@ CSST-Galaxy-AGN Discussion

AGN feedback in Simulations

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Composite Figure: X-ray+Radio+Optical

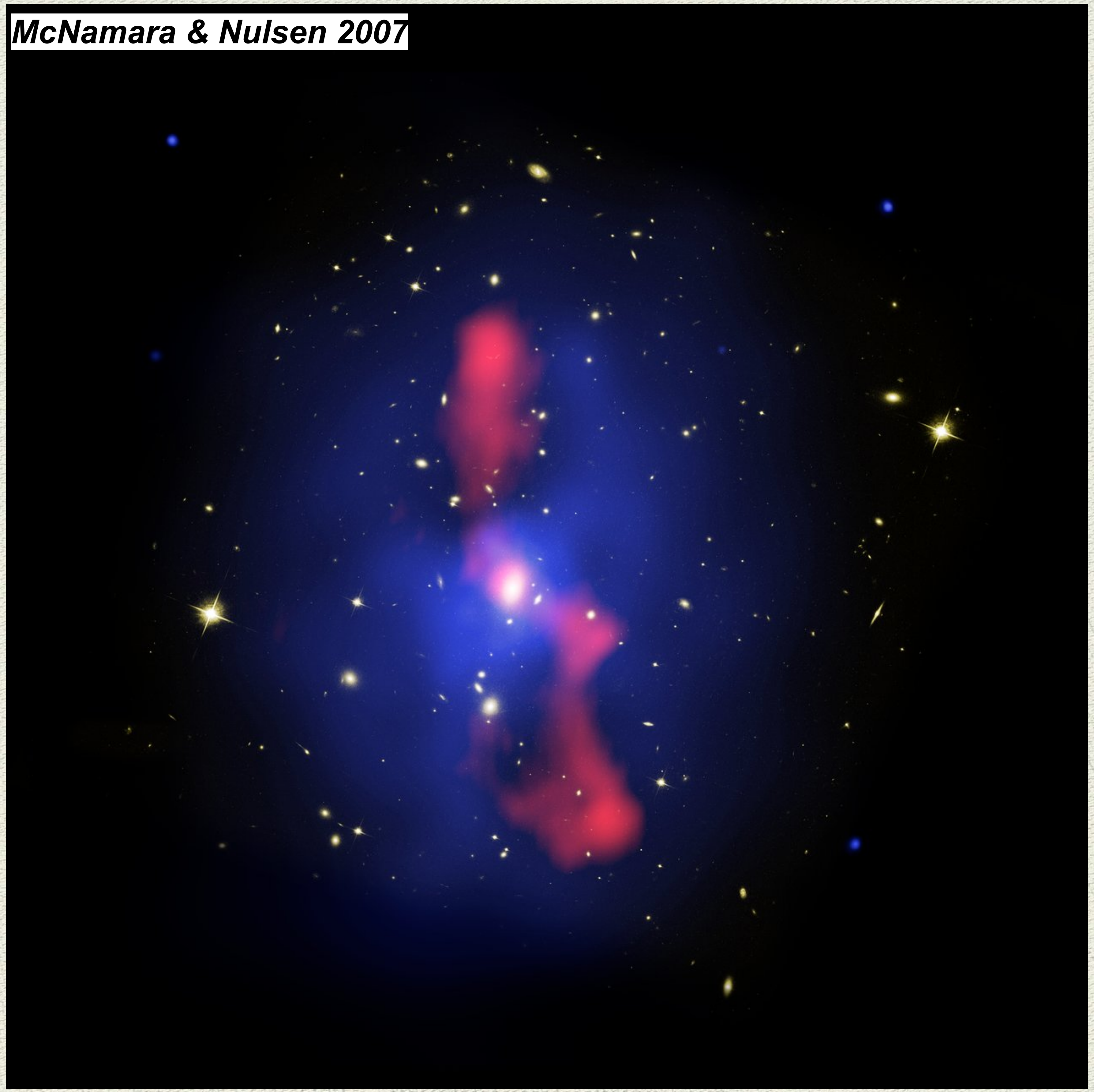
Perseus A (NGC 1275)

Contents

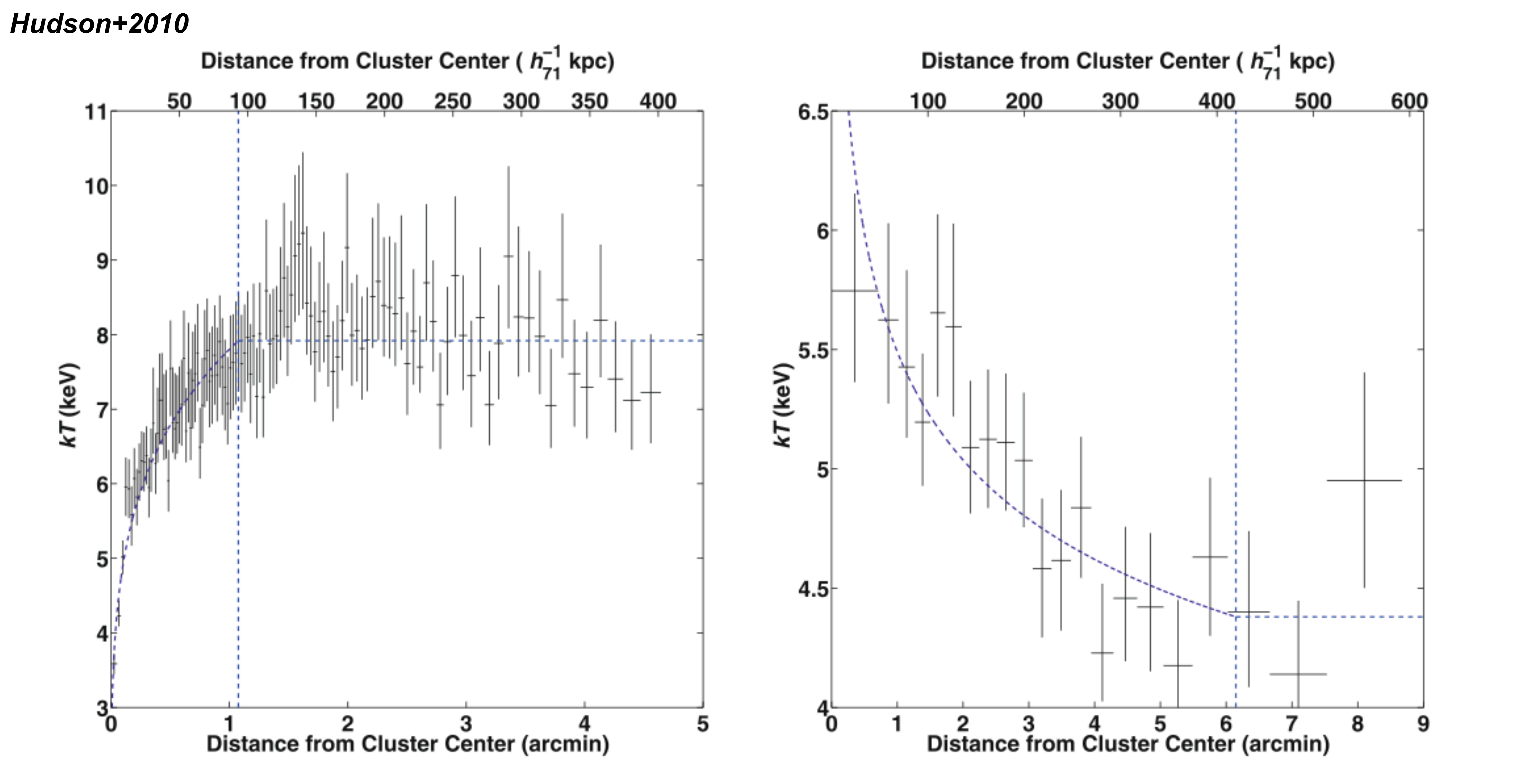
- "AGN Feedback"—The missing puzzle?
- Feedback models — two-mode scenario or others
- Feedback in Cosmological Simulations
- Summary
- Role of future observations (CSST)

Why AGN feedback—obs. side

Mass & energy output



Cool-core clusters

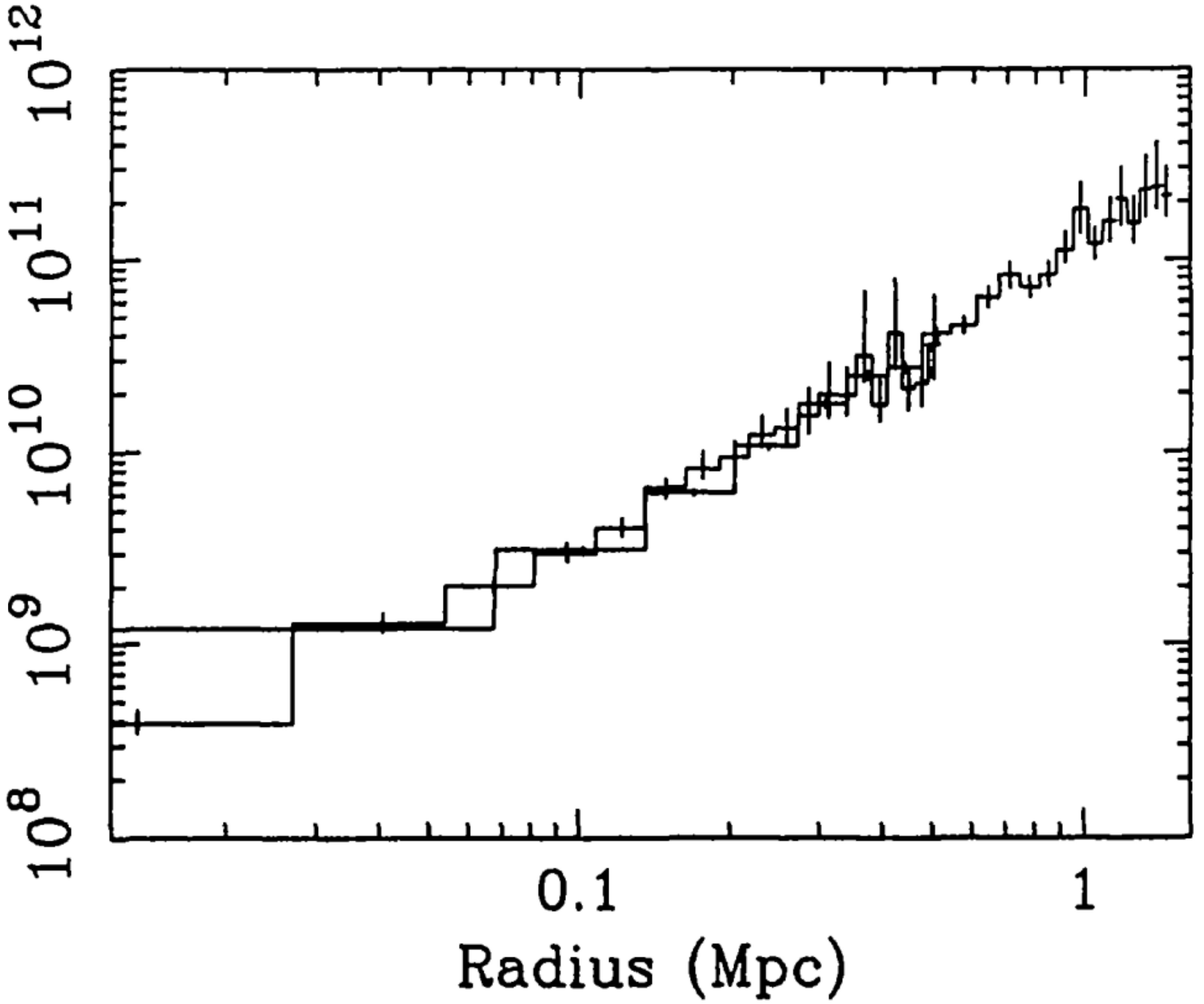


Why AGN feedback—obs. side

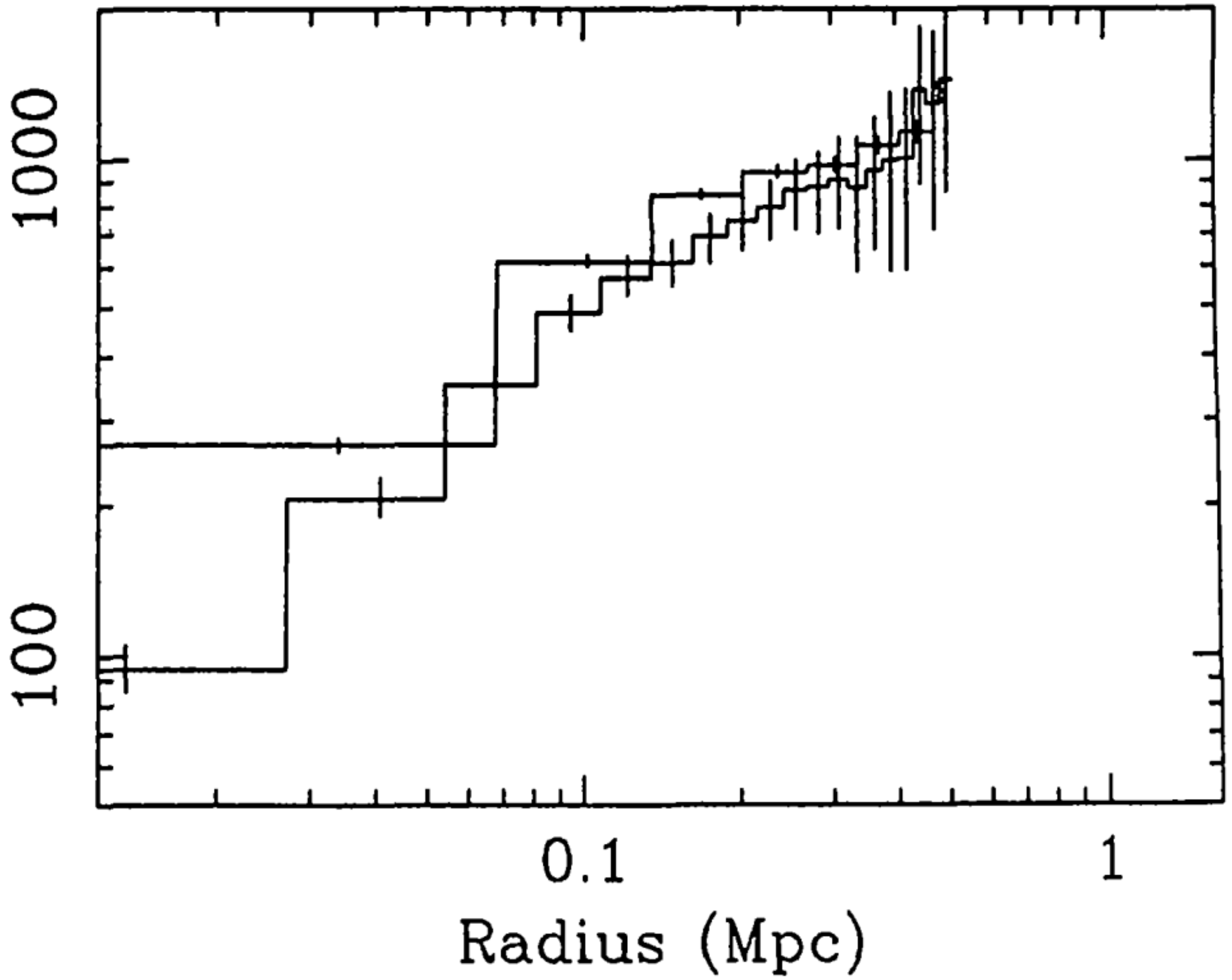
Cooling flow problem

Fabian+1994

Cooling time (yr)



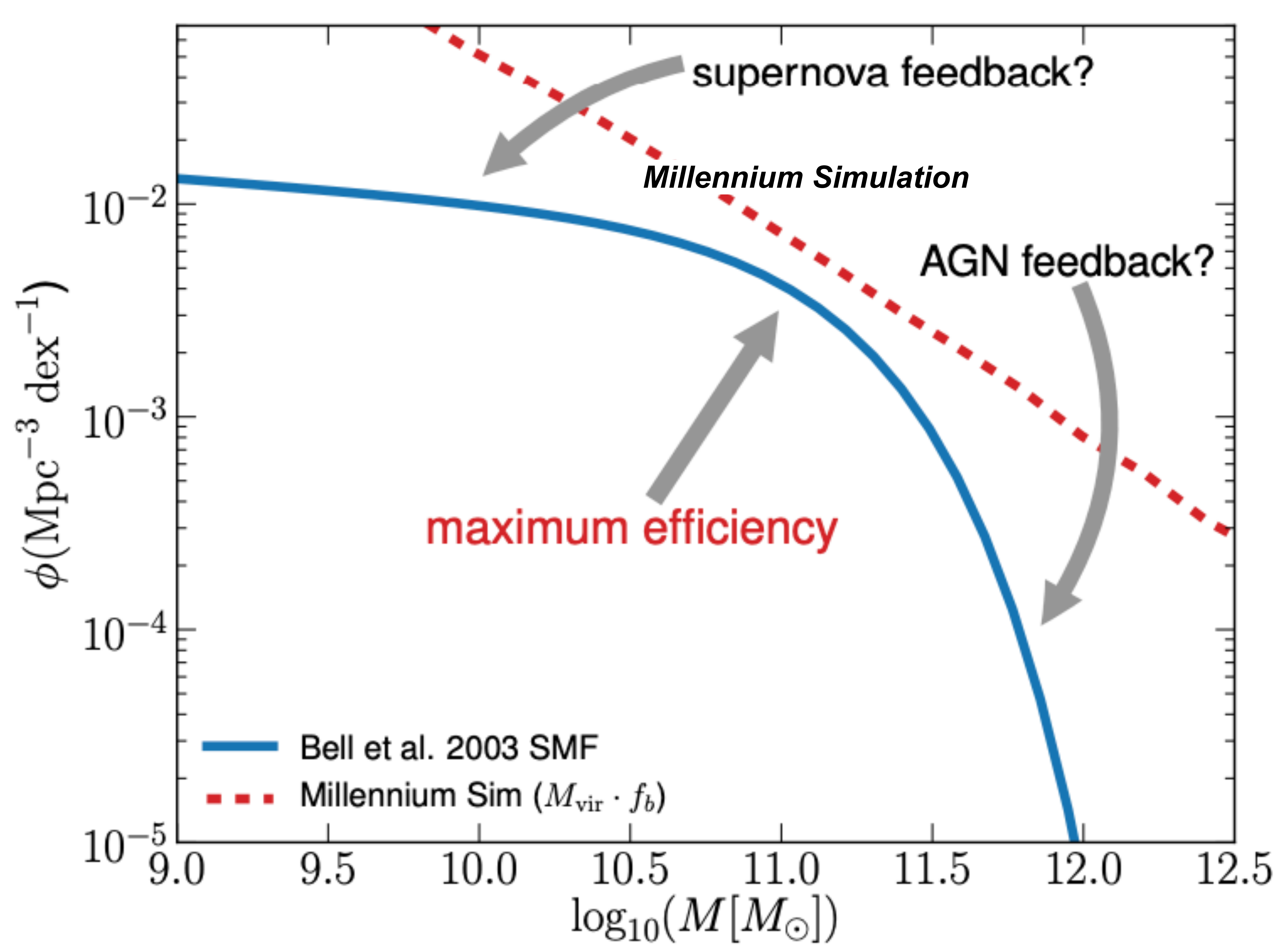
Cooling rate ($M_\odot$/yr)



