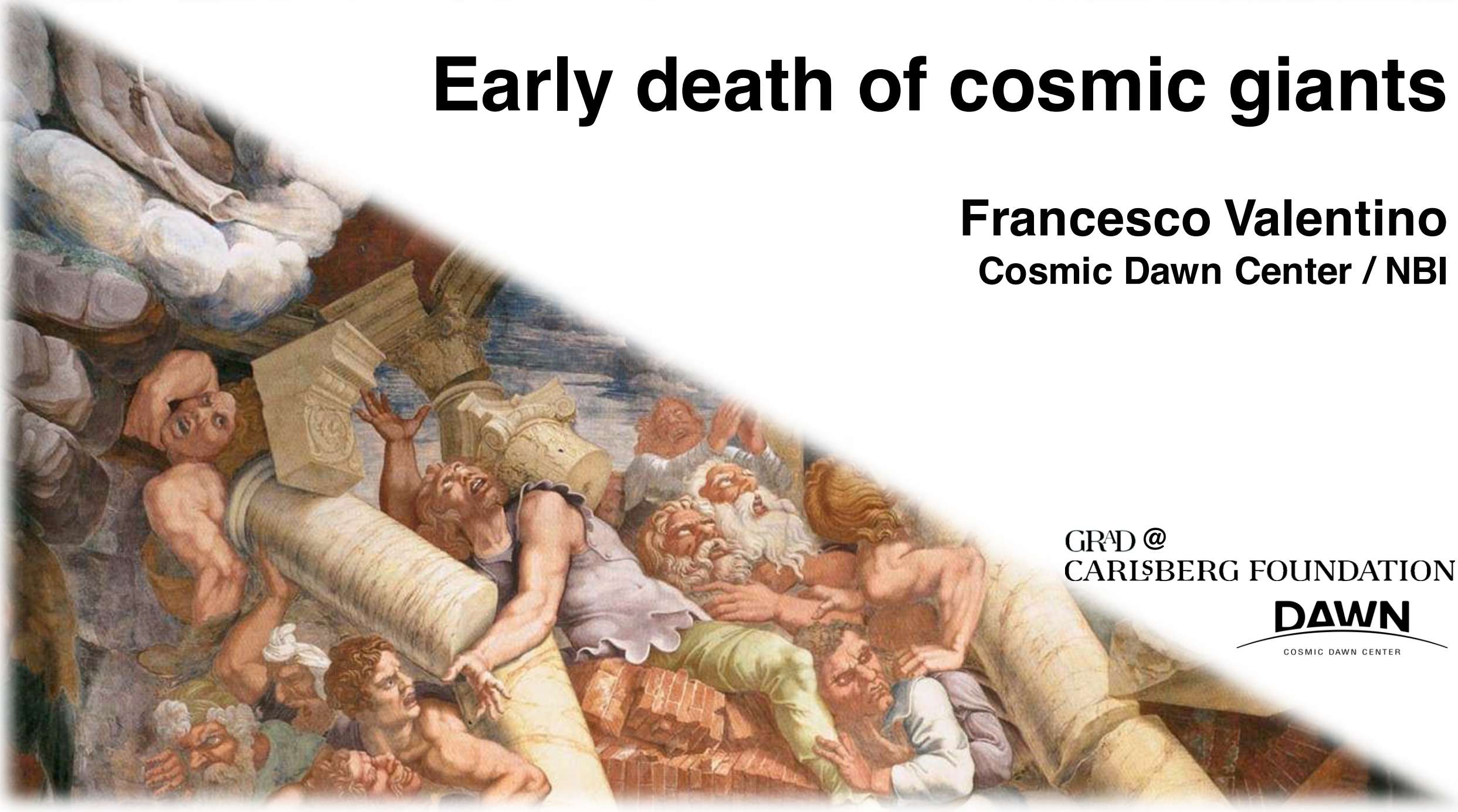

Early death of cosmic giants

Francesco Valentino

Cosmic Dawn Center / NBI

GRAD @
CARLSBERG FOUNDATION

DAWN
COSMIC DAWN CENTER

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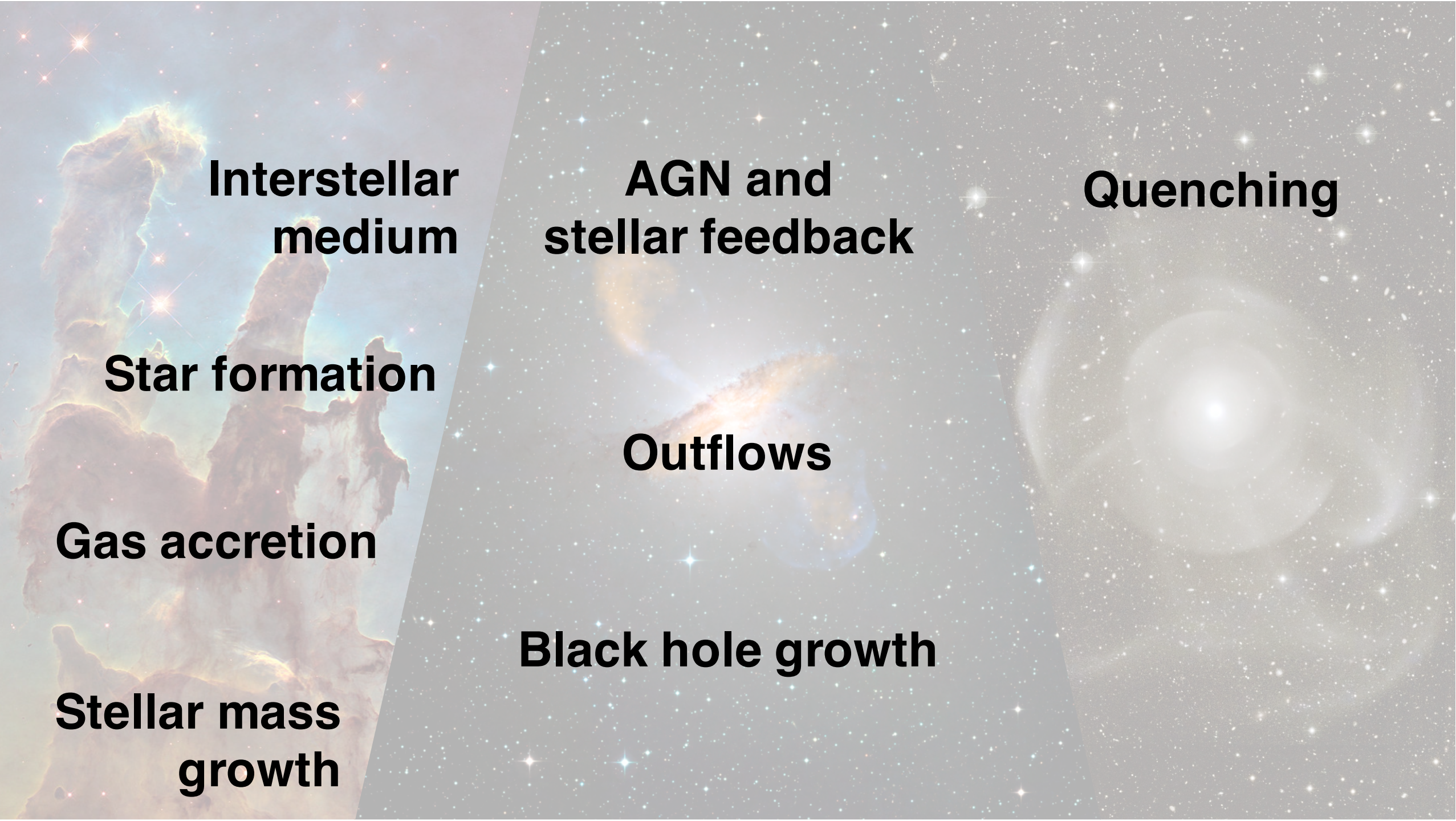
Galaxies: Rise And Death


Interstellar medium
AGN and stellar feedback
Quenching
Star formation
Outflows
Gas accretion
Black hole growth
Stellar mass growth

(Rise)

Interstellar medium

Valentino+2018
Valentino+2020 b,c

Gas accretion

Daddi,
Valentino+2021

AGN and stellar feedback

Outflows

Black hole growth

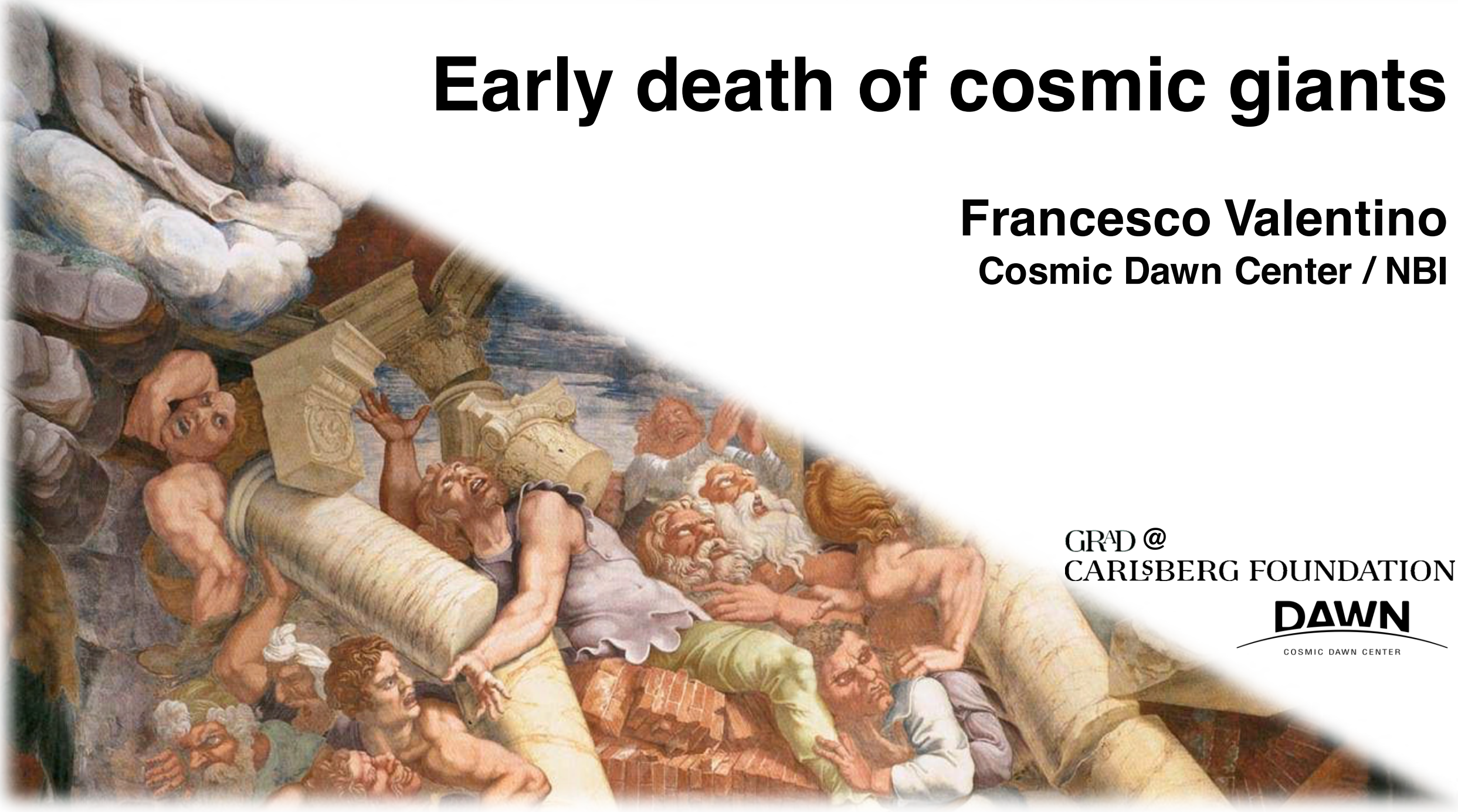
(Death)

Quenching

Tanaka,
Valentino+2019

Valentino+2020a

Gobat+FV 2018,
2020
Magdis+FV 2021



Early death of cosmic giants

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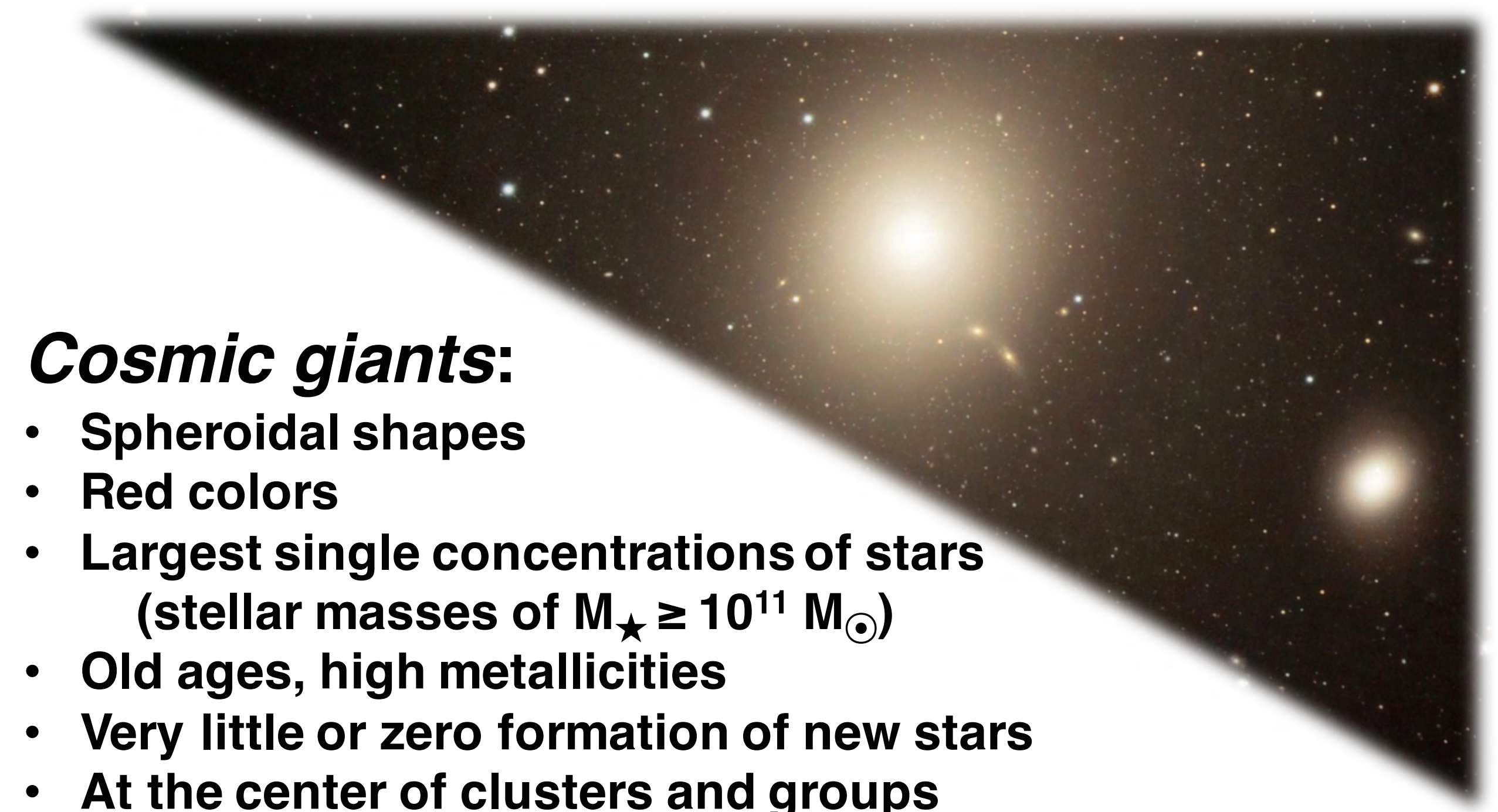
COSMIC DAWN CENTER

The chamber of the giants

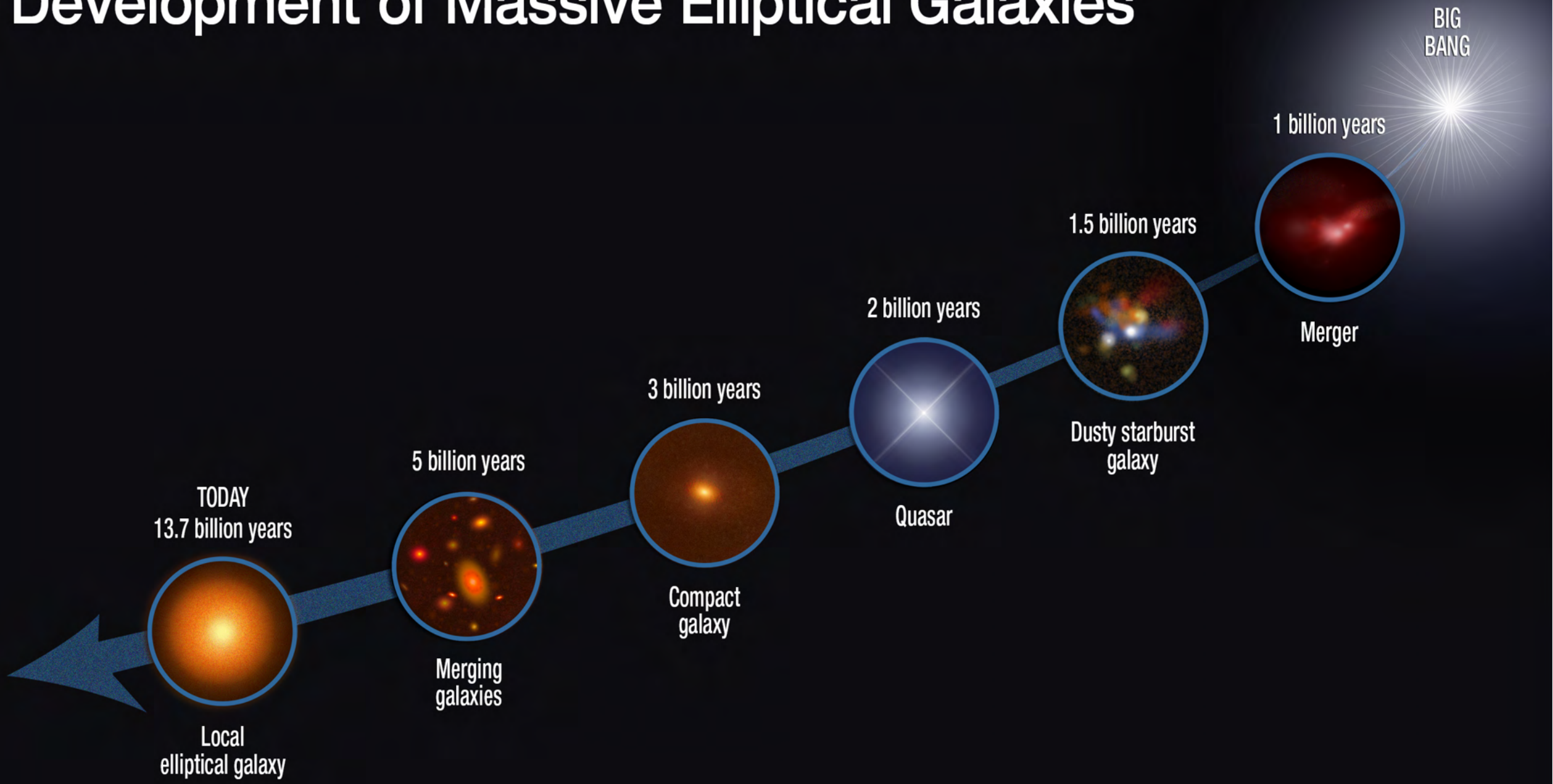
Giulio Romano (1531-1536)
Palazzo Te – Mantua (Italy)



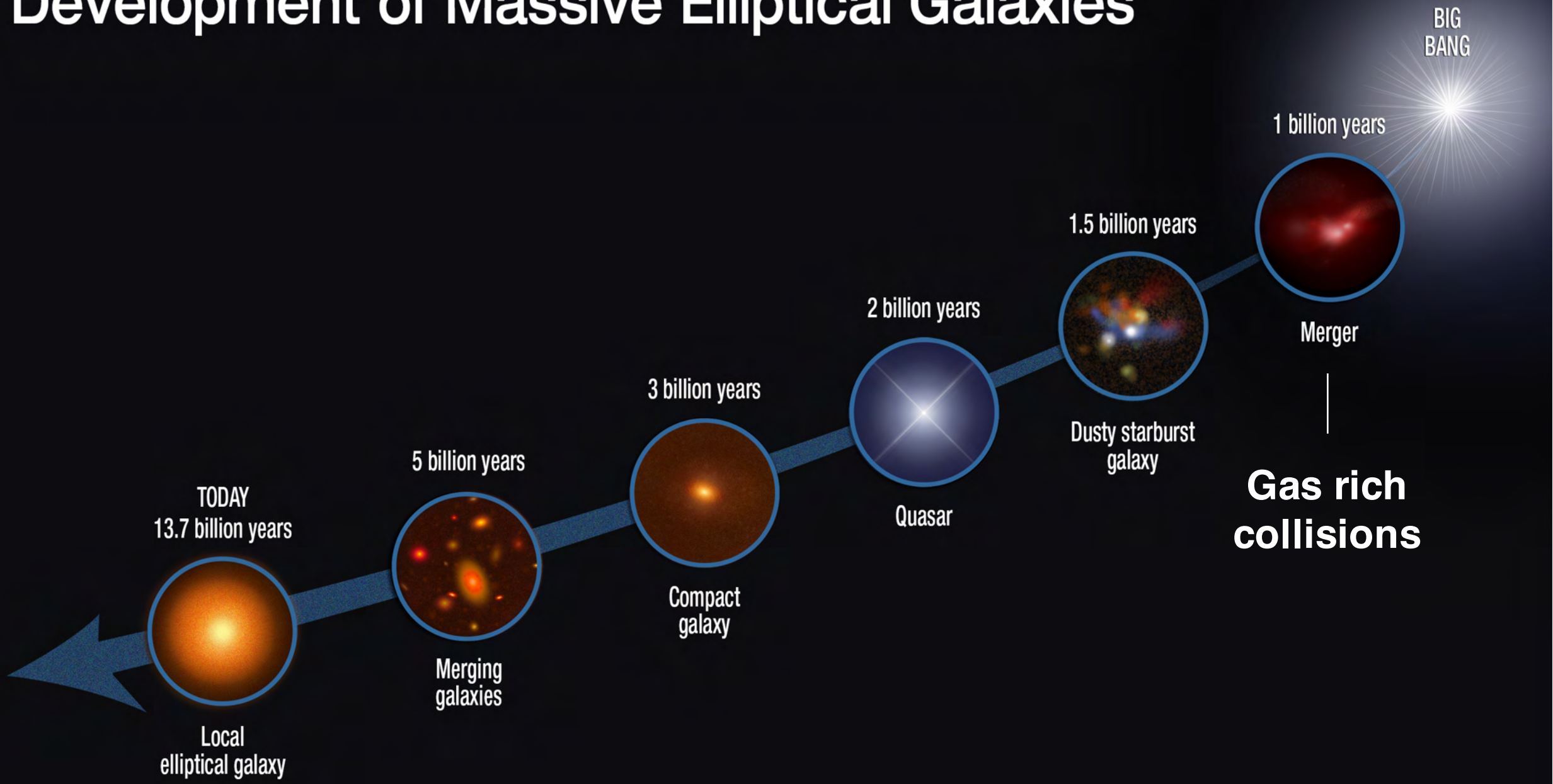
Cosmic giants:

- 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

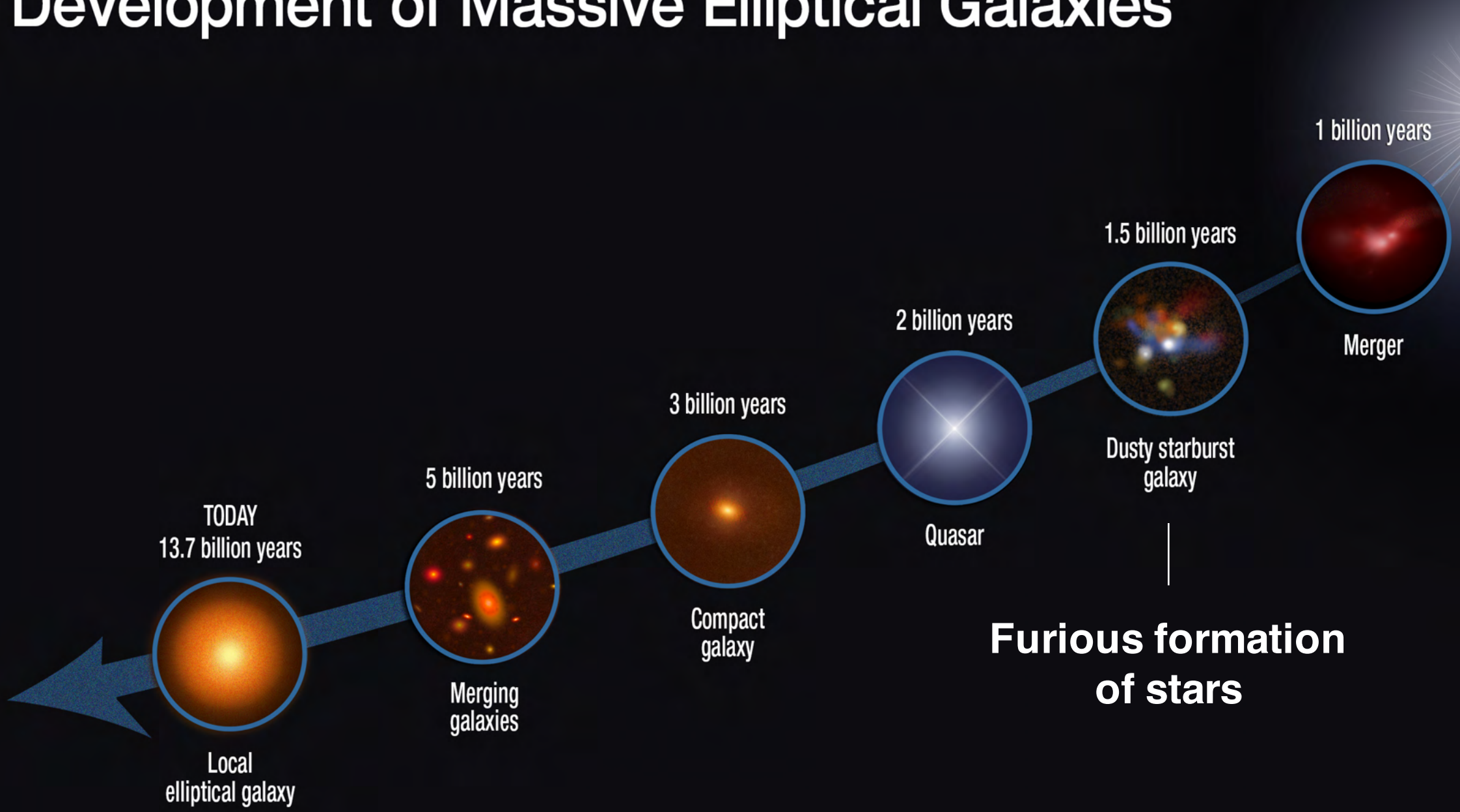
Development of Massive Elliptical Galaxies



