THE EFFECTS OF ENVIRONMENT IN Z=1-2 GALAXY CLUSTERS

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Transformational Science in the Era of ALMA: Multi-Wavelength Studies of Galaxy Evolution
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z = 1.243 (Eisenhardt+08)
Galaxy properties are linked to environment...

Can we identify an epoch of active star formation in clusters cores?

What does this transition tell us about galaxy evolution?
THE EPOCH OF STAR FORMATION IN CLUSTERS

Adapted from Murphy+11

Total star formation activity (M_☉ yr⁻¹ Mpc⁻³)

- All galaxies
- Normal galaxies
- Dusty high star formation galaxies

Age of the Universe (billions of years)
THE EPOCH OF STAR FORMATION IN CLUSTERS

at $z \approx 1$, SF still quenched in cluster cores...

Individual clusters show increased SF fraction in clusters at $z > 1.4$ (e.g. Tran+10, Hilton+10, Hayashi+11, Fassbender+11, Santos+14, and more)

Adapted from Murphy+11
THE EPOCH OF STAR FORMATION IN CLUSTERS

at $z \sim 1$, SF still quenched in cluster cores...

Need infrared observations and large cluster survey including $z = 1 - 2$

Adapted from Murphy+11
• IRAC Shallow/Distant Cluster Survey (Eisenhardt+08)
  • 9 square degrees, 300 clusters with uniform mass ($M_{\text{halo}} \sim 10^{14} M_\odot$)
  • IRAC overdensities
  • spec-z or photo-z and stellar mass estimates
  • mass limited cluster and field samples ($M_\star \geq 10^{10} M_\odot$)
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THE EPOCH OF STAR FORMATION IN CLUSTERS

UDS Field Galaxies (Viero+13)

Mass-limited cluster and field galaxy samples

Stack on HerMES SPIRE imaging

see also Brodwin et al. 2013

Alberts et al. 2014
PACS (and SCUBA-2) Analysis of $z=1-2$ cluster galaxies

Alberts et al. (a,b), in prep

Alex Pope (UMass)
Mark Brodwin (UMKC)
Ranga-Ram Chary (Caltech)
Arjun Dey (NOAO)
Peter Eisenhardt (Caltech)
Anthony Gonzalez (UFlorida)
Buell Jannuzi (Steward Obs.)
Greg Snyder (STScI)
Adam Stanford (UC Davis)
Dan Stern (JPL/Caltech)
Greg Zeimann (UPenn)
Ryan Cybulski (UMass)
Jim Geach (UHertfordshire)
Sun Mi Chung (Ohio State)
IR-LUMINOUS CLUSTER GALAXIES WITH PACS

DEEP PACS maps, typical SFGs (SFR>~100 M_☉/yr)

11 spectroscopically-confirmed clusters (M_{halo} \geq 10^{11.4} M_☉)

z=1-1.8
MASS NORMALIZED TOTAL SFR

LARGE CLUSTER-TO-CLUSTER VARIATION!
MASS NORMALIZED TOTAL SFR

LARGE CLUSTER-TO-CLUSTER VARIATION!
THE ISM IN Z=1.75 CLUSTER GALAXIES

$M_{ISM}$ DETERMINED USING DEEP SCUBA-2 MAP

$T_{DUST} = 25$ K
Assume $M_{\text{ISM}} \sim M_{\text{gas}}$

Median $f_{\text{gas}} = 0.4$

Median $\tau_{\text{depletion}} = 0.5$ Gyr
Conclusions

+ Active star formation in clusters at $z>1.4$
+ Transition epoch to effective environmental quenching
+ Have field-like $M_{\text{ISM}}$ and short gas depletion timescales
+ Follow-up with ALMA:
  + Redshifts
  + CO gas mass and $M_{\text{ISM}}$
    + molecular vs atomic?
    + $\alpha_{CO}$ in clusters?