Galaxy Build-up in the first 1.5 Gyr: Stellar Mass Functions, Balmer Breaks at z ~ 9, and a Massive Quiescent Galaxy at z = 7.3

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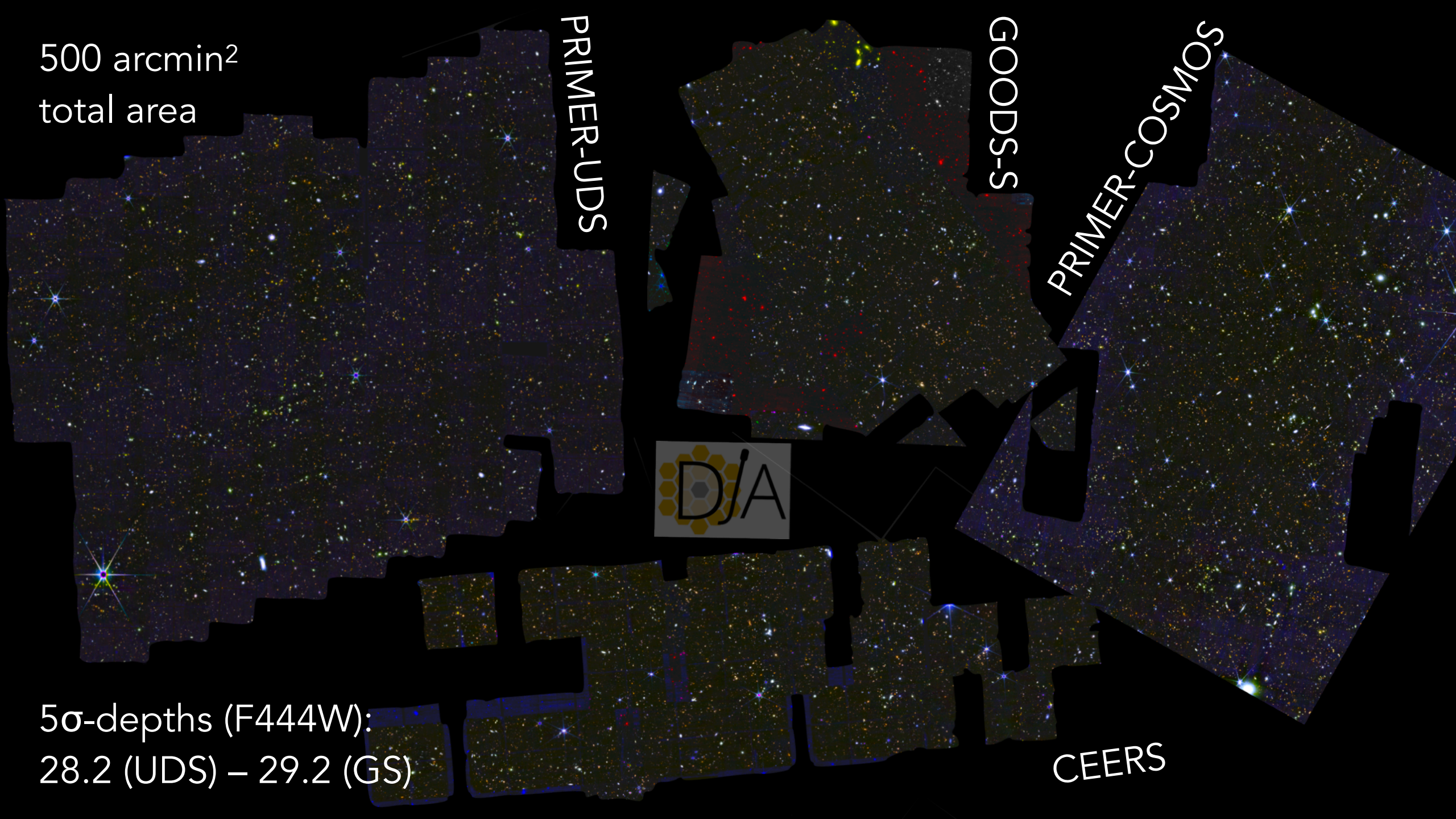
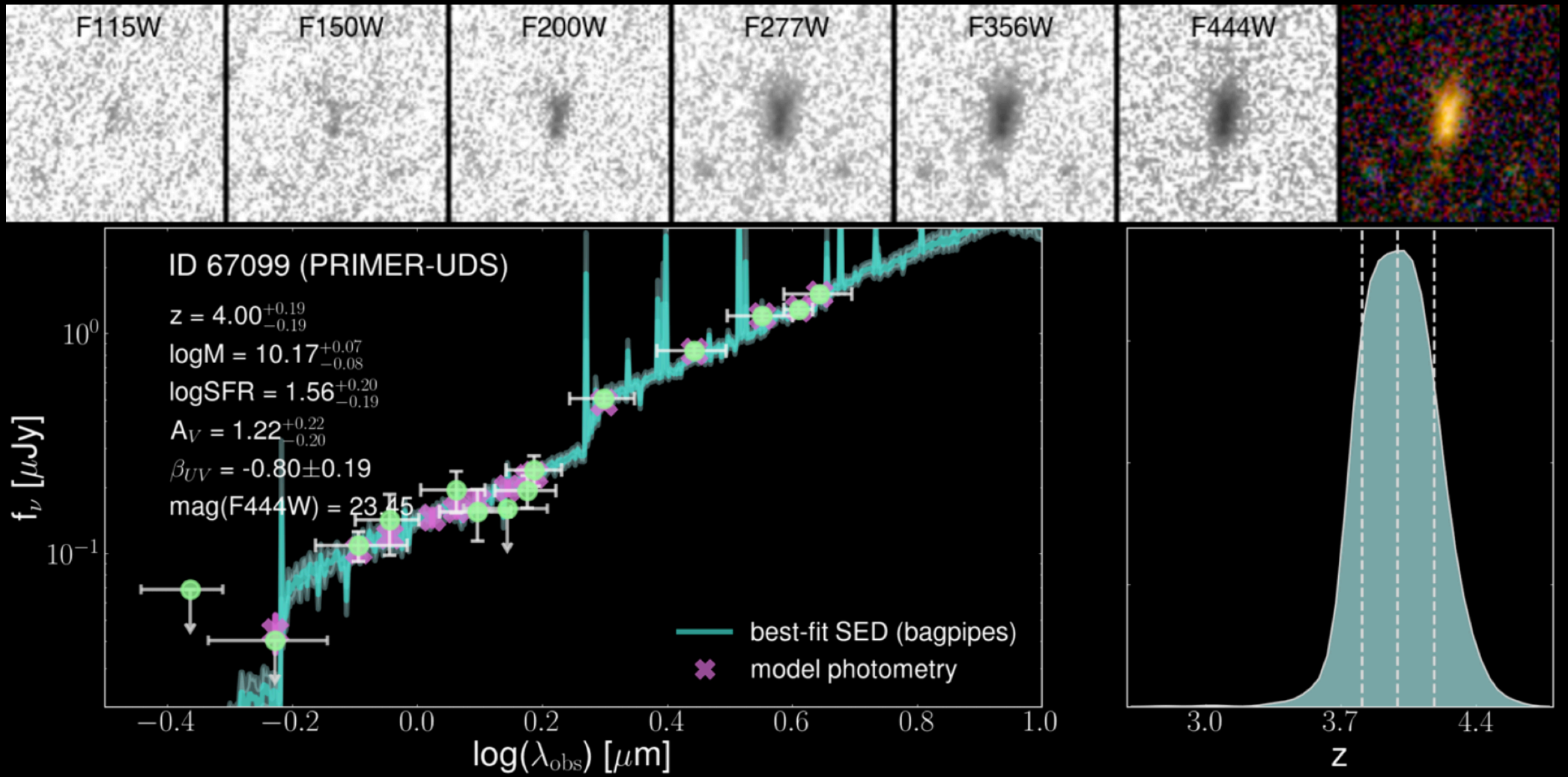
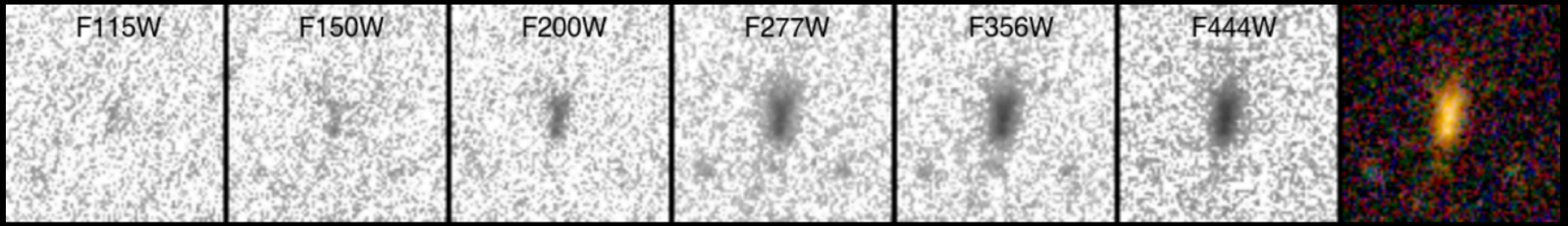
University of Geneva,
Sintra, 21.10.2024

