PROBING BURSTY STAR FORMATION IN THE FIRST GALAXIES WITH JWST

Viola Gelli

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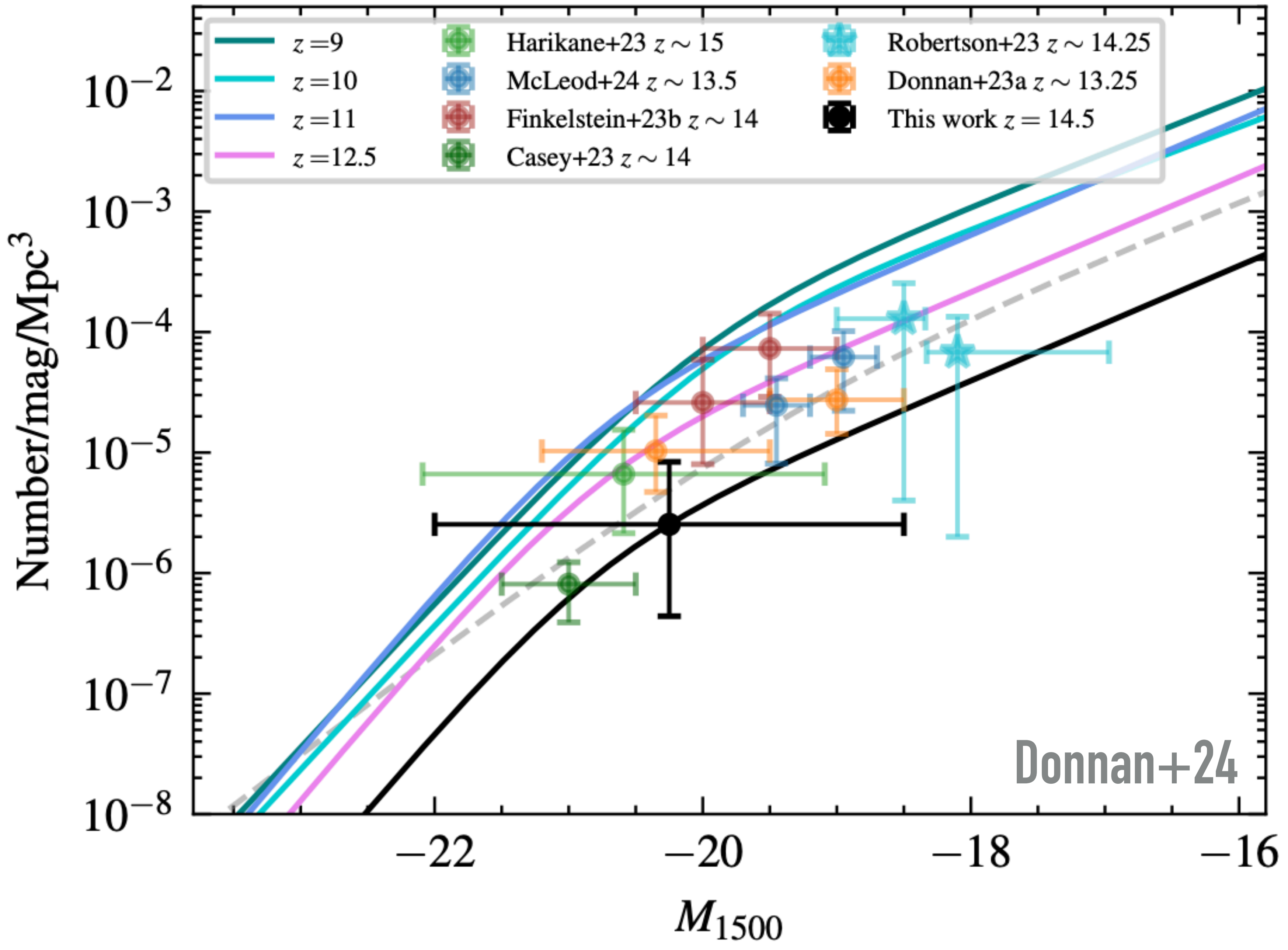
UNIVERSITY OF COPENHAGEN

DAWN

HIGH-Z STAR FORMATION WITH JWST

Surprising abundance of UV bright galaxies at $z > 10$



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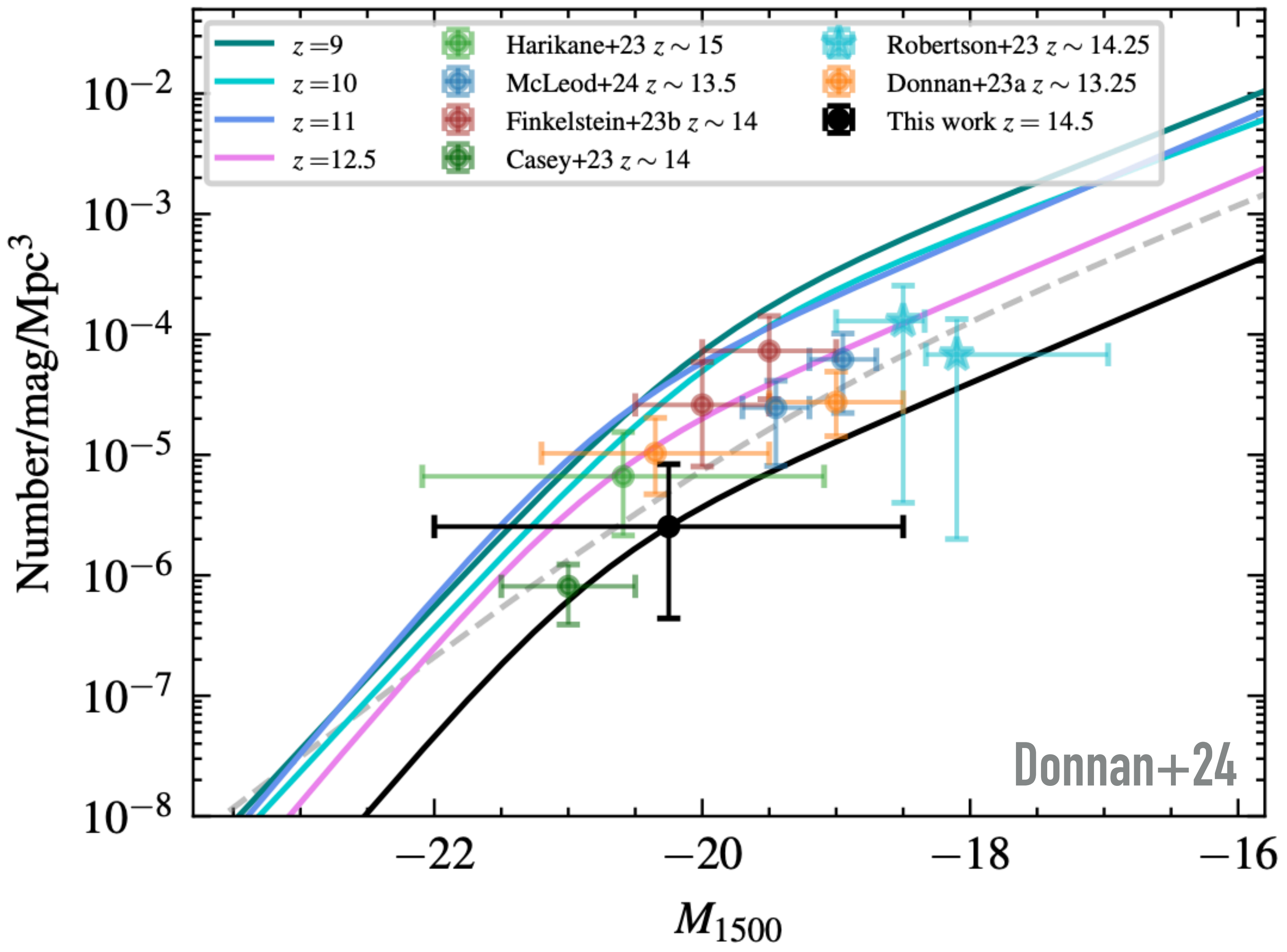
Why?

$$L_{\rm UV} \propto SFR \propto \epsilon_\star f_b \frac{dM_h}{dt}$$



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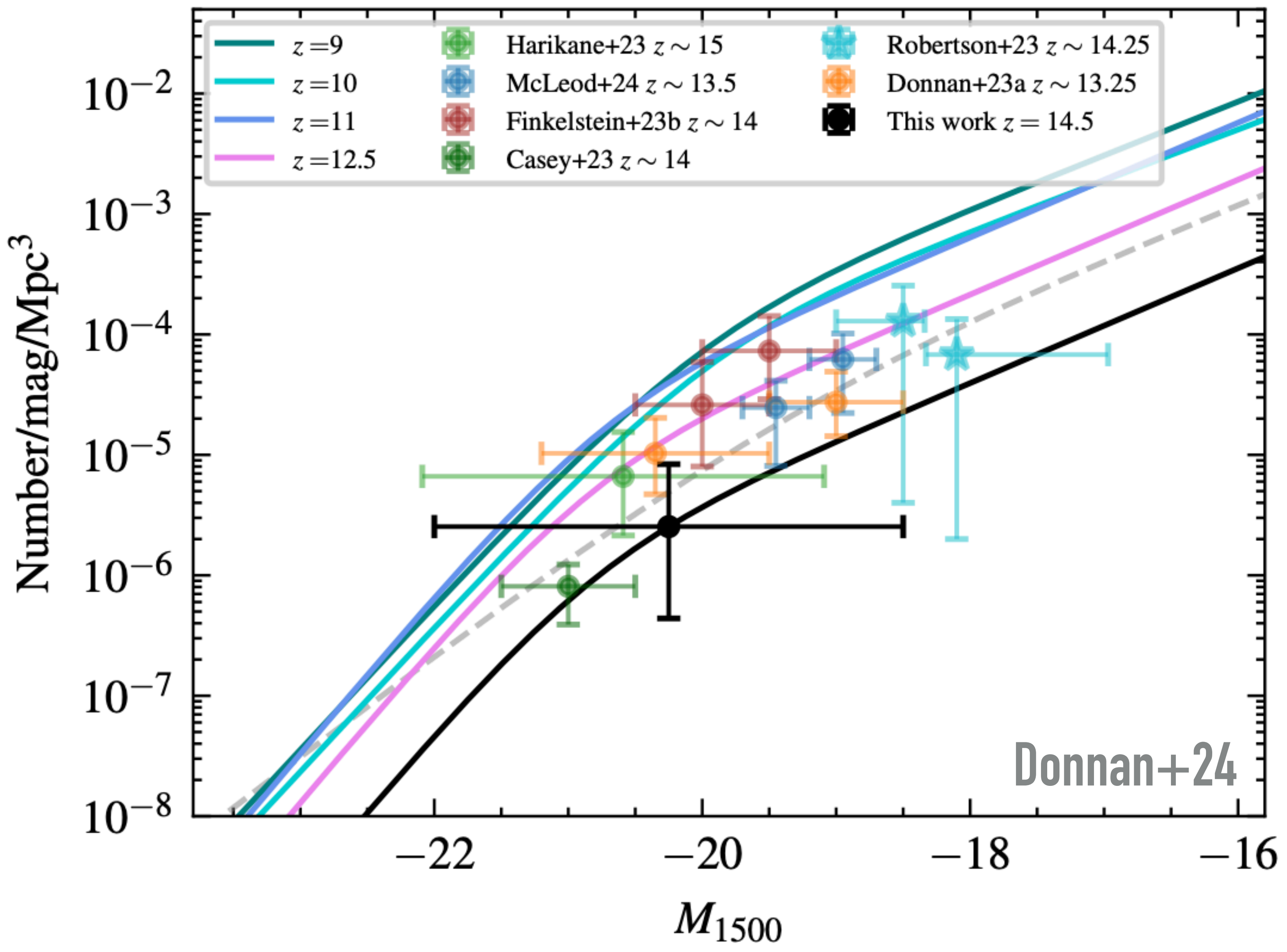

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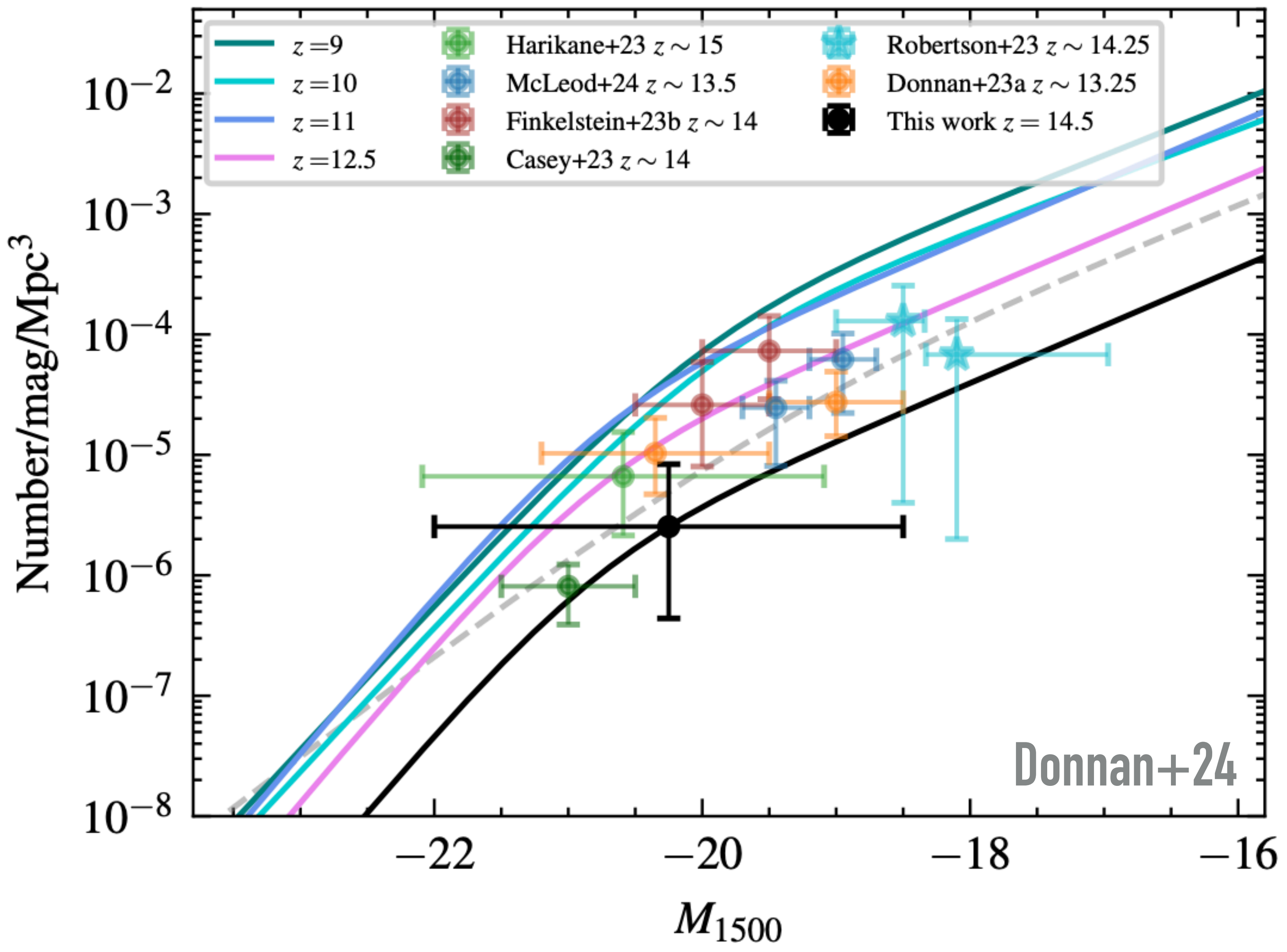

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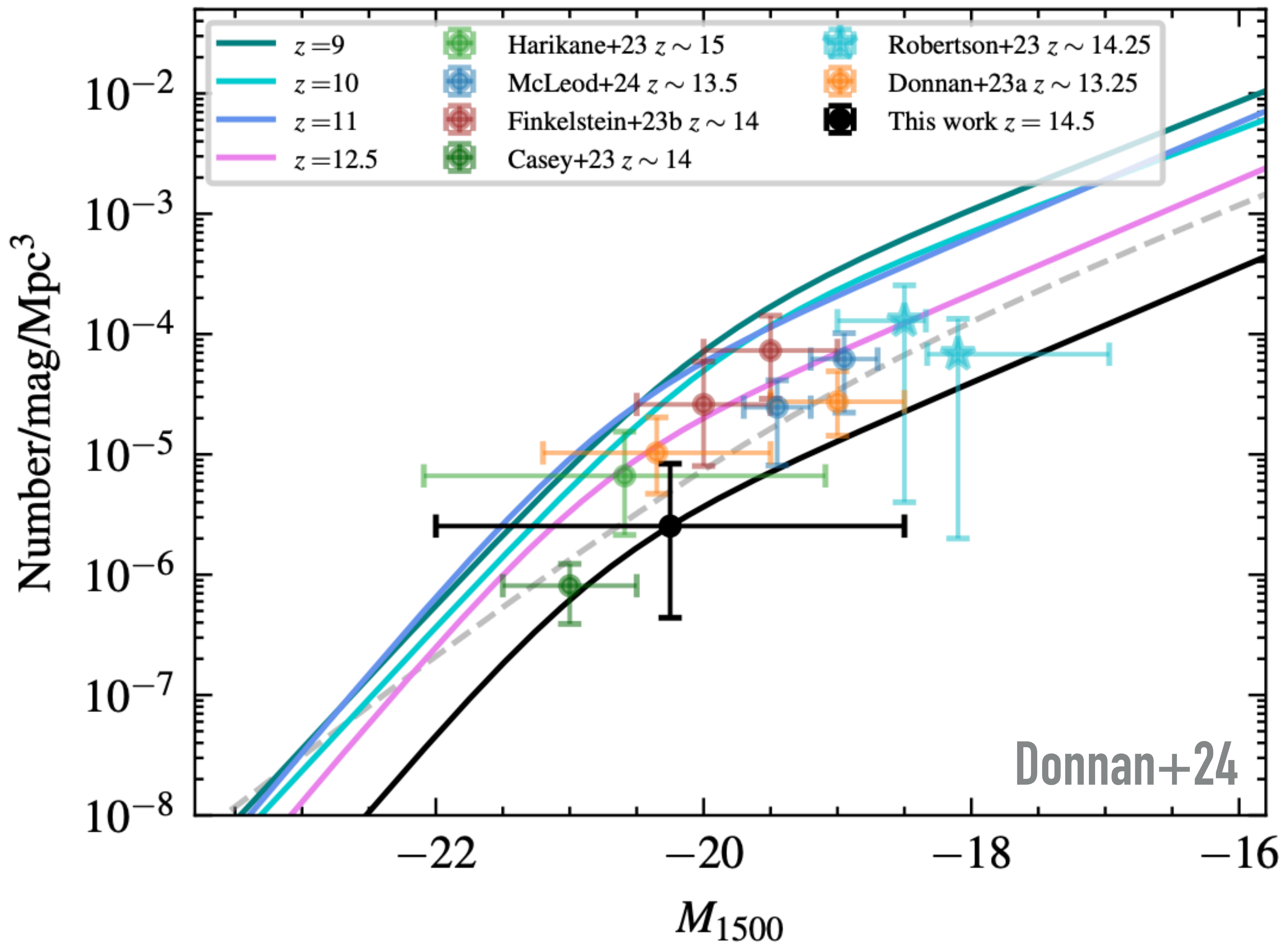

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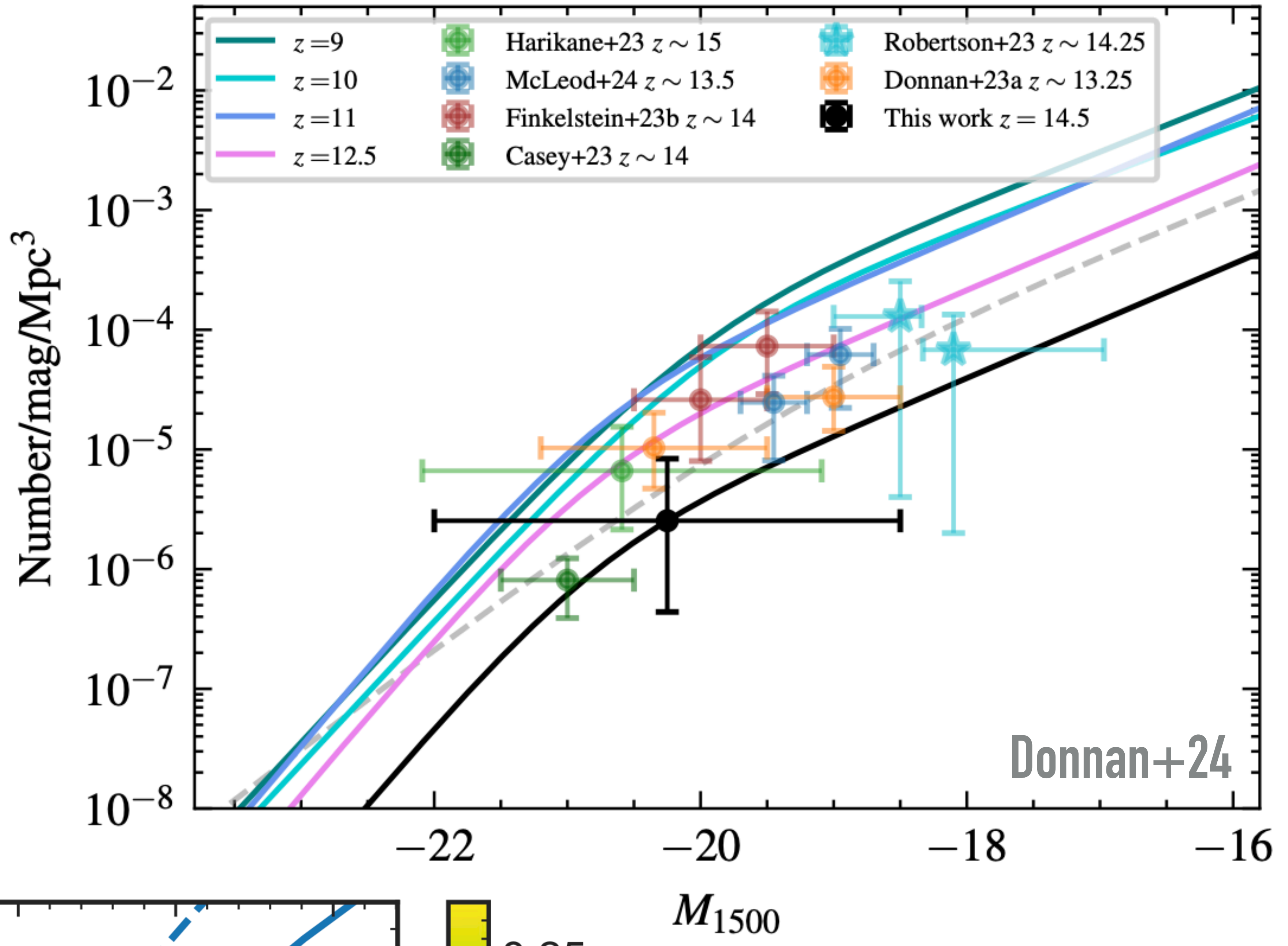

