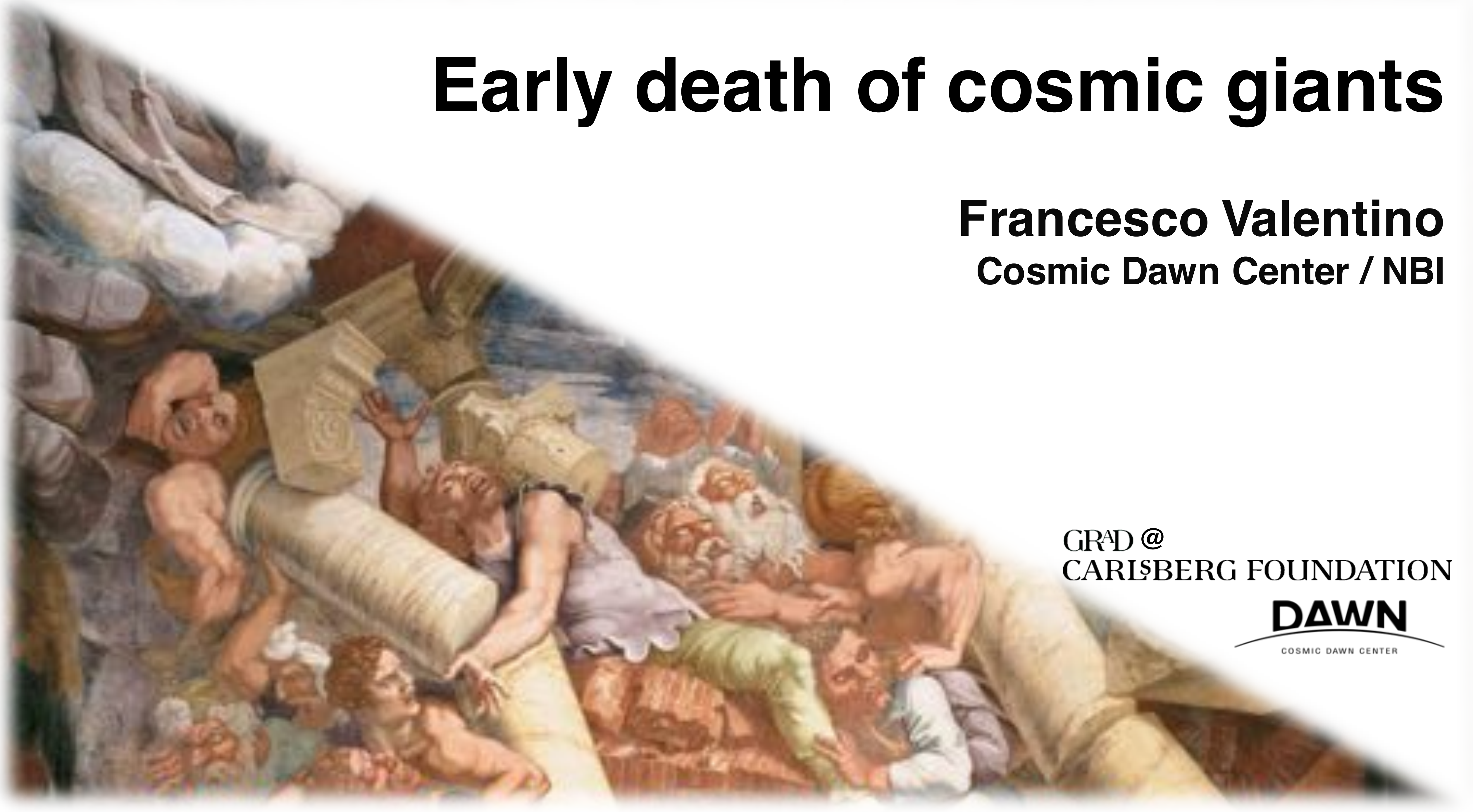

Early death of cosmic giants

Francesco Valentino
Cosmic Dawn Center / NBI

GRAD @
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DAWN
COSMIC DAWN CENTER

GRAD @ CARLSBERG FOUNDATION

Galaxies: Rise And Death

The Astrophysical Journal, 869:27 (20pp), 2018 December 10 https://doi.org/10.3847/1538-4357/aaeb88

CrossMark

A Survey of Atomic Carbon [C I] in High-redshift Main-sequence Galaxies

Francesco Valentino[1,2], Georgios E. Magdis[1,2,3], Emanuele Daddi[4], Daizhong Liu[5], Manuel Aravena[6], Frédéric Bournaud[4], Anna Cibinel[7], Diane Cormier[4], Mark E. Dickinson[8], Yu Gao[9], Shuowen Jin[4,10], Stéphanie Juneau[8], Jeyhan Kartaltepe[11], Min-Young Lee[12], Suzanne C. Madden[4], Annagrazia Puglisi[4], David Sanders[13], and John Silverman[14]

[1] Cosmic Dawn Center (DAWN), Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, DK-2100 Copenhagen Ø; DTU-Space, Technical University of Denmark, Elektrovej 327, DK-2800 Kgs. Lyngby; francesco.valentino@nbi.ku.dk

Valentino+2018, ApJ, 869, 27

The properties of the interstellar medium of galaxies across time as traced by the neutral atomic carbon [C I]

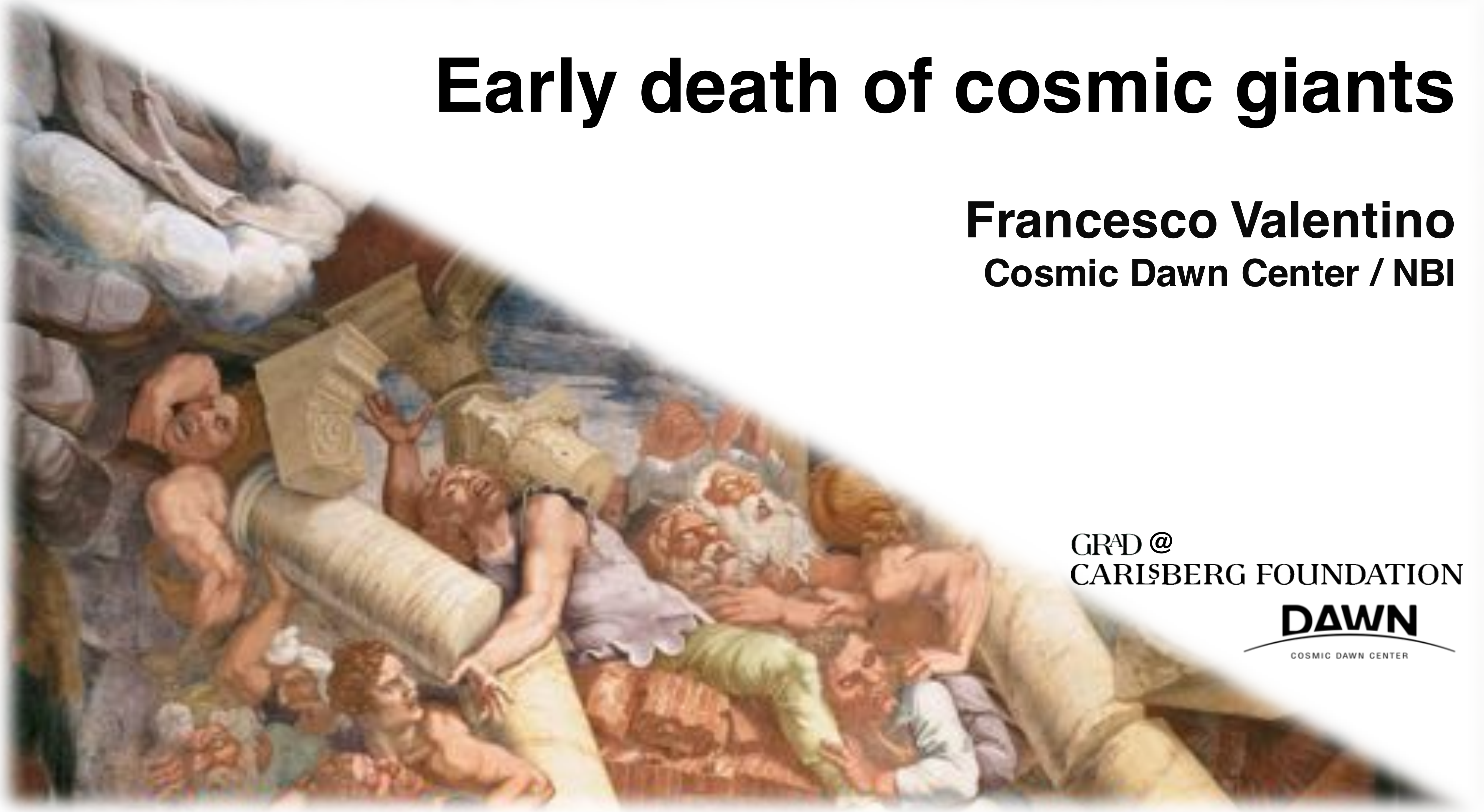
Francesco Valentino,[1,2] Georgios E. Magdis,[1,2,3,4] Emanuele Daddi,[5] Daizhong Liu,[6] Manuel Aravena,[7] Frédéric Bournaud,[5] Isabella Cortzen,[1,2] Yu Gao,[8] Shuowen Jin,[9,10] Stéphanie Juneau,[11] Jeyhan S. Kartaltepe,[12] Vasily Kokorev,[1,2] Min-Young Lee,[13,14] Suzanne C. Madden,[5] Desika Narayanan,[1,15,16] Gergö Popping,[17] and Annagrazia Puglisi[5]

[1] *Cosmic Dawn Center (DAWN)*

Valentino+2019a (submitted)

Early death of cosmic giants

Francesco Valentino
Cosmic Dawn Center / NBI



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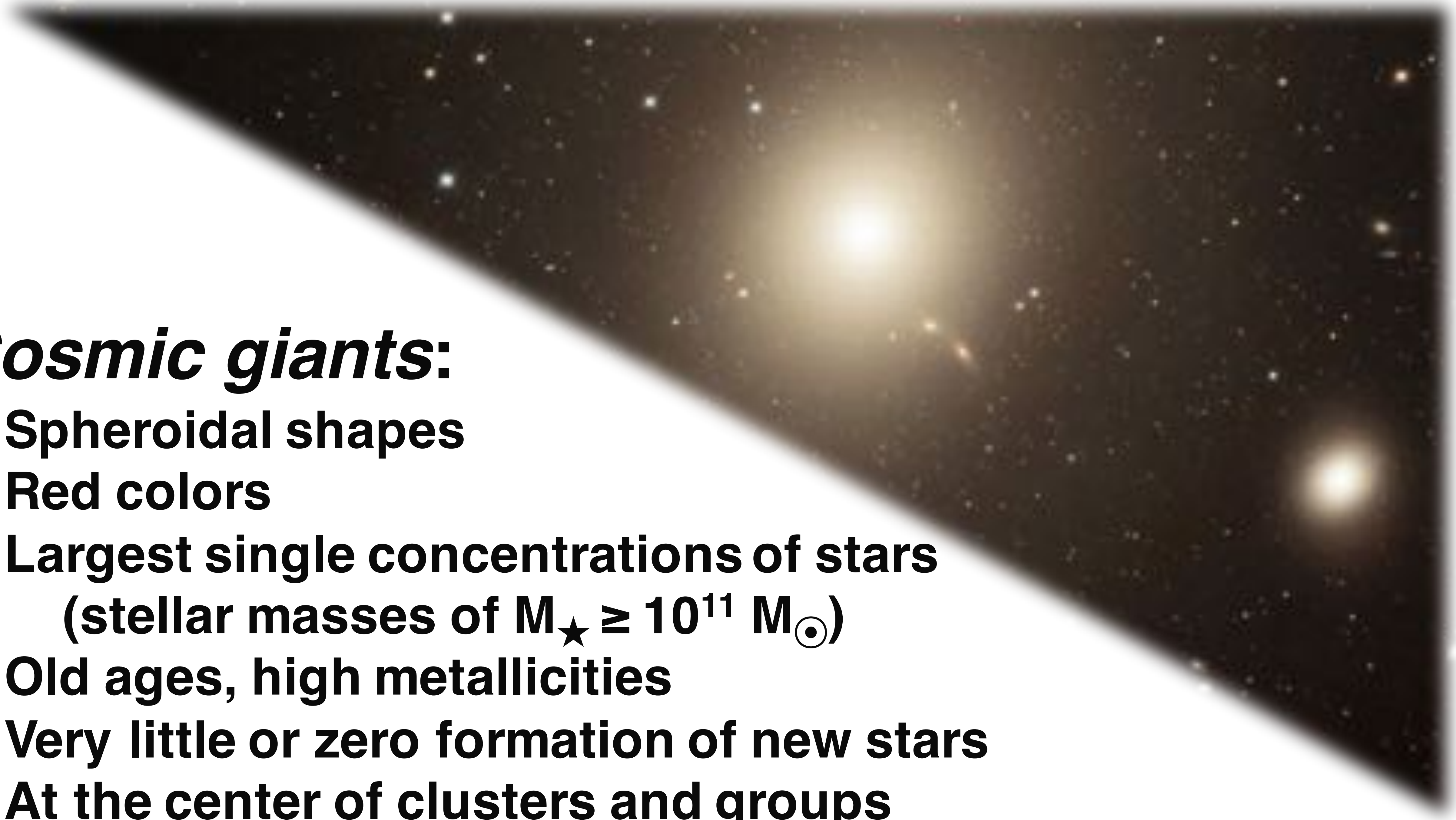
DAWN
COSMIC DAWN CENTER

The chamber of the giants

Giulio Romano (1531-1536)
Palazzo Te – Mantua (Italy)

