

Three regimes of black hole feedback

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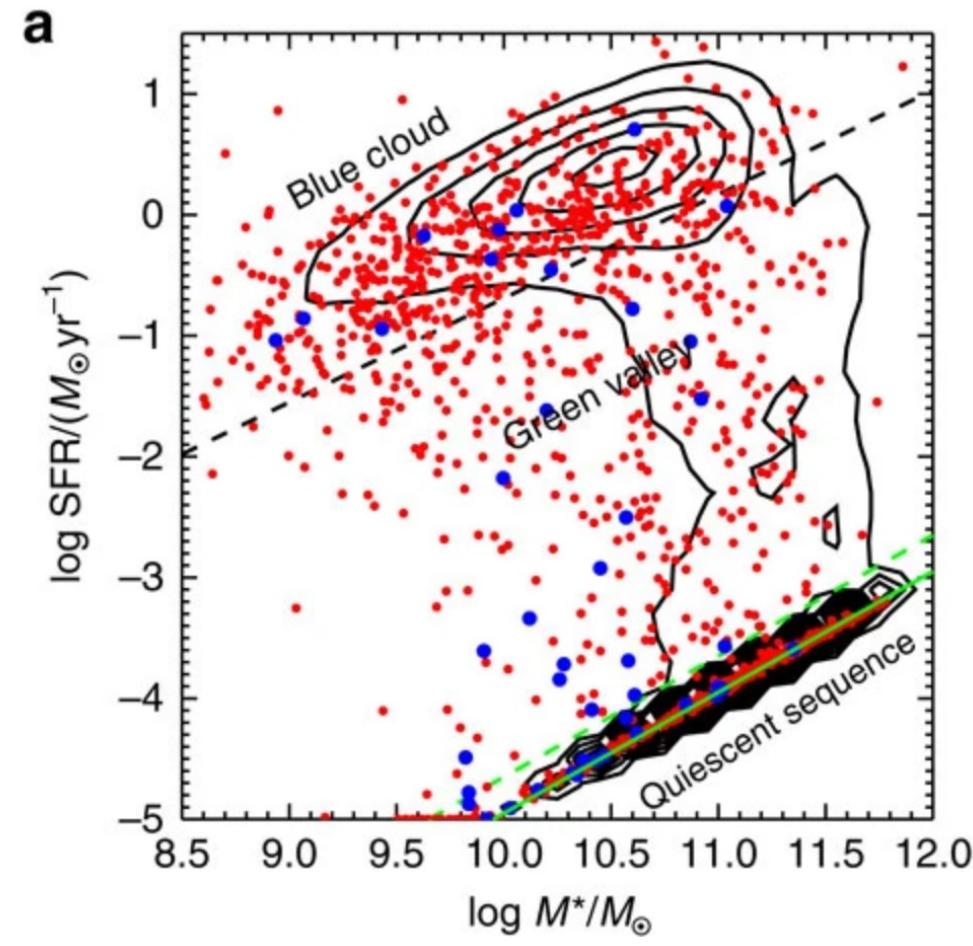
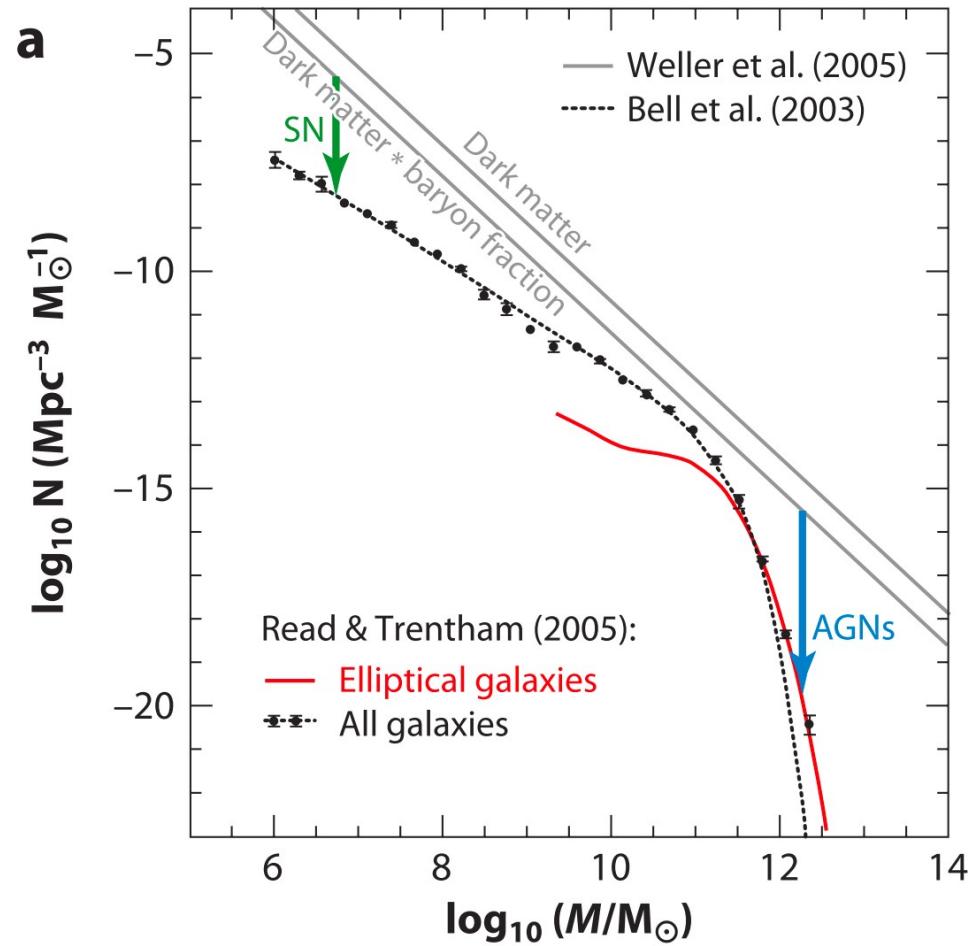
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Active galactic nuclei feedback is invoked to explain the observed exponential decline of massive galaxies



