Super-early galaxies seen by JWST.

A change of paradigm?

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INTERSTELLAR erc CORTÉS

Unterstützt von / Supported by Alexander von Humboldt Stiftung / Foundation

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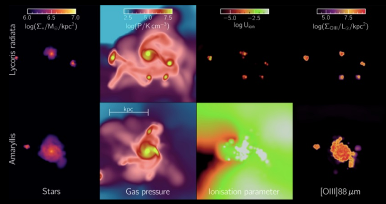
JWST DISCOVERY

- Unexpectedly large number of luminous galaxies at $z \gtrsim 10$
- These galaxies tend to be massive ($M_* \gtrsim 10^9 M_\odot$)
- They also tend to be have blue colors
- Four of them undetected in [OIII]/dust continuum by ALMA

Bakx et al. 2022; Popping 2022; Yoon et al. 2022; Kaasinen et al. 2022; Fujimoto et al. 2022
For an interpretation: Kohandel et al 2023



Kohandel+23

NEW!

- GN-z11: NOEMA (80.6hr) dust continuum: F < 13 uJy! Fudamoto, AF+2023

Castellano et al. 2022; Santini et al. 2022; Adams et al. 2023; Furtak et al. 2022; Donnan et al. 2022; Atek et al. 2022; Yan et al. 2022; Topping et al. 2022; Finkelstein et al. 2022; Rodighiero et al. 2022; Naidu et al. 2022; Bradley et al. 2022; Whitler et al. 2022; Barrufet et al. 2022; Trussler et al. 2022; Leethochawalit et al. 2022; Harikane et al. 2022; Curti et al. 2022; Robertson et al. 2022, Curtis-Lake et al. 2023; Tacchella et al 2023; Bunker et al. 2023; Hsiao et al. 2023; Dressler et al. 23; Austin et al. 2023; Adams et al. 2023; McLeod et al. 2023.

SOLUTIONS, PLEASE.

I.
Increase SF efficiency
(or stochastic SFR)

III.
Reduce dust attenuation

$$L_{\rm UV} \propto {\rm SFR}\, \kappa_{1500}\, e^{-\tau}$$

II.
Increase UV production efficiency
(PopIIIs, top-heavy IMF)

I.

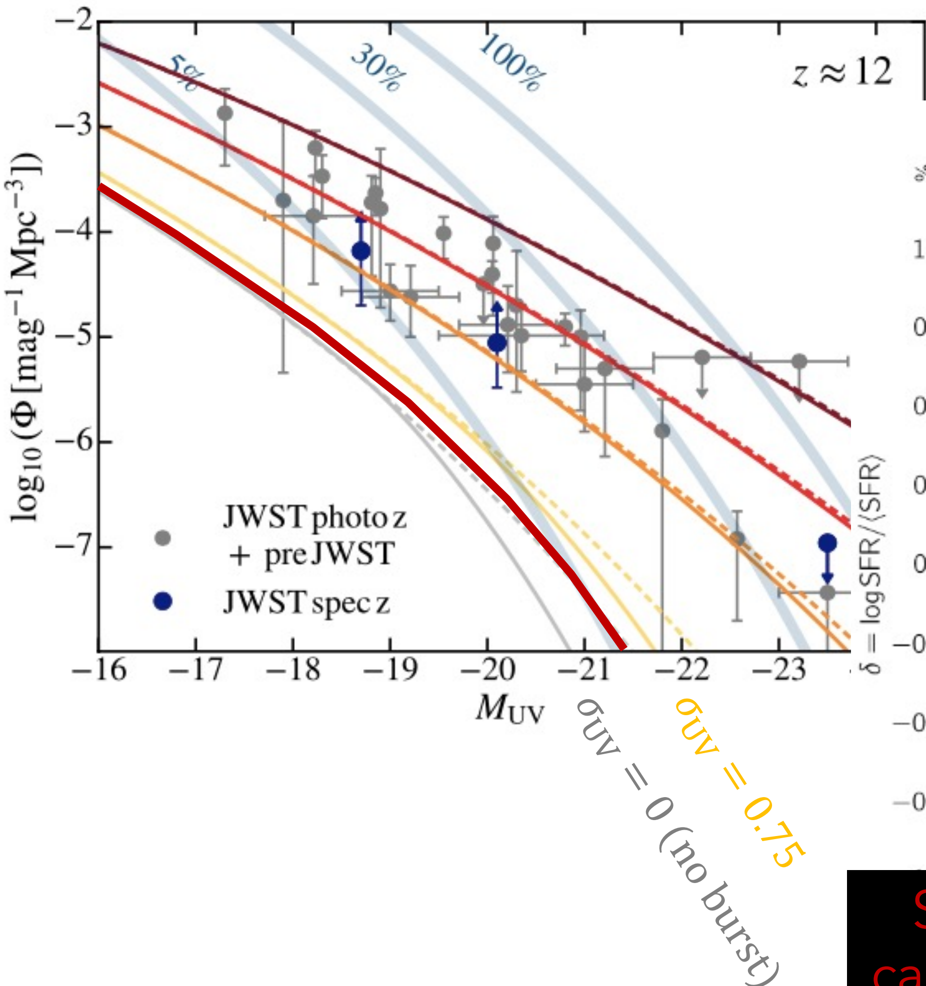
Increase SF efficiency

(or stochastic SFR)

