The impact of feedback on the distribution and state of matter in the Universe

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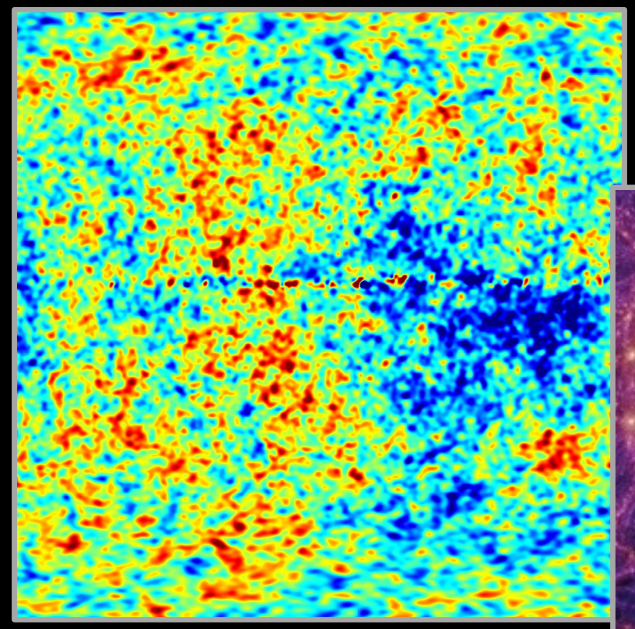
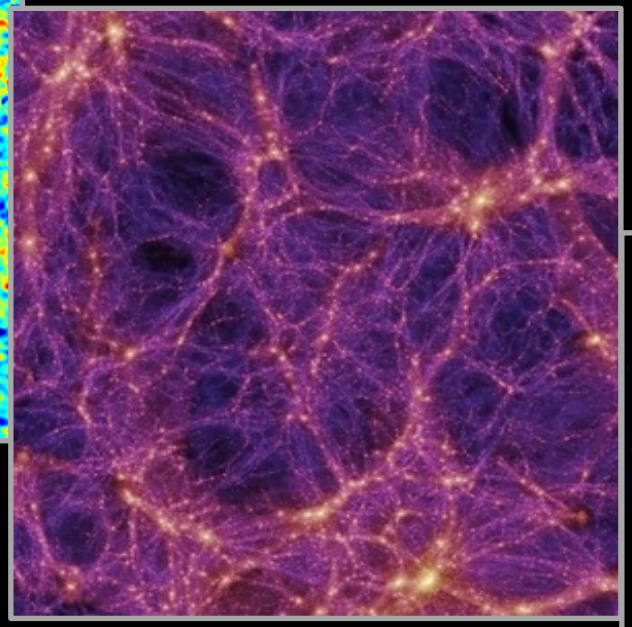
Early Universe



Large-scale Structure

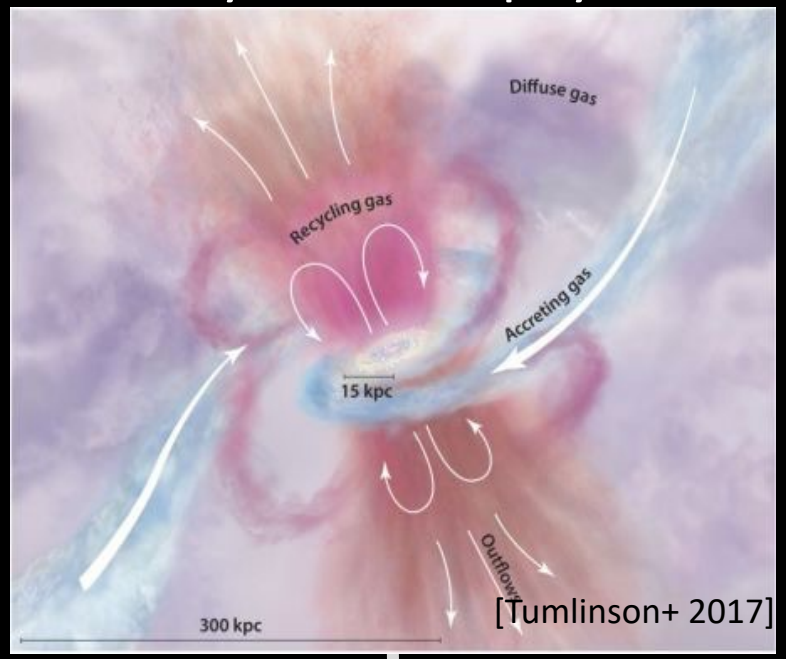


Galaxy Formation

Star formation

Can we explain this?

Baryonic astrophysics



[Tumlinson+ 2017]

Background cosmology

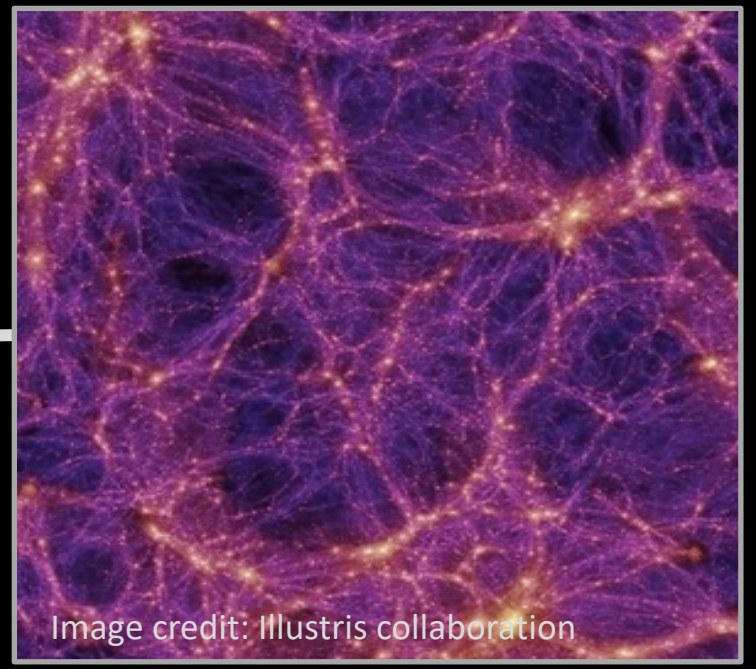
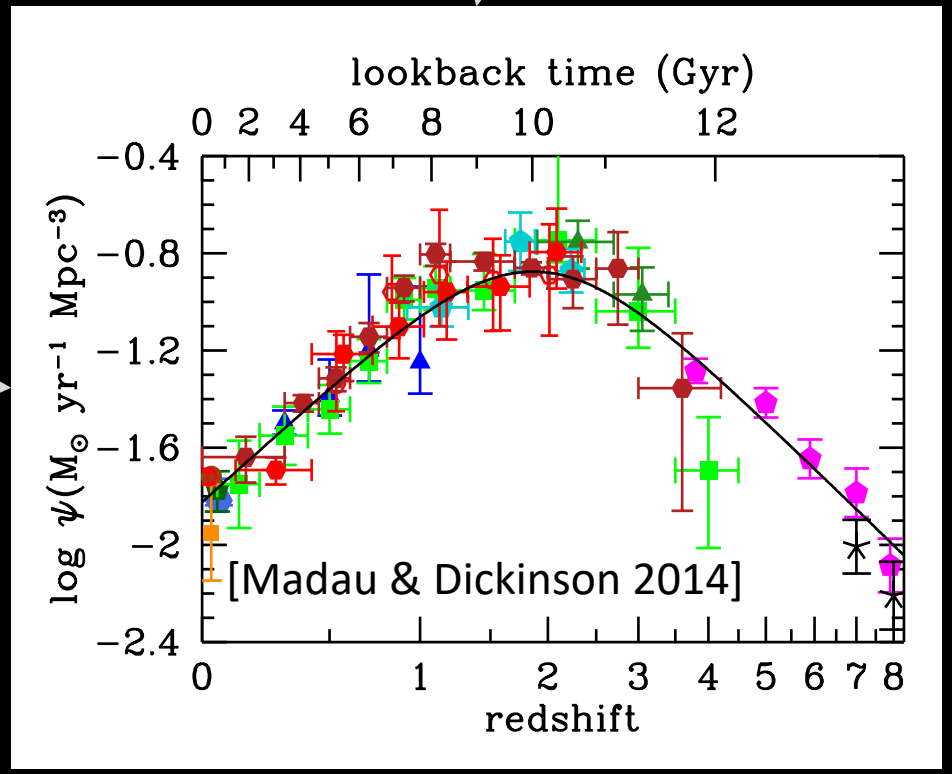
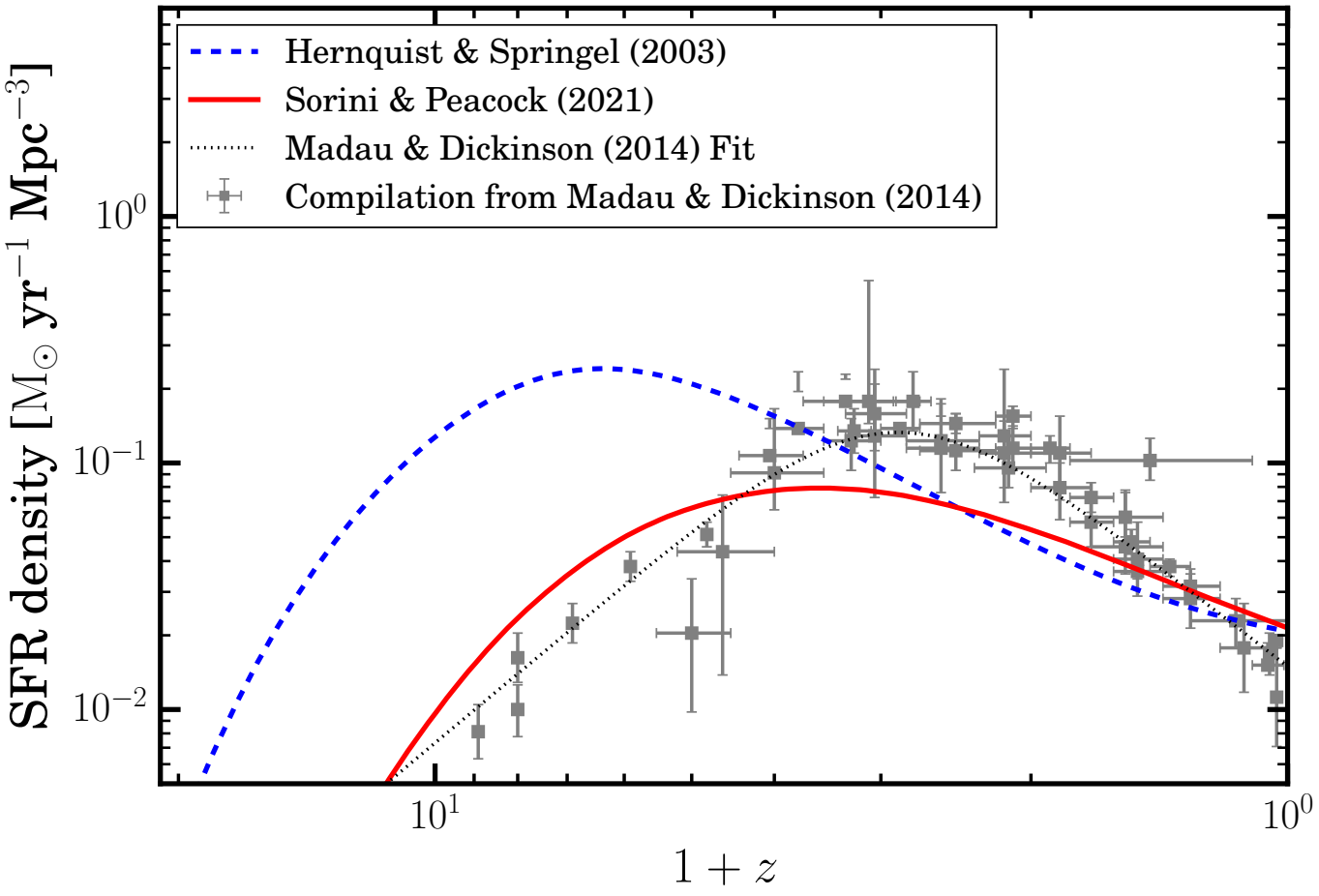


