Local and Large-Scale Environmental Influences on Galaxy Gas Content

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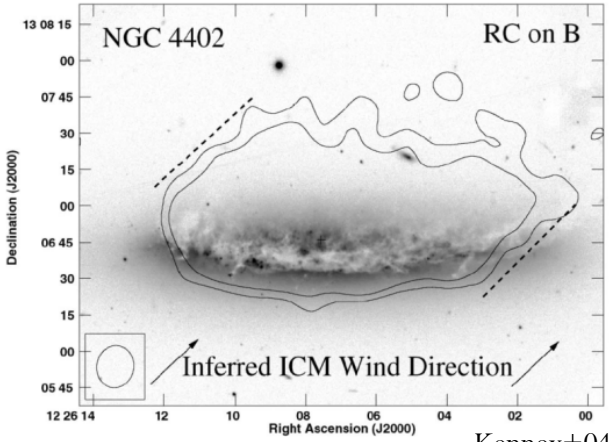
Motivation

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

Gas replenishment

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



Kenney+04

Gas removal/cutoff

- Tidal/ram-pressure/viscous stripping
- starvation

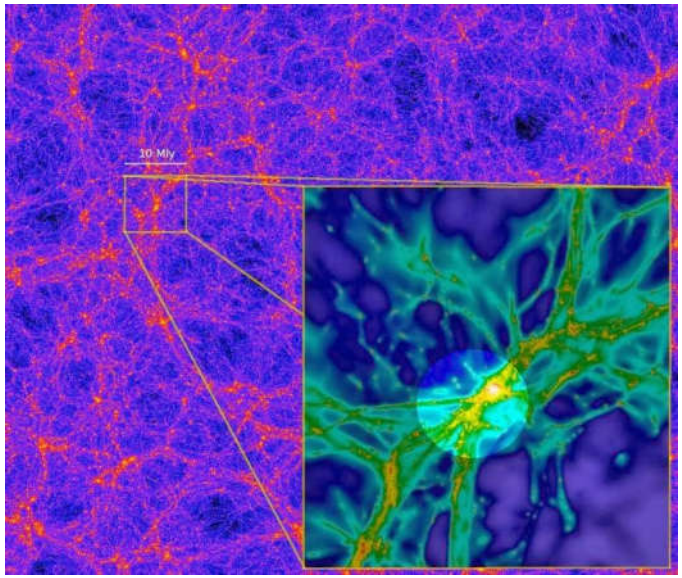
Important in small groups, low-mass halos?

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:

