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Galaxy Luminosity Functions from Deep Spectroscopic Samples

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Abstract

We present R-band galaxy luminosity functions (GLFs) from spectroscopic samples of six nearby clusters with mean velocities from 2000 - 20000 km/s and velocity dispersions 700 -1250 km/s. In the case of the nearest cluster, Abell 1060, our sample extends to $M_R = -14$ (7 magnitudes below M^*). We find no evidence for differences in the GLF between the field and clusters except for an enhancement of the luminous tip ($M < -22.5$) in clusters. We estimate that our composite GLF is representative of at least $\sim 60\%$ of all clusters. However, the GLF of non-emission line (NEL) galaxies is significantly steeper in clusters, and systematic discrepancies exist between the NEL GLF of different clusters. The results in this paper are also published in [3].

1.1 Introduction

The galaxy luminosity function (GLF) is an important constraint on models of galaxy evolution. In the past [6, 8], GLF determinations in the densest environments, massive galaxy clusters, have suffered from several problems. First, they have usually been calculated using statistical background subtraction methods to account for interlopers from back- and foreground field populations. This method has been shown by [9] to be potentially subject to severe biases. Second, studies of the GLF in predominantly blue magnitude bands [4] may be affected by dust and star formation.

Our study, the Las Campanas Nearby Cluster Survey [3], remedies these problems by determining R-band GLFs from spectroscopic samples of six clusters at $cz < 20{,}000$ km/s. Data for these clusters are given in table 1.1. We adopt a magnitude limit of $m_R = 18$. For galaxies around this limit, our spectroscopic catalog is 30-50% complete; it is almost 100% complete for galaxies with $m_R < 17$.

Our analysis treats the sampling fraction as a functions of apparent magnitude and surface brightness. We perform object detection and photometry using Source-Extractor [1]. We identify galaxies using a combination of two automatic methods and visual inspection. We calculate the GLFs using a stepwise maximum likelihood method [5] adapted for a two-dimensional distribution and use a χ^2 optimization to fit Schechter functions [7] to the resulting binned distributions. For our analysis, we assume $\Omega_m = 0.3$, $\Omega_\lambda = 0.7$, and $H_0 = 100$ km s^{-1} Mpc^{-1}.

Table 1.1. *The Clusters*

Cluster	N	$\bar{cz}$ [km/s]	Δm [mag]	cz range [km/s]	σ [km/s]	$r_{sampling}$ [Mpc]
A1060	252	3683 ± 46	32.85	2292 - 5723	724 ± 31	0.48
A496	241	9910 ± 48	35.03	7731 - 11728	728 ± 36	1.24
A1631	340	13844 ± 39	35.78	12179 - 15909	708 ± 28	1.71
A754	415	16369 ± 47	36.16	13362 - 18942	953 ± 40	2.00
A85	280	16607 ± 60	36.19	13423 - 19737	993 ± 53	2.03
A3266	331	17857 ± 69	36.35	14129 - 21460	1255 ± 58	2.19

1.2 Results and Discussion

1.2.1 What are the Field and Cluster GLFs?

Fig. 1.1 shows our composite GLFs and corresponding Schechter parameters for the field and clusters. All Schechter fits are carried out down to a magnitude limit of $M_R = -17$. The top row shows the GLFs for all galaxies, the middle row shows emission line (EL) galaxies (galaxies with an [OII] $\lambda 3727$ equivalent width of 5 Å or more), and the bottom row shows non-emission line (NEL) galaxies. Schechter functions provide acceptable fits in all cases.

1.2.2 Are Field and Cluster GLFs Similar?

We compare field and cluster GLFs non-parametrically (using χ^2 tests) and parametrically (using their error contours in Schechter parameter space (M^*, α)). Both tests show that the overall GLFs in the field and clusters are consistent with each other, as are the EL GLFs. However, the GLFs of NEL galaxies are highly discrepant. The faint end slope, α, of the NEL GLF is significantly steeper in clusters than in the field. Fig. 1.2 shows the 1σ and 2σ error contours of the Schechter fits in parameter space.

We apply a third test to detect possible differences between field and cluster GLFs at the high-luminosity end of the GLF, to which the comparisons above may not be sensitive. We ask whether the observed numbers of galaxies in the most luminous tip of the GLF ($M_R < -22.5$) could be reproduced by assuming a universal 'bright end fraction' (i.e., the fraction of galaxies with $M_R < -22.5$) and normalizing both GLFs to produce the correct number of galaxies at $M_R < -20$. Such a universal bright end fraction is ruled out. The luminous tip of the cluster GLF is enhanced versus the field.

We point out that [4], a spectroscopic survey of the cluster GLF in the b_J-band, find small but significant differences between the field and cluster GLF in terms of the Schechter parameters M^* and α, in the sense of the cluster GLF being steeper by $\Delta\alpha \approx 0.1$ and brighter by $\Delta M^* \approx 0.3$. Aside from the fact that the b_J-band has a stronger sensitivity to recent star formation and dust extinction, and may therefore exhibit a systematically different behaviour, we cannot rule out offsets of this order of magnitude between our field and cluster R-band GLFs. Our strongest 2σ limit on the difference in faint end slopes is $\alpha_{cluster} - \alpha_{field} \approx 0.06 \pm 0.3$.

