Stellar Feedback and the Cosmic Baryon Cycle in Galaxy Evolution

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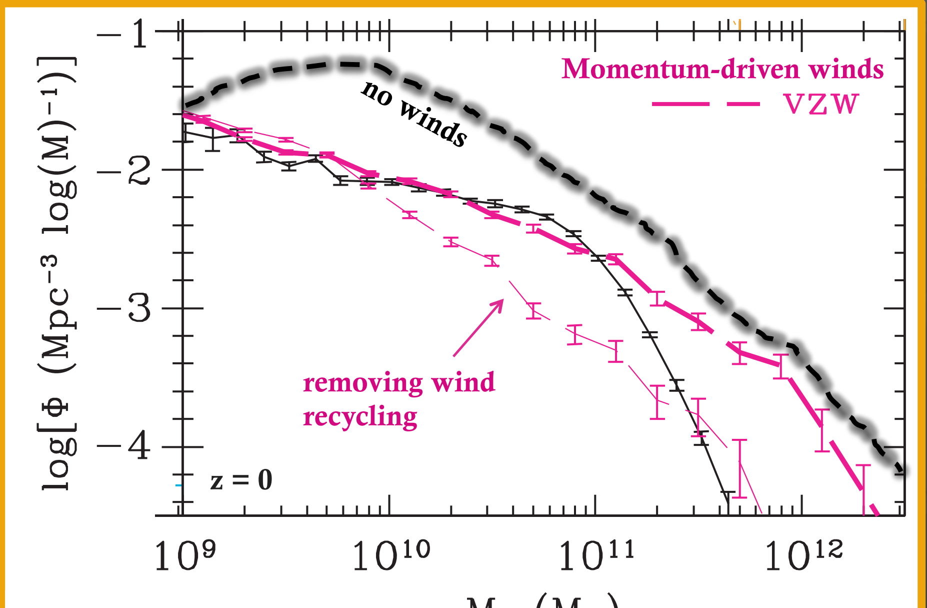
Physics and demography of AGN and starburst winds, EWASS 2017

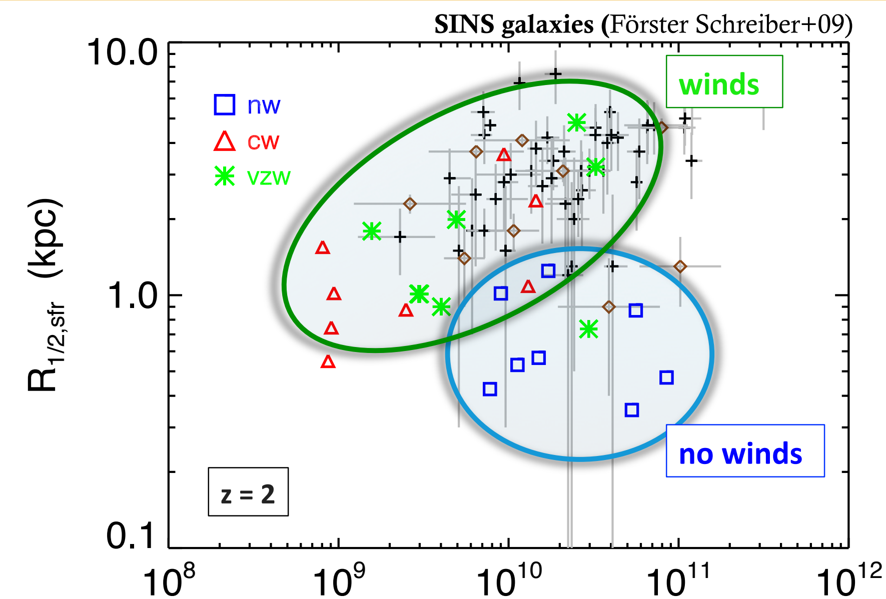
Winds are key in galaxy evolution models

(e.g. Somerville & Davé 2015, Naab & Ostriker 2016)



Oppenheimer+2010

→Winds required to match GSMF and wind recycling contributes late time accretion



Anglés-Alcázar+2014

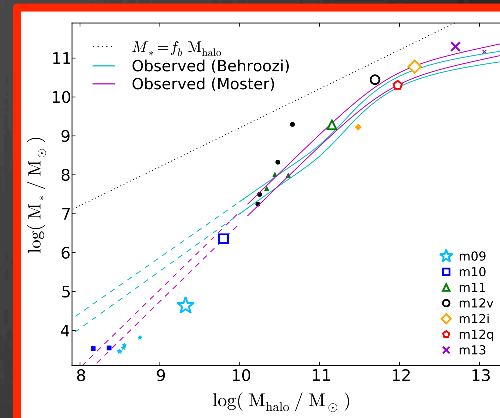
→Winds required to produce disk galaxies with more realistic sizes and central baryonic distributions

FIRE simulations

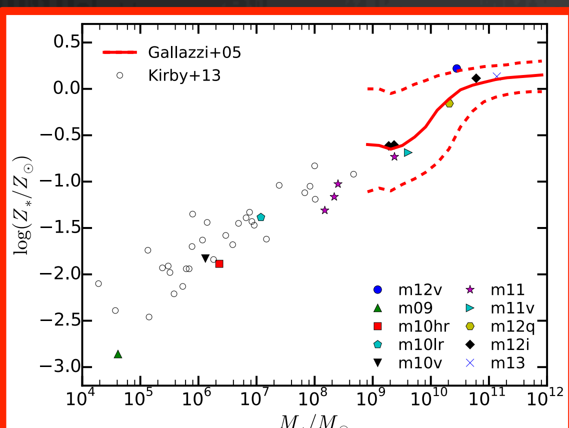
Connecting local and global processes in galaxies

High resolution cosmological zoom simulations with mass, momentum, energy, and metal feedback from stellar population synthesis models

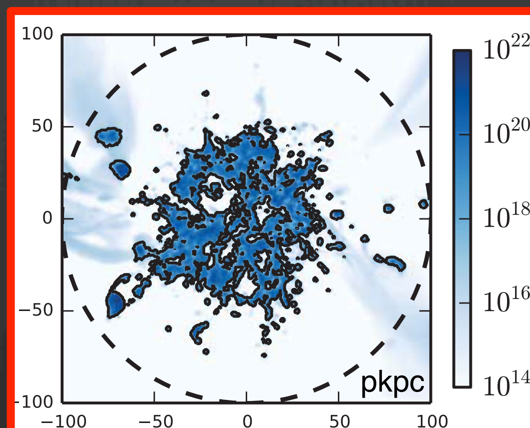
$M_{STAR} - M_{HALO}$ relation: Hopkins+14