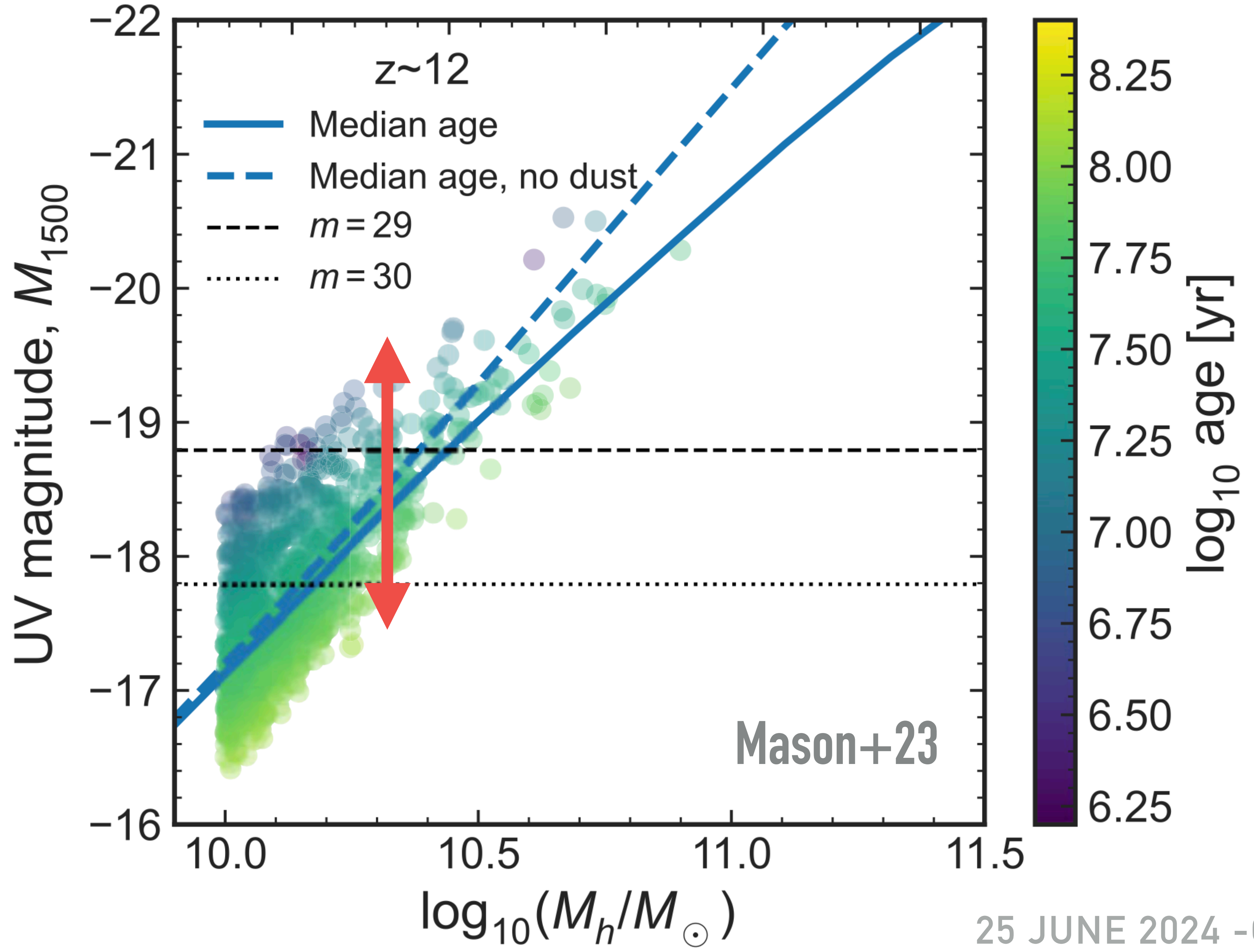

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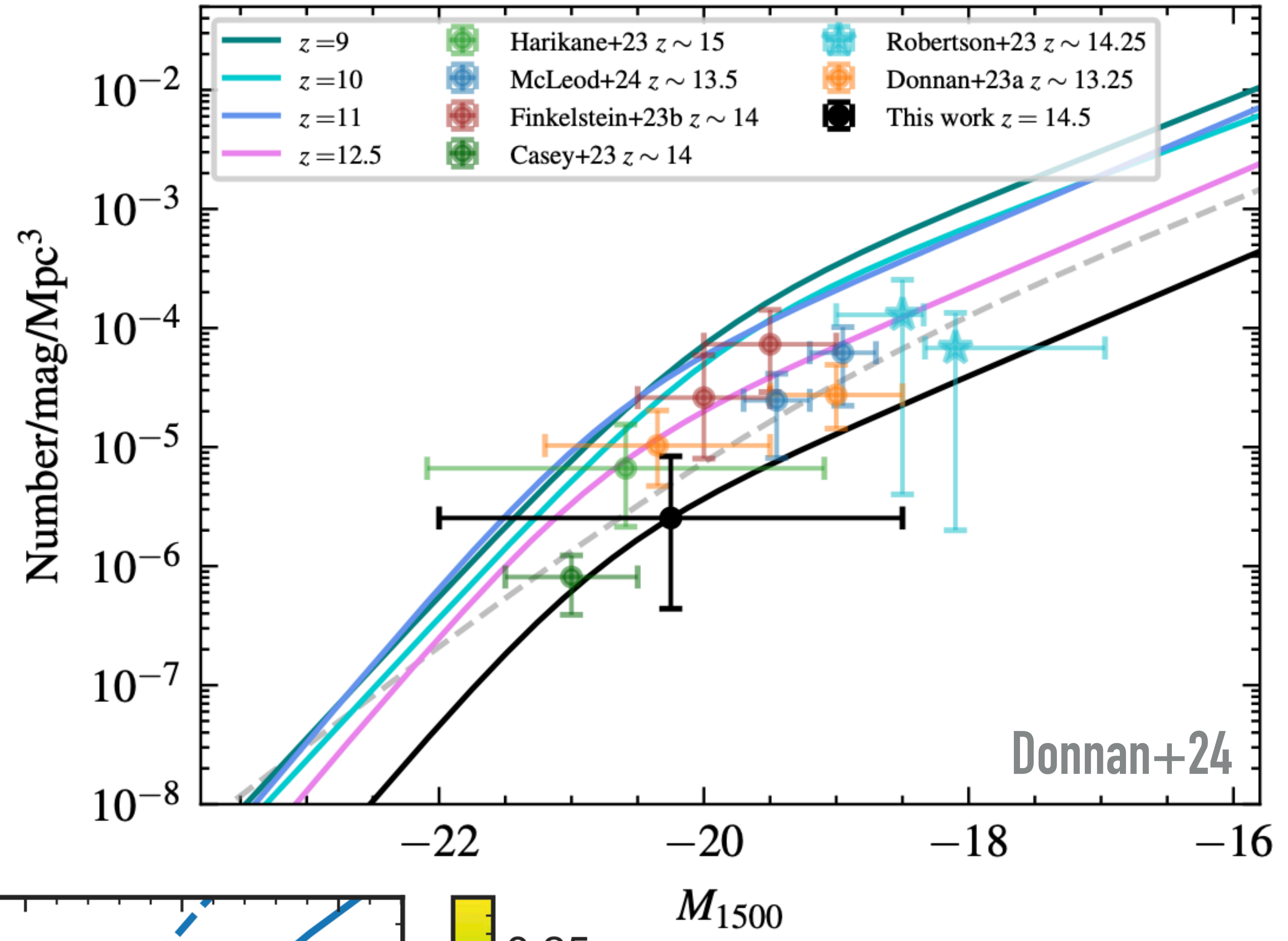
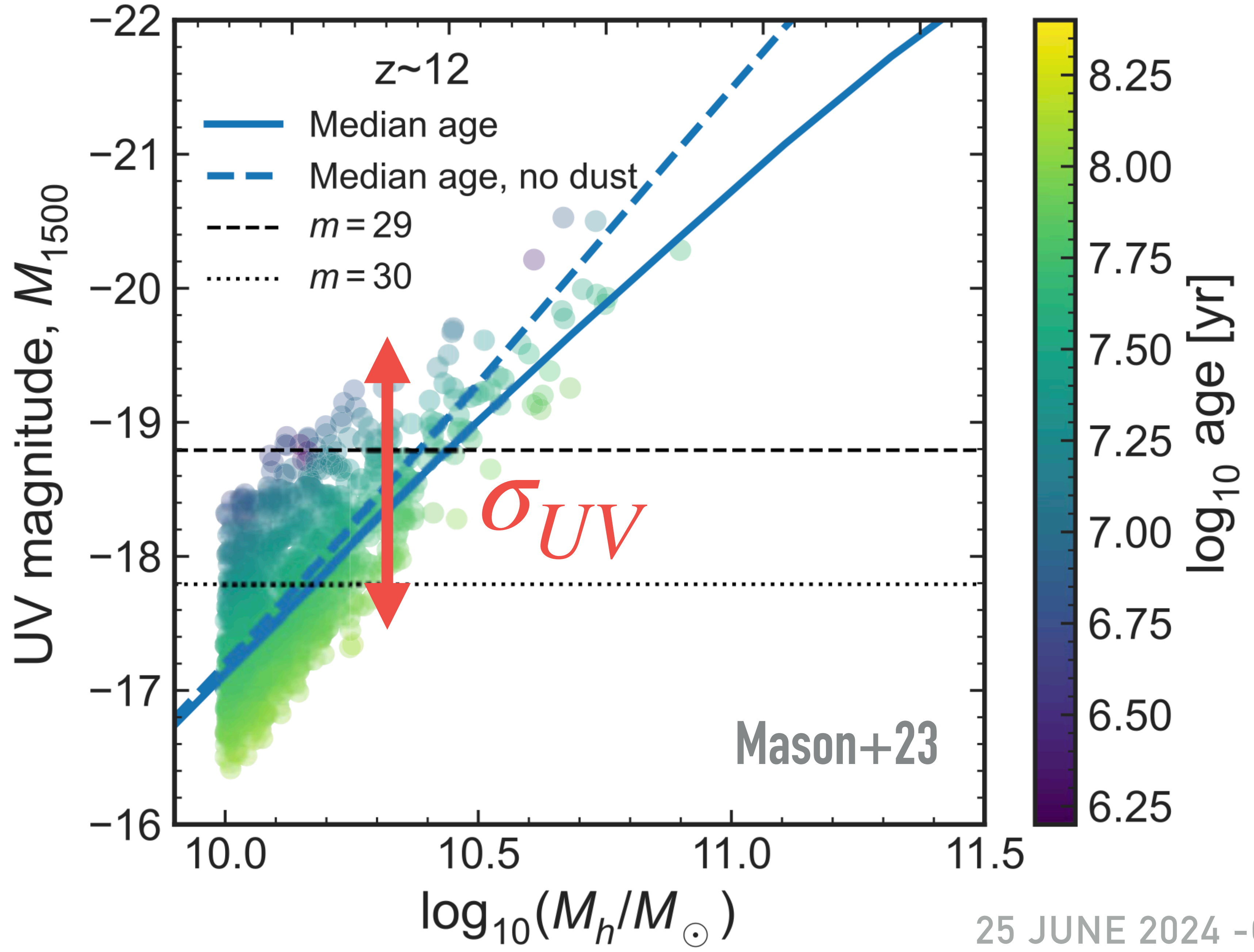
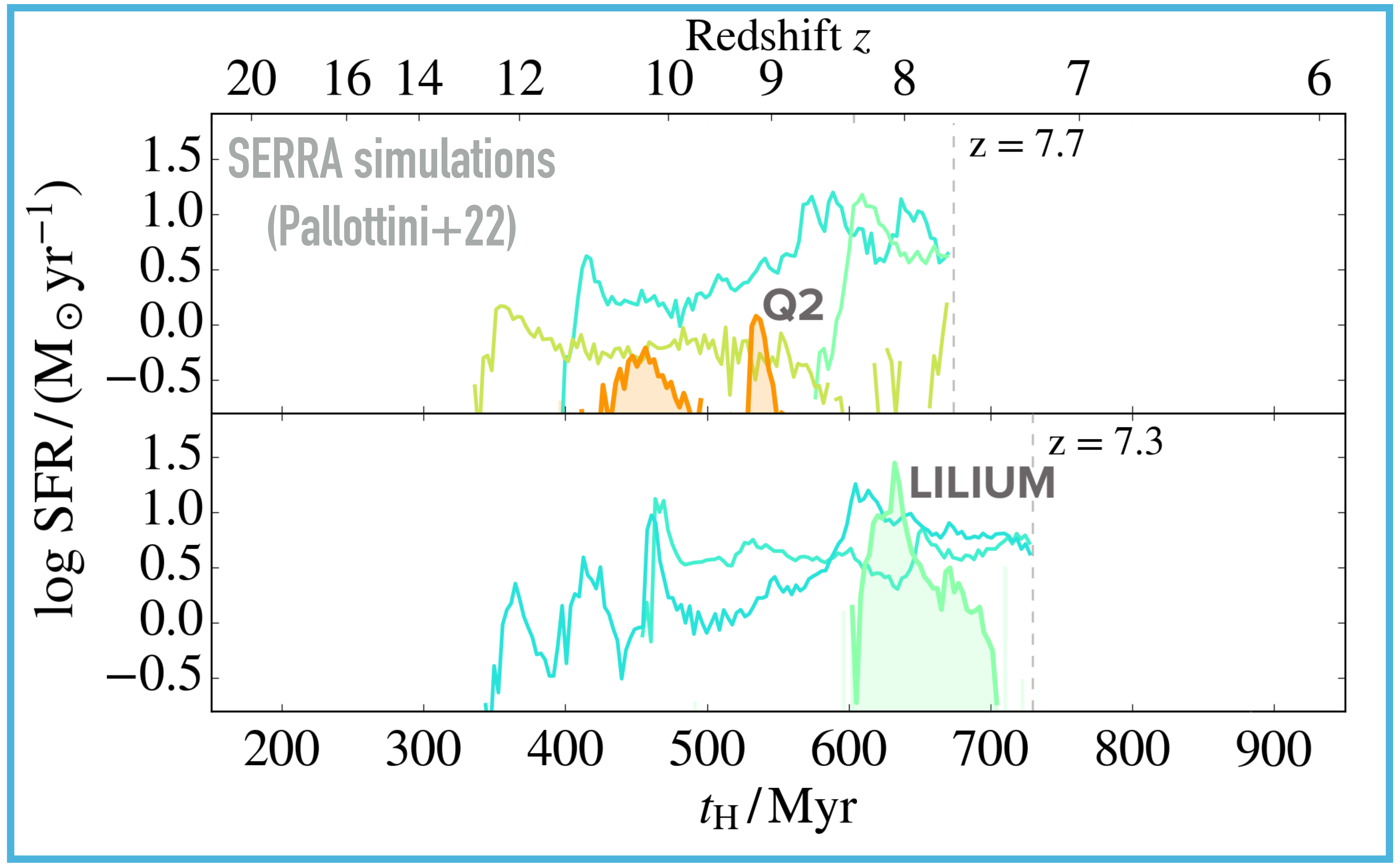




STOCHASTIC STAR FORMATION IN THE FIRST GALAXIES

SIMULATIONS PREDICTIONS

- Strongly feedback regulated and ***time-variable SFH***



Gelli, Salvadori, Ferrara, Pallottini, Carniani 2023, ApJL

STOCHASTIC STAR FORMATION IN THE FIRST GALAXIES

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- Strongly feedback regulated and ***time-variable SFH***
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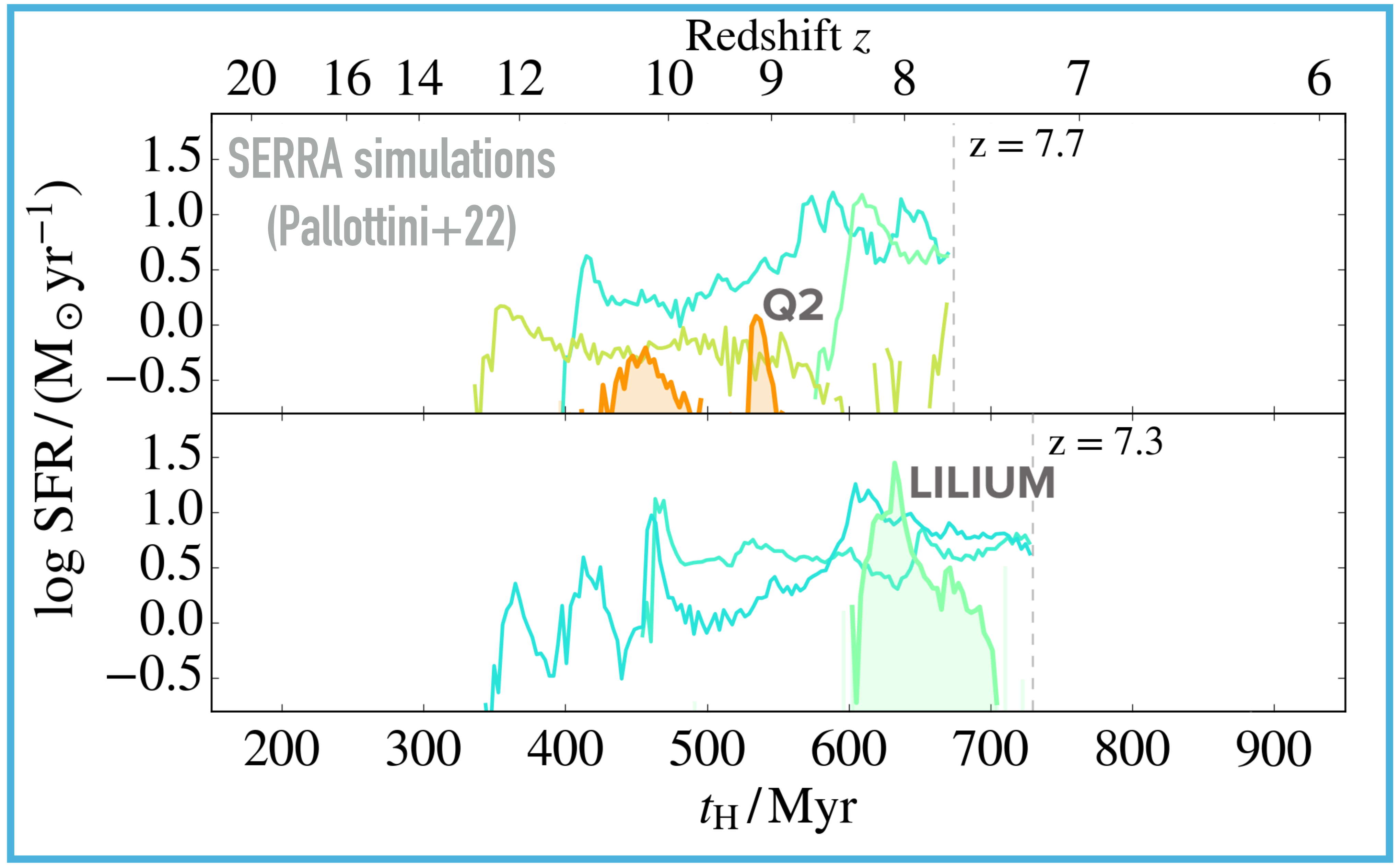

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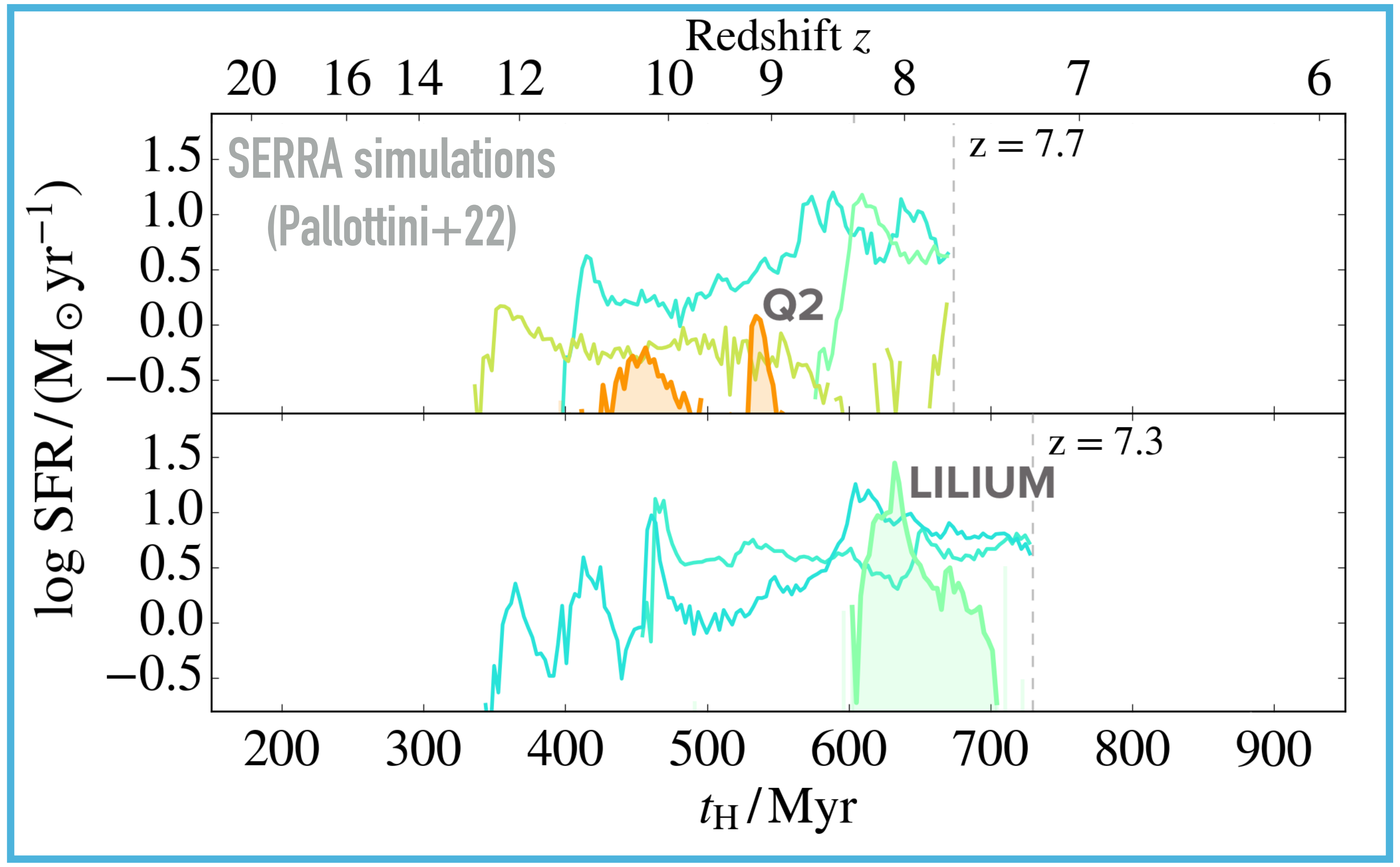

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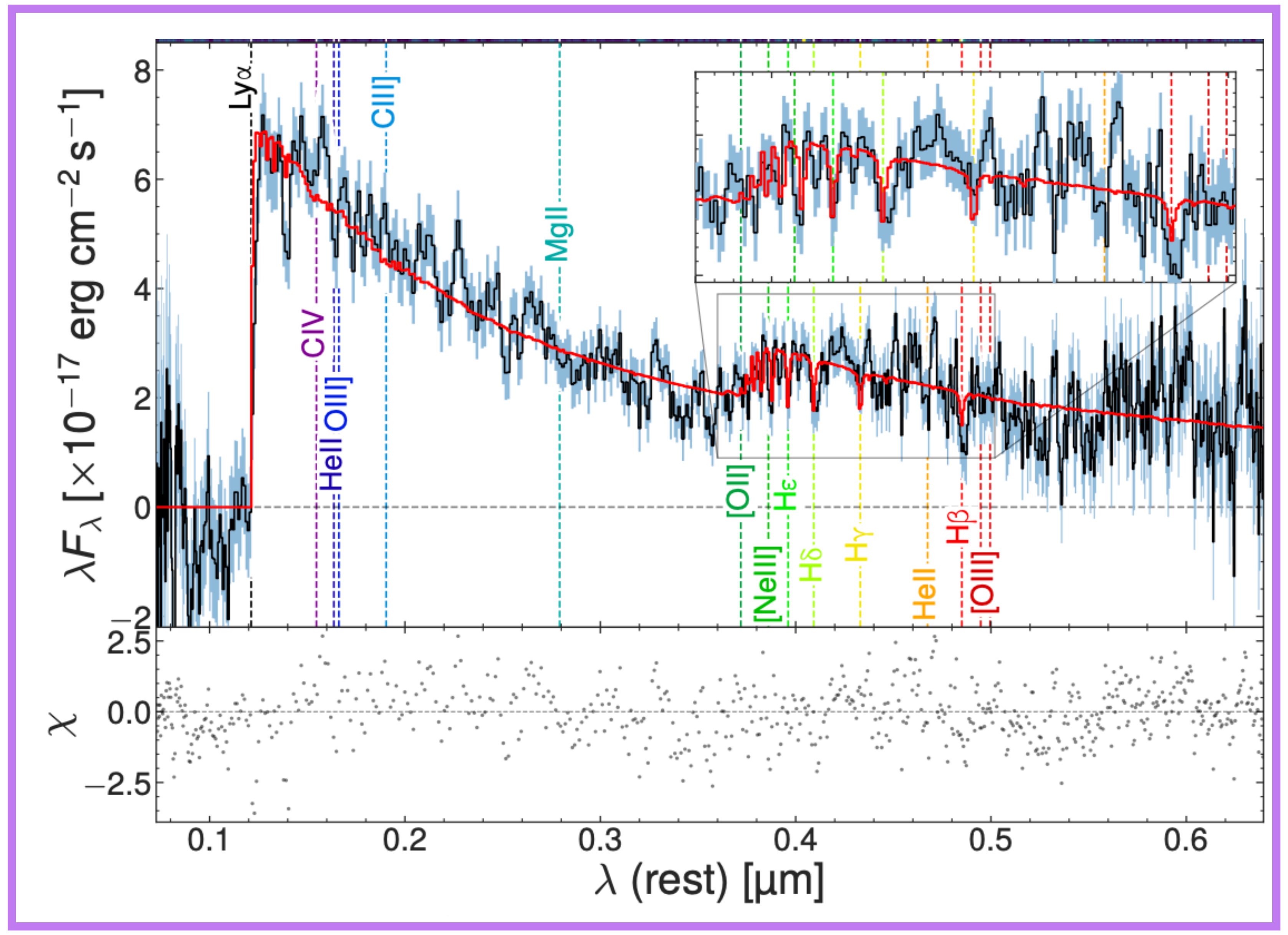
JWST OBSERVATIONS

- Detections of the first low-mass ***quenched*** post starburst galaxies (Looser+23, Strait+23)



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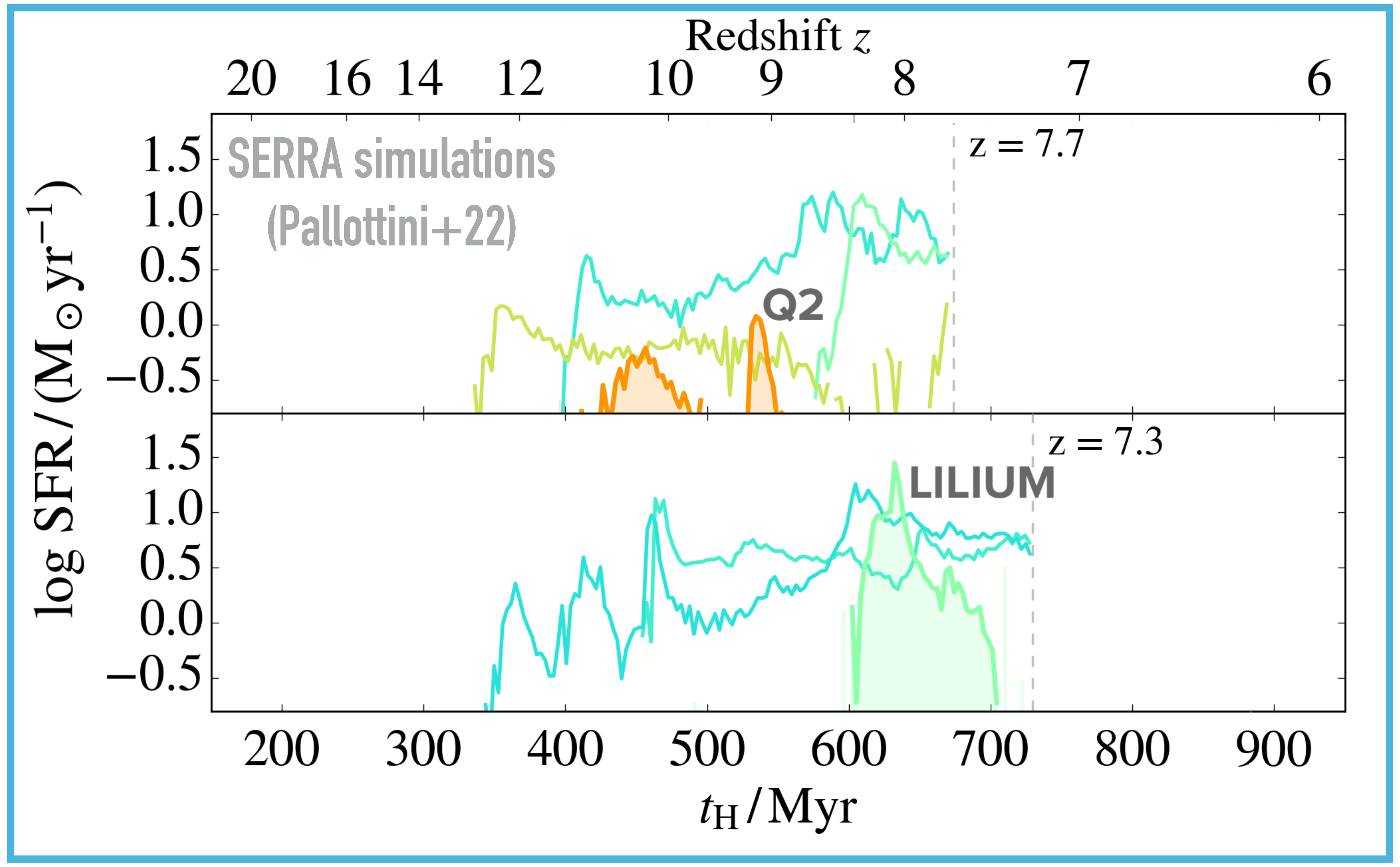

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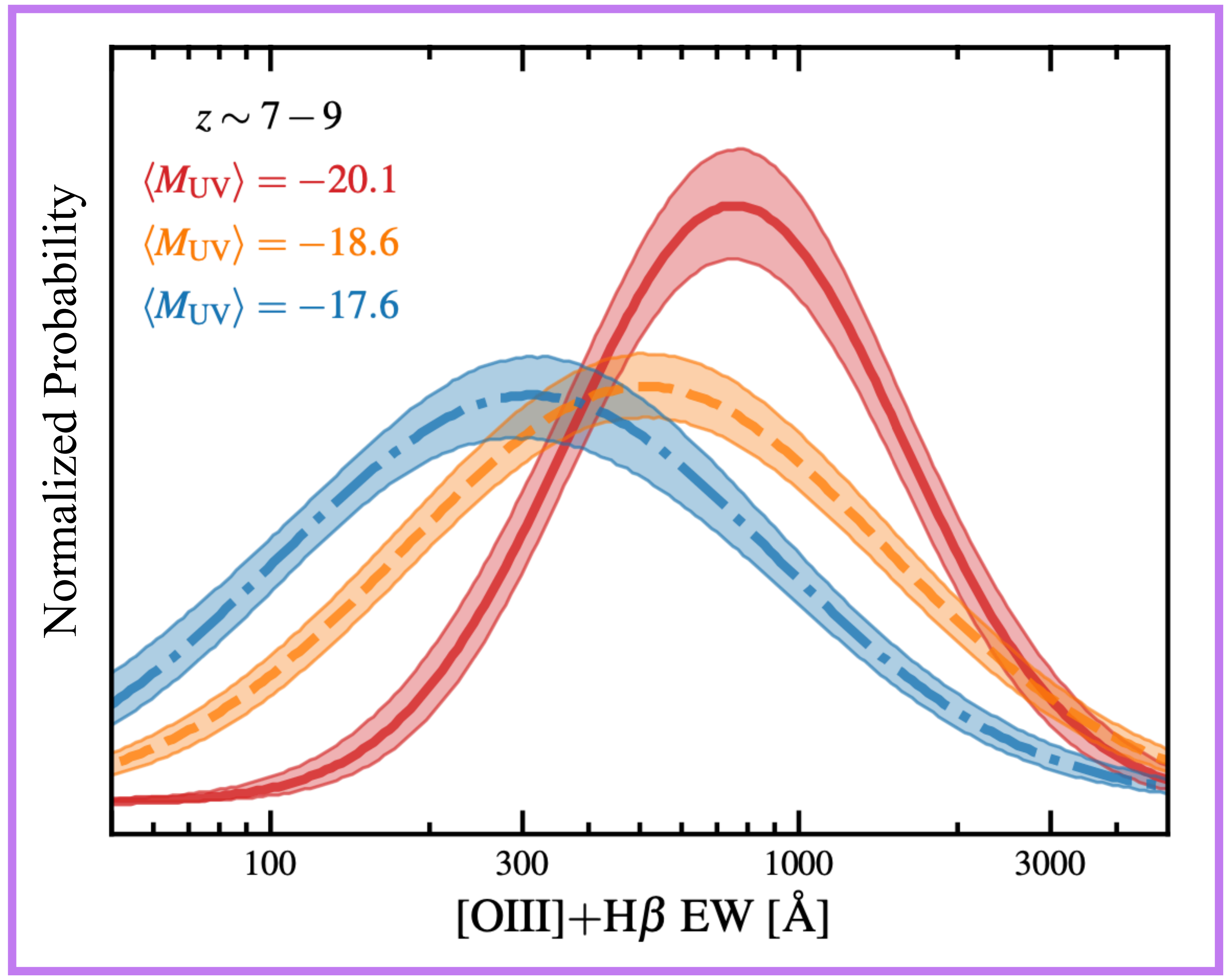