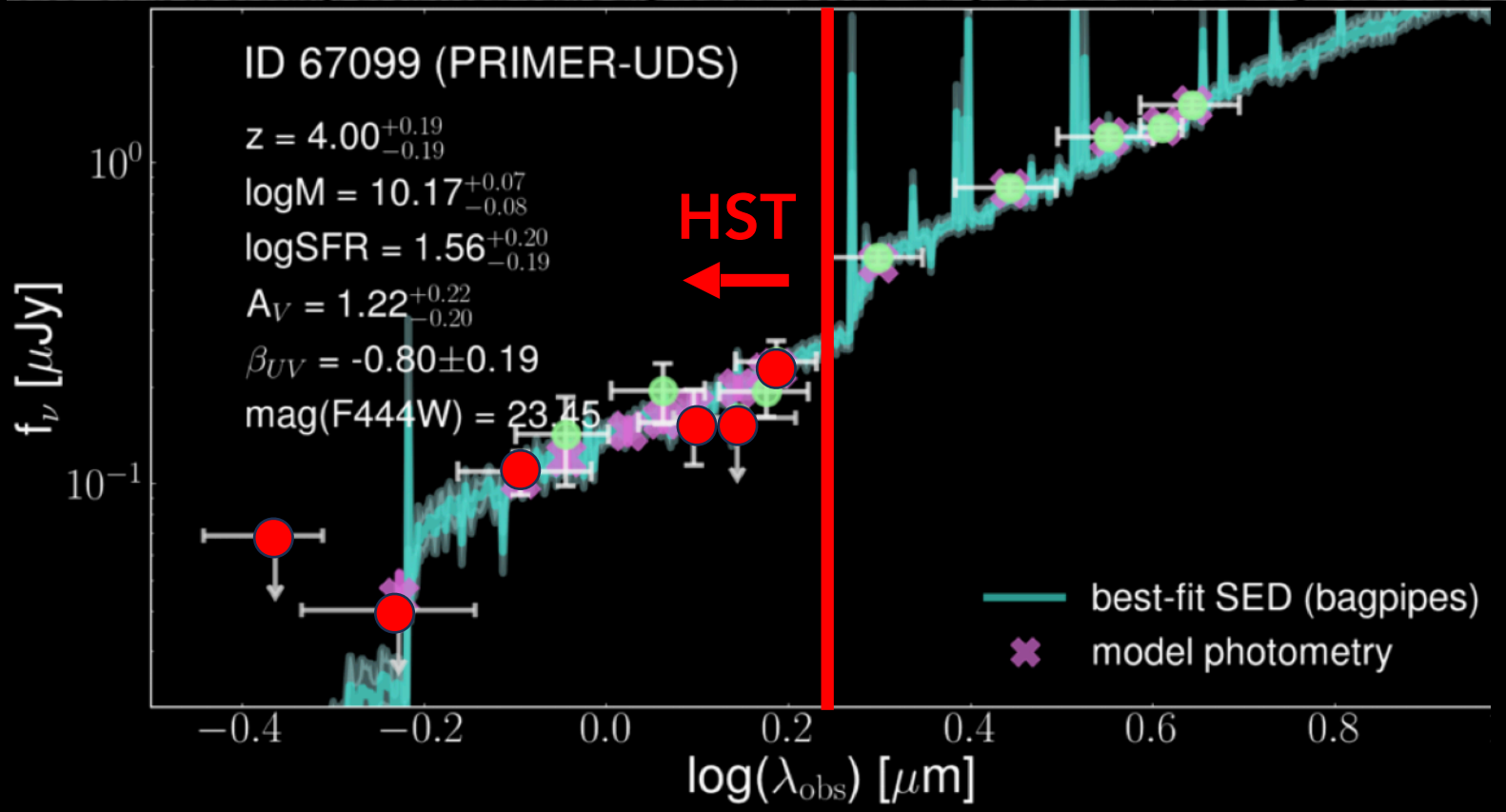

500 arcmin²
total area
PRIMER-UDS
GOODS-S
PRIMER-COSMOS
DJA
CEERS
5σ-depths (F444W):
28.2 (UDS) – 29.2 (GS)

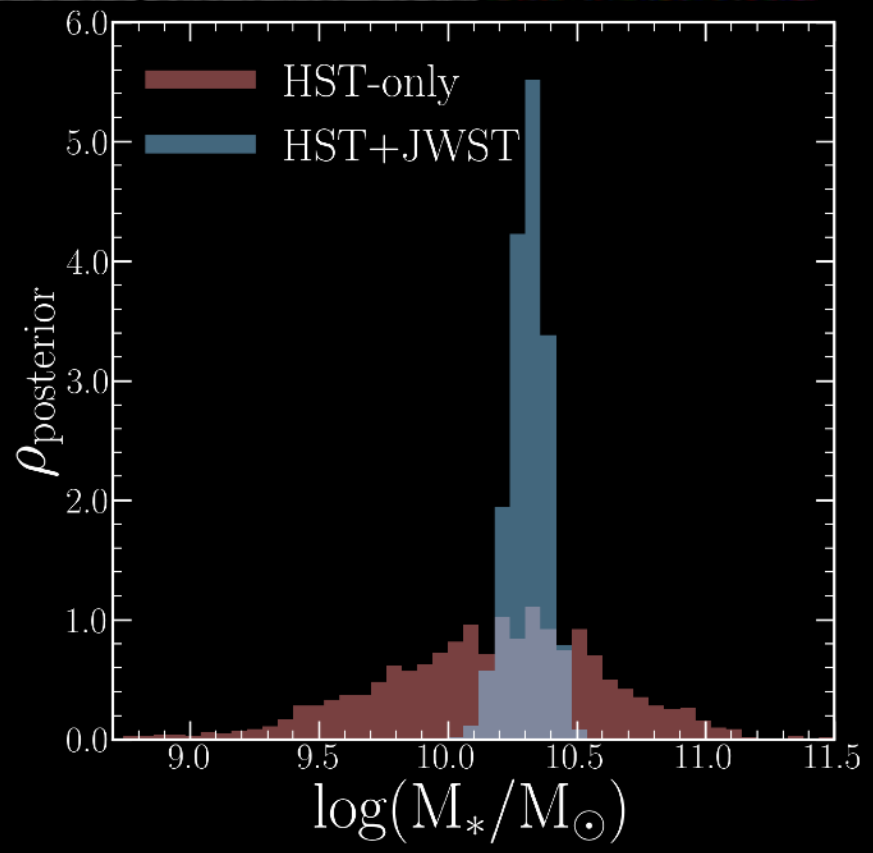
Sample selection + SED-fitting

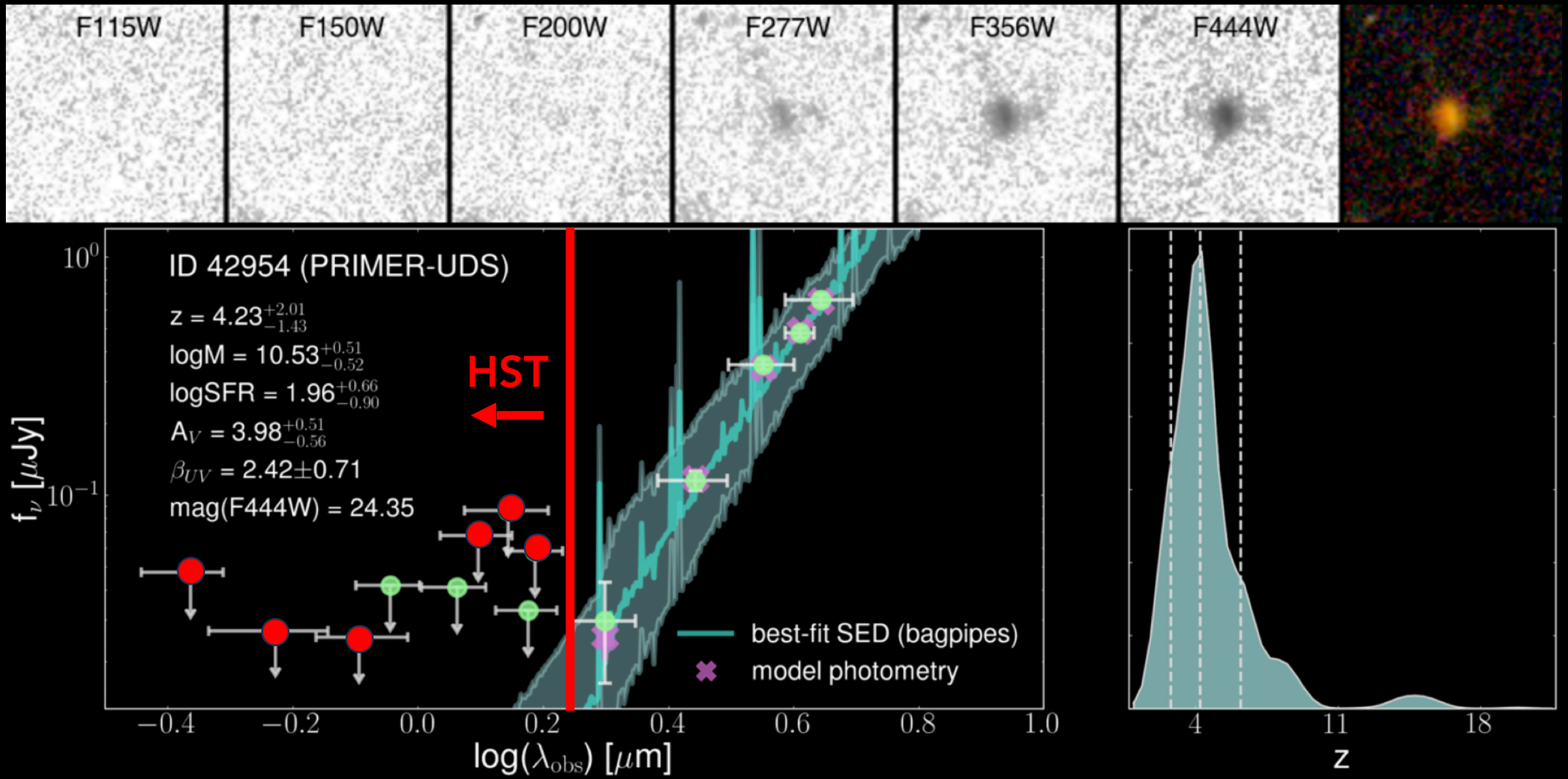
- Generate photometric catalogs (HST + JWST)
- Run eazy (Brammer+ 2008) to obtain photometric redshifts
- Pre-select a sample of $z > 3$ galaxies
- Run bagpipes (Carnall+ 2018) on the pre-selected sample to get final redshifts and physical parameters


F115W
F150W
F200W
F277W
F356W
F444W
ID 67099 (PRIMER-UDS)
z = 4.00$^{+0.19}_{-0.19}$
logM = 10.17$^{+0.07}_{-0.08}$
logSFR = 1.56$^{+0.20}_{-0.19}$
A_V = 1.22$^{+0.22}_{-0.20}$
β_{UV} = -0.80±0.19
mag(F444W) = 23.15
best-fit SED (bagpipes)
model photometry
f_ν [μJy]
10^0
10^{-1}
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
log(λ_{obs}) [μm]
3.0
3.7
4.4
z

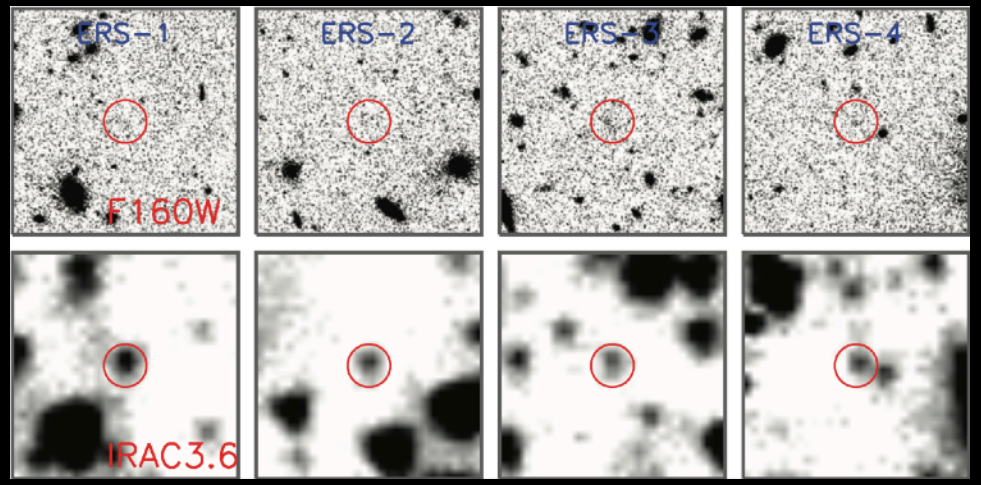

F115W
F150W
F200W
F277W
F356W
F444W


ID 67099 (PRIMER-UDS)
z = 4.00+0.19−0.19
logM = 10.17+0.07−0.08
logSFR = 1.56+0.20−0.19
AV = 1.22+0.22−0.20
βUV = -0.80±0.19
mag(F444W) = 23.15
HST
best-fit SED (bagpipes)
model photometry
fν [μJy]
log(λobs) [μm]