Why AGN feedback—sim. side

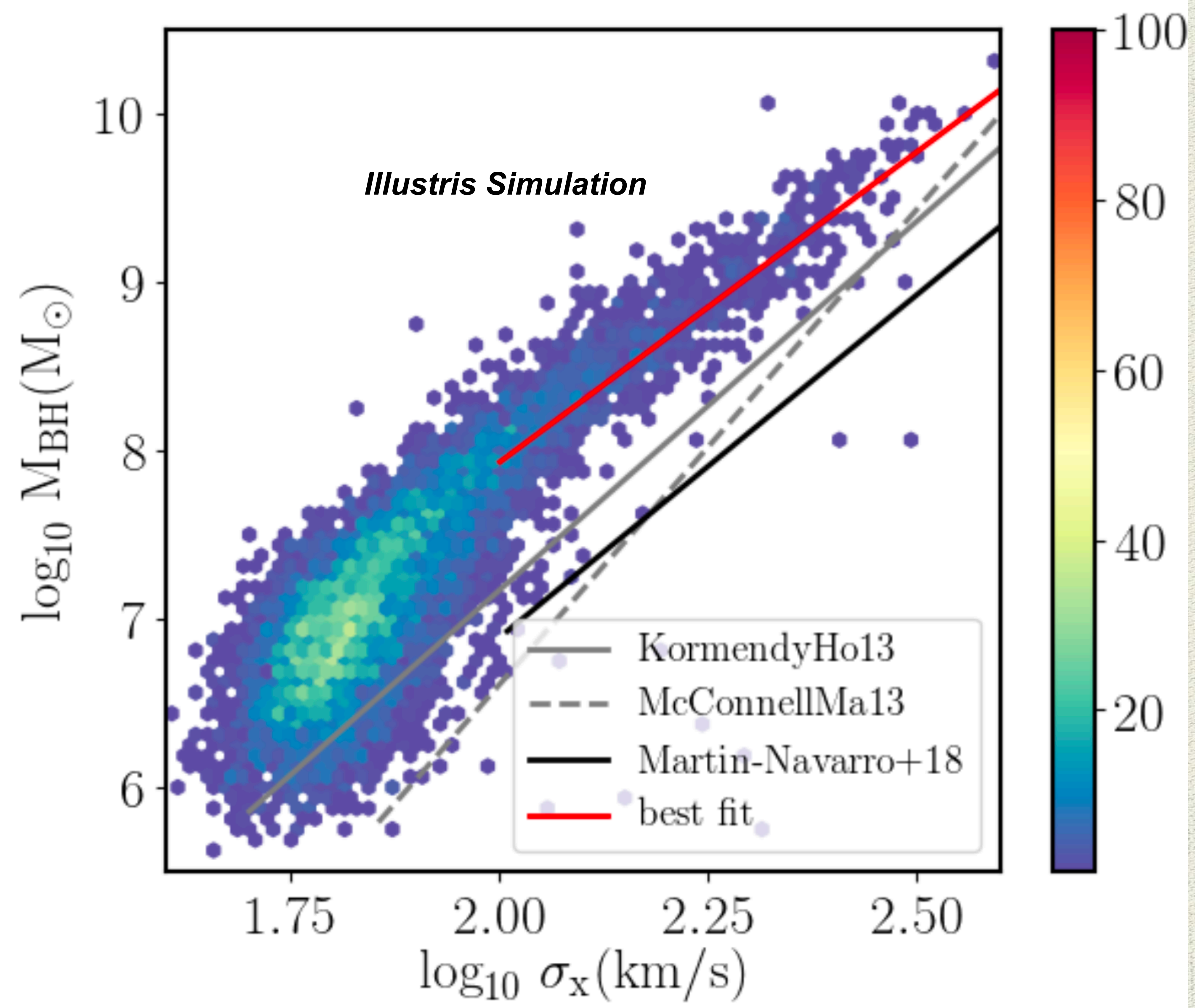
Overproduction of stellar mass

Mutch+2018



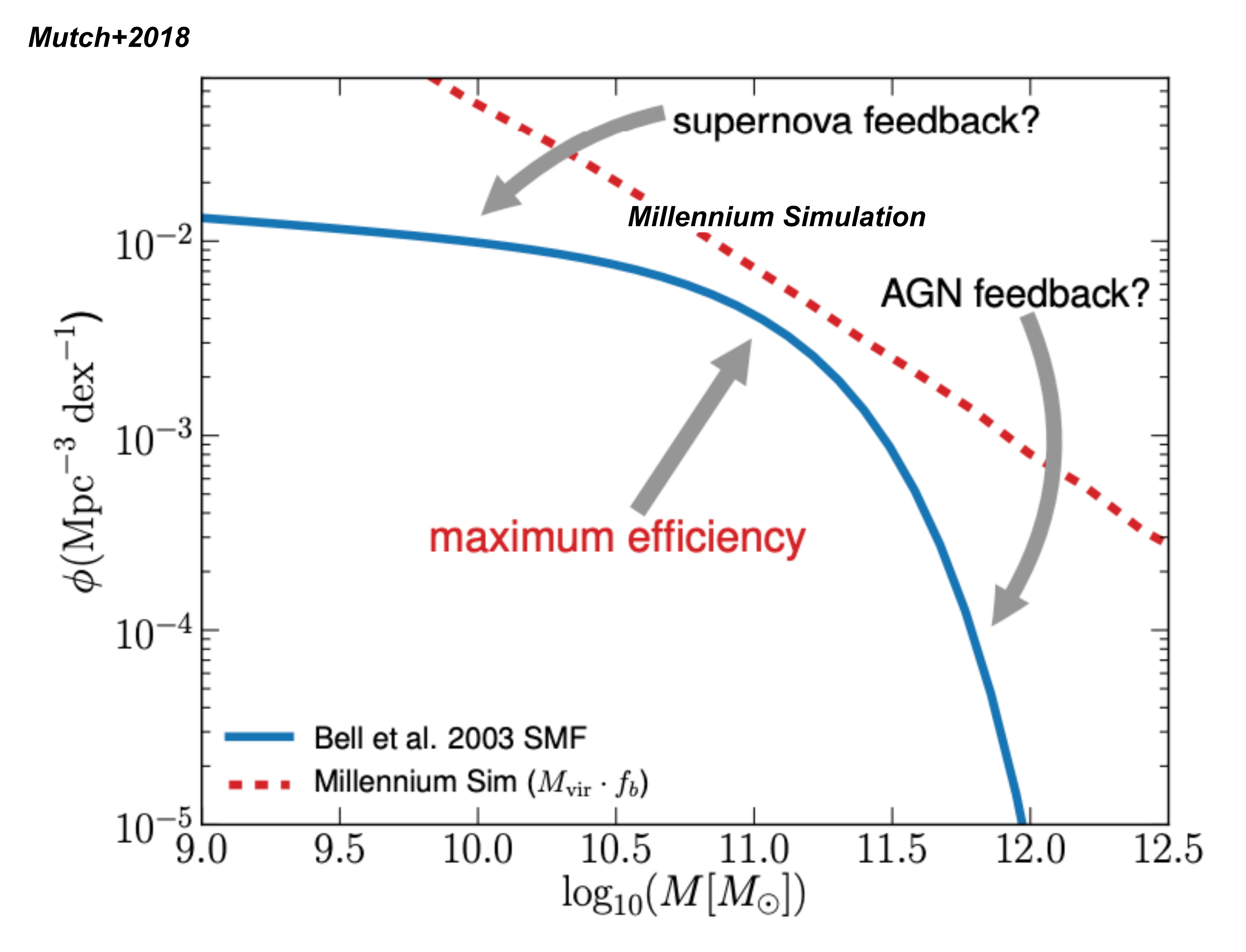
Location relative to M-sigma relation

Li+2019

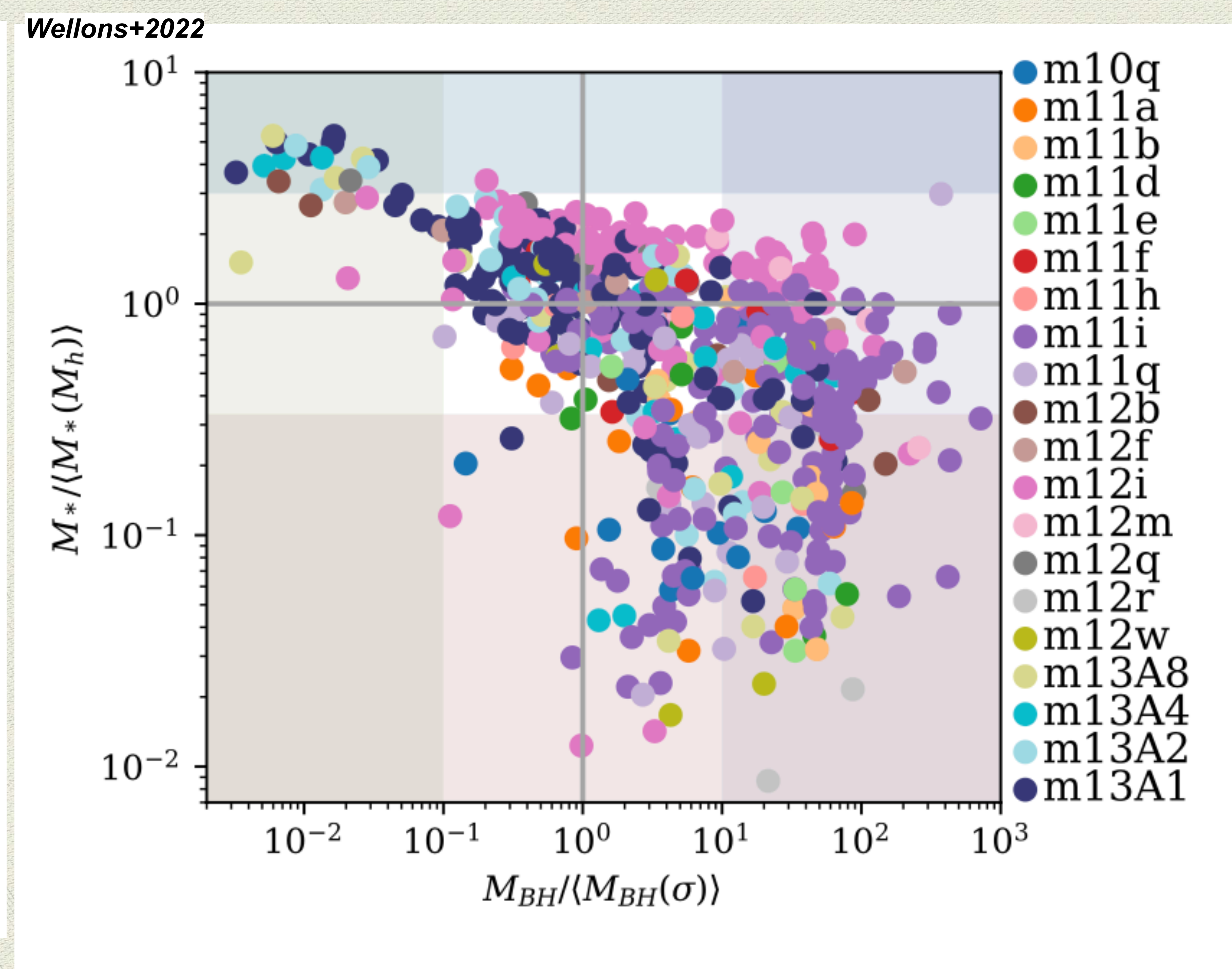


Why AGN feedback—sim. side

Overproduction of stellar mass



Location relative to M-sigma relation



Feedback models

- Depend on SMBH feeding models (last talk by Li)
  - Two-mode feedback (most frequently used)
    - Quasar mode (high $\dot{M}$) & radio mode (low $\dot{M}$)
  - Others: radiative feedback; cosmic ray (from AGN); Jet feedback (Wellon+2022)
  - Feedback from super-Eddington accretion
    - Radiation; outflows (Kitaki+2021,Hu+2022); Jets (Yang+2022, Curd+2022)

Feedback models

Ward+2022

Simulation	Mode Name	Criteria	Injection Energy Type	Direction	Description
TNG	Thermal	$\lambda_{\rm Edd} \geq \chi\,(M_{\rm BH})$	Thermal	Isotropic	Continuous thermal energy injection into small local environment
	Kinetic	$\lambda_{\rm Edd} < \chi\,(M_{\rm BH})$	Kinetic	Random (averages isotropic)	Pulsed momentum kick in random direction
EAGLE	Thermal (single mode)	Always active	Thermal	Isotropic	Pulsed thermal injection
SIMBA	Wind	Always active	Kinetic	Bipolar	Kinetic kick, $v \leq 1000$ km s^{-1}
	Jet	$\lambda_{\rm Edd} < 0.2$ $M_{\rm BH} > 10^{7.5} M_{\odot}$	Kinetic (& few % thermal)	Bipolar	Kinetic kick, $v \leq 7000$ km s^{-1}, temperature raised to $T_{\rm halo}$
	X-ray	$\lambda_{\rm Edd} < 0.02$ $f_{\rm gas} < 0.2$	Thermal (non-ISM gas) or thermal & kinetic (ISM gas)	Isotropic	Local thermal heating

Table 1. A summary of the subgrid implementations for AGN feedback in the three simulations. We note that, for simplicity, we neglect the X-ray mode in SIMBA as it has negligible impact on the initial quenching of galaxies (Davé et al. 2019). Refer to Section 2.1 for the definitions of $\chi\,(M_{\rm BH})$ and $\lambda_{\rm Edd}$.

Feedback models

Habouzit+2021

	Illustris	TNG100	TNG300	Horizon-AGN	EAGLE	SIMBA
AGN feedback						
Single or 2 modes	2 modes	2 modes	2 modes	2 modes	single mode	2 modes
High acc rate model	isotropic thermal	isotropic thermal	isotropic thermal	isotropic thermal	isotropic thermal	kinetic
Feedback efficiency	$0.05 \times 0.2 = 0.01$	$0.1 \times 0.2 = 0.02$	$0.1 \times 0.2 = 0.02$	$0.15 \times 0.1 = 0.015$	$0.1 \times 0.15 = 0.015$	$0.03 \times 0.1 = 0.003$
Low acc rate model	thermal hot bubble	pure kinetic winds	pure kinetic winds	kinetic bicanonical winds	–	kinetic/ X-ray
Feedback efficiency	$0.35 \times 0.2 = 0.07$	$\leqslant 0.2 \times 0.2 = 0.04$	$\leqslant 0.2 \times 0.2 = 0.04$	$1 \times 0.1 = 0.1$	–	$0.3 \times 0.1 = 0.03$
Transition btw. modes	$f_{\rm Edd} = 0.05$	$\min(0.002 \left(\frac{M_{\rm BH}}{10^8\,{\rm M}_\odot}\right)^2, 0.1)$	$\min(0.002 \left(\frac{M_{\rm BH}}{10^8\,{\rm M}_\odot}\right)^2, 0.1)$	0.01	–	0.2

Feedback models

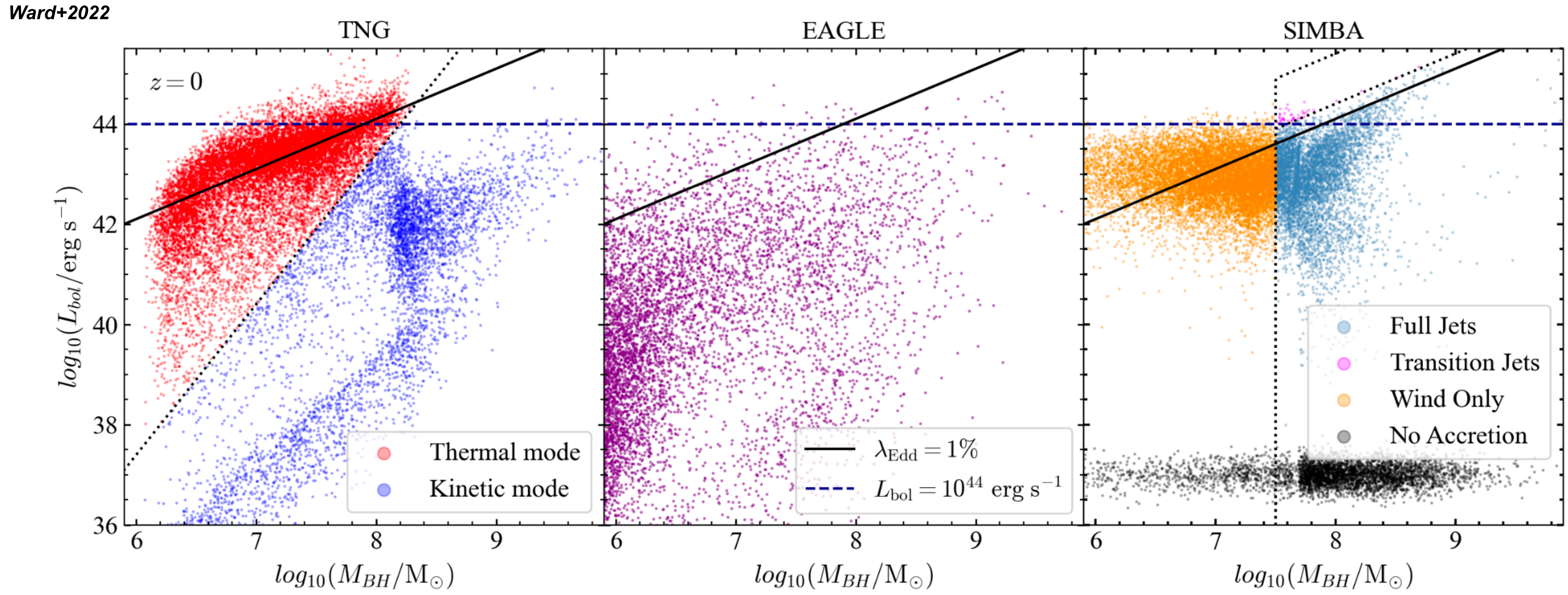


Figure 2. Bolometric luminosity (calculated from SMBH accretion rate; Equation 5) versus black hole mass for the simulations. The dotted lines in TNG and SIMBA show the boundaries between the different feedback modes that can be active. We also show our two AGN definitions (Section 2.4): the solid black line shows a constant Eddington ratio of λ_{Edd}= 1% and the blue dashed line shows a high luminosity cut of L_{bol}= 10^{44} ergs^{-1}.

Simple summary

	Illustris	TNG	EAGLE	FIRE	HORI ZON	NIHAO	OWLS	SIMBA
Thermal	✓	✓	✓		✓	✓	✓	
Kinetic	✓	✓		✓	✓			✓
Super-Edd								
Others			Do not distinguish	Quasar driven wind & (others)				X-ray

Motivations for two-mode feedback

- Resolution (can not resolve BH scale)
- Thermal energy: high accretion (<1), thin accretion disk provide radiative pressure & heating.
- Momentum energy: pressure and dragging of jets; subsequent shock & cocoon
- Radiation: soft x-ray excess, disk emission, corona emission, etc