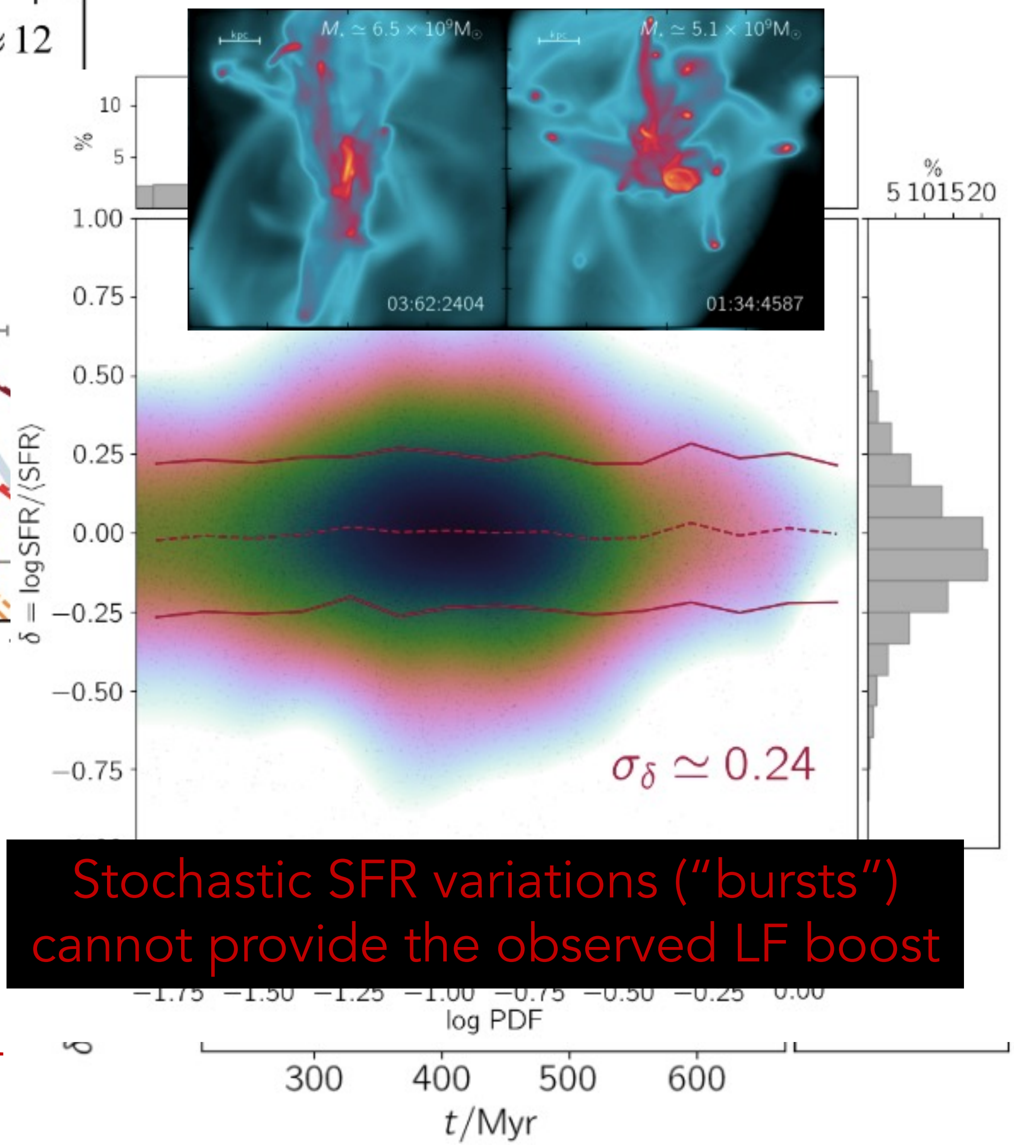
Stochastic SFR

SERRA simulations
243 galaxies @z=7.7

Shen+23



Pallottini & AF 2023 (arXiv:2307.03219)