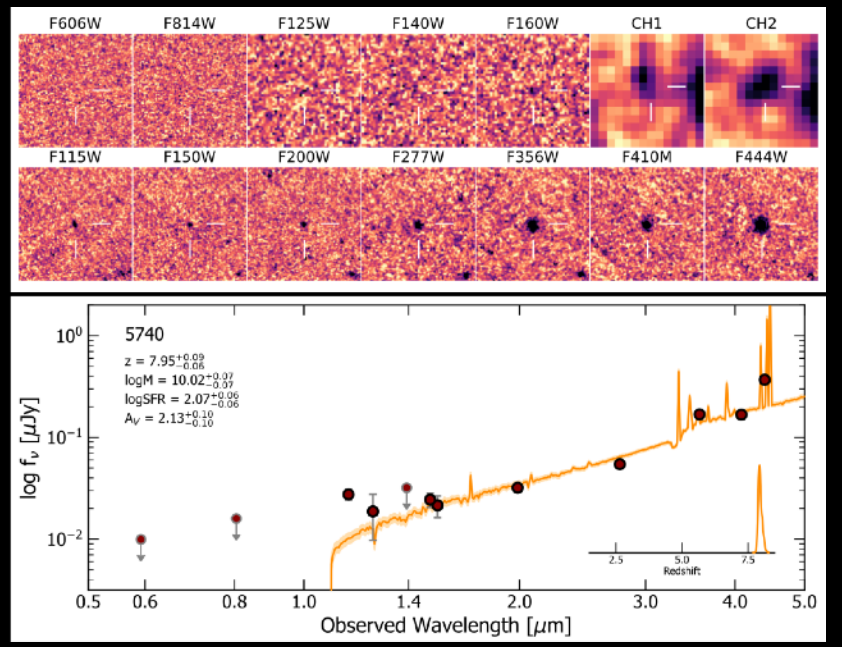

HST-only
HST+JWST
ρposterior
log(M*/M⊙)


F115W
F150W
F200W
F277W
F356W
F444W
ID 42954 (PRIMER-UDS)
z = 4.23$^{+2.01}_{-1.43}$
logM = 10.53$^{+0.51}_{-0.52}$
logSFR = 1.96$^{+0.66}_{-0.90}$
A_V = 3.98$^{+0.51}_{-0.56}$
β_{UV} = 2.42±0.71
mag(F444W) = 24.35
HST
best-fit SED (bagpipes)
model photometry
f_ν [μJy]
10^0
10^{-1}
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
log(λ_{obs}) [μm]
4
11
18
z

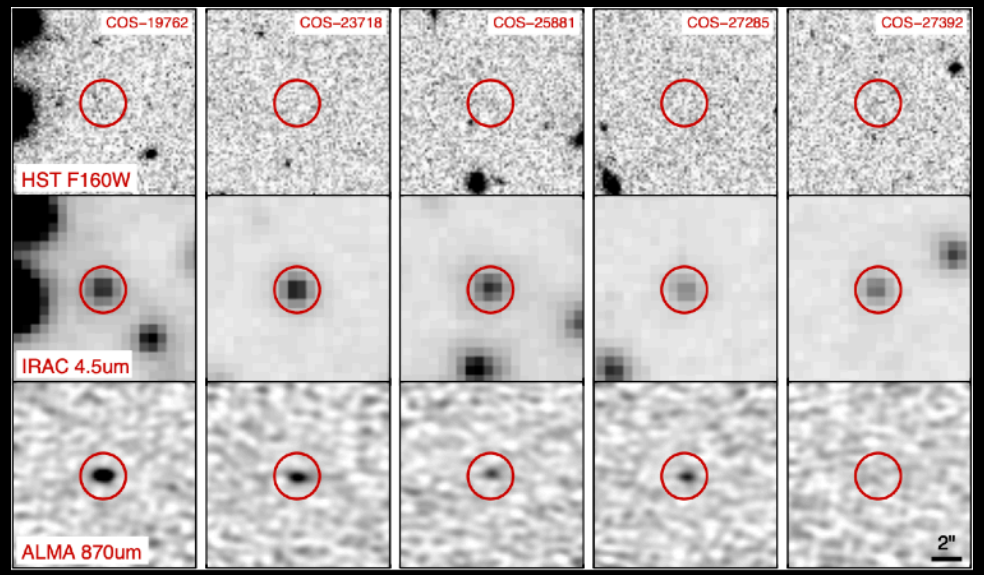
Huang+ 2011



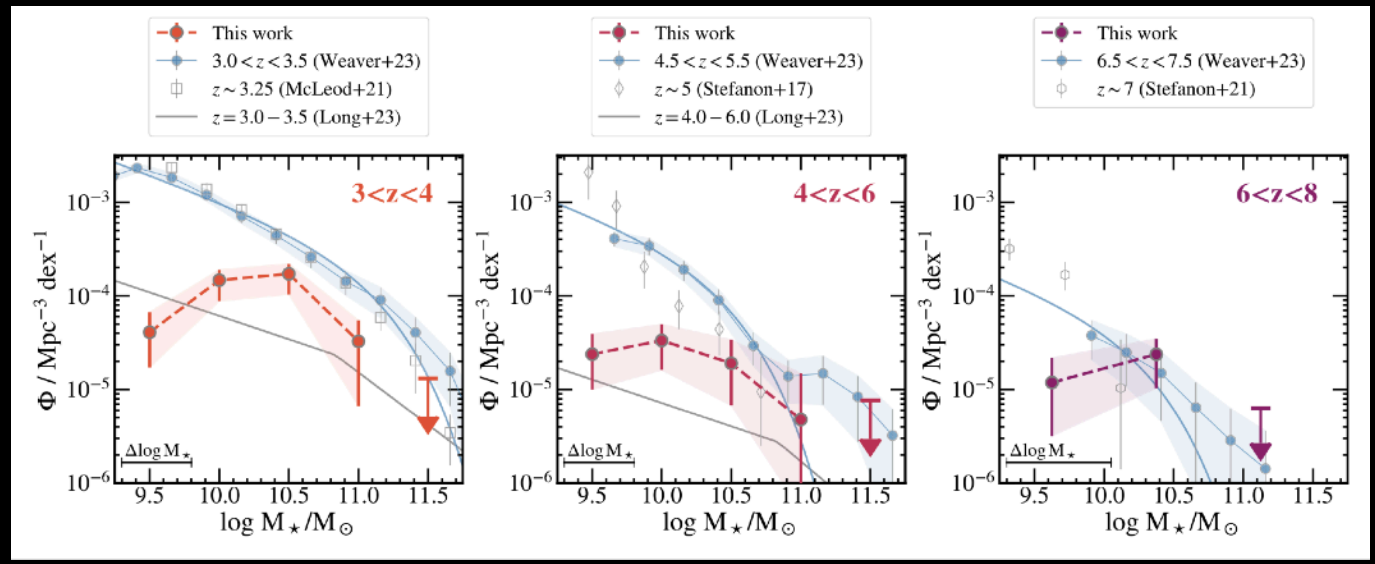
Barrufet, …, AW, + 2023



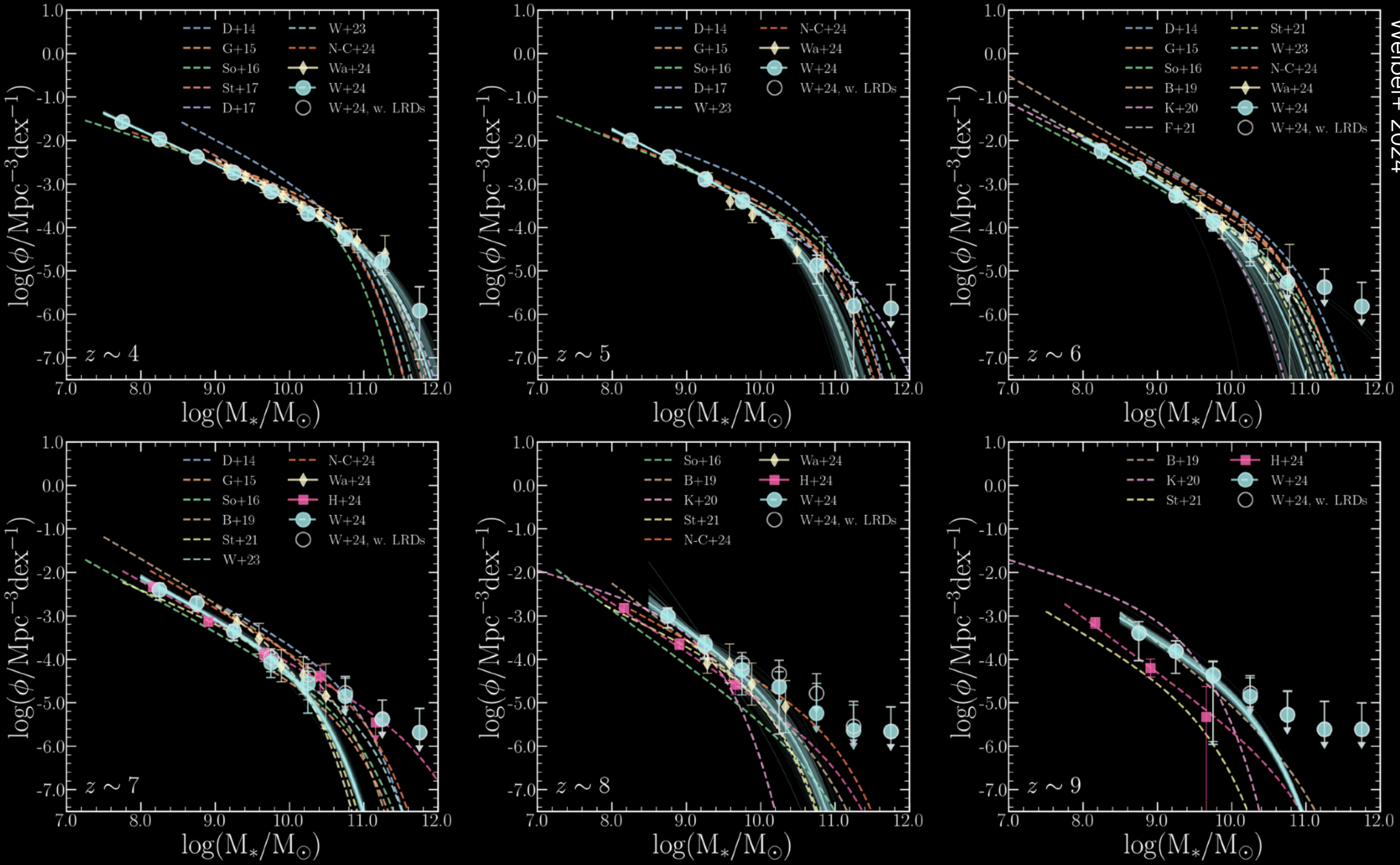
see also: e.g., Caputi+12, Wang+14, Simpson+15, Stefanon+15, Fujimoto+16, Alcalde Pampliega+18, Xiao+23, Nelson+23, Pérez-Gonzalez+23, Rodighiero+23, Williams+23



