Local and Large-Scale Environmental Influences on Galaxy Gas Content

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Motivation

Galaxy gas content influenced by dark matter halo and its internal environment

Gas replenishment

• Cosmological accretion rates depend on halo mass
• Key scales:
  • $M_{\text{halo}} < 10^{11.4}$ — cold accretion dominance, gas-dominated galaxies common (Keres+09, Kannappan+13)
  • $M_{\text{halo}} > 10^{12}$ — hot mode accretion dominance, “quenched” galaxies common (bimodality mass; Kauffmann+03)

Gas removal/cutoff

• Tidal/ram-pressure/viscous stripping
• starvation

Important in small groups, low-mass halos?
Motivation

What about the influence of the environment on scales larger than individual halos?

- Several proposed processes:
  - Flyby interactions (e.g., Wetzel et al. 2014)
  - Competitive gas accretion (Hearin et al. 2015)
  - Ram-pressure stripping of halo gas by IGM (Bahe et al. 2013)
  - Variations in IGM temperature/cooling time (Cen et al. 2011)

- Halo assembly bias: earlier halo formation time in overdense regions
  - Possibly reflected in galaxy properties, like gas content

Klypin+11
Key Questions

- Are group-scale processes that lower gas content (i.e., starvation, stripping) at work in low-mass groups?
- Is galaxy gas content entirely regulated by the group dark matter halo and its internal environment, or does larger-scale environment also play a role?

Need a survey that:

A. extends to low halo masses
B. has complete and unbiased gas information
C. has well-understood and diverse large-scale environments
The RESOLVE Atomic Gas (HI) Census

- Integrated atomic hydrogen gas (HI) via 21cm emission
- ALFALFA Survey data + deep pointed GBT and Arecibo observations
- **Not flux limited:** complete HI data
  - strong detections or upper limits (5-10% of $M_*$) for all galaxies
Progress to date

~95% complete to date
(S/N > 5 or $1.4 \times \frac{M_{\text{HI}}}{M_{\text{stars}}} < 0.1$)

RESOLVE

Original completeness limits (ALFALFA only)

Log baryonic mass

Fraction Complete

9.0 9.5 10.0 10.5 11.0 11.5

Log stellar mass

Fraction Complete

8.5 9.0 9.5 10.0 10.5 11.0 11.5

Full Survey
A semester
B semester
Environment Metrics

- **Group Identifications**
  - Friends-of-Friends (FoF) group identification
  - Central/satellite designation

- **Group dark matter halo mass ($M_h$)**
  - Halo Abundance Matching (HAM) w/ integrated group stellar mass (also explore using integrated group baryonic mass)
  - $10^{11} - 10^{14} \, M_\odot$

- **Relative large-scale structure density ($\rho_{\text{LSS}}$)**
  - Projected mass density within distance to 3rd nearest group (not galaxy!)

- **Large-scale structure classification**
  - FoF on groups + visual classification into filaments, walls, etc.
Filament      Cluster
Wall          (\(M_{\text{halo}}>10^{13}\))
Blob          unclassified

RESOLVE-A

RESOLVE-B
Influence of dark matter halo

- \( G/S = \text{gas-to-stellar mass ratio} \)
- Satellite gas content decreases with increasing halo mass
  - Suggests satellite gas depletion down to at least \(10^{12} \, M_\odot\)
- Smooth relation for centrals, but this is built in!

< 20 points in bin, bootstrapped uncertainties possibly unreliable
Behavior of centrals strongly linked halo abundance matching approach

Consistent behavior for satellites independent of approach

- HAM w/ stellar mass
- HAM w/ baryonic mass (stellar + gas mass)

**Behavior of centrals**

- Consistent behavior for satellites independent of approach

**Log G/S vs. Log stellar Mass**

- **Centrals**
  - HAM w/ stellar mass
  - HAM w/ baryonic mass (stellar + gas mass)

- **Satellites**
  - Consistent behavior independent of approach
Median G/S vs Large-scale structure

- $M_h \leq 10^{12}$: Walls are more gas-poor compared to filaments
- Offsets not driven by different stellar mass distributions
Gas deficiency and large-scale density

![Graph showing fraction with G/S < 0.1 vs. log LSS density for different groups of centrals: All Centrals, Filament Centrals, and Wall Centrals. The graph also shows the log group halo mass categories: 11.0-11.4, 11.4-12.0, and 12.0-13.0.](image-url)
Gas deficiency and large-scale density

- Walls more gas-poor at fixed halo mass and density
- Many gas-poor galaxies in typically gas-dominated halo mass regime
What drives low gas fractions?

- Unusually gas-poor systems typically found close to more massive halos
  - Gas stripping from flyby?
  - Gas supply cut off due to competition with nearby halos (Hearin+15)
  - Many gas-poor galaxies fall within splashback radius of massive halo (More+15) → could already be considered satellites

![Diagram](image-url)
Why are walls more gas poor?

• $M_h < 10^{11.4}$ gas-poor centrals in close proximity to $M_h > 10^{12}$ groups more abundant in walls

• Walls have higher flyby interaction rate? Stronger tidal field?

• Ram pressure stripping by IGM (unknown how this may vary between walls and filaments)?

• Walls are more evolved large-scale structures (assembly bias)?
  • Largest structures (by number of groups)
  • Highest overdensities
  • Most massive groups/clusters ($> 10^{13}$) typically found nearby

• Processes depleting gas content at work longer?
  • Also, possibly hotter IGM in earlier forming structures (Cen+11) $\rightarrow$ longer gas cooling times
Summary

Combining the highly complete HI census with multi-scale environment metrics in the RESOLVE survey, we find:

- Group processes that lower gas content appear active in halos at least down to $M_h = 10^{12} \, M_\odot$
- The G/S vs $M_*$ relationship for centrals cannot be decoupled from the built-in biases associated with halo abundance matching
- At group halo masses $\leq 10^{12} \, M_\odot$, galaxies in large-scale walls have systematically lower gas fractions than galaxies in large-scale filaments
- Below $10^{12} \, M_\odot$, the fraction of gas poor centrals increases with LSS density. This dependence is strongest for walls, which have higher gas-depleted fractions at both fixed halo mass and fixed density
- Unusually gas-poor systems tend to reside close to much more massive halos, suggesting their low gas content is caused by gas stripping and/or starvation induced by the larger group.