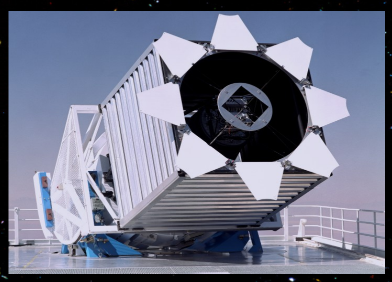

Effect of Halo Mass on HI Gas Content of Galaxies in Groups and Clusters

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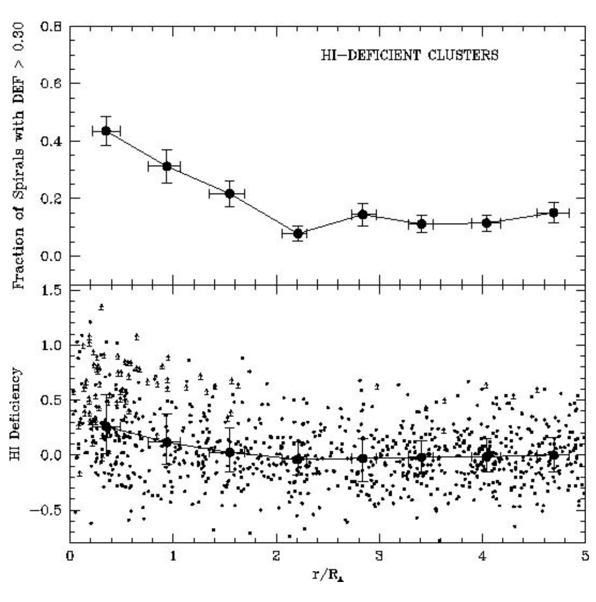
Abstract: We combine data from ALFALFA and SDSS with the information on halo properties from the SDSS galaxy group catalog, to investigate the HI gas depletion in galaxies for a wide range of group halo masses ($10^{12.5}$ h^{-1} M$_\odot$ <M$_h$<$10^{15.0}$ h^{-1} M$_\odot$). Although we look for a systematic decrease of the HI gas fraction toward the center of groups seen more prominently in massive halos, no strong statistical evidence of the variation of HI gas fraction distribution is found for all halo masses. However we find that the detection fraction of HI gas bearing galaxies decreases toward the center of groups more significantly for galaxies in massive halos (M$_h$>$10^{13.85}$ h^{-1} M$_\odot$). We interpret our observation using the ram pressure stripping depending on halo mass, galaxy stellar mass and ICM density. Our work implies that deeper HI surveys are required for complete analysis by probing gas-poor galaxies in groups and clusters.

1. Gas depletion in groups and clusters



HI deficiency of galaxies in nearby clusters (Solanes et al. 2001)

- Groups and clusters are the environment where galaxy evolution is driven by complex gravitational and hydrodynamic processes.
- Previous HI observational campaigns of nearby clusters (Solanes et al. 2001) show clear evidence of HI deficiency toward the center.
- Several recent studies suggest that HI gas depletion depends on group halo mass (Catinella et al. 2013, Fabello et al. 2012, Hess and Wilcott 2013).
- HI gas depletion expects to decrease toward the center of group halo more significantly in massive halos than in less massive halos.
- To check this hypothesis, we need a study of the HI gas content in galaxies for a wide range in halo mass and cluster-centric locations.

2. Cross-matching Catalog

<u>Arecibo Legacy Fast ALFA (ALFALFA) survey:</u>

Flux limited HI blind survey detecting ~30000 extragalactic HI sources out to z~0.06, only 40% of them available as catalog (Haynes 2011)

<u>Improved SDSS photometry:</u>

NASA Sloan Atlas catalog (Blanton et al. 2011) with z<0.055 and proper correction to the 'off-centered' spectroscopic samples

<u>SDSS with group catalog:</u>

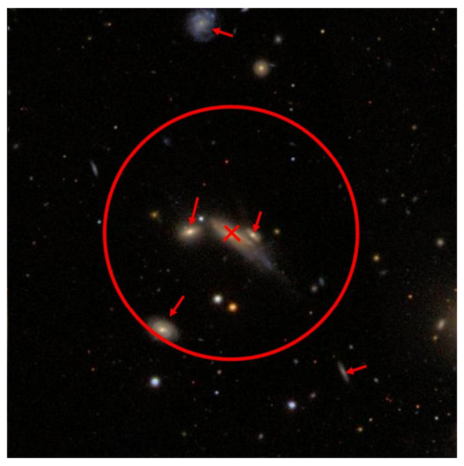
Assigning galaxies to halo using SDSS halo group catalog with 0.01 < z < 0.2 (Yang et al. 2007)