Image credit: Illustris collaboration



[Madau & Dickinson 2014]

Modelling star formation history



- **Analytical models**:
  [Hernquist & Springel 2003; Rasera & Teyssier 2006; Behroozi+ 2013, 2019; Moster+ 2018; Sharma & Theuns 2019; Fukugita & Kawasaki 2021]
- **Semi-analytic models**
  [White & Frenk 1991; Kauffmann+ 1993; Cole+ 2000; Somerville+ 2008]
- **Full hydrodynamic simulations**
  [e.g. Hopkins+ 14; Vogelsberger+ 2014; Schaye+ 2015; Pillepich+ 2018; Davé+ 2016, 2019]

Star formation and feedback

Gas accretion and cooling

↓

Star formation

↓

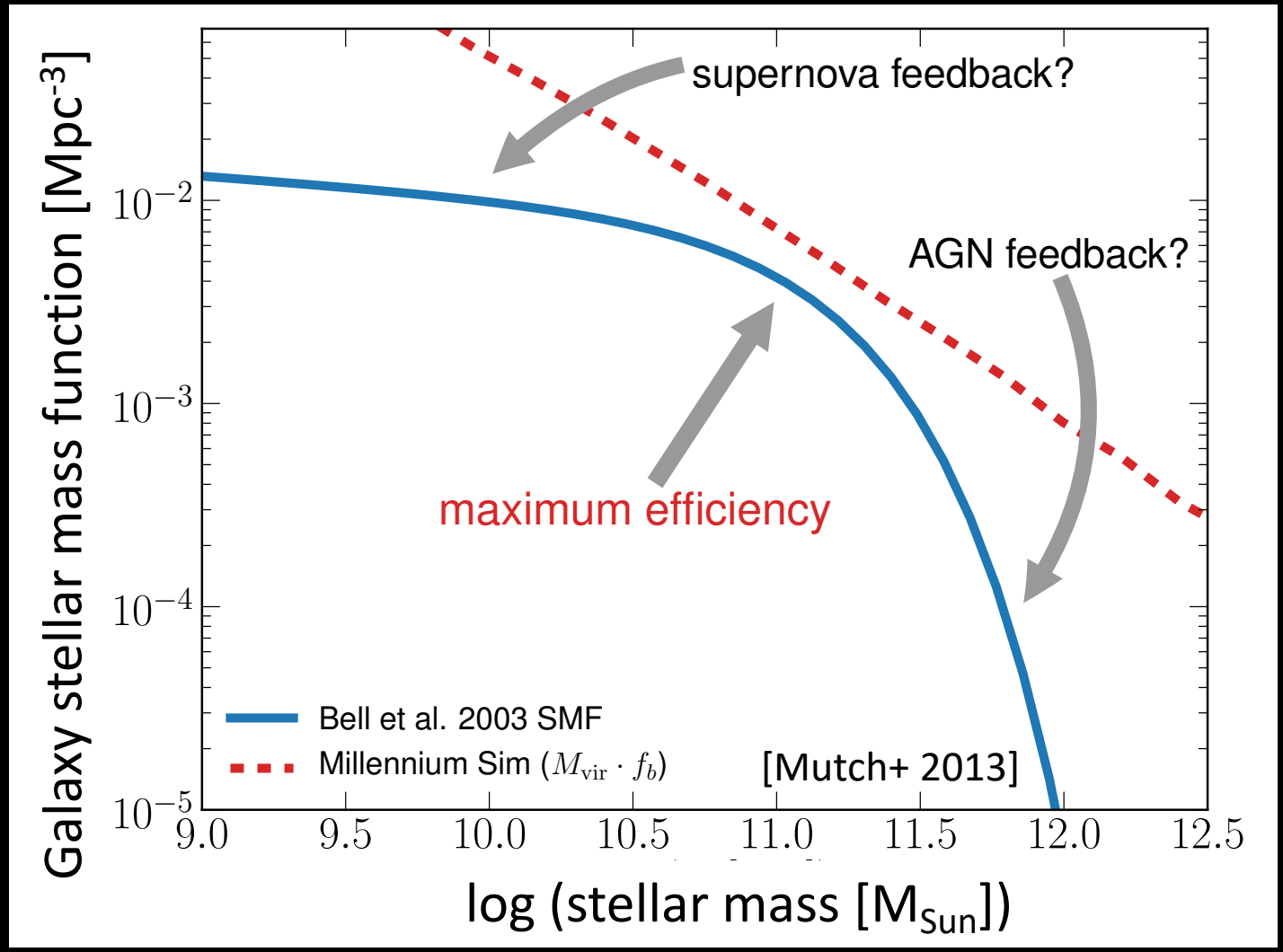
Stellar & AGN-driven outflows

↓

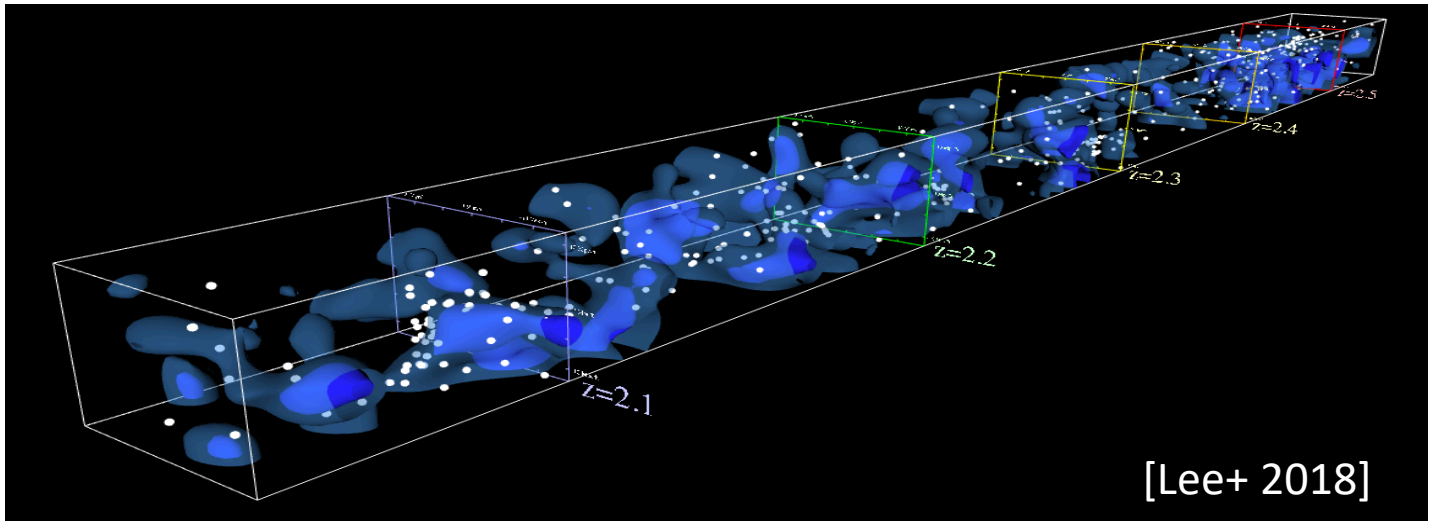
Gas heating & depletion

↓

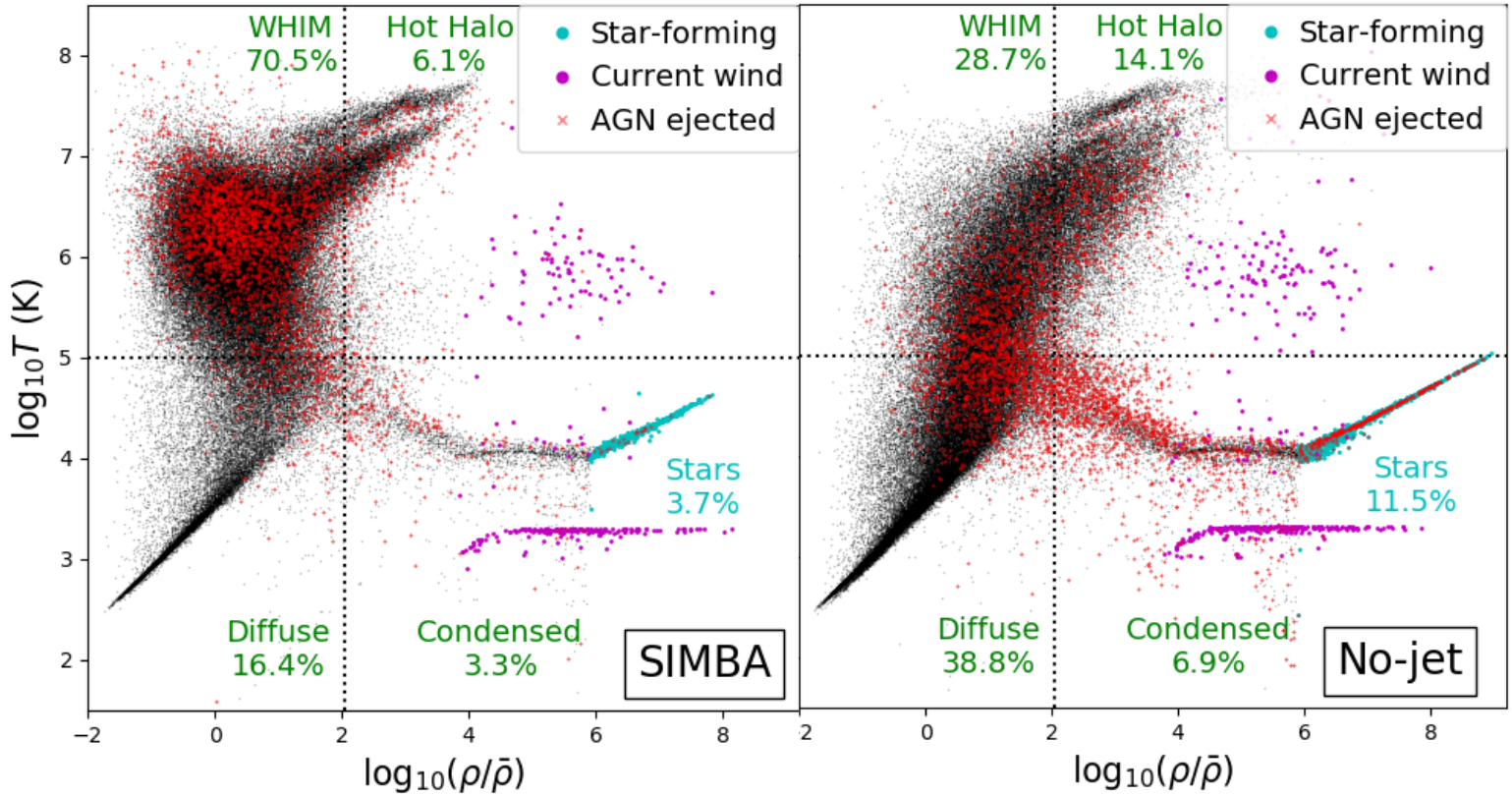
Star formation is suppressed



Feedback and the intergalactic medium



- Distribution of diffuse gas?
  [Lee+ 2014, 2016, 2018, 2021; Krolewski+ 2018; Horowitz+ 2019; Nagamine+ 2021]
- Impact of feedback on IGM statistics?
  [Meiksin+ 2015, 2017; Ravoux+ 2020; Appleby, Davé, DS+ 2021; Nagamine+ 2021]
- Impact on thermal state of IGM?
  [Rahmati+ 2013a,b, 2015; Sorini+ 2020; see also Sorini+ 2016, Kooistra+ 2022a, b]



[Christiansen, Davé, DS+ 2020]