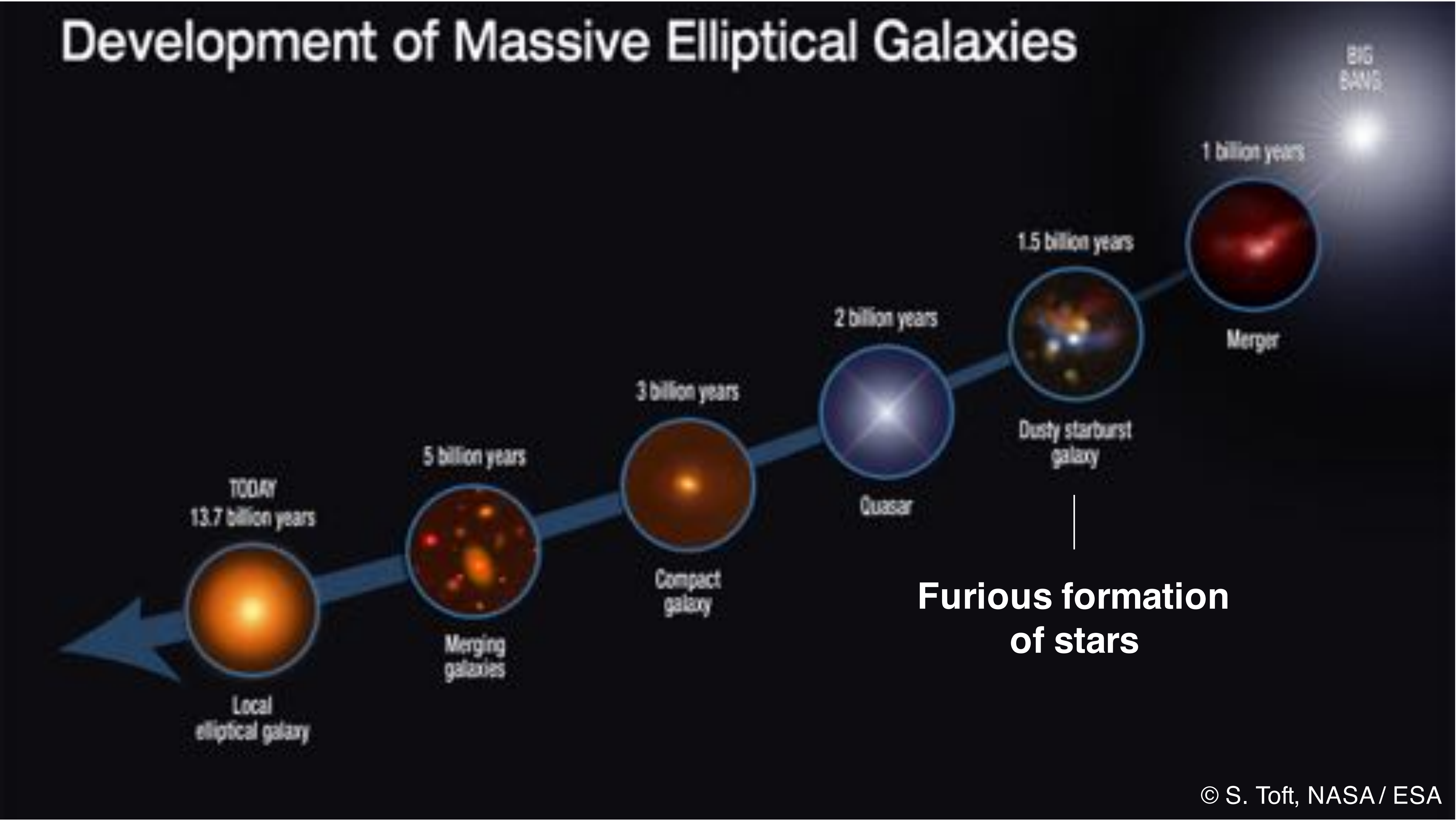


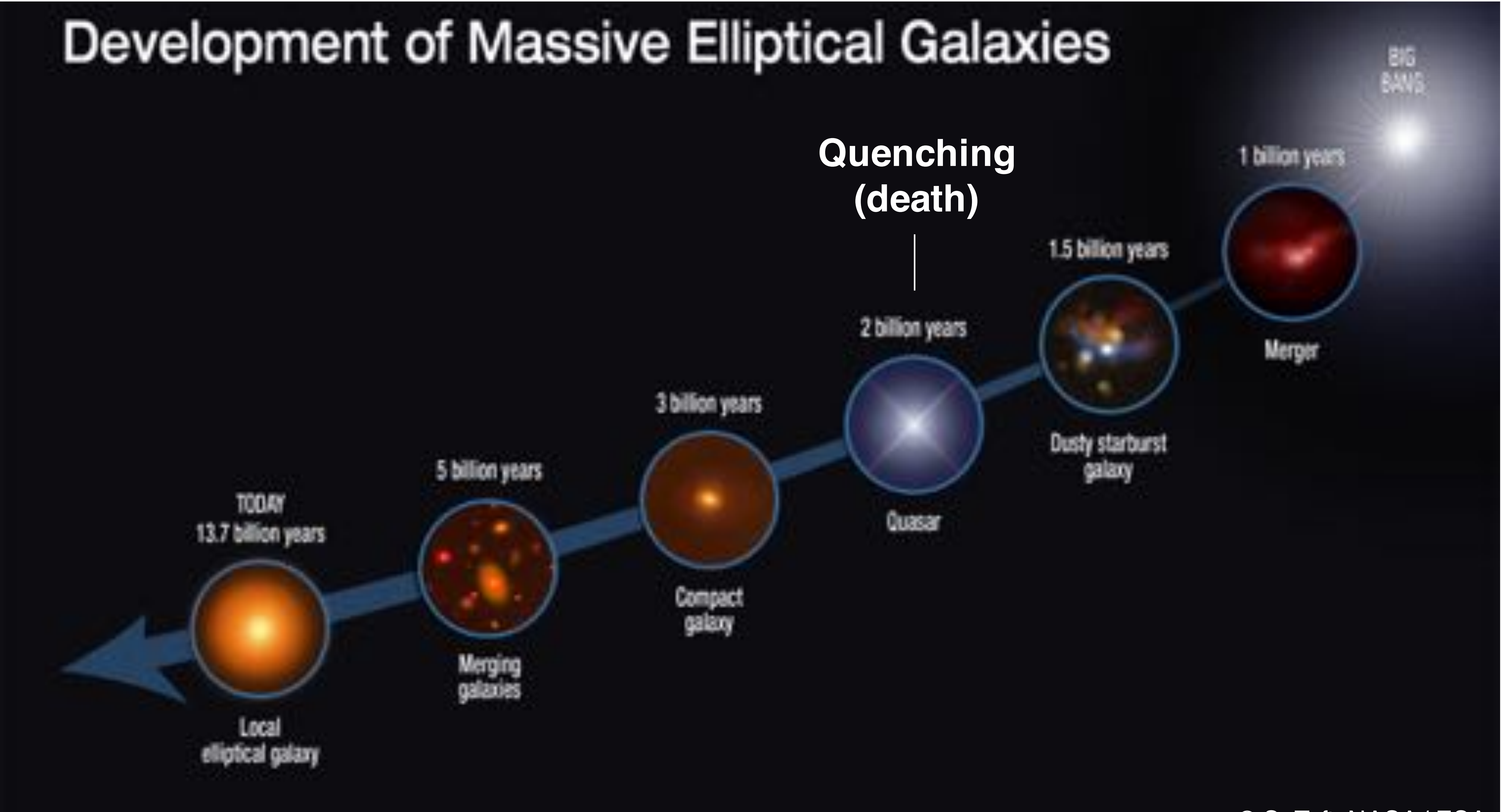
***Cosmic giants*:**

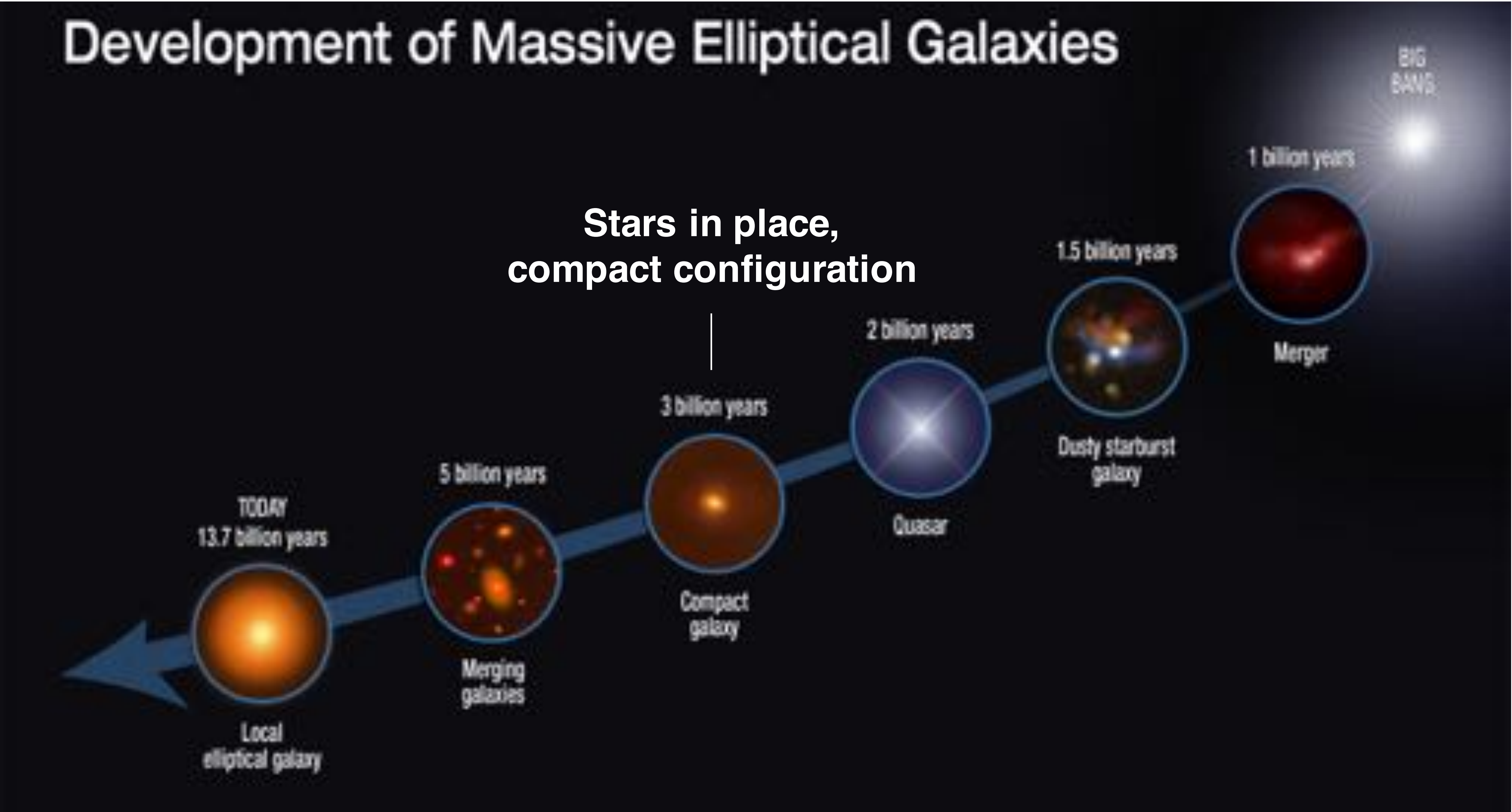
- **Spheroidal shapes**
- **Red colors**
- **Largest single concentrations of stars (stellar masses of $M_\star \geq 10^{11}\ M_\odot$)**
- **Old ages, high metallicities**
- **Very little or zero formation of new stars**
- **At the center of clusters and groups**

Development of Massive Elliptical Galaxies

Development of Massive Elliptical Galaxies


Development of Massive Elliptical Galaxies
BIG BANG
1 billion years
Merger
1.5 billion years
Dusty starburst galaxy
2 billion years
Quasar
3 billion years
Compact galaxy
5 billion years
Merging galaxies
TODAY
13.7 billion years
Local elliptical galaxy
Furious formation of stars
© S. Toft, NASA / ESA


Development of Massive Elliptical Galaxies
BIG BANG
Quenching
(death)
1 billion years
Merger
1.5 billion years
Dusty starburst galaxy
2 billion years
Quasar
3 billion years
Compact galaxy
5 billion years
Merging galaxies
TODAY
13.7 billion years
Local elliptical galaxy

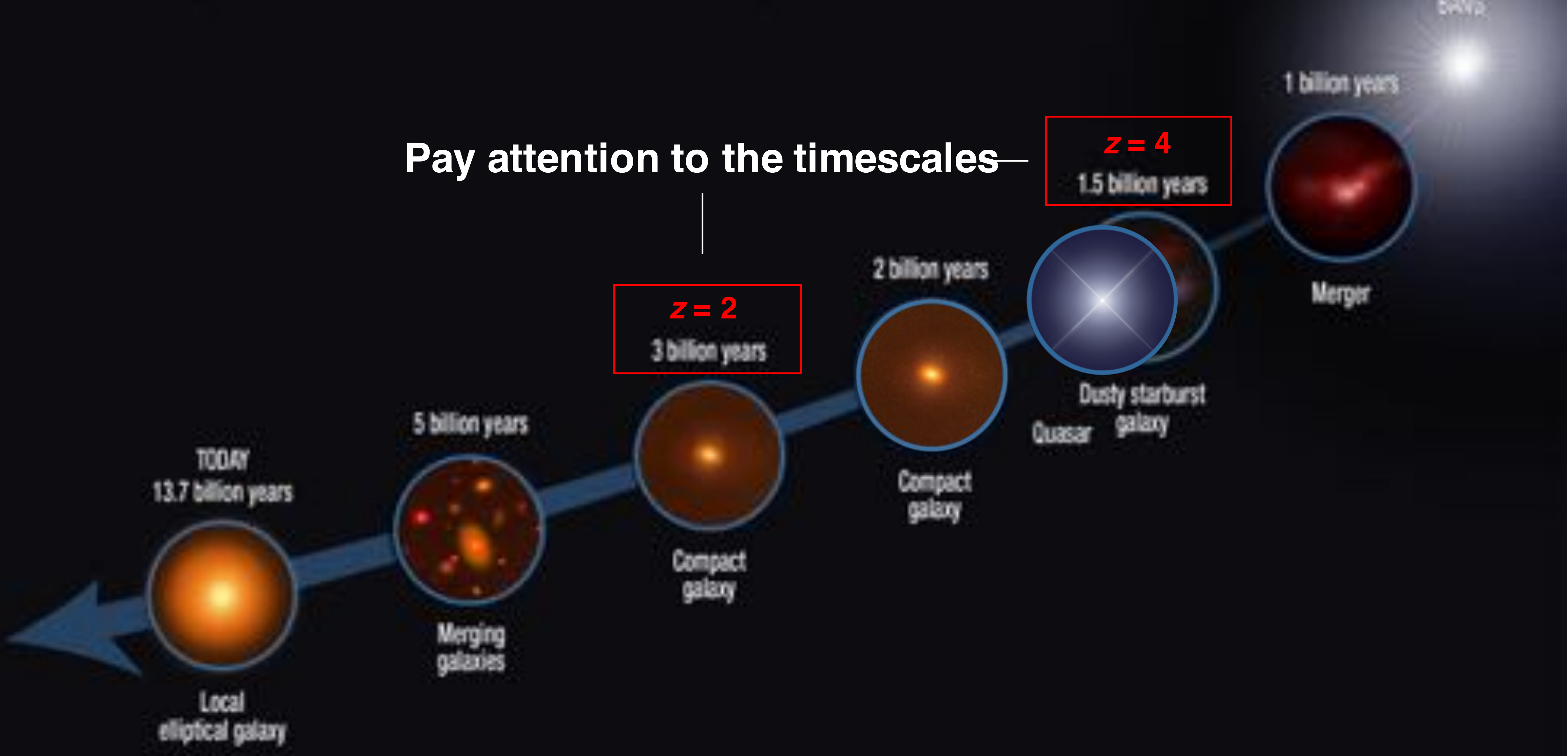

Development of Massive Elliptical Galaxies
BIG BANG
1 billion years
Merger
1.5 billion years
Dusty starburst galaxy
2 billion years
Quasar
Stars in place,
compact configuration
3 billion years
Compact galaxy
5 billion years
Merging galaxies
TODAY
13.7 billion years
Local elliptical galaxy

Development of Massive Elliptical Galaxies

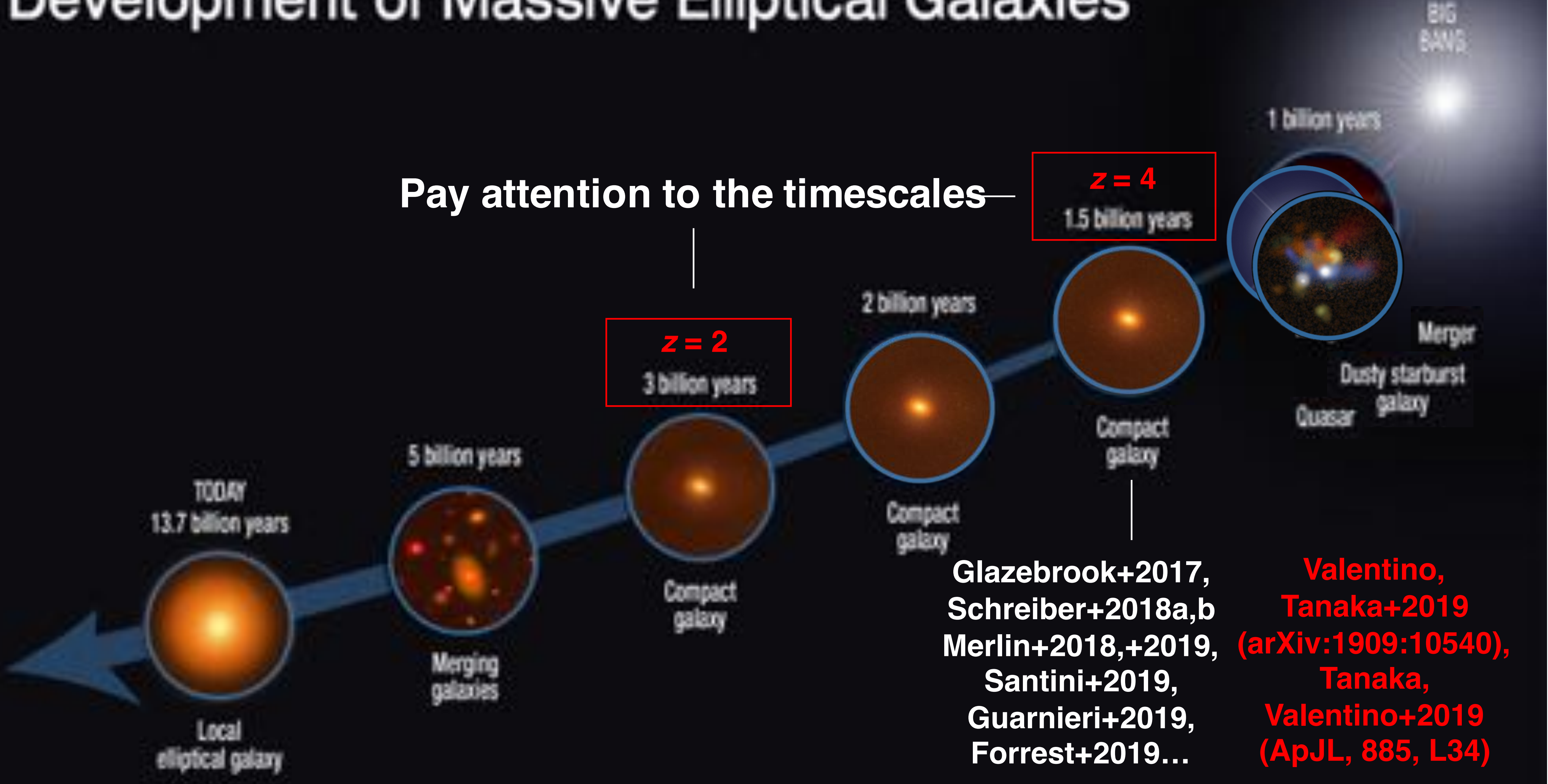
Development of Massive Elliptical Galaxies

Pay attention to the timescales

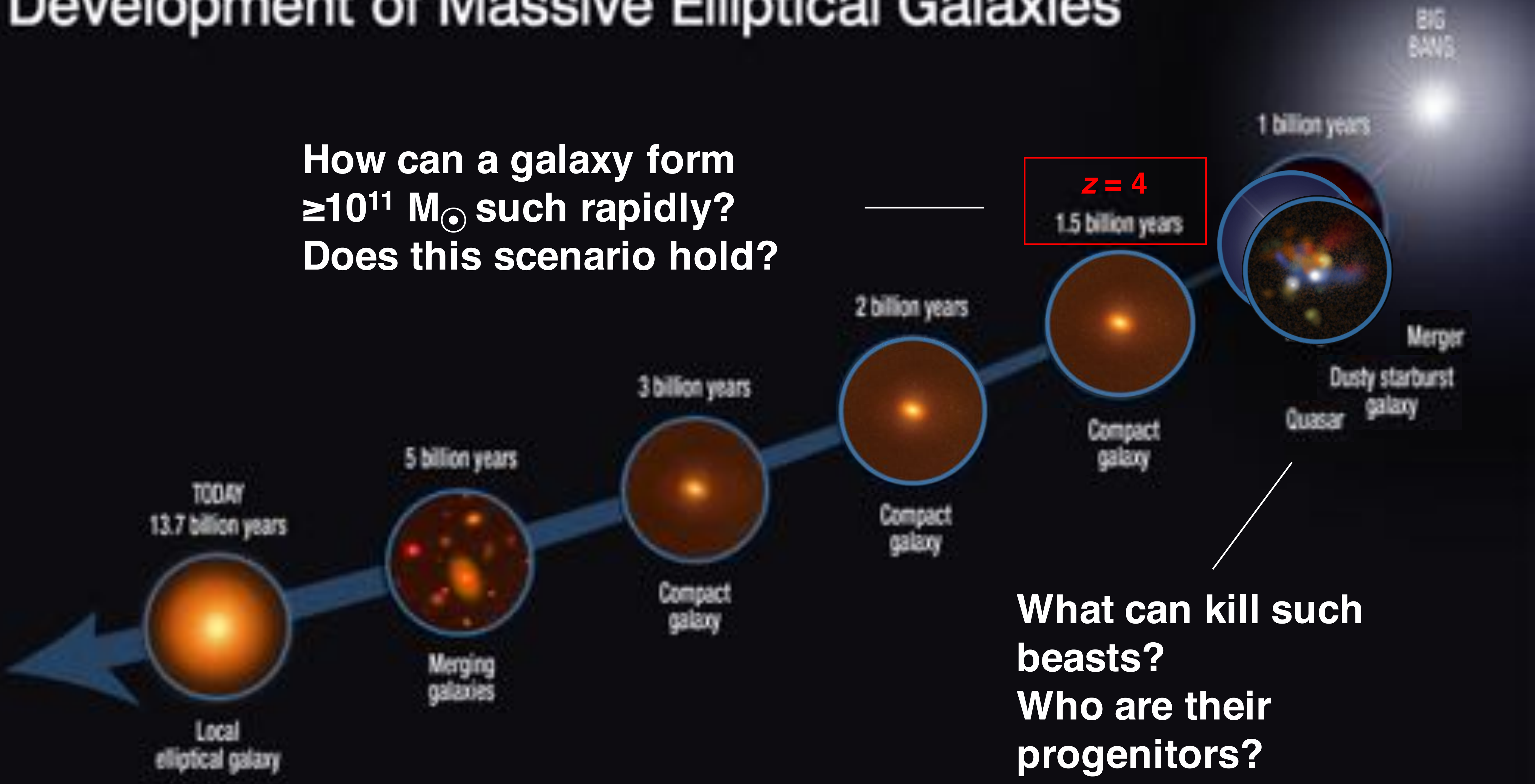
Development of Massive Elliptical Galaxies



Development of Massive Elliptical Galaxies



Development of Massive Elliptical Galaxies

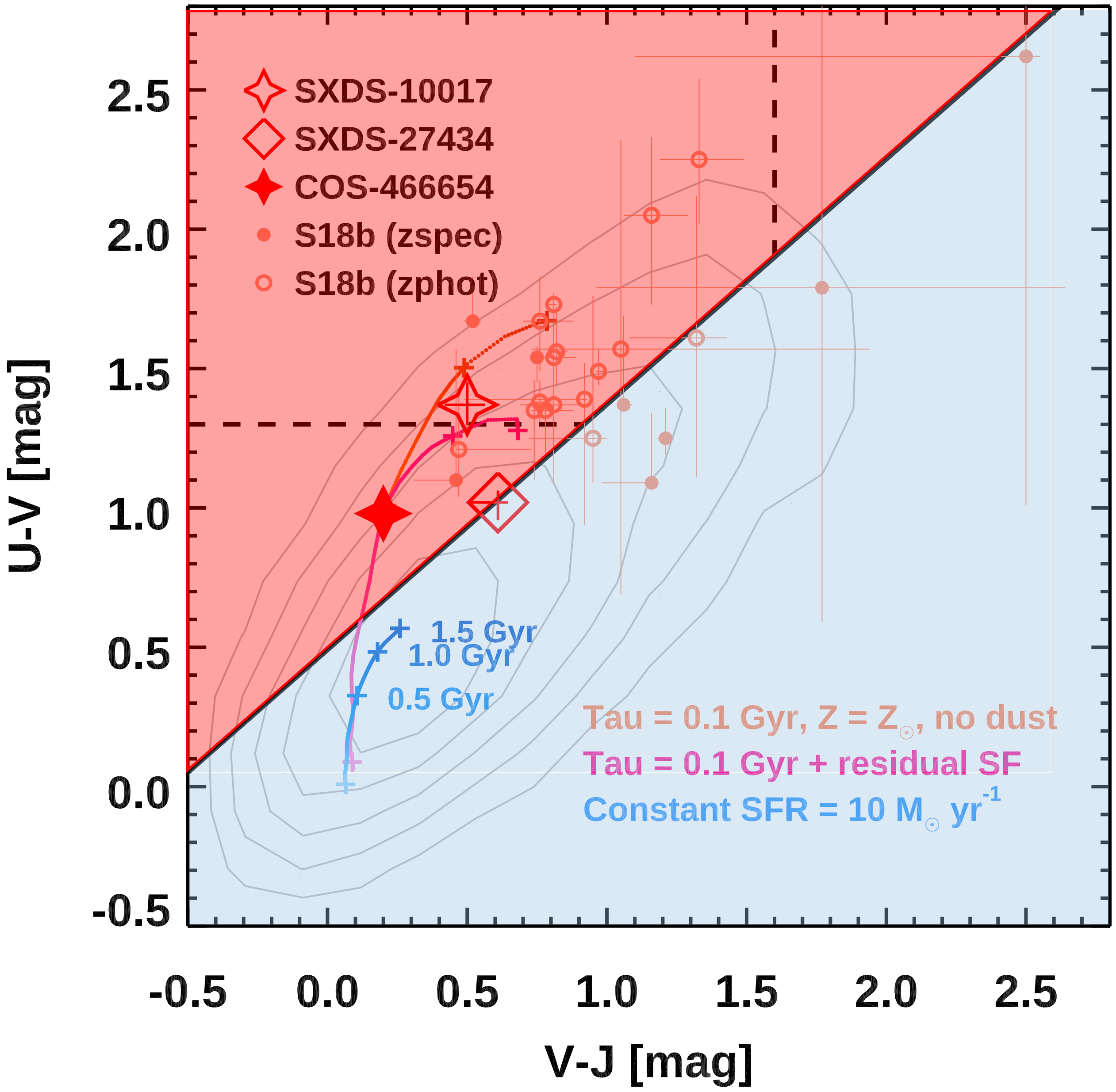


How can a galaxy form $\geq 10^{11}$ $M_\odot$ such rapidly?
Does this scenario hold?

