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The Dwarf Galaxy Distribution in Abell 2218

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Abstract

We present results from an ultra-deep ($R \sim 26$ mag) photometric study of the rich galaxy cluster Abell 2218, based on archival HST images covering the central $1.3\,h^{-2}\,\mathrm{Mpc}^2$. We find the faint end of A2218's luminosity function to be steep, but its slope to increase with increasing cluster-centric radius and decreasing local galaxy density. ($\alpha = -1.12 \pm 0.05$ for $r \leq 300\,h^{-1}$ kpc, $\alpha = -1.39 \pm 0.05$ beyond this radius). We find strong evidence of luminosity segregation manifested by variation in the dwarf-to-giant ratio with local galaxy density. We find the dwarf galaxy population to have a more extended distribution than the giant galaxies and there appears to be a deficiency of dwarf galaxies in the cluster core.

1.1 Introduction

The galaxy luminosity function (LF) is a fundamental descriptor of the galaxy population and, as such, contains important information on the formation and evolution of galaxies. The LF will contain the combined imprints of the formation process together with the effects of any subsequent evolutionary processes which modified the initial luminosity distribution. In this context, rich clusters are important testing grounds, representing the most extreme environments in which galaxies reside and, within the hierarchical clustering framework, the ultimate example of where build up through merging has taken place. Additionally, galaxies in this environment are likely to be susceptible to such processes as galaxy 'harassment' (Moore et al. 1996), ram-pressure stripping (Gunn & Gott 1972) and cluster tidal effects (Byrd & Valtonen 1991, Bekki et al. 2001), all of which can severely modify their star forming activity and hence luminosity.

We have conducted an ultra-deep ($R \sim 26$ mag) photometric study of the well known rich cluster Abell 2218 (z=0.18), and present here results on the luminosity-dependent trends seen in its population going ~ 9 mags down its luminosity function. This is the first step in tracking these trends with environment within this rich cluster, with future weak lensing (Smith et al. 2003) and X-ray imaging (Nulsen et al. 2003) analyses being used to correlate these with its mass and gas distributions.

1.2 Observations and Data Analysis

Our study is based on archival HST* images of Abell 2218 obtained as part of a program to study weak gravitational lensing (by G. Squires and collaborators). This program obtained a mosaic of 22 pointings with WFPC2, each involving a 8400 s exposure in the F606W passband. The mosaic provides coverage of a roughly square area on the sky with a total area of 82 arcmin^2 corresponding to $1.3\,h^{-2}$ Mpc^2.

Objects were automatically detected and photometered using the SExtractor package (Bertin & Arnouts 1996). The BEST_MAG parameter was used as a measure of total galaxy magnitude. A total of 8038 objects were detected above the completeness limit of $R_{F606W} = 25.8$ mag. The SExtractor parameter CLASS_STAR was used to perform star-galaxy separation. Objects with indeterminate CLASS_STAR values were classified by visual inspection.

Field galaxy subtraction was done stastistically using the F606W HDF-north and HDF-south frames obtained from the HST data archive and analyzed using SExtractor with an identical set of parameters as those used on the Abell 2218 data. Galaxy number counts at the bright end were taken from the Millennium Galaxy Catalog (MGC) ground based counts of Liske et al. (2003) and converted to the R_{F606W} passband (Baldry et al. 2002). The field counts from the HDF's and the MGC are in excellent agreement for the magnitude range in which they overlap.

1.3 Results

1.3.1 *Luminosity Function*

The luminosity distribution of all galaxies detected in Abell 2218 is well fitted by a Schechter (1976) function with $M^{\star}_{F606W} = -20.09 \pm 0.10$ and $\alpha = -1.26 \pm 0.05$ over the range $-22 < M_{F606W} < -13.7$. However, the wide field provided by the 22 WFPC2 pointings allows us to study the behaviour of the LF as a function environment within the cluster. In Fig. 1, we show the LF for two different regions of the cluster: the central core ($r \leq 300\,h^{-1}$ kpc) and the region peripheral to this. It can be clearly seen that the LF for the core region (*filled circles*) has a significantly flatter faint-end slope than that for the outer region (*open squares*). This is confirmed by the Schechter function fits to the data (*solid* and *dashed lines*), with the core LF having a faint-end slope parameter $\alpha = -1.12 \pm 0.05$ compared to an α of -1.37 $\pm$ 0.05 for the outer region LF.

