First stars, super-early galaxies: clues from JWST

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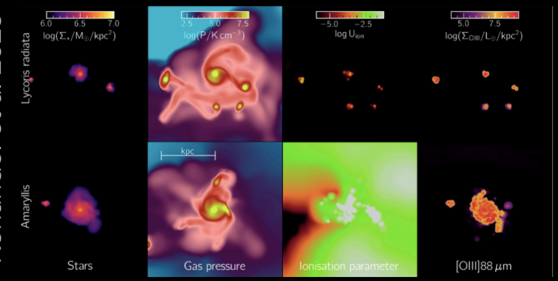
JWST DISCOVERY

- 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] 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 et al al 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

SOLUTIONS, PLEASE.

III.
Reduce dust attenuation

I.
Increase SF efficiency

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

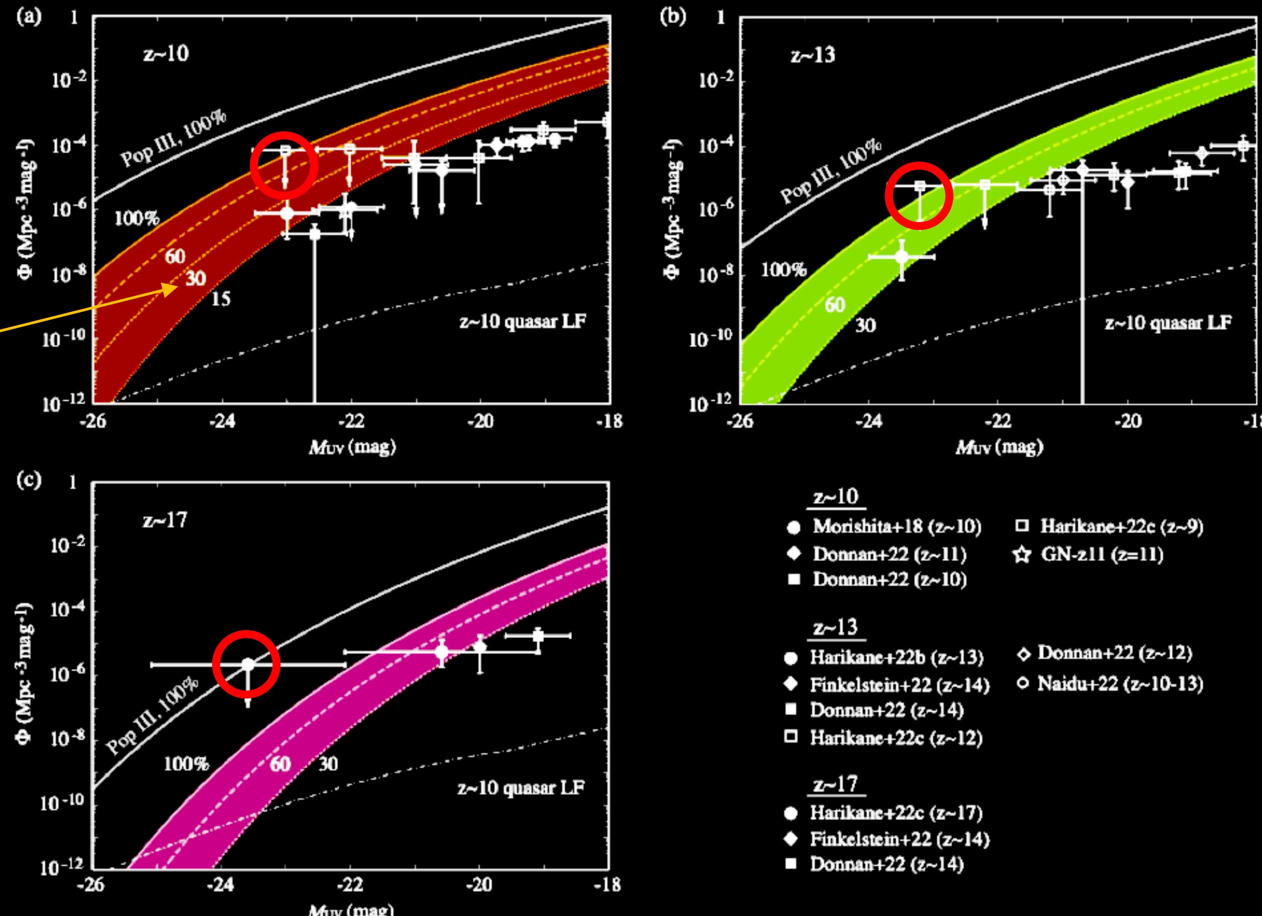
II.
Increase UV production efficiency

HYPER-EFFICIENT STAR FORMATION?

