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The Reddening to the Galaxy IC 342 from CCD *BV* Photometry of its Brightest Stars

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ABSTRACT. The intrinsic luminosity and distance to the low-galactic-latitude galaxy IC 342 have been a matter of some debate, largely due to the uncertainty in the estimates for the extinction. The dynamical influence of IC 342 on the Local Group may be more significant than has commonly been believed if a high reddening value and a low distance modulus to this galaxy is confirmed. In an effort to estimate the reddening independently for this galaxy, we have obtained CCD *BV* photometry for 117 stars brighter than $V=22.0$ mag in a field centered near a spiral arm in IC 342. The plume of main sequence and slightly evolved blue supergiant stars is detected at $V=19.4$ mag. However, the plume is centered at a color of $(B-V)=0.54$ mag. A comparison with similar color–magnitude-diagram data for the brightest stars in IC 1613 suggests that these stars in IC 342 are reddened by $E(B-V)=0.79 \pm 0.05$ mag ($A_B=3.32\pm0.21$ mag). This value is in good agreement with the similarly high values suggested by the Burstein–Heiles conversions of Galactic H I column density to color excess, and especially by the recent measurement of the Balmer decrement of H II regions by McCall.

1. INTRODUCTION

Recently McCall (1989) has applied Balmer-decrement techniques to spectroscopic observations of H II regions in the relatively nearby galaxy IC 342 to derive a total reddening to that galaxy. Based upon an average of three independent methods, he derives a total extinction of $A_B=3.05\pm0.25$ mag [$E(B-V)=0.73\pm0.06$ mag, adopting $R_B=A_B/E(B-V)=4.2$ hereafter]. This extinction is about two magnitudes higher than some previous estimates ($A_B=0.59$ mag from Sandage and Tammann 1974; $A_B=1.25$ mag from de Vaucouleurs et al. 1976), but comparable to others ($A_B=2.2$ mag from Ables 1971; $A_B=3.36$ mag from Burstein and Heiles 1984). IC 342 is very close to the Galactic plane ($l=138\overset{\circ}{.}2$, $b=+10\overset{\circ}{.}6$), and in any such individual case, simple statistical models (such as those based on a smooth extrapolation of a cosecant law) are intrinsically uncertain. Therefore, a more direct measure is always desirable. McCall reviews the evidence for large and for small reddenings, and concludes that the large (spectroscopic) determinations are to be preferred. He then considers the impact of such a reddening on the distance to IC 342 and the ensuing contribution of this galaxy to the local gravitational field. Although IC 342 has not previously been considered to be a kinematic member of the Local Group (e.g., Yahil et al. 1977), McCall concludes that four galaxies (the Milky Way, M31, IC 342, and Maffei 1) may in fact be dynamically interacting. If true, the Local Group timing arguments, which assume that M31 and the Milky Way are essentially dynamically isolated, may need revision.

The following short note reports an independent, but direct, measurement of the total reddening (foreground and internal) to stars in IC 342 using *BV* CCD photometry. We find (for the field measured by us) that the reddening is indeed high, in support of the Burstein and Heiles (1984) model and in support of the Balmer decrement measurements of McCall (1989).

2. OBSERVATIONS

In 1988 January, two fields in the galaxy IC 342 were observed at the prime focus of the Canada–France–Hawaii Telescope (CFHT) using the double-density RCA CCD camera (RCA2). One field was centered on the nuclear region of IC 342; the second was offset approximately 3 arcmin to the north so as to fall on a spiral arm. The night was photometric. Preliminary details of the data reduction for this run can be found in Freedman and Madore (1988).

Only the second set of observations will be discussed here inasmuch as the nuclear frame resolved very few member stars. The frames were first bias subtracted and then flat fielded using frames taken on an illuminated region of the dome. Ten bias frames and three independent flat fields for each filter were individually averaged for this purpose. Extraction of photometry for stellar images was performed using DAOPHOT (Stetson 1987). Table 1 gives the (x,y) positions V, B, $(B-V)$ photometry and DAOPHOT errors for all 117 stars brighter than $V=22.0$ mag found and matched on the two frames. For purposes of orientation and identification, in Fig. 1 the measured CCD frame of IC 342 is shown on a reproduction of a photographic plate of IC 342 taken by us at the CFHT prime focus in 1985. The brightest stars in Table 1 are identified in Fig. 2, which is a reproduction of the V CCD exposure. Star No. 21 in Table 1, which is the brightest blue supergiant candidate in this field in IC 342, is also marked.