Endsley+23b

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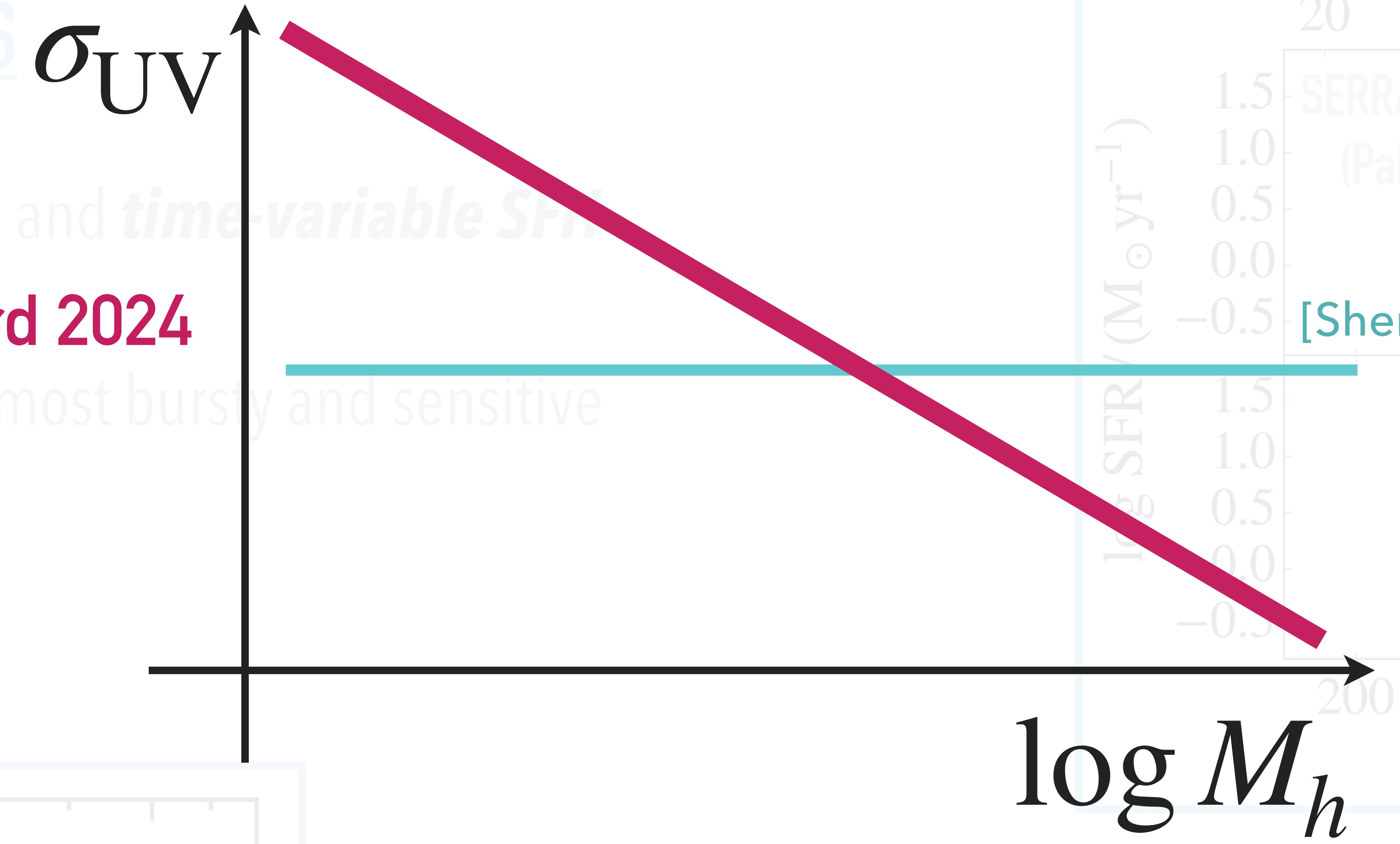
Gelli, Mason & Hayward 2024
arXiv:2405.13108



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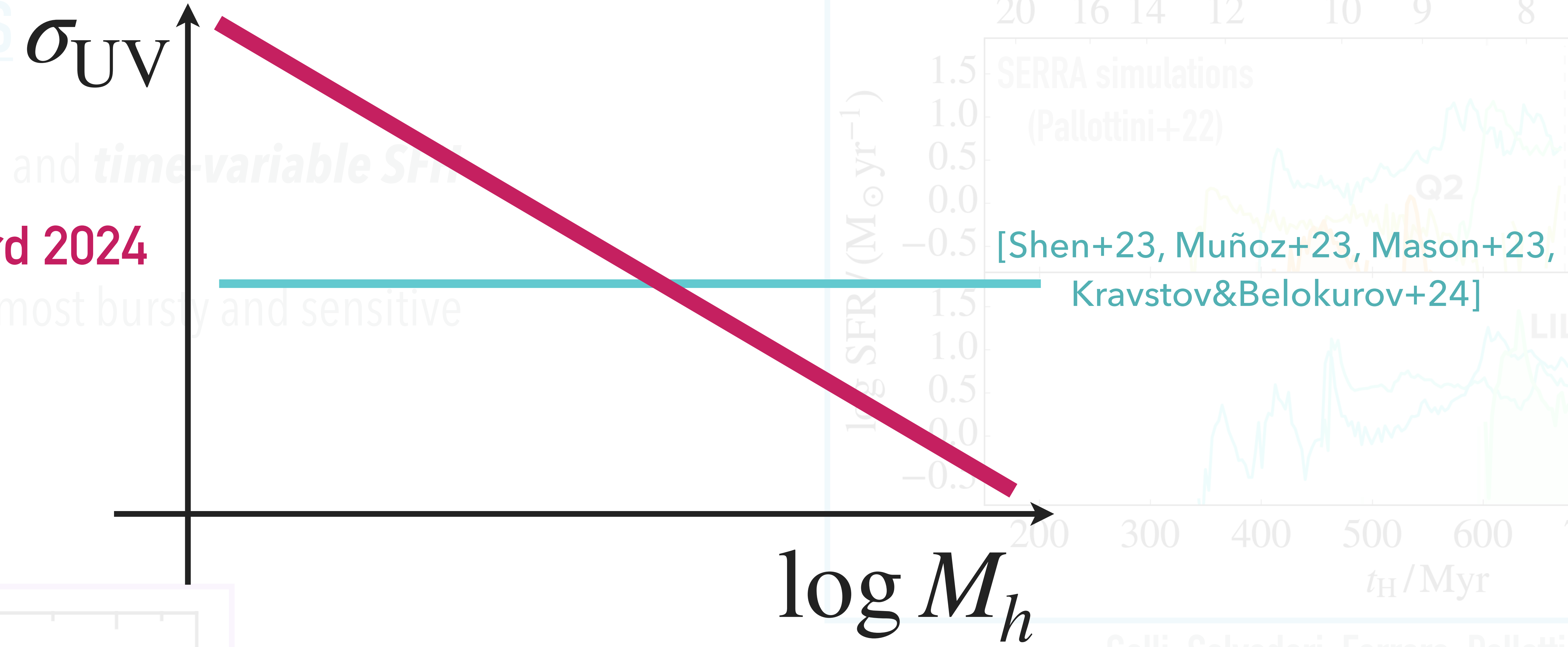


What are the implications of a mass-dependent scatter?

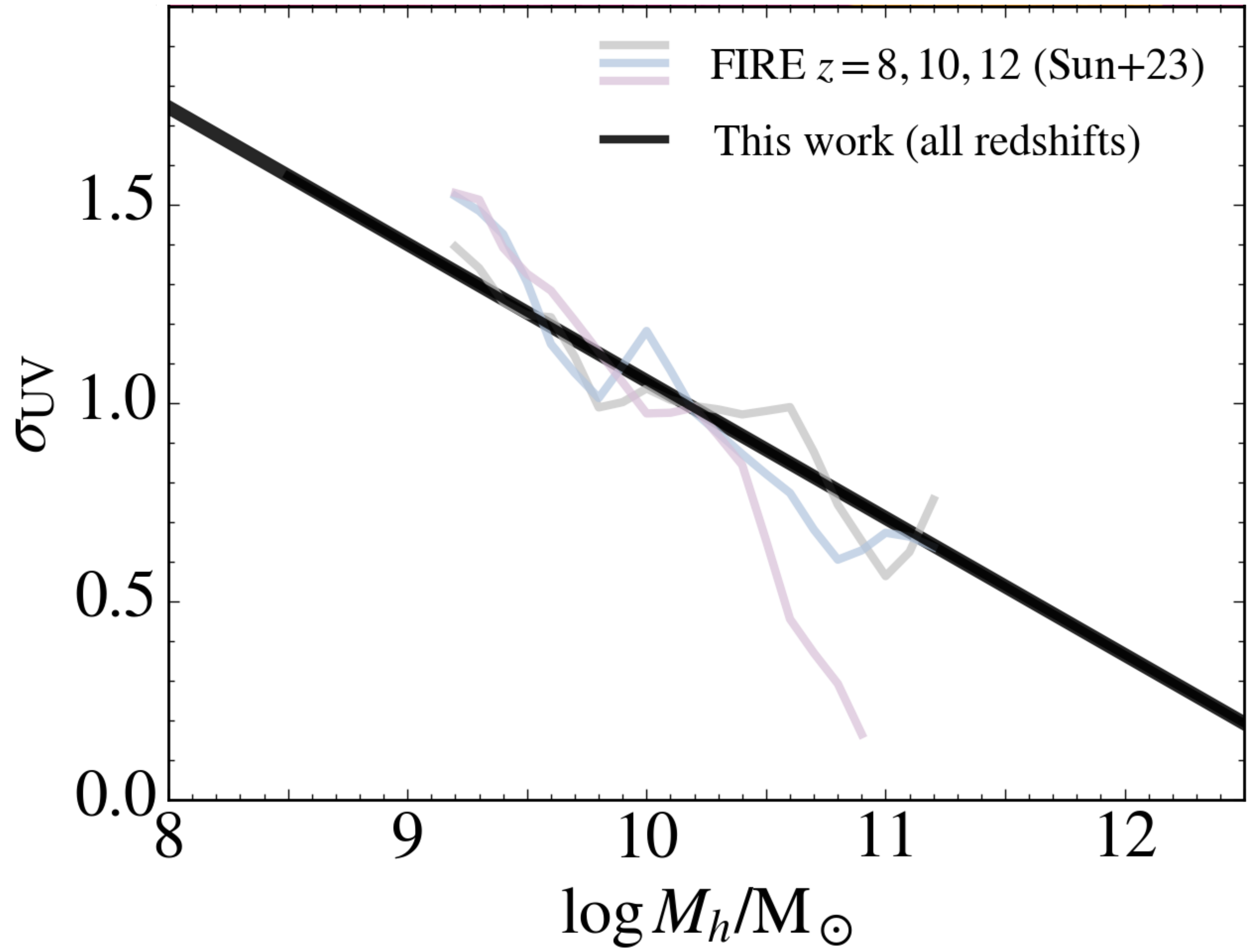
Can we probe stochastic star-formation with JWST?

MASS-DEPENDENT UV SCATTER MODEL

SIMPLE ANALYTICAL MODEL:

→ *Increasing scatter towards low halo mass:*

$$\sigma_{UV} \propto v_{esc}^{-1} \propto M_h^{-1/3}$$



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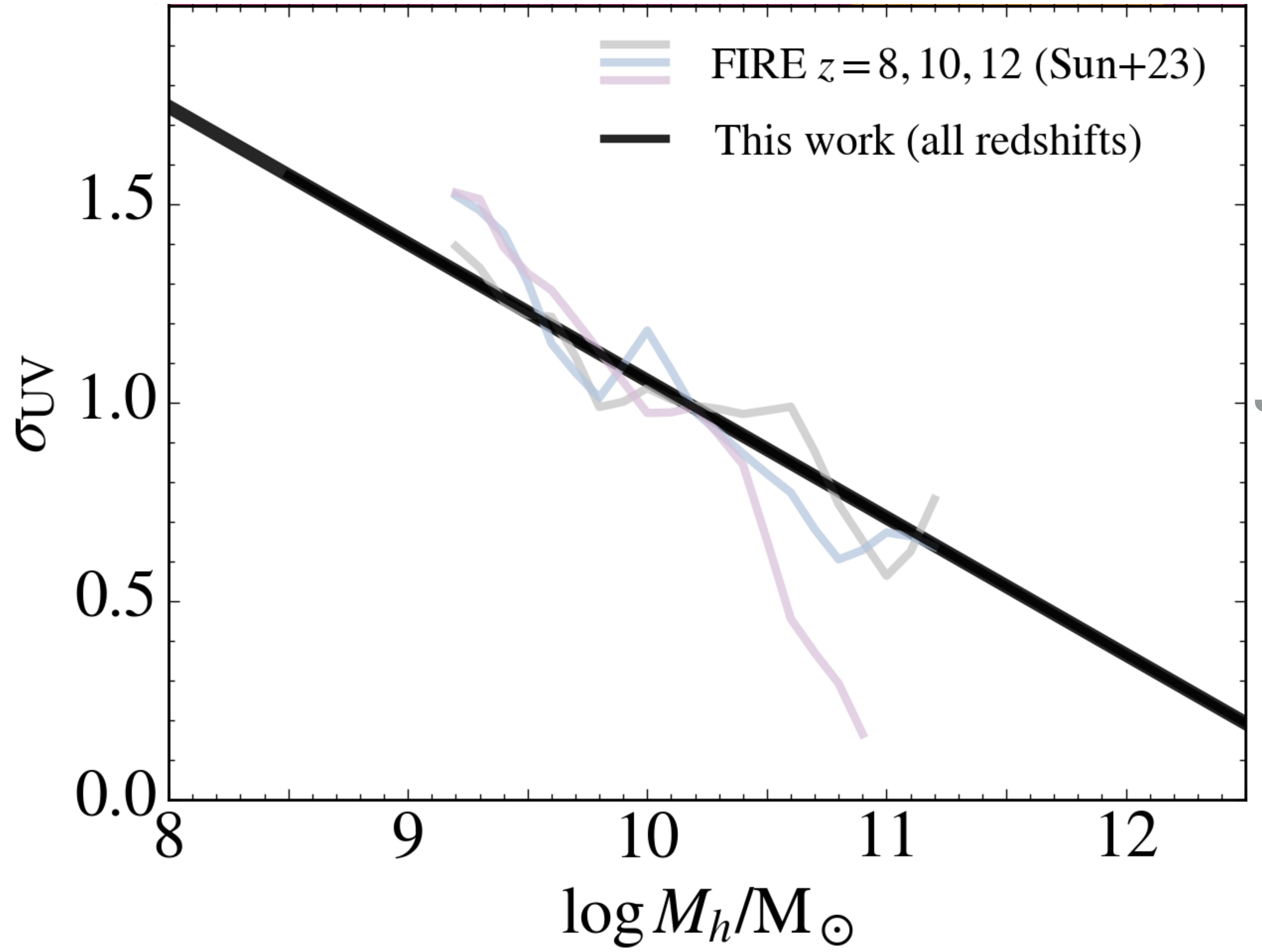
$z = 5$ *calibration*



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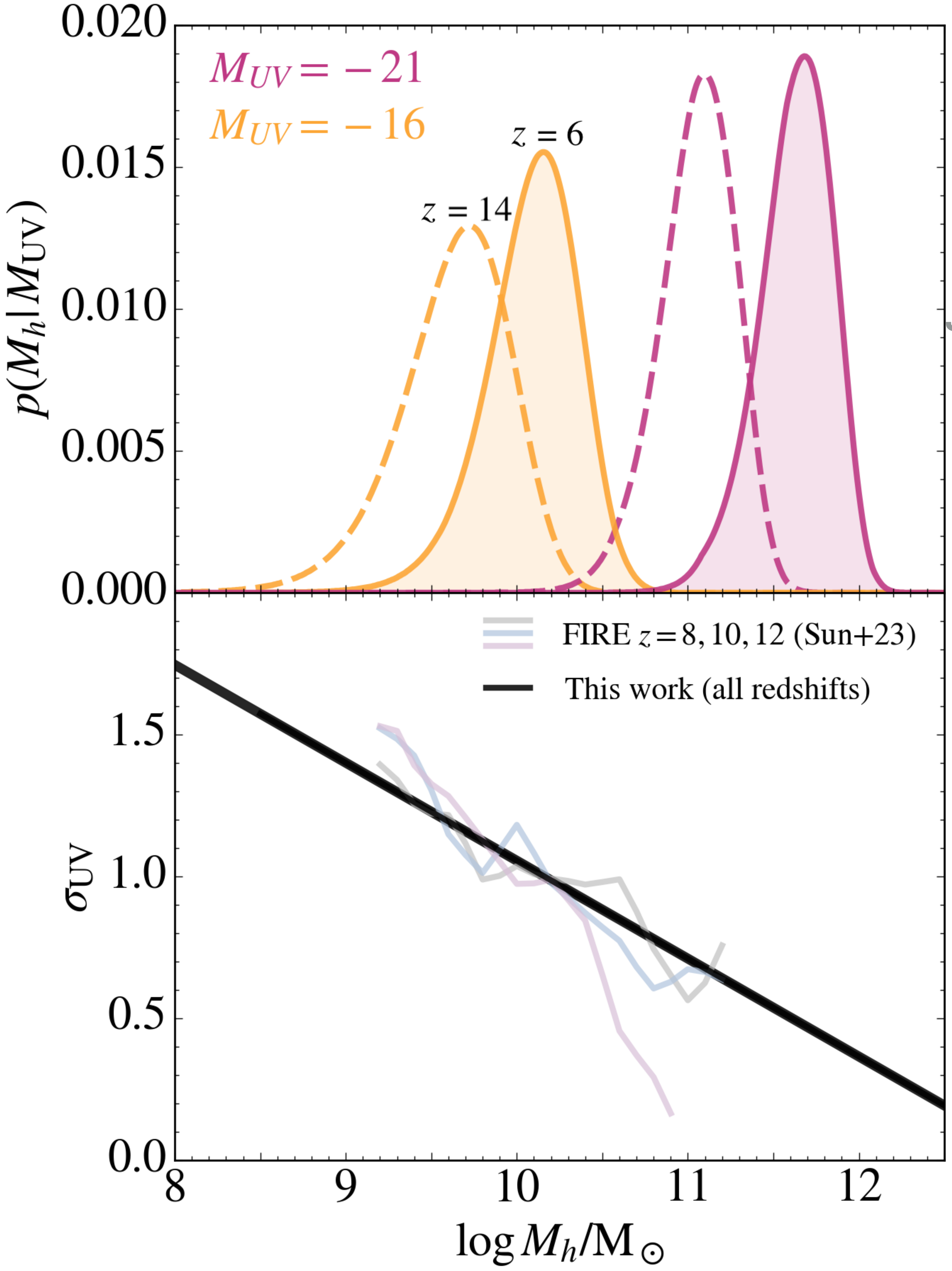
→ *Probability for a halo* M_h *to have luminosity* M_{UV}

$$p(M_{\rm UV} \mid M_h) = \frac{1}{\sqrt{2\pi}\sigma_{\rm UV}(M_h)} \exp\left(\frac{-[M_{\rm UV} - M_{{\rm UV},c}(M_h, z)]^2}{2\sigma_{\rm UV}^2(M_h)}\right)$$



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→ *Proba*

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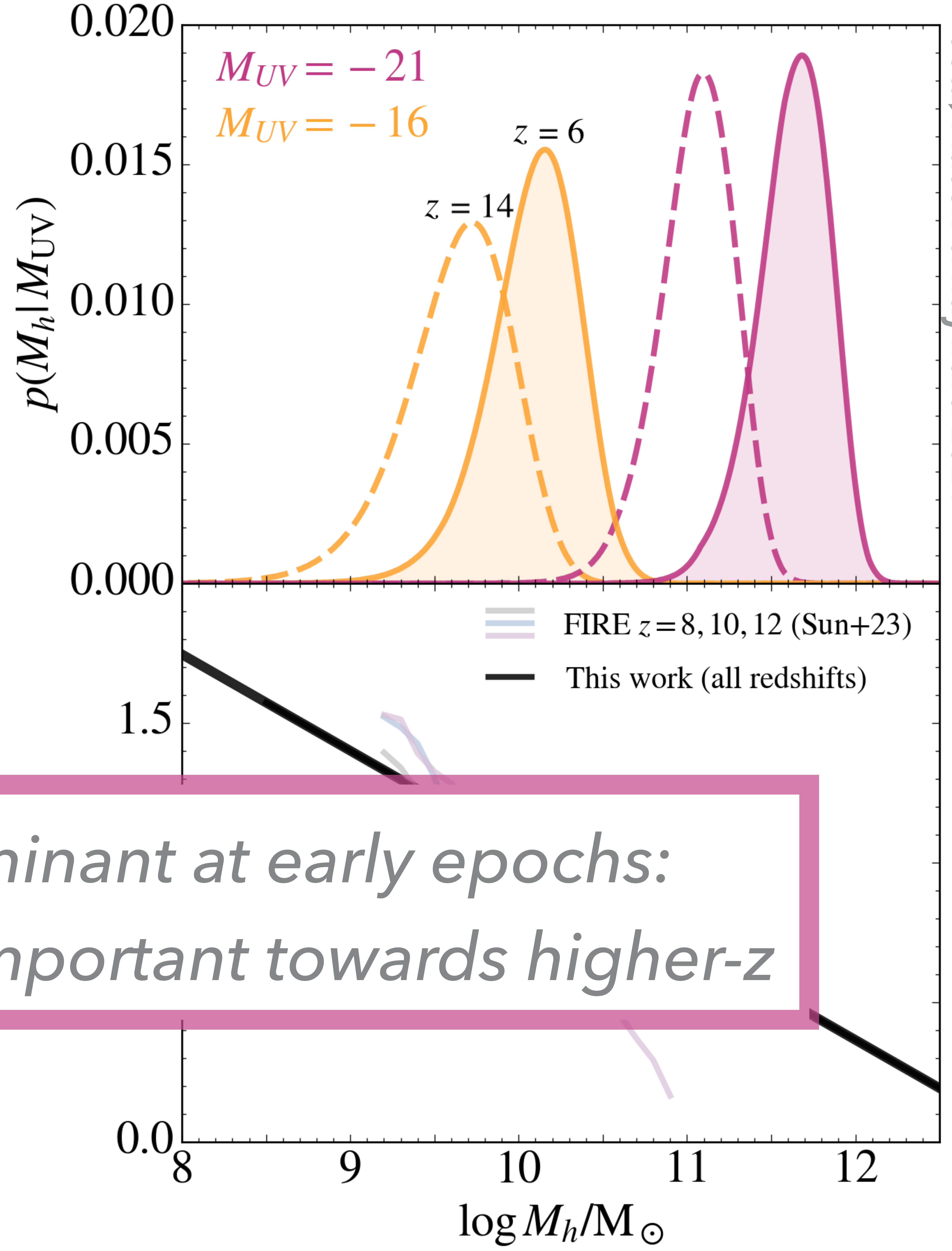
In ΛCDM *low-mass haloes dominant at early epochs:*
the UV-scatter effect will be more important towards higher-z



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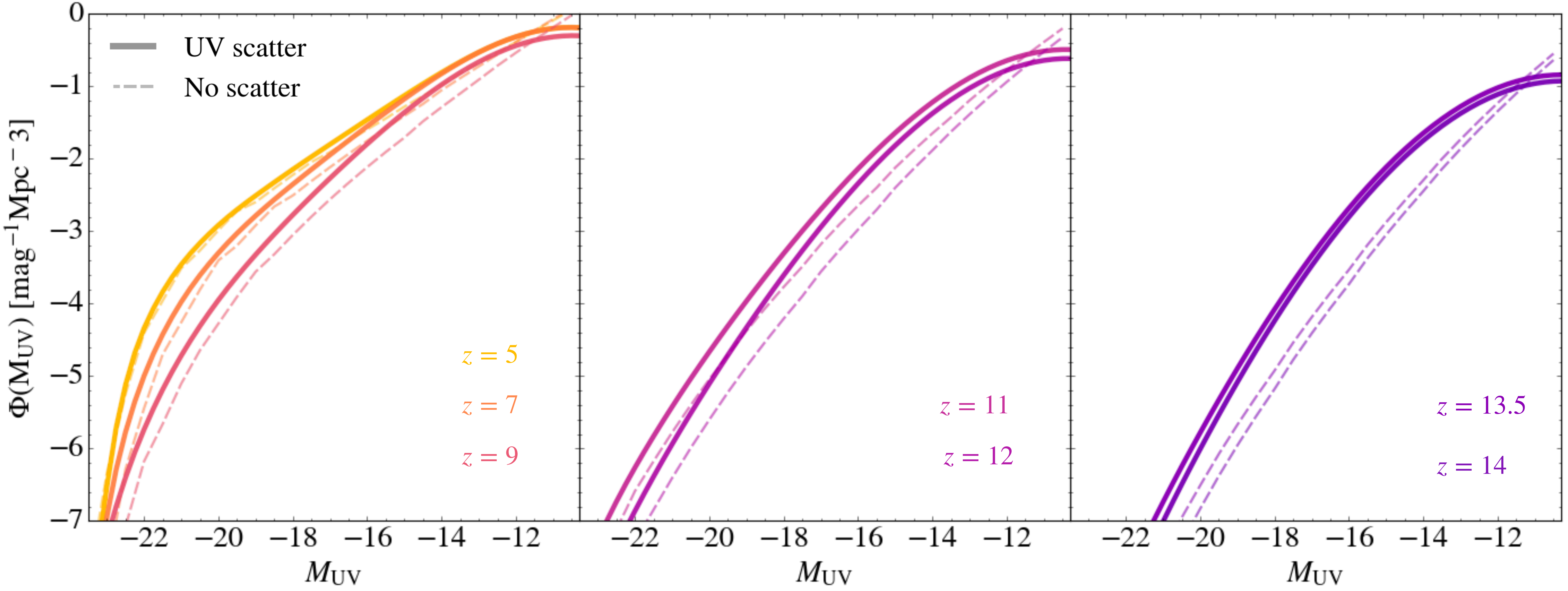
MASS-DEPENDENT UV SCATTER MODEL

LUMINOSITY FUNCTIONS

$$\Phi(M_{\rm UV}) = \int_{M_{h,min}}^{\infty} dM_h \, p(M_{\rm UV} \mid M_h) \, \frac{dn}{dM_h}$$



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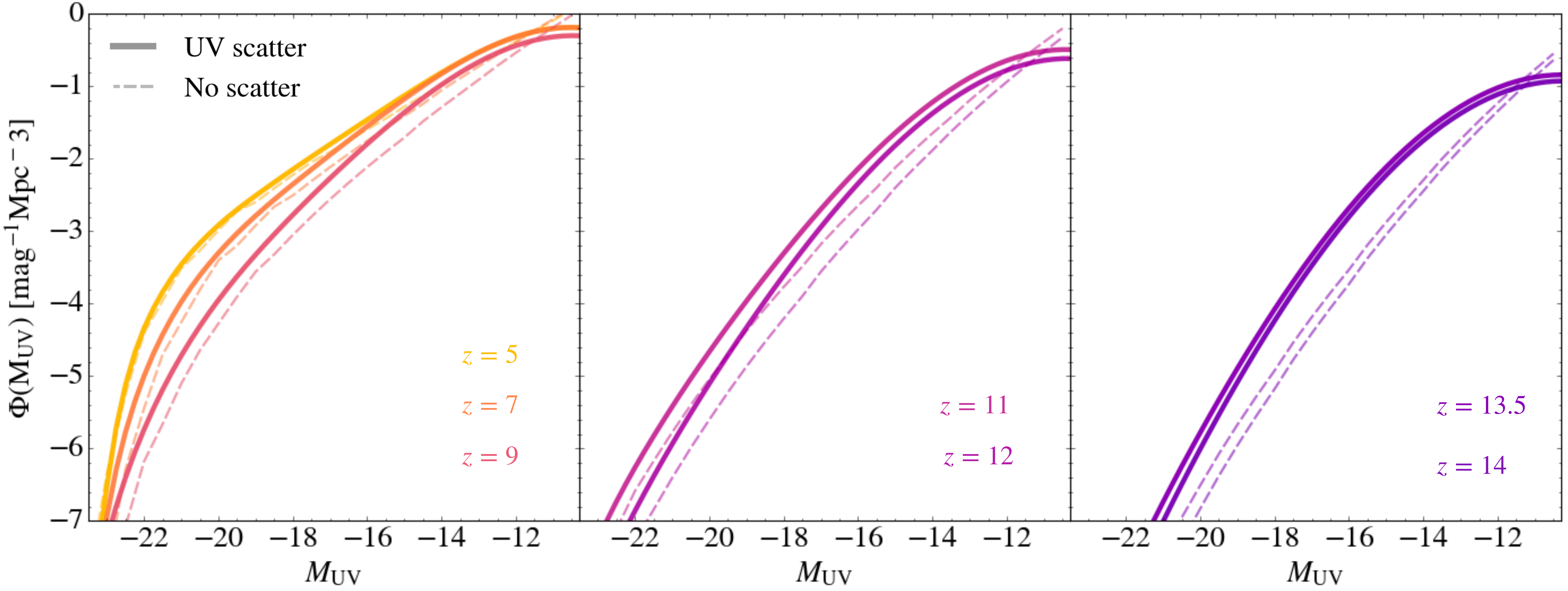

