



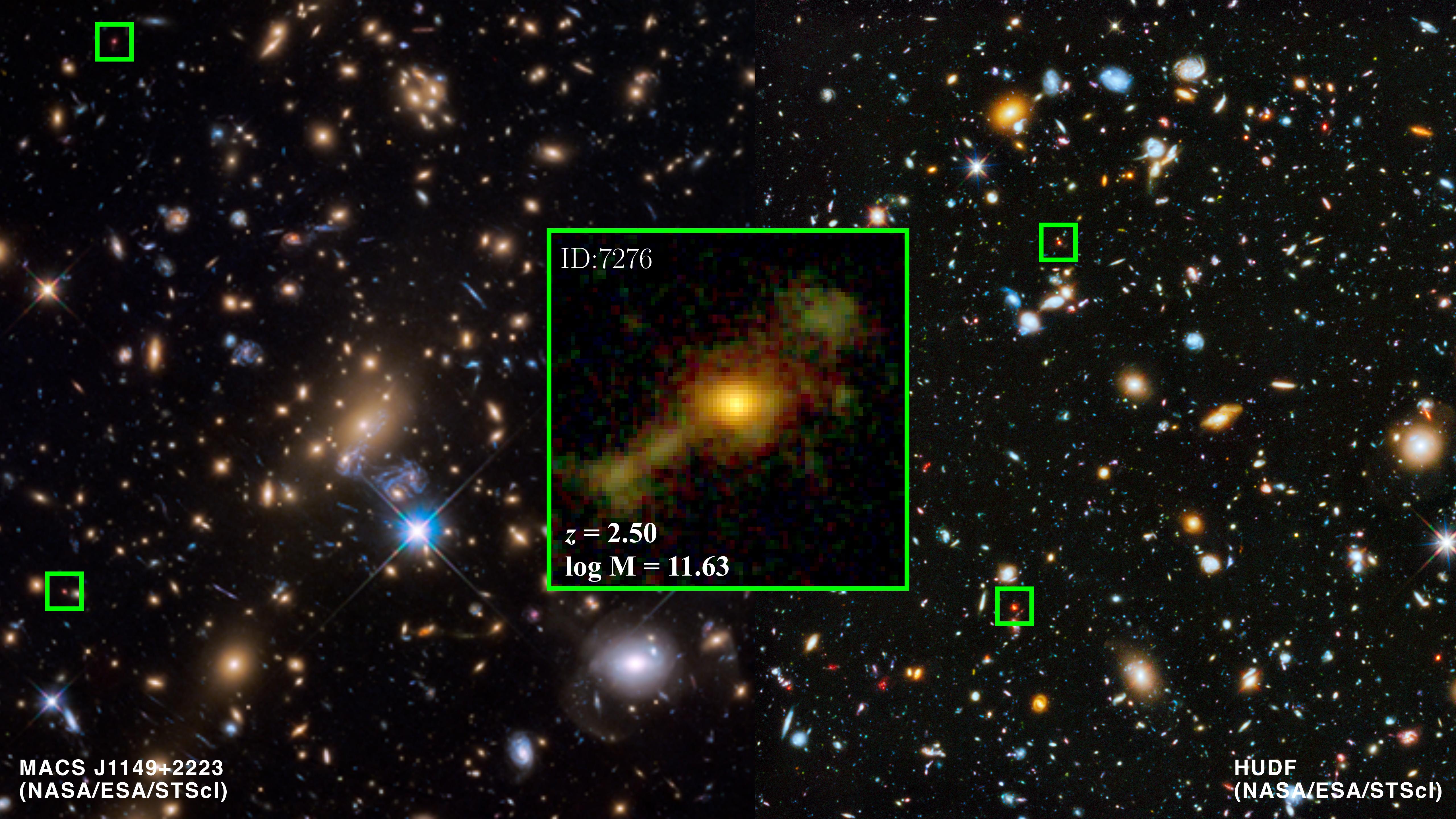
# Probing evolution and quenching histories of massive galaxies at high redshift



STScI | SPACE TELESCOPE  
SCIENCE INSTITUTE

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Gabe Brammer (U. Copenhagen), Xin Wang (IPAC), Charlotte  
Mason (CfA), and GLASS collaborators

Nov 21 2019 @ Subaru20th Anniversary Conference



ID:7276

$z = 2.50$   
 $\log M = 11.63$



MACS J1149+2223  
(NASA/ESA/STScI)

HUDF  
(NASA/ESA/STScI)

# Formation of massive galaxies?



**M 87 (NGC 4486)**

Ultra-high-sensitivity HDTV I.I. color camera (NHK)

Exp. 8 sec. (8 frames coadded) January 16, 1999

**Subaru Telescope, National Astronomical Observatory of Japan**

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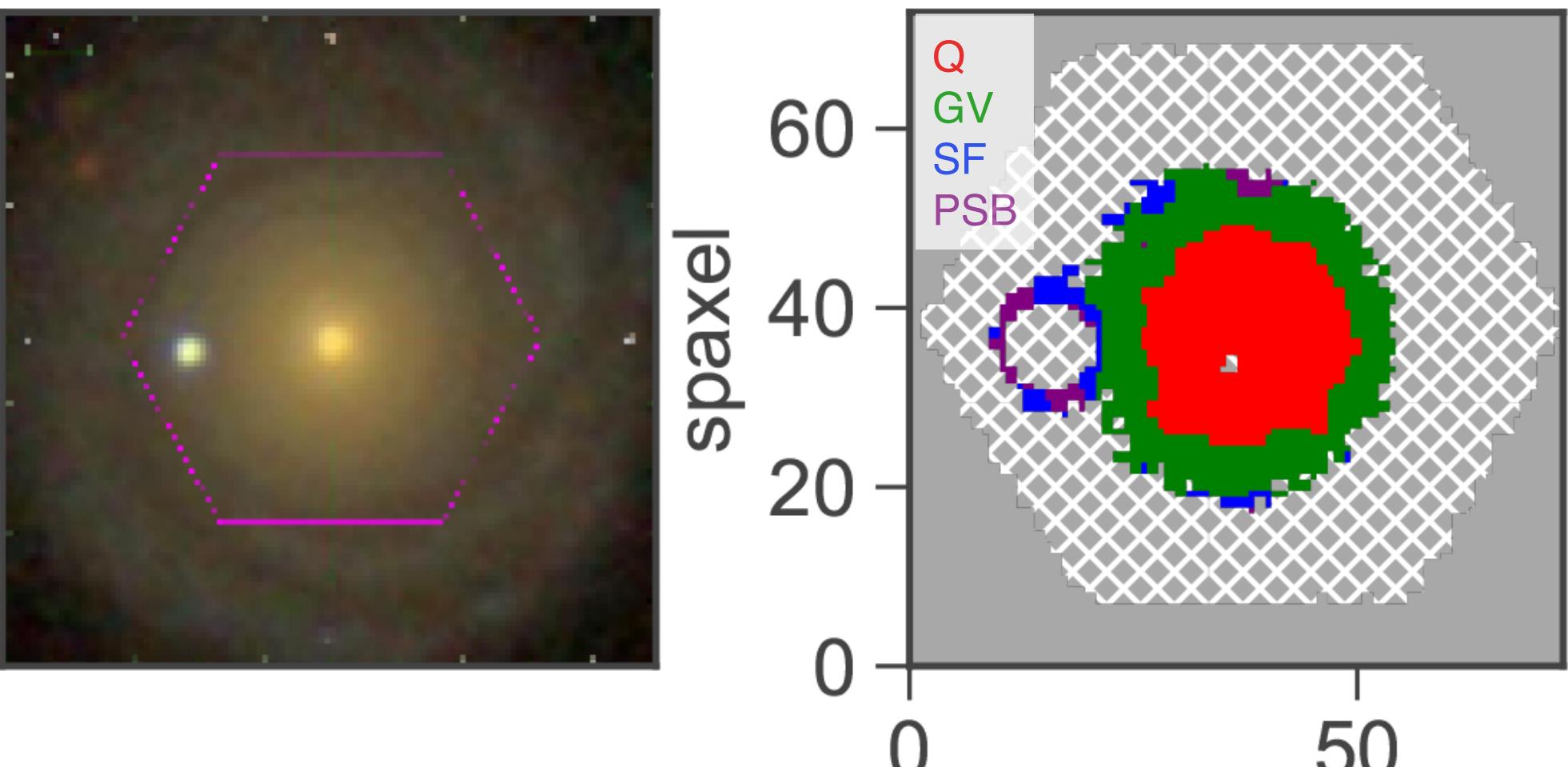
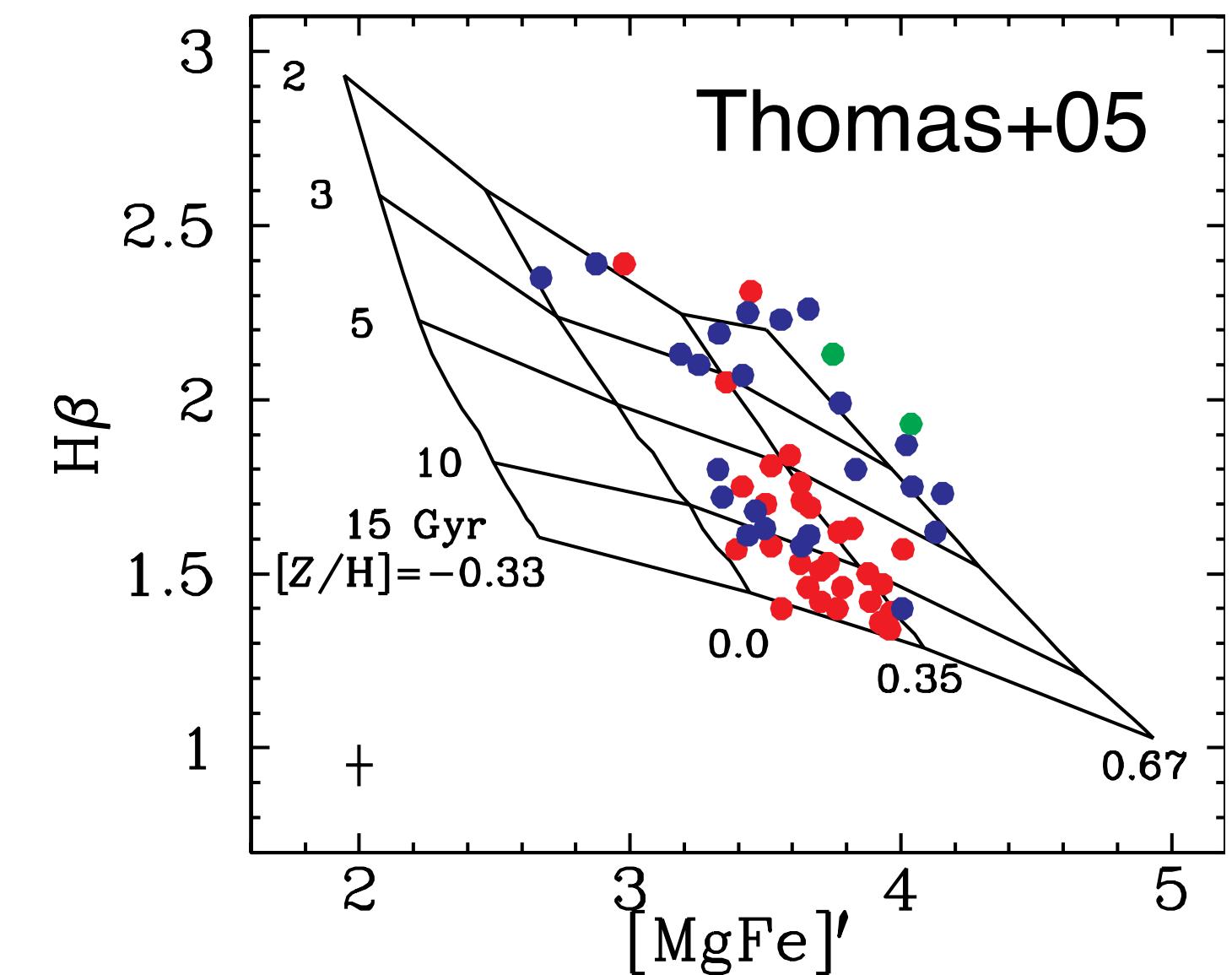


# Rise and Fall - When did massive galaxies form and quench?

## Fossil record / Stellar pop. analysis

- HR diagram - only if stars are resolved. (Cen A)
- High S/N spectra to absorption lines/Lick indices
- Spatially resolved properties

