arXiv:0802.3908v1 [astro-ph] 26 Feb 2008

**FULL TITLE**
ASP Conference Series, Vol. **VOLUME**, **YEAR OF PUBLICATION**
**NAMES OF EDITORS**

# Morphological Transformations of Galaxies in the A901/02 Supercluster from STAGES

A.L. Heiderman (UT Austin), S. Jogee (UT Austin), D.J. Bacon (Portsmouth), M.L. Balogh (Waterloo), M. Barden (Innsbruck), F.D. Barazza (EPFL), E.F. Bell (MPIA), A. Böhm (AIP), J.A.R. Caldwell (UT Austin), M.E. Gray (Nottingham), B. Häußler (Nottingham), C. Heymans (UBC, IAP), K. Jahnke (MPIA), E. van Kampen (Innsbruck), S. Koposov (MPIA), K. Lane (Nottingham), D.H. McIntosh (UMass), K. Meisenheimer (MPIA), C. Y. Peng (NRC-HIA), H.-W. Rix (MPIA), S.F. Sanchez (CAHA), R. Somerville (MPIA), A.N. Taylor (SUPA), L. Wisotzki (AIP), C. Wolf (Oxford), & X. Zheng (PMO)

**Abstract.** We present a study of galaxies in the Abell 901/902 Supercluster at $z \sim 0.165$, based on *HST* ACS F606W, COMBO-17, *Spitzer* 24$\mu$m, XMM-Newton X-ray, and gravitational lensing maps, as part of the STAGES survey. We characterize galaxies with strong externally-triggered morphological distortions and normal relatively undisturbed galaxies, using visual classification and quantitative CAS parameters. We compare normal and distorted galaxies in terms of their frequency, distribution within the cluster, star formation properties, and relationship to dark matter (DM) or surface mass density, and intra-cluster medium (ICM) density. We revisit the morphology density relation, which postulates a higher fraction of early type galaxies in dense environments, by considering separately galaxies with a low bulge-to-disk ($B/D$) ratio and a low gas content as these two parameters may not be correlated in clusters. We report here on our preliminary analysis.

## 1. Introduction

The systematic quest to understand how galaxies evolve as a function of epoch and environment remains in its infancy. Galaxies in cluster environments may differ from field galaxies due to high initial densities leading to early collapse. Furthermore, the relative importance of galaxy-galaxy interactions (e.g., galaxy harassment, tidal interactions, minor mergers, and major mergers) and galaxy-ICM interactions (e.g, ram pressure stripping and compression) are likely to differ between cluster and field environments due to the different number density of galaxies, galaxy velocity dispersions, ICM density, and DM density.

In order to constrain how galaxies evolve in cluster environments, we present a study based on the STAGES survey of the Abell 901/902 supercluster (Gray et al. 2008). The survey covers 0.5 $\times$ 0.5 degrees on the sky, and includes high resolution ($0.1''$, corresponding to 280 pc at $z \sim 0.165$[1]) *HST* ACS F606W images, along with COMBO-17, *Spitzer* 24$\mu$m, XMM-Newton X-ray data, and gravitational lensing maps (Gray et al. 2002; Heymans et al. 2008). The STAGES survey is complemented with accurate spectrophotometric redshifts

[1]We assume in this paper a flat cosmology with $\Omega_M = 1 - \Omega_\Lambda = 0.3$ and $H_0$ =70 km s$^{-1}$ Mpc$^{-1}$.

with errors $\delta_z/(1+z)\sim 0.02$ down to $R_{\rm Vega}$=24 from the COMBO-17 survey (Wolf et al. 2004), and stellar masses (Borch et al. 2006). Star formation rates (SFRs) are derived from the COMBO-17 UV and *Spitzer* 24$\mu$m data (Bell et al. 2007).

The supercluster sample of 2309 galaxies covers a broad range of luminosities, encompassing both dwarf and larger galaxies (E to Sd). We present many of our results separately for bright ($M_V \leq$ -18; 798 galaxies), and faint galaxies (-18 $< M_V \leq -15.5$; 1286 galaxies). This is because the morphological characterization is less robust for small dwarf galaxies, than for normal galaxies, due to surface brightness, spatial resolution (280 pc), and contamination from field galaxies.