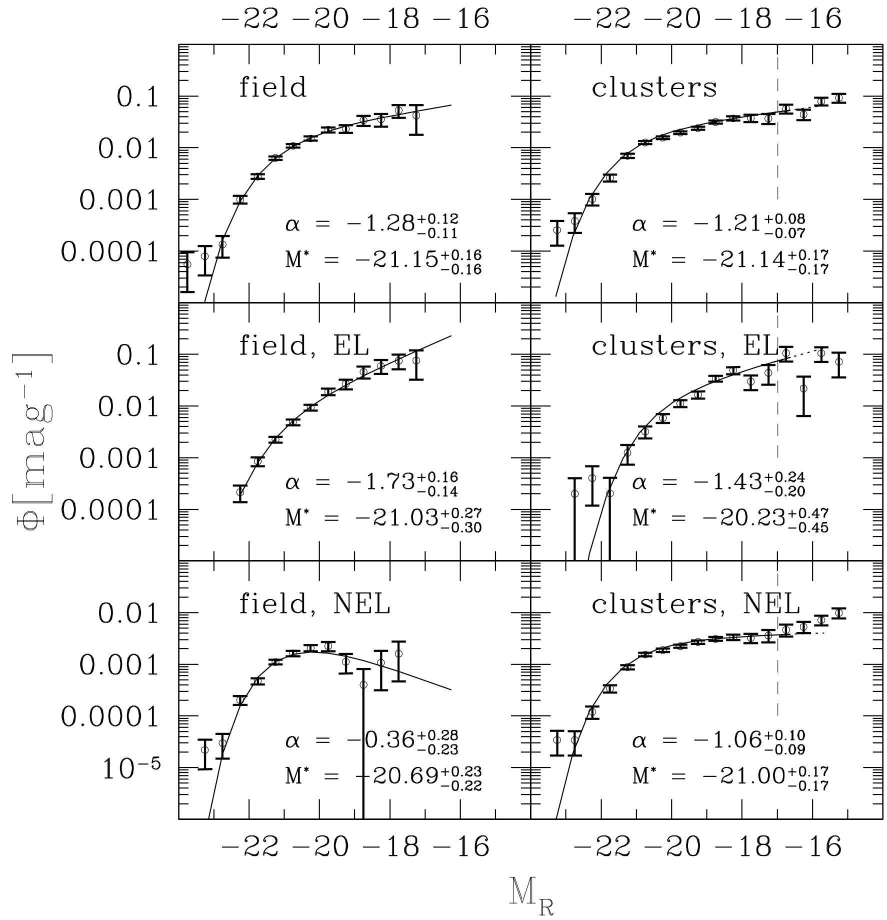

Fig. 1.1. Composite GLFs for the field and clusters for all galaxies (top row), emission line galaxies (middle row) and non-emission line galaxies (bottom row)

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1.2.3 Does a "Universal" Cluster Galaxy Luminosity Function Exist?

We derive GLFs for the six individual clusters to examine a) whether the differences between cluster GLFs can be explained solely by statistical fluctuations, and b) more generally, the degree of uniformity of the GLF in clusters (i.e., the fraction of all clusters that are consistent with our composite GLF).

To address the first question, we compare the clusters using χ^2 tests down to a common absolute magnitude limit of $M_R = -18.35$, as well as to a deeper limit of up to -17 for those clusters that have data at these faint magnitudes. This test examines whether the differences between the six GLFs in our sample could have arisen solely from statistical fluctuations. A negative answer implies the existence of systematic discrepancies between clusters and rules out the existence of a universal shape of the GLF.

To address the second question, we compare each cluster GLF to a composite GLF formed from the five remaining clusters (thereby ensuring that the two GLFs are statistically inde-