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TABLE 1
Positions and CCD photometry for Stars in IC 342

Star	x	y	V	B	$(B-V)$	σ_V	σ_B
1	245	731	15.52	16.66	1.14	0.02	0.01
2	357	163	16.61	17.68	1.07	0.00	0.00
3	178	139	16.75	17.86	1.11	0.00	0.00
4	504	72	17.06	17.99	0.93	0.00	0.00
5	590	590	17.66	18.54	0.88	0.01	0.00
6	200	303	18.00	18.99	0.99	0.01	0.01
7	76	540	18.01	18.89	0.88	0.00	0.01
8	529	623	18.06	19.19	1.13	0.03	0.01
9	107	320	18.39	19.45	1.06	0.01	0.01
10	614	43	18.40	19.47	1.07	0.01	0.01
11	414	650	18.51	19.38	0.87	0.01	0.01
12	452	595	18.56	19.81	1.25	0.01	0.01
13	577	433	18.60	19.54	0.94	0.01	0.01
14	550	256	18.73	19.82	1.09	0.01	0.01
15	457	609	18.85	20.22	1.37	0.01	0.01
16	346	83	18.92	19.88	0.96	0.01	0.01
17	242	262	18.99	19.99	1.00	0.01	0.01
18	248	578	19.10	20.47	1.36	0.01	0.01
19	506	509	19.14	20.38	1.24	0.01	0.01
20	34	624	19.15	20.09	0.95	0.01	0.01
21	334	46	19.37	19.87	0.50	0.01	0.01
22	55	208	19.56	21.28	1.71	0.02	0.02
23	14	703	19.69	20.72	1.03	0.01	0.01
24	511	662	19.75	21.03	1.28	0.02	0.01
25	592	692	19.75	21.11	1.36	0.02	0.03
26	35	503	19.80	20.93	1.13	0.01	0.01
27	129	352	19.92	21.04	1.12	0.02	0.02
28	349	88	19.96	20.48	0.52	0.02	0.02
29	459	663	19.99	21.73	1.74	0.03	0.03
30	178	688	20.00	20.95	0.95	0.01	0.01
31	586	697	20.14	20.77	0.63	0.02	0.03
32	23	612	20.20	21.70	1.50	0.03	0.02
33	104	526	20.20	21.38	1.18	0.01	0.02
34	98	511	20.23	21.40	1.17	0.01	0.02
35	264	620	20.25	20.76	0.52	0.02	0.03
36	245	452	20.27	20.86	0.59	0.02	0.01
37	351	94	20.27	20.69	0.43	0.02	0.02
38	129	713	20.27	21.57	1.30	0.02	0.03
39	604	361	20.28	20.84	0.55	0.02	0.02
40	399	744	20.29	20.62	0.33	0.03	0.05
41	330	701	20.32	20.76	0.44	0.02	0.01
42	190	156	20.32	21.72	1.40	0.02	0.03
43	126	571	20.39	21.61	1.22	0.01	0.02
44	343	35	20.40	20.98	0.58	0.03	0.02
45	113	561	20.44	21.10	0.66	0.01	0.02
46	254	107	20.45	21.16	0.71	0.02	0.01
47	256	198	20.45	21.47	1.01	0.03	0.03
48	592	711	20.49	21.13	0.64	0.02	0.03
49	397	741	20.50	20.79	0.29	0.04	0.05
50	347	159	20.52	20.92	0.40	0.03	0.02
51	247	468	20.53	21.19	0.66	0.02	0.02
52	232	85	20.56	21.22	0.66	0.03	0.04
53	299	681	20.62	21.09	0.47	0.03	0.02
54	169	657	20.66	21.31	0.65	0.02	0.03
55	472	187	20.68	21.15	0.47	0.04	0.05
56	456	700	20.79	21.64	0.85	0.03	0.04
57	610	483	20.80	22.48	1.68	0.02	0.05
58	8	60	20.81	21.80	0.99	0.03	0.04
59	524	560	20.82	22.15	1.34	0.03	0.03

TABLE 1
(Continued)