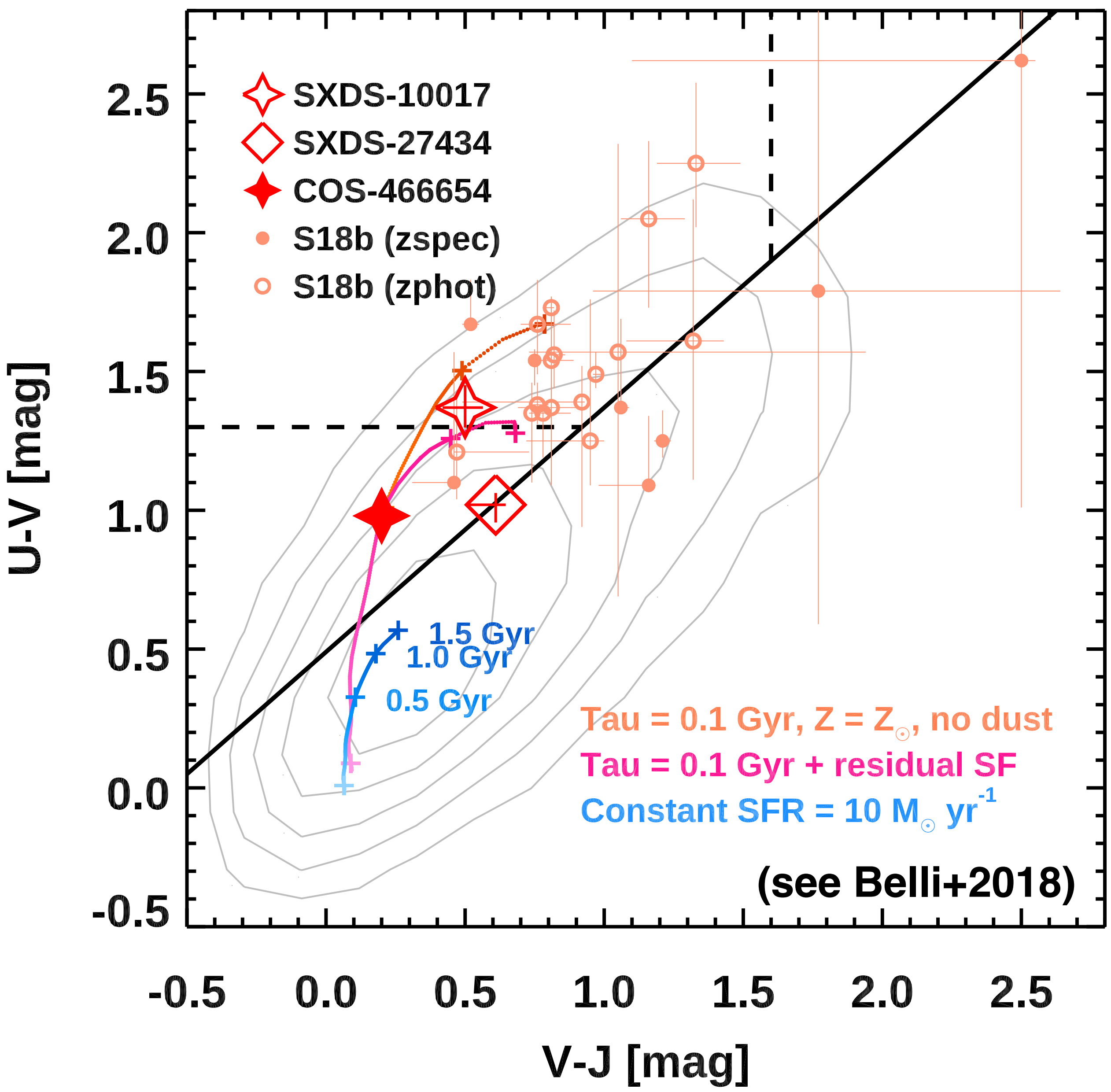
What can kill such beasts?
Who are their progenitors?

How to spot a dead cosmic giant?

(By looking at its light distribution and colors)



How to spot a dead cosmic giant?
I. Red colors (*UVJ, NUVrJ* rest-frame diagram)



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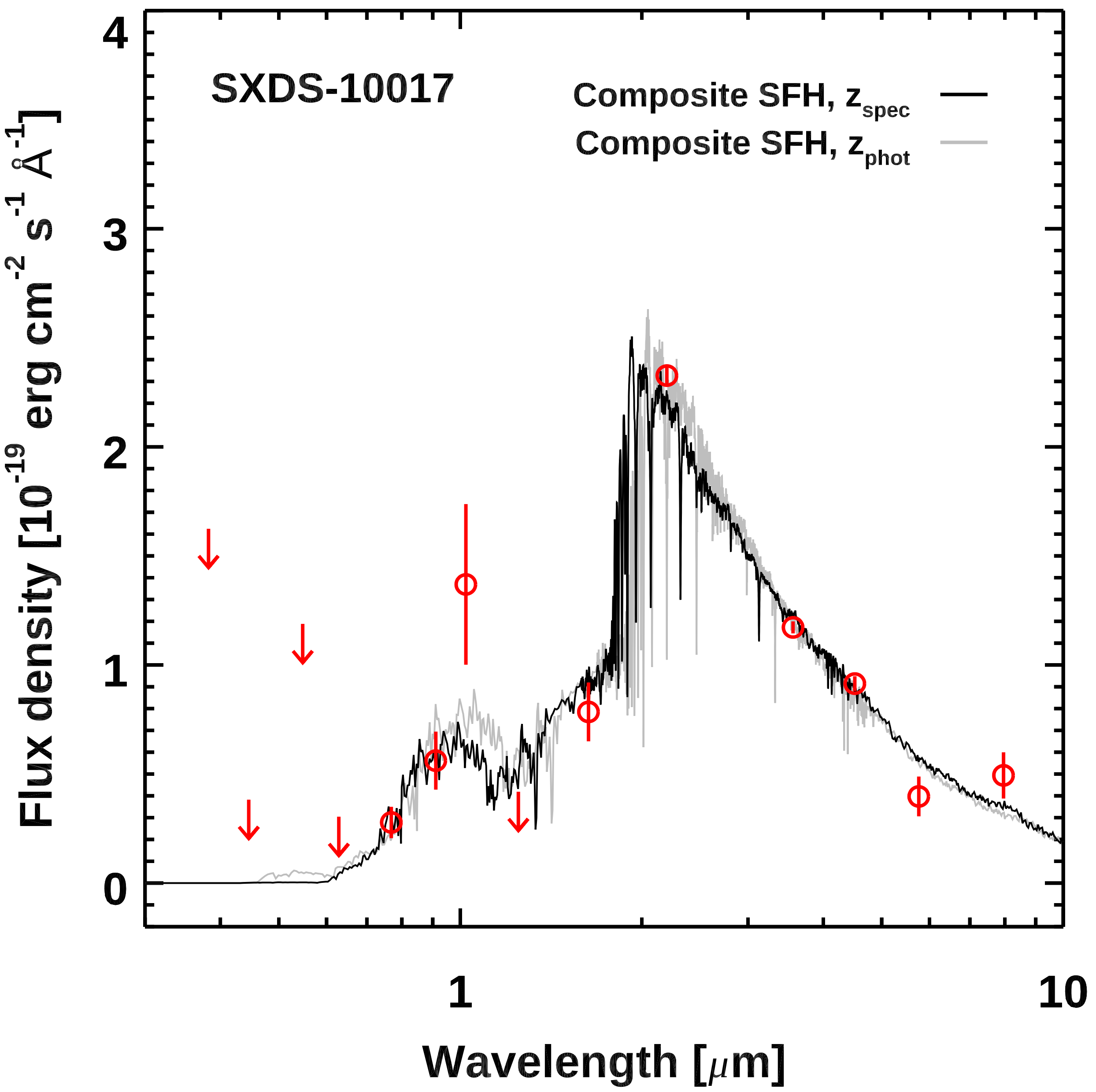
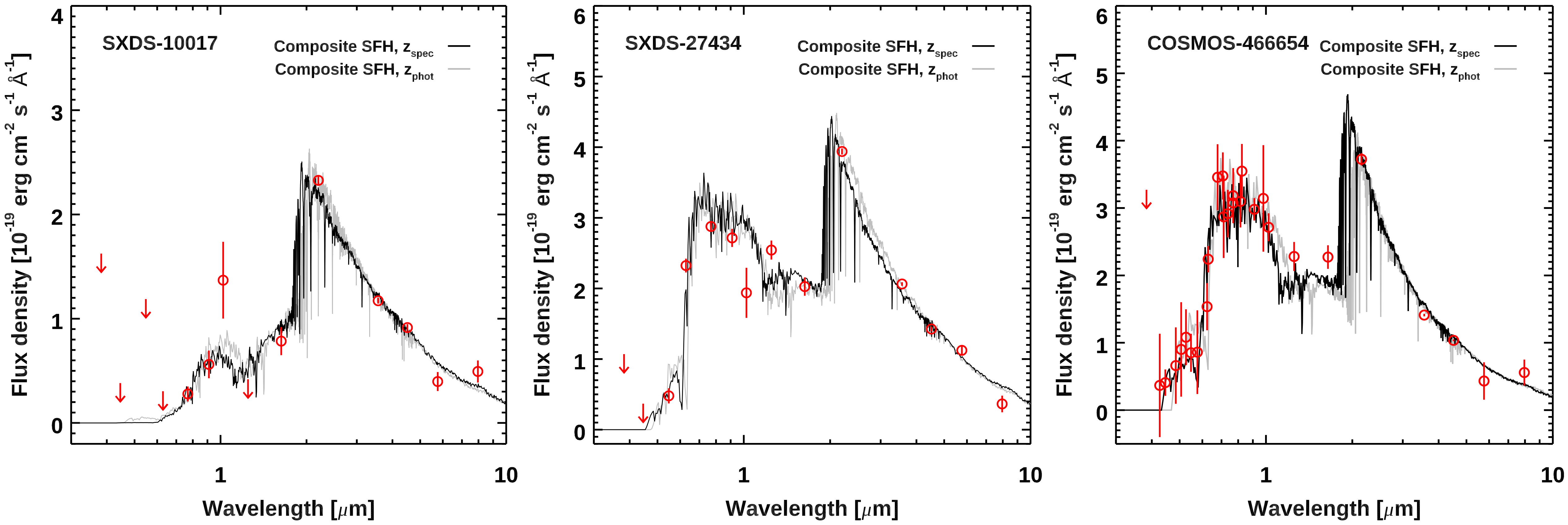


How to spot a dead cosmic giant?

I. Red colors (*UVJ, NUVrJ* rest-frame diagram)

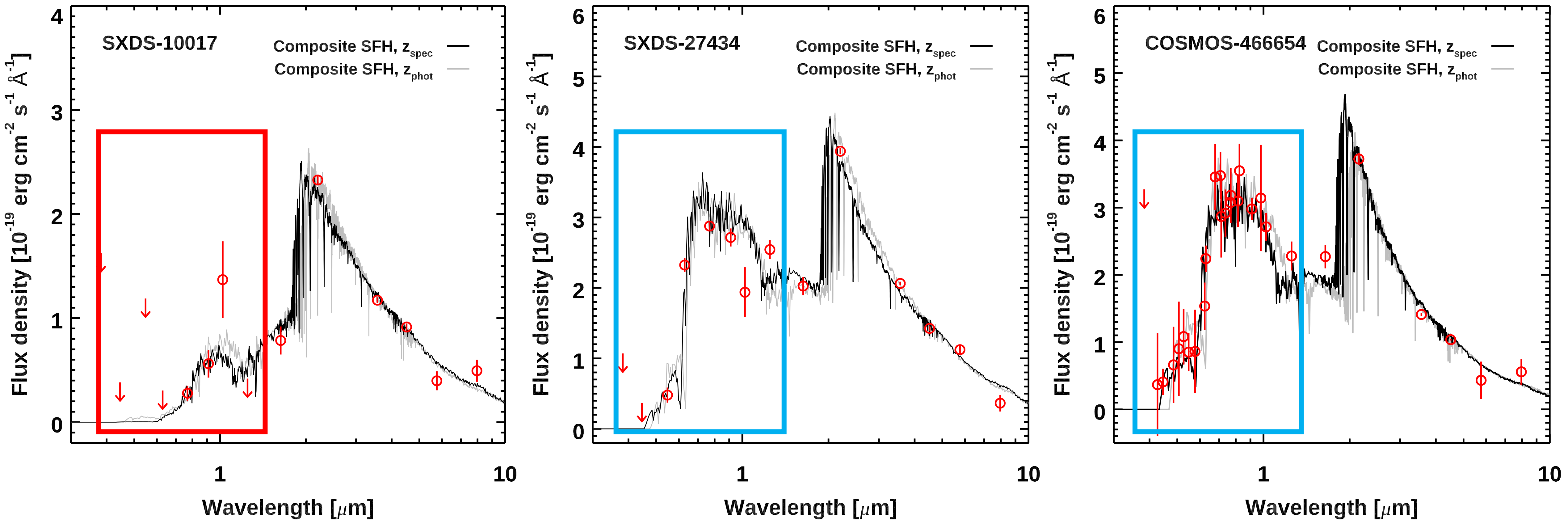
II. Modeling of the Spectral Energy Distribution (SED)



SXDS-10017
SXDS-27434
COSMOS-466654
Composite SFH, z_{spec}
Composite SFH, z_{phot}
Flux density [10^{-19} erg cm^{-2} s^{-1} Å^{-1}]
Wavelength [μm]

