The interplay of dual black hole accretion and feedback modes in SIMBA

Daniel Anglés-Alcázar - University of Connecticut

SIMBA Collaboration Meeting, Flatiron Institute, May 1st 2023

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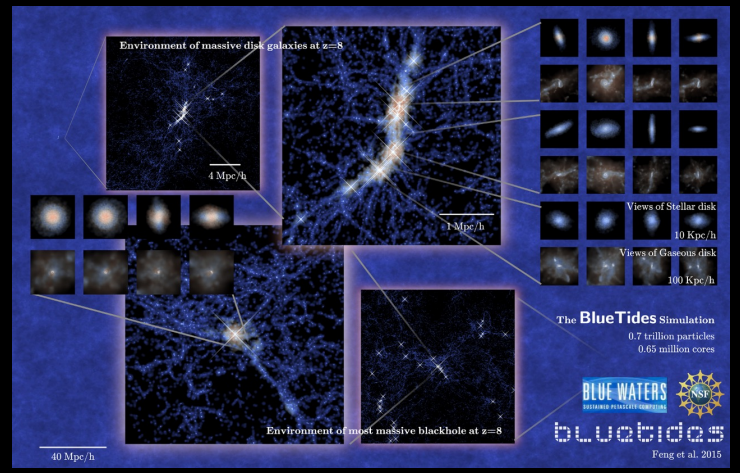
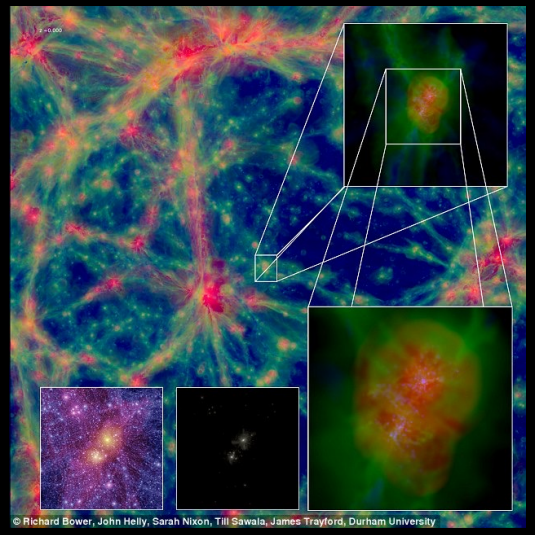
Large-volume cosmological hydrodynamic simulations with black holes

Blue Tides (Feng+2016)



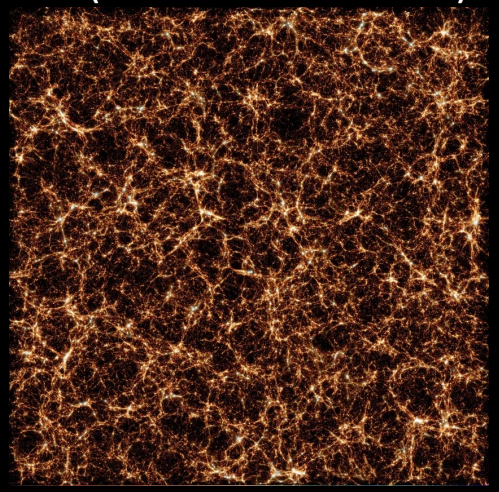
Eagle (Schaye+2015)



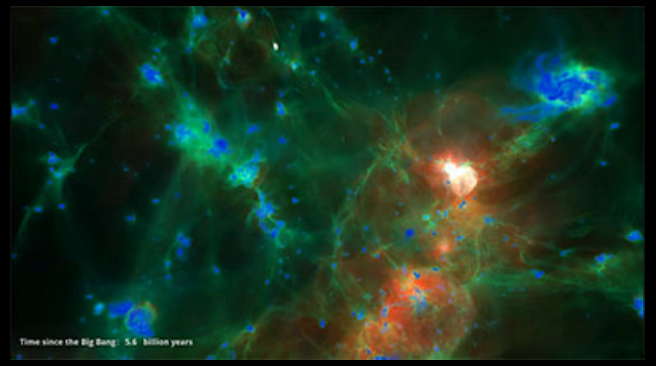
Illustris-TNG (Weinberger+2017,Pillepich+2018)

Horizon-AGN
(Dubois+2014, Volonteri+2016)

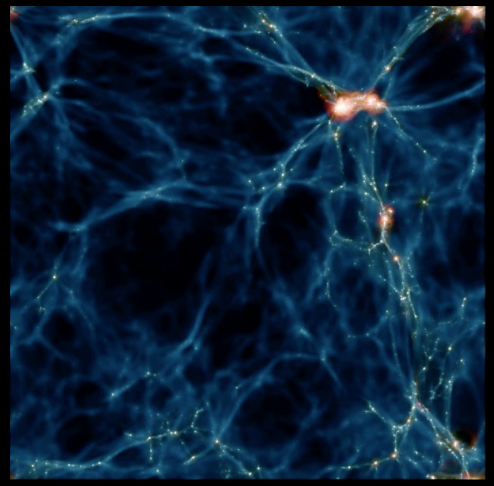
Magneticum
(Hirschmann+2014)



Illustris (Genel+2014,
Vogelsberger+2014)



Romulus
(Tremmel+2017)



Different hydrodynamics, star formation, stellar feedback, AGN feedback… but very similar BH accretion!

Bondi accretion

$$\dot{M}_{\mathrm{Bondi}} = \alpha \frac{4\pi G^2 M_{\mathrm{BH}}^2 \rho}{\left(c_{\mathrm{s}}^2 + v^2\right)^{3/2}}$$

→ Spherically symmetric accretion: neglects angular momentum

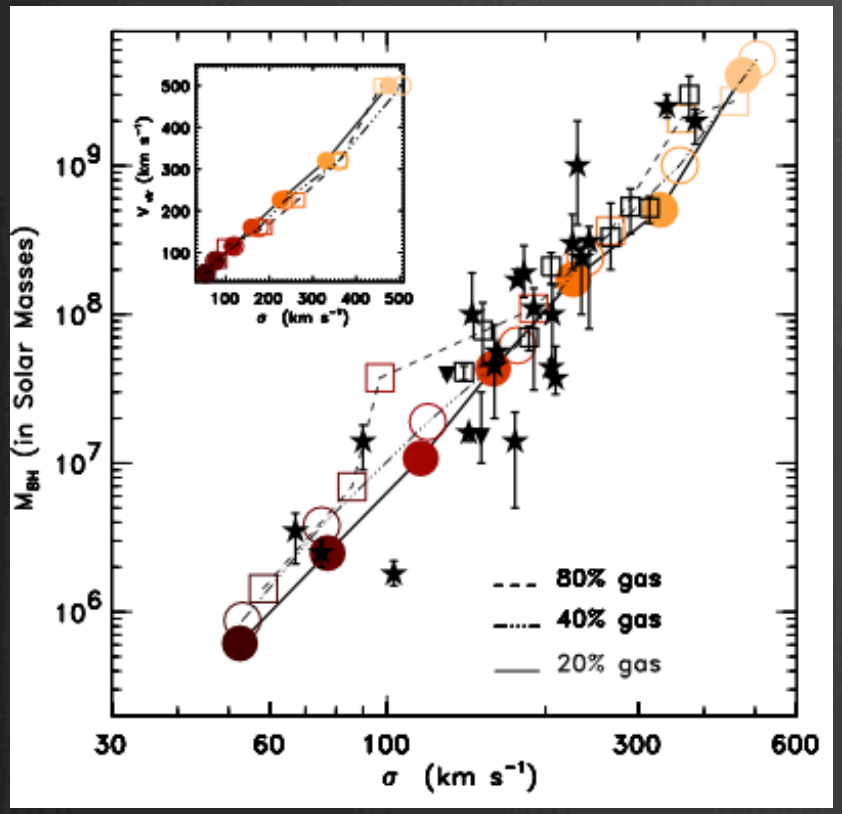
→ Strong dependence on M_{BH}: suppression at low mass and divergence at high mass

→ Black hole needs to self-regulate by construction, conditioning feedback implementation

Black hole-galaxy correlations: accretion or feedback driven?

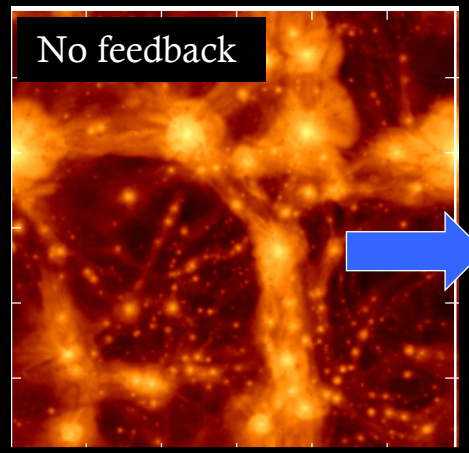
Bondi accretion
→ **Feedback** drives BH-host relation

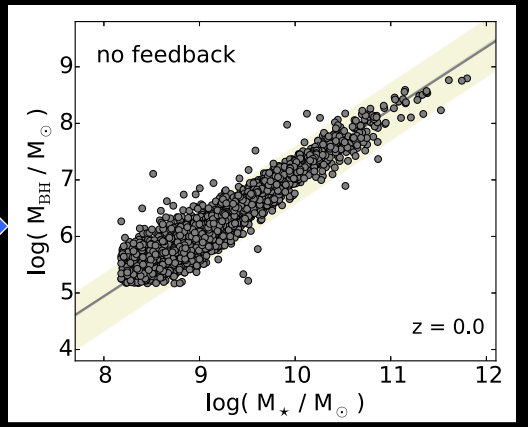
Black hole mass vs. velocity dispersion



Di Matteo+05 and many others

Gravitational Torque accretion
→ **Accretion** drives BH-host relation





Anglés-Alcázar+2013, 2015, 2017a

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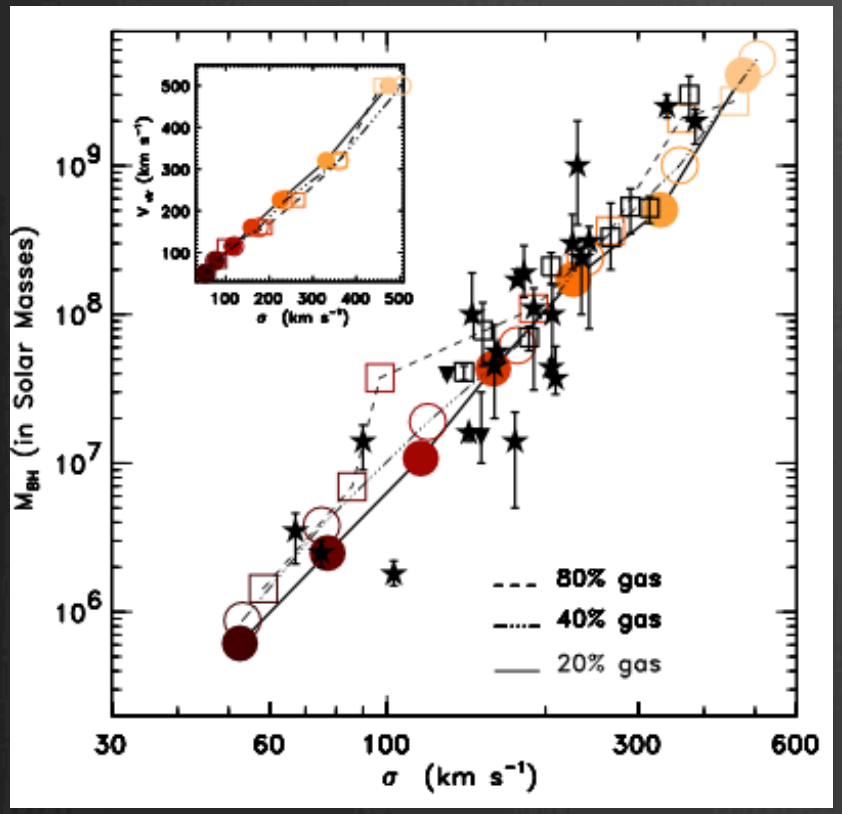