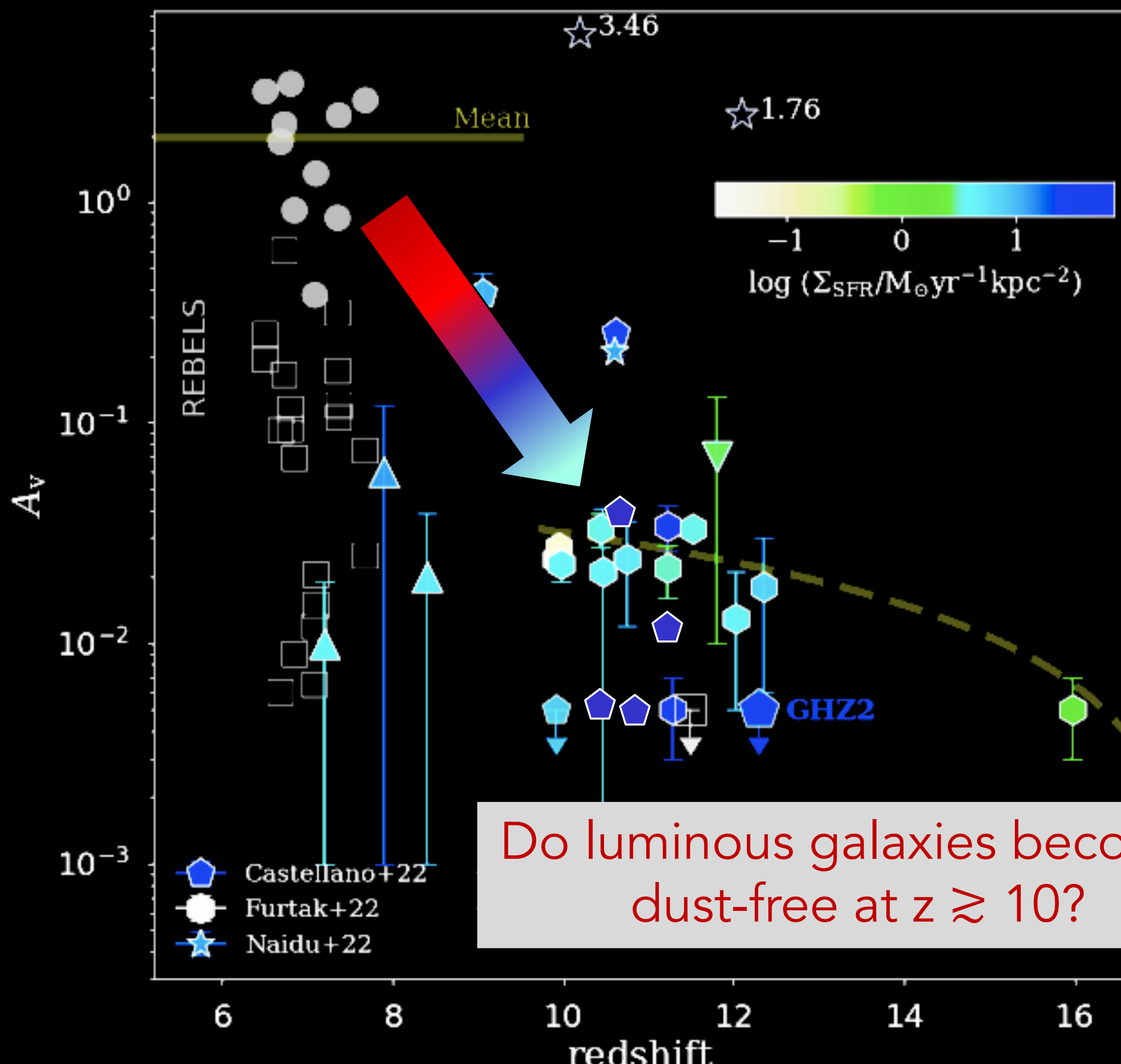
Stochastic SFR variations ("bursts") cannot provide the observed LF boost

$$\sigma_{\mathrm{UV}} = 2.5\sigma_\delta = 0.61$$

III.
Reduce dust attenuation

ARE 'BLUE MONSTERS' DUST-FREE?

Ziparo, AF+22



Do luminous galaxies become dust-free at z ≳ 10?

WHY AREN'T THEY OBSCURED?

Ziparo, AF+22

GHZ2/GL-z13 key properties

Castellano+22

Stellar mass	$M_* = 10^{9.2}\, M_\odot$
Dust mass	$M_d = 3\text{x}10^6\, M_\odot$
UV sizes	$r_e < 500$ pc

expected $$\tau_{1500} > 25 \left(\frac{M_d}{3\times10^6\, M_\odot}\right)\left(\frac{500\ \mathrm{pc}}{r_e}\right)^2$$

observed $$\tau_{1500} \lesssim 0.01$$

2500x less opaque!

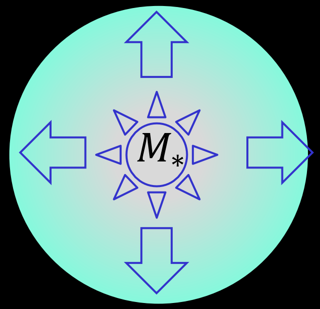
Dust ejected by radiatively-driven outflows?

Dusty outflow physics

Fiore, AF+22

Classical Eddington luminosity

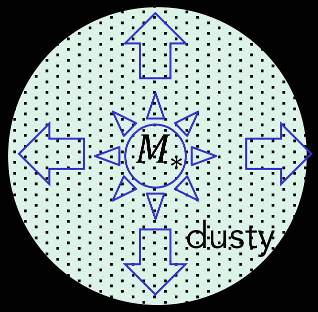
$$L_E = \frac{4\pi G M_* m_p c}{\sigma_T}$$