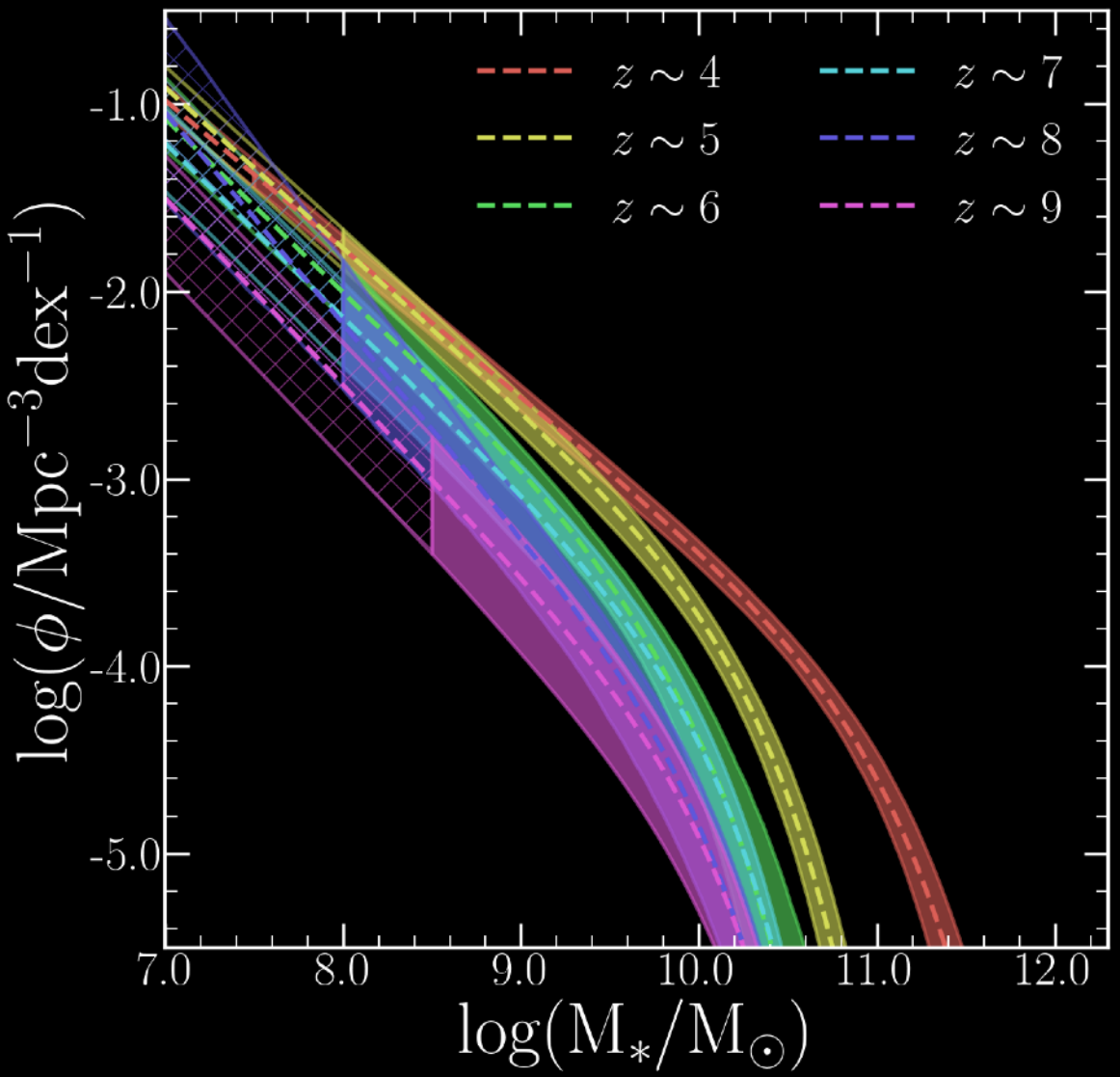
Wang+ 2019

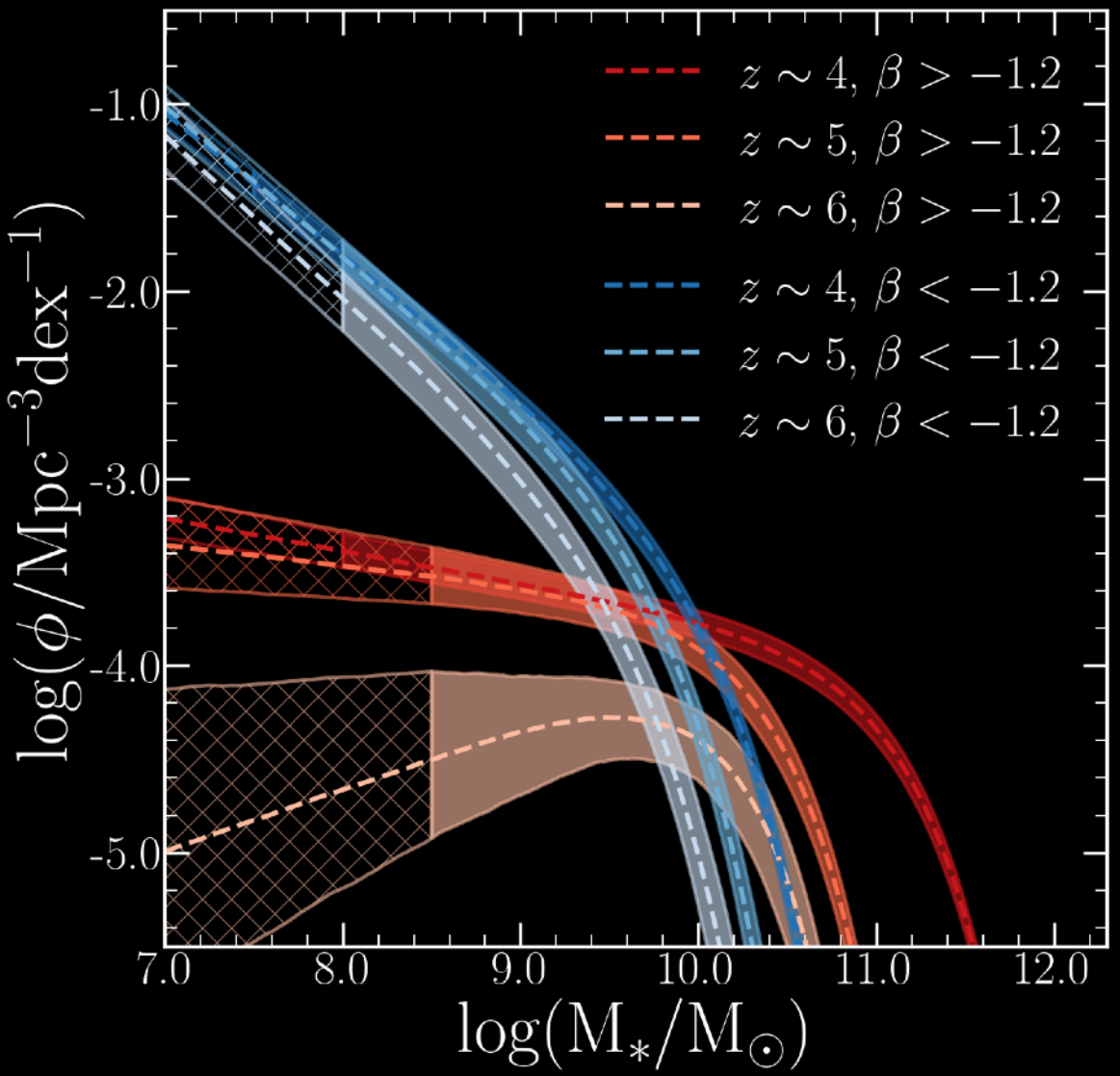


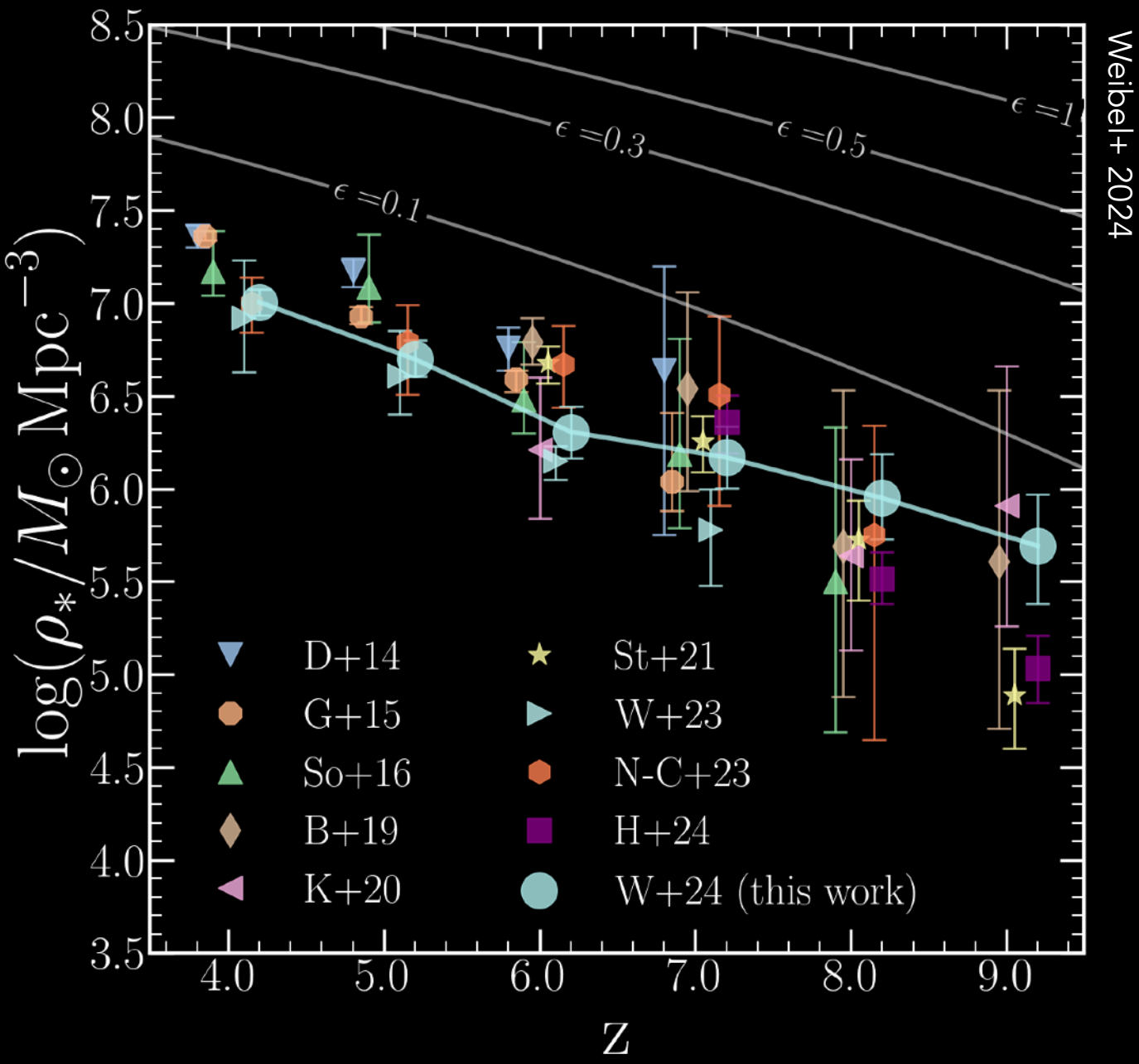
Gottumukkala, …, AW, + 2024

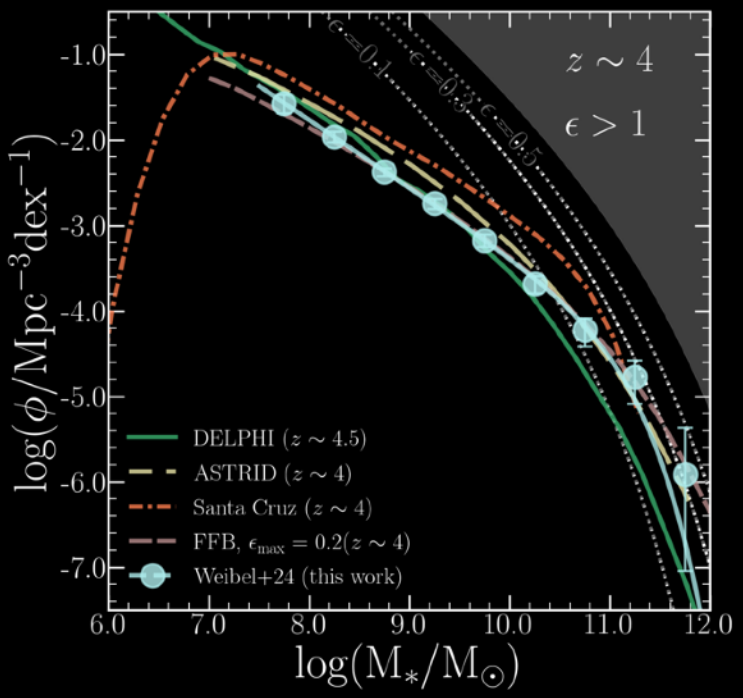

D+14
G+15
So+16
St+17
D+17
W+23
N-C+24
Wa+24
W+24
W+24, w. LRDs
$z \sim 4$
$z \sim 5$
$z \sim 6$
$z \sim 7$
$z \sim 8$
$z \sim 9$
B+19
K+20
St+21
F+21
H+24
$\log(\phi/\mathrm{Mpc}^{-3}\mathrm{dex}^{-1})$
$\log(M_*/M_\odot)$
Weibel+ 2024