UV Luminosity Function evolution

star formation efficiency

$$\mathrm{SFR} = f_* \frac{dM_g}{dt}$$



Inayoshi+22

$$\gtrsim 100\%\ efficiency!$$

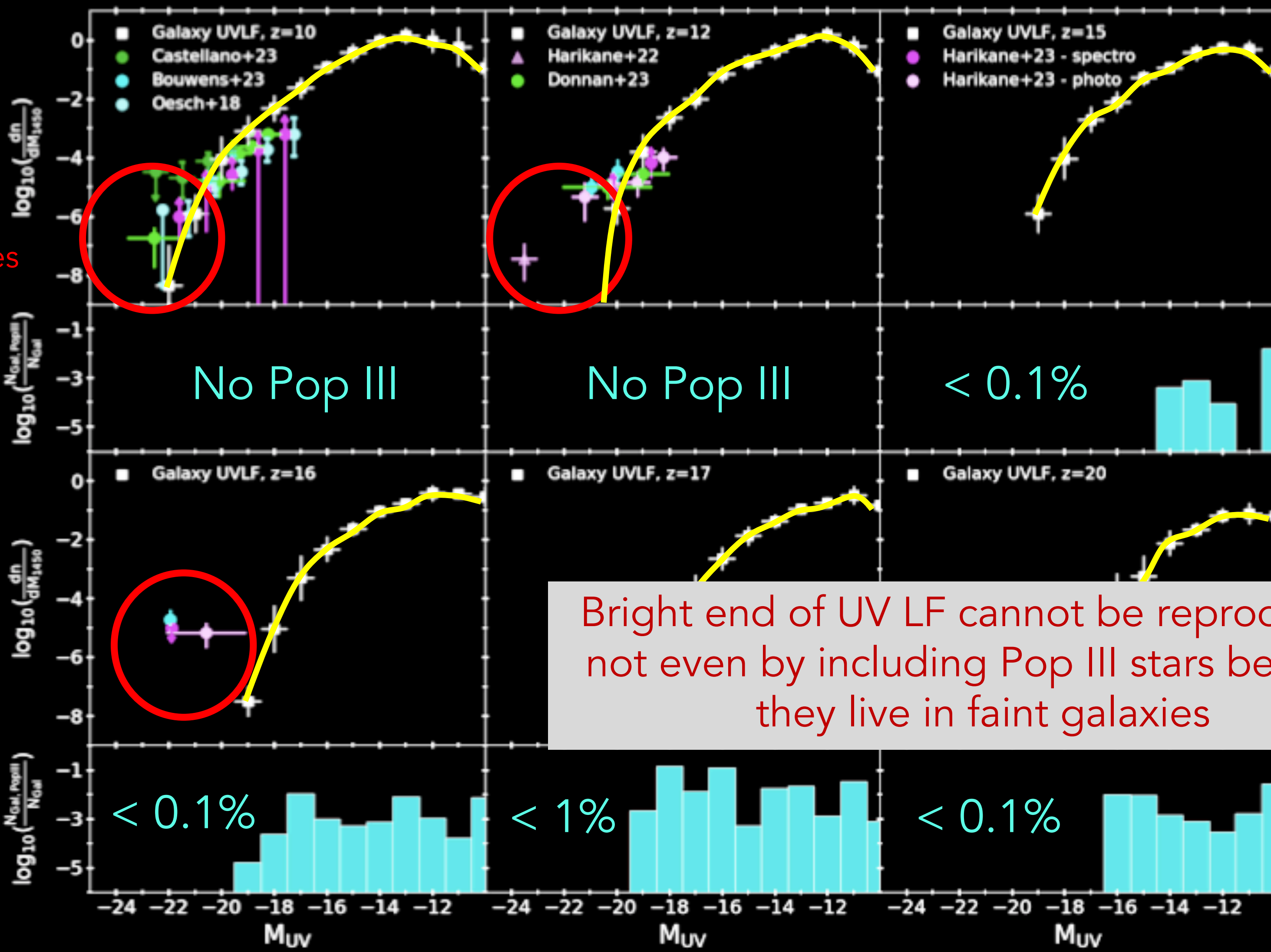
Donnan+22, Finkelstein+22, Harikane+22, Yan+22, Atek+22

Pop III Stars?