'Effective' Eddington luminosity for a dusty gas

$$\sigma_d = A\sigma_T, \qquad A \approx 450 - 600$$

$$\frac{4\pi G M_* m_p c}{A\,\sigma_T} = L_E^{eff} = A^{-1} L_E$$



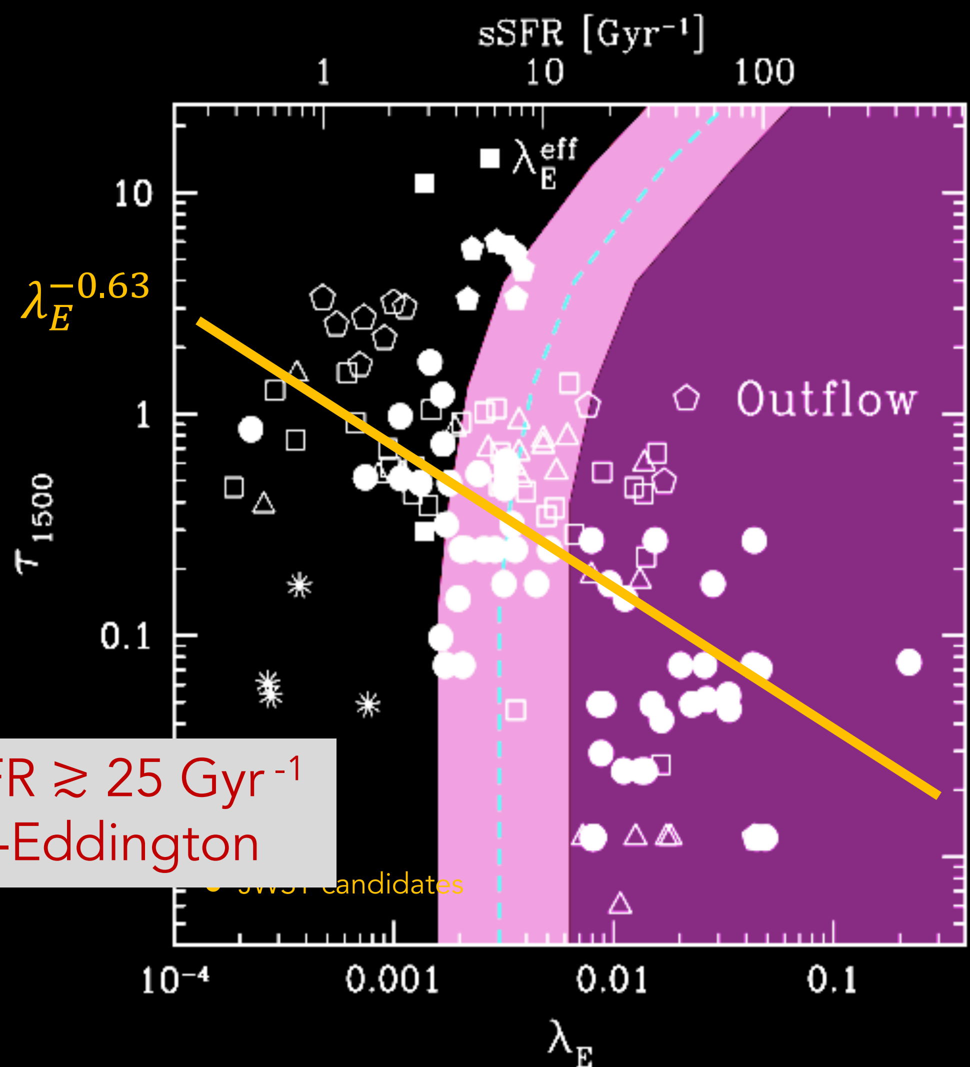
$$\lambda_E = \frac{L}{L_E} \propto \frac{\mathrm{SFR}}{M_*} \equiv \mathrm{sSFR}$$

An empirical test

Fiore, AF+22

$\lambda_E \propto \mathrm{sSFR}$

$\tau_{1500} \propto \lambda_E^{-0.63}$



134 Galaxies @ $z > 6.5$

Galaxies with sSFR ≳ 25 Gyr $^{-1}$ become super-Eddington

MODEL.ZIP

star formation rate

$$\mathrm{SFR} = \varepsilon_\star f_b \, \frac{M}{t_{ff}}$$

free-fall time

$$t_{ff} = [4\pi G\rho(z)]^{-1} = 0.06\, H(z)^{-1}$$

stellar mass

$$M_\star = \mathrm{SFR}\, t_{ff} = \langle \varepsilon_\star \rangle \, f_b \, M$$