Heavens+04, Tojeiro+07, Panter+08, Thomas+10, Wang+18, Lin+19

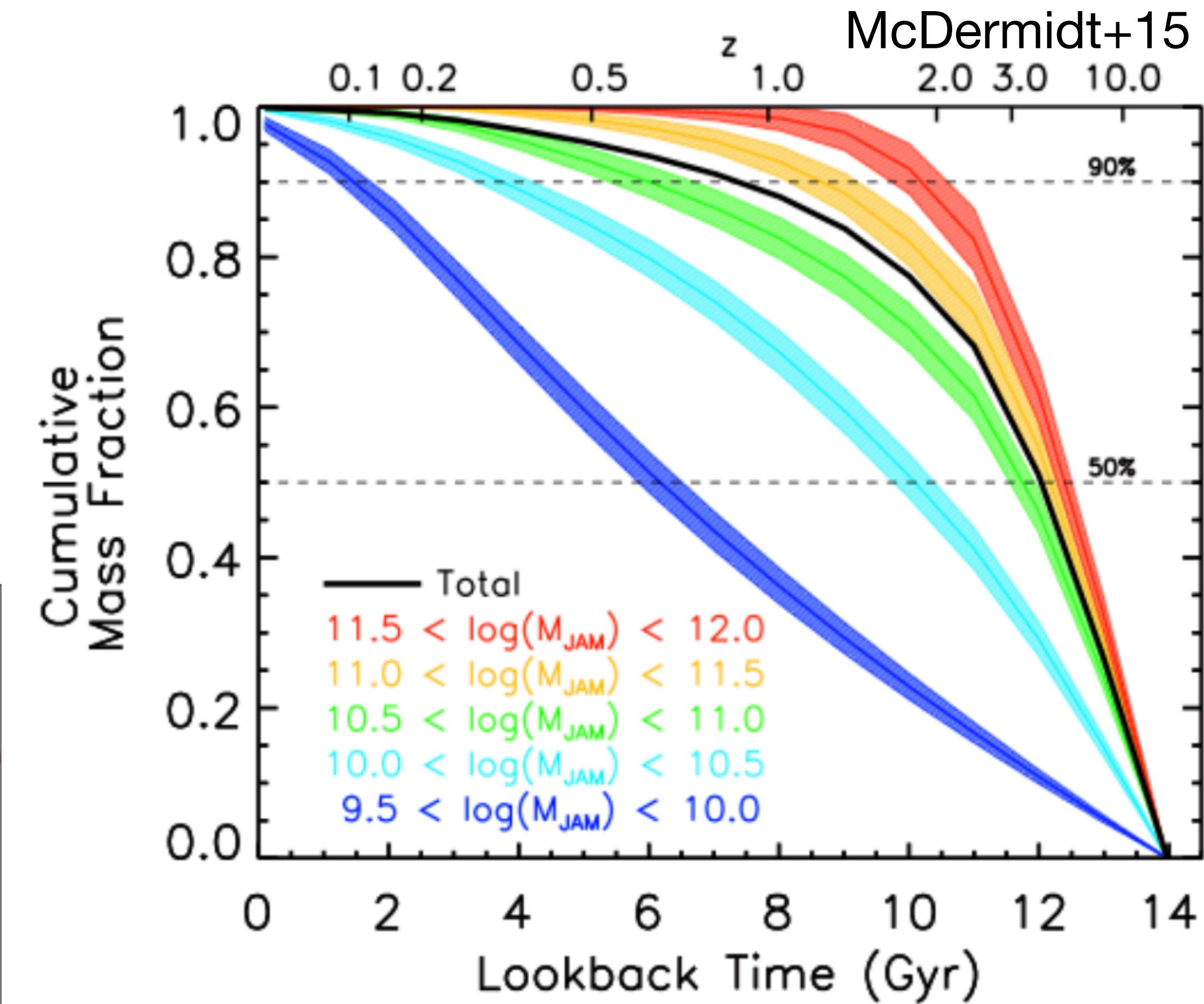
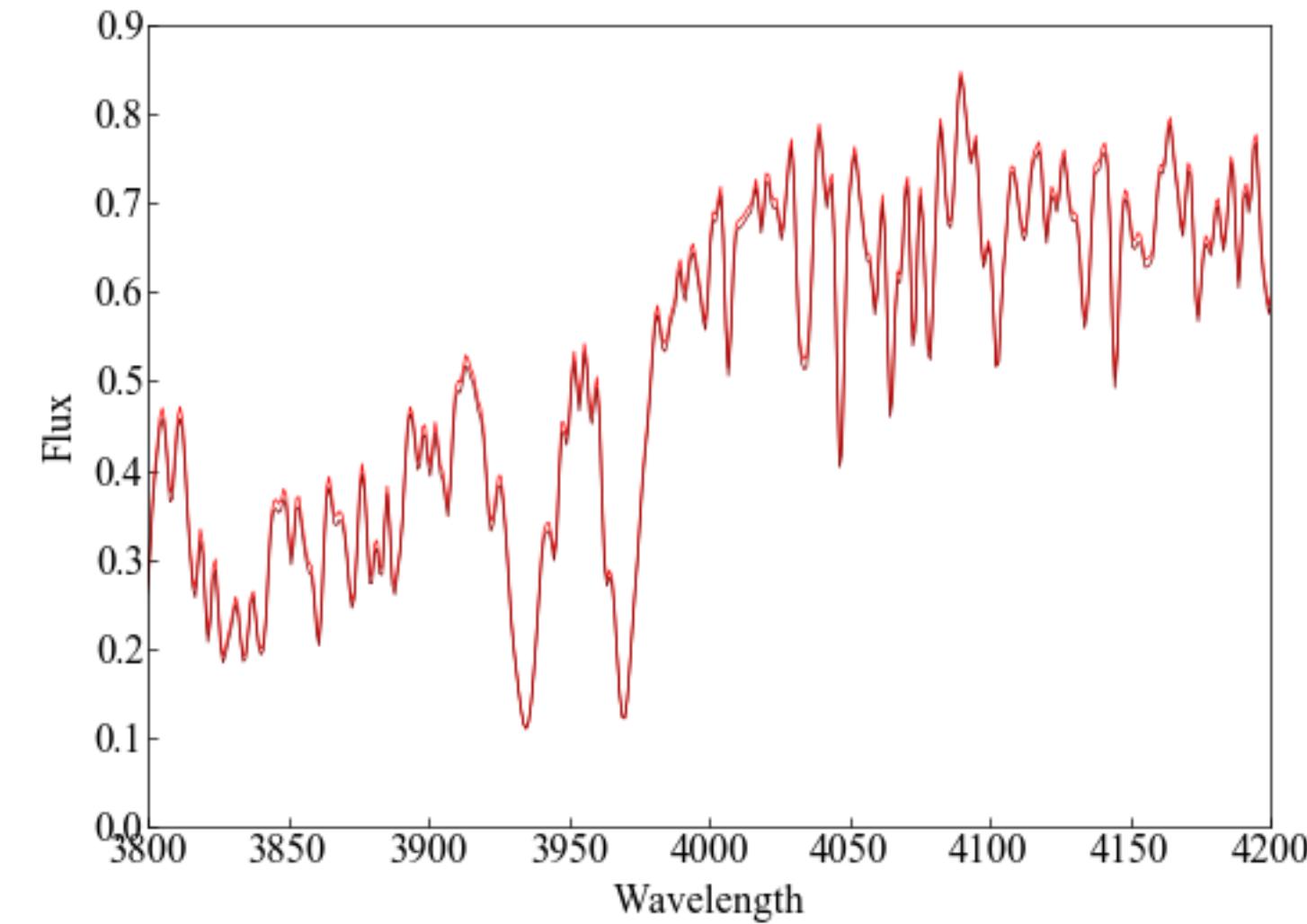
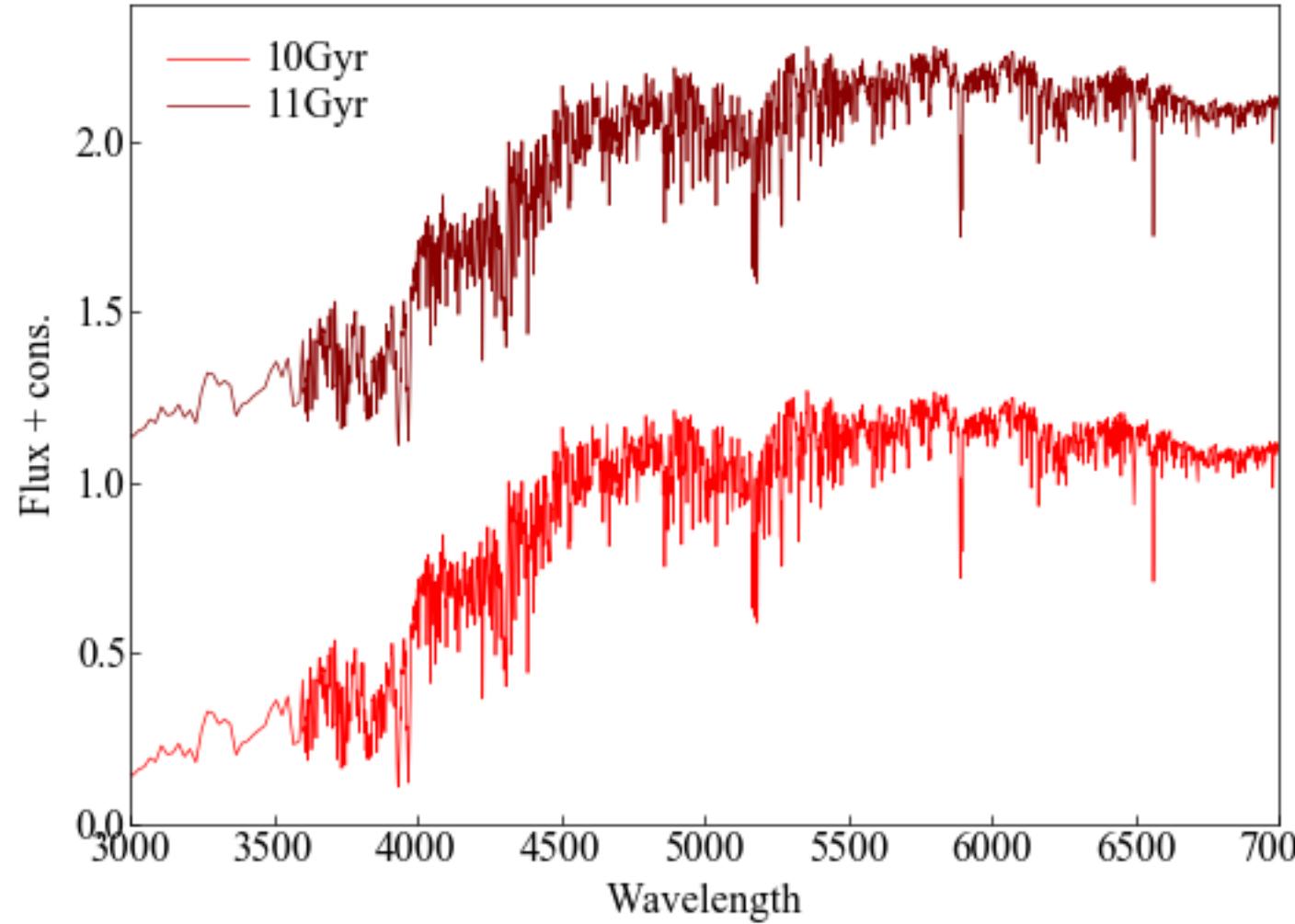




# Rise and Fall - When did massive galaxies form and quench?

## “More than 10Gyr ago” “bursty SF”

- Not sensitive at >10Gyr  
(age-Z, systematics in models/velocity dispersion)
- Limit is z~2 from local universe  
(when SF of massive galaxies are done already!!)



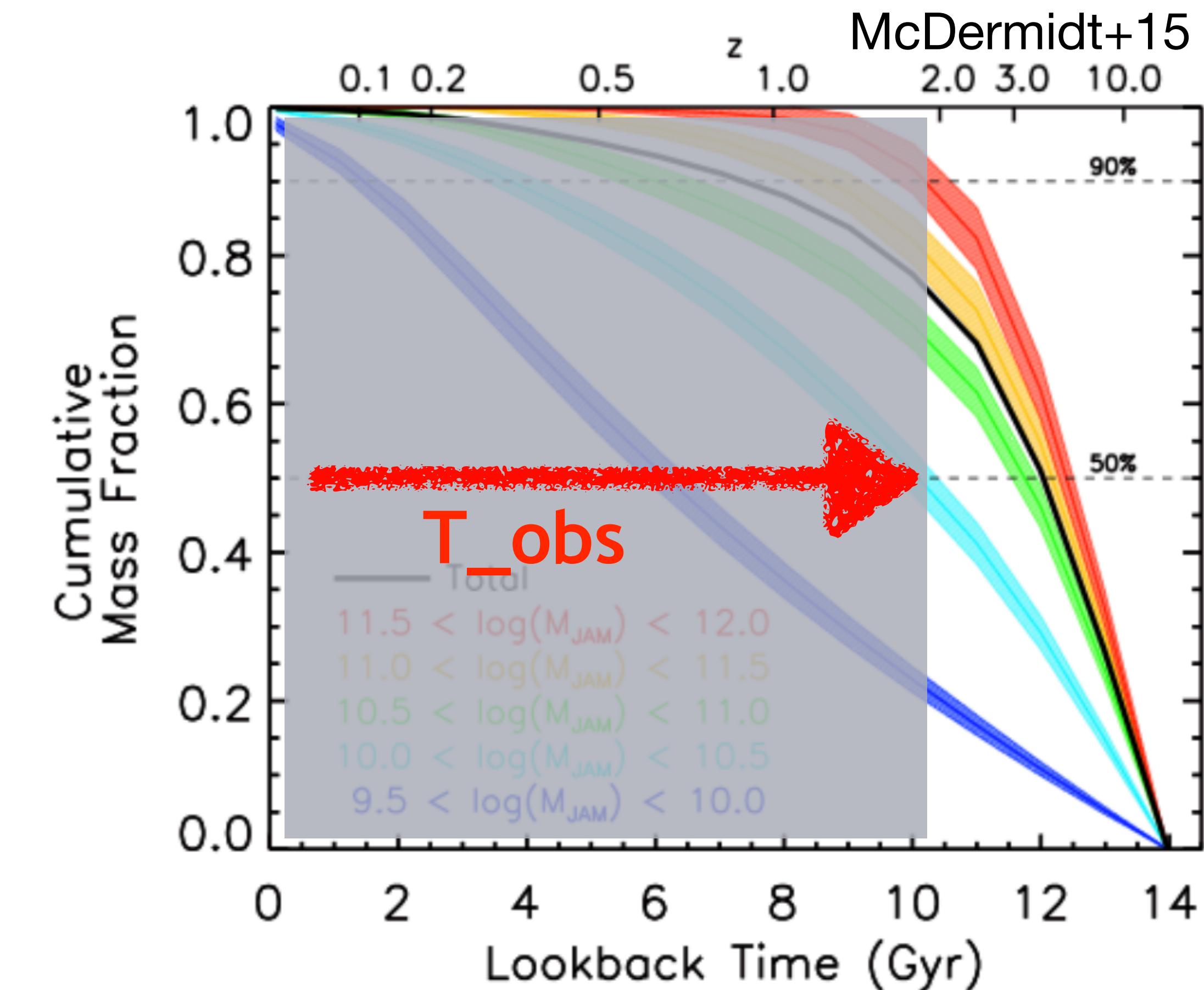
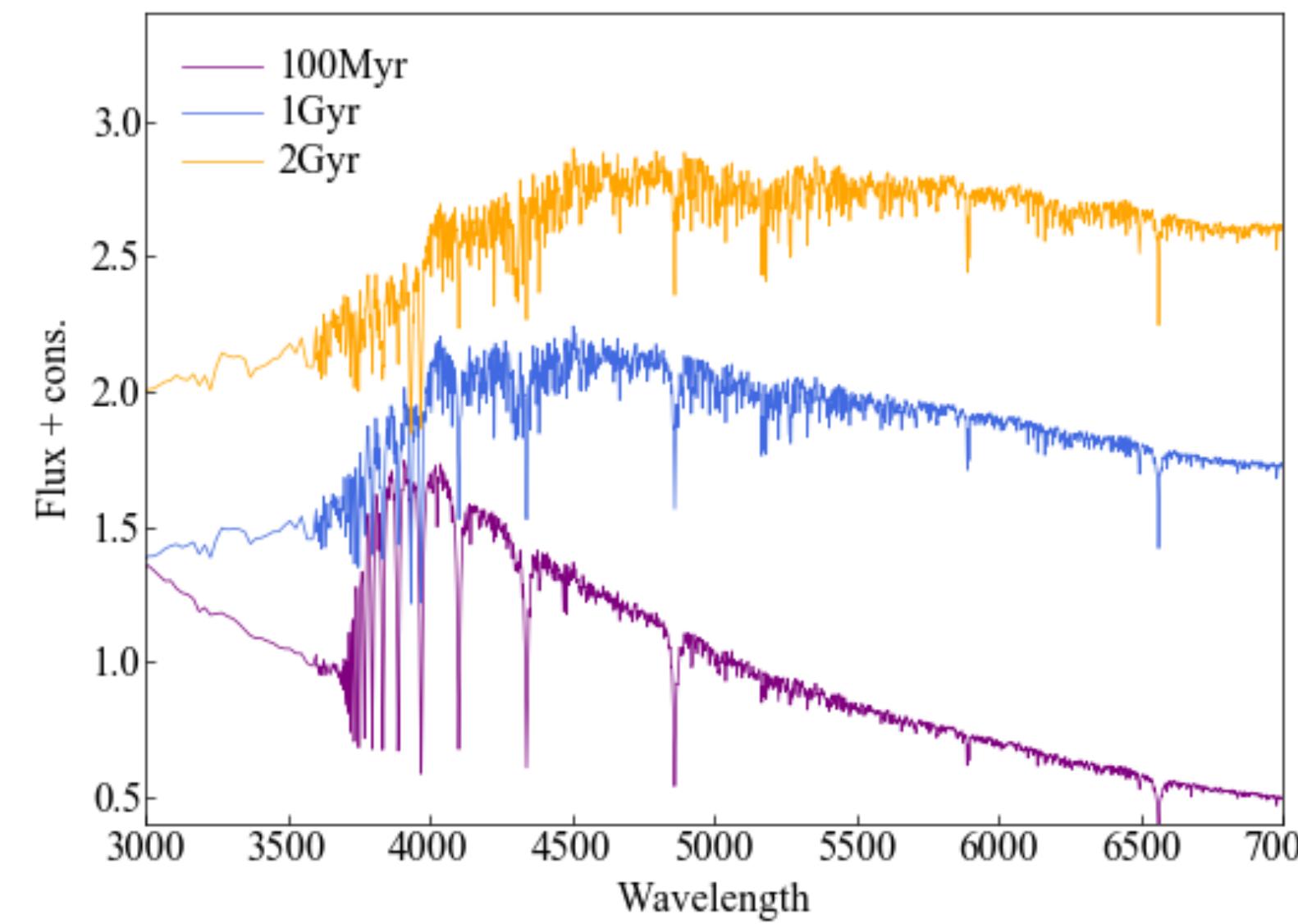
See also review by C.Conroy (2013)