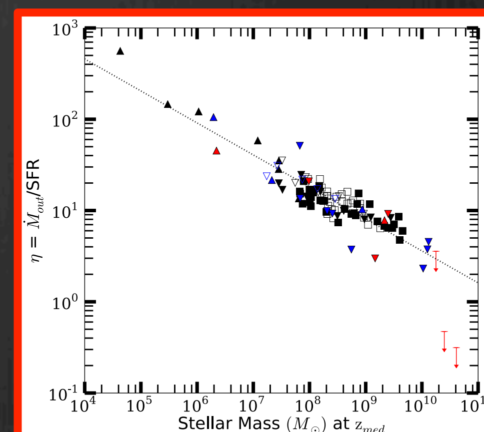
Mass–Metallicity relation: Ma+15



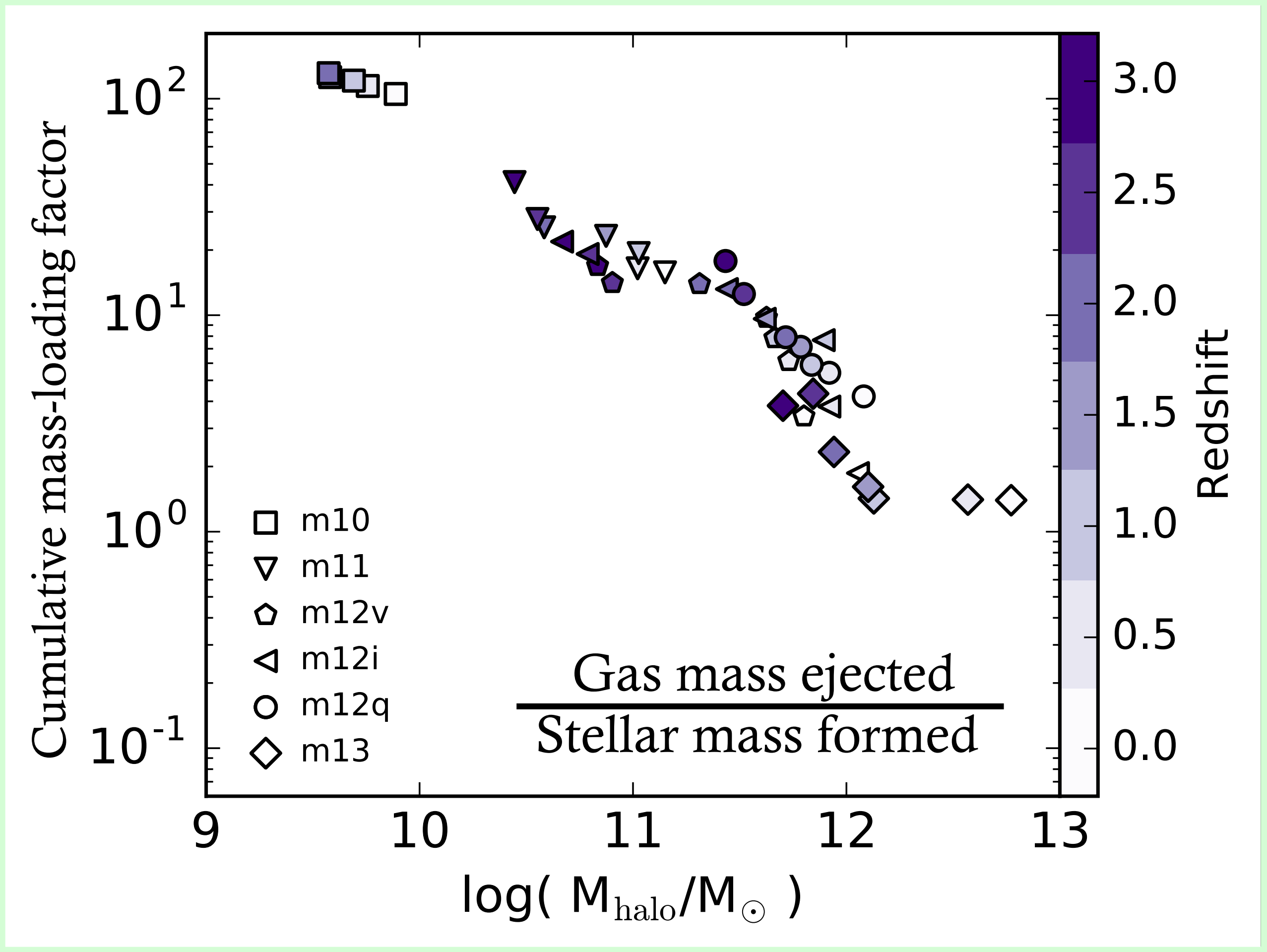
HI in z=2 CGM: Faucher-Giguère+15



Powerful outflows: Muratov+15



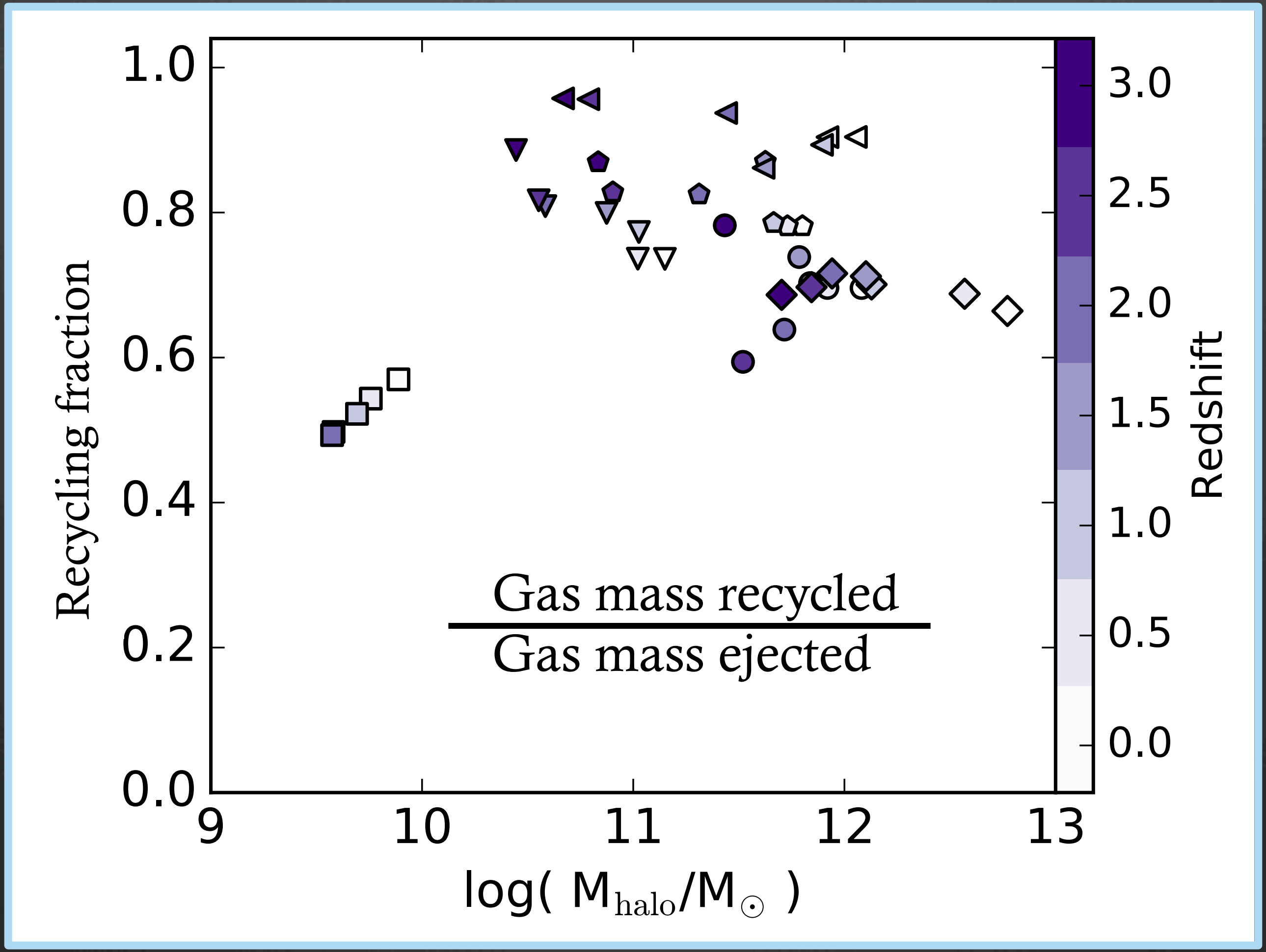
Mass-loading of winds



→ **Mass-loading factor larger for low mass galaxies (see also Muratov+15)**

Anglés-Alcázar+2017, MNRAS in press (arXiv:1610.08523)

Wind recycling?