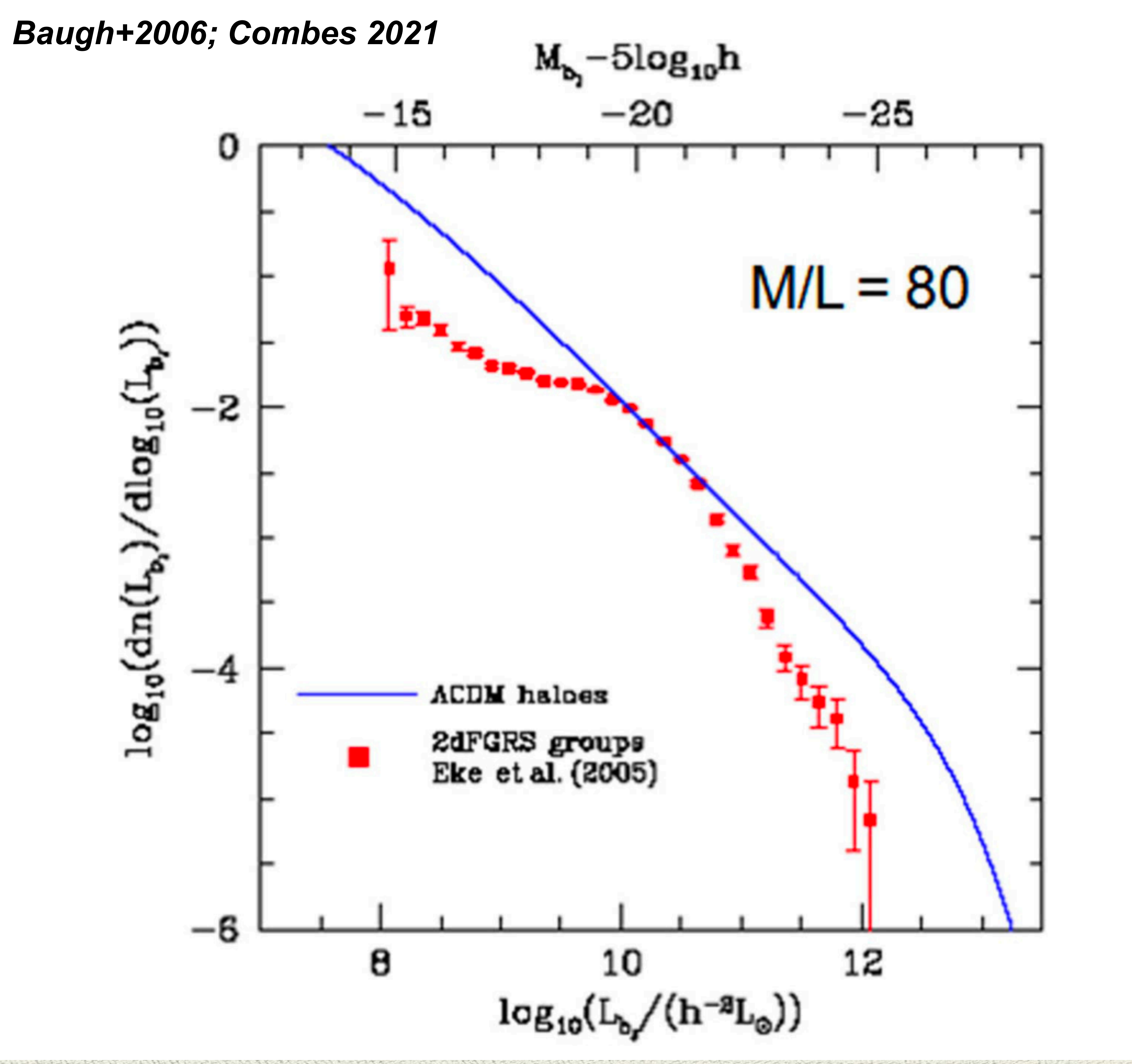
AGN Feedback in simulations

Model variability

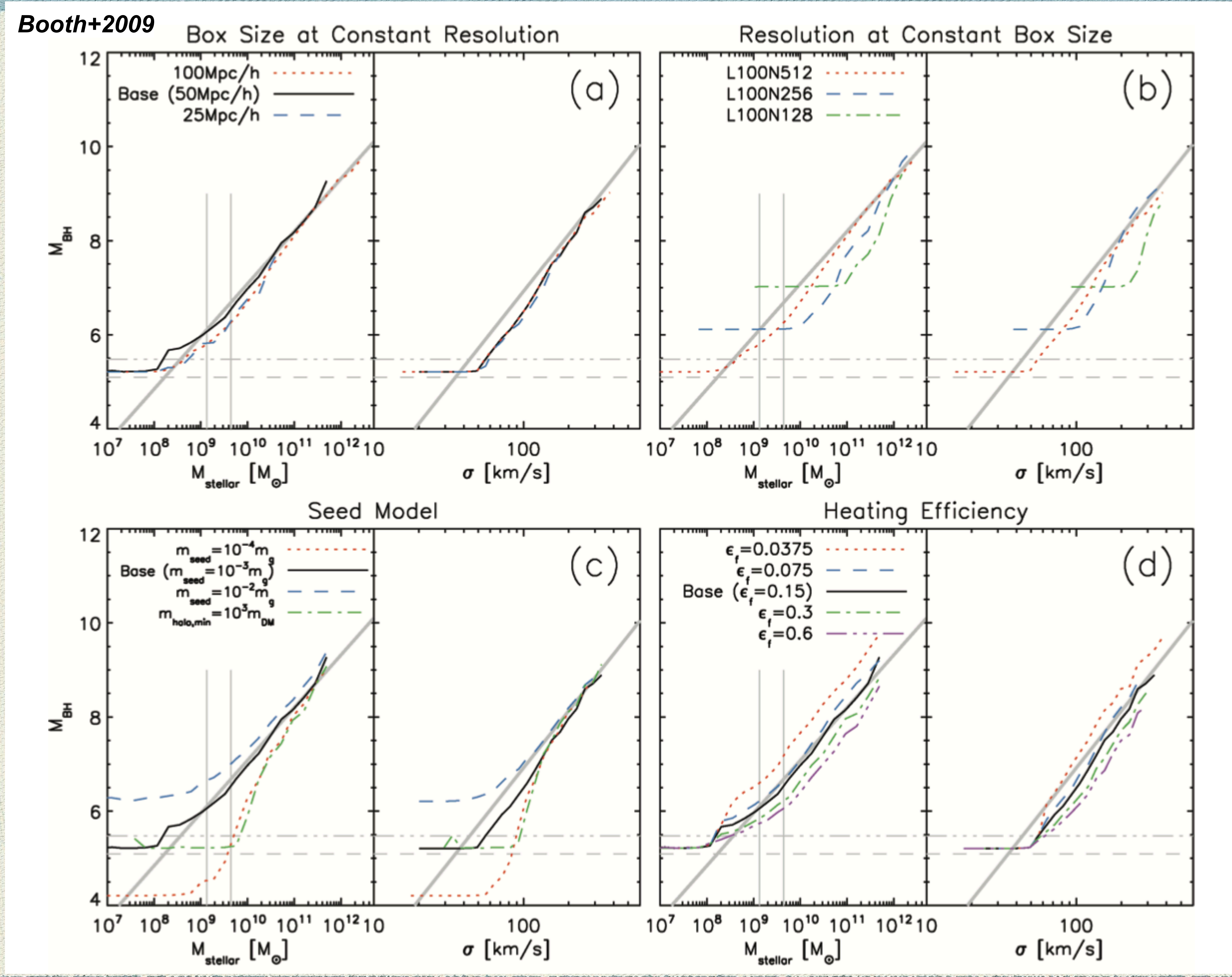
- Transition Eddington ratio (BH mass dependent)
- Radiative efficiency (density, spin dependent)
- Thermal energy injection (delta_T),
- Collimation/anisotropic factor
- Wind (jet) density, velocity, etc

Model variability and fine tuning

- Present observation (z=0), one or several relations:
    - Galaxy mass size relation
    - M-sigma relation
    - Galaxy color bimodality

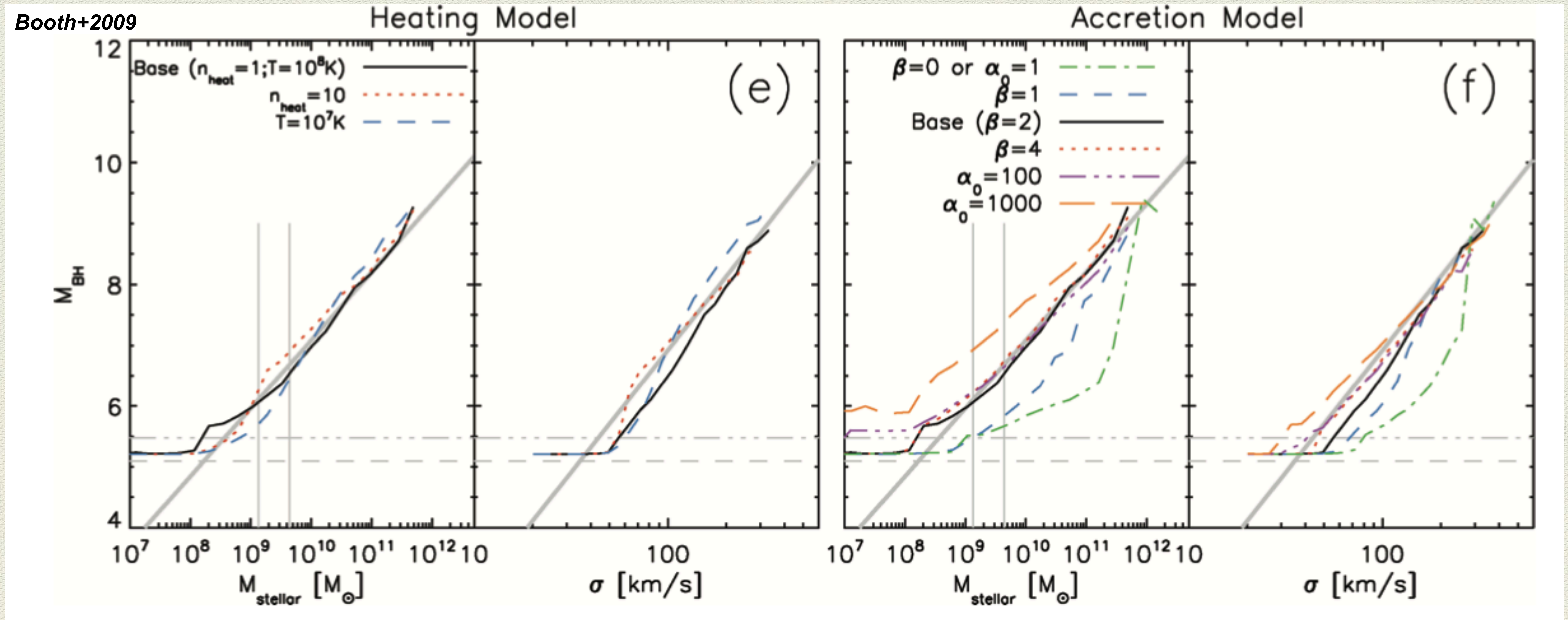


Tuning & Parameters



- Resolution
- Seed model
- Radiative efficiency

Tuning & Parameters

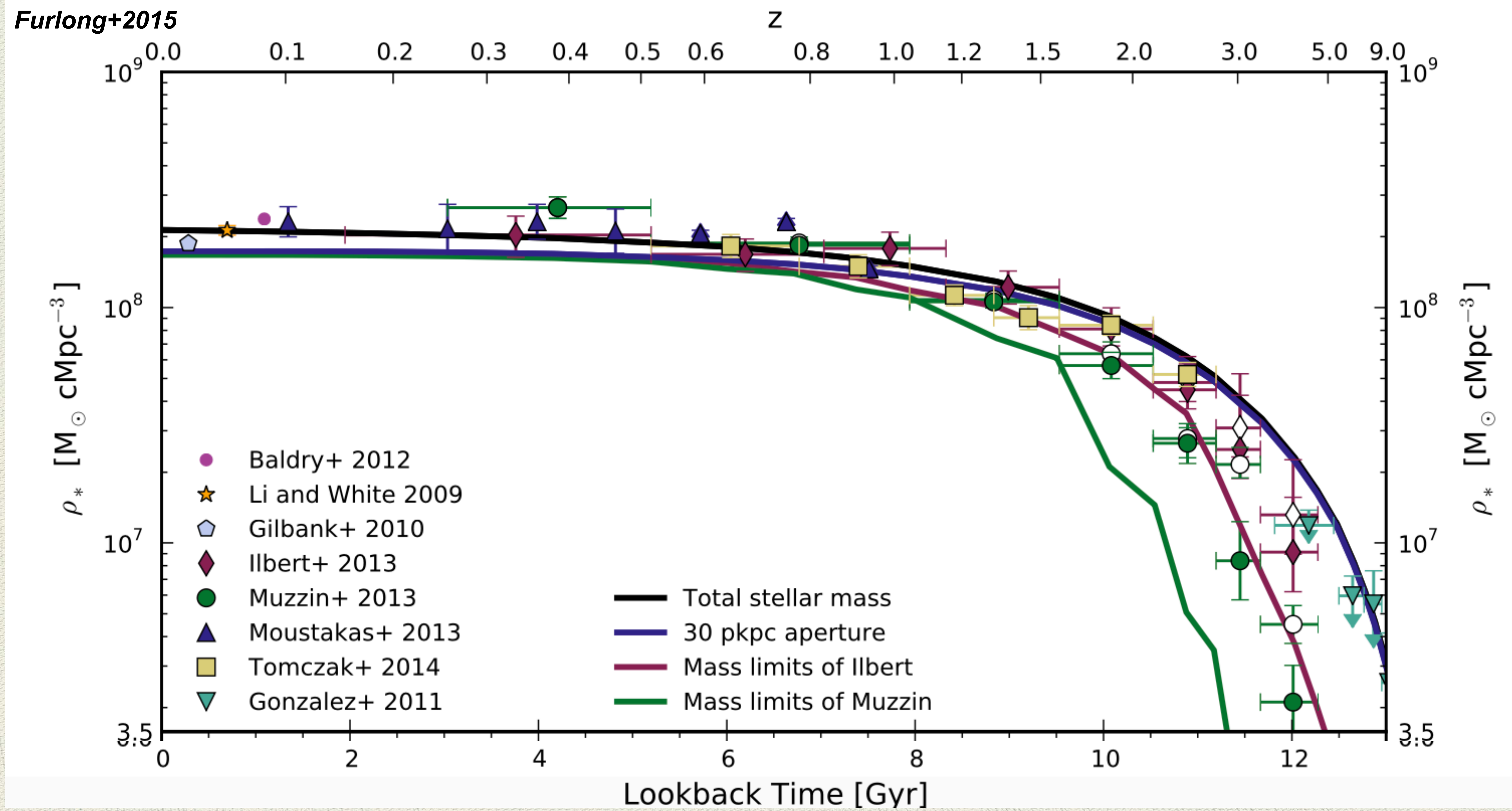


Numerical issue

Accretion model

See Wellons+2022 for similar discussion

Pure thermal feedback—EAGLE



Reproduce stellar mass density up to z=2 and beyond.

Pure thermal feedback—EAGLE

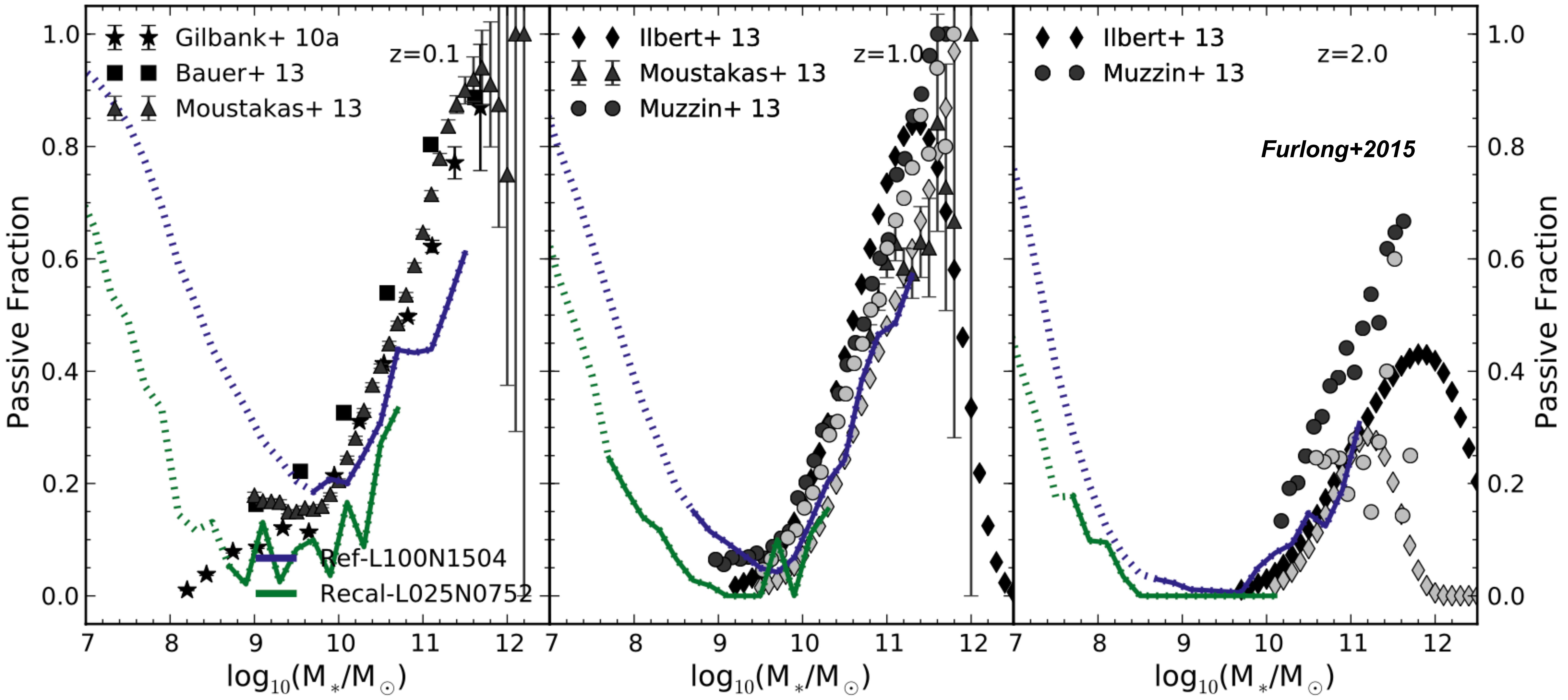
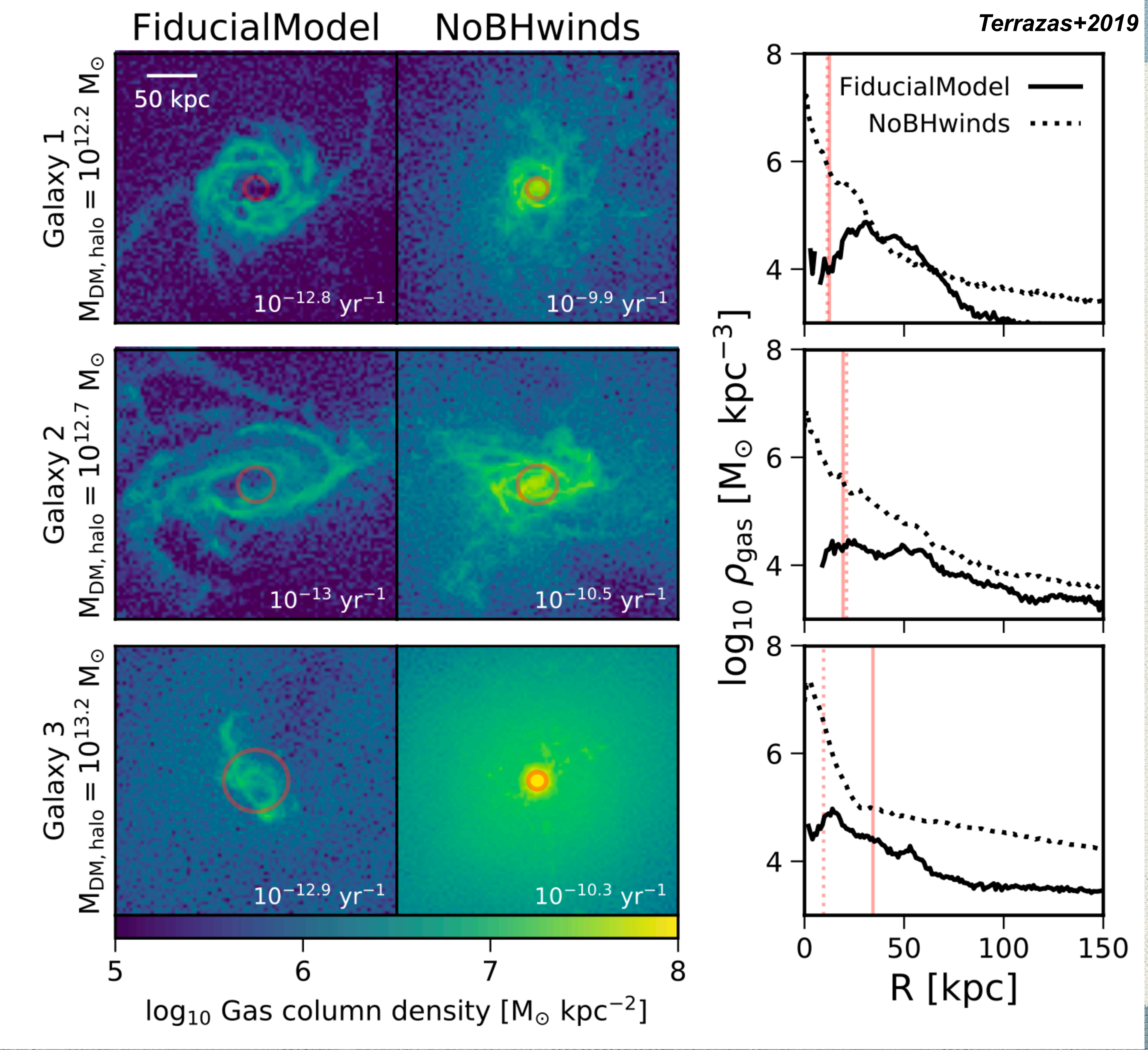


Figure 6. The passive fraction as a function of galaxy stellar mass for Ref-L100N1504 and Recal-L025N0752 in blue and green, respectively, where galaxies with an SSFR below the horizontal dotted lines in Fig. 5 are defined as passive. Lines are dotted when the stellar mass falls below that corresponding to 30 star-forming particles for the SSFR limit. Data points show observations as indicated in the legends. The black points represent the observational redshift bin below the simulation redshift, while the grey curves are from the redshift bin above the simulation snapshot. Above 10^9 $M_\odot$, the simulated passive fractions show similar normalization and slope with stellar mass to observations at all redshifts, with a small deficit of passive galaxies of around 15 per cent in the mass range $10^{10.5}$ to $10^{11.5}$ $M_\odot$. The upturn at low masses, below 10^9 $M_\odot$ is a numerical artefact.

