Molecular Gas and the Last Gasp of Star Formation in High Redshift Cluster Galaxies

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The supply-side economics of regulating star formation
Molecular Gas Supply as a Driver of Star Formation

- SFR is correlated with $M_{\text{mol-gas}}$.
- Galaxies on the star formation main sequence at $z > 1$ 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)

\[ \log (\text{SFR}) = \log \left( \frac{M_{\text{mol-gas}}}{\alpha} \right) \]

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Carilli & Walter 2013 ARAA
What drives the overall decline in SFRs with time

- The decline in SFR is mirrored by a decline in $M_{\text{gas}}/M_{\text{star}}$

- What governs star formation at high redshift


- Obstacles include:
  - There are few CO(1-) gas mass measurements at z>1
  - Few blind CO studies
  - There are no tests of molecular gas abundances in dense environments.

- Are we missing galaxies with interesting properties
- How does supply-side regulation work in urban environments?

Carilli & Walter 2013 ARAA
Robustly measuring the molecular gas

- We would like to study molecular gas to get
  - baryon budgets, mass fractions
  - gas consumption times
  - physical gas conditions
  - effect of environment

- Use CO as tracer of H$_2$

- $M(H_2) = \frac{L_{\text{CO}}}{\alpha}$

- Uncertain excitation makes conversion of CO luminosity to gas mass uncertain.

- CO($J=1 \rightarrow 0$) has minimal excitation corrections

- JVLA is uniquely capable

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

- many (>30) spectroscopically confirmed members WFC3 Grism
  - Papovich, et al. + Rudnick 2010; Tanaka et al. (2010); Momcheva in prep.

- subsequently diffuse x-ray emission marginally detected
- $M=10^{14} M_{\text{sol}}$
  - Pierre et al. 2011

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

- Deepest ever VLA image taken in CO. 45h on source + 60h on source in 2014B

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$\sigma_{\text{CO}} \approx 275 \text{ km/s}$

$m_{\text{star}} \sim m_{\text{dyn}}$ for both galaxies

$S_{\text{co}} \Delta v = 0.10 \text{ Jy km/s}$

FWHM = 644 ±200 km/s
S/N = 5.4

$z_{\text{grism}} = 1.621$
$z_{\text{line}} = 1.627$

$S_{\text{co}} \Delta v = 0.13 \text{ Jy km/s}$

FWHM = 655 ± 140 km/s
S/N = 5.2

$z_{\text{grism}} = 1.631$
$z_{\text{spec}} = 1.624$
$z_{\text{line}} = 1.623$
• Galaxies are on/below star formation main sequence

wuyts et al. (2011)
• Fit using MAGPHYS (da Cunha et al. 2008)

• Highly obscured galaxies
Dynamical constraints favor MW-like $\alpha_{\text{CO}}$

Our galaxies are massive and have large reservoirs of molecular gas.

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

$$\frac{M_{\text{gas}}}{M_{\text{star}}} = 1.5-2.5$$

At the high end of gas fractions for equivalently massive galaxies
• low SFR for amount of CO gas compared to targeted surveys

Adapted from Carilli & Walter 2013 ARAA
• low SFR for amount of CO gas compared to targeted surveys

• 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.
• 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)

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

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

• No additional gas accretion is allowed over 2 Gyr to \( z \sim 1 \).

• Is this a sign of an environmental truncation of gas accretion?
Summary

• 2 secure CO(1-0) detections in a z=1.62 galaxy cluster
• 50% increase in all high-redshift CO(1-0) detections.
• High stellar mass, high gas fractions, but low star formation efficiency.
  • What keeps the gas from forming stars?
• No additional accretion allowed.
  • Is this a sign of the truncation of accretion?
• Highlights importance of blind CO surveys (e.g. Decarli et al. 2014) and deep surveys in dense high-redshift environments.