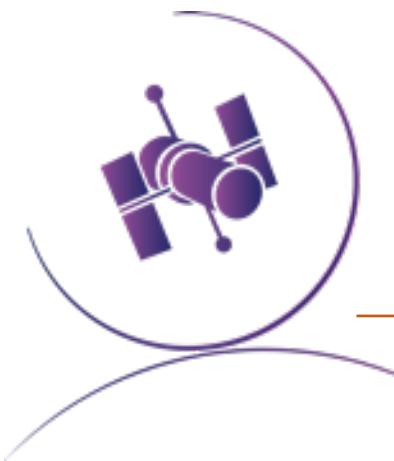
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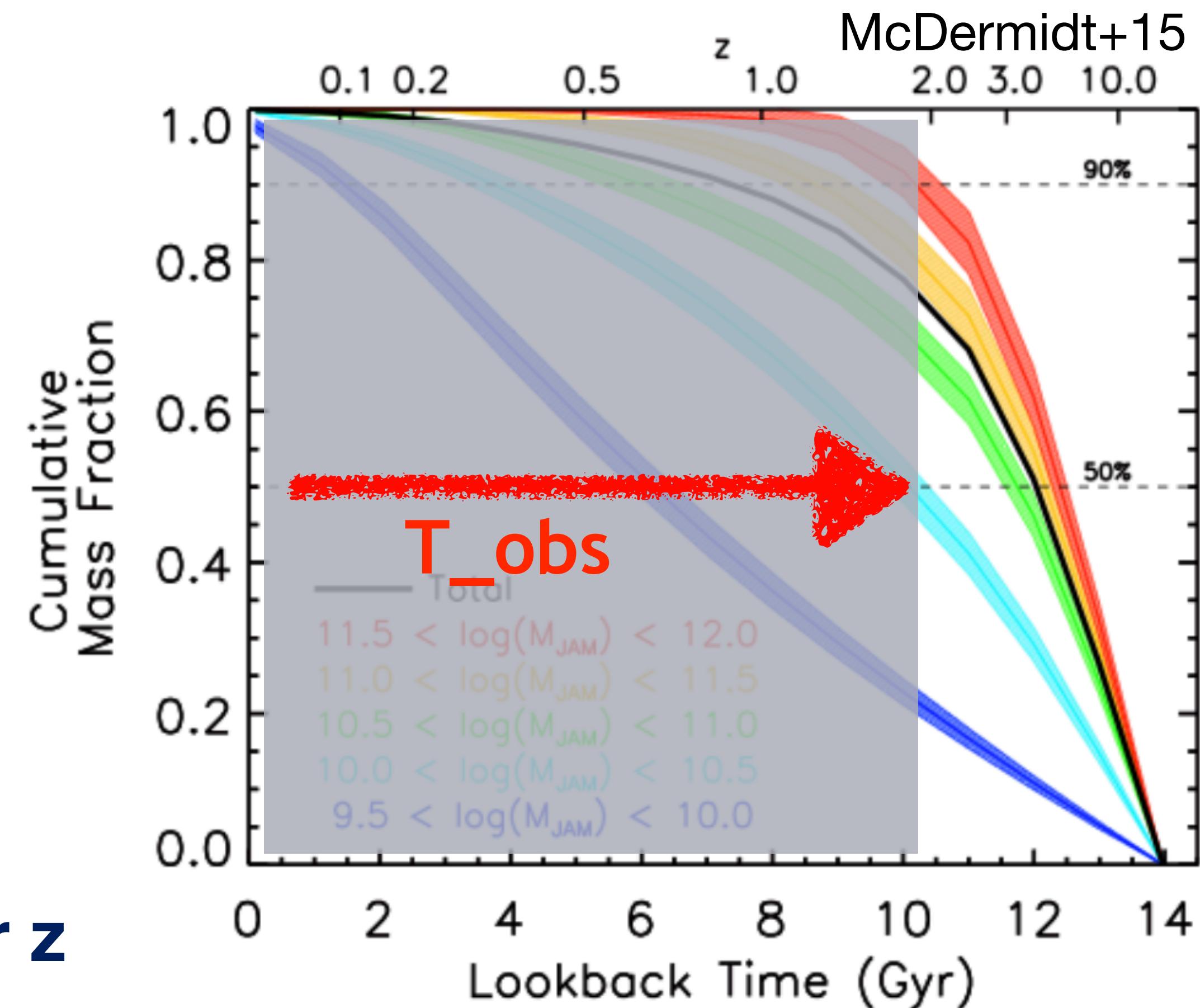
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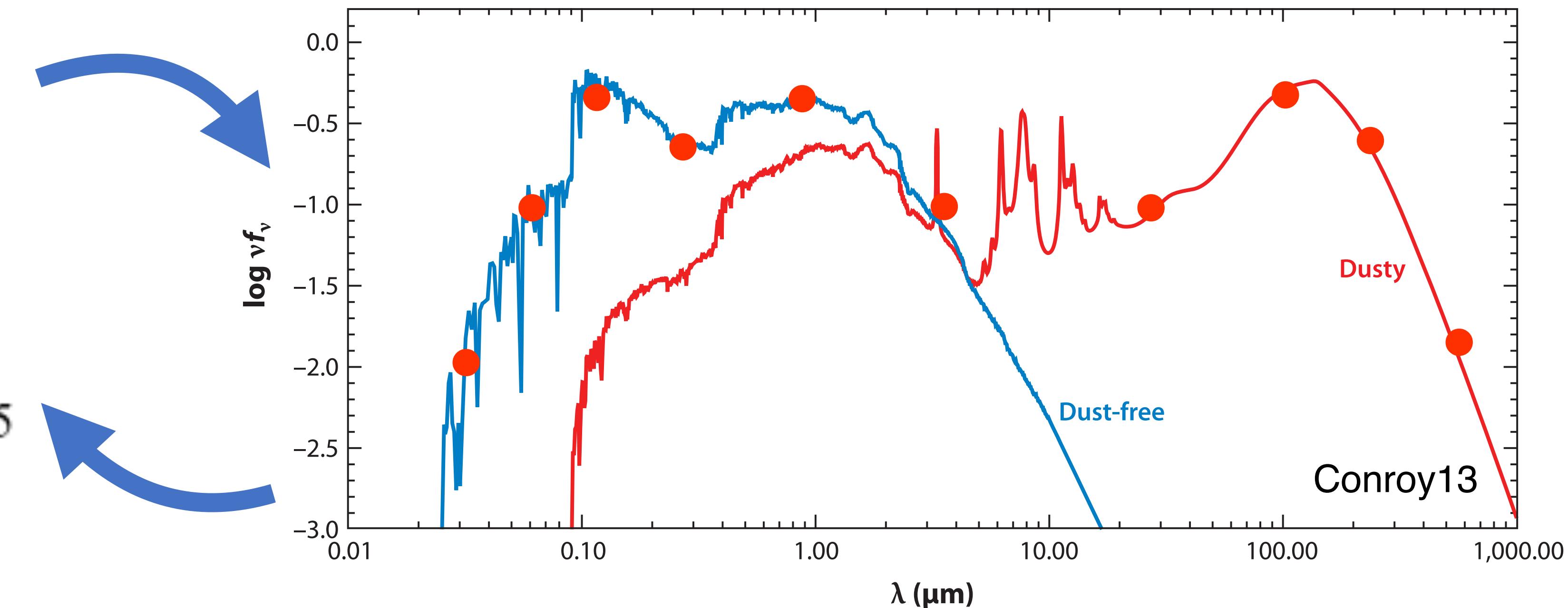
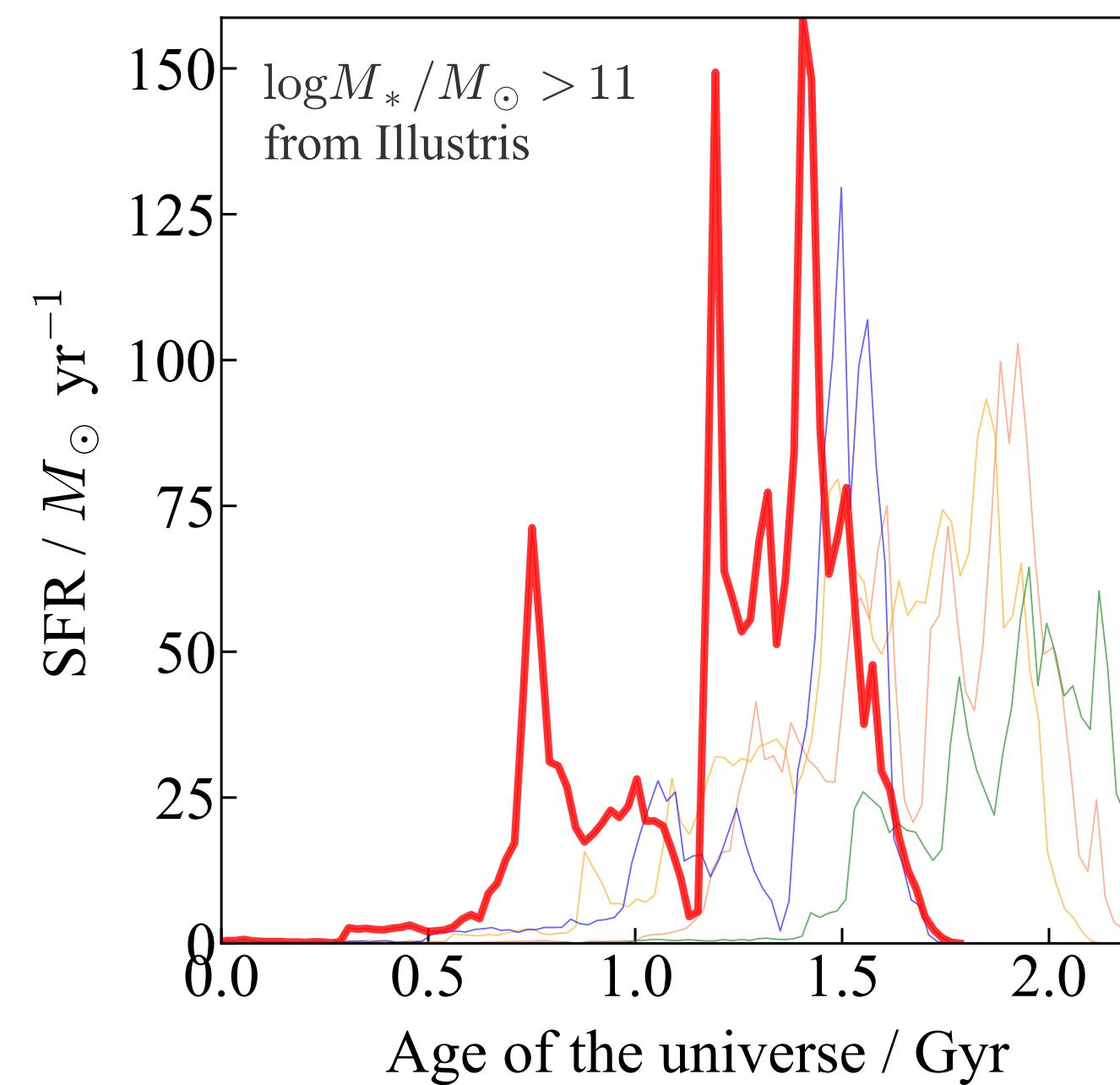
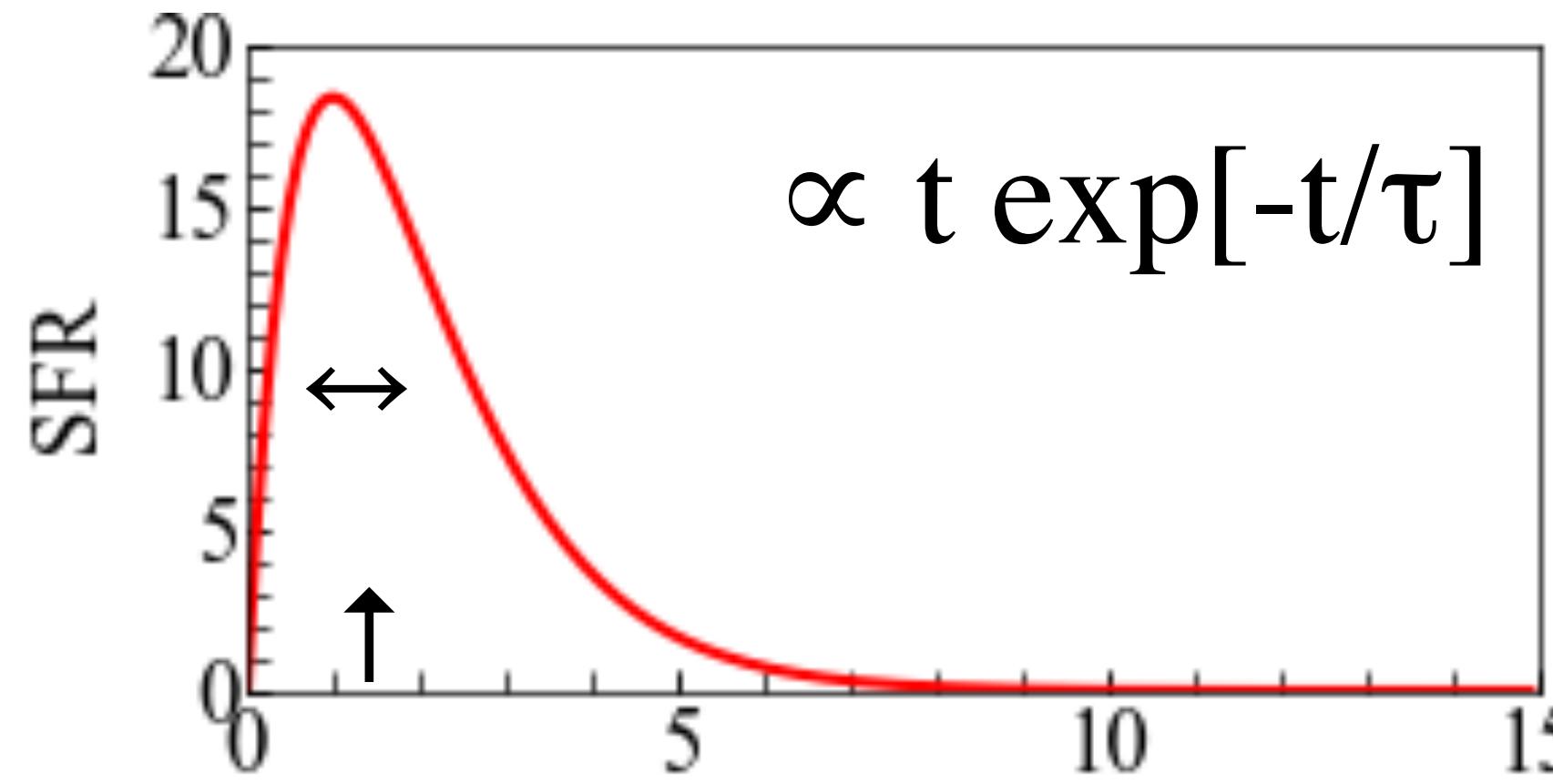
## Stellar population analysis of high-z galaxies

