A composite K-band Luminosity Function for Cluster Galaxies

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We present a composite K-band luminosity function for 10 clusters at low redshift, where member galaxies are identified from an existing spectroscopic survey (the 2dF galaxy redshift survey). Our kinematically selected K-band luminosity function is well fitted by a Schechter function with $M_K = -24.50 + 5 \log h$ and $\alpha = -0.98$ over $-27 < < M_K - 5 \log h < -22$. This is very similar to the 2dF field value and suggests that the integrated mass accretion history of galaxies does not vary strongly with environment.

1 Introduction

Clusters of galaxies are important for studies of galaxy formation and evolution because they contain a volume-limited sample of galaxies observed at the same cosmic epoch and therefore provide a snapshot of galaxy properties in a homogeneous (high-density) environment to lookback times approaching $2/3$ of the Hubble time. Clusters are, however, special environments, which are known to affect the morphology and star formation history of their members (e.g., Dressler 1980). If we wish to use cluster galaxies as evolutionary probes we need to understand the effects of the cluster environment, in order to relate our findings to the more general evolution of field galaxies. This has recently become possible with large redshift surveys (such as 2dF and the SDSS) which allow us to consider large samples of clusters spanning a wide range of properties, and to extend the analysis to the lower density groups and the general field.

The main conclusions of these studies are: (i) the optical luminosity function of galaxies is independent of the cluster environment; there is little variation between the field and clusters; (ii) star-forming galaxies have the same luminosity function in all environments, while quiescent objects show a significant difference, in that clusters contain a population of dwarf ellipticals which is missing in the general field. The most likely explanation for this involves the systematic suppression of star formation in low luminosity spirals and irregulars as they infall into clusters and their transformation into dwarf ellipticals on very short timescales, while giant galaxies appear to have resided in the cluster environment for very large epochs (Lewis et al. 2002, Christlein & Zabludoff 2003; De Propris et al. 2003, 2004; Gomez et al. 2003; Balogh et al. 2004; Popesso et al. 2006).

This of course leaves some questions open: what is the role of mergers in the environmental transformation of galaxies? How much does the mass of galaxies change after star formation is suppressed? Are there any detectable differences between field and clusters, owing to their very different densities and (presumably) merger histories? What is the relative role of star formation and mergers in assembling galaxies?

In order to answer these questions we need to study mass-selected samples of galaxies, to probe the stellar mass assembly history directly, and compare to observations in bluer bands to understand the cumulative effect of star formation. Observations in the $K$-band, which provide a measure of stellar masses (Gavazzi et al. 1996; Bell & de Jong 2001), while minimally affected by star formation or dust, allow us to achieve these aims.

The purpose of this paper is to present preliminary conclusions from a subset ($\sim 15\%$) of the observations of an ongoing infrared imaging survey. We will assume the WMAP cosmology with $\Omega_M = 0.73$ and $\Omega_{\Lambda} = 0.27$ and $H_0 = 100$ km s$^{-1}$ Mpc$^{-1}$.

2 Observations

To this end, we began an observing campaign to image all clusters originally studied by De Propris et al. (2003) in the $K$-band. These clusters have highly complete membership information, to the limits of the 2dF survey, at least three (and sometimes more) photometric bands and the spectra can be used to derive crude information on the galaxies’ star formation histories.

Since the mean redshift of the clusters is $<z> = 0.07$ these objects span large areas on the sky. We therefore need to obtain $K$-band data over regions approaching one degree on the sky or more. The 2MASS data are not serviceable...
for our purposes, as the imaging is too shallow, the star-
galaxy separation erratic and inconsistent, and the photom-
etry inadequate for galaxies other than local ones, owing to
the very short exposures on a 1.3m telescope. We decided
to carry out deep imaging on 4m-class telescopes, with an
integration time of 300s, to achieve sufficient depth, espe-
cially for the low surface brightness regions of galaxies, to
obtain a fair estimate of the total luminosity of galaxies.

Observations for the first ten clusters were carried out
with the ISPI array on the CTIO 4m telescope in 2007 and
2008 (a total of ten nights, although 7 were lost to weather).
The ISPI array covers ~ 10.5' on the sky and we obtained
mosaics of ISPI images to image the extent of our clusters
out to their Abell radius (typically about one degree on the
sky).

The data consist of three coadded 20s exposures at each
pointing, dithered in a five-point pattern with 20'' steps, to
obtain a total integration time of 300s in the inner 10'' of
each ISPI field. The data were reduced in the usual way (for
infrared data): after flatfielding and dark subtraction, we
removed a running median of imaging frames, to deal with
the sky subtraction, and the carried out alignment and cor-
rections for the field distortions, with final co-addition of all
images to produce a single frame.