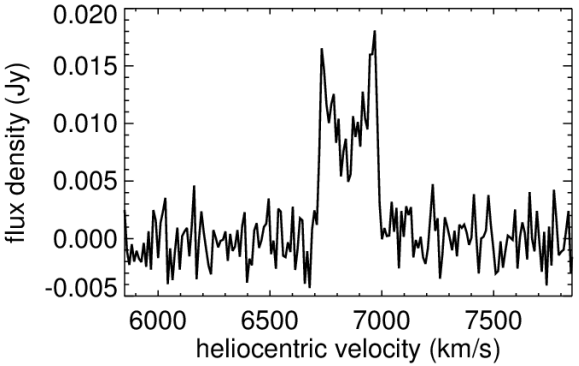
A. extends to low stellar masses

B. has complete and unbiased gas information

C. has well-understood and diverse large-scale environments

The RESOLVE Atomic Gas (HI) Census

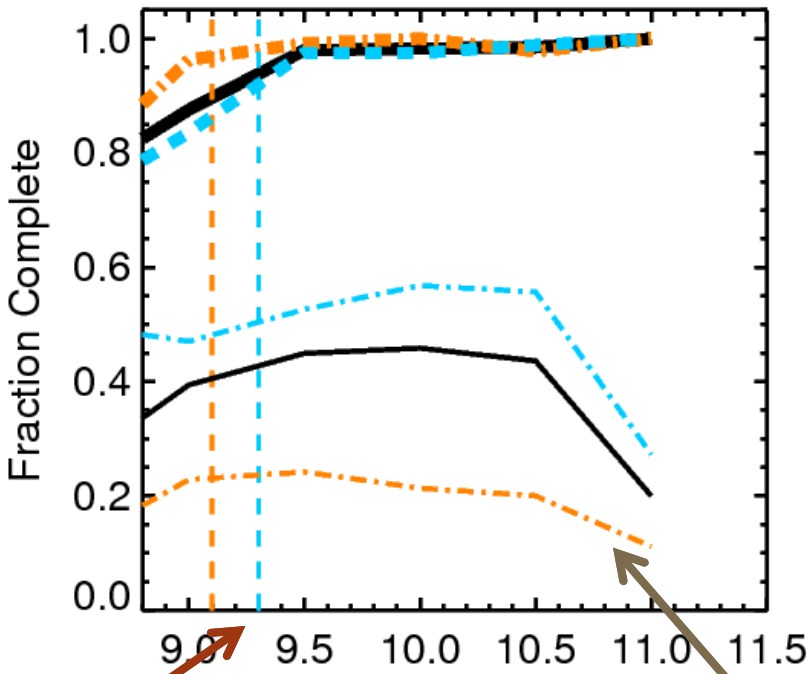
- Integrated atomic hydrogen gas (HI) via 21cm emission
- ALFALFA Survey data + deep pointed GBT and Arecibo observations
- ***Not*** **flux limited: *complete* HI data**
  - strong detections or upper limits (5-10% of M_*) for *all* galaxies

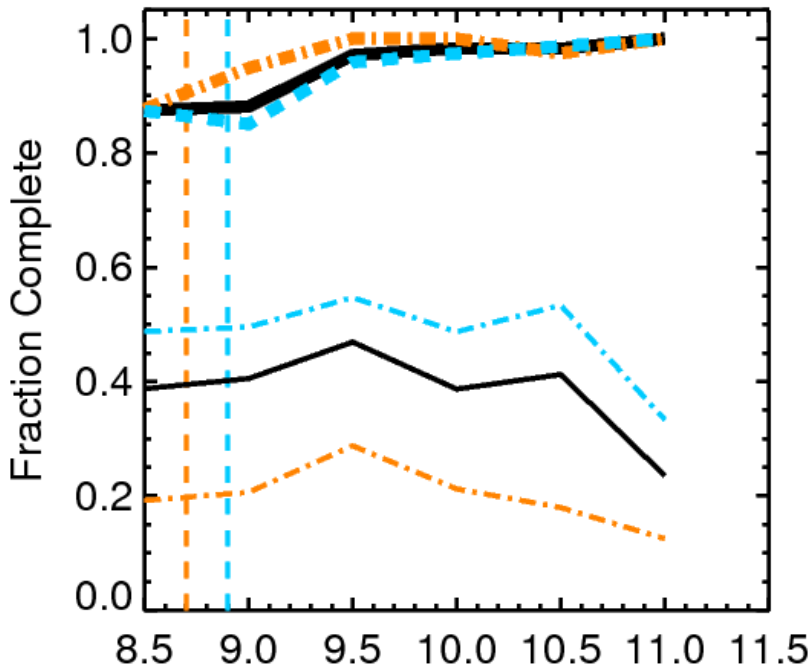


GBT

Arecibo

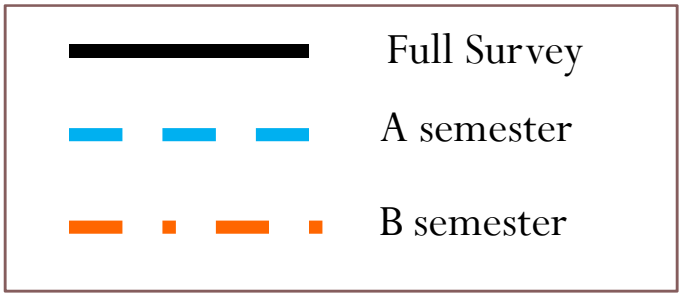
Progress to date





RESOLVE completeness limits

Original completeness (ALFALFA only)