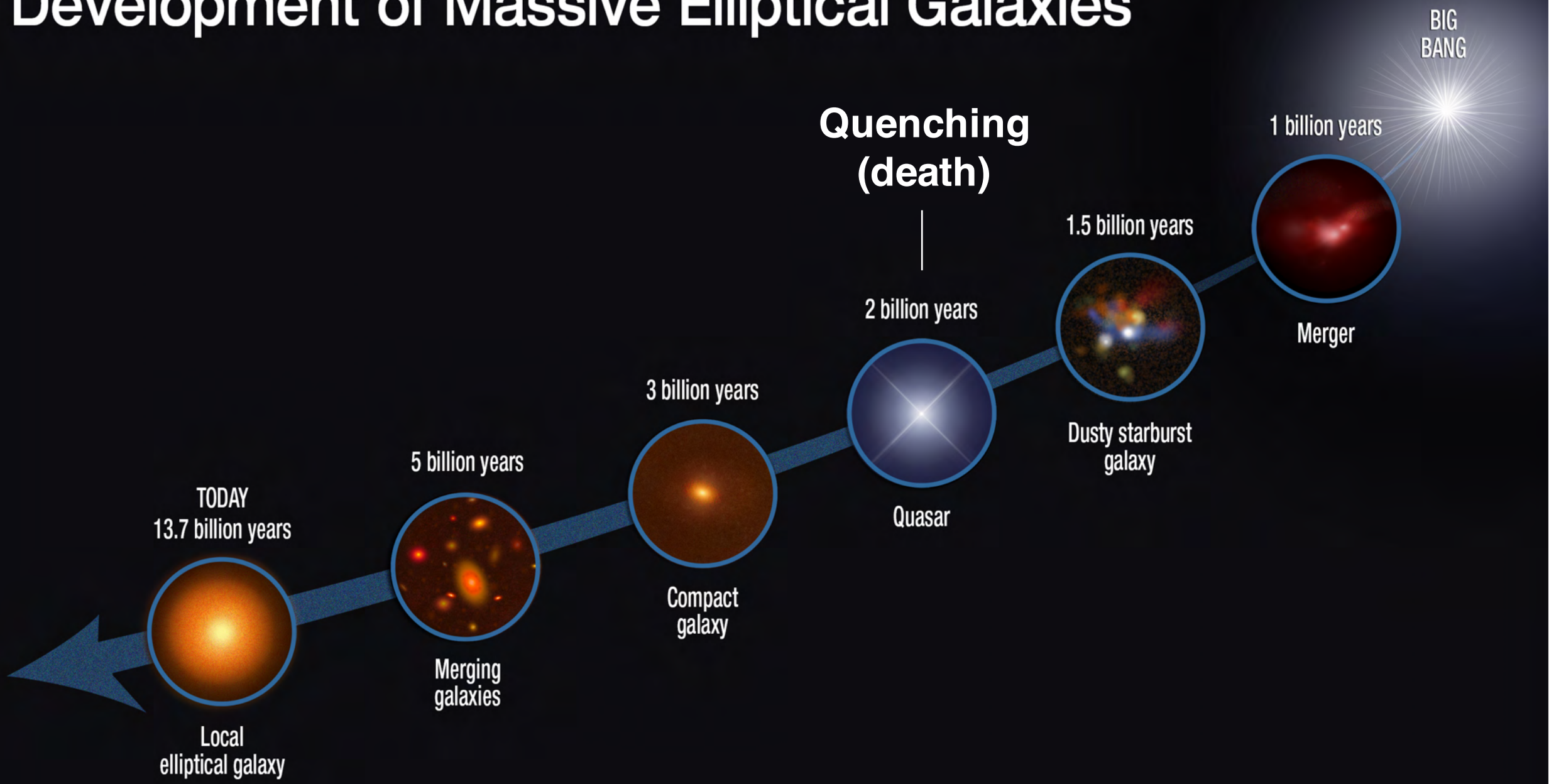
Development of Massive Elliptical Galaxies



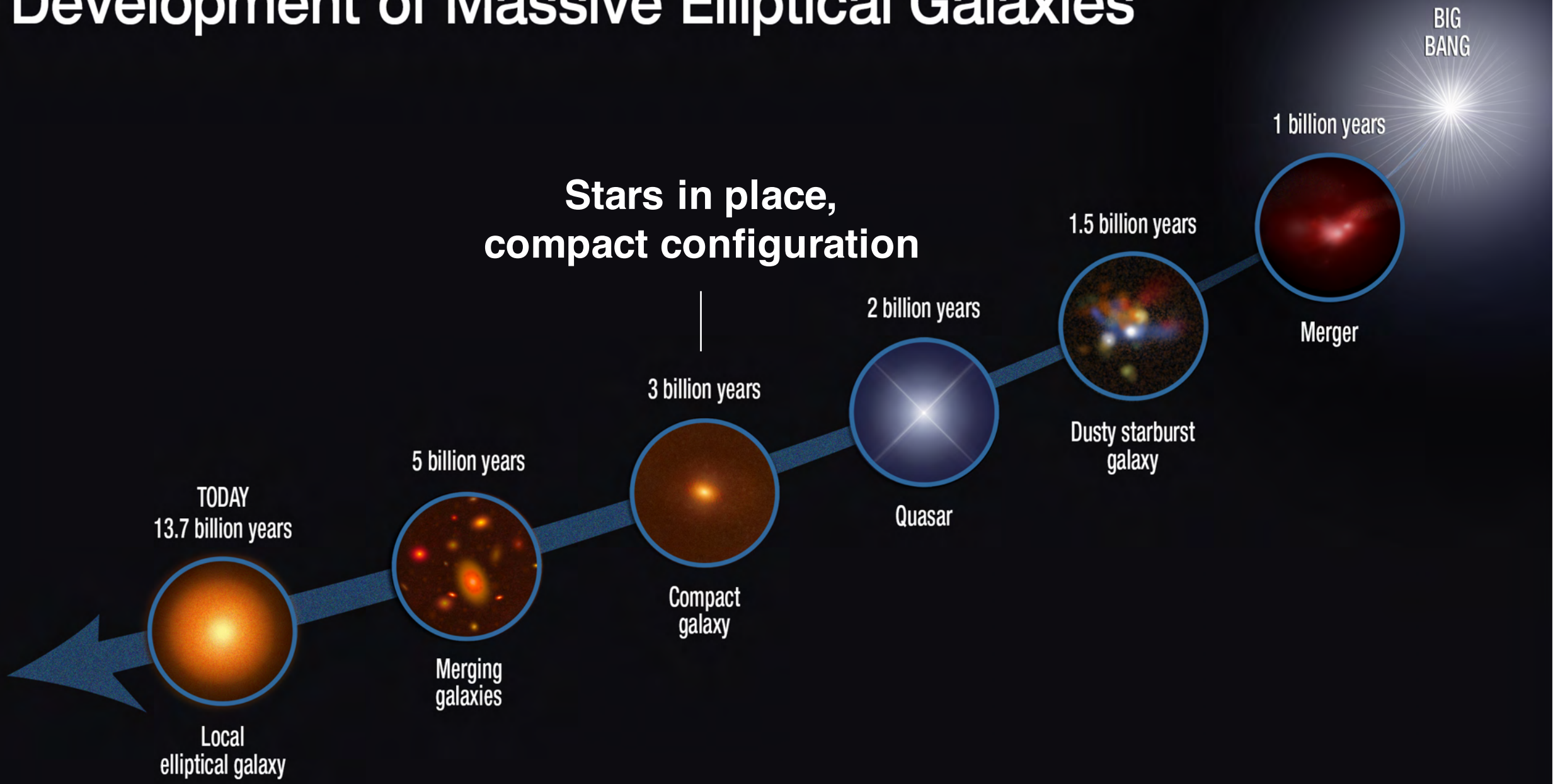
Development of Massive Elliptical Galaxies

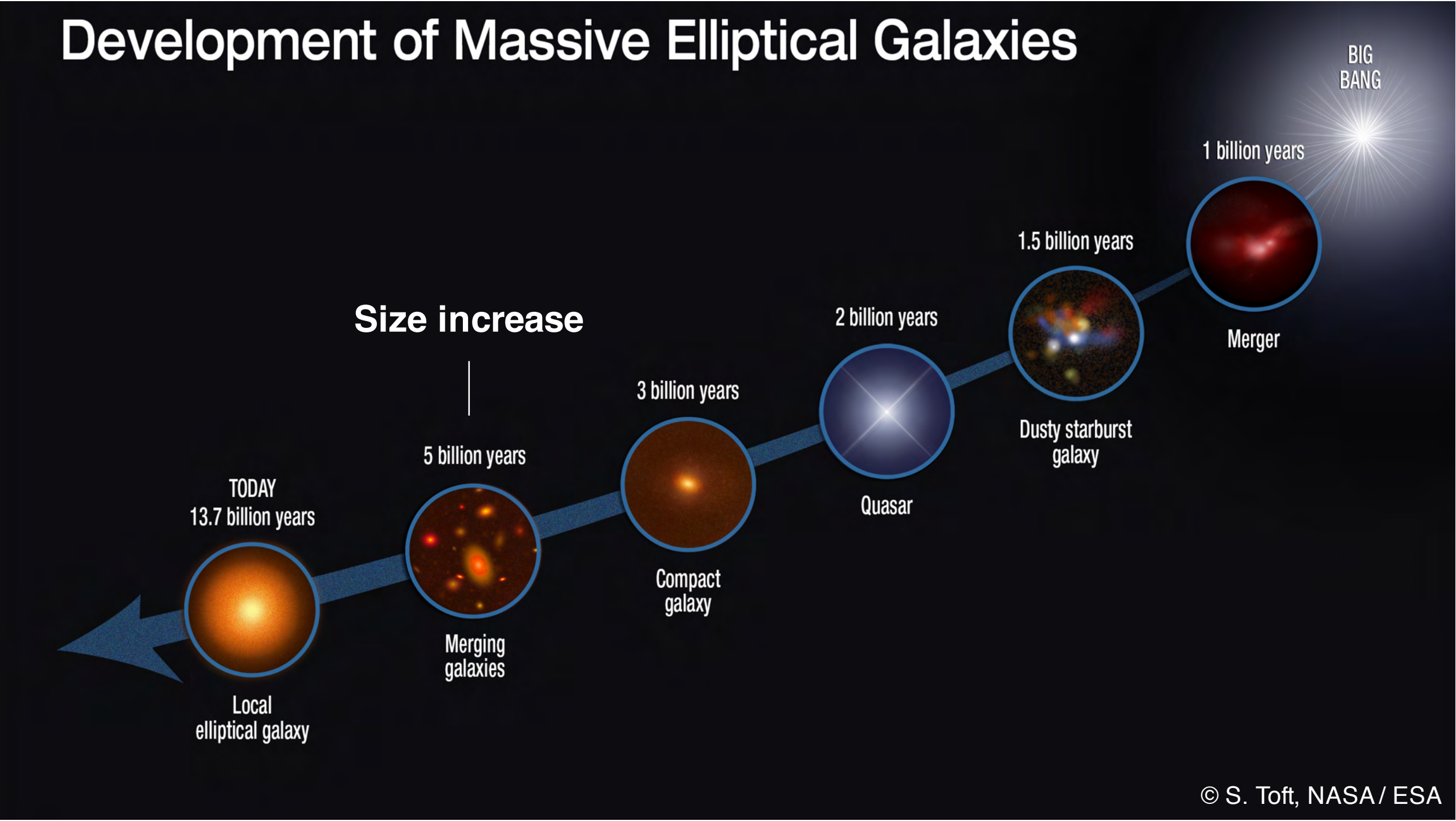


Development of Massive Elliptical Galaxies

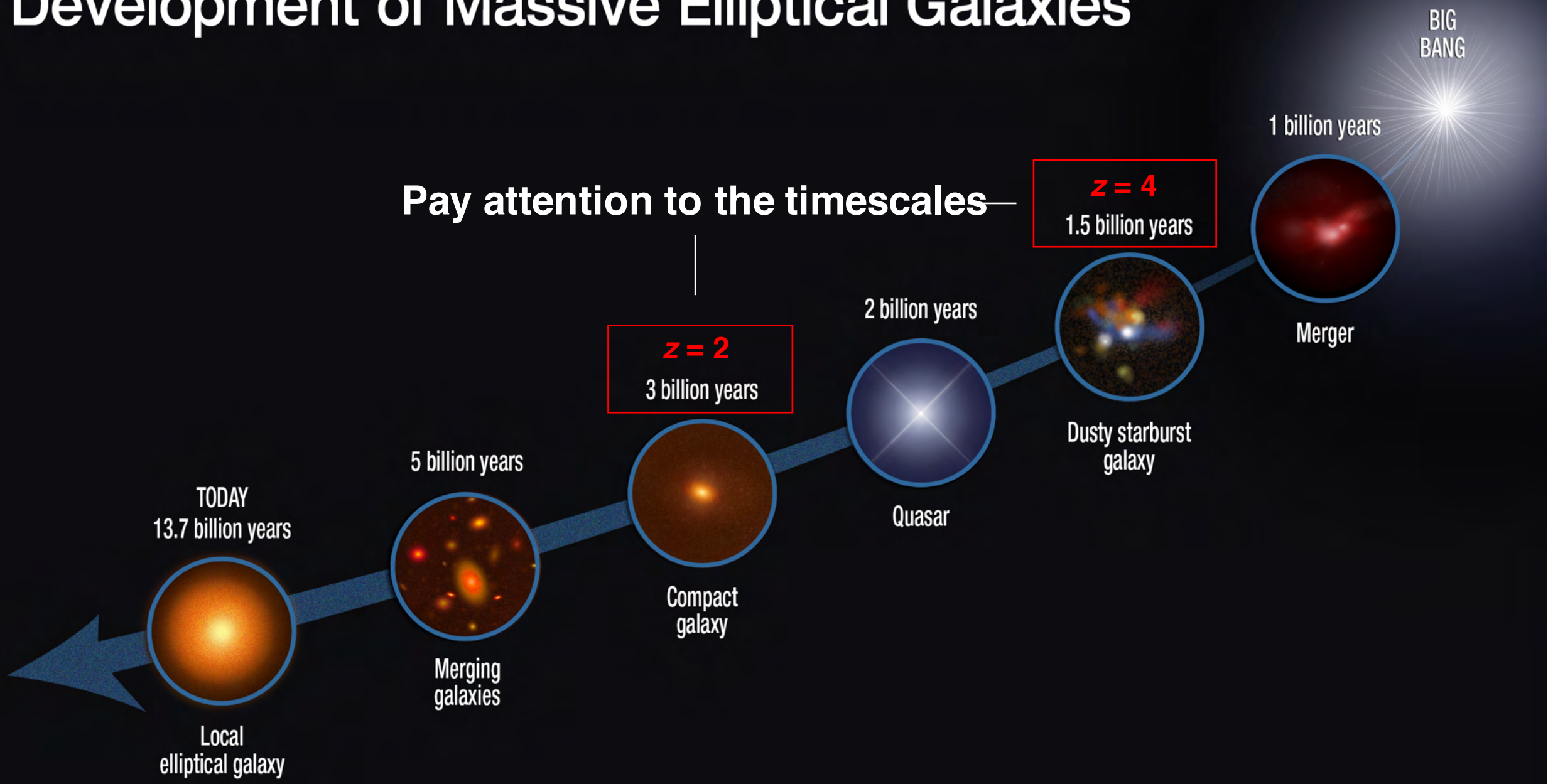


Development of Massive Elliptical Galaxies

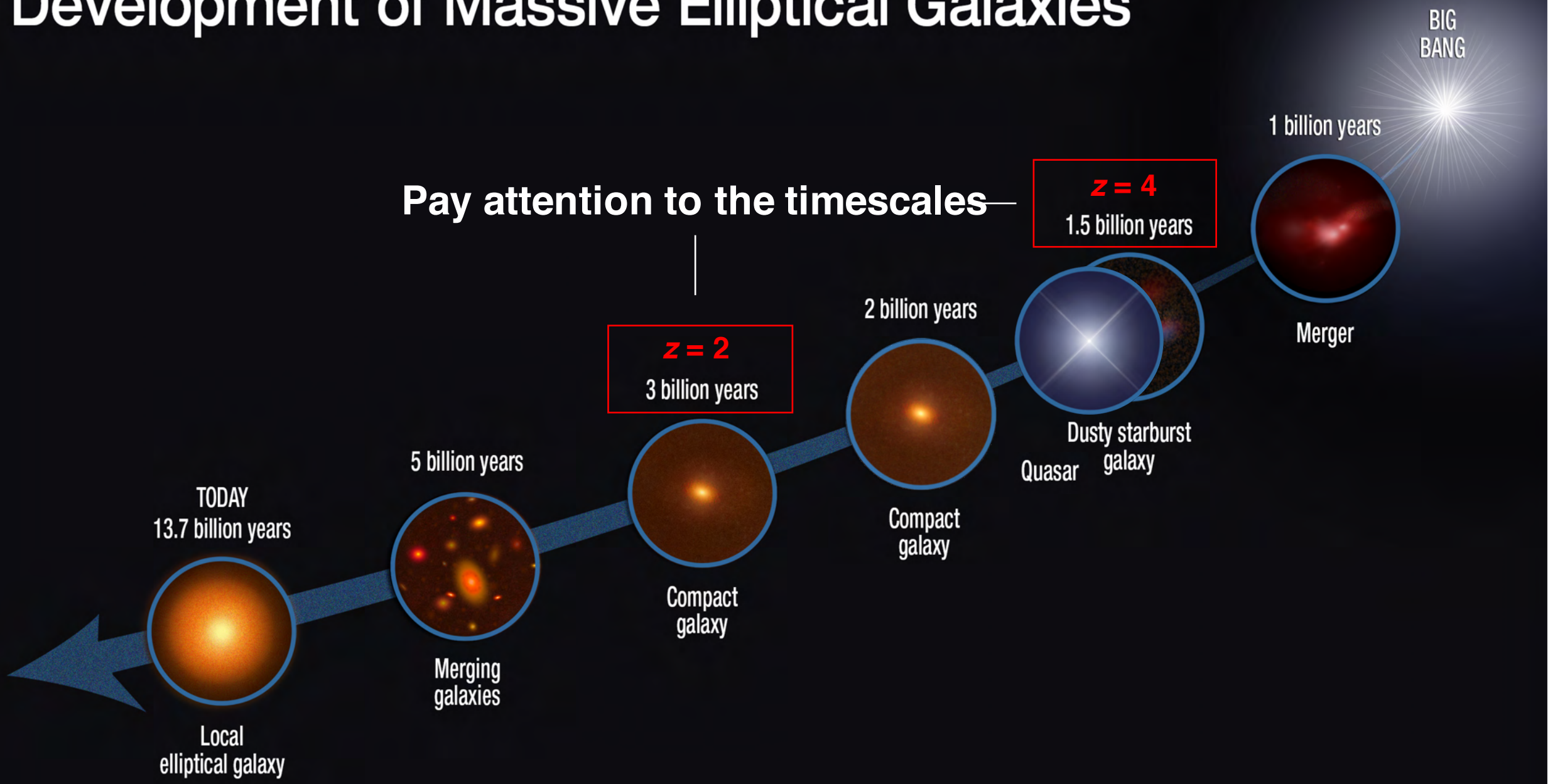



Development of Massive Elliptical Galaxies
BIG BANG
1 billion years
1.5 billion years
2 billion years
3 billion years
5 billion years
TODAY
13.7 billion years
Size increase
Merger
Dusty starburst galaxy
Quasar
Compact galaxy
Merging galaxies
Local elliptical galaxy
© S. Toft, NASA / ESA

Development of Massive Elliptical Galaxies



Development of Massive Elliptical Galaxies



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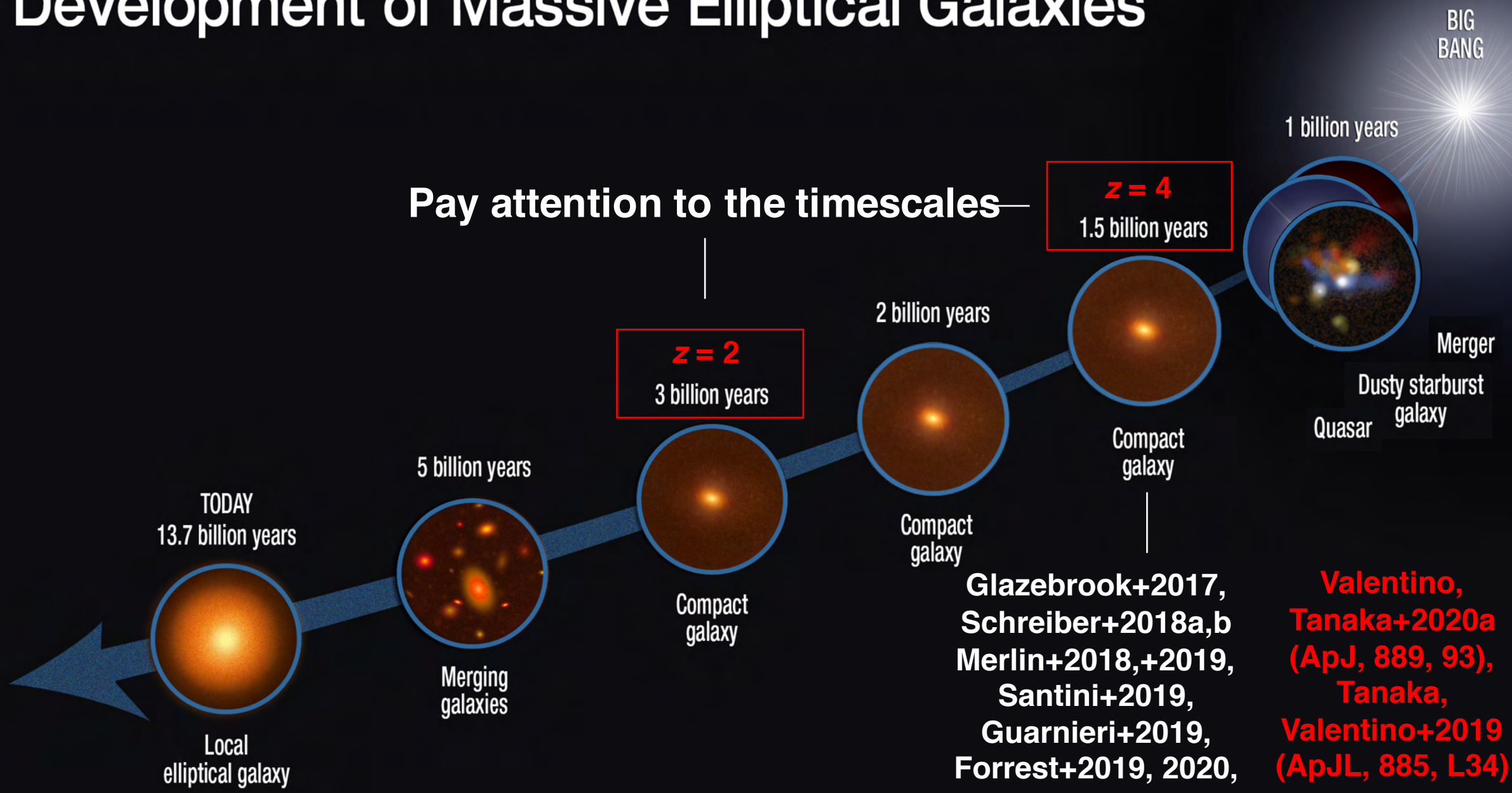


Glazebrook+2017, Schreiber+2018a,b Merlin+2018,+2019, Santini+2019, Guarnieri+2019, Forrest+2019, 2020, Carnall+2020, Esdaile+2020,…

Valentino, Tanaka+2020a (ApJ, 889, 93), Tanaka, Valentino+2019 (ApJL, 885, L34)

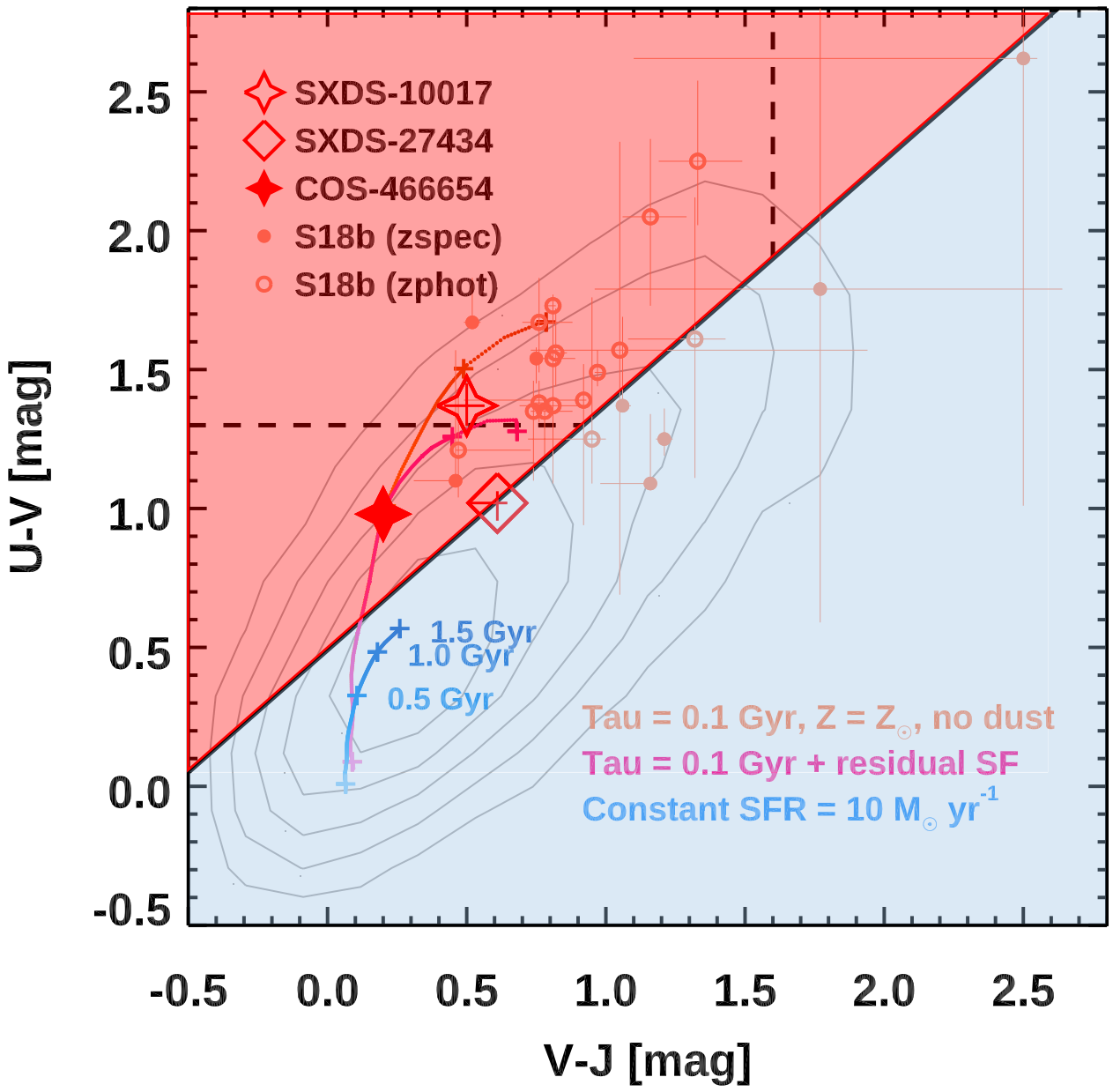
Development of Massive Elliptical Galaxies

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?

