Merger-driven star formation activity in Cl J1449+0856 at z=1.99 as seen by ALMA and VLA

R. Coogan¹,² E. Daddi² M. Sargent¹ V. Strazzullo³
F. Valentino⁴ R. Gobat⁵ et al.

¹University of Sussex
²CEA Saclay
³Ludwig-Maximilians-Universität
⁴DARK Cosmology Centre
⁵KIAS

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An old cluster in a young Universe

CL J1449+0856

X-ray detected cluster at $z=1.99$! Spectroscopically confirmed.
Observations: ALMA and JVLA

Tracing cold molecular gas through $^{12}$CO

$^{12}$CO as a tracer for cold H$_2$ gas. $M_{H_2} = \alpha_{CO} L_{CO}$

**ALMA:**
- **Continuum** at 850µm, 2mm, 3mm: dust
- CO rotational transitions J=4-3, J=3-2: excited, dense gas

**JVLA:**
- Continuum at 7mm
- CO rotational transition J=1-0: total molecular gas reservoir

Detect cold gas at different densities, different modes of star-formation: MS or SB?
Continuum detections of star-forming galaxies

**Figure: 850\(\mu\)m continuum**

**Figure: 2mm continuum**
Molecular gas detections through CO J=4-3

Secure detections of excited, dense molecular gas in cluster galaxies

Coogan et al., MNRAS submitted
CO Spectral Line Energy Distributions

- 50% of galaxies have starburst excitation properties in the cluster
- ∼6% expected in the field

R. Coogan et al.
Merger-driven star formation activity
PNCG, Lyon 2017
50% of galaxies have starburst excitation properties in the cluster
\(\sim 6\%\) expected in the field
Star Formation Efficiency

SFR-L′$_{CO[10]}$ relation, sSFR

What drives the high SB fraction? Environmental influences?

Strazzullo et al., submitted, Coogan et al., submitted

0.5 1.0 1.5 2.0 2.5
log$_{10}$($\text{SFR (M}_\odot \text{ yr}^{-1})$)

A2

A1

13

S7

Stracciuolo et al., submitted, Coogan et al., submitted

R. Coogan et al.
Star Formation Efficiency

SFR-L'_{CO[10]} relation, sSFR

> 50% of SFR coming from starburst galaxies in the cluster
c.f. \sim 18% in the field

What drives the high SB fraction? Environmental influences?

Strazzullo et al., submitted, Coogan et al., submitted
What drives the high SB fraction?

Merger-driven star formation activity

Coogan et al., submitted
What drives the high SB fraction?

High fraction of mergers and interactions driving the high starburst fraction

R. Coogan et al., submitted
Dust Masses and H$_2$ masses

- $L'_{CO(10)}$ and $M_d$ consistent, $\alpha_{CO}$ and G/D from FMR

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Coogan et al., submitted
## Dust Masses and H$_2$ masses

Gas fractions and depletion timescales

<table>
<thead>
<tr>
<th>ID</th>
<th>$\mu_g$</th>
<th>$\log T_{dep}$ (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1.00$^{+1.66}_{-0.62}$</td>
<td>7.97±0.35</td>
</tr>
<tr>
<td>A2</td>
<td>1.00$^{+1.66}_{-0.62}$</td>
<td>7.98±0.35</td>
</tr>
<tr>
<td>A6</td>
<td>0.64$^{+0.75}_{-0.35}$</td>
<td>8.58±0.24</td>
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<tr>
<td>13</td>
<td>0.46$^{+0.54}_{-0.25}$</td>
<td>8.53±0.24</td>
</tr>
<tr>
<td>3</td>
<td>0.39$^{+0.46}_{-0.21}$</td>
<td>8.63±0.27</td>
</tr>
<tr>
<td>1</td>
<td>0.22$^{+0.25}_{-0.12}$</td>
<td>8.56±0.25</td>
</tr>
<tr>
<td>N7</td>
<td>0.86$^{+1.00}_{-0.46}$</td>
<td>8.49±0.25</td>
</tr>
</tbody>
</table>

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Coogan et al., MNRAS submitted

### Lower G/D

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Our fit

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Bethermin+ (2015)
Low-metallicity Galaxies

Preliminary Work

Magdis et al., 2012, Valentino et al. 2015, Coogan et al., in prep.

Direct observations of dust and gas in low-Z galaxies at $z=2$

Effect of low-Z on high-J CO transitions - different SFR tracers

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Effect of low-Z on high-J CO transitions - different SFR tracers
A transitioning cluster provides insight into environmental influence on the gas content of galaxies

High fraction of starburst-like excited galaxies

High fraction of mergers and interactions

Outlook

Resolved gas observations
Gas and dust content of passive galaxies
Low-metallicity galaxies at high z