→ Mass-loading factor larger for low mass galaxies (see also Muratov+15)

→ All galaxies recycle 50-95% of the ejected mass!

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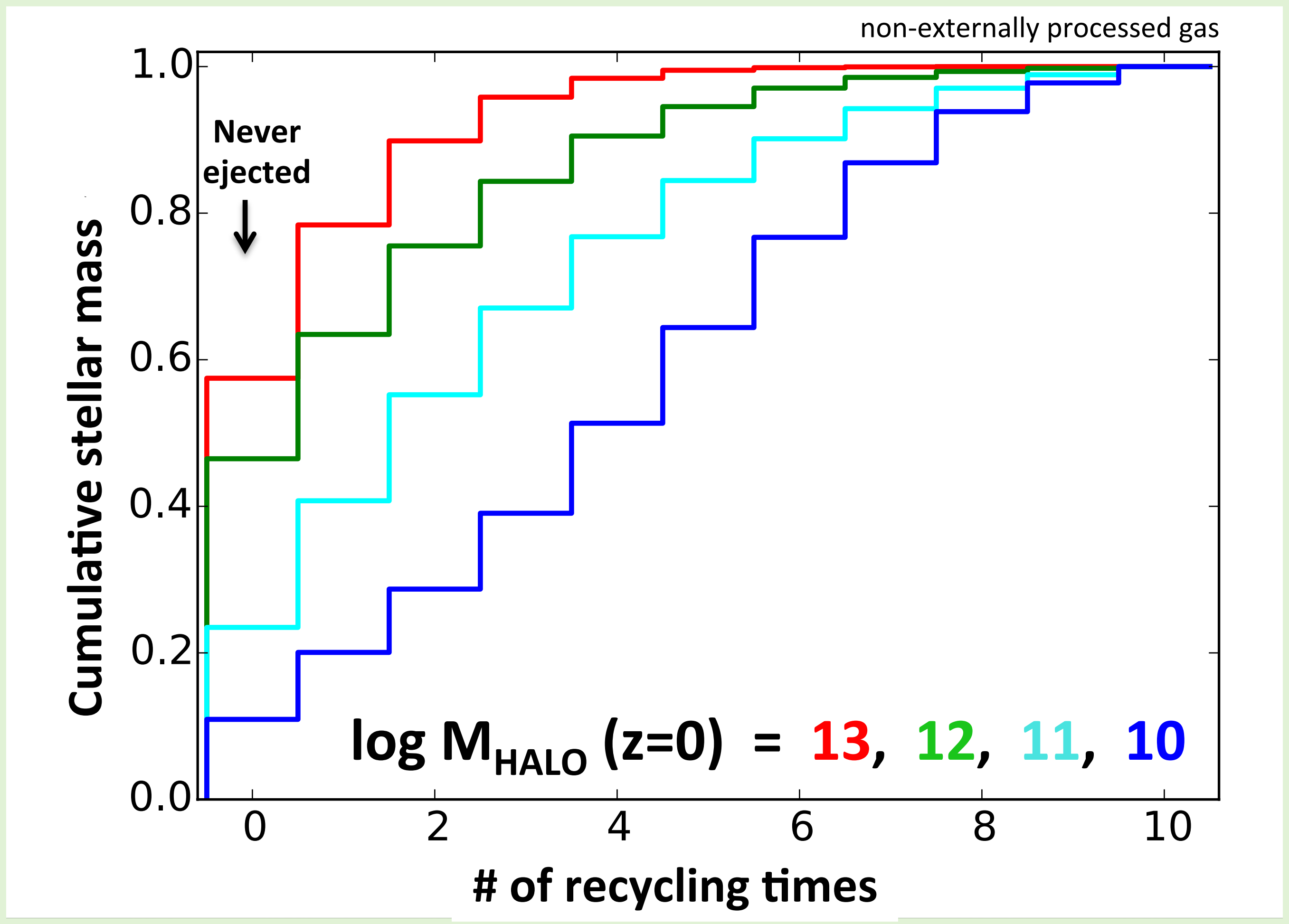
Recurrent wind recycling



→ Gas cycles thru galaxies more often in lower mass halos prior to forming stars

→ 50% of mass recycled more than [1, 2, 3, 6] times in log M_{HALO} = [13, 12, 11, 10]

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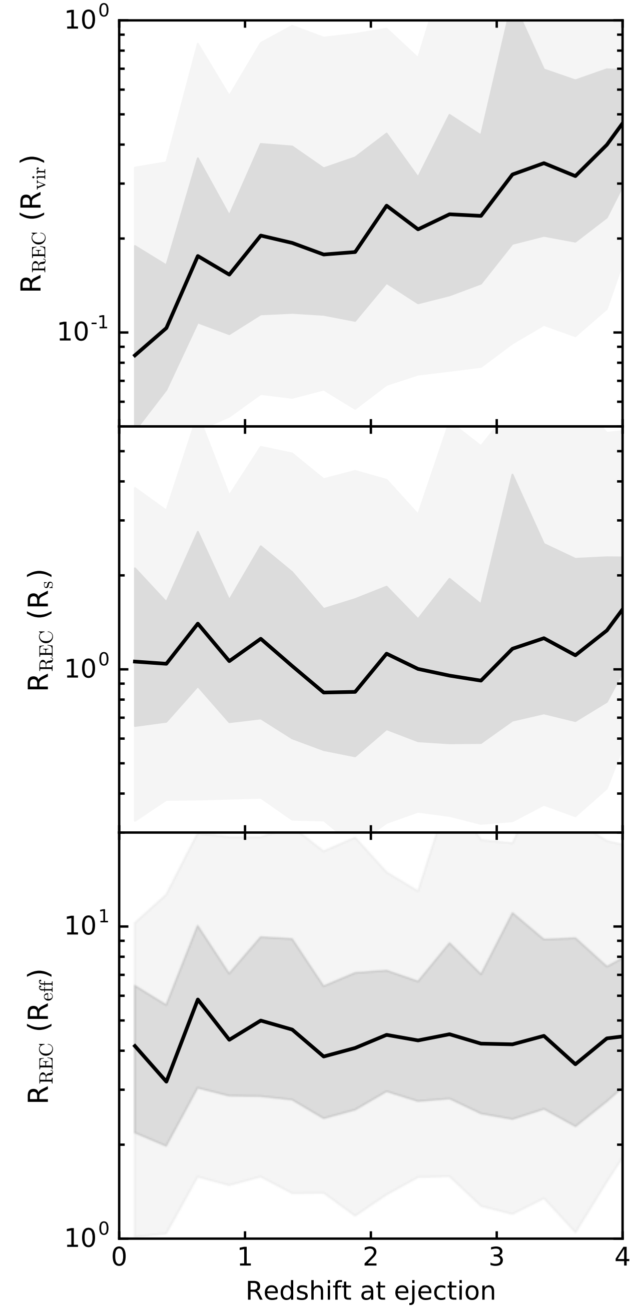
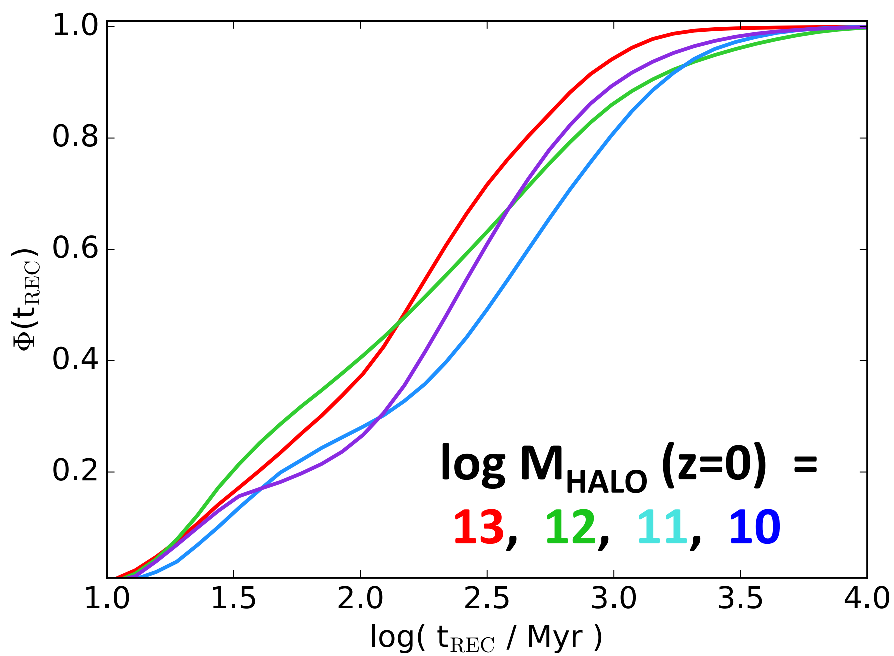
Recycling distance