Passive fraction

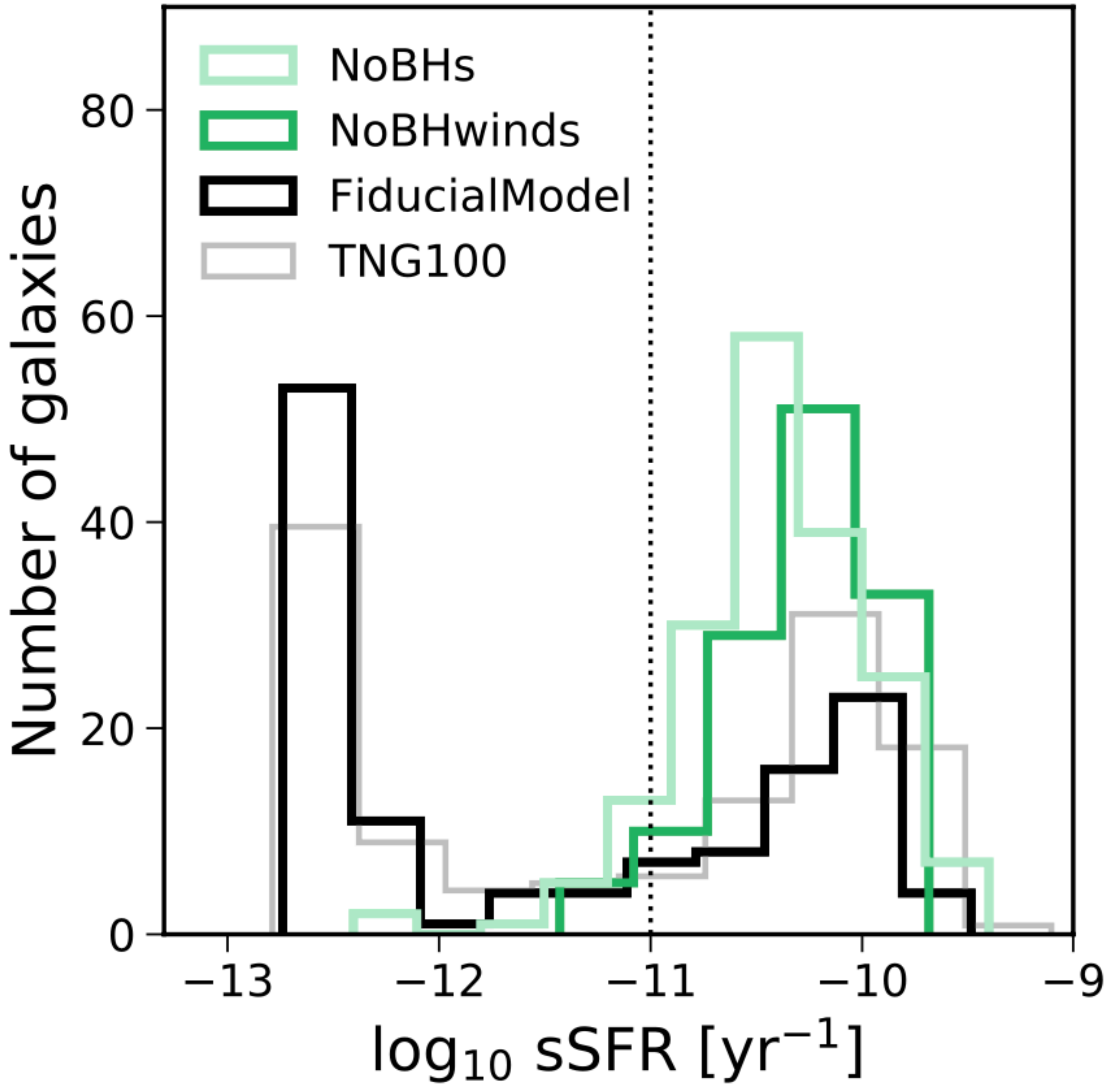
Wind feedback—TNG



- Ejective feedback: push away central gas.

Wind feedback—TNG

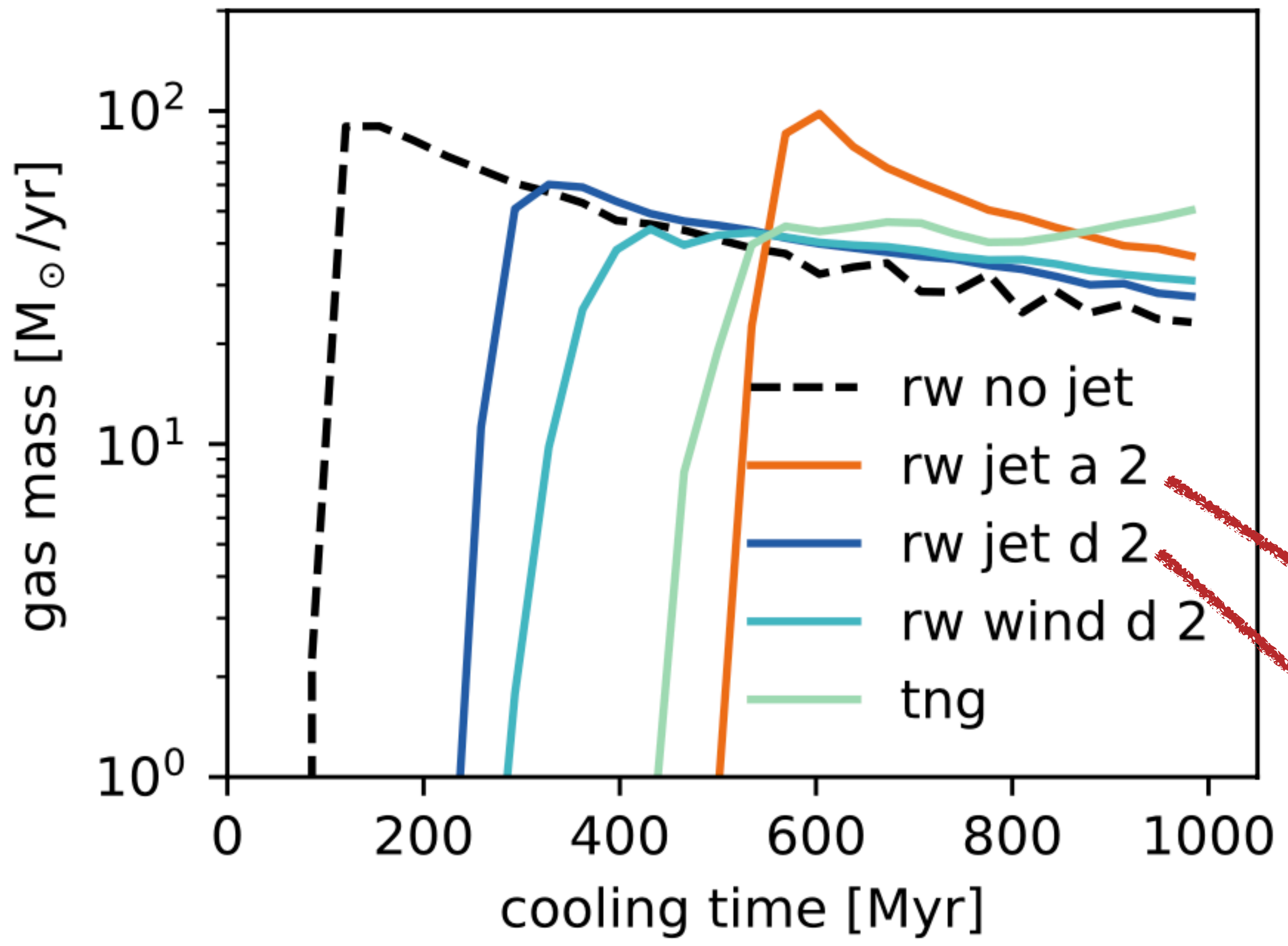
Terrazas+2019



- Kinetic feedback is needed to reproduce the quiescent galaxy population.
- (In TNG)

Jet Feedback in Cool-core Clusters

Weinberger+2022



Name	Model	Time	Jet Density	Resolution
rw jet a 1	rw17	250 Myr	10^{-28} g cm^{-3}	2.5×10^3 $M_\odot$
rw jet a 2	rw17	250 Myr	10^{-28} g cm^{-3}	3.1×10^2 $M_\odot$
rw jet a 3	rw17	250 Myr	10^{-28} g cm^{-3}	39 $M_\odot$
rw jet a 4	rw17	250 Myr	10^{-28} g cm^{-3}	4.9 $M_\odot$
rw jet a 5	rw17	25 Myr	10^{-28} g cm^{-3}	0.61 $M_\odot$
rw jet b 2	rw17	250 Myr	10^{-27} g cm^{-3}	9.4×10^3 $M_\odot$
rw jet c 2	rw17	250 Myr	10^{-26} g cm^{-3}	9.4×10^4 $M_\odot$
rw jet d 2	rw17	250 Myr	10^{-25} g cm^{-3}	3.1×10^5 $M_\odot$
rw wind d 2	rw17	250 Myr	10^{-25} g cm^{-3}	3.1×10^5 $M_\odot$
tng	rw17a	250 Myr	-	9.4×10^4 $M_\odot$
rw no jet	-	250 Myr	-	9.4×10^4 $M_\odot$

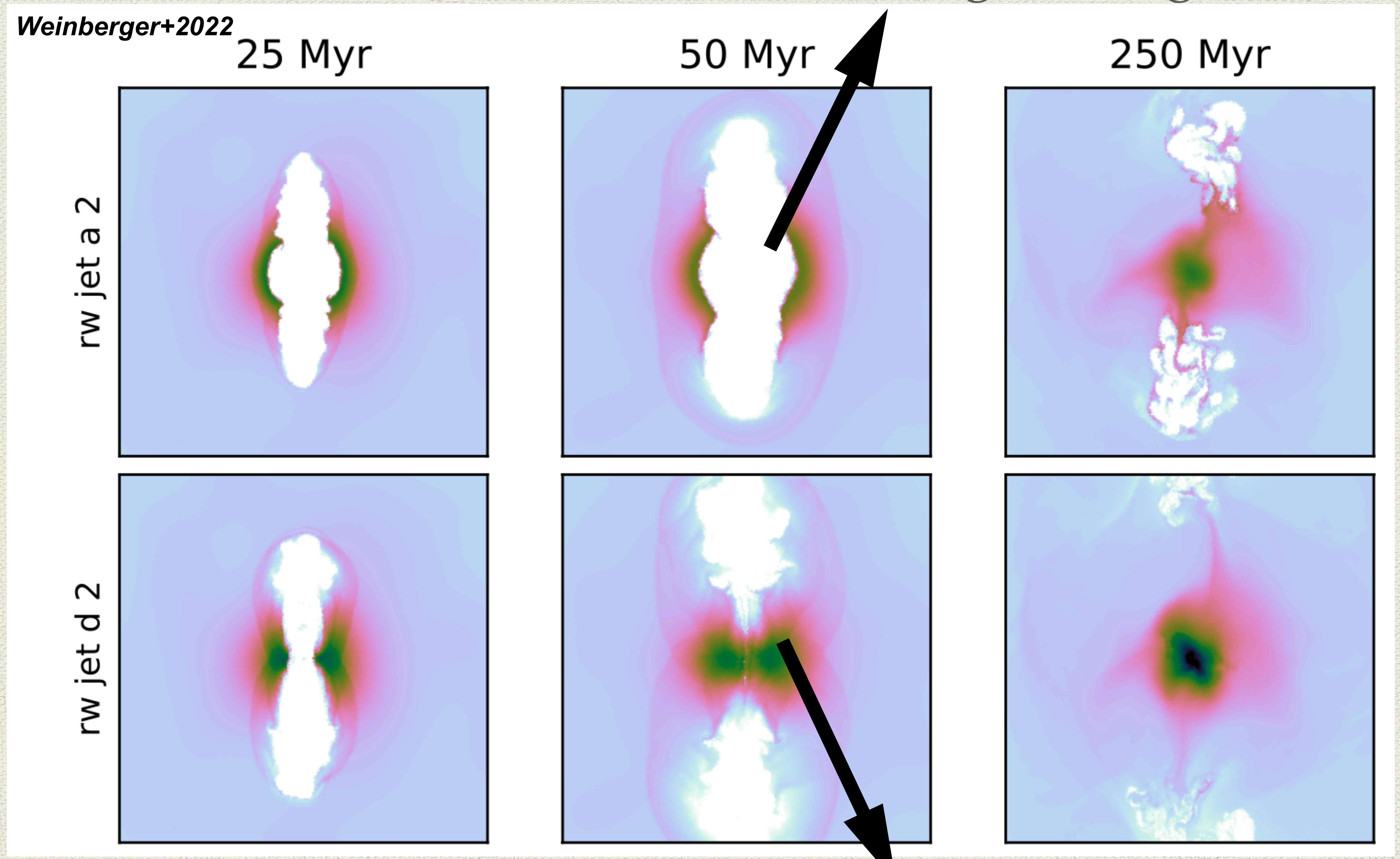
Light jet

Heavy jet

- Light jets suppress the cooling more significantly

Jet feedback

Long cooling time



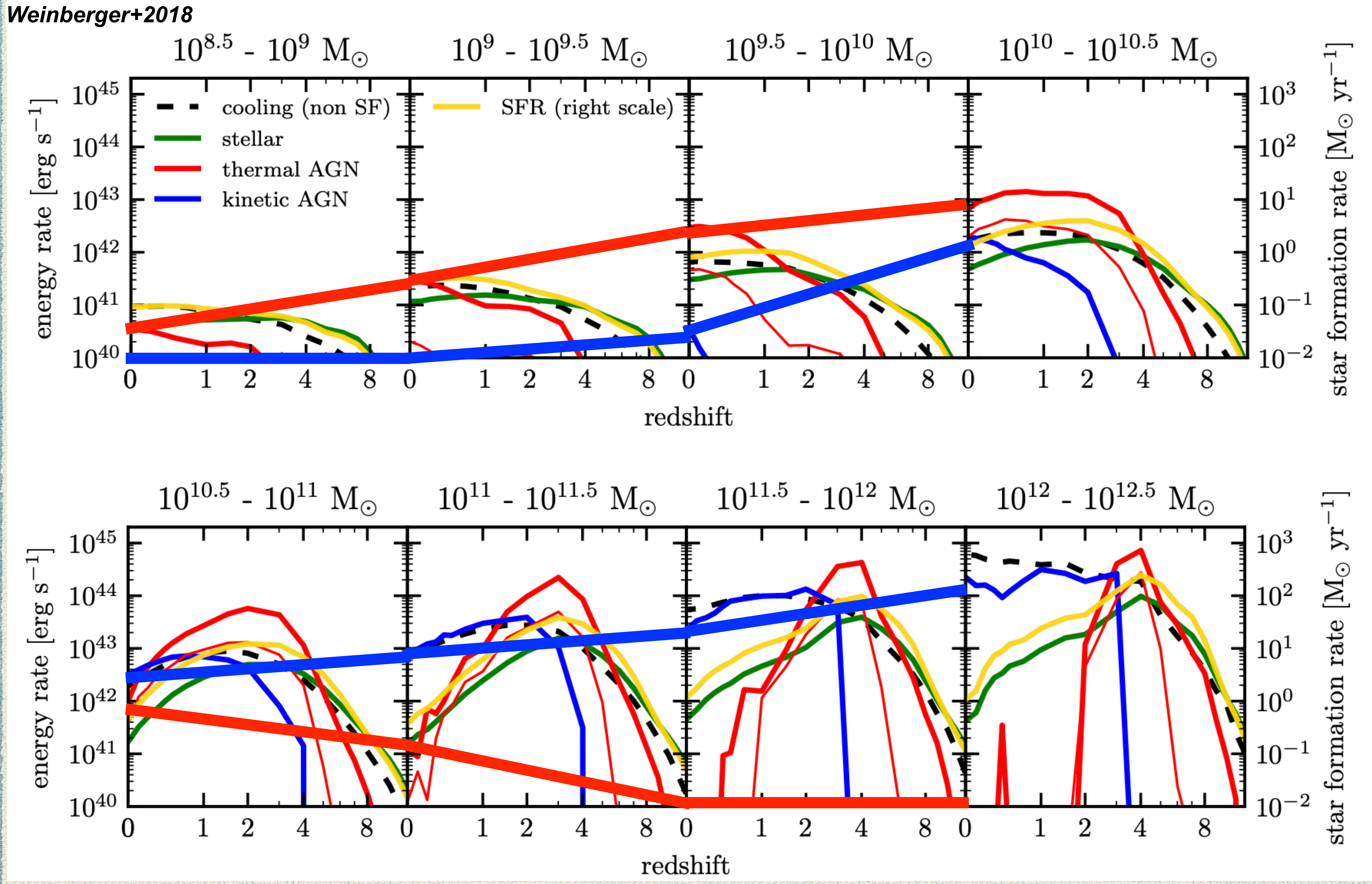
Short cooling time

- Heavy jet leaves a smaller cocoon of jetted material present in the center
- Ejective & preventative

Major uncertainties

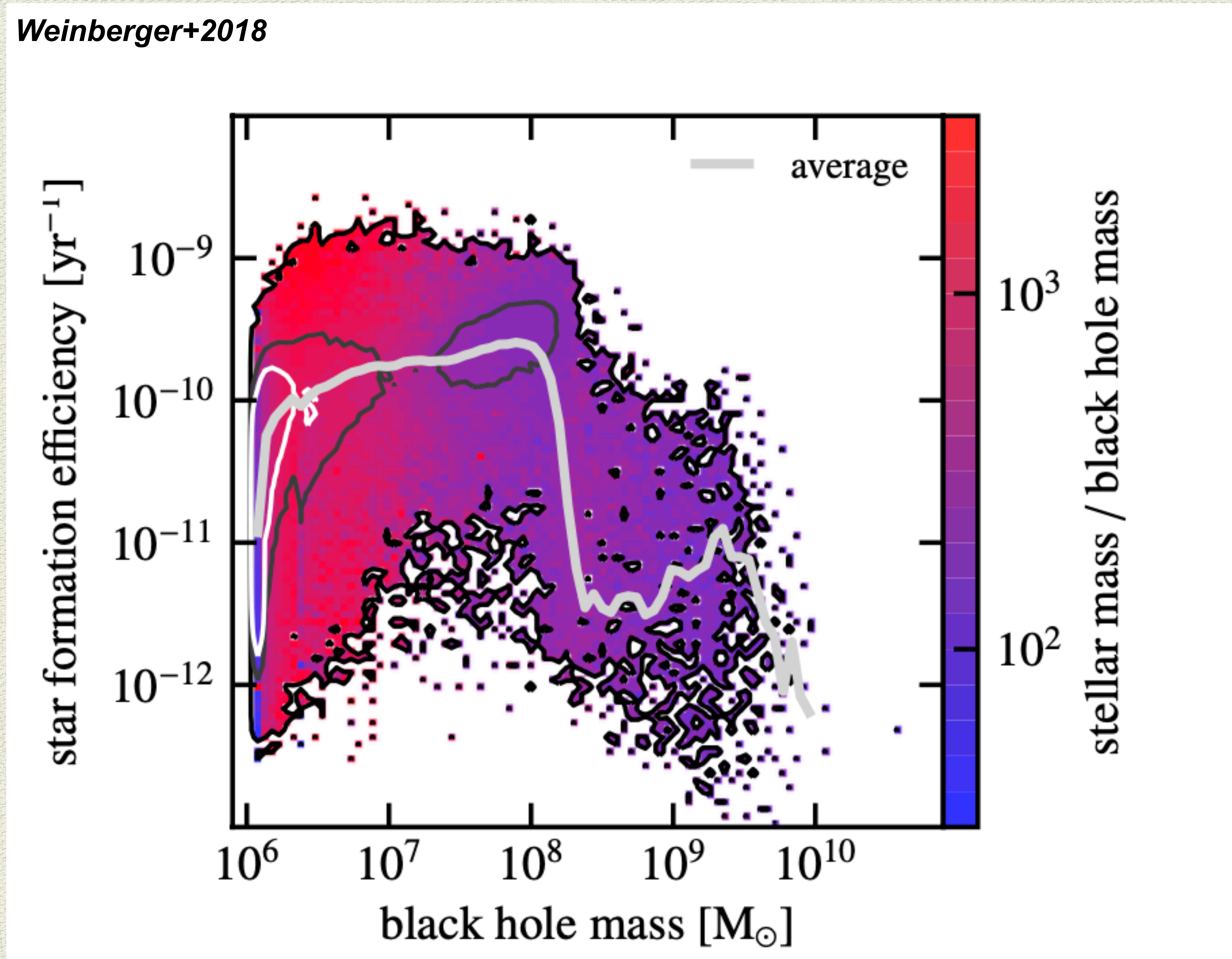
- Thermal feedback: energy injection rate and timescale
- Jet: collimation, density, velocity
- Wind: density, velocity, isotropiness

