Early death of cosmic giants

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Star formation
Gas accretion
Stellar mass growth

Interstellar medium

AGN and stellar feedback
Outflows
Black hole growth

Quenching
AGN and stellar feedback

Quenching

Tanaka, Valentino+2019
Valentino+2020a
Gobat+FV 2018, 2020
Magdis+FV 2021

(Rise)

Interstellar medium

Valentino+2018
Valentino+2020 b,c

Gas accretion

Daddi, Valentino+2021

AGN and stellar feedback

Outflows

Black hole growth

(Death)
Early death of cosmic giants

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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

**TODAY**  
13.7 billion years

Local elliptical galaxy

**5 billion years**

Merging galaxies

**3 billion years**

Compact galaxy

**2 billion years**

Quasar

**1.5 billion years**

Dusty starburst galaxy

1 billion years

Merger

Gas rich collisions

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BIG BANG
Furious formation of stars
Development of Massive Elliptical Galaxies

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
13.7 billion years
TODAY
Local elliptical galaxy
Development of Massive Elliptical Galaxies

Stars in place, compact configuration

- TODAY 13.7 billion years
- Local elliptical galaxy
- Merging galaxies
- Compact galaxy
- Quasar
- Dusty starburst galaxy
- Merger
- 1 billion years
- BIG BANG
Development of Massive Elliptical Galaxies

Pay attention to the timescales—

- $z = 2$
  3 billion years
- $z = 4$
  1.5 billion years
- Merger
- Dusty starburst galaxy
- Quasar
- Compact galaxy
- Merging galaxies
- Local elliptical galaxy
- TODAY
  13.7 billion years
Development of Massive Elliptical Galaxies

Pay attention to the timescales—

$z = 2$
3 billion years

$z = 4$
1.5 billion years

Merger

TODAY
13.7 billion years

Local elliptical galaxy

Merging galaxies

Compact galaxy

Compact galaxy

Dusty starburst galaxy

Quasar

1 billion years
Development of Massive Elliptical Galaxies

Pay attention to the timescales...

z = 4
1.5 billion years

z = 2
3 billion years

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)
How can a galaxy form \( \geq 10^{11} \, \text{M}_\odot \) 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)
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, NUVrJ rest-frame diagram)

II. Modeling of the Spectral Energy Distribution (SED)
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

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

\[ z = 3.767 \pm 0.103 \pm 0.001 \]

Two secure confirmations

\[ z = 4.0127 \pm 0.0005 \pm 0.0005 \]

\[ z = 3.775 \pm 0.002 \pm 0.003 \]
- 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 $z\sim4$ (Tanaka, Valentino+2019)
Size + mild stellar mass increase, constant velocity dispersion?

- Effective radius [kpc]
- Stellar mass \([M_\odot]\)
- Velocity dispersion \([\text{km s}^{-1}]\)

**LEGAC**
- \(z \sim 0.6-1\)
- \(z \sim 2\)

**Tanaka, Valentino+2019**
- \(z = 4.012\)

**Stellar mass**
- \([M_\odot]\)

**SDSS**
- \(z \sim 0\)
$$z = 4.012$$

$$z \sim 2$$

$$z \sim 0.6-1$$

(LEGA-C)

Log (effective radius [kpc])

Stellar mass $$[M_{\odot}]$$

Dynamical mass $$[M_{\odot}]$$

1.63 log($$\sigma_\star$$) – 0.84 $$\Sigma_\star$$

Currently from HSC i-band, Hawk-I K-band + adaptive optics on its way

Mass fundamental plane (Bezanson+2013)
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 $z \sim 4$

Candidates:
Sub-mm galaxies at $z \geq 4$
Who are their progenitors?

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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)
- 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 $z \sim 4$

Candidates:
Sub-mm galaxies at $z \geq 4$
Are there enough?
Deep interferometric sub-mm survey (also some “normal” galaxies)

Shallow sub-mm surveys (only extreme starbursting galaxies)

Are there enough?

Quiescent galaxies at $3 < z < 4$
Yes, when observing deep enough.

Are there 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
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)

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 $z \sim 4$ confirmed via $K$-band spectroscopy.

A “mature” $z=4$ galaxy, with a velocity dispersion compatible with $z \sim 2$ scaling relations (Tanaka, Valentino+2019, ApJL, 885, L34)

They formed in short ($\sim 50$-150 Myr) and intense (SFR$\sim 1000$-$3000 \, M_\odot \, \text{yr}^{-1}$) 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 $z \sim 3$, but struggle at progressively higher redshifts.
A population of massive, quiescent/quenching galaxies already in place at z~4 confirmed via $K$-band spectroscopy.

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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 $z\sim0-2$ (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.