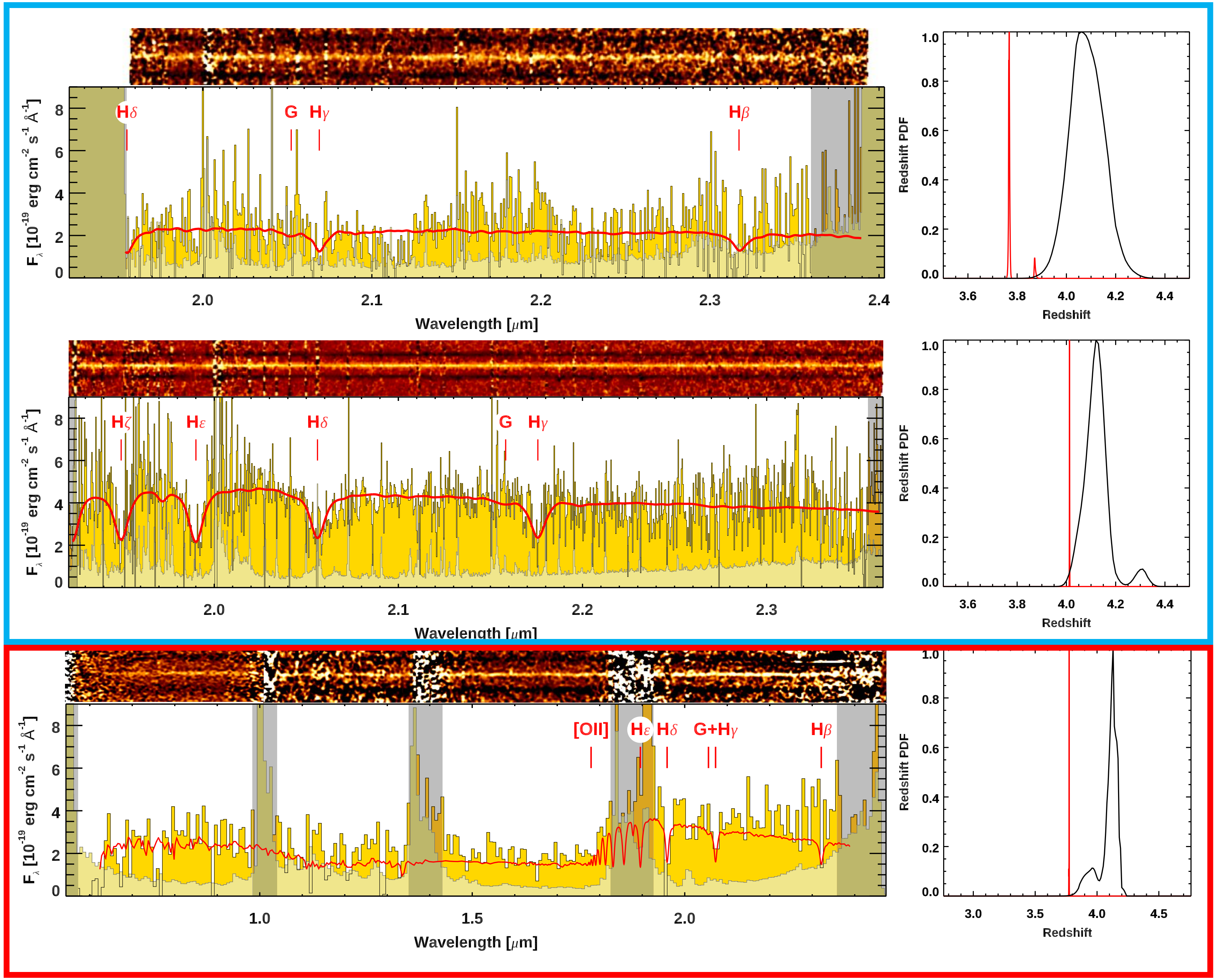
Old and dead

Young(er) and dying



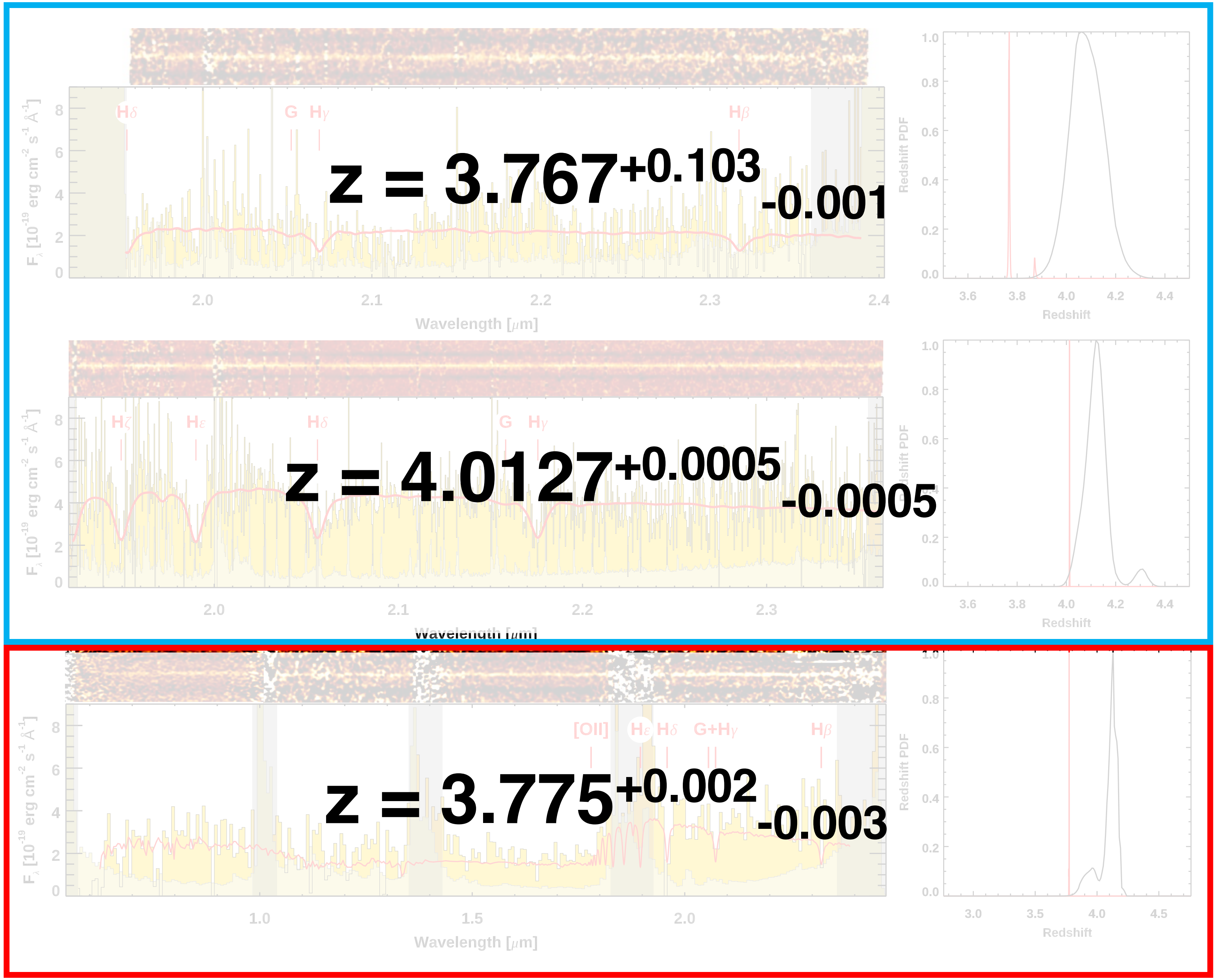
How to be sure that a giant is dead (or dying)?

(By looking for absorption signatures)



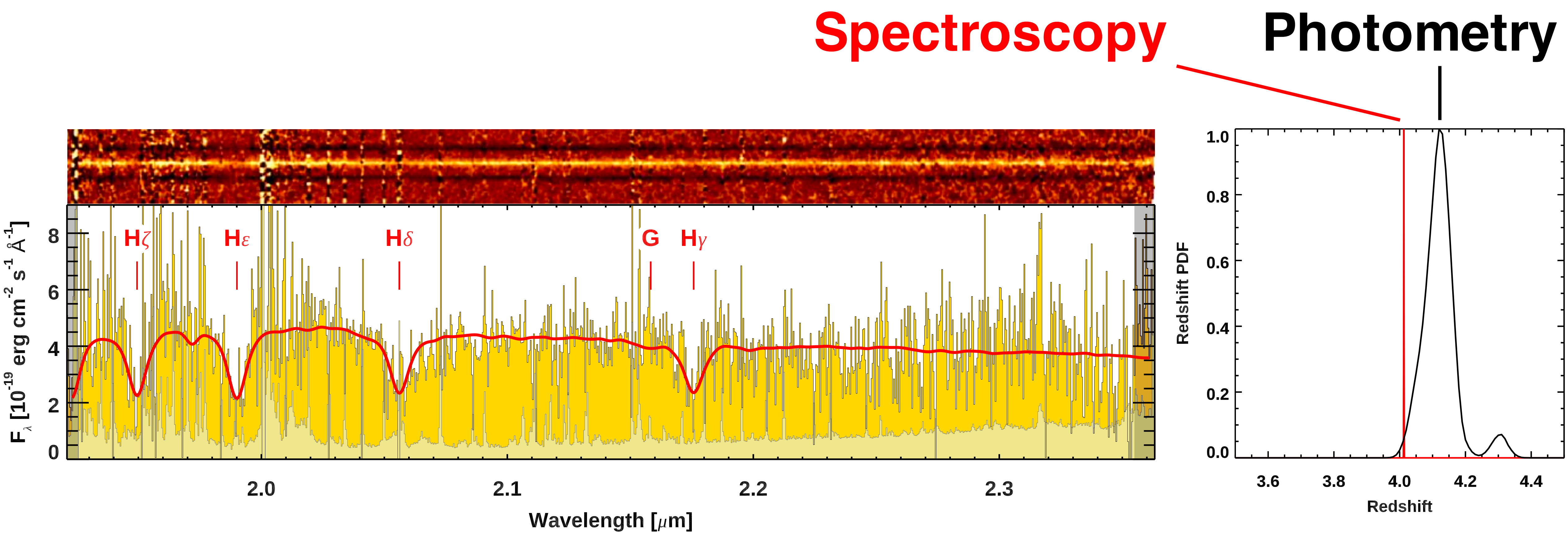
***K*-band spectroscopy with Keck/MOSFIRE and VLT/X-Shooter**

~1 night per target ($K_{AB} \gtrsim 22$)

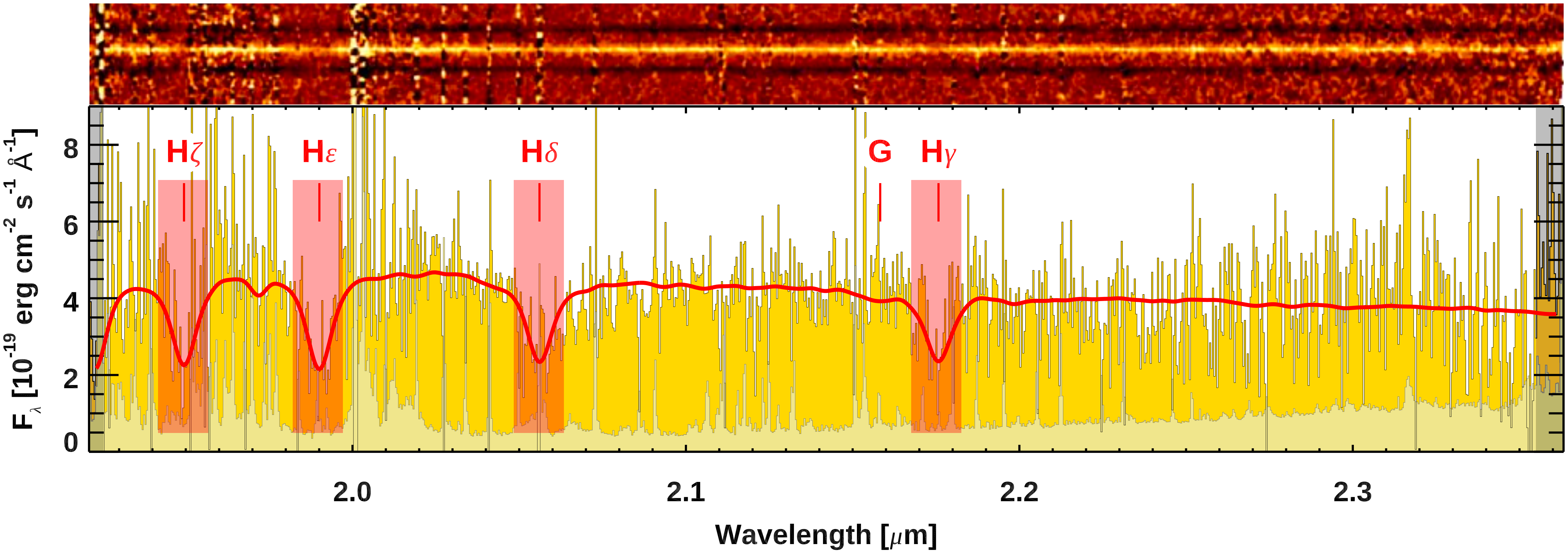


One tentative constraint

Two secure confirmations



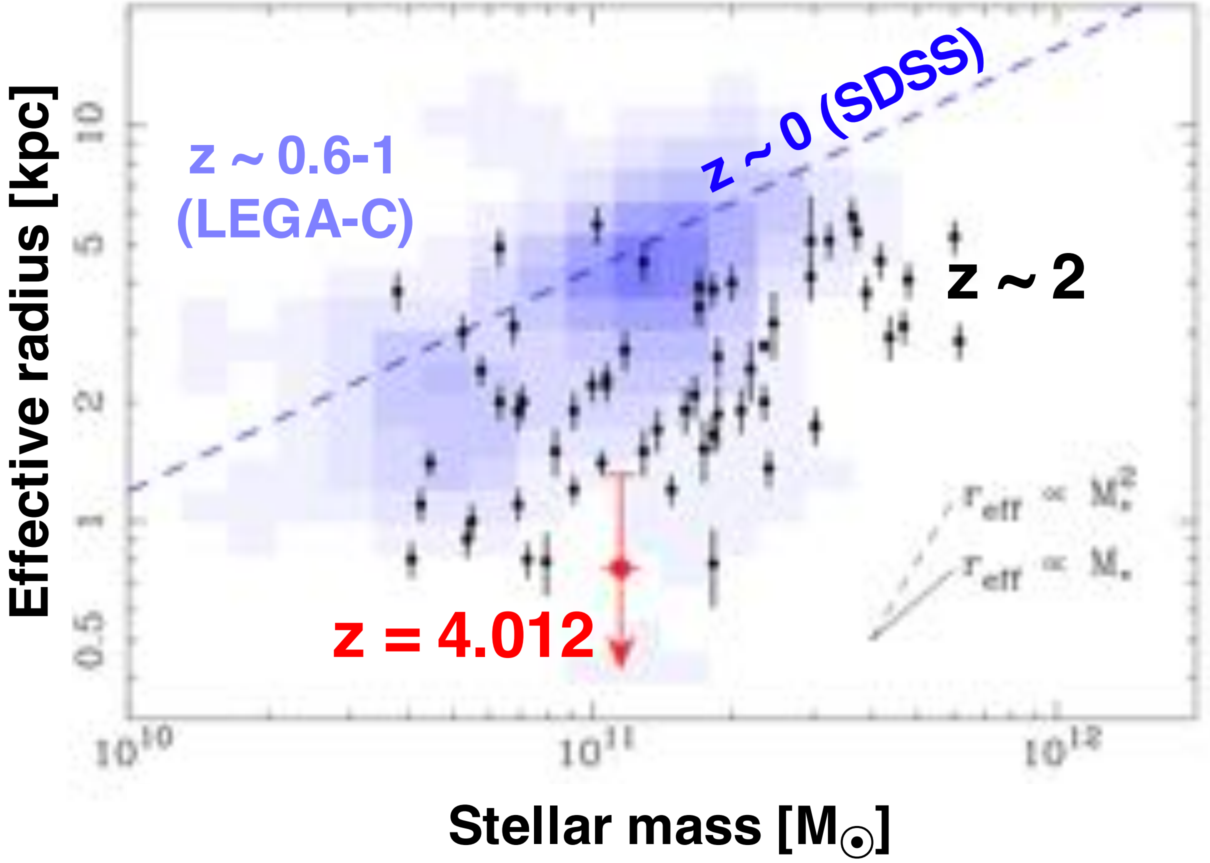
- **No optical emission lines**
- **No far-infrared / sub-mm detection**
- **Little or zero ultraviolet continuum emission**

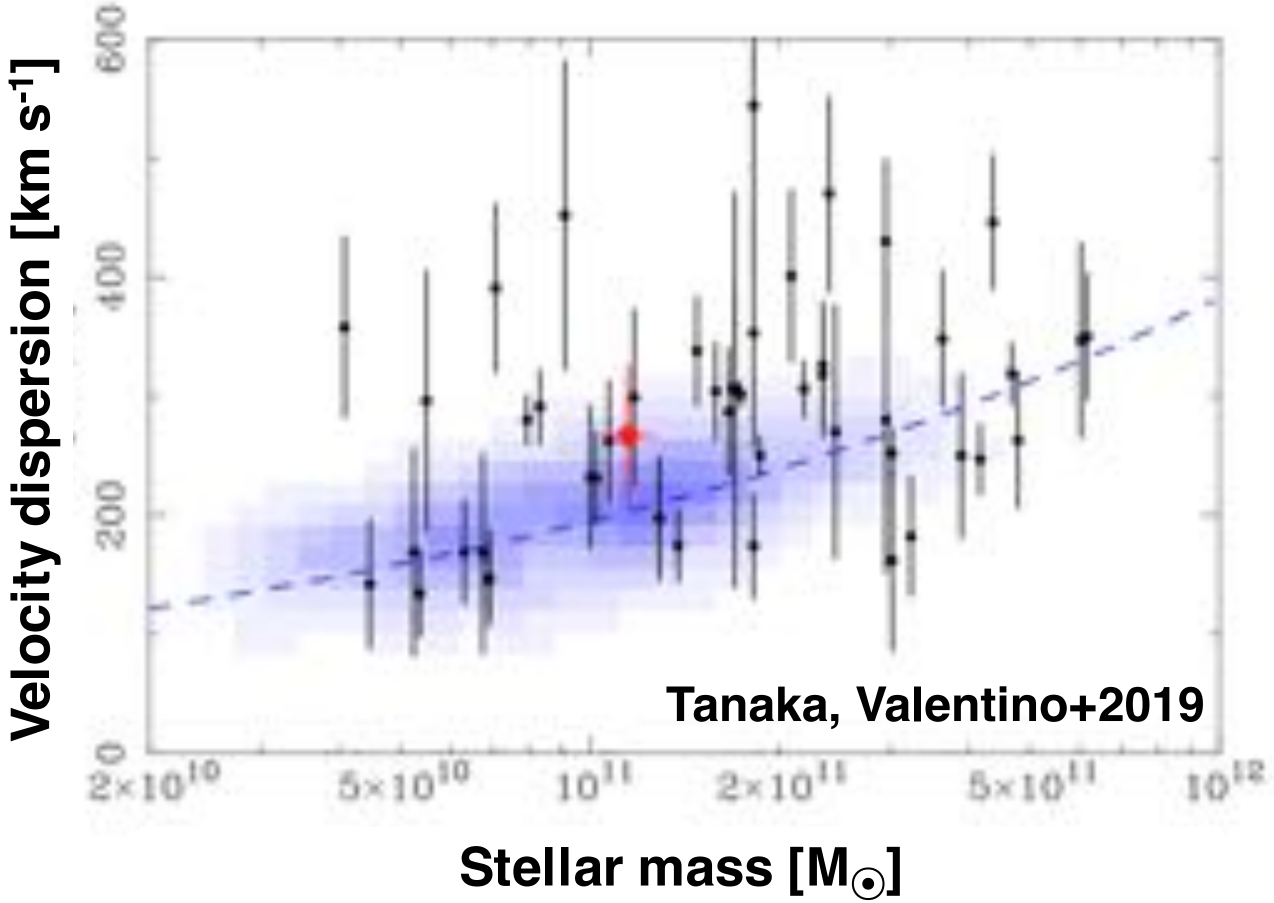


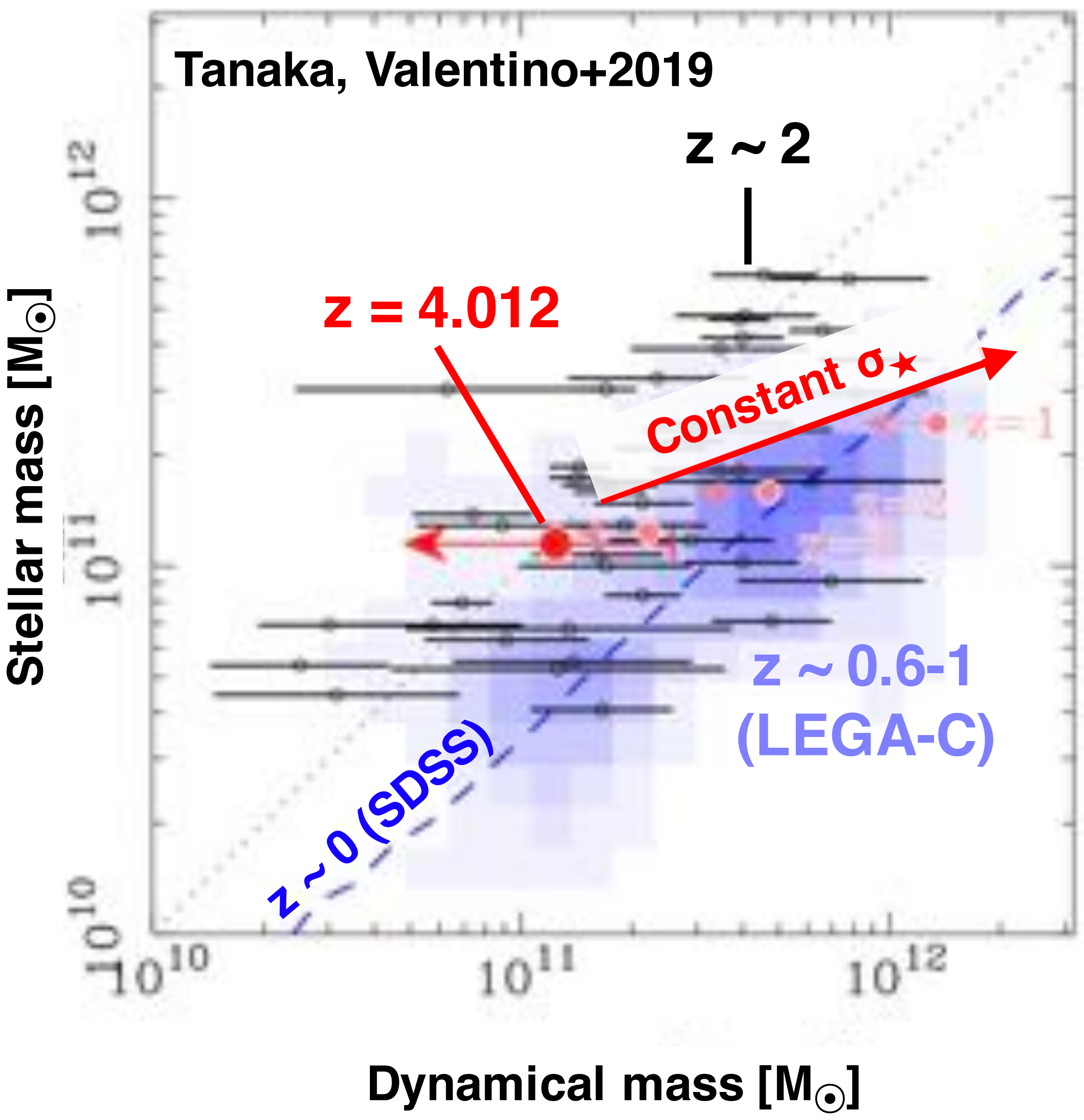
Stellar velocity dispersion of $\sigma_\bigstar = 268 \pm 59$ km s^{-1}

