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CARBON STAR SURVEY IN THE LOCAL GROUP. VI. THE DWARF SPHEROIDAL GALAXY NGC 205

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ABSTRACT

We present a CFH12K survey of the carbon stars in NGC 205 and its surrounding field. We find that the number of C stars in NGC 205 is low (~500) for its luminosity and that very few C stars are seen outside of the 10′ isophote, suggesting tidal stripping by M31. Their $\langle M_I \rangle = -4.54$, a magnitude nearly identical to what has been found in other galaxies with numerous C stars. Stars with accurate $(R-I)$ photometry, to $I \approx 22.5$, are used to determine the outer profile of NGC 205. A King profile with $r_t = 19.'77 \pm 3.'00$ fits the data for distances larger than 7′. This r_t implies that NGC 205 reached a minimum distance to M31 of ~42 kpc. The spatial distribution of C stars in the surrounding field reveals that some C stars belong to to the disk of M31, seen in projection, and that a surplus of C stars seen west of NGC 205 could be part of tidal debris left along its orbit. Finally, we report evidence of a transient period of enhanced star formation that occurred 1–2 Gyr ago in the northwest half of NGC 205.

Key words: galaxies: individual (NGC 205) — galaxies: stellar content — galaxies: structure — stars: carbon

On-line material: machine-readable table

1. INTRODUCTION

Carbon stars, the brightest members of the intermediate-age population, have been identified during the last decades in several Local Group galaxies. The narrowband photometric technique to differentiate C stars from M stars, originally proposed by Palmer & Wing (1982), has been quite successful in reaching much fainter magnitudes than the classification based on spectroscopic techniques, thus allowing us to survey well beyond the Galactic halo. What we today call the CN-TiO approach was developed in the 1980s by Cook, Aaronson, & Norris (1986) and Richer and collaborators, who targeted several nearby galaxies, including, for example, NGC 205, observed by Richer, Crabtree, & Pritchet (1984). C stars, being bright in the *I* band, can be detected from short exposures, which do not saturate images with mostly older fainter giant stars, thus facilitating identification in crowded fields.

Because the CCDs available in the 1980s were quite small, early surveys were not able to provide a global view of the late-type star population of most Local Group galaxies. A small field of view leads to small number statistics, making the interpretation of the observations risky at best. For this reason, a coherent understanding of the relationship between the number of C and M stars and the chemical composition of the population or the star formation history of the galaxy is still lacking. Indeed, Groenewegen's (1999) summary of the carbon star populations of different metallicity now needs a major update thanks to current (CN-TiO) surveys identifying hundreds of C stars per galaxy.

To pursue our effort to obtain mean magnitude and mean color, as well as the spatial distribution of C stars in dwarf galaxies of the Local Group, we present results for NGC 205, a close satellite of M31. NGC 205 is a peculiar dwarf elliptical galaxy because it contains dozens of bright early-type stars and dust lanes in its central parts. Photometric studies of NGC 205, in the optical, have been done by Mould, Kristian, & Da Costa (1984) and more recently by Lee (1996). NGC 205 is believed to be moderately metal-poor; Mould et al. (1984) estimated its [Fe/H] to be −0.9 from the color of its giant branch.

Being at a projected distance of less than 40′ (~9 kpc) from the center of M31, NGC 205 may be even closer to M31 than the Sagittarius dwarf spheroidal galaxy is to the Milky Way. Its position, relative to the huge M31, complicates enormously the study of its structure, its outer population, and its probable tidal features. Carbon stars may help in this respect, provided that those belonging to M31 do not interfere. Carbon stars have been found to be ideal probes for investigating the low-density outer parts of galaxies (Albert, Demers, & Kunkel 2000; Letarte et al. 2002). Even though we do not expect to find C stars in the halo of M31, NGC 205 is so close to the central parts of M31 that the numerous C stars seen in its outer disk should contribute significantly to the C star counts near NGC 205.

2. OBSERVATIONS

The results are based on images obtained with the CFH12K mosaic in 2000 September. The camera consists of a $12,000 \times 8000$ pixel mosaic covering a field of $42' \times 28'$,

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each pixel corresponding to 0."206. Images were obtained through Mould I (2×400 s) and R (3×400 s) filters and CN (3×700 s) and TiO (3×700 s). In spite of very good seeing (0."8), sky conditions during the observations were nonphotometric.

The images obtained with each filter were combined and averaged. They were then analyzed using the DAOPHOT II/ALLSTAR package. The data reduction is detailed in Letarte et al. (2002). As explained by Battinelli, Demers, & Letarte (2003), secondary standards were obtained at Asiago Observatory to calibrate the M31 images and the NGC 205 observations reported here. A description of the calibration can be found in Battinelli et al. (2003).

3. RESULTS

3.1. *The Color-Magnitude Diagram*

To place in perspective our CFH12K field with the geometry of M31/NGC 205, we present, in Figure 1, a schematic representation of the M31 disk. We adopt $i = 77.^\circ 7$ for the inclination of its disk and $37.^\circ 7$ for the position angle of its major axis (de Vaucouleurs 1958). The straight line from the center of M31 reaches the center of NGC 205. Note that, intentionally, NGC 205 is not at the center of the CFH12K field. One would then expect that the surface density of the foreground/background star counts would show a strong gradient, because the CFH12K field includes a range of radial distances of the disk, bulge, and inner halo of M31. The database includes 208,000 stars with R, I observations, 129,000 of them having color errors of less than 0.10 mag. Stars in the dense part of NGC 205 do have larger photometric errors in magnitude and in color than stars in the field. This implies that a selection based on photometric errors would lead to a deficiency of stars in the central parts of NGC 205. The global color-magnitude diagram (CMD) for stars with $\sigma_{R-I} < 0.10$ mag is shown in Figure 2. An

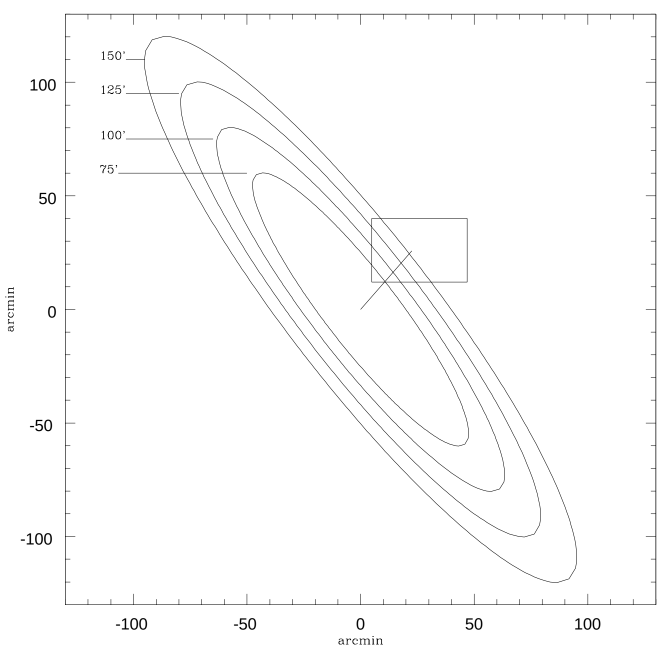

FIG. 1.—Schematic representation of the disk of M31, and the CFH12K field that includes NGC 205. The CFH12K samples the M31 disk at major-axis distances greater than 70′.