Photometry was carried out using the standard Sextrac-
tor routines (Bertin & Arnouts 1996), and we calibrated our
data directly on 2MASS stars (Jarrett et al. 2000) present
in our images. We used the Sextractor ‘stellarity’ param-
eter and matched to the higher resolution data in the Su-
percosmos database (Hamby et al. 2001) to separate stars and
galaxies. We finally matched all galaxies to the redshift
database of the 2dF survey (Colless et al. 2001), as well as
all other available redshift data in the NED database (prin-
cipally data from the SDSS and the MGC surveys) for our
observed fields.

We used the same approach as in De Propris et al. (2003)
to correct for spectroscopic incompleteness in our K-band
photometric survey, and its match to existing spectroscopic
surveys. For each absolute magnitude bin we computed the
fraction of members, non members, and galaxies whose red-
shift is unknown, and applied a statistical correction to de-
rive the likely number of cluster members in each bin. For
galaxies brighter than $K = 14$ the spectroscopic data are
nearly 100% complete, while the spectroscopic complete-
ness drops rapidly fainter than $K = 15$. We plan to event-
ually exploit the deep photometry and partial redshift in-
formation to study the dwarf galaxy population in greater
detail.

We derived the composite luminosity function for our
10 clusters following the method outlined in Colless (1989)
and fitted this with a Schechter function using a maximum-
likelihood technique. Figure 1 shows the derived LF and
the error ellipses. The best fit values are $M^*_K = -24.50 +
5 \log h$ and $\alpha = -0.98$. These are in good agreement
with the values derived for Coma by De Propris et al. (1998)
and by Lin et al. (2004). They are also in very good agreement

$$\frac{\text{Number}}{\text{Area}} = 10^{-0.4 M_K} \text{dex}^{-1} \text{mag}^{-1}$$

with the field value from the 2dF/2MASS data of Cole et al.
(2001).

3 Discussion and Future Work

The $K$-band LF we derive for cluster galaxies differs from
other work (except De Propris et al. 1998) in that we iden-
tify cluster members spectroscopically and we therefore know
the membership status of nearly every galaxy in our images.

Our LF is comparable in precision to the much larger
study of Lin et al. (2004) but achieves greater accuracy at
the faint end, even with only ten clusters, thanks to the pre-
cision afforded by the highly complete spectroscopic infor-
mation. In the future we hope to extend our sample of clus-
ters and to obtain images of the more nearby objects in the
sample of De Propris et al. (2003), using wide arrays such
as NEWFIRM or Omega2000, to firm up the shape of the
faint end of the LF.

The most interesting conclusion we derive from these
data is the essential similarity of field and cluster LFs in
the $K$-band. This was already noted by De Propris et al.
(2003) and Christlein & Zabludoff (2003), who showed that
$M^*$ and $\alpha$ for cluster and field galaxies differed only at
the $< 10\%$ level. Here, our comparison is for stellar mass
functions, as probed by the $K$-band light. The slope $\alpha$
is the same as in Cole et al. (2001), while $M^*$ is about 0.2m
brighter, but well within errors.

This suggests that the mass function of galaxies, the in-
tegral of the merger and star formation history of all objects
down to the present epoch, does not depend on environment.
With more data we will be able to probe the dependency (or
lack thereof) on cluster properties (X-ray luminosity, velo-
city dispersion, Bautz-Morgan type), galaxy ‘spectrophoto-
metric’ class (based on spectral features), morphology (based on our images) and radial distance from the cluster centre.

The observed lack of environmental dependency is somewhat surprising: one would expect that the merger histories, and the star formation histories, of galaxies in clusters and fields would be very different. Therefore the stellar mass function should show the results of several Gyrs of differential evolution. The observed lack of environmental dependence, not only in these $K$-band luminosity functions but also in previous work based on $B$ and $R$ band data (De Propris et al. 2003, Christlein & Zabludoff 2003) suggests that either early types dominate the shape of the LF for galaxies more massive than about 20% of $L^*$, or that the stellar populations of such galaxies are predominantly old.

However, it is possible there is a conspiracy between mergers and star formation in producing nearly similar mass distributions in very different environments. Conversely, the evidence that most massive galaxies formed early (‘down-sizing’ - Perez-Gonzalez et al. 2008), argues that the two mass function would converge to similar values at the present epochs, and that only dwarfs would show significant cluster to field variation. Observations at higher redshift are needed to explore this issue further. Nevertheless, a solid understanding of the local situation, as we are trying to achieve in this project, is paramount to our interpretation and assessment of high redshift data.

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