Title: The properties of the CGM and its relationship with galaxies in the COLIBRE simulations

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Subject: Cosmology

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Abstract:

The upcoming COLIBRE project promises to provide a generational leap in the capabilities of cosmological, hydrodynamical simulations of galaxy formation. The simulations model the evolution of cold gas down to temperatures of 10 K, alongside the formation and evolution of dust, in large cosmological volumes, and incorporate new prescriptions for cooling, chemical enrichment, and feedback associated with star formation and black hole growth. COLIBRE's flagship simulations have been run in much larger cosmological volumes, at a given resolution, than its predecessor (EAGLE), producing commensurately larger galaxy populations to study.

In my talk I will present a census of baryons in the circumgalactic medium (CGM) for the flagship COLIBRE simulations, as a function of halo mass and gas phase, and present some initial comparisons with available observational data. I will discuss how the properties of the CGM are influenced by COLIBRE's new prescriptions for feedback from star formation and AGN, and compare the importance of these feedback channels for different halo mass ranges. In turn, I will demonstrate how the properties of the CGM relate to the cold atomic and molecular gas reservoirs of galaxies, and how the effects of feedback on the CGM play a crucial role in future star formation activity and quenching. I will end by exploring why diversity exists in the properties of galaxies and their CGM in haloes of the same mass, by showing that galaxy-CGM ecosystems with different properties exhibit markedly different histories in terms of mass assembly, mergers, and feedback.

The properties of the CGM and its relationship with galaxies in the COLIBRE simulations

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and the COLIBRE team

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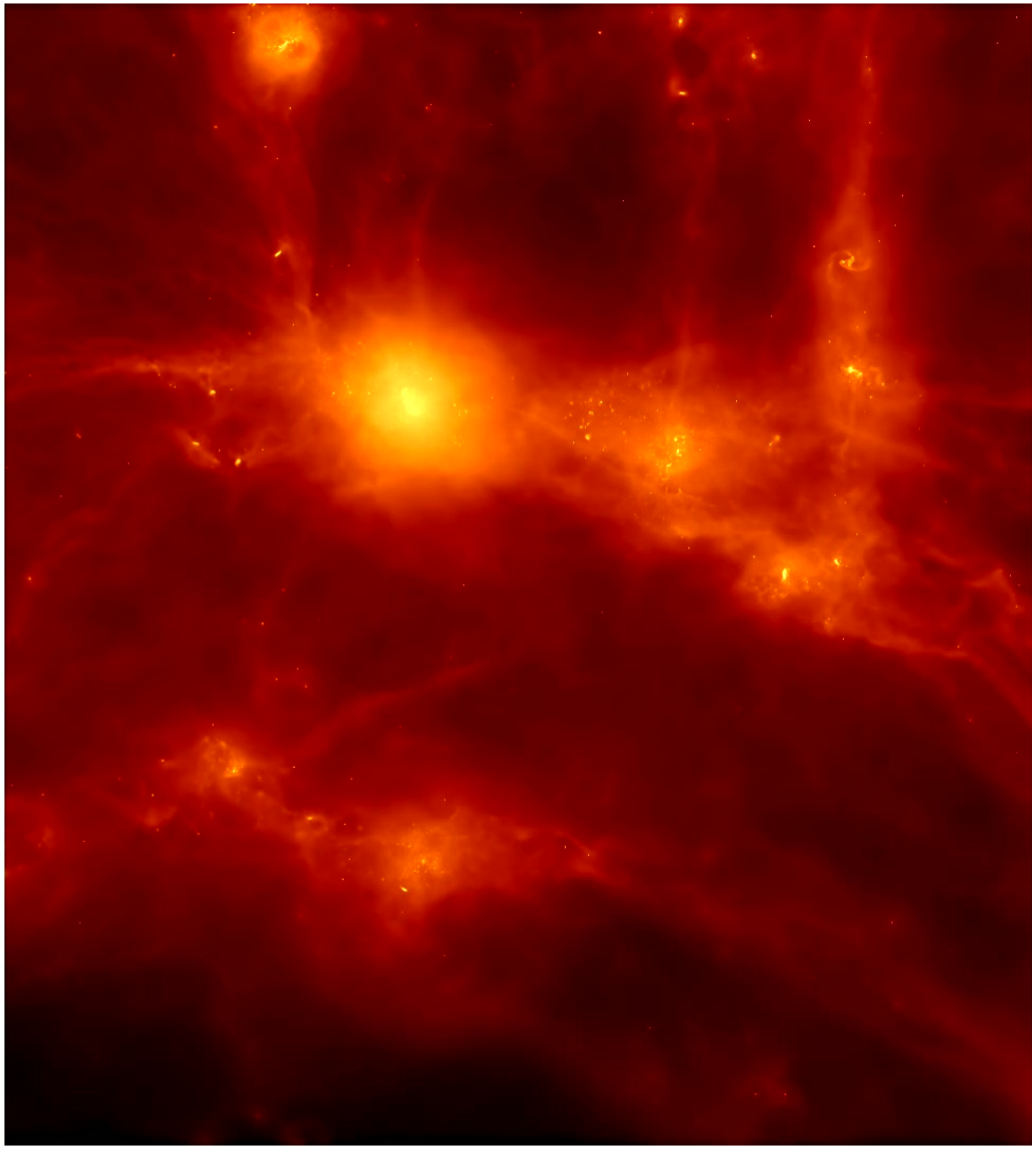
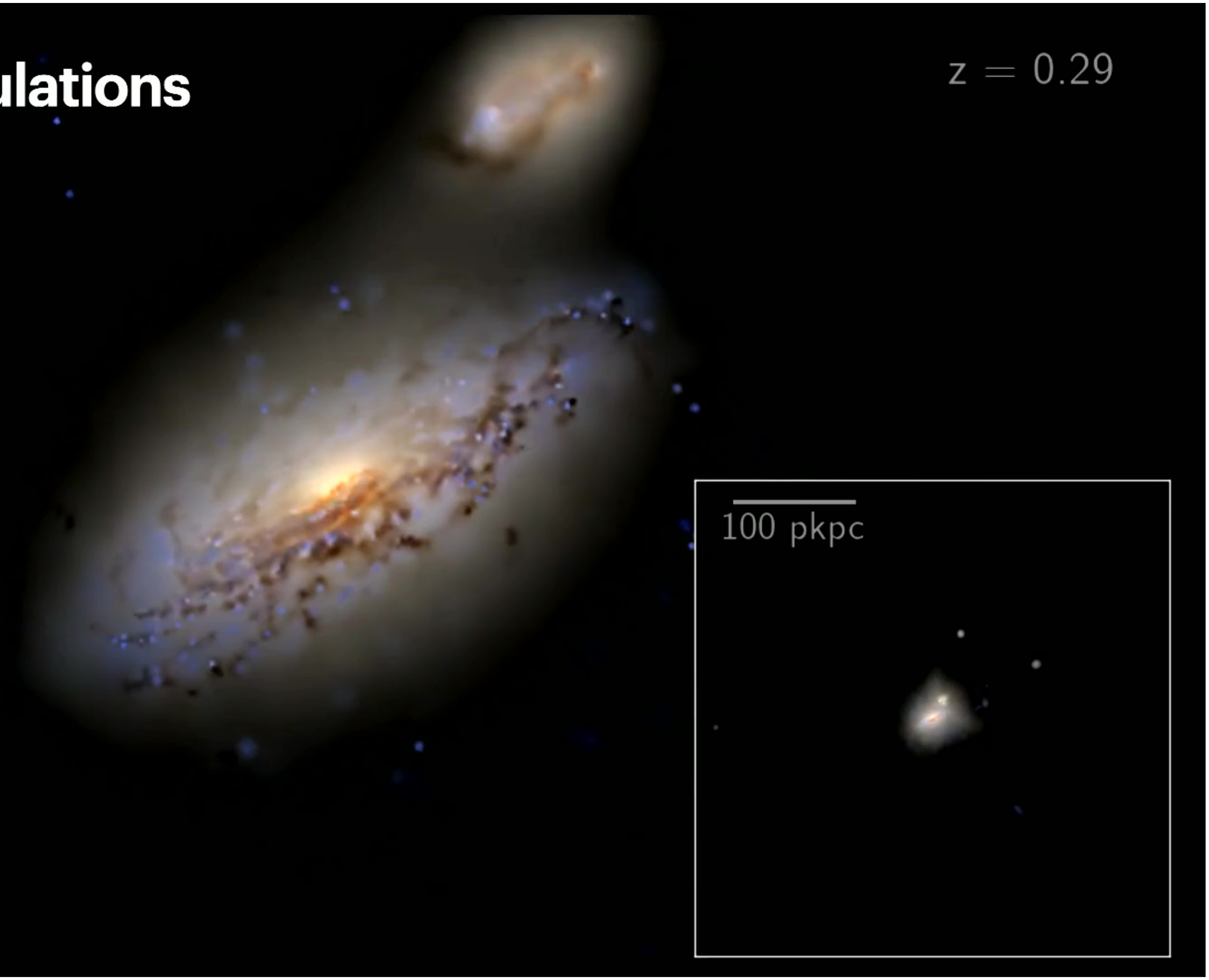