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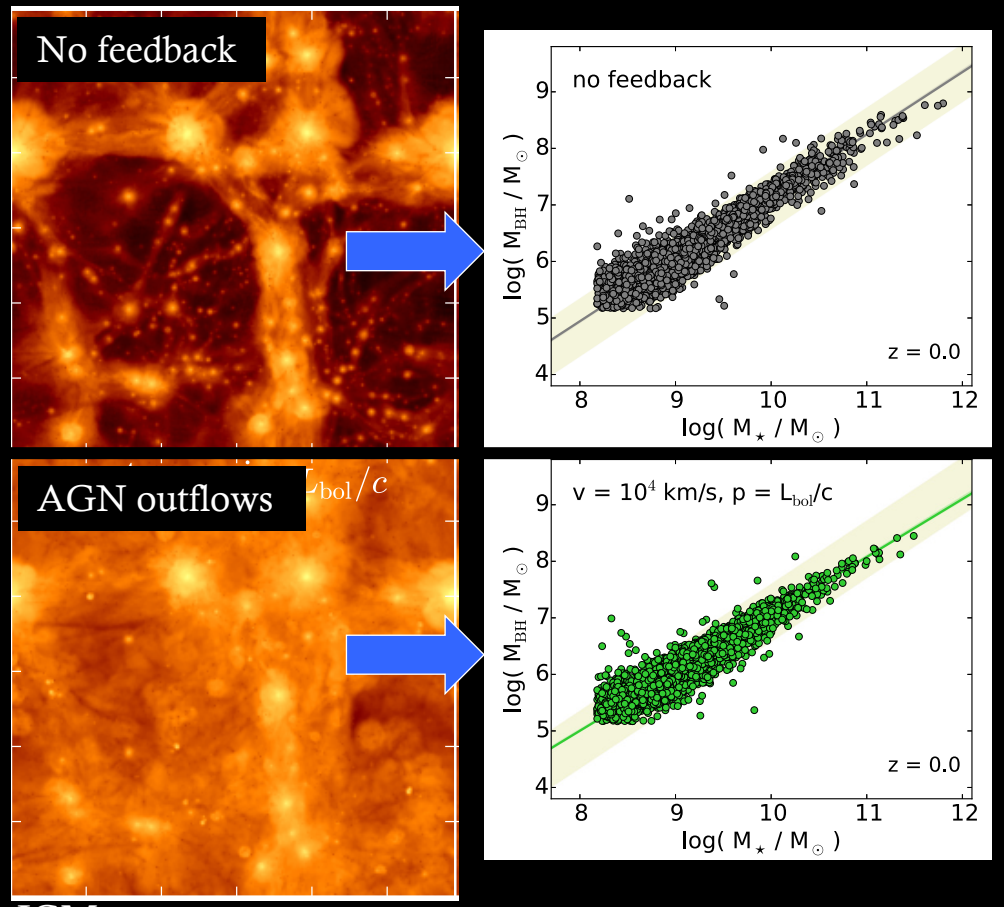


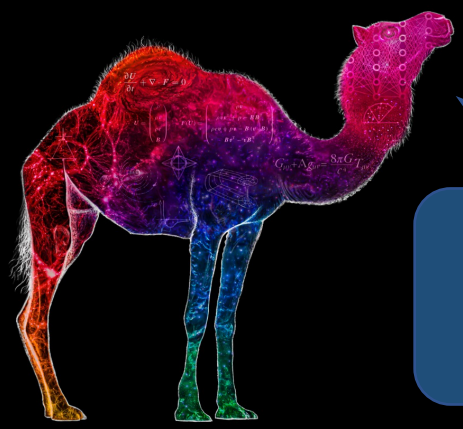
IGM temperature

Anglés-Alcázar+2013, 2015, 2017a

Villaescusa-Navarro, Anglés-Alcázar, Genel et al. (2021)
Ni, Genel, Anglés-Alcázar, Villaescusa-Navarro et al. (2023)

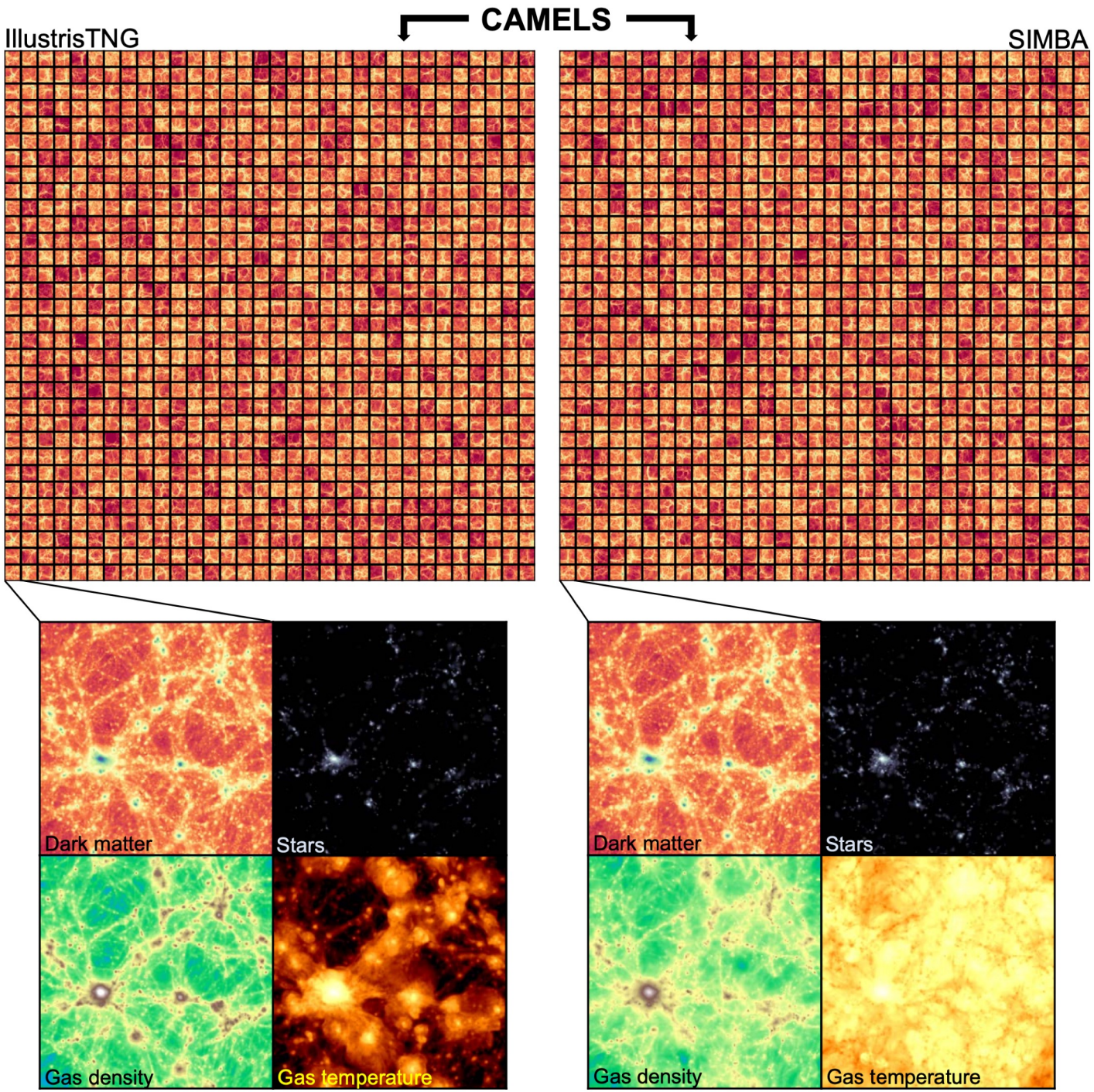
Variations of:

- Cosmological parameters: Ω_m and σ_8
- Mass/energy of Supernova-driven winds: A_{SN1} and A_{SN2}
- Mass/energy of AGN-driven winds: A_{AGN1} and A_{AGN2}
- Initial random phase



Thousands of simulations designed to train machine learning algorithms

CAMELS



Two-mode black hole growth in SIMBA

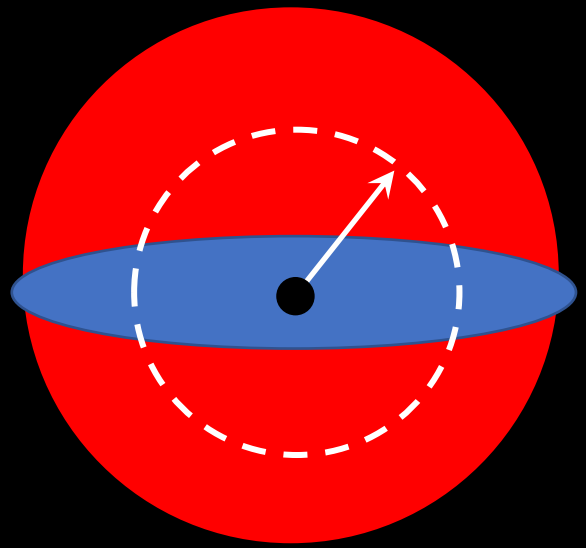
Bondi accretion + **Gravitational Torque accretion**

$$\dot{M}_{\rm Bondi} = \frac{4\pi\, G^2\, M_{\rm BH}^2\, \rho}{\left(c_{\rm s}^2 + v^2\right)^{3/2}}$$

