Dwarf Galaxies in the Leo I Group: the Group Luminosity Function beyond the Local Group

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Abstract

We present first results of a survey of the Leo I group at 10 Mpc for $M_R \leq -10$ dwarf galaxies. This is part of a larger program to measure the faint end of the galaxy luminosity function in nearby poor groups. Our method is optimized to find Local-Group-like dwarfs down to dwarf spheroidal surface brighnesses, but we also find very large LSB dwarfs in Leo I with no Local Group counterpart. A preliminary measurement of the luminosity function yields a slope consistent with that measured in the Local Group.

1 Introduction

The classical picture of the dependence of the luminosity function (LF) on environment is that richer environments have steeper faint-end slopes. The range of measured slopes, using α of the Schechter (1976) formalism, was considered to vary from $\alpha \simeq -1.4$ in rich clusters to $\alpha \simeq -1$ for the low-density field. Galaxy groups have long been included with the field in these models, taking the Local Group (LG) slope of $\alpha = -1.1$ (Pritchet & van den Bergh 1999) as the prototype. As the LFs are superpositions of the LFs of individual morphological types, this suggests that dwarf galaxies contribute a larger fraction by luminosity in denser environments.

Yet, there have a been a number of observational constraints on determining the LF to dwarf luminosities of $M_B > -16$, where this steepening occurs. Many photometric surveys do not reach much fainter than this potential turn-up at $M_B \sim -16$, as dwarfs are notoriously difficult to detect at any significant distance. This has often led to a trade-off in group and cluster studies between the distance of a galaxy sample (and thus the limiting magnitude) and angular sky coverage, as the nearer groups and clusters cover substantial and almost unwieldy fractions of the sky. This leads to further difficulties in membership classification, as the more distant groups and clusters require statistical membership determination using control fields for the faintest galaxies which can prove problematic (*c.f.* Valotto, Moore, & Lambas 2001). Finally, as we probe fainter dwarf galaxies, we also probe fainter surface brightnesses which introduce significant surface-brightness selection effects.

2 Our Survey

With our R-band survey of the Leo I group, we probe a nearby poor group to observational limits approaching those of the LG. Leo I is a poor group at a distance of 10 Mpc and contains NGC 3379 as a member. The best work on the LF of the group to date is the photographic work of

"Dwarf Galaxies and their Environment"; Bad Honnef, Germany, 23-27 January 2001; Eds. K.S. de Boer, R.-J.Dettmar, U. Klein; Shaker Verlag

Ferguson & Sandage (1991). These data reached a limiting magnitude of $M_B = -14.2$ (adjusted for $m - M = 30$), which for a $\langle B - R \rangle = 1.3$ corresponds to $M_R = -15.5$. Our program is designed to extend these limits.

The strategy of our survey has three main features which mitigate some of the more insidious observational difficulties. First, our imaging survey uses the KPNO 0.9m+MOSAIC, which has a $59' \times 59'$ field of view with eight mosaiced CCDs. Thus, we have R-band imaging of over seven square degrees in Leo I with the advantage of the linear response of CCDs. Second, the proximity of Leo I at 10 Mpc allows for galaxy membership classification on a galaxy-by-galaxy basis, using morphology, photometric parameters, radial profiles, colors, and in many cases, directly measured distances. Finally, we have developed a detection technique that optimizes detection of very low-surface-brightness (LSB) dwarfs, extending our survey to both faint luminosities and faint surface brightnesses which approach the limits measured in the Local Group.

Our detection method is two-fold. First we use the traditional method of standard SExtractor detection to find high-surface-brightness (HSB) objects. We then complement this with our optimized method, which is based on the work of Dalcanton (1995) for finding large LSB galaxies in the field. We mask our image of high-surface-brightness features, and then convolve it with a filter of the shape and size we expect for dwarf galaxies at 10 Mpc. In Figure 1a, we show an example of a dwarf in our sample that is not detected by our traditional method. In the central panel, we show the masked image, and in the right panel, the same image convolved with a $5''$ exponential kernel. The aperture size shown is the detection aperture from the optimized method, where the dwarf is now a significant detection. Our method is described more fully in Flint et al. (2001).