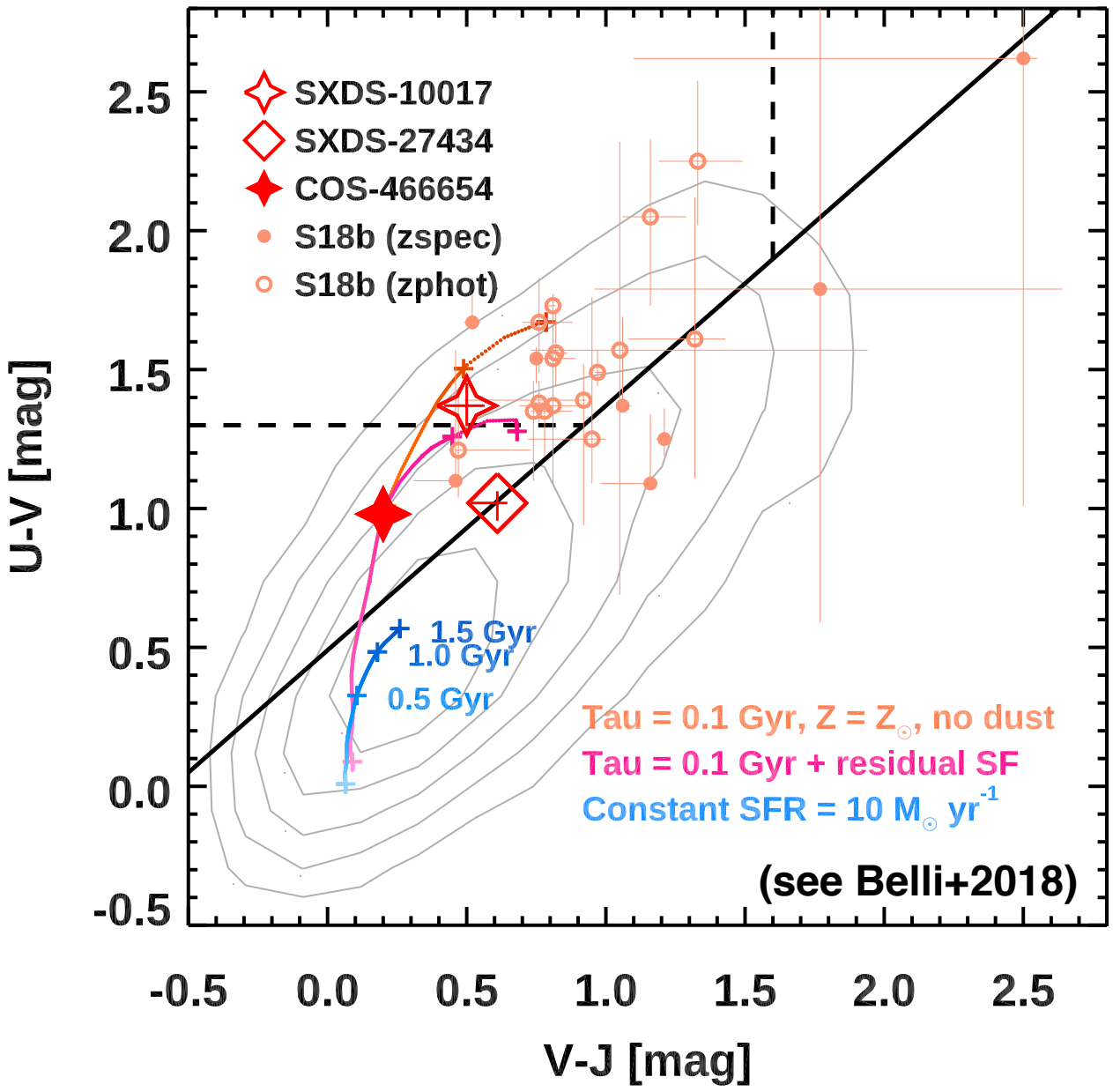
How to spot a dead cosmic giant?

(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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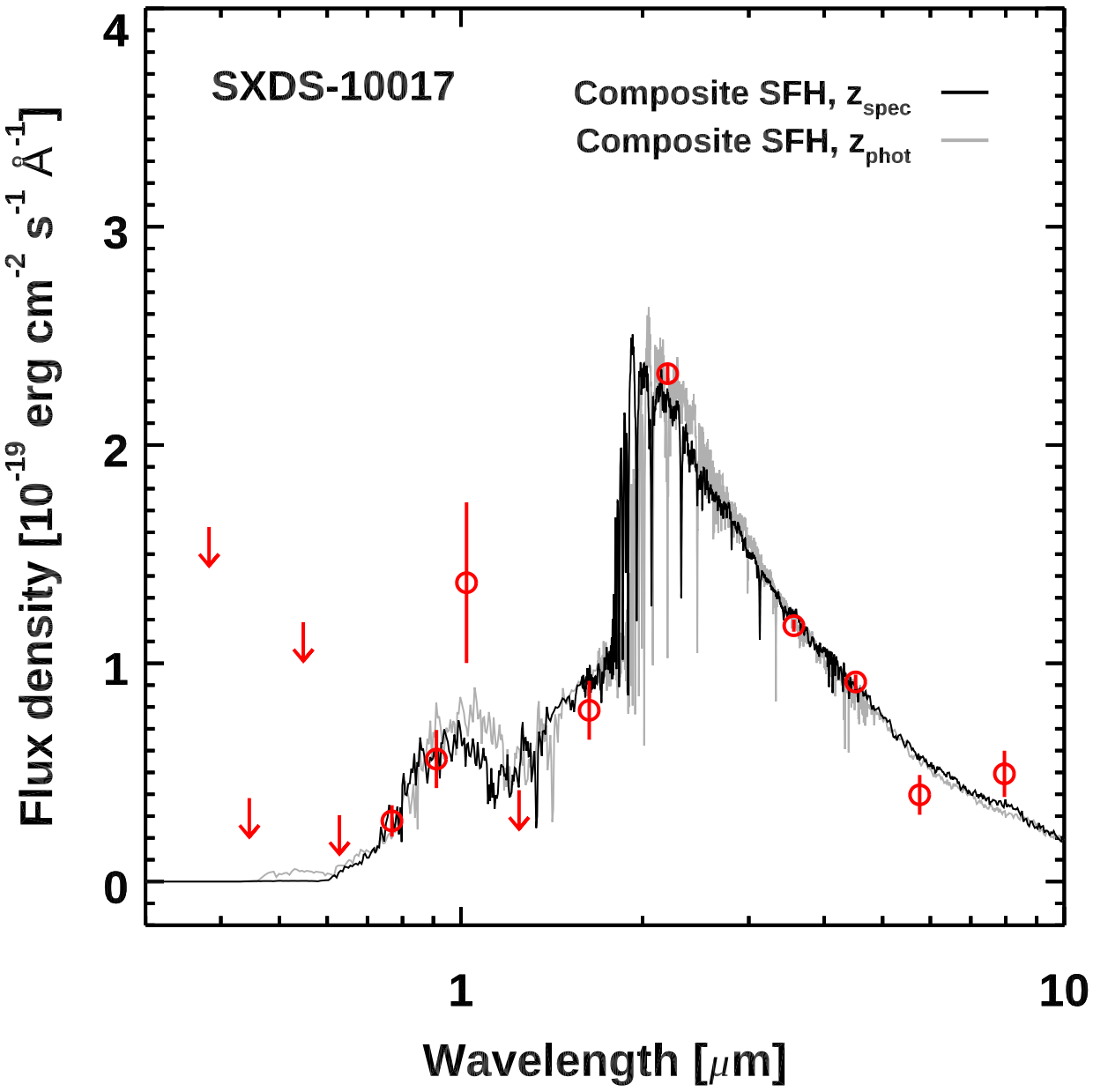
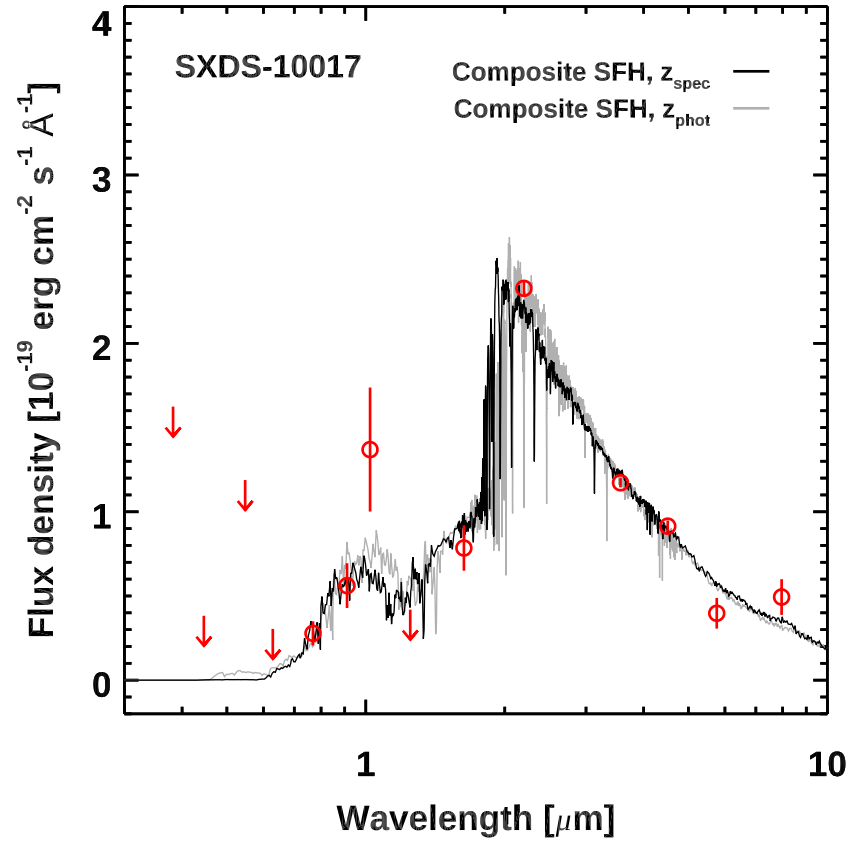
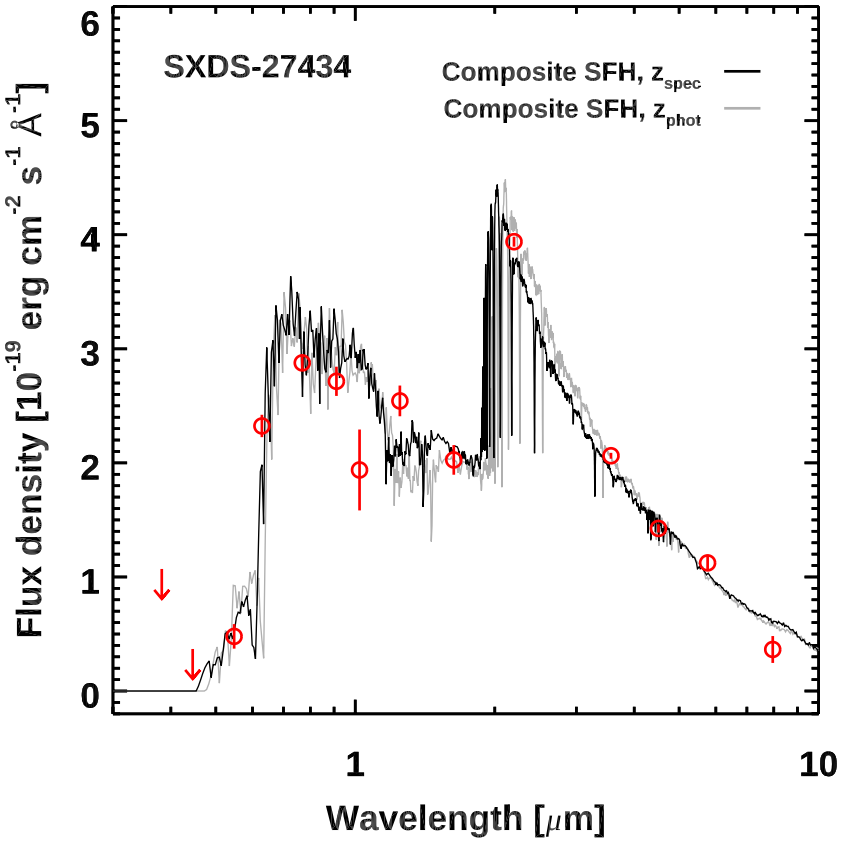


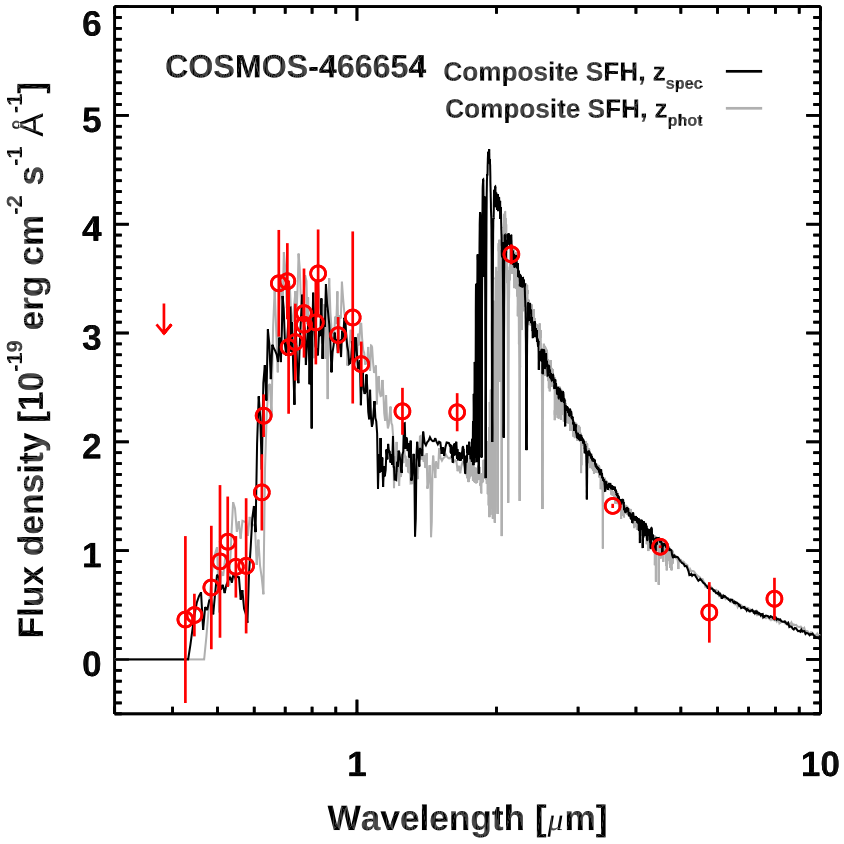
How to spot a dead cosmic giant?

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

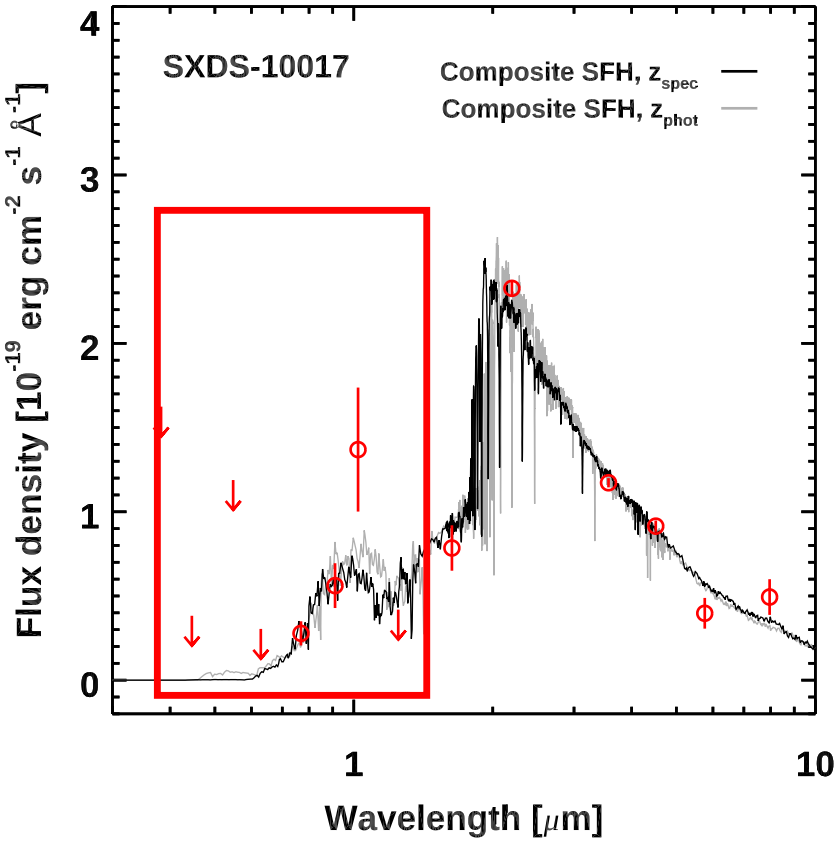
II. **Modeling of the Spectral Energy Distribution (SED)**


SXDS-10017
Composite SFH, z_spec
Composite SFH, z_phot
Flux density [10^-19 erg cm^-2 s^-1 Å^-1]
Wavelength [μm]

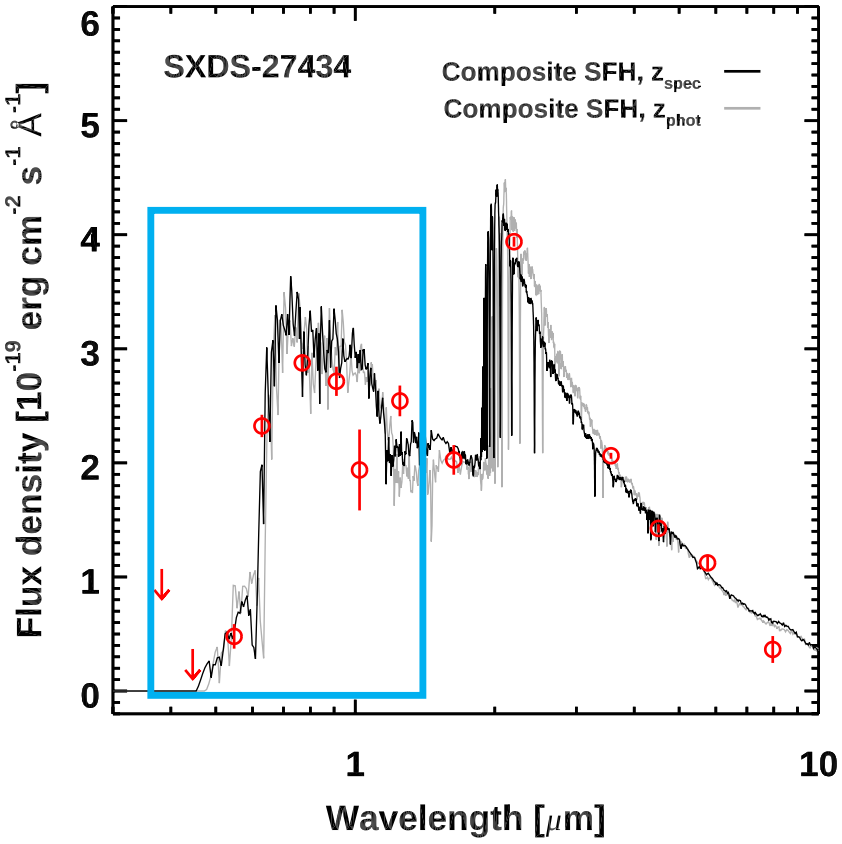

SXDS-27434
Composite SFH, z_spec
Composite SFH, z_phot
Flux density [10^-19 erg cm^-2 s^-1 Å^-1]
Wavelength [μm]

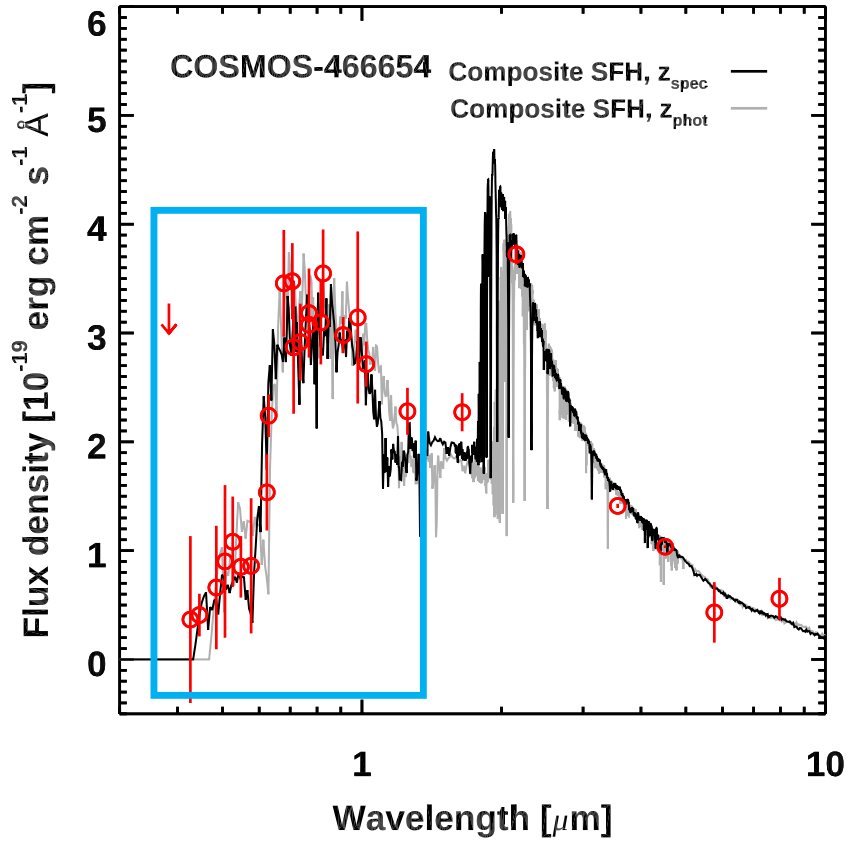

COSMOS-466654
Composite SFH, z_spec
Composite SFH, z_phot
Flux density [10^-19 erg cm^-2 s^-1 Å^-1]
Wavelength [μm]