Recycling time



→ Most recycling occurs within R_{vir}

→ Recycling zone independent of mass/redshift

= Halo scale radius = 5 x stellar effective radius

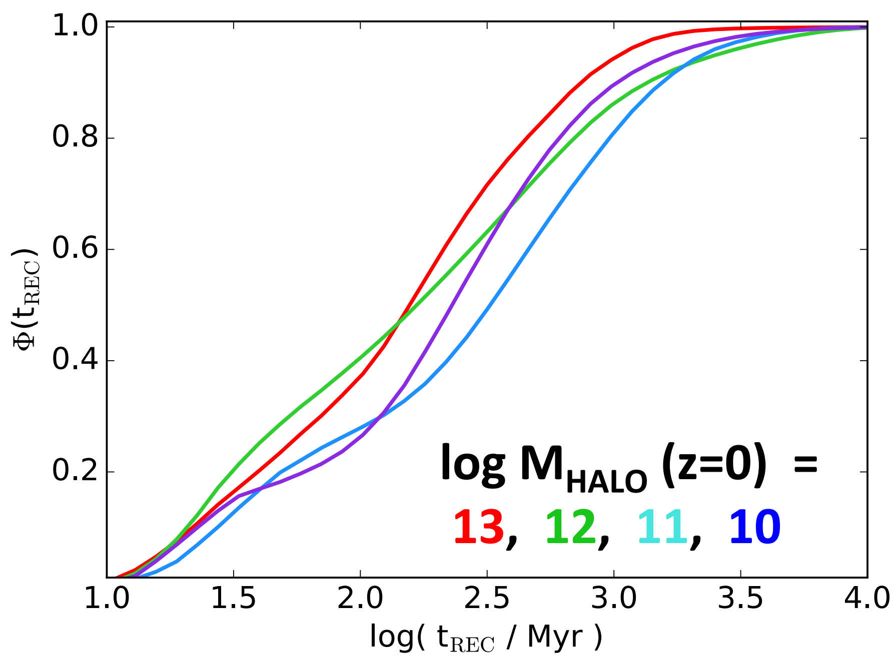
(CGM obs. e.g. Chen+2010, Tumlinson+2011, Werk+2014 Ford+2016, Liang+2016)

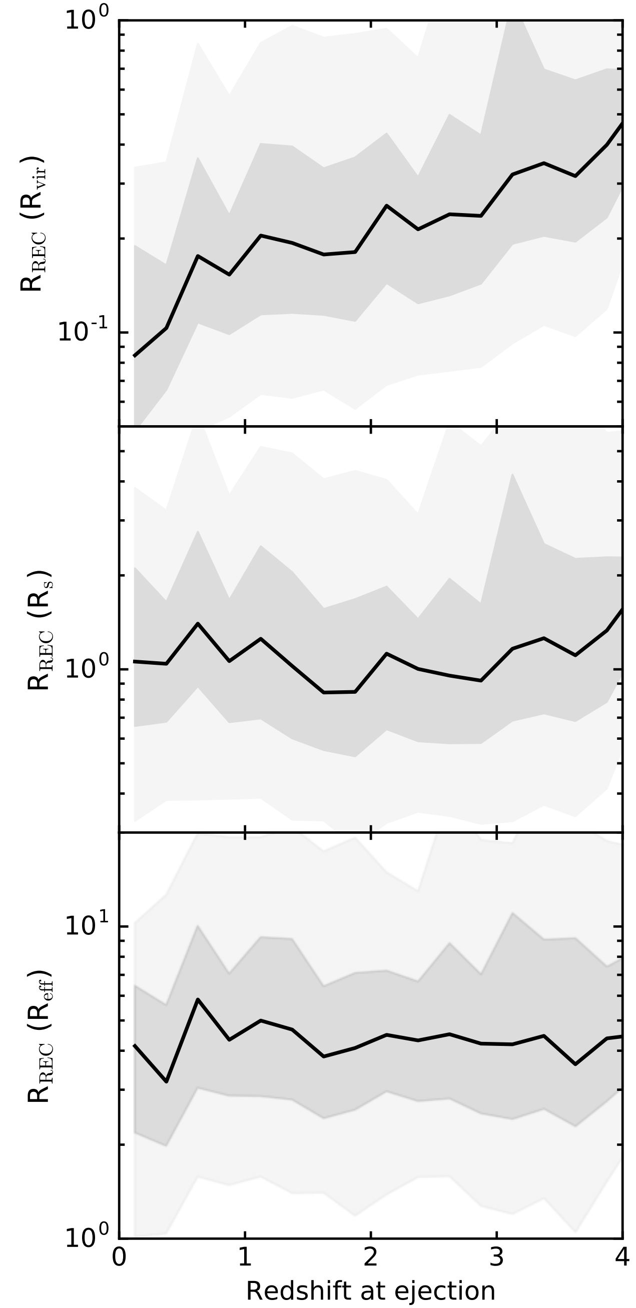
→Wind re-accretion time: 10 Myr - 1 Gyr

(shorter than Oppenheimer+2010; Christensen+2016)

