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Characterizing Barred Galaxies in the Abell 901/902 Supercluster from STAGES

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Abstract. In dense clusters, higher densities at early epochs as well as physical processes, such as ram pressure stripping and tidal interactions become important, and can have direct consequences for the evolution of bars and their host disks. To study bars and disks as a function of environment, we are using the STAGES ACS *HST* survey of the Abell 901/902 supercluster ($z \sim 0.165$), along with earlier field studies based the SDSS and the Ohio State University Bright Spiral Galaxy Survey (OSUBSGS). We explore the limitations of traditional methods for characterizing the bar fraction, and in particular highlight uncertainties in disk galaxy selection in cluster environments. We present an alternative approach for exploring the proportion of bars, and investigate the properties of bars as a function of host galaxy color, Sérsic index, stellar mass, star formation rate (SFR), specific SFR, and morphology.

1. Introduction

The most important internal driver of disk galaxy evolution are stellar bars, because they efficiently redistribute angular momentum between the disk and dark matter halo (e.g., Combes & Sanders 1981; Weinberg 1985; Athanassoula 2002). To put bars in a cosmological context, we must determine what effects environment has on bar and galaxy evolution. The bar fraction and properties in clusters relative to that found in field galaxies depend on several factors, such as the epoch of bar formation, the higher densities in clusters at early times leading to earlier collapse of dark matter halos, and the relative importance of processes such as ram pressure stripping, galaxy tidal interactions, mergers, and galaxy harassment. For example, tidal interactions can induce a bar in a dynamically cold disk, but they may also heat the disk, making it less unstable to bar formation. Previous studies have found opposing results for the bar fraction in isolated galaxies and those that are perturbed or in clusters (van den Bergh 2002; Varela et al. 2004). We use our large supercluster sample of galaxies (∼2000 over $M_{\rm V}$ -15.5 to -24.0) from the STAGES survey of the Abell 901/902 supercluster ($z \sim 0.165$) to investigate the fraction and properties of bars and their host disks in a dense environment.

2. STAGES Data and Sample

To study galaxies in a dense cluster environment, we use the Space Telescope A901/902 Galaxy Evolution Survey (STAGES; Gray et al., in preparation). The Abell 901/902 supercluster ($z \sim 0.165$, number of galaxies per unit area N=250 Mpc^{-2}) consists of three clusters: A901a, A901b, and A902 with an average core separation of ~ 1 Mpc. The A901 clusters show irregular X-ray morphologies, suggesting that they are not yet relaxed (Ebeling et al. 1996). The STAGES survey includes high resolution *HST* ACS F606W images (PSF $\sim 0.1''$, corresponding to ~ 300 pc at $z \sim 0.165$[1]) of the Abell 901/902 supercluster, along with spectrophotometric redshifts of accuracy $\delta_z/(1+z) \sim 0.02$ down to $R_{\rm Vega}$= 24 from the COMBO-17 survey (Wolf et al 2004). Multi-wavelength coverage is available for this field from *GALEX*, *Spitzer*, and XMM-Newton. Dark matter maps for the supercluster have been constructed using gravitational lensing by Gray et al. (2002) and Heymans et al. (2008, MNRAS submitted). The cluster sample contains 798 bright, $M_{\rm V} \leq -18.0$, galaxies.

3. Method for Identification and Characterization of Bars

To identify and characterize the properties of bars, we employ the widely used method of fitting ellipses to the galaxy isophotes out to sky level with the iraf task 'ELLIPSE' (e.g., Friedli et al. 1996; Jogee et al. 1999; Knapen et al. 2000;

