ALMA Observations of Gas-rich Galaxies in z~1.6 Galaxy Clusters: Evidence for Higher Gas Fractions in High-Density Environments

Noble et al. 2017, ApJL, 842, 21

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Breakthroughs in Galaxy Evolution

Decline in cosmic **star formation rate** density

**Existence of** star-forming main sequence

What drives these trends?
Breakthroughs in Galaxy Evolution

Decline in cosmic molecular gas mass density

Dependence on star-forming main sequence

Decarli et al. 2017

Gas Regulator

credit: A. Saintonge
Evolution of Molecular Gas in the Field

0

COLD GASS
(e.g. Saintonge+2011, 2012; Kauffmann+2012)

1

PHIBSS 1/2
(e.g. Tacconi+2010, 2013, 2017)

PEP
(e.g. Magnelli+2012)

2

Lensed Galaxies
(e.g. Baker+2004; Coppin+2007; Saintonge+2013)

3

SMGs
(e.g. Reichers+2011; Hodge+2012)

redshift
Evolution of Molecular Gas in Clusters

- **z < 0.5**
  - Stark+1986
  - Kenney&Young 1989
  - Fumagalli+2009
  - Scott+2013
  - Boselli+2014
  - Mok+2016
  - Cybulski+2016
  - Geach+2011
  - Jablonka+2012
  - N~100

- **1 < z < 1.5**
  - Wagg+2012
  - Casasola+2013
  - Aravena+2012
  - N < 5

- **Protoclusters**
  - Emonts+2013
  - Chapman+2015
  - Dannerbauer+2017
  - N < 5

- **z > 1.5**
  - missing massive clusters
  - …until this year (e.g. Noble et al. 2017; Rudnick et al. 2017; Hayashi et al. 2017)

redshift
Why $z > 1.5$ clusters?

$z \sim 0$

$z \sim 1$

$z \sim 1.6$

Balogh et al. 2016
van der Burg et al. 2014
Nantais et al. 2016
3 SpARCS Clusters at z~1.6

- ~115 spectroscopically confirmed cluster members
- Richness-based masses >10^{14} \, M_\odot
- 11-band photometry for stellar masses (ugrizYK[3.6][4.5][5.0][8.0])
- MIPS and Herschel-imaging (24/250/350/500 \, \text{um}) for infrared-SFRs

Nantais et al. 2016
ALMA CO (2-1) Observations

13 hours of Band 3 ALMA Cycle 3 time for 3 $z \sim 1.6$ SpARCS clusters to detect CO 2-1

CO (2-1) detection in $z \sim 1.6$ cluster galaxy!

2 pointings (FOV $\sim 110''$) per cluster, encompassing 49 known spectroscopically-confirmed cluster members

11 CO (2-1) detections with S/N $> 5$ in $z \sim 1.6$ cluster galaxies

88.23 GHz, 100 km/s channel rms $\sim 0.17$ mJy/beam per channel beam $\sim 4.4'' \times 2.2''$

Noble et al 2017
ALMA CO (2-1) Observations

Noble et al. 2017

30" x 30" CO Moment 0
6" x 6" HST

Close pairs

6" x 6" HST
30" x 30" CO Moment 0

Noble et al. 2017
SFR - $M_\star$ Plane

- $z \sim 1.6$ cluster CO detections
- pair galaxies

MS at $z = 1.6$

SFR ($M_\odot$ yr$^{-1}$)

$M_\text{stellar}$ ($M_\odot$)

Star Formation Rate

Gas Fraction

- higher SFE
- higher gas fraction
- lower SFE
- lower gas fraction

$f_{\text{gas}} = M_{\text{gas}} / (M_{\text{gas}} + M_{\text{stellar}})$

Noble et al. 2017

see Saintonge et al. 2011, 2016; Genzel et al. 2015
Gas Fractions in $z\sim1.6$ Cluster Galaxies

\[ f_{\text{gas}} = \frac{M_{\text{gas}}}{M_{\text{gas}} + M_{\text{stellar}}} \]

scaling relation, 
$\log M_{\text{stellar}} = 10.9$

$\log M_{\text{stellar}} = 11.2$

field at $z=1.6$
(Generel+2015)

$\frac{\text{SFR} - \text{SFR}_{\text{MS}}}{\text{SFR}_{\text{MS}}}$

$z\sim1.6$ cluster galaxies are at systematically higher gas fractions ($4\sigma$) than the field

clusters require different conversion between CO and $H_2$ from field?
($M_{\text{mol}} = \alpha_{\text{CO}} \times L_{\text{CO}}$)

Noble et al. 2017
Not all clusters are the same...

Nantais et al. 2016

Need more clusters!

Rudnick et al. submitted

$\frac{\text{SFR} - \text{SFR}_{\text{MS}}}{\text{SFR}_{\text{MS}}}$

$\log M_{\text{stellar}} = 10.9$

$\log M_{\text{stellar}} = 11.2$

$\log M_{\text{stellar}} = 10.0$

$\log (M_{\text{stellar}})$

$f_{\text{gas}} = \frac{M_{\text{gas}}}{M_{\text{gas}} + M_{\text{stellar}}}$

Rudnick et al. (JVLA)

Nantais et al. 2016

Rudnick et al. submitted

Noble et al. 2017
Conclusions

• 11 CO (2-1) detections in z~1.6 SpARCS clusters

• evidence for systematically higher gas fractions in SpARCS clusters compared to the field scaling relations at z~1.6
  - clusters require different conversion between CO and H$_2$ from field?
  - high cluster-to-cluster variation

• high-z clusters look to be exciting prospects for detecting gas-rich galaxies
  - need more CO observations!

Thank You!