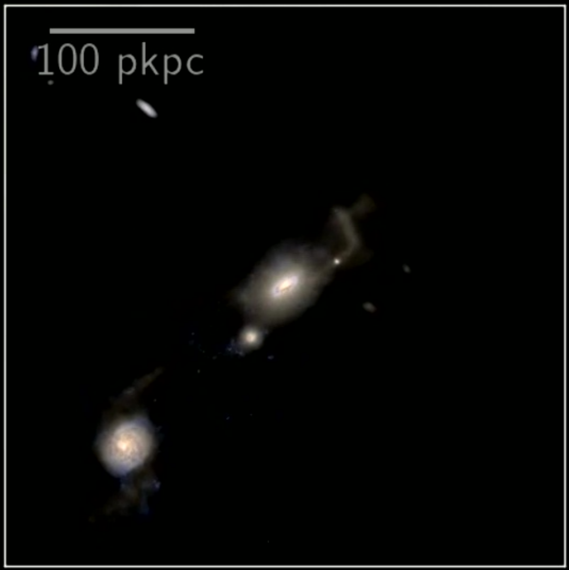
The COLIBRE simulations

- Direct modelling of cold gas, with cooling allowed down to 10 K
- Formation/evolution of molecular gas & dust
- New stellar & AGN feedback models, calibrated using emulators to produce realistic galaxy populations in large volumes

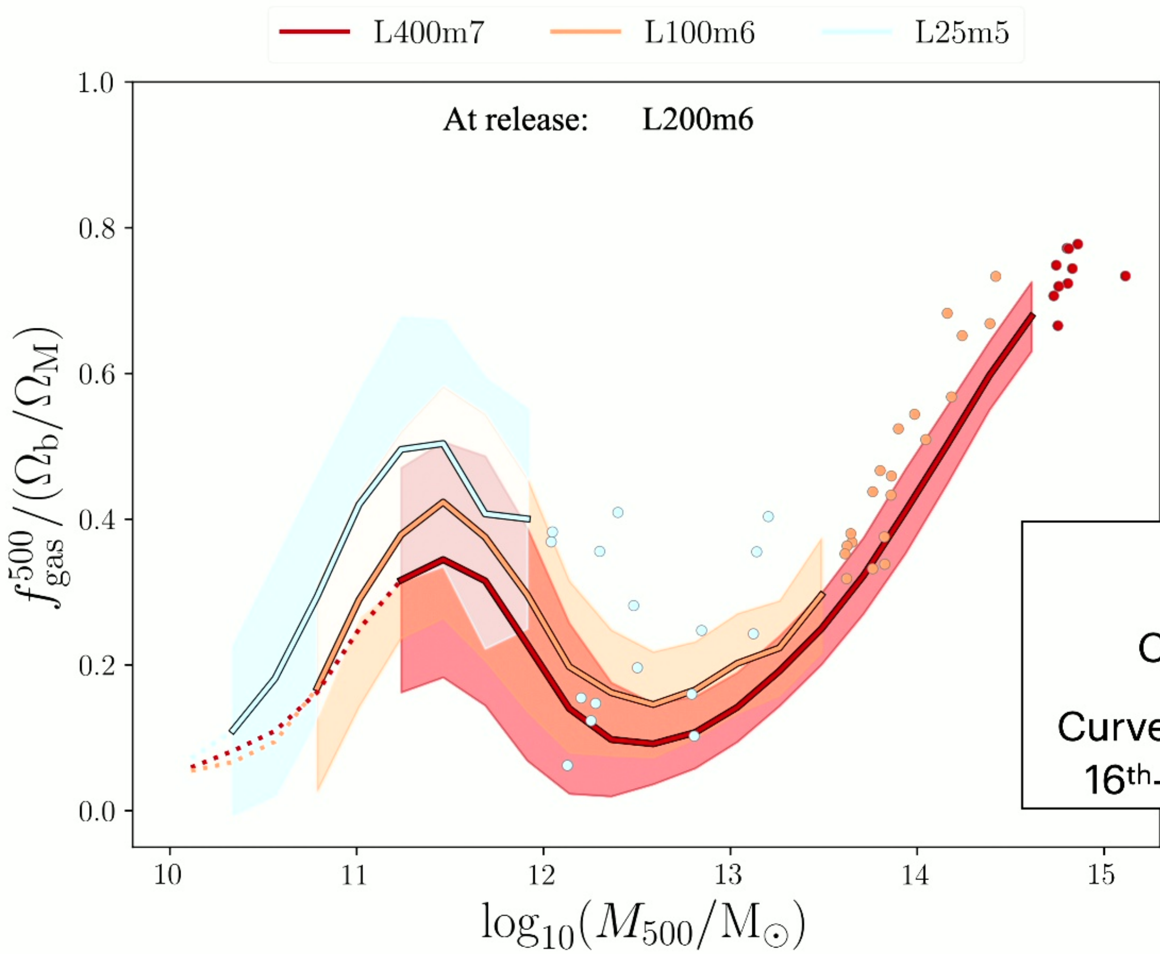


The COLIBRE simulations

COLIBRE connects the evolution of the **hottest gas** to the **coldest gas** in large populations of realistic galaxies