*Accretion onto supermassive black holes
drives active galactic nuclei feedback*

Energetics

$$L = \eta \dot{M}_{\text{BH}} c^2$$

Bolometric luminosity

Black hole accretion rate

Radiative efficiency

The diagram illustrates the Eddington luminosity equation $L = \eta \dot{M}_{\text{BH}} c^2$. It features three arrows pointing towards the equation: an orange arrow from the text "Bolometric luminosity" above the equation, a green arrow from the text "Black hole accretion rate" to the right of the equation, and a blue arrow from the text "Radiative efficiency" pointing upwards towards the left side of the equation.

Energetics

$$E_{\text{feedback}} = \epsilon_f \eta \dot{M}_{\text{BH}} c^2$$

Feedback energy

Coupling strength

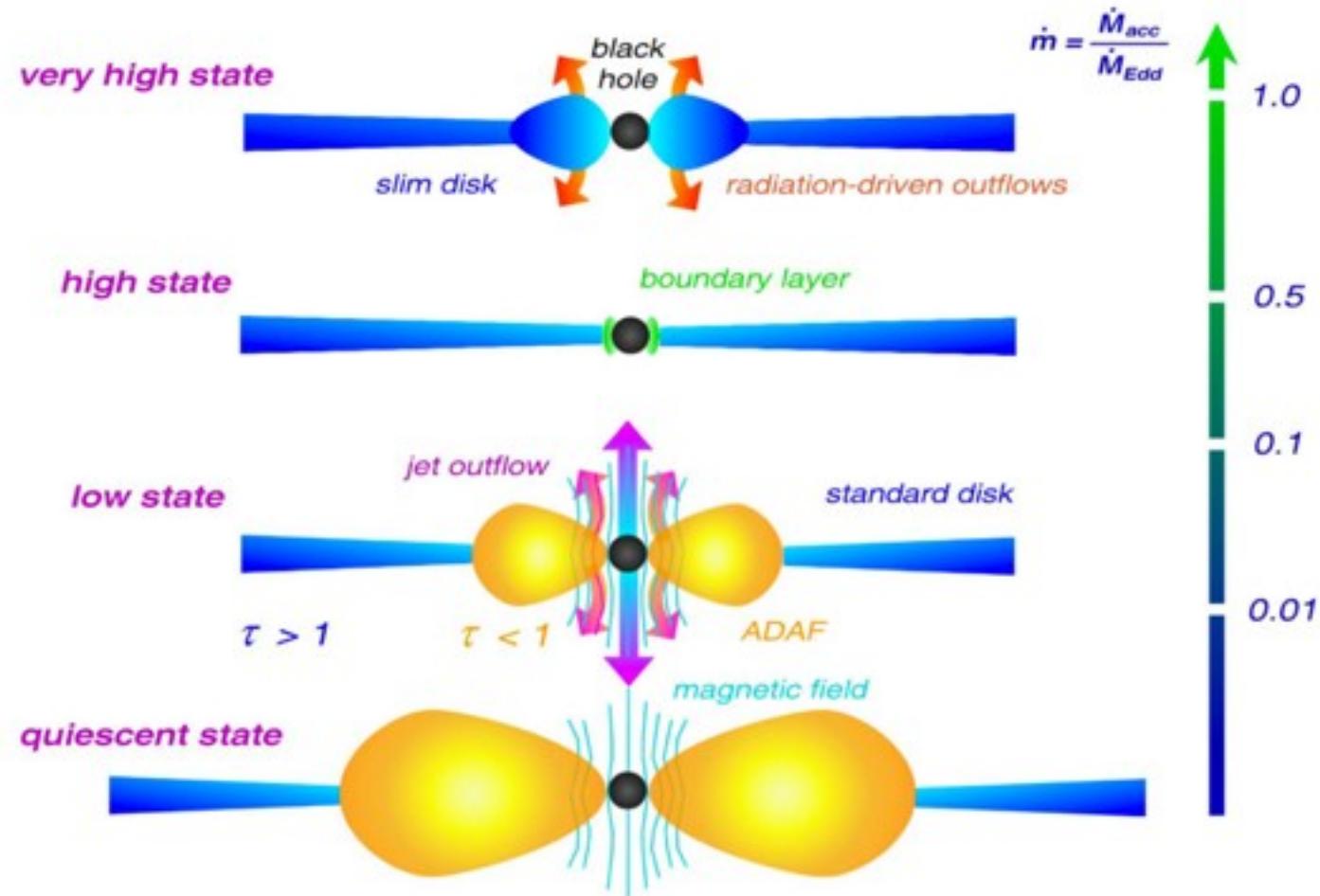
Black hole accretion rate

Radiative efficiency