<u>Matching:</u>

Step1: Assign NASA Sloan Atlas galaxies to SDSS groups

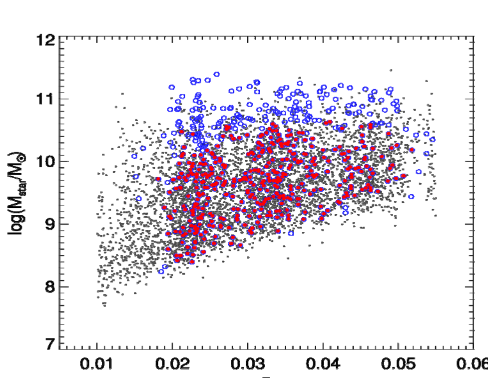
Step2: Match to the ALFALFA using Δ40" and Δ300 km/s

Step3: Exclude the multiple sources within the Arecibo beam



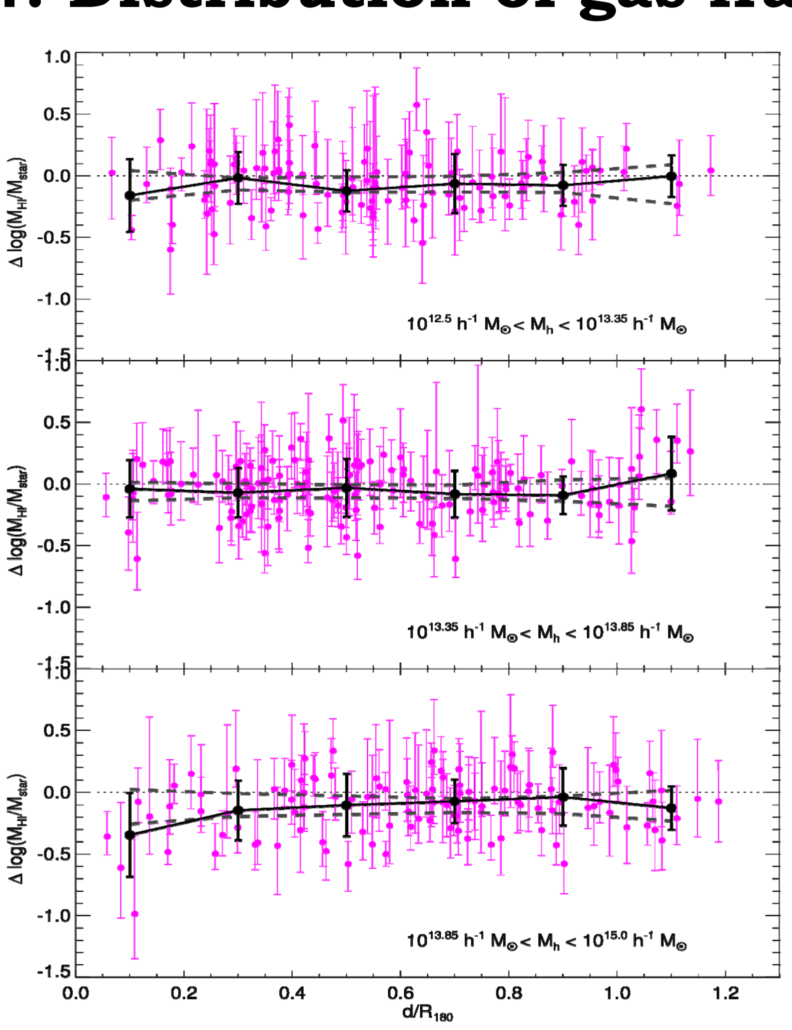
HCG069: Marked galaxies are the member of compact group and red circle represents the 3.5 arcmin Arecibo beam. The galaxy at the center (×) is the match between SDSS and ALFALFA. Eliminating multiple galaxies in the Arecibo beam results in excluding galaxies possibly experiencing tidal interaction within 20 kpc at z=0.01 and 105 kpc at z=0.055.