Feedback

Structure of halos

- Density profiles
  [e.g. Schaller+ 2015, Pllepich+ 2018b; Macciò + 2020]
- Shape
  [e.g. Chua+ 2019, 2021; Cataldi+ 2021]
- Number of subhalos
  [e.g. Fattahi+ 2016; Sawala+ 2016; Despali & Vegetti 2017]

Star formation history

[e.g. van de Voort+ 2011; Vogelsberger+ 2013; McCarthy+ 2017; Weinberger+ 2017; Salcido+ 2018, 2020]

CGM/IGM

[e.g. Suresh+ 2015; Keating+ 2016; Turner+ 2014, 2017; Sorini+ 2018, 2020; Fielding+ 2020]

Large-scale structure

- Cluster count cosmology
  [e.g. Debackere+ 2020, 2021]
- Void statistics
  [e.g. Pallas+ 2017]
- Matter power spectrum
  [e.g. Hellwing+ 2016; Barreira+ 2019; van Daalen+ 2020]
- Matter bispectrum [Foreman+ 2020]

Effect of baryons on halos and LSS in the Simba simulation

BH accretion

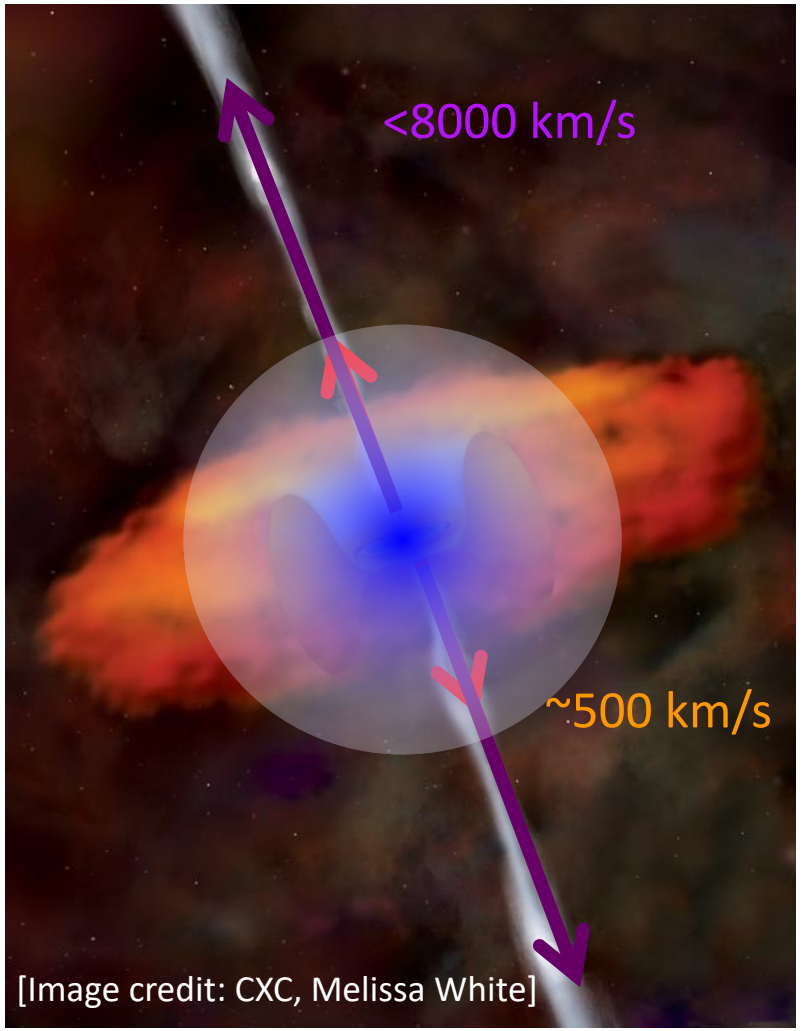
- HOT MODE [Bondi 1952]
- COLD MODE: torque-limited accretion [Hopkins & Quataert 2011; Anglés-Alcázar+ 2013, 2015, 2017a]

Stellar feedback

SN + stellar winds scaling relations based on FIRE zoom-in simulations [Muratov+ 2015; Anglés-Alcázar+ 2017b]

AGN feedback

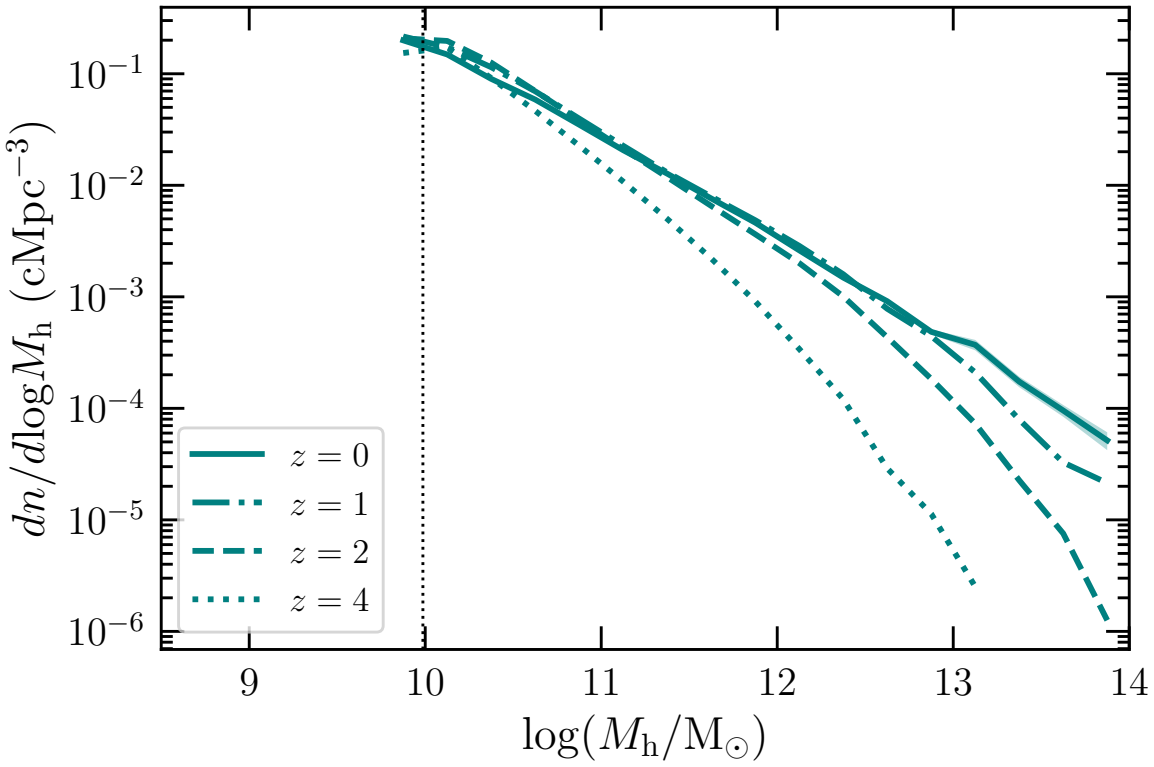
- AGN WINDS
- JETS $M_{BH}>10^{7.5}\ M_{Sun}$ & $f_{Edd}<0.2$
- X-RAY HEATING $M_{BH}>10^{7.5}\ M_{Sun}$ & $f_{Edd}<0.2$ & $f_{gas}<0.2$



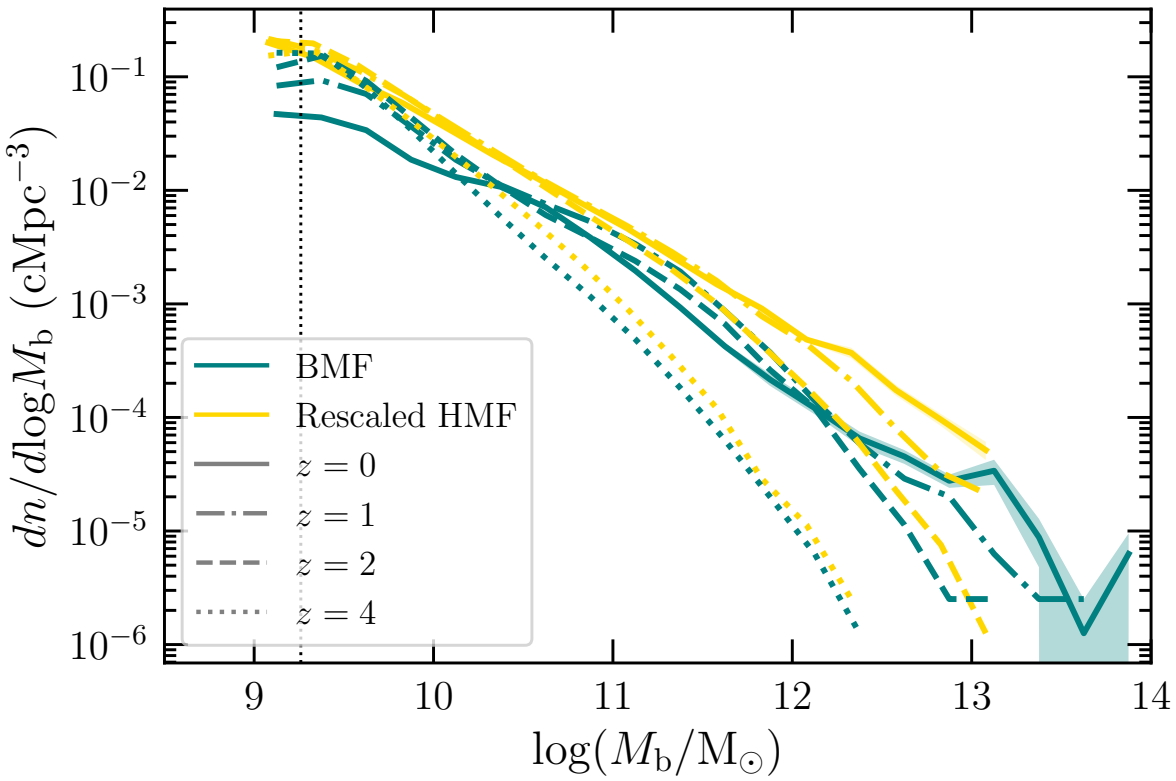
[Davé+ 19]