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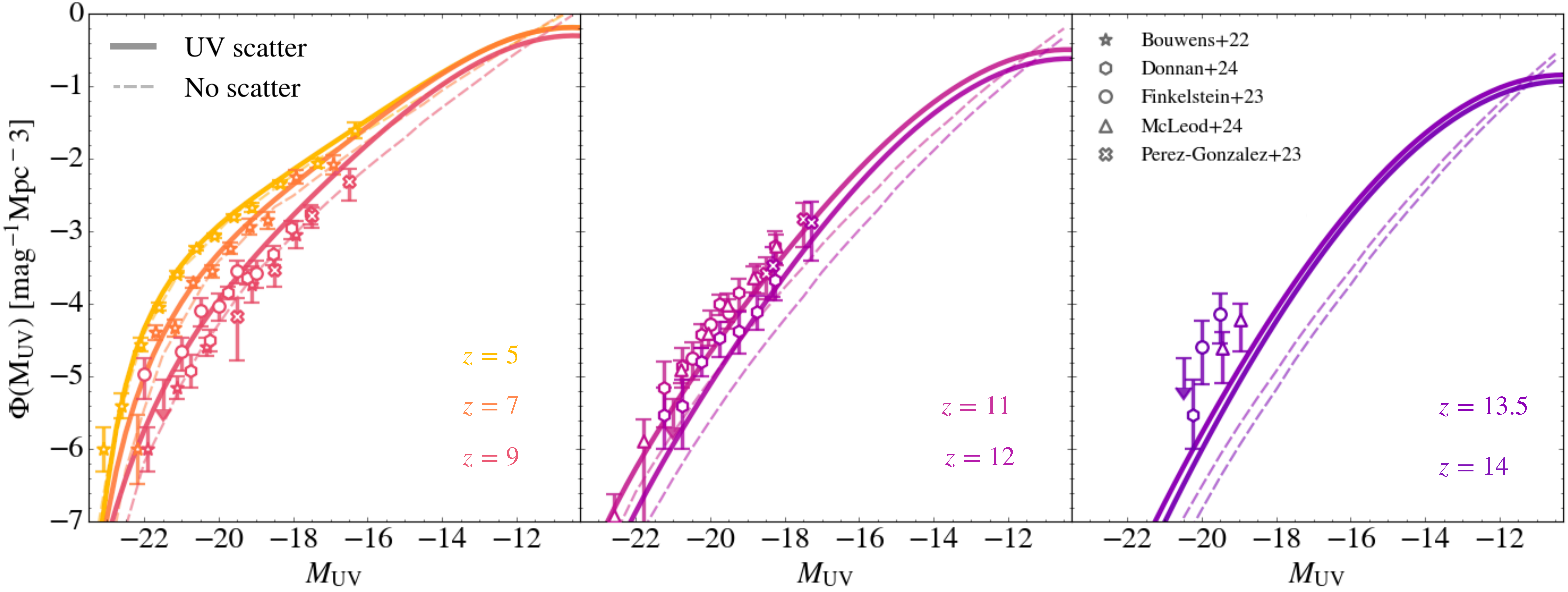

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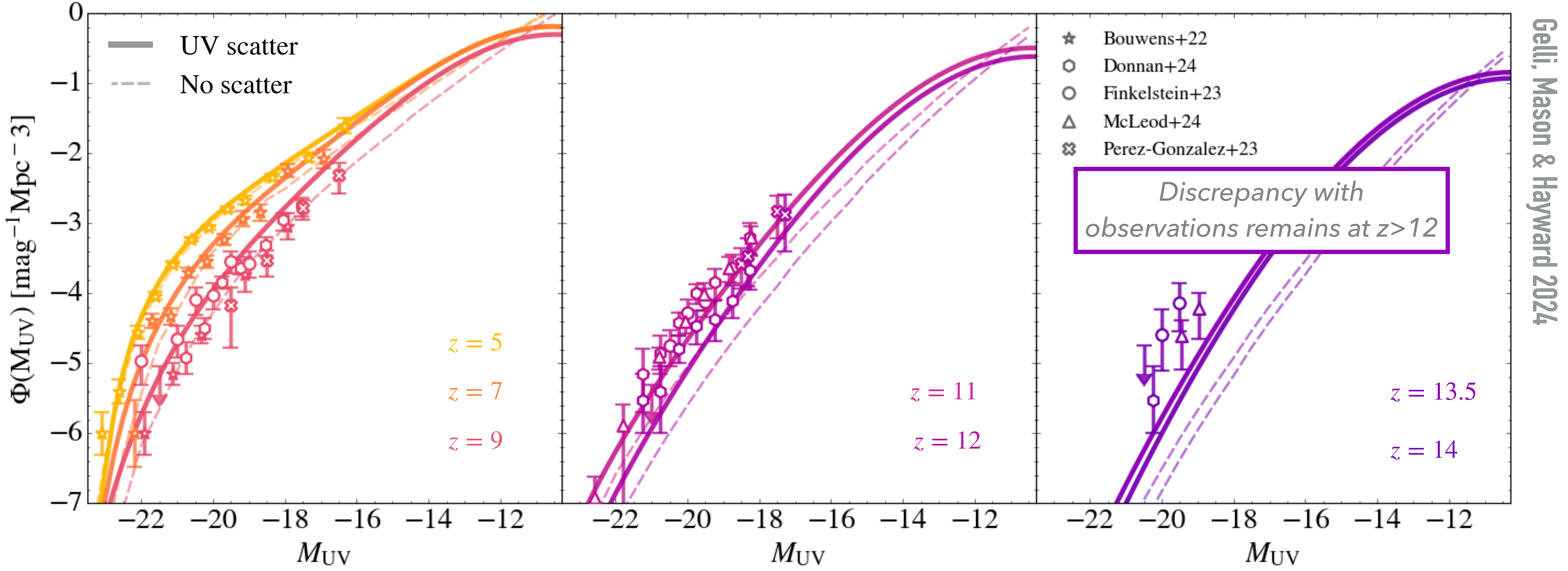

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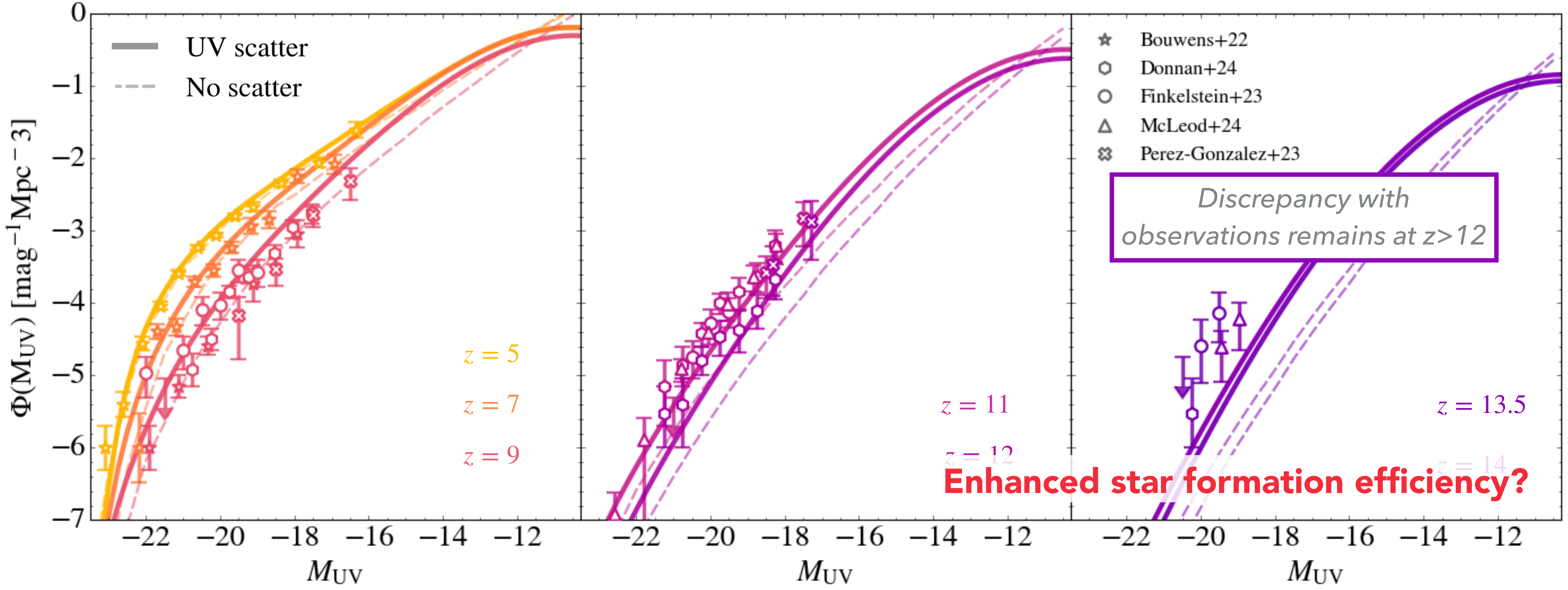

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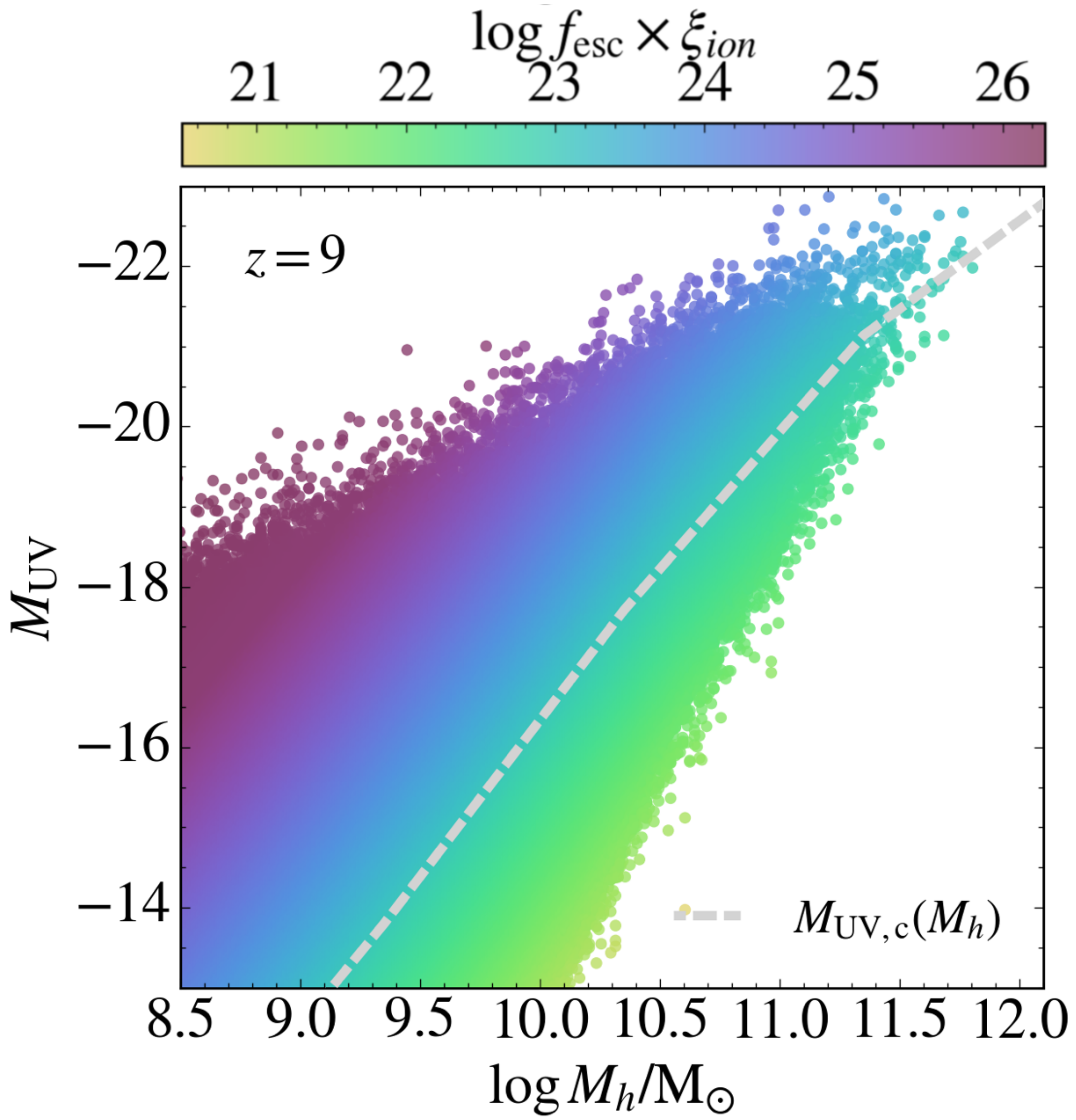
REIONIZATION HISTORY

Up-scattered halos contribute more to reionization



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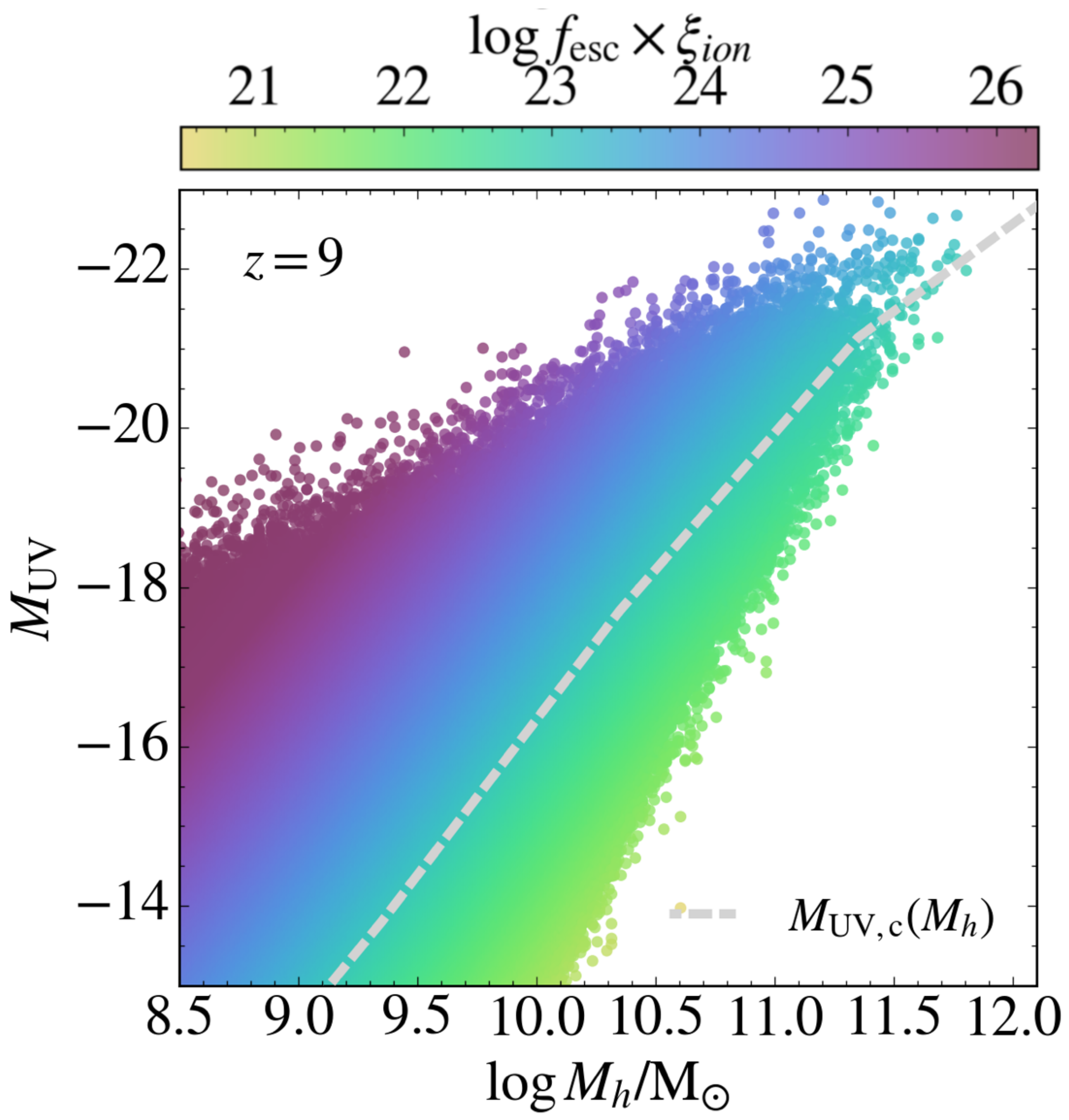

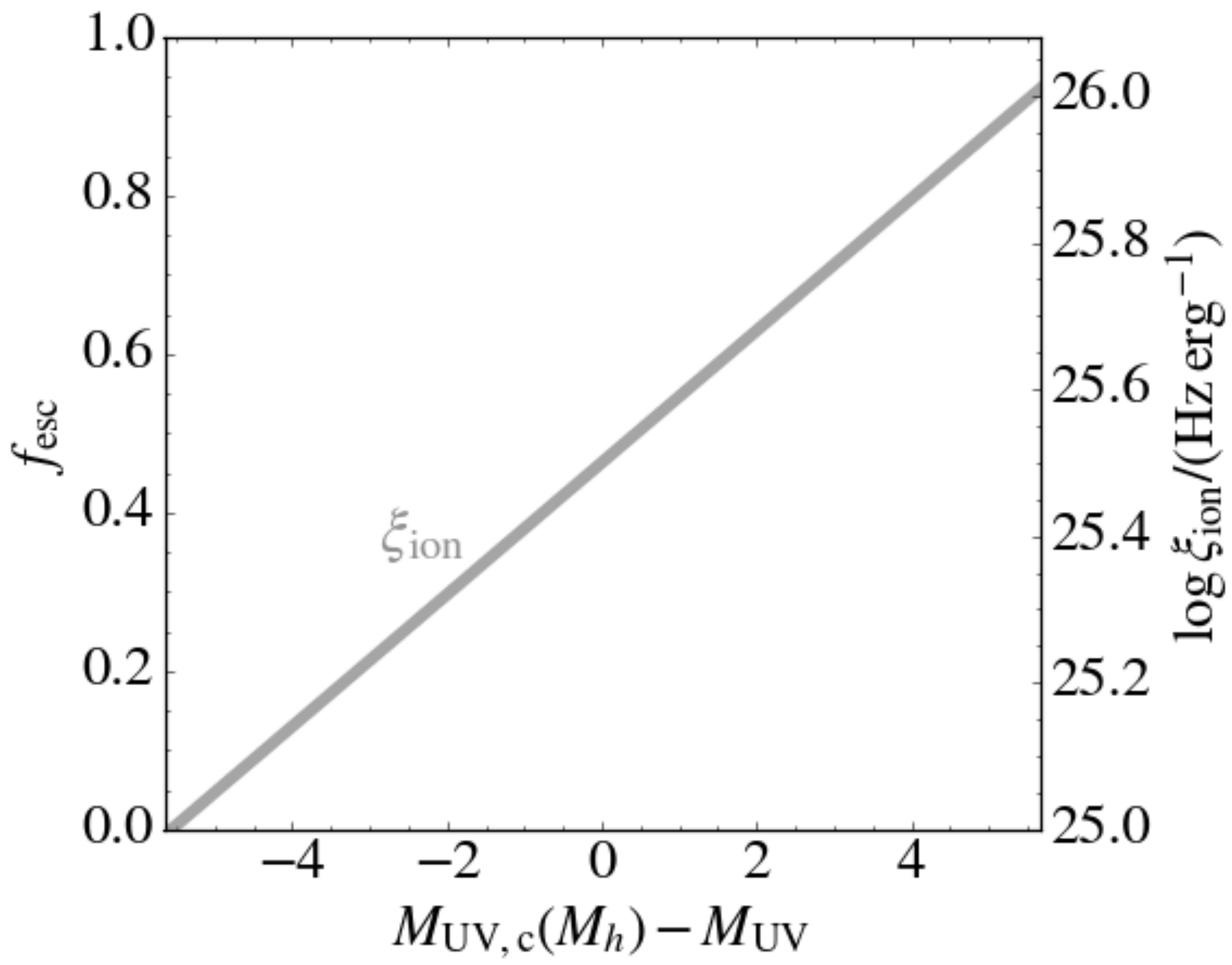

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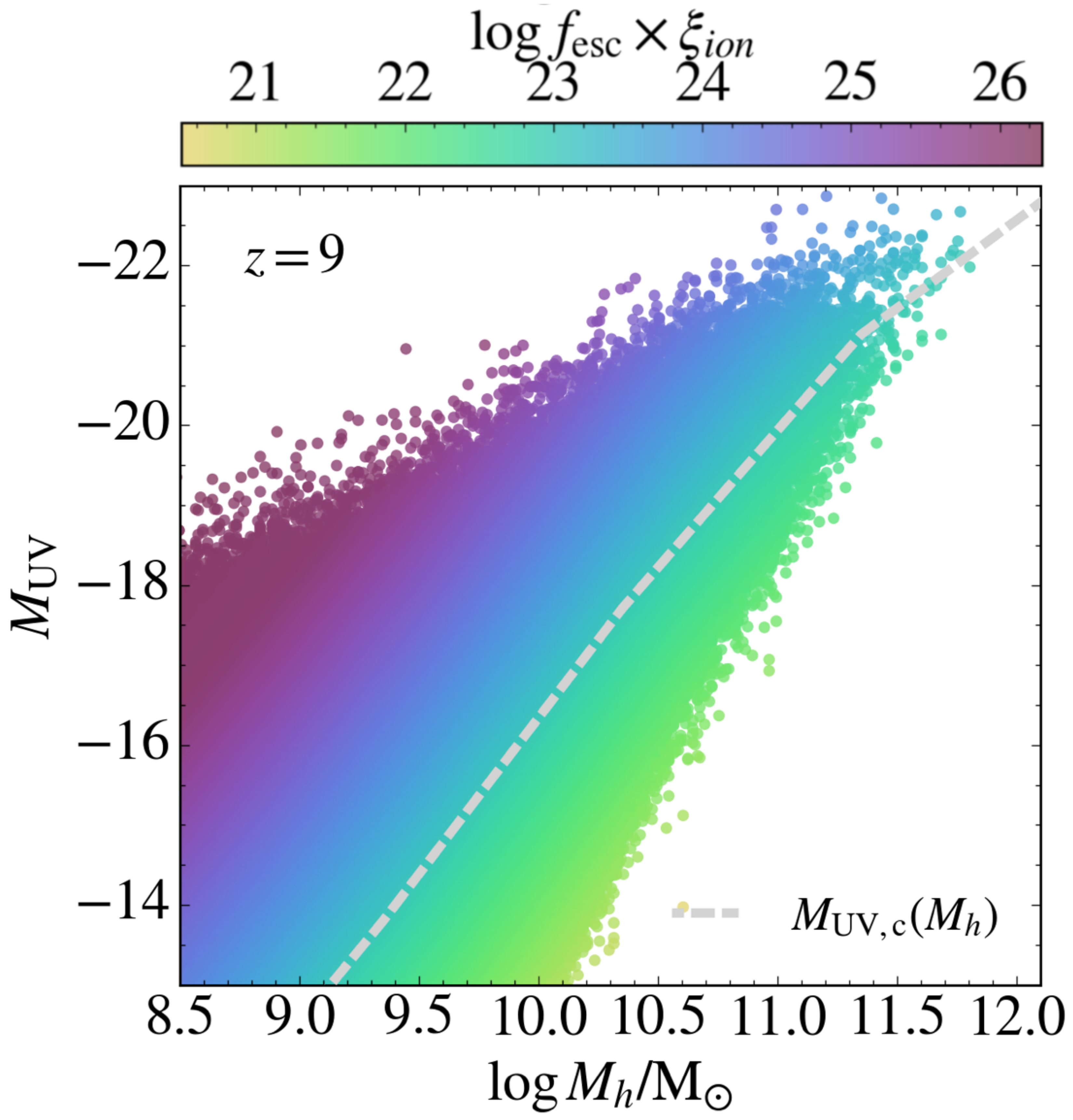

