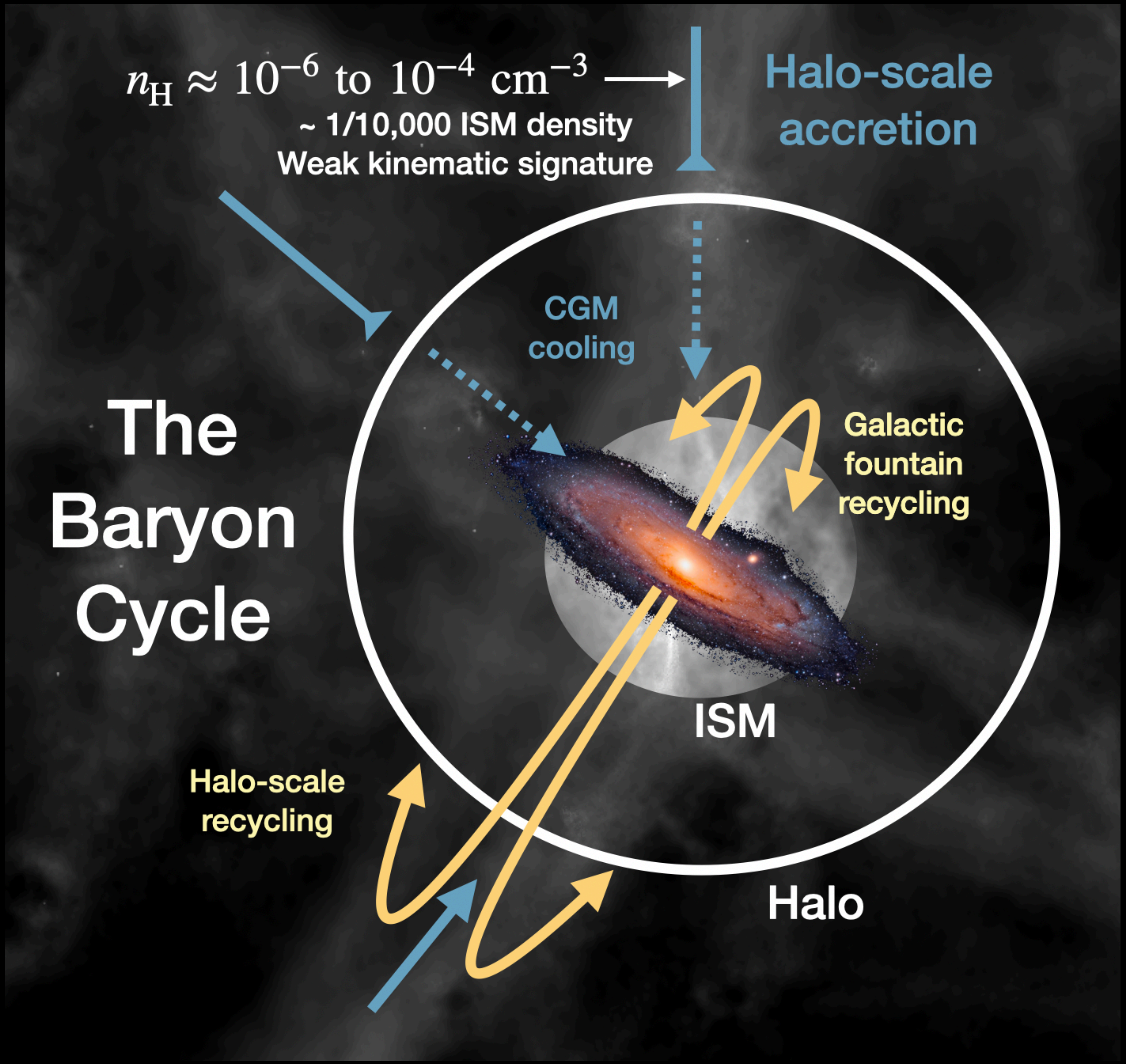
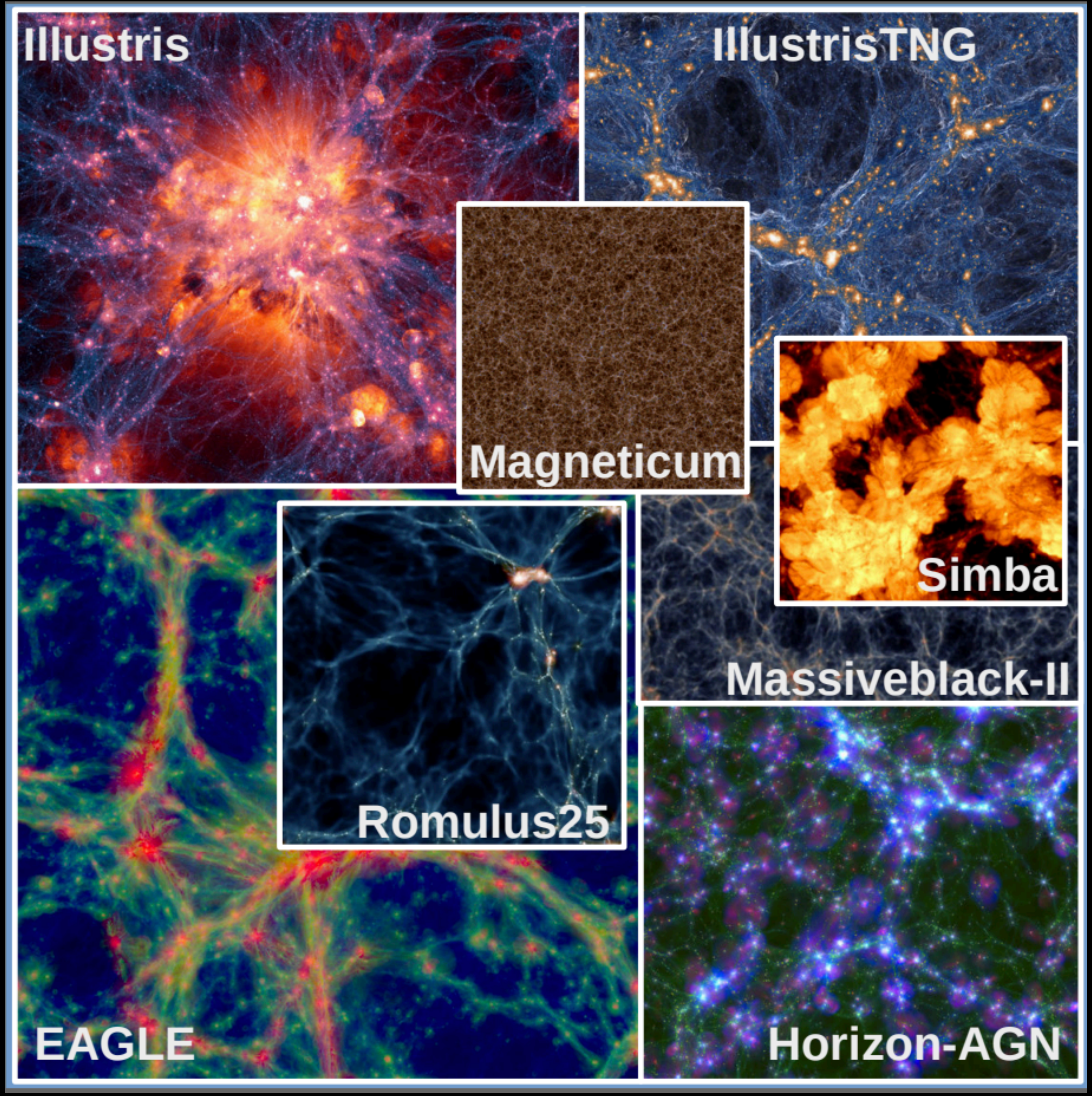
The baryon cycle in modern cosmological simulations