Hopkins & Quataert (2010,2011)

$$\dot{M}_{\rm Torque} \approx \alpha_{\rm T}\, f_{\rm disk}^{5/2} \times \left(\frac{M_{\rm BH}}{10^8\,{\rm M}_\odot}\right)^{1/6} \left(\frac{M_{\rm disk}(R_0)}{10^9\,{\rm M}_\odot}\right) \times \left(\frac{R_0}{100\,{\rm pc}}\right)^{-3/2} \left(1 + \frac{f_0}{f_{\rm gas}}\right)^{-1} {\rm M}_\odot\,{\rm yr}^{-1}$$

Bondi accretion of HOT gas
$T > 10^5$ K



Torque accretion of COLD gas
$T < 10^5$ K

→ Accretion = Bondi + Torque
→ Both channels can operate simultaneously

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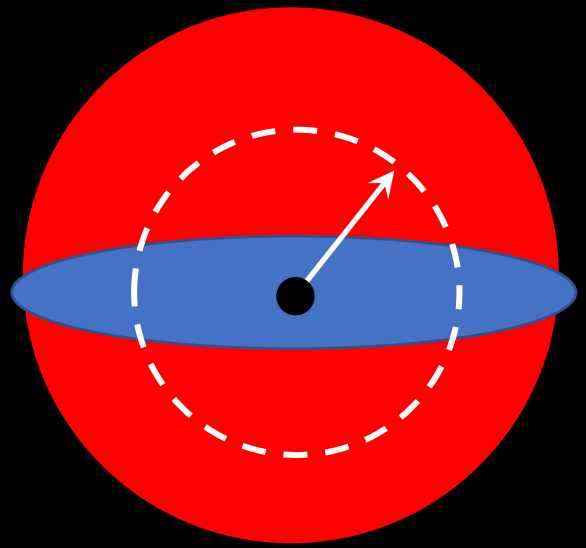

Torque accretion of COLD gas
$T < 10^5$ K

→ Accretion = Bondi + Torque
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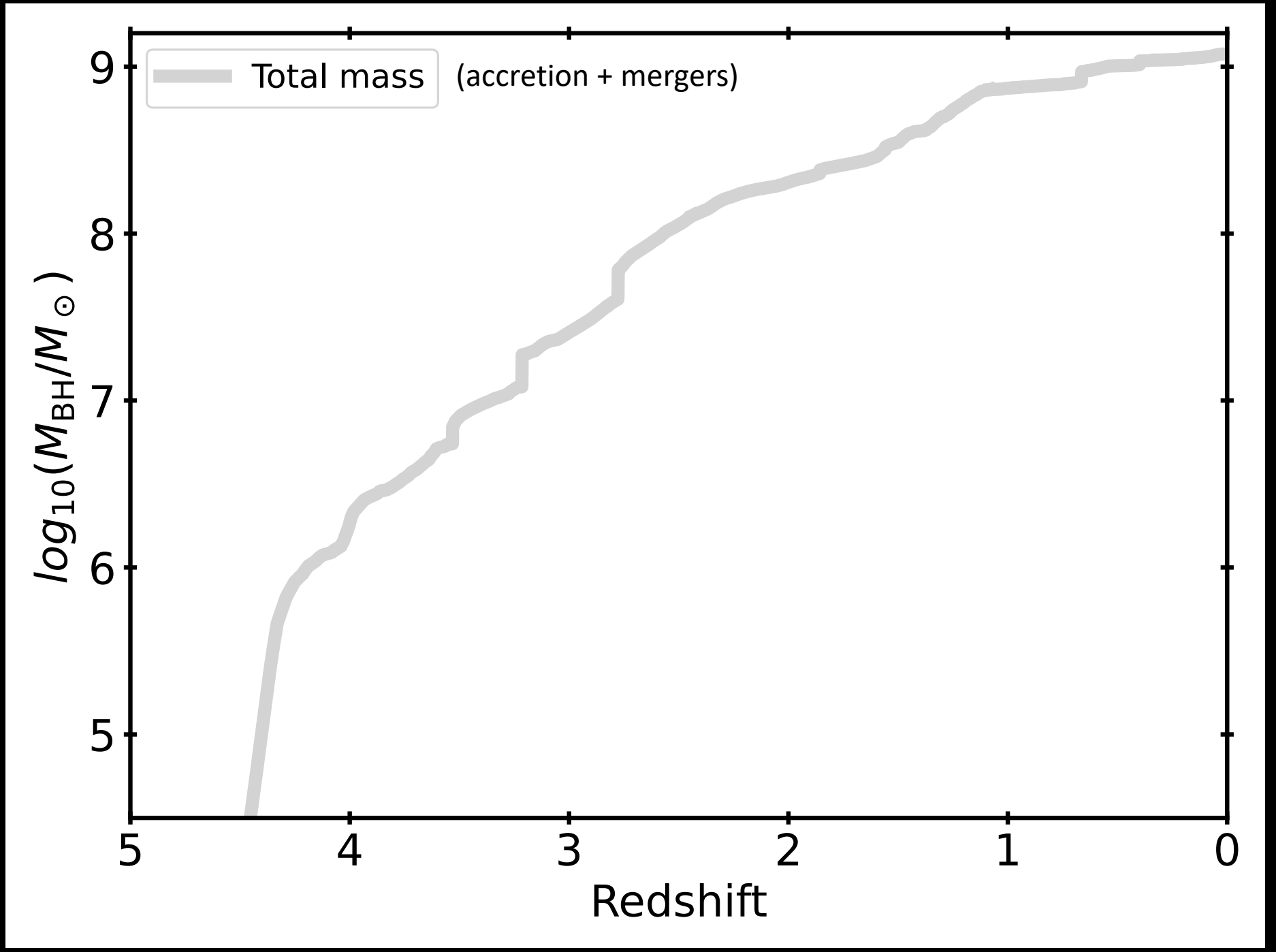
"First hybrid accretion model in the market!"

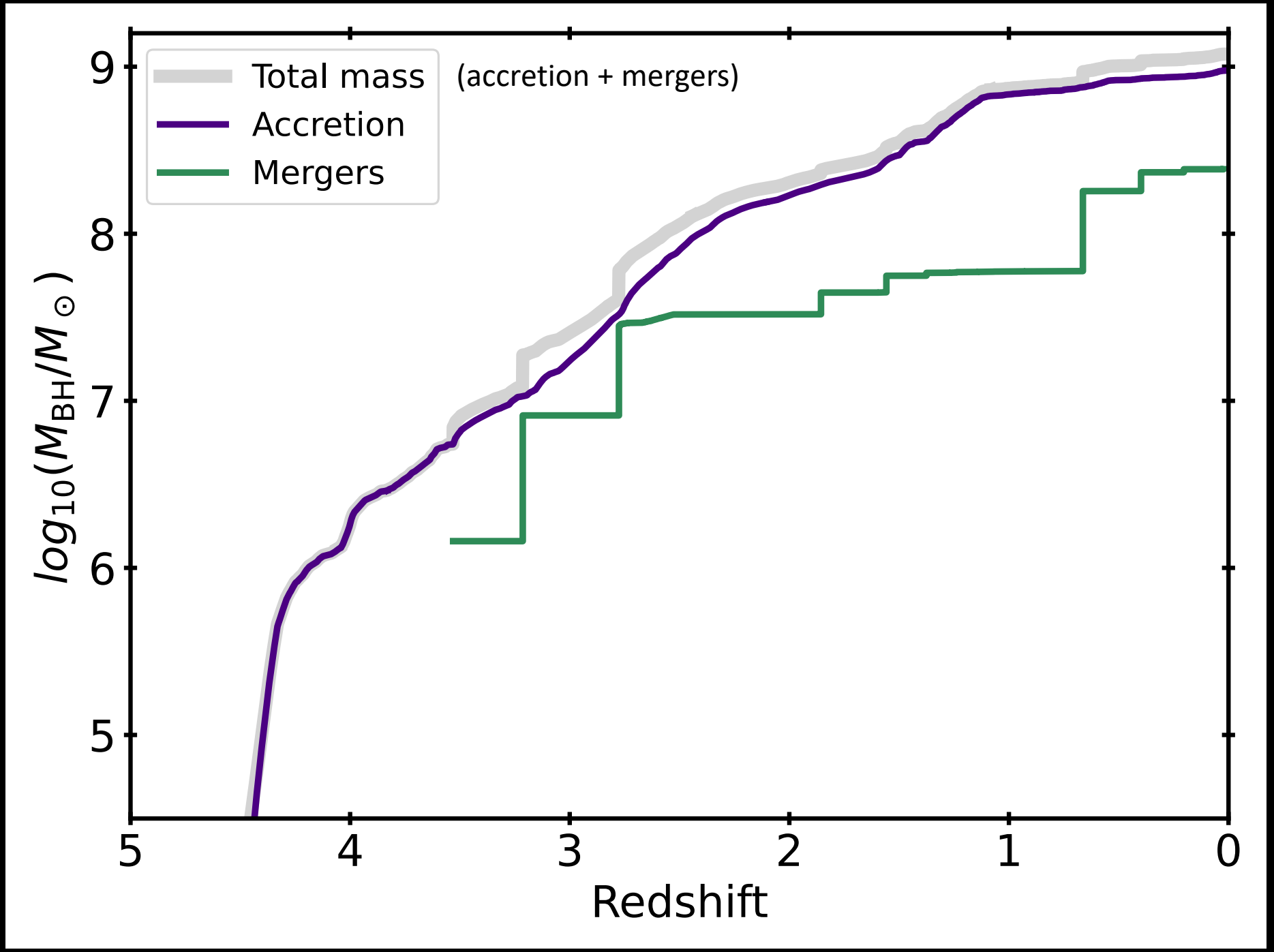
Simba:

Contributions of accretion vs mergers to black hole growth



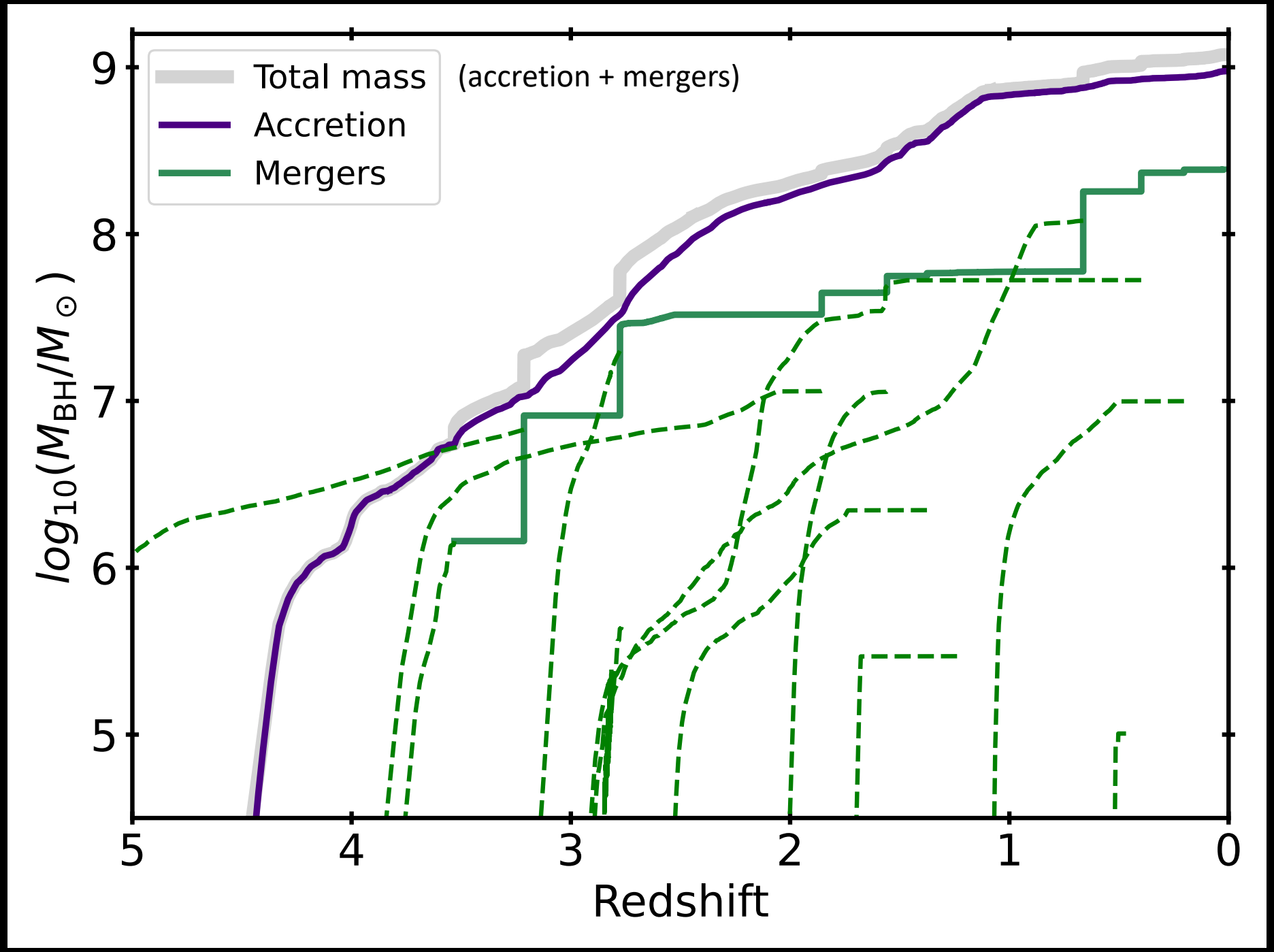
Simba:

Contributions of accretion vs mergers to black hole growth



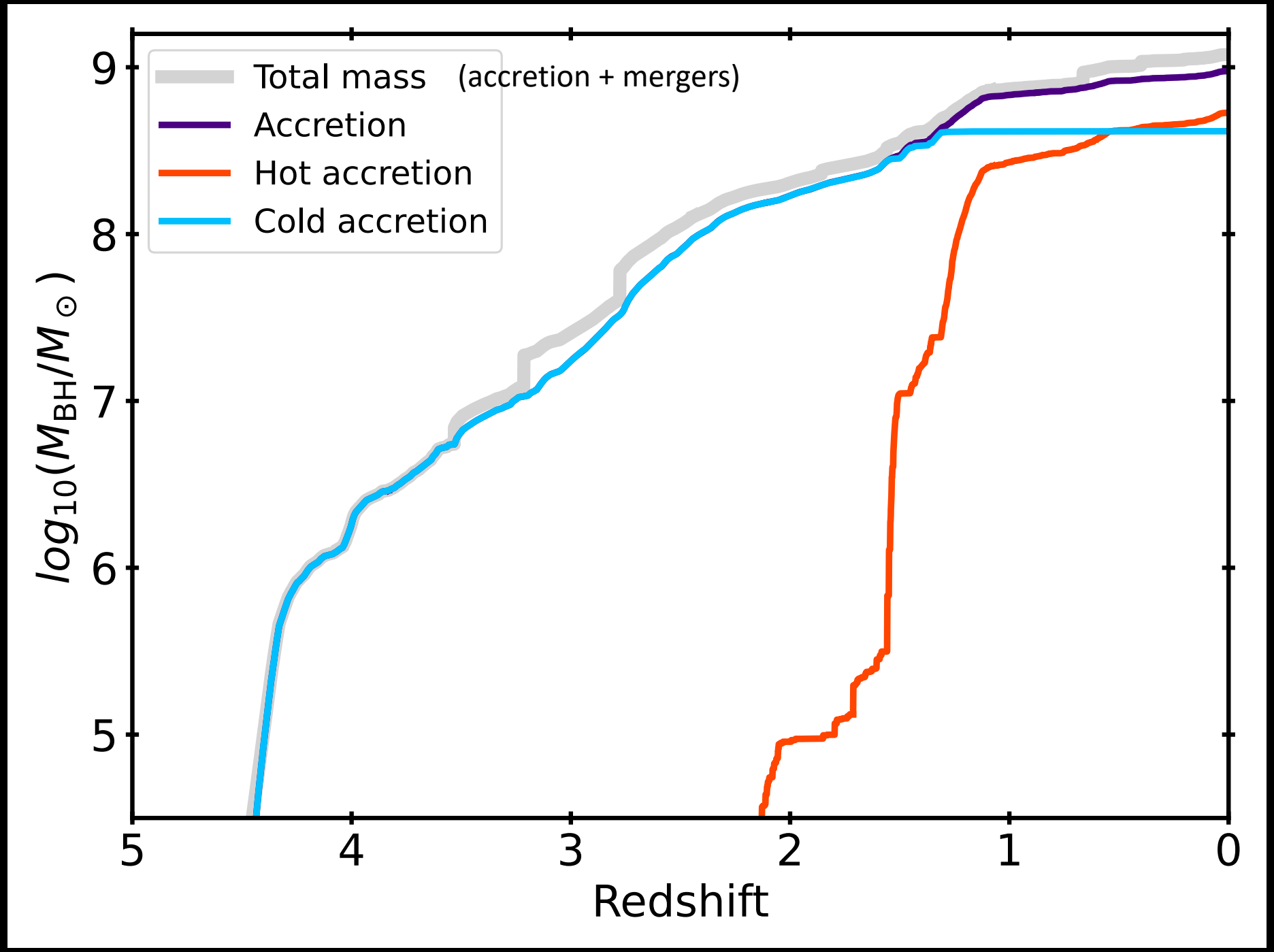
Simba:

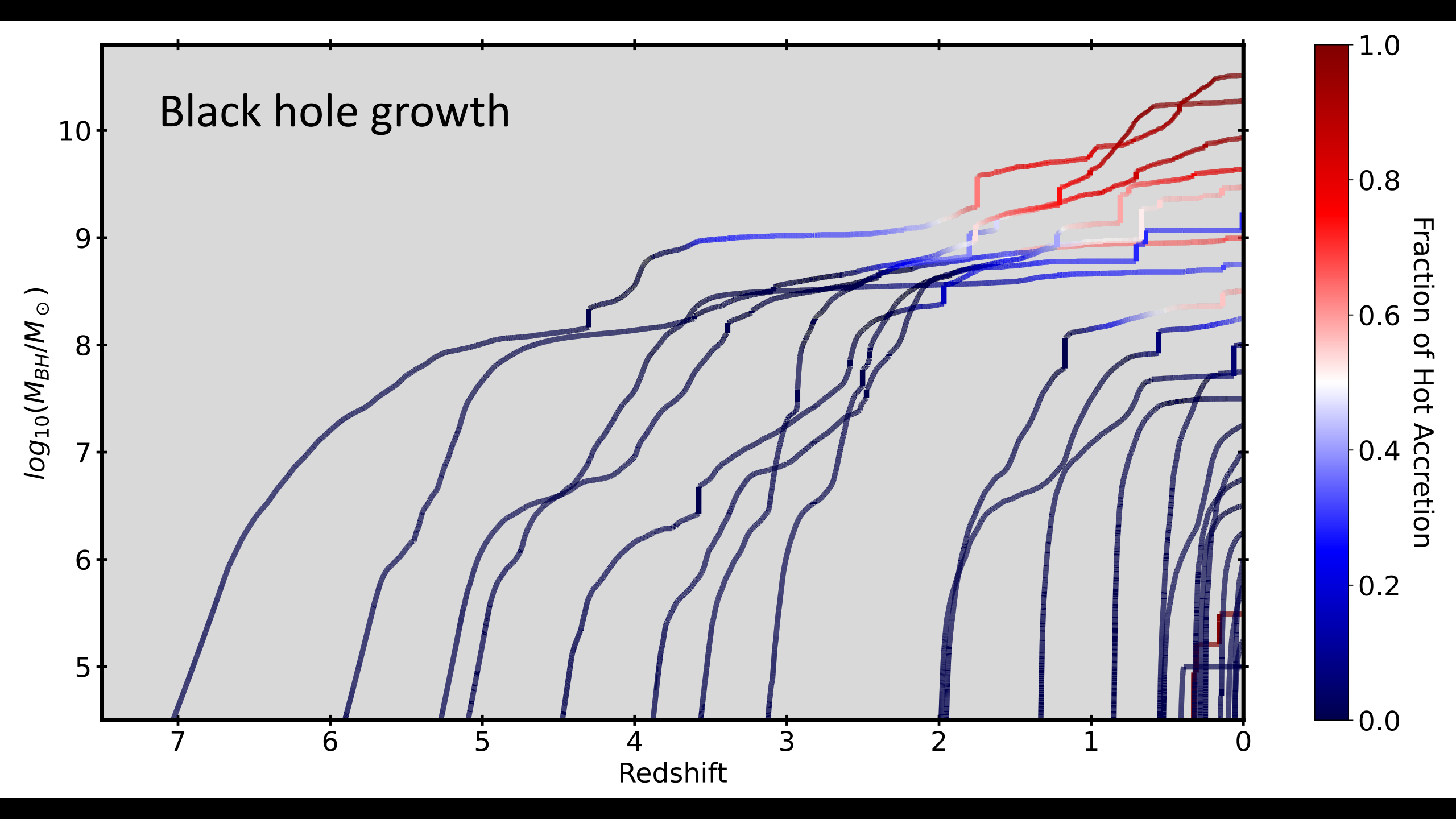
Contributions of accretion vs mergers to black hole growth