Star	x	y	V	B	$(B-V)$	σ_V	σ_B
60	78	40	20.91	22.22	1.31	0.04	0.04
61	256	590	20.94	21.75	0.81	0.03	0.04
62	184	676	20.95	21.36	0.41	0.03	0.02
63	331	72	20.97	22.31	1.34	0.04	0.05
64	371	696	21.00	21.59	0.58	0.04	0.03
65	405	789	21.01	21.69	0.67	0.03	0.04
66	387	592	21.04	21.65	0.61	0.03	0.02
67	366	237	21.06	21.68	0.63	0.03	0.03
68	191	287	21.09	21.78	0.70	0.03	0.04
69	383	128	21.11	21.49	0.38	0.03	0.03
70	245	96	21.12	21.67	0.55	0.03	0.03
71	272	361	21.13	21.71	0.58	0.04	0.05
72	234	457	21.16	22.32	1.17	0.04	0.04
73	351	40	21.16	21.75	0.60	0.05	0.04
74	224	96	21.18	21.95	0.77	0.03	0.04
75	345	103	21.19	21.71	0.52	0.04	0.03
76	426	448	21.21	21.60	0.40	0.05	0.03
77	180	50	21.21	22.53	1.33	0.04	0.05
78	328	34	21.22	21.97	0.75	0.10	0.05
79	323	665	21.23	22.20	0.98	0.03	0.05
80	374	29	21.25	21.85	0.60	0.04	0.03
81	121	478	21.30	21.77	0.47	0.04	0.05
82	217	8	21.32	21.84	0.51	0.04	0.04
83	248	101	21.33	21.85	0.52	0.03	0.03
84	63	510	21.34	21.92	0.58	0.04	0.04
85	480	509	21.38	23.09	1.71	0.03	0.06
86	290	622	21.38	21.89	0.50	0.05	0.04
87	333	455	21.39	21.96	0.57	0.04	0.04
88	491	424	21.40	22.07	0.67	0.05	0.04
89	496	716	21.41	21.94	0.52	0.04	0.04
90	119	562	21.43	21.96	0.53	0.03	0.05
91	141	490	21.44	21.81	0.37	0.04	0.04
92	439	164	21.48	21.96	0.48	0.05	0.05
93	353	48	21.49	22.14	0.65	0.06	0.05
94	414	676	21.55	22.11	0.55	0.04	0.05
95	560	309	21.56	22.04	0.49	0.05	0.04
96	213	95	21.60	22.14	0.54	0.04	0.05
97	168	670	21.62	22.09	0.47	0.04	0.05
98	561	397	21.63	22.02	0.40	0.06	0.05
99	435	170	21.64	22.05	0.40	0.06	0.05
100	310	483	21.67	22.14	0.47	0.06	0.03
101	128	320	21.68	22.30	0.62	0.06	0.05
102	563	238	21.68	22.29	0.61	0.05	0.04
103	281	625	21.69	22.23	0.54	0.05	0.06
104	555	239	21.70	22.29	0.59	0.06	0.04
105	281	86	21.72	22.36	0.64	0.06	0.06
106	375	712	21.77	22.26	0.49	0.05	0.05
107	417	766	21.84	22.50	0.66	0.06	0.06
108	371	755	21.84	22.25	0.40	0.06	0.06
109	557	234	21.85	22.75	0.91	0.06	0.05
110	501	391	21.86	22.92	1.05	0.06	0.07
111	240	67	21.87	22.45	0.58	0.06	0.06
112	275	608	21.87	22.51	0.64	0.09	0.07
113	236	67	21.87	22.52	0.65	0.06	0.07
114	390	125	21.88	22.35	0.47	0.05	0.05
115	569	264	21.91	22.21	0.30	0.09	0.06
116	40	569	21.97	22.59	0.62	0.07	0.07
117	380	707	22.00	22.20	0.20	0.06	0.05