Effect of baryons on mass function more important at lower *z*

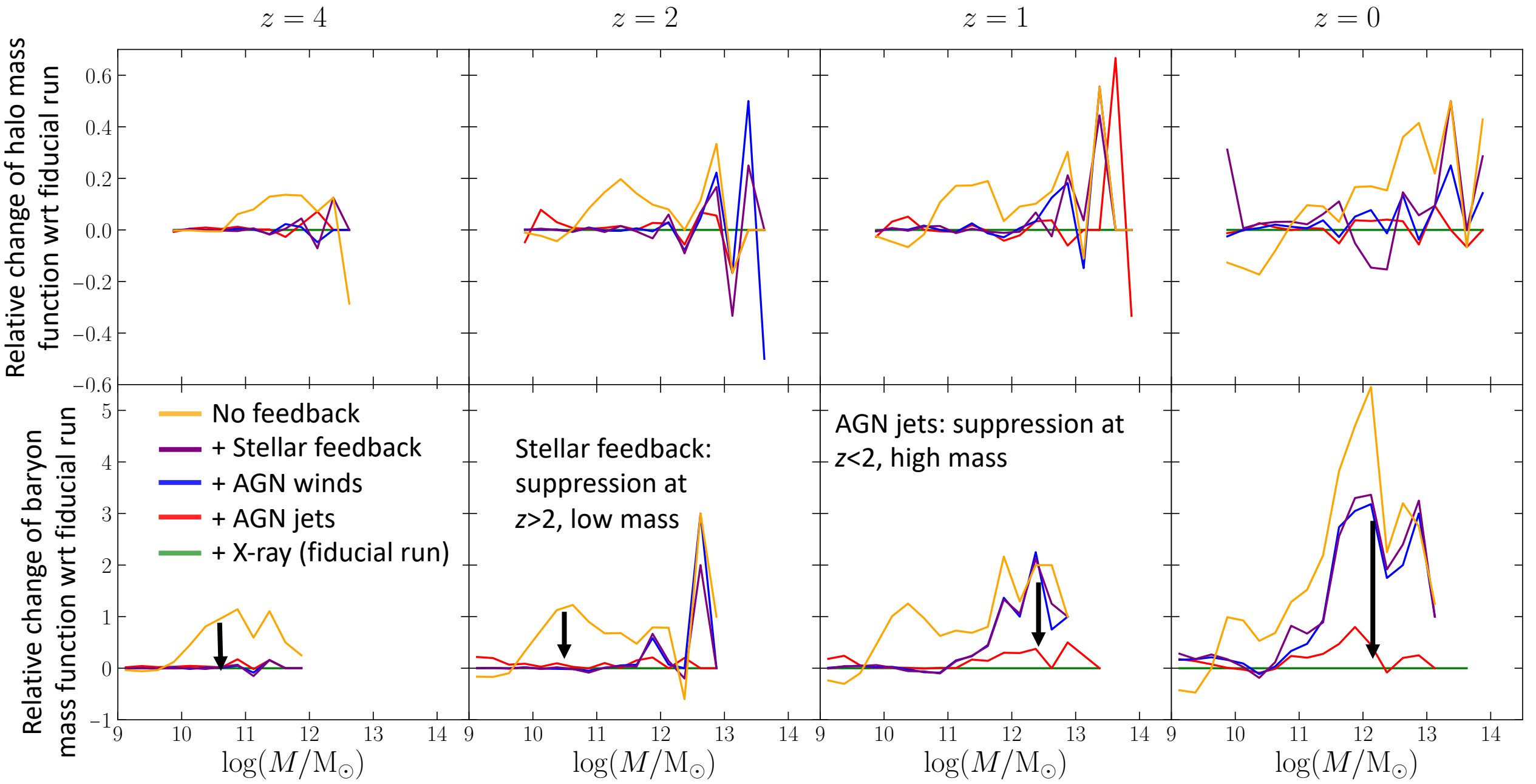
HALO MASS FUNCTION



BARYONIC MASS FUNCTION

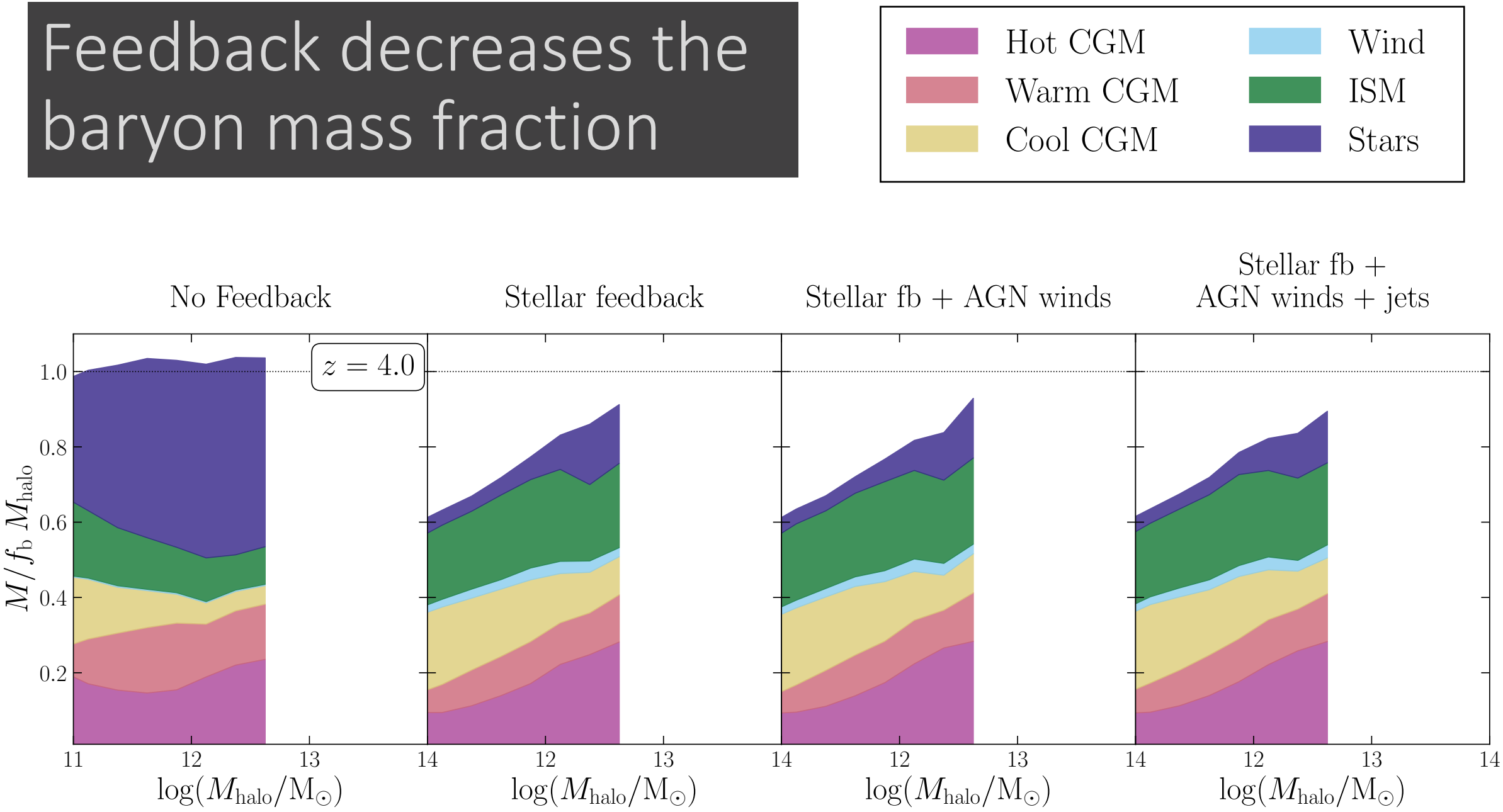


[Sorini+ sub.]


$z = 4$
$z = 2$
$z = 1$
$z = 0$
Relative change of halo mass function wrt fiducial run
Relative change of baryon mass function wrt fiducial run
No feedback
+ Stellar feedback
+ AGN winds
+ AGN jets
+ X-ray (fiducial run)
Stellar feedback: suppression at z>2, low mass
AGN jets: suppression at z<2, high mass
$\log(M/\mathrm{M}_\odot)$

[Sorini+ sub.]

Feedback decreases the baryon mass fraction



[Sorini+ sub.]

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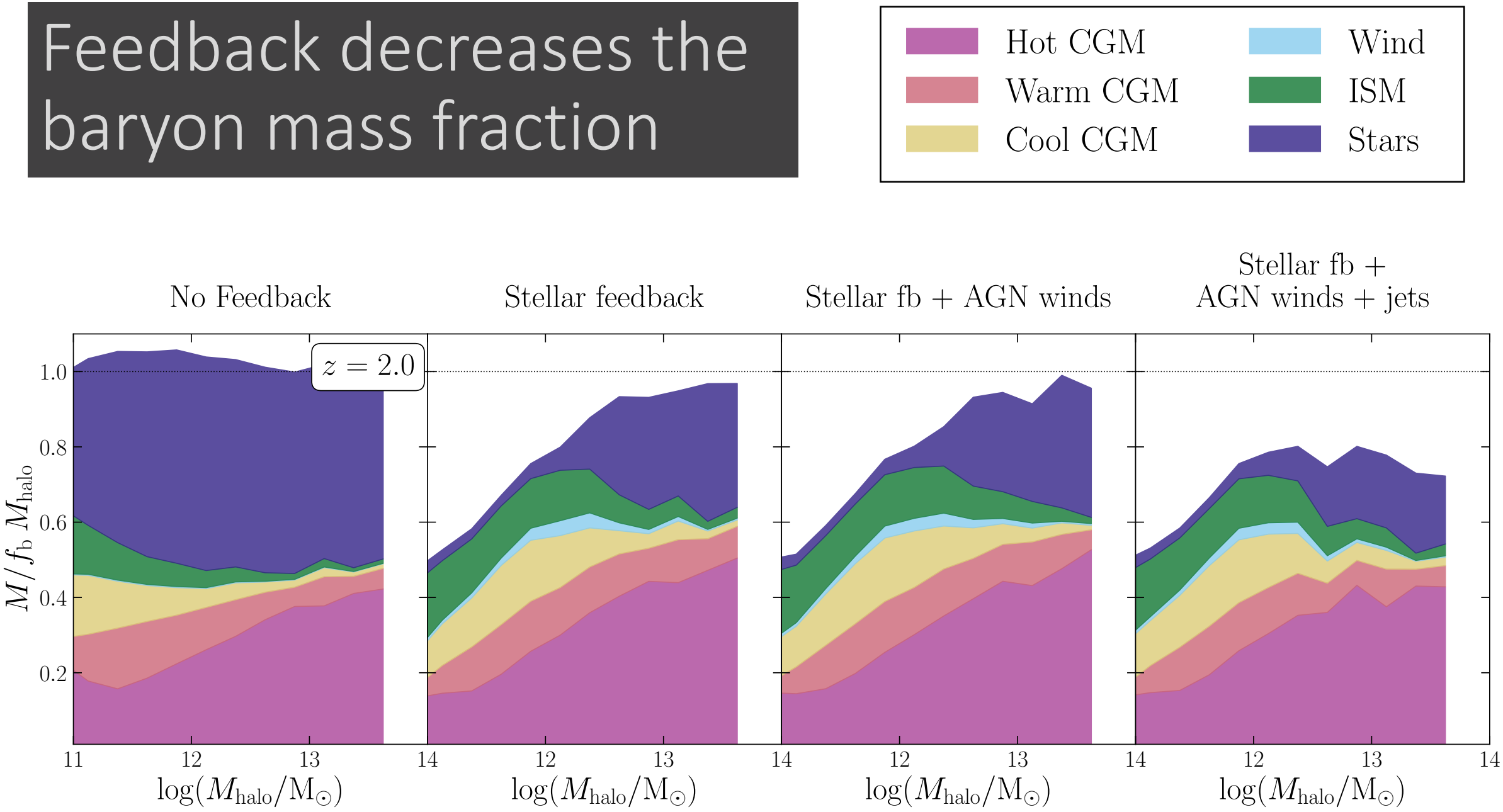
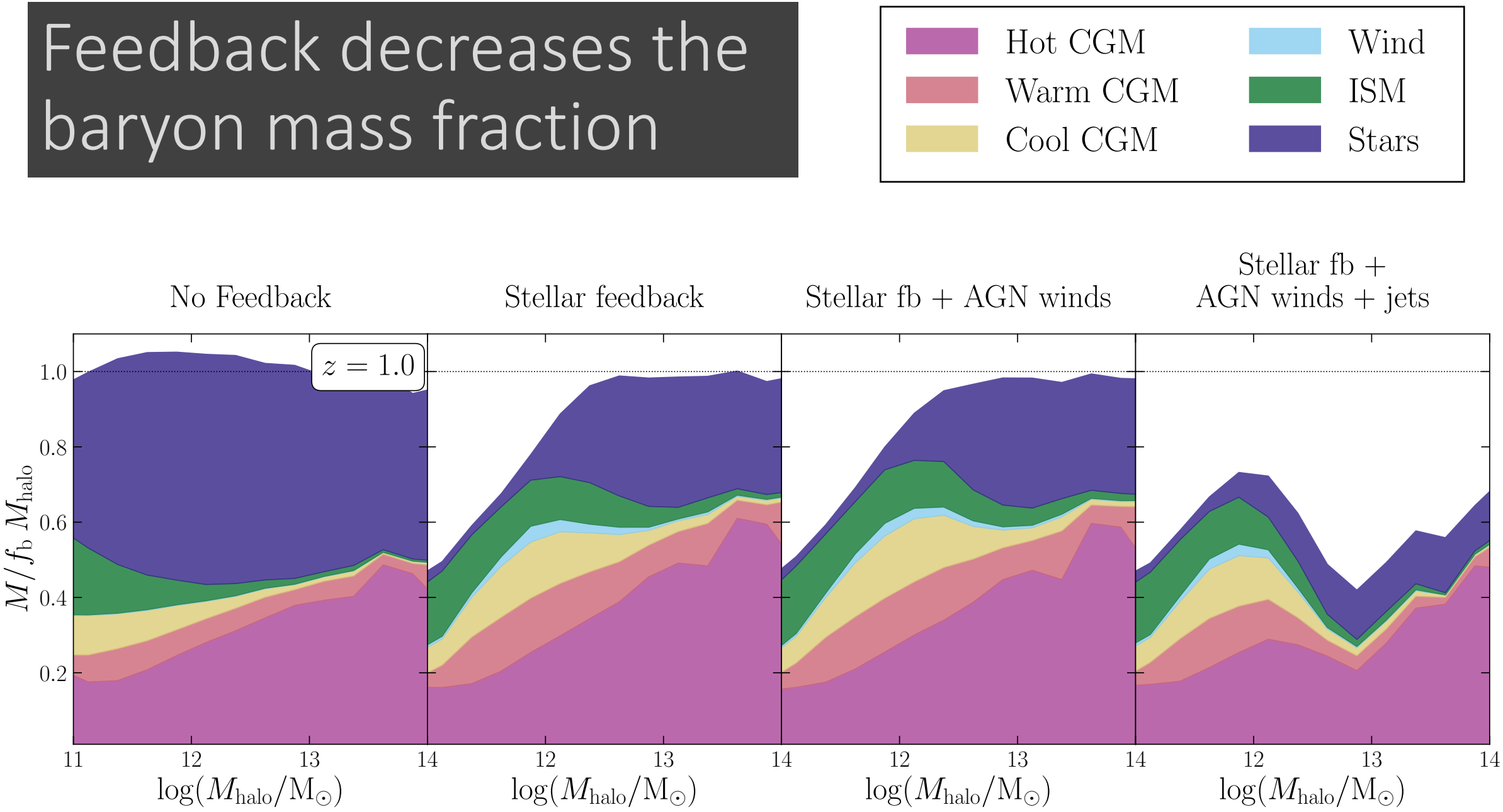