Simba:

Contributions of cold vs hot accretion to black hole growth




Black hole growth
$log_{10}(M_{BH}/M_\odot)$
10
9
8
7
6
5
7
6
5
4
3
2
1
0
Redshift
1.0
0.8
0.6
0.4
0.2
0.0
Fraction of Hot Accretion

Two-mode black hole feedback in SIMBA

→ Kinetic, collimated winds (Anglés-Alcázar+2017a)

Wind mode

Eddington ratio > 0.02
Momentum flux = 20 L_{bol}/c
Velocity = 1000 km/s
(Perna+2017)
3% L_{bol} , 600 M_{BH}

Jet mode

Log M_{BH} > 7.5
Eddington ratio < 0.02
Momentum flux = 20 L_{bol}/c
Velocity = 8000 km/s
30% L_{bol} , 75 M_{BH}

+ X-ray heating (Choi+2012)

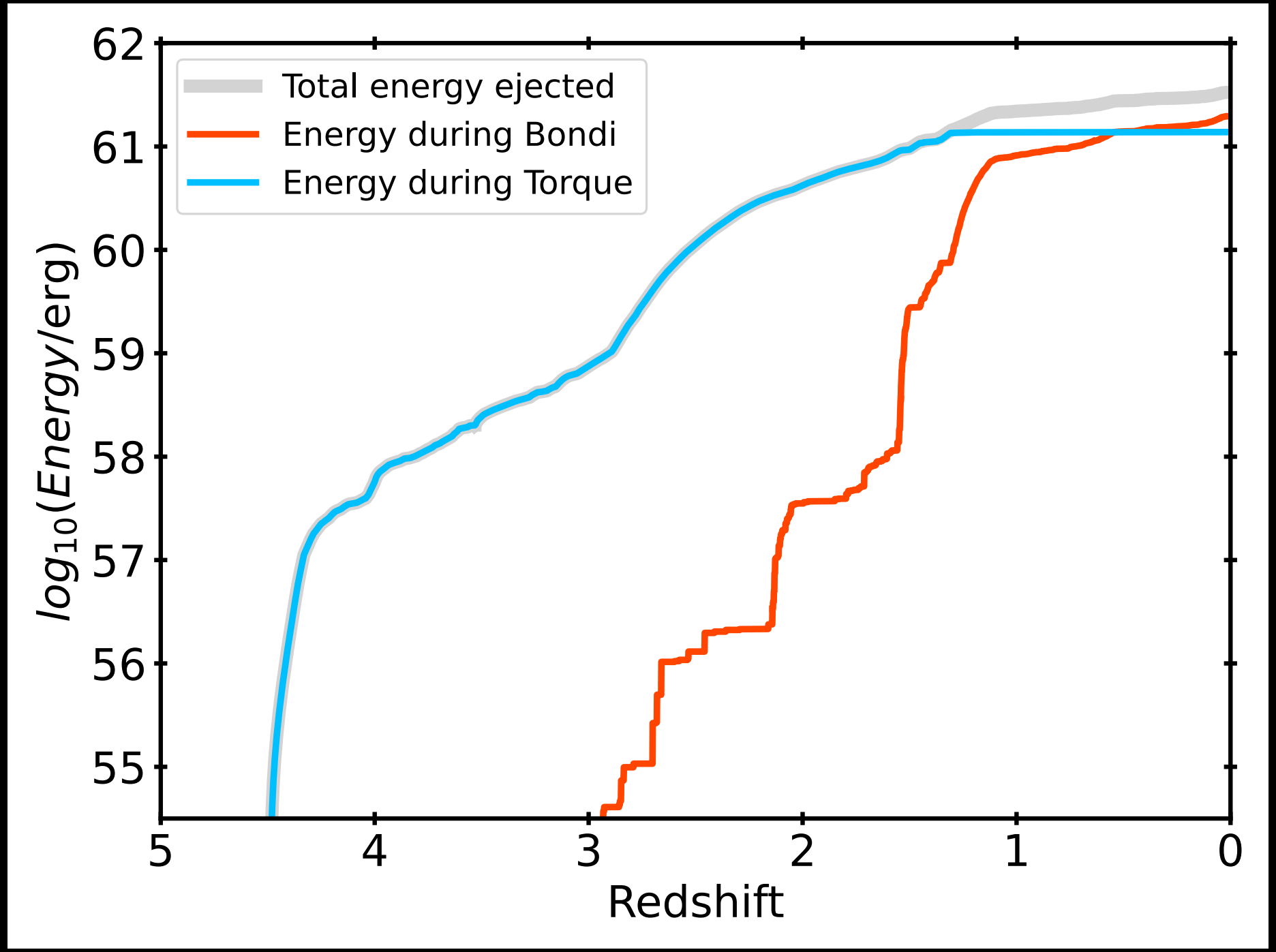
Same momentum flux but different ejection velocity:

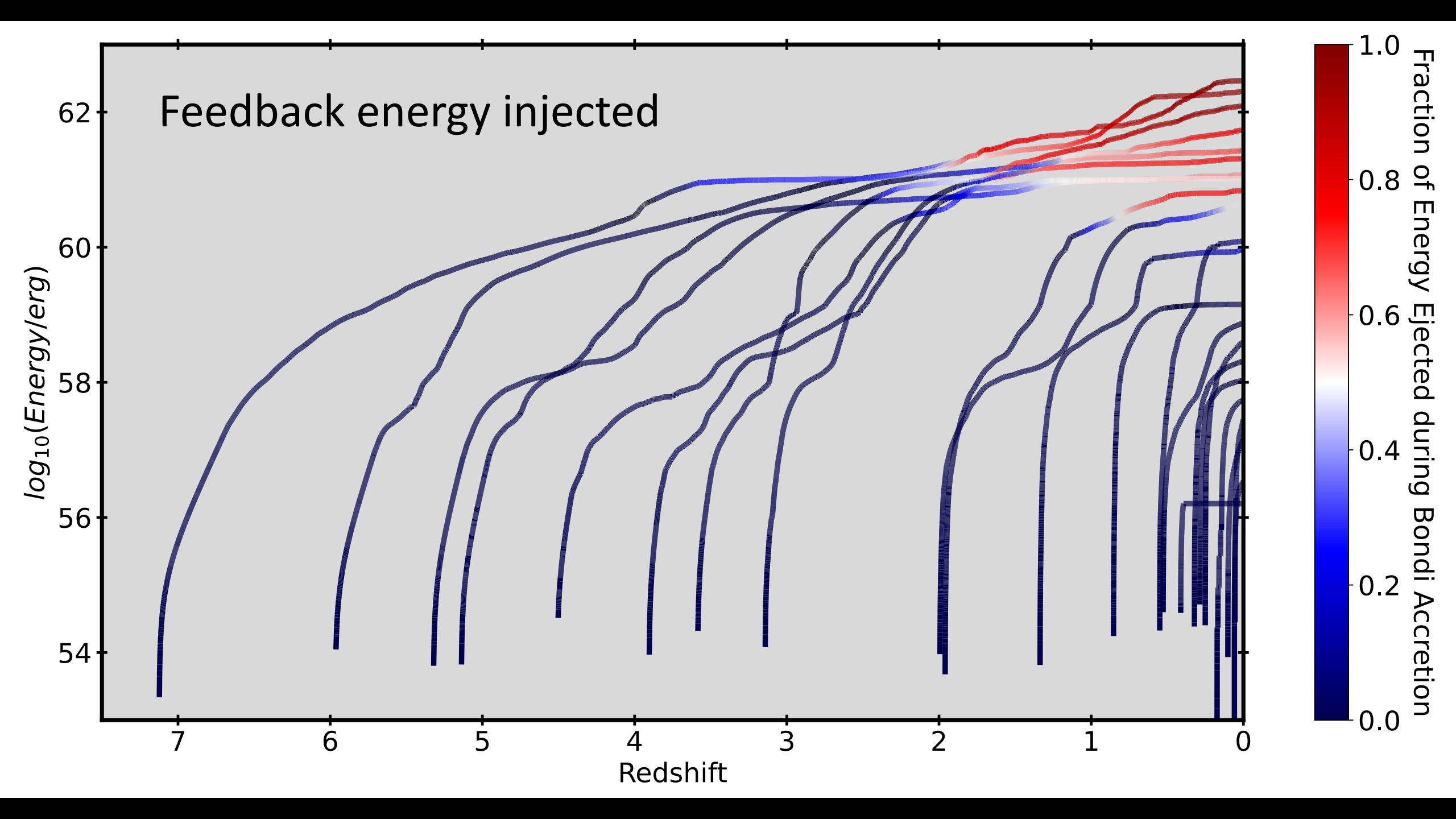
$$v_{\mathrm{w,EL}} = 500 + 500(\log M_{\mathrm{BH}} - 6)/3 \ \ \mathrm{km\,s^{-1}}$$

$$v_{\mathrm{w,jet}} = v_{\mathrm{w,EL}} + 7000 \log (0.2/f_{\mathrm{Edd}}) \ \ \mathrm{km\,s^{-1}}$$

Simba:

Contributions of cold vs hot accretion to … feedback!