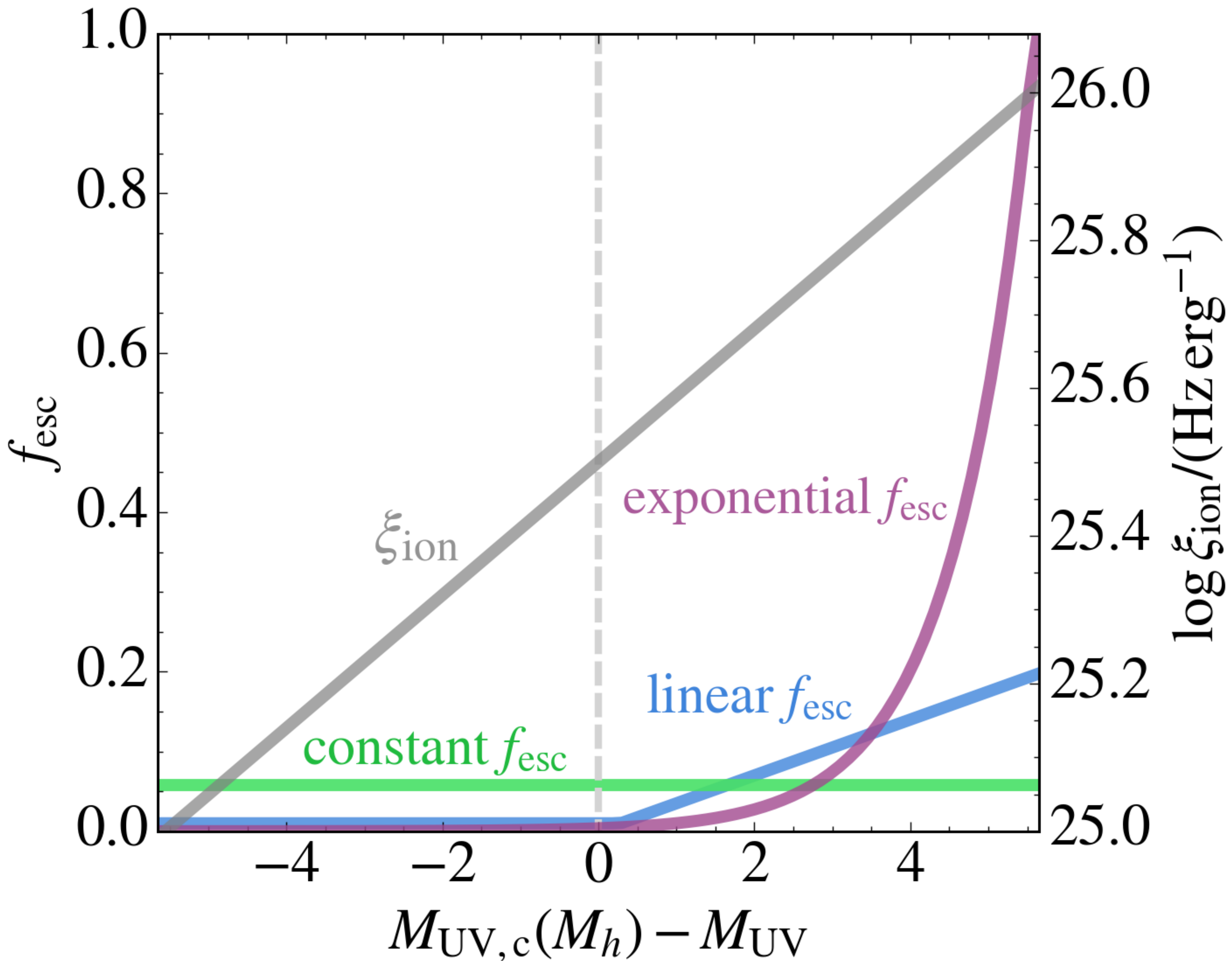

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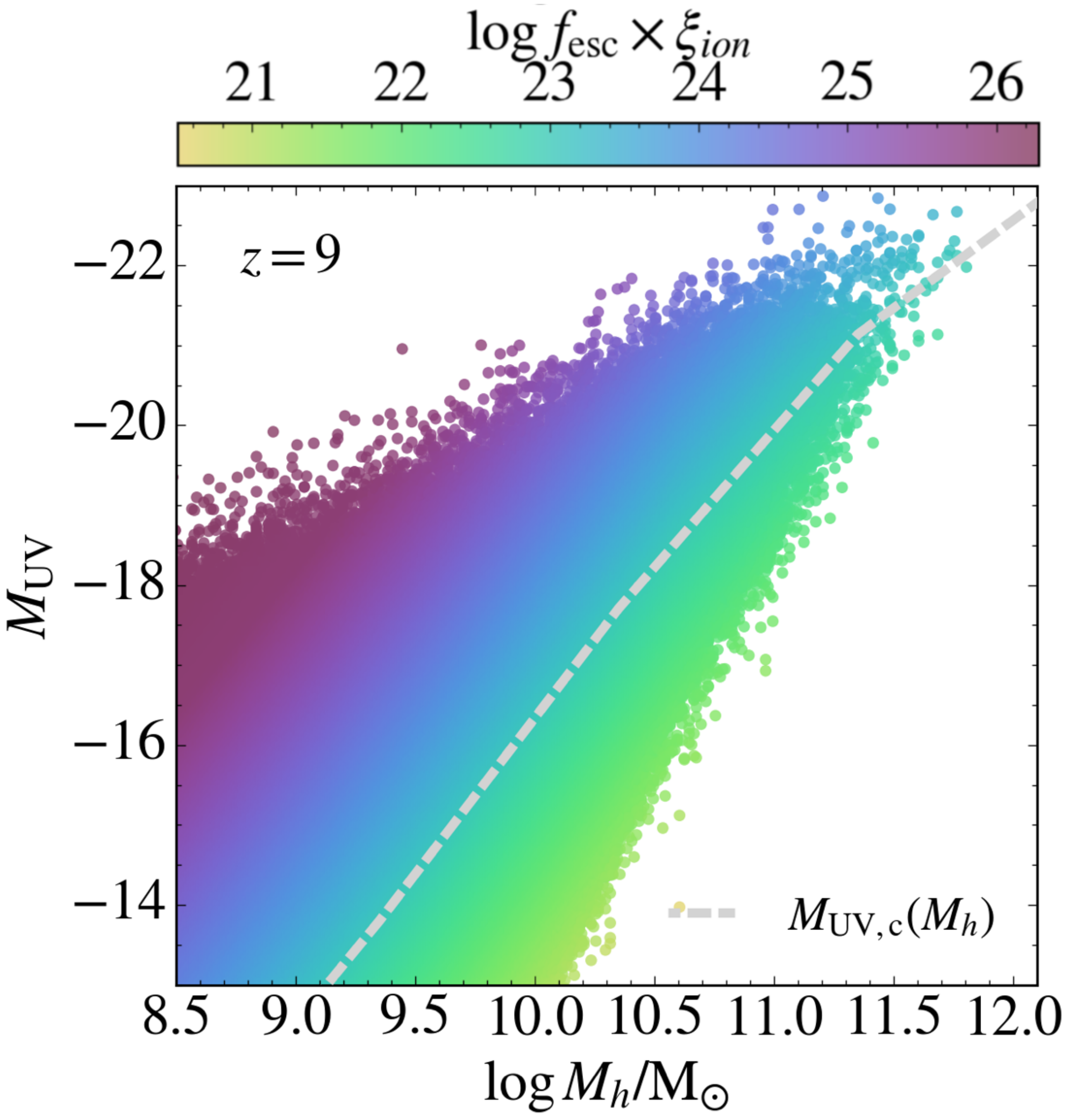

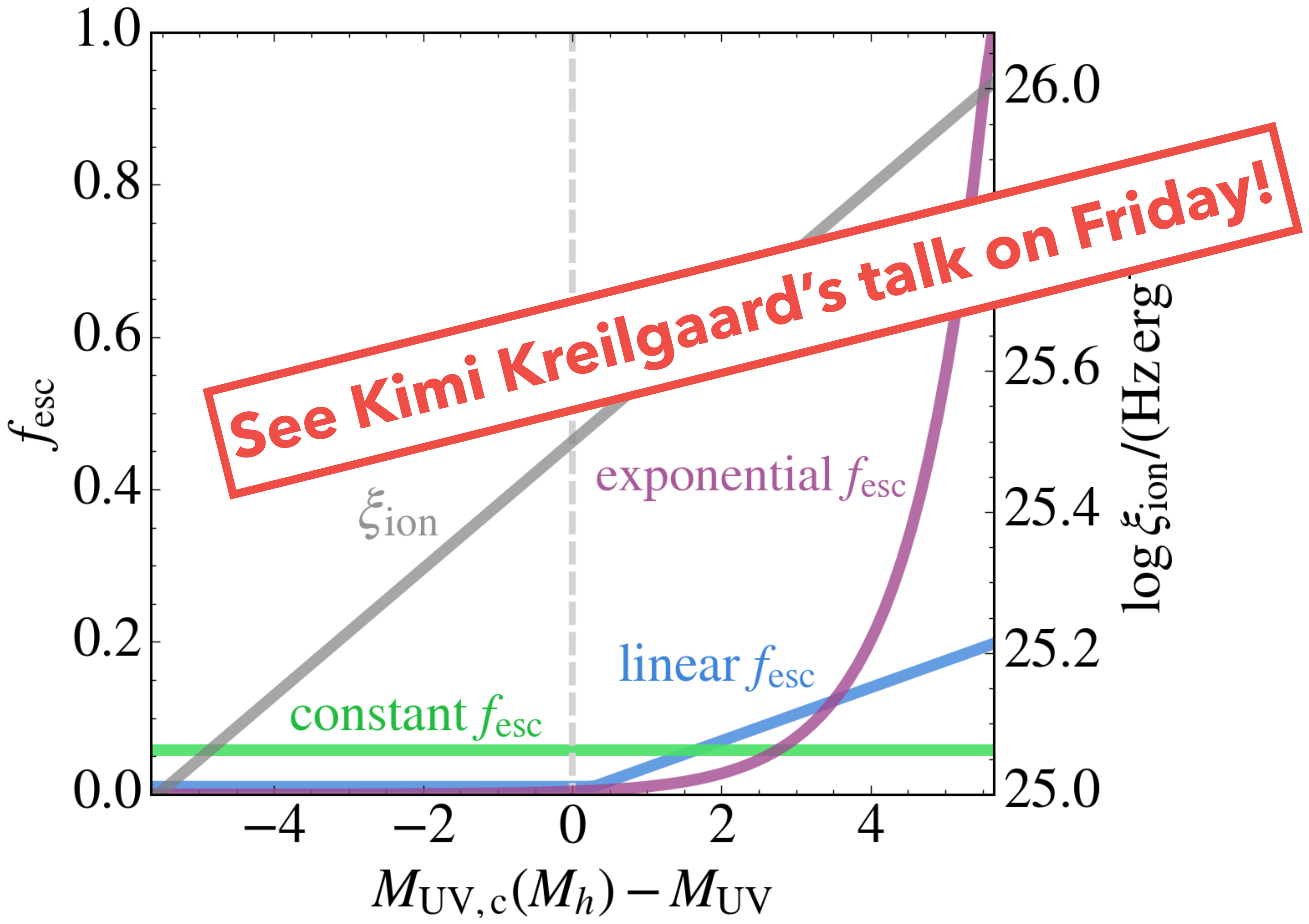

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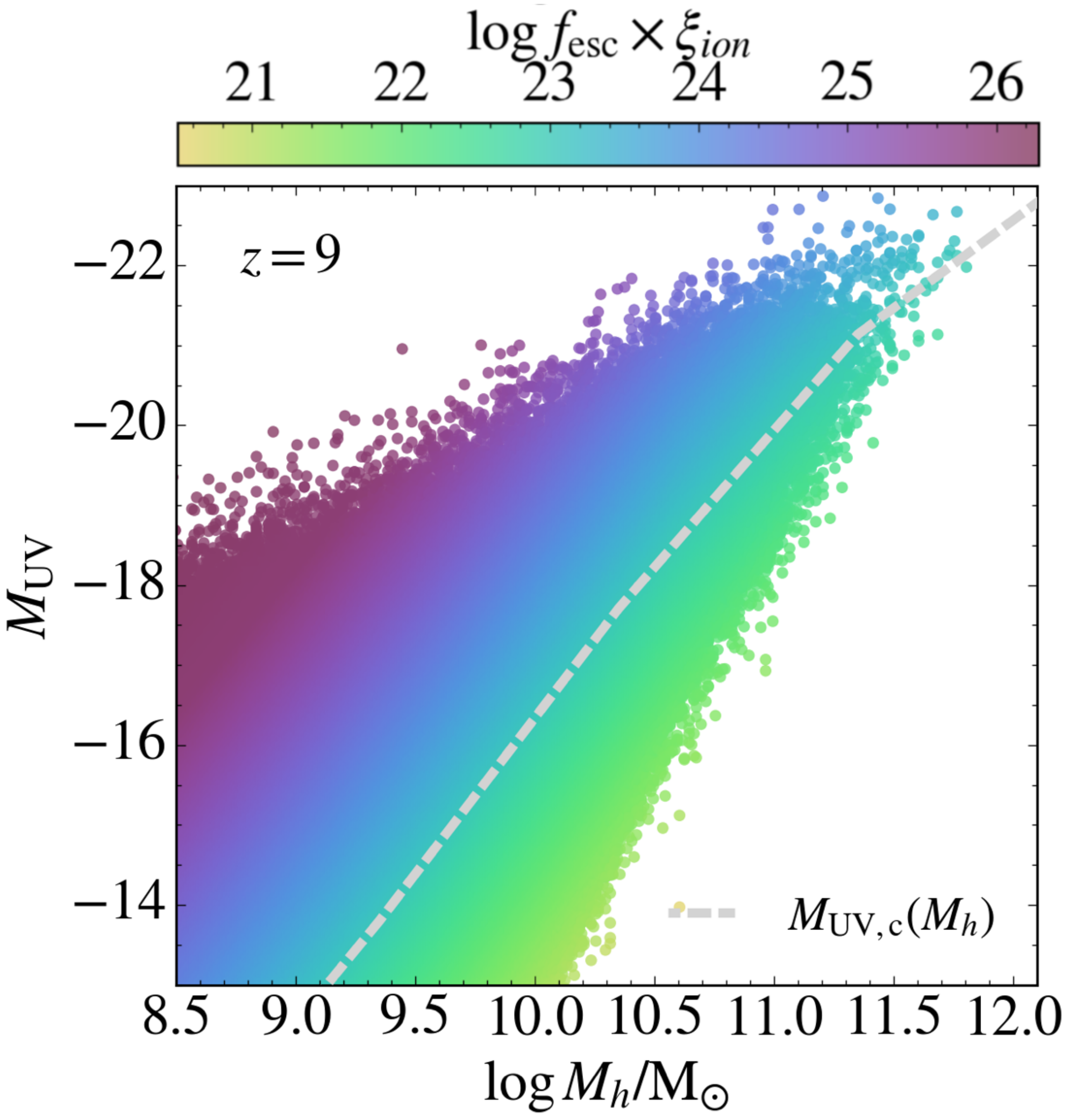

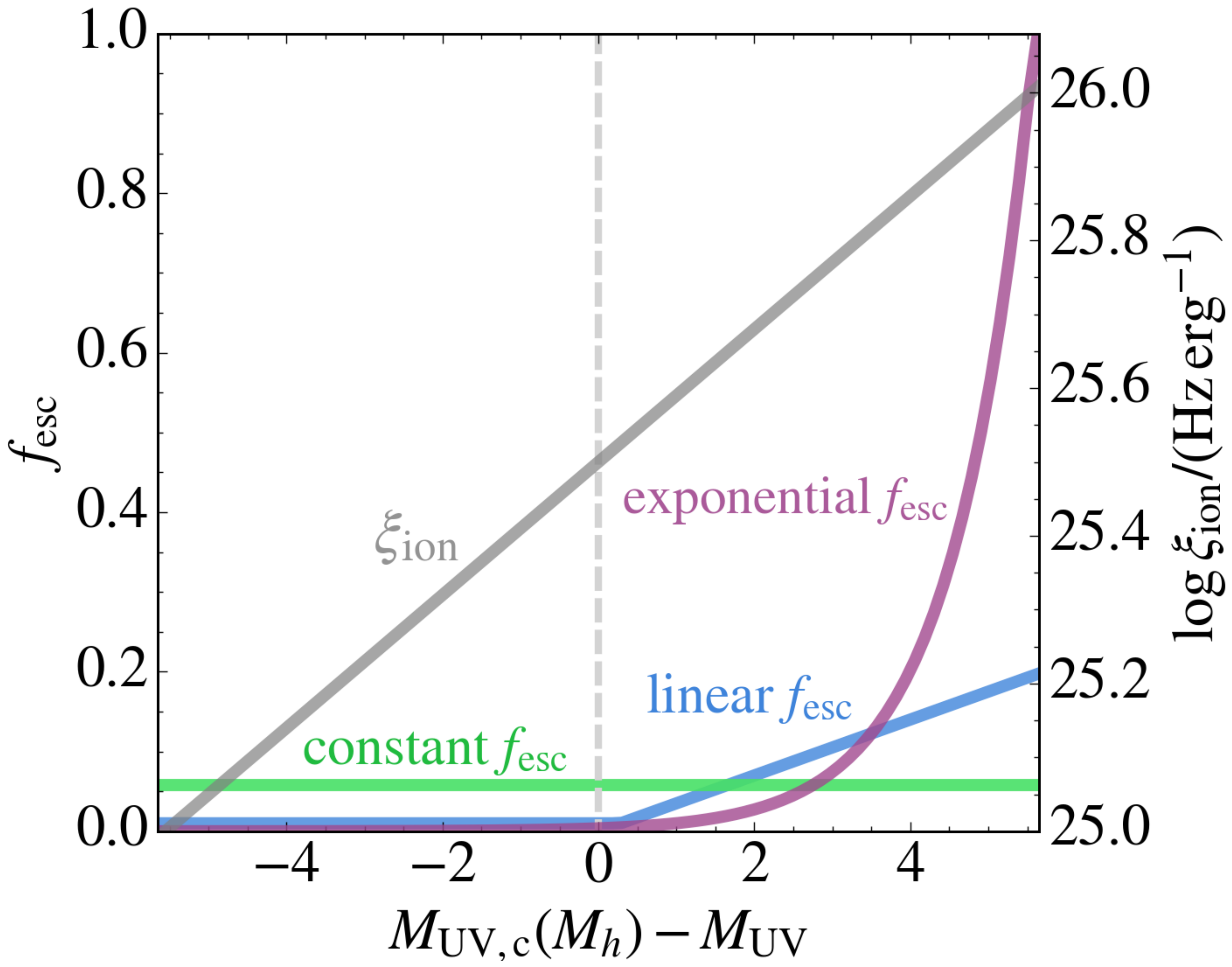

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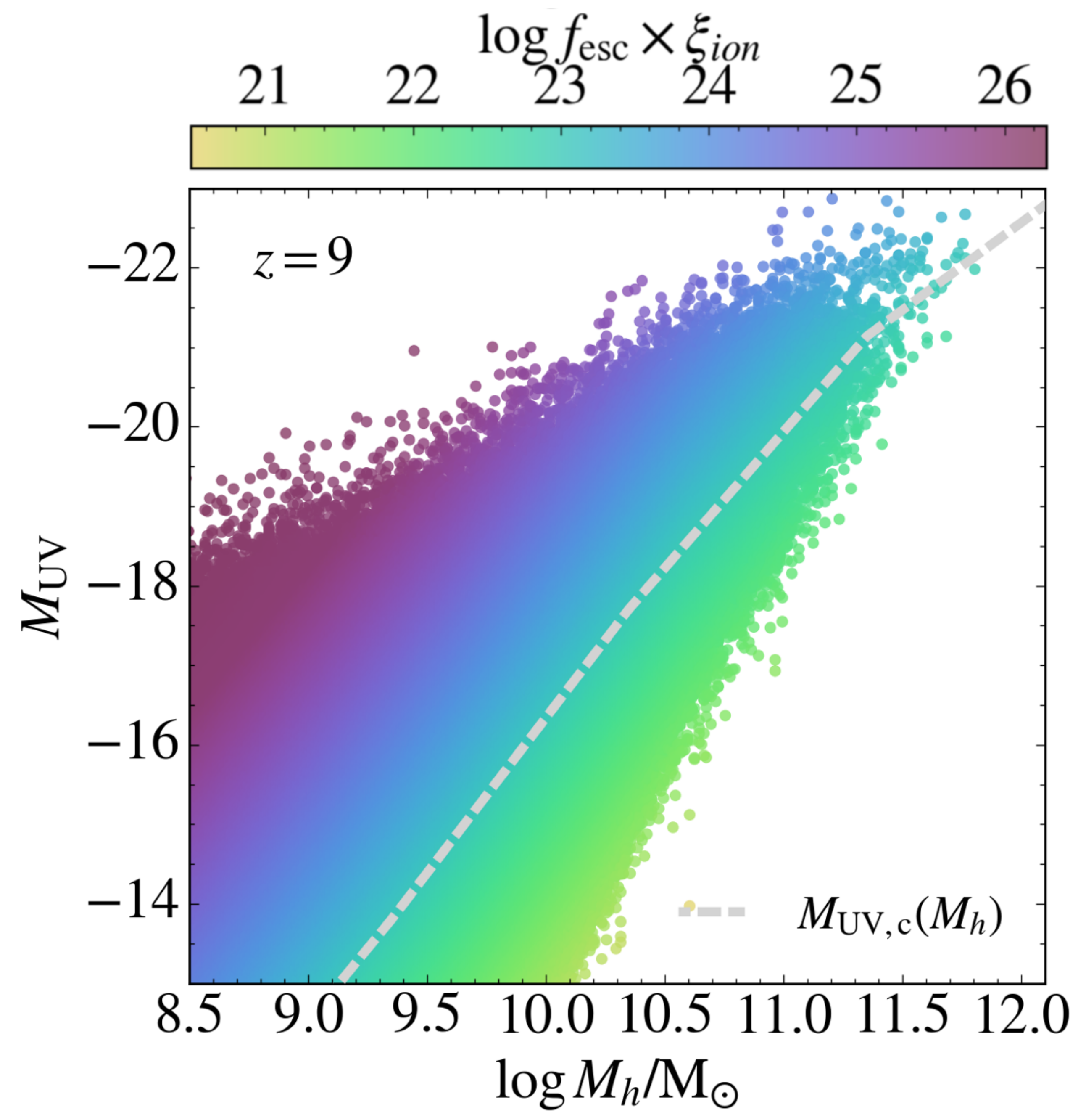

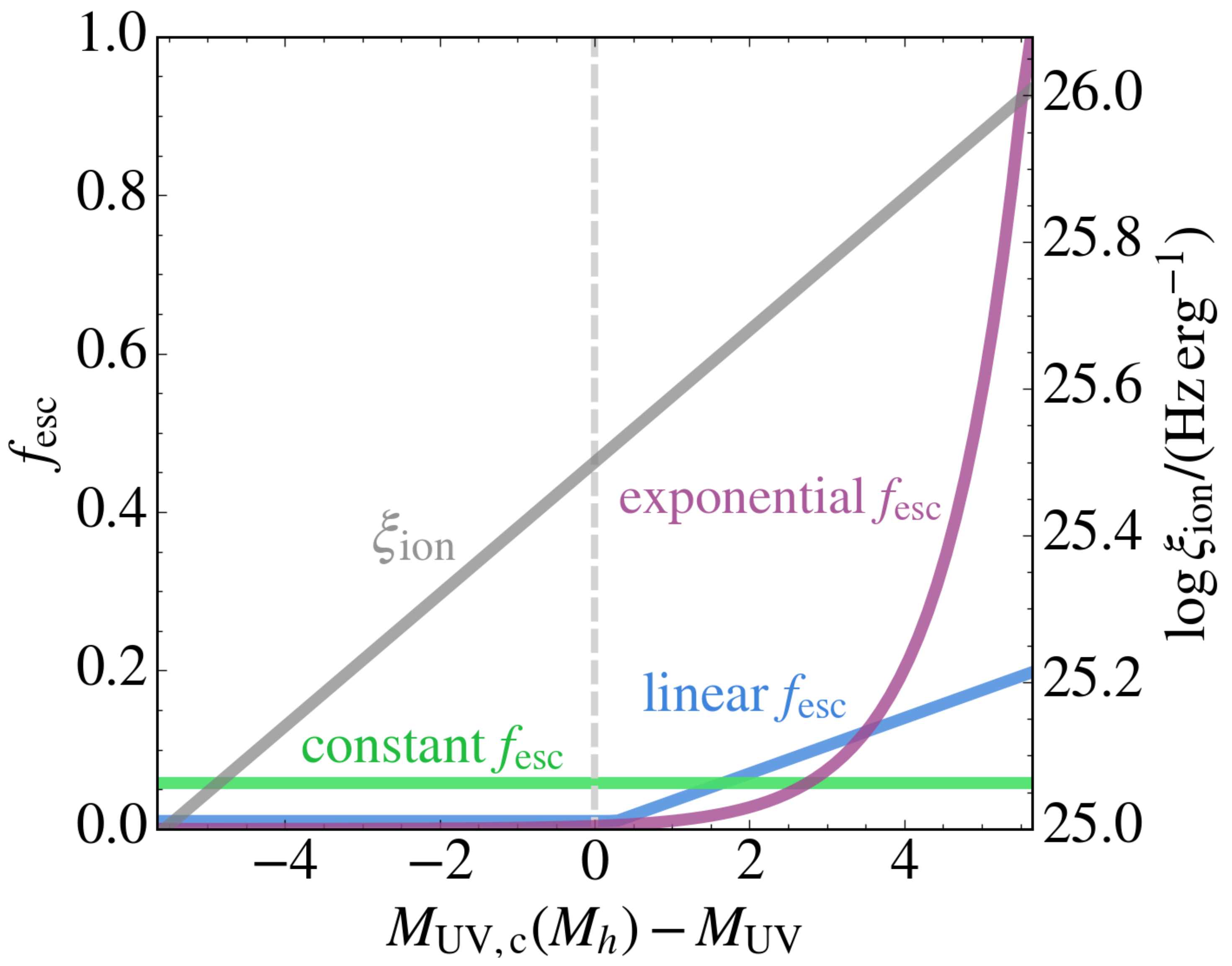

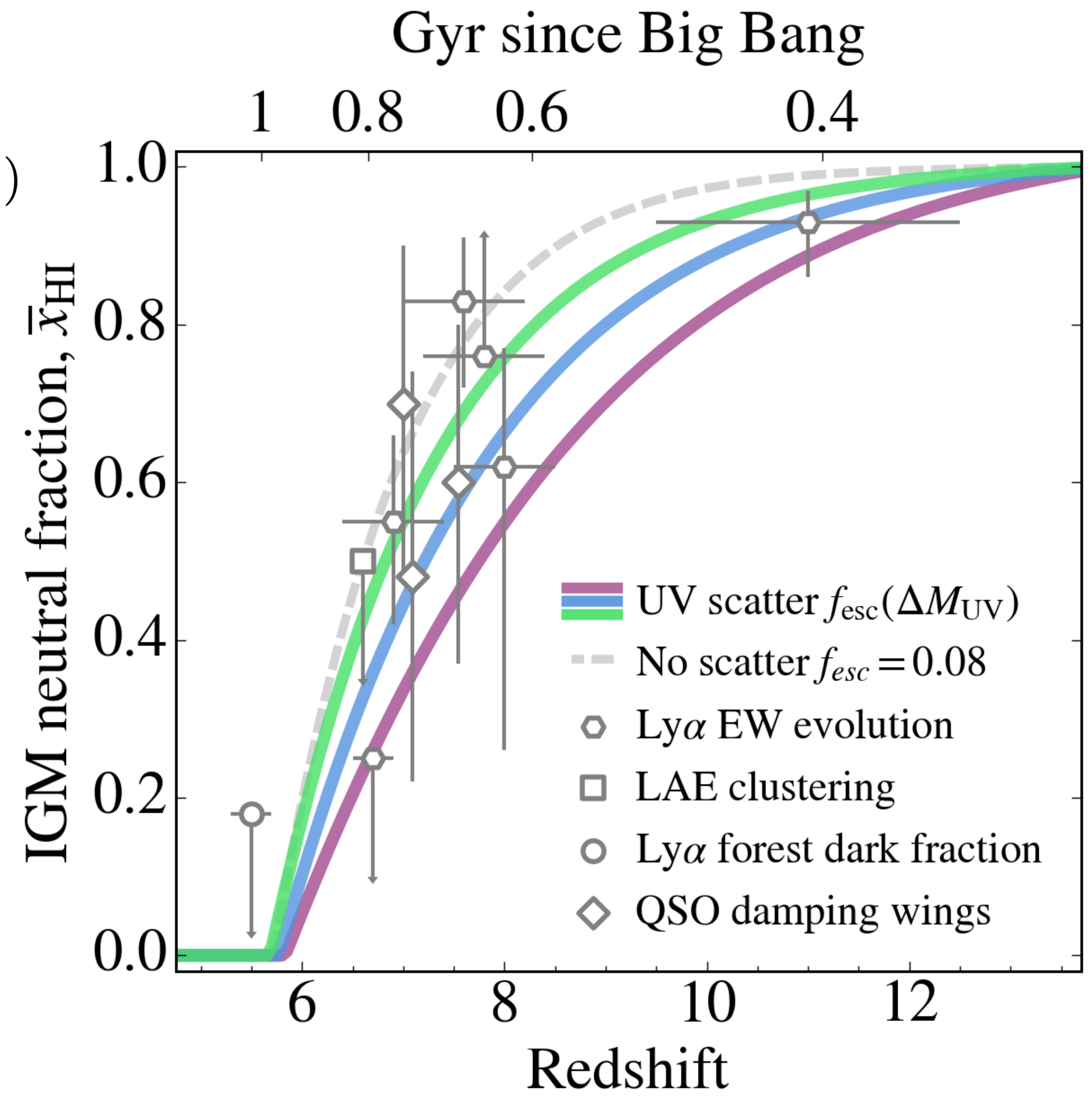

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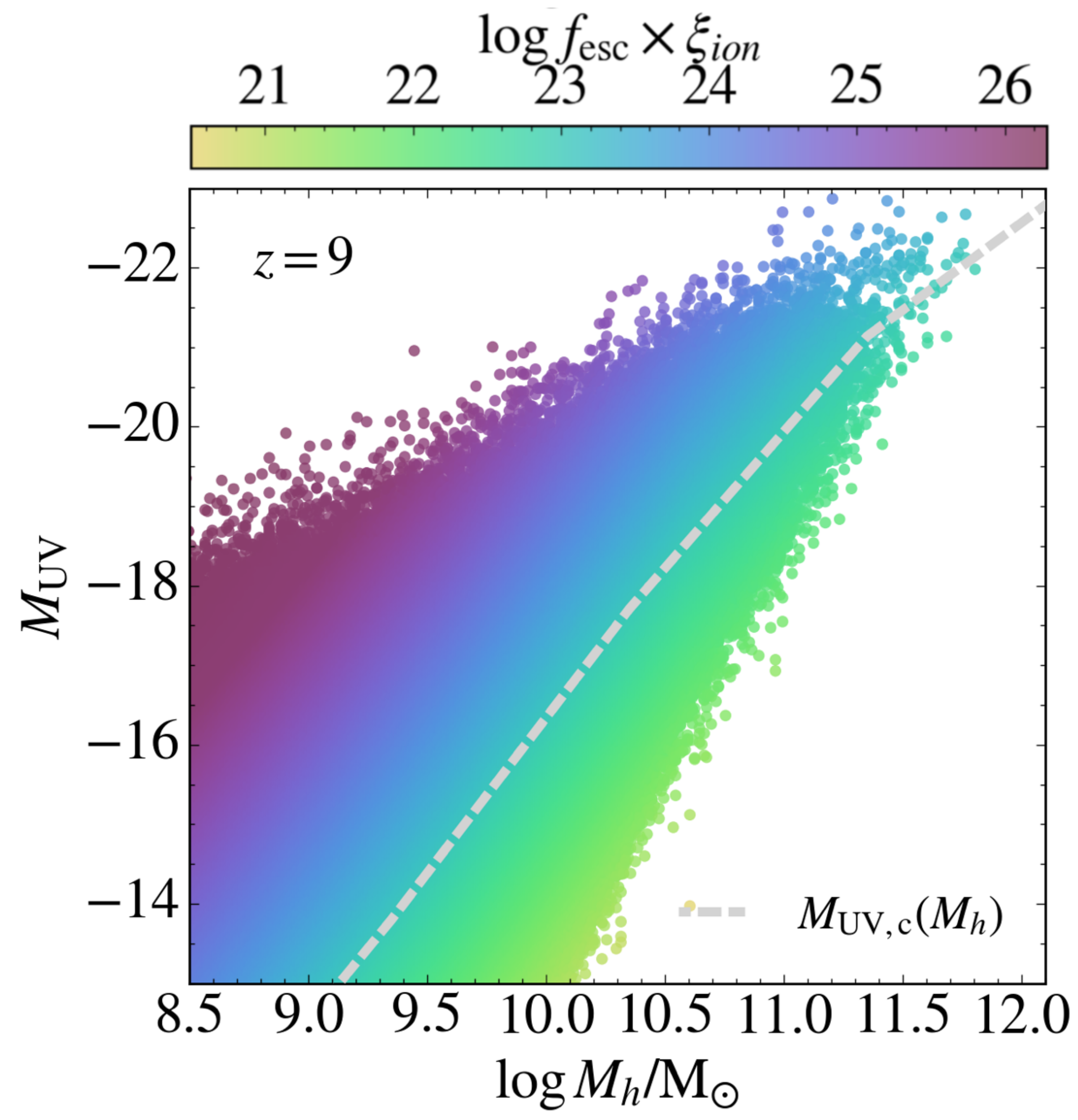