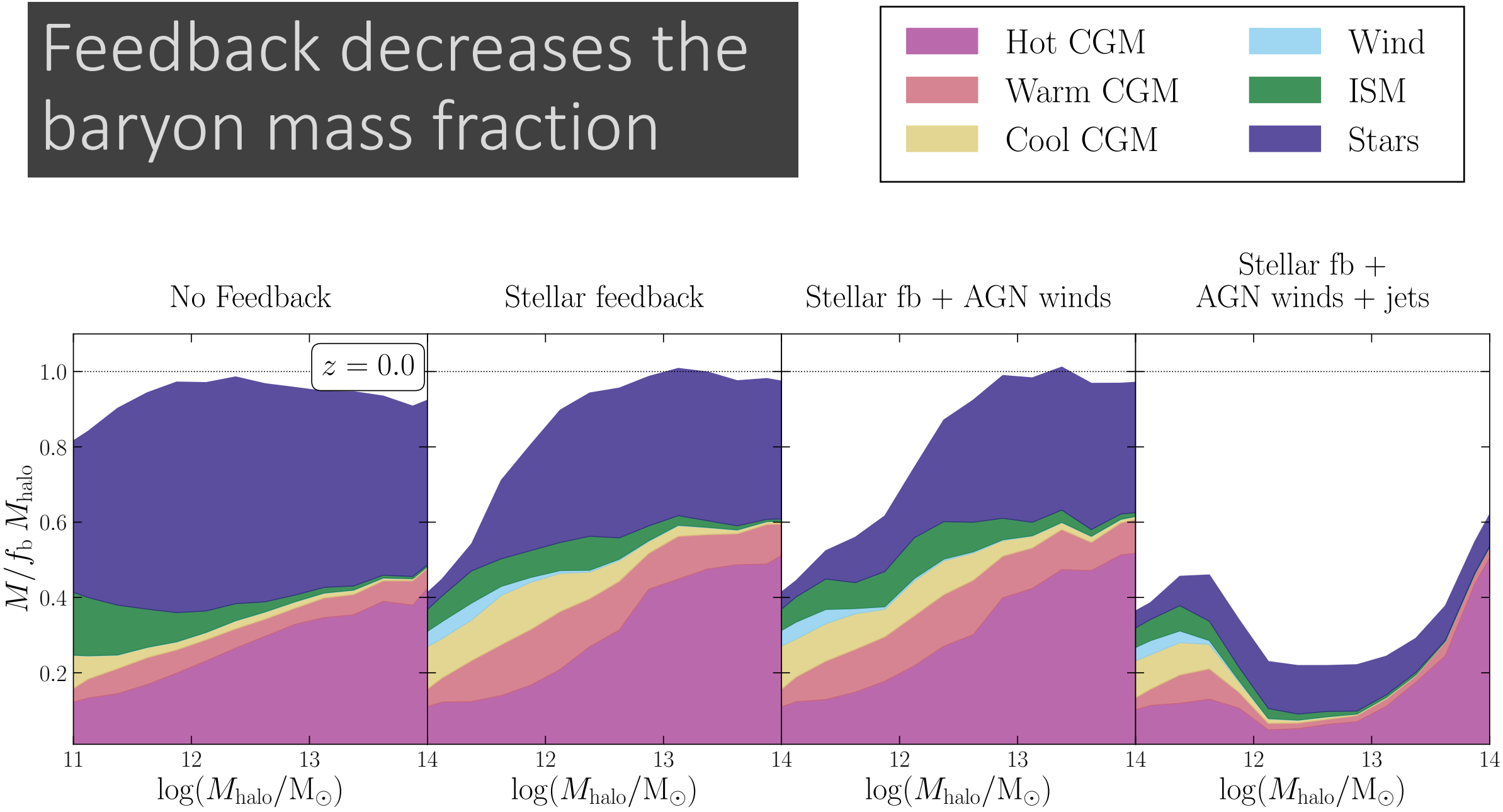
[Sorini+ sub.]

Feedback decreases the baryon mass fraction



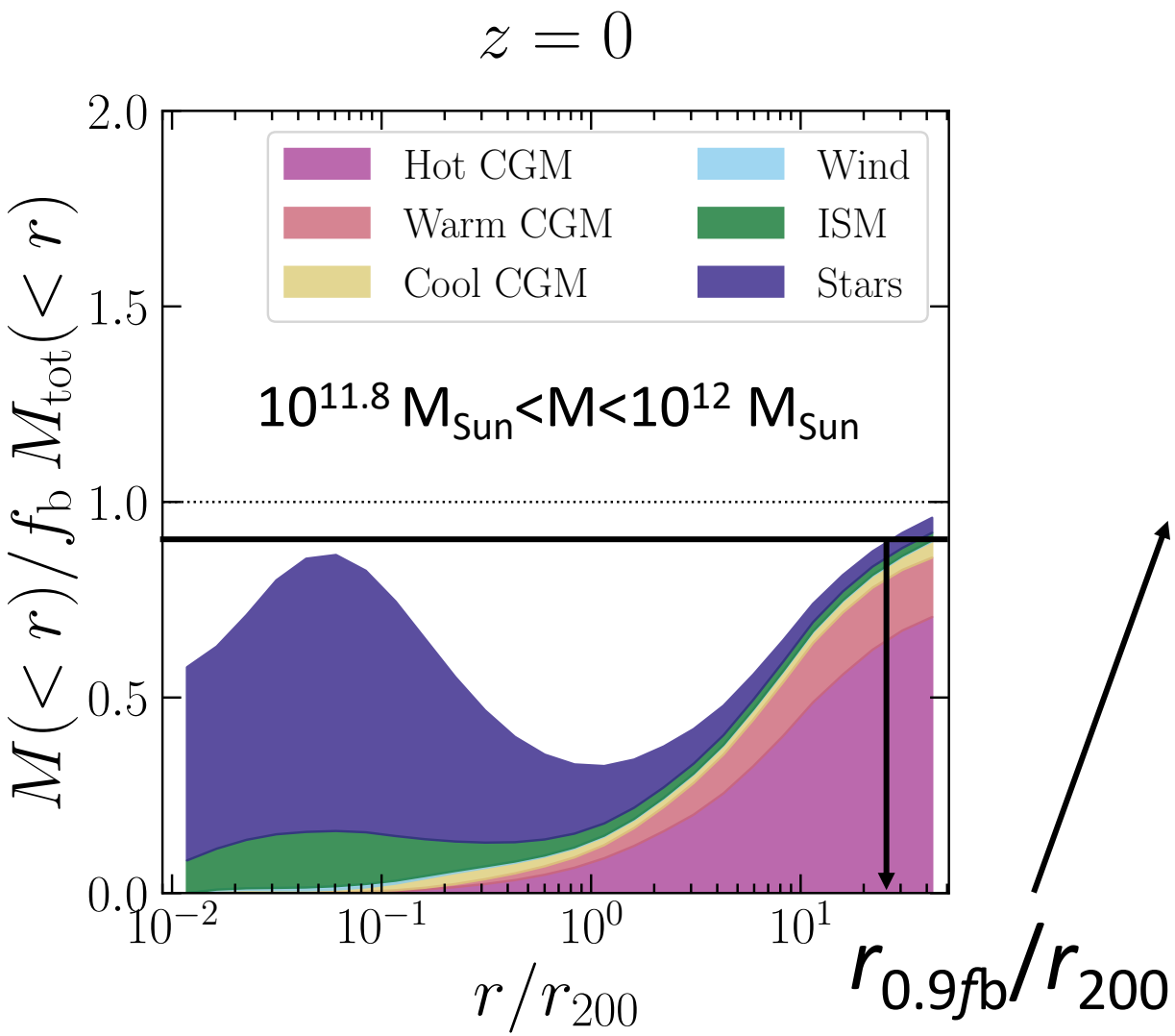
[Sorini+ sub.]

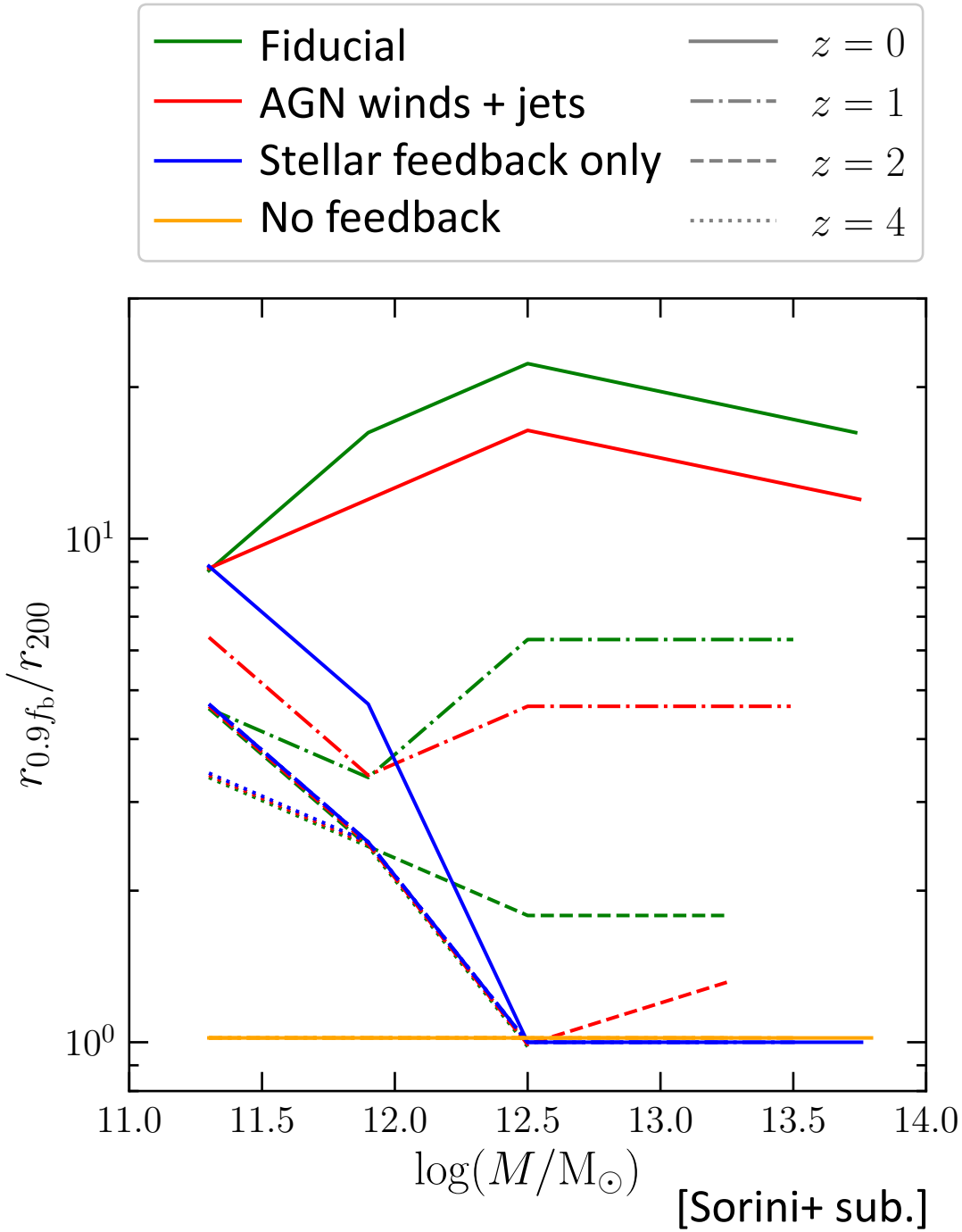
Feedback decreases the baryon mass fraction



[Sorini+ sub.]