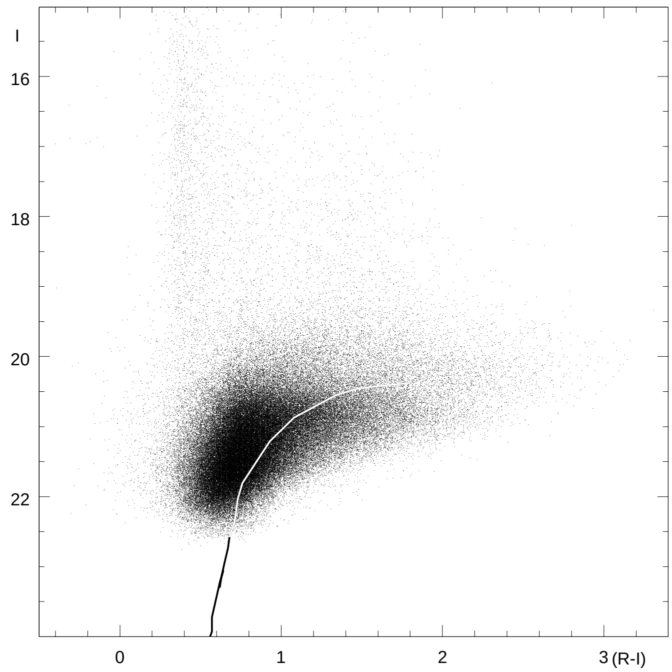

FIG. 2.—Color-magnitude diagram of the whole CFH12K field. Stars with color error larger than 0.1 mag. are excluded. An AGB isochrone, for $z = 0.004$, is traced.

isochrone (13 Gyr, $z = 0.004$) from Bertelli et al. (1994) is drawn to show that our photometry reaches $\sim$2 mag below the tip of the red giant branch (TRGB). A number of very red stars are seen in the field, a few reaching $(R-I) > 3.0$; such red stars have been seen in the disk of M31 (Battinelli et al. 2003). The isochrone does not go far enough to the red to match the observed population.

One interesting peculiarity of the CMD is the narrow vertical ridge extending toward bright magnitudes. This feature is characteristic of the CMDs of high Galactic latitude fields. It is better defined when $V-I$ or $R-I$ colors are used rather than $B-V$. The discontinuity in color is due to the numerous halo stars near the main-sequence turnoff ($M_v = +4$) seen along the line of sight. The recent multicolor survey toward the south Galactic pole by Prandoni et al. (1999) shows very well this discontinuity. This feature as been explained by Galactic models; see Bahcall (1986) for a review. The spatial distribution of the stars of the CMD is plotted in Figure 3. The diagonal lines represent sections of ellipses traced in Figure 1. As expected, a strong gradient in the stellar density is seen from the southeast to the northwest. The asymmetry of the outer parts of NGC 205 as well as the lack of stars in its very center are obvious.

In order to differentiate the stellar population of NGC 205 from that of the foreground/background, we display, in Figure 4, the CMD of three areas of the field. The NGC 205 area includes stars (28,500) within an elliptical area of semimajor axis equal to 2000 pixels (about 7′). We adopt here the shape and orientation of NGC 205 as determined by Hodge (1973), namely, $\epsilon = 0.50$ and a position angle of the major axis of some 150°. Both of these parameters are known to vary with distances (Choi, Guhathakurta, & Johnston 2002). The southeast and northwest corners are triangular areas having 4000 pixels along X and Y. The three areas have roughly the same size. The southeast CMD and