Feedback energy injected
62
60
58
56
54
$log_{10}(Energy/erg)$
7
6
5
4
3
2
1
0
Redshift
1.0
0.8
0.6
0.4
0.2
0.0
Fraction of Energy Ejected during Bondi Accretion

Two-mode black hole feedback in SIMBA

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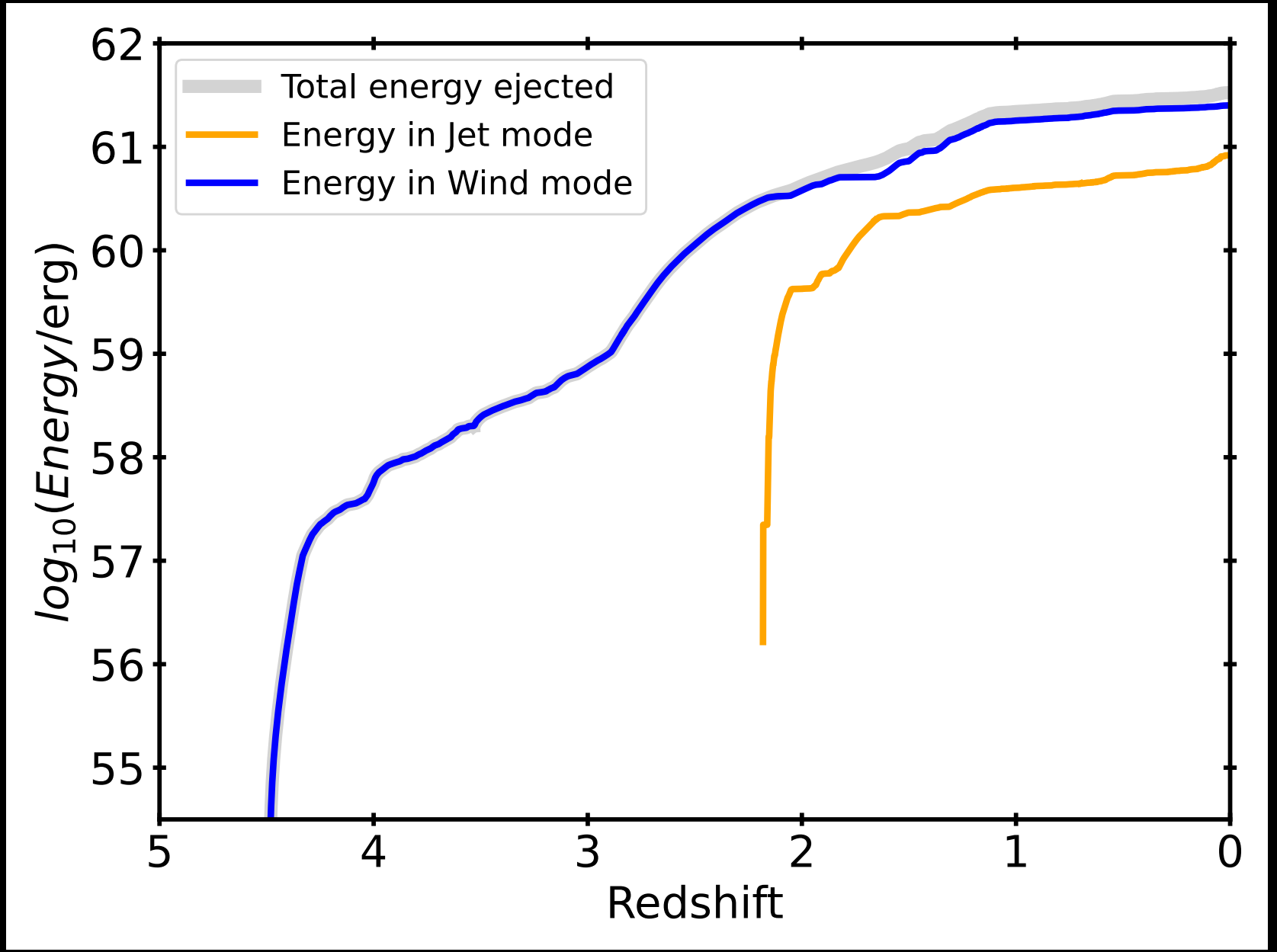

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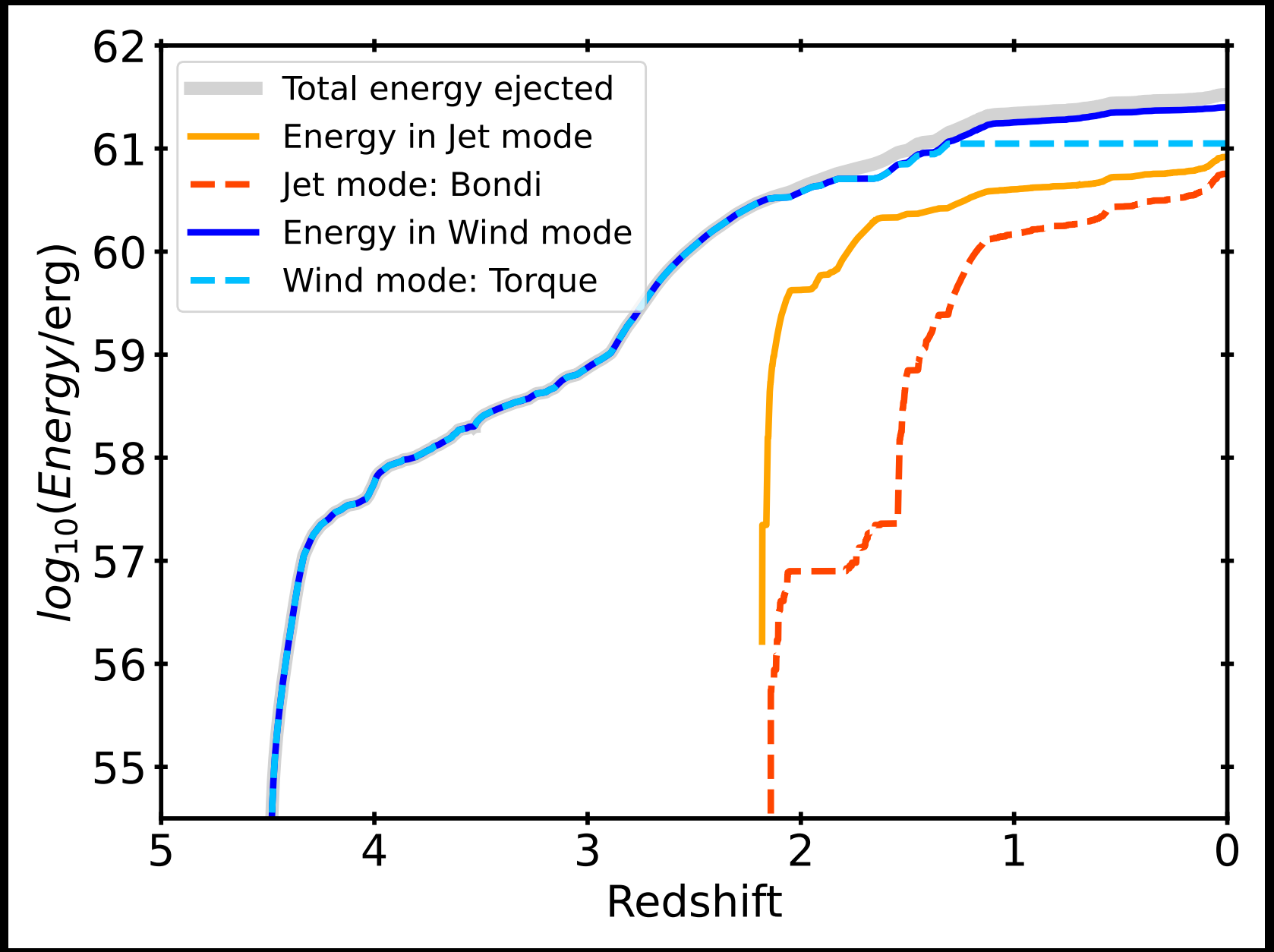

Mass ejected

Wind mode

Eddington ratio > 0.02
Momentum flux = 20 L_{bol}/c
Velocity = 1000 km/s
(Perna+2017)
3% L_{bol} , 600 M_{BH}