- At which time scale did they form?
- What quenched (massive) galaxies?
- Evolutionary connection to SFGs at higher z
- Contribution to reionization?





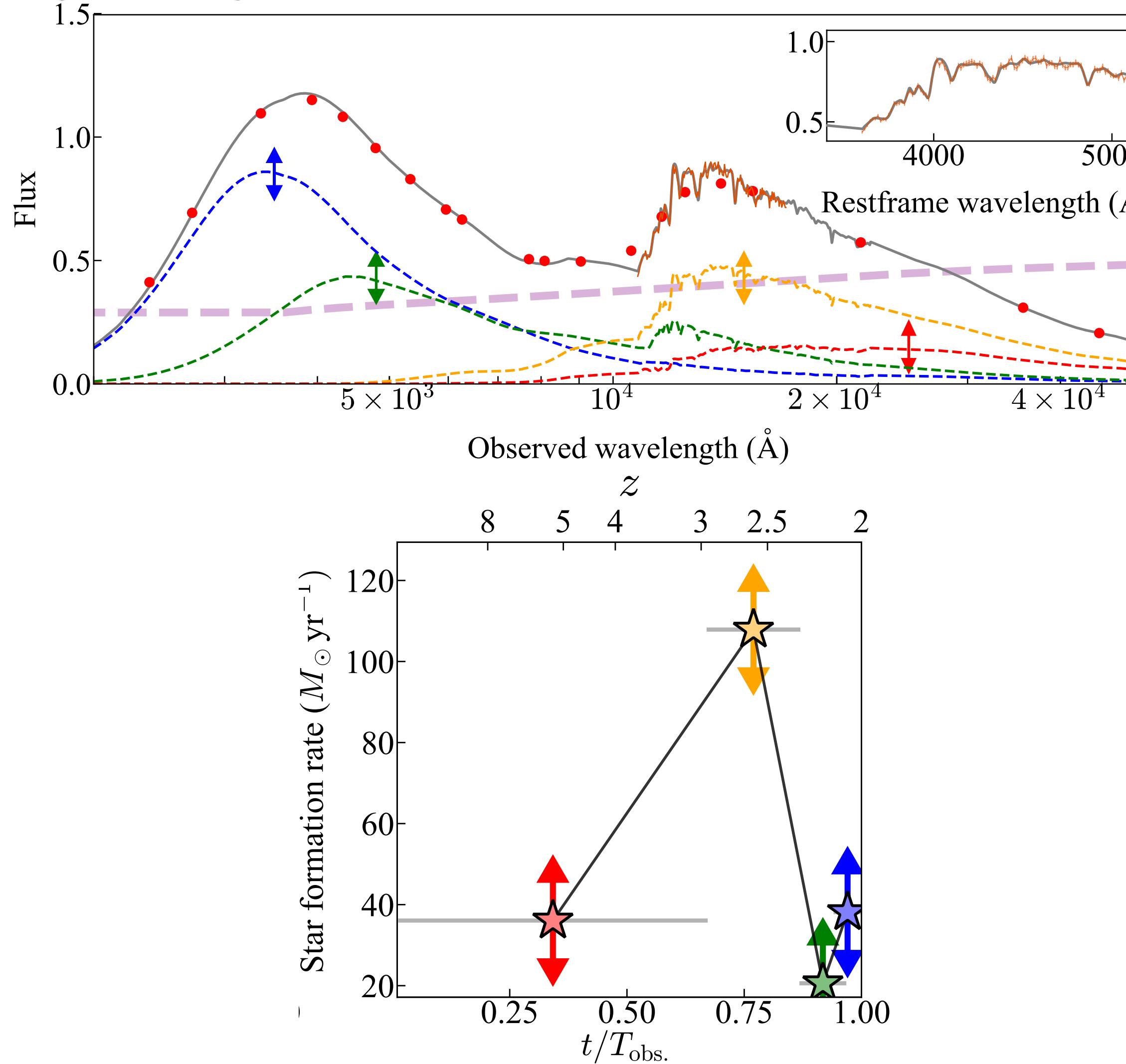
# How We Reconstruct Star Formation Histories



**Functional forms are not real galaxy SFHs!**  
**How does this affect results? (stellar mass, age)**  
**Systematic bias in sample selection?**  
**(talk contribution by Pacifici/Belli/Valentino)**



# How We Reconstruct Star Formation Histories



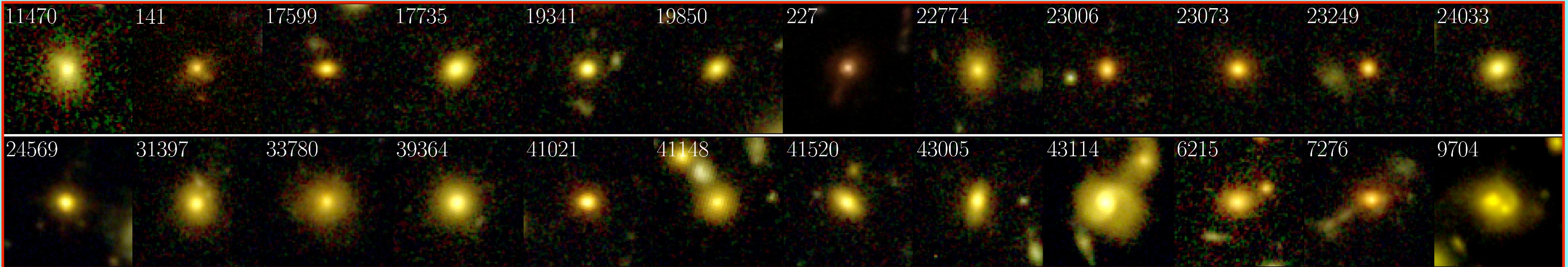
**GSF is a flexible SED fitting code  
(Grism SED Fitter; Morishita+18,19)**

- Linear combination of templates at various ages; i.e. Non-functional form SFH (cf. tau model)
- can leave  $Z^*$  as free parameter for each age
- choice in dust curves
- Mid/Far-IR dust emission

Similar concept as;  
Heavens+04, Tojeiro+07, Panter+08, Kelson+14, Chauke+18

## 1. HST NIR grism observations of 24 galaxies at z~1.6-2.5

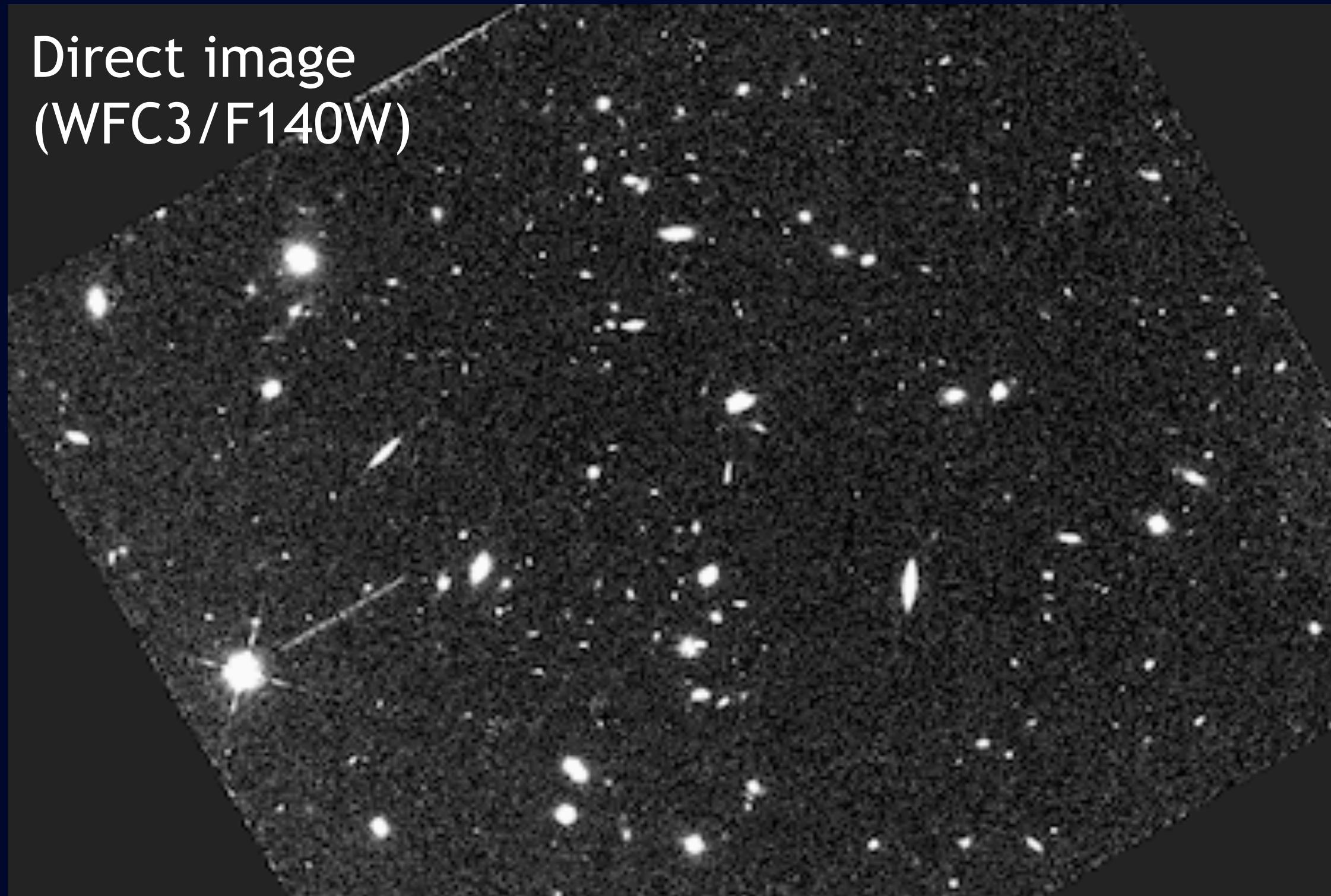
- HFF and CANDELS fields
- Very deep (10-40 orbits) spectra constrain SFH from Balmer absorption lines/4000A break
- Functional vs. Flexible - Systematics?