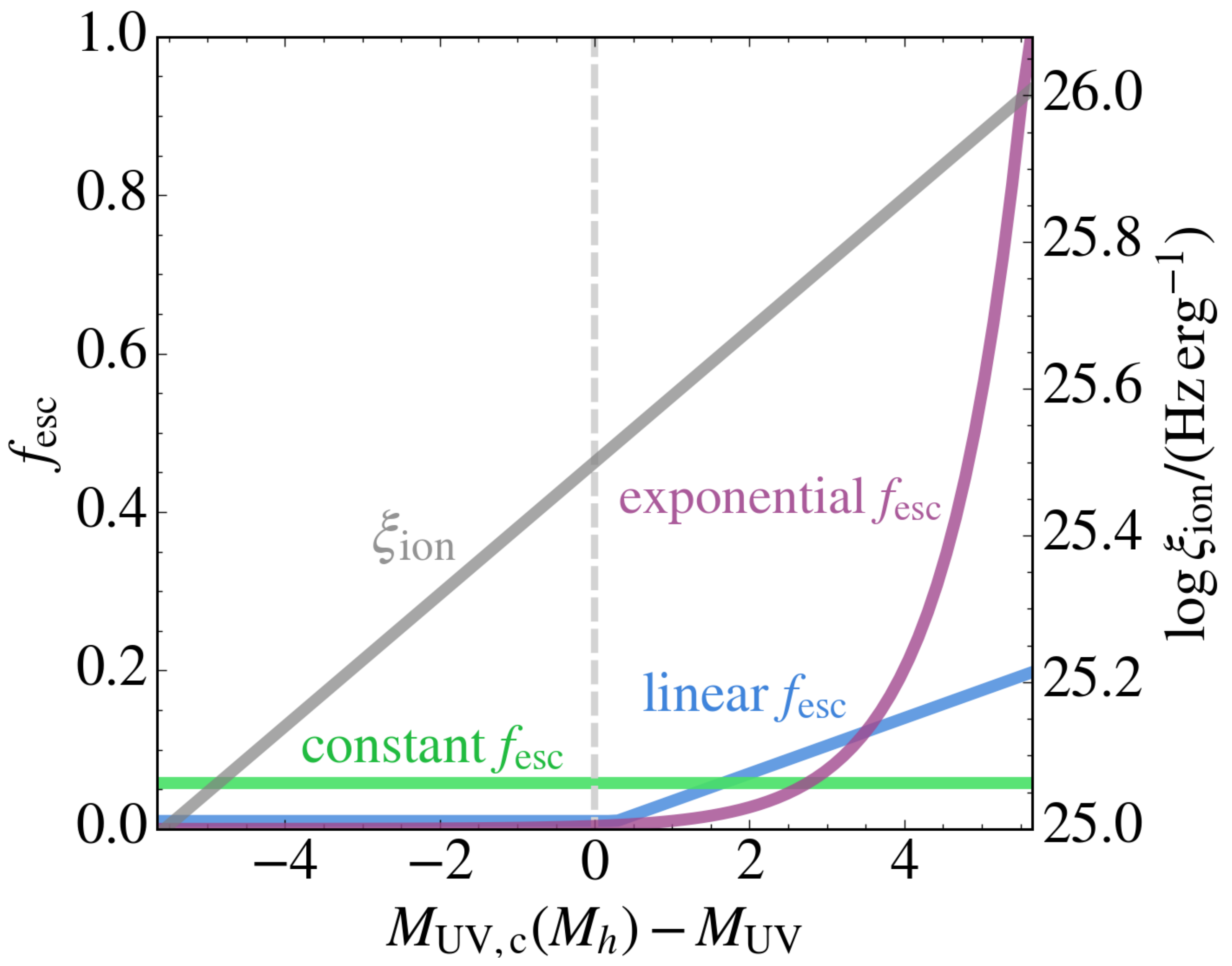

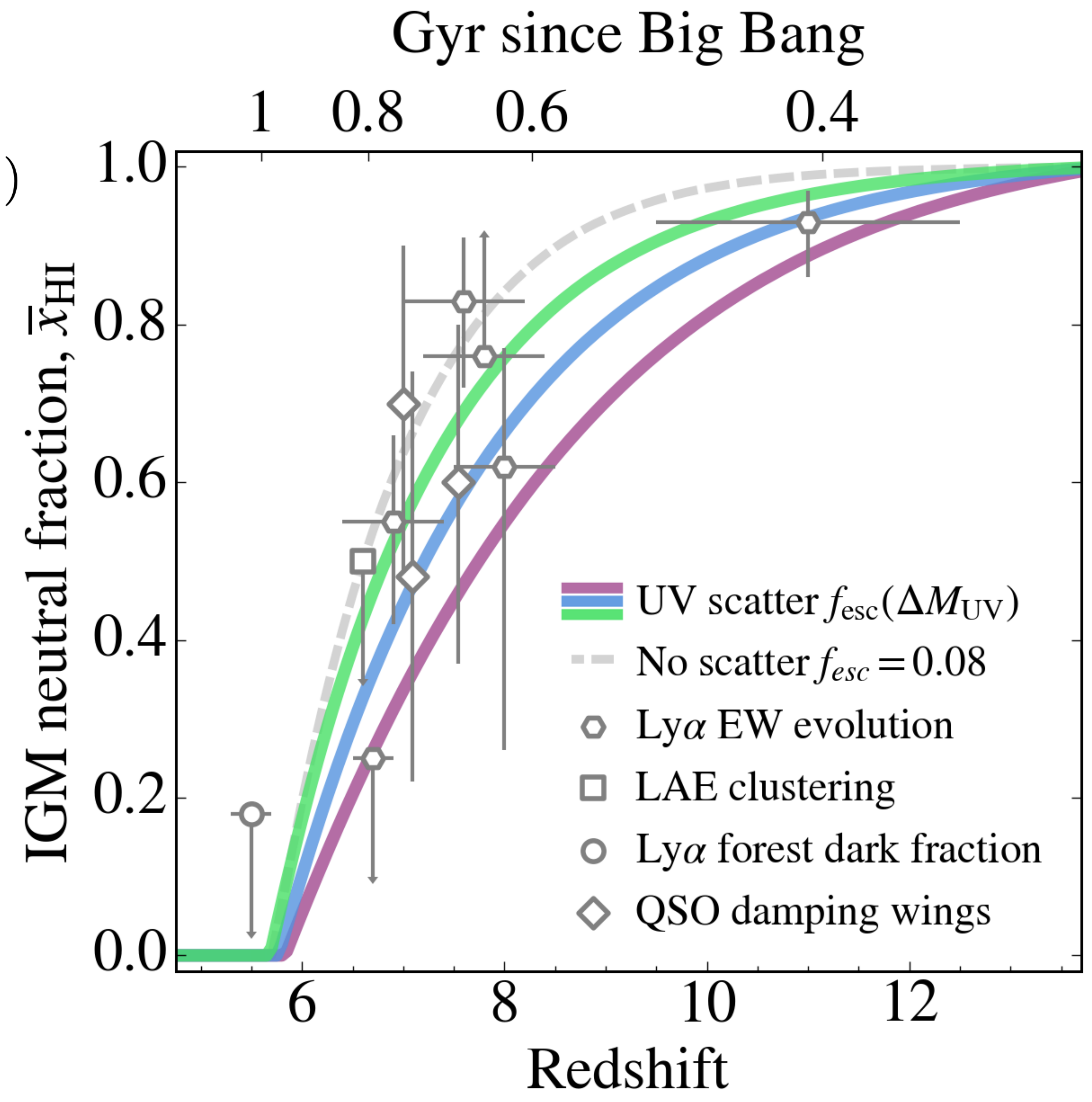

Gelli, Mason & Hayward 2024

*Stochastic star-formation predicts an **earlier start** and **more gradual** reionisation*

CONSTRAINING HIGH-Z STOCHASTICITY

CLUSTERING OF GALAXIES

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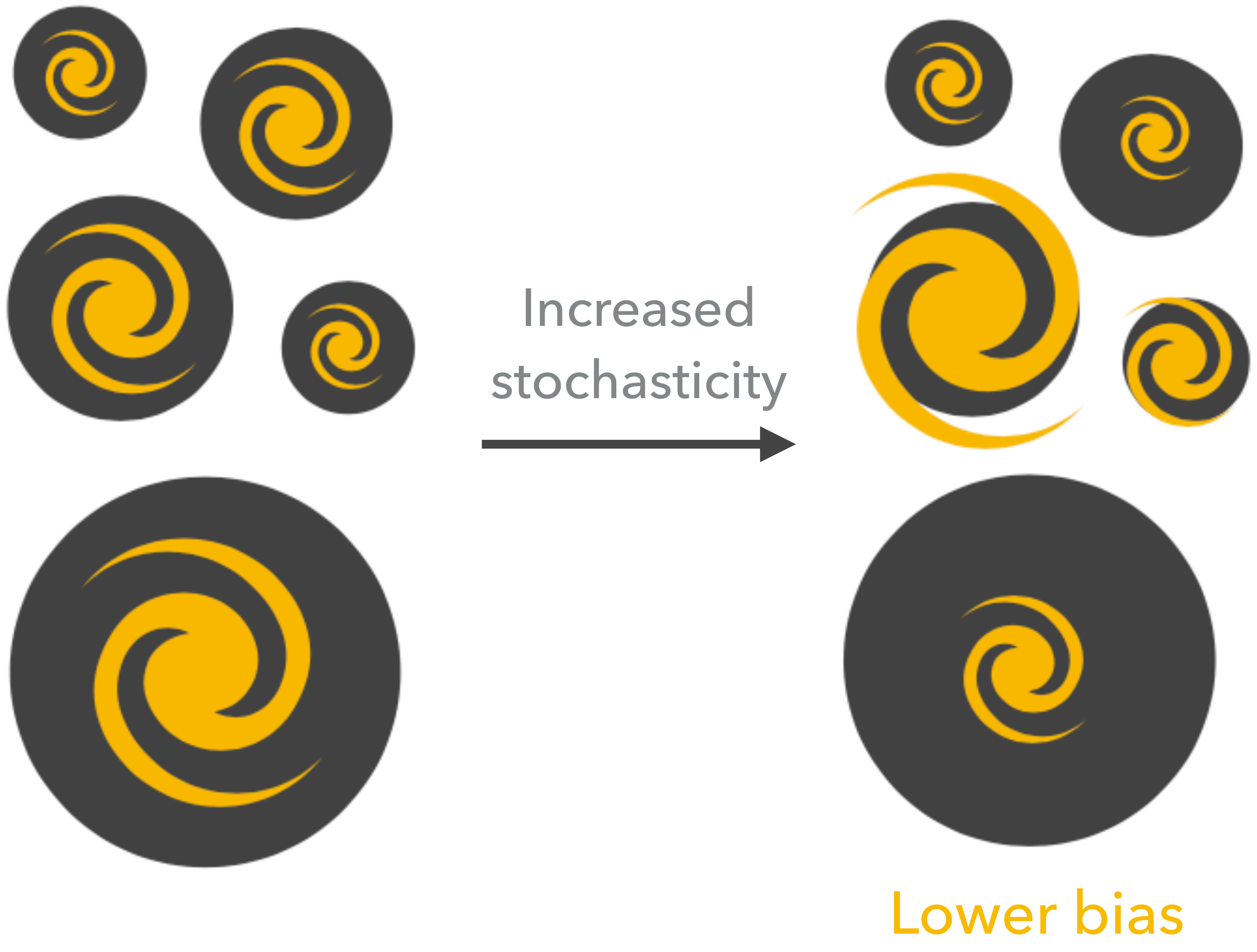

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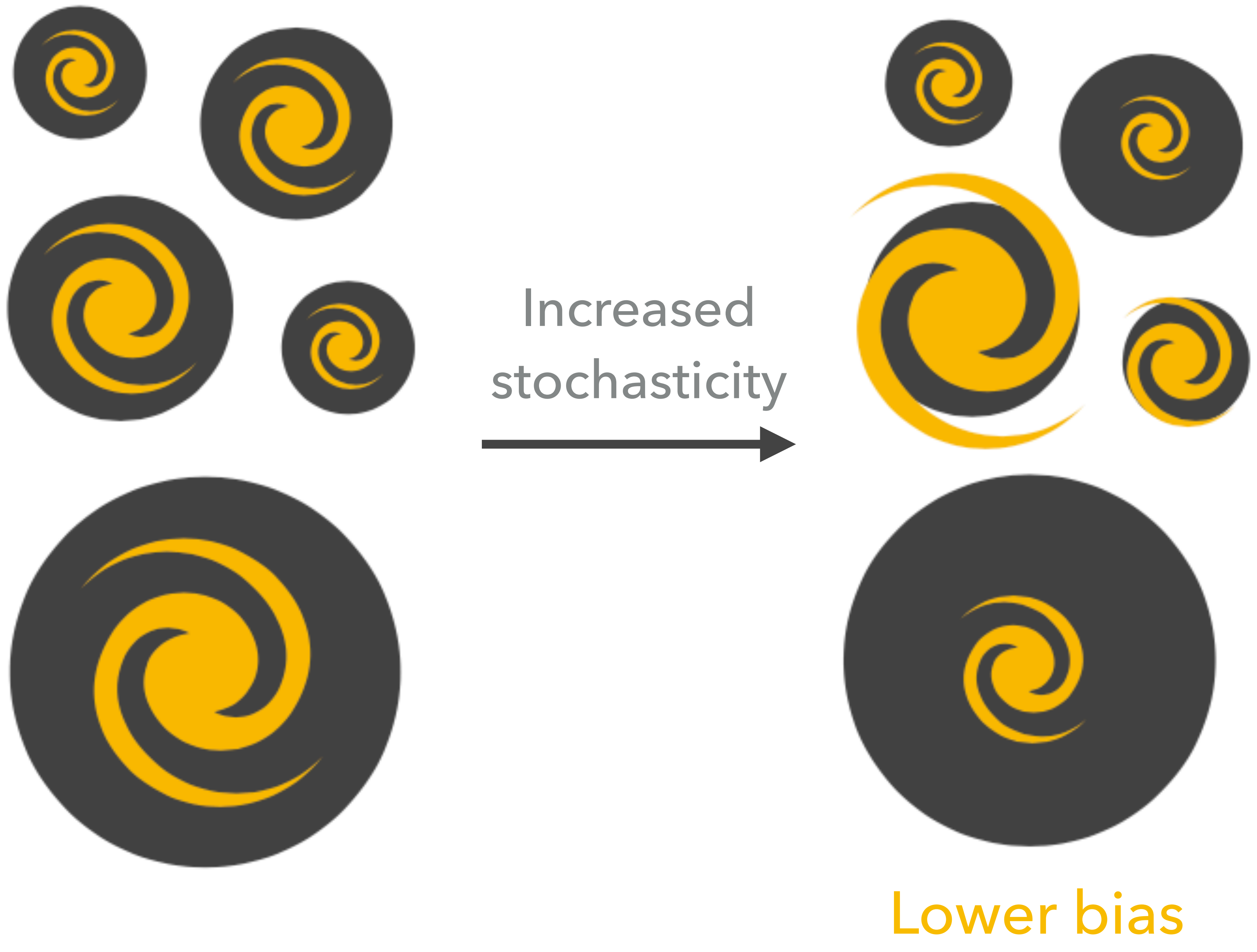

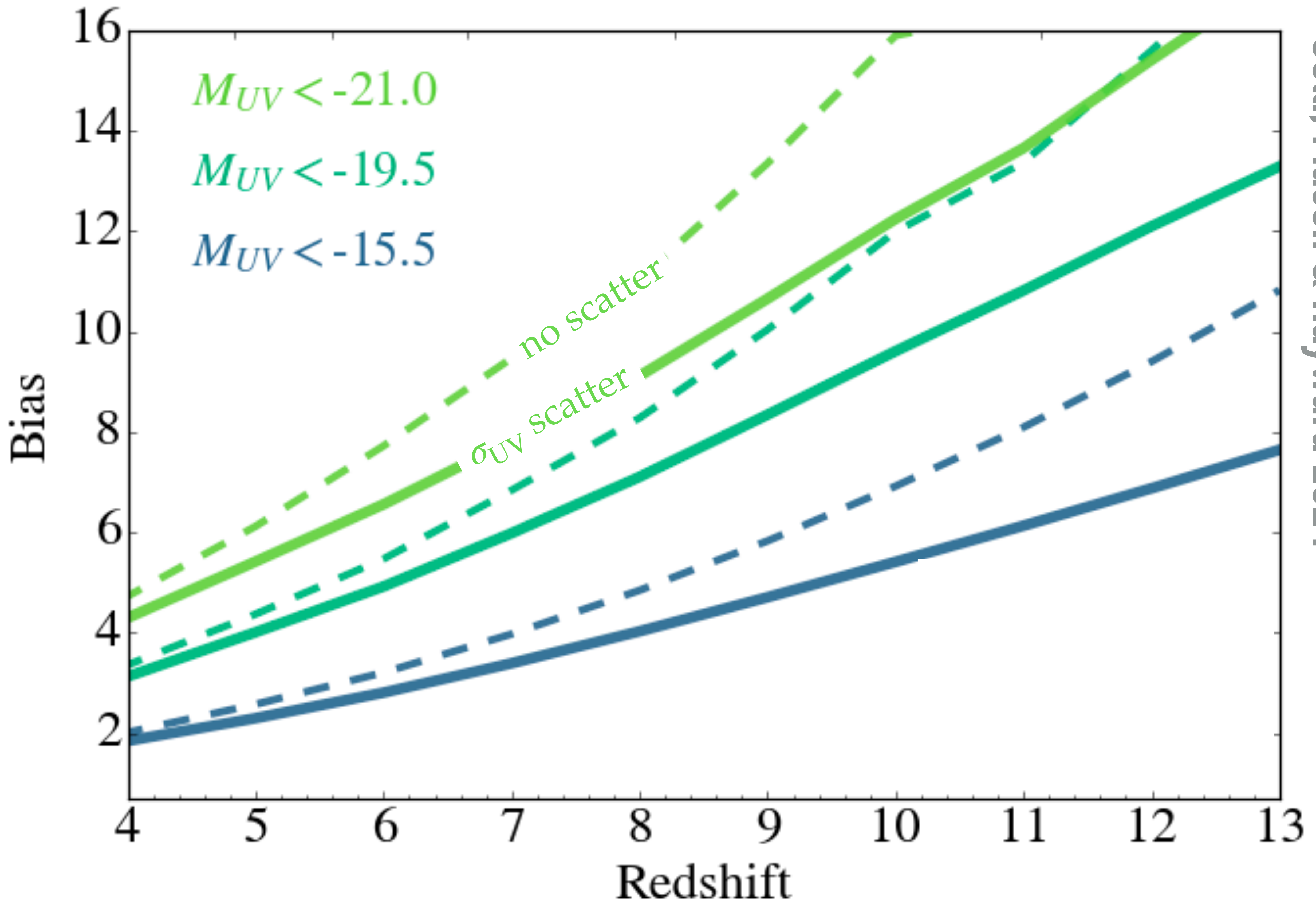

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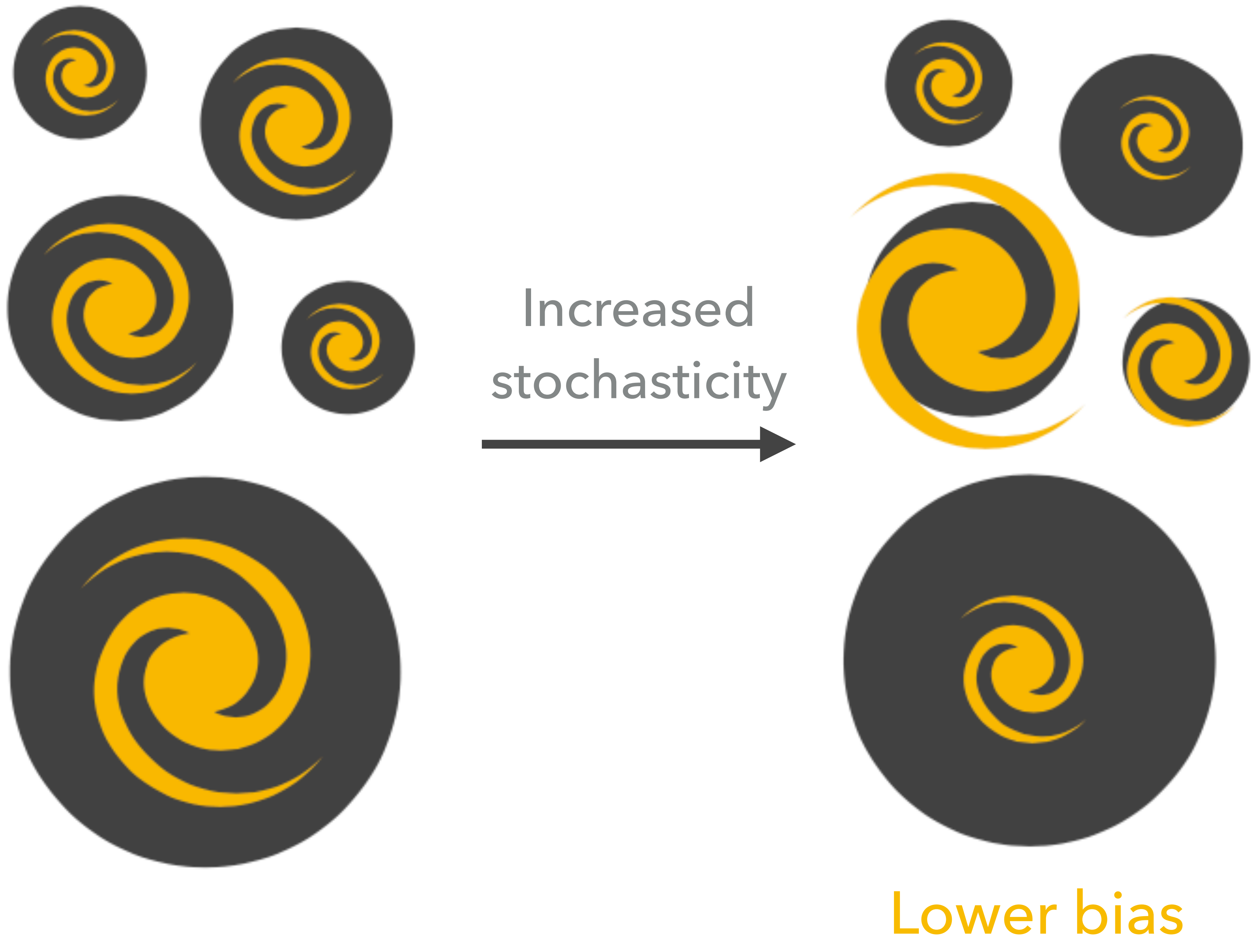