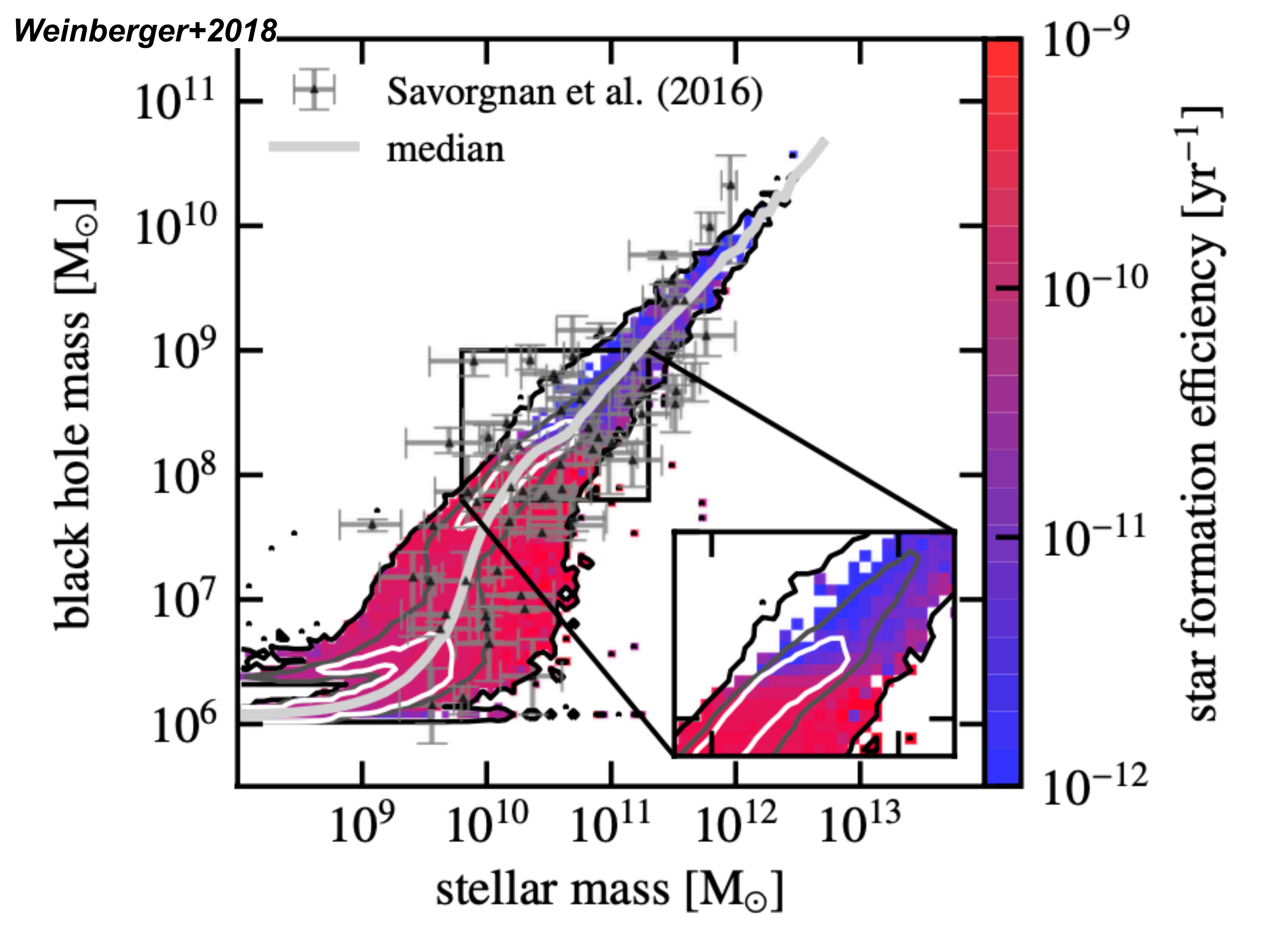
Feedback on quenching & BH growth



- Thermal feedback dominates at low mass end
- Kinetic feedback dominates at high mass end
- Stellar feedback dominate at high-z and low mass end

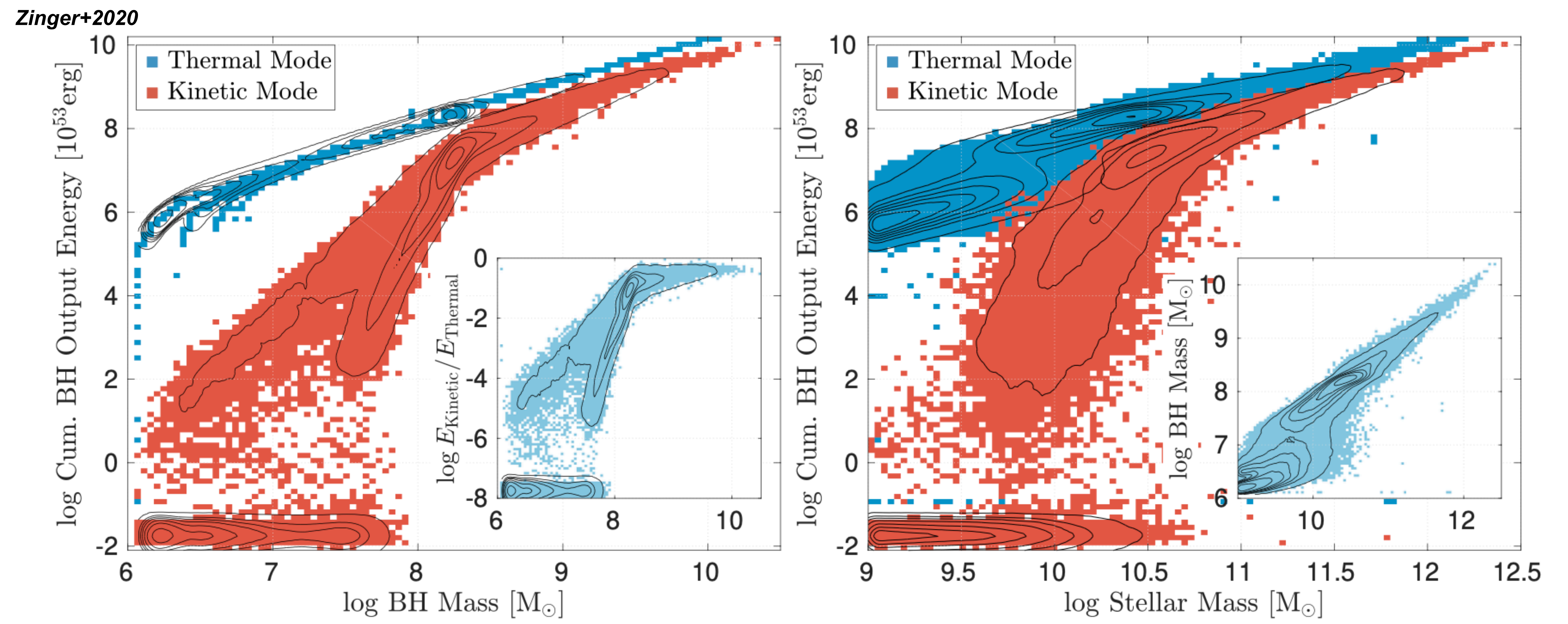
Feedback on quenching & BH growth





- A drop in SFR and SFE around BH mass 1e8 Msolar.

Feedback on quenching & BH growth



(a) Energy injected vs. BH mass

(b) Energy injected vs. stellar mass

Feedback on quenching & BH growth

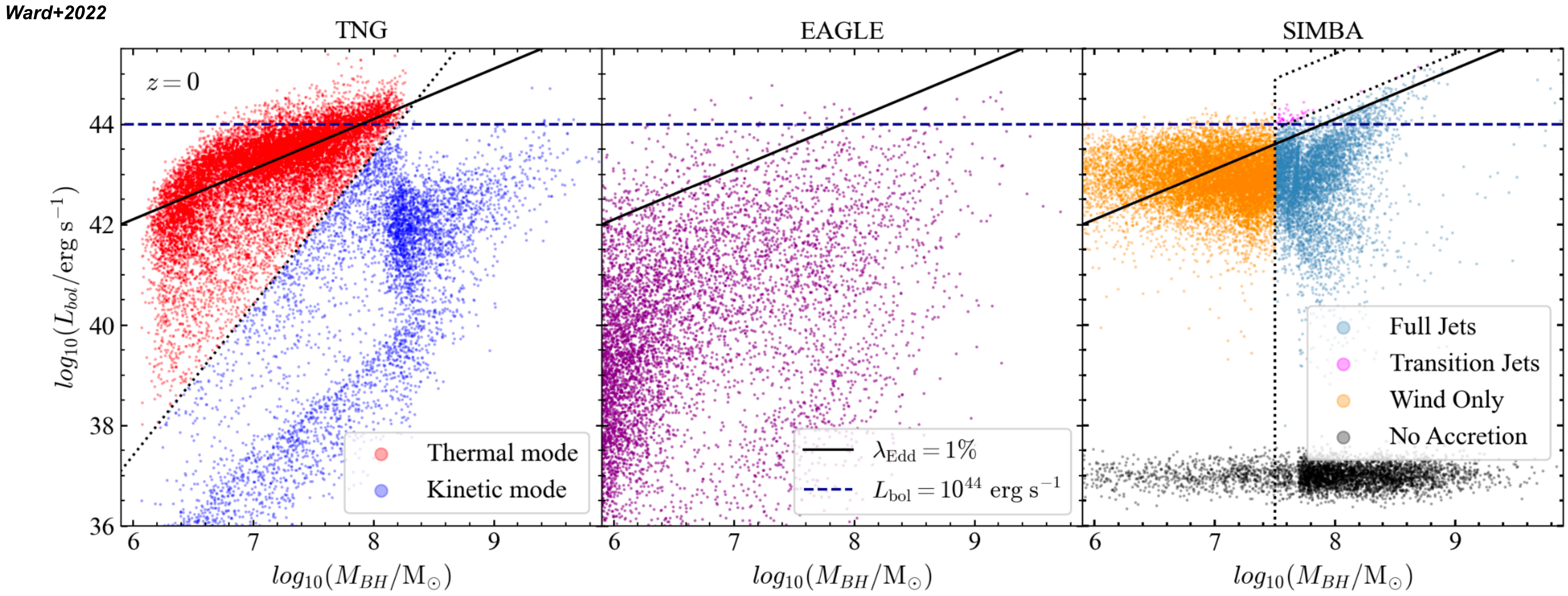
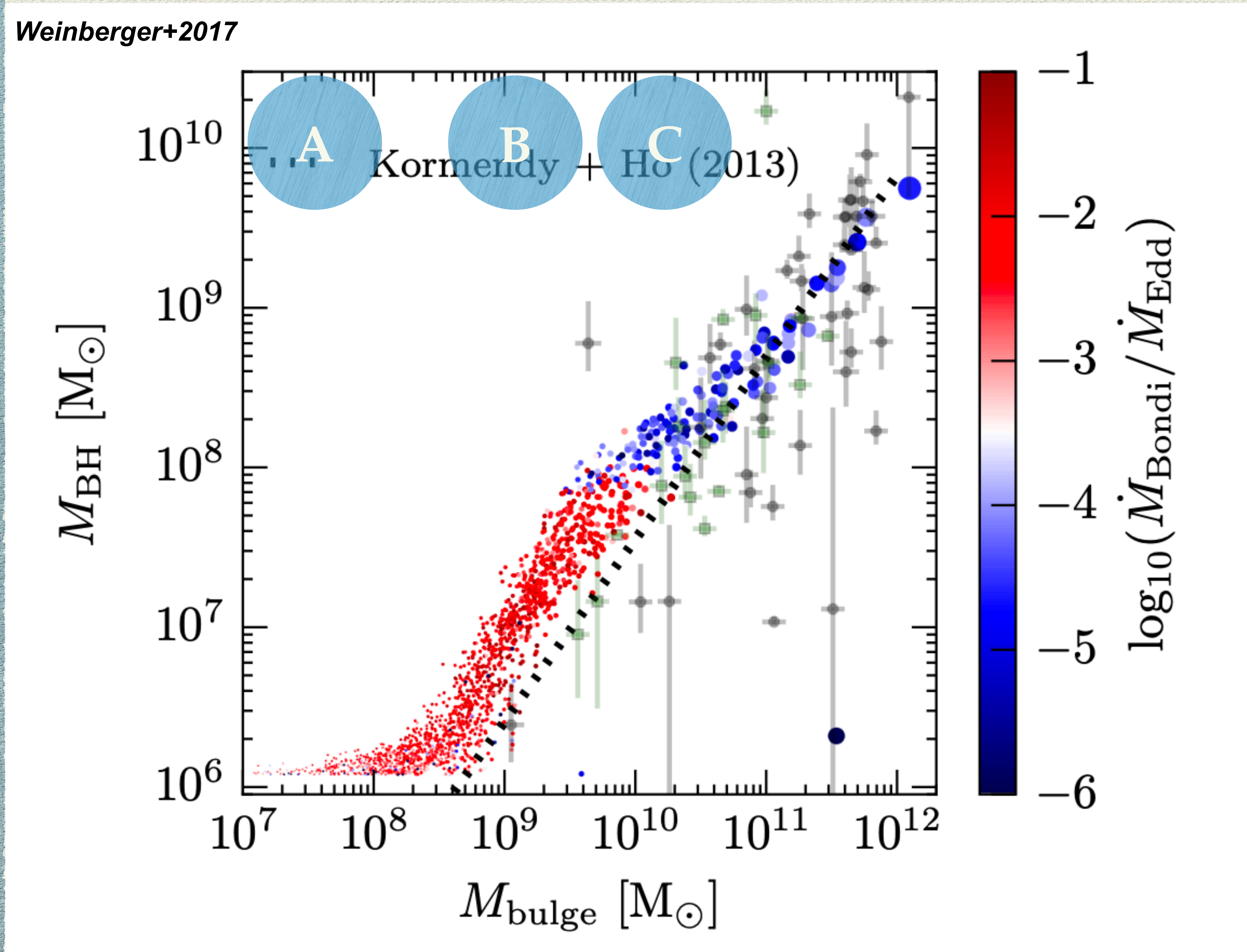


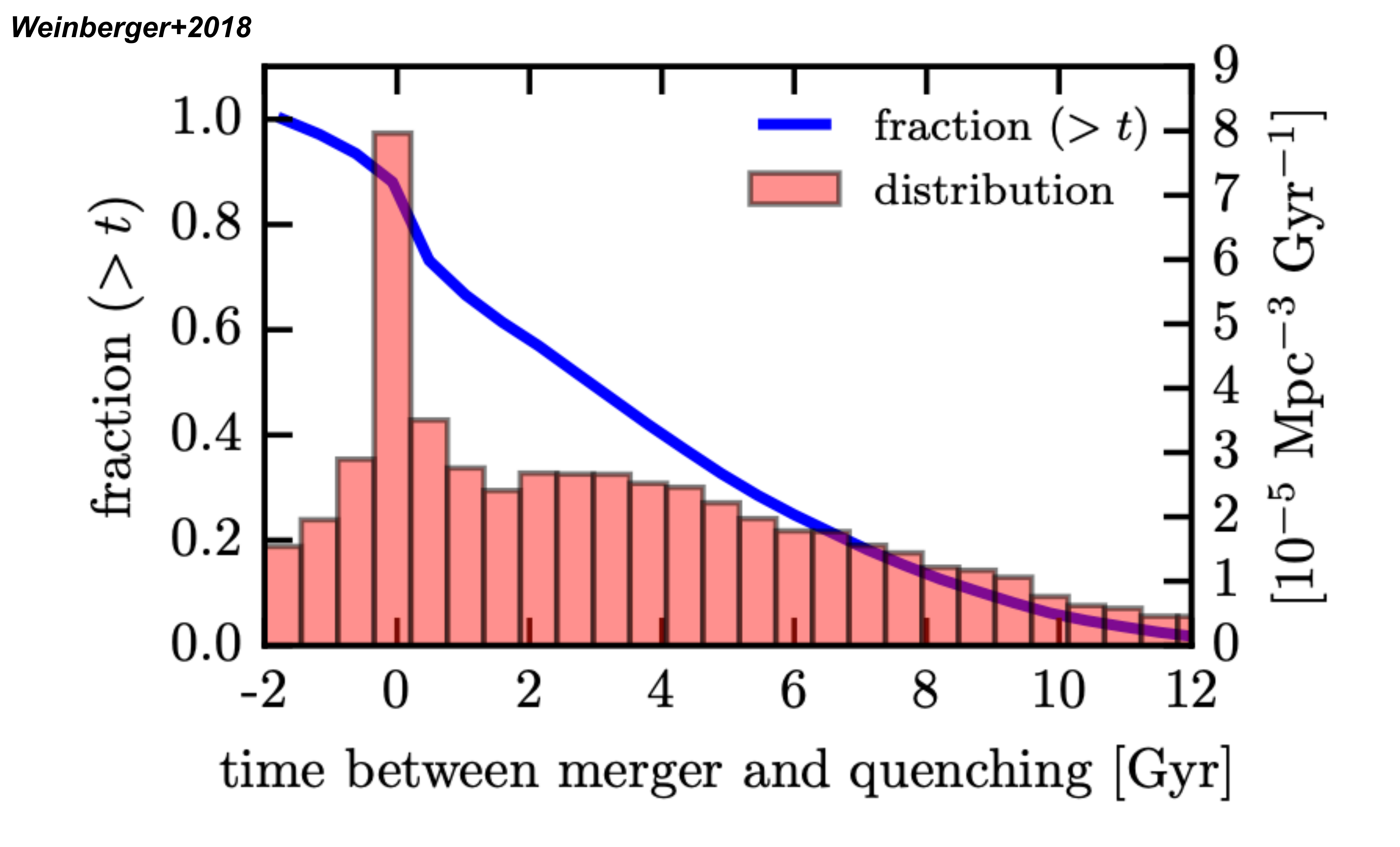
Figure 2. Bolometric luminosity (calculated from SMBH accretion rate; Equation 5) versus black hole mass for the simulations. The dotted lines in TNG and SIMBA show the boundaries between the different feedback modes that can be active. We also show our two AGN definitions (Section 2.4): the solid black line shows a constant Eddington ratio of λ_{Edd}= 1% and the blue dashed line shows a high luminosity cut of L_{bol}= 10^{44} ergs^{-1}.