Total gas fractions

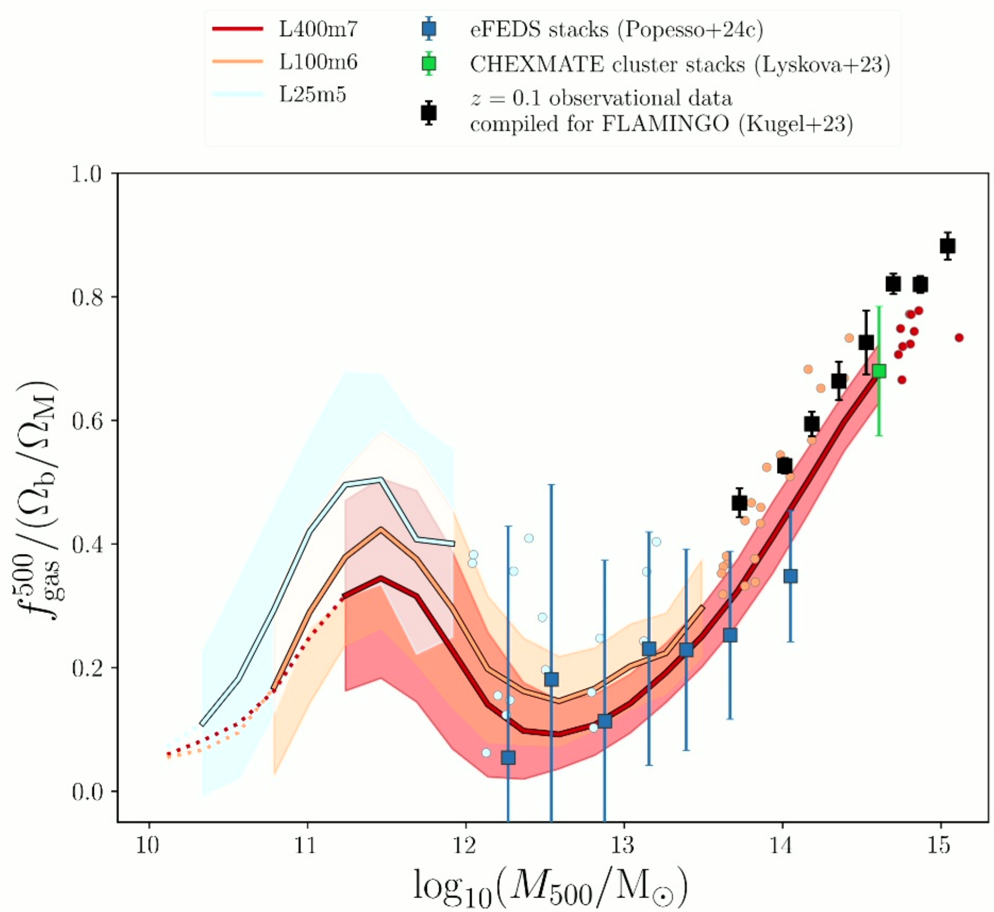


$z = 0$

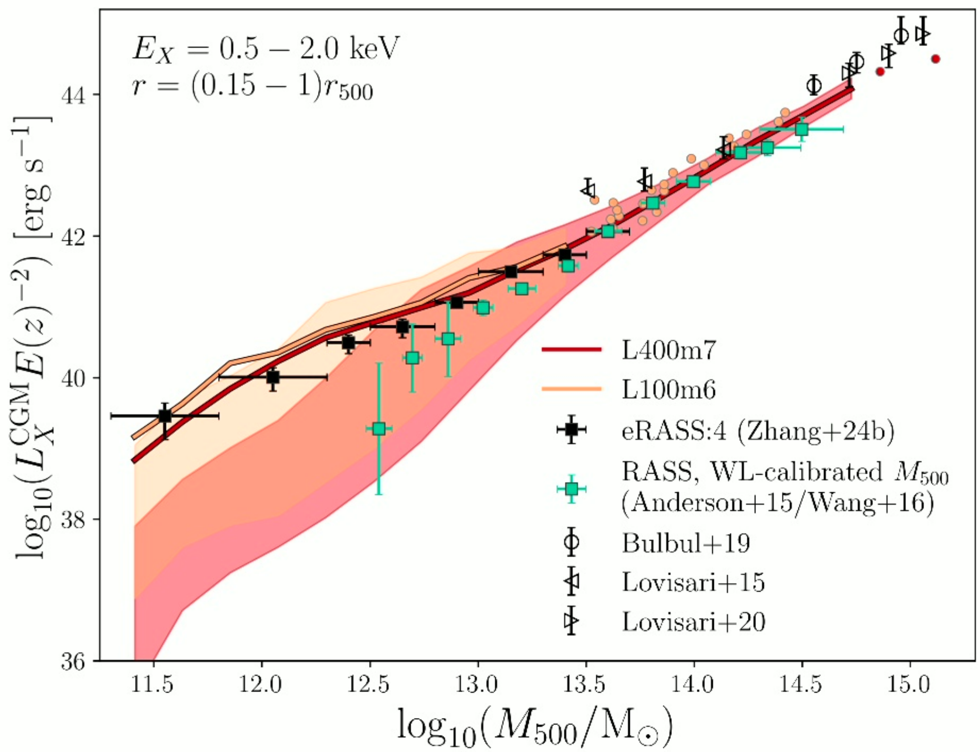
Central haloes

Curves show median & 16th-84th percentiles

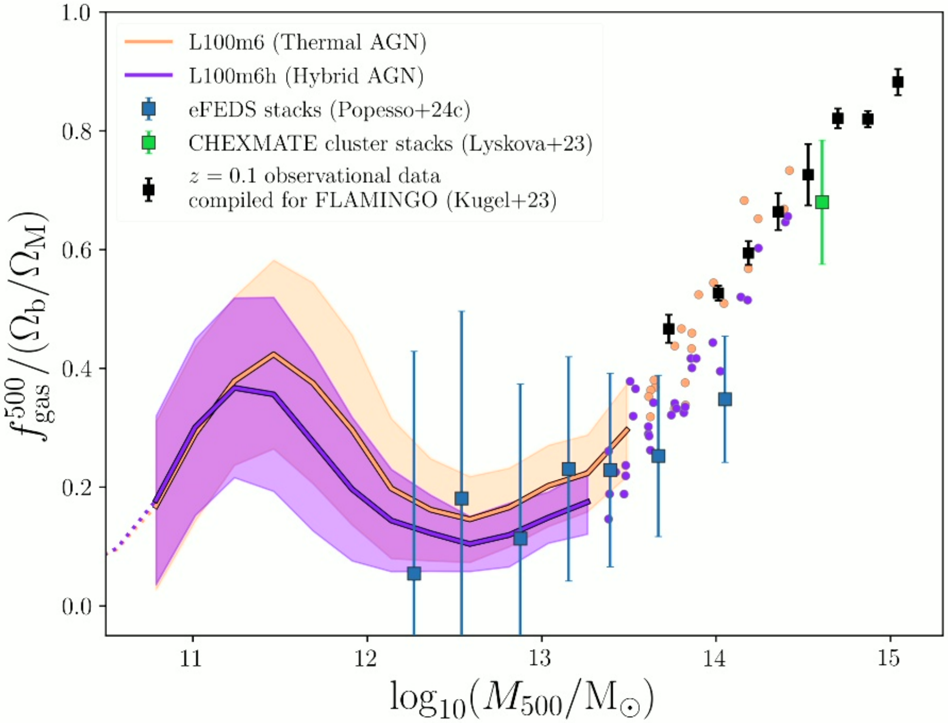
Comparison with X-ray stacks

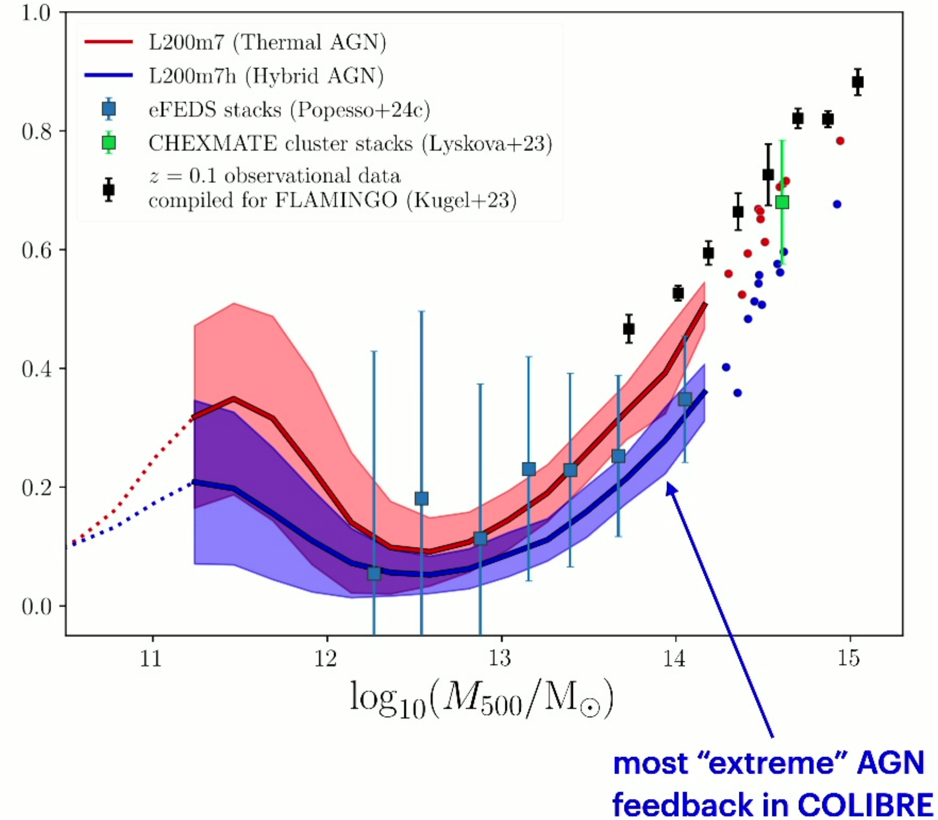


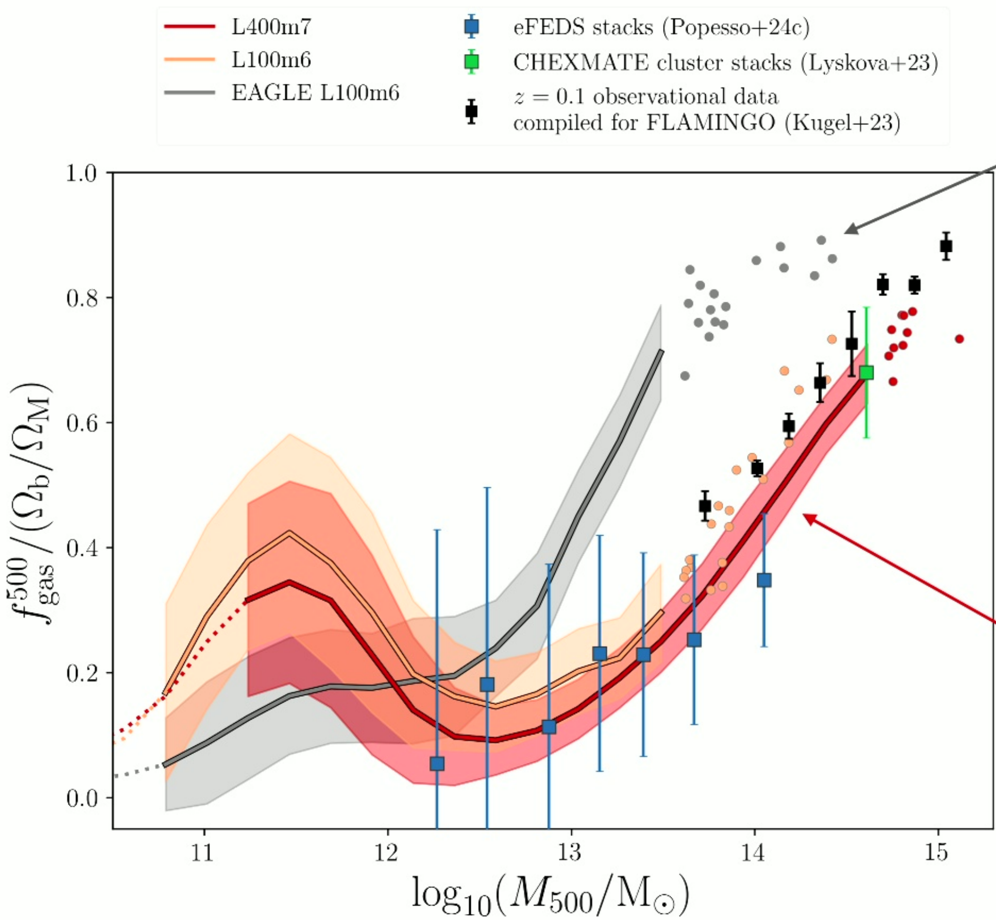
For X-ray stacks curves show **mean** & 10th-90th percentiles



AGN feedback:
