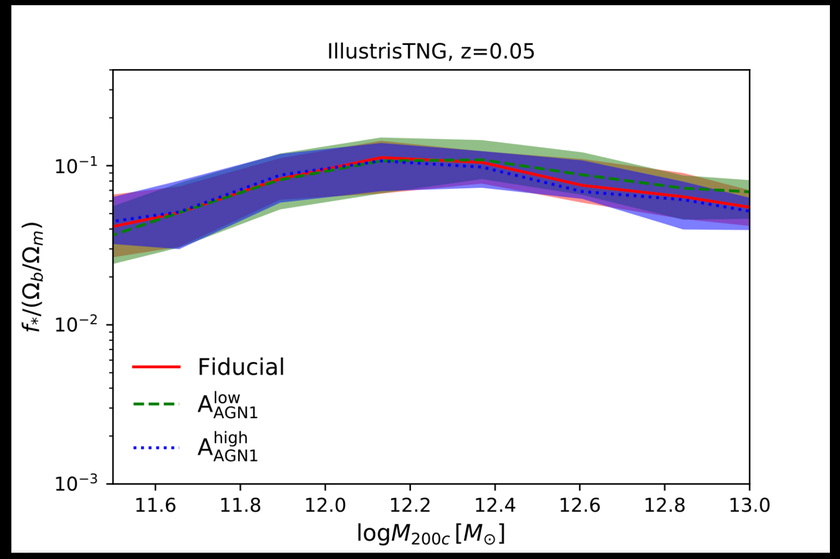
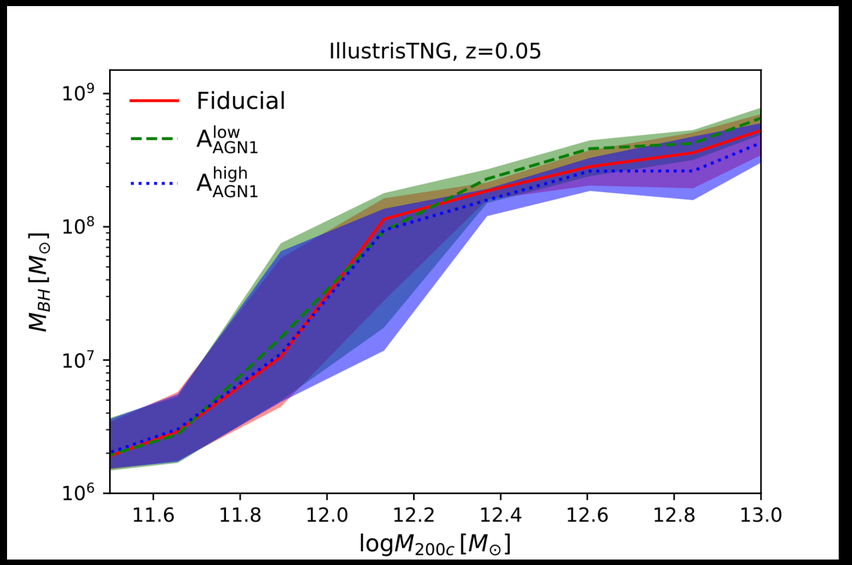

SIMBA, z=0.05
Fiducial
A_{SN1}^{low}
A_{SN1}^{high}
$M_{BH}\,[M_\odot]$
10^9
10^8
10^7
10^6
11.6
11.8
12.0
12.2
12.4
12.6
12.8
13.0
$\log M_{200c}\,[M_\odot]$