Feedback on quenching & BH growth



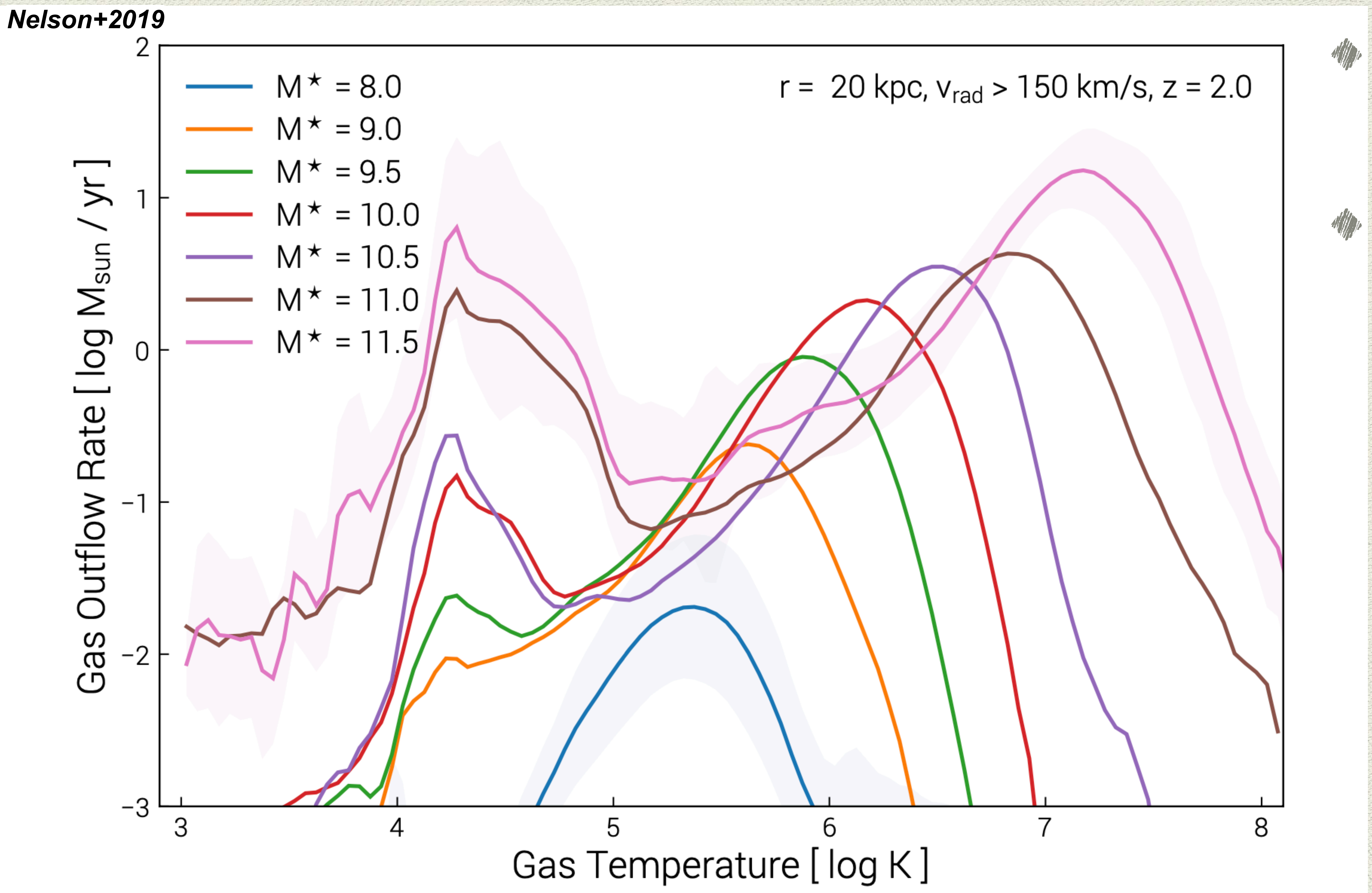
- A: just after seeding, gas is dilute.
- B: Quasar mode feedback & BH grows faster.
- C: Thermal mode regulates BH growth

Feedback on quenching & BH growth



- Decoupling between quenching and merger

Feedback on gas

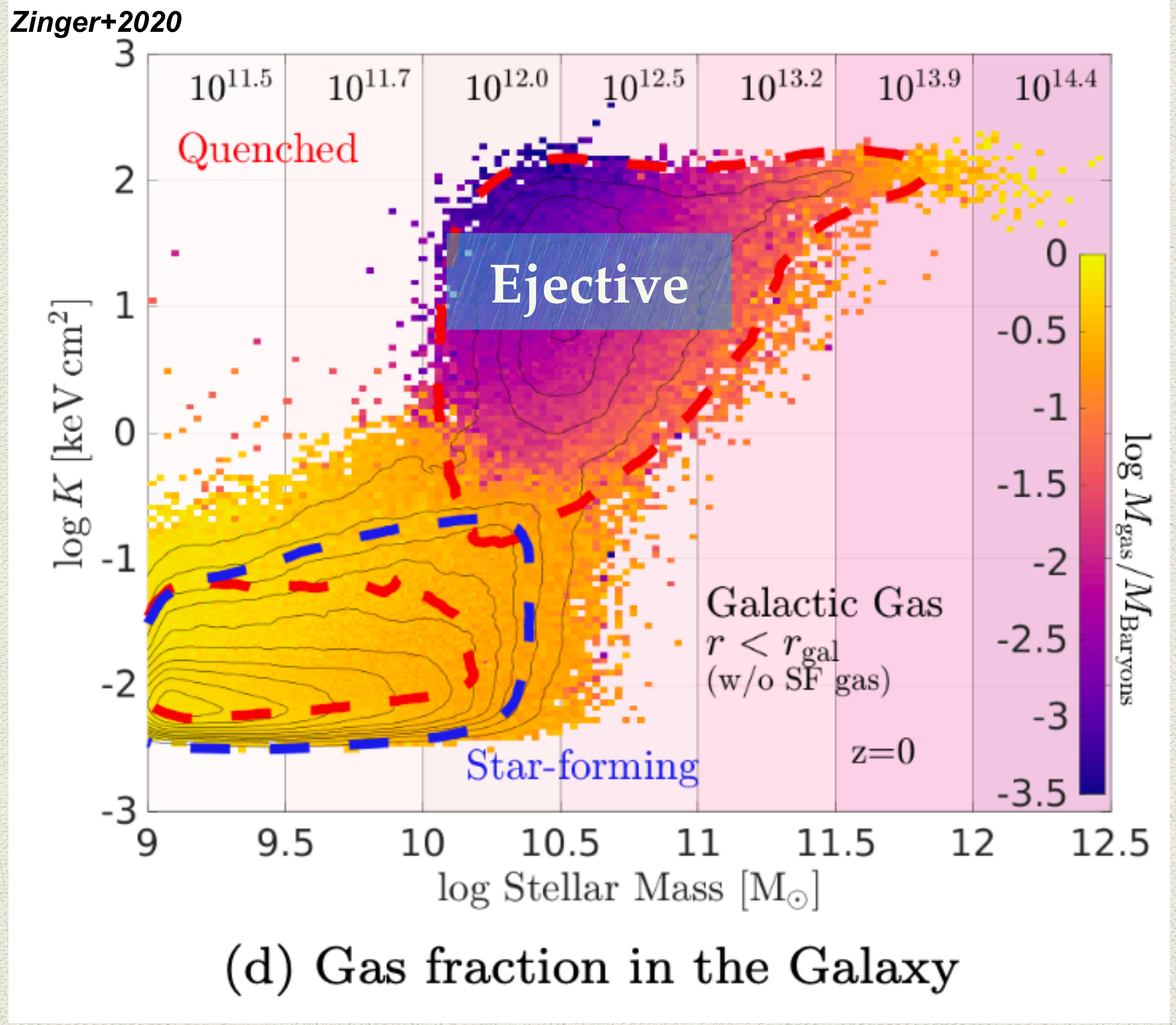


- Hot comp.: virtualized gas
- Cold comp.:
  - cooling process (possibly in outflow)
  - Ejective feedback: launching formerly dense ISM out into halo

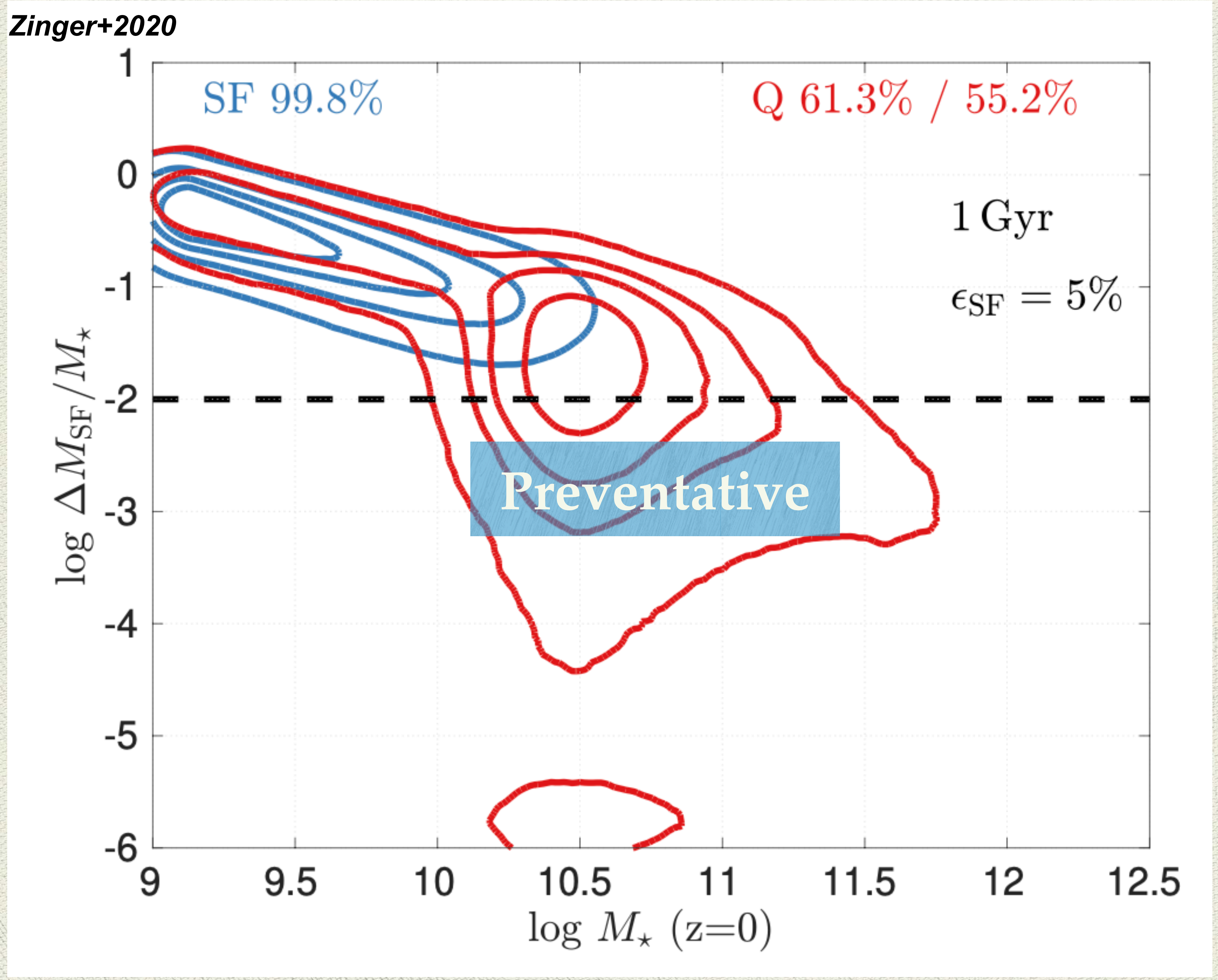
Feedback on CGM

BH feedback is both ejective & preventative

Low M_gas/M_Baryons for the quenched



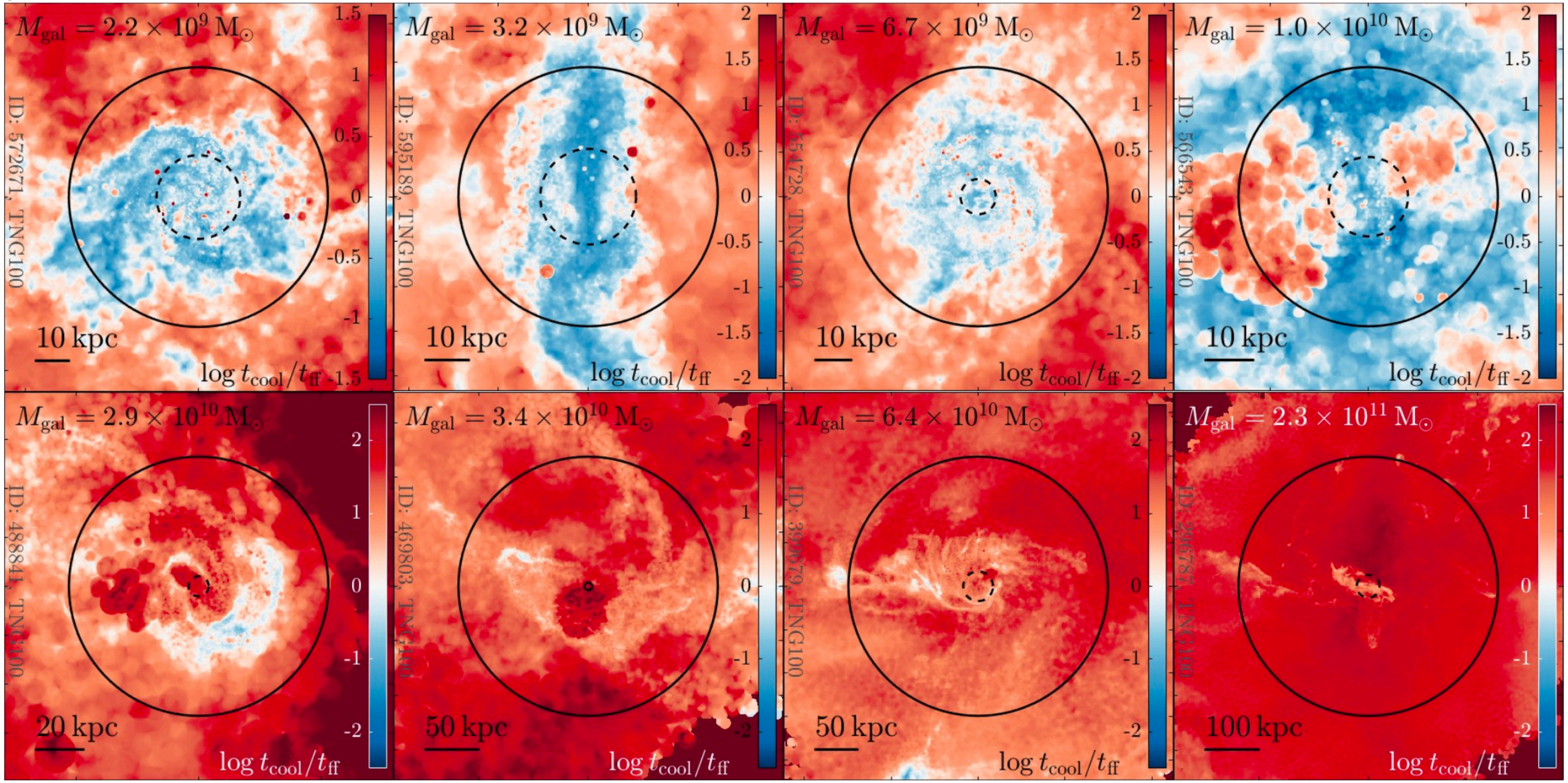
Most Long t_cool galaxies are quenched in 1Gyr