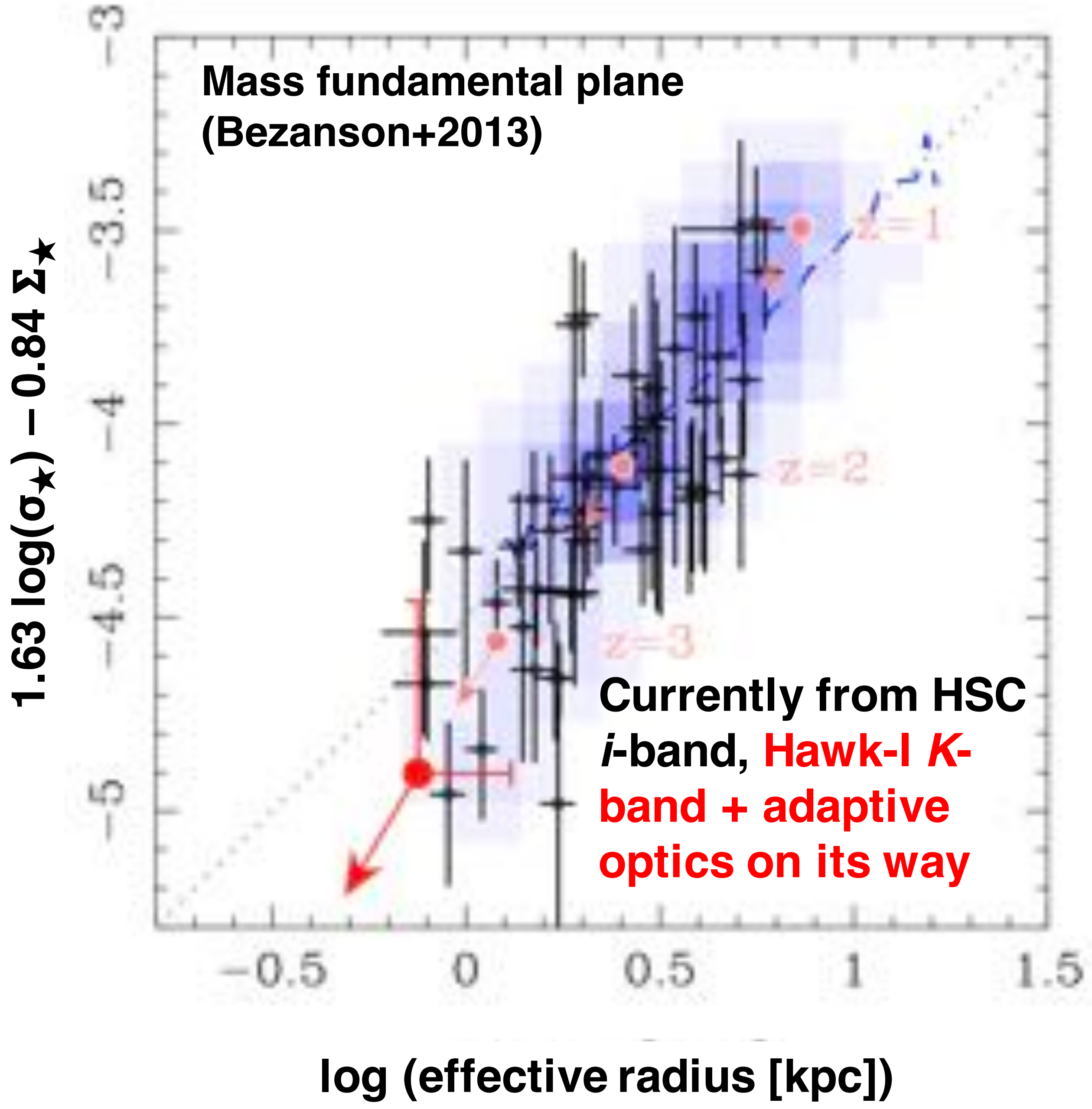
→ First assessment of the stellar dynamics of a(n unlensed) massive galaxy at z~4 (Tanaka, Valentino+2019)

Size + mild stellar mass increase, constant velocity dispersion?

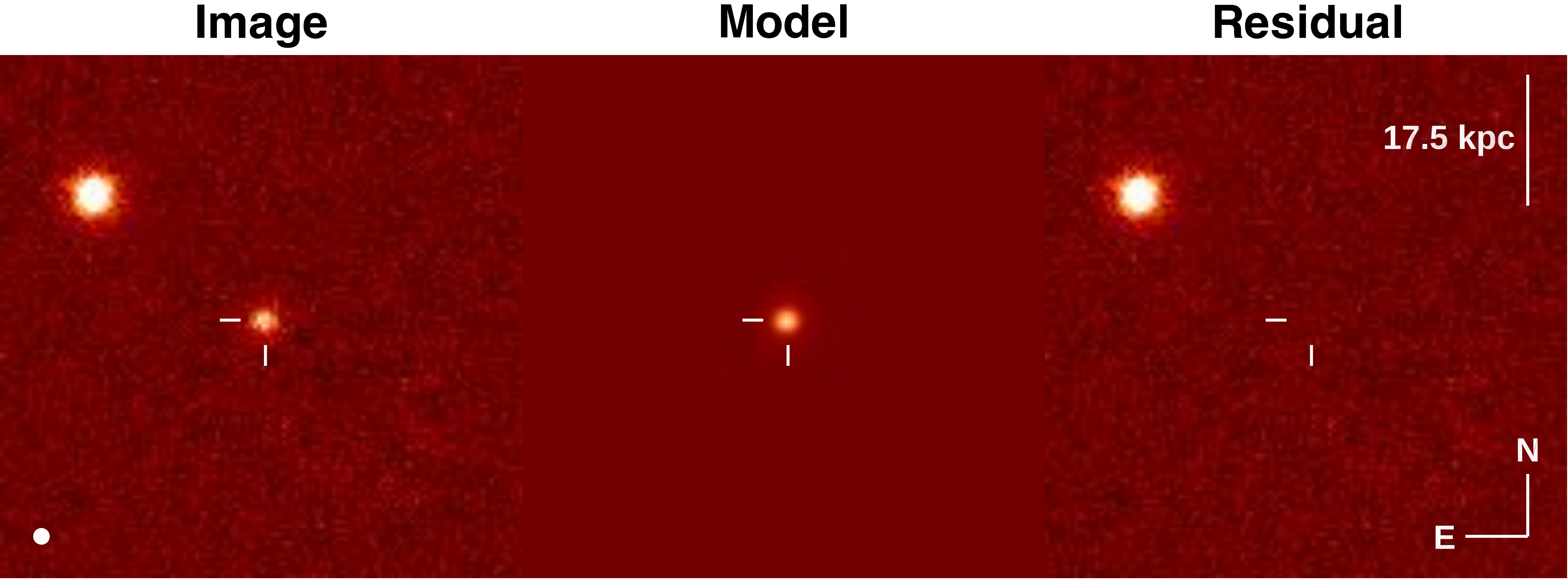





Tanaka, Valentino+2019
z ~ 2
z = 4.012
Constant σ★
z ~ 0.6-1
(LEGA-C)
z ~ 0 (SDSS)
Stellar mass [M☉]
Dynamical mass [M☉]
10^10
10^11
10^12


Mass fundamental plane
(Bezanson+2013)
Currently from HSC i-band, Hawk-I K-band + adaptive optics on its way
1.63 log(σ★) − 0.84 Σ★
log (effective radius [kpc])
−0.5
0
0.5
1
1.5
−3
−3.5
−4
−4.5
−5

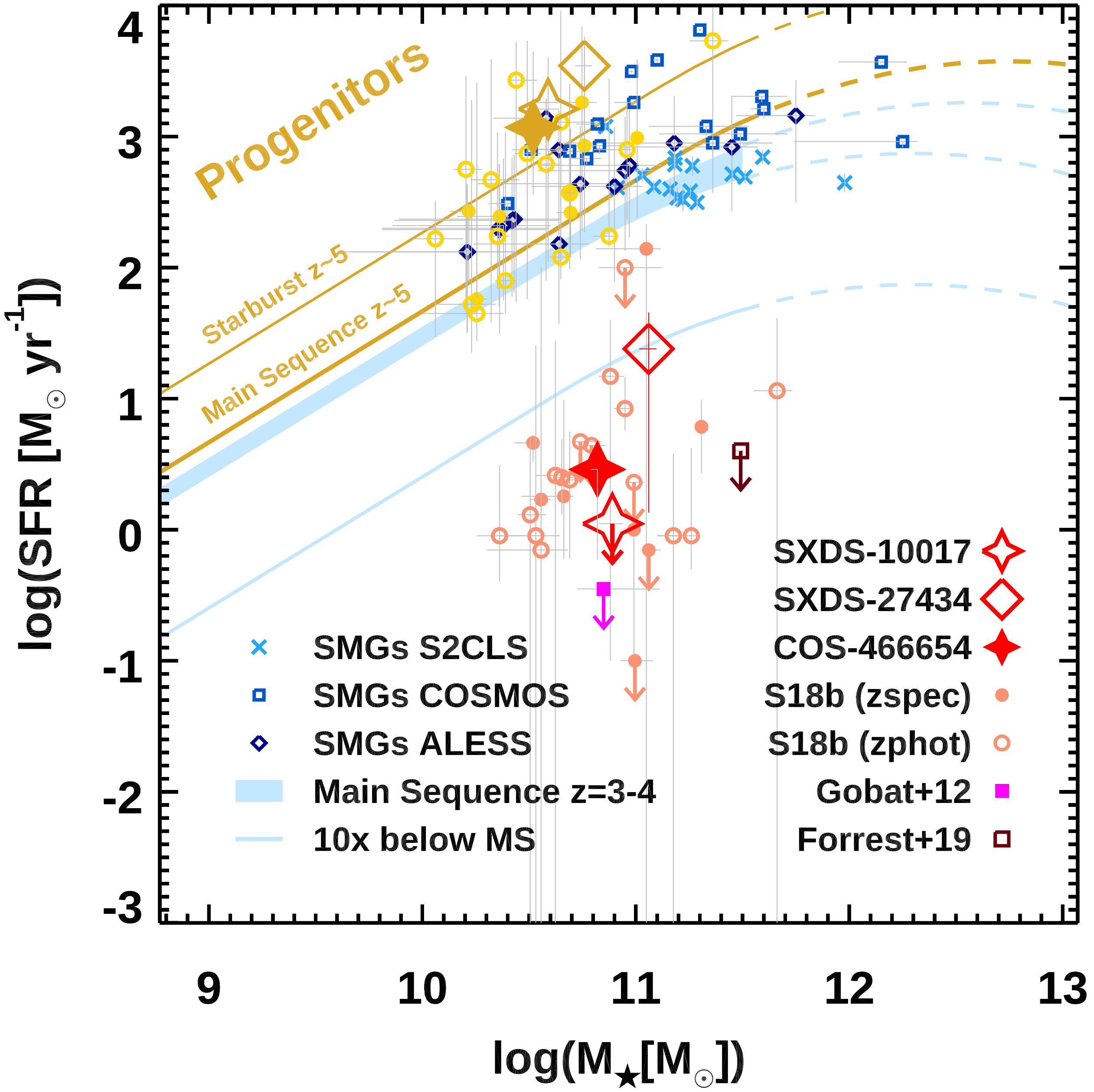
HSC i-band 0.6” seeing



Hawk-I + Adaptive Optics *K*-band 0.34” seeing

Who are their progenitors?

(Dusty star-forming galaxies, but not necessarily extreme)



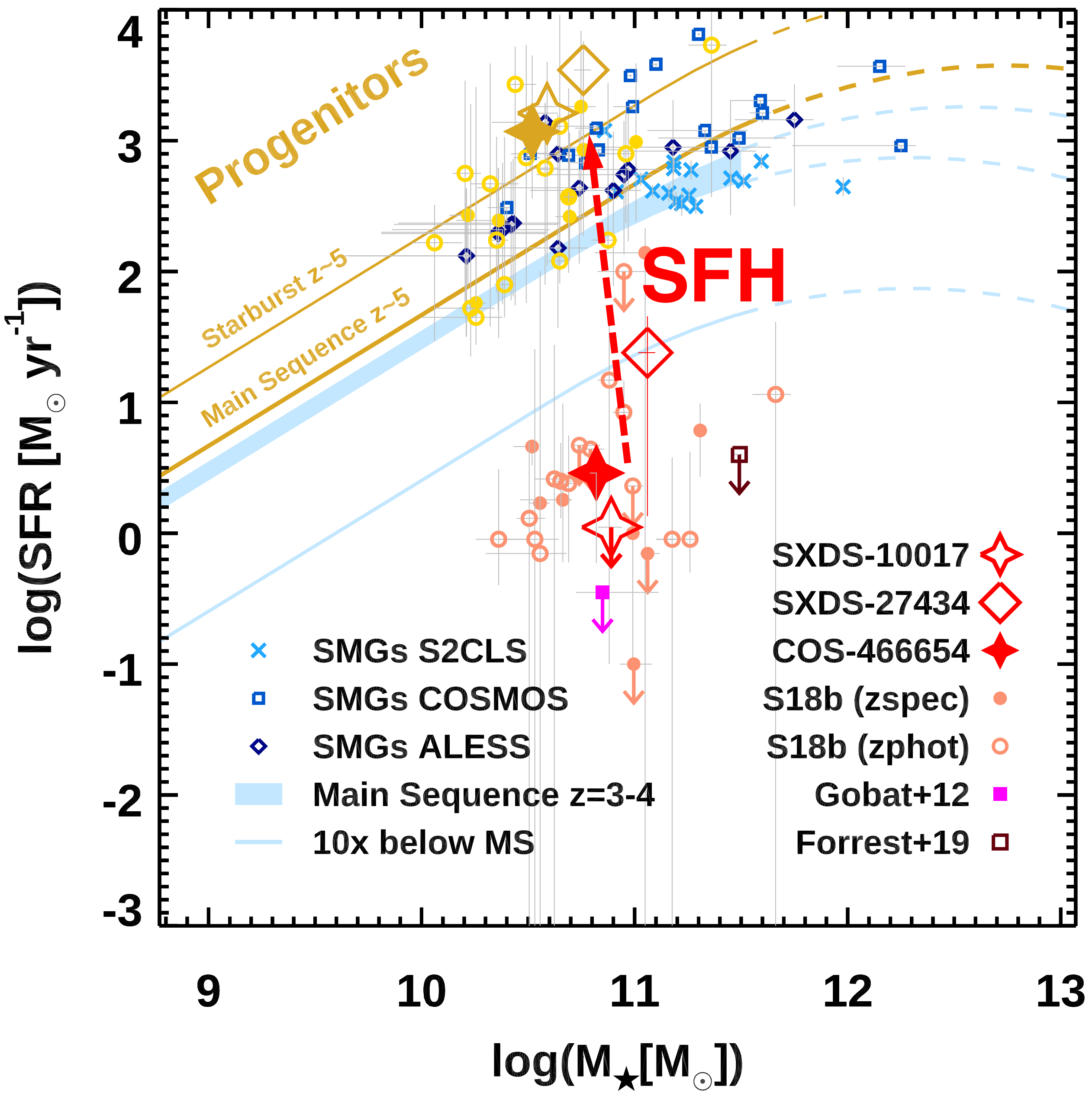
Who are their progenitors?

We look for a population:

- with properties compatible with the predictions from SED modeling
- numerous enough to match the quiescent objects at z~4

Candidates:

Sub-mm galaxies at z $\gtrsim$ 4



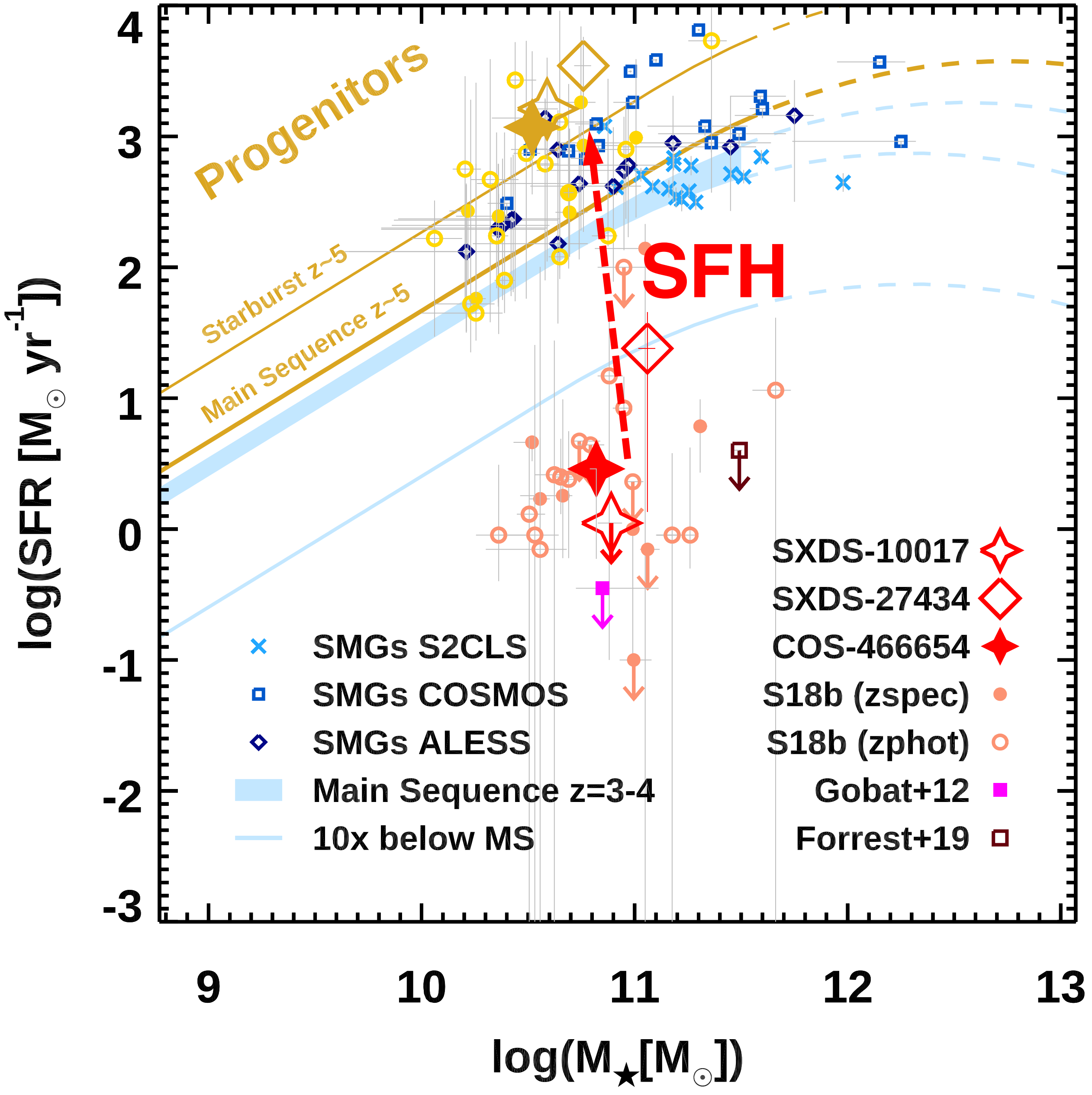
Who are their progenitors?