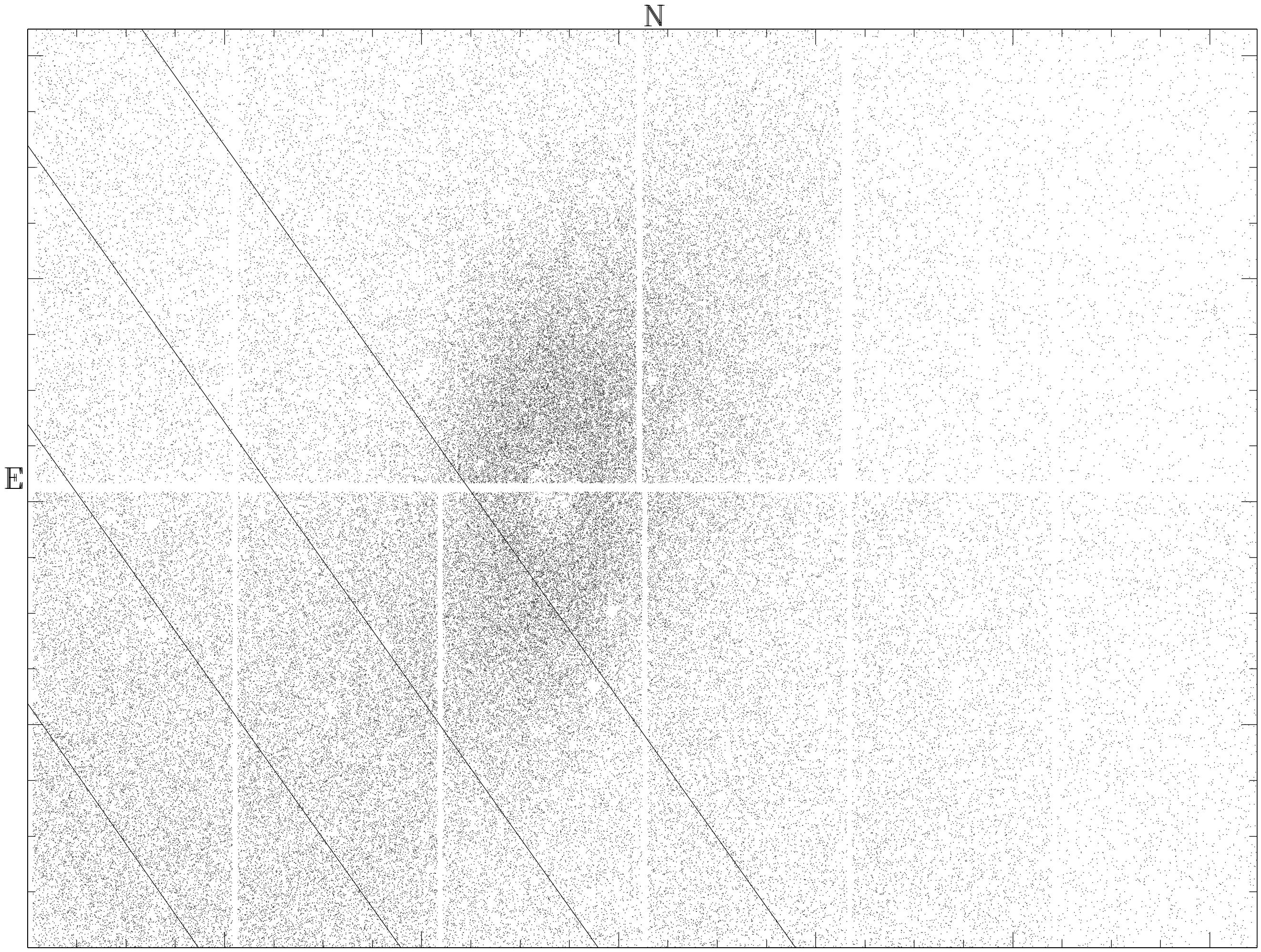

FIG. 3.—Spatial distribution of the 128,000 stars plotted on the CMD. The diagonal lines correspond to sections of the M31 ellipses traced in Fig. 1. The gaps between CCDs, in both X and Y, range from 28 to 43 pixels. The average gap in the X direction is 7″.8, while it is 6″.8 in the Y direction.

the northwest CMD represent the bulge/halo population of M31 rather than its outer disk. Indeed, two photometric surveys (Mould & Kristian 1986; Pritchet & van den Bergh 1988) done at $\sim 40'$ along the minor axis of M31 in the opposite direction to NGC 205 concluded that the disk population amounts to less than 3% of the stars seen. The reason for this is simply the low stellar density of the disk at these large projected distances. Inspection of the three CMDs reveals that the southeast CMD contains very red giants not seen in the other two. This is surely explained by a metallicity difference between the bulge/halo of M31 and NGC 205. Pritchet & van den Bergh (1988) determine a $[\mathrm{Fe/H}] \approx -1.0$ for the area at $40'$.

3.2. *Adopted Distance and Reddening for NGC 205*

NGC 205 is known to be a satellite of M31, but its exact distance from M31 is uncertain. It is located at $37'$ from the center of M31, which would correspond to 8.2 kpc if the two galaxies were at the same distance from us. The outer isophotes of NGC 205 are distorted (Hodge 1973; Choi et al. 2002), presumably as a result of tides exerted by M31; NGC 205 must then not be too far from M31. Van den Bergh (2000) adopts a formal unweighted mean distance of $(m-M)_0 = 24.54 \pm 0.09$ for NGC 205, marginally different from his M31 adopted distance of $(m-M)_o = 24.4 \pm 0.1$. This suggests that NGC 205, at 809 ± 33 kpc, is behind M31, located at 759 ± 35 kpc. We adopt the above modulus for NGC 205.

There is no direct measurement of the color excess toward NGC 205. A search of the literature reveals that a foreground reddening of $E(B-V) = 0.035$ is simply taken from Burstein & Heiles (1984). However, the estimation of the reddening from dust infrared emission by Schlegel, Finkbeiner, & Davis (1998) yields $E(B-V) = 0.083$. We adopt this later estimate, which leads to $E(R-I) = 0.07$ and $A_I = 0.12$ according to Rieke & Lebofsky (1985) transformation. G dwarfs in the Galactic disk, seen along the line of sight toward NGC 205, form a vertical ridge on the CMD (Fig. 2). Its observed color at $(R-I) \approx 0.40$ supports to adopted reddening.

3.3. *Identification of Carbon Stars*

C stars are identified from their position on the (CN–TiO) versus $(R-I)$ diagram. The zero point of the (CN–TiO) color index is adjusted using featureless hotter stars. Following Brewer, Richer, & Crabtree (1995), the mean (CN–TiO) of all stars with $(R-I)_0 < 0.45$ is set at zero.

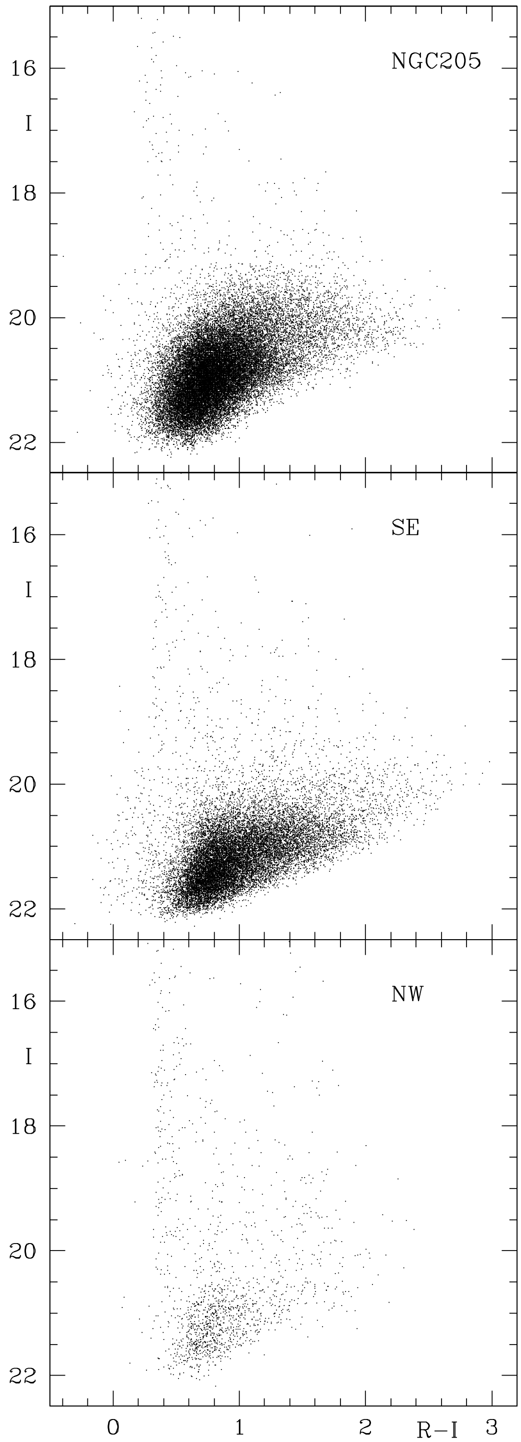

FIG. 4.—Comparison of the CMD of three regions of the field; see text for description.