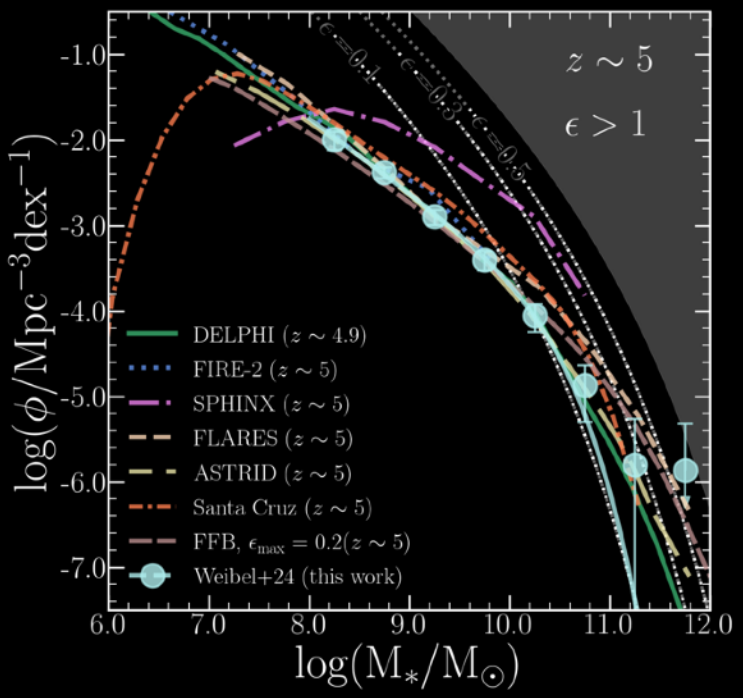
Weibel+ 2024

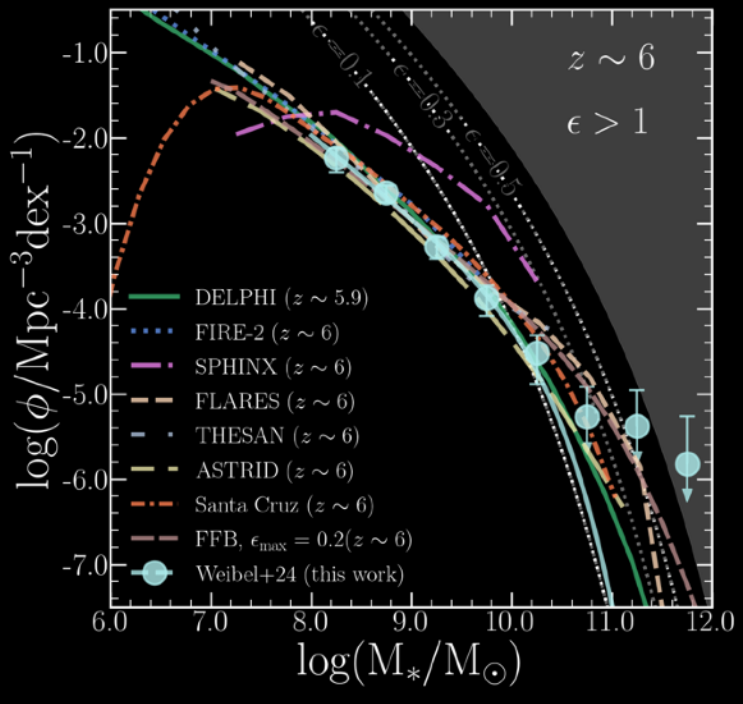

$z \sim 4$
$z \sim 5$
$z \sim 6$
$z \sim 7$
$z \sim 8$
$z \sim 9$
$\log(\phi/\mathrm{Mpc}^{-3}\mathrm{dex}^{-1})$
$\log(M_*/M_\odot)$

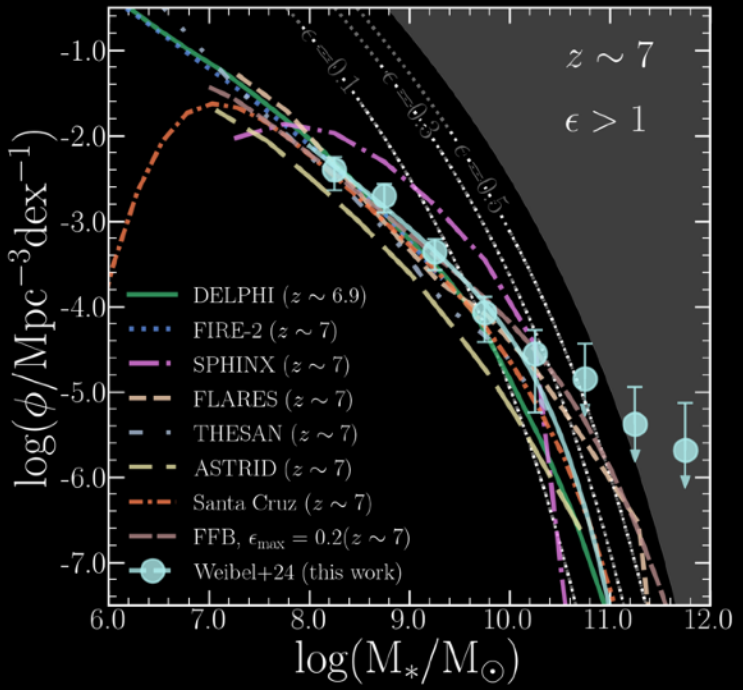

$z \sim 4, \beta > -1.2$
$z \sim 5, \beta > -1.2$
$z \sim 6, \beta > -1.2$
$z \sim 4, \beta < -1.2$
$z \sim 5, \beta < -1.2$
$z \sim 6, \beta < -1.2$
$\log(\phi/\mathrm{Mpc}^{-3}\mathrm{dex}^{-1})$
$\log(M_*/M_\odot)$

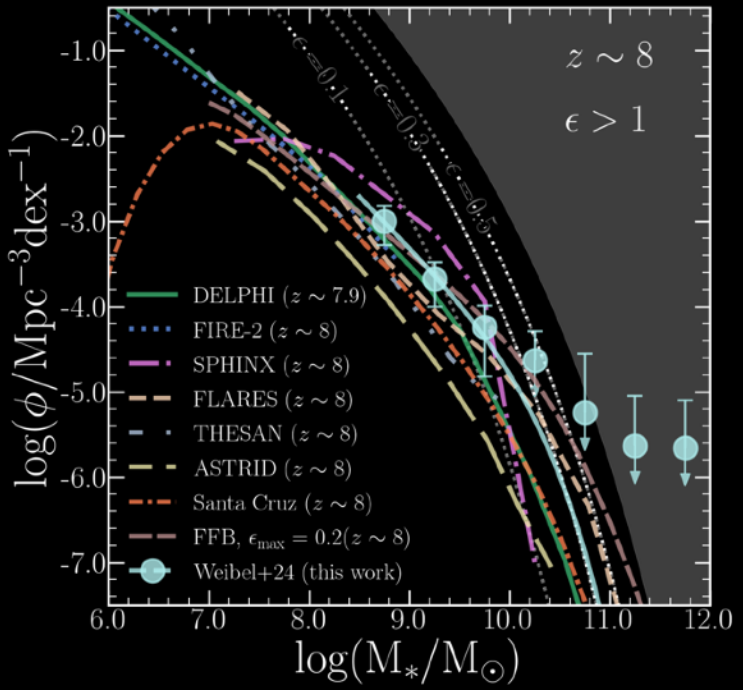

ϵ =0.1
ϵ =0.3
ϵ =0.5
ϵ =1
D+14
G+15
So+16
B+19
K+20
St+21
W+23
N-C+23
H+24
W+24 (this work)
$\log(\rho_*/M_\odot\,\mathrm{Mpc}^{-3})$
z
Weibel+ 2024

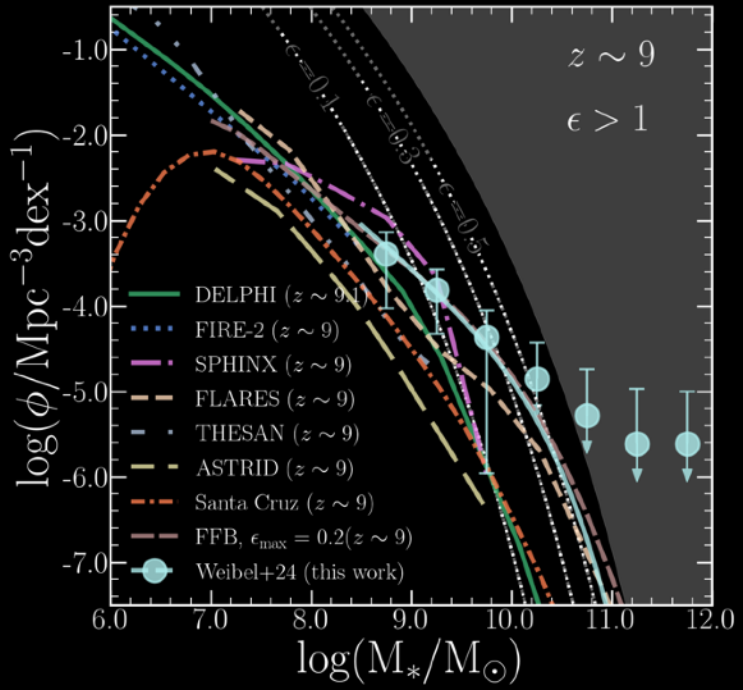

$z \sim 4$
$\epsilon > 1$
$\epsilon_{\rm max}=0.1$
$\epsilon_{\rm max}=0.3$
$\epsilon_{\rm max}=0.5$
DELPHI ($z \sim 4.5$)
ASTRID ($z \sim 4$)
Santa Cruz ($z \sim 4$)
FFB, $\epsilon_{\rm max} = 0.2 (z \sim 4)$
Weibel+24 (this work)
$\log(\phi/{\rm Mpc}^{-3}{\rm dex}^{-1})$
$\log({\rm M}_*/{\rm M}_\odot)$