## 2. Methodology and Preliminary Results

Using the CAS code (Conselice et al. 2000), the concentration (C), asymmetry (A), and clumpiness (S) parameters were derived from the *HST* ACS F606W images. Given that the CAS merger criteria (A>S and A>0.35) tend to capture only a fraction of interacting/merging galaxies (e.g., Conselice 2006; Jogee et al. 2007), we also characterize the morphological properties via visual classification. In order to identify galaxies that are distorted due to a recent merger or tidal interaction, we take special care to classify galaxies into three distinct visual classes: (1) Galaxies with *externally-triggered* distortions: These distortions, triggered by tidal interactions or mergers, include double or multiple nuclei inside a common body, tidal tails, arcs, shells, ripples, or tidal debris in body of galaxy, warps, offset rings, and extremely asymmetric SF or spiral arms on one side of the disk. Galaxies are classified as strongly or weakly distorted, according to whether the distortions occupy a large or small fraction of the total light. (2) Galaxies with *internally-triggered* asymmetries (classified as Irr-1): Internally-triggered asymmetries are due to stochastic star-forming regions or the low ratio of ordered to random motions, common in irregular galaxies. These asymmetries tend to be correlated on scales of a few hundred parsecs, rather than on scales of a few kpc. (3) Relatively *undistorted symmetric* galaxies (classified as Normal).

The assumed correlation implicit in the Hubble sequence, between a high $B/D$ and a low gas and dust content, can often fail in cluster environments, where systems of low $B/D$ may have smooth featureless disks (e.g., Koopmann & Kenney 1998). This begs the question of whether the classical morphology-density relation, which claims a larger fraction of early-type galaxies in dense environments, is driven by a larger fraction of gas-poor galaxies in such environments, or a larger fraction of bulge-dominated systems, or both. In order to address this question, we visually classify the clumpiness and $B/D$ ratio of galaxies separately, classifying galaxies into five categories: pure bulge (pB), bulge plus disk (B+D) clumpy or smooth, and pure disk (pD) clumpy or smooth. We present below extracts of our preliminary findings.

*1. Fraction of strongly distorted galaxies:* Visual classification shows that ~3% and ~0.4% of bright ($M_V \leq$ -18) and faint (-18 $< M_V \leq -15.5$) galaxies are strongly distorted, respectively. (The results for faint galaxies are highly uncertain.). The distortion fraction for bright galaxies in Abell 901/902 is lower than the values of 7% to 9% reported in the field for bright ($M_B \leq$ -20; Lotz et al. 2007) or massive ($M \geq 2.5 \times 10^{10}$ $M_\odot$; Jogee et al. 2007) galaxies.

*2. CAS recovery rate:* The CAS merger criteria (A>S and A>0.35) capture 54% and 40% of the strongly distorted galaxies in the bright and faint samples, respectively.

*3. Distribution of strongly distorted vs normal galaxies:* Most strongly distorted galaxies lie outside the cluster cores, avoid the peaks in DM surface mass density ($\kappa \geq 0.1$) and ICM density (Fig. 1A). These results are consistent with high galaxy velocity dispersions in the core being unfavorable to mergers and strong tidal interactions. It may also be due, at least in part, to the predominance in the core of gas-poor systems (see point 6 below; Fig. 1B), which tend to show shorter-lived tidal signatures.

*4. SFR of strongly distorted vs normal galaxies:* The UV-based SFR ranges primarily from 0.001 to 15 $M_\odot$ yr$^{-1}$ and rises with stellar mass (Fig. 1D). The average $SFR_{UV}$ is enhanced only by a modest factor of $\sim 4$ in strongly distorted galaxies compared to normal galaxies (Fig. 1C). A similar result is reported for distorted galaxies in field galaxies at $z \sim 0.2$ (e.g., Jogee et al. 2007). For 12% of the 798 bright galaxies having *Spitzer* 24$\mu$m detection, the UV+IR-based SFR ranges primarily from 0.01 to 50 $M_\odot$ yr$^{-1}$, and the median ratio of ($SFR_{UV+IR}/SFR_{UV}$) is $\sim 3$, indicating significant amounts of obscured star formation.

*5. Specific SFR (SSFR) of strongly distorted vs normal galaxies:* The SSFR or SFR per unit stellar mass is on average lower at higher stellar mass, consistent with a large fractional growth happening in lower mass galaxies at later times (Fig. 1D). Only a modest enhancement in $SSFR_{UV}$ is seen in distorted galaxies compared to normal galaxies.

*6. The Morphology-Density relation in A901/02:* Smooth (gas-poor) galaxies cluster in regions of high ICM density while clumpy (gas-rich) systems dominate at low ICM densities (Fig 1B). The ratio of smooth (gas-poor) galaxies to very clumpy (gas-rich) galaxies within the central 0.3 Mpc is (89%:11%), (75%:25%), and (86%:14%), respectively, for A901a, A901b, and A902. These values are comparable to the ratio of (80%:20%) for early-type to late-type galaxies in the classical morphology-density relation (Dressler 1980). Future work will explore whether the ratio of bulge-dominated galaxies to disk-dominated galaxies also shows a similar trend with galaxy number density.

**Acknowledgments.** AH and SJ acknowledge support from NSF grant AST-0607748, LTSA grant NAG5-13063, and HST-GO-10861 from STScI, which is operated by AURA, Inc., for NASA, under NAS5-26555.