The diagram illustrates the components of feedback energy. It features a central equation $E_{\text{feedback}} = \epsilon_f \eta \dot{M}_{\text{BH}} c^2$. Four arrows point from labels to specific terms in the equation: an orange arrow points to ϵ_f (labeled 'Feedback energy'), a yellow arrow points to η (labeled 'Coupling strength'), a green arrow points to \dot{M}_{BH} (labeled 'Black hole accretion rate'), and a blue arrow points to c^2 (labeled 'Radiative efficiency').

Black hole states

Accretion physics is complicated



Quasar mode

$$\eta \sim 0.1$$

$$\epsilon_f \sim 0.05$$



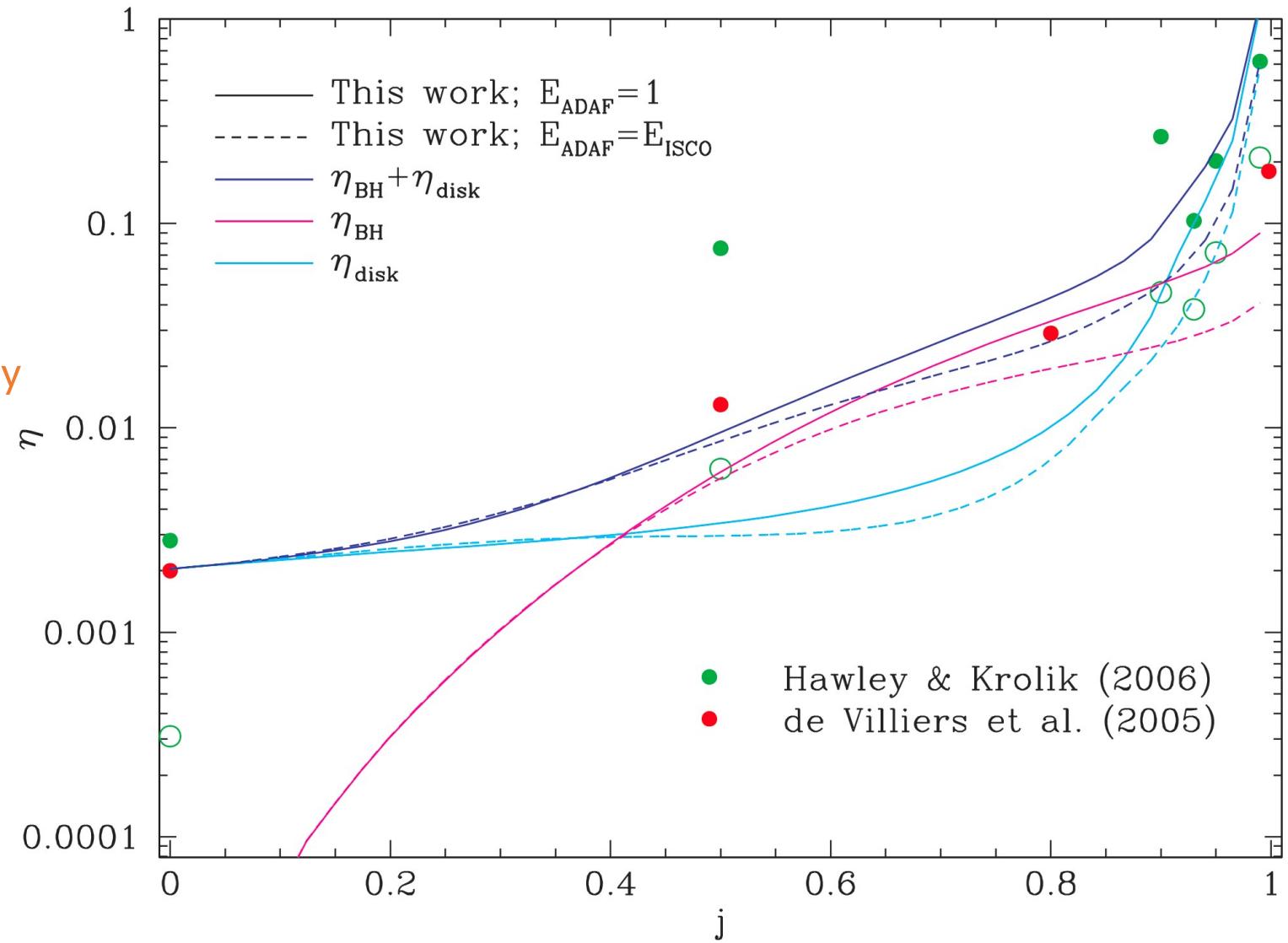
ADAF mode

Efficiency fit to BH+disk jet

Jet may have more than 100% efficiency

“Isotropic” component

$$\eta \sim \dot{M}_{\text{BH}} / \dot{M}_{\text{Edd}}$$



Slim disk mode

$$\eta_{\text{high}}(j, r) = \frac{r}{16} A(j) \left[\frac{0.985}{r + B(j)} + \frac{0.015}{r + C(j)} \right]$$