Dr. Ruby Wright
Postdoctoral Researcher
University of Helsinki

Building Galaxies From Scratch — Vienna, 2024

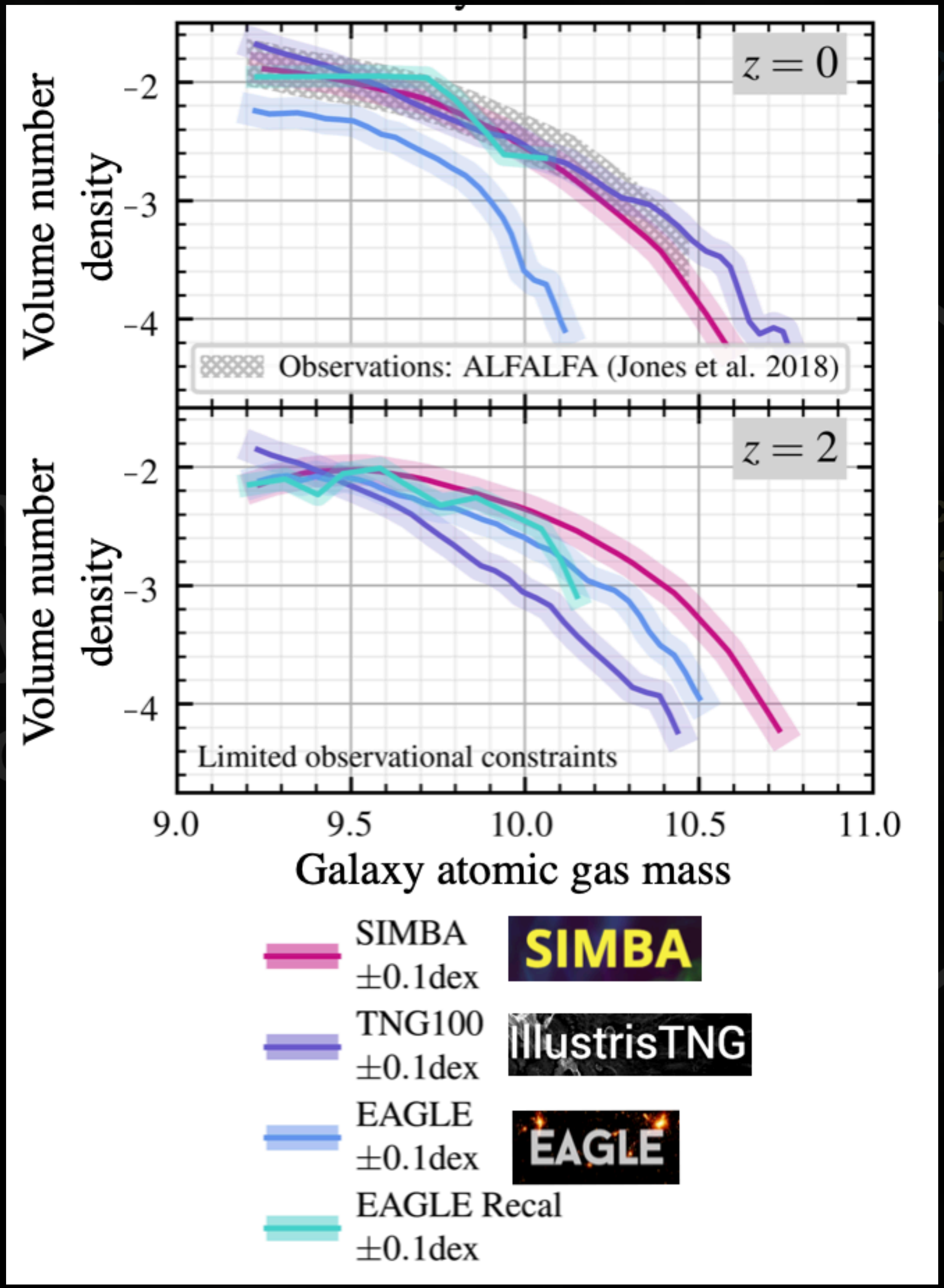


From Vogelsberger et al. (2020)