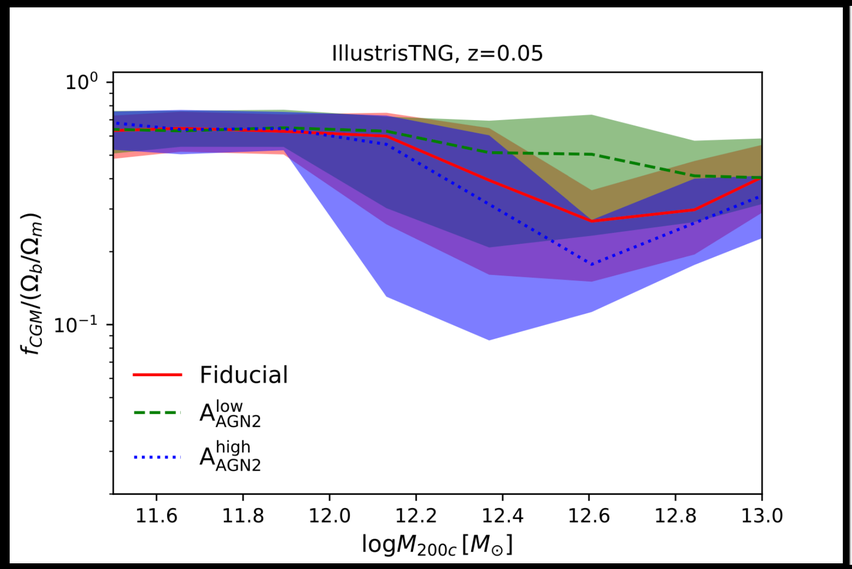
IllustrisTNG A_{AGN1}

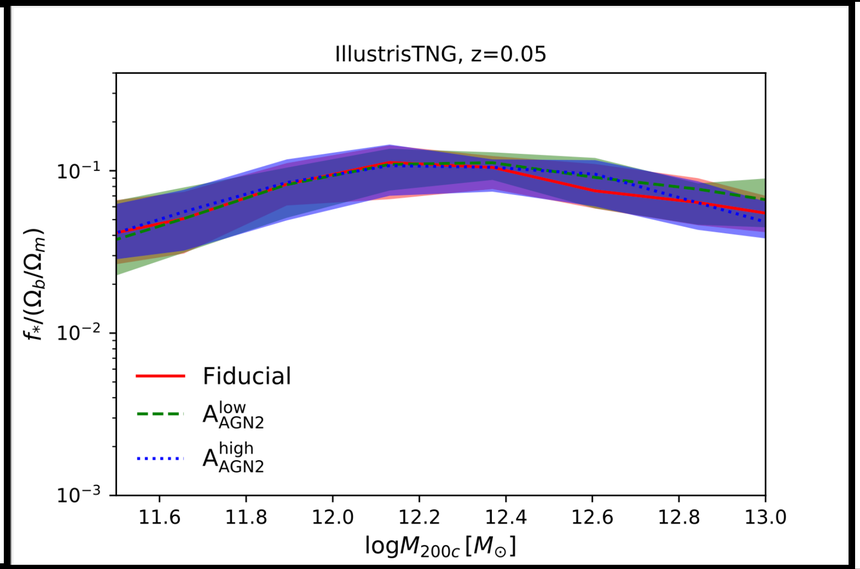


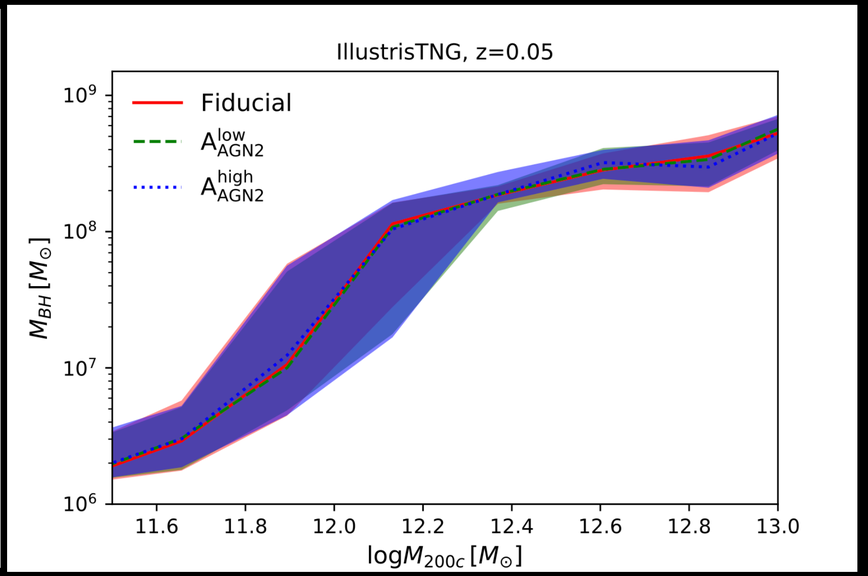




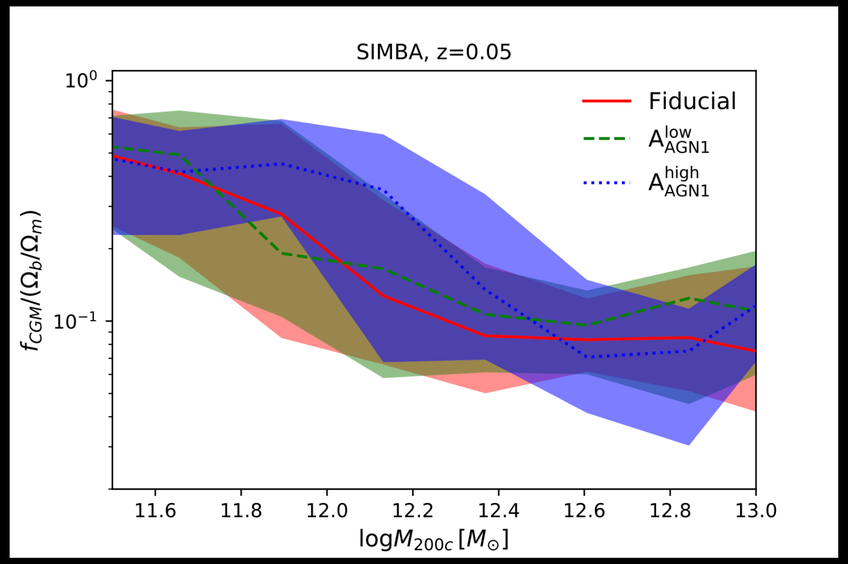
IllustrisTNG A_{AGN2}







SIMBA A_{AGN1}


SIMBA, z=0.05
Fiducial
A^{low}_{AGN1}
A^{high}_{AGN1}
$f_{CGM}/(\Omega_b/\Omega_m)$