specific star formation rate

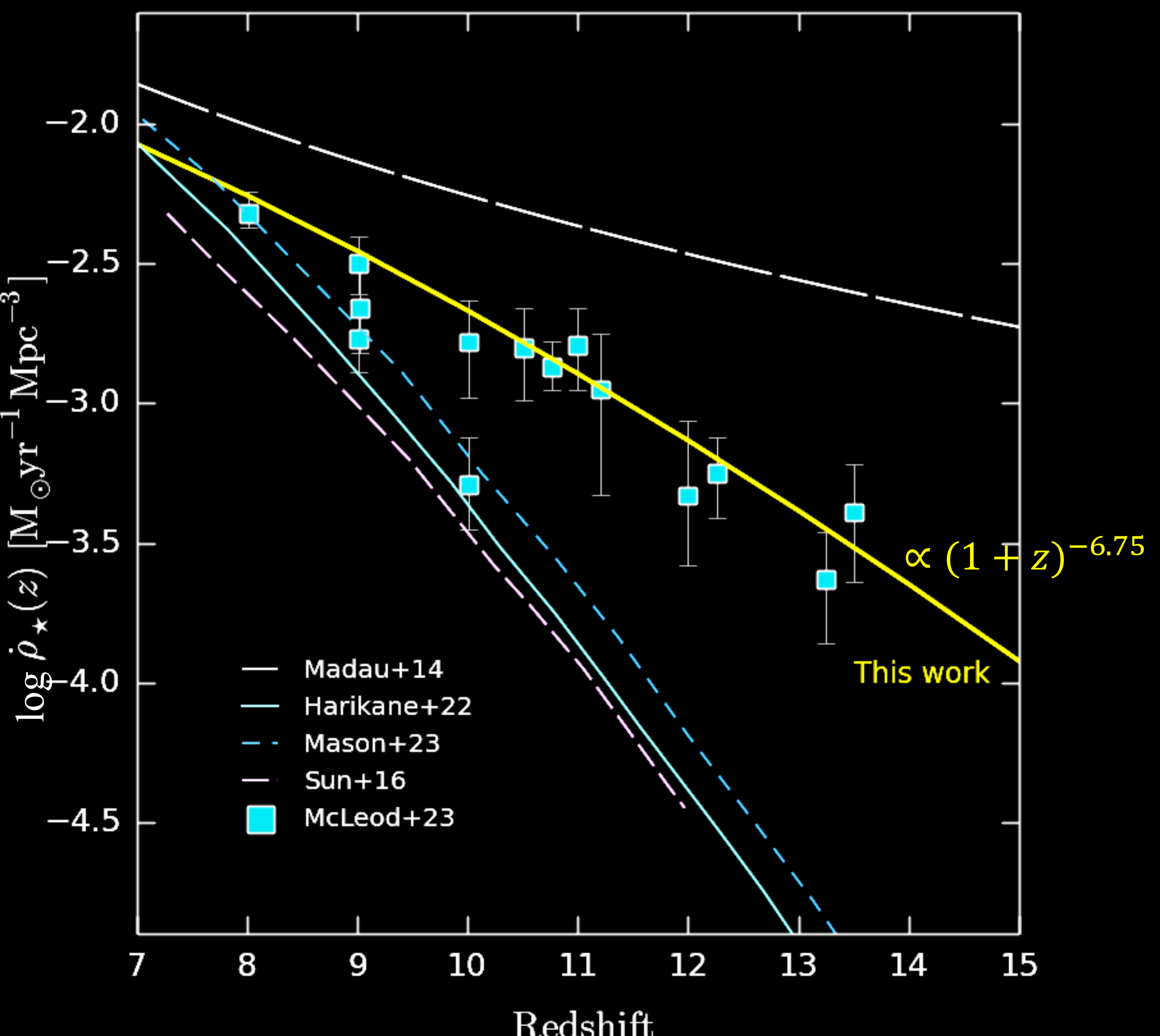
$$\mathrm{sSFR} = 0.64 \, \frac{\varepsilon_\star}{\langle \varepsilon_\star \rangle} \, (1+z)^{3/2} \quad \mathrm{Gyr}^{-1}$$

outflow velocity

$$v_\infty = 830 \left[\frac{\varepsilon_\star}{f_M} \, \frac{\mathrm{sSFR}}{\mathrm{sSFR}^*} \right]^{1/2} \, M_{\star,9}^{5/12} \quad \mathrm{km\ s}^{-1}$$