purely thermal (fiducial model) or hybrid thermal + jet (Huško+25)







EAGLE

Fixed $\Delta T_{\rm AGN}$

becomes inefficient in group & cluster haloes

COLIBRE

$\Delta T_{\rm AGN} \propto M_{\rm BH}$

stays efficient across the mass range

COLIBRE

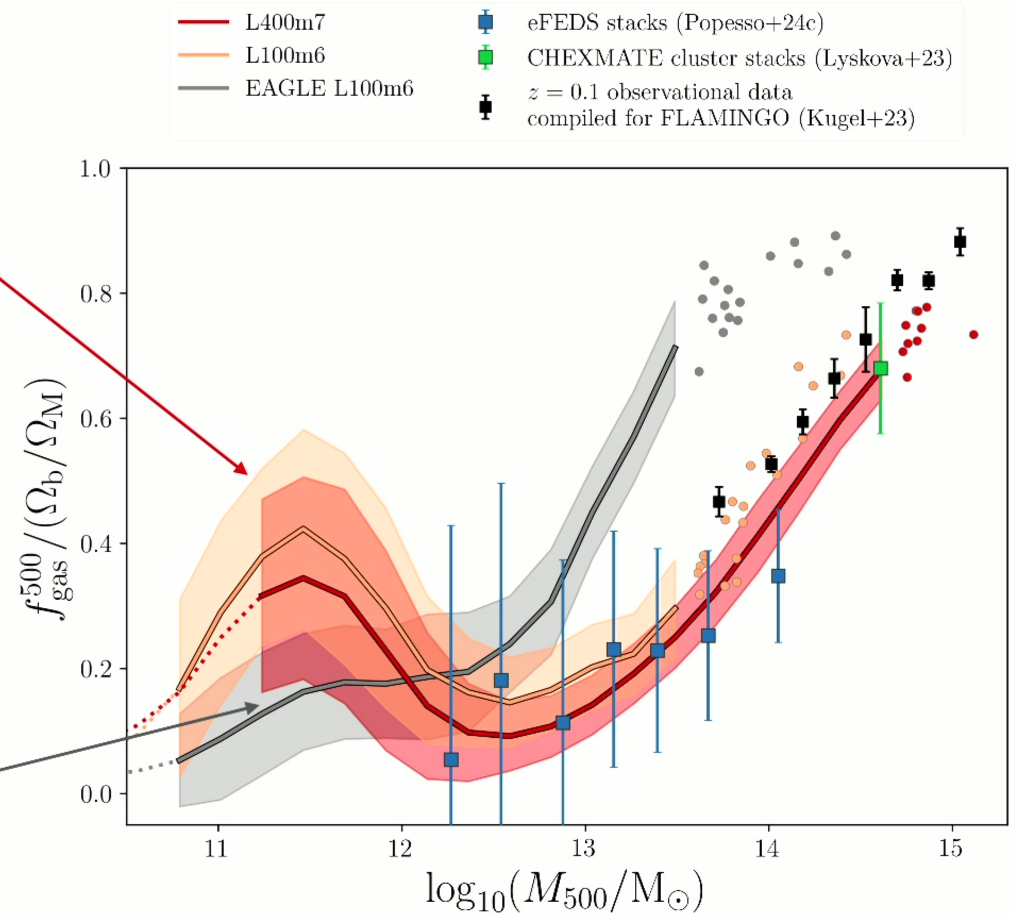
SF regulated with a milder effect on the CGM, through a combination of:

- Variable $\Delta T_{\rm SN}$ thermal feedback
- Lower-energy kinetic feedback driving turbulence in the ISM