Old and dead



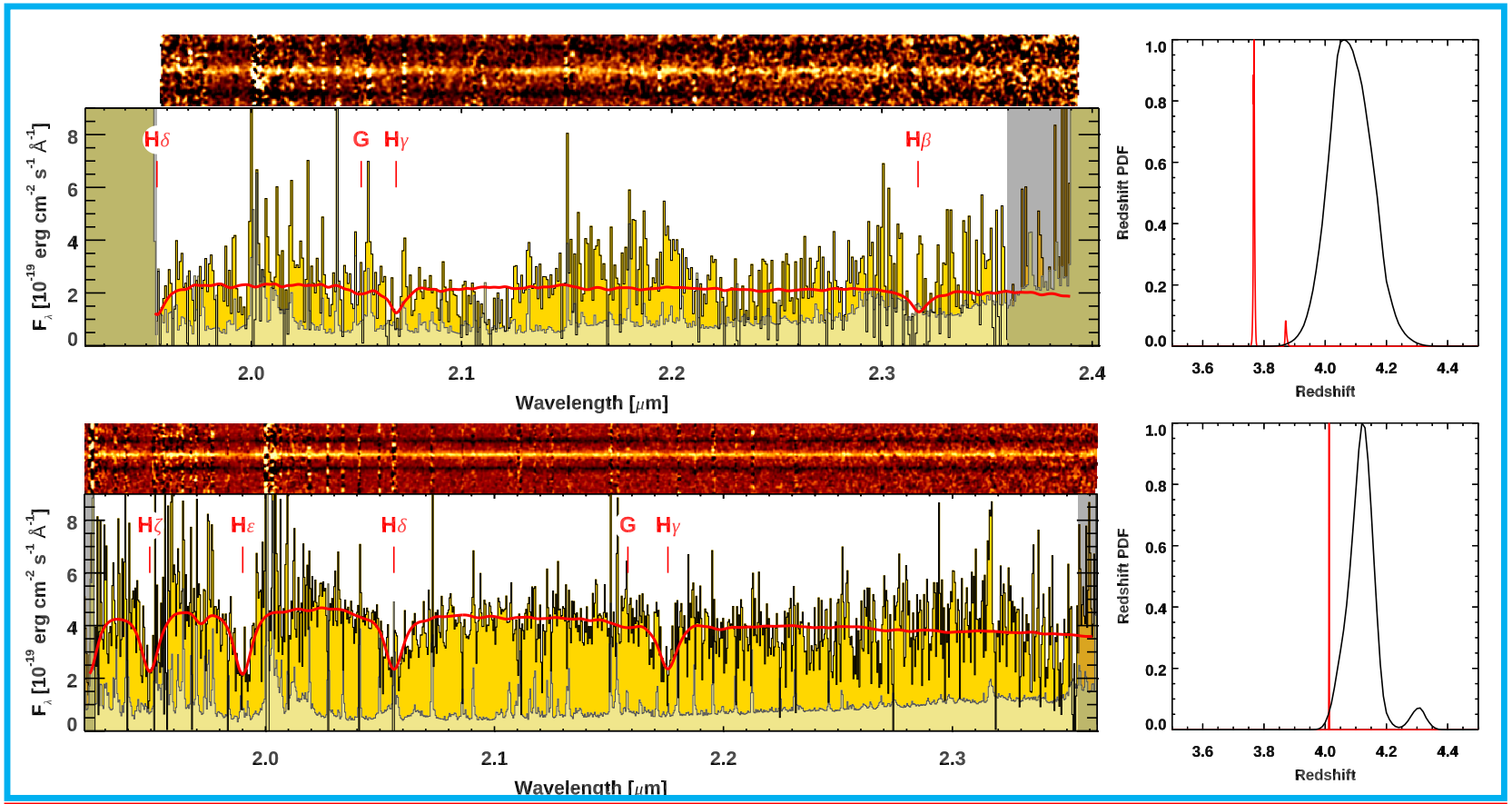
Young(er) and dying





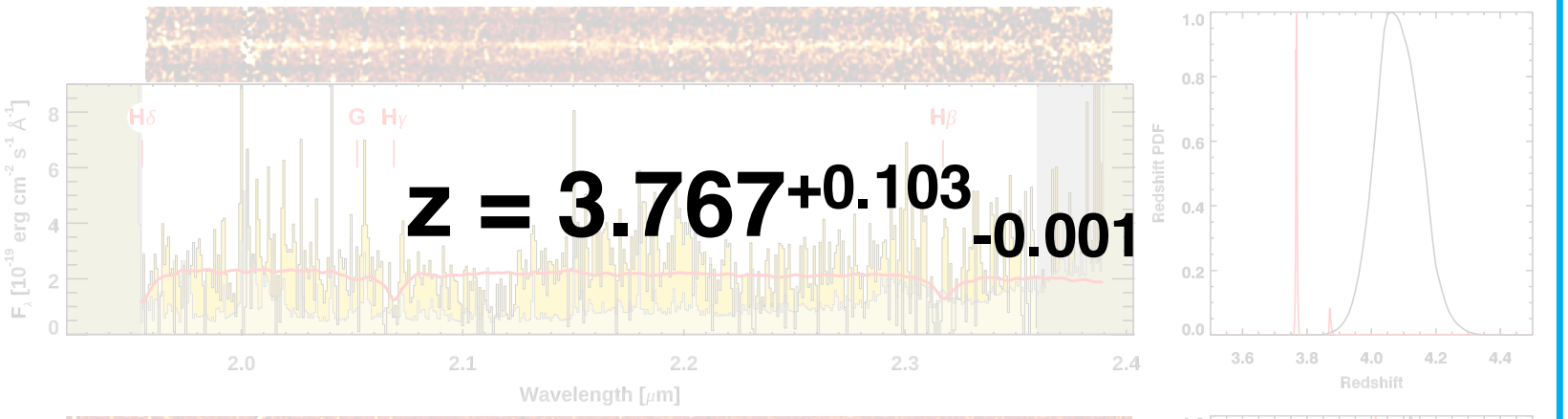
How to be sure that a giant is dead (or dying)?

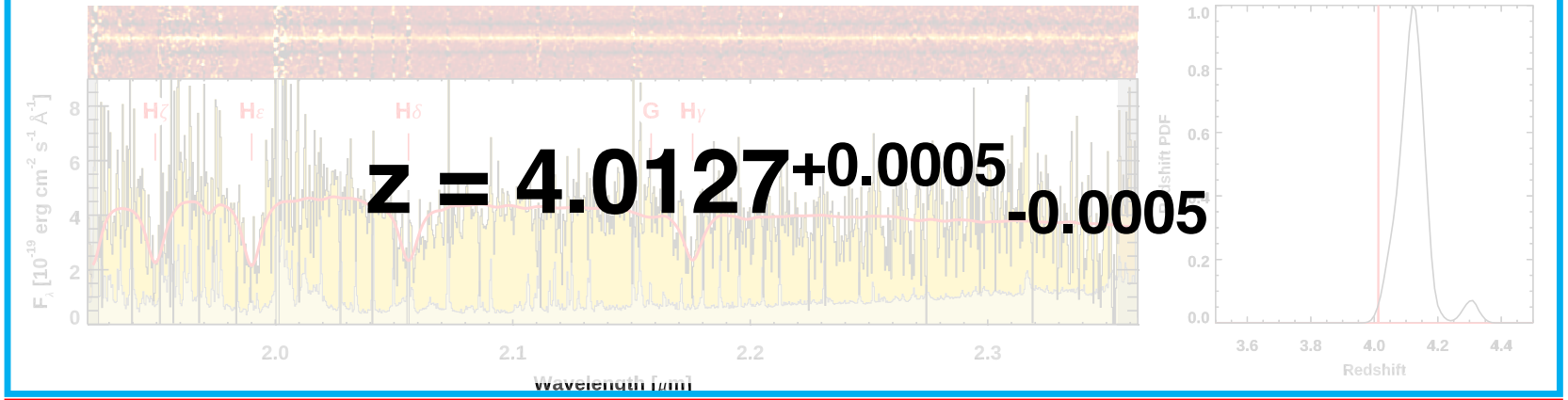
(By looking for absorption signatures)



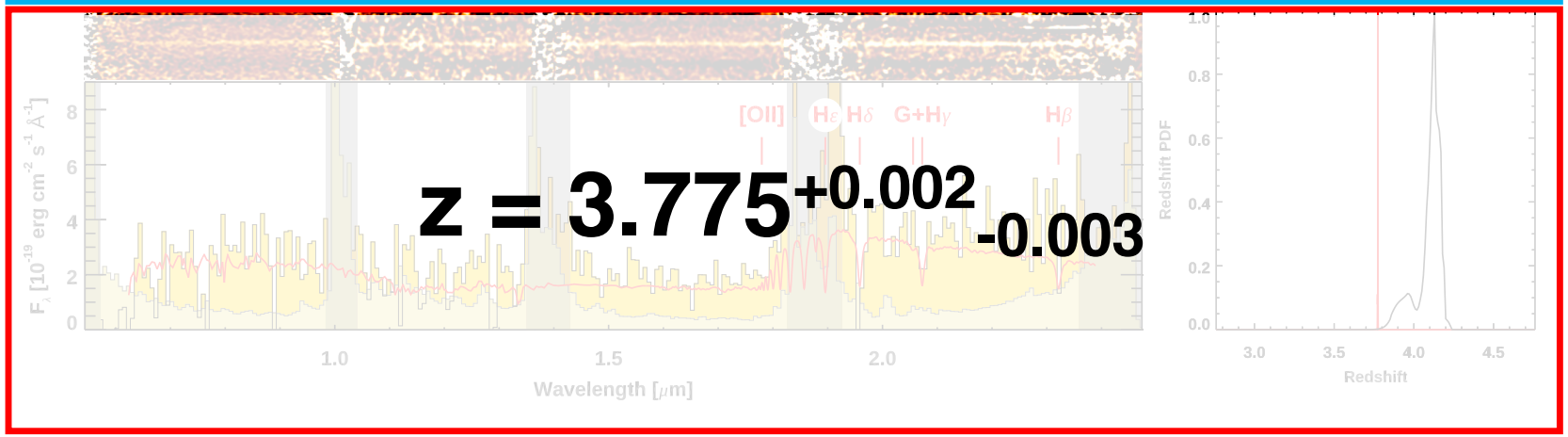
***K*-band spectroscopy with Keck/MOSFIRE and VLT/X-Shooter**

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





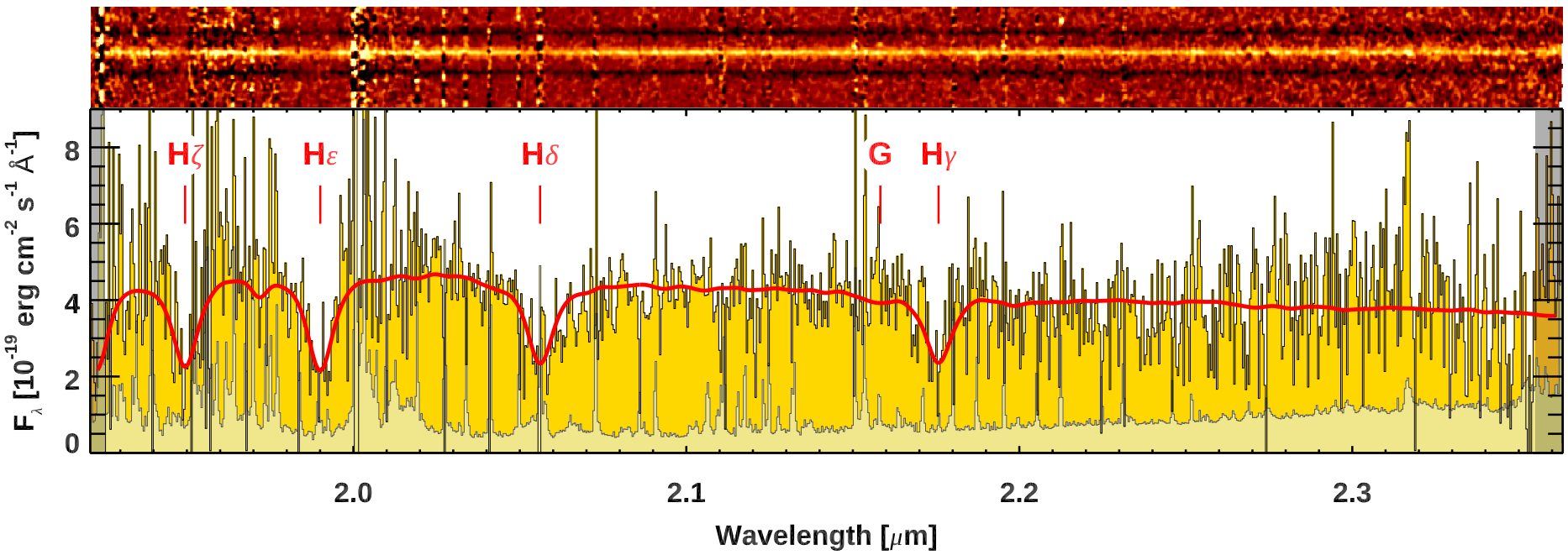
One tentative constraint

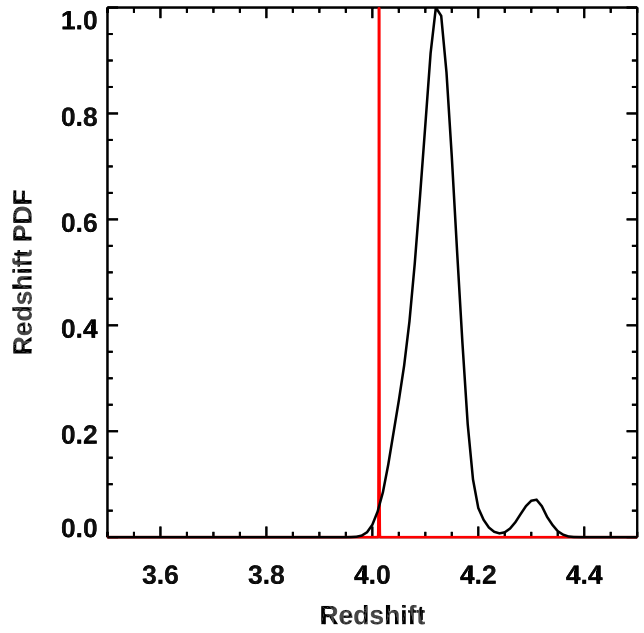


Two secure confirmations

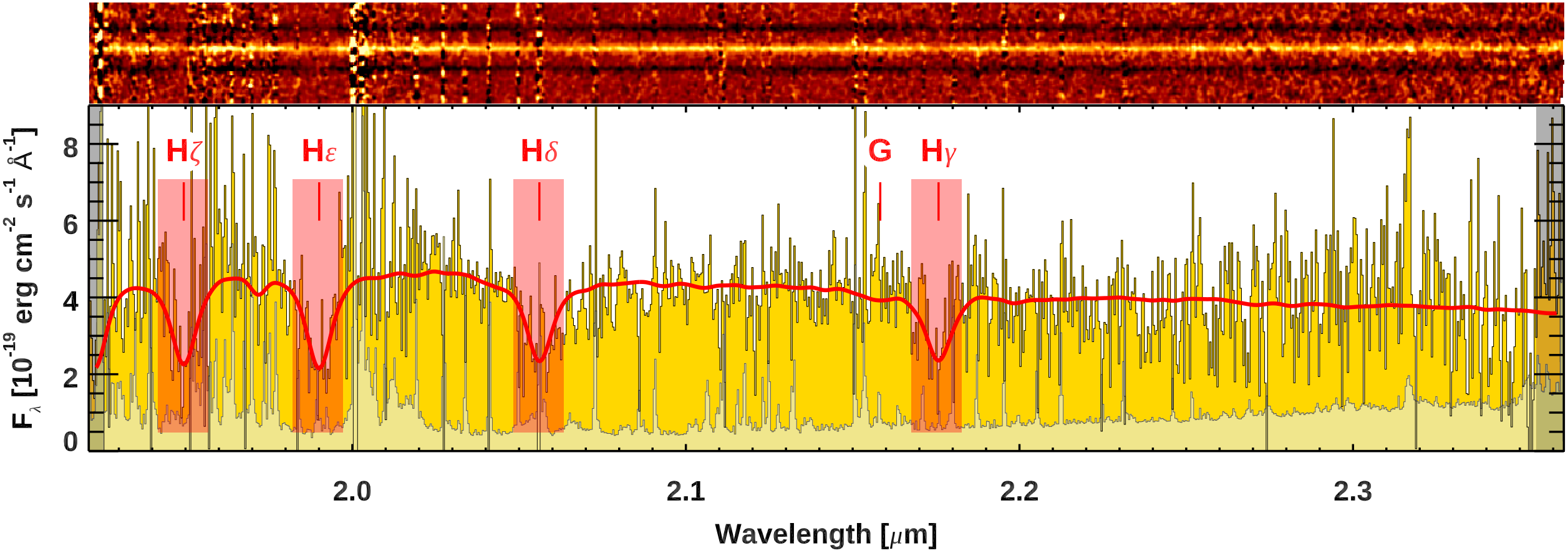
Spectroscopy

Photometry





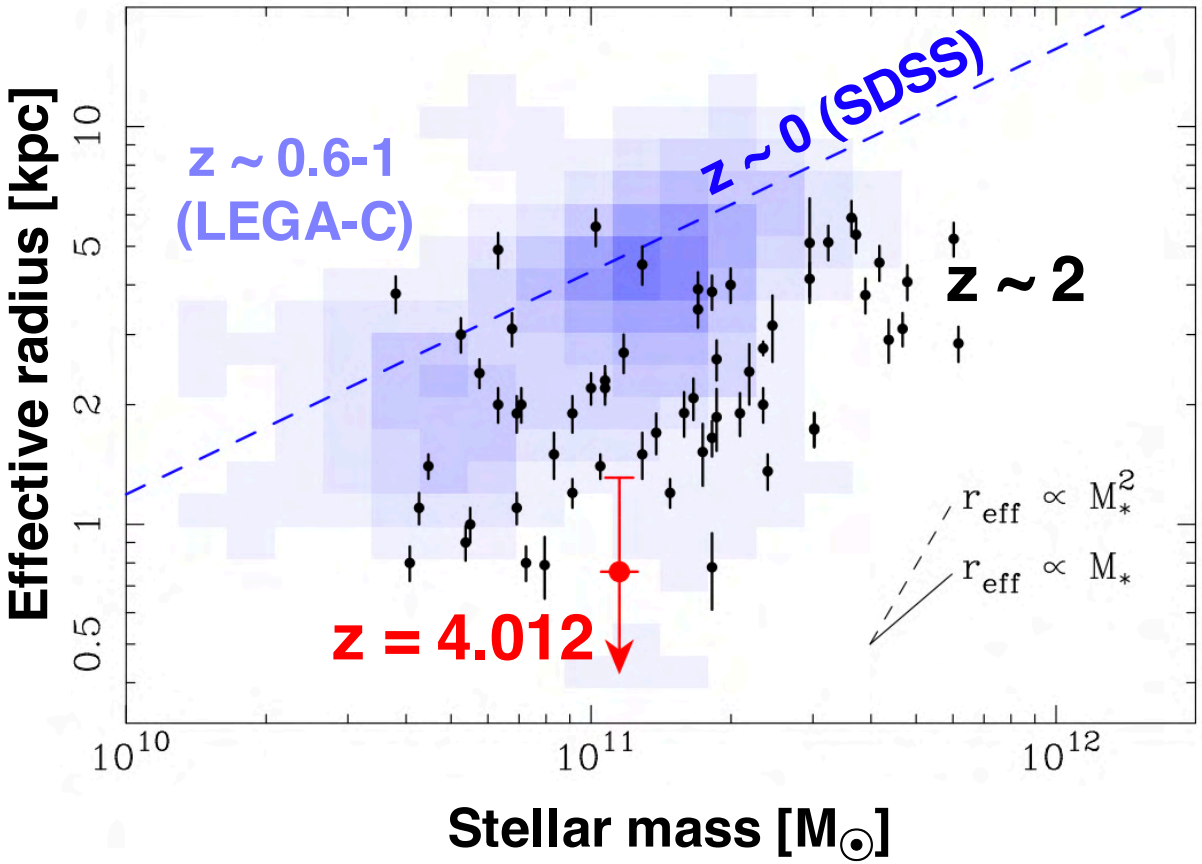
- No optical emission lines
- No far-infrared / sub-mm detection
- Little or zero ultraviolet continuum emission

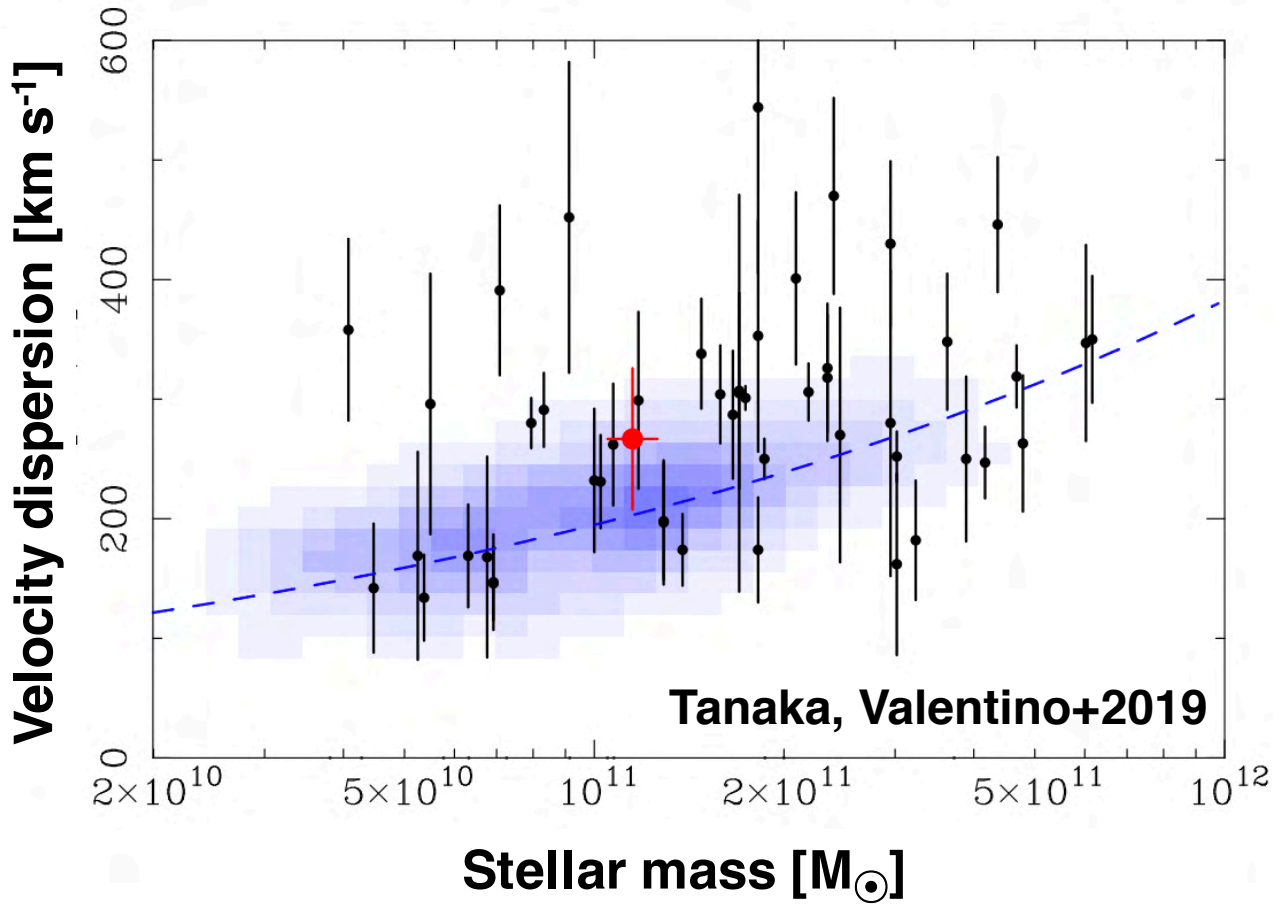


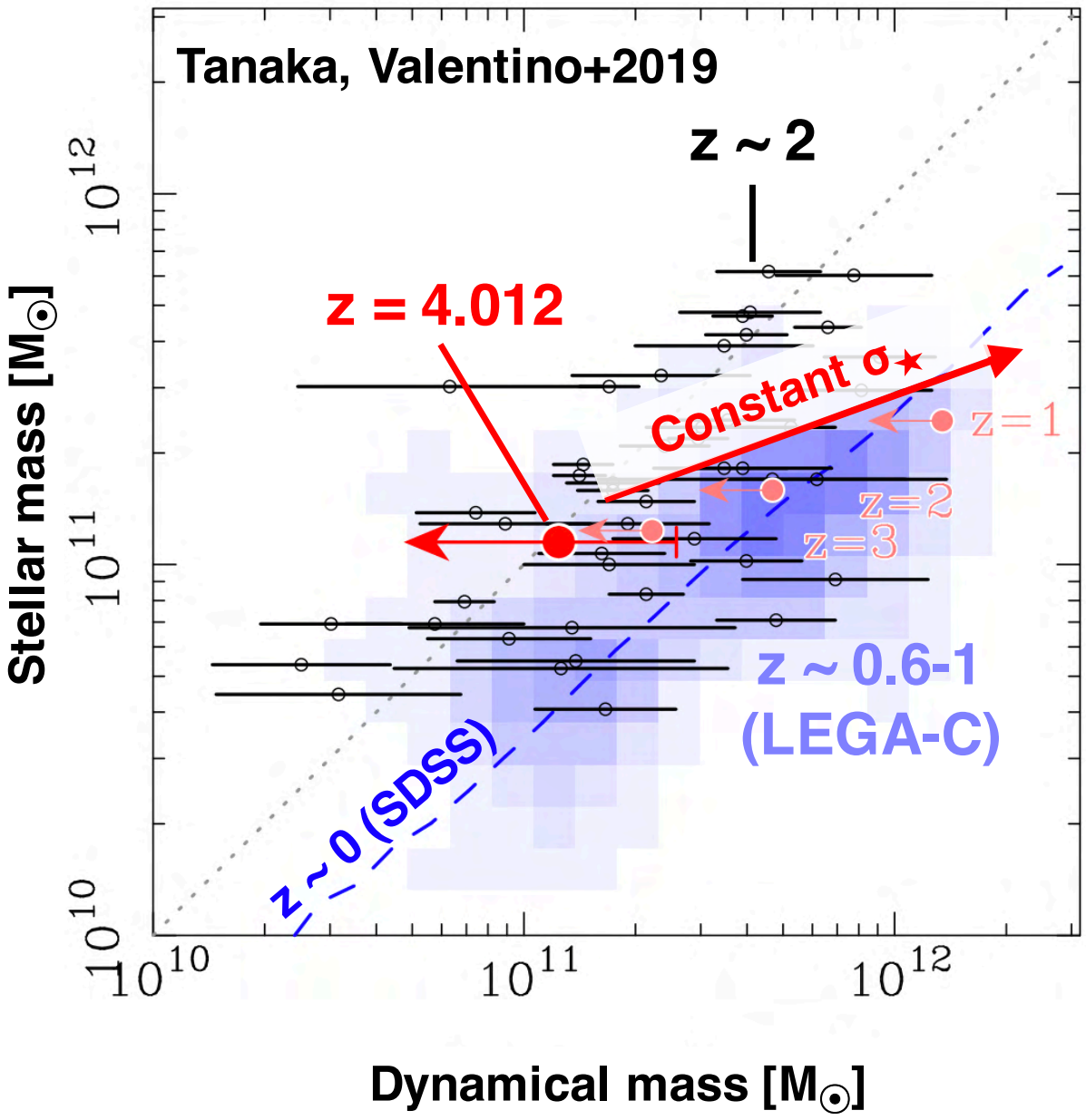
Stellar velocity dispersion of $\sigma_\star = 268 \pm 59$ km s^{-1}

