Quiescent galaxies at $z \sim 4$: formation and evolution

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The chamber of the giants (detail), Giulio Romano, 1531-1536
Early death of cosmic giants

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Development of Massive Elliptical Galaxies

Pay attention to timescales

$z = 4$
1.5 billion years

$z = 2$
3 billion years

Glazebrook et al. 2017,
Schreiber et al. 2018a,b,
Merlin et al. 2018, 2019,
Santini et al. 2019,
Guarnieri et al. 2019,
Forrest et al. 2019...

Valentino, Tanaka et al. 2019
(arXiv:1909:10540),
Tanaka, Valentino et al. 2019
(arXiv:1909:10721)

Local elliptical galaxy
Merging galaxies
Compact galaxy
Compact galaxy
Quasar
Dusty starburst galaxy
Merger

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

How can you 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)

(see Belli+2018)
How to spot a dead cosmic giant?

I. Red colors ($UVJ$, $NUV_rJ$ rest-frame diagram)

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

$$sSFR = \frac{SFR}{M_★}$$

$$M_★ \gtrsim 10^{11} M_☉$$
Old and dead

Young(er) and dying

Masayuki Tanaka’s talk
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

$\sim 1$ night per target ($K_{AB} \gtrsim 22$)
One tentative constraint

$z = 3.767^{+0.103}_{-0.001}$

Two secure confirmations

$z = 4.0127^{+0.0005}_{-0.0005}$

+ velocity dispersion (Tanaka's talk)

$z = 3.775^{+0.002}_{-0.003}$
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 $z \sim 4$

Candidates:
Sub-mm galaxies at $z \geq 4$
When did they die?

Spectrophotometric modeling → Star formation history (Schreiber+2018, Belli+2018)

Short (~50-150 Myr) and intense (SFR~1000-3000 M⊙ yr⁻¹) burst of star formation followed by an abrupt quenching
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)
Are there enough?
Deep interferometric sub-mm survey (also some “normal” galaxies)

Shallow sub-mm surveys
(only extreme starbursting galaxies)

Quiescent galaxies at 3 < z < 4

Are there enough?
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.)
Quiescent galaxies:

- Yes, in the latest large box simulations at $z \sim 3$.
- No, not in the old small box simulations and at $z \sim 3.7$.

(see also Merlin+2019+EAGLE)

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 $z\sim4$ confirmed via $K$-band spectroscopy.

They formed in short ($\sim50$-$150$ Myr) and intense (SFR$\sim1000$-$3000$ $M\odot$ 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.

Simulations roughly catch the evolution of quiescent galaxies at $z\sim3$, but struggle at progressively higher redshifts.