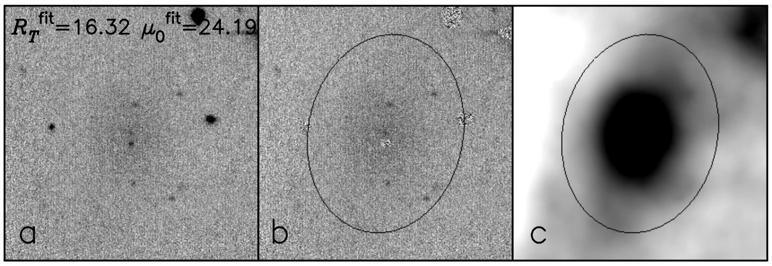


Figure 1: **a:** Dwarf in Leo I, undetected by traditional method. **b:** The image masked of HSB features. **c:** The image convolved with $5''$ exponential kernel, now showing up as a significant detection.

3 Selection Function

An advantage of our detection procedure is that it is completely automated; thus, we can run extensive Montecarlo simulations to tune our detection parameters, quantify our completeness, and calculate our errors in measuring photometric parameters. We generate artificial galaxies, input them to our data images, and apply both our detection methods to recover them. We then calculate a recovery fraction as a function of both input central surface brightness (μ_0) and input total magnitude (R_T). Our simulations for one field are shown in Figure 2, where the greyscale indicates recovery fractions of 90% (darkest), 70%, 50%, 30%, and 10% (lightest). LG galaxies, if seen at a distance of 10 Mpc, are plotted for comparison. While we don't detect dwarfs like Draco and Ursa Minor, we find that without our optimized method, we would only detect objects with $\mu_0 < 23.5$ and so would miss dwarfs like And II and fainter. Furthermore, these data were taken with the MOSAIC's engineering grade chips which are difficult to flat field. We estimate that with flatter data, we could extend our method one magnitude in total magnitude and two magnitudes in central surface brightness. Yet, even with these limitations, we find that at the 90% completeness level we can find dwarfs similar to Antlia and Sculptor, and at the 50% completeness level, dwarfs similar to Tucana and Leo II (Flint et al. 2001).

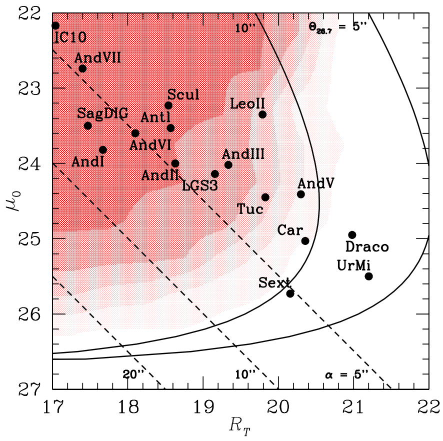


Figure 2: Selection Function for one field. Greyscale indicates recovery fractions of 90% (darkest), 70%, 50%, 30%, and 10% (lightest). The dotted lines are lines are lines of constant exponential scale length, and the solid lines are lines of constant isophotal size at a limiting surface brightness of 26.7 R mag/$''$.