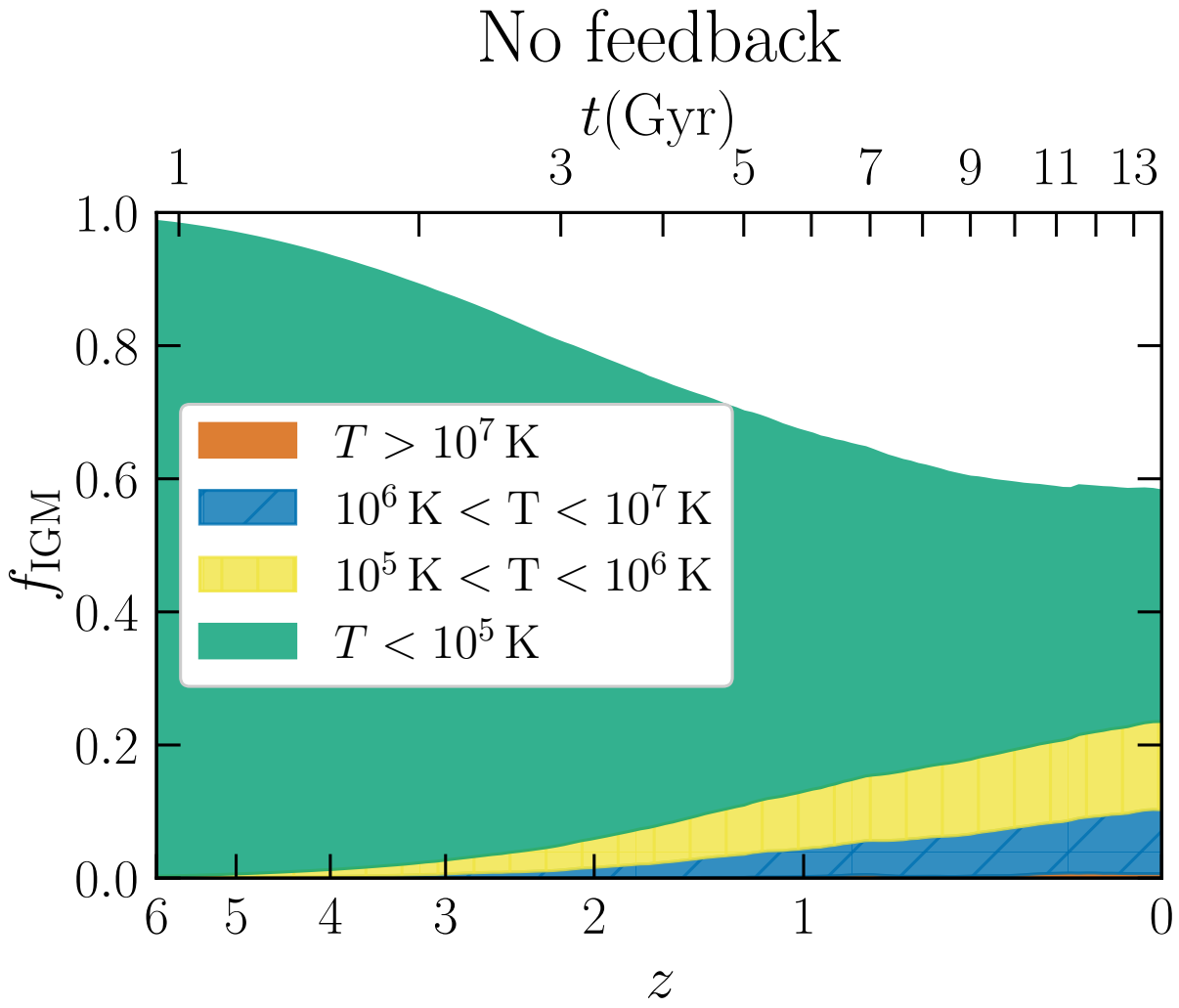
AGN jets push baryons out to ~20 r_{200} by z=0





[Sorini+ sub.]

z<2: AGN jets transfer hot gas from halos to the IGM



[Sorini+ sub.]

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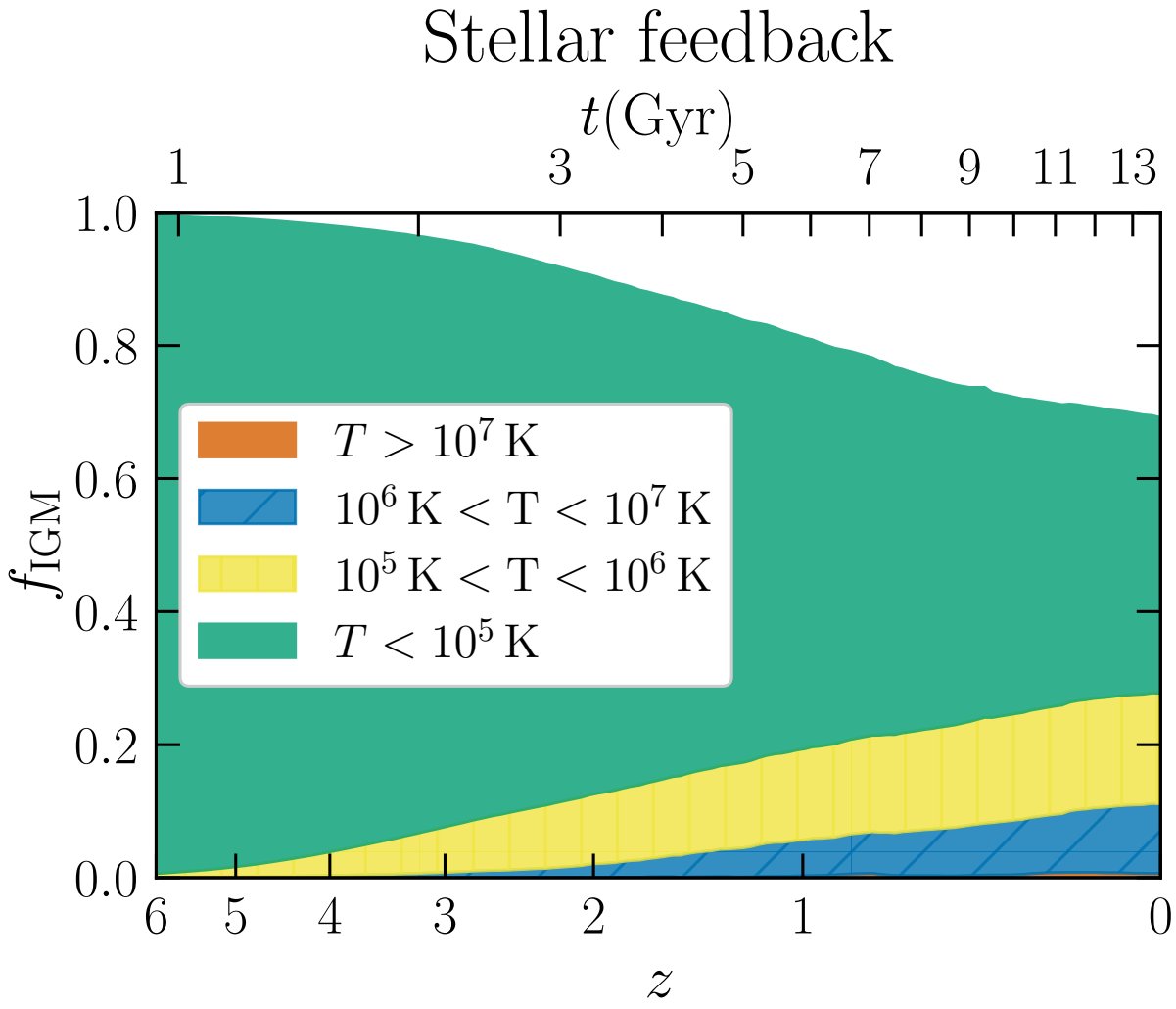