10^0
10^{-1}
11.6
11.8
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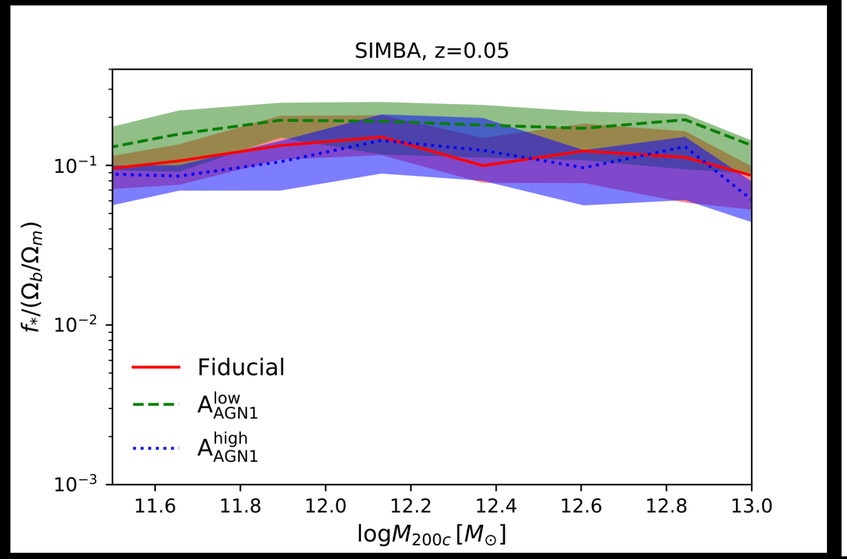
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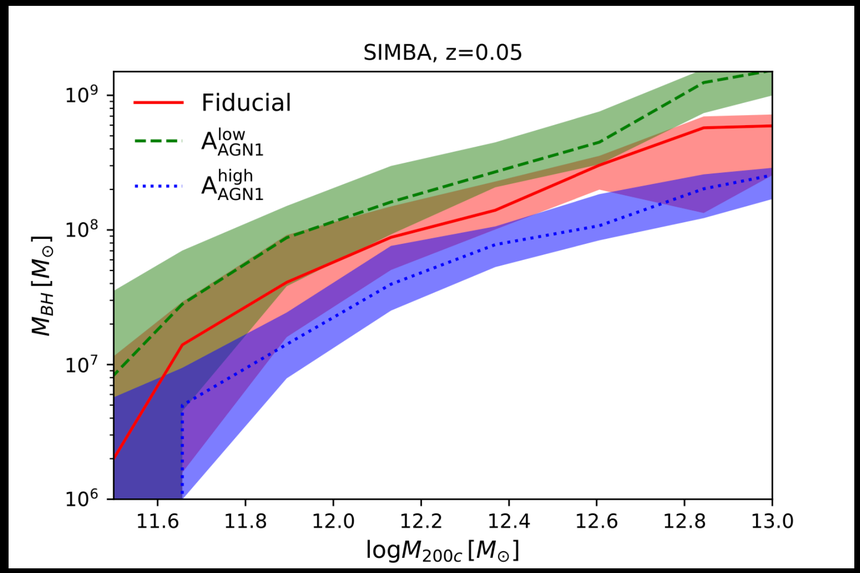
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11.6