This result is contrary to that of several other studies which find little evidence for any change in the luminosity function with cluster-centric radius and, if anything, find a steeper faint-end slope in the cluster core (Bernstein et al. 1995, Valotto et al. 1997, De Propris et al. 2003). On the other hand, Lobo et al. (1997) found the Coma cluster LF to have a flatter slope in the groups around the two giant elliptical galaxies NGC 4874 and NGC 4889, implying a lack of faint galaxies in these regions.

1.3.2 *Dwarf-to-giant Ratio*

The radially divided LFs in Fig. 1 show a galaxy distribution in which dwarf galaxies become more prominent with increasing radius and hence decreasing galaxy density. However, this difference is only statistically significant at the 1σ level because of the strong

* Based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the data archive at the Space Telescope Science Institute. STScI is operated by the Association of Universities for Research in Astronomy, Inc. under NASA contact NAS 5-26555.

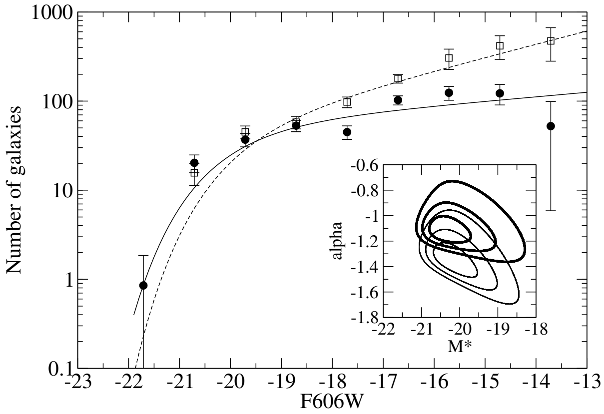

Fig. 1.1. The LF of galaxies in Abell 2218 for two spatially separated samples. The *filled circles* show the galaxy luminosity distribution for all galaxies within the core region ($r < 300\,h^{-1}$ kpc) and the *open squares* for the rest of the cluster field covered in our study. The *solid* and *dashed* lines are Schechter function fits to the data. *Inset:* 1σ, 2σ and 3σ error ellipses for the core region (*thick line*) and outer region (*thin line*).

coupling between M^* and α. To determine whether there is luminosity segregation we must use another measure. Here, the "dwarf-to-giant" (DGR) ratio – the ratio of the number of galaxies with $-15 > M_{F606W} > -18$ to those with $M_{F606W} < -18$, as introduced and defined by Driver, Couch & Phillipps (1998; hereafter DCP) – is well suited for this purpose.

Fig. 2 shows the DGR for Abell 2218 plotted as a function of local giant galaxy density. The DGR was calculated for each dwarf galaxy by finding the distance to the 10th nearest $M_{F606W} < -18$ galaxy and counting the number of dwarf galaxies within the same region. The average DGR values in equal sized local density bins are plotted as the *filled circles* in Fig. 2. Also shown are the DGR values for Abell 2254 (*open triangles*) from Smith, Driver & Phillipps (1997; hereafter SDP); these authors find a dwarf population which is more spatially extended than the giants in this cluster, with a DGR ≈ 3 in the densest regions and increasing to DGR ≈ 6 in the outskirts. DCP, in a study of 7 Abell/ACO clusters, also found a DGR which was smallest in the densest clusters (DGR ≈ 0.8 in Abell 3888) and largest in the poorest (DGR ≈ 3.1 in A0204) clusters. By splitting each of these clusters into an inner region ($r < 0.56$ Mpc) and an outer region ($0.56 < r < 0.74$ Mpc), DCP found the DGR to decrease with radius in two of the seven clusters, and to increase with radius in the remaining five. Taking DCP's estimates of the mean local galaxy densities in these inner and outer regions, we are able to plot their data in Fig.2 (*filled* and *open* square, respectively). As can be seen in this figure, our new study of Abell 2218 shows the DGR to increase with decreasing local density, consistent with the trend seen by SDP in A2254 and in the majority of the DCP sample.