Following our procedure (see, e.g., Letarte et al. 2002), we apply a criterion for the selection of stars to be plotted on the color-color diagram. Indeed, C stars are among the brightest giants; thus, we do not want to pollute the diagram by including fainter stars having (CN–TiO) color of poorer quality. The criterion could be a magnitude cutoff or, in our case, a photometric error cutoff. Only stars with $\sigma < 0.10$ are retained. Here σ is related to the photometric errors, as given by DAOPHOT, of the two color indices by

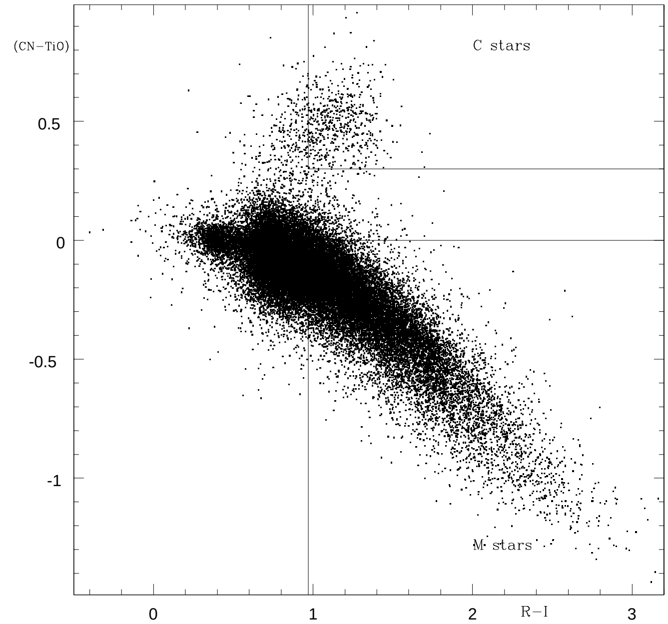

FIG. 5.—Color-color diagram of the whole CFH12K field. More than 500 C stars are found in the box.

$\sigma = (e^2_{R-I} + e^2_{\mathrm{CN-TiO}})^{1/2}$. Figure 5 presents the color-color diagram of 39,700 stars satisfying the criterion. We define two boxes, with blue limits at $(R-I)_0 = 0.90$, containing C stars and M stars. A C star branch is seen to emerge from the central "ball." It has been shown by Demers & Battinelli (2002) that the bluer stars on the C branch, on the left side of the C box, are genuine C stars. They are fainter and show a much larger magnitude dispersion than those in the box. The M star box contains M giants at the distance of M31/NGC 205 along with Galactic giants and dwarfs. Galactic giants are obviously quite bright, while the dwarfs can be of any magnitude and cannot readily be distinguished from the M31/NGC 205 M giants. One needs to compare star counts in fields away from the galaxies to evaluate the foreground contribution.

The spatial distribution of the 532 C stars identified is displayed in Figure 6. The southeast and northwest regions

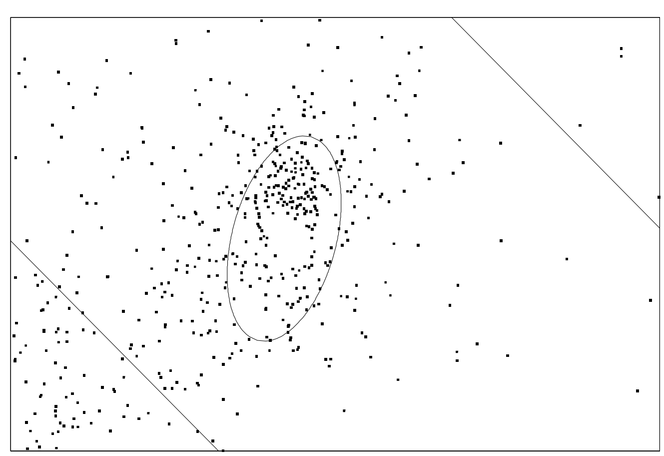

FIG. 6.—Spatial distribution of the C stars. The three regions under discussion are outlined. There is an obvious deficiency of C stars near the center of NGC 205; this is certainly due to crowding.

TABLE 1
C Stars in NGC 205 and Its Surroundings

ID	R.A.	Decl.	I	σ_I	$R-I$	σ_{R-I}	CN–TiO	$\sigma_{\mathrm{CN-TiO}}$
1................	0 38 11.81	41 44 07.10	20.535	0.019	1.380	0.070	0.406	0.051
2................	0 38 14.59	41 37 35.90	19.810	0.015	1.133	0.024	0.378	0.041
3................	0 38 18.87	41 31 46.40	20.184	0.016	1.130	0.027	0.533	0.050
4................	0 38 25.62	41 53 12.70	20.176	0.015	1.255	0.045	0.438	0.035
5................	0 38 25.65	41 53 42.50	19.897	0.014	1.179	0.039	0.476	0.034
6................	0 38 39.55	41 48 45.00	19.831	0.012	1.062	0.027	0.636	0.034
7................	0 38 43.84	41 40 12.00	20.331	0.017	1.296	0.032	0.733	0.055
8................	0 39 04.06	41 33 54.70	19.554	0.009	1.254	0.013	0.502	0.029
9................	0 39 06.89	41 41 21.60	19.618	0.009	1.401	0.015	0.560	0.031
10..............	0 39 07.44	41 47 31.10	20.309	0.019	1.372	0.030	0.506	0.041
11..............	0 39 14.85	41 34 37.50	19.986	0.012	1.025	0.015	0.403	0.039
12..............	0 39 20.39	41 46 14.00	20.601	0.027	0.979	0.044	0.352	0.066
13..............	0 39 21.71	41 33 30.70	19.470	0.008	1.071	0.011	0.426	0.027
14..............	0 39 21.78	41 47 41.50	20.209	0.015	0.982	0.025	0.453	0.041
15..............	0 39 21.85	41 38 24.90	21.047	0.024	1.015	0.036	0.599	0.077
16..............	0 39 21.88	41 34 05.50	20.508	0.029	1.135	0.038	0.562	0.066
17..............	0 39 23.87	41 45 31.80	20.751	0.022	1.009	0.038	0.554	0.061
18..............	0 39 24.48	41 37 06.00	19.982	0.011	1.386	0.019	0.674	0.043
19..............	0 39 31.27	41 45 09.70	20.384	0.021	1.207	0.031	0.385	0.052

Note.—Table 1 is published in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content. Units of right ascensions are hours, minutes and seconds, and units of declination are degrees, arcminutes and arcseconds.

and the 2000 pixel ellipse representing the central area of NGC 205 are outlined. A surface density gradient, from southeast to northwest, and a deficiency of C stars in the core of NGC 205 are obvious. This point is discussed in § 4.2.1. J2000.0 coordinates of the C stars, along with their I magnitudes, $(R-I)$, and (CN–TiO) colors are listed in Table 1. Because we sample not only NGC 205 but a section of the disk, bulge, and halo of M31, the global color-color diagram represents a mixture of populations. As a first step in investigating differences between the C stars in different positions in the field, in Figure 7 we compare the color-color diagram of the three areas described above. The comparison of the NGC 205 diagram with the southeast region reveals some interesting details. The M star branch extends much farther to the red [and (CN–TiO) < -1.0] in the southeast area. This indicates the metal-rich M31 population and was seen by Battinelli et al. (2003) in M31's disk. There are very few blue C stars in the southeast region, again a peculiarity seen in the M31 disk. A few C stars are seen in the northwest region; if they belong to the projected disk of M31, they would be quite far. Further comparison between the NGC 205 and the field C stars is discussed in § 4.3.

