Probing the End of Star Formation in Distant Group and Cluster Galaxies

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Molecular Gas Supply as a Driver of Star Formation

- SFR is correlated with $M_{\text{mol-gas}}$.
- Typical main-sequence galaxies have short gas consumption timescales (0.7 Gyr).
- Implies continuous gas accretion. (Daddi et al. 2008; Aravena et al. 2010; Tacconi et al. 2010; Tacconi et al. 2013)

Whitaker et al. (2012)
What drives the overall decline in SFRs with time

• The decline in SFR is mirrored by a decline in gas supply

• Massive galaxies in high-z dense environments may evolve more rapidly (Fassbender et al. 2014; Huertas Company et al. 2013; Papovich et al. 2012; Rudnick et al. 2012; Lotz et al 2014)

• Almost no CO observations of high-z dense environments.

What is SFR-M$_\text{gas}$ relation in dense environments?

How does environment regulate the gas supply?

Carilli & Walter 2013 ARAA
A z=1.62 cluster as an ideal CO target

- Many (>30) spectroscopically confirmed members
  - Papovich, et al. + Rudnick 2010; Tanaka et al. (2010); Momcheva in prep.

- Subsequently diffuse x-ray emission marginally detected
  - M~10^{14} M_{\odot}
    - Pierre et al. 2011

- Star-forming galaxies in the cluster core
  - Tran et al. 2010; Santos et al. 2014

- Deepest ever JVLA image taken in CO. 45h on source
CO Detections

\[ \sigma_{\text{CO}} \approx 275 \text{ km/s} \]
• Galaxies are on/below star formation main sequence

wuyts et al. (2011)
• galaxies are among the most massive

• galaxies are among the most gas rich

\[ \frac{M_{\text{gas}}}{(M_{\text{gas}} + M_{\text{star}})} = 0.6 - 0.7 \]

\[ \frac{M_{\text{gas}}}{M_{\text{star}}} = 1.5 - 2.5 \]
• What is preventing the CO from forming stars?
  • Are the physical conditions of the gas different?
  • Is the stability of gas different?

• Deep blind CO surveys and spatially resolved studies are needed to answer this question.

lower SFE

PHIBSS 1<z<2.5

Our Cluster

Decarli et al. 2014

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• Field galaxies have \( \sim 0.7 \) Gyr gas consumption timescales and require replenishment. (Daddi et al. 2008; Aravena et al. 2010; Tacconi et al. 2010; Tacconi et al. 2013)

• Cluster galaxies have long gas consumption timescales (1-4Gyr), assuming constant SFR.

• 80% of \( 10^{11} \) M\(_{\odot} \) galaxies in z~1 clusters are passive.

• No additional gas accretion is allowed over 2 Gyr to z~1.

• Potential sign of high-z environmental truncation of gas accretion
Fighting zombies: how to keep dead galaxies dead

• The universe is filled with gas. How do we keep dead galaxies from getting new gas and forming stars again?

• Mass loss will rejuvenate internal gas supply

  • $M_{\text{return}} \sim 0.5*M_{\text{star}}$ for Chabrier IMF

• Quiescent fraction is much higher in dense environments. Can we track down why?

With:

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Isolating the environment where gas accretion is shut off

• Use spectral indices to determine relative stellar ages of galaxies

• “Older” galaxies have less than 2% of stellar mass formed in last Gyr.

• There is weak emission in “older” galaxies

• Not star formation: Likely diffuse and heated by pAGB stars → stellar mass loss + accretion

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Rudnick et al. in prep.
• Old galaxies in groups and clusters have lower emission than in the field

• Emission fraction in younger galaxies is the same in every environment
Galaxies in the field experience mass loss and gas accretion.

Gas is absent in groups + clusters \(\Rightarrow\) decoupling of accretion from cosmic web.

Gas is absent in cluster cores \(\Rightarrow\) additional ram pressure stripping.

These processes affect the gas, but they don’t necessarily shut off star formation.

Stack of All EDisCS clusters


Rudnick et al. in prep.
Summary

- CO observations of z>1.5 clusters are telling us about the demise of the massive cluster population.
- Clusters are preventing gas accretion at z>1.5
- Need more deep CO observations in high-z dense environments.
- The group and cluster environment cut off gas accretion in old galaxies.
- Clusters exhibit addition stripping processes that can trim hot gas reservoirs from massive galaxies.