We look for a population:

- with properties compatible with the predictions from SED modeling
- numerous enough to match the quiescent objects at z~4

Candidates:

Sub-mm galaxies at z ≳ 4



Who are their progenitors?

We look for a population:

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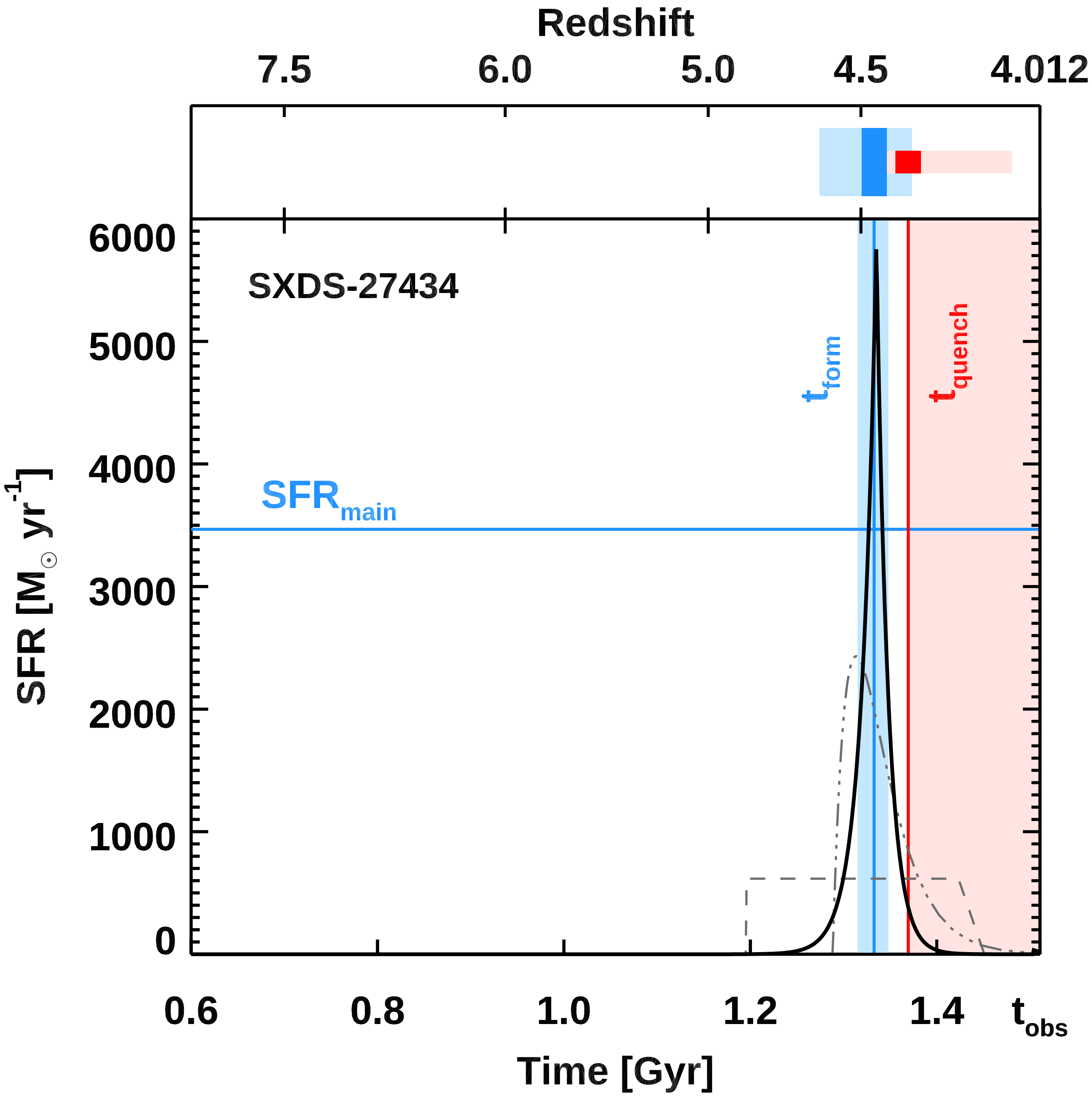
- numerous enough to match the quiescent objects at z~4

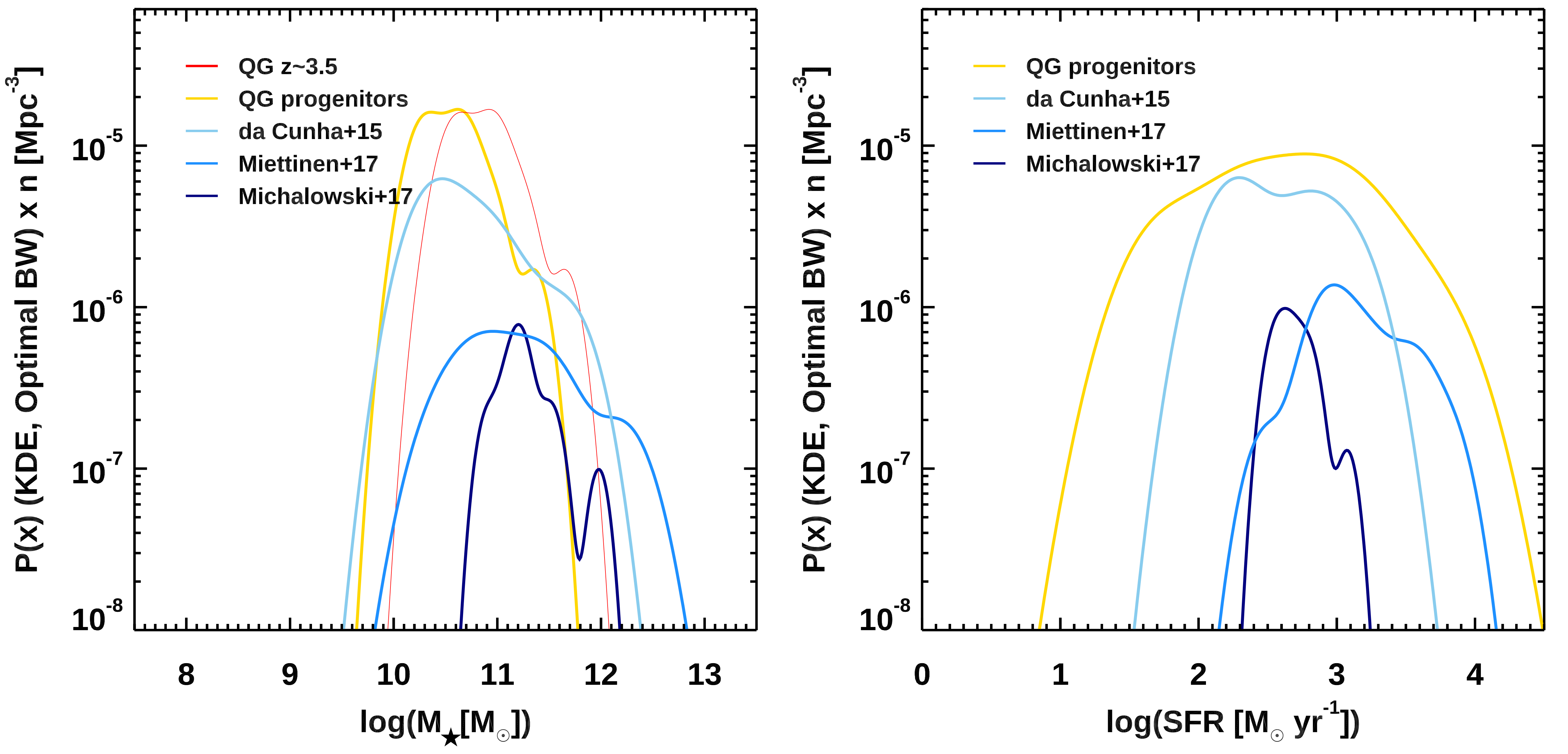
Candidates:

Sub-mm galaxies at z ≳ 4

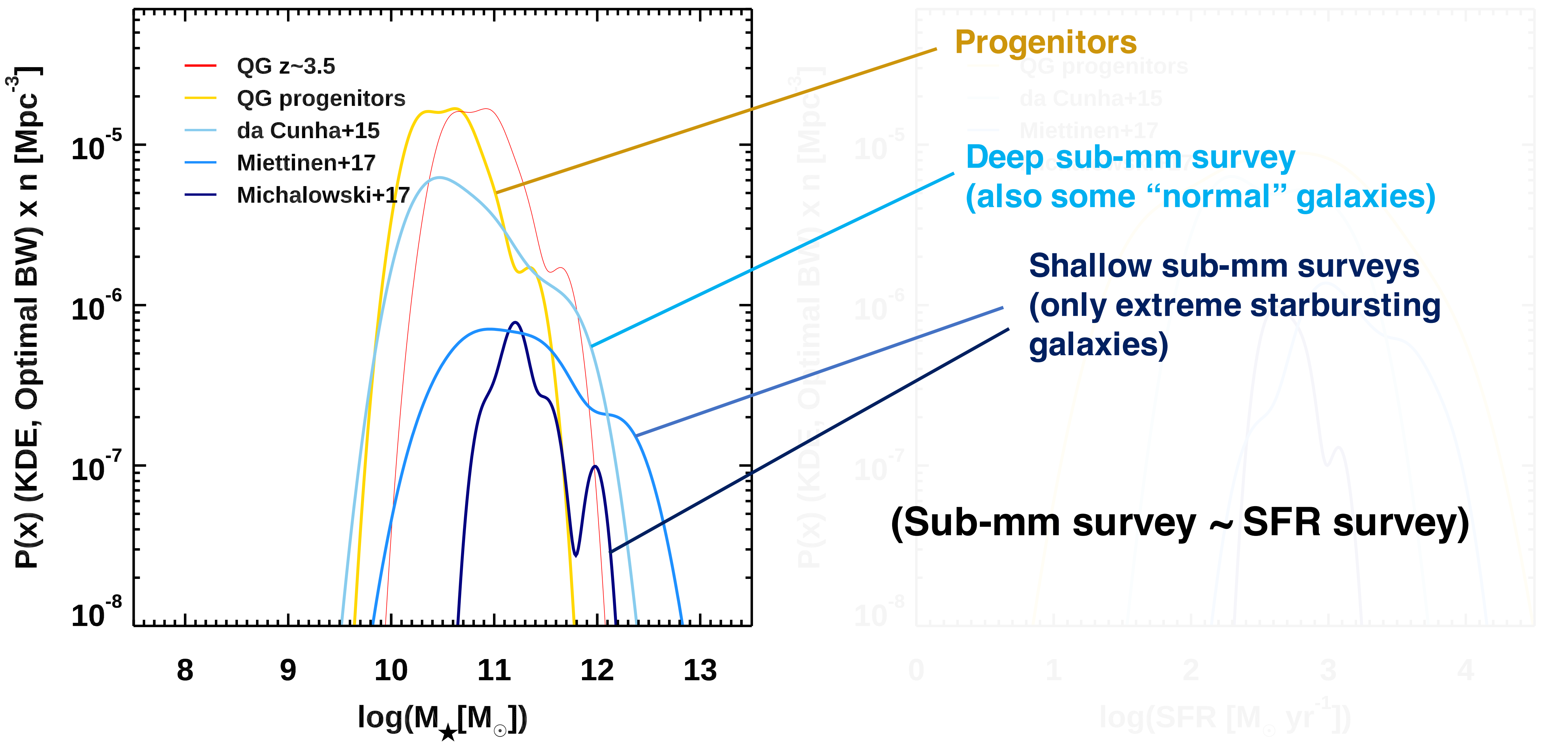


When did they die? Spectrophotometric modeling → Star formation history (Schreiber+2018, Belli+2018)

Short (~50 Myr) and intense ($SFR \sim 1000\text{-}3000\ M_\odot\ yr^{-1}$) burst of star formation followed by an abrupt quenching



QG z~3.5
QG progenitors
da Cunha+15
Miettinen+17
Michalowski+17
P(x) (KDE, Optimal BW) x n [Mpc^-3]
10^-5
10^-6
10^-7
10^-8
8
9
10
11
12
13
log(M★[M☉])
QG progenitors
da Cunha+15
Miettinen+17
Michalowski+17
P(x) (KDE, Optimal BW) x n [Mpc^-3]
10^-5
10^-6
10^-7
10^-8
0
1
2
3
4
log(SFR [M☉ yr^-1])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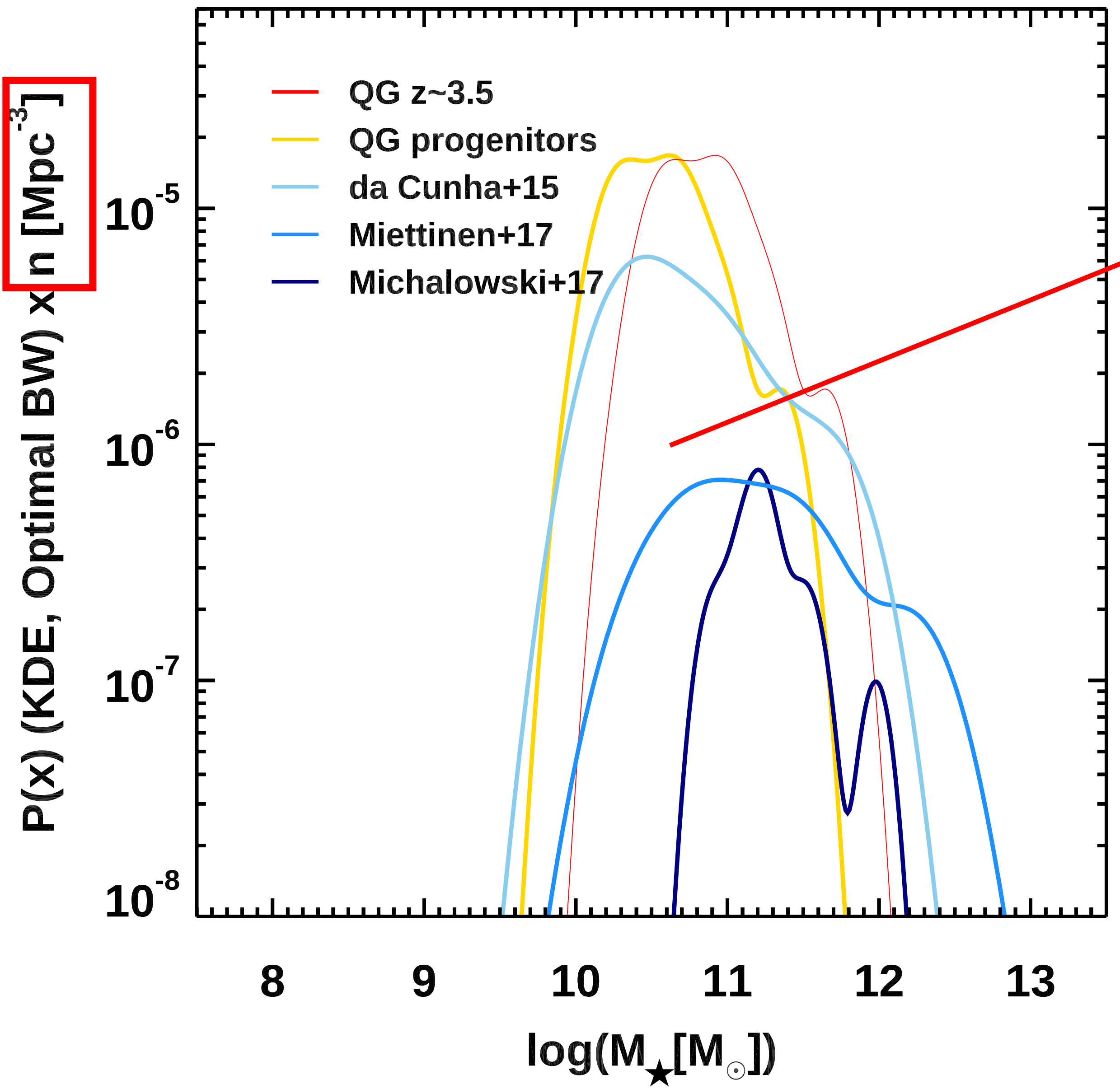
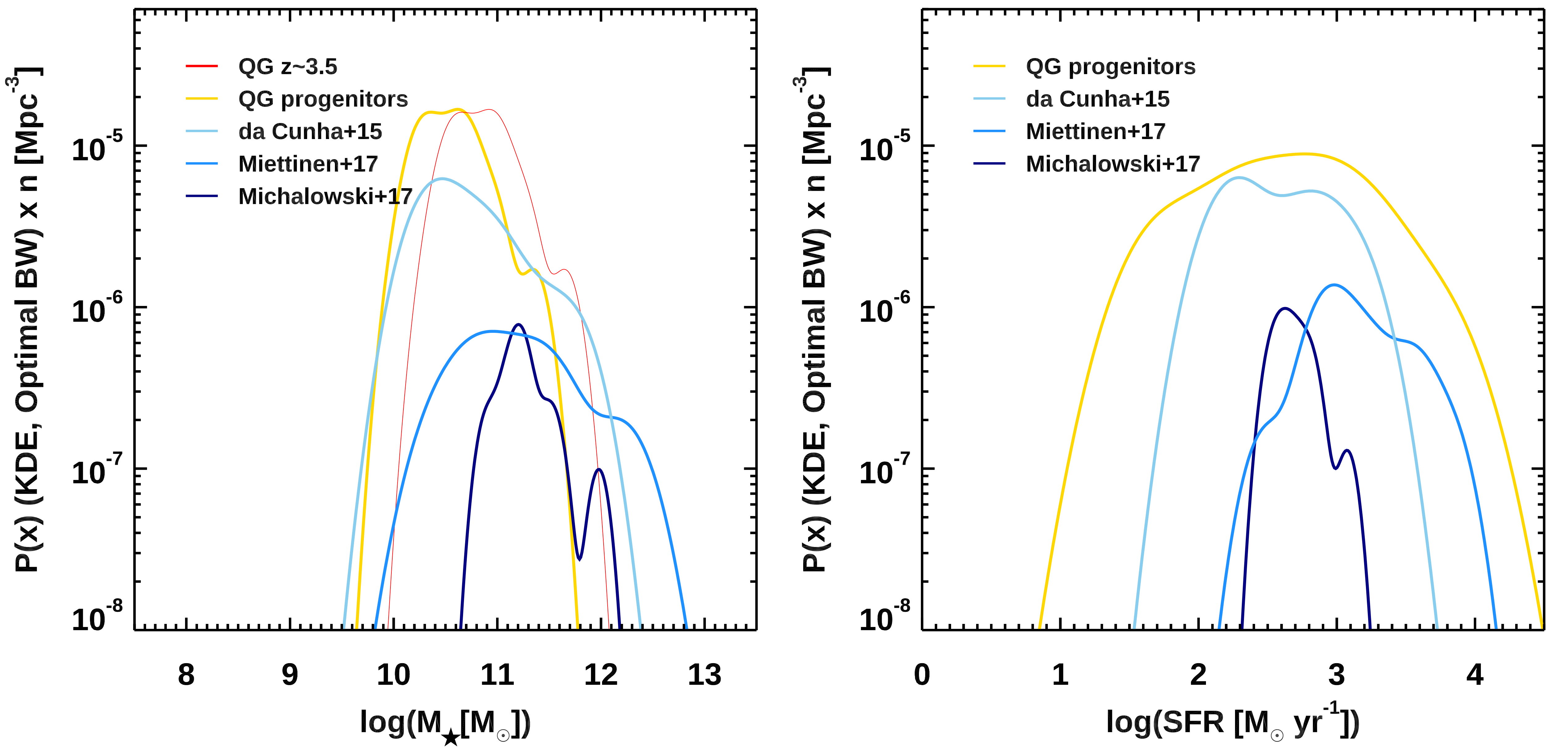
Michalowski+17
P(x) (KDE, Optimal BW) x n [Mpc^-3]
10^-5
10^-6
10^-7
10^-8
8
9
10
11
12
13
log(M★[M☉])
Progenitors
Deep sub-mm survey
(also some “normal” galaxies)
Shallow sub-mm surveys
(only extreme starbursting
galaxies)
(Sub-mm survey ~ SFR survey)