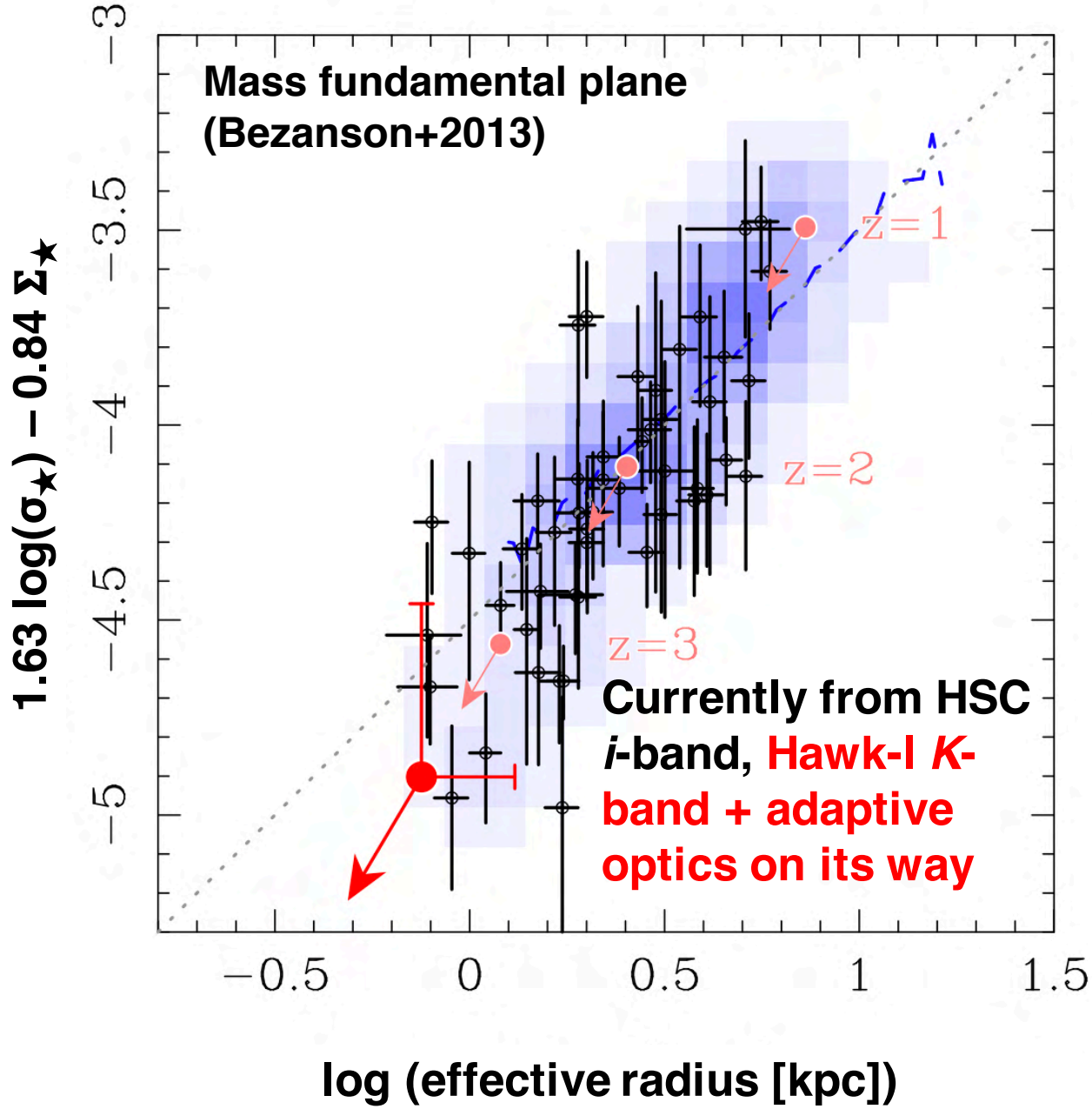
→ First assessment of the stellar dynamics of a(n unlensed) massive galaxy at z~4 (Tanaka, Valentino+2019)

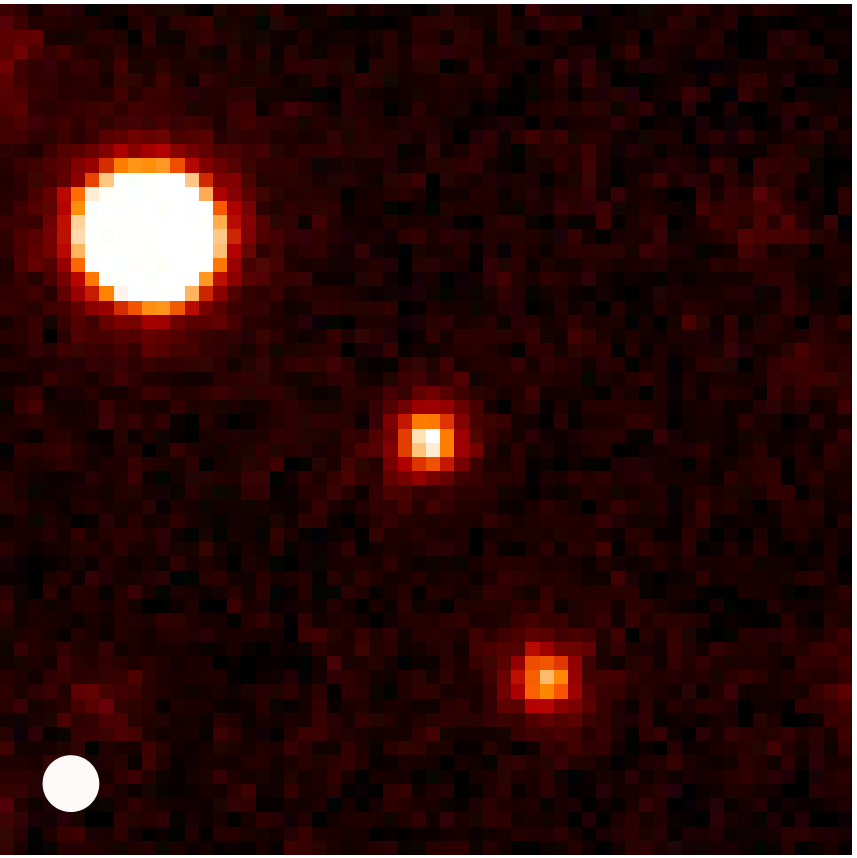
Size + mild stellar mass increase, constant velocity dispersion?



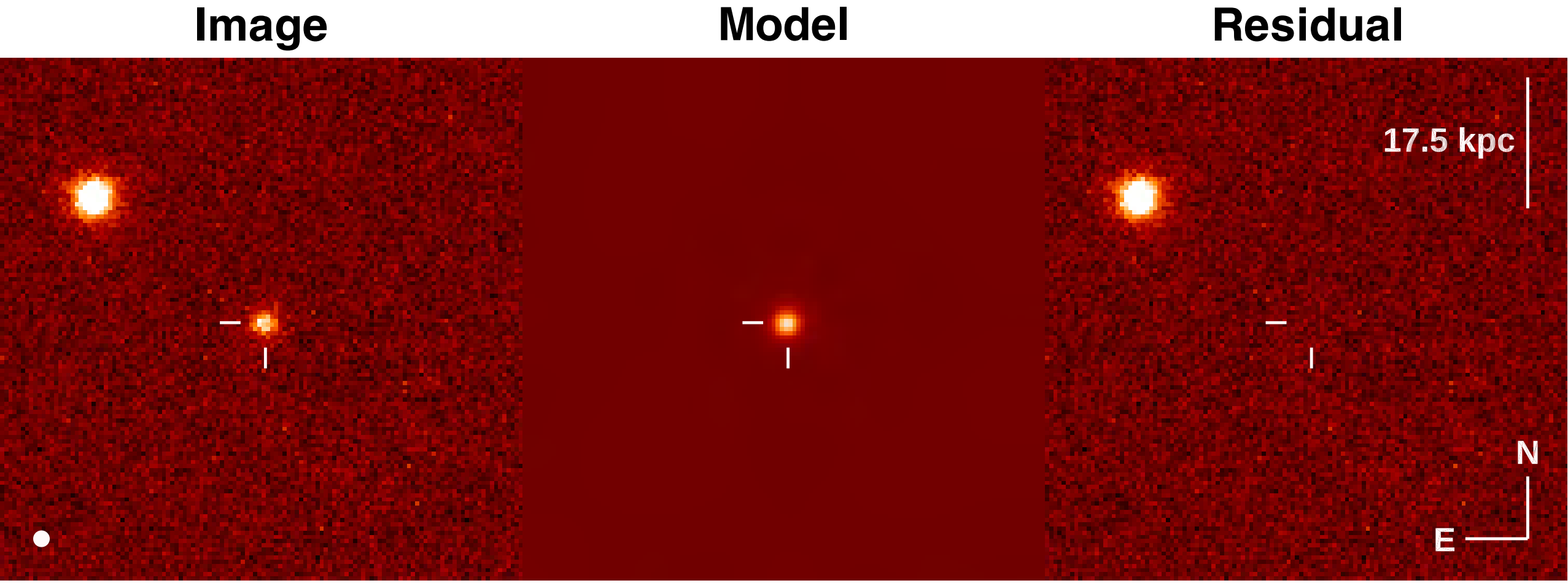



Tanaka, Valentino+2019
z ~ 2
z = 4.012
Constant σ★
z=1
z=2
z=3
z ~ 0.6-1
(LEGA-C)
z ~ 0 (SDSS)
Stellar mass [M⊙]
Dynamical mass [M⊙]
10^10
10^11
10^12


Mass fundamental plane
(Bezanson+2013)
z=1
z=2
z=3
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])
−3
−3.5
−4
−4.5
−5
−0.5
0
0.5
1
1.5



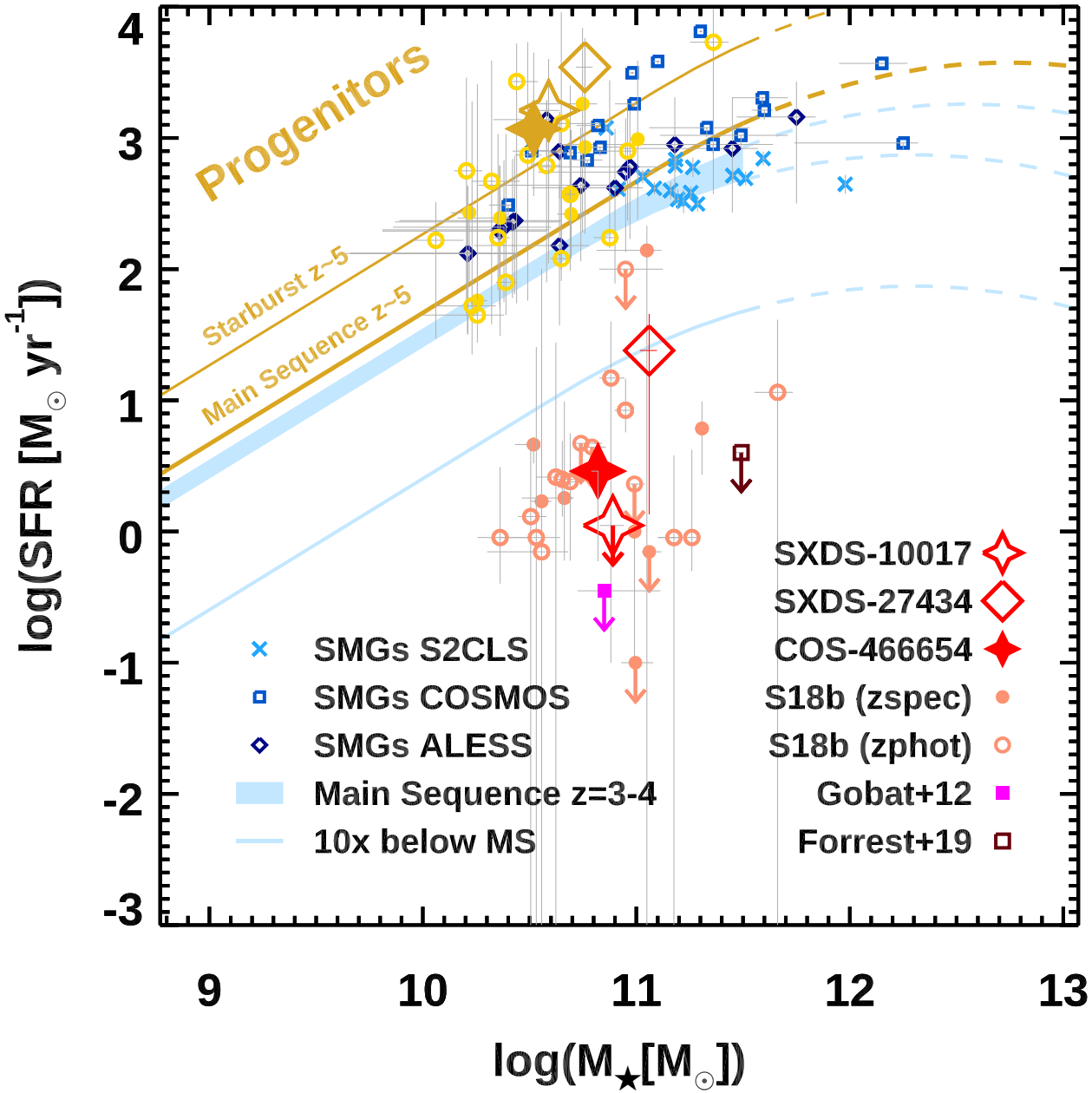
HSC i-band 0.6” seeing



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

Who are their progenitors?

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



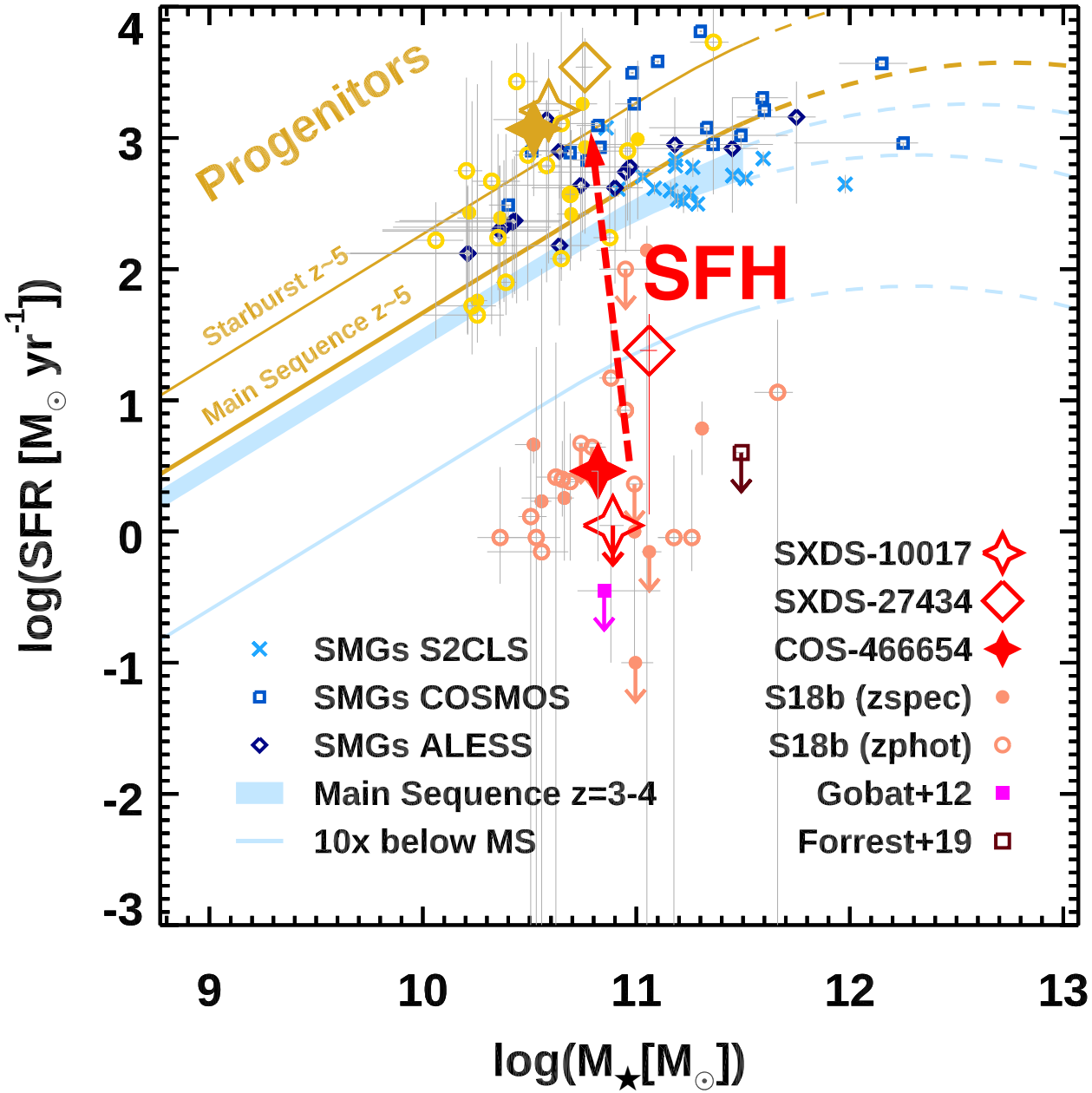
Who are their progenitors?

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 $z \gtrsim 4$



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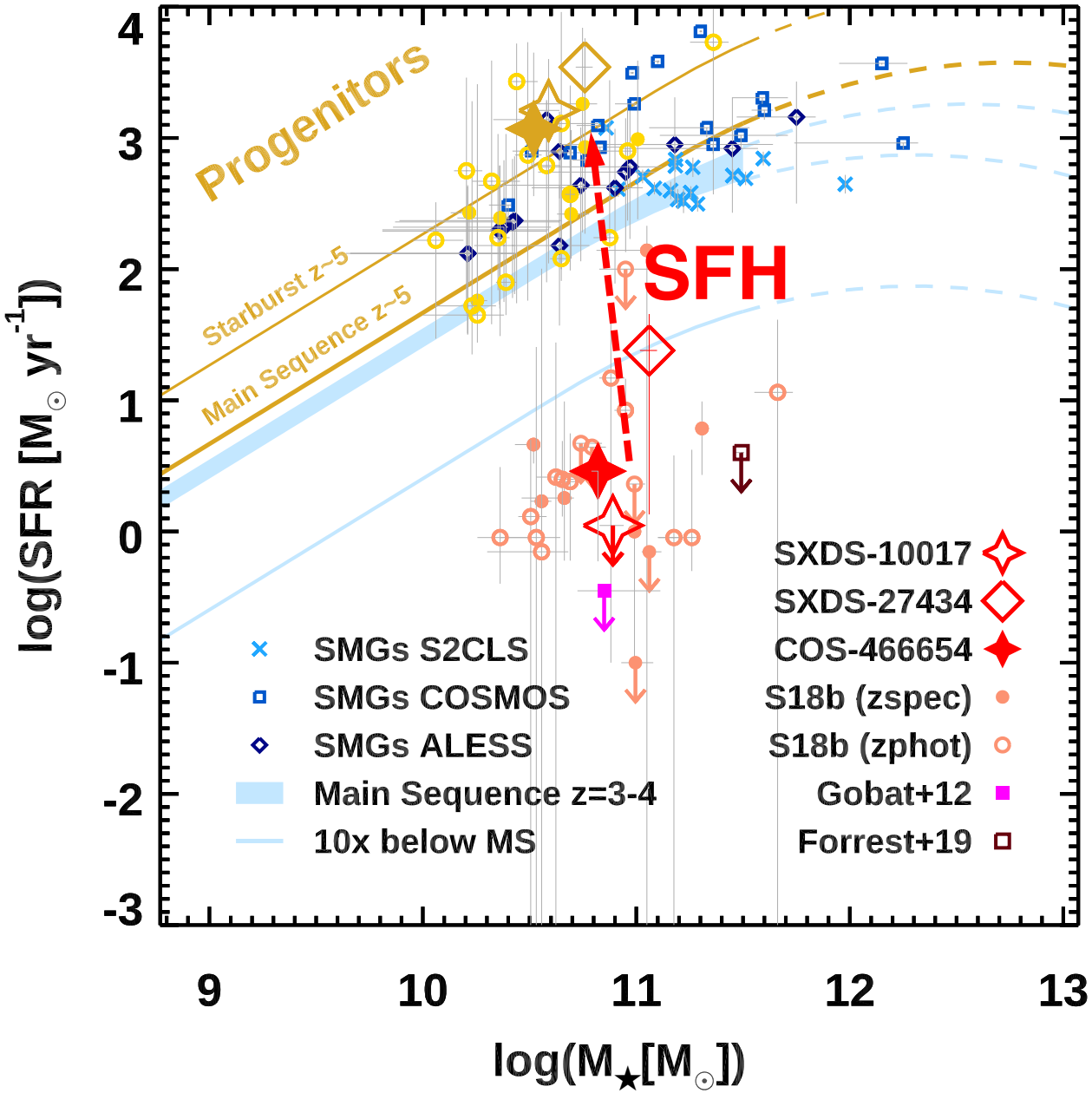