TEST#1: SFR DENSITY

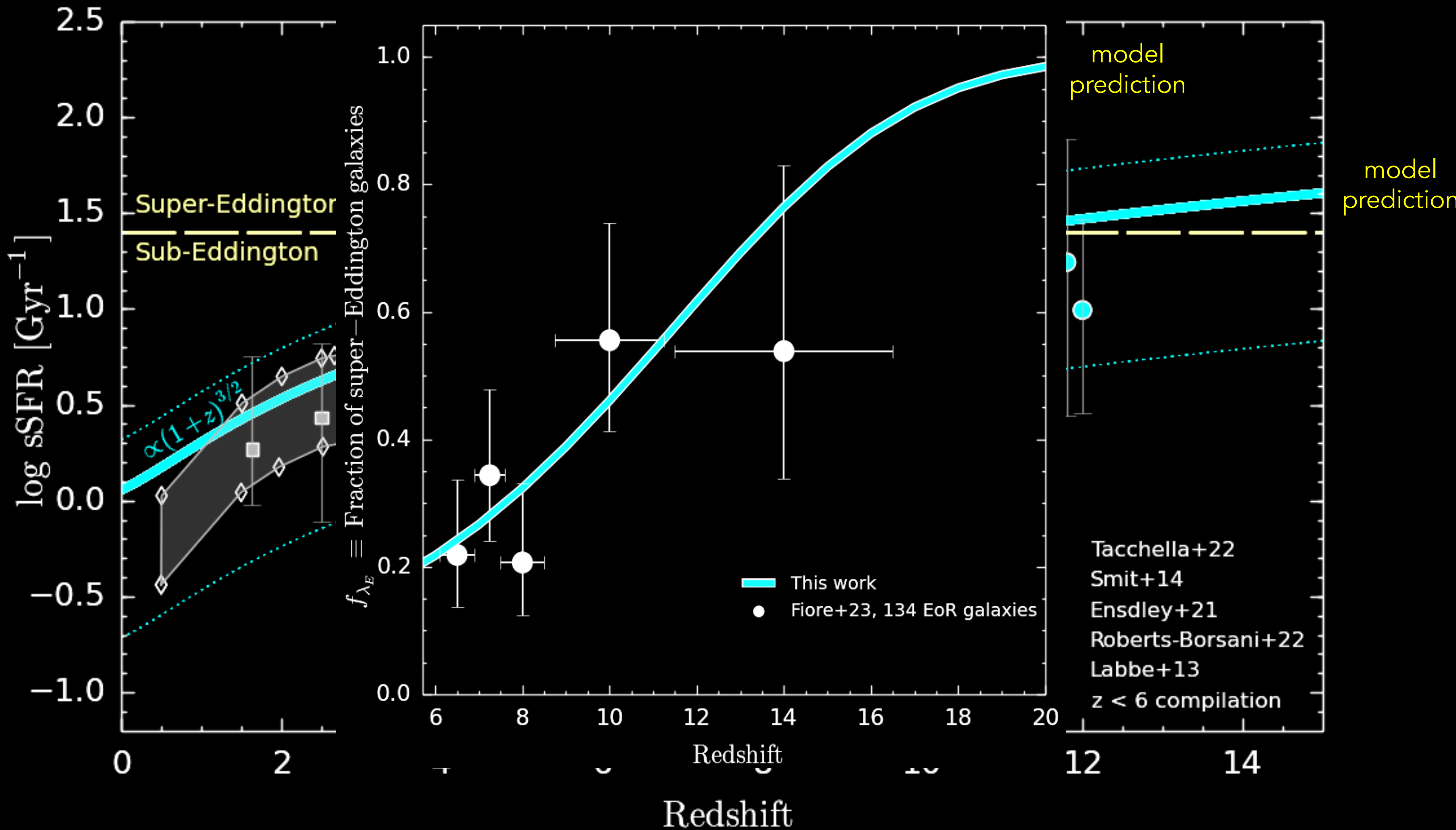
Ferrara+23, in prep.



TEST#2: SUPER-EDDINGTON FRACTION

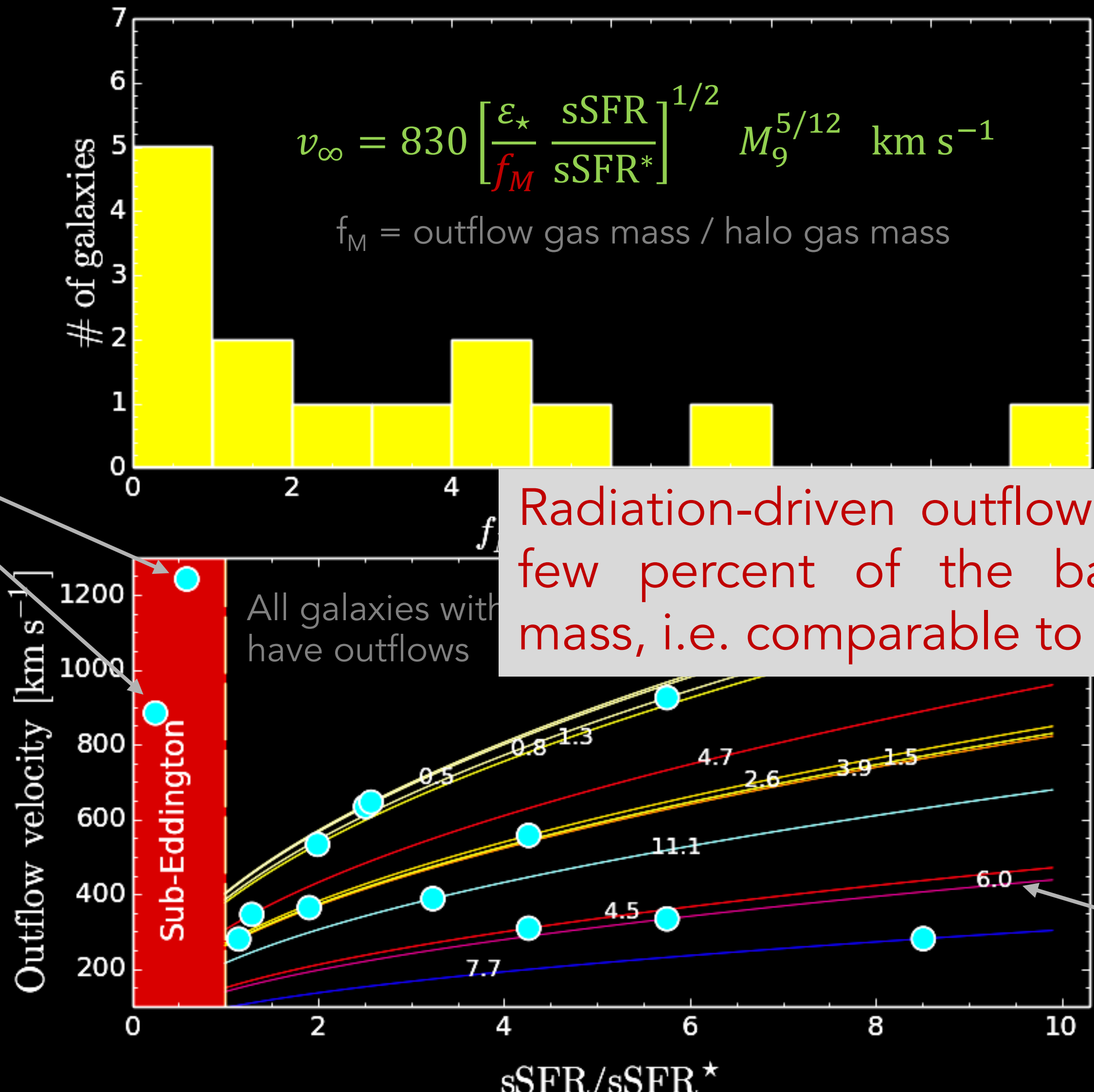
Ferrara+23, in prep.