## References

Bell, E., et al. 2007, ApJ, 663, 834
Borch, A., et al. 2006, A&A, 453, 869
Conselice, C., Bershady, M. A., & Jangren, A. 2000, 529, 886
Conselice, C. J. 2006,ApJ, 638, 686
Dressler, A. 1980, ApJ, 236, 351
Gray, M., et al. 2002, ApJ, 568, 141
Gray, M., et al. 2008, in preparation.
Heymans, C. et al. 2008, MNRAS, submitted.

Jogee, S. et al. 2007, to appear in Proceedings of "Formation and Evolution of Galaxy Disks", organized by the Vatican Observatory in Rome, 1-5 October 2007.
Koopmann, R., & Kenney, J. 1998, ApJ, 497, 75
Wolf, C., et al. 2004, A&A, 421, 913

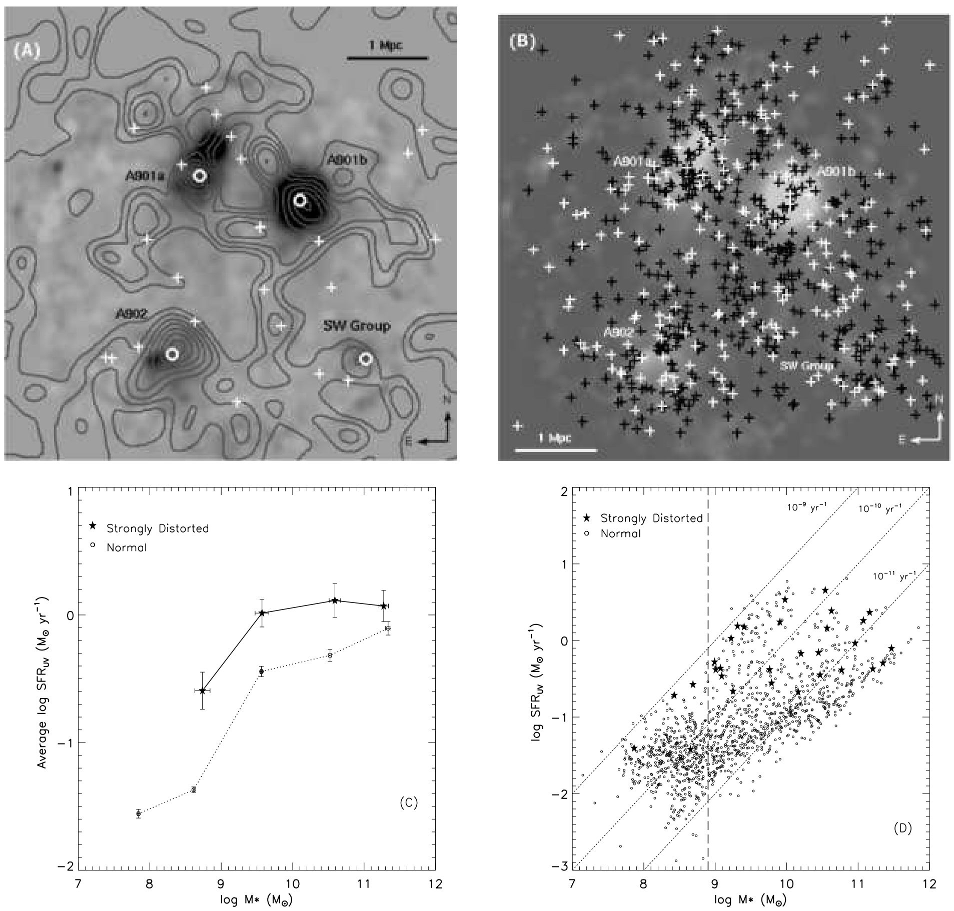


Figure 1. **(A)** Strongly distorted galaxies (white crosses) are overplotted on the ICM density (greyscale) and DM surface mass density $\kappa$ (contours ranging from 0.2 to 0.12, in steps of 0.2). Most strongly distorted galaxies lie outside region of high ICM density and DM peaks ($\kappa \sim 0.1$). **(B)** We revisit the morphology-density relation by overplotting the distribution of bright ($M_V \leq -18$) smooth (gas-poor) galaxies (black crosses) and clumpy (gas-rich) galaxies (white crosses) on the ICM density. Smooth (gas-poor) galaxies populate the highest density regions. **(C)** The average $SFR_{UV}$ is plotted as a function of stellar mass. It is enhanced by a modest factor of 4 in strongly distorted galaxies compared to normal systems. **(D)** Strongly distorted (black filled stars) and normal relatively undisturbed (open circles) galaxies are plotted on the $SFR_{UV}$ *versus* stellar mass plane. Loci of constant specific $SFR_{UV}$ are marked in units of $yr^{-1}$. The dashed vertical line denotes the COMBO-17 mass completeness limit for the red sequence. Note that $SFR_{UV}$ for red sequence galaxies are upper limits.