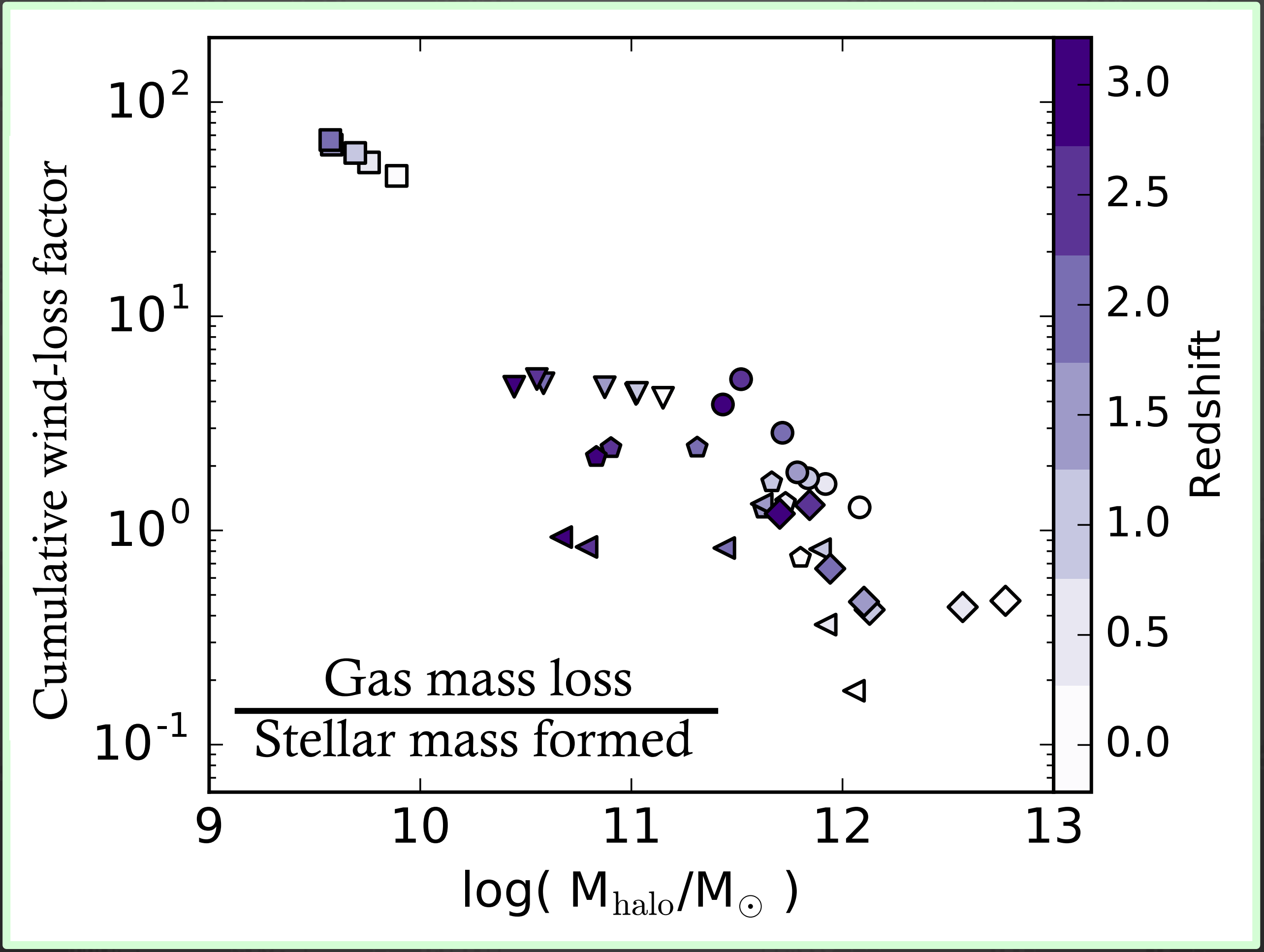
→Important parameter for SAMs!

(e.g. Henriques+2013; White+2015)





Gas loss in winds



→ Lower mass galaxies lose more mass in winds per unit stellar mass formed

→ 75% of the gas lost is deposited in the IGM at z=0 and 25% remains in the CGM

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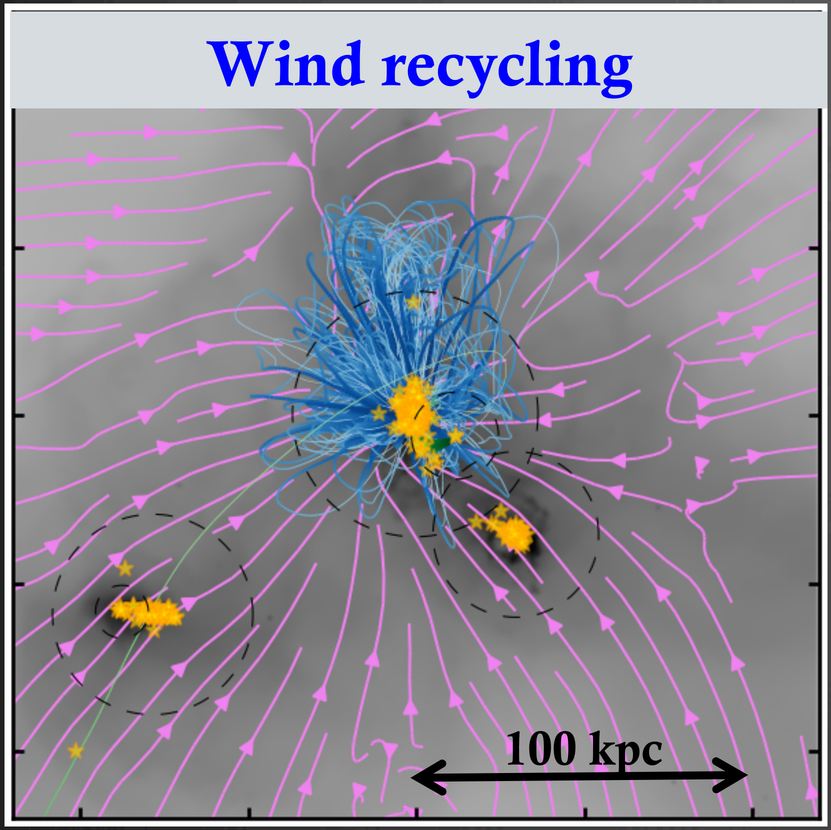
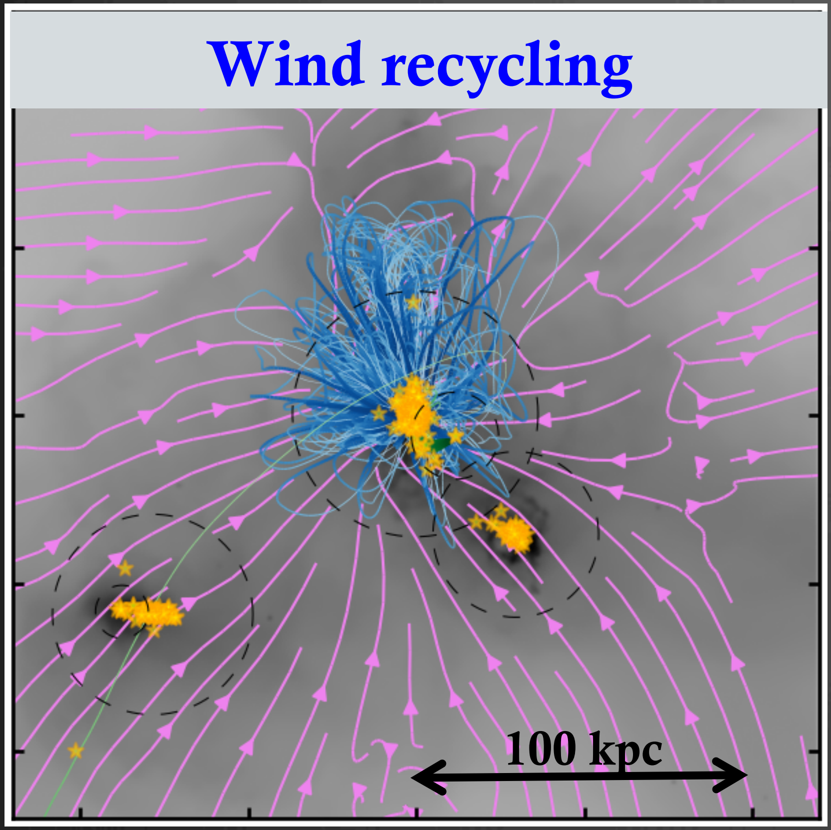