UV Luminosity Function evolution

Shortage of bright galaxies

Fraction of galaxies hosting Pop III

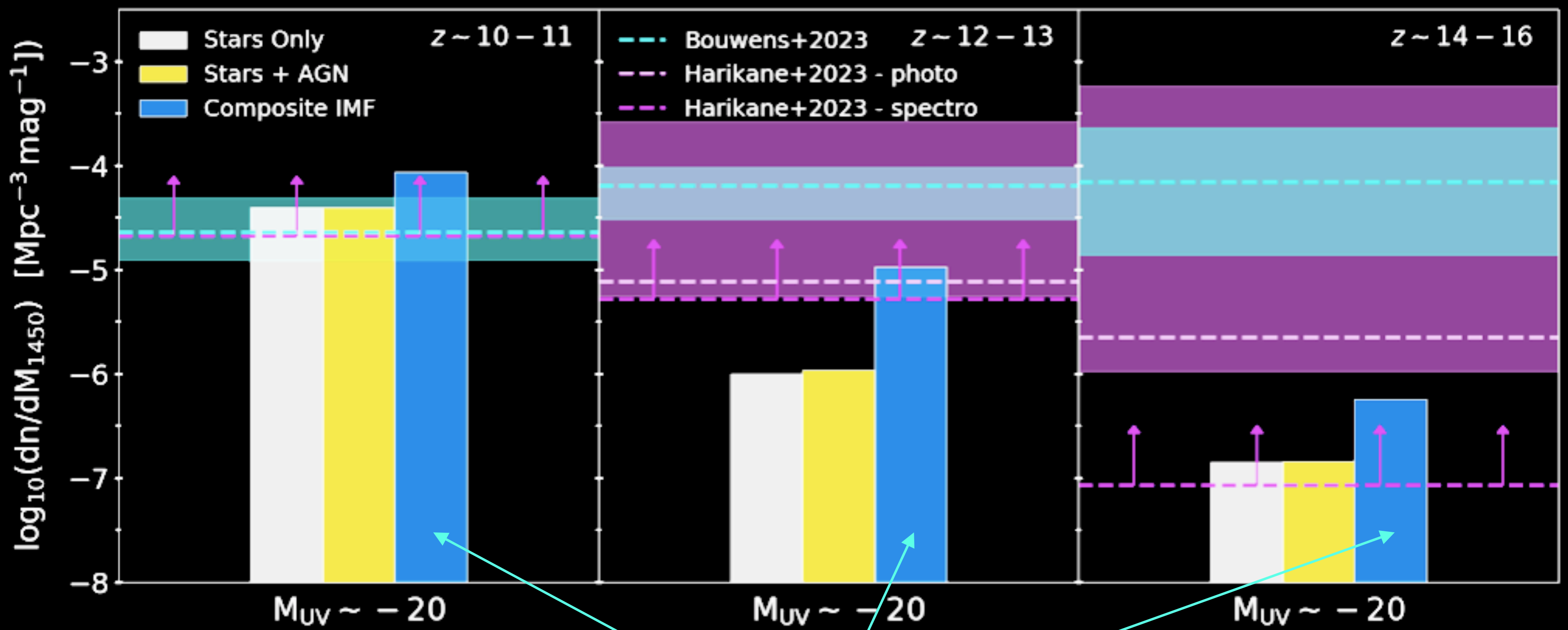


Bright end of UV LF cannot be reproduced, not even by including Pop III stars because they live in faint galaxies

Trinca+23

Pop III Stars?

Difference between observed and predicted UV Luminosity Function at M_{UV} = -20 at 3 redshifts.