↑
Spin

Inverse, Eddington-scaled accretion rate

Fit constants

Synthesis Model

Rennehan+’24
arXiv: 2309.15898

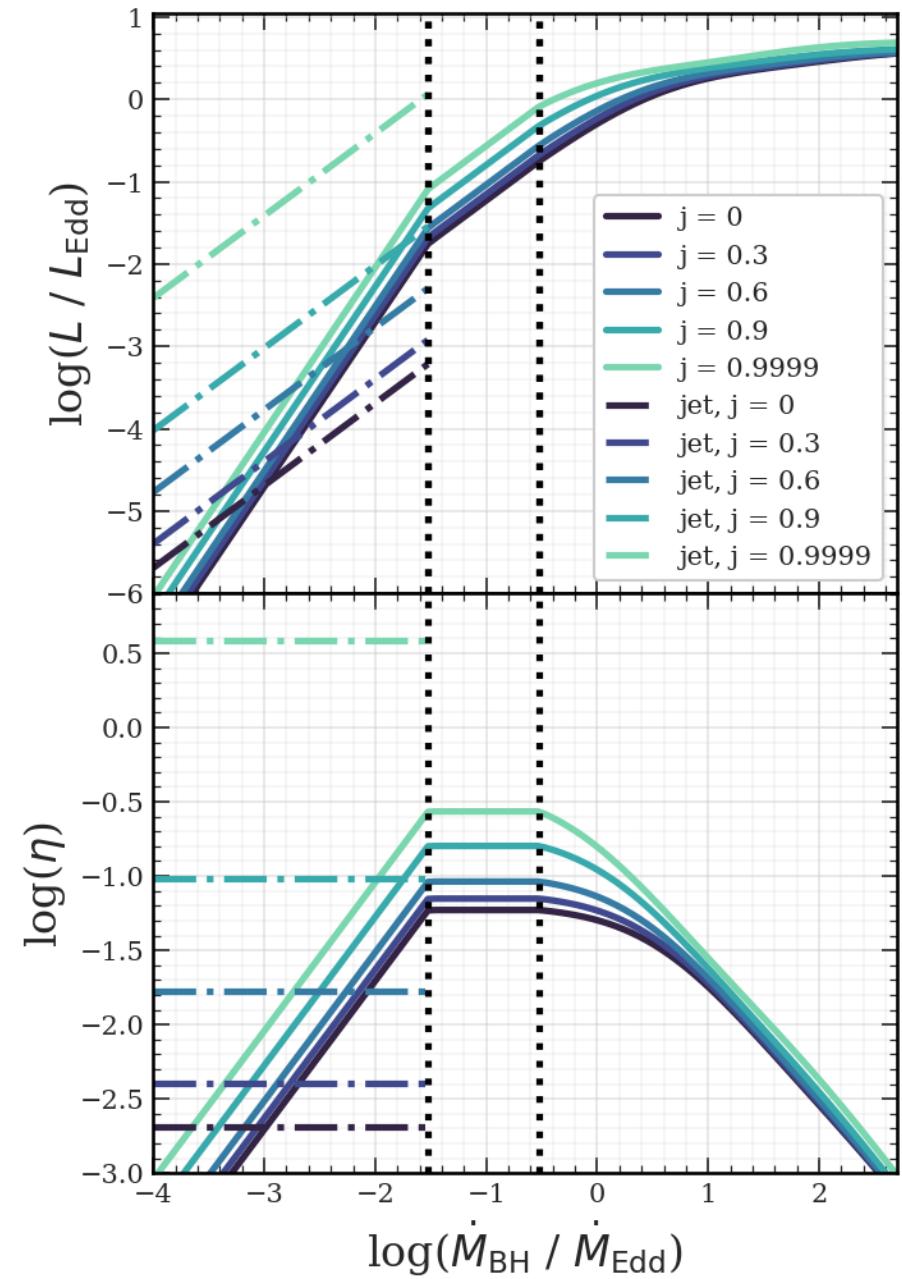
$$\eta \sim \dot{M}_{\text{BH}} / \dot{M}_{\text{Edd}}$$