1.3.3 Radial Profile of Galaxies

How galaxies of different luminosities are distributed *spatially* within Abell 2218 is shown in Fig. 3, where we plot the radial density profiles of the giant ($M_{F606W} < -18$) and dwarf ($-15 < M_{F606W} < -13.5$) galaxies, as well as those at intermediate luminosities ($-18 <$

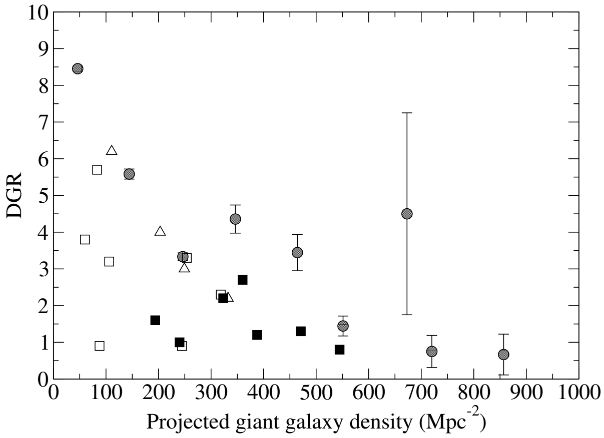

Fig. 1.2. Dwarf-to-Giant ratio variation with local giant galaxy density. *Filled circles* are from our study of Abell 2218; *open triangles* are the data for A2554 from SDP; *filled* and *open squares* represent the central and outer regions, respectively, of the clusters studied by DCP

$M_{F606W} < -15$). We see that the giant galaxies (*filled squares*)have the steepest profile, which if fitted by a power law ($N \propto r^{\alpha}$) has a slope of $a = -0.80 \pm 0.11$. In comparison, the intermediate luminosity galaxies have a flatter profile, with $a = -0.44 \pm 0.08$. Despite the large uncertainties in the dwarf galaxy numbers at different radii, it would appear that their surface density *decreases* towards the centre of the cluster, with a power-law fit having slope $a = 0.57 \pm 0.18$.

1.4 Concluding Remarks

In reporting here on our deep photometric study of the galaxy population within the central ~ 1 Mpc of Abell 2218, we have focussed on how galaxies of different luminosity, in particular dwarfs and giants, differ in terms of their number and surface density as a function of environment within the cluster. We find the LF to have a faint-end slope which steepens with increasing distance from the cluster centre. The ratio of dwarfs to giants (DGR) is smallest in the core and at the highest local galaxy densities, and becomes increasingly higher at larger radii and lower densities. The dwarf galaxy population has a much flatter radial profile than brighter cluster members, with evidence that it has a positive slope. In combination, these results point to there being a *deficiency* of dwarf galaxies in the core of Abell 2218, relative to other regions of the cluster. This conclusion is consistent with similar trends seen in other clusters by DCP, SDP, and Lobo et al. (1997), and further emphasises the notion of a large and ubiquitous dwarf galaxy population in clusters (e.g., Driver et al. 1994) needs to be qualified by the specific location (and hence environment) that one is studying.

As Phillipps et al. (1998a) have already discussed, current semianalytical models of hierarchical structure formation (e.g., Kauffmann et al. 1997) make predictions that are qualitatively consistent with our findings in the sense that cluster mass halos have a much lower number of dwarfs per unit giant galaxy light than do galaxy group halos. Of course, these do not include the effects of mechanisms such as galaxy harassment, ram pressure stripping, and cluster tides which may well be important in clusters, particularly in their cores. Only

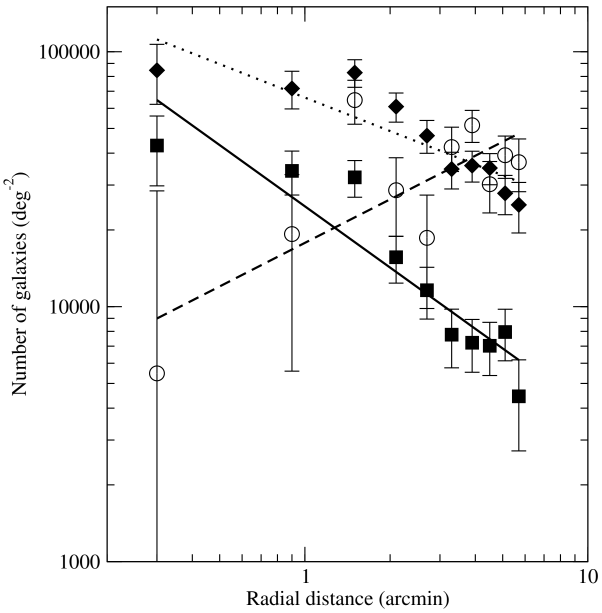

Fig. 1.3. The radial distribution of galaxies in Abell 2218; *filled squares* are galaxies with $M_{F606W} < -18$, *diamonds* $-18 < M_{F606W} < -15$, and *open circles* $-15 < M_{F606W} < -13.5$.

with further detailed observations of Abell 2218's mass and gas components, intepreted with equally detailed numerical modelling, might we be able to discriminate between these different effects.

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