The Gemini/HST Galaxy Cluster Project: The end of passive galaxy evolution for early-type galaxies

H₀ = 70 km/s/Mpc
Ωₘ = 0.3  Λ = 0.7

Inger Jørgensen, Kristin Chiboucas, Ricardo Schiavon
Ruth Grützbauch, Alexa Villaume, Omega Smith, Kathleen Flint, Jordi Barr, Marcel Bergman

z = 0.54
Science Goals

• Constrain the models for galaxy formation and evolution by mapping the star formation history in cluster galaxies
  – As a function of galaxy mass
  – As a function of redshift
  – As a function of environment
  – Model for passive evolution: no new stars, no merging
    \[ \Delta \text{age} = \text{look back time}, \Delta [M/H] = 0, \Delta [\alpha/Fe] = 0 \]

• Establish the scaling relations as a function of redshift and galaxy mass

• Interpret changes in scaling relations and absorption line strengths using single stellar population models
Selected Key Results

• van Dokkum et al. 2007:
  – Salpeter IMF & $z_{\text{form}} \sim 4$
  – Top heavy IMF & $z_{\text{form}} \sim 2$

• Kelson et al. 2002, 2006:
  – $z=0.33$ cluster, FP & line indices, 19 galaxies
  – E & S0: same ages; Extended star formation histories

• EDisCS Sánchez-Blázquez et al. 2009; Saglia et al 2010:
  – 24 poorer clusters/groups $z=0.45-0.75$
  – 40% of low mass galaxies ($M<10^{11} M_\odot$) enter the red sequence in this redshift interval
  – $M>10^{11} M_\odot : z_{\text{form}} > 1.5$; size and velocity dispersion evolution
Sample Selection: Clusters

$L_{x,500} > 10^{44}$ ergs/s  \quad Redshift = 0.15 – 1.0

X-ray data calibrated by Piffaretti et al. 2011
Observational data

• Gemini/GMOS imaging in 3-4 filters
• Gemini/GMOS spectroscopy
  – 20-50 cluster members per cluster
  – 1-2 mag deeper than most previous studies
  – Higher S/N spectra (median S/N≈30 / Å\text{rest} at z=0.8-0.9)
  – Color selected; No initial morphological selection; \( n_{\text{Sersic}}>1.5 \)
    redshift, velocity dispersion: \( z, \sigma \)
    absorption line indices: \( \text{Mgb}, <\text{Fe}>, \text{H}\beta \) (redshift < 0.7)
    \( \text{C4668, CN3883, Fe4383, H}\delta+\text{H}\gamma \) (all redshifts)

• HST: ACS or WFPC2 imaging =>
  2D photometry, effective parameters, morphology
RXJ1226.9+3332  \( z=0.89 \)  GMOS-N 36h open shutter

HST/ACS imaging
2D fitting with GALFIT (Peng et al. 2002)

RXJ0152.7-1357 $z=0.83$

Data
Model
Residuals

ID 737 $n=3.7$
ID 643 $n=3.6$
ID 1567 $n=3.2$
ID 1385 $n=1.1$

Chiboucas et al. 2009
Size evolution?

No significant evolution of size or velocity dispersion as a function of redshift

Result from Saglia et al. 2010 (EDisCS) at $z=0.86$

$r_e \propto (1+z)^{-0.5}$

$\sigma \propto (1+z)^{0.41}$

Mass = $5 \sigma^2 r_e / G$
The Gemini/HST Galaxy Cluster Project

Fundamental Plane


Mass = 5 \sigma^2 r_e / G

Passive evolution: \Delta \log M/L \approx 0.935 \Delta \log \text{age}
Models for mass or velocity dispersion dependent z_{\text{form}} (Thomas et al. 2005)
Line indices vs Velocity dispersions

Models based on Thomas et al. 2005
Zero point changes of scaling relations

\[ \log \sigma \geq 2.24 \quad \text{(Mass} \geq 10^{11} \, M_\odot) \]
\[ \log \sigma < 2.24 \quad \text{(Mass} < 10^{11} \, M_\odot) \]

\[ z_{\text{form}} = 1.45 \] and \[ z_{\text{form}} = 2.25 \] correspond to low and high Mass (vel. disp.) models based on Thomas et al. 2005

Line indices

Age, [$M/H$], [$\alpha/Fe$] distributions

- Age differences as seen from Balmer lines vs log $\sigma$
- MS0451.6-0305: [$M/H$] $\sim0.2$ dex lower than the other clusters.
  - K-S test $P < 0.2\%$ probability of MS0451.6-0306 sample and low-z sample being drawn from same parent sample
- RXJ0152.7-1357: [$\alpha/Fe$] $\sim0.3$ dex higher than the other clusters.
  - K-S test $P<<0.01\%$

Mean ages, $[\text{M/H}], [\alpha/\text{Fe}]$

Age, $[\text{M/H}], [\alpha/\text{Fe}]$ from mean line indices with sample divided by velocity dispersion

- MS0451.6-0305: $[\text{M/H}] \sim 0.2$ dex lower than the other clusters
- RXJ0152.7-1357: $[\alpha/\text{Fe}] \sim 0.3$ dex higher than the other clusters

$z_{\text{form}} = 1.45$ and $z_{\text{form}} = 2.25$ correspond to low and high Mass (vel. disp.) models based on Thomas et al. 2005

$\log \sigma \geq 2.24$ (Mass $\geq 10^{11} \ M_\odot$)

$\log \sigma < 2.24$ (Mass $< 10^{11} \ M_\odot$)
The Gemini/HST Galaxy Cluster Project

RXJ0152.7-1357  
z=0.83  
0.5 Mpc

Cluster Environment
Global X-ray properties

MS0451.6-0305

X-ray data calibrated by Piffaretti et al. 2011

• FPs (M/L-Mass or M/L-log σ) for z=0.5-0.9 clusters are consistent with passive evolution with mass dependent redshift of last star formation episode, z_{form}
• Redshift dependences on line indices – log σ relations are smaller than expected from the FP and passive evolution
• Age, [M/H], [α/Fe] distributions and cluster mean values show cluster-to-cluster differences in [M/H] and [α/Fe], in contradiction to passive evolution
• Cluster environment (cluster merging, cluster mass and density) may be the cause of the differences
• The evolutionary path of cluster galaxies depend on galaxy mass (velocity dispersion) and cluster environment, the latter yet to be quantified