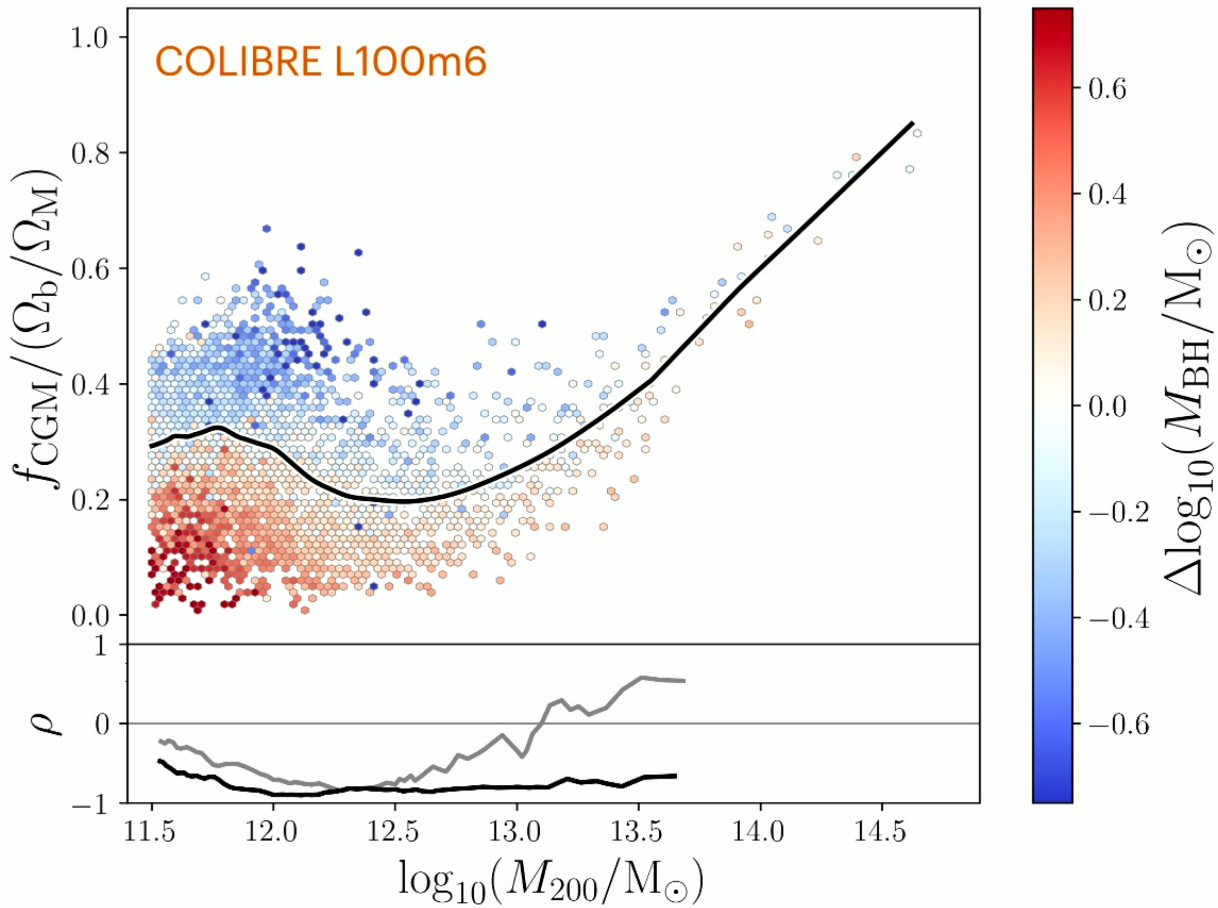
EAGLE

Strong thermal feedback with fixed $\Delta T_{\rm SN}$

Expels lots of halo gas in the process of regulating SF

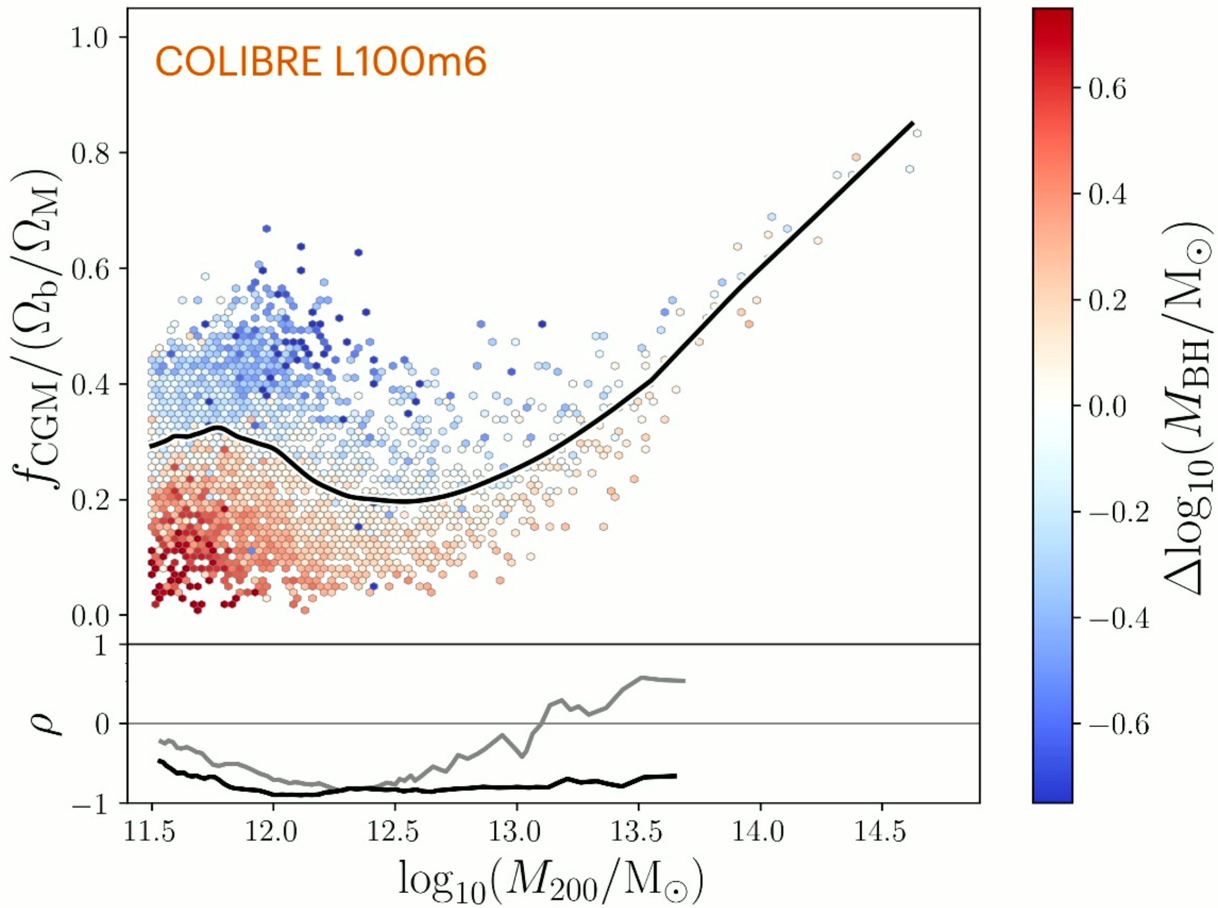


Scatter in the gas content of the CGM is driven by integrated AGN feedback



Scatter in the gas content of the CGM is driven by integrated AGN feedback

Gas within r_{200} excluding the ISM