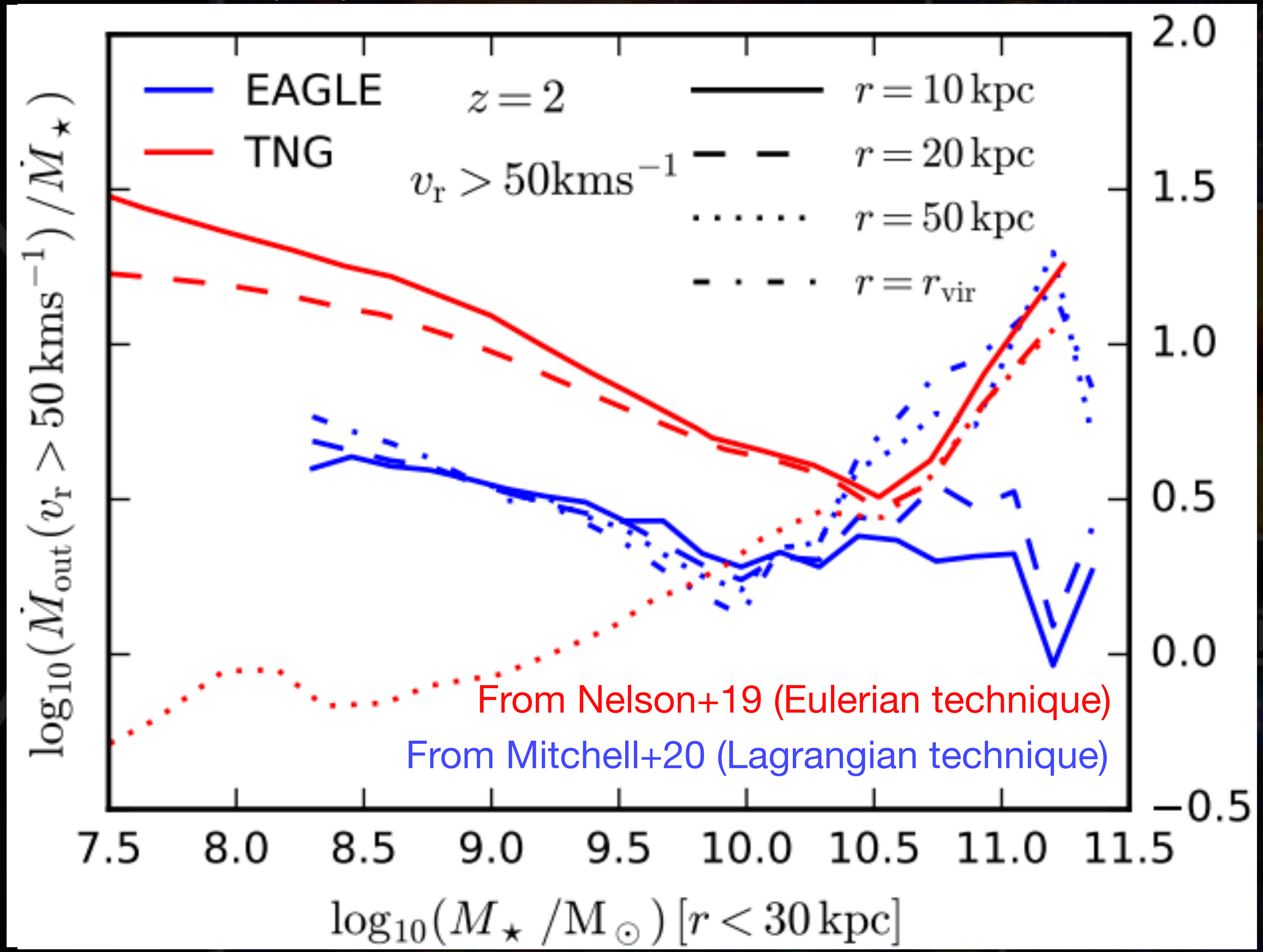


From Vogelsberger et al. (2020)

Adapted from Davé et al. (2020)



From Mitchell et al. (2020)



How do these simulations compare in terms of the baryon cycle if we compare them on equal footing?

