THE GAS CONTENT AND STAR FORMATION ACTIVITY IN GALAXY PROTOCLUSTERS: EVIDENCE OF ENVIRONMENTAL QUENCHING?

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Image: https://www.ucl.ac.uk/star/research/stars_galaxies/high_redshift_galaxies

Epoch of Galaxy Quenching 2020
“Nebulae of all types except the irregular are represented among its members, but elliptical nebulae and early spirals are relatively much more numerous than among the nebulae at large. The predominance of early types is a conspicuous feature of clusters in general […]”

Hubble & Humason (1931)
Clusters at $z \sim 1-2$

- How does environment affect the evolution of galaxies?
- When does quenching occur? What is the typical timescale?
- Does the SFE vary with environment?

Effects already in place at $z \sim 1.5!$
How does environment affect the evolution of galaxies?
When does quenching occur? What is the typical timescale?
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Studies of clusters at $z \gtrsim 2$ are necessary to understand the environmental effects on galaxy evolution!

Effects already in place at $z \sim 1.5$!
The COSMOS $z=2.47$ and $z=2.10$ structures

$z=2.47$; $N \sim 60$; SFR $\sim 4500 M_\odot/yr$; $V = 15000$ cMpc$^3$

$z=2.10$; $N \sim 100$; SFR $\sim 5300 M_\odot/yr$; $V = 15000$ cMpc$^3$

Casey et al. 2015, 2016; Diener et al. 2015; Chiang et al. 2015; Wang et al. 2016, 2018, Gomez-Guijarro 2019; Zavala et al. 2019; Champagne et al. in prep.

We conducted ALMA Band 6 (1.2mm) observations of ~65 (spectroscopically confirmed) protocluster members with an average depth of $\sigma \sim 40$ uJy. Most of them are main-sequence galaxies (no extreme DSFGs).

Tracing the Rayleigh-Jeans regime ($\lambda_{\text{rest}} \sim 350\text{um}$) -> gas mass tracer (e.g. Scoville et al. 2014,2016)

Complete sample at $M^* \gtrsim 1 \times 10^{10} M_\odot$. 
The ISM and the SFE

Control sample & Field Star formation law
Scoville et al. 2016

Protocluster member galaxies does not show an increased star formation efficiency

From ALMA 1.2mm

Zavala et al. 2019

Stacking

SED fitting

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Molecular gas mass [$M_\odot$] vs. SFR [$M_\odot$ yr$^{-1}$] plot

Tacconi et al. 2018 relation

Scoville et al. 2016
Gas fractions

Most detections are in agreement with the field

A population of massive gas poor galaxies! (even at z~2.5)

Cluster-to-cluster variations -> different evolutionary stages (even at fixed z)

Lee et al. 2017; Gomez-Guijarro et al. 2019; Tadaki et al. 2019
Evidence of a quiescent population of galaxies?

A **quiescent** population of galaxies (massive, red, and gas-poor) in an overdense environment at z~2.5!
Evidence of environmental quenching?

The fraction of detected galaxies in blind surveys or field galaxies is higher than the one found for the protocluster member galaxies (80% vs 40%) (same $z$, $M^*$, and $\sigma_{\text{rms}}$)

An excess of high-mass passive (gas-poor) galaxies in the protocluster structure!

Accelerated evolution, even before virialization

Timescale for environmental quenching: $\Delta t < 800$ Myr

Zavala et al. 2019
Take-home messages:

• Protocluster member galaxies do not show an increased star formation efficiency nor an enhanced gas fraction when compared with the field.

• Protocluster galaxies experience an accelerated evolution which results in an excess of massive gas-poor galaxies (even at $z=2-2.5$).

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Mergers? AGN feedback? Ram pressure stripping? Enhanced gas volume density?
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¡Gracias!