Areas = comoving number densities (= number of galaxies / comoving volume)



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10^-5
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8
9
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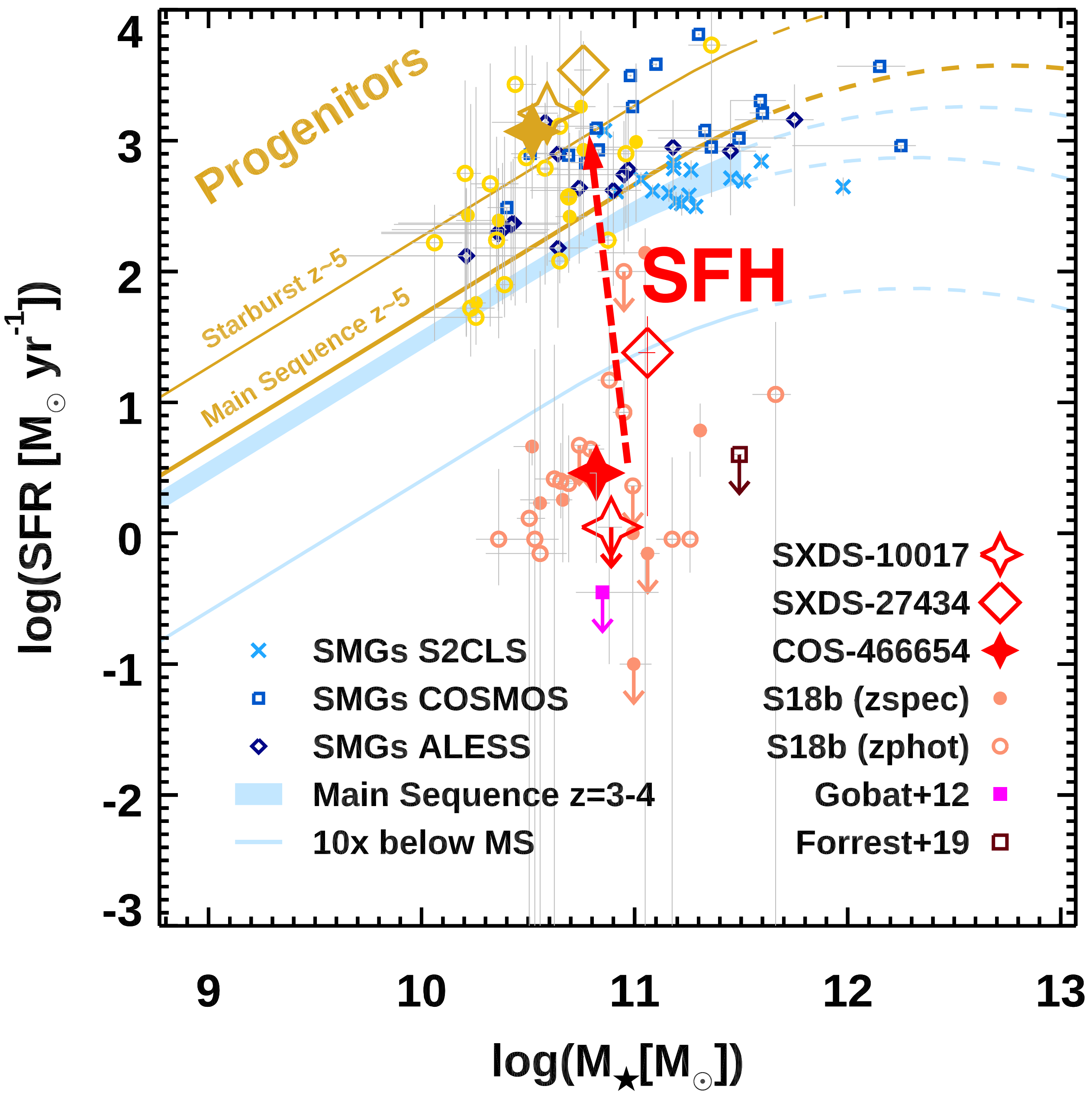
11
12
13
log(M★[M☉])
QG progenitors
da Cunha+15
Miettinen+17
Michalowski+17
P(x) (KDE, Optimal BW) x n [Mpc^-3]
10^-5
10^-6
10^-7
10^-8
0
1
2
3
4
log(SFR [M☉ yr^-1])

- Deep sub-mm surveys are fundamental
- Not all the progenitors are extreme starbursts (i.e., sub-mm galaxies in the common meaning, see also Wang+2019, Williams+2019)
- Systematics and selection effects (observed wavelength, single-dish vs interferometry, etc.) cannot be neglected



Who are their progenitors?

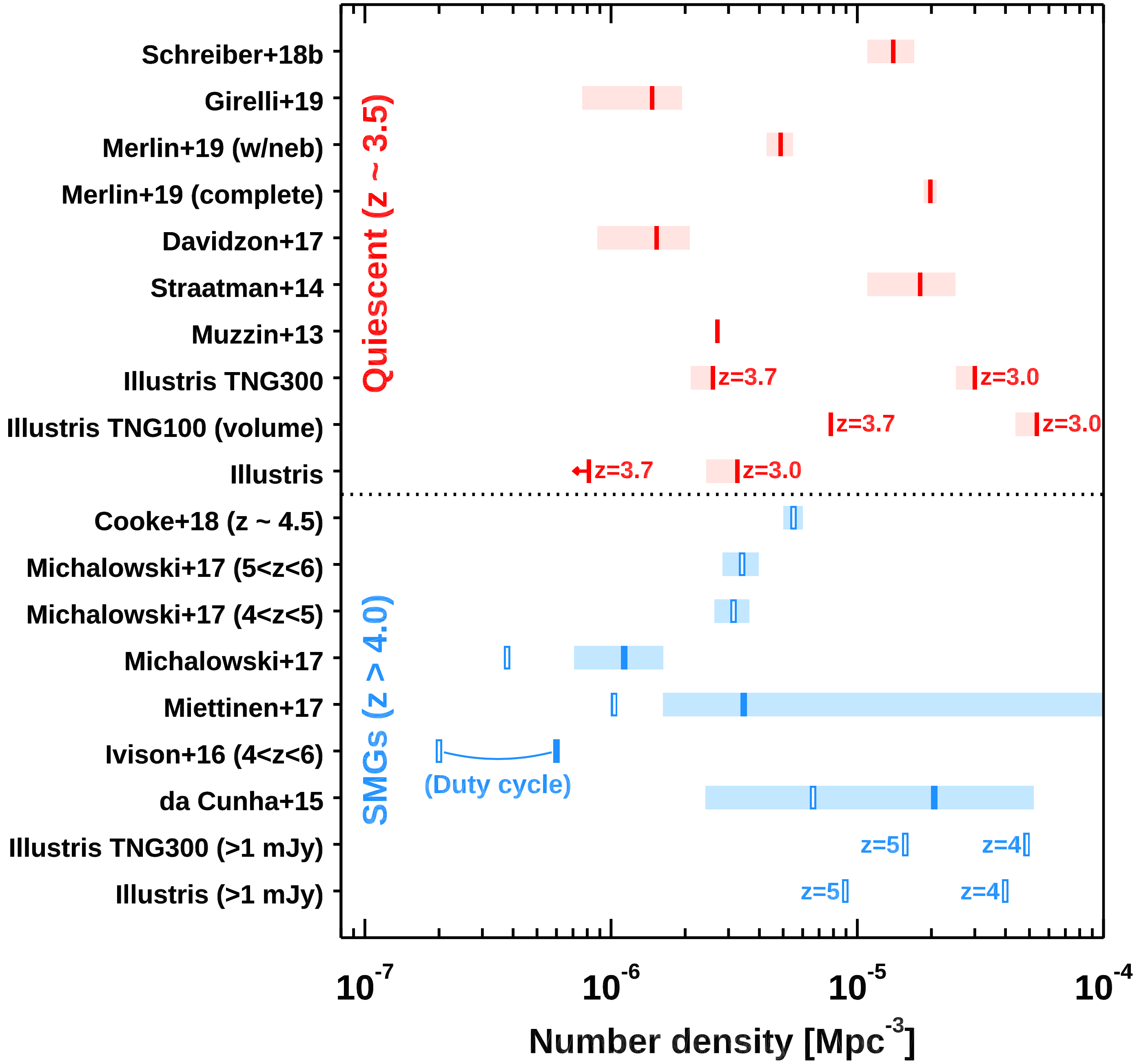
We look for a population:

- with properties compatible with the predictions from SED modeling
- **numerous enough to match the quiescent objects at z~4**

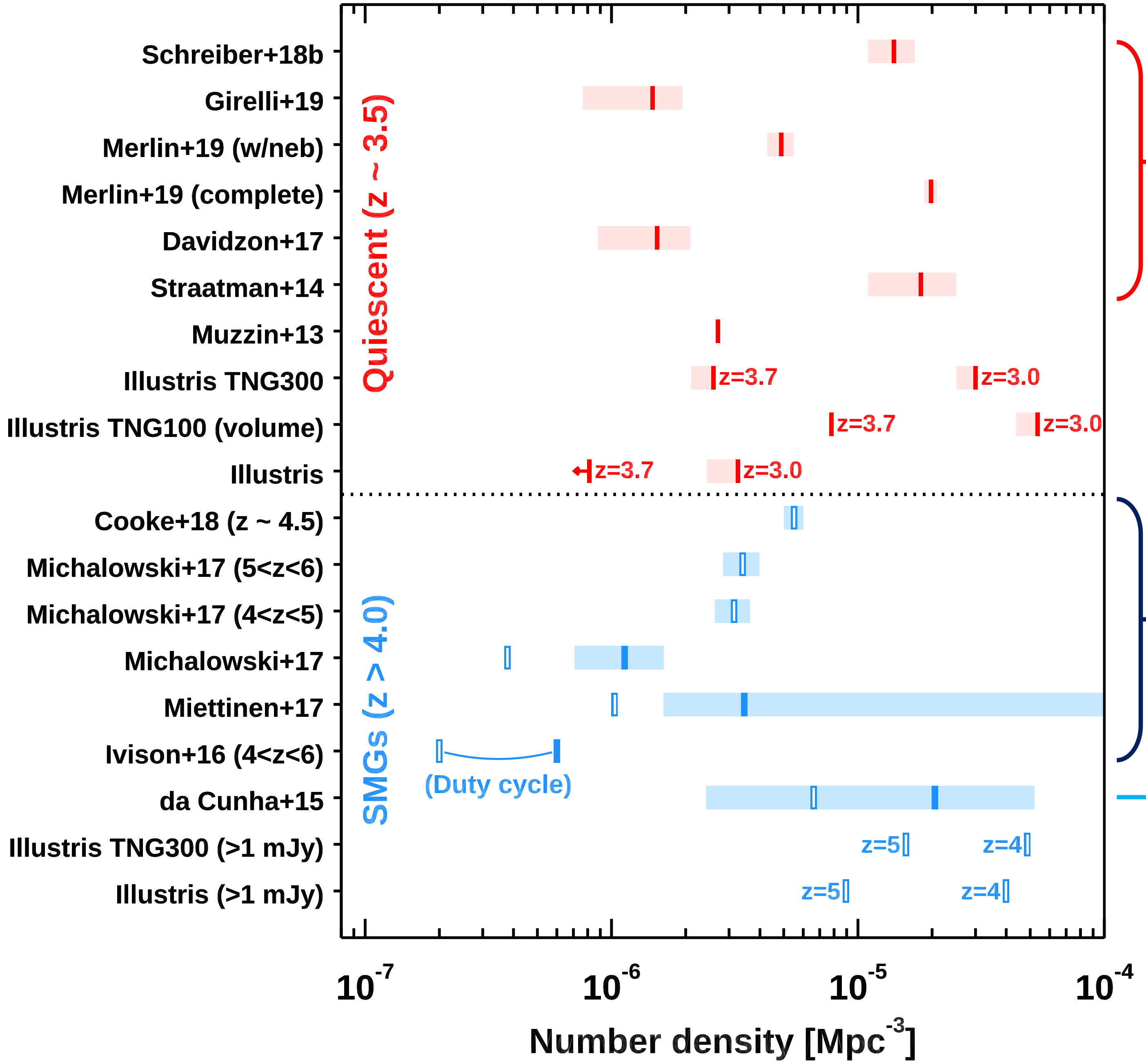
Candidates:

Sub-mm galaxies at z ≳ 4

Are there enough?



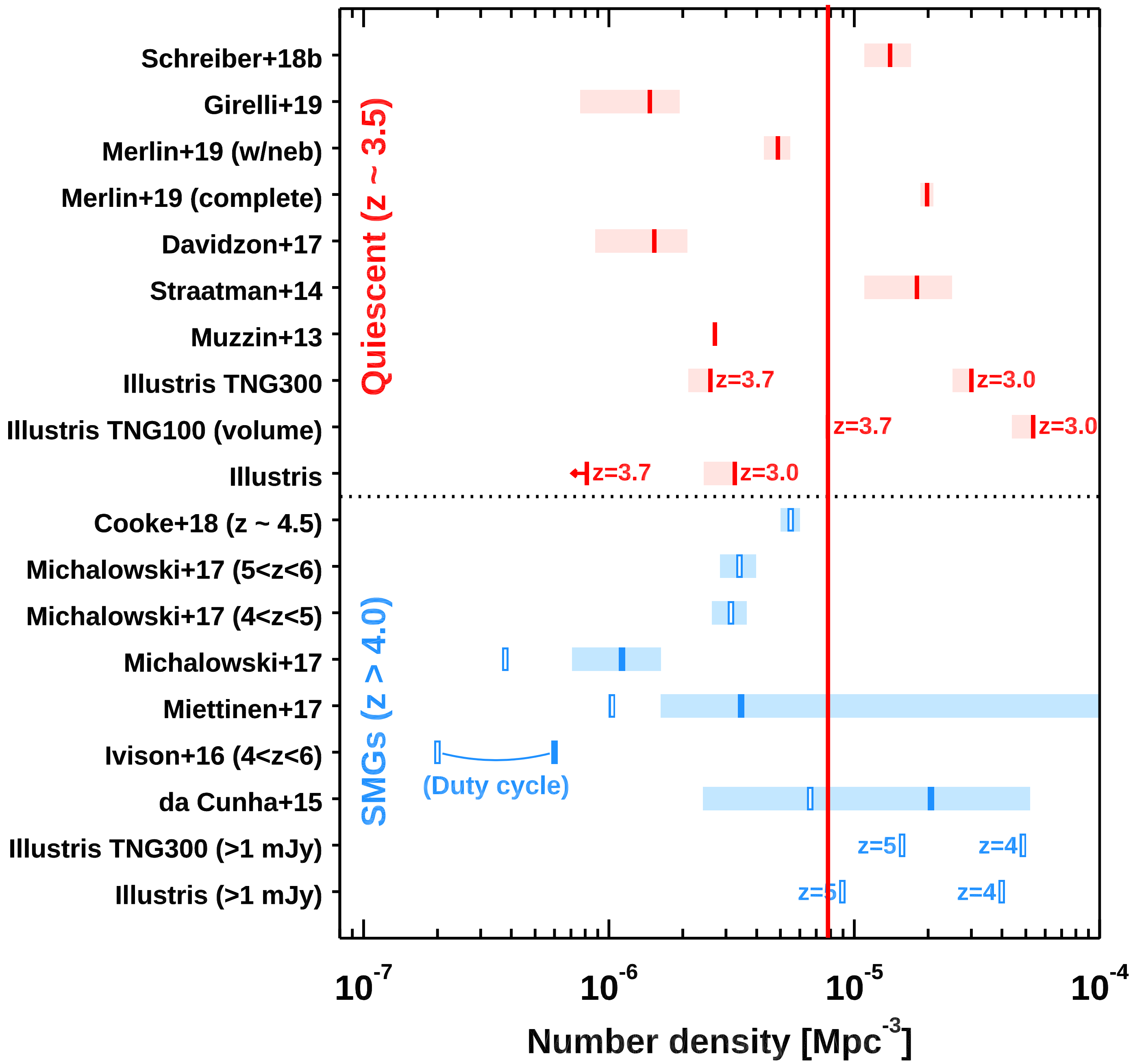
Are there enough?