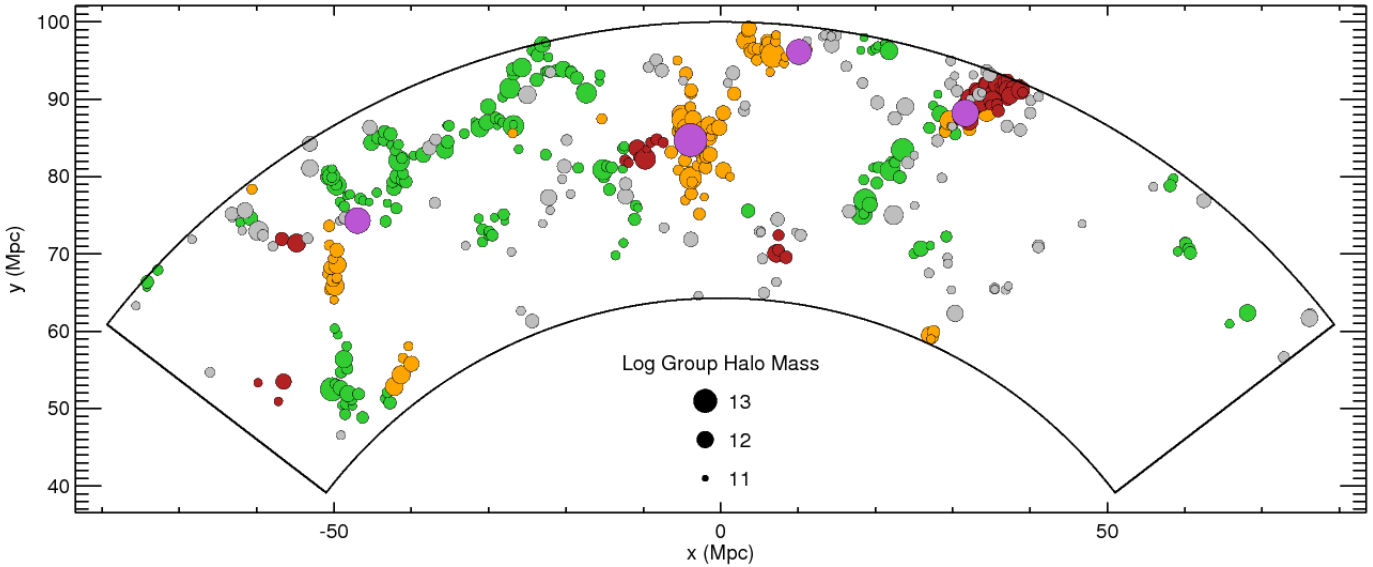
~95% complete to date

(S/N>5 or $1.4 \times M_{HI}/M_{stars} < 0.1$)

Environment Metrics

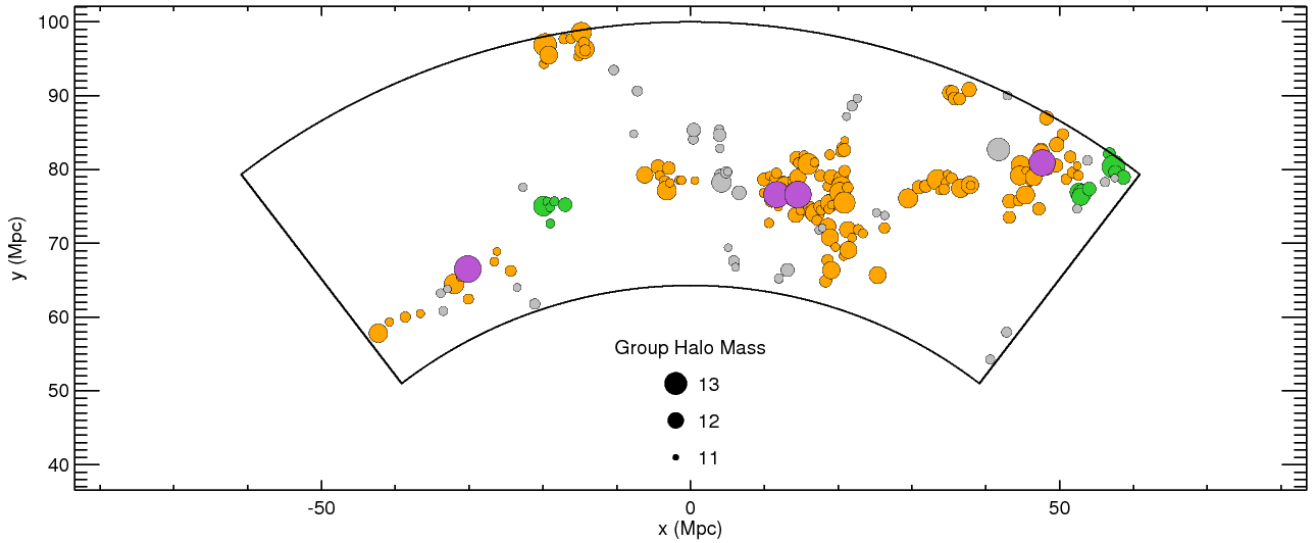
- **Group Identifications**
  - Friends-of-Friends (FoF) group identification
  - Central/satellite designation
- **Group dark matter halo mass (M_h)**
  - Halo Abundance Matching (HAM) w/ integrated group stellar mass (also explore using integrated group baryonic mass)
  - $10^{11} - 10^{14}\ M_\odot$
- **Relative large-scale structure density (ρ_{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
Wall
Blob
Cluster
($M_{halo}>10^{13}$)
unclassified



