The massive red sequence of cluster galaxies at redshift 1.4

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The red sequence

RXJ0153 (z=0.83)  CL0016 (z=0.55)  SDSS (z=0)

field  field  field

group  group  group

restframe U-V (Vega)  restframe V (Vega)

Tanaka et al. 2005
The red sequence (color-mass)

Environmental dependence

underdense

overdense

SDSS Baldry et al. 2006
Environments at high redshifts

The need for high redshift

- Deep surveys probe environments only up to group densities. To probe the highest density environments need to find (elsewhere) and follow up massive clusters.

- “Time machine” vs “fossil record” approach: probe both star formation and mass assembly history.

- The closer the observations to the formation epoch, the tighter the constraints we get.
Clusters red sequence(s)

model redshift evolution of the red sequence
(apparent magnitudes and colors)
(Kodama & Arimoto 1997 models)
Clusters red sequence(s)

model redshift evolution of the red sequence
(apparent magnitudes and colors)
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The red sequence of galaxy clusters may be observed as a conspicuous feature in color-magnitude diagrams at all redshifts.

XMMU J2235-2557

- X-ray luminous massive cluster at $z=1.39$ (Mullis et al. 2005)

- The most massive cluster known at $z>1$
  ($L_{X,bol}<1\text{Mpc} \sim 10^{45}\text{erg/s}$, $M_{200} \sim 6 \times 10^{14}M_{\text{sun}}$, $M_{\text{proj}<1\text{Mpc}} \sim 10^{15}M_{\text{sun}}$)

- Multi-wavelength coverage (X U R i z J H Ks $3.5\mu\text{m}$ $4.6\mu\text{m}$) from Chandra, VLT, HST, Spitzer

- Extensive spectroscopy secured 30 cluster members

- A well evolved structure at $1/3$ of the Universe age
The red sequence at $z \sim 1.4$

The color-magnitude diagram in the core of XMMU J2235
The red sequence at $z \sim 1.4$

The color-magnitude diagram in the core of XMMU J2235

obvious interlopers removed (spec. and photo-z)
The red sequence at $z \approx 1.4$

obvious interlopers (spec. and photo-z) and disk galaxies removed
The red sequence at $z \approx 1.4$

A clear, tight red sequence is already in place, dominated by massive early types.

The bulk of the stellar populations formed at $z \approx 3$.

Bright galaxy populations in cluster core dominated by massive early types, hosting ~passively evolving stellar populations.
The red sequence at $z \sim 1.4$
The mass-size relation at $z \sim 1.4$

- Local early types, SDSS (Shen et al. 2003)
- XMMU J2235 red sequence early types
Models: semi-analytical predictions

Menci et al. 2008
Models: semi-analytical predictions

Menci et al. 2008
Models: hydrodynamic simulations

Hopkins et al. 2010
Models: hydrodynamic simulations

- Tracks of Individual Galaxies
- Identical Dry Mergers
- Minor/Late Accretion
- Adiabatic Expansion
- M/L Gradients
- Observational Effects
- M$_*$ Uncertainties

Hopkins et al. 2010
Outlook

- A tight red sequence of massive early types is already in place at 1/3 of the Universe present age

- Stellar populations formed at high redshift

- Stellar masses $>10^{11} M_{\text{sun}}$ already assembled in single galaxies

- Evolved morphology, but smaller sizes (more compact than local)

→ redshift $\sim 1.5$ already too late for big action in the most massive structures (go to $z>2$ protoclusters)

→ explore gas content, fraction and evolution

→ not just red sequence galaxies - probe the starforming populations