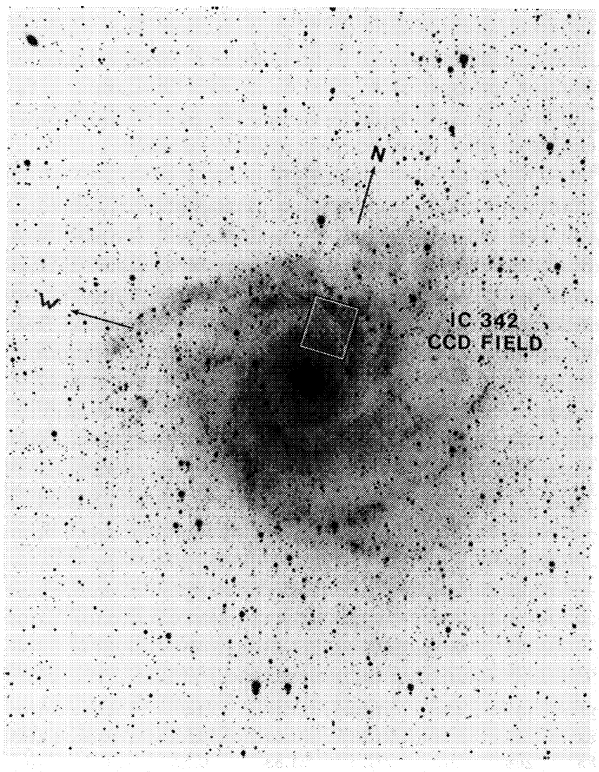

FIG. 1—A reproduction of a plate of IC 342 take at the prime focus of the CFHT. The area marked corresponds to the region over which stellar photometry was obtained on the CCD frame shown in detail in Fig. 2. North is at the top, west to the left. The CCD field, as marked, is 2.1 by 3.4 arcmin.

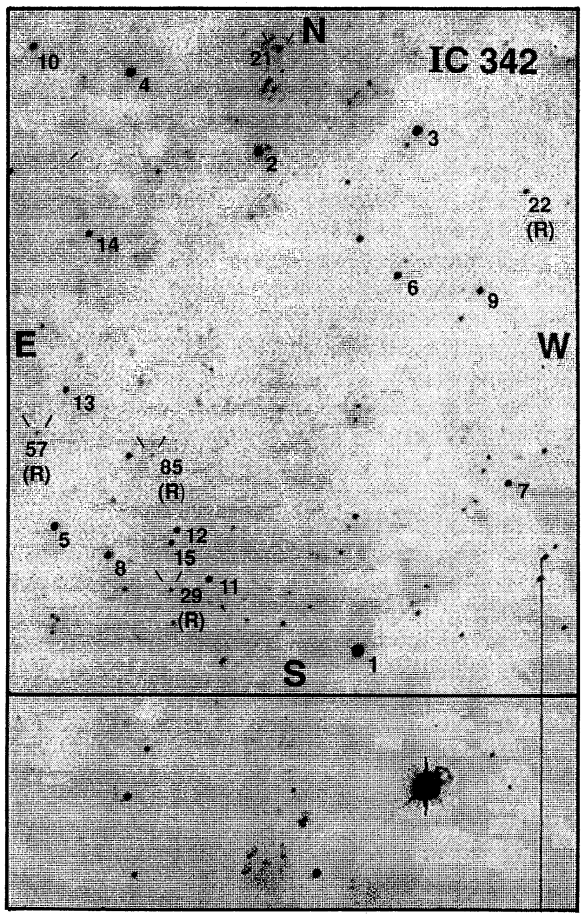

FIG. 2—A reproduction of the V-band CCD frame of IC 342 showing the identifications of the dozen or so brightest stars identified by their numbers in Table 1. Note that the orientation in reflected with respect to Fig. 1; north is at the top, but west is to the right.

3. THE COLOR–MAGNITUDE DIAGRAM AND TOTAL REDDENING

In Fig. 3 we plot the $V-(B-V)$ color–magnitude diagram for the stars in Table 1. We note the following attributes of the distribution. A population of stars at $(B-V)\sim 1.2\pm 0.3$ mag is seen to populate the color–magnitude diagram from $V=15.5$ mag to the frame limit ($V\sim 21$ mag at that color). Brighter than $V=19.0$ mag, these stars are almost certainly all Galactic foreground stars. Fainter than $V=19.0$ mag, this population may contain some intermediate-spectral-type supergiants in IC 342 itself, but again the dominant population is most likely foreground Galactic contamination. To the blue, a second distinct component in the color–magnitude diagram is observed at $(B-V)\sim 0.5$ mag. This plume of "blue" stars (marked by circled dots in Fig. 3) is here identified with the blue plume of main-sequence stars and slightly evolved supergiants as seen in all of the color–magnitude diagrams of galaxies with noteworthy Population I components (see Freedman 1985 and references therein). The only other possibly identifiable and distinct component consists of only four stars (Nos. 22, 29, 57, and 85) at $(B-V)\sim 1.7$ mag. These may be red supergiants in IC 342, but variability studies, proper motions, or direct spectroscopy are needed to confirm this possibility. The brightest red supergiant candidate on this frame (No. 22) appears at $V\sim 19.6$ mag.