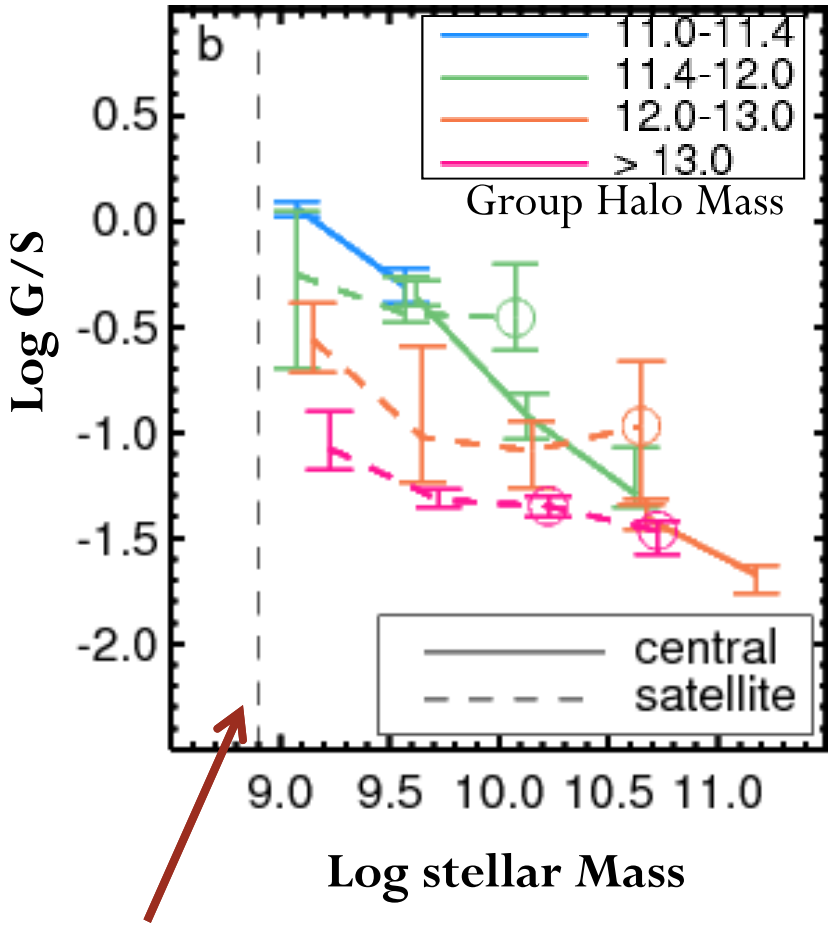
RESOLVE-A

RESOLVE-B



Influence of dark matter halo

- **G/S = 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!**

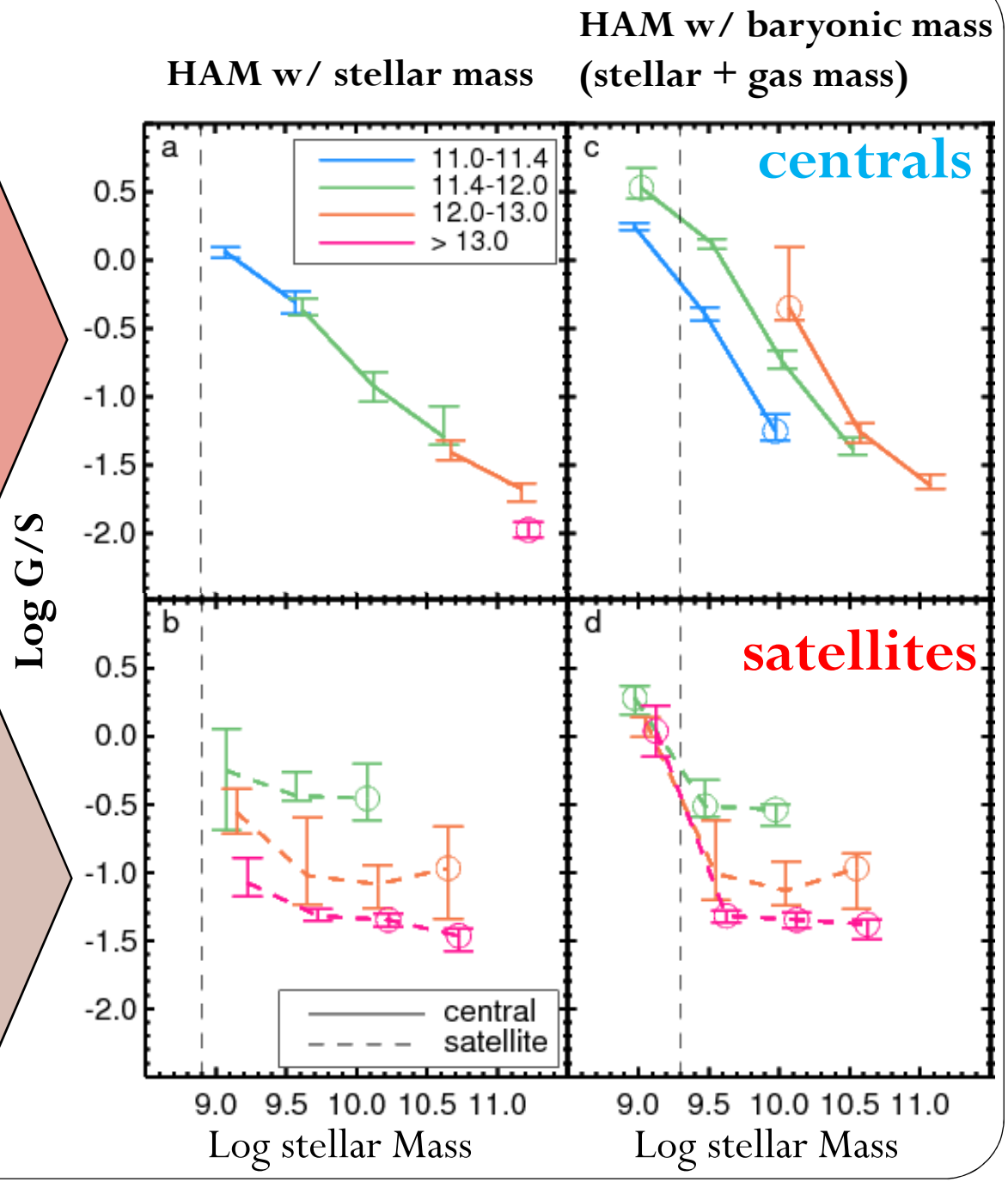