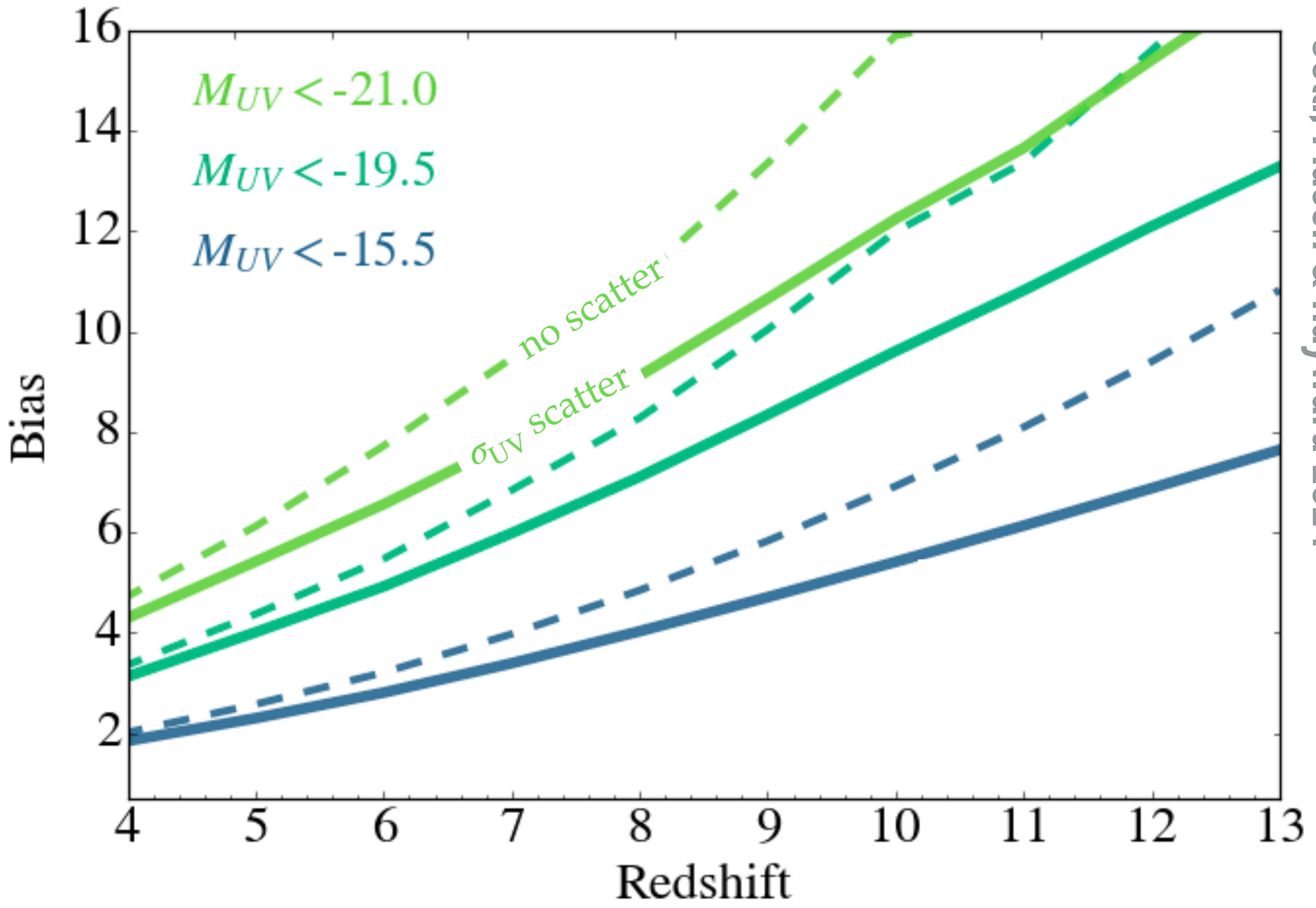

Gelli, Mason & Hayward 2024

Stochastic star formation leads to ***lower galaxy bias*** *at higher redshifts*

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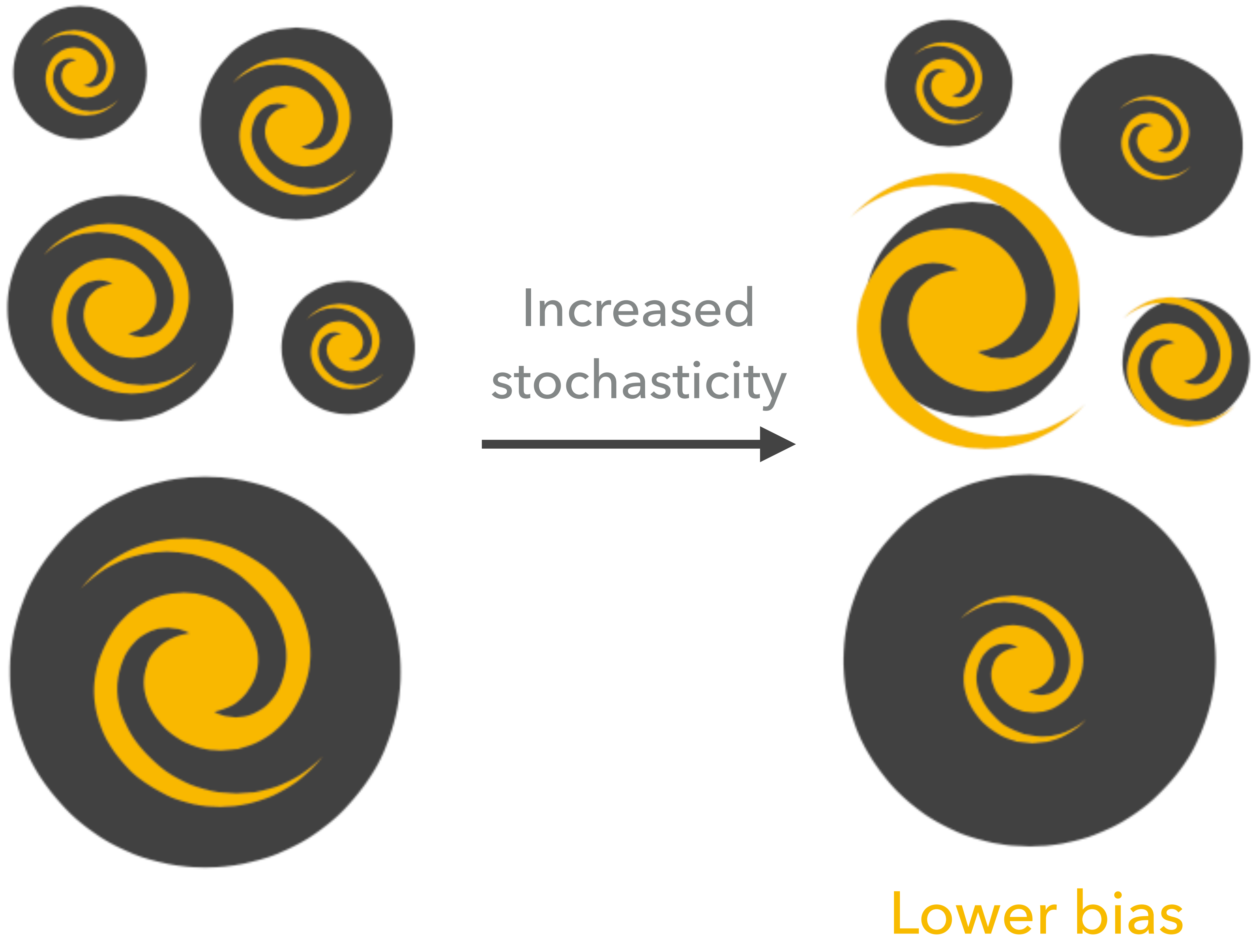
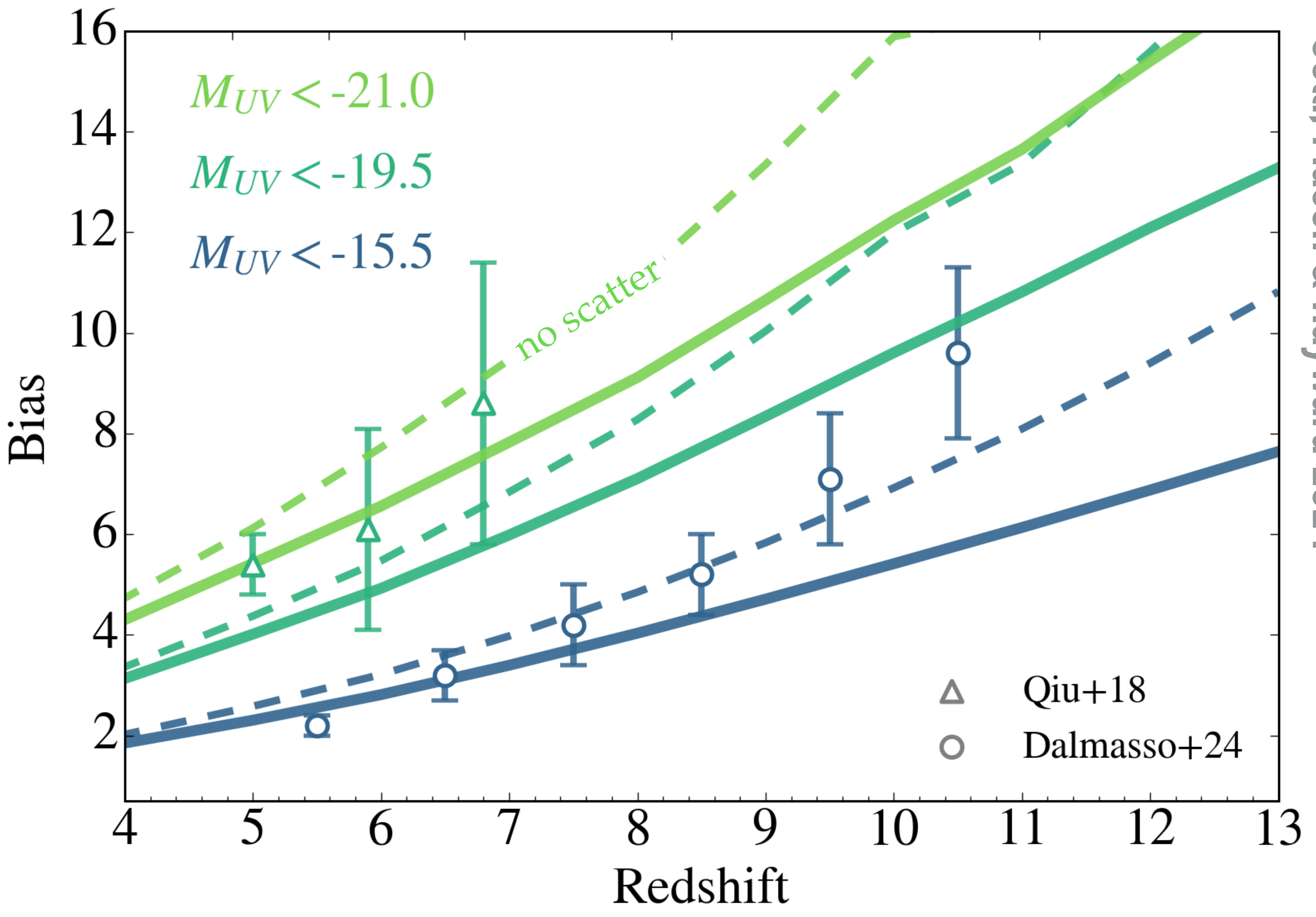
CLUSTERING OF GALAXIES

$$b_{\rm eff}(M_{\rm UV}) = \phi_{\rm UV}^{-1} \int {\rm d}M_{\rm h} \frac{{\rm d}n}{{\rm d}M_{\rm h}} b(M_{\rm h}) P(M_{\rm UV}|M_{\rm h})$$



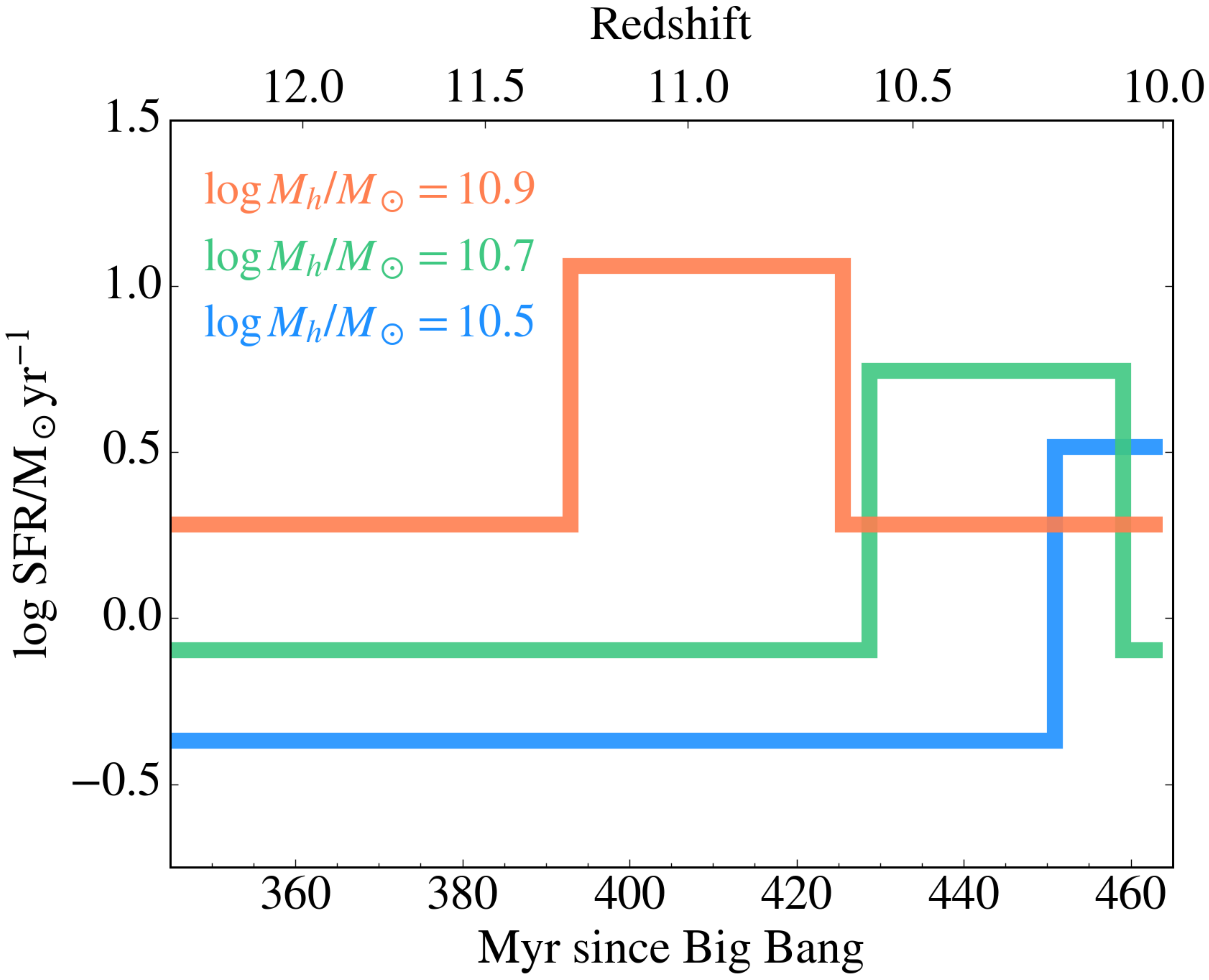


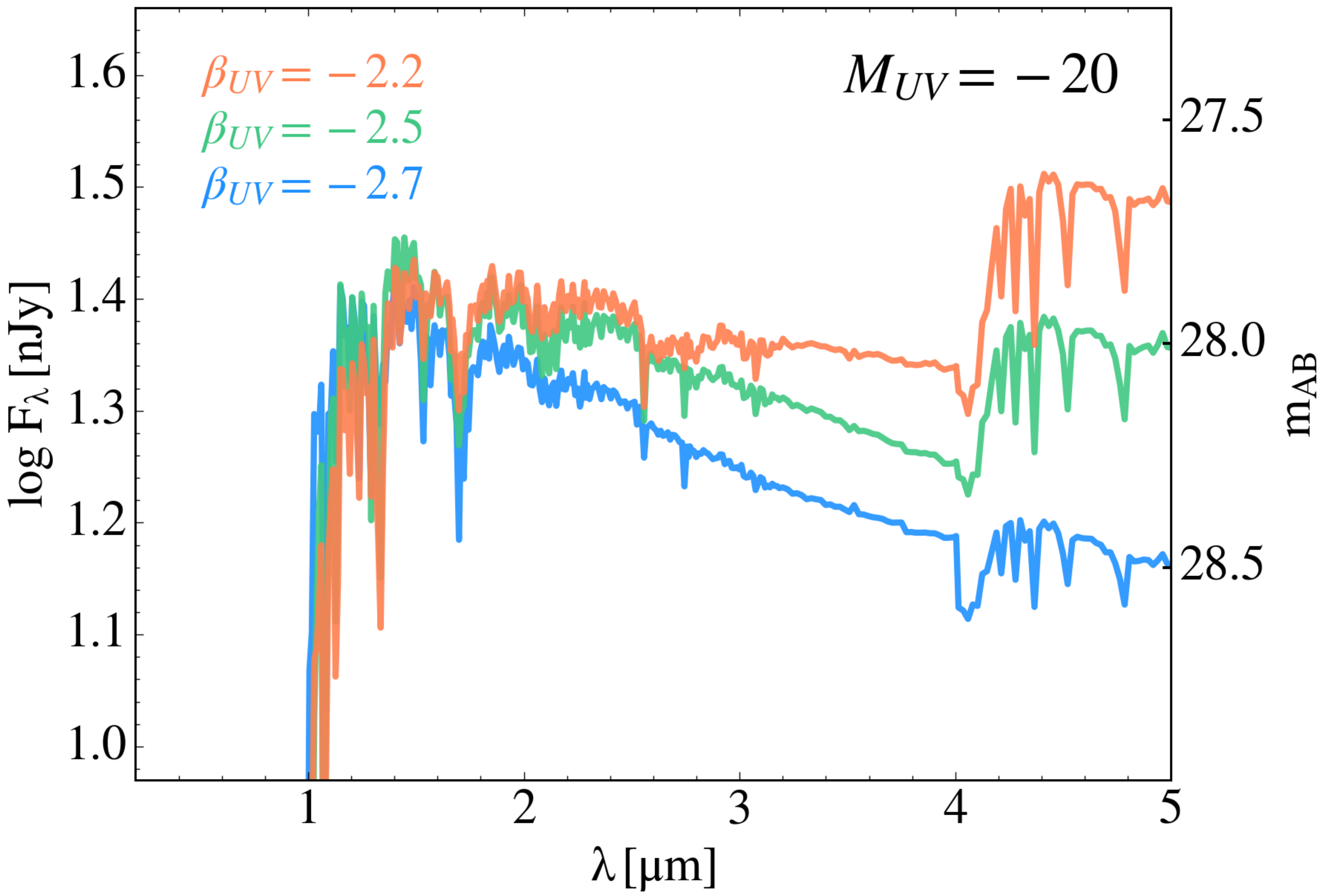
Gelli, Mason & Hayward 2024

*Stochastic star formation leads to **lower galaxy bias** at higher redshifts*

CONSTRAINING HIGH-Z STOCHASTICITY

SPECTRAL ENERGY DISTRIBUTIONS

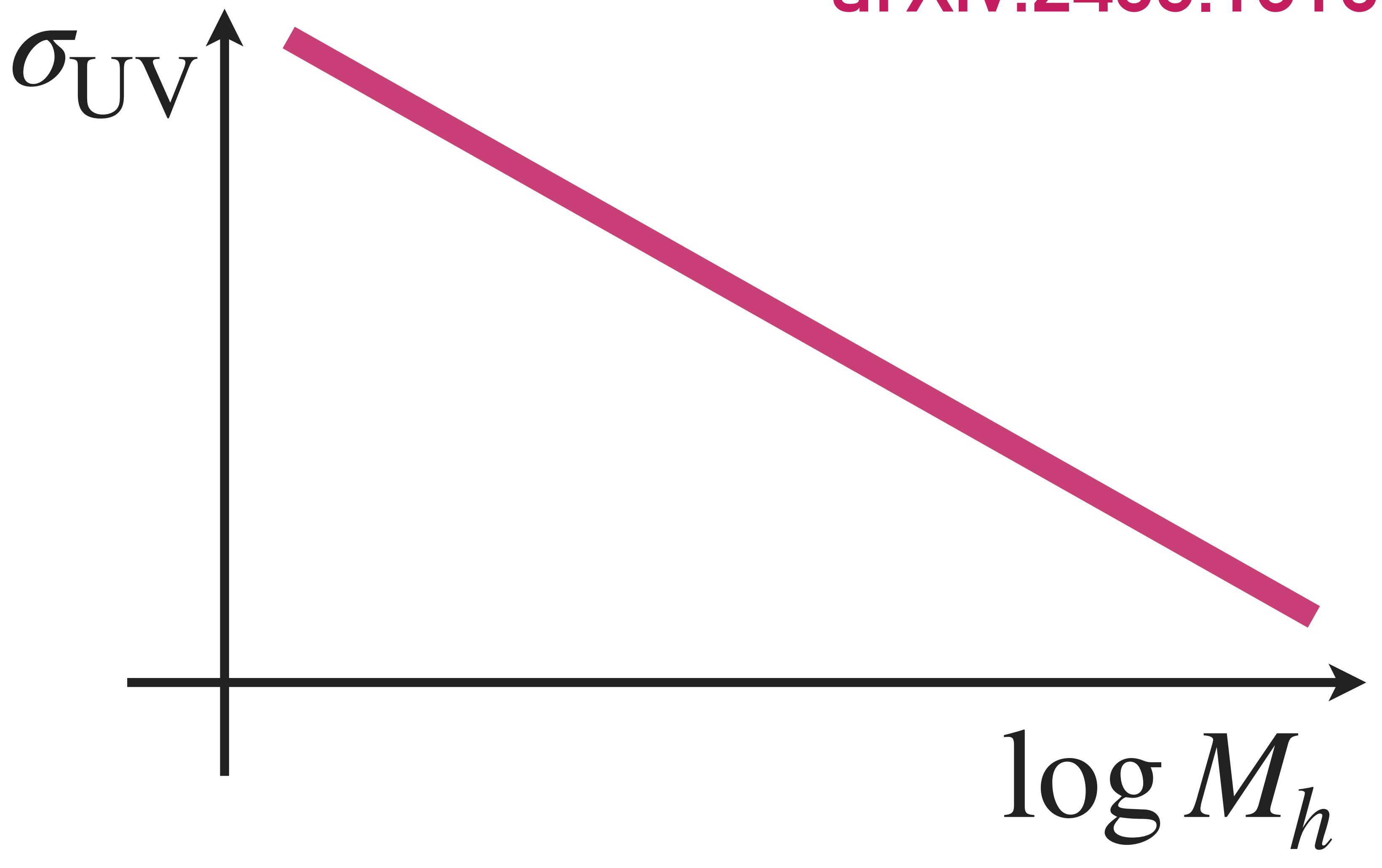




*Bursty star formation produces broader ranges of **UV slopes**, **Balmer breaks** and **emission line strengths** for galaxies with the same M_{UV}*

CONCLUSIONS

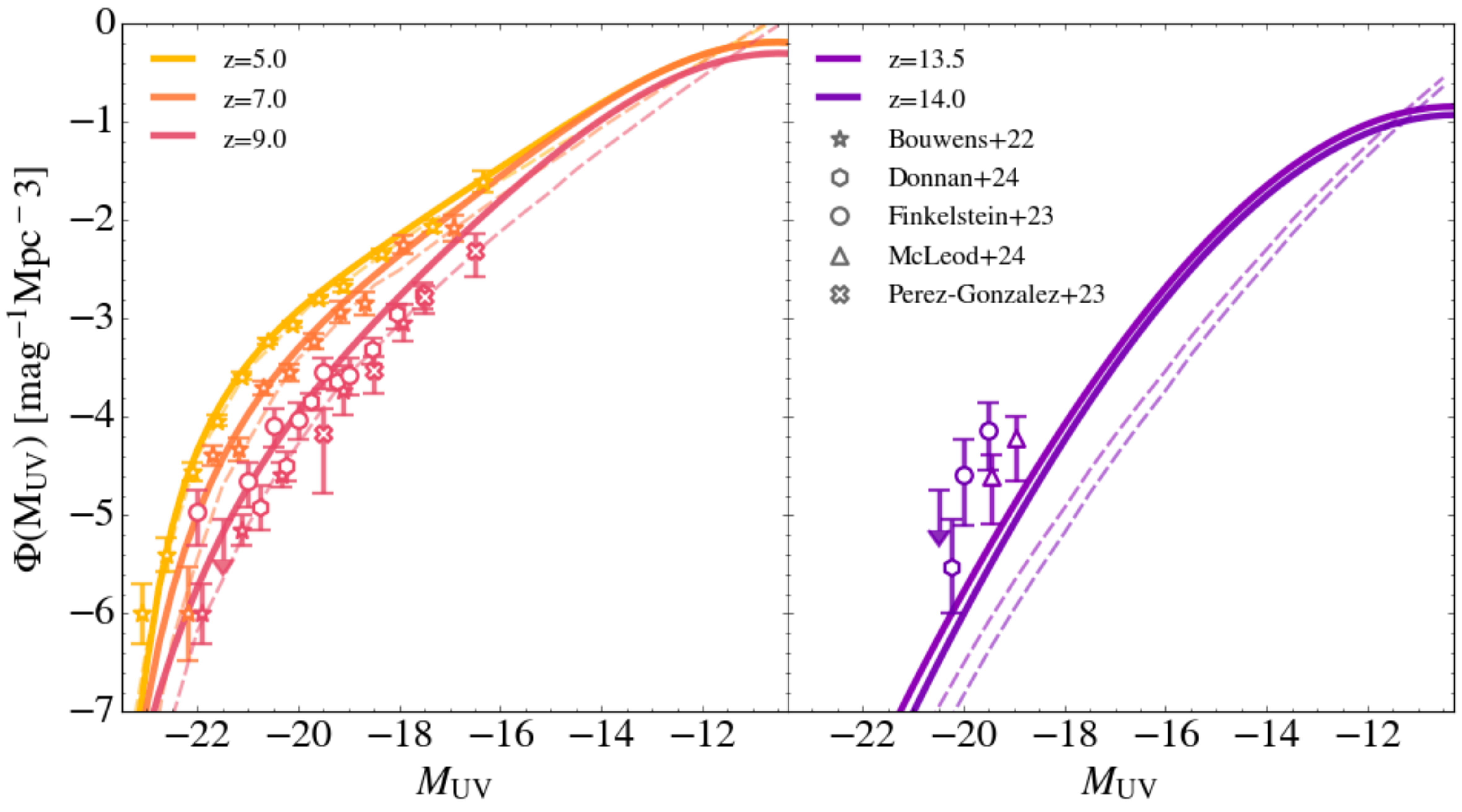
Gelli, Mason & Hayward 2024
arXiv:2405.13108



- Bursty star formation at high-z leads to a stochasticity in the UV luminosities of galaxies

- A σ_{UV} increasing towards lower M_h predicts:
  - Higher UV LFs towards higher z
  - Reionization starts earlier and is more gradual
  - Lower galaxy bias
  - Broad ranges of β_{UV}, Balmer breaks and emission line strengths for galaxies with the same M_{UV}

- Stochasticity is not enough to reproduce $z > 12$ LFs: enhanced SFE at high-z?



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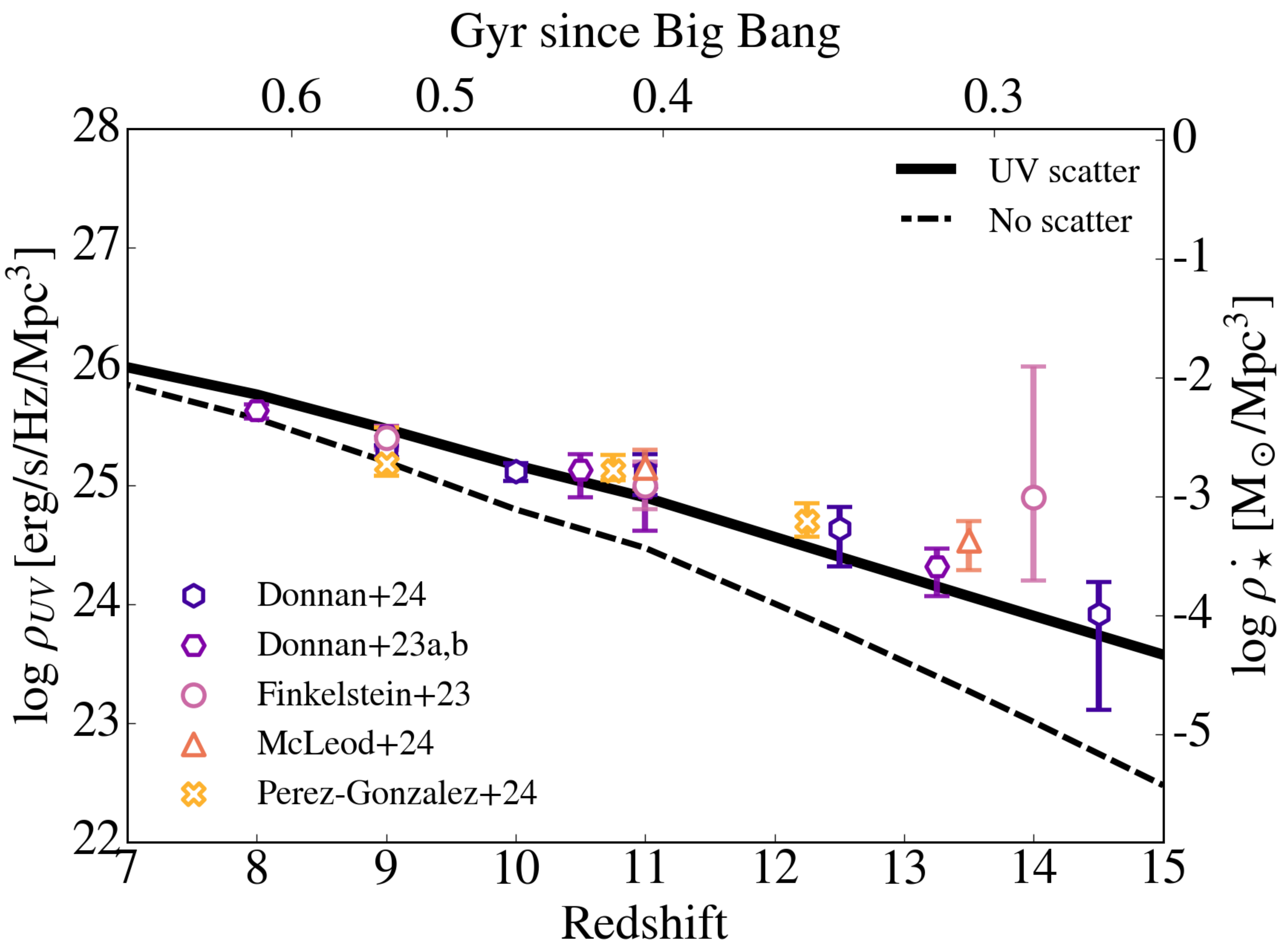
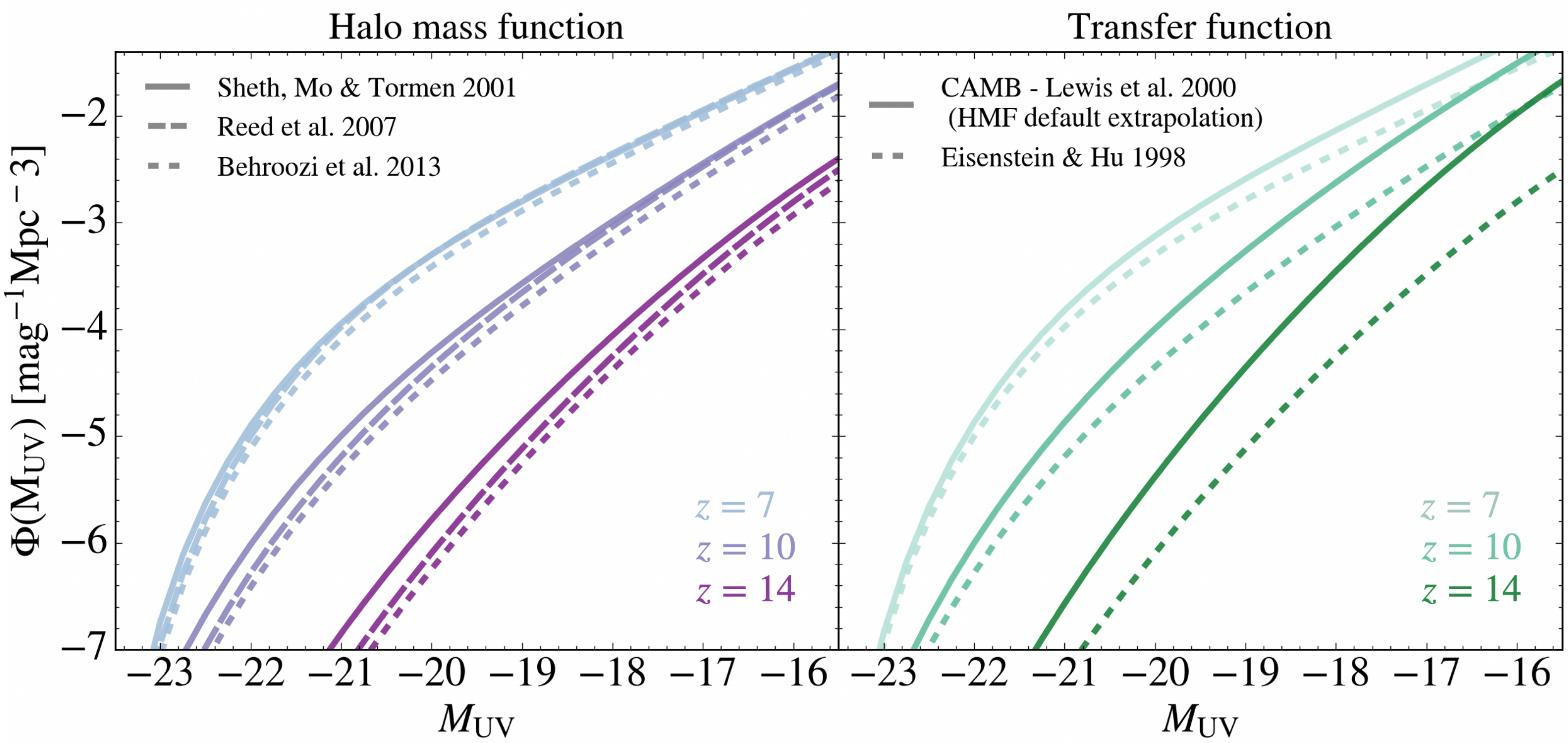
MASS-DEPENDENT UV SCATTER MODEL