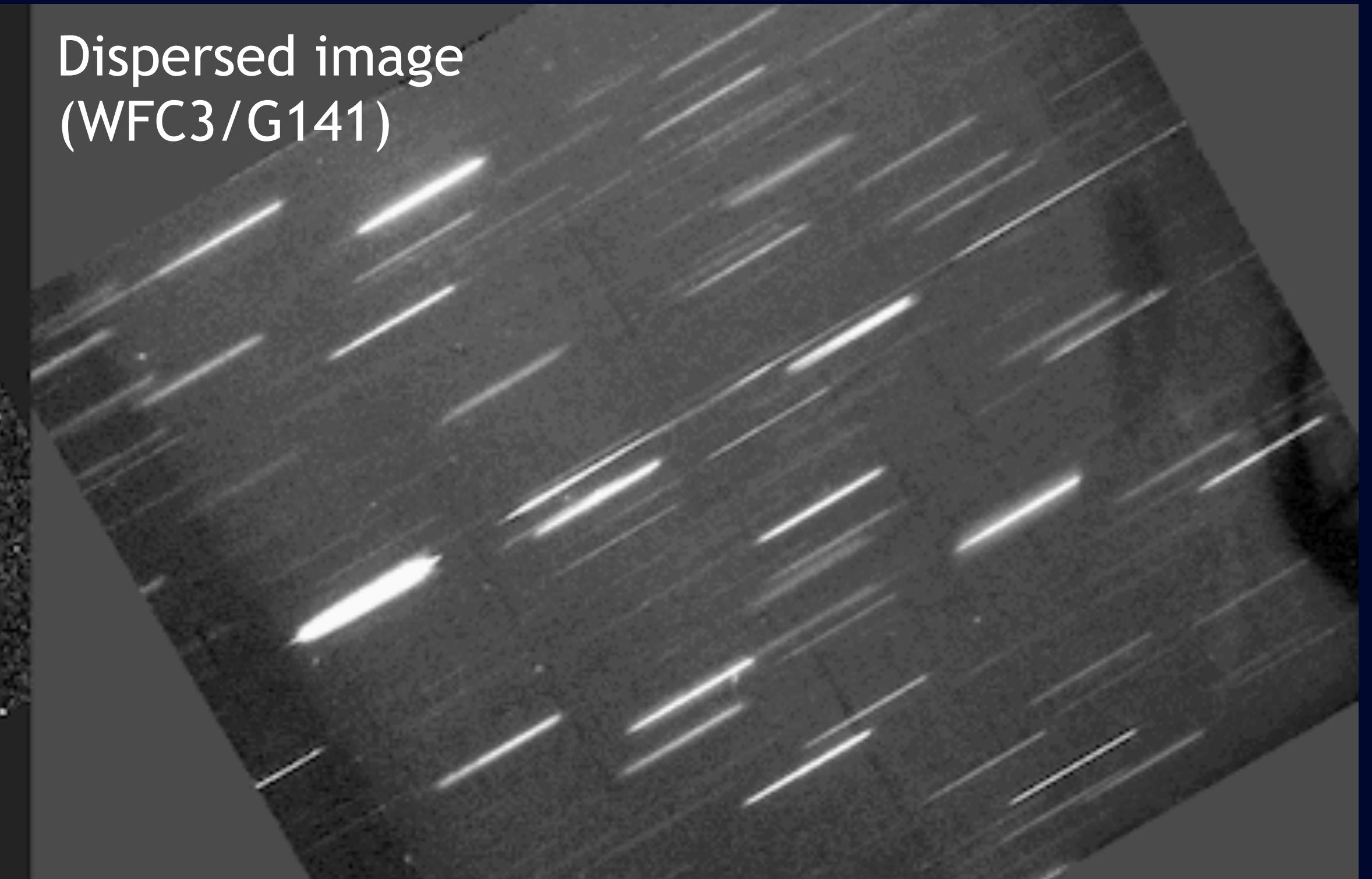
## 2. Extending to galaxies only with broadband data

- Higher redshift quenching/star forming galaxies
- Ground-based & Spitzer photometry is the key player
- Future JWST and TMT

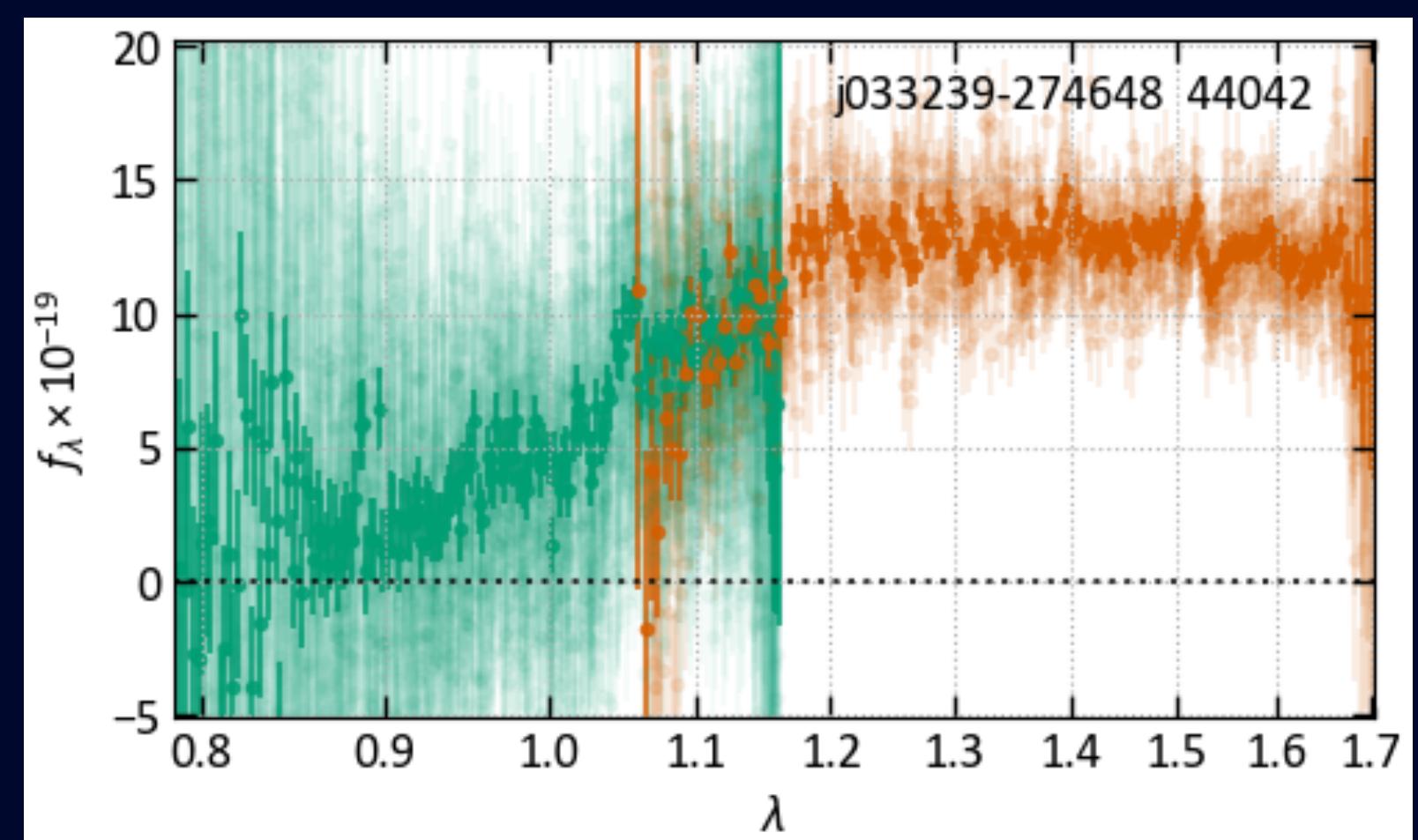
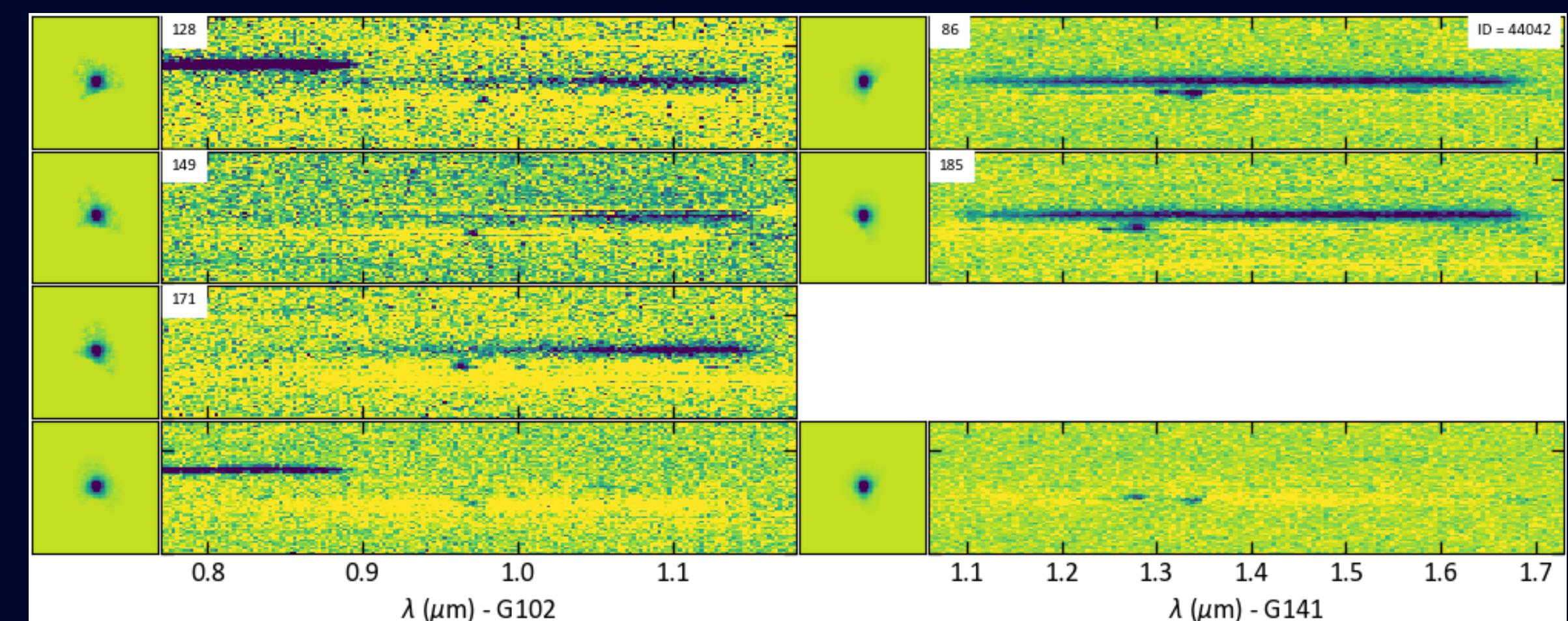
Direct image  
(WFC3/F140W)



Dispersed image  
(WFC3/G141)

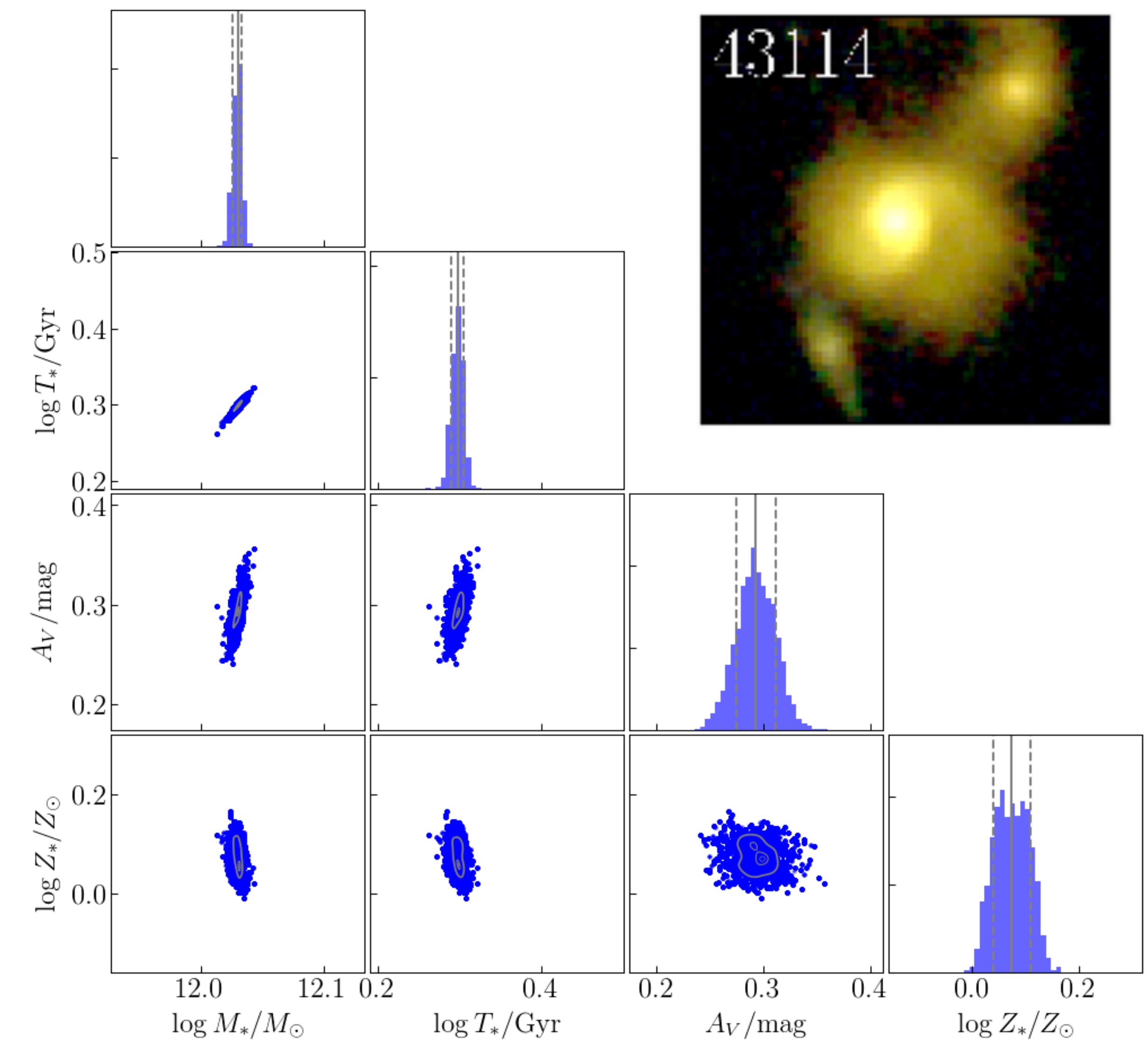
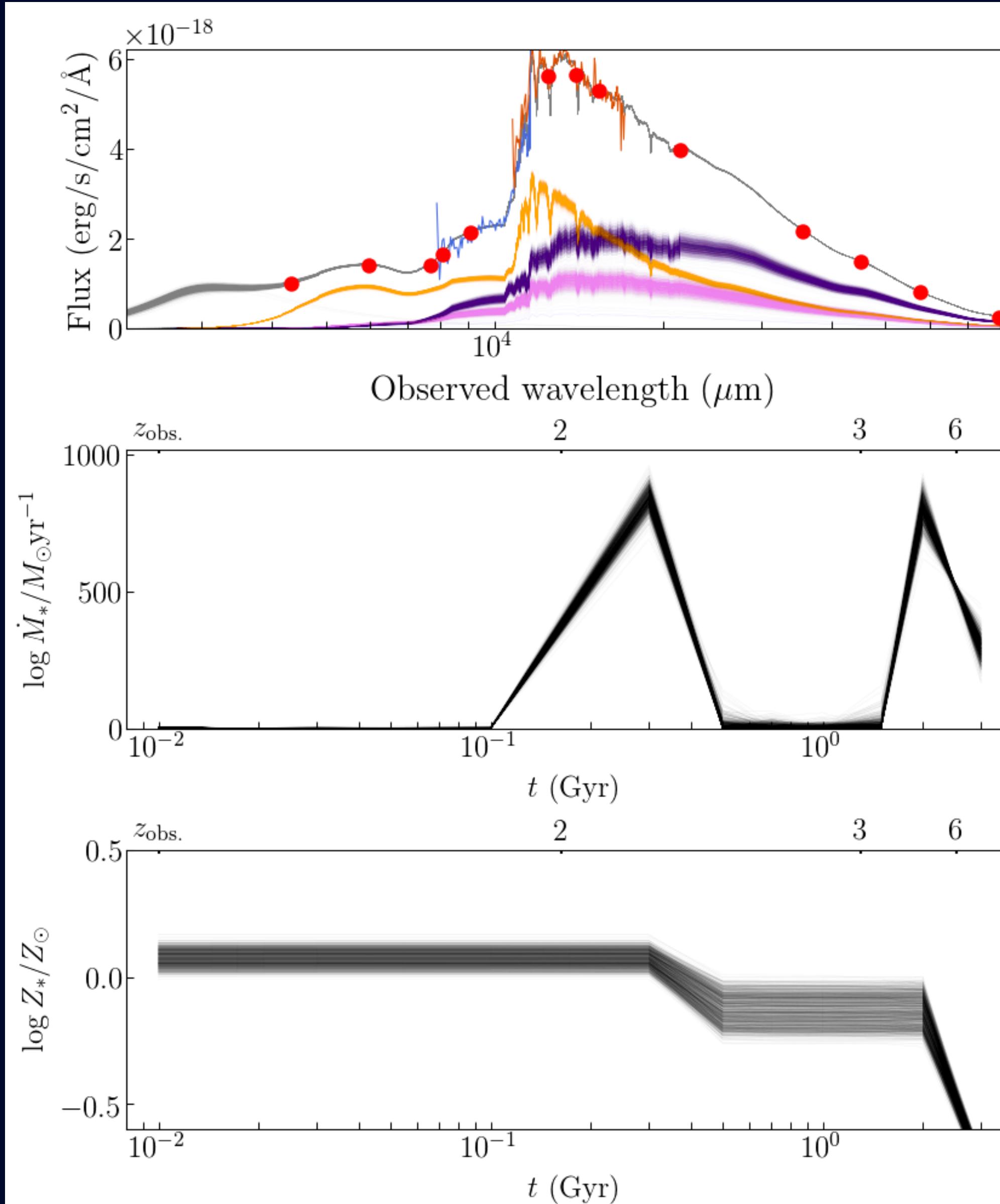