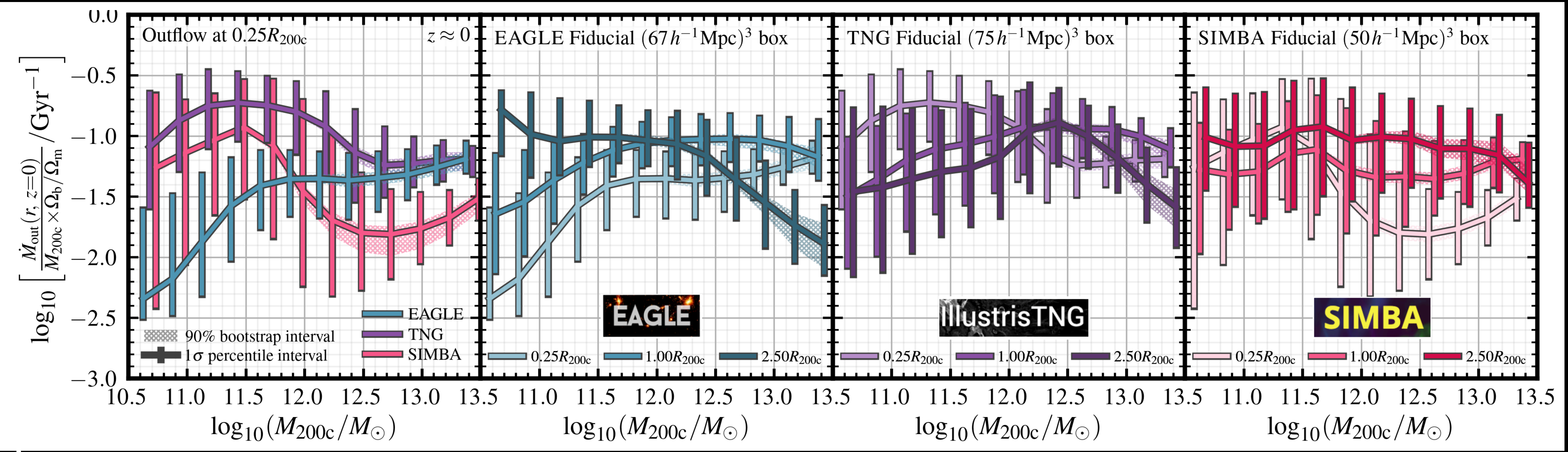
	EAGLE	IllustrisTNG	SIMBA
Gas element mass resolution	$\approx 1.8 \times 10^{6}\,\mathrm{M}_{\odot}$	$\approx 1.4 \times 10^{6}\,\mathrm{M}_{\odot}$ (TNG100)	$\approx 1.8 \times 10^{7}\,\mathrm{M}_{\odot}$
Hydrodynamics	GADGET + ANARCHY (SPH)	AREPO (MVM)	GIZMO (MFM)
Stellar feedback	Thermal only (no decoupling) $\Delta\,T_{\mathrm{SF}} = 10^{7.5}\,\mathrm{K}$	Thermal & kinetic (decoupled) η based on σ_{DM}	Thermal & kinetic (decoupled) $\eta\,(M_{\star})$ from FIRE
AGN feedback	Thermal only (no decoupling) One-mode, isotropic $\Delta\,T_{\mathrm{AGN}} = 10^{8.5}\,\mathrm{K}$	Thermal & kinetic (no decoupling) Two-mode, isotropic Low f_{edd}: kinetic; high f_{edd}: thermal	Thermal & kinetic (decoupled) Two-mode, kinetic feedback bipolar Low f_{edd}: kinetic & thermal; high f_{edd}: kinetic

Gas flow rates from Eulerian technique (i.e. instantaneous flux, no gas element tracking) ⟶

$$\dot{M}\,(r = R) = \frac{1}{\Delta r} \times \sum_{r_i \in R \pm \Delta r/2} \left(m_i \frac{\vec{v_i} \cdot \vec{r_i}}{|\vec{r_i}|} \right)$$

Outflow rates at ISM scale for each simulation (z=0)