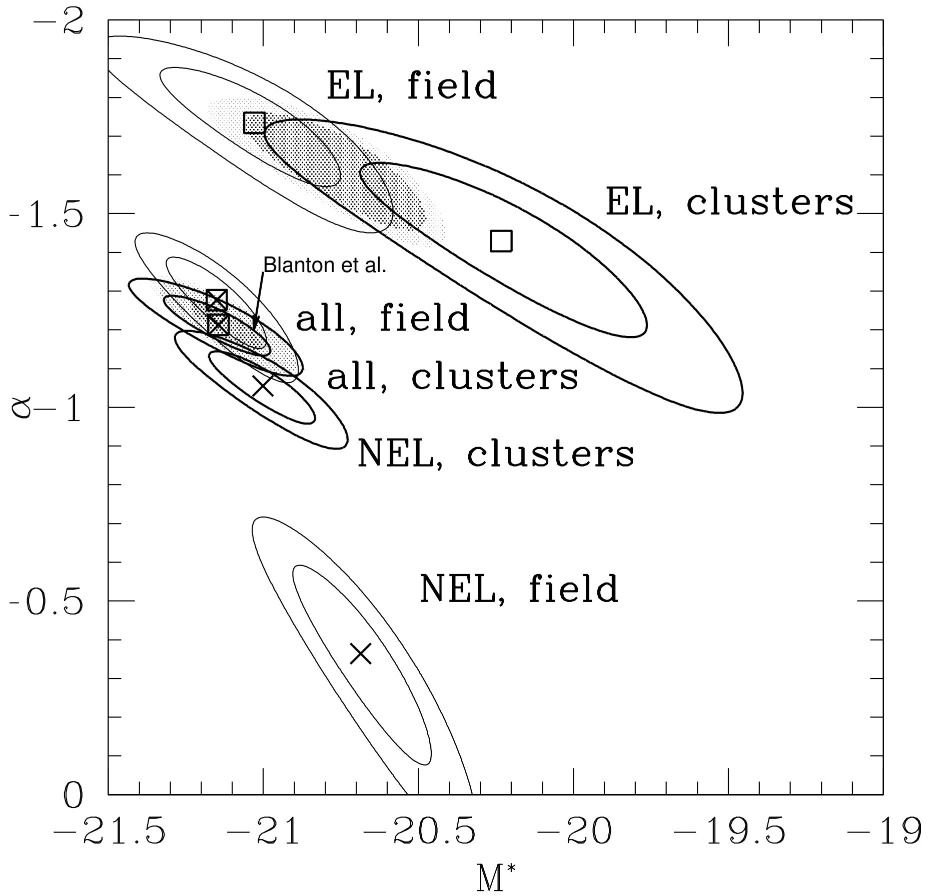

Fig. 1.2. 1σ and 2σ error contours in Schechter parameter space for our Schechter fits to the field and cluster composite GLFs down to $M_R = -17$ mag. The arrow shows the field GLF from [2] with a transformation $M_R - M_{r^*} = -0.2$. Shaded regions show Schechter parameters simultaneously consistent with two different GLFs. The error contours for the field and cluster NEL GLFs are disjoint, showing that they are highly discrepant.

pendent). From the fraction of six clusters that are consistent with the composite GLF, we can infer (using binomical statistics) constraints on the fraction of all clusters consistent with our composite GLF at the 2σ level. This test is less sensitive than the first one, but provides quantitative upper and lower limits on the uniformity of the cluster GLF.

For the overall GLF, we find that the distribution of χ^2 probabilities is consistent with a normal distribution; only one out of 15 comparisons shows inconsistency at the 2σ level. The second test shows that all six clusters are consistent with the 5-cluster composite GLFs. From this, we infer that our composite GLF is representative of at least 60% of all clusters that obey similar selection criteria as our sample (60% is a 2σ lower bound). Our data are consistent with a universal cluster GLF.

For the EL GLF, we find no evidence for systematic differences between GLFs from the

χ^2 comparisons. The second test shows five out of six clusters to be consistent with the composite. This implies that at least 40% of all clusters are consistent with our composite GLF. Again, a universal shape for the EL GLF in clusters cannot be ruled out.

For the NEL GLF, χ^2 probabilities from cluster-to-cluster comparisons are generally lower than expected from statistical fluctuations alone. The distribution of probabilities is not consistent with a normal distribution. A universal NEL GLF is therefore ruled out. The second test shows five out of six clusters to be consistent with the composite. This yields a lower limit of 40% of all clusters. Therefore, even though the direct χ^2 comparisons rule out a universal NEL GLF (i.e., 100% uniformity), our composite NEL GLF is still representative of a large fraction of clusters.

1.3 Conclusions

Using a new, deep spectroscopic sample and a stepwise maximum likelihood algorithm that we have modified to account for sampling fractions that vary both in magnitude and surface brightness, we have calculated R-band galaxy luminosity functions for six nearby clusters, as well as composite cluster and field GLFs. The deepest GLF for an individual cluster, A1060, extends to $M_R = -14$ ($M^* + 7$), making this the deepest spectroscopic survey of the cluster GLF to date. The composite GLF in clusters is consistent with a Schechter function with $M_R^* = -21.14^{+0.17}_{-0.17}$ and $\alpha = -1.21^{+0.08}_{-0.07}$. Employing the same methods, we calculate the field GLF using non-cluster members, which allows for a homogeneous comparison of cluster and field environments. The field GLF is best fit with a Schechter function with $M_R^* = -21.15^{+0.16}_{-0.16}$ and $\alpha = -1.28^{+0.12}_{-0.11}$, in agreement with other recent determinations of the field GLF [2]. We also find that:

(1) There is a considerable degree of uniformity among the GLFs of our six clusters. We estimate that, at a 2σ confidence level, our overall composite cluster GLF is representative of at least 60% of all clusters obeying similar selection criteria down to $M_R = -18.35$.
(2) The composite cluster and field GLFs are indistinguishable in our sample, except for a significant enhancement in the luminous tip ($M_R < -22.5$) of the cluster GLF.
(3) The GLFs of non-emission line (quiescent) galaxies vary significantly among clusters.
(4) The GLF of non-emission line galaxies varies significantly between the field and all the clusters, corresponding to a steepening of the faint end slope for $M_R < -17$.

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