◯ < 20 points in bin, bootstrapped uncertainties possibly unreliable

Stellar mass completeness limit

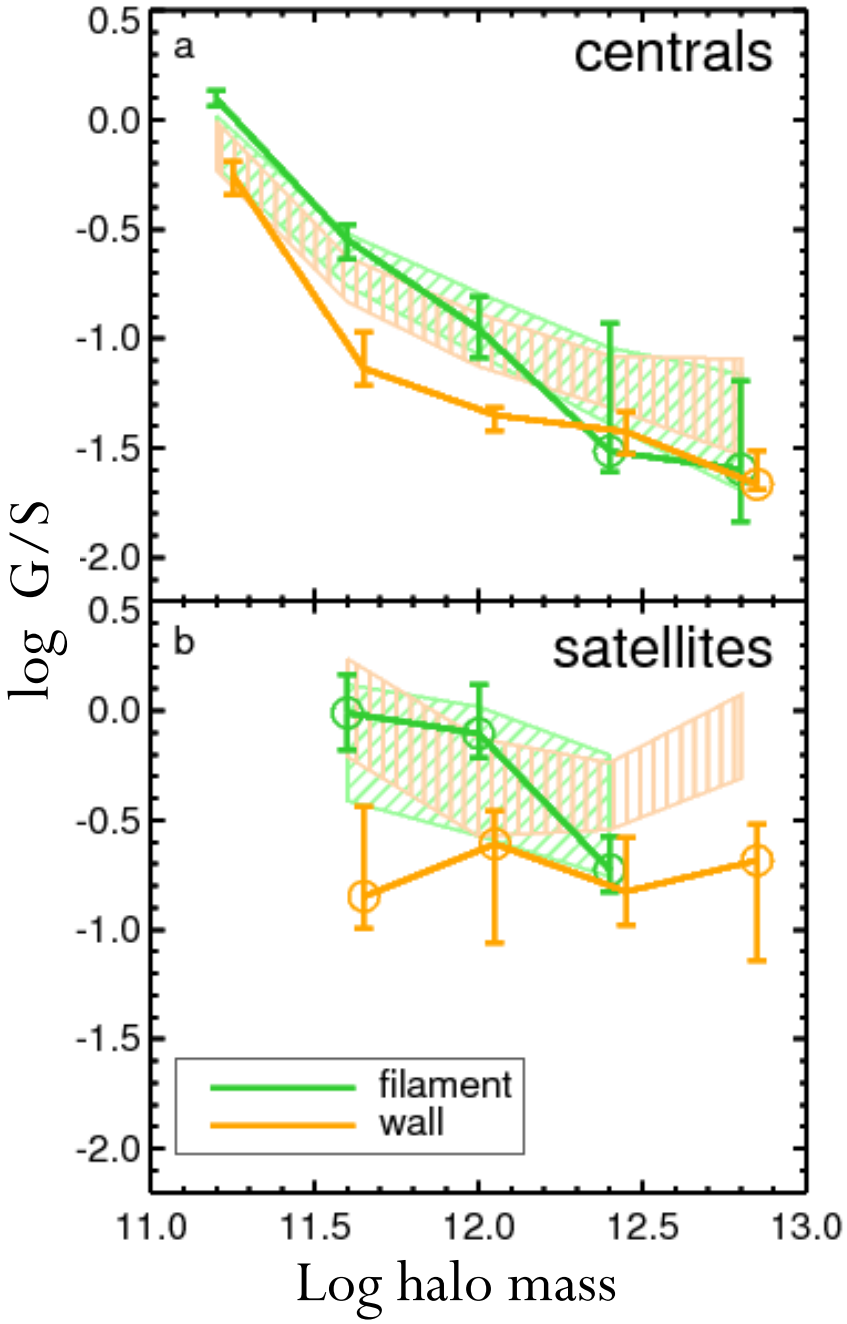
Behavior of centrals strongly linked halo abundance matching approach