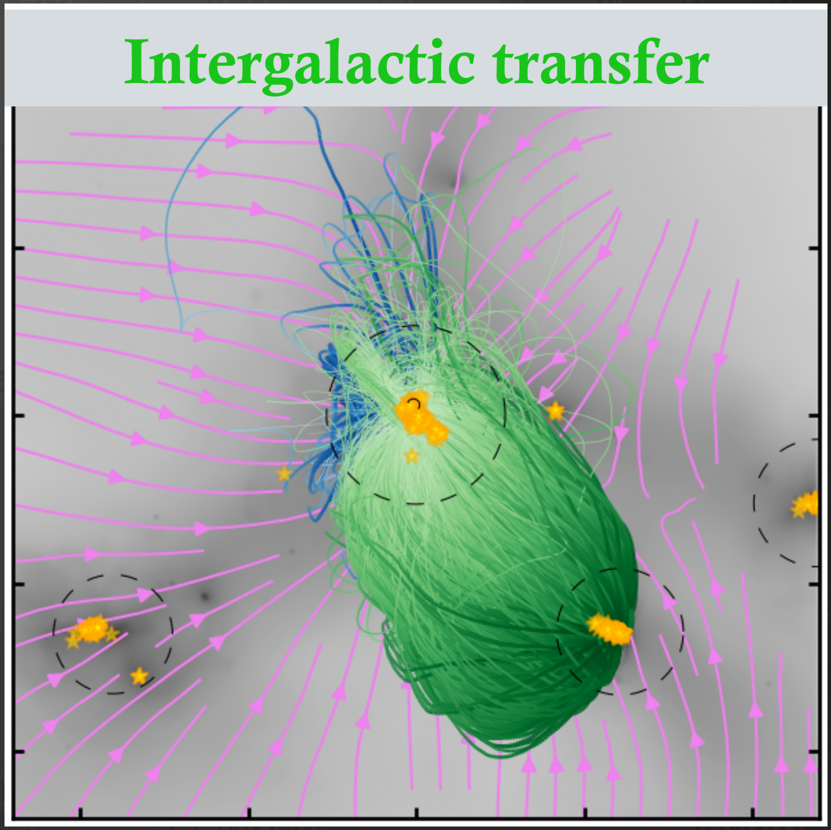
Gas ejected from the central galaxy and recycled back