4. DISCUSSION

4.1. *The Extent of NGC 205*

In the previous section we differentiate M31 stars and NGC 205 stars by selecting quite conservative spatial sets. Our data extend to sufficiently large distances to allow us to sample well the stellar density of NGC 205 and its environment. Investigation of the isodensity contours of NGC 205 is complicated by the well-known fact (Hodge 1973; Kent 1987; Choi et al. 2002) that its elliptical contours are twisted. This trend is much more pronounced in the inner parts and can be neglected if only the outer regions are under consideration. In our approach, we simply assume that the orientation of the major axis of the isodensity contours is constant and that their ellipticity is also constant. Furthermore, it is known that NGC 205 and M32 exhibit composite surface brightness profiles: no single King model, exponential profile, or power-law profile fits the observed profile at all radii (Kent 1987; Mateo 1998; Choi et al. 2002).

For this study, we select stars with good $(R-I)$ photometry; the database reaches $I \approx 22.5$ and corresponds to the CMD displayed in Figure 2 and the spatial distribution presented in Figure 3. The foreground stars exhibit a strong surface density gradient, decreasing from the southwest to the northeast of the field. The surface density ranges from 175.94 stars per arcmin^2 in the southeast to 15.40 stars per arcmin^2 in the northwest. Taking into account the positions of the elliptical isophotes of NGC 205, we adopt an *average* of 110 stars per arcmin^2 for the stellar surface density of the foreground, to be subtracted from the NGC 205 counts. We count stars within elliptical annuli; the logarithm of the surface density (number of stars per arcmin^2, corrected for the foreground) is plotted, as a function of the angular semimajor axis of the ellipse, in Figure 8. As expected, there is a strong deficiency of stars near the center. This is due to the poor photometric quality of the stellar images. A section of the density profile can be fitted to a power law with a scale length of $2'.85 \pm 0'.10$, corresponding to 670 pc. This value agrees well with the exponential scale lengths determined by Choi et al. (2002) from the surface brightness profile of NGC 205 at various radii. They quote 150″ for $75'' < r < 250''$ and 170″ for $150'' < r < 250''$. They also mention a subtle downward break at $r = 300''$. The overall profile, displayed in Figure 8, appears to curve downward and does not satisfy a power law to the end of our data points. A King model can, however, be fitted quite well to the outer points, as shown in the inset of Figure 8, leading to a tidal radius, as defined by King (1962), of $19'.77 \pm 3'.00$ or 4.6 kpc, a huge value, implying that NGC 205 has never been very close to M31. To our knowledge, this is the first estimate of the tidal radius of NGC 205; previous profiles

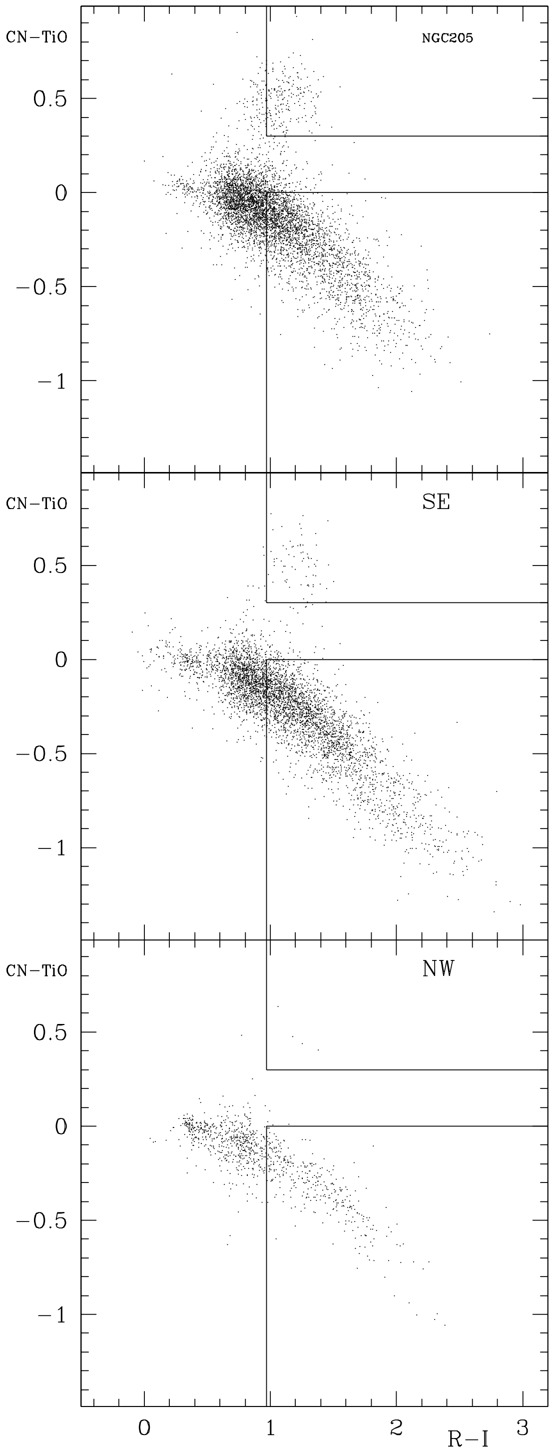

FIG. 7.—Color-color diagrams of the same regions of Fig. 4. Note the difference in the photometric properties of NGC 205, C stars, and those in the southeast corner corresponding to the outer disk of M31.