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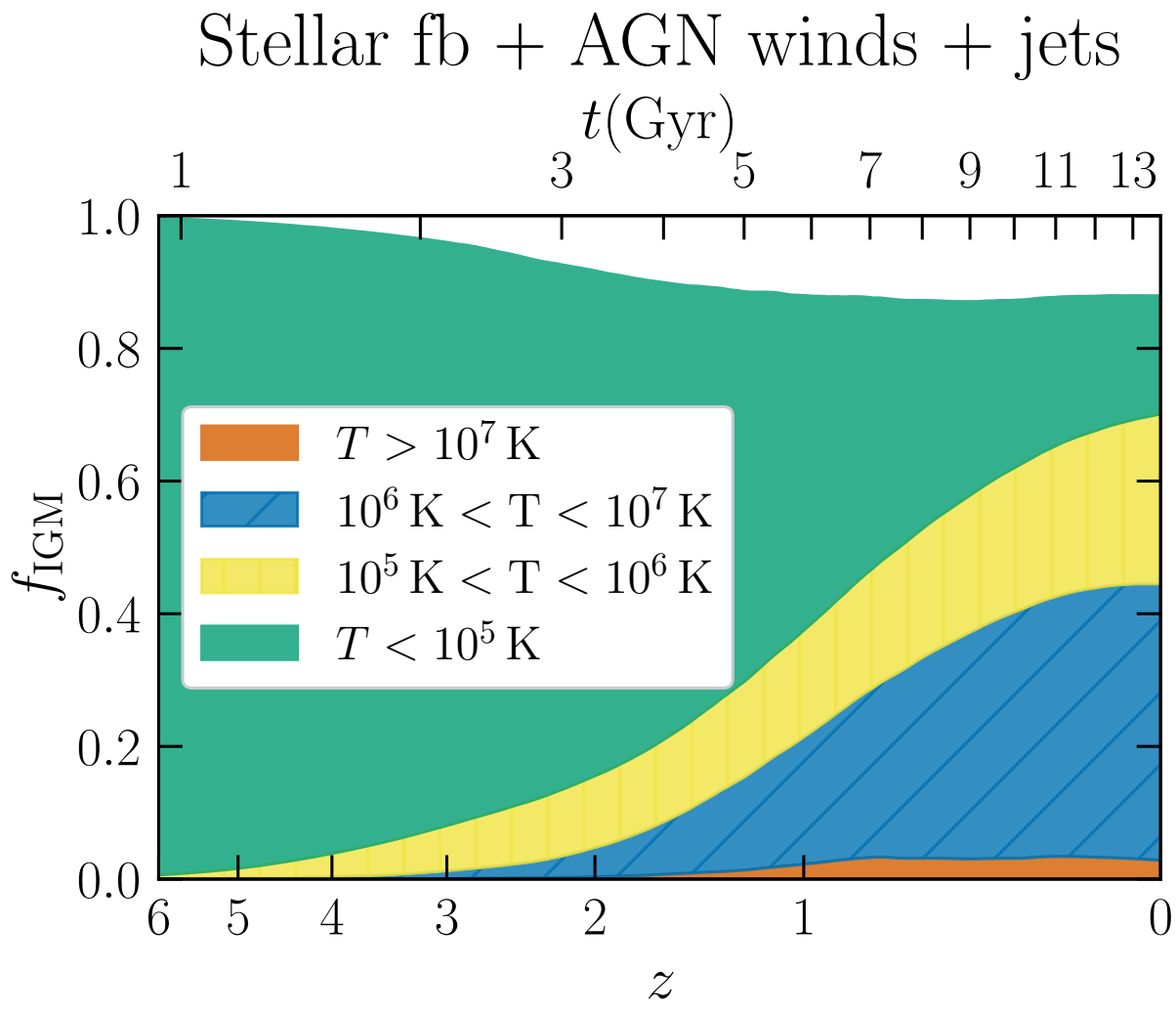
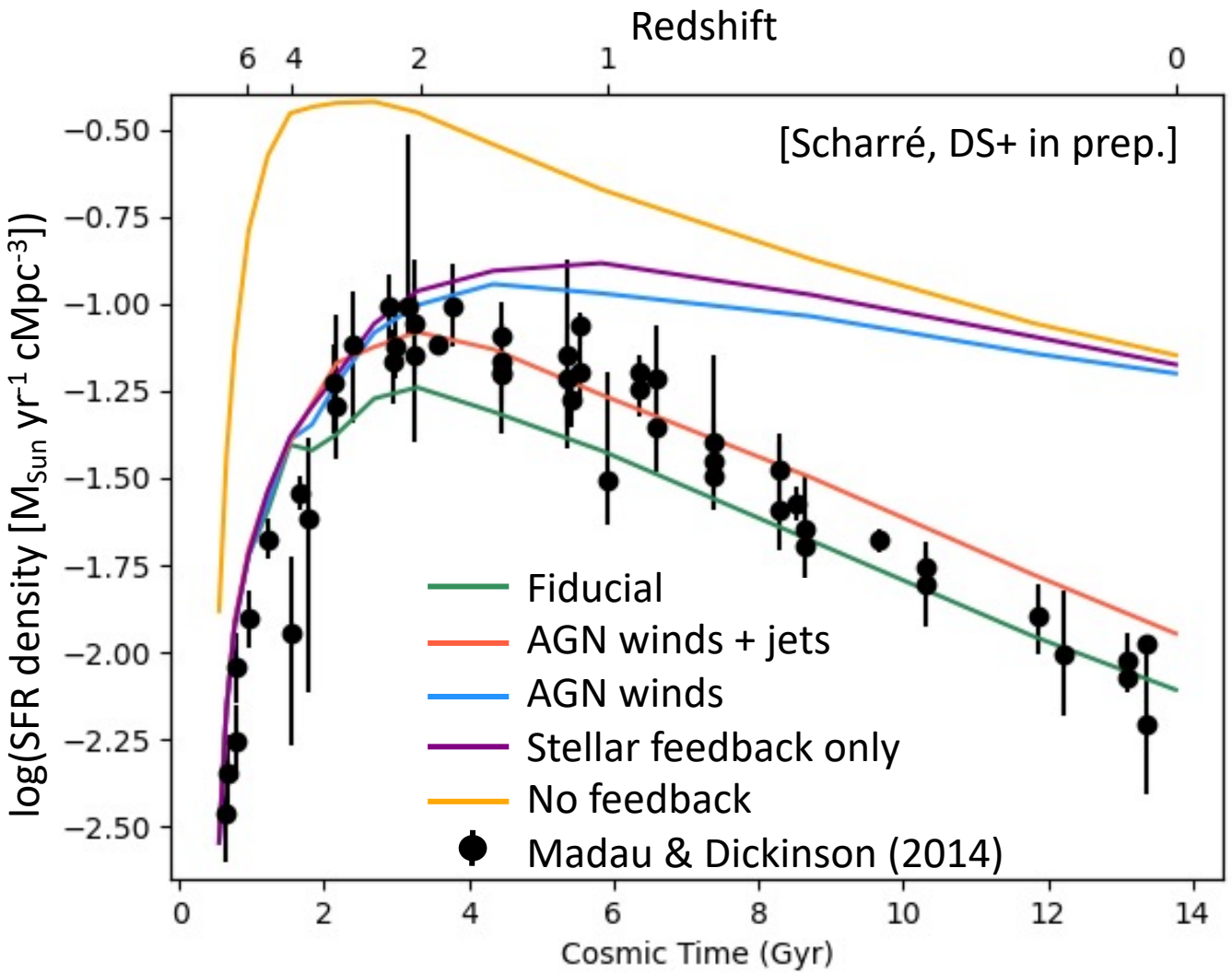


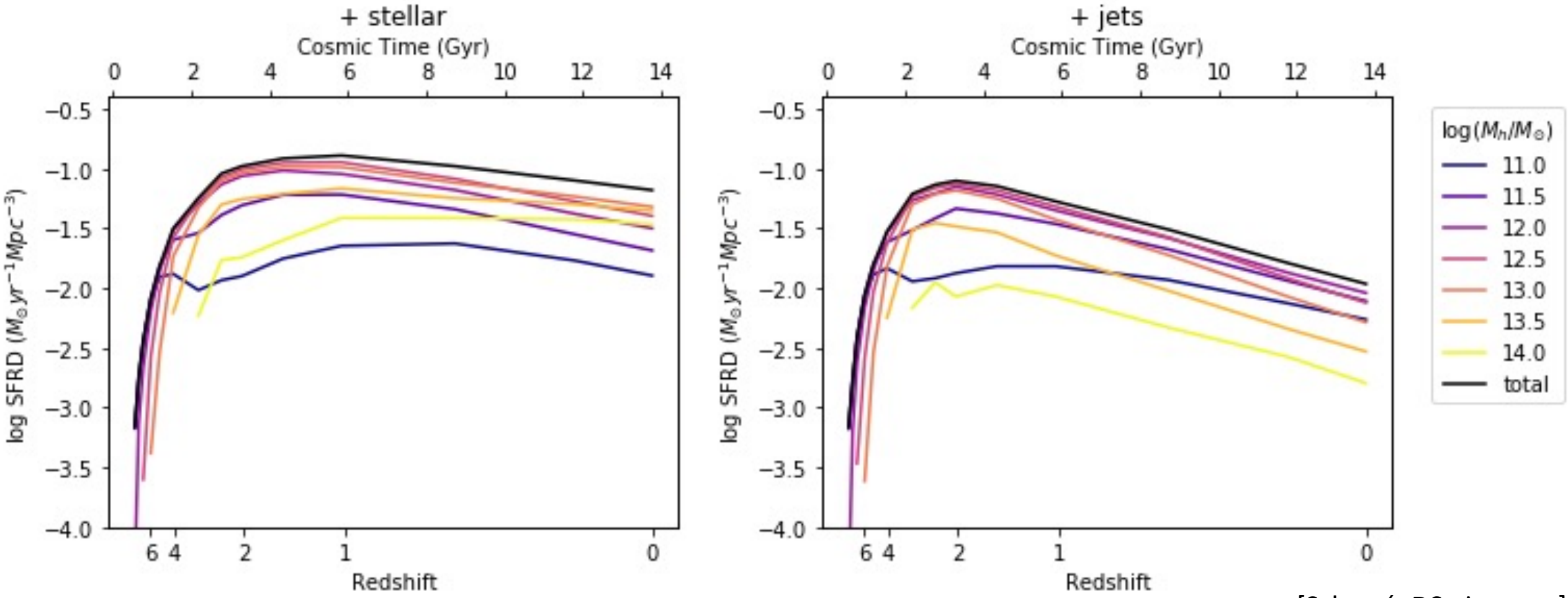
[Sorini+ sub.]

AGN jets suppress late-time star formation



[see also Vogelsberger+2013, Weinberger+ 2017]

Which halos contribute the most?



[Scharré, DS+ in prep.]

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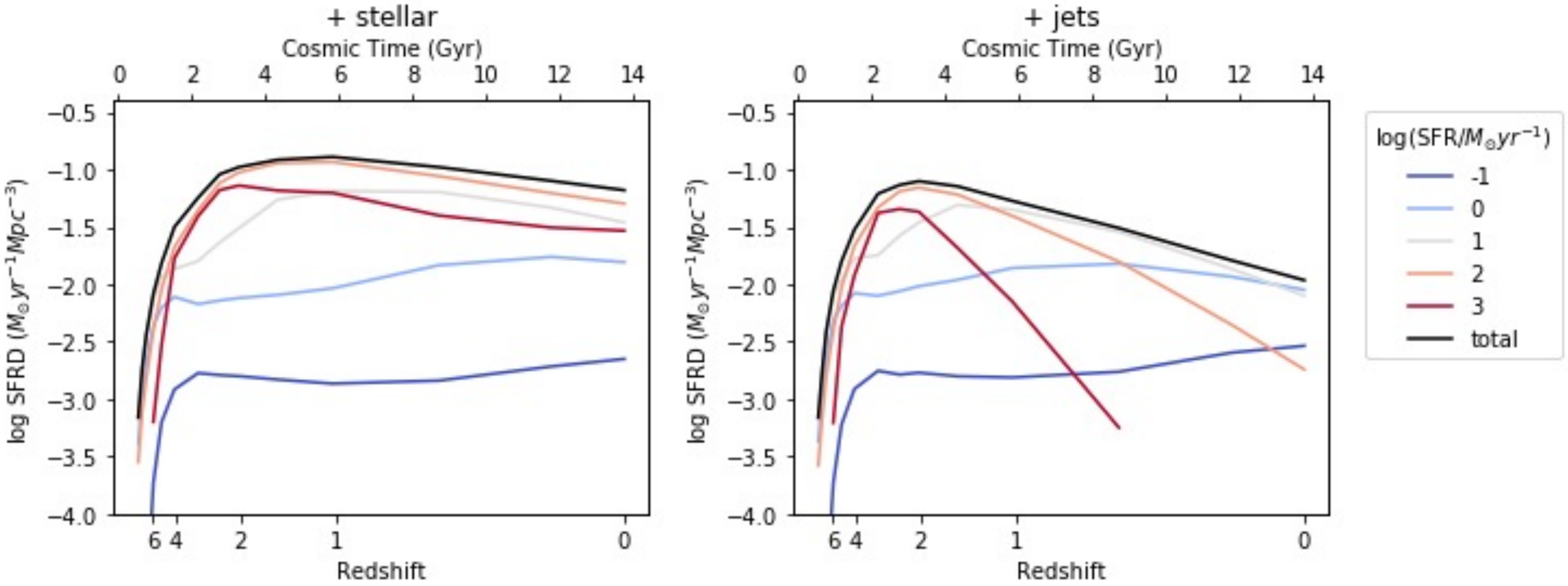
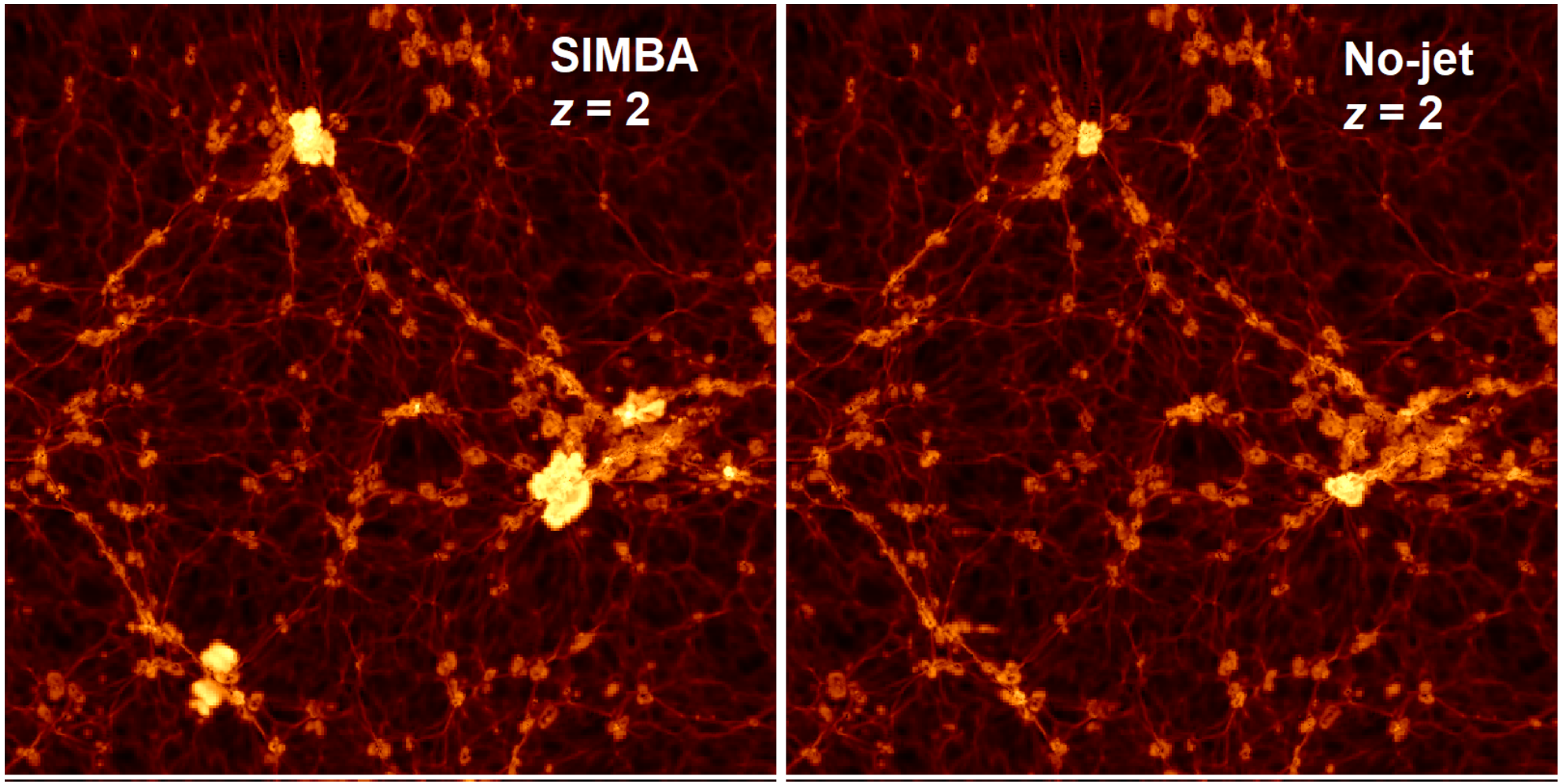