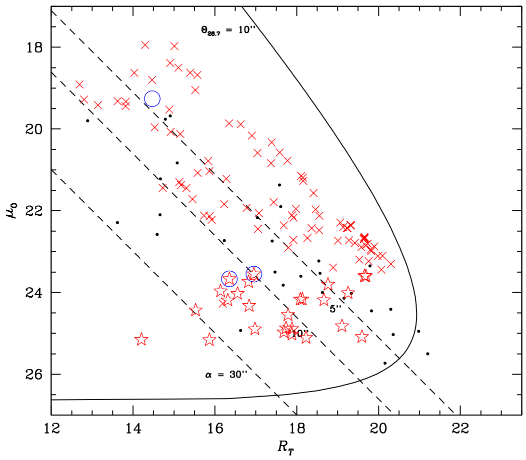
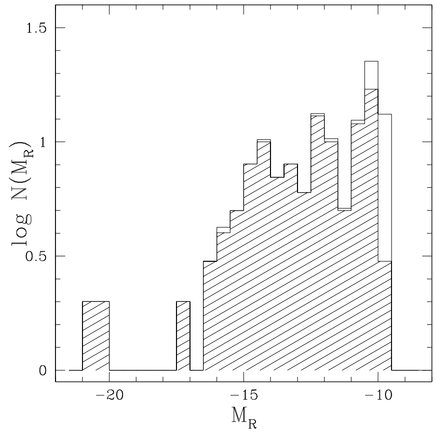


Figure 3: Group candidates for 80% of the imaging data. Crosses are objects detected with the traditional method, while stars are objects detected only through the optimized method. Dotted and solid lines are the same as in the previous figure, and the filled dots are comparison Local Group galaxies.

4 First Results

First results from Leo I are shown in Figure 3. Here we plot our detections in the same way as Figure 2, where the filled dots are LG galaxies again for comparison. Here the crosses are objects detected via our traditional method. The stars are objects which would not have been detected without using the optimized method. These detections have had a preliminary membership classification, using their position in this figure, profile type, and morphology. Using our sample of follow-up observations, we find that objects falling in the upper right area of the figure typically are small, higher-redshift background objects. We find some degree of contamination from background spirals around the Freeman's Law value of $\mu_0 \simeq 20$, where the open circle indicates a background spiral removed from the sample. Ironically, however, we find the most robust membership classification so far for the lowest-surface-brightness objects, where the circled stars are examples of dwarfs we have identified as members via spectroscopic redshifts and surface-brightness fluctuations (SBF). Our follow-up program is on-going and includes velocity measurements from both HI and optical

Figure 4: Preliminary luminosity function for 80% of Leo I data, adopting $m-M=30$. Filled histogram: raw galaxy counts. Open histogram: galaxy counts scaled for completeness as a function of (μ_0, R_T) using results from the simulations.



spectroscopy, SBF, and colors for all candidates. In this way, we also hope to guard against contamination from field LSB galaxies, cosmologically dimmed high-z galaxies, and possibly diffuse light from $z \gtrsim 0.6$ galaxy clusters.

An interesting feature of our sample is that we find a few galaxies which deviate from the typical $R_T - \mu_0$ relation followed by the LG galaxies in Figure 3. These galaxies, if members, are large, LSB dwarfs not seen in the LG. Similar galaxies have previously been discovered in other environments such as Virgo (Impey, Bothun, & Malin 1988) and M81 (Caldwell et al. 1998).

5 Luminosity Function

With the data in Figure 3, we can begin to construct the group LF. In Figure 4, in the shaded histogram, we show the raw galaxy counts for the 80% of the data analyzed to date. We then weight these raw counts for incompleteness as quantified through the Montecarlo simulations, as a function of both μ_0 and R_T. The scaled LF is shown as the open histogram in Figure 4. A preliminary measurement of the faint-end slope yields $\alpha = -1.2$, which is consistent with $\alpha = -1.1$ measured in the Local Group (Pritchet & van den Bergh 1999).

6 Summary

We present a new program for robustly detecting low-luminosity dwarfs at a distance of 10 Mpc in the Leo I group. Using an optimized, filter-detection technique for finding low-surface-brightness dwarfs, we probe the group luminosity function to $M_R \simeq -10$, $\mu_0 = 24.5$ at the 50% completeness level. We use follow-up observations and morphological membership classification to construct a preliminary luminosity function which appears to be consistent with that of the Local Group. We also find several large, LSB dwarfs which, if they are members, deviate from the $R_T - \mu_0$ relation and have no counterpart in the Local Group.

References

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