determined from the integrated light did not reach far enough or could not take into account the light from M31 (Hodge 1973). Once the tidal radius is known, the perigalactic distance R_p between the two galaxies can be inferred from equation (12) in King's (1962) paper,

$$r_{\rm lim} = R_p(M_{\rm NGC\,205}/M_{\rm M31})^{1/3} .$$

The total mass of NGC 205, as determined by Held, Mould,

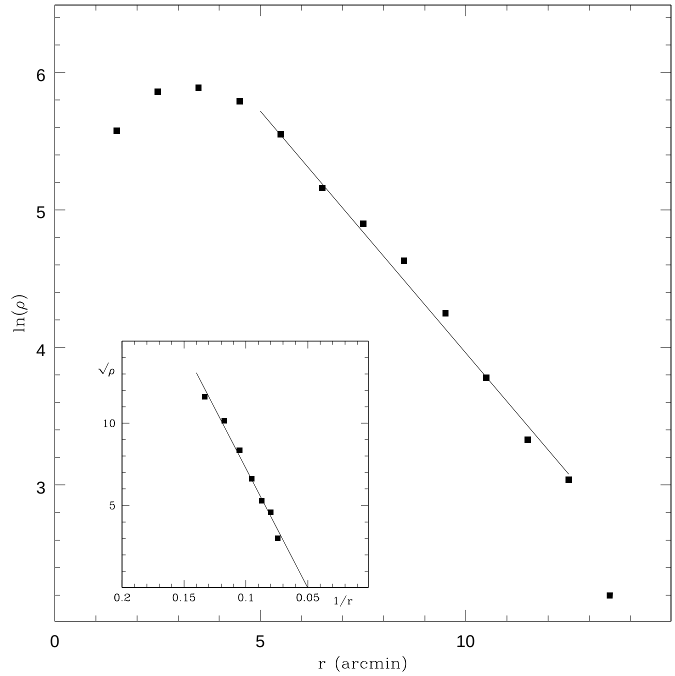

FIG. 8.—Stellar density profile of NGC 205. A section of the profile can be fitted to a power law. Inset shows that the outer points allow us to determine the tidal radius according to King (1962).

& de Zeeuw (1990), is $7.5 \times 10^8\ M_\odot$, while Hodge (1992) suggests for M31 a total mass of $3 \pm 1 \times 10^{11}\ M_\odot$. Such values along with our tidal radius estimate lead us to conclude that the perigalactic distance of NGC 205 is at least ∼42 kpc. This distance difference is too small to be detectable when the $\langle I \rangle$ of C stars in NGC 205 and M31 are compared.

4.2. *The Total Number of* C *Stars in NGC 205*

Our survey leads to the identification of 532 C stars in the whole CFH12K field. Some of these stars belong to NGC 205, while other are in M31. In order to obtain a reliable estimate for the number of C stars in NGC 205 we first have to evaluate the contribution of the M31 foreground to the total number. We proceed as we did to determine the total contribution from the foreground. Analysis of the number of C stars per arcmin^2 in regions well outside NGC 205 shows that their number density varies from the southeast to the northwest; this analysis is described in the next section. The density of foreground C stars over the face of NGC 205, defined as an ellipse with a semimajor axis of 15′ (twice as long as the ellipse drawn on Fig. 6), varies from 0.52 ± 0.02 stars per arcmin^2 in the southeast to 0.05 ± 0.02 stars per arcmin^2 in the northwest, being on average 0.29 ± 0.03 stars per arcmin^2.

We then count the number of C stars in elliptical annuli, as defined before. The surface density is calculated for each annulus and the foreground is subtracted. The logarithm of the surface density (number of C stars per arcmin^2) is plotted as a function of the angular distance on Figure 9. We see again a strong deficiency of stars near the center. The profile is linear up to 10′, with a scale length of $3\farcm9 \pm 0\farcm2$, larger than the scale length determined from all stars. At larger radii the surface density drops appreciably. This trend is seen even in the foreground unsubtracted data and thus cannot be explained by an overestimate of the foreground

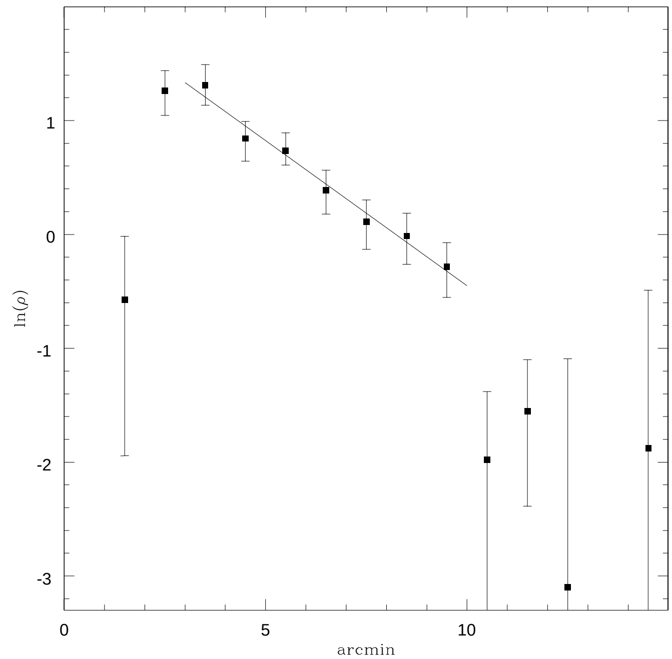

FIG. 9.—NGC 205 C star density profile. A linear fit, with a scale length of 3′.9, fits the data from 3′ to 10′.

density. The number of C stars in NGC 205 within 10′ from its center is estimated, from an extrapolation of the power law of Figure 9, to be 497. In that area there should be 44 additional foreground C stars. We have identified 289 C stars in that ellipse, just a bit more than 50% of the expected ones. This low completeness factor is due to crowding and to the increase of the photometric errors near the center. The number of C stars could be increased slightly by relaxing the error criterion on (CN–TiO); we are however not justified to do so. In the annulus with $10' < a < 15'$ we identify 76 C stars, 55 of which are expected to be foreground stars. Thus, the number of C stars belonging to NGC 205 outside of 10′ is quite small. That is the reason for the large errors associated with the last points of Figure 9.

The total number of C stars in NGC 205 is therefore estimated to be between 500 and 550. This number is lower than expected for a dwarf galaxy as bright as NGC 205 ($M_v = -16.6$; Mateo 1998). NGC 6822, which is slightly fainter, contains over 900 C stars. NGC 205 may offer the first hint that the dwarf elliptical galaxies do not follow the number versus magnitude relation (see Battinelli & Demers 2000) defined nearly exclusively by dwarf irregular galaxies. Our ongoing investigation of NGC 185 and NGC 147 should help to solve this question.

4.2.1. *The Spatial Distribution of* C *Stars in NGC 205*

Form a simple inspection of the distribution of C stars inside the ellipse drawn in Figure 6, we can see that the two halves of this galaxy contain quite different numbers of stars, the northwest half being much more populated. The local densities of C stars in points located symmetrically to the center can differ by more than a factor of 4. To look into the nature of such differences we determine the number of C stars and their average photometric properties in two circular areas of 1′.7 radius (500 pixels) located along the major axis at 3′.7 from the center. The number of C stars found in the northwest and southeast circles are $N_{\rm NW} = 46$ and $N_{\rm SE} = 12$, respectively, yielding a ratio $N_{\rm NW}/N_{\rm SE} = 3.8$. In spite of this outstanding overabundance of C stars in the northwest area, the average values and σ for I, $(R-I)$, and (CN–TiO) in the two circles do not show any significant difference and, as expected, the mean magnitude and colors are identical. This makes us confident that no photometric bias or differential reddening affect the selection of C stars in the two regions. We can increase the number of C stars in the southern half by relaxing our acceptance criterion. The additional "C stars" *are not fainter stars* but stars with poorly determined (CN–TiO) index; thus, the effect is to introduce an unacceptable scatter in the color-color plot. To retain the purity of our photometry, we refrain from doing so.