+

$$\eta \sim \text{const.}$$

+

$$\eta \sim (\dot{M}_{\text{BH}} / \dot{M}_{\text{Edd}})^{-1}$$

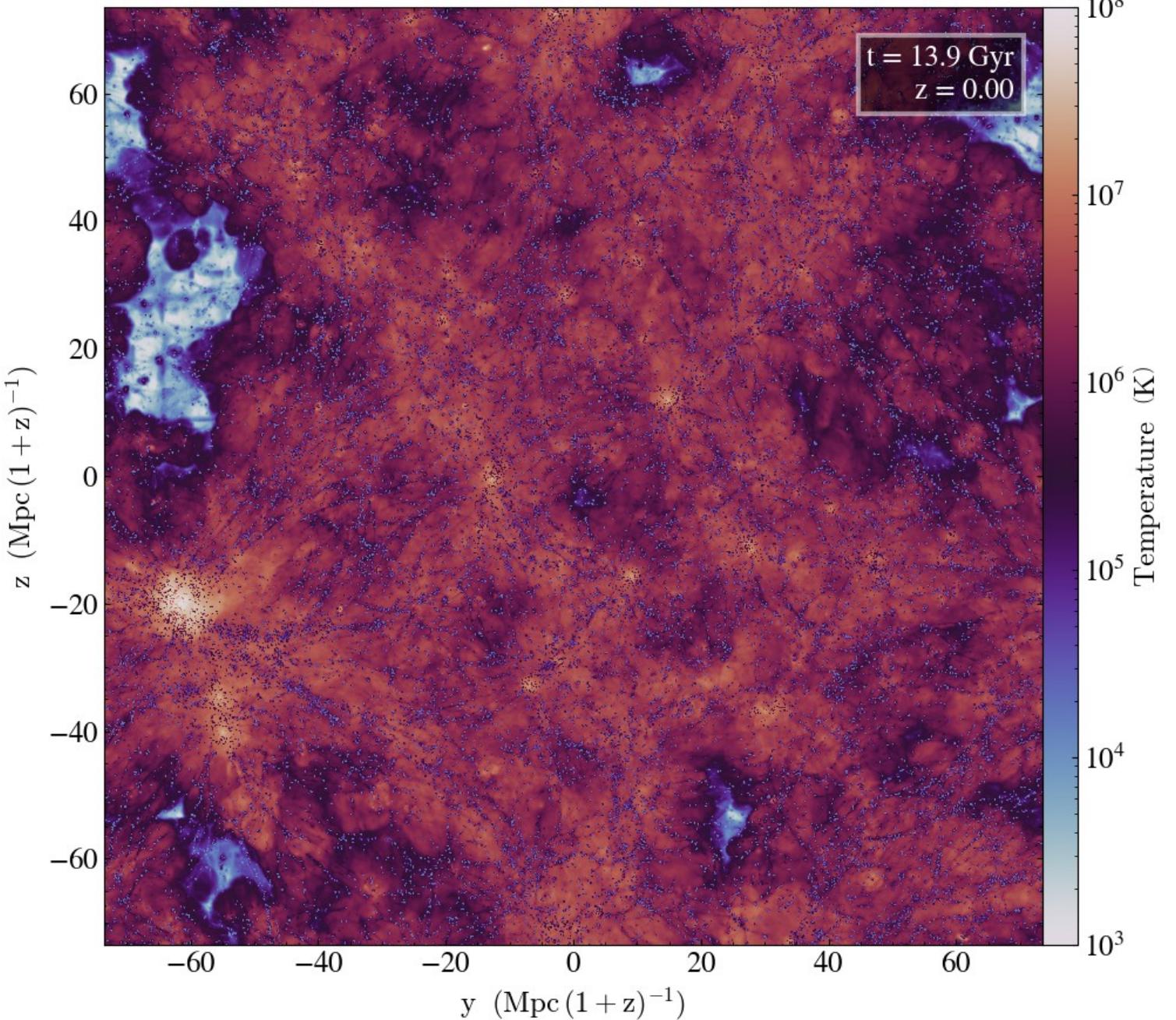


Cosmological simulations

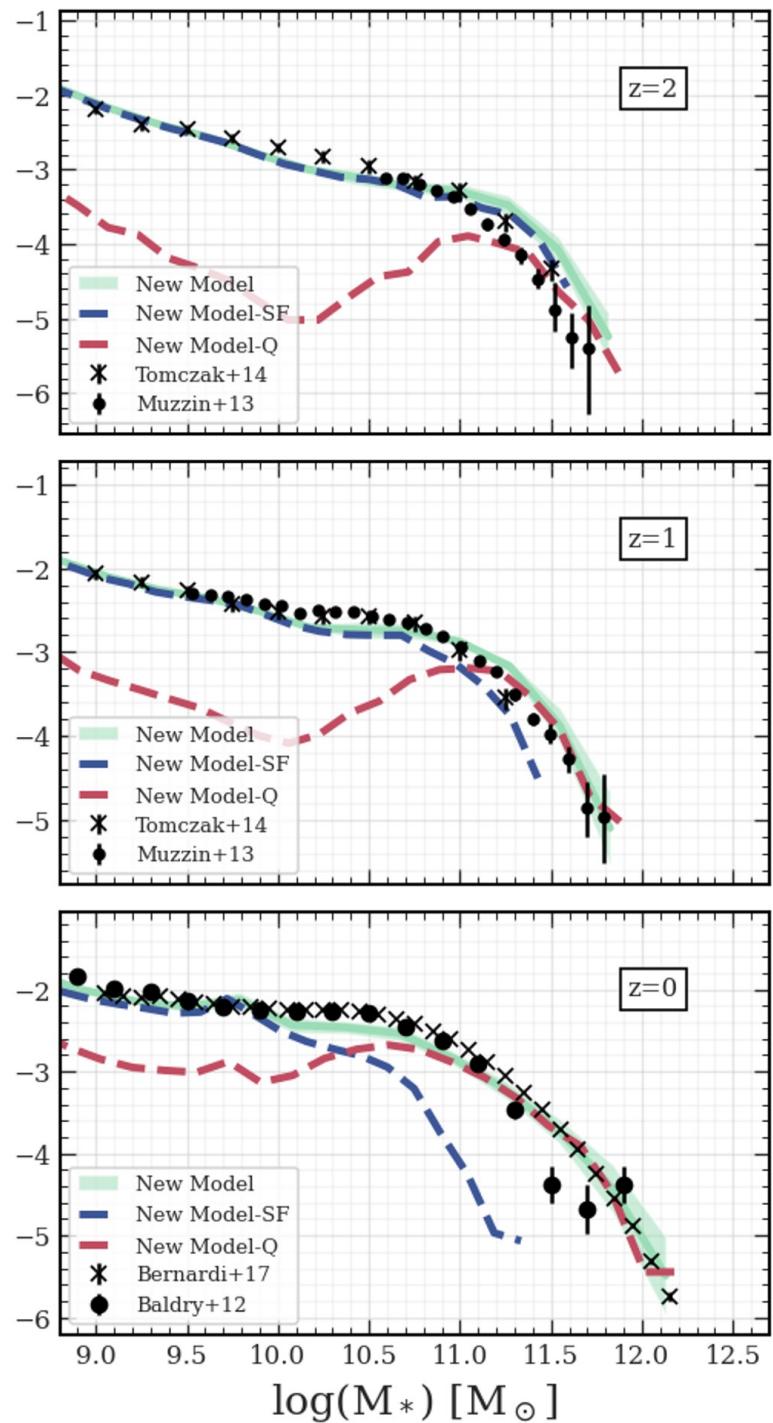
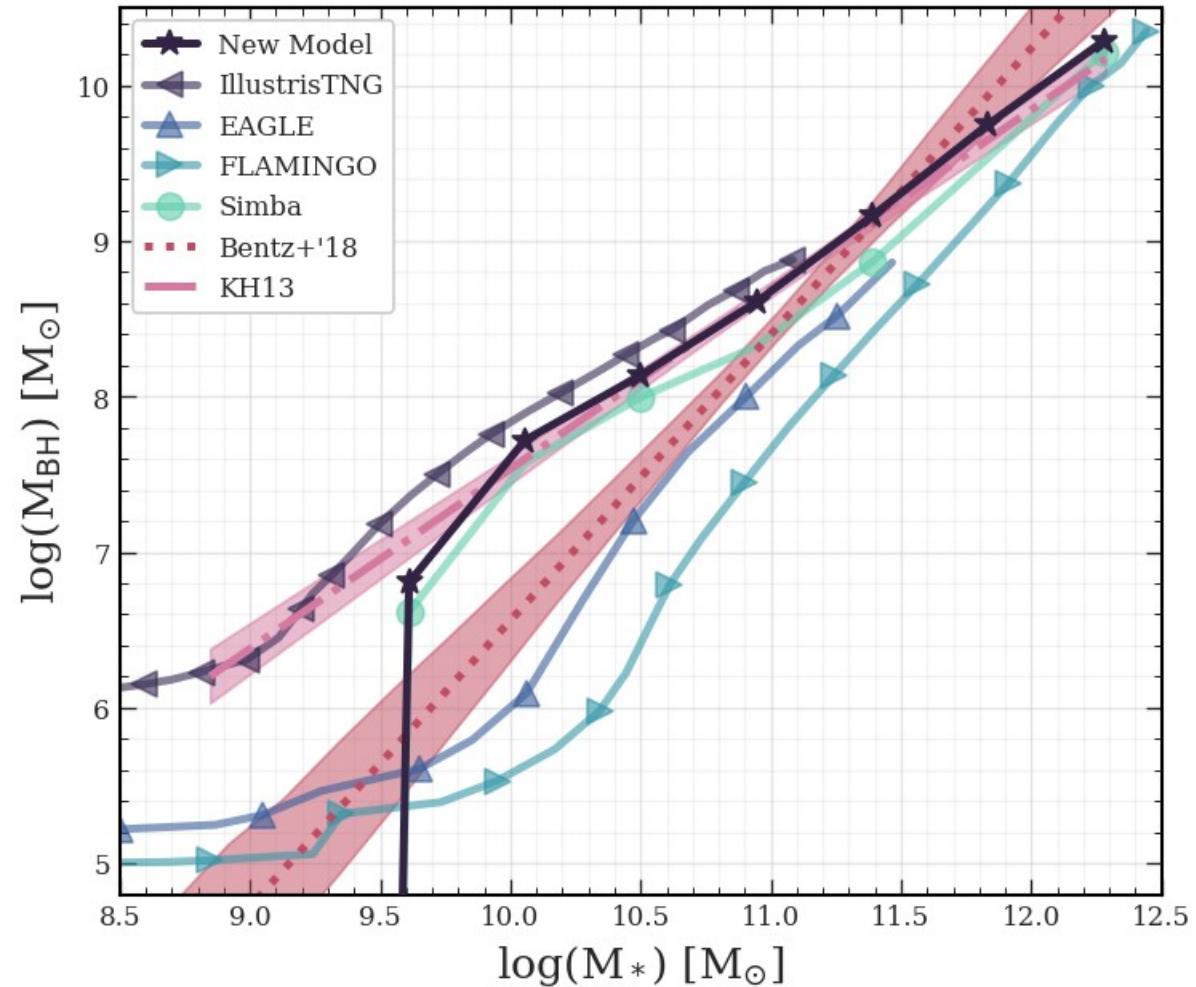
- We wanted to explore low-resolution, large-volume cosmological simulations.
- We used the **Simba** simulations as a base and heavily modified the AGN feedback model.
- We ran 650 calibration simulations to find the best parameters.