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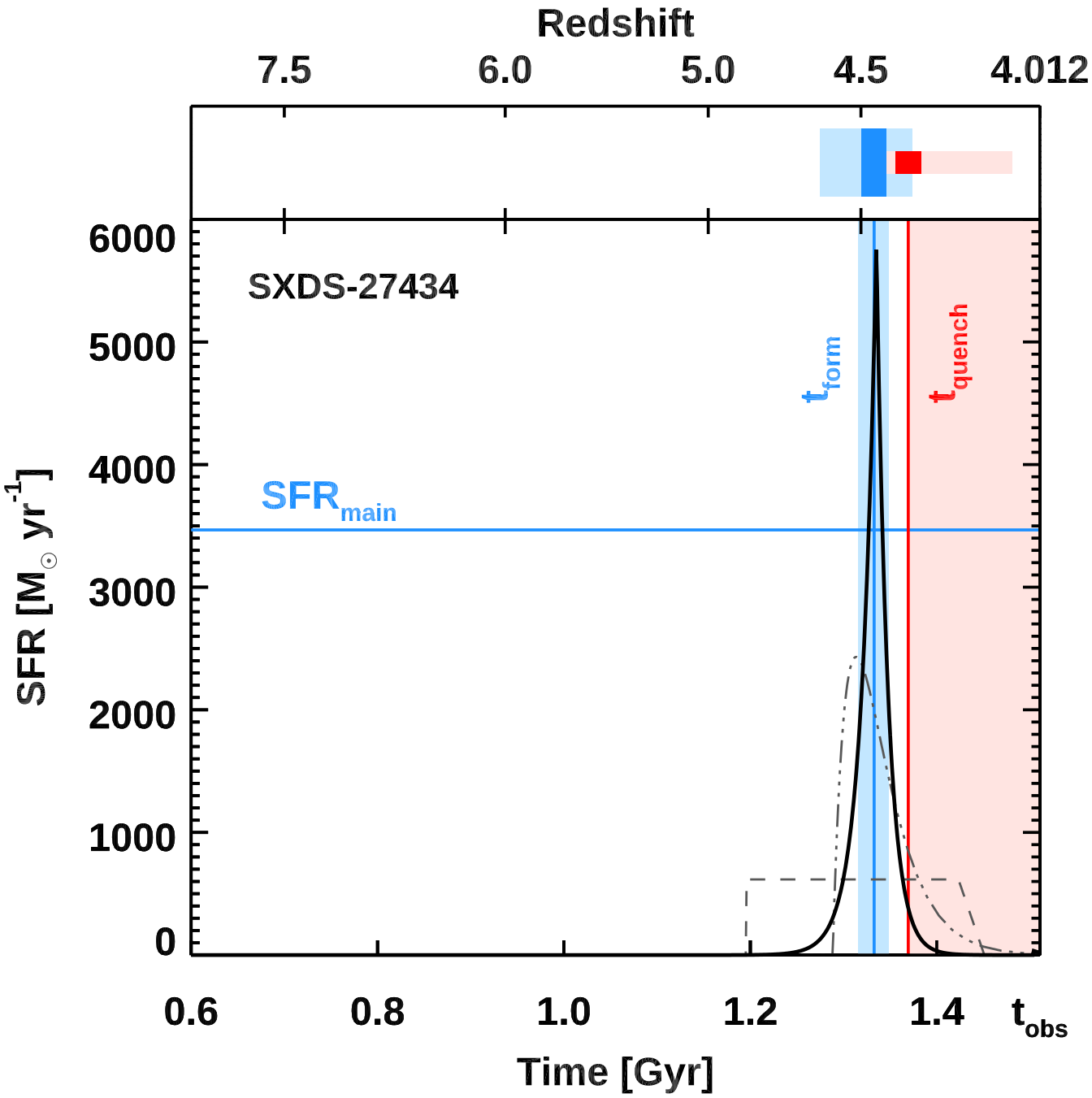
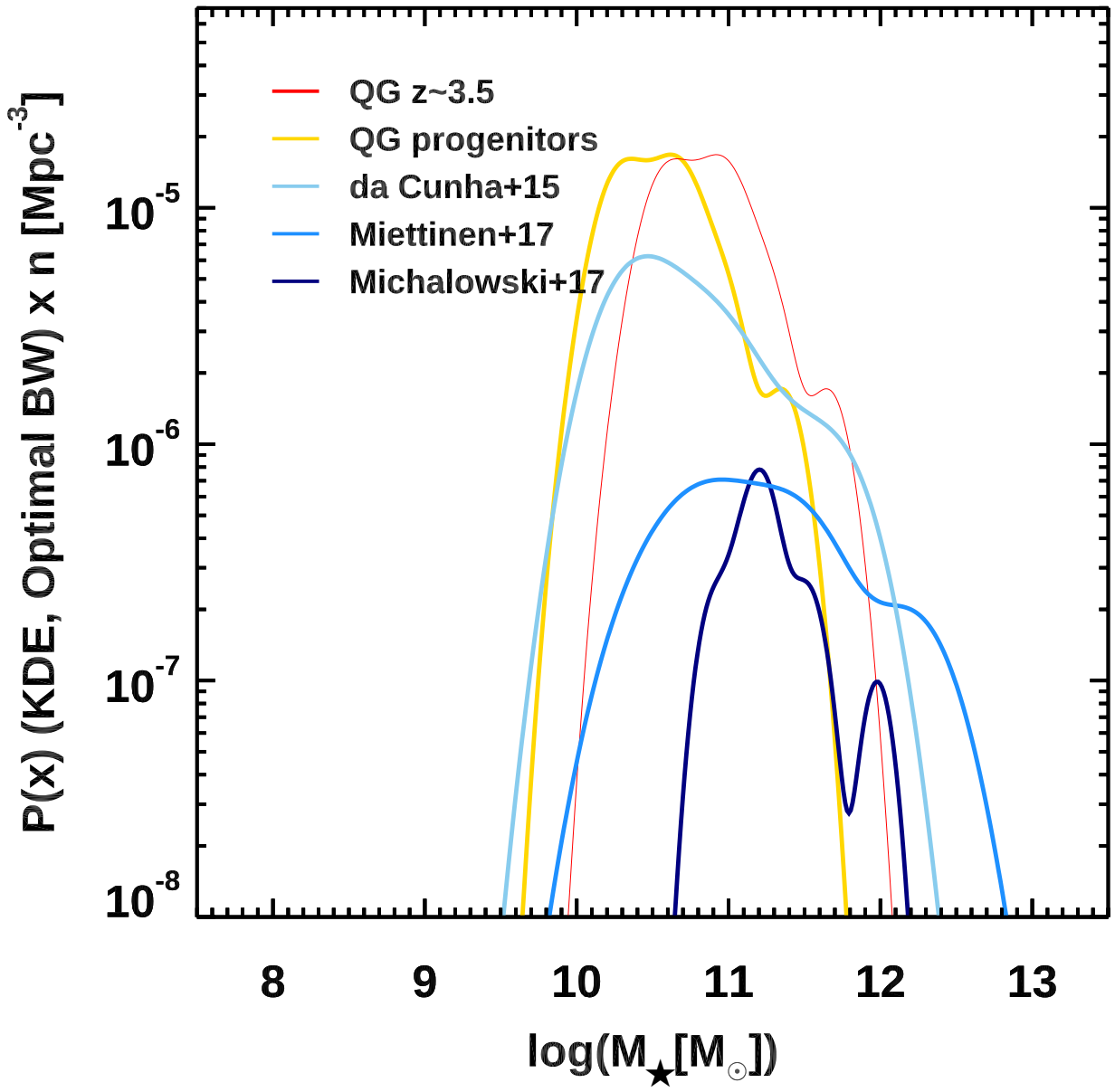
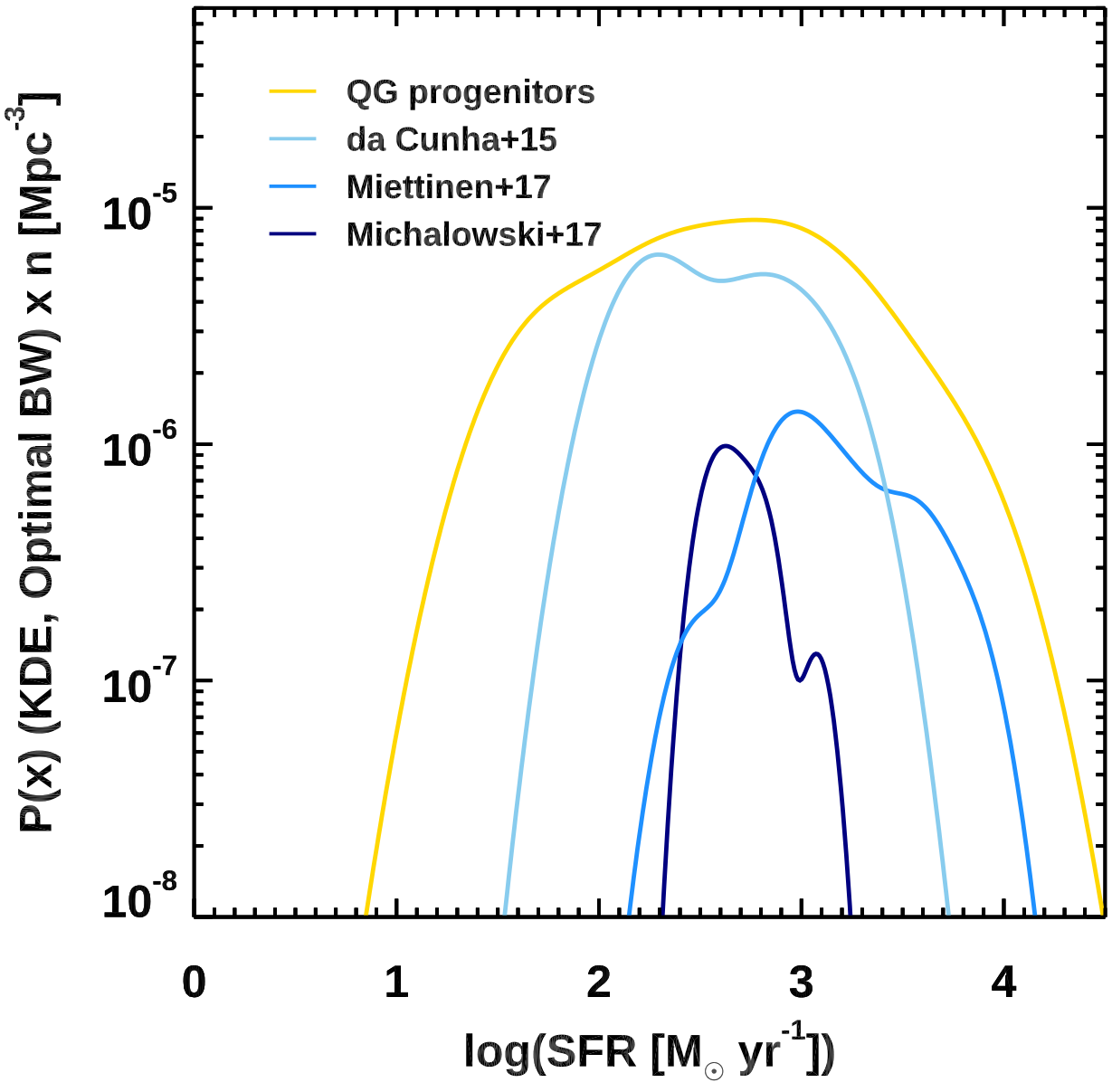
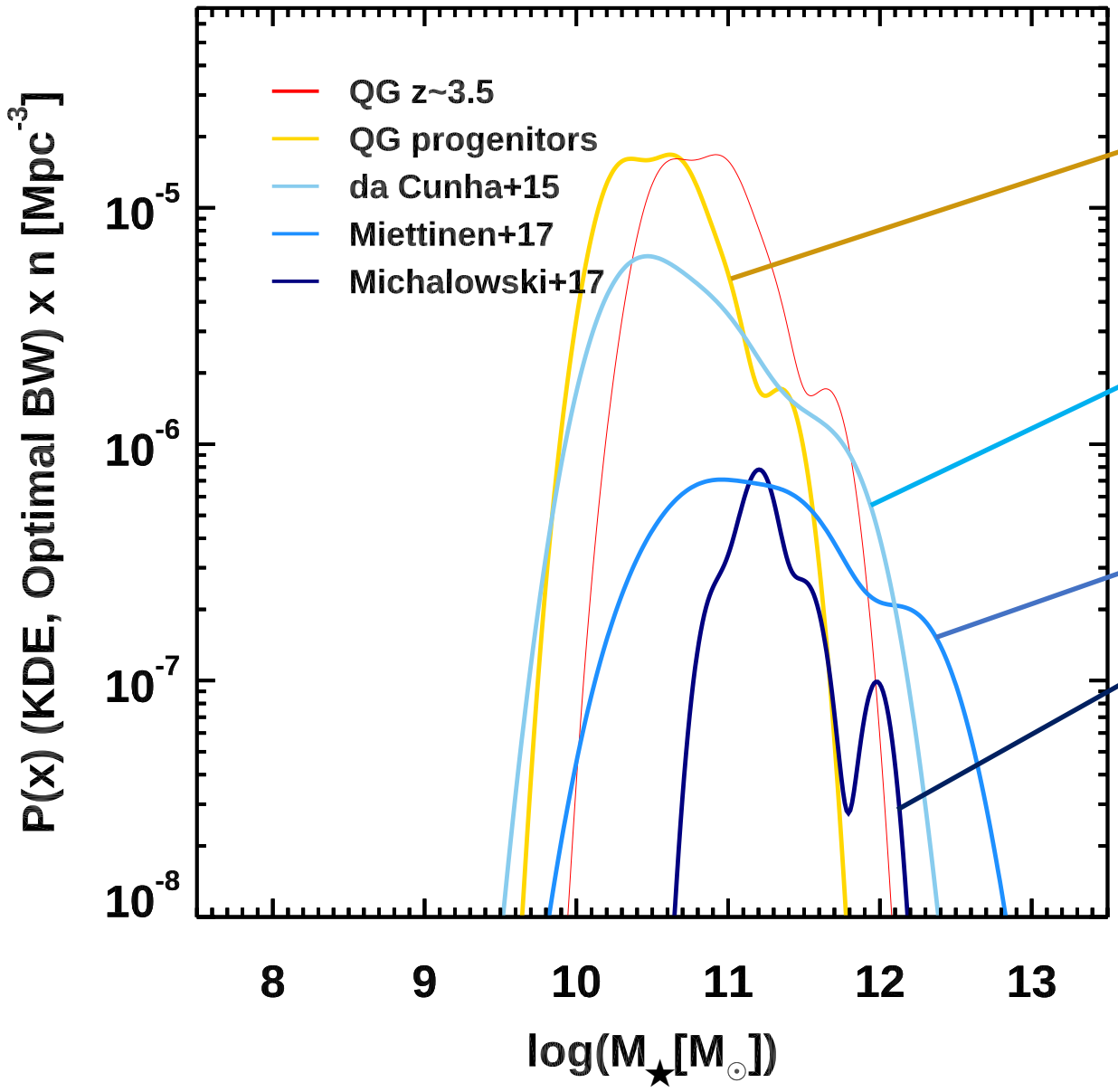


When did they die? Spectrophotometric modeling → Star formation history (Schreiber+2018, Belli+2018)

Short (~50-150 Myr) and intense (SFR~1000-3000 $M_\odot$ 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$_\star$[M$_\odot$])


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$_\odot$ yr^{-1}])

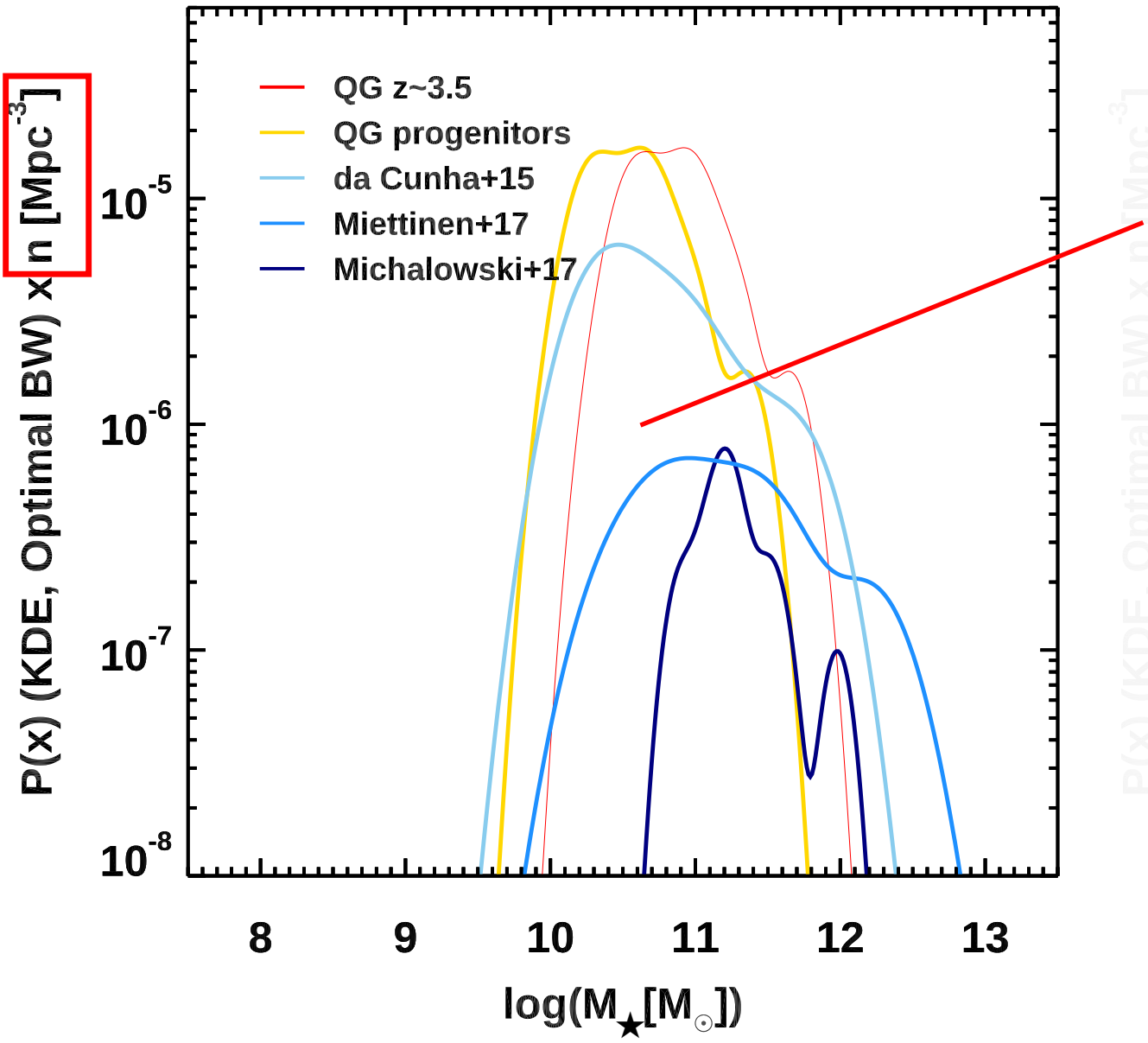


Progenitors

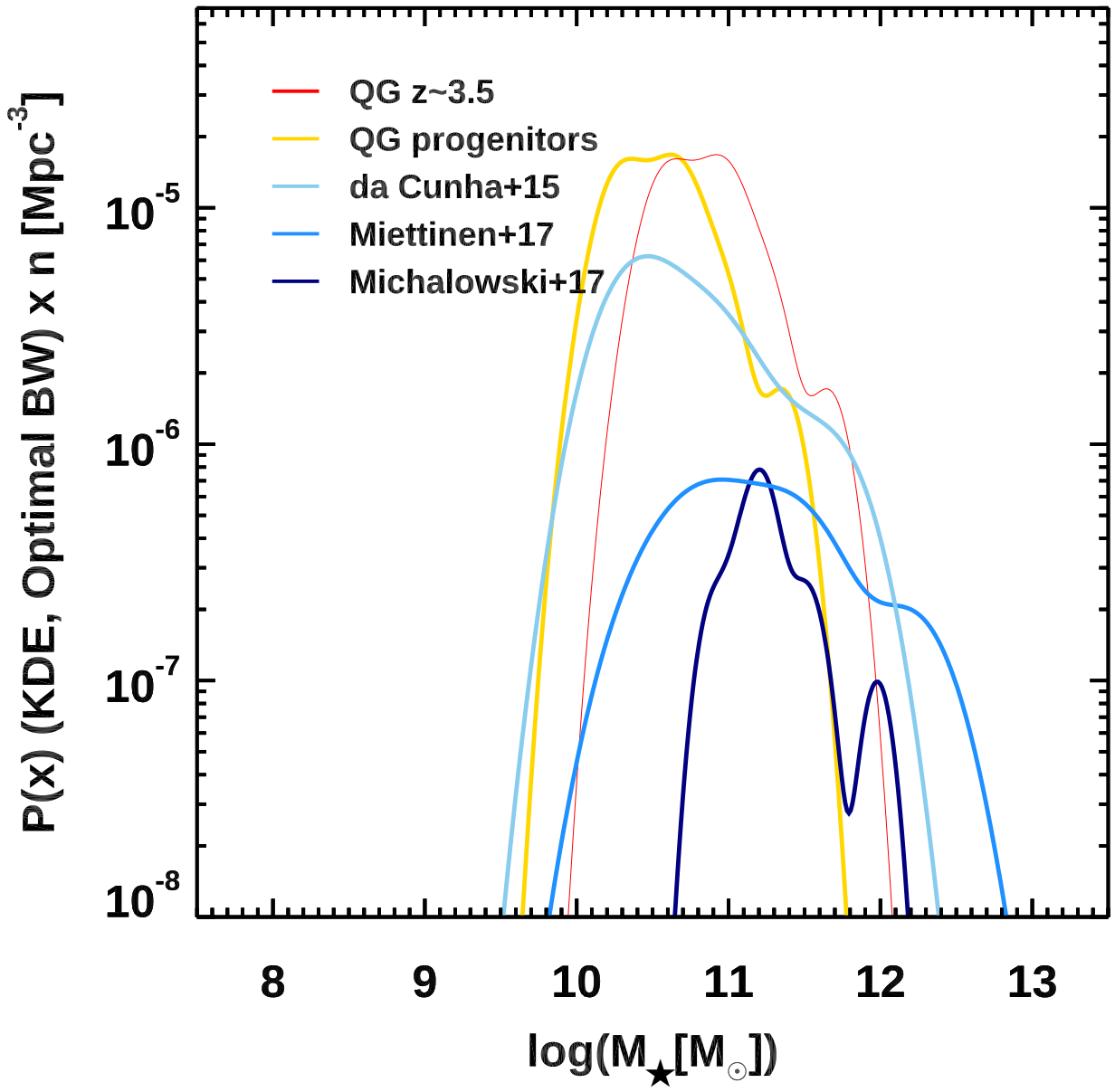
Deep sub-mm survey (also some "normal" galaxies)

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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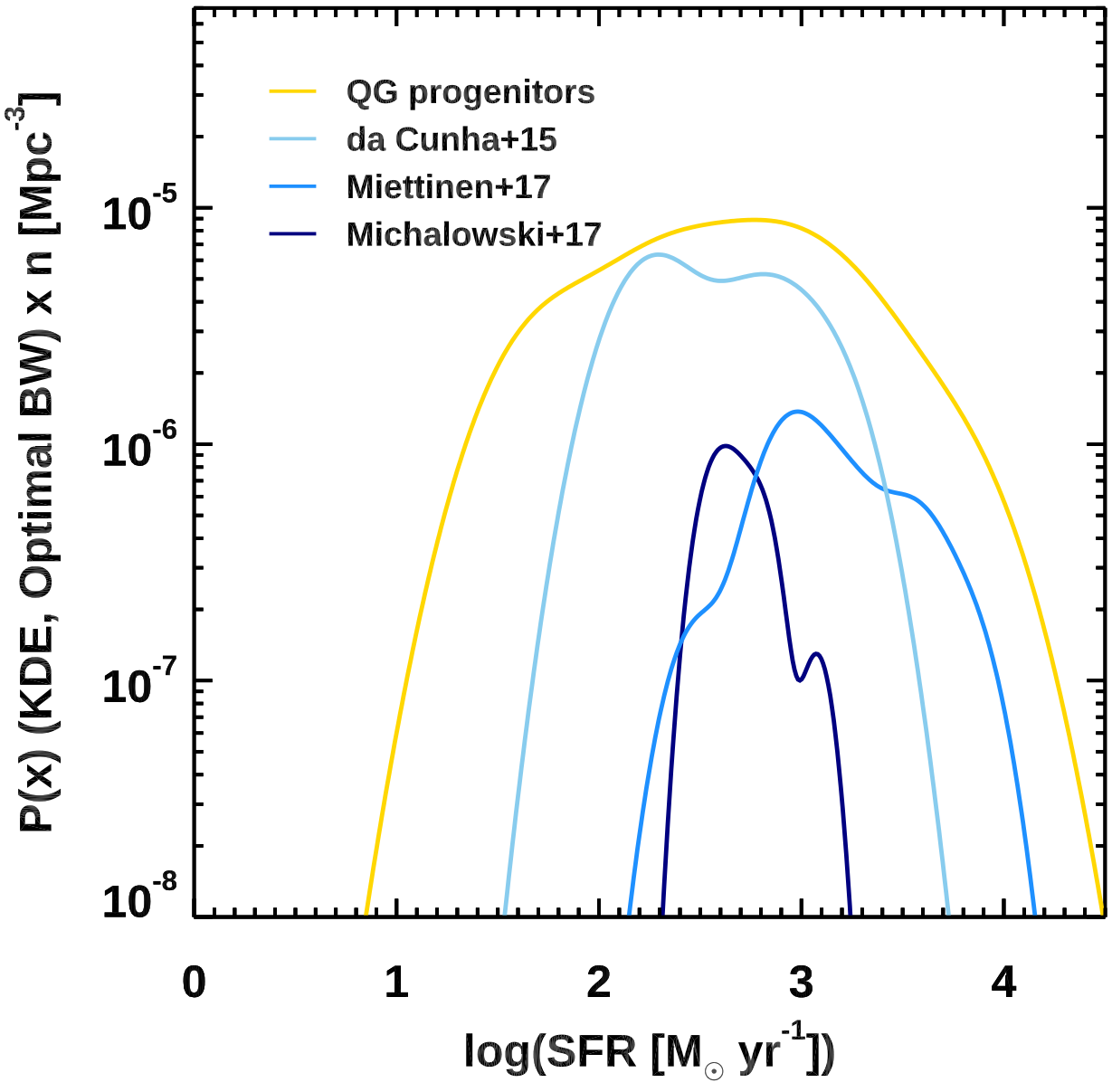
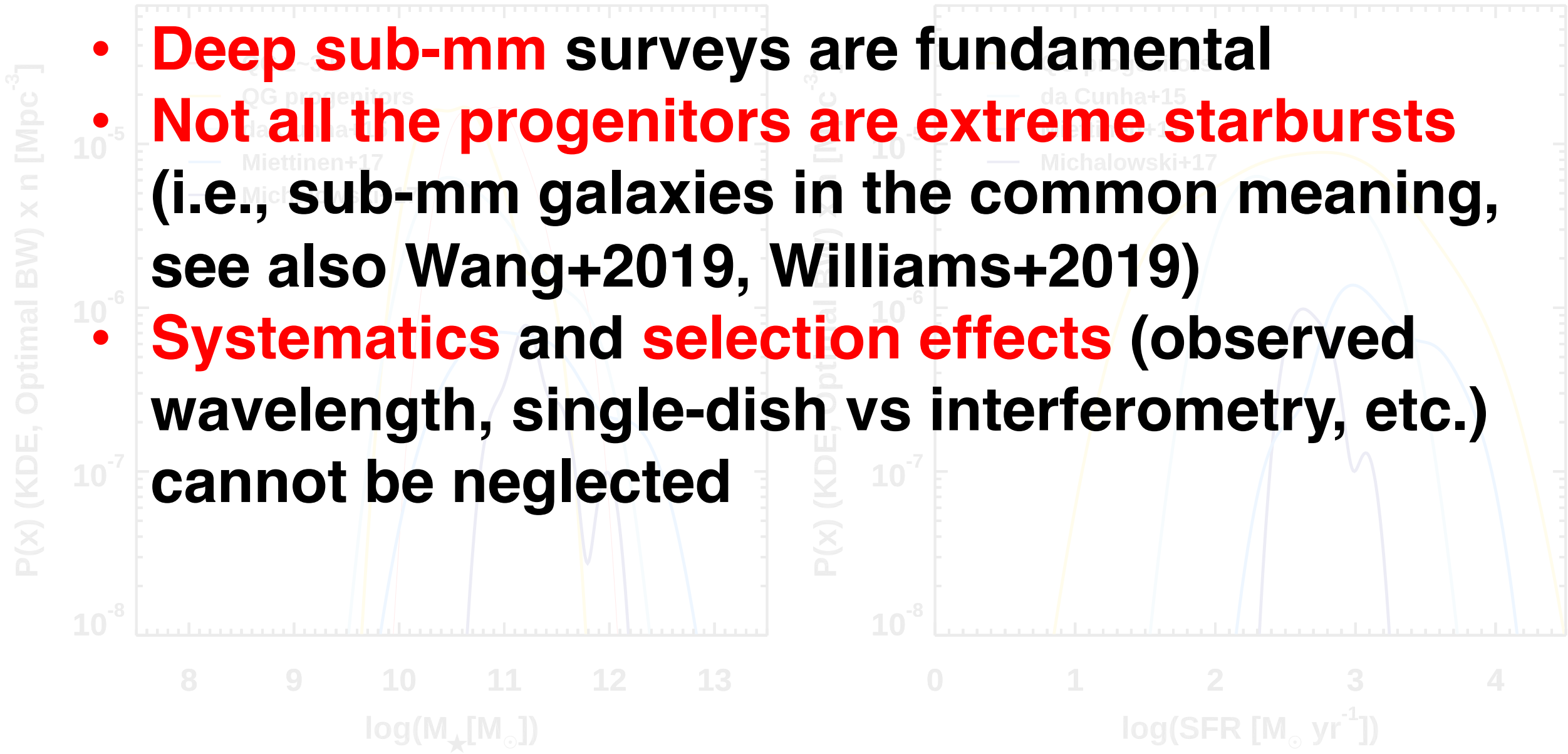
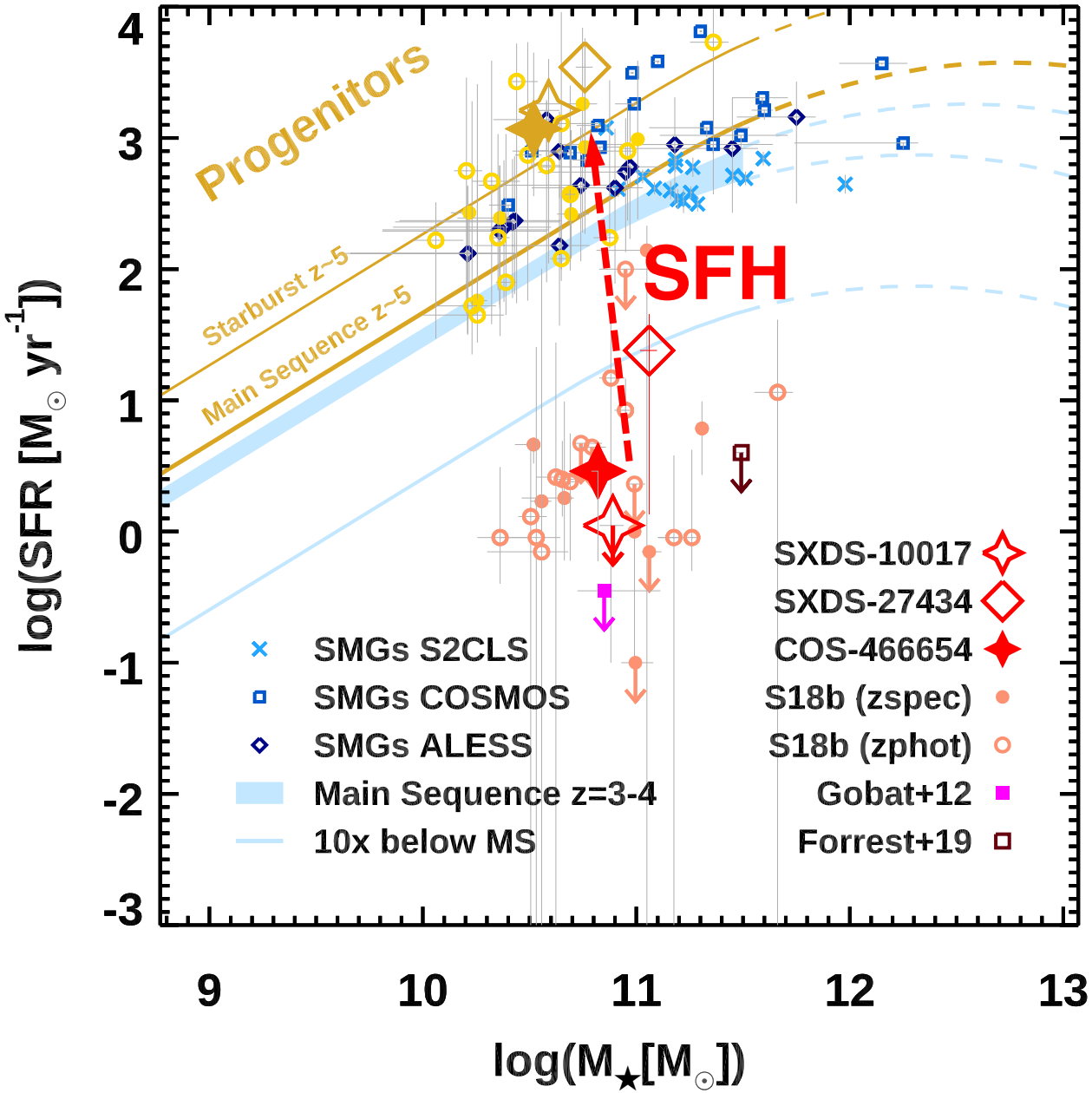
P(x) (KDE, Optimal BW) x n [Mpc^{-3}]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
8
9
10
11
12
13
log(M$_\star$[M$_\odot$])