Quiescent galaxies at 3 < z < 4

Shallow sub-mm surveys (only extreme starbursting galaxies)

Deep interferometric sub-mm survey (also some “normal” galaxies)



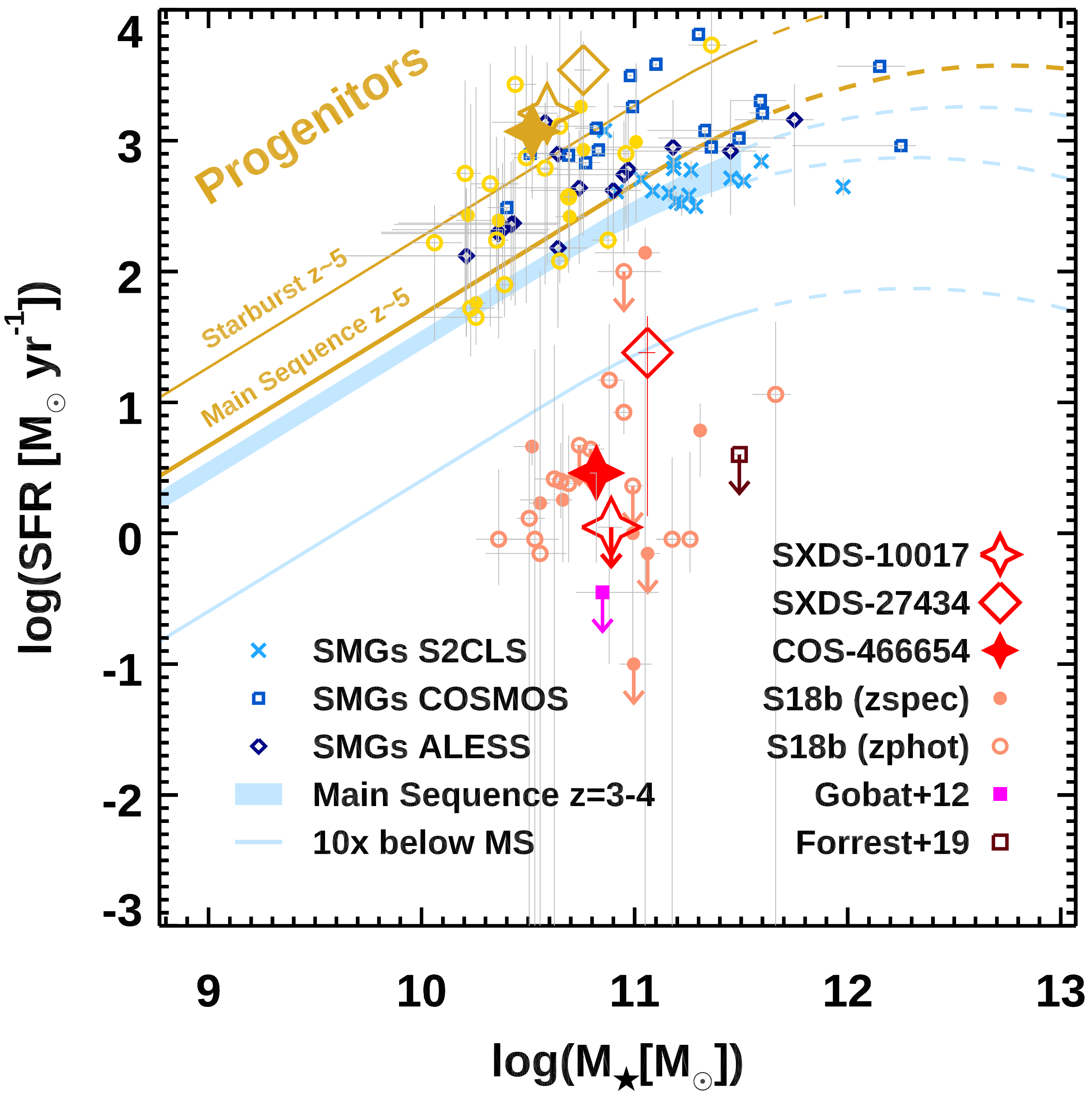
Are there enough?

Yes, when observing deep enough.

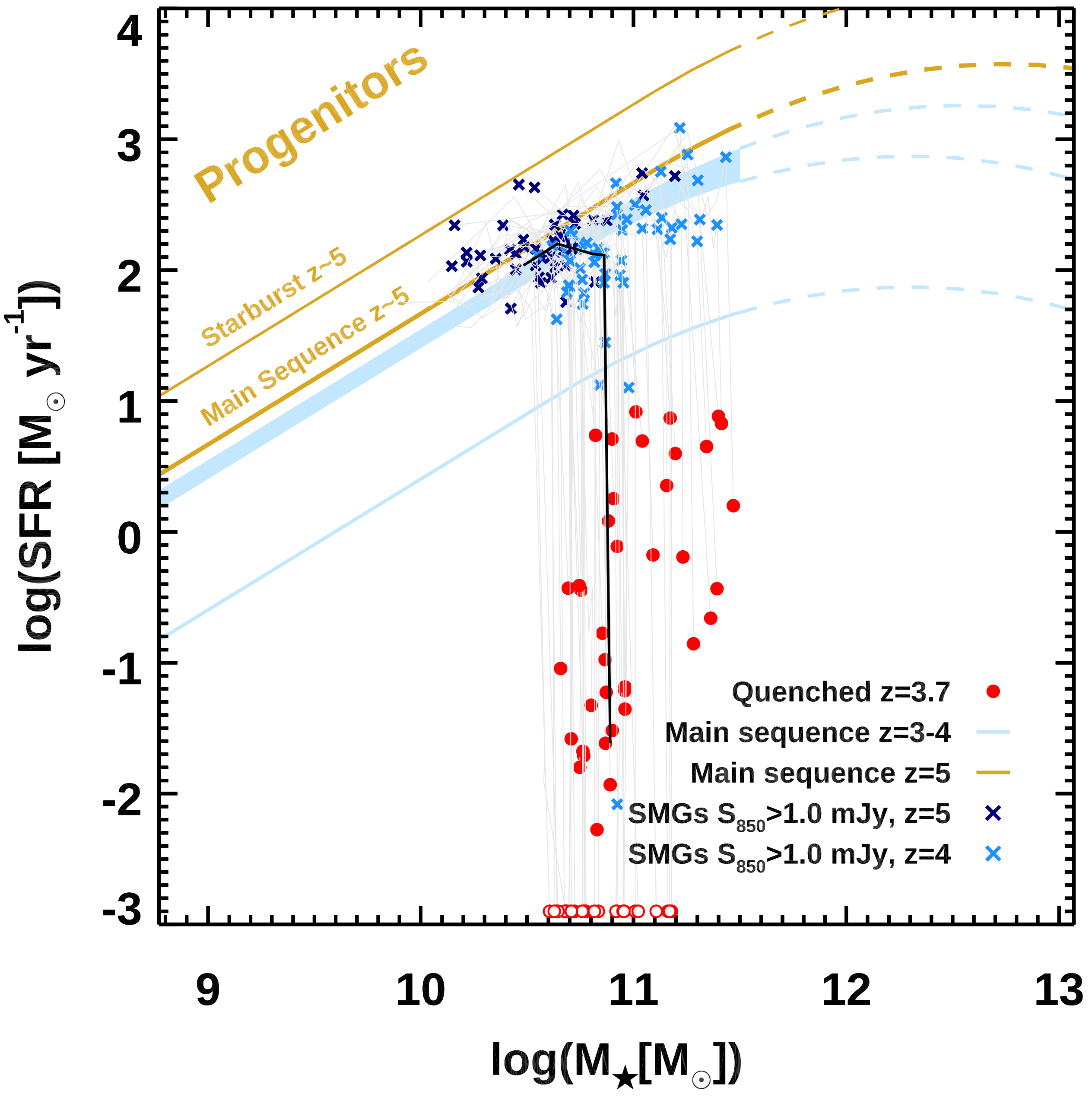
- **Deep sub-mm** surveys are fundamental
- **Not all the progenitors are extreme starbursts** (i.e., sub-mm galaxies in the common meaning, see also Wang+2019, Williams+2019)
- **Systematics** and **selection effects** (observed wavelength, single-dish vs interferometry, etc.) cannot be neglected
- **Number densities** roughly matching

Can we model the early death of cosmic giants?

(Only partially: something is missing)

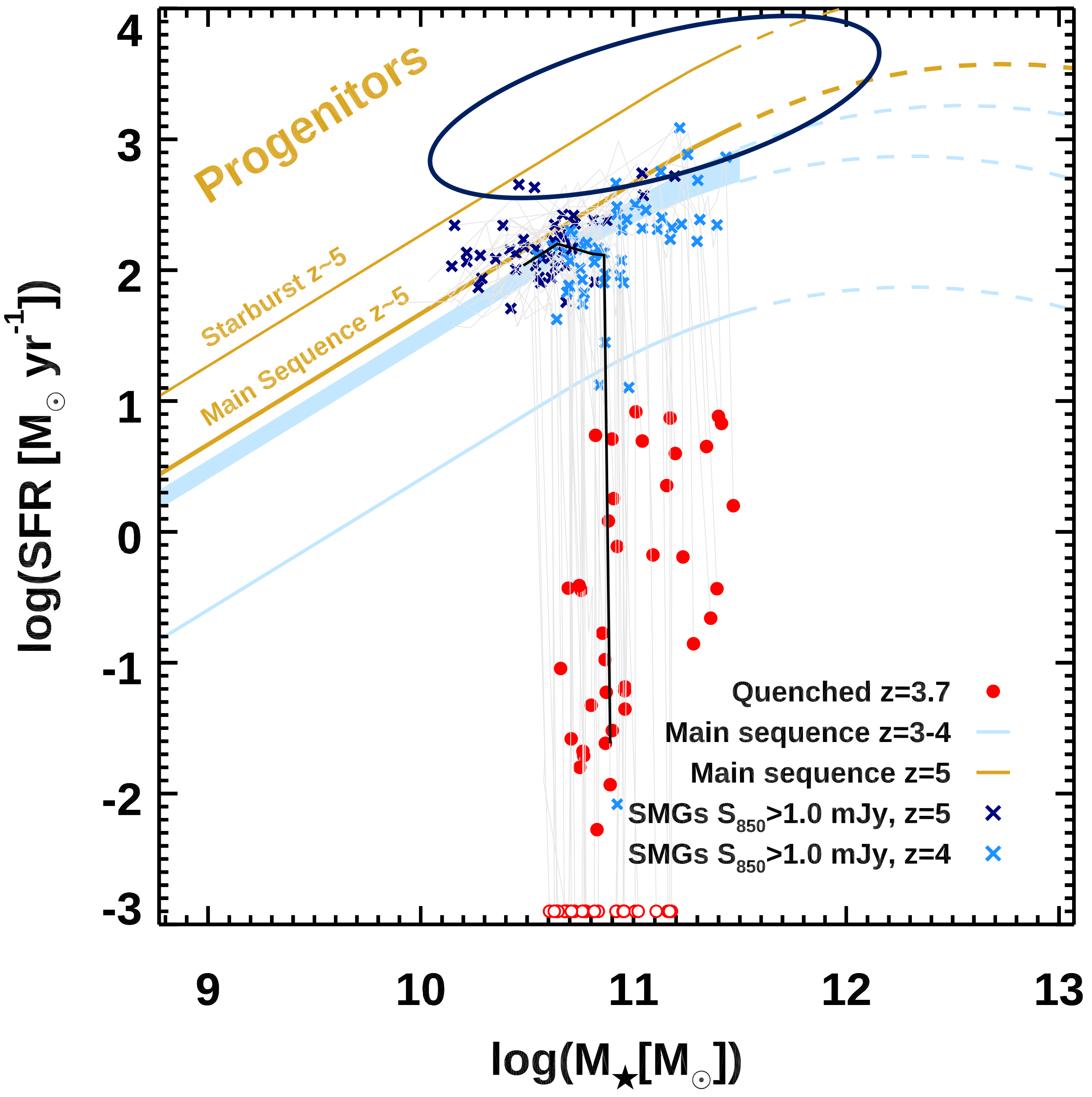


Observations



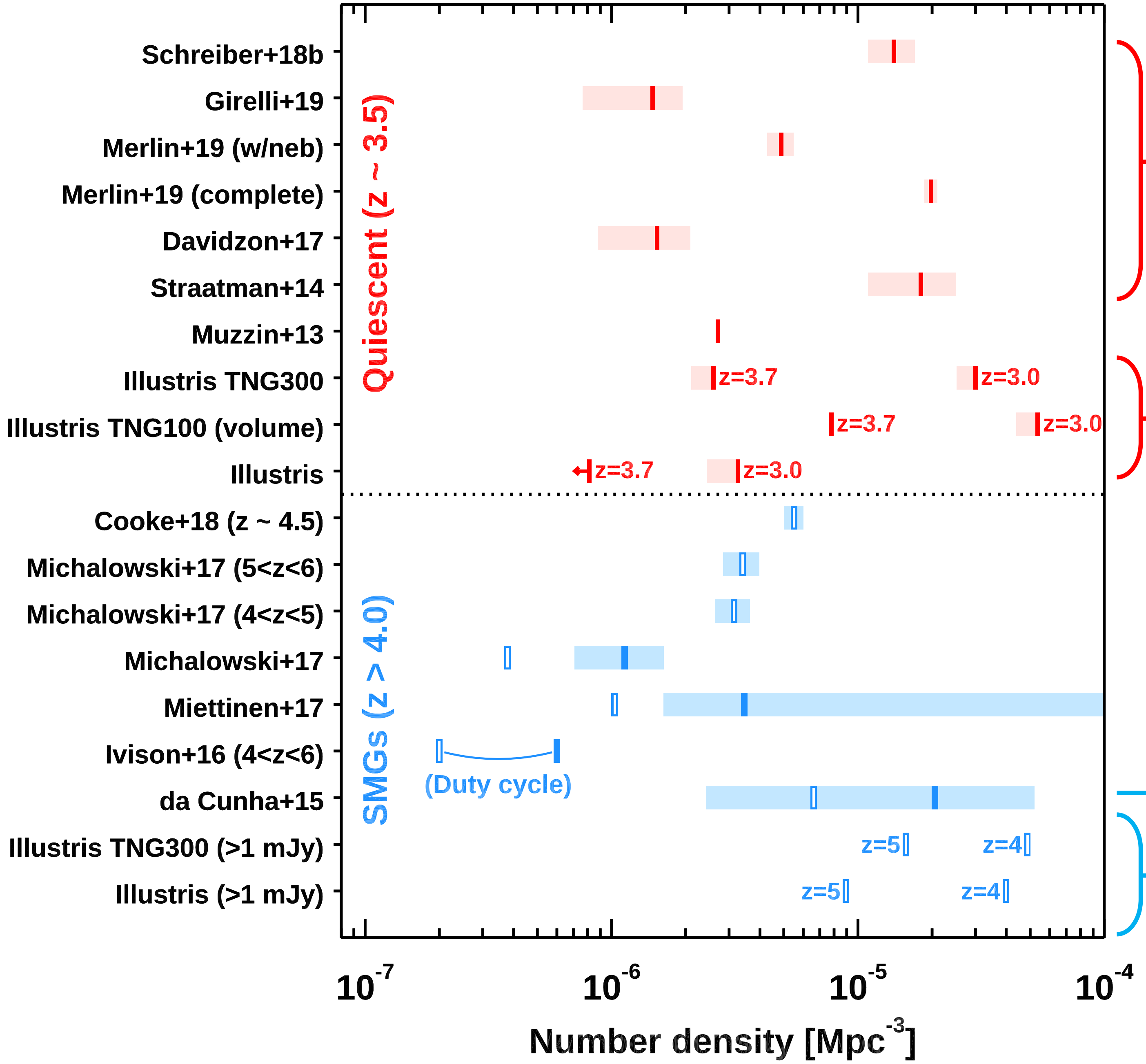
IllustrisTNG simulation

(Nelson+2019a, Hayward, Sparre+ in prep.)



- **Dearth of extreme SFRs**
- **Roughly matching stellar masses**

Are there enough?

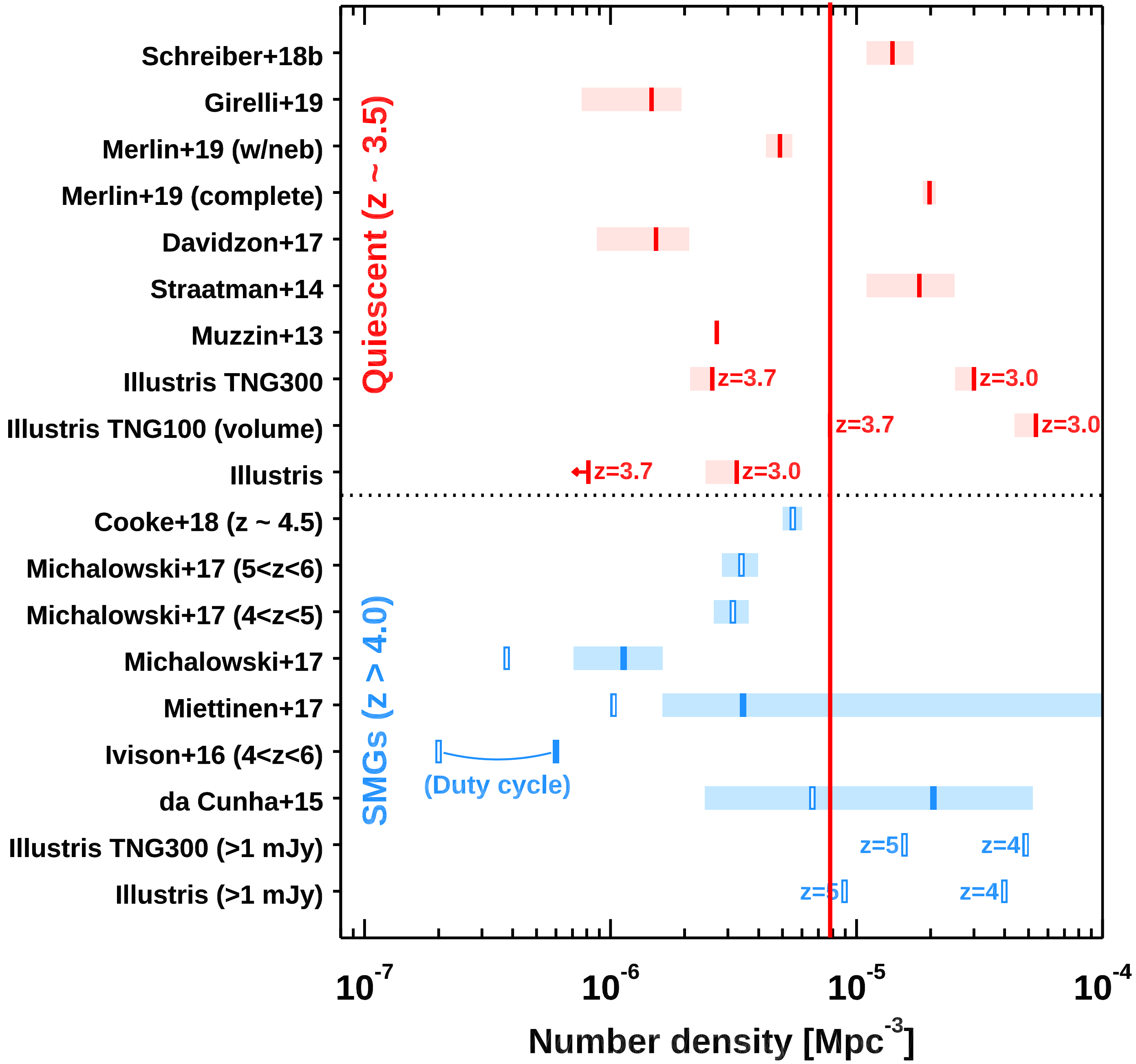


Observations (quiescent)

Simulations (quiescent)

Deep interferometric sub-mm survey

Simulations (Hayward+ in prep.)



Are there enough?

Quiescent galaxies:

- **Yes, in the latest large box simulations at z~3.**
- **No, not in the old small box simulations and at z~3.7.**

(see also Merlin+2019)

Sub-mm galaxies (deep):

- **Yes, both in old and new simulations**

The early death of cosmic giants

(The end of this story)

A population of massive, quiescent/quenching galaxies already in place at z~4 confirmed via *K*-band spectroscopy.

A "mature" z=4 galaxy, with a velocity dispersion compatible with z~2 scaling relations (Tanaka, Valentino+2019, ApJL, 885, L34)

They formed in short (~50 Myr) and intense (SFR~1000-3000 $M_\odot$ yr^{-1}) bursts of star formation followed by an abrupt quenching.

Dusty star forming galaxies from deep sub-mm surveys (including "normal" objects) are good candidate progenitors: matching numbers and properties (Valentino, Tanaka+2019, arXiv:1909:10540)

Simulations roughly catch the evolution of quiescent galaxies at z~3, but struggle at progressively higher redshifts.

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