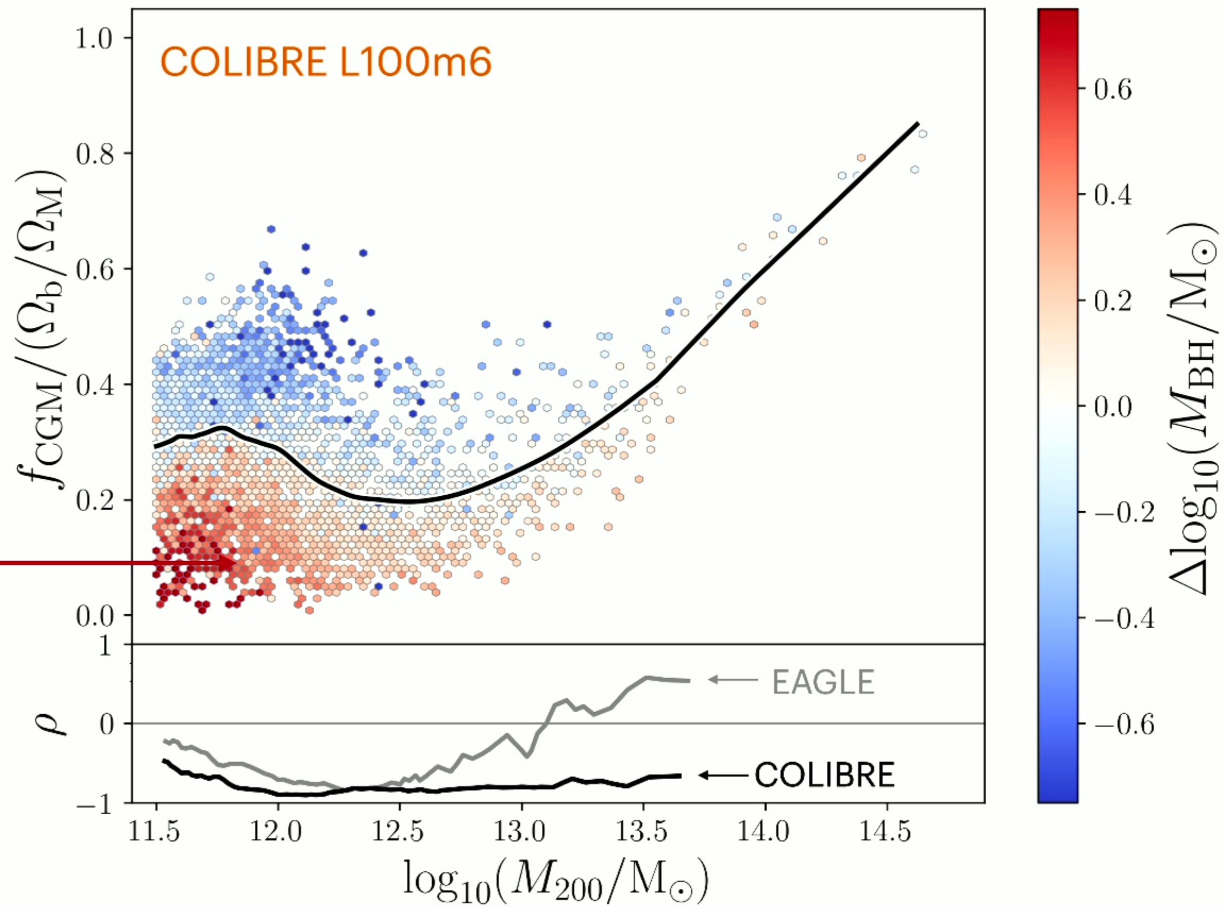


Residuals of $M_{\rm BH} - M_{200}$ relation

Scatter in the gas content of the CGM is driven by integrated AGN feedback

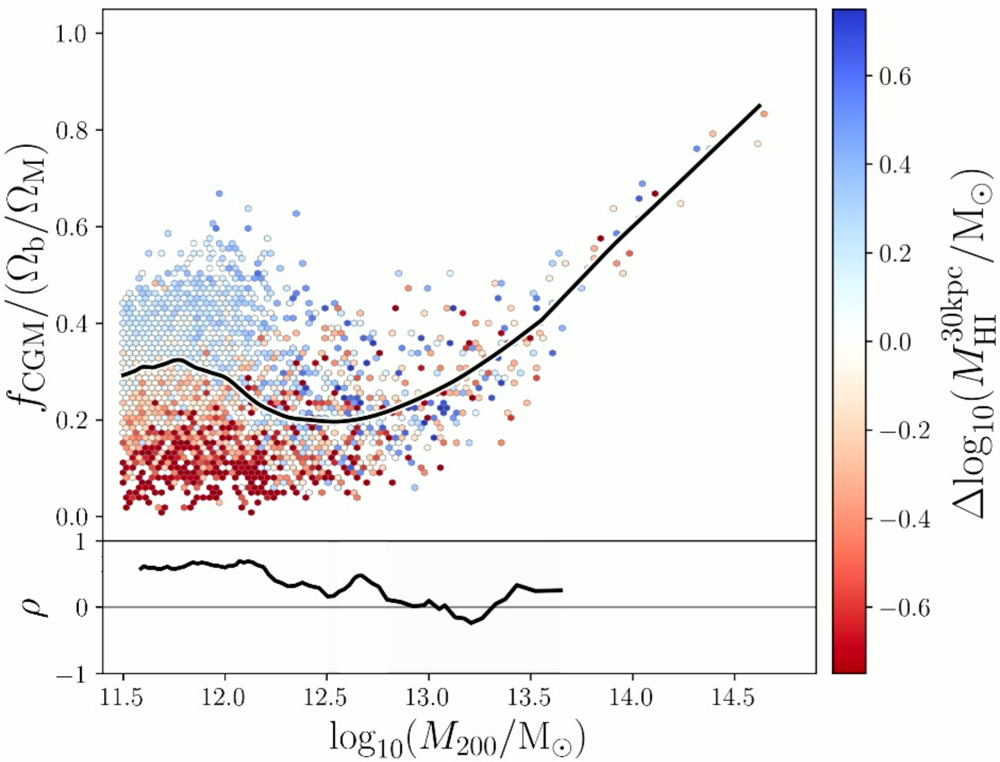
AGN-driven CGM expulsion is **preventative**:

- The CGM is reconfigured at a lower density, inhibiting cooling
- The balance of gas temperatures changes little, however