Deviations from mean sSFR ≃ 2x in 8<z<10.
Consistent with stochastic SFR predictions



TEST#3: OUTFLOWS IN JADES

Ferrara+23, in prep.



Outliers. AGN?

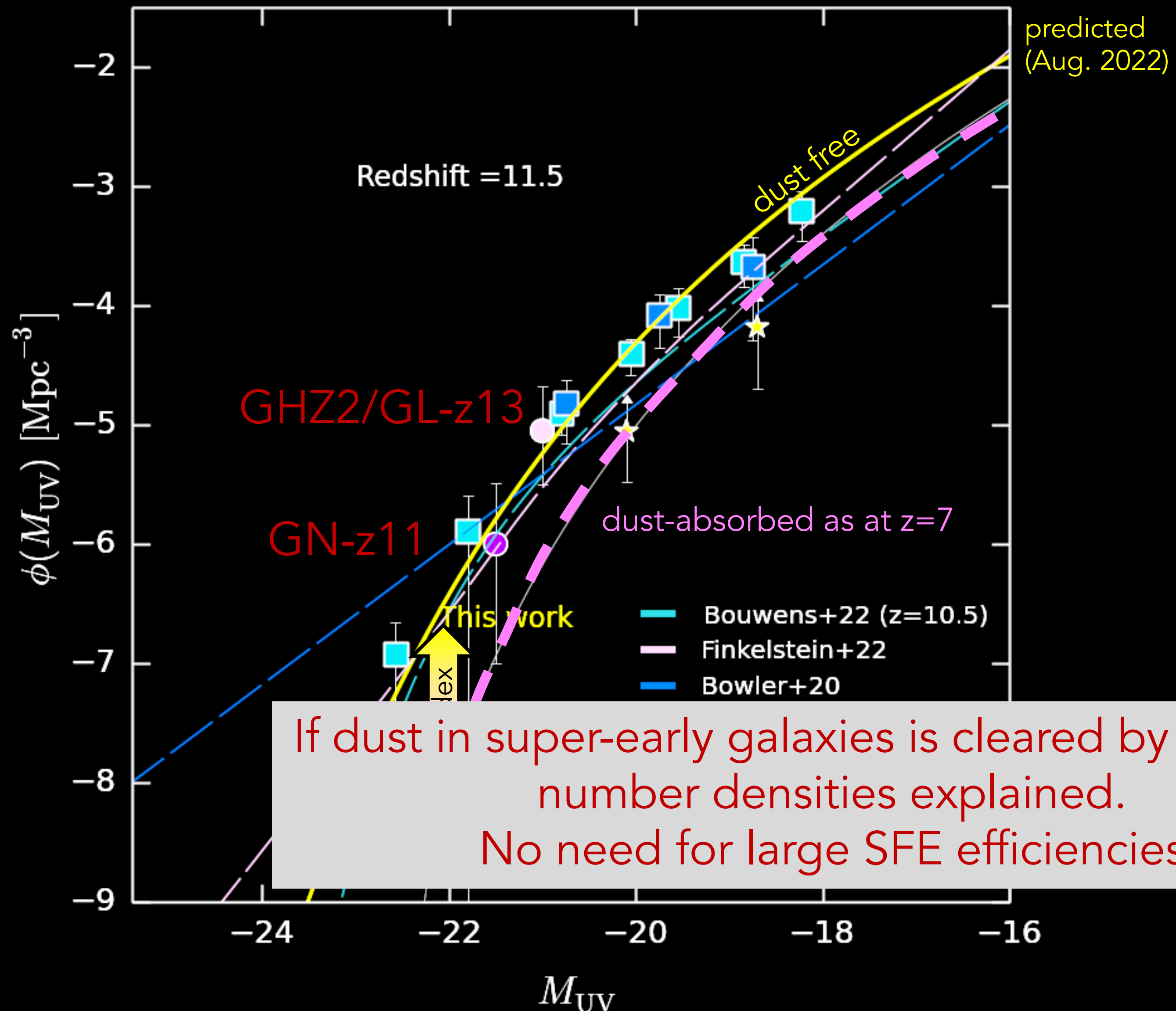
Radiation-driven outflows carry away few percent of the baryonic <u>halo</u> mass, i.e. comparable to galaxy mass