2 billion particles

Used best calibration in
2x1024³ simulation;
(150 cMpc)³.



Reasonable Calibrations



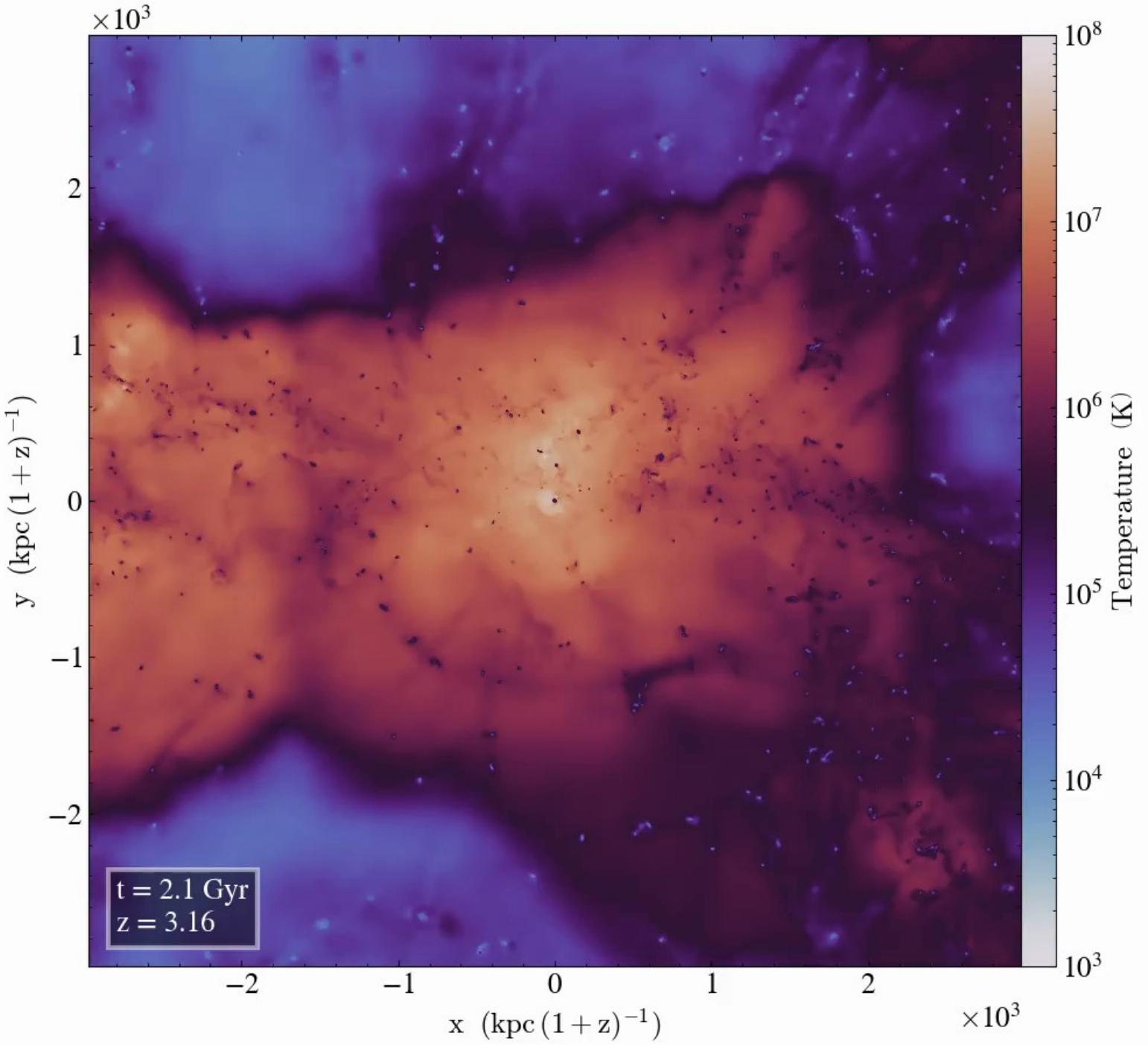
Comparisons: Kormendy & Ho '13, Bentz+18