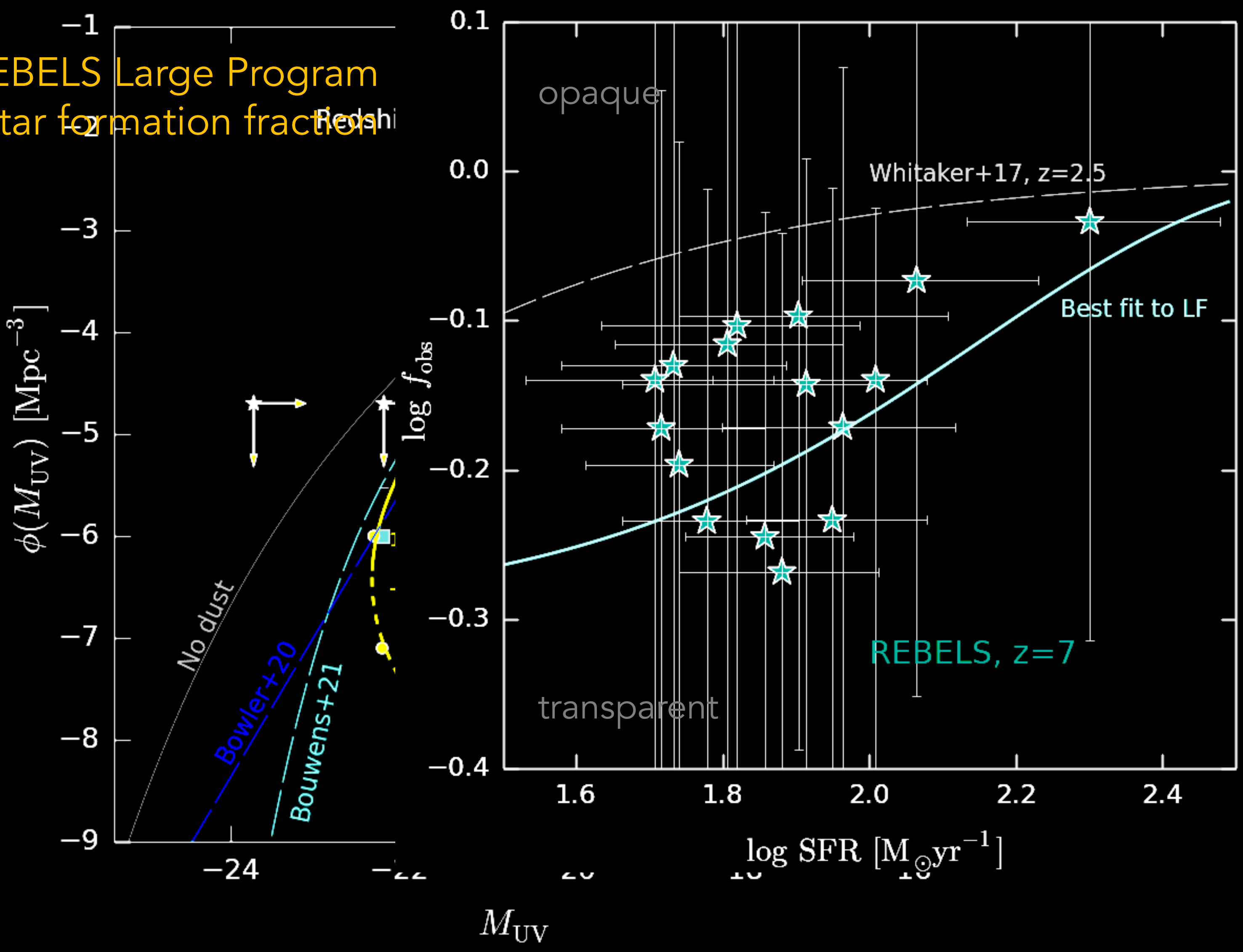


Kroupa IMF + m^{-1} power law from 10 to 300 Msun

ANCHORING THE UV LF @z=7

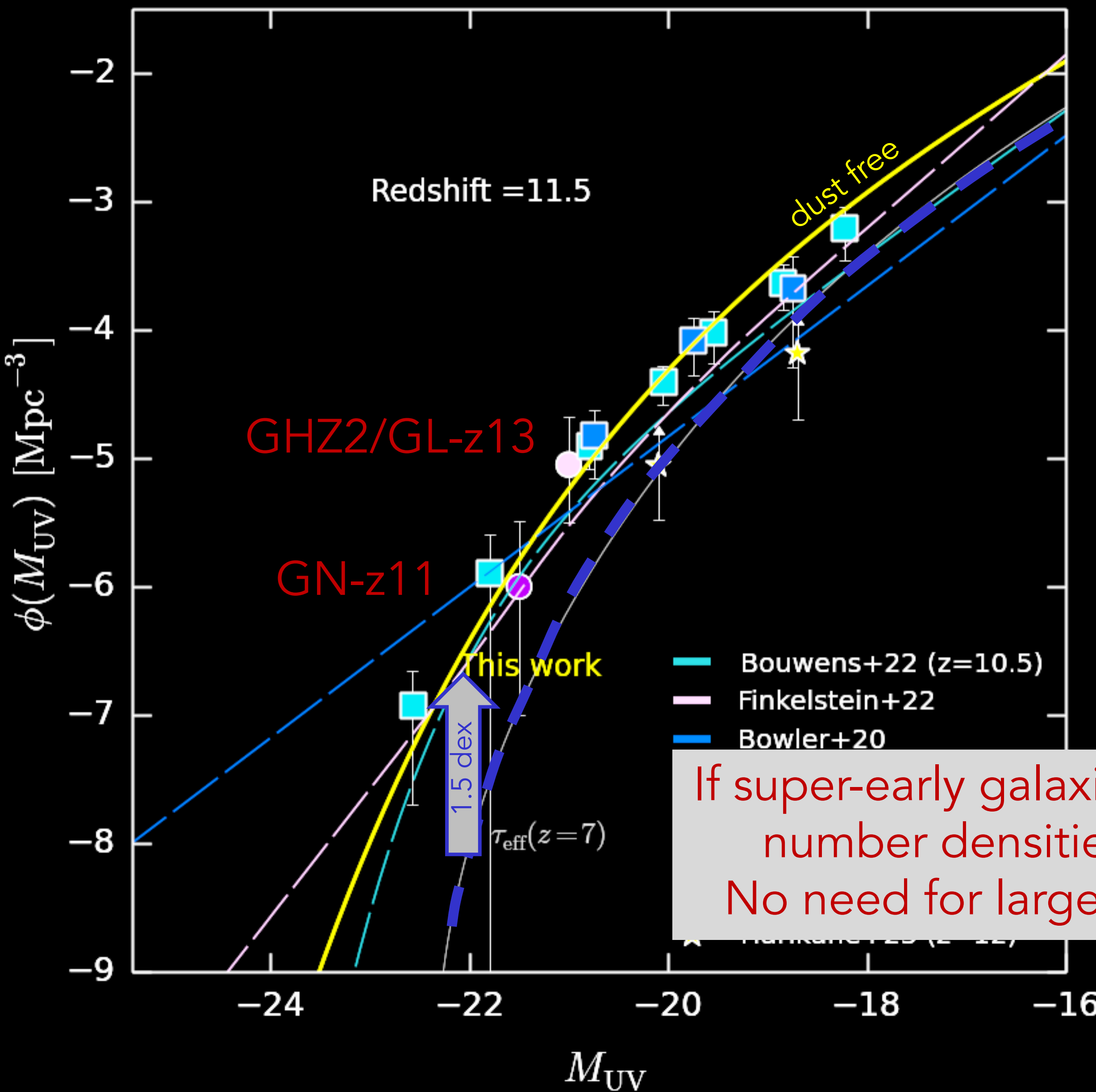
Ferrara+22b
arXiv:2208.00720

ALMA REBELS Large Program
obscured star formation fraction



SUPER-EARLY GALAXY ABUNDANCES

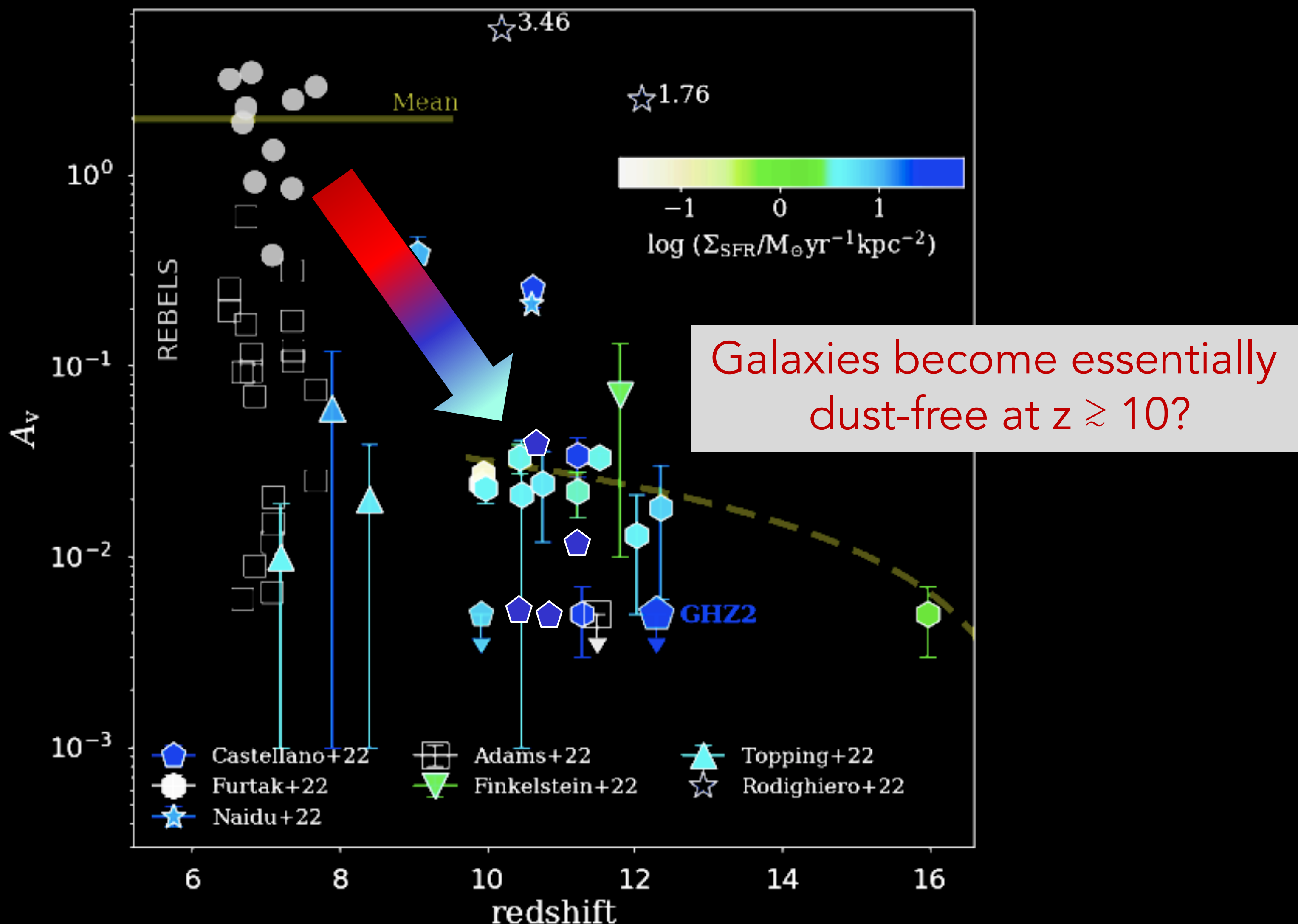
Ferrara+22b
arXiv:2208.00720



If super-early galaxies are dust-free, number densities explained.
No need for large SF efficiencies

JWST 'BLUE MONSTERS'

Ziparo, AF+22



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