LUMINOSITY DENSITY





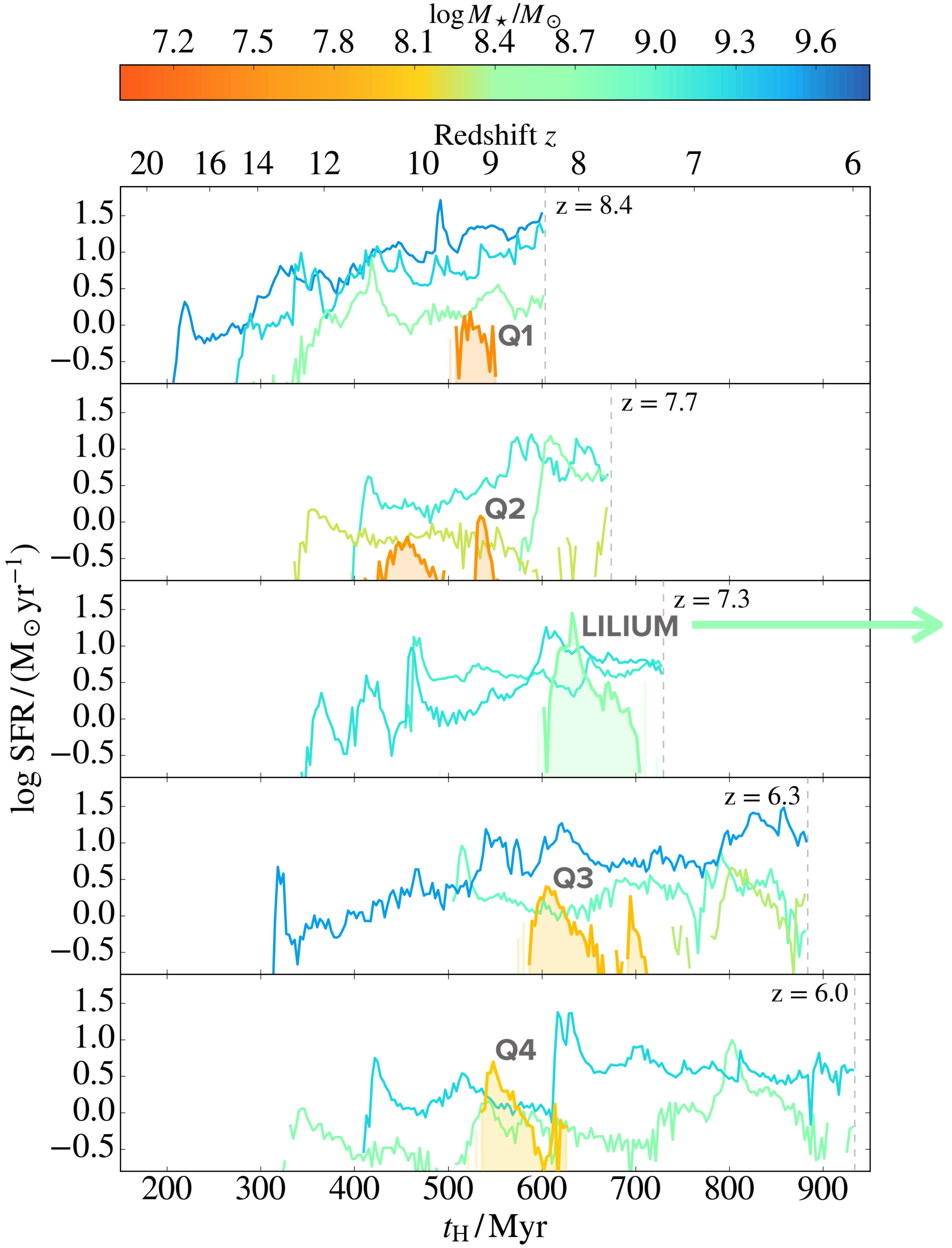
Halo mass function
Transfer function
Sheth, Mo & Tormen 2001
Reed et al. 2007
Behroozi et al. 2013
CAMB - Lewis et al. 2000
(HMF default extrapolation)
Eisenstein & Hu 1998
z = 7
z = 10
z = 14
z = 7
z = 10
z = 14
Φ(M_UV) [mag^-1 Mpc^-3]
M_UV
M_UV
−2
−3
−4
−5
−6
−7
−23
−22
−21
−20
−19
−18
−17
−16

QUIESCENT LOW-MASS GALAXIES IN SIMULATIONS

Gelli et al. 2023a, ApJL

STAR FORMATION HISTORIES

- ✦ Feedback-regulated, bursty evolution
- ✦ Periods of quiescence
- ✦ SN feedback



LILIUM

$z = 7.3$

$SFR = 0$

$\log M_\star/\mathrm{M}_\odot = 8.7$

$t_{\rm quench} \sim 20\,\mathrm{Myr}$

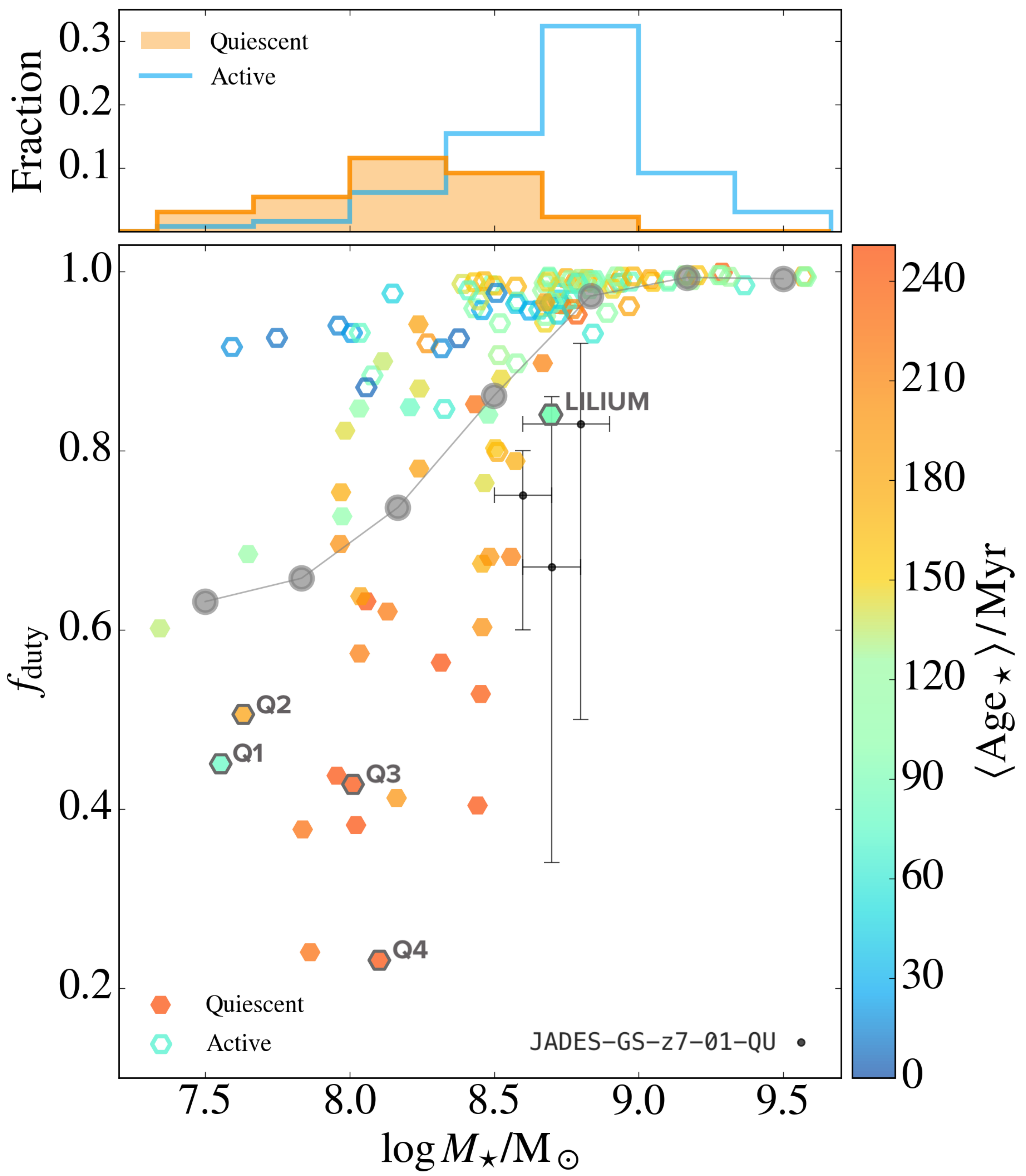
$f_{duty} \sim 0.8$

QUIESCENT LOW-MASS GALAXIES IN SIMULATIONS

Gelli et al. 2024, ApJL

DUTY CYCLES

$$f_{\rm duty} = \frac{\Delta t_{\rm on}}{t_{\rm obs} - t_{\rm form}}$$



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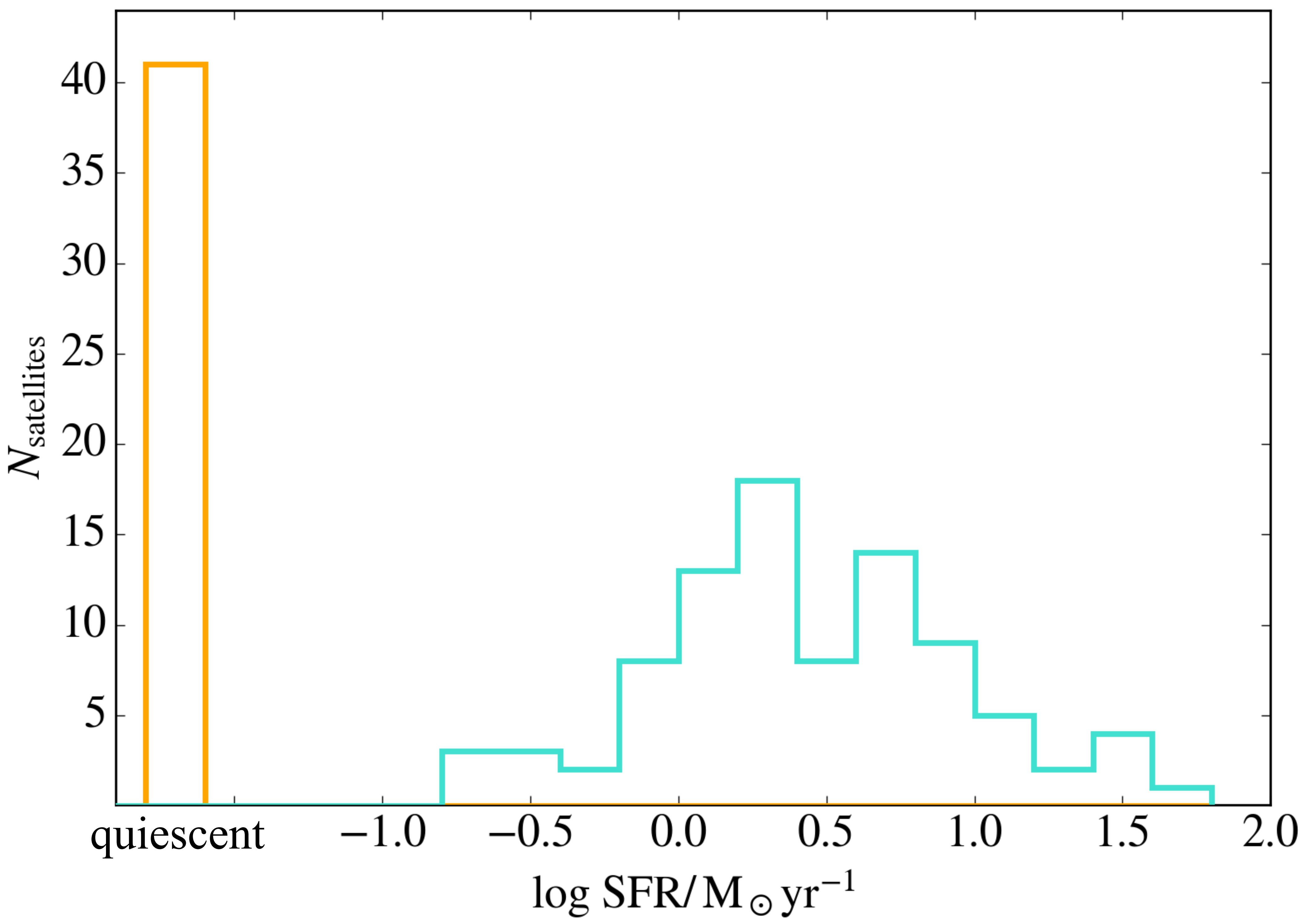
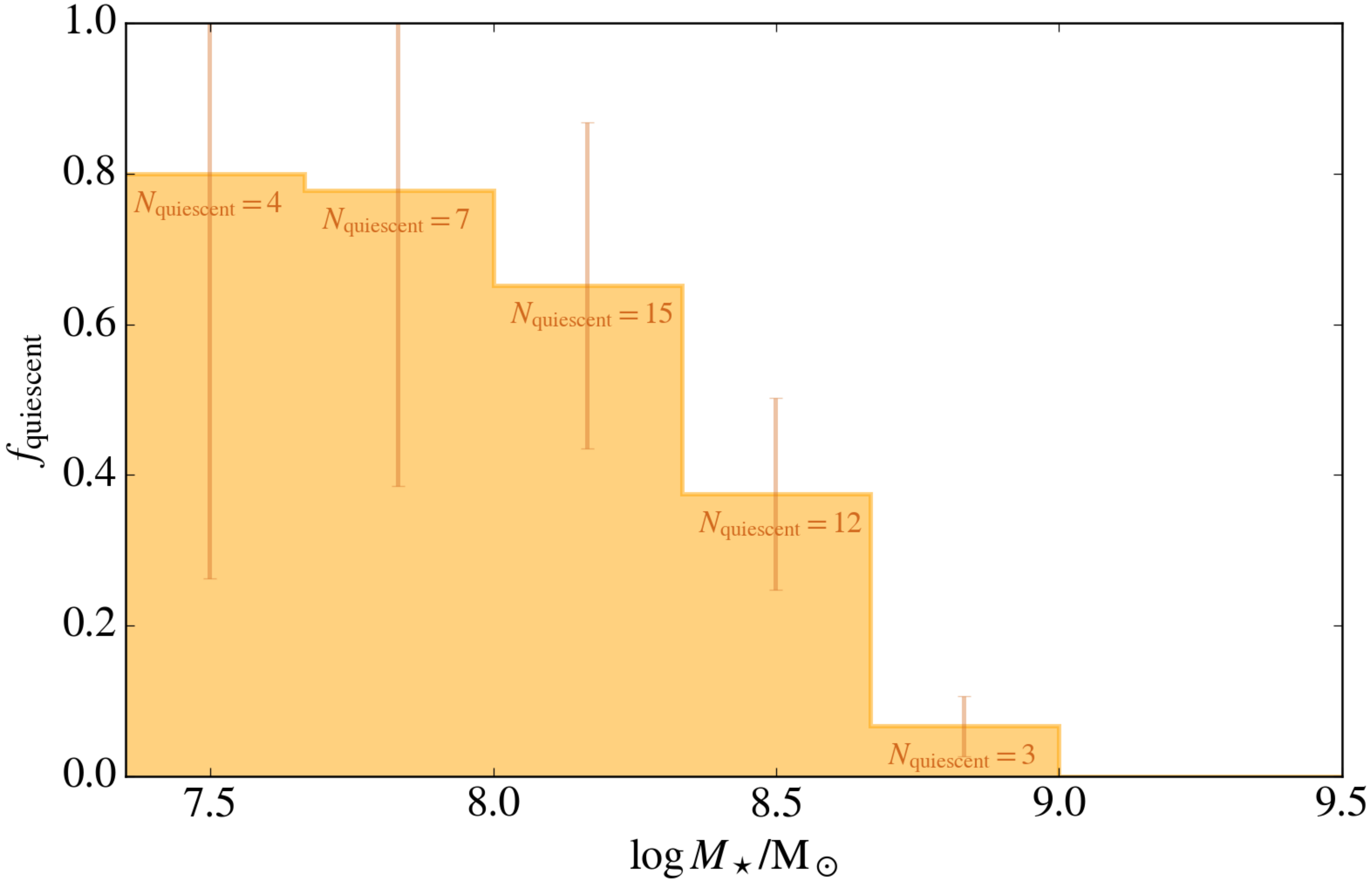
QUIESCENT LOW-MASS GALAXIES IN SIMULATIONS

$6 < z < 8$



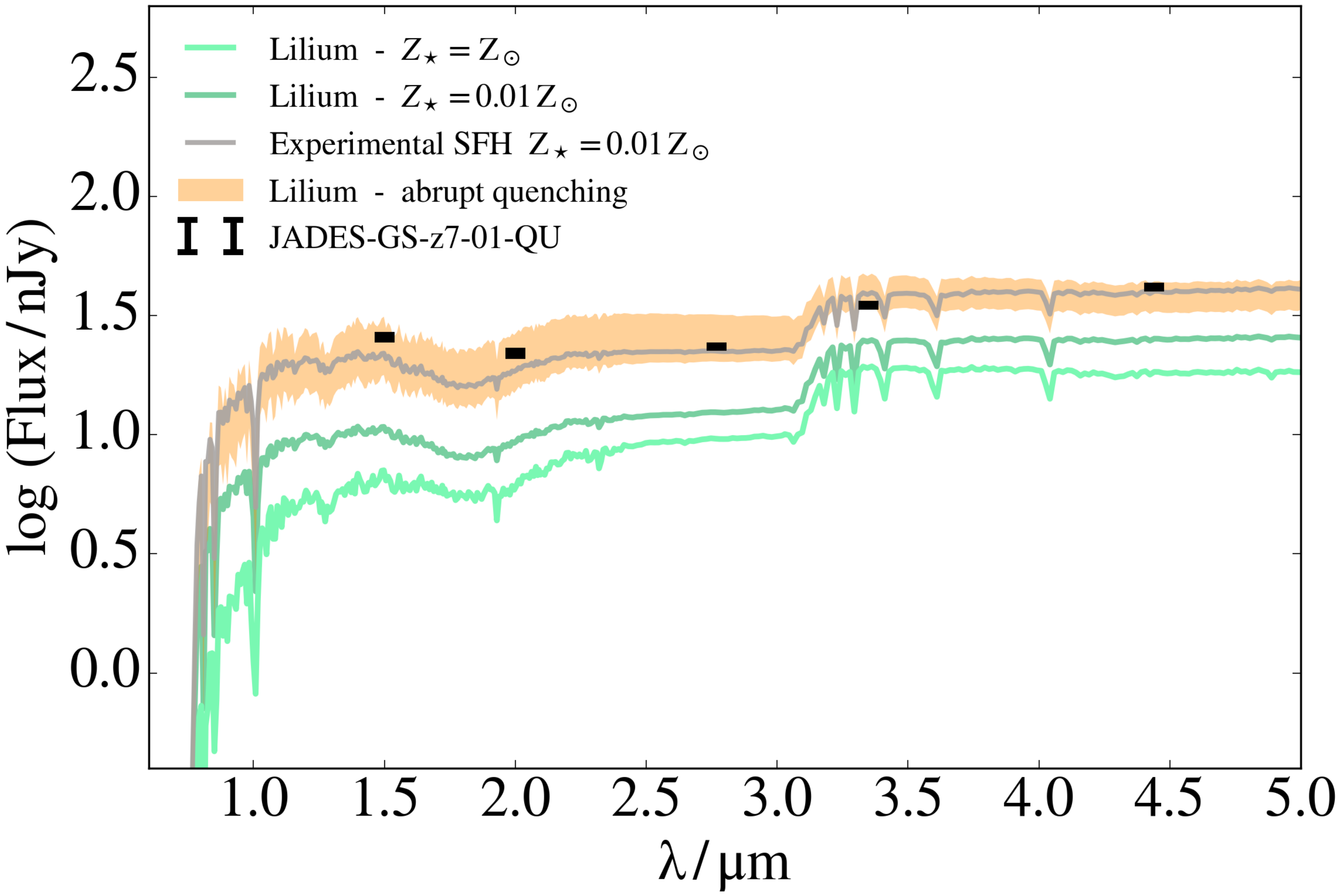


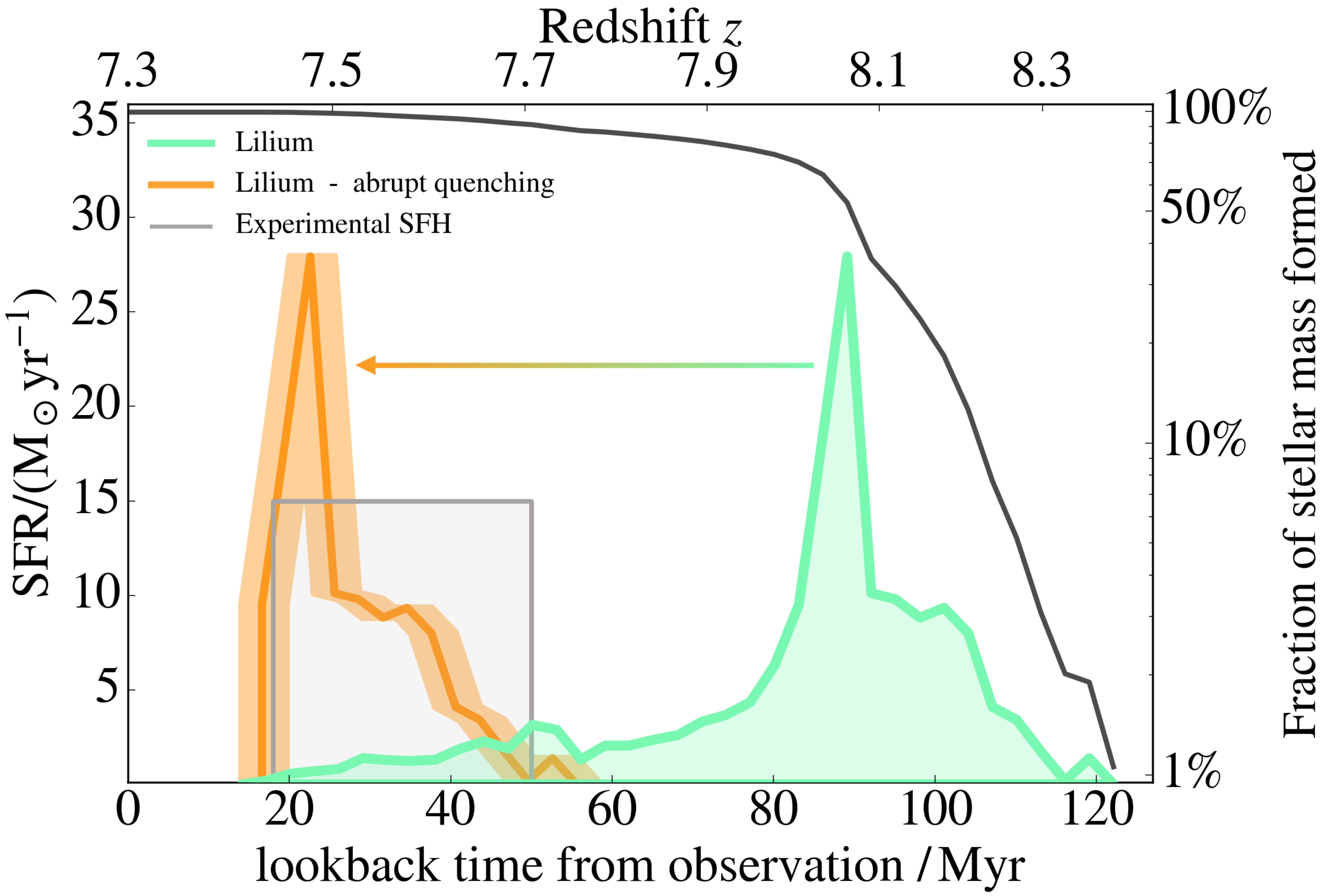
~30% OF THE GALAXIES ARE QUIESCENT

DOMINANT POPULATION AT $M_\star < 10^{8.3}\mathrm{M}_\odot$

INTERPRETING JADES-GS-Z7-01-QU

Gelli et al. 2024, ApJL





ABRUPT QUENCHING is needed in JADES-GS-Z7-01-QU

CAN SN QUENCH SF IN HIGH-Z GALAXIES?

Gelli et al. 2024, arXiv:2310.03065

SN-QUENCHING CONDITION

Energy rate injected by SNe $\dot{E}^{+} \geq \dot{E}^{-}$ Cooling rate of the halo

$G(t, Z_\star)\,\mathrm{SFR}$

$\frac{M_g}{\mu m_p} k_b T_{vir} \frac{1}{t_{cool}}$

Top-hat SFH

$M_\star = \mathrm{SFR}\Delta t_b$

Minimum SFR required for a burst to suppress SF

$$\mathrm{SFR} \geq \frac{f_b M_h(z, T_{vir})}{\tau + \Delta t_b} \equiv \mathrm{SFR}_{\min}$$

$$\tau = \frac{3}{2} \frac{\mu m_p G(\Delta t_b, Z_\star)}{n \Lambda(T_{vir}, Z)}$$

GALAXIES WITH LOWER

M_h, Z, z

ARE MORE EASILY QUENCHED

CAN SN QUENCH SF IN HIGH-Z GALAXIES?

Gelli et al. 2024, arXiv:2310.03065

SN-QUENCHING CONDITION

$$\mathrm{SFR} \geq \frac{f_b M_h(z, T_{vir})}{\tau + \Delta t_b} \equiv \mathrm{SFR_{min}}$$