Consistent behavior for satellites independent of approach

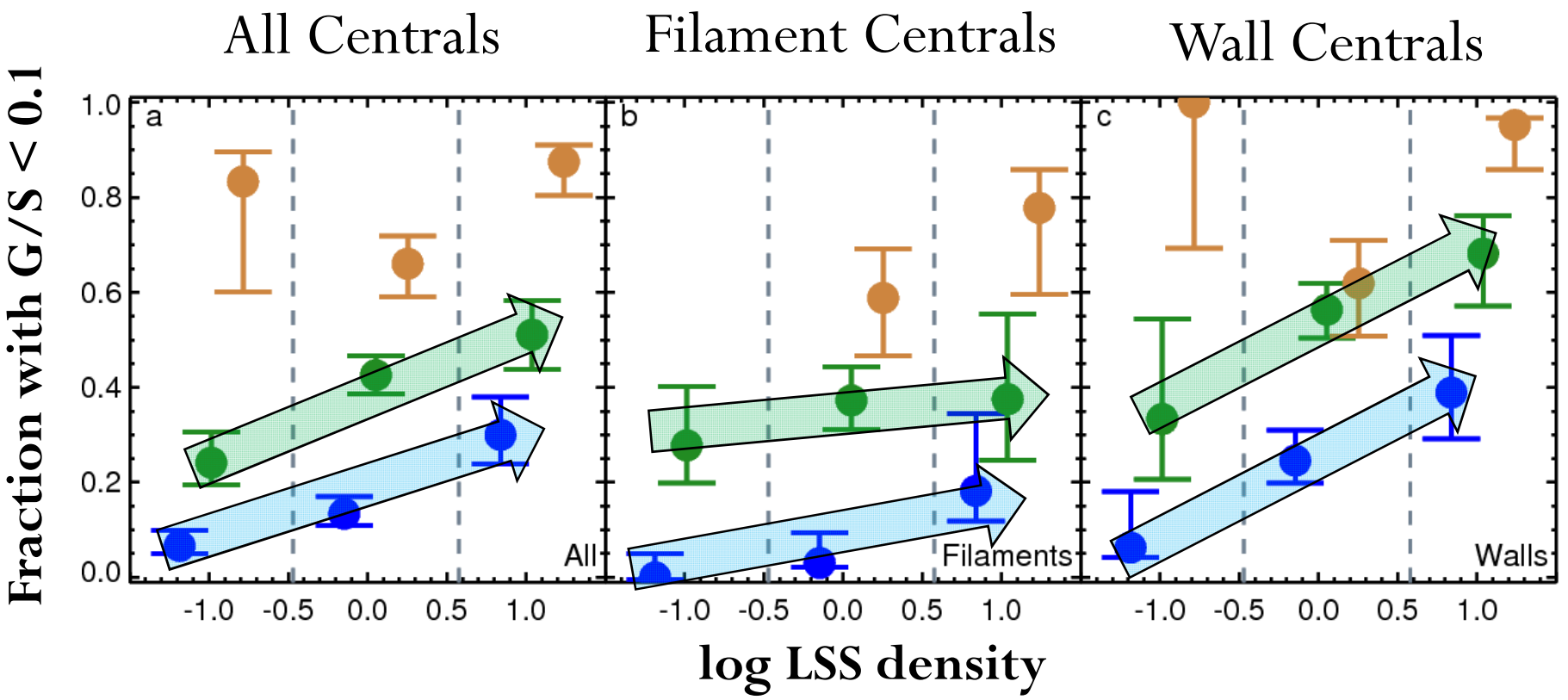


Median G/S vs Large-scale structure

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