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

Marinova & Jogee 2007). We generate plots of the surface brightness (SB), ellipticity (e), and position angle (PA) as a function of radius for each galaxy. We also plot overlays of the fitted ellipses onto the galaxy image. We use both the overlays and radial plots to identify bars. A galaxy is identified as barred if (a) the e profile rises to a global maximum while the PA stays constant and (b) after the global max, the e drops and the PA changes characterizing the disk region. To ensure reliable morphological classification, we exclude all galaxies with outer $e > 0.5$ ($i > 60^o$). With our PSF of $\sim 0.1''$, ($\sim 300\,\mathrm{pc}$ at $z \sim 0.165$), we cannot reliably detect bars with diameter smaller than $\sim 1.8\,\mathrm{kpc}$. However, such small bars are usually nuclear bars, whereas we focus only on primary bars, which have diameters greater than 2 kpc. When working in the rest-frame optical, bars heavily obscured by dust and SF will be missed, while such bars can be detected in the rest-frame NIR (Eskridge et al. 2000, Knapen et al. 2000, Marinova & Jogee 2007). Furthermore, partially obscured bars can be missed in ellipse-fits because dust and SF along the bar can cause the PA to vary marginally more than the 10^o allowed by the constant PA criterion. In fact, studies of nearby galaxies suggest that the bar fraction increases by a factor of ~ 1.3 in the NIR, compared to the optical (Marinova & Jogee 2007). As we do not have rest-frame NIR images for Abell 901/902, we resort to a second method of classifying bars: visual classification. The visual classification method tends to capture partially obscured bars somewhat better than ellipse fits, because visual classification takes into account, not only the stellar light in the bar, but also secondary signatures, such as the shape of dust lanes, the overall morphology of the disk, and spiral arms.

4. Preliminary Analysis

All bar studies to date carried out in field samples define the bar fraction f_{bar} as the ratio (number of barred *disks*/ total number of *disks*). An accurate determination of f_{bar} therefore hinges on an accurate way to identify disk galaxies. In field samples, both locally and at intermediate redshifts, two techniques are widely used to identify disks: Sérsic cuts (n <2.5) based on single component fits, and luminosity-color cuts to isolate blue cloud galaxies from the red sequence. These methods have limitations even in field samples: the Sérsic cut can miss bright disks with prominent bulges (where n >2.5) and the luminosity-color selection misses bright disks with red colors (caused by old stellar populations or dust-reddening).

In dense cluster environments, where disk galaxies can be red, and where the luminosity function is dominated by faint dwarf galaxies, it becomes even harder to identify disks via either method. We illustrate these uncertainties in disk selection in the supercluster as follows. The barred galaxies identified in § 3, from ellipse fit and visual classification, are plotted on the color-luminosity (Figure 1a) and Sérsic -luminosity (Figure 1b) planes. Because bars are disk signatures, we can use the strongly barred galaxies missed by the two methods as a lower limit on their failure to select disk galaxies. For bright galaxies, we find that 46% (45/97) and 40% (39/97) of disks with prominent, visually-identified bars are missed, respectively, by the blue cloud color-luminosity cut and Sérsic cut.

It is clear that the uncertainties in disk selection will cause a large and dominant error in the optical bar fraction $f_{\rm bar}$ in clusters. We therefore adopt the following approach in the A901/902 supercluster (1) We define a new quantity $P_{\rm bar}$ as the proportion of *all galaxies* (rather than disk galaxies), which are barred. Thus, $P_{\rm bar}$ is not as heavily affected as $f_{\rm bar}$ by the uncertainties in disk selection. (2) We explore how $P_{\rm bar}$ and bar properties vary as a function of galaxy properties, such as color (Figure 1a), stellar mass (Figure 1c,d) , SFR (Figure 1c), specific SFR (Figure 1d), and bulge-to-disk ratio. (3) When comparing the frequency of bars in clusters to that in the field, we can only use $f_{\rm bar}$, since no measurements of $P_{\rm bar}$ exist in the field. We estimate $f_{\rm bar}$ by selecting disks via visual classification, rather than from color-luminosity or Sérsic cuts. Disk are identified visually based on features such as spiral arms and stellar bars, or the presence of a bulge+disk from the light distribution.