Tracing gas flows

Tracing gas flows

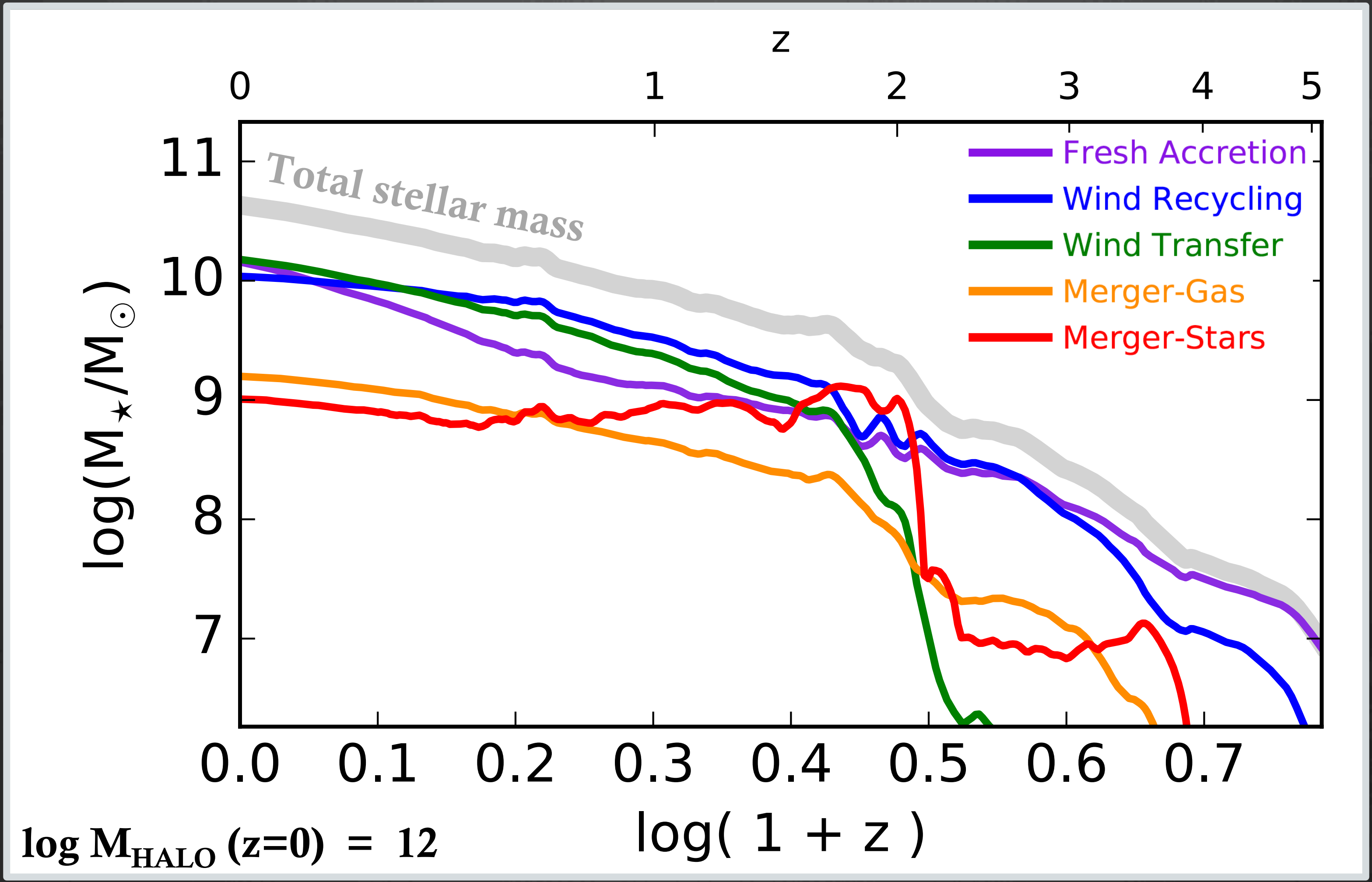


Gas ejected from the central galaxy and recycled back



Gas ejected from other galaxies and accreted onto the central galaxy

Origin of stellar content of galaxies

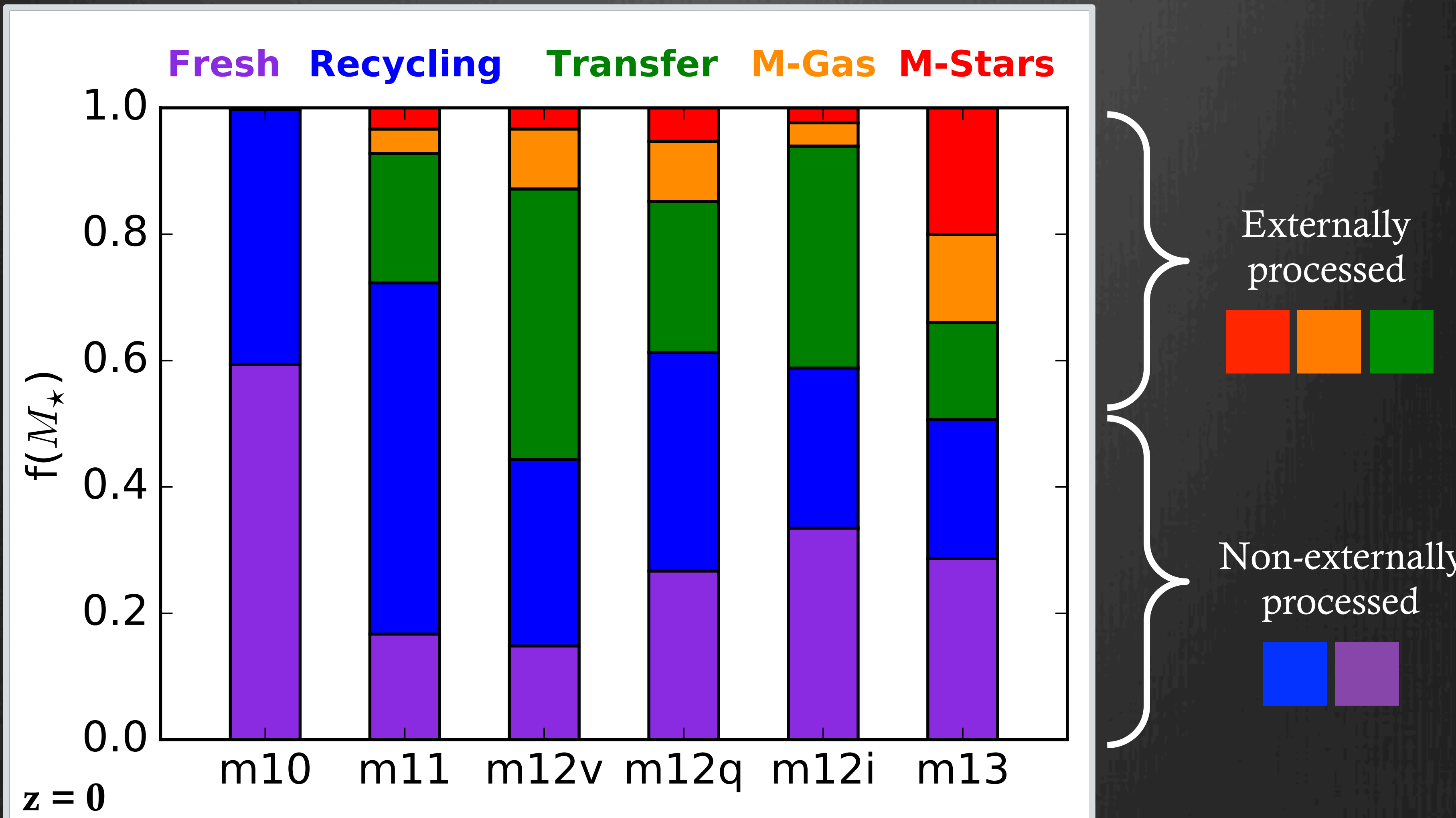


→ Fresh gas accretion dominates first but wind recycling takes over

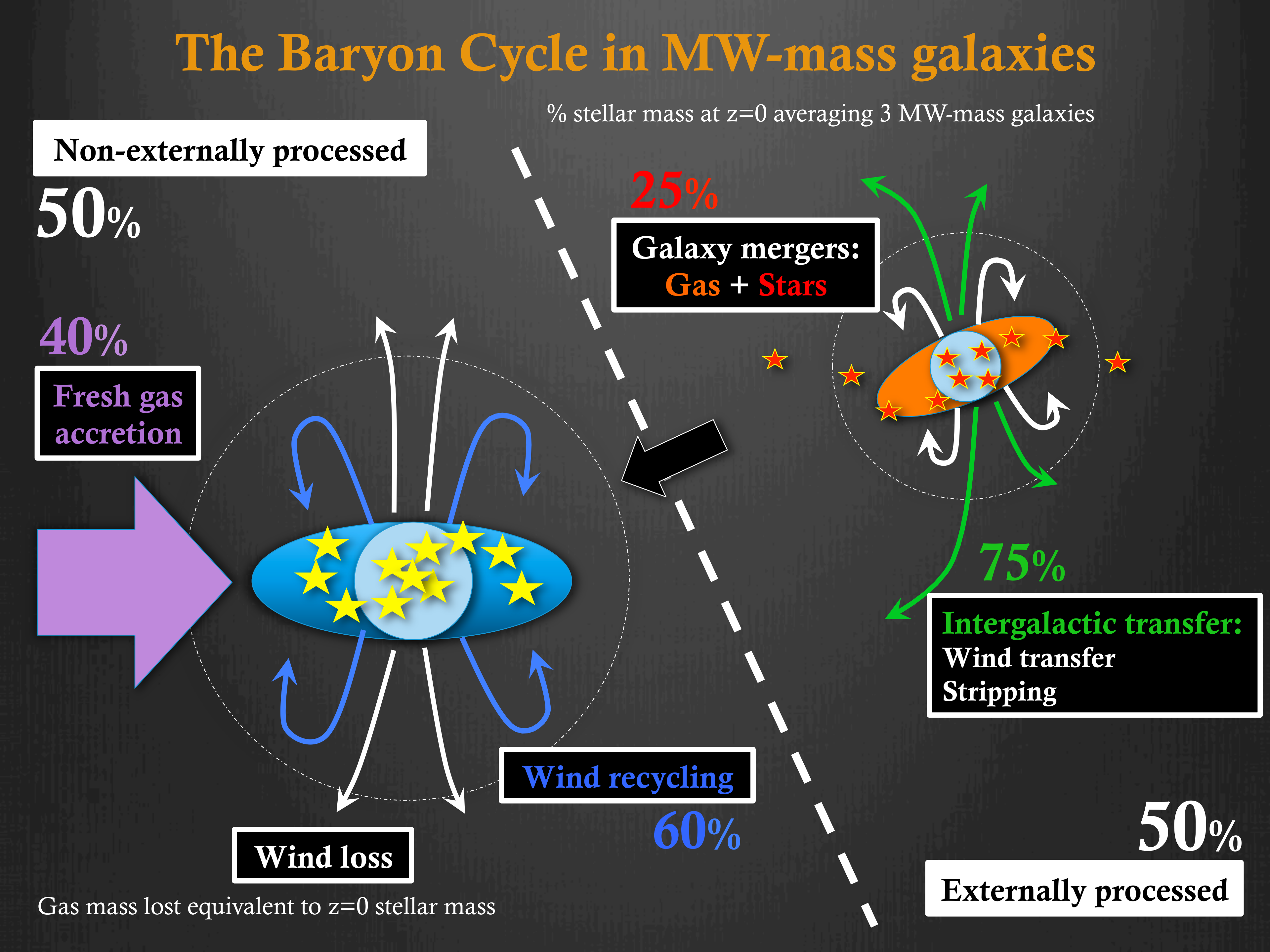
→ Stars + gas from galaxy merger at z=2, but intergalactic transfer dominates