Gas deficiency and large-scale density



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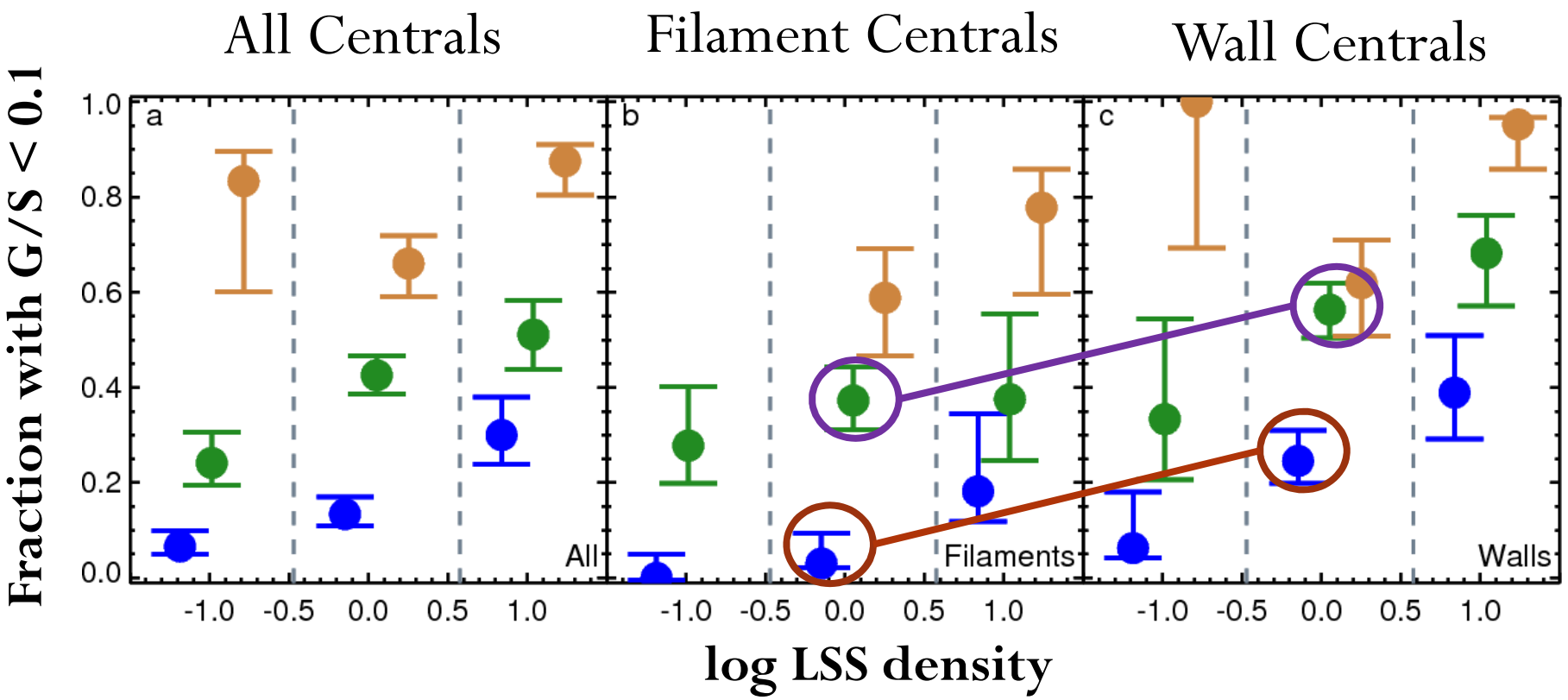