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

2500x less opaque!

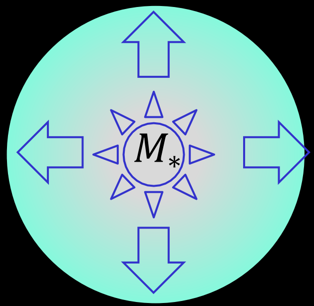
Dust ejected by radiatively-driven outflows?

Dusty outflow physics

Fiore, AF+22

Classical Eddington luminosity

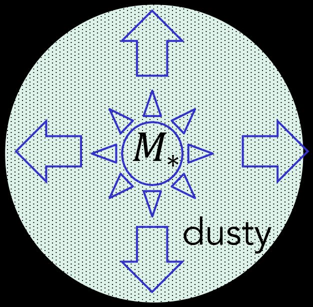
$$L_E = \frac{4\pi G M_* m_p c}{\sigma_T}$$



'Effective' Eddington luminosity for a dusty gas

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

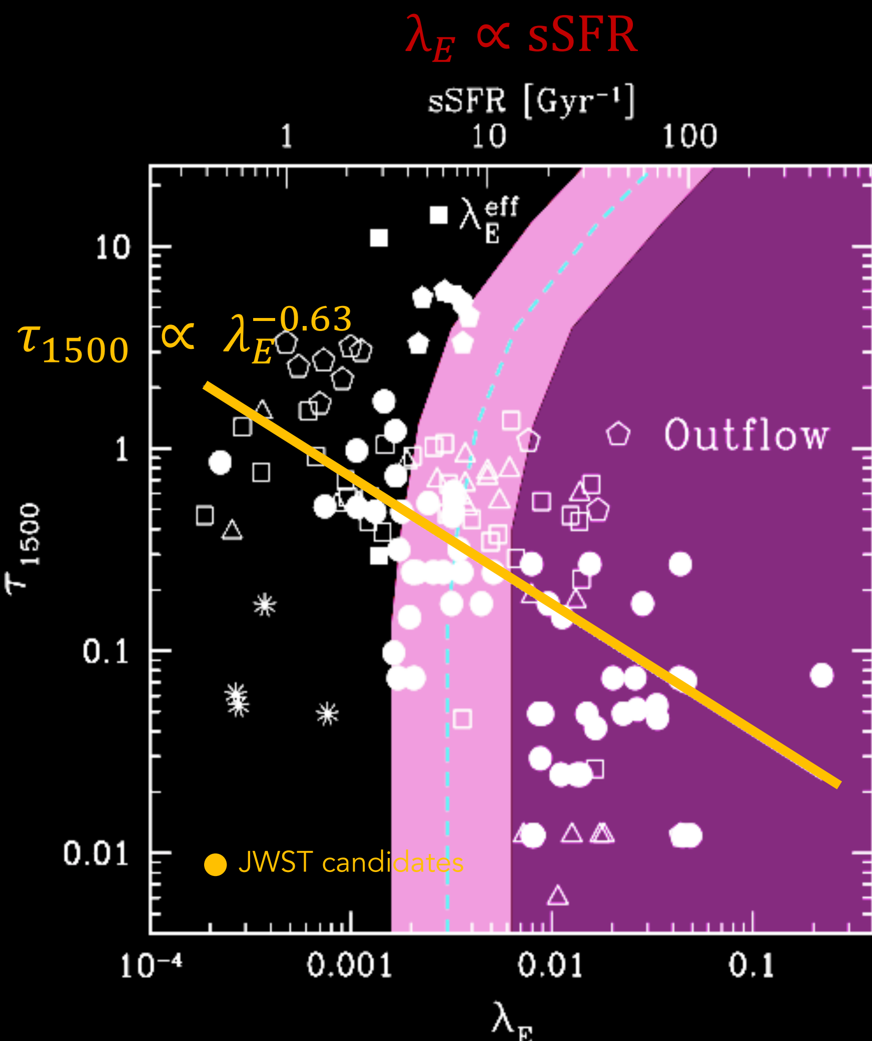
$$\frac{4\pi G M_* m_p c}{A\,\sigma_T} = L_E^{eff} = A^{-1} L_E$$