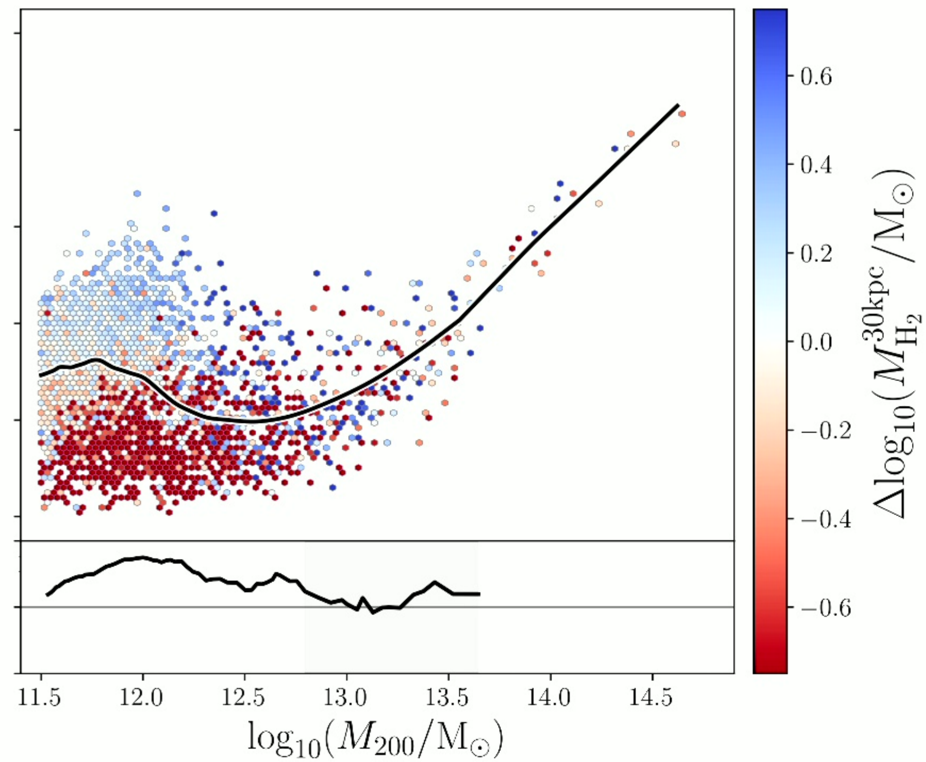


Galaxies that lack cold gas reside in gas-poor haloes

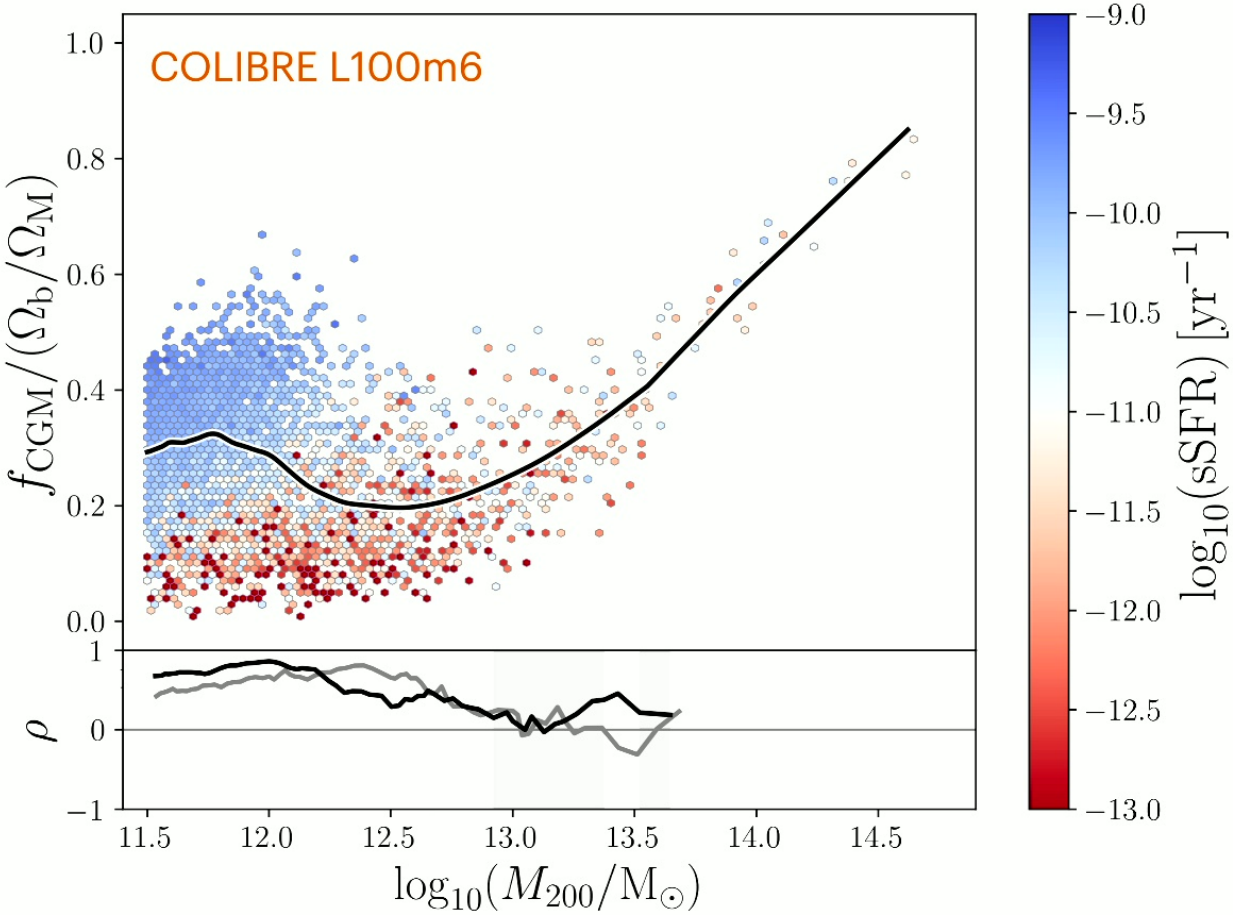
Atomic hydrogen mass in central galaxy



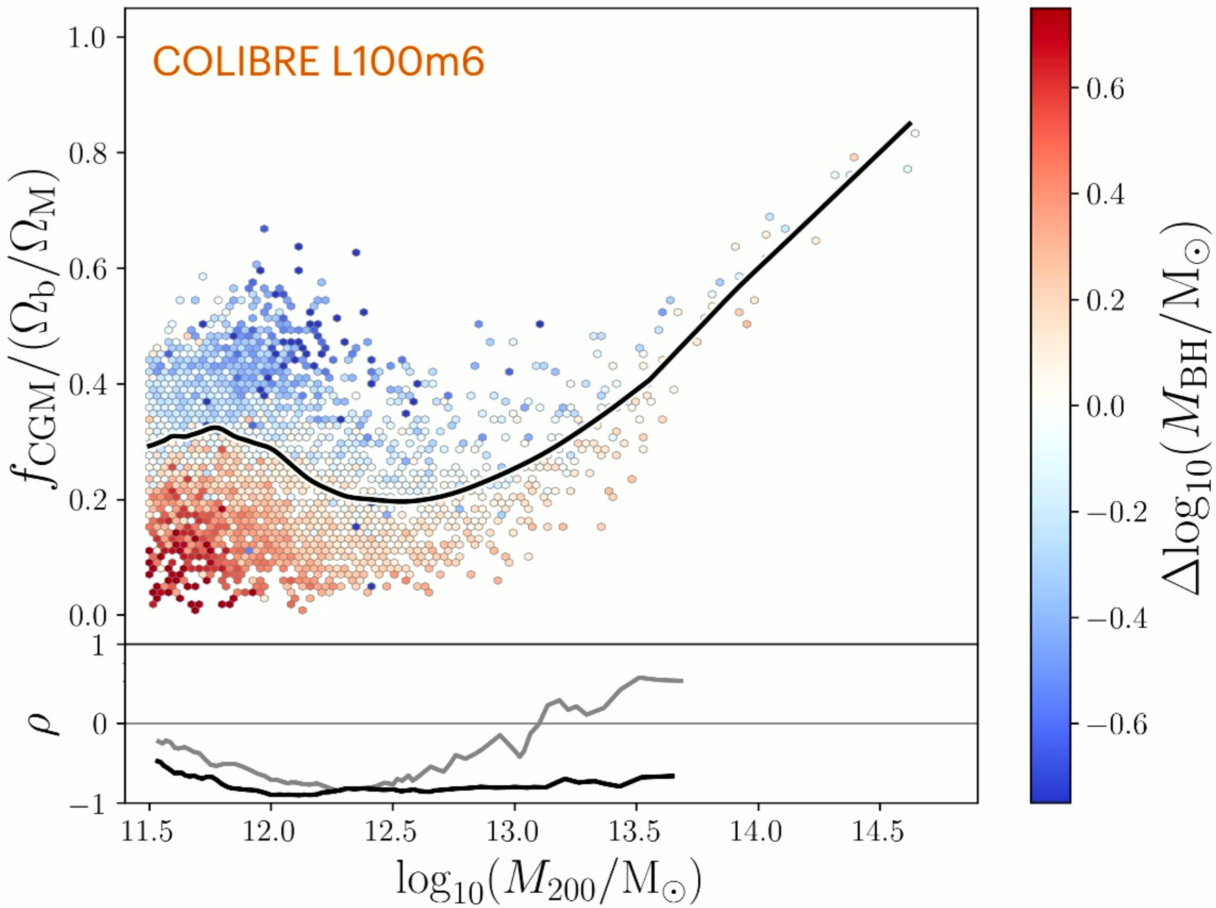
Molecular hydrogen mass in central galaxy