Comparison between gas outflow rates at different scales in each simulation

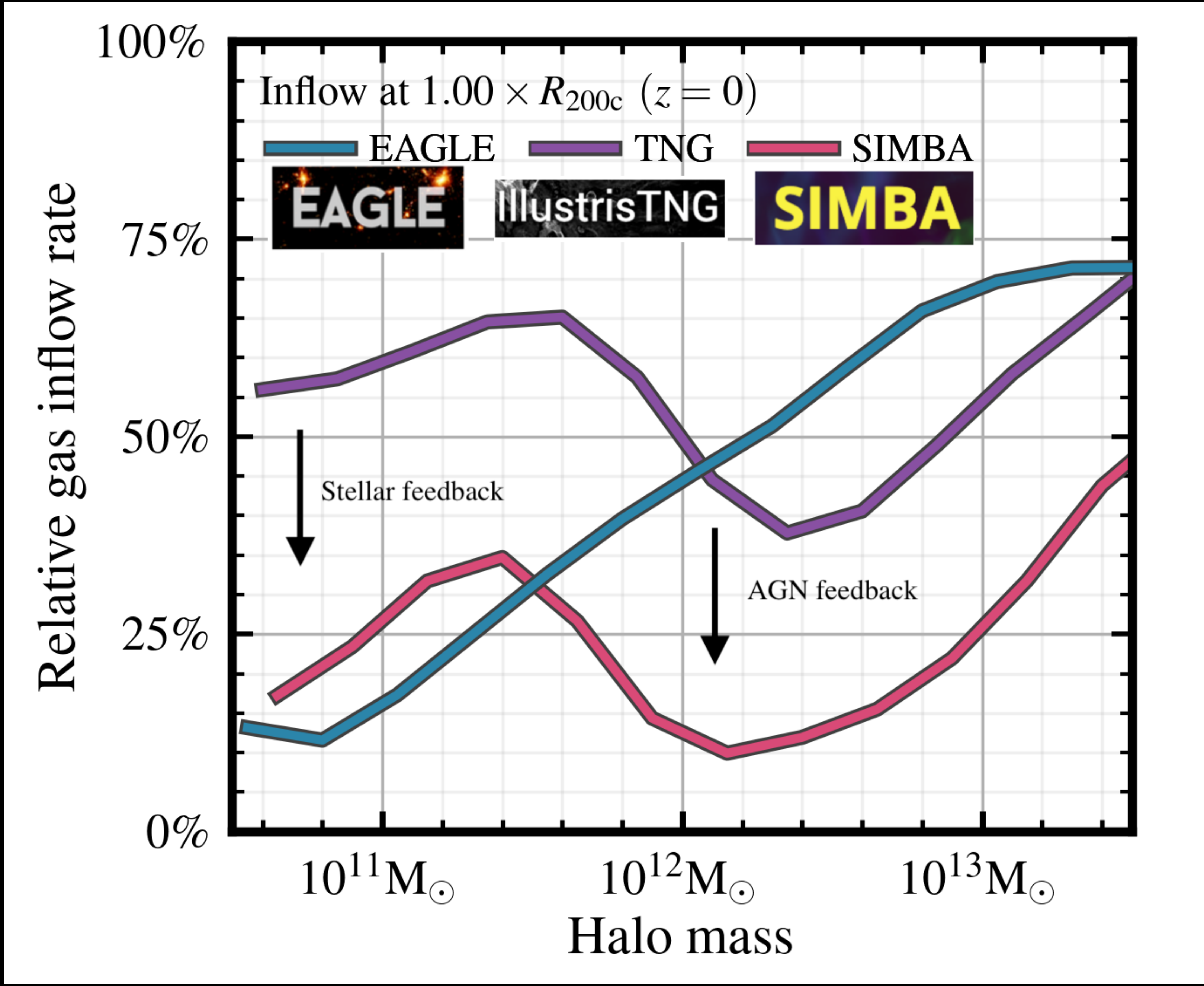


Adapted from Wright et al. (submitted)

Stellar and AGN-driven feedback driven outflows reach different scales in each of the simulations

0.25 R_{200}	"ISM" scale (lightest colours)
1.00 R_{200}	"Halo" scale (intermediate colours)
2.50 R_{200}	"IGM" scale (darkest colours)

Adapted from Wright et al. (submitted)