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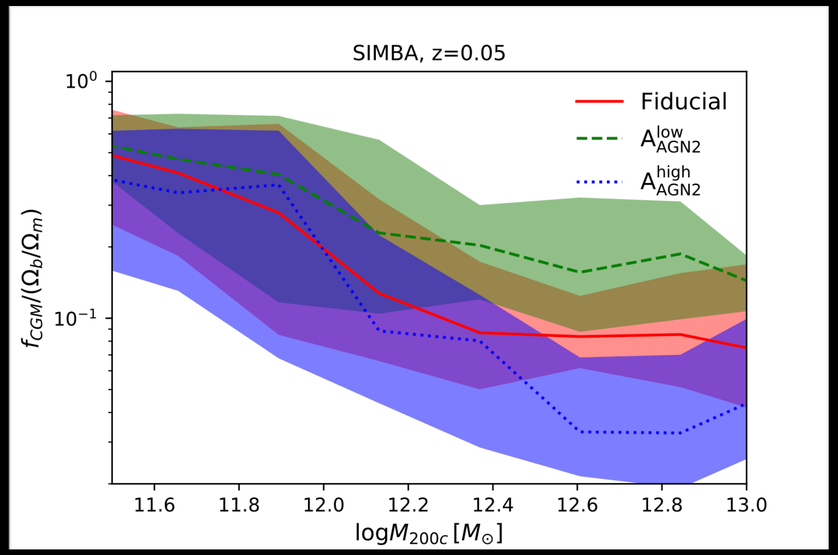
SIMBA A_{AGN2}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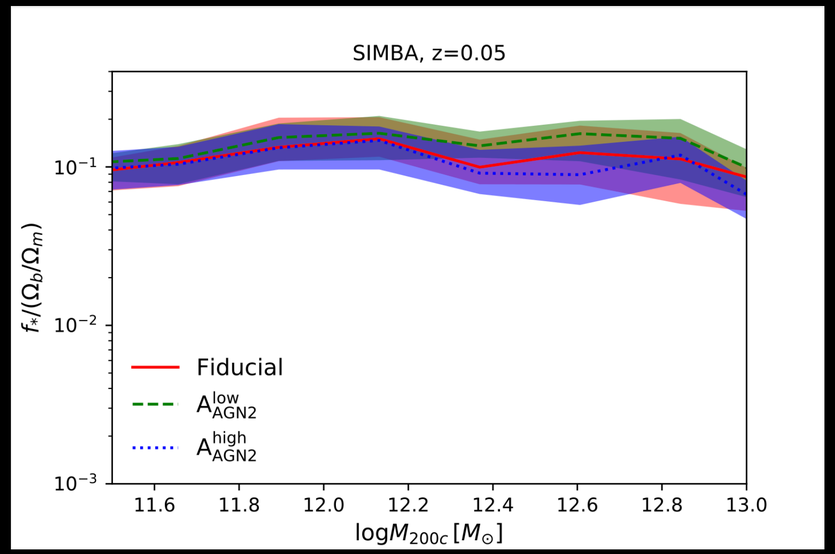
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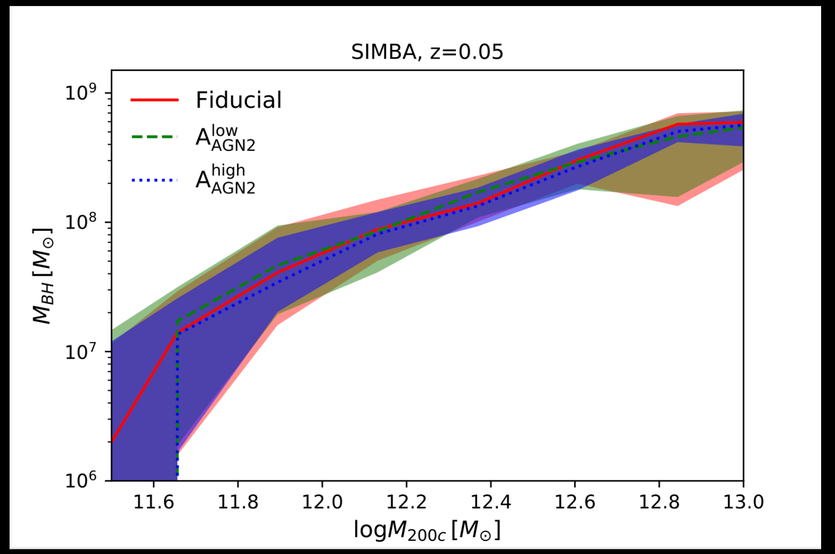
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