If we perform the same analysis on the sample, S_1, of stars with good photometry in all the four filters, the full equivalence of the photometric properties persists, while the ratio $N_{\rm NW}/N_{\rm SE}$ drops to 1.7. Finally, considering stars with at least R and I good photometry (sample S_2), again no variation is reported in the local photometric properties, and the ratio $N_{\rm NW}/N_{\rm SE} = 1.1$.

One possible interpretation of these numbers is that the star formation rate (SFR) in the northwest part of NGC 205 was for a certain period, say 1–2 Gyr (age of the bulk of C stars), sensibly higher than in the southeast half. When we consider the sample S_1, this transient boost of the SFR in the northwest half is still visible, since the contribution of intermediate-age stars in S_1 is not negligible. The S_2 sample reaches fainter magnitudes than S_1, and thus contains a larger number of old and faint stars. For this reason, the contribution of intermediate-age stars to the total number becomes negligible. The fact that for S_2 the total number of stars in the two areas is essentially the same means that the SFR enhancement in the northwest area lasted for a short period, and so did not much affect the time integral of the SFR. This conclusion does not conflict with Davidge's (1992) assertion that AGB stars are uniformly distributed over the central region of NGC 205. This statement refers to a $70'' \times 112''$ field that includes the optical center of NGC 205.

4.3. *The* C *Star Population of NGC 205 and Its Surroundings*

In order to disentangle the NGC 205 and M31 C star populations, we split the C stars into two groups: those within an ellipse of semimajor axis equal to 10′ and those outside an ellipse of semimajor axis 19′.8, the tidal radius previously determined. The first set obviously contains mostly NGC 205 C stars, while the second set should contain almost none. Figure 10 contrasts the magnitude distributions of these two groups. The luminosity function (LF) of the NGC 205 C stars has a Gaussian shape with $\langle I \rangle = 20.12$, corresponding to $\langle M_I \rangle = -4.54$ and $\sigma = 0.38$ mag, somewhat larger than seen in other galaxies. The C stars outside of the tidal radius have a rather different LF. Such different LFs obviously require an explanation, which we address later in this section. The question arises as to the origin of the field C stars: disk, bulge, or halo of M31, or tidal stripping from NGC 205? As we earlier traced in Figure 2, the outer disk of M31, from $r \approx 70'$ (16 kpc), is seen in the CFH12K field. From the recent investigation of Battinelli et al. (2003), we know the surface density of C stars in the disk from 75′ to about 130′. We can in principle

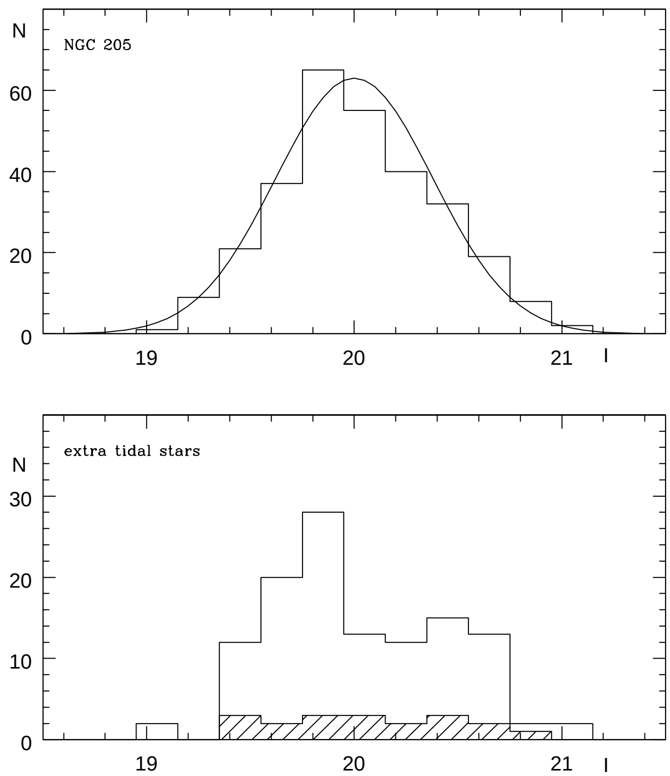

FIG. 10.—Magnitude distribution of C stars within a 10′ ellipse from the center of NGC 205 compared with the magnitude distribution of the 119 C stars outside of a 19.′8 ellipse. The shaded histogram corresponds to the 19 stars seen west of NGC 205.

directly compare these densities. Figure 11 presents such a comparison, where we plot the logarithm of the surface density (stars per arcmin^2) versus the angular distance *along the major axis*. We take into account the fact that NGC 205 is nearly along the minor axis of the M31's ellipses, and thus the angular distances are compacted. The open squares represent the disk surface density, while the filled squares are our density estimates for regions *obviously outside* of NGC 205. Unlike the M31 disk points, our data points are plagued by small number statistics; for example, there are only 68 C stars in the southeast corner region, and on the western side of the field the density of C stars is extremely low. The disk profile declines sharply with distances, while the profile in the NGC 205 direction has a shallower slope. Nevertheless, for a major-axis distance less than $\approx 125'$ both profiles more or less agree, although our counts may be marginally lower. At large distances, on the western side of NGC 205, the C stars do not follow the disk profile. This behavior suggests that some field C stars are part of the bulge and/or inner halo population, or could have been tidally stripped from NGC 205.

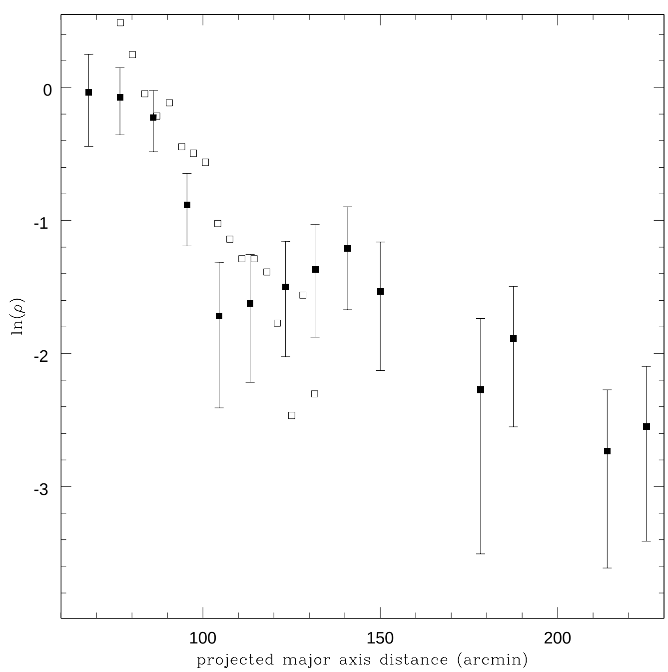

FIG. 11.—Comparison of the surface density profile of C stars in the NGC 205 field (*filled squares*) with those in the southwestern disk of M31 (*open squares*) from Battinelli et al. (2003).