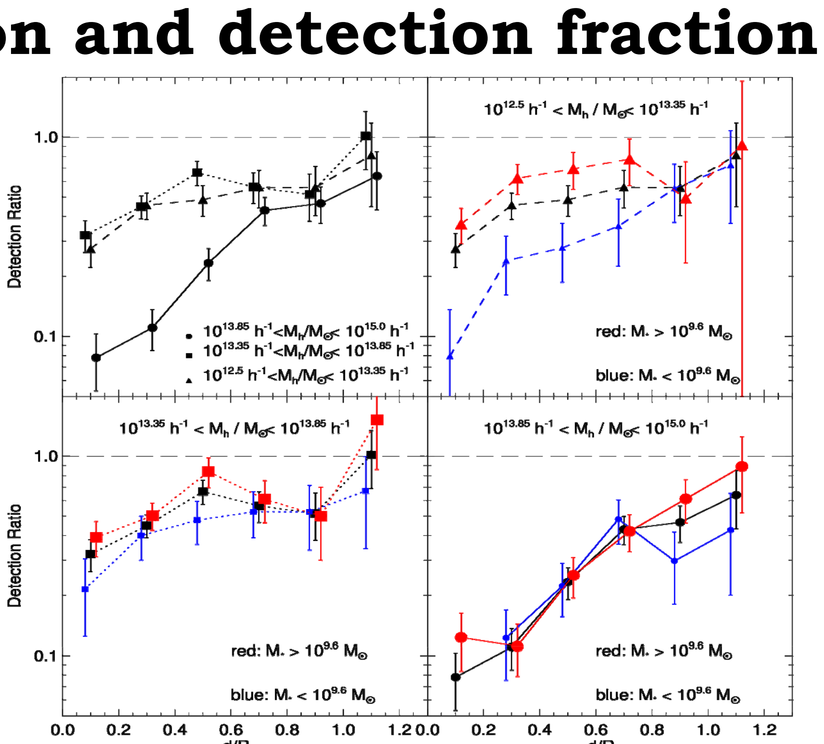
3. Group sample and Control sample



- Group sample (390, red) : galaxies in groups with more than 4 members and with 8 comparison samples, excluding close (likely tidally interacting) pairs
- Control sample (4372, gray) : isolated galaxies for comparison
- Group galaxies are compared to the control samples with similar M$_*$ and z (Δlog M$_*$<0.1 and Δz<0.001)

4. Distribution of gas fraction and detection fraction

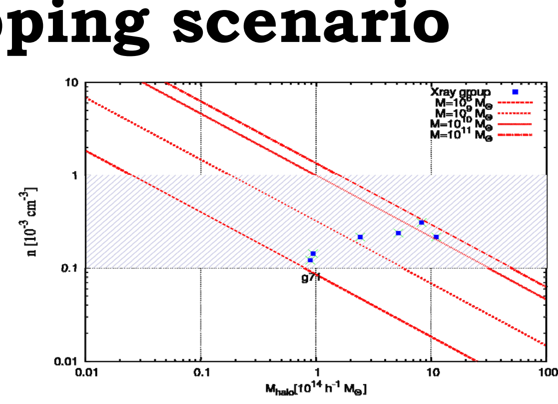




- No significant decrease of gas fraction relative to the control sample for all halo mass bins
- However, a significant decrease of detection fraction relative to the control sample at the center seen more prominently in massive halos than less massive halos
- Need better sensitivity to probe gas-poor galaxies

5. Ram pressure stripping scenario

- Weak impact of tidal stripping in our sample.
- Ram pressure stripping can explain our observation.
- The Gunn and Gott (1972) criterion can be modified by using electron density (n), halo mass (M$_h$) and galaxy stellar mass (M$_*$):



Plane of halo mass and mean electron density where a region for effective ram pressure stripping can be determined for given galaxy stellar mass and electron temperature

$$\left(\frac{n}{10^{-3}\mathrm{cm}^{-3}}\right)\left(\frac{M_h}{10^{14}h^{-1}M_\odot}\right)^{2/3} \gtrsim 1.24\left(\frac{M_*}{10^{10}M_\odot}\right)^{0.58}\left(1+0.25\times\frac{M_*}{10^{10}M_\odot}\right)^{-1}$$

- For typical ICM/IGM density (10^{-3} ~10^{-4} cm^{-3}, hatched region), there is a threshold halo mass for given M$_*$, that makes ram pressure dominate the galaxy gravitational force and strip the gas.
- For 10^9M$_\odot$ galaxy, the ram pressure stripping becomes effective when the galaxy is in a halo with M$_h$>10^{14} h^{-1} M$_\odot$.
- Halo mass range for efficient ram pressure stripping for given stellar mass range in our sample ($10^{8.4}$ M$_\odot$ <M$_*$<$10^{10.6}$ M$_\odot$) and typical ICM/IGM density (5×10^{-4} cm^{-3}) is M$_h$>$10^{13.6}$ h^{-1} M$_\odot$ which is comparable to the most massive halo mass bin in our study.

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