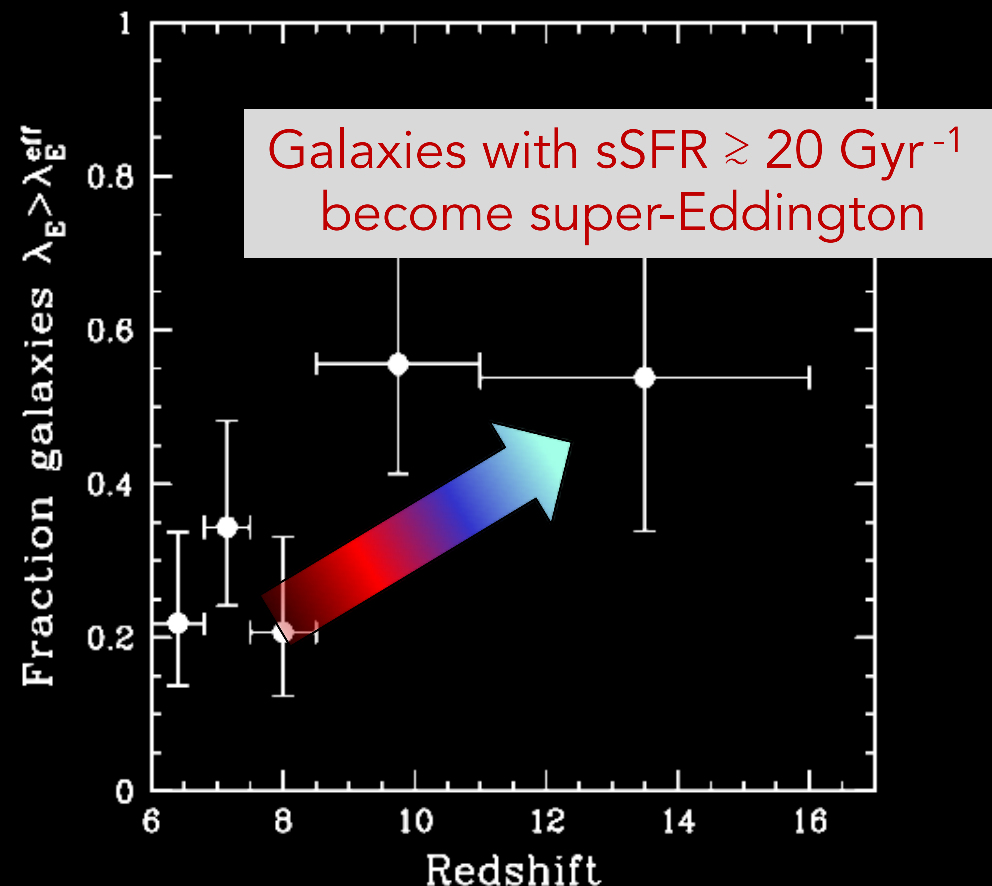


$$\lambda_E = \frac{L}{L_E} \propto \frac{\mathrm{SFR}}{M_*} \equiv \mathrm{sSFR}$$