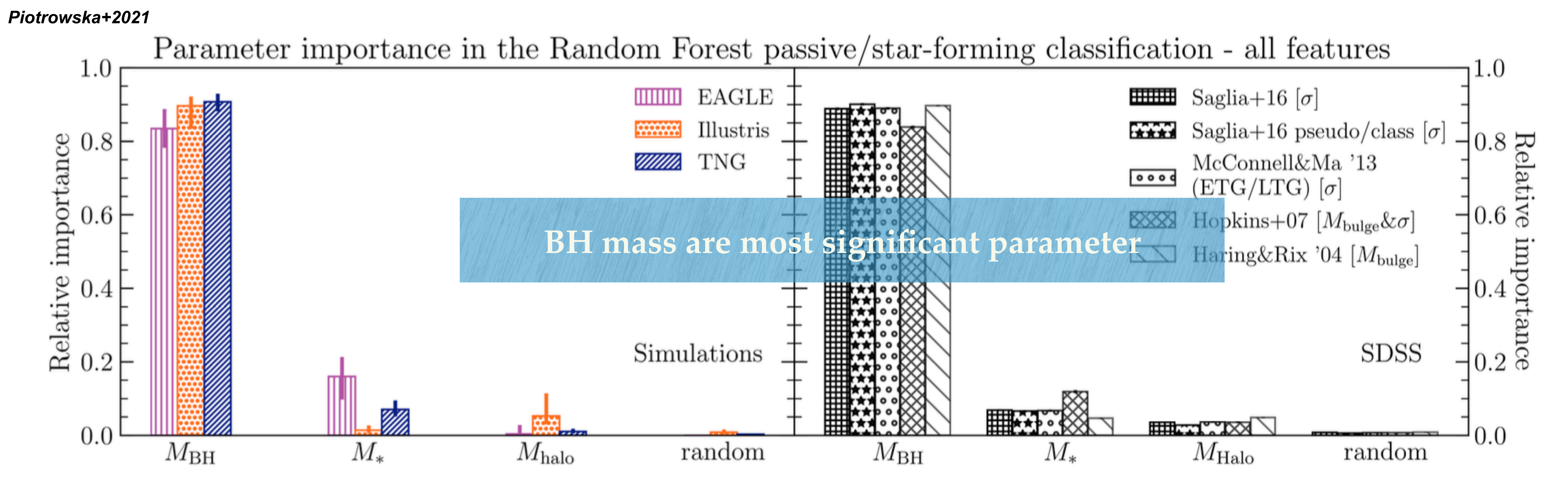
Feedback on CGM

Cooling timescale

Zinger+2020

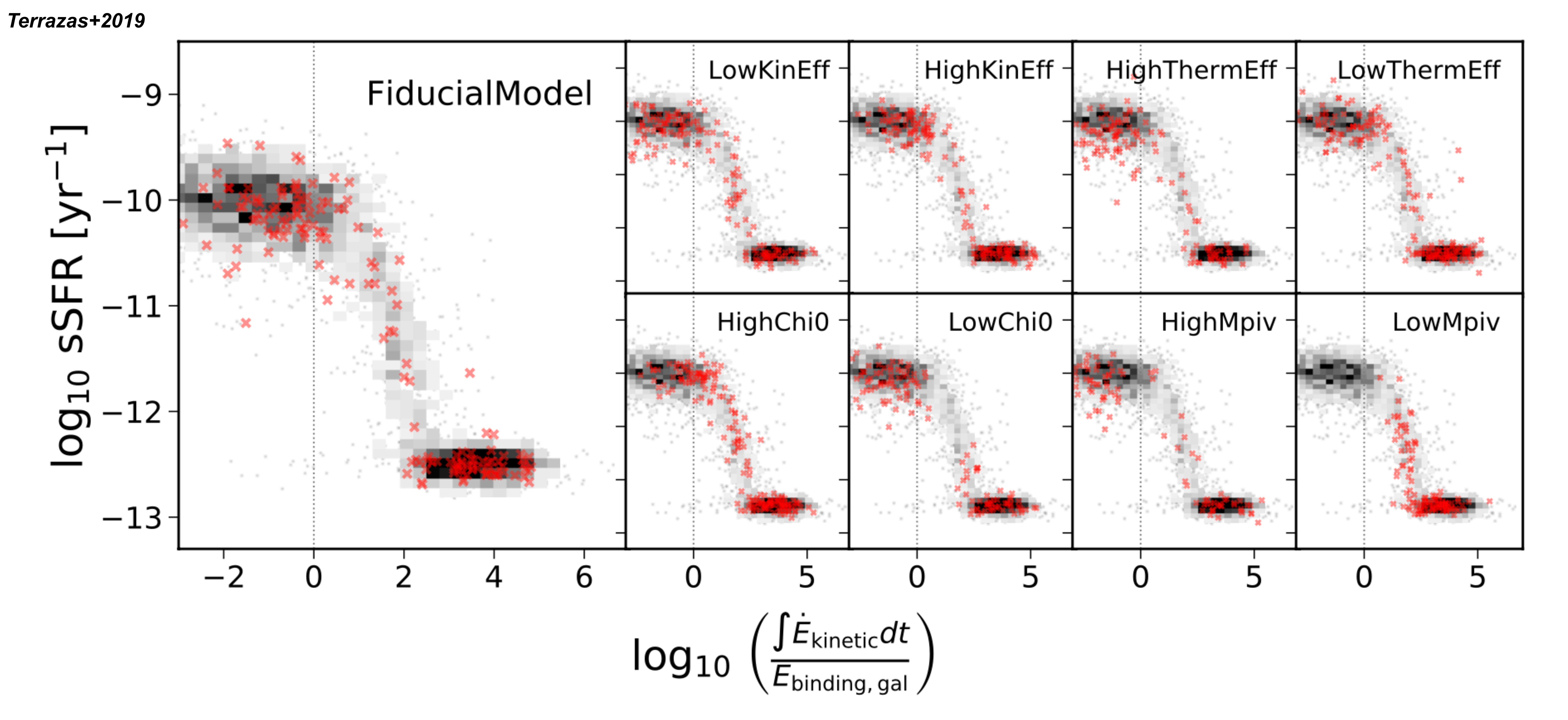


Instant or integrated feedback

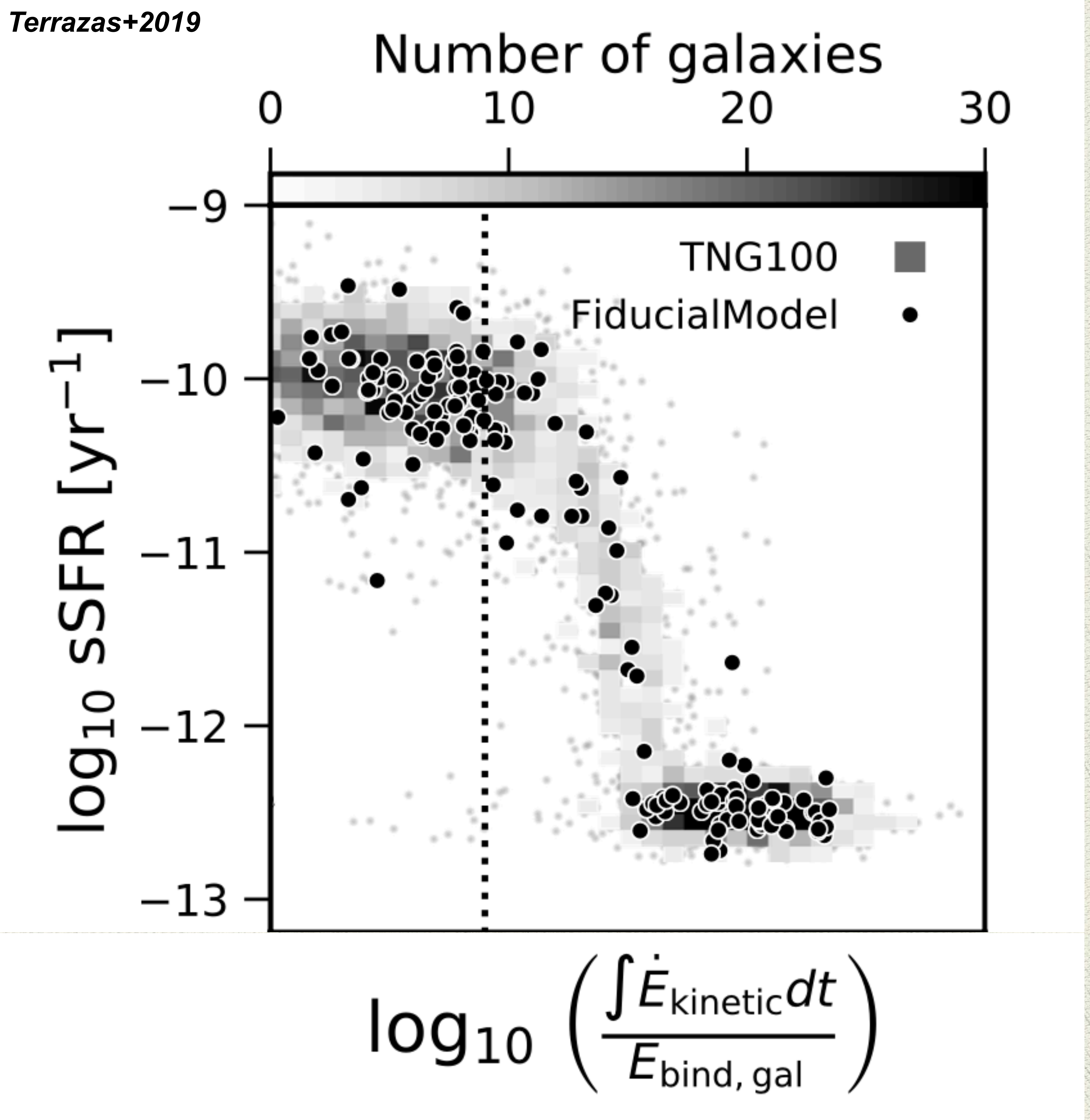


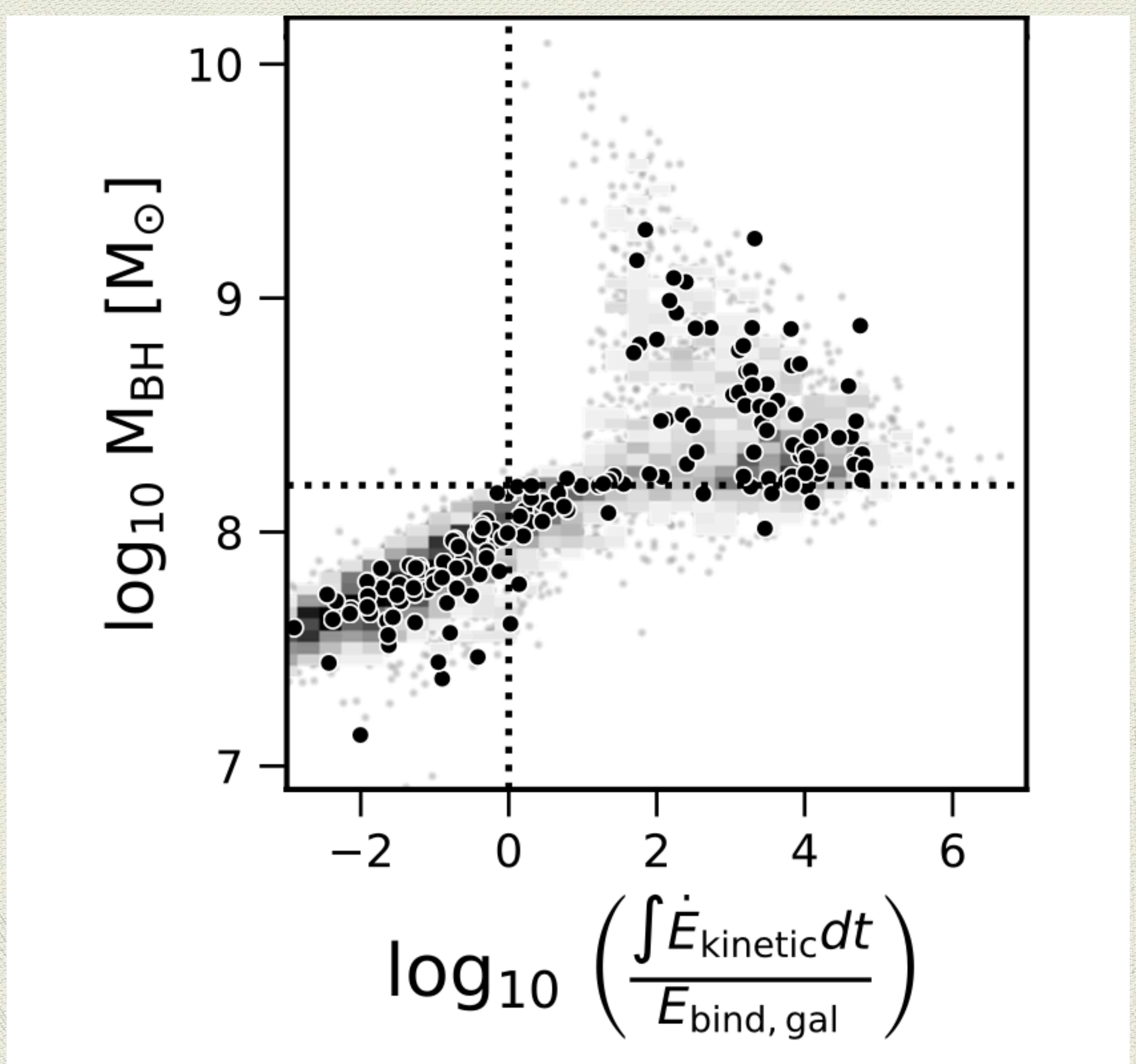
- Random forest: supervised machine learning.

Instant or integrated feedback



Instant or integrated feedback

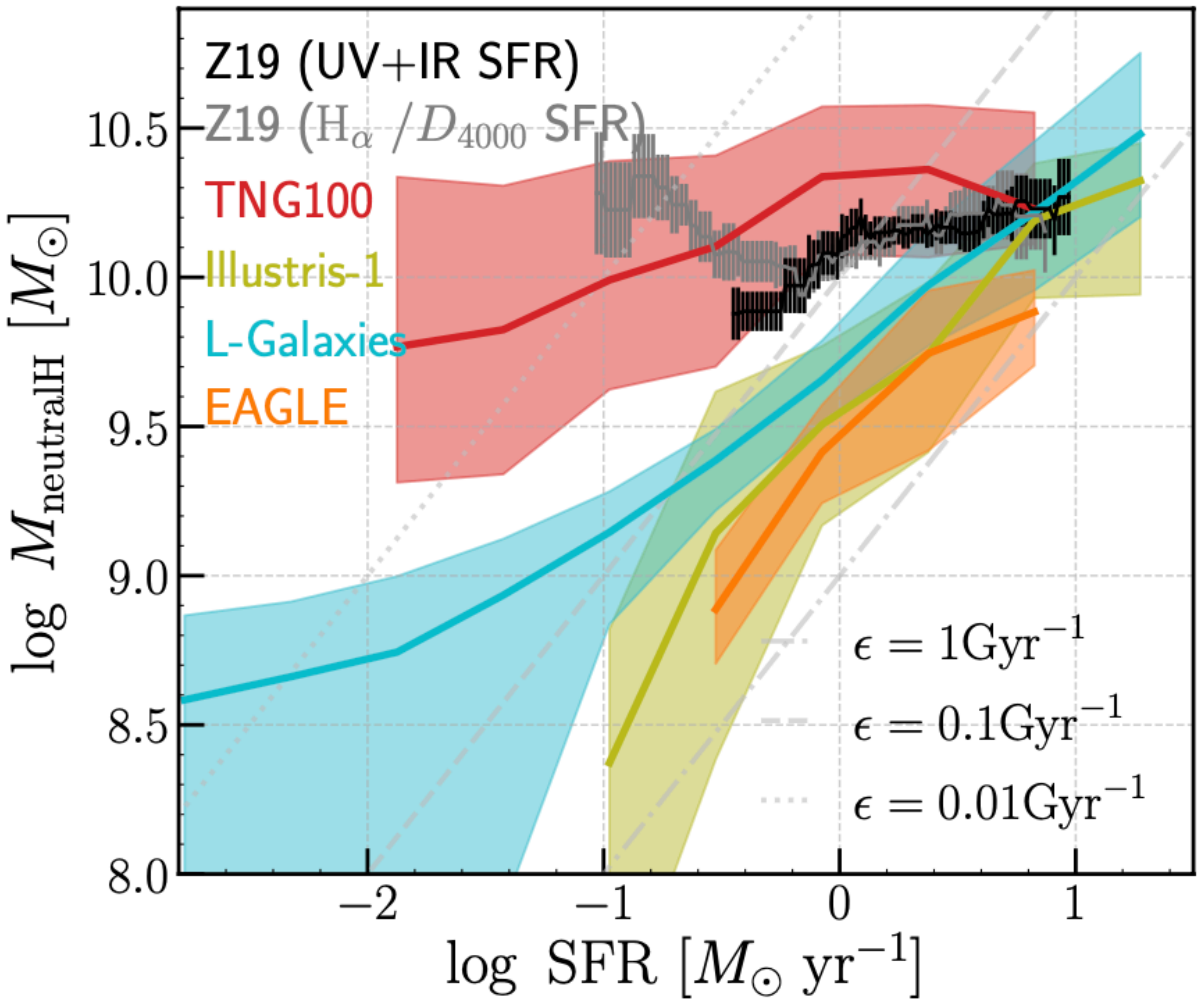




Constraints from other obs.

Cold gas constraints

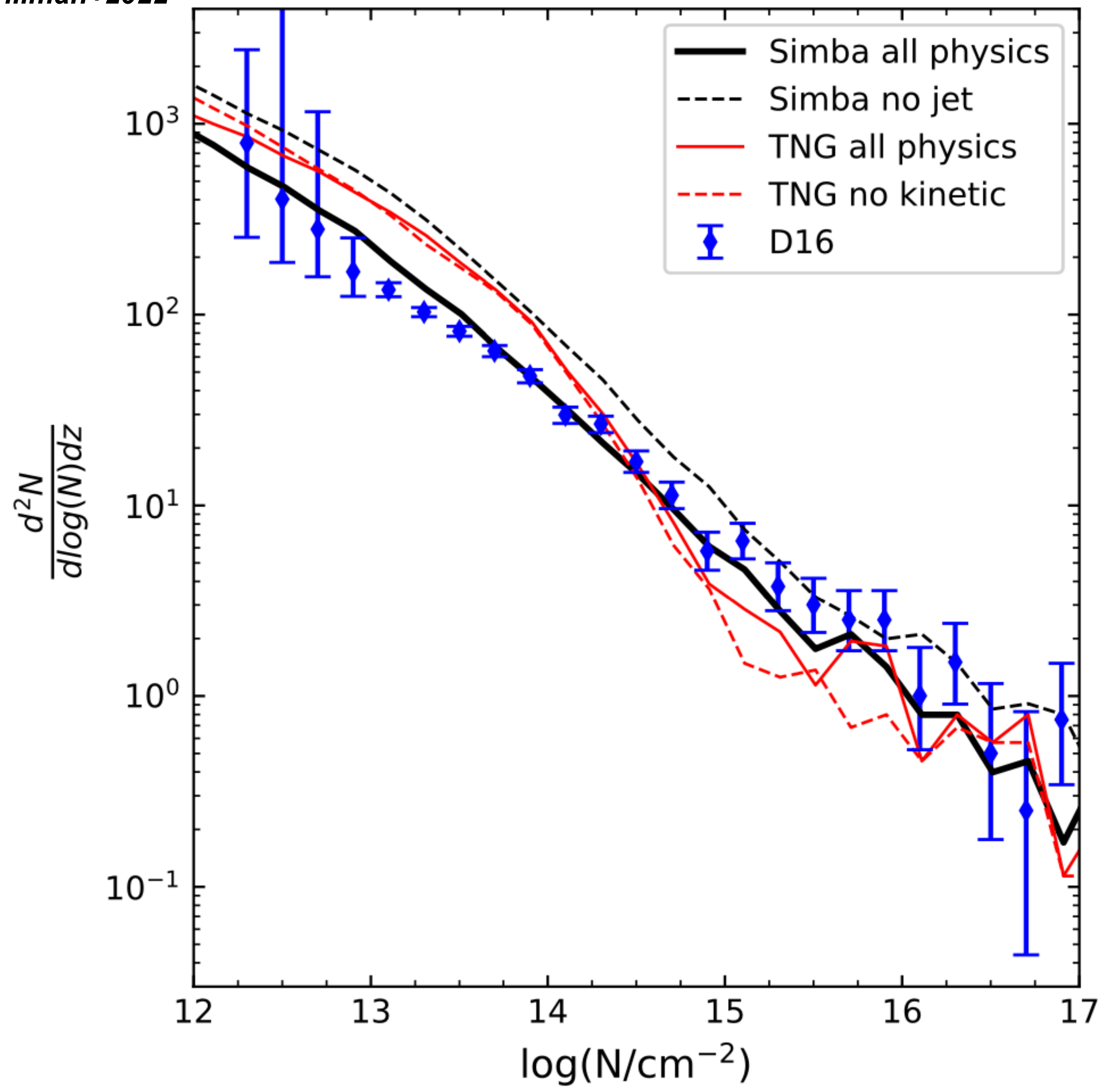
Shi+2022



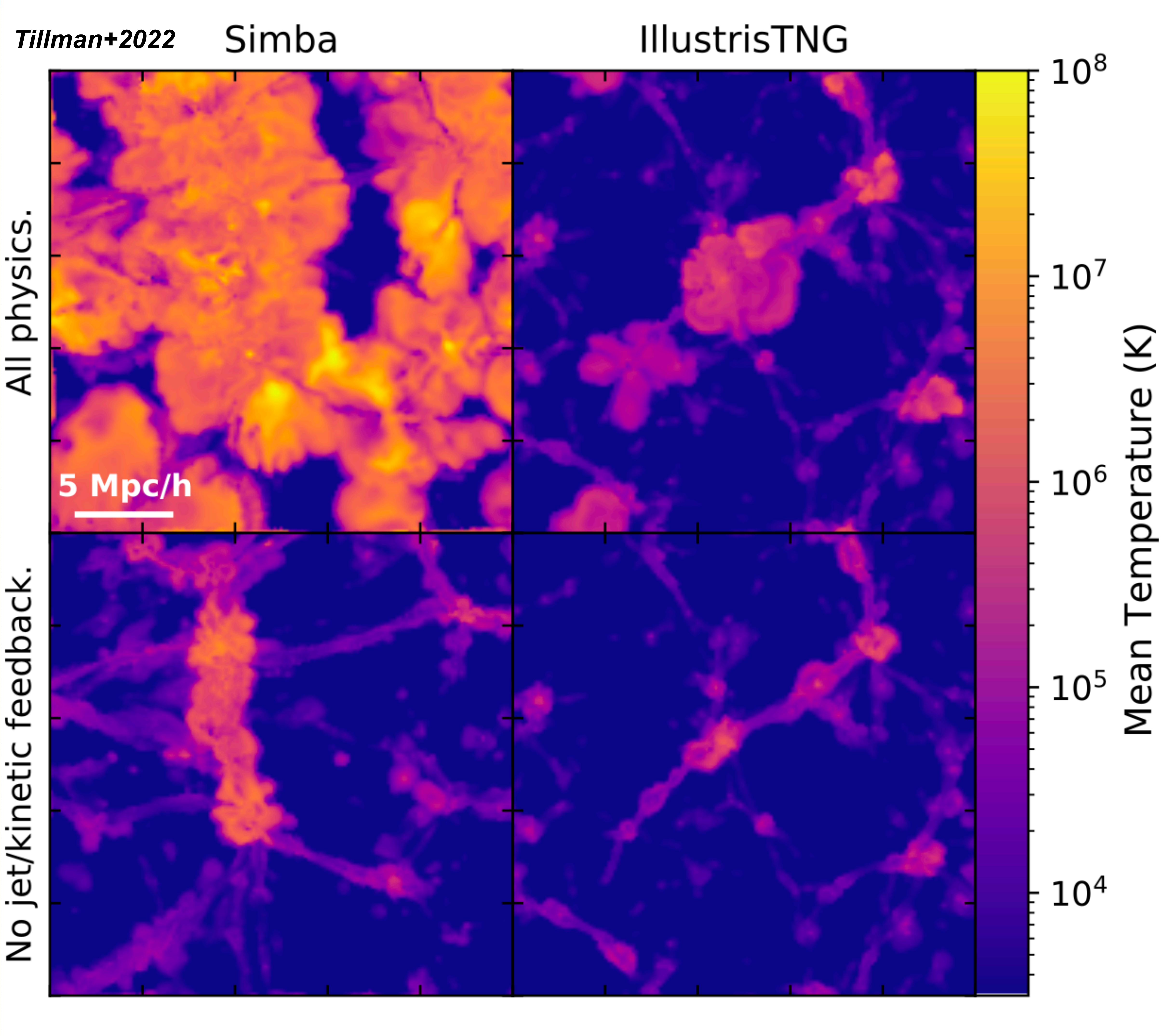
- Consistent at high SFR end
- Low SFR:
  - TNG: ✓
  - Others: ✗