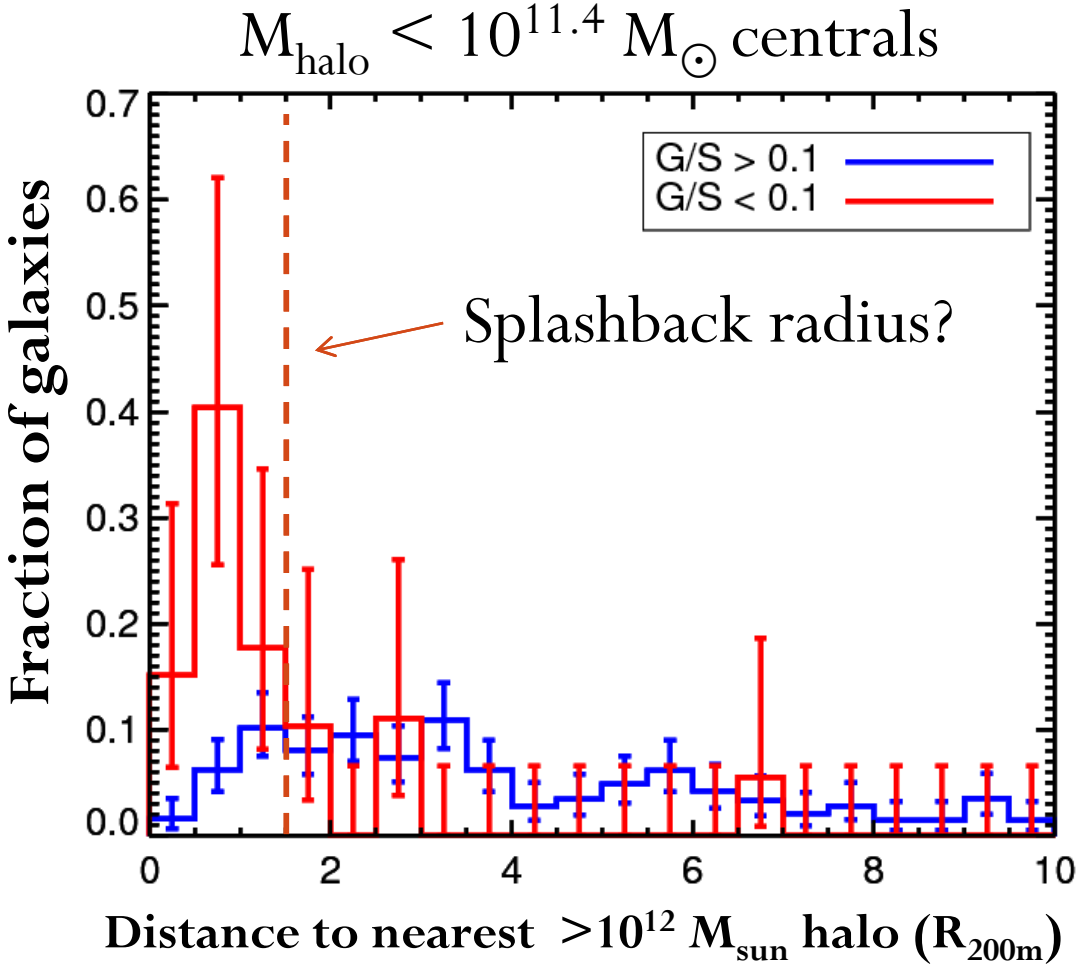
Log Group Halo Mass

- 11.0-11.4
- 11.4-12.0
- 12.0-13.0

- 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**



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) → 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.