Grizli



By G.Brammer,  
one of the three grism masters

Data from GLASS,3DHST,Refsdal,PRIMUS,CLEAR campaigns



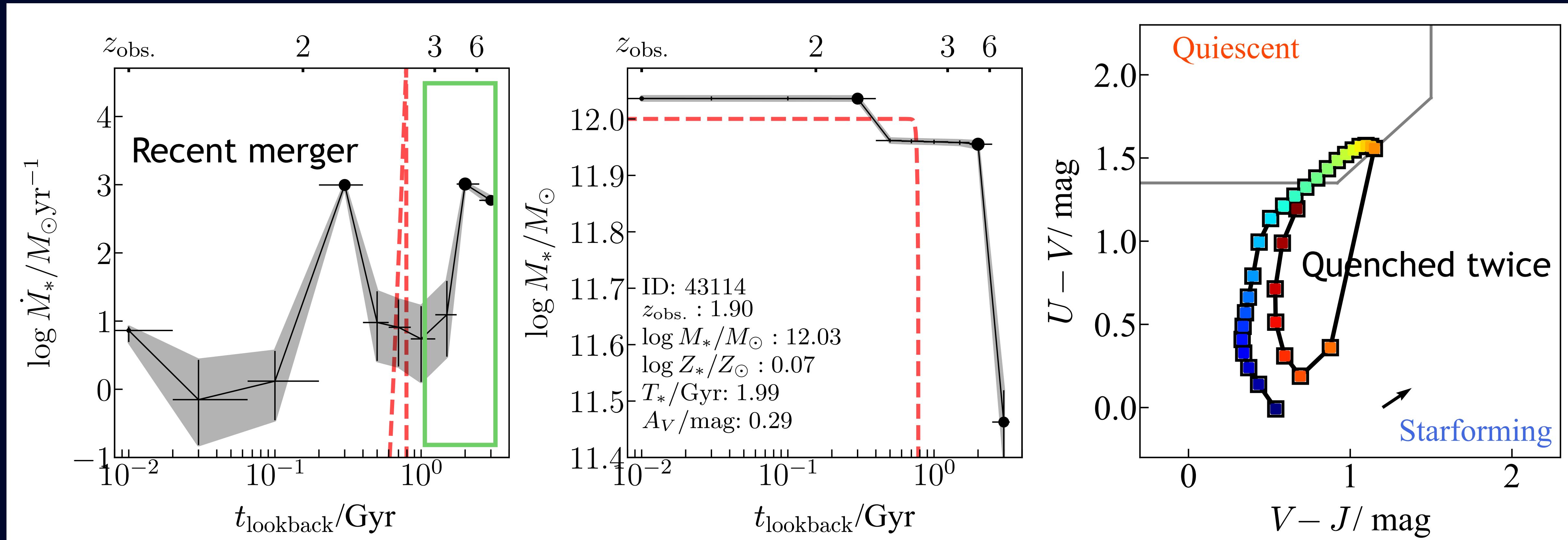
See also: van Dokkum&Brammer10, Ferreras+12

Gray: func. free SFH  
Red : exponential SFH fit

SF history

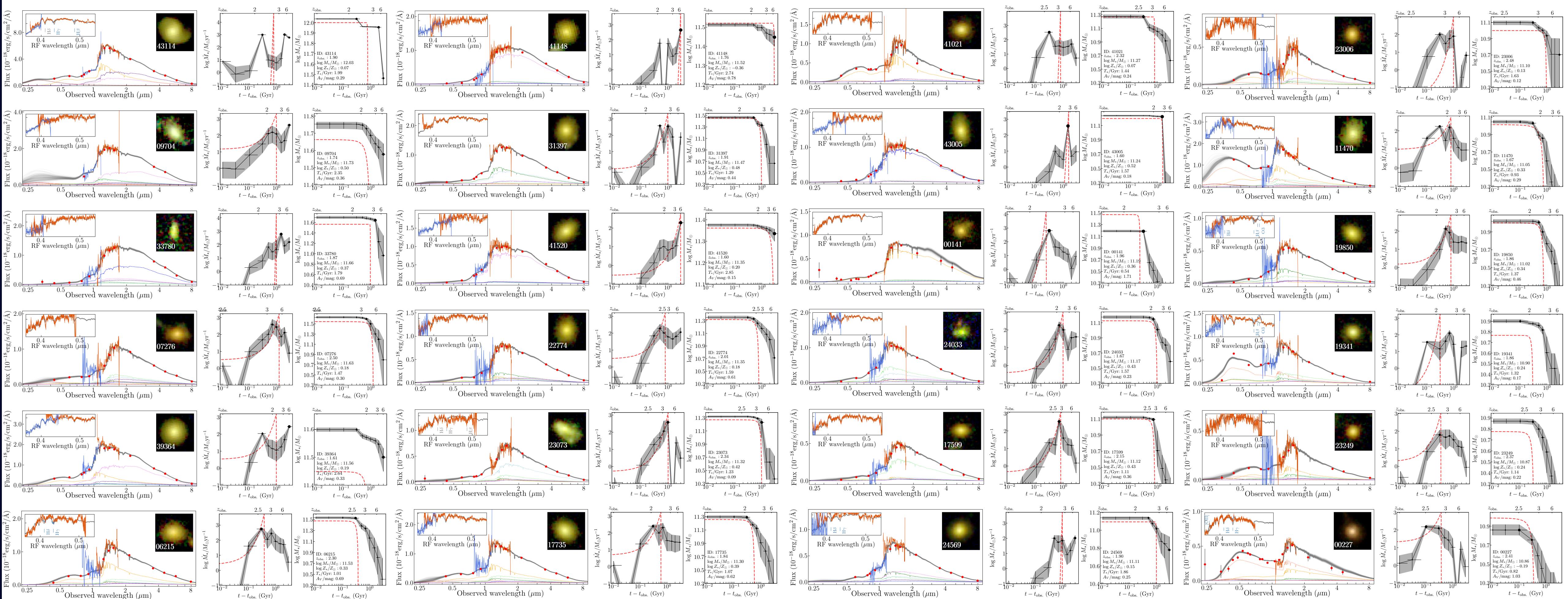
Mass growth history

UVJ color



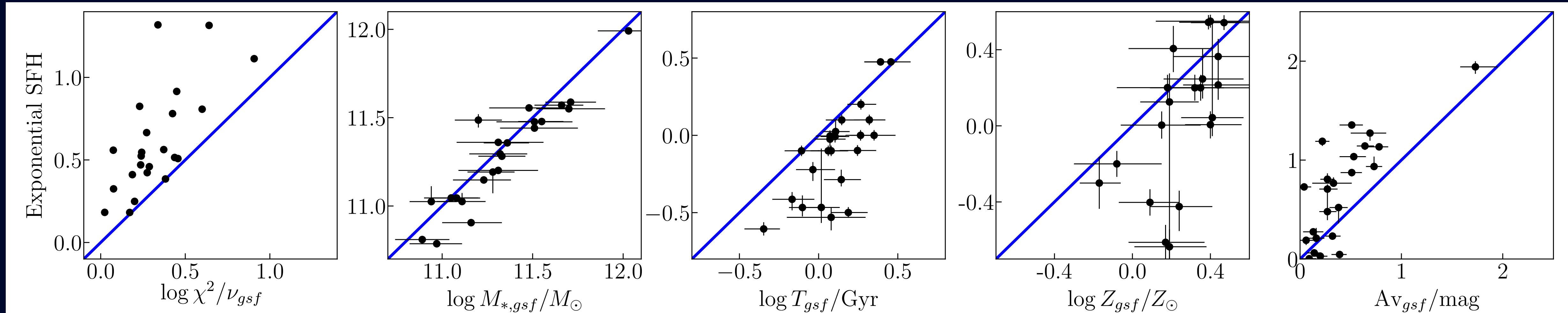
- Functional forms cannot reproduce dual peaks
- Underestimates stellar mass
- Error propagates to other parameters (e.g.,  $Z^*$ )

# 24 quiescent galaxies with SF and metallicity histories (Morishita+18,19)



# When do we stop using a “simple” form for SFHs?

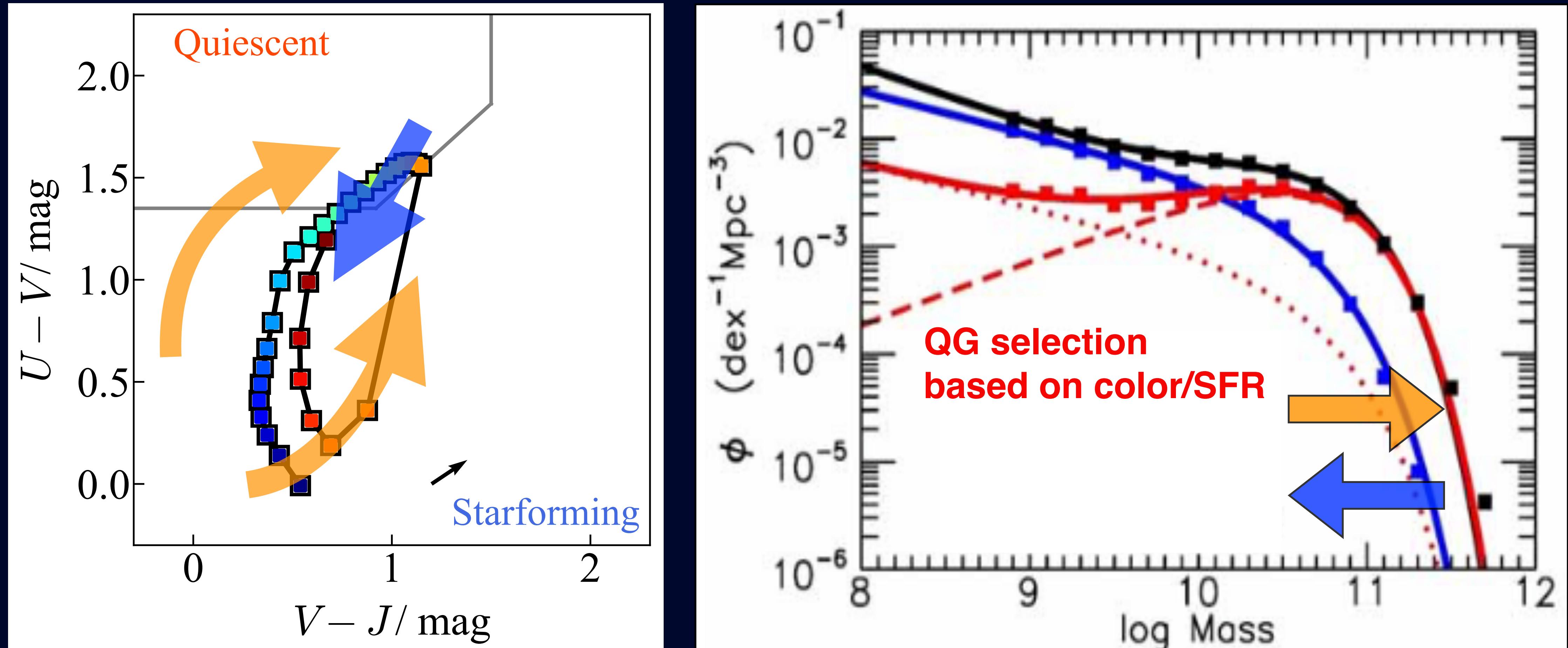
gsf compared to Tau model



With same galaxies/data, functional SFHs:

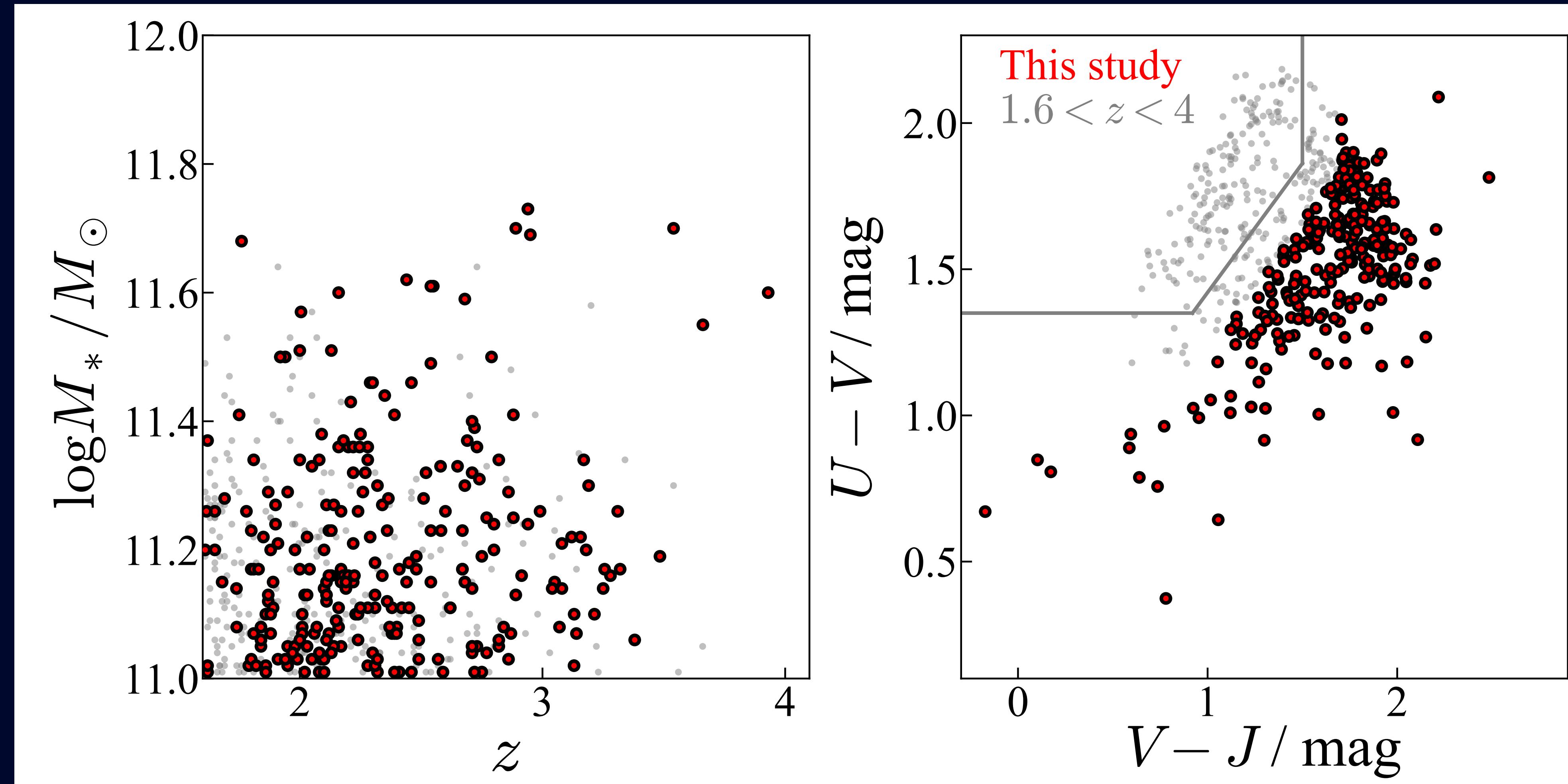
- Show deviation in individual SFHs for most galaxies
- Underestimate in stellar mass ( $\sim 0.15$  dex, except very young galaxies; Leja+19)
- Error propagates to other parameters (e.g.,  $Z^*$ )

# When do we stop using a “simple” form for SFHs?



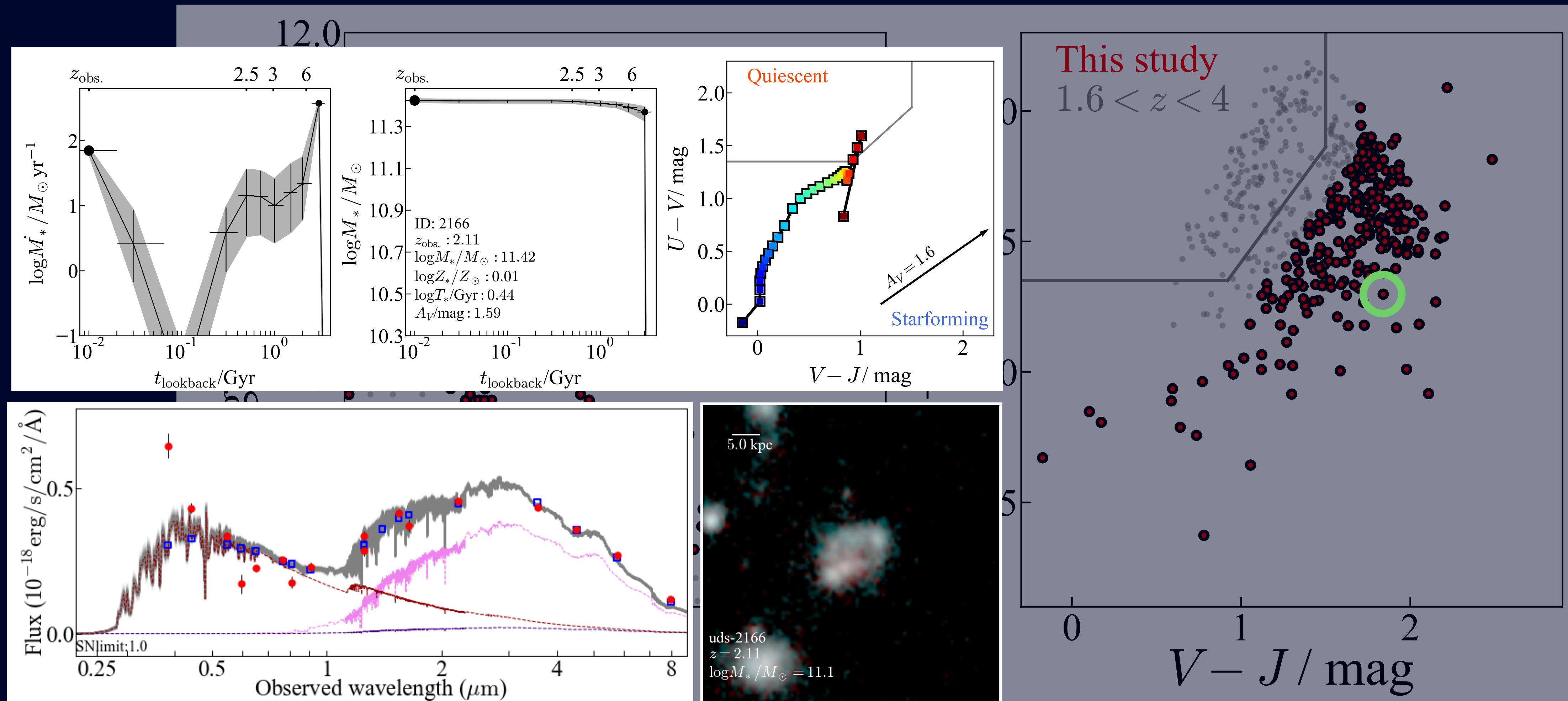
Galaxy evolution is not one-directional (as suggested by e.g. Treu+05, Kaviraj+11)  
Simple form of SFH cannot capture backward movement  
e.g. How much is mass function affected?

# Galaxies are fluid at z~2



**~30% of currently SF galaxies once quenched  
Some of them show evidence of mergers, but not all.**

# Galaxies are fluid at z~2



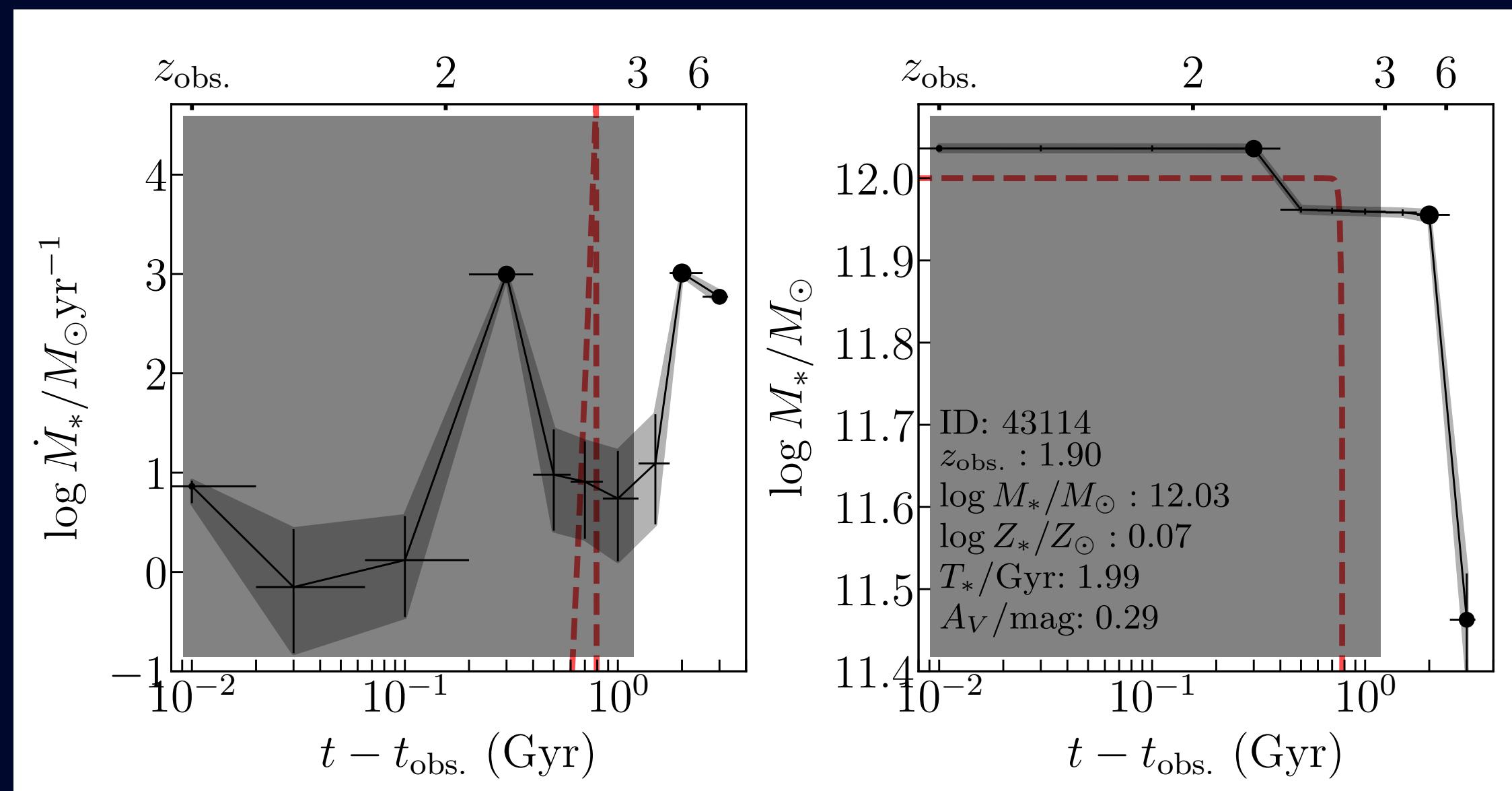
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Some of them show evidence of mergers, but not all.**

## Questions for community: What quench massive galaxies at high-z? What is the smoking gun evidence?

- How spatially did massive galaxies quench? e.g. inside-out quenching? (Morishita+15)
  - Maybe compact galaxies (red and blue nuggets) are good candidates to look at the first phase of quenching (e.g. Dekel&Burkert14; Stellar FB vs AGN?)
- > Resolving spectroscopy ( $R>2000$ ;  $<1\text{kpc}$ ) is needed (cf. JWST/NIRSPEC IFU $\sim 1\text{kpc}$ )
- > Lens magnification helps a lot (e.g. REQUIEM; Whitaker's talk) while waiting for TMT
- Any insight from *quenching* galaxies at  $z>5$ ? Connection to SMGs? (Casey/Wang's talk)
  - > SF/Outflow evidence around old population?
  - > Where is the dust gone?