Jet mode

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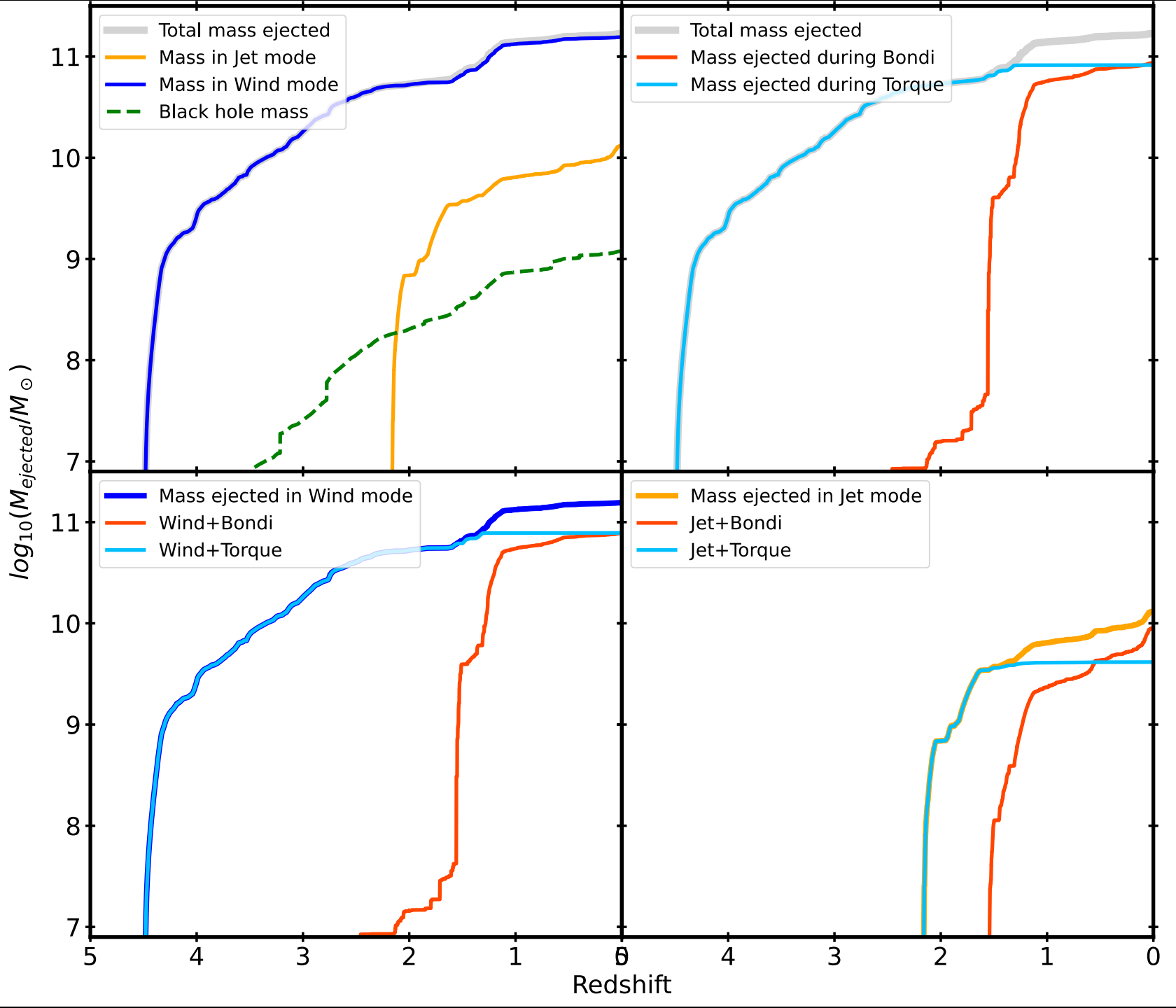
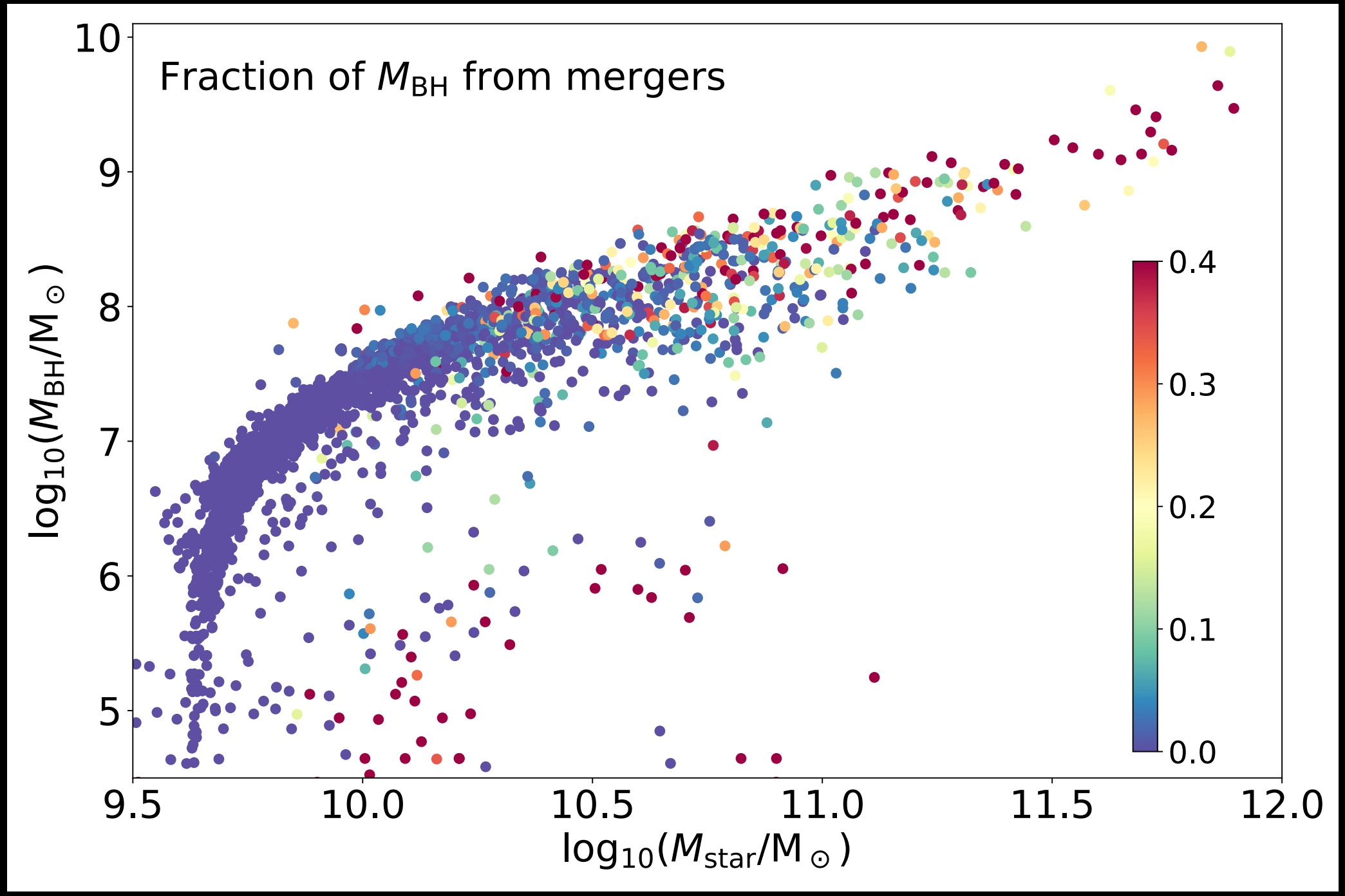
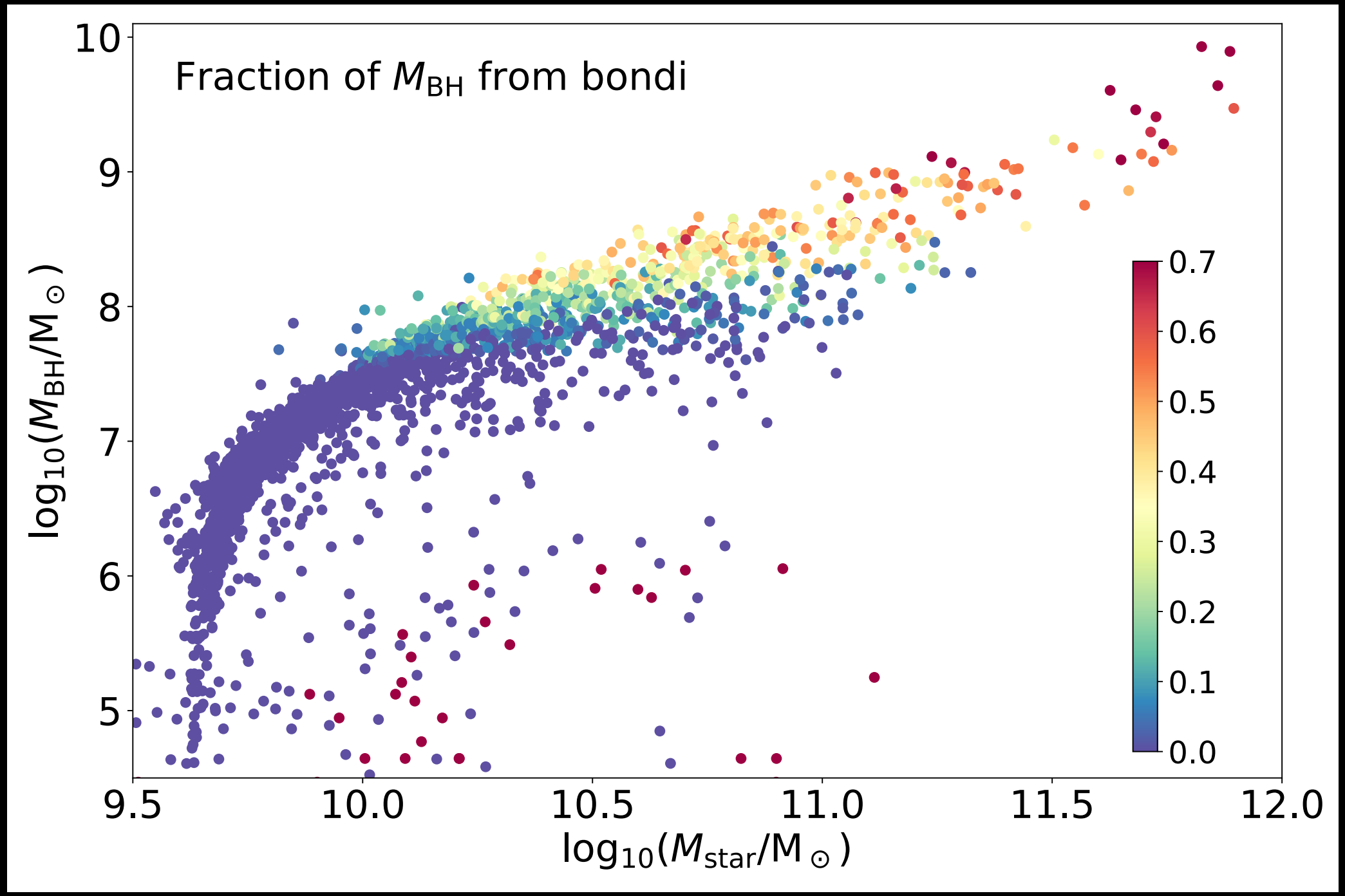
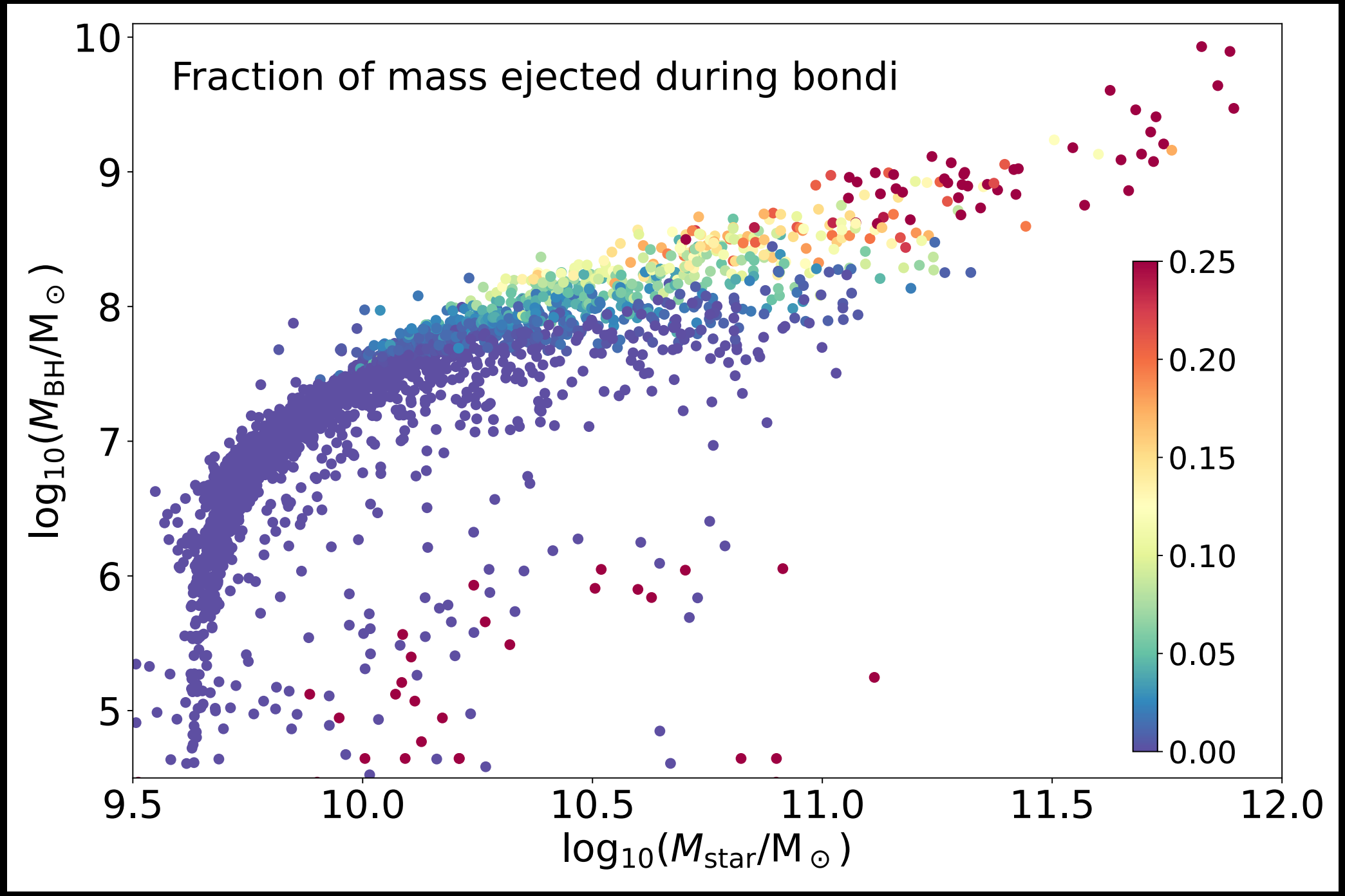
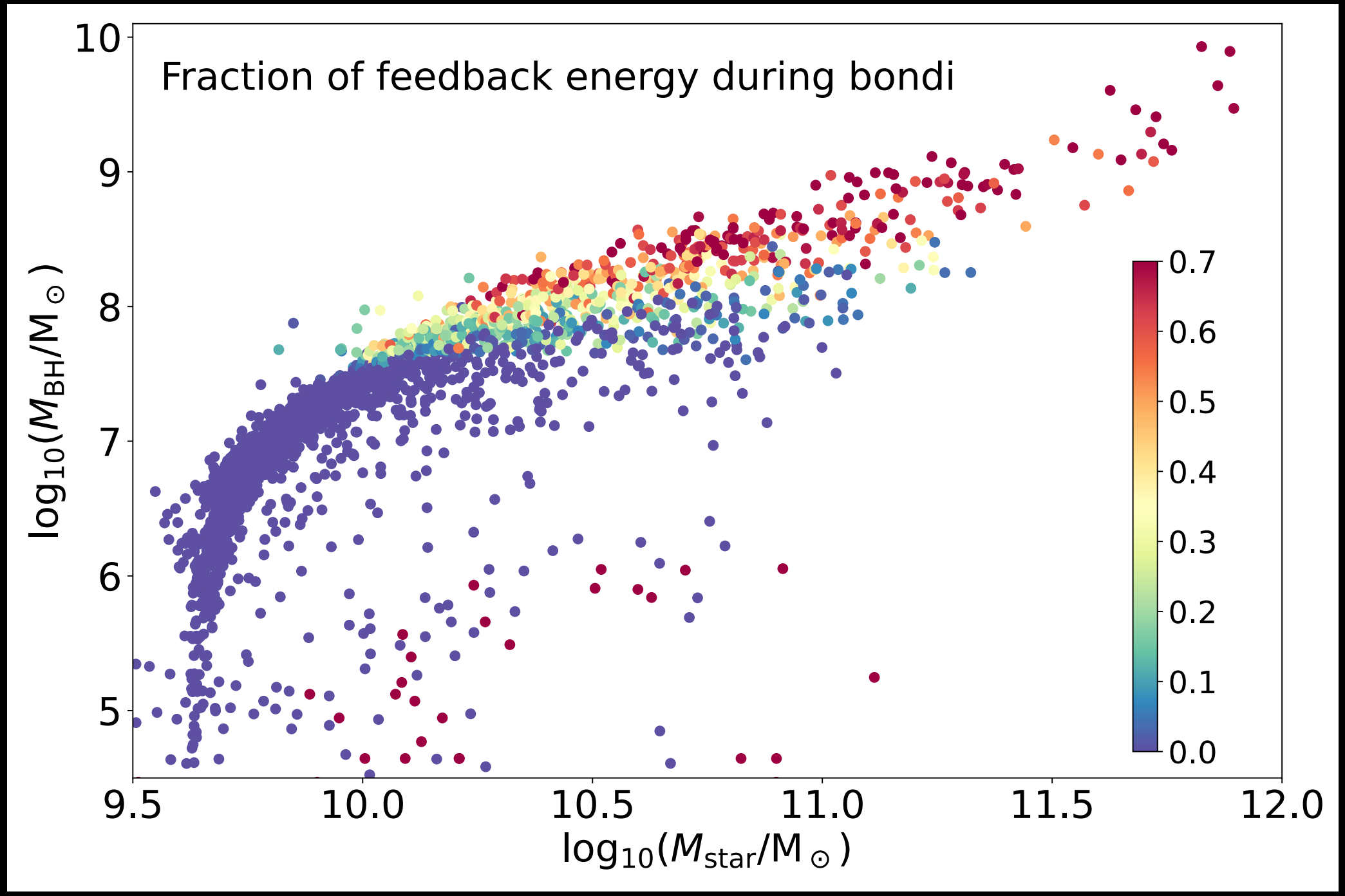
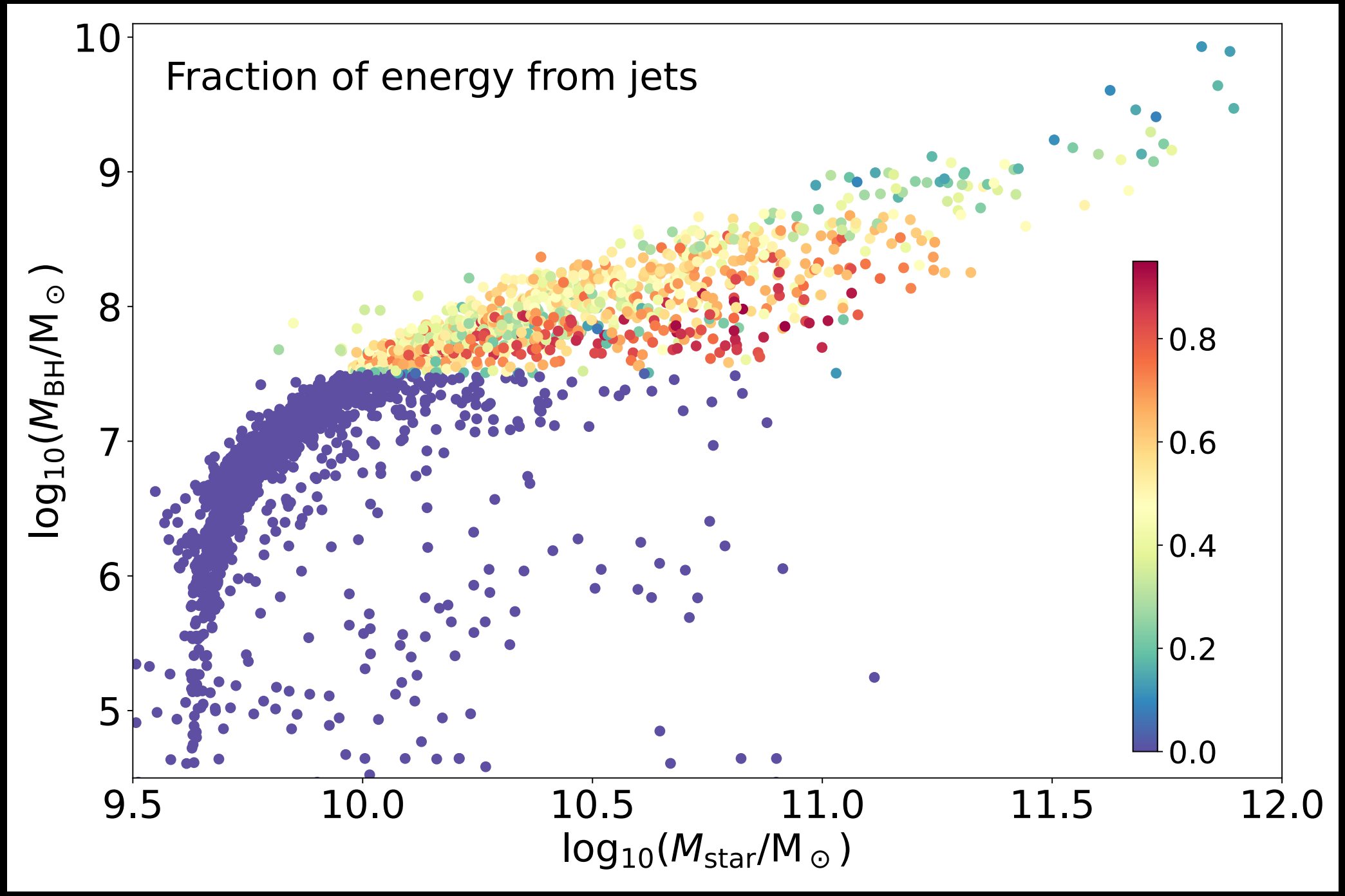