Simulations: Schaye+'15, Pillepich+'18, Davé+'19, Schaye+'23



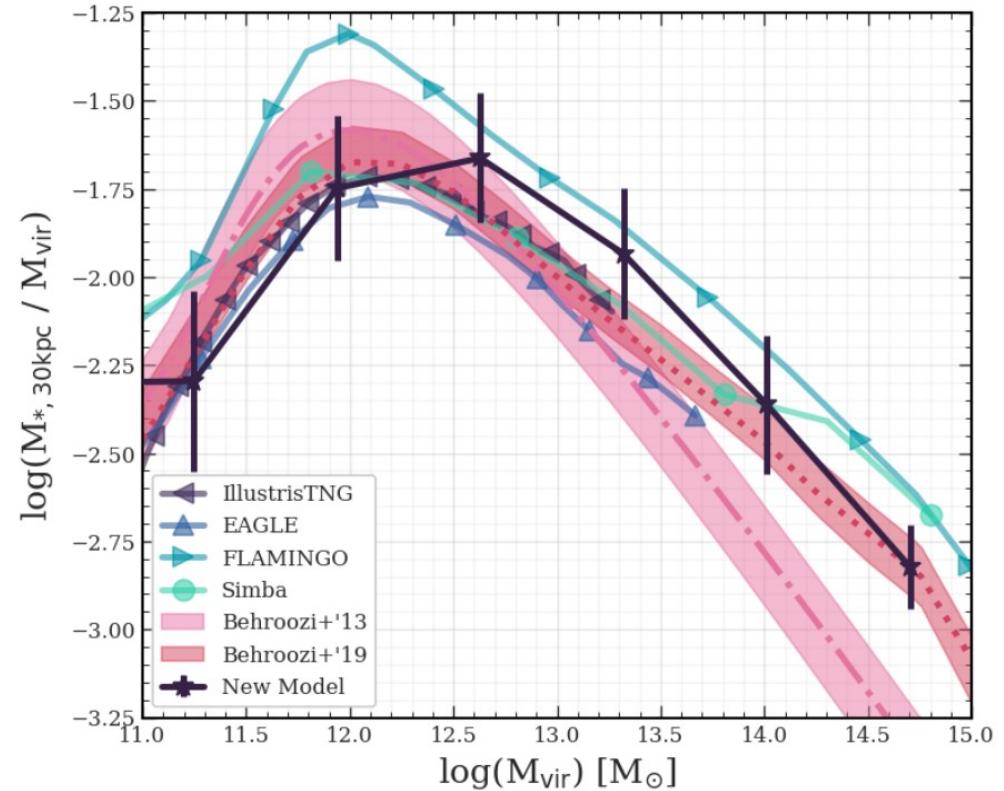
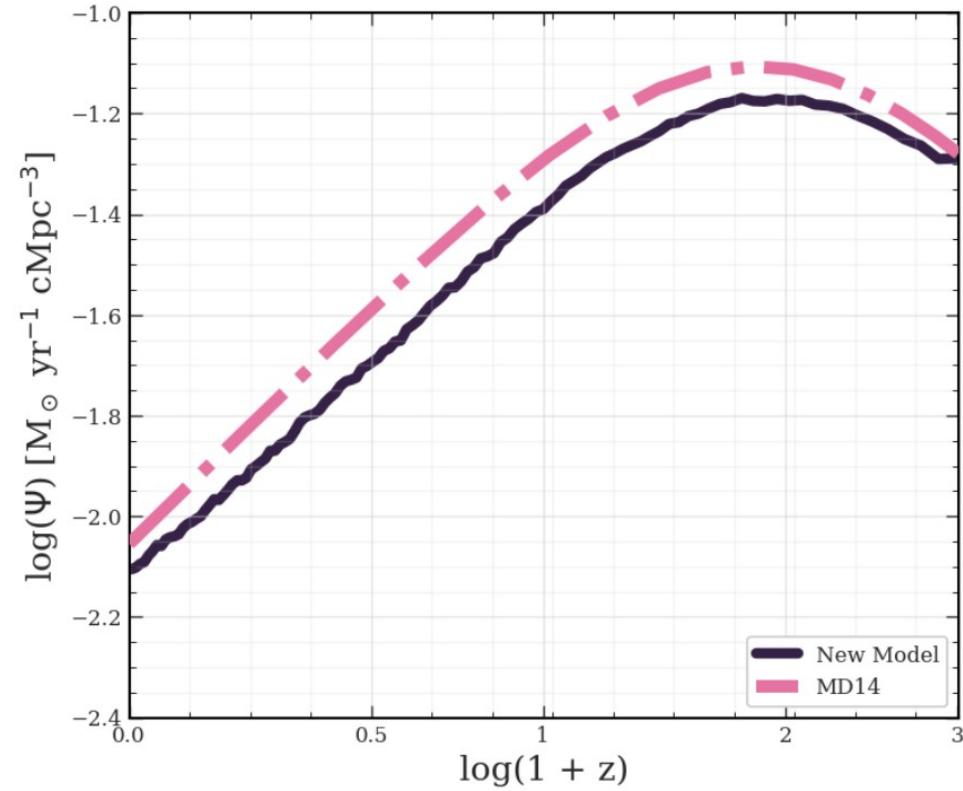
Summary

- Introduced an AGN feedback synthesis model across accretion states, for cosmological simulations.
- Provided a calibrated, large-volume simulation; data publicly available.
- I'll give you the code, I don't care.



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Calibration re-run



Calibration

6 parameters to calibrate; 648 simulations; calibrate at $z = 2$