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$_\odot$ 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





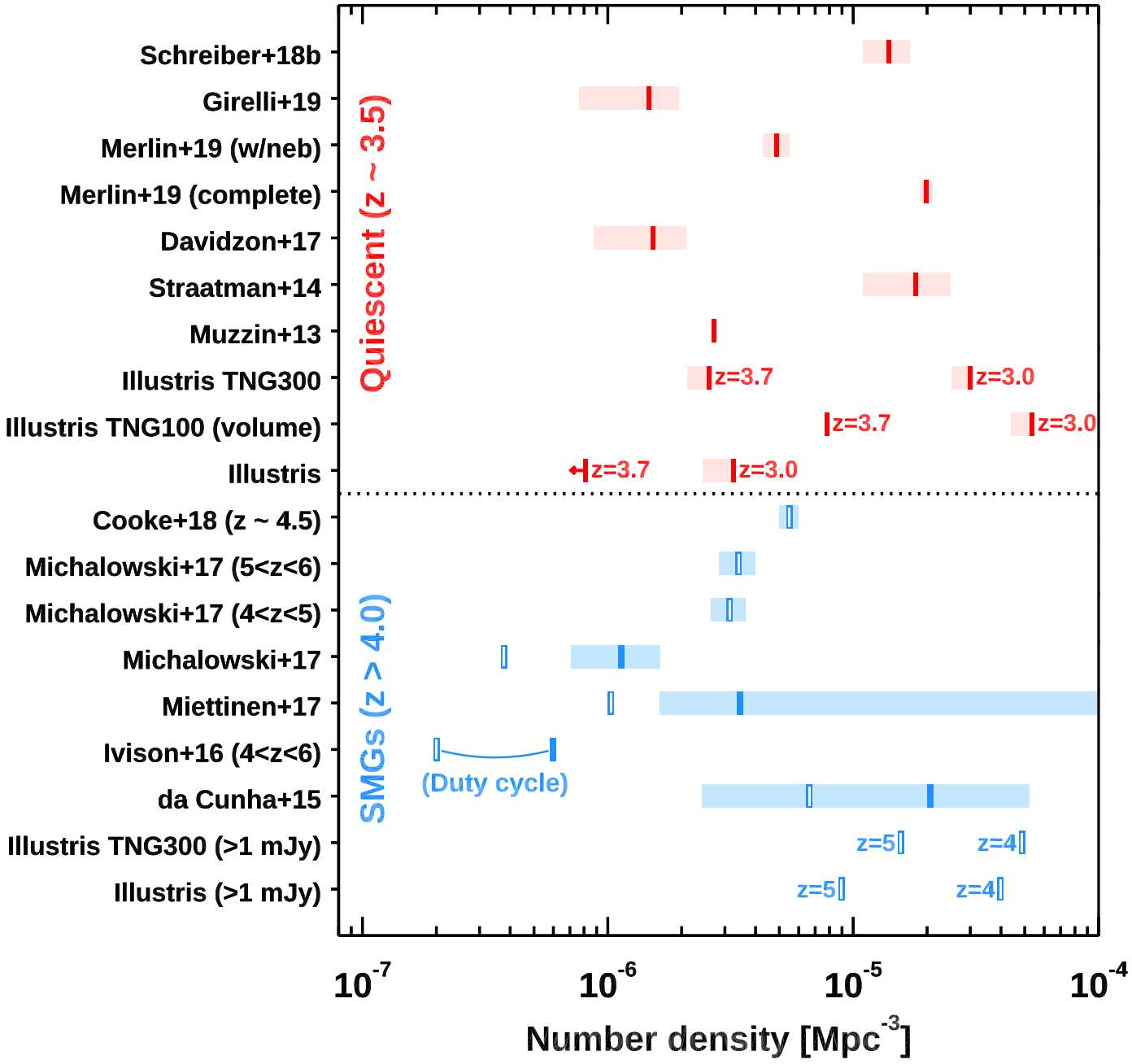
Who are their progenitors?

We look for a population:

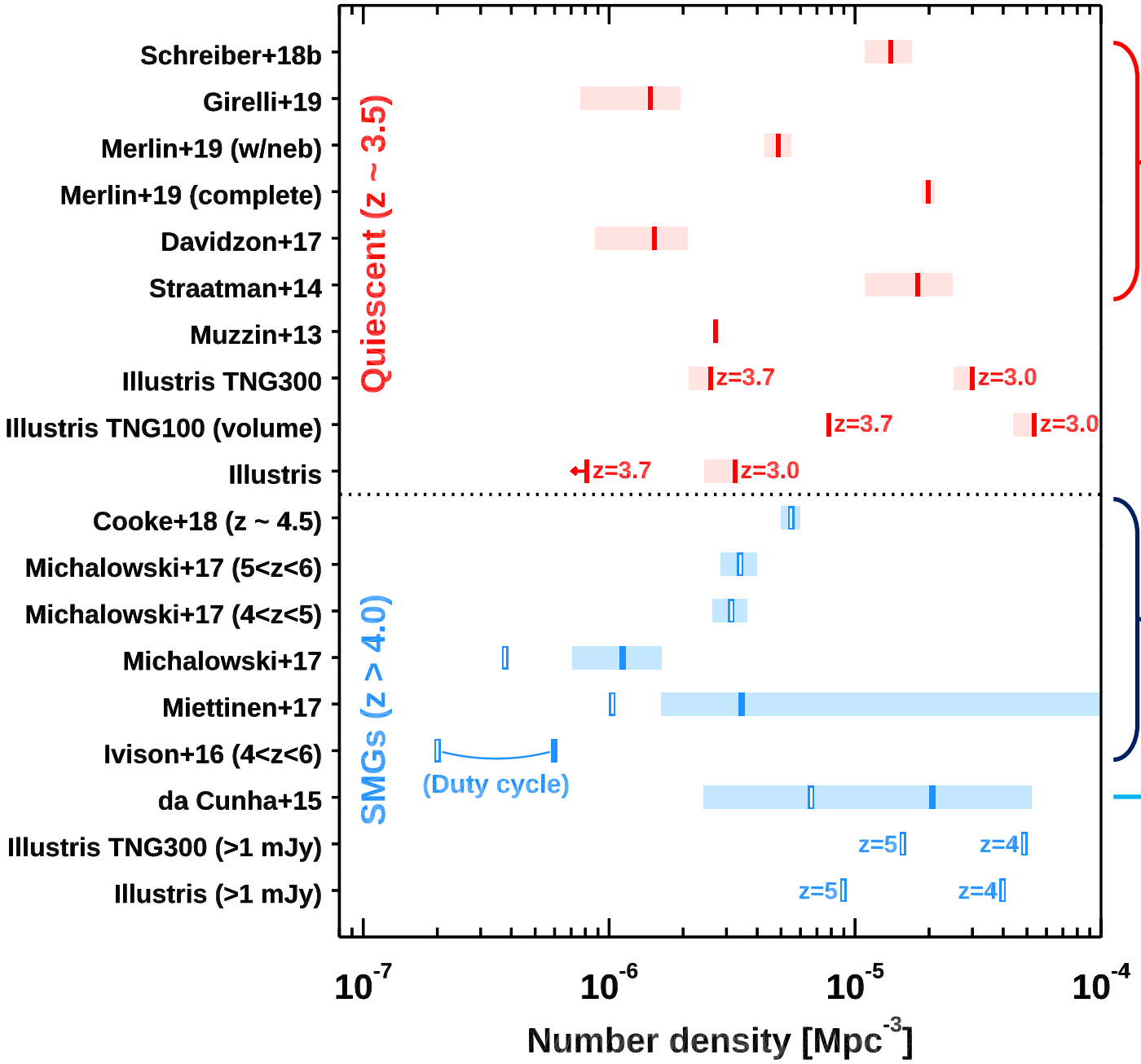
- with properties compatible with the predictions from SED modeling
- **numerous enough to match the quiescent objects at z~4**

Candidates:

Sub-mm galaxies at $z \gtrsim 4$



Are there enough?

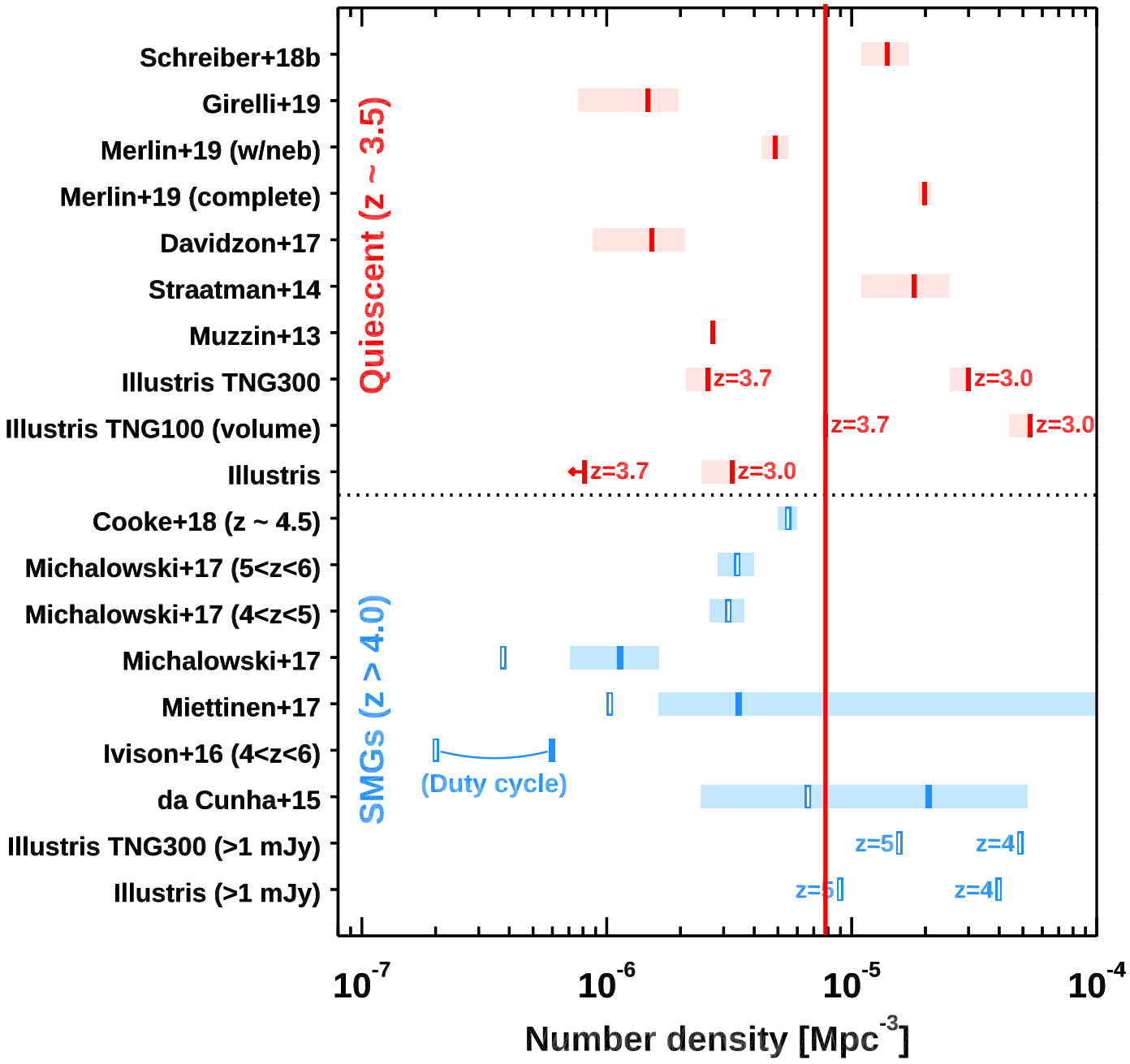


Are there enough?

Quiescent galaxies at 3 < z < 4

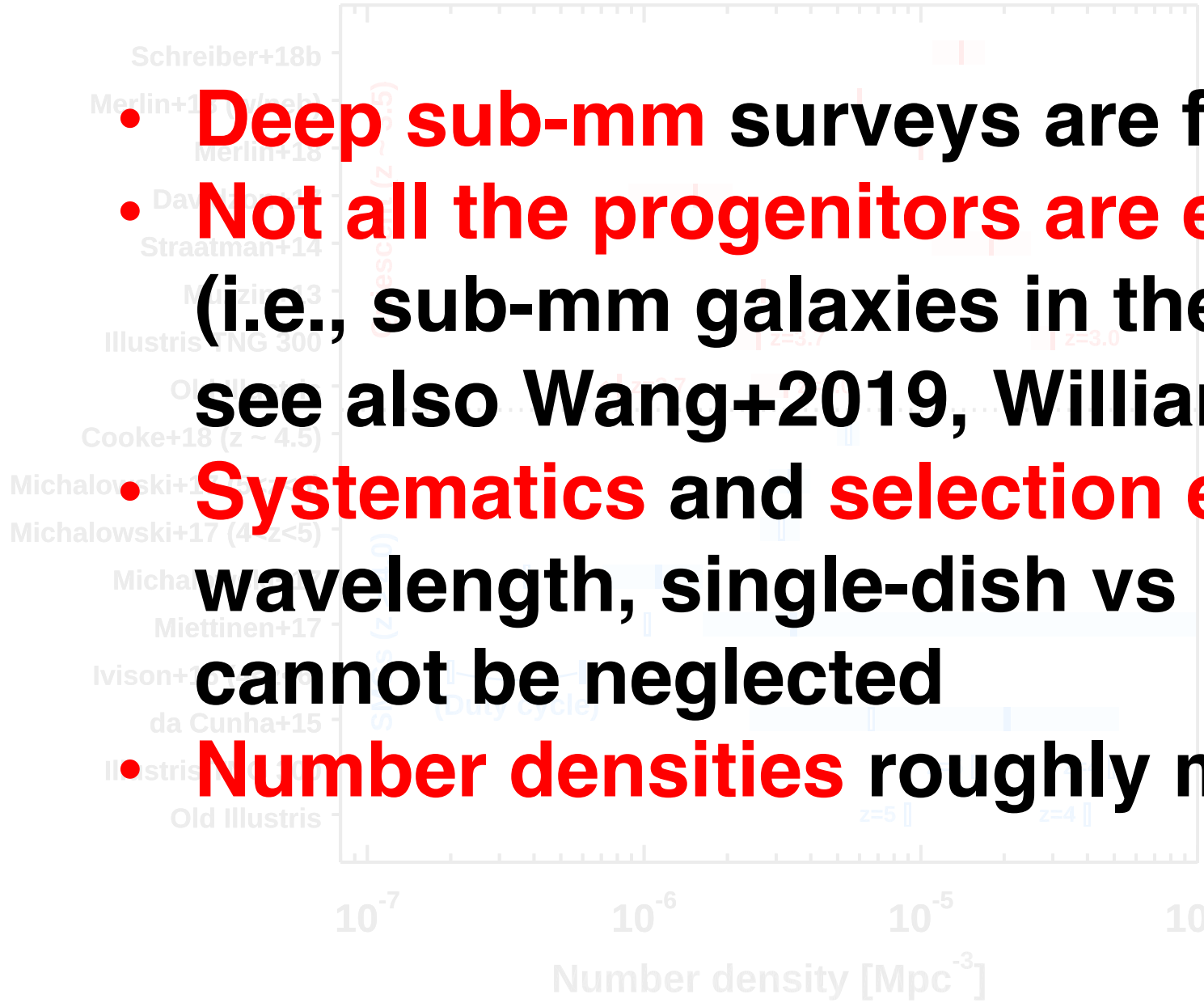
Shallow sub-mm surveys (only extreme starbursting galaxies)

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



Are there enough?

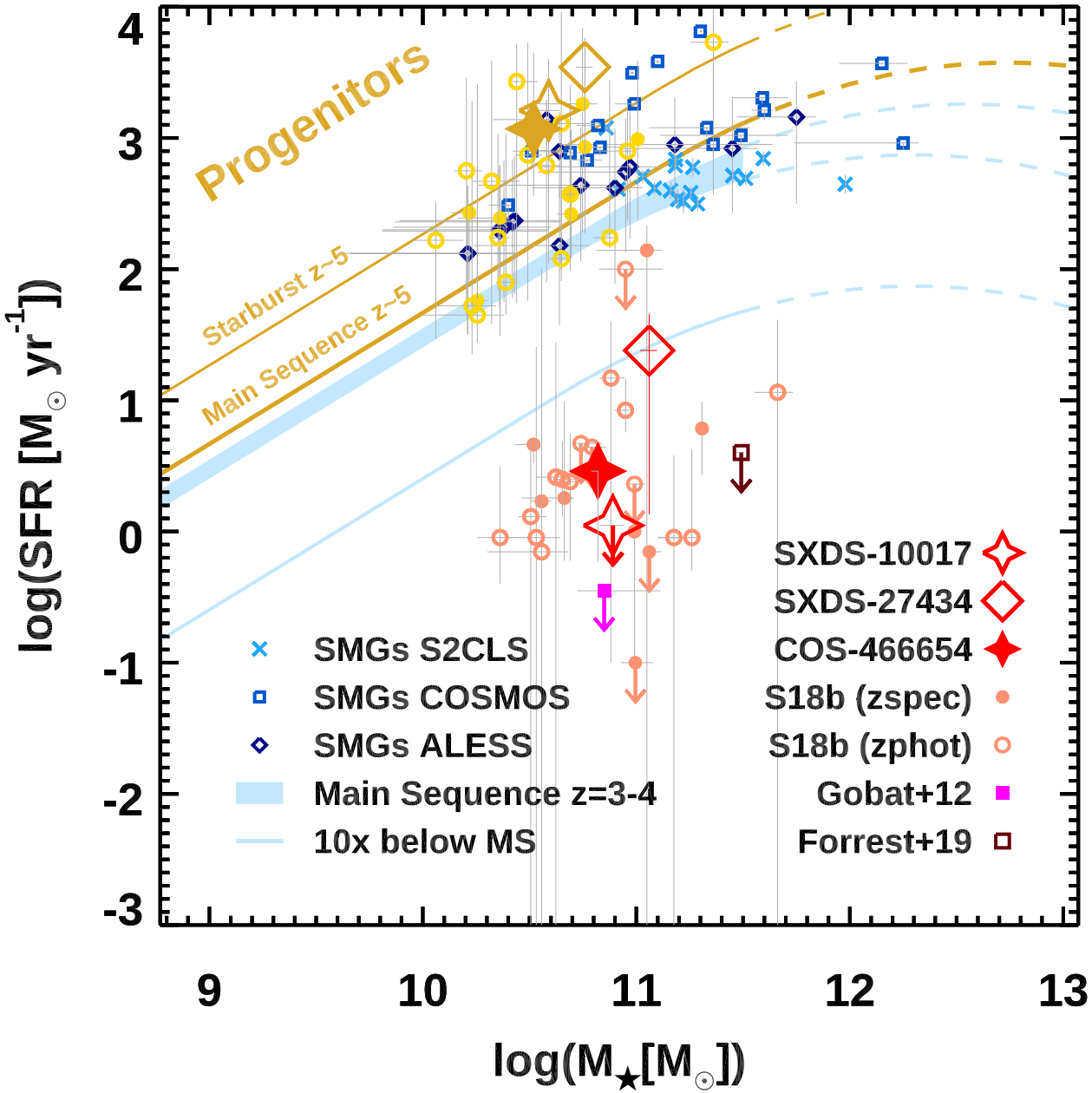
Yes, when observing deep enough.



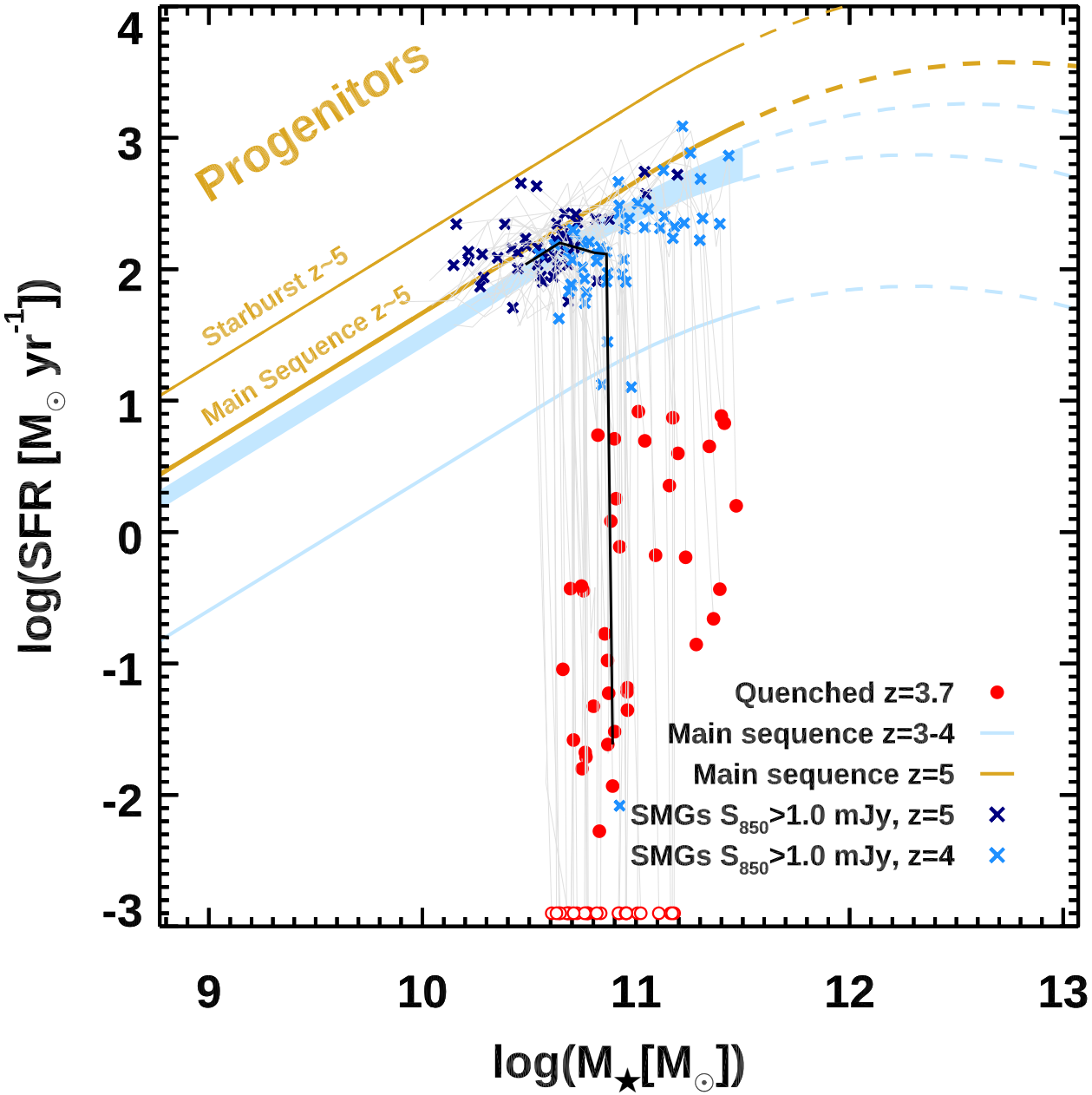
- **Deep sub-mm** surveys are fundamental
- **Not all the progenitors are extreme starbursts** (i.e., sub-mm galaxies in the common meaning, see also Wang+2019, Williams+2019)
- **Systematics** and **selection effects** (observed wavelength, single-dish vs interferometry, etc.) cannot be neglected
-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

Can we model the early death of cosmic giants?