Column density distribution function

Tillman+2022

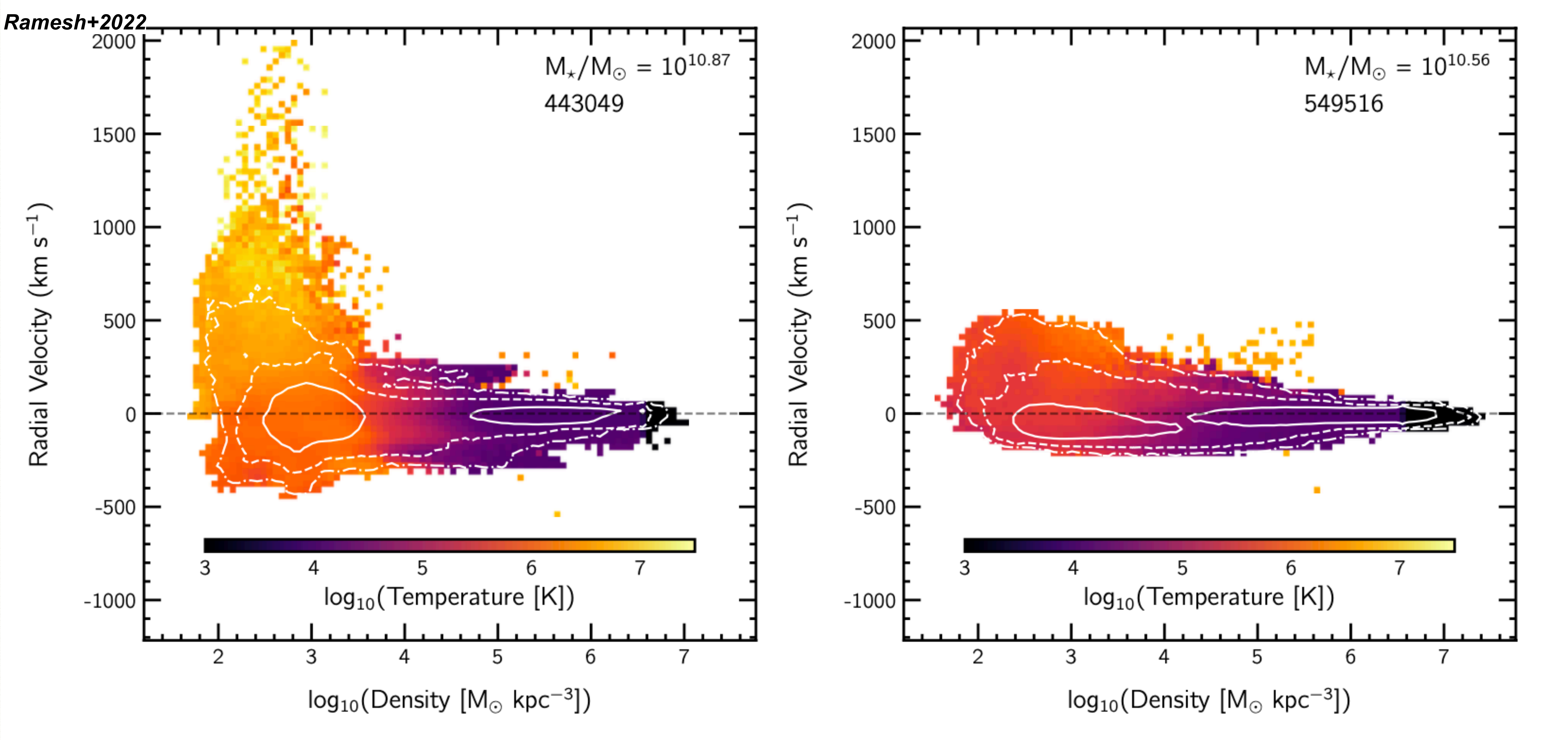


- SIMBA: jets have a effects;
  - Long-range feedback
- TNG: isotropic winds

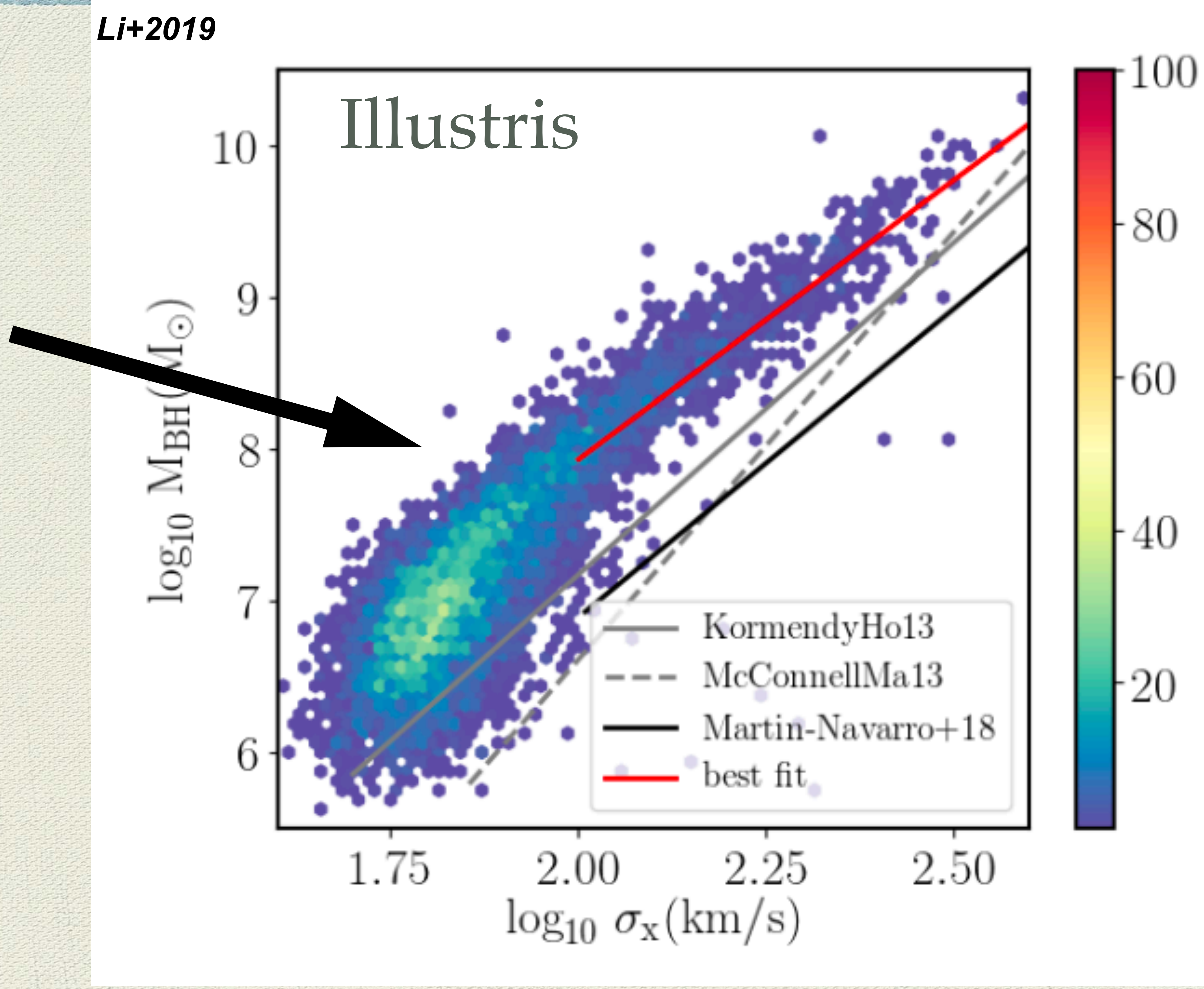

Tillman+2022
Simba
IllustrisTNG
All physics.
No jet/kinetic feedback.
5 Mpc/h
10^8
10^7
10^6
10^5
10^4
Mean Temperature (K)

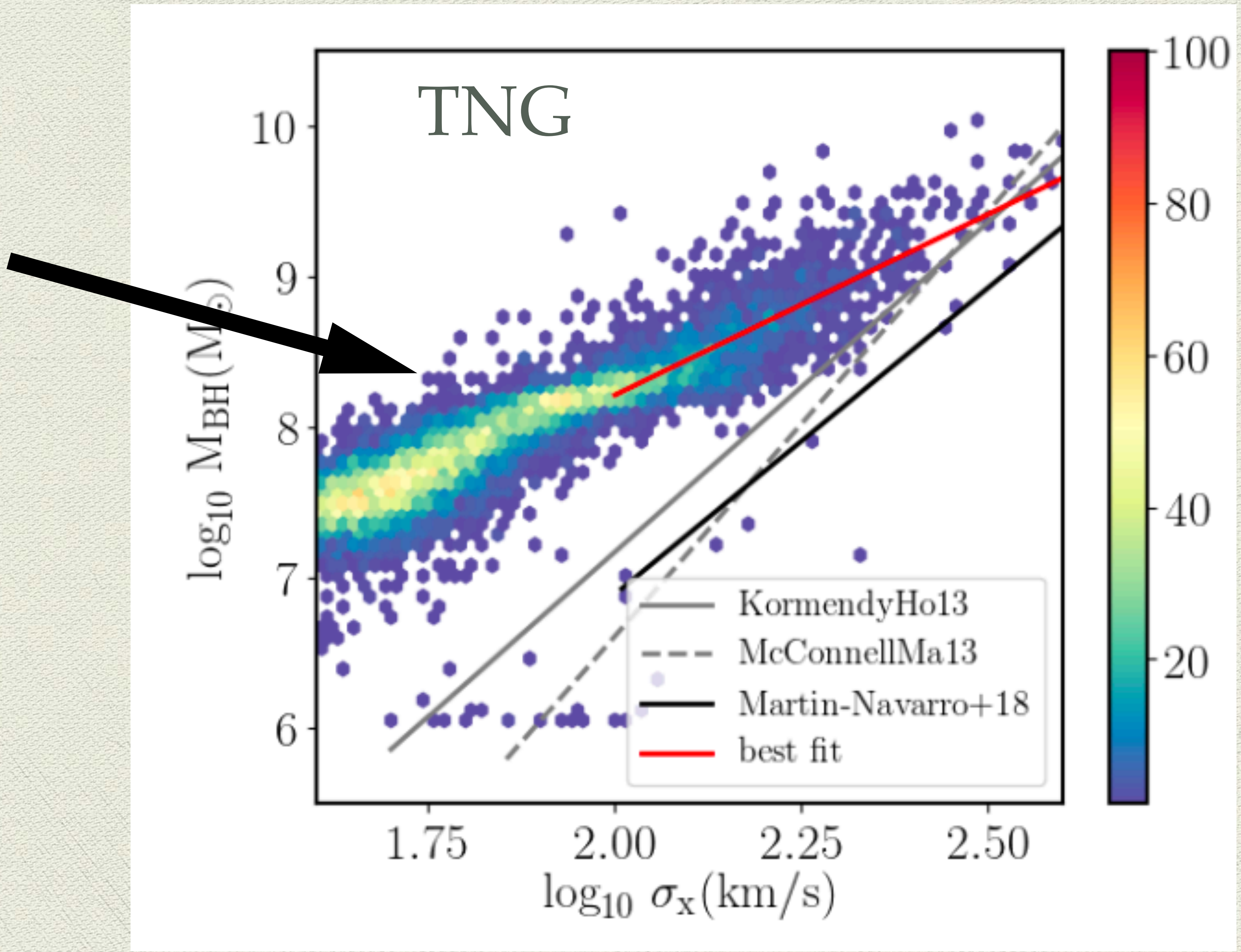
Halo gas properties

Kinetic feedback: hot gas with high velocity



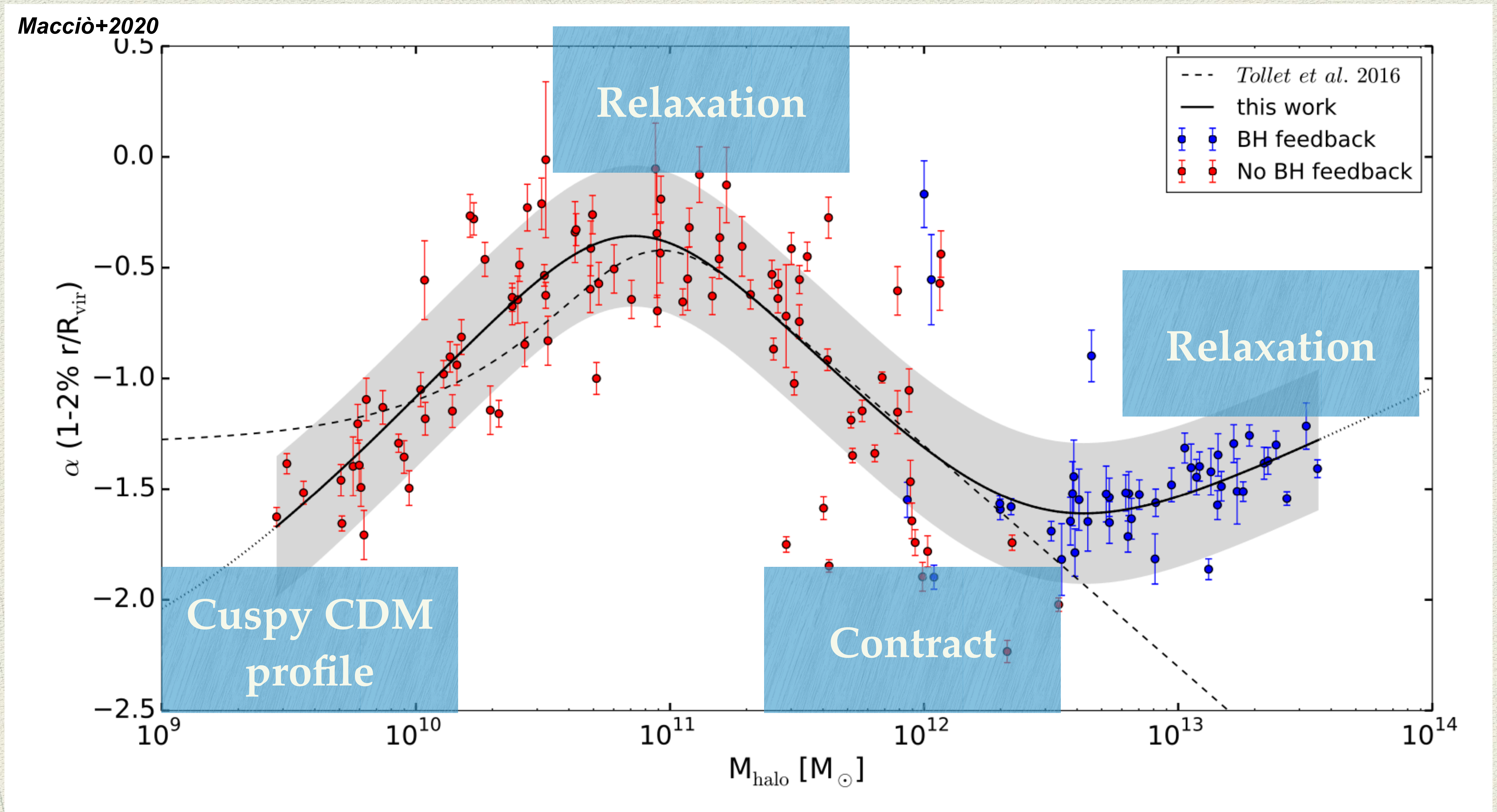
BH mass—galaxy properties



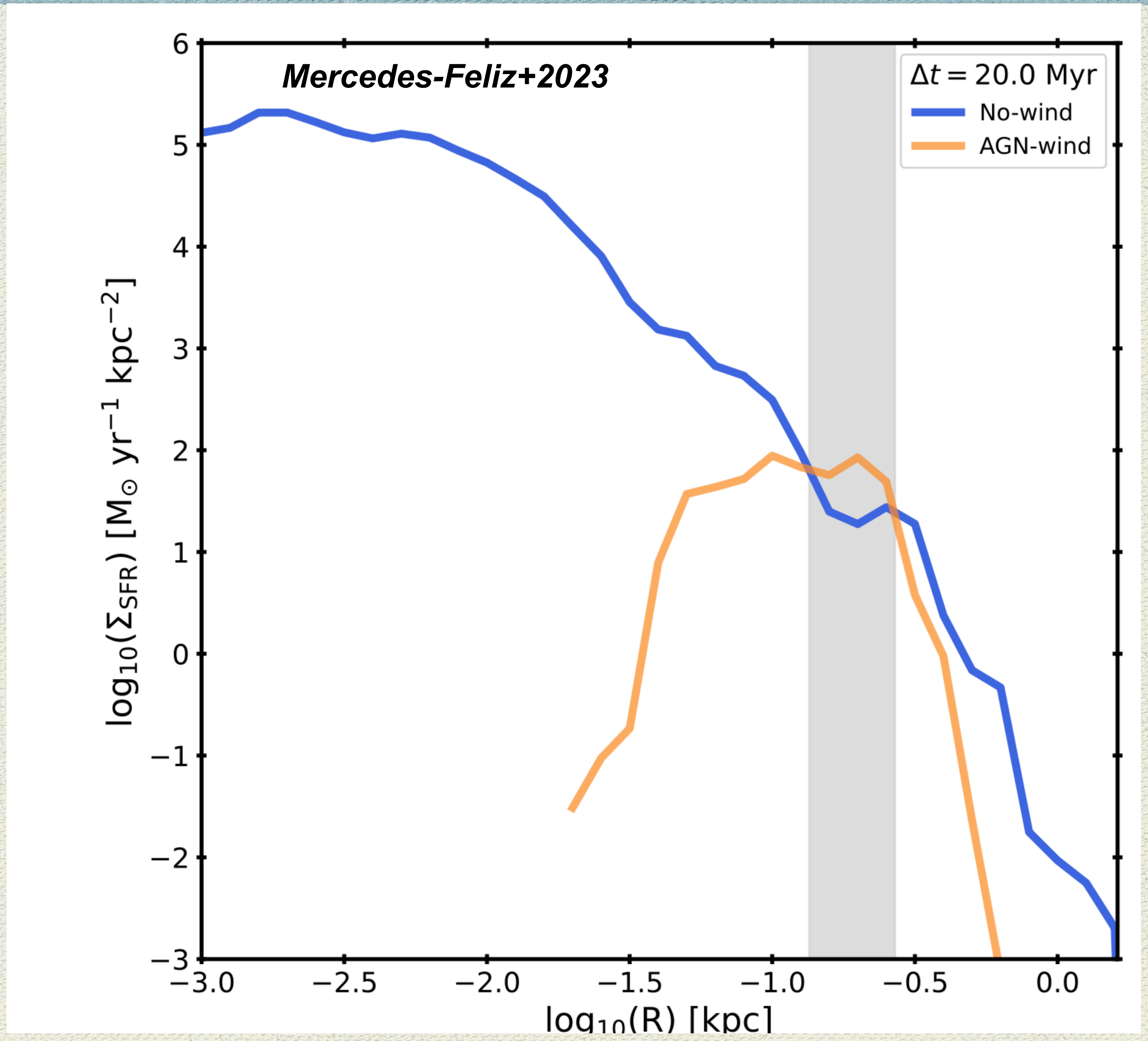


- Overmassive SMBHs: in-efficient feedback in quasar mode

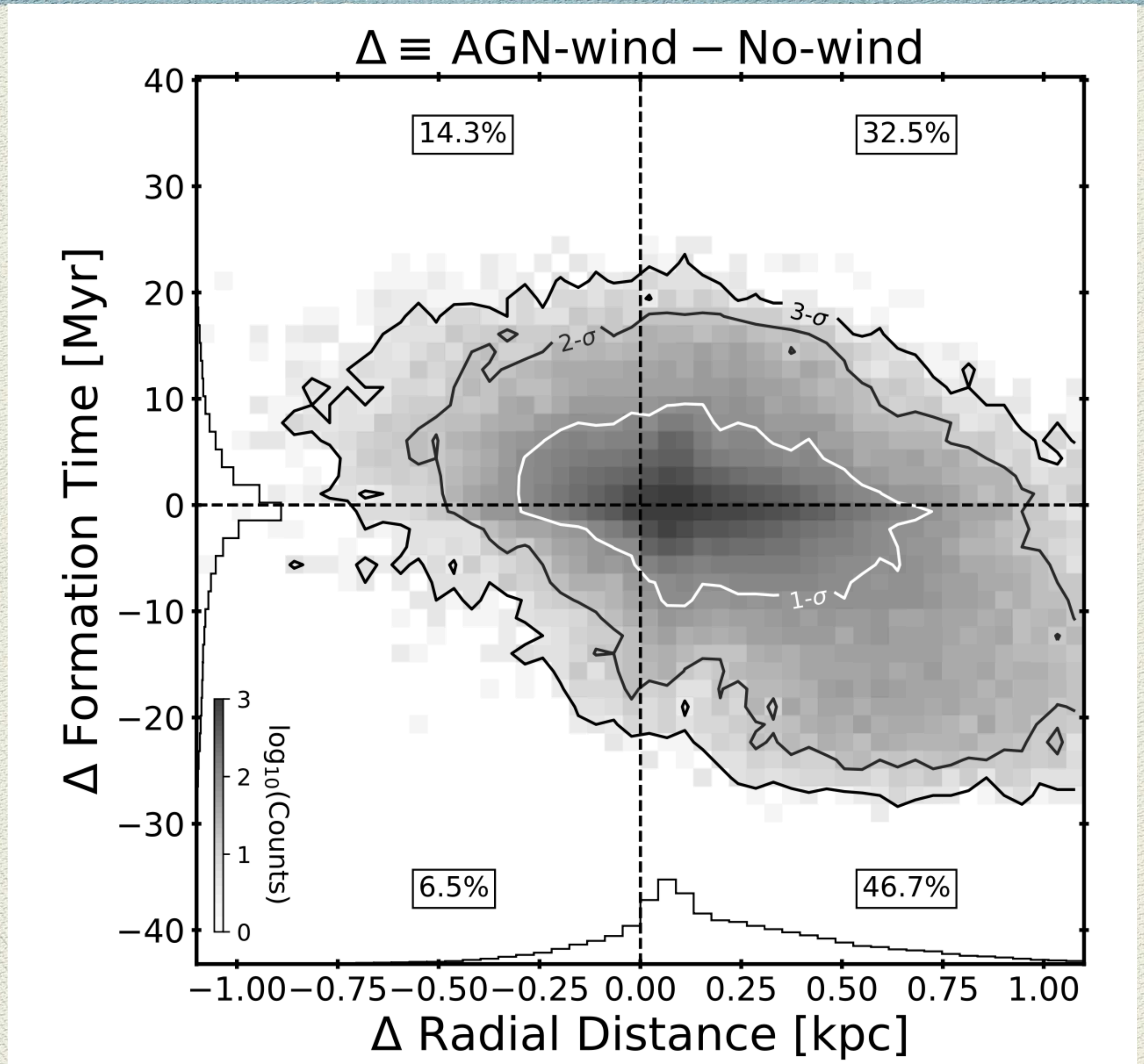
Dark matter density shape



Local positive feedback



Local SFR enhancement



In presence of QSO wind,
Stars tend to form early at large distance

Summary

- Important but with big uncertainties.
- Focusing on one or several observation relations-> more predictive
- Numerical uncertainties: resolution issue
- Seed modeling & super-Eddington feedback

CSST role

- More galaxy & AGN sample
- Gas dynamics, winds and jets
- Galaxy clustering->dark matter halo properties