Carniani+23
3 < z <9

f_M

SUPER-EARLY LUMINOSITY FUNCTION

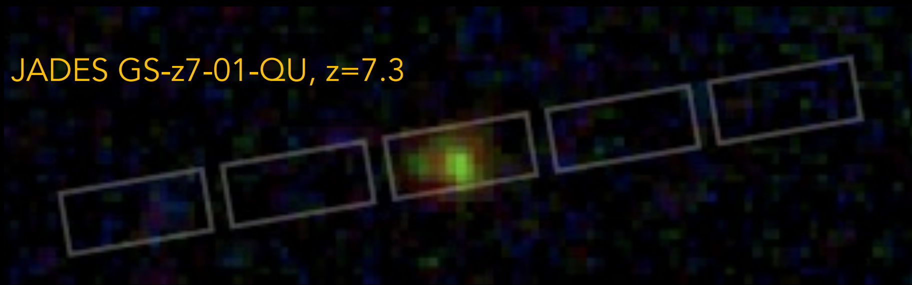
Ferrara+23
arXiv:2208.00720



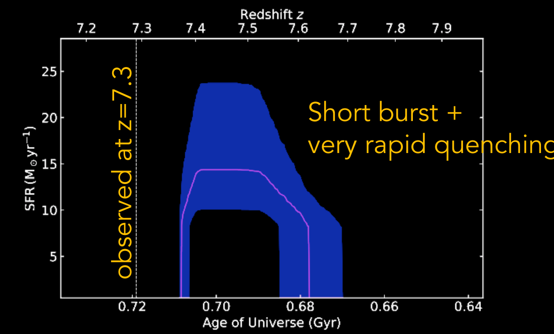
If dust in super-early galaxies is cleared by outflows, number densities explained.
No need for large SFE efficiencies

QUIESCENT GALAXIES IN THE EOR

Gelli+23

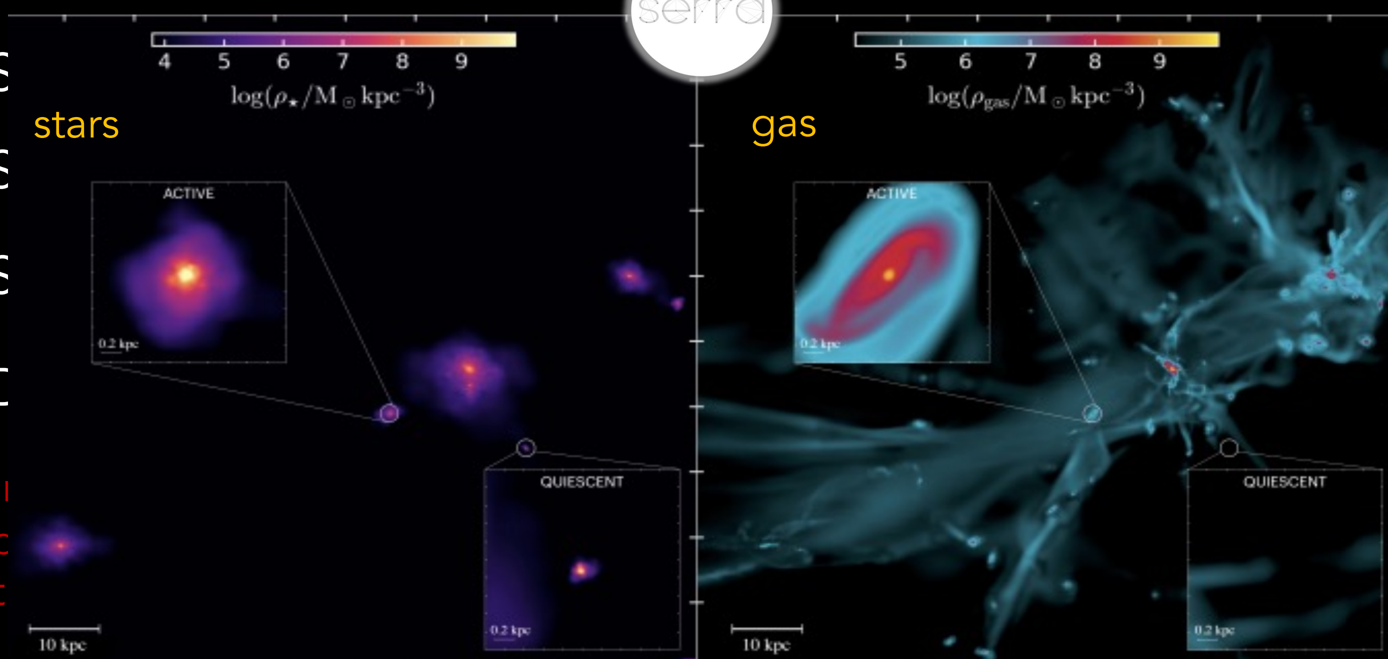


Looser+23



JADES GS-z7-01-QU properties

Looser+23



Pallottini+22

Summary

- Radiation-driven dust outflows are almost unavoidable at high redshift.
- They clear dust from early, massive galaxies making them blue and abundant.
- They (temporarily, abruptly) quench star formation making the galaxy quiescent.