$z \sim 5$
$\epsilon > 1$
$\epsilon_{\rm max}=0.1$
$\epsilon_{\rm max}=0.3$
$\epsilon_{\rm max}=0.5$
DELPHI ($z \sim 4.9$)
FIRE-2 ($z \sim 5$)
SPHINX ($z \sim 5$)
FLARES ($z \sim 5$)
ASTRID ($z \sim 5$)
Santa Cruz ($z \sim 5$)
FFB, $\epsilon_{\rm max} = 0.2 (z \sim 5)$
Weibel+24 (this work)
$\log(\phi/{\rm Mpc}^{-3}{\rm dex}^{-1})$
$\log({\rm M}_*/{\rm M}_\odot)$

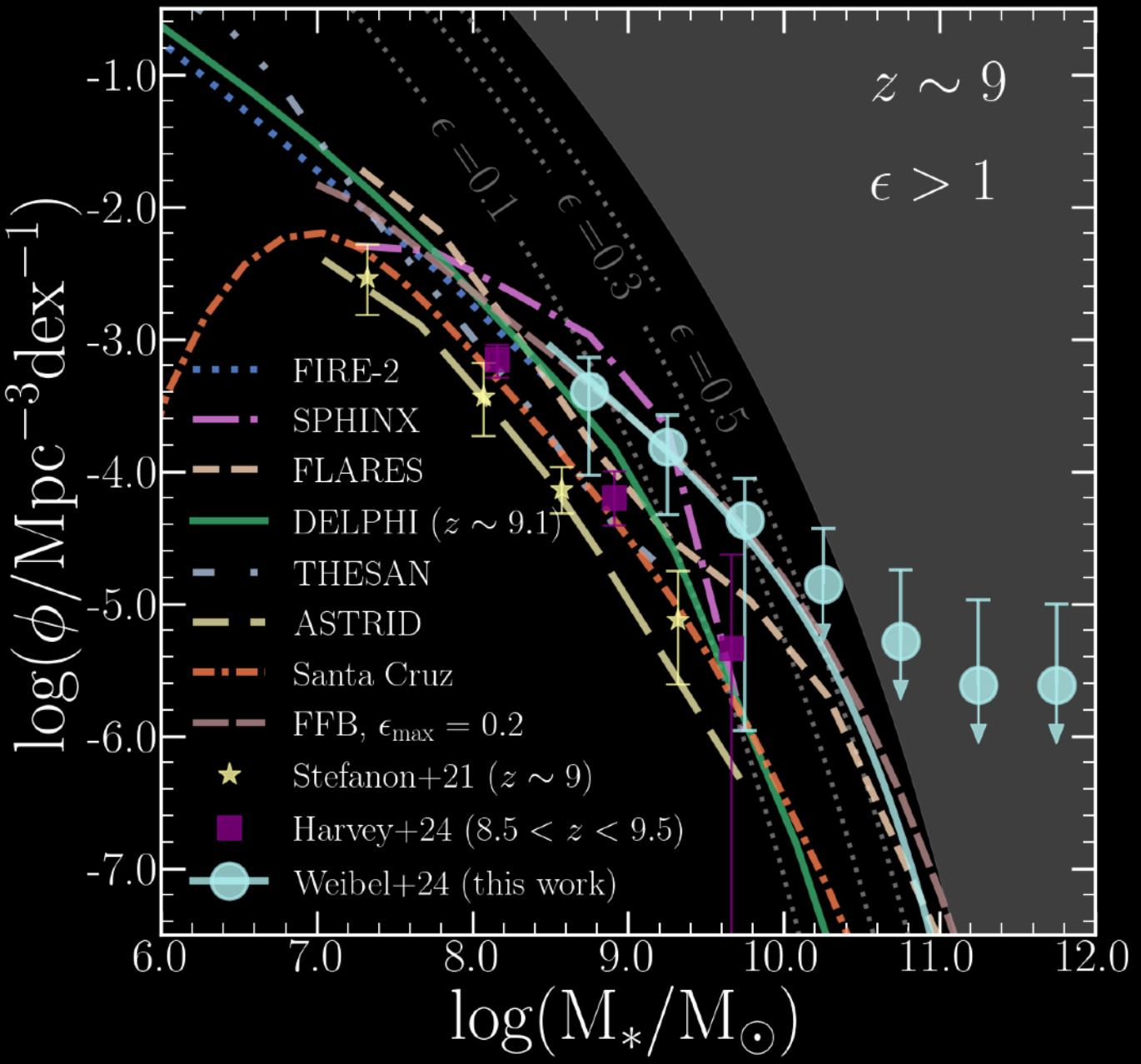

$z \sim 6$
$\epsilon > 1$
$\epsilon_{\rm max}=0.1$
$\epsilon_{\rm max}=0.3$
$\epsilon_{\rm max}=0.5$
DELPHI ($z \sim 5.9$)
FIRE-2 ($z \sim 6$)
SPHINX ($z \sim 6$)
FLARES ($z \sim 6$)
THESAN ($z \sim 6$)
ASTRID ($z \sim 6$)
Santa Cruz ($z \sim 6$)
FFB, $\epsilon_{\rm max} = 0.2 (z \sim 6)$
Weibel+24 (this work)
$\log(\phi/{\rm Mpc}^{-3}{\rm dex}^{-1})$
$\log({\rm M}_*/{\rm M}_\odot)$


$z \sim 7$
$\epsilon > 1$
$\epsilon_{\rm max}=0.1$
$\epsilon_{\rm max}=0.3$
$\epsilon_{\rm max}=0.5$
DELPHI ($z \sim 6.9$)
FIRE-2 ($z \sim 7$)
SPHINX ($z \sim 7$)
FLARES ($z \sim 7$)
THESAN ($z \sim 7$)
ASTRID ($z \sim 7$)
Santa Cruz ($z \sim 7$)
FFB, $\epsilon_{\rm max} = 0.2 (z \sim 7)$
Weibel+24 (this work)
$\log(\phi/{\rm Mpc}^{-3}{\rm dex}^{-1})$
$\log({\rm M}_*/{\rm M}_\odot)$


$z \sim 8$
$\epsilon > 1$
$\epsilon_{\rm max}=0.1$
$\epsilon_{\rm max}=0.3$
$\epsilon_{\rm max}=0.5$
DELPHI ($z \sim 7.9$)
FIRE-2 ($z \sim 8$)
SPHINX ($z \sim 8$)
FLARES ($z \sim 8$)
THESAN ($z \sim 8$)
ASTRID ($z \sim 8$)
Santa Cruz ($z \sim 8$)
FFB, $\epsilon_{\rm max} = 0.2 (z \sim 8)$
Weibel+24 (this work)
$\log(\phi/{\rm Mpc}^{-3}{\rm dex}^{-1})$
$\log({\rm M}_*/{\rm M}_\odot)$

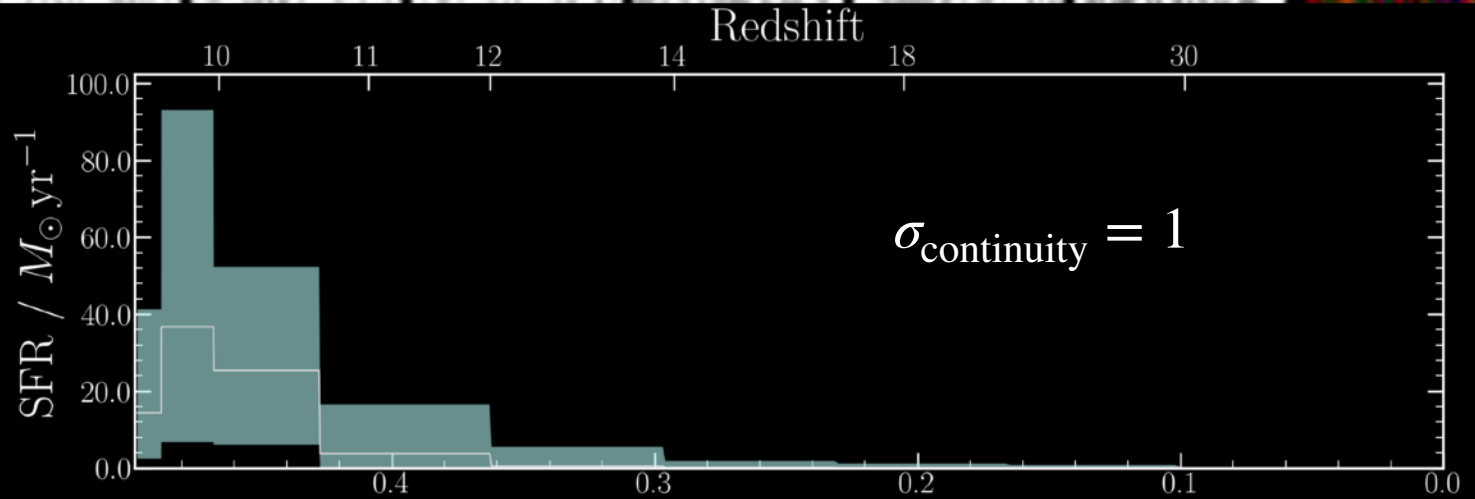

$z \sim 9$
$\epsilon > 1$
$\epsilon_{\rm max}=0.1$
$\epsilon_{\rm max}=0.3$
$\epsilon_{\rm max}=0.5$
DELPHI ($z \sim 9.1$)
FIRE-2 ($z \sim 9$)
SPHINX ($z \sim 9$)
FLARES ($z \sim 9$)
THESAN ($z \sim 9$)
ASTRID ($z \sim 9$)
Santa Cruz ($z \sim 9$)
FFB, $\epsilon_{\rm max} = 0.2 (z \sim 9)$
Weibel+24 (this work)
$\log(\phi/{\rm Mpc}^{-3}{\rm dex}^{-1})$
$\log({\rm M}_*/{\rm M}_\odot)$

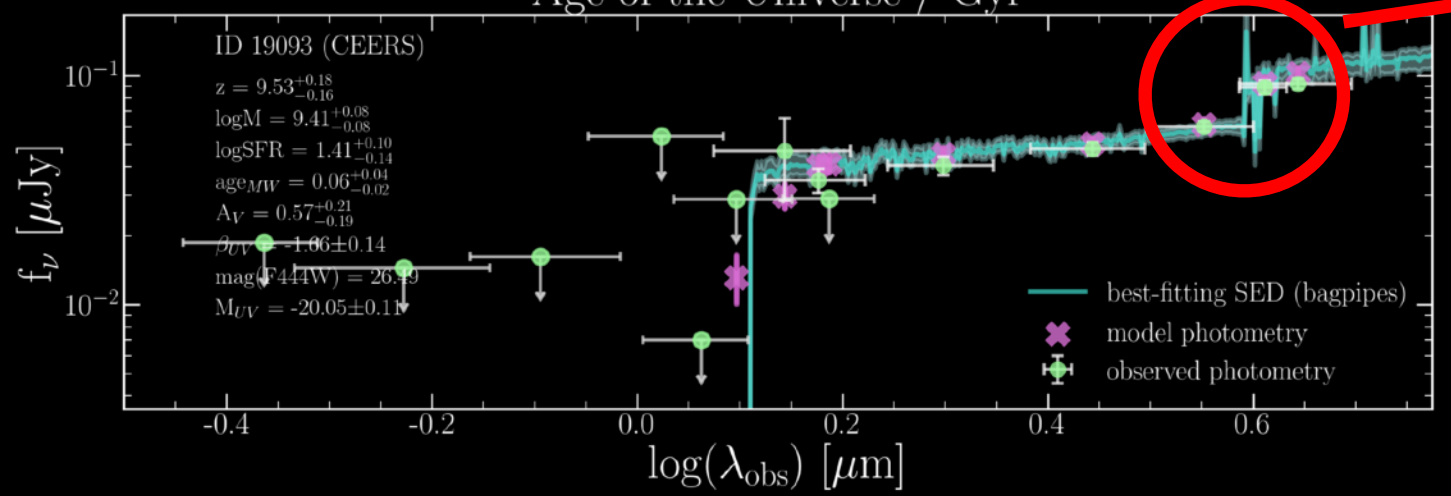
Weibel+ 2024


$z \sim 9$
$\epsilon > 1$
$\epsilon = 0.1$
$\epsilon = 0.3$
$\epsilon = 0.5$
FIRE-2
SPHINX
FLARES
DELPHI ($z \sim 9.1$)
THESAN
ASTRID
Santa Cruz
FFB, $\epsilon_{max} = 0.2$
Stefanon+21 ($z \sim 9$)
Harvey+24 ($8.5 < z < 9.5$)
Weibel+24 (this work)
$\log(\phi/\mathrm{Mpc}^{-3}\mathrm{dex}^{-1})$
$\log(M_*/M_\odot)$
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0