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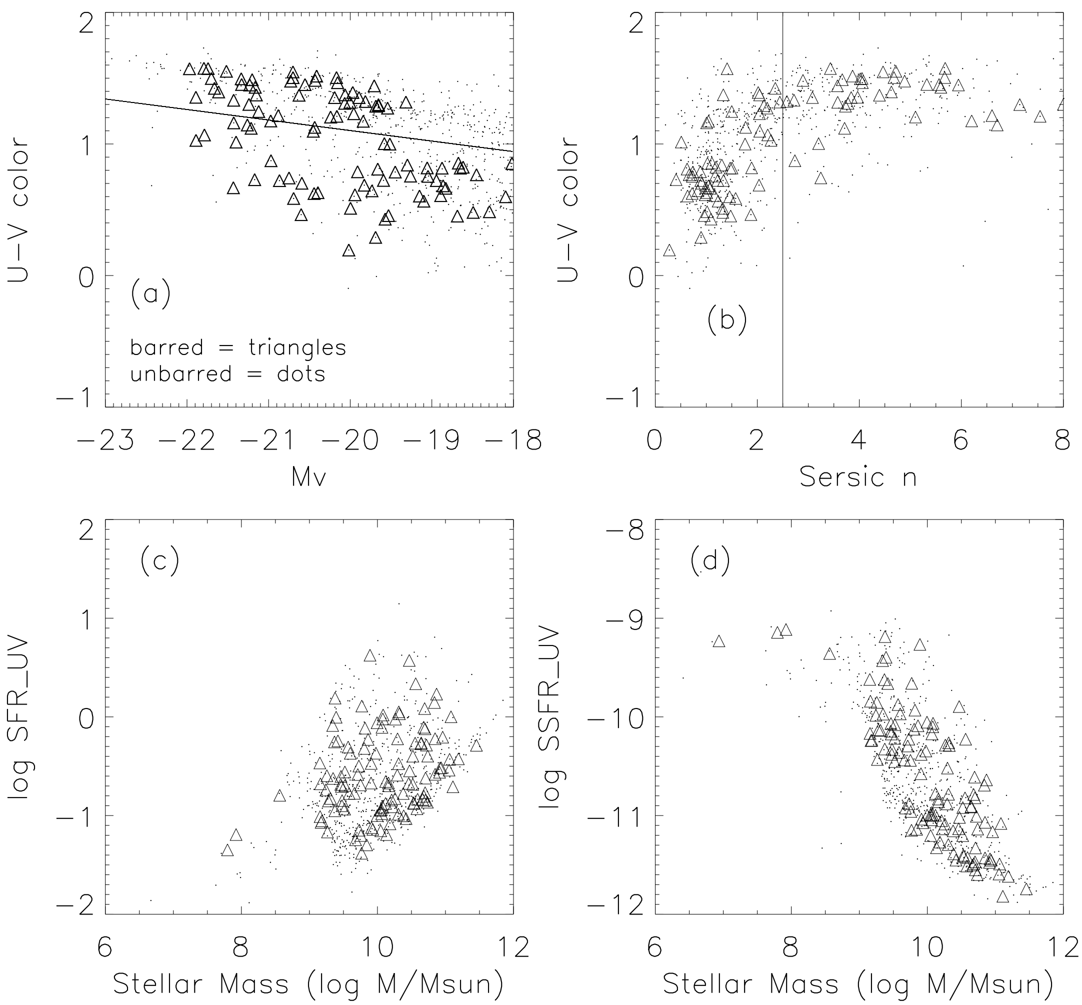

Figure 1. (a) Bright galaxies in rest-frame U-V vs. $M_{\rm V}$ plane. Galaxies with visually-identified strong bars are marked as triangles. Many of these lie on the red sequence and would be missed by assuming disks lie only in the blue cloud. (b) Rest-frame U-V color vs. Sérsic n plane. Many disks with prominent bars would be missed by a Sérsic cut $n < 2.5$. (c) SFR vs. stellar mass. (d) Specific SFR vs. stellar mass. Values for red sequence galaxies are upper limits.