# Quenched/Quenching population at higher redshift?

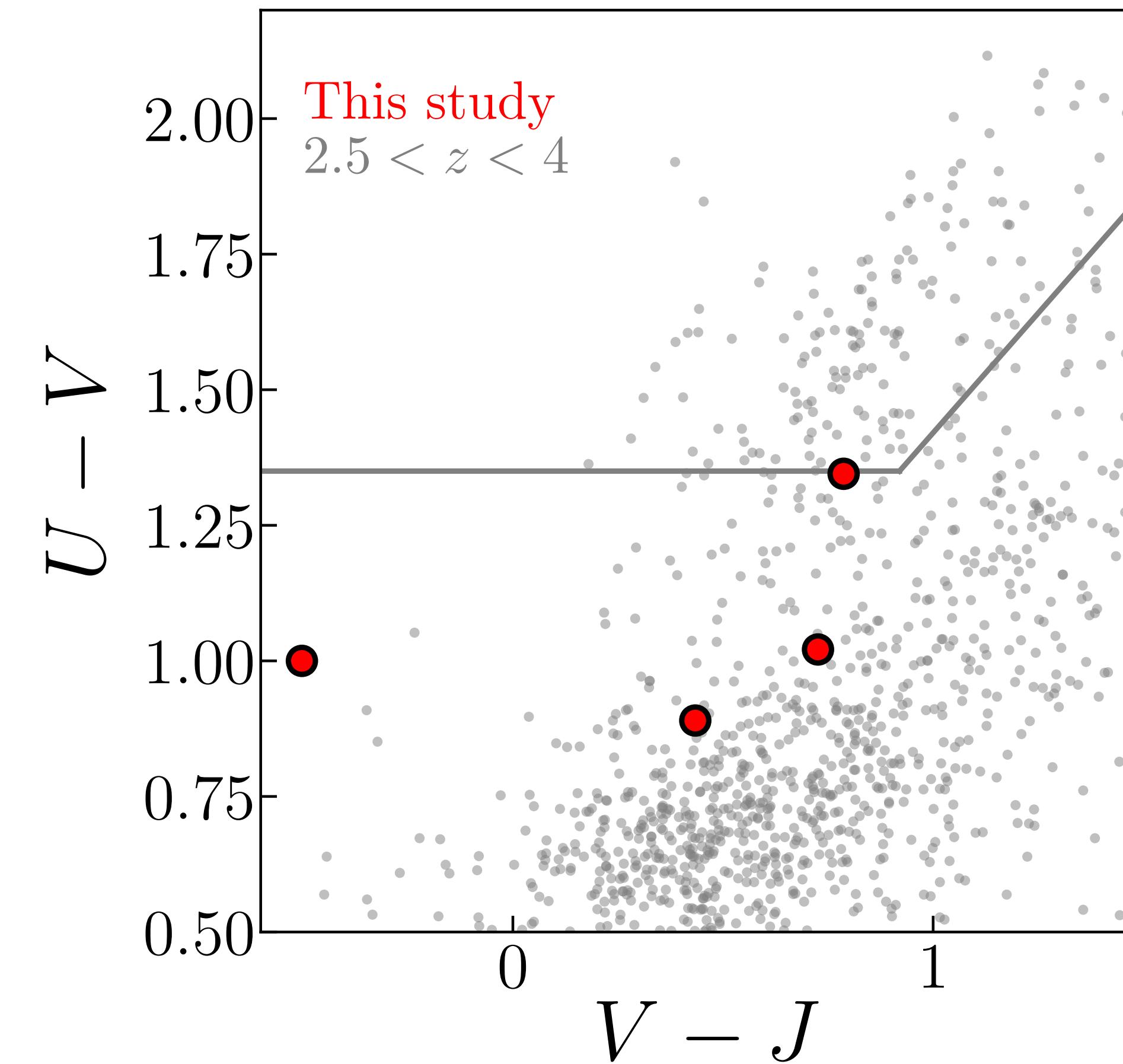
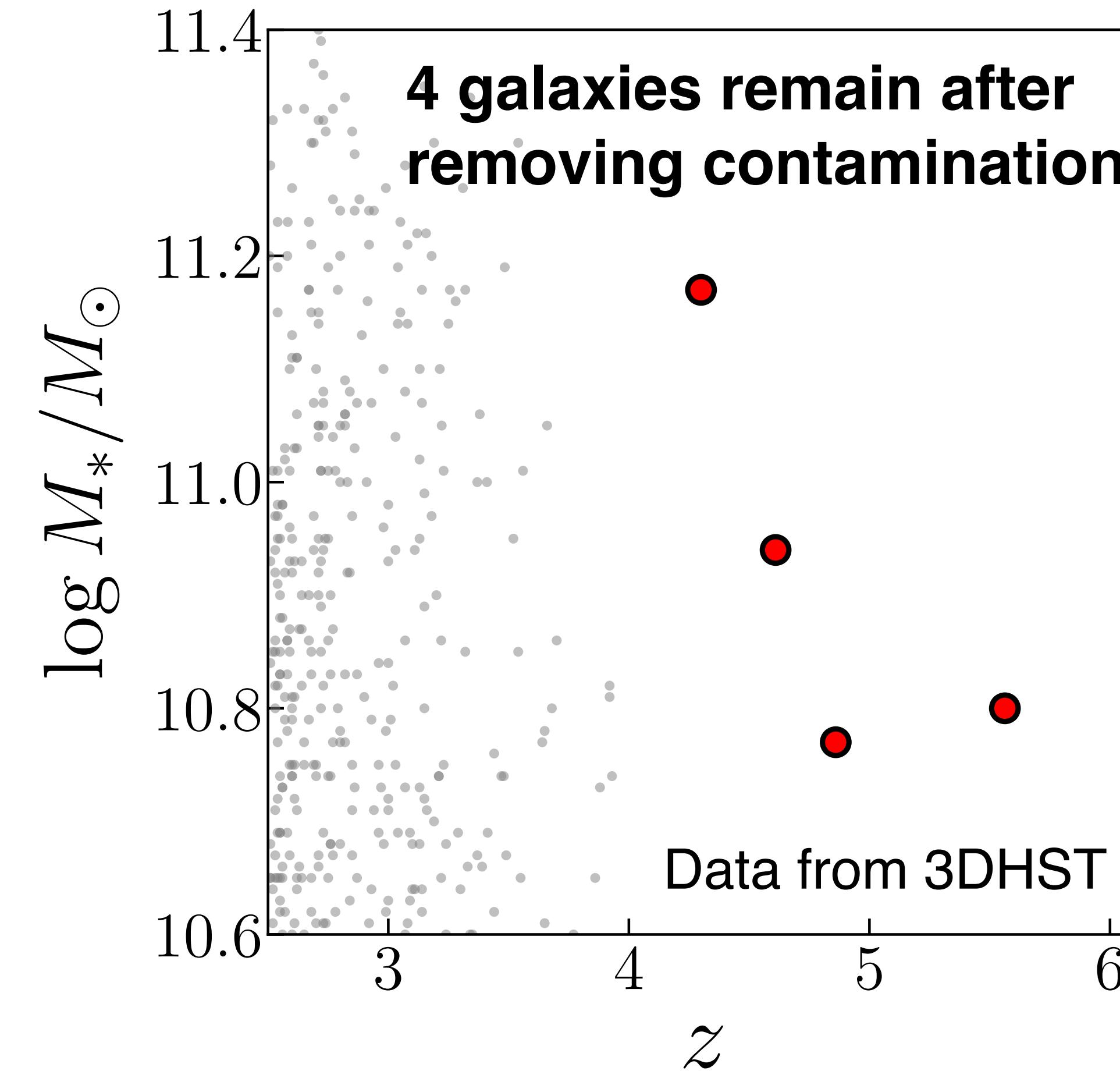
How will Subaru/JWST/TMT answer our questions?





# Massive quenching population candidates at $z > 4$ ?

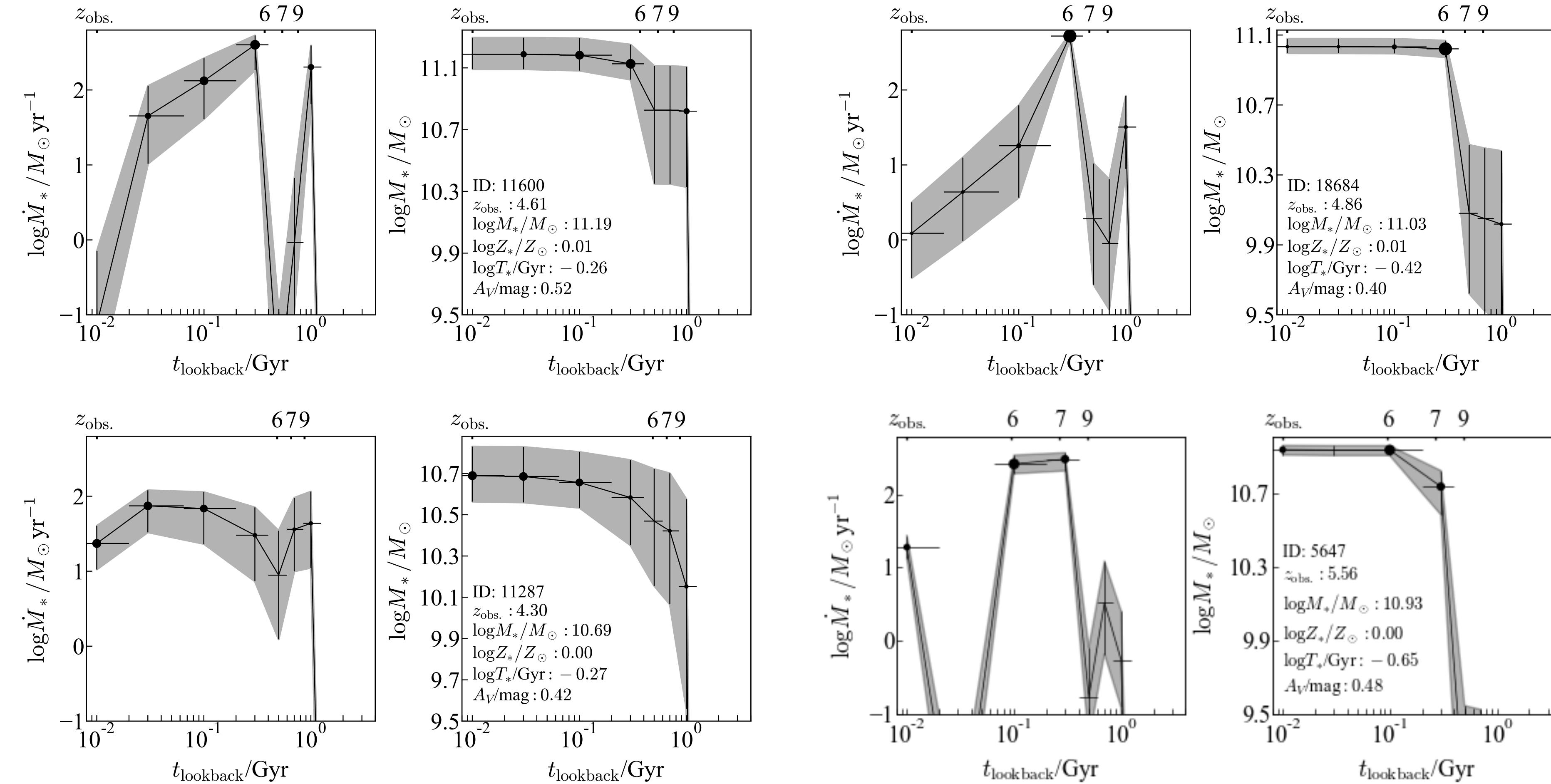
Morishita in prep.





# Massive quenching population candidates at $z>4$

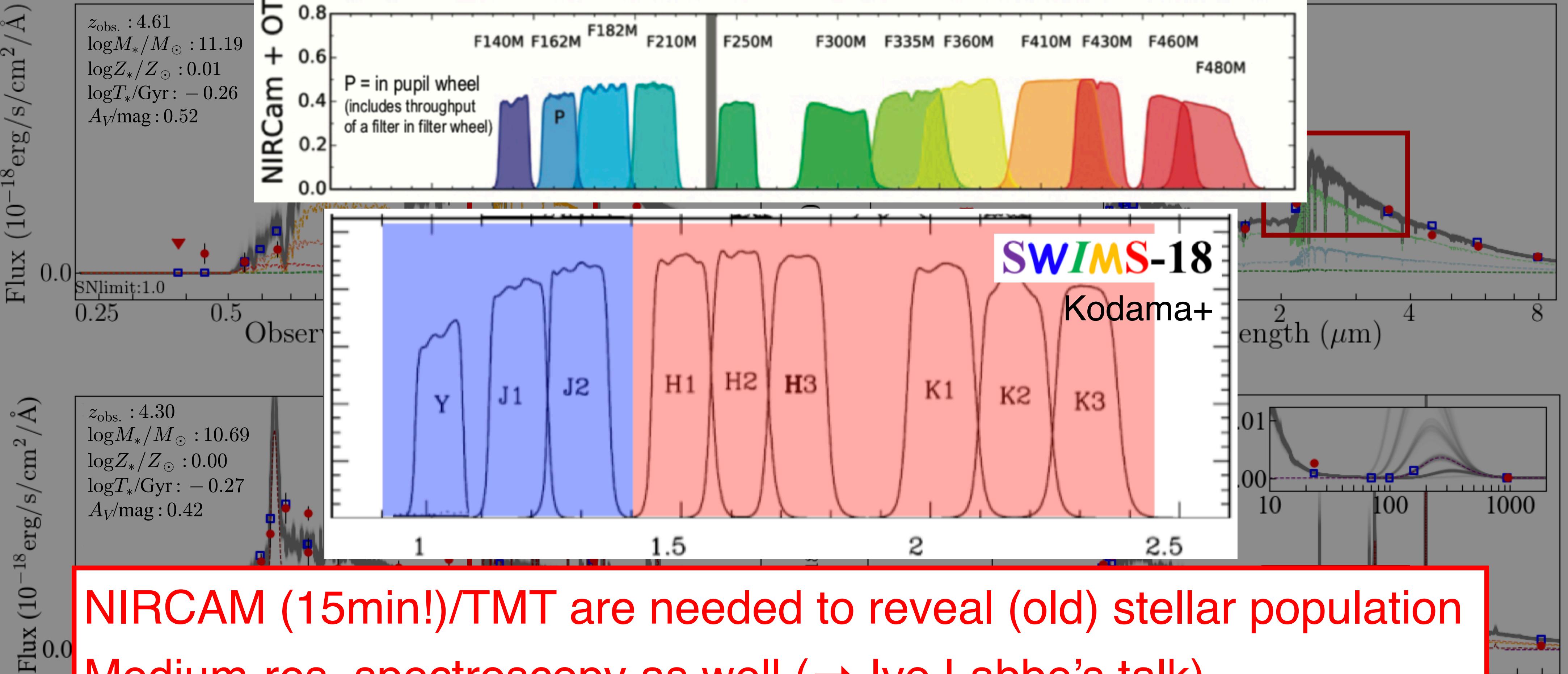
Morishita in prep.



**Evidence for old population? Too massive to exist?**  
(cf.  $\sim 10^9 M_\odot$  in GD-z11 & MACS1149JD1 ( $z \sim 9$ ); Oesch+16, Hashimoto+18)



# Massive

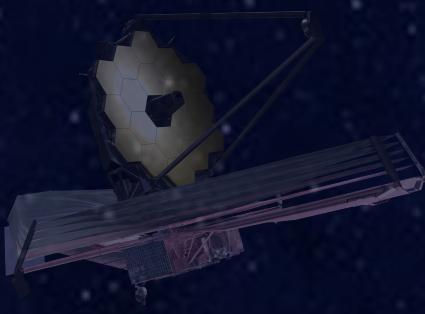


NIRCAM (15min!)/TMT are needed to reveal (old) stellar population

Medium-res. spectroscopy as well ( $\rightarrow$  Ivo Labbe's talk)

SWIMS/ULTIMATE-Subaru for much larger number

Morishita in prep.



# Summary

- Flexible SFH fitter provides better fit quality, is useful to know more detailed histories of individual galaxies - dual peak in SFH
- Simplification in SFHs underestimates stellar mass & miss once-quenched-but-rejuvenated population - Galaxies are fluid at  $z \sim 2$
- There is a growing evidence of matured population in high- $z$  star-forming/green valley galaxies - Ly $\alpha$  emitter with old population
- Gravitational lens, then JWST & TMT will reveal stellar population of  $z \sim 4-8$  galaxies and inside - How spatially galaxies quenched at high- $z$ ?