Outlook: Focus on $z \sim 9$

PRELIMINARY



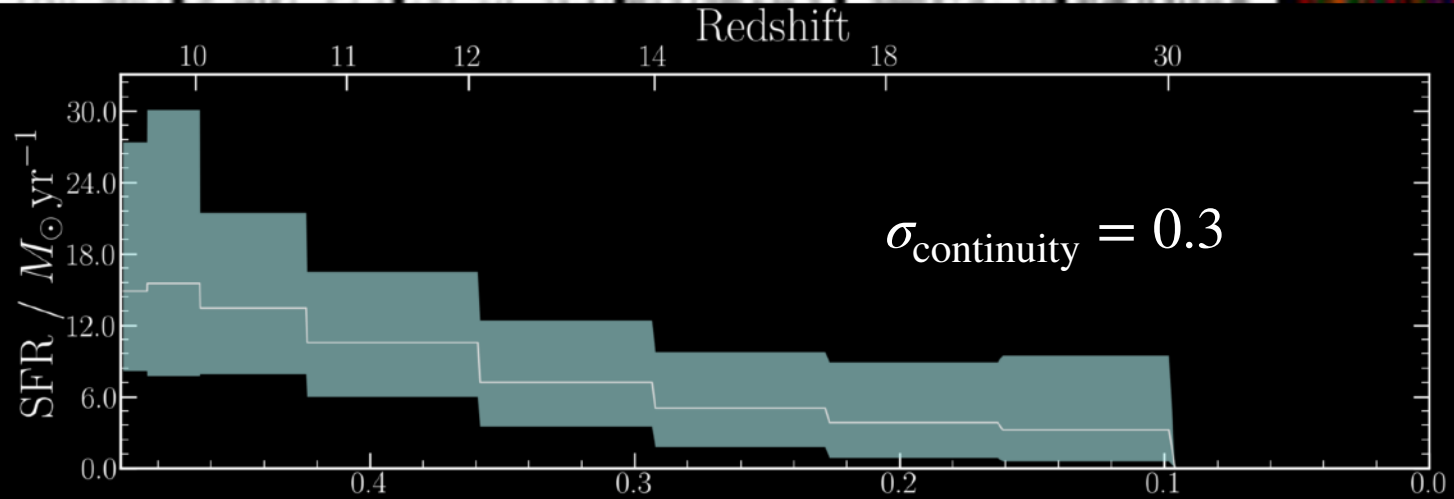


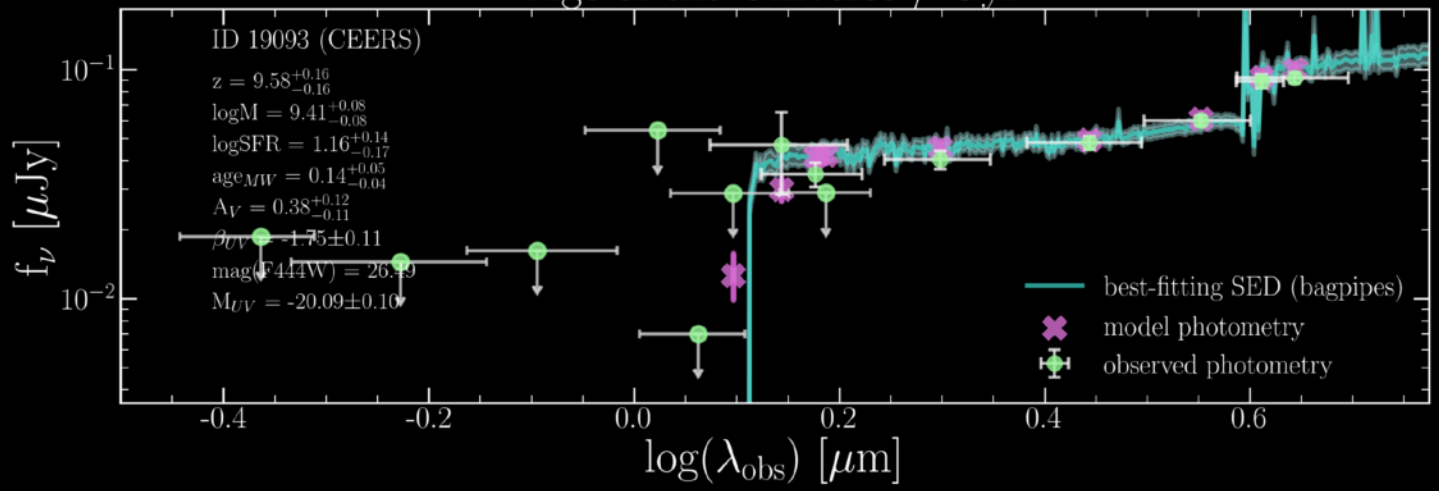
Balmer Break?