Fraction of z = 0 stellar mass

From dwarfs to elliptical galaxies

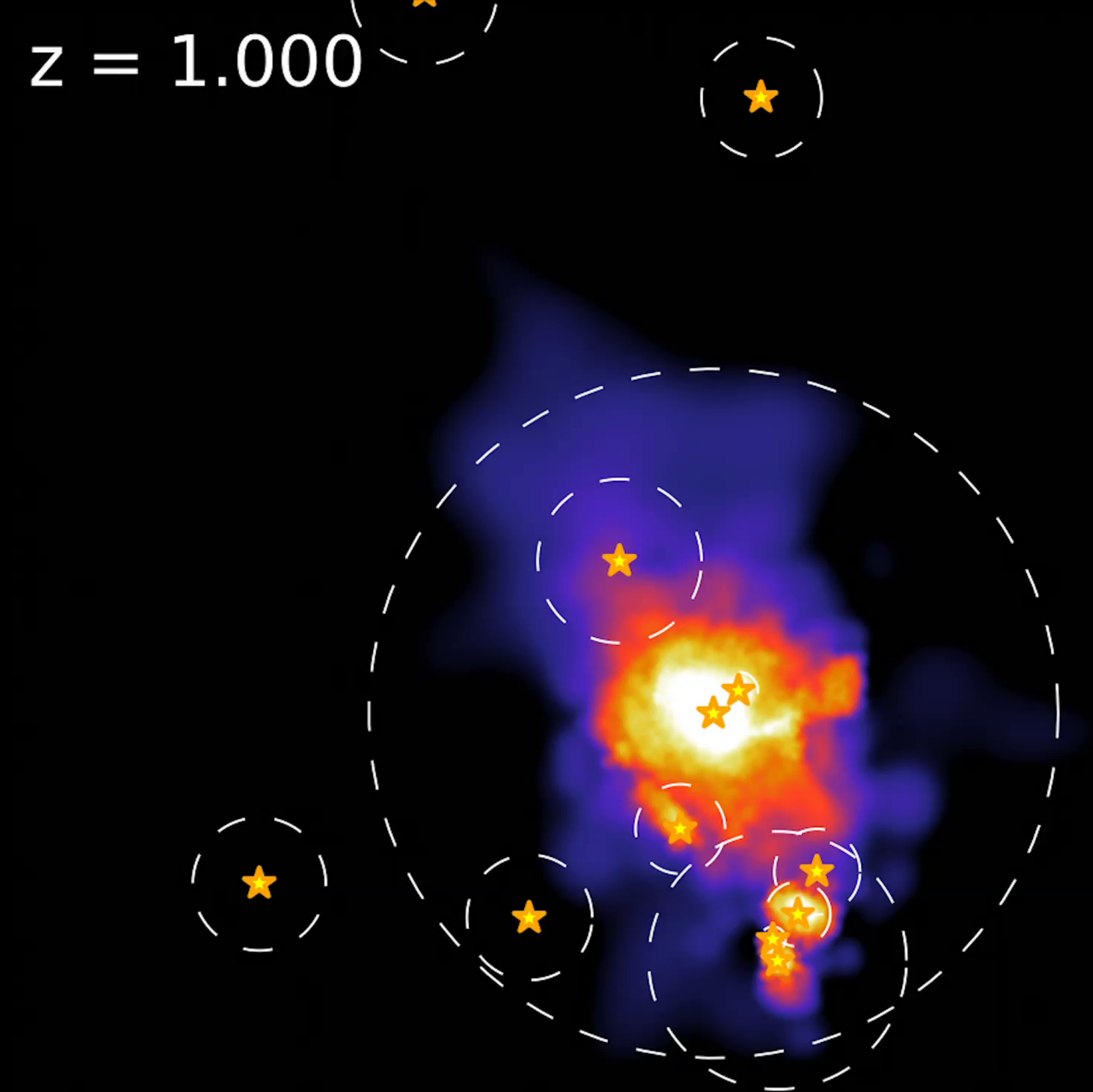


Increasing halo mass: log M_{HALO} = 10 → 13


The Baryon Cycle in MW-mass galaxies
% stellar mass at z=0 averaging 3 MW-mass galaxies
Non-externally processed
50%
25%
Galaxy mergers:
Gas + Stars
40%
Fresh gas accretion
75%
Intergalactic transfer:
Wind transfer
Stripping
Wind recycling
60%
50%
Wind loss
Externally processed
Gas mass lost equivalent to z=0 stellar mass

Intergalactic Transfer

From small satellites onto a Milky-Way mass galaxy



Orbiting satellites experience bursts of star formation, driving quasi-spherical outflows that accrete onto the central galaxy

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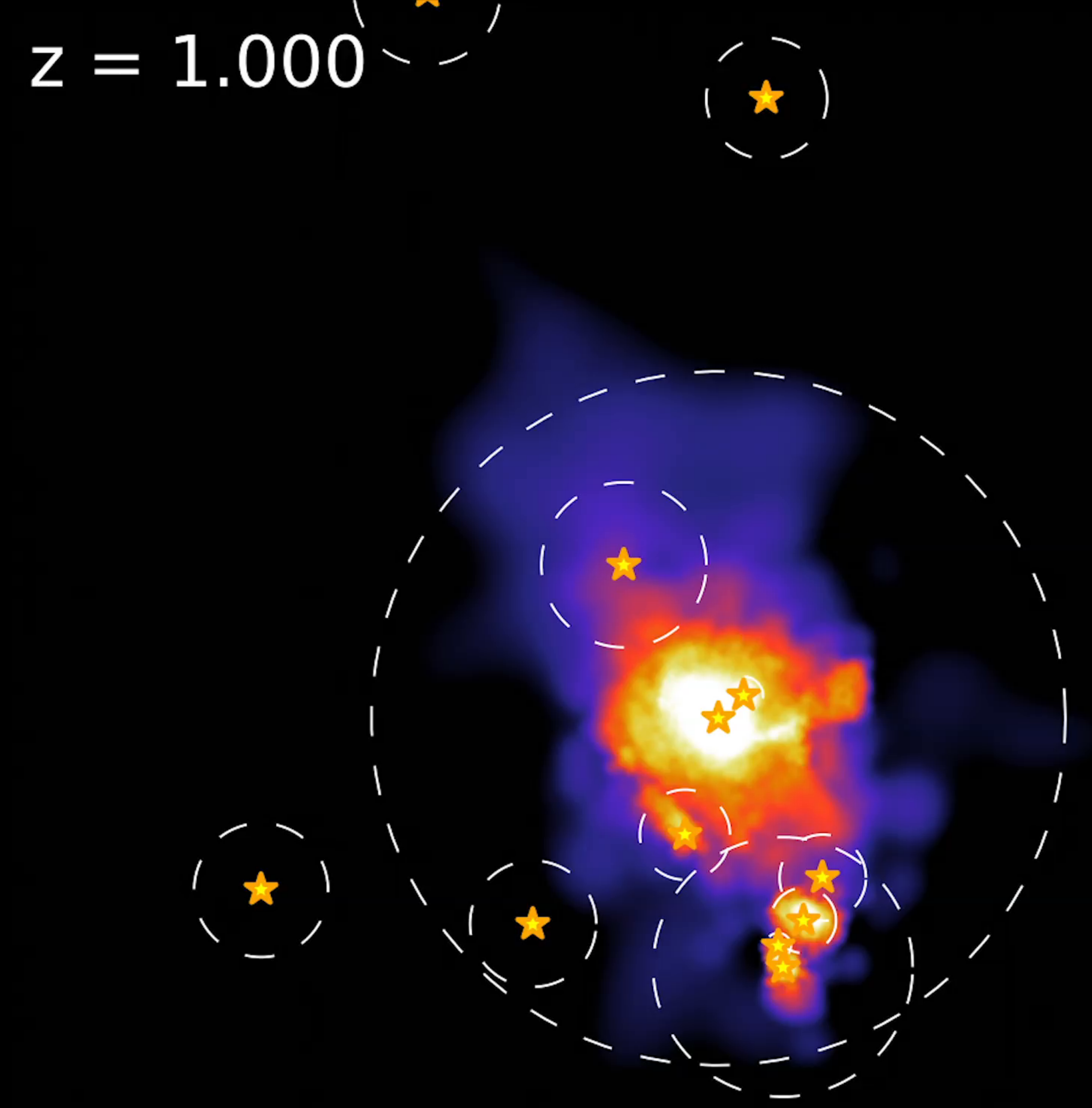

Intergalactic Transfer

- ✓ 1/3 of M_{star} at z=0
- ✓ Can dominate gas accretion at late times

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