It is relatively easy to evaluate M31's bulge and disk contributions to the total star counts in our field. Knowing the central brightness of the disk and bulge along with the fact that the bulge's profile follows de Vaucouleurs' $r^{1/4}$ law (with an effective semimajor axis $a_e = 17.'5$ with a flattening $b_e/a_e = 0.6$; de Vaucouleurs 1958), while the disk has an exponential profile (with a scale length of 22′; Battinelli et al. 2003), we calculate that in the southeast corner there should be 4 times more bulge stars than disk stars per arcmin^2. The profile of the bulge is much shallower than the disk, declining by a factor of ~ 20 over the whole field, while several scale lengths of the disk are seen in projection. The CFH12K field intercepts the minor axis of the bulge between 15′ and 54′, or from 1.5 to 5 b_e. We therefore expect to see bulge stars in our field. This does not imply, however, the occurrence of C stars among them. Indeed, the presence of a substantial intermediate-age population in the bulge of M31 is still quite controversial. From high-resolution ground-based observations, Davidge (2001) concludes that the bulge is dominated by old stars because the intermediate-age population is centrally located and does not even dominate the central regions. However, Rich, Mould, & Graham (1993) observed what they believe to be bright AGB stars in several locations in the bulge. They suspect, however, that blends could be responsible for most of these bright stars. Simulations by Davidge (2001) have confirmed this assumption. However, the field, symmetrical to ours, observed by Mould & Kristian (1986) contains red stars brighter than the TRGB; these stars could very well be C or M AGB stars. Morris et al. (1994) also believe, from *V*, *I* photometry, that an 8 kpc minor axis field contains AGB stars. The problem here is the separation of the disk and bulge contributions. A surface density profile of the bulge bright red stars, presumed to be AGB, has been published by Mould (1986). The profile is traced along the minor axis (from 3′ to 6′). An extrapolation of that profile, having a scale length of only $1.'6$, indicates that the surface density of AGB stars in the CFH12K field (between 15′ and 50′) should be quite low. One finds densities ranging from 0.1 ± 1.0 on the eastern end to 4×10^{-12} stars per arcmin^2 at the other end. Since C stars constitute a small fraction of the AGB stars, we can then conclude that there should not be any bulge C stars in our field.

If we reasonably assume that the halo of M31, like the Milky Way's halo, does not contain intermediate-age stars, we must thus conclude that the C stars seen on the western side of NGC 205 must be tidally stripped stars from NGC 205 lying along its orbit.

TABLE 2
Properties of C Stars in NGC 205 and Surrounding Field

Region	n	$\langle I \rangle$	$\langle M_I \rangle$	$\langle (R-I)_0 \rangle$	C/M
NGC 205 10′ ellipse	289	20.12	−4.54	1.08	0.09
East side	100	20.11	...	1.15	...
West side	19	20.19	...	1.11	...

Having established that the C stars seen west of NGC 205 do not fit the M31 C star distribution, we return to the LF displayed in the lower panel of Figure 10. The 119 C stars outside of the tidal radius can easily be divided into two subsets: 100 stars to the east of NGC 205, belonging to M31, and 19 stars to the west of NGC 205, proposed to be tidal debris. The magnitude distribution of these 19 stars is represented in Figure 10 by the shaded histogram. Clearly, the extratidal stars include mostly M31 stars having a LF peak nearly identical to those of NGC 205. The western subset, however, shows a flat LF, implying that these stars are not concentrated at a unique distance from us. This is, we believe, a signature of tidal debris lying along the orbit of NGC 205. Table 2 summarizes the photometric properties of the C stars in the three regions under discussion. The same adopted reddening is applied to the entire CFH12K field.

4.4. *The NGC 205 C/M Ratio*

To determine the C/M ratio of NGC 205 we need to estimate the number of Galactic foreground M stars and also the M31 contribution to the M stars. As previously (Battinelli et al. 2003), and following Brewer et al. (1995), we define M-type AGB stars as stars fainter than $I_0 = 18.50$ with $M_{\rm bol} < -3.5$. The $M_{\rm bol}$ of each M star is obtained following the procedure outlined by Battinelli et al. (2003) and assuming that all stars are at the distance of NGC 205.

To evaluate the external contribution to the M star counts of NGC 205, we proceed as we did in evaluating the total number of C stars (§ 4.2). We calculate that 11.56 M stars per arcmin^2 do not belong to NGC 205. We can in this way take into account the M31 and Galactic M stars. This yields $4425 - 1816 = 2609$ M stars in a 10′ ellipse, leading to a $\mathrm{C/M} = (289 - 55)/2609 = 0.09 \pm 0.01$.

This ratio is similar to the one found in the disk of M31 20 kpc from its center (Battinelli et al. 2003) and would suggest that the metallicity of NGC 205 is not too different from that in the outer disk of M31. According to Brewer's et al. (1995) equation (3), linking the abundance to the C/M ratio, the above ratio corresponds to $[m/\mathrm{H}] = 0.06$. This equation, however, is derived from the Pritchet et al. (1987) compilation, which included many galaxies with C/M ratios based on poor statistics. With the new homogeneous data being currently published, a new calibration would certainly be useful.

5. CONCLUSION

Our wide-field survey has revealed the presence of numerous C stars inside and outside of NGC 205. Because NGC 205 is very near M31 and because M31 contains a substantial number of C stars, the interpretation of the observed distribution of C stars around NGC 205 is complicated. However, taking into account the radial density variation of C stars, we conclude that there are 19 extratidal C stars, seen on the western side of NGC 205. Extratidal C stars could also be present on the eastern side, but they cannot be easily isolated from those in M31's disk.

High-resolution H I maps of NGC 205 by Young & Lo (1997) show that the H I isodensity contours are asymmetric relative to the stellar body of NGC 205. The contour gradient being steeper on the southeast side suggests that this side of NGC 205 is plowing into the halo of M31. The C stars seen on the western field would than be in the wake of NGC 205. Clearly, radial velocities of these C stars is required to to confirm this hypothesis and establish their origin.

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