See
Roberts-Borsani+ 2020
Laporte+2021
Trussler+ 2024

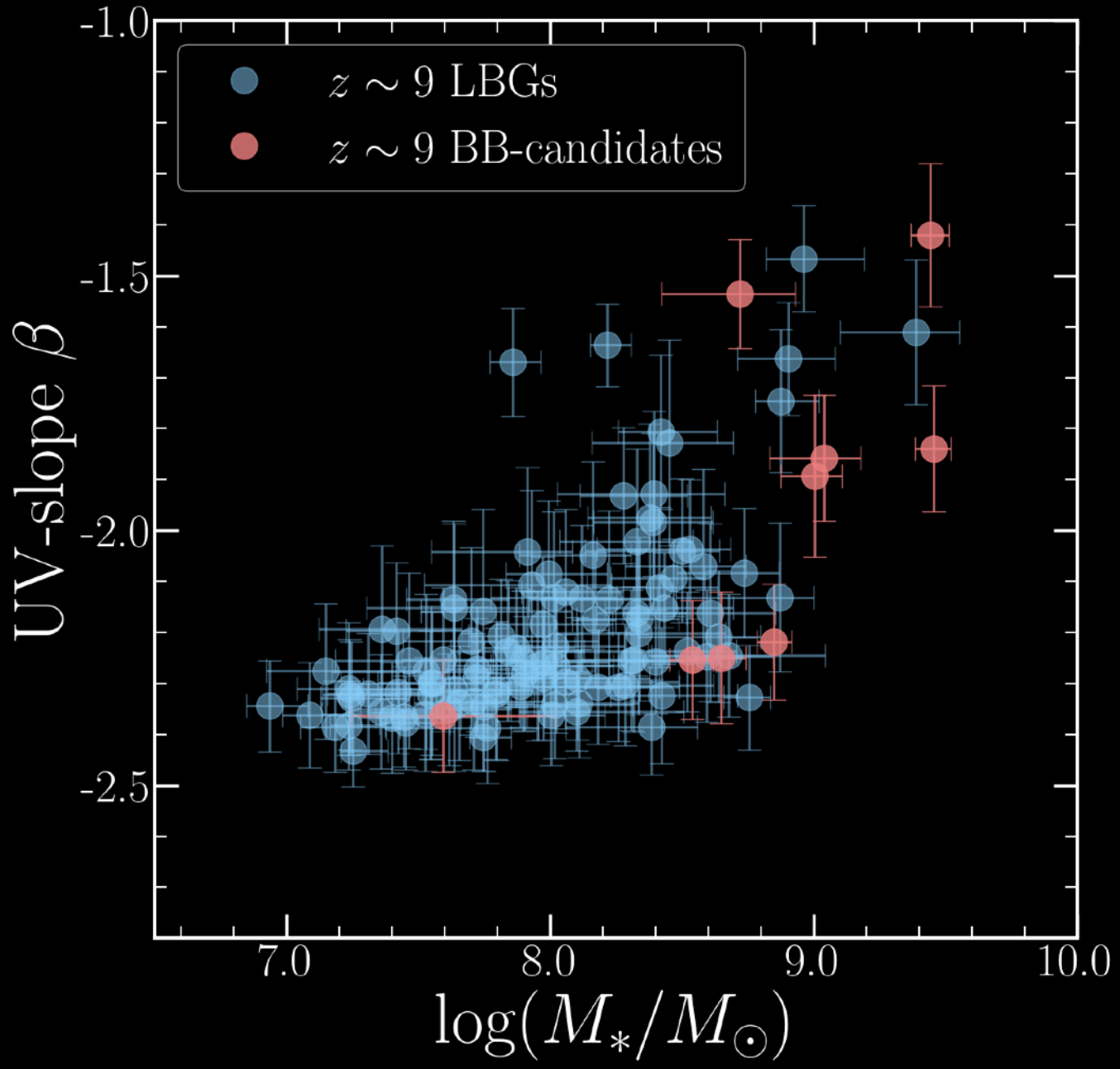
Outlook: Focus on $z \sim 9$

PRELIMINARY

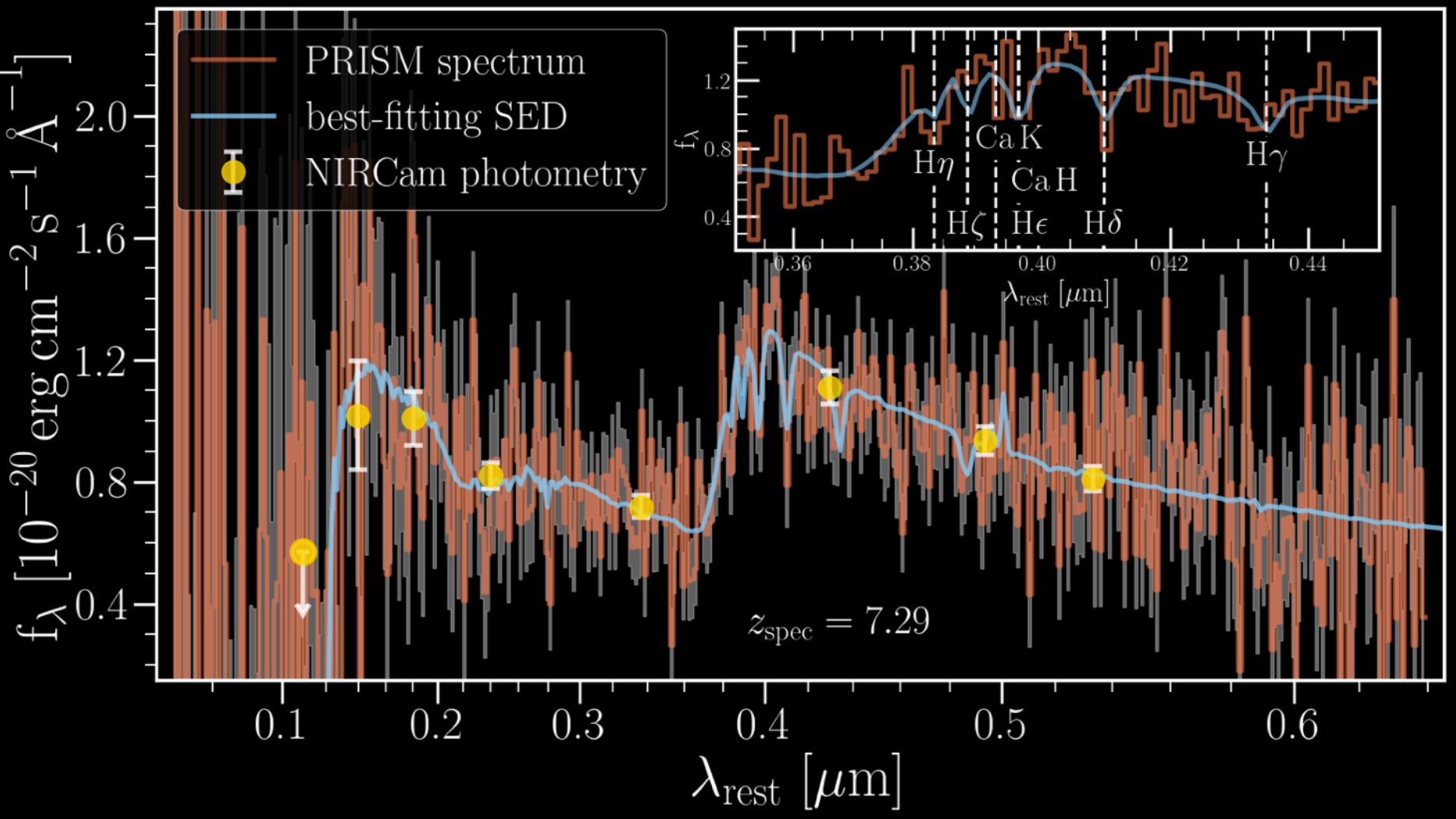




PRELIMINARY



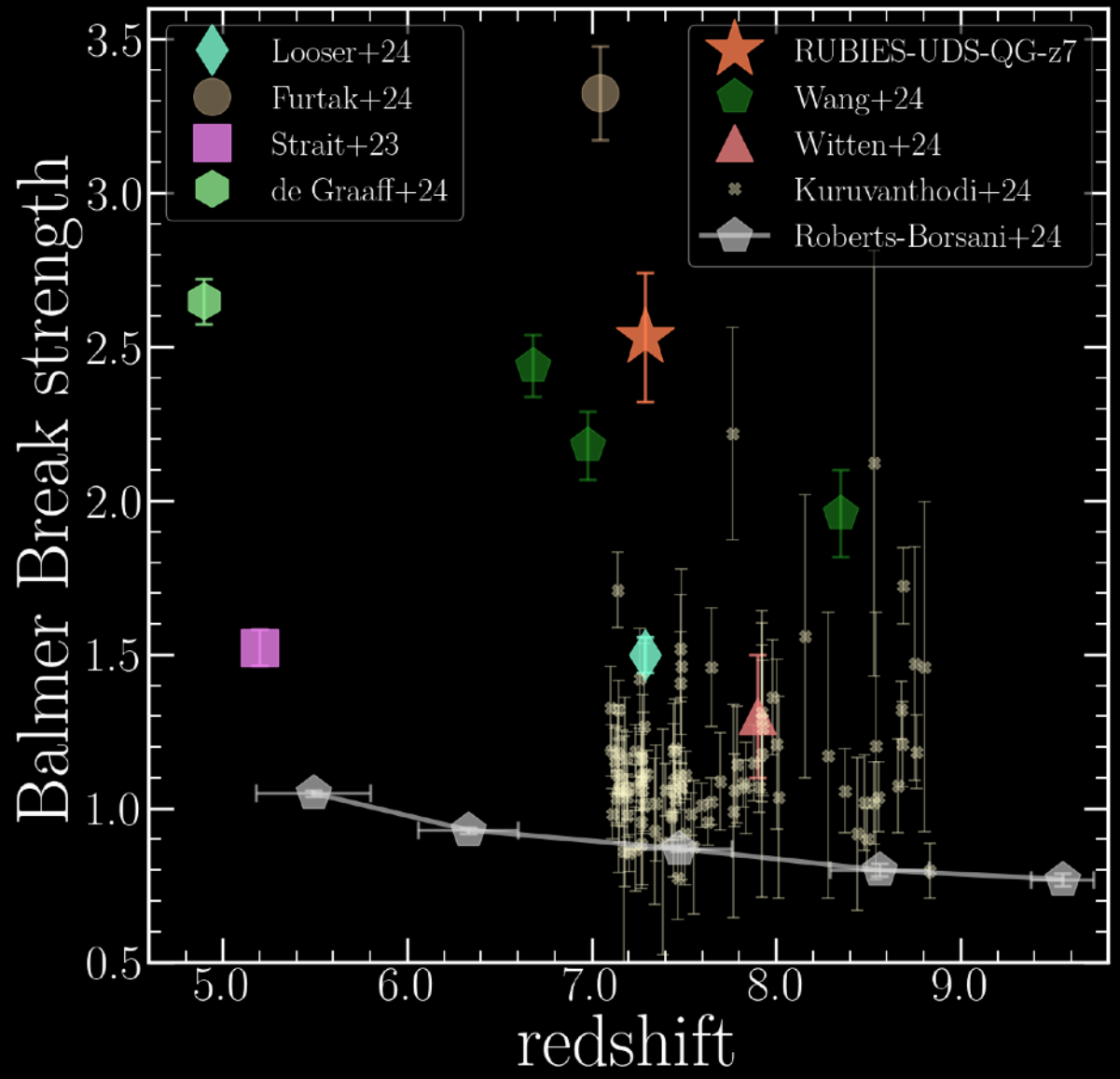
A massive quiescent galaxy at z = 7.3

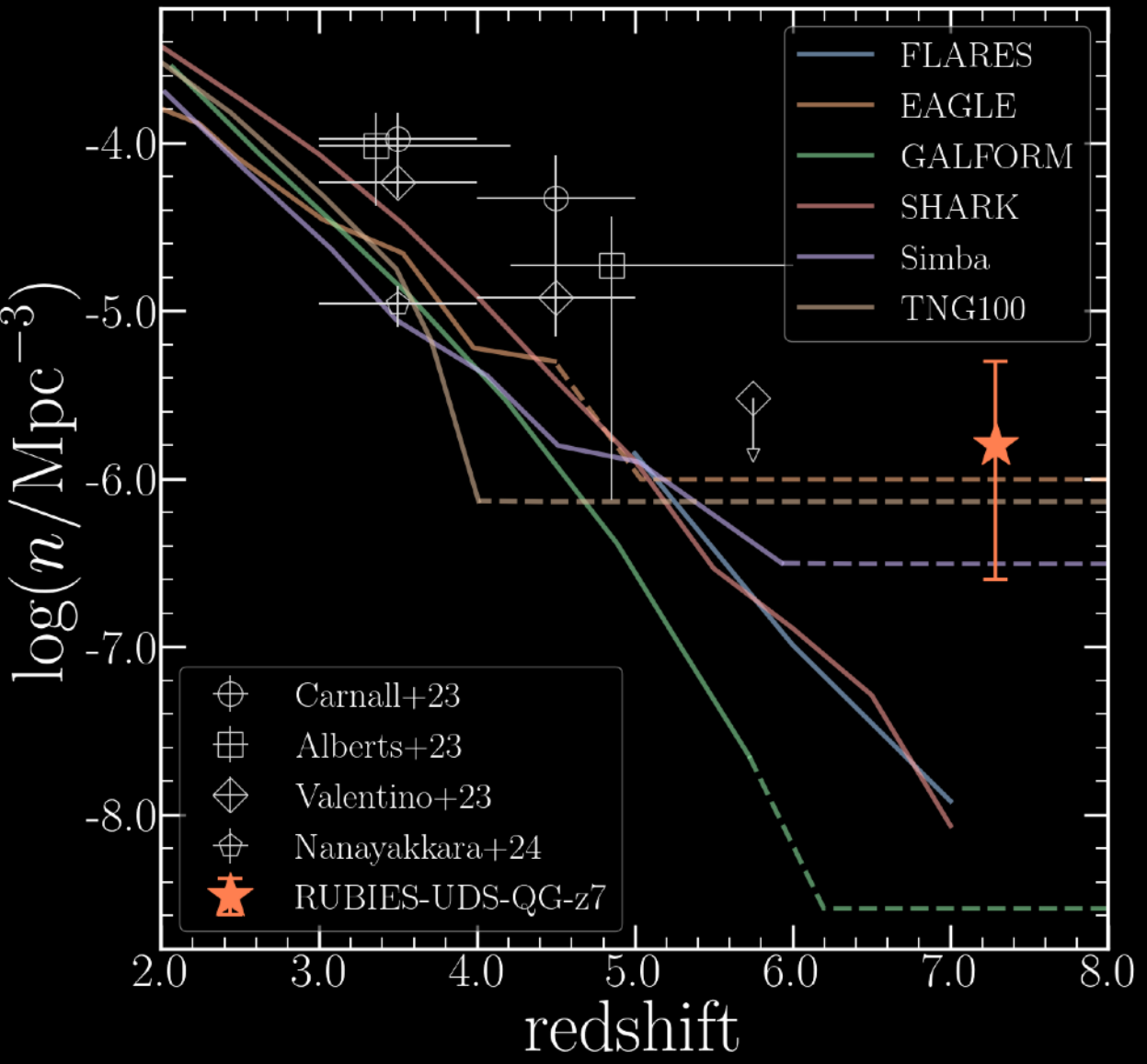


Weibel+ 2024b

$\log(M_*/\mathrm{M}_\odot) \sim 10.23 \quad \log(\Sigma_*/\mathrm{M}_\odot\,\mathrm{kpc}^{-2}) \sim 11 \quad \log(\mathrm{sSFR}_{50\,\mathrm{Myr}}/\mathrm{yr}^{-1}) \sim -10$

Weibel+ 2024b





Summary

- JWST SMFs at $z \sim 4-9$ are broadly consistent with pre-JWST results
- The high mass end of the SMF evolves rapidly from $z \sim 4-6$, driven by the build-up of UV-red, massive, dusty and quiescent galaxies
- More work is needed at $z \sim 9$ to infer accurate stellar masses and put tighter constraints on simulations
- Searching public JWST-imaging, we find ~10 objects with potential (weak) Balmer Breaks at $z \sim 9$ ($\sim 8\%$ of all LBGs at $z \sim 9$)
- They may be observed in an "off-state" among a population of galaxies with bursty SFHs, or they may have extended SFHs —> how to distinguish?
- We find a massive ($\log(M_*/\mathrm{M}_\odot) > 10$) quiescent galaxy at z = 7.3, whose strong Balmer Break (~2.5) and early quenching challenges simulations