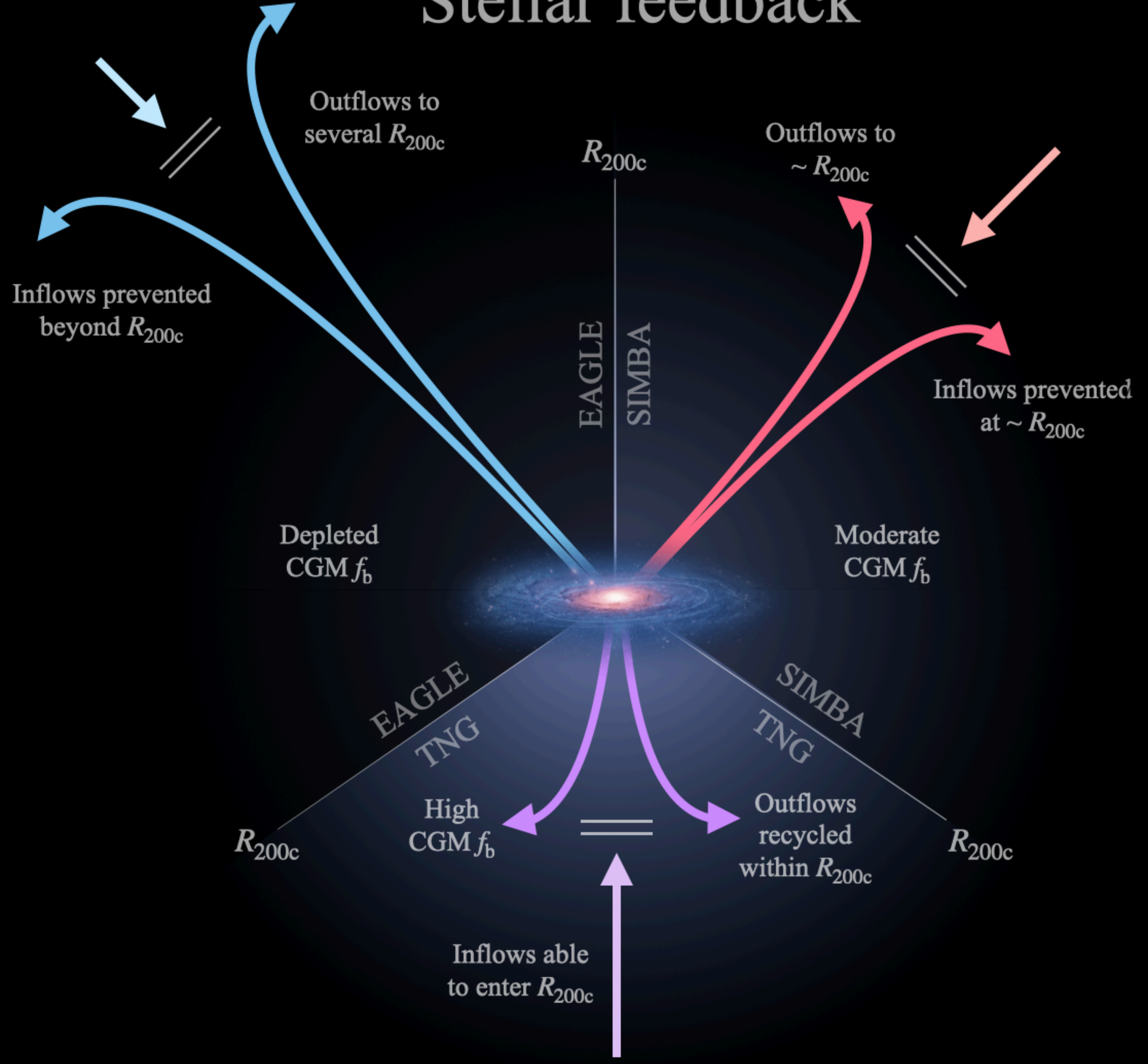


What about gas *inflows?*

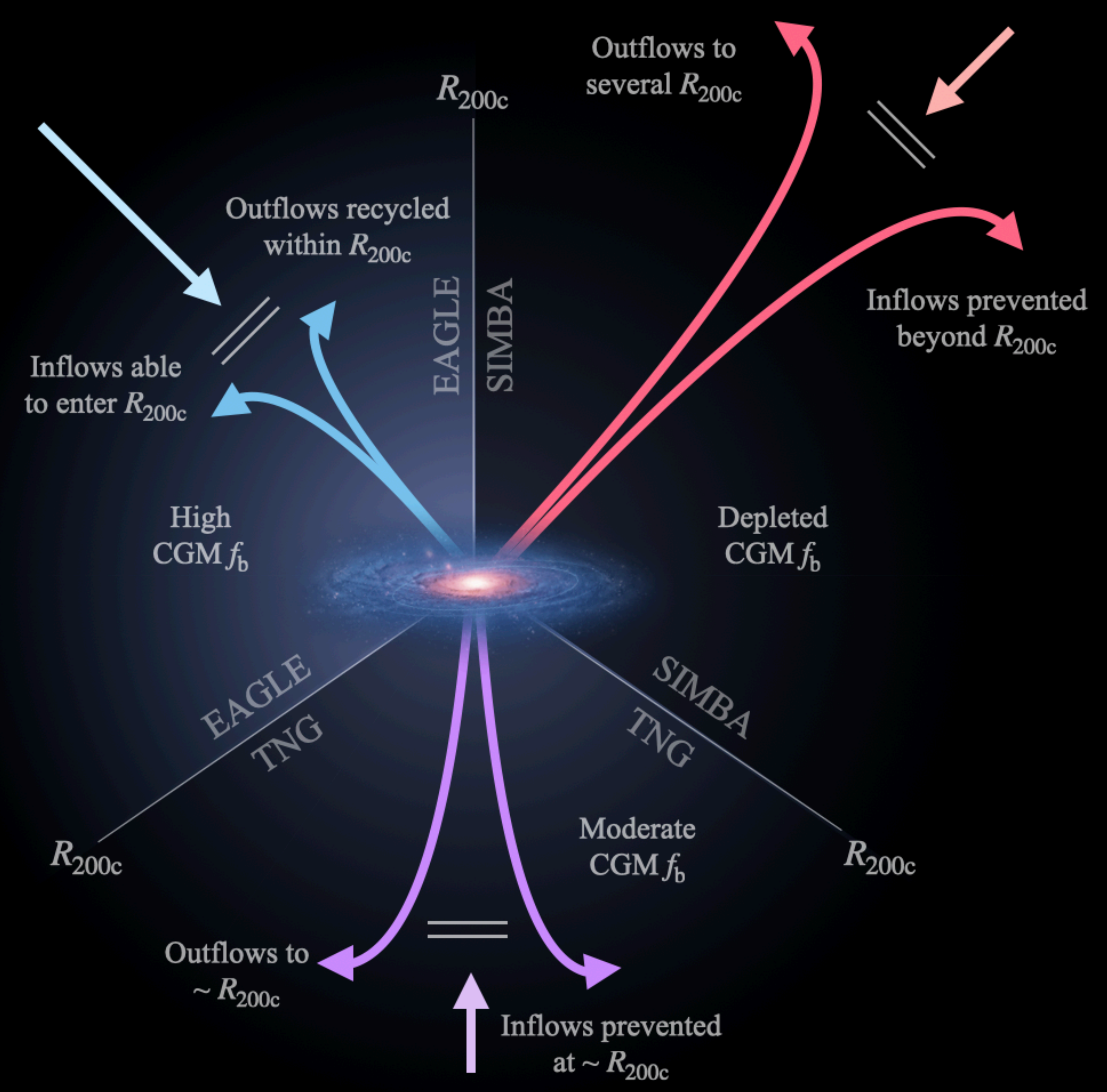
Important to consider "preventative" and "ejective" feedback separately

Gas inflows are directly influenced by the scale that feedback-driven outflows reach

Stellar feedback



AGN feedback



arXiv: 2402.08408

Each simulation produces similar GSMFs for different physical reasons in terms of the baryon cycle and gas flows

What do we do with this information?

If you want to understand a process that may be sensitive to the operation of gas flows (e.g. halo baryon distribution, metallicity gradients …) then it is important to note that the results may vary from simulation to simulation

It is worth considering testing a given conclusion using different simulations to understand the whether a result is robust (both qualitatively and quantitatively) to different model methodologies

How do we narrow down which scenarios are physically accurate?

The region we see the biggest differences between models is the CGM, but the resolution of this generation of cosmological simulations is probably inadequate to natively understand its detailed phase structure, beyond total gas content

SZ-effect and group/cluser X-ray gas fractions are sensitive to total gas content, beginning to push to lower halo masses with e.g. Simons Observatory

Carefully forward modelled observables with the next generation of cosmological simulations will be imperative