AN EMPIRICAL TEST

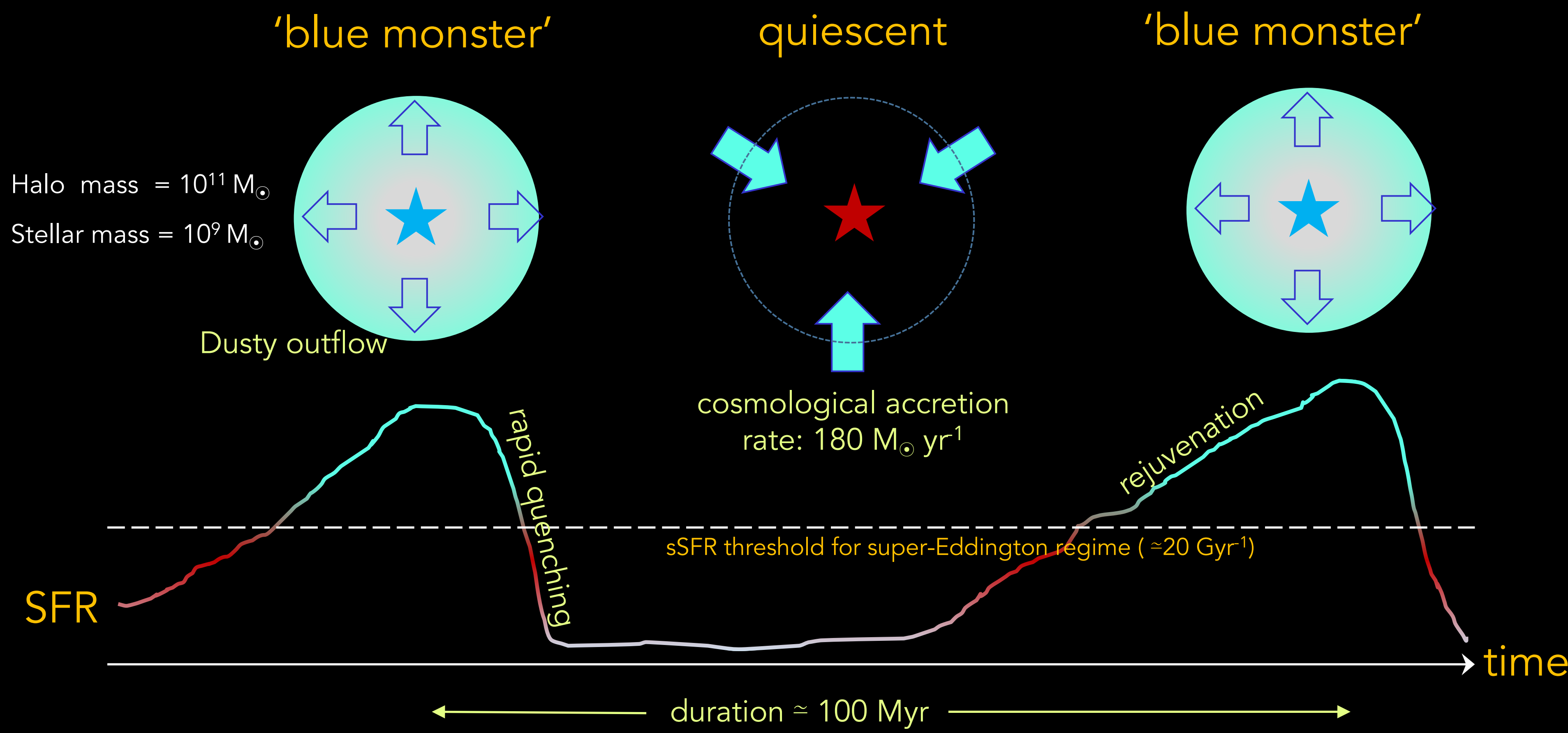
Fiore, AF+22





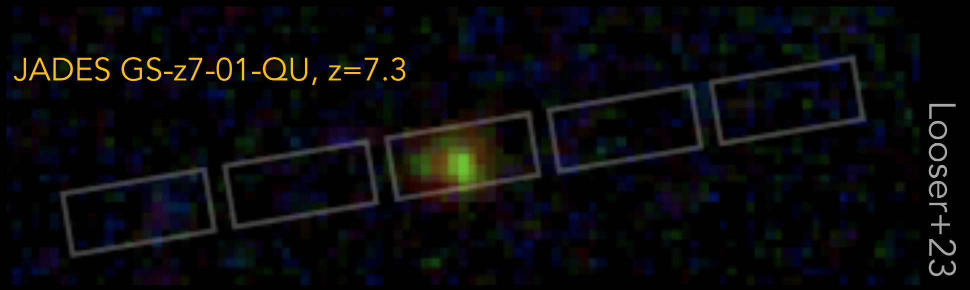
134 Galaxies @ $z > 6.5$

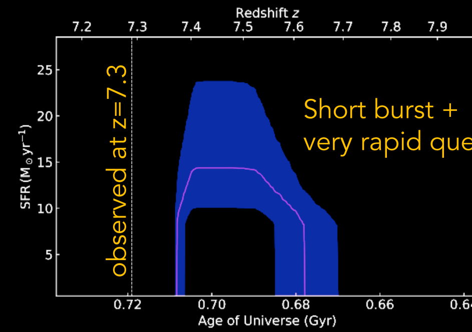
OUTFLOW SCENARIO

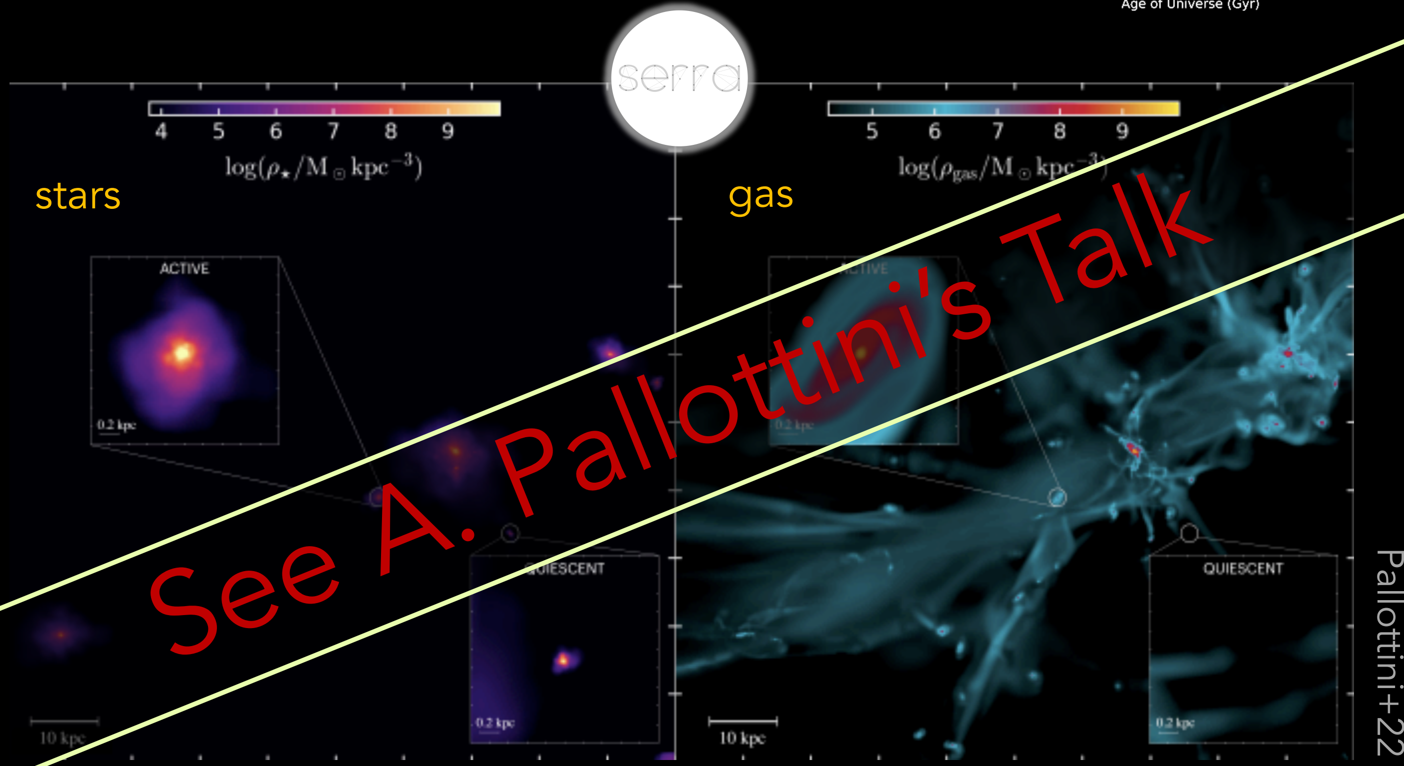


Quiescent galaxies in the EoR

Gelli+23







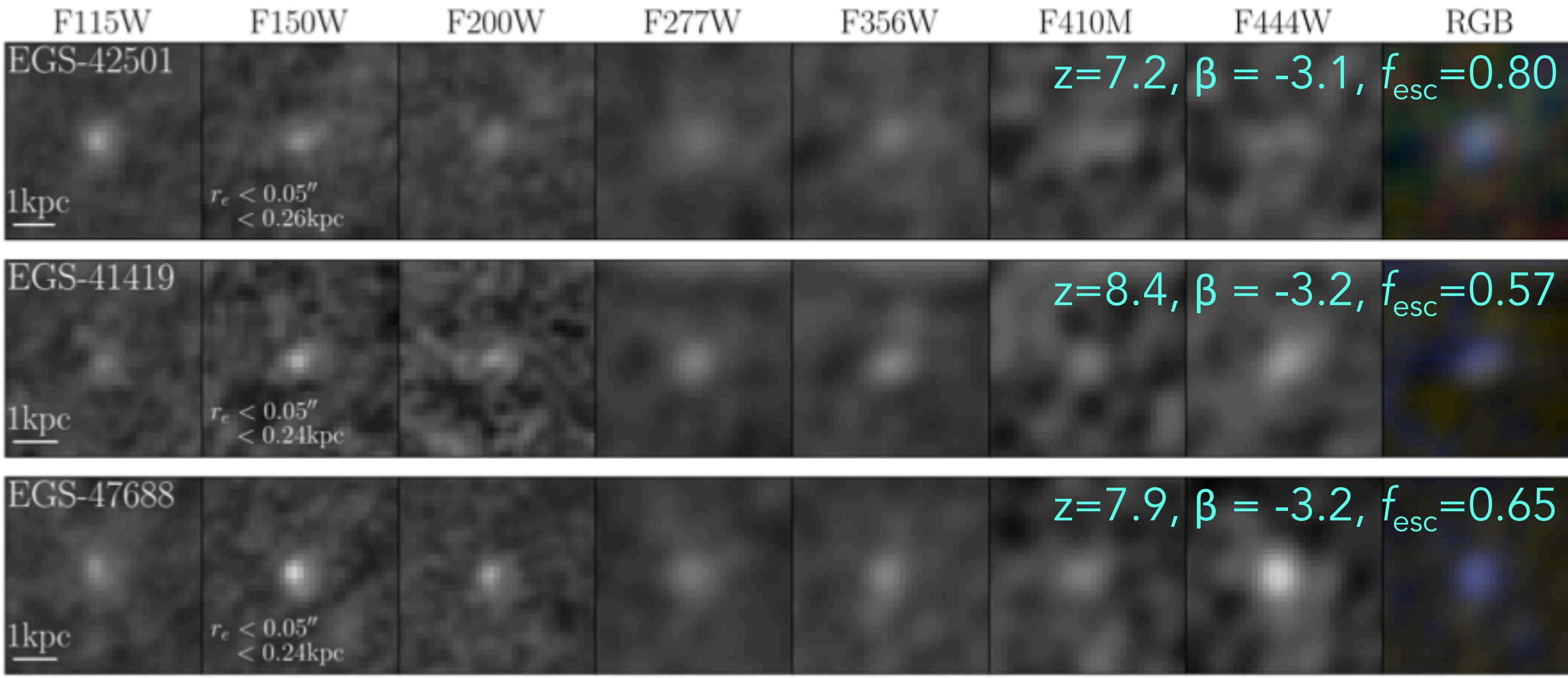
See A. Pallottini's Talk

OUTFLOWS: IMPLICATIONS

- Blue colors ($\beta \lesssim -2.5$)
- Low dust attenuation ($A_\mathrm{V} \lesssim 0.1$)
- Little/no evolution of the bright end of the LF at z>8
- Outflow signatures (Lya offset, P-Cygni profiles, broad wings..)
- Large LyC escape fractions

JWST LEAKERS AT Z>7

Topping+22 (CEERS)



$$f_{esc} \approx 1.3\times10^{-4}\times10^{-1.22\beta}$$

Chisholm+20

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, abruplty) quench star formation making the galaxy quiescent.