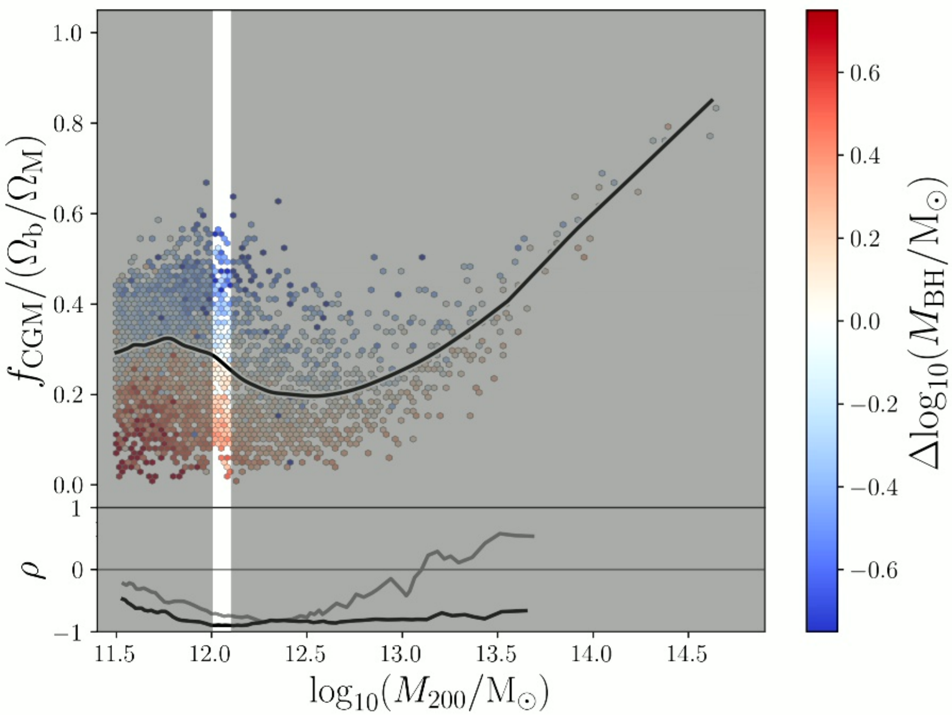


Expelling the CGM is a crucial step in galaxy quenching

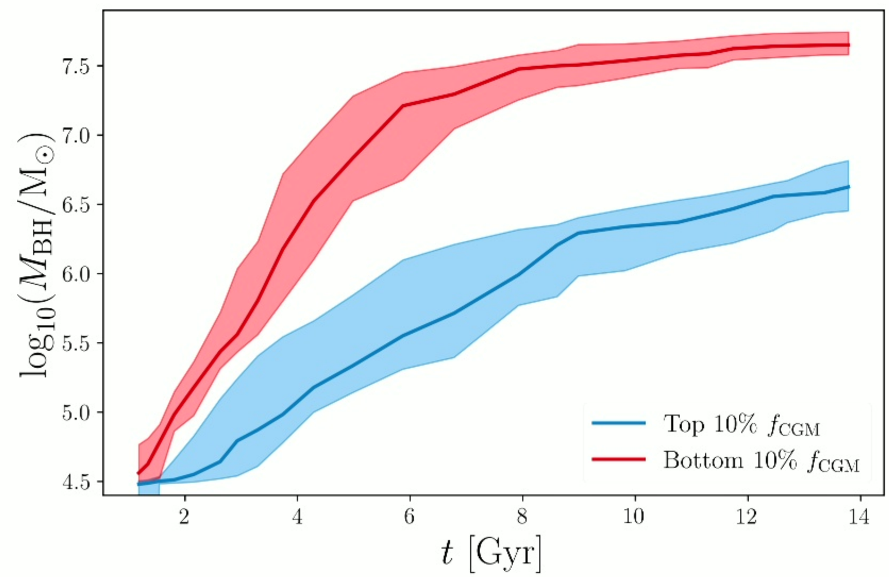


Why is there diversity at fixed halo mass?

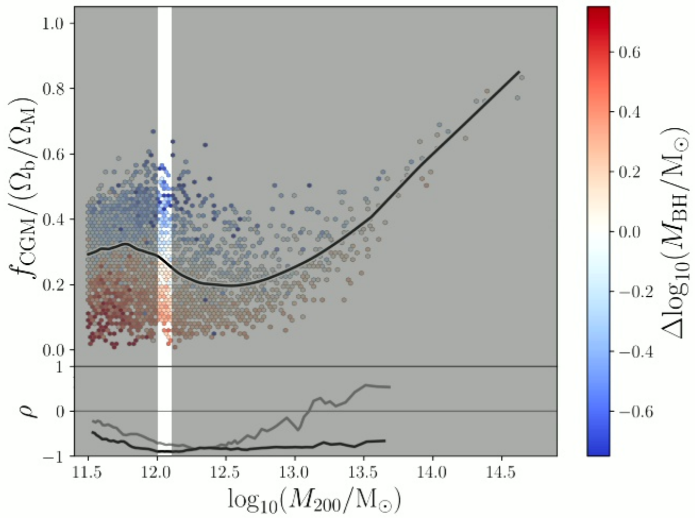


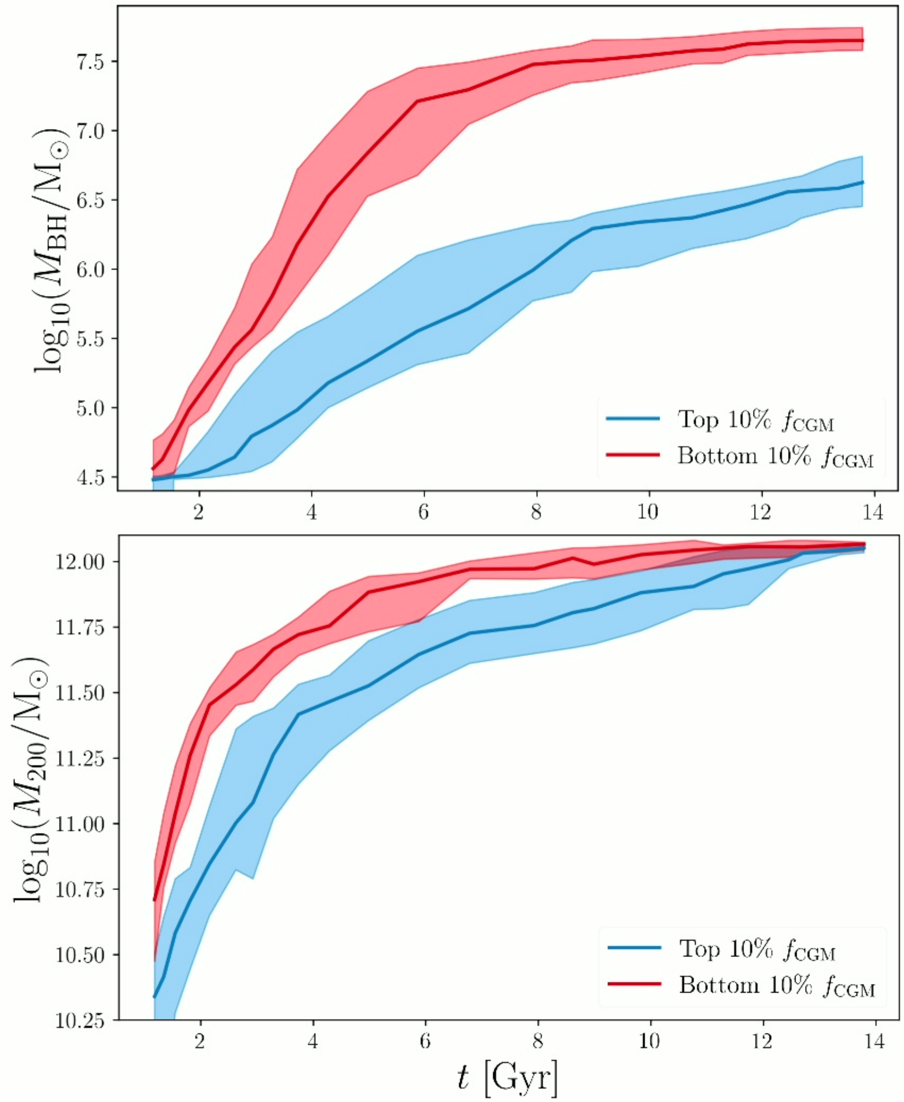


$f_{\rm CGM}/(\Omega_{\rm b}/\Omega_{\rm M})$
ρ
$\log_{10}(M_{200}/{\rm M}_\odot)$
$\Delta\log_{10}(M_{\rm BH}/{\rm M}_\odot)$



$\log_{10}(M_{\rm BH}/{\rm M}_\odot)$
t [Gyr]
Top 10% $f_{\rm CGM}$
Bottom 10% $f_{\rm CGM}$





Gas poor haloes:

- form earlier
- have higher concentrations/binding energies

The BH needs to grow more & inject more energy to regulate inflows as a result

e.g. Booth & Schaye (2010), Davies *et al*. (2019/20)

Summary

- The COLIBRE simulations produce halo gas fractions that are consistent with recent observational constraints
- COLIBRE's fiducial AGN feedback model is more effective in high-mass haloes and yields lower $f_{\rm gas}$ than the EAGLE simulations
- COLIBRE's new stellar feedback model can regulate star formation with a milder effect on the CGM, yielding higher $f_{\rm gas}$ than the EAGLE simulations for low-mass haloes
- Scatter in the CGM mass fraction is driven by the integrated AGN feedback energy injected
- Baryon expulsion reconfigures the CGM at a lower density, preventing cooling and leading to lower atomic and molecular gas masses in galaxy, and the quenching of star formation
- The properties of the CGM are shaped by the assembly history of the galaxy/halo ecosystem
- **Much more still to come:**
  - **Exploration of how feedback affects the CGM's balance of gas phases**
  - **Detailed study of X-ray predictions, including SF/quenched bimodality**
  - **Exploration of COLIBRE's alternative hybrid thermal+jet AGN feedback model**