[Scharré, DS+ in prep.]

Jets turn on at z<2



[Christiansen, Davé, DS+ 2020]

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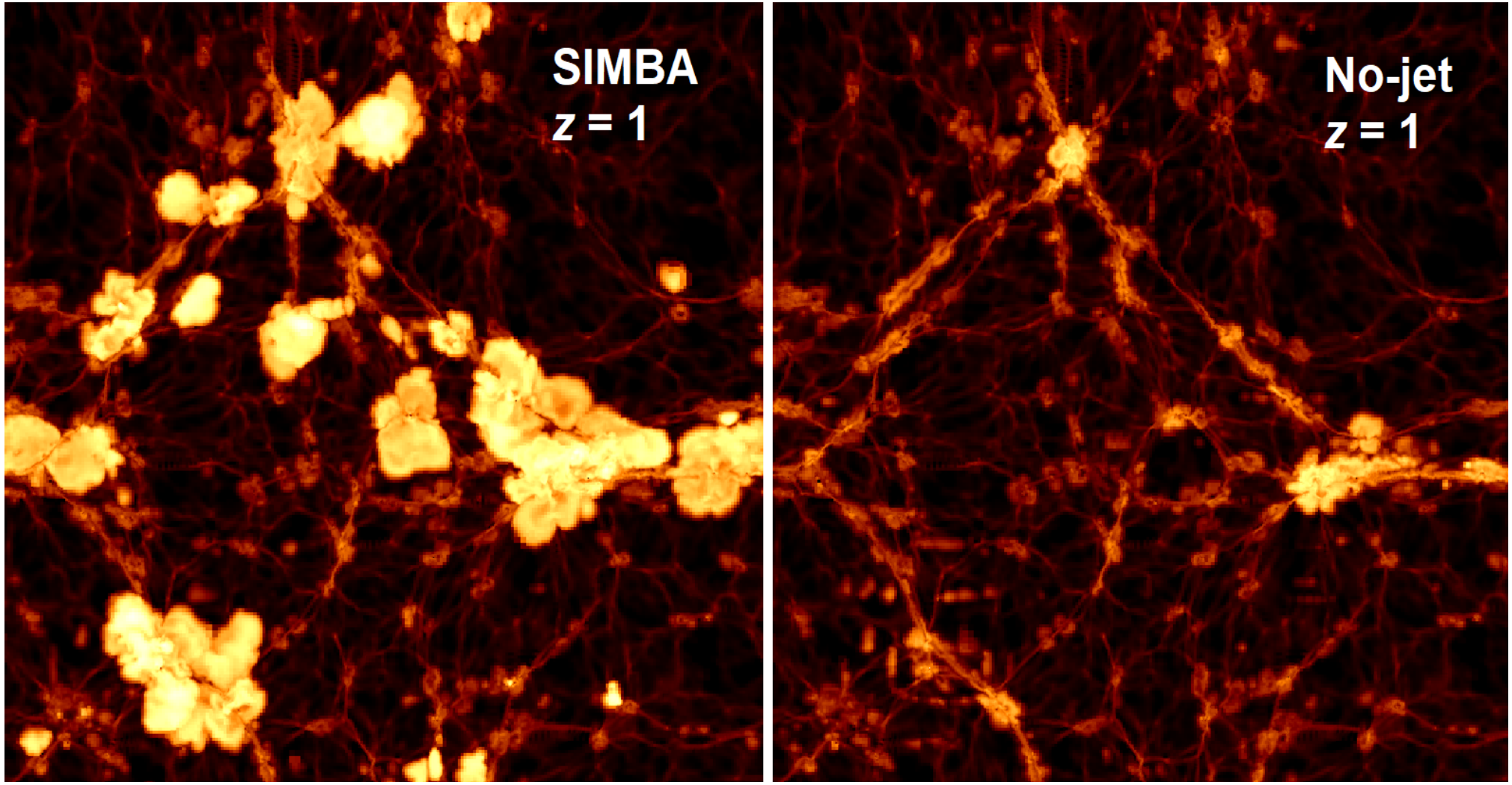

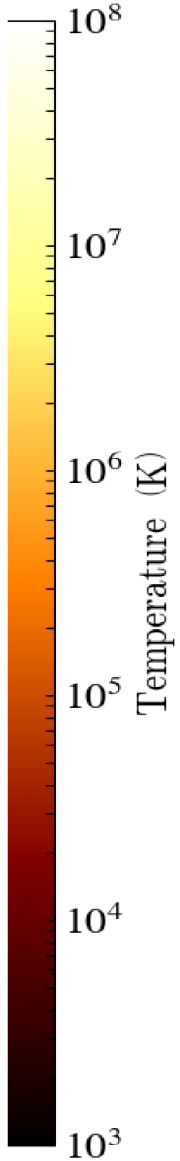

[Christiansen, Davé, DS+ 2020]

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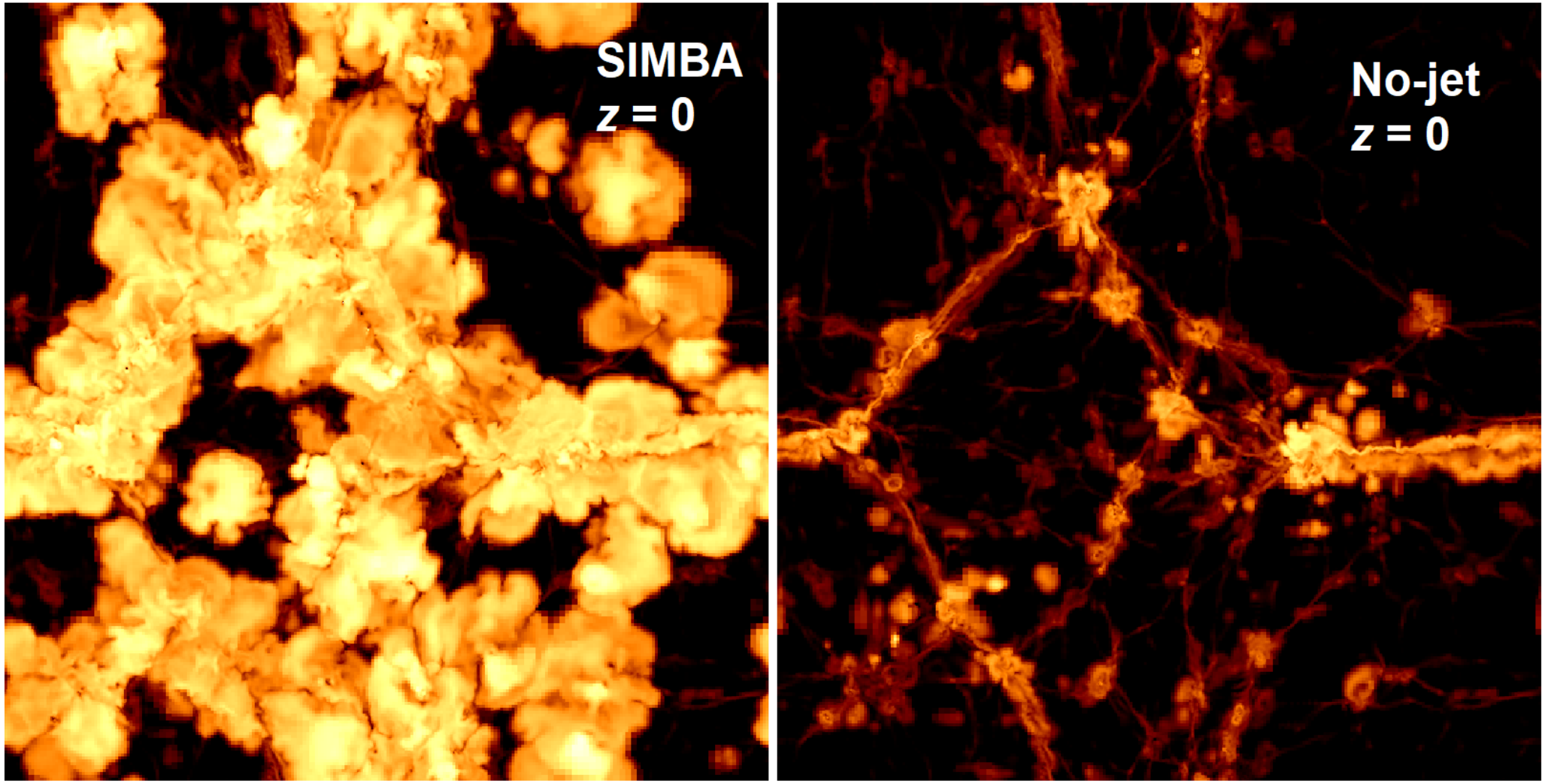

[Christiansen, Davé, DS+ 2020]

arXiv:2111.13708

Conclusions

Main mechanisms shaping the distribution of baryons in the universe, the thermal state of the IGM and star formation history:

- Stellar feedback in lower mass halos at $z>2$
- AGN jets in higher mass halos at $z<2$