Fraction of M_{BH} from mergers
$\log_{10}(M_{BH}/M_\odot)$
$\log_{10}(M_{star}/M_\odot)$
10
9
8
7
6
5
9.5
10.0
10.5
11.0
11.5
12.0
0.4
0.3
0.2
0.1
0.0


Fraction of M_{BH} from bondi
$\log_{10}(M_{BH}/M_\odot)$
$\log_{10}(M_{star}/M_\odot)$
10
9
8
7
6
5
9.5
10.0
10.5
11.0
11.5
12.0
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0


Fraction of mass ejected during bondi
10
9
8
7
6
5
$\log_{10}(M_{BH}/M_\odot)$
9.5
10.0
10.5
11.0
11.5
12.0
$\log_{10}(M_{star}/M_\odot)$
0.25
0.20
0.15
0.10
0.05
0.00


Fraction of feedback energy during bondi
10
9
8
7
6
5
$\log_{10}(M_{BH}/M_\odot)$
9.5
10.0
10.5
11.0
11.5
12.0
$\log_{10}(M_{star}/M_\odot)$
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0


Fraction of energy from jets
10
9
8
7
6
5
$\log_{10}(M_{BH}/M_\odot)$
9.5
10.0
10.5
11.0
11.5
12.0
$\log_{10}(M_{star}/M_\odot)$
0.8
0.6
0.4
0.2
0.0

→ Physically motivated models of black hole accretion/feedback that match a broad range of galaxy properties

→ Emerging connection between host galaxy, accretion mode, and feedback mode