(Only partially: something is missing)

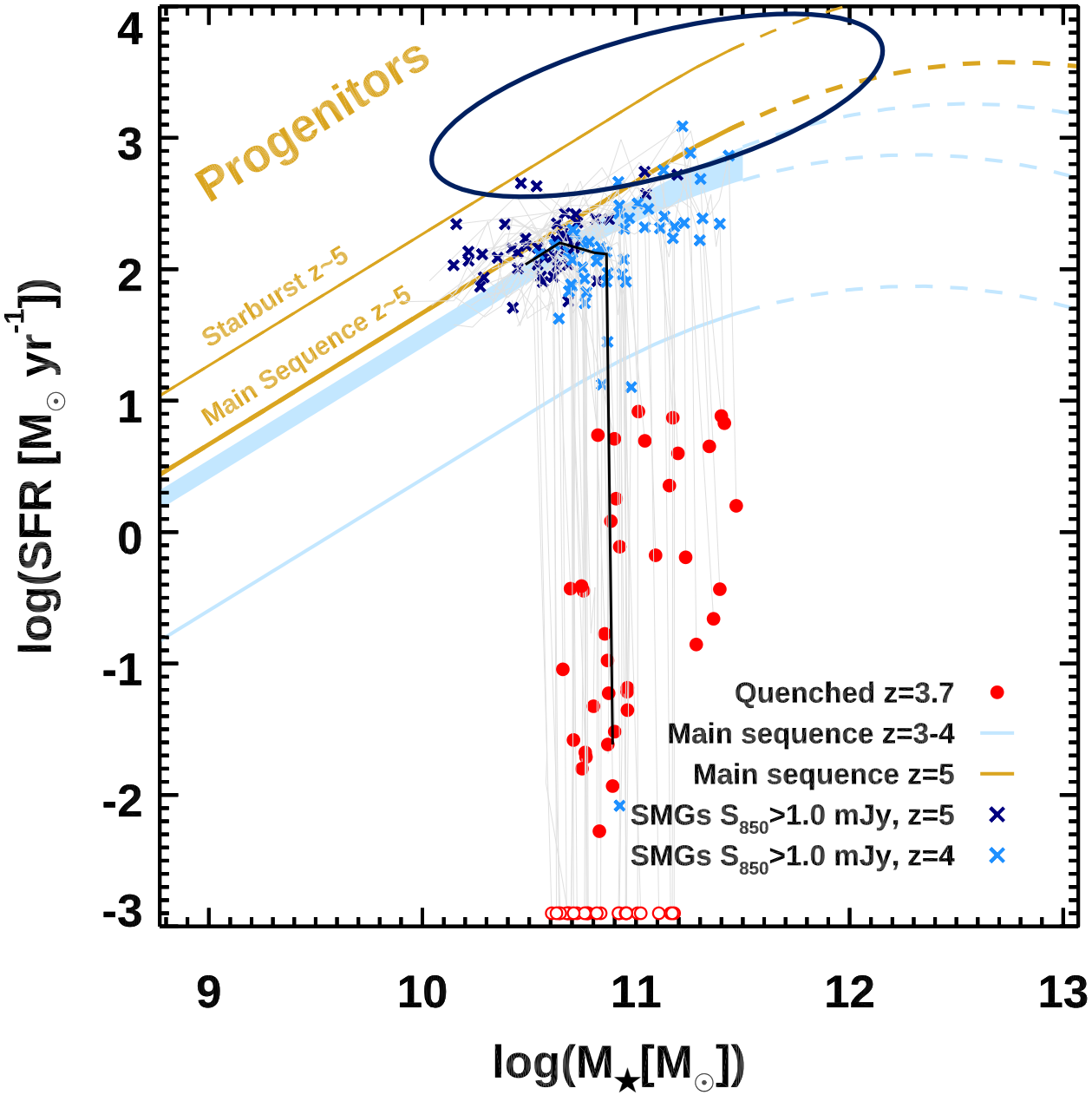


Observations

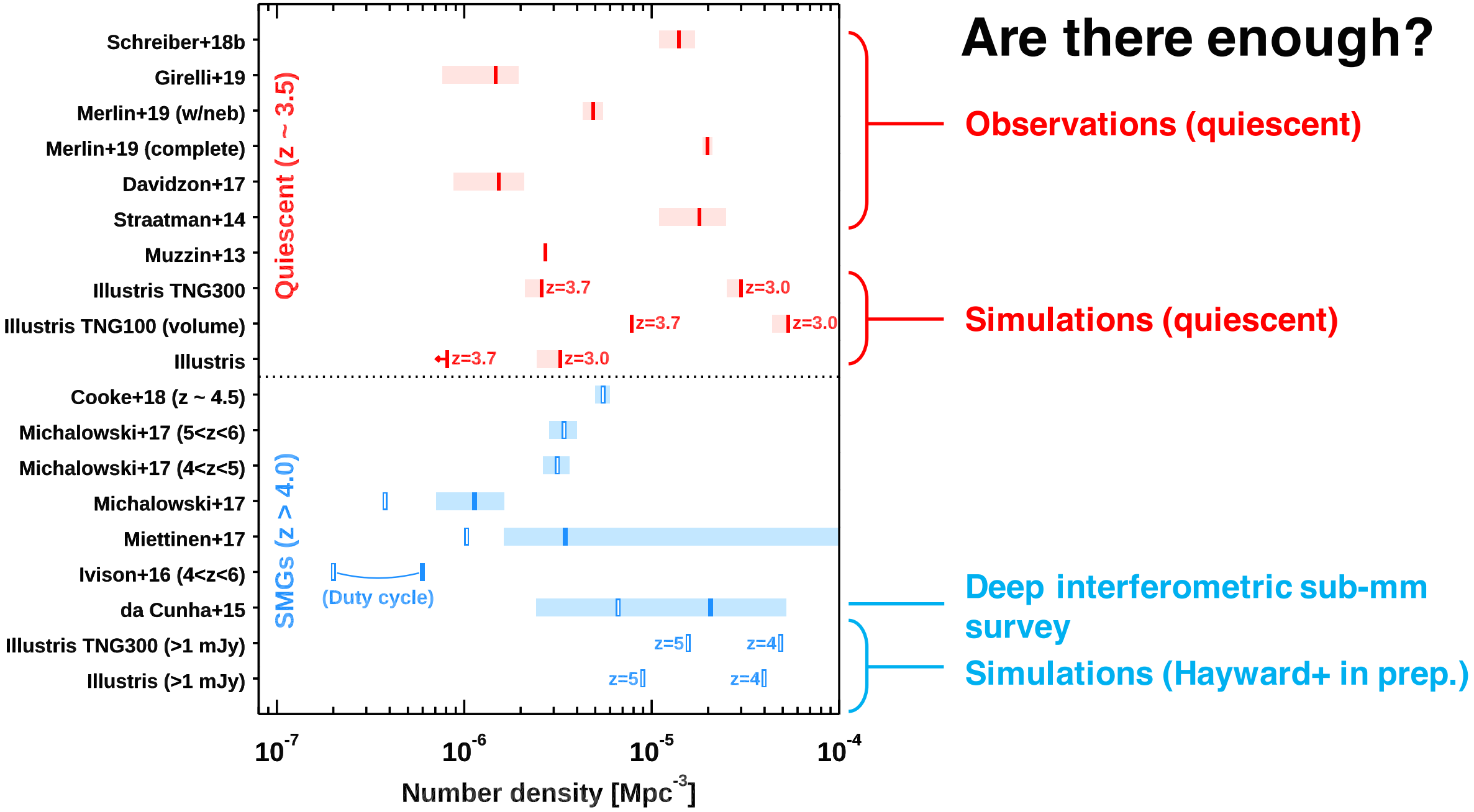


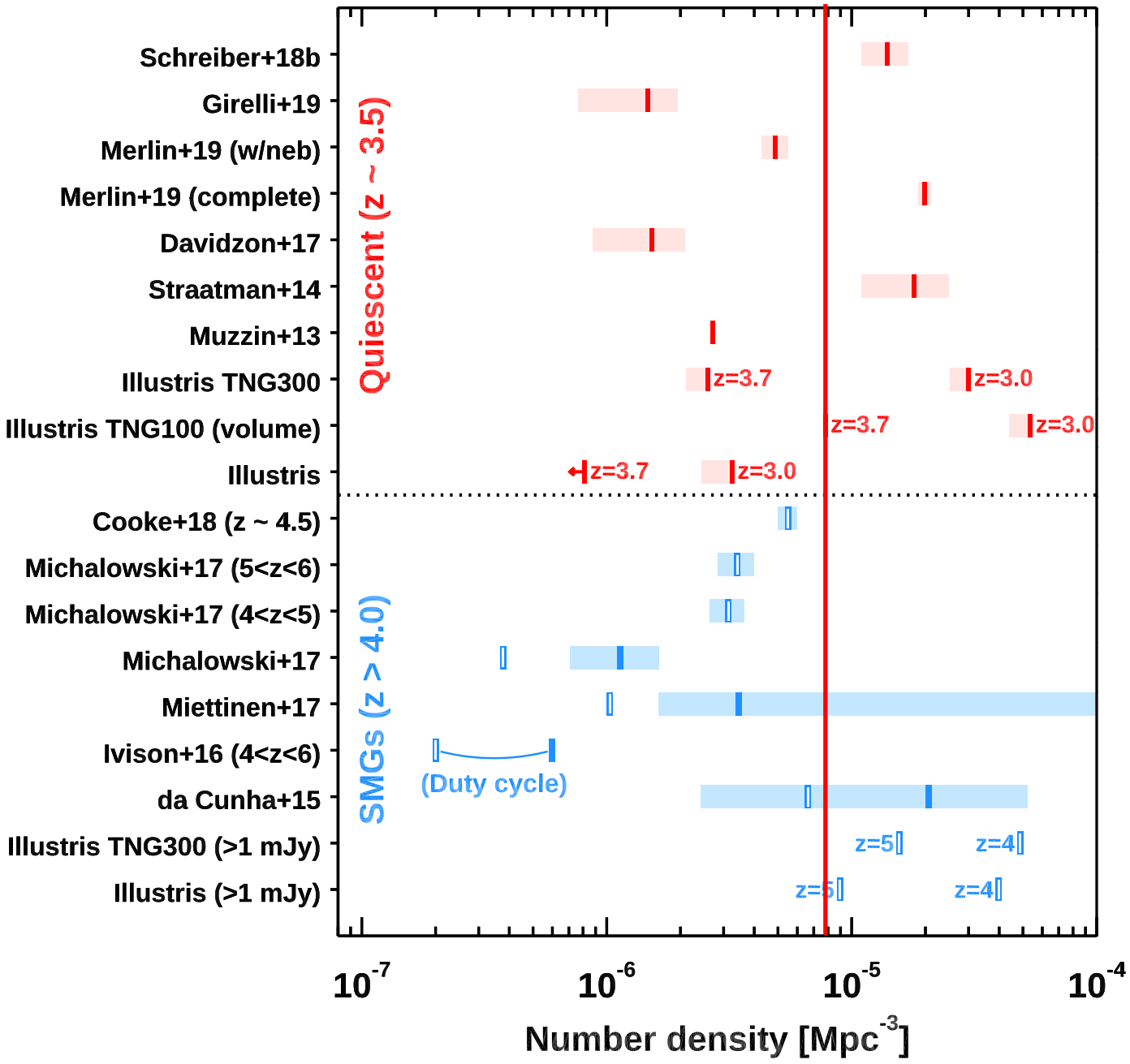
IllustrisTNG simulation

(Nelson+2019a,
Hayward+2021)



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


Schreiber+18b
Girelli+19
Merlin+19 (w/neb)
Merlin+19 (complete)
Davidzon+17
Straatman+14
Muzzin+13
Illustris TNG300
Illustris TNG100 (volume)
Illustris
Cooke+18 (z ~ 4.5)
Michalowski+17 (5<z<6)
Michalowski+17 (4<z<5)
Michalowski+17
Miettinen+17
Ivison+16 (4<z<6)
da Cunha+15
Illustris TNG300 (>1 mJy)
Illustris (>1 mJy)
Quiescent (z ~ 3.5)
SMGs (z > 4.0)
z=3.7
z=3.0
z=3.7
z=3.0
z=3.7
z=3.0
(Duty cycle)
z=5
z=4
z=5
z=4
10^-7
10^-6
10^-5
10^-4
Number density [Mpc^-3]
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)

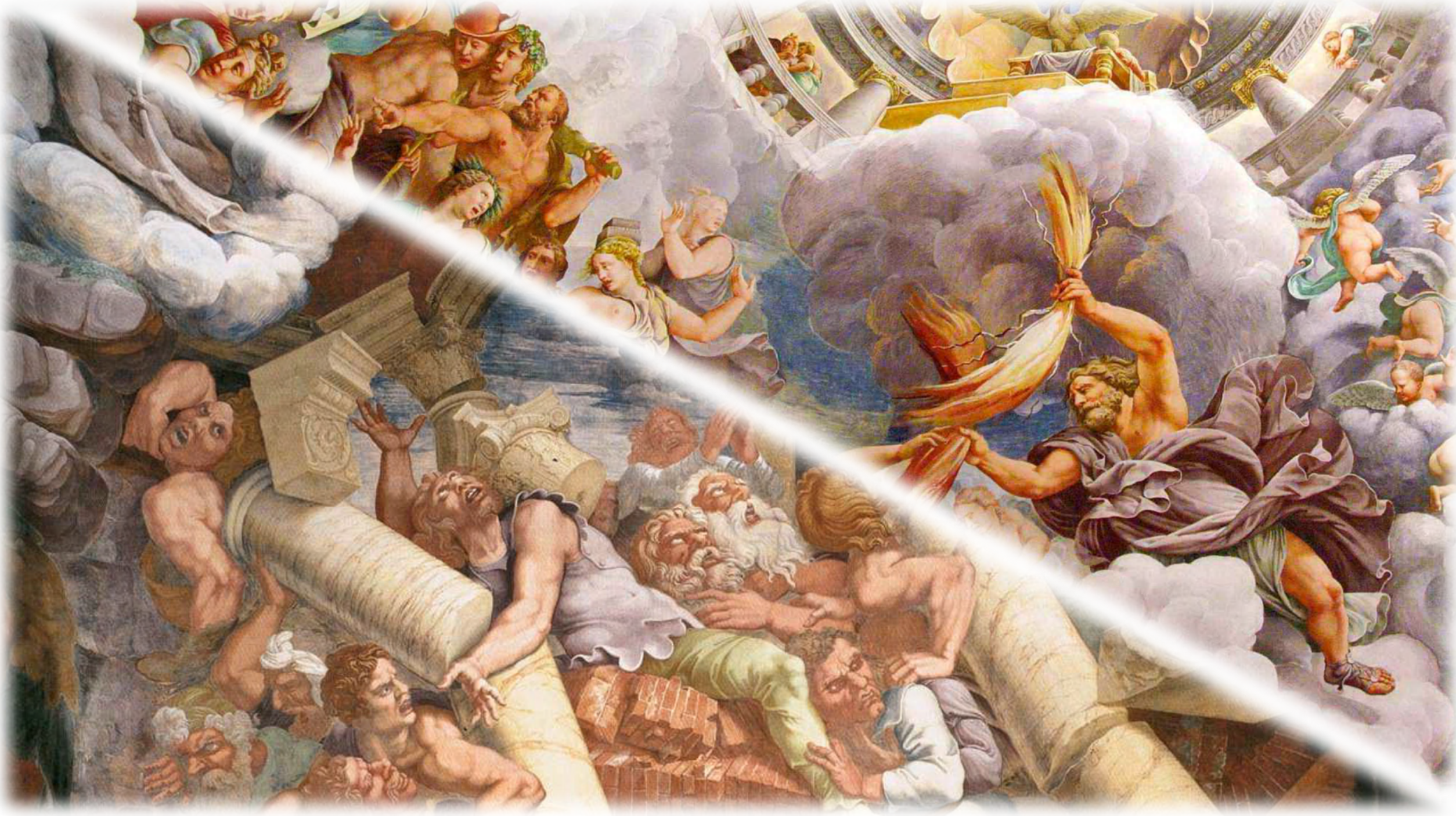
A population of massive, quiescent/quenching galaxies already in place at z~4 confirmed via *K*-band spectroscopy.

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 (~50-150 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+2020a, ApJ, 889, 93)

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



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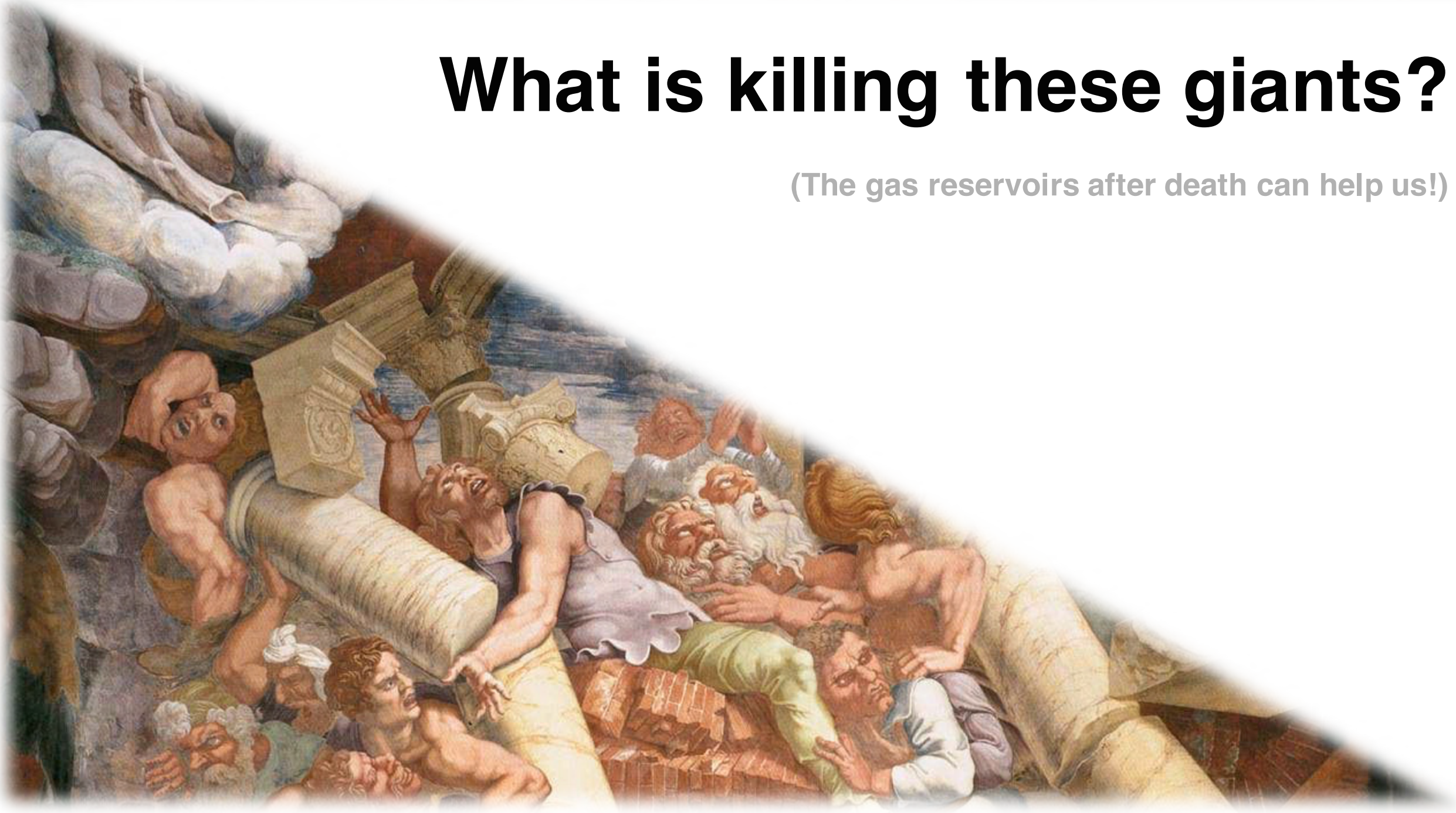
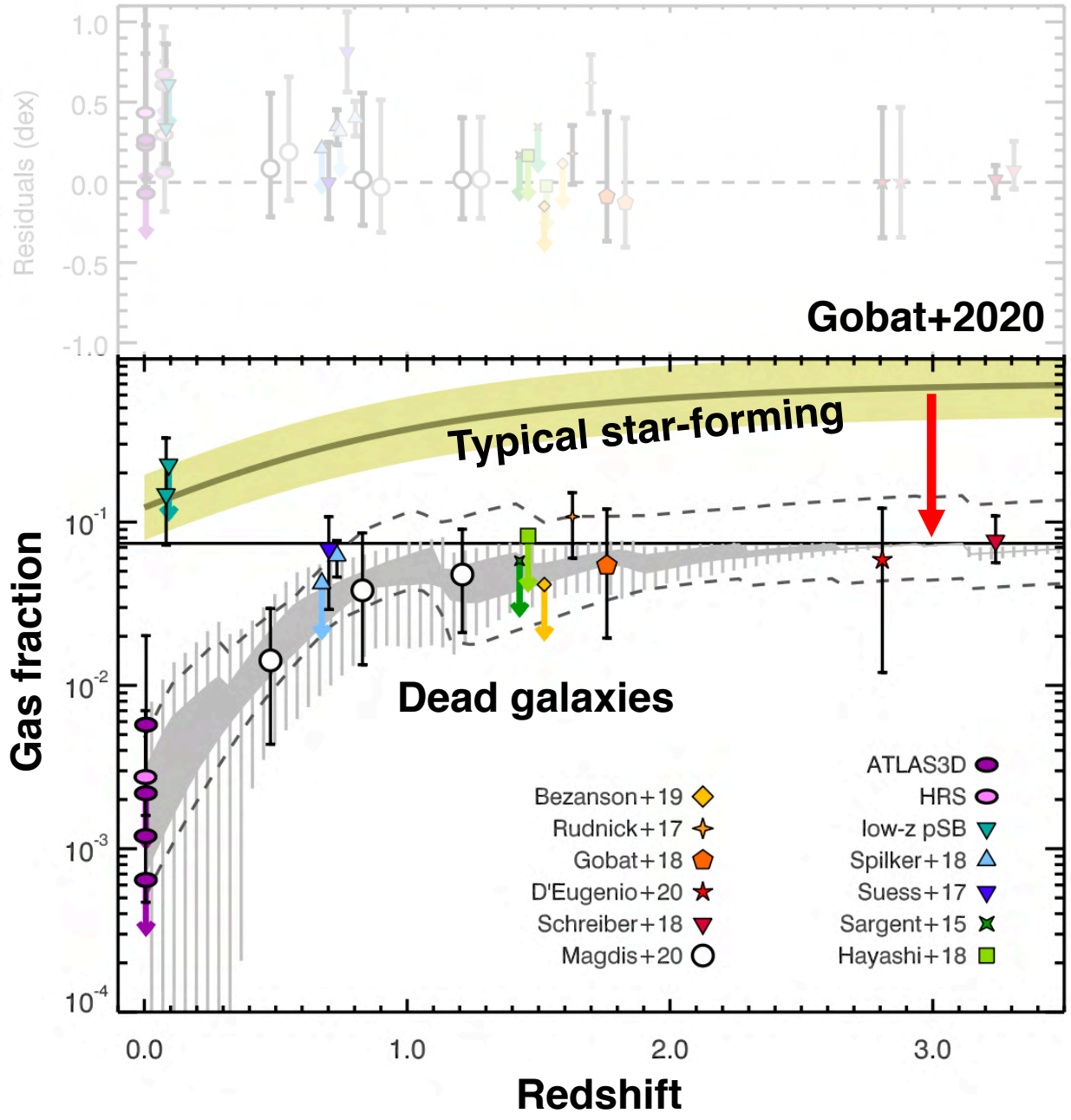
What is killing these giants?

(The gas reservoirs after death can help us!)





Based on stacking of hundreds of galaxies, significant cold dust (and gas) reservoirs are present after quenching at z~0-2 (Gobat+18, +20, Magdis+21).

A simple empirical model based on gas depletion and progenitor bias can reproduce the evolution with redshift of the gas fraction in quenched galaxies.