There is little doubt that the plume observed at (B

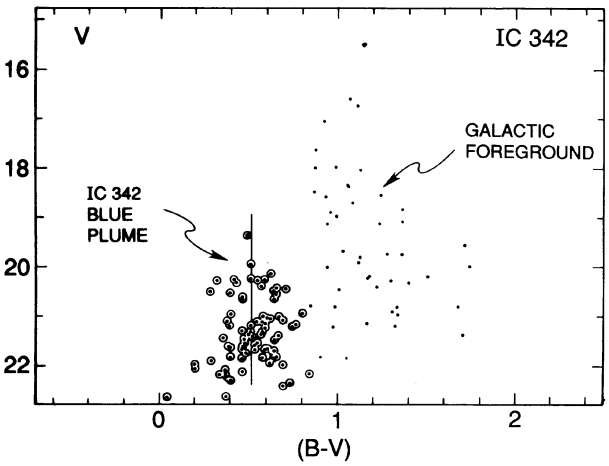

FIG. 3—The color–magnitude diagram for the 141 stars in IC 342 as given in Table 1. The circled dots represent our best guess of the probable members of the blue plume intrinsic to IC 342. The four stars at $V\sim 1.7$ mag are red supergiant candidates in IC 342.

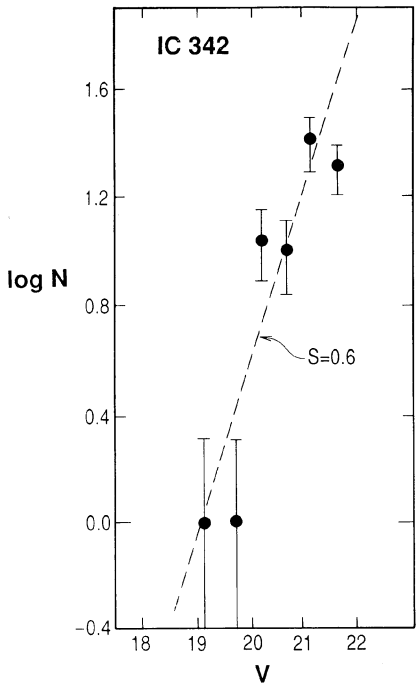

FIG. 4—The logarithmic luminosity function for the blue stars ($B-V \leqslant 0.8$ mag) in IC 342. The solid line has a slope equal to that found by Freedman (1985) to be representative of luminosity functions for a sample of 10 nearby galaxies.

$-V) \sim 0.5$ mag is the main-sequence blue plume, despite its much redder color as compared to other (less reddened) galaxies so far studied. Still, to further test this question, the luminosity function for the IC 342 plume was constructed. According to Freedman (1985) all of the galaxy luminosity functions for the brightest blue stars in nearby galaxies have statistically equivalent slopes of $d(\log N)/dm = 0.6$. All stars fainter than $V = 19.0$ mag and bluer than $(B-V) \sim 0.8$ mag were binned into 0.5-mag intervals, and the results are plotted in Fig. 4. The data for these stars are noisy but entirely consistent with the universal slope found for the young population in other similar galaxies.

Based on a study of similar observations of stars in IC 1613 (Freedman 1988) the color of the blue plume is adopted to be $(B-V) = -0.25$ mag (see also Schmidt-Kaler 1982). Given that identification, it is straightforward to difference these two colors and derive a direct estimate of the total reddening: Galactic foreground reddening plus that within IC 342 itself, amounting to $E(B-V) = 0.79$ mag. The photometric scatter in the IC 342 plume is observed to be ± 0.12 mag in $(B-V)$, which with 70 stars being measured gives *a formal error on the mean reddening* of only ± 0.014 mag. A more realistic external error would be ± 0.05 mag which comes directly from the uncertainty in adopting an appropriate color for the blue plume, which in turn depends on the intrinsic luminosity and evolutionary mix of brightest stars present in any given system; however, in no case are the stars expected to be bluer than $(B-V) = -0.33$ mag.

Noting the obvious and patchy gradient of Galactic foreground extinction over the entire region occupied by IC 342 we hasten to emphasize that additional direct determinations of the reddening at other positions in IC 342 may well yield large deviations from the value cited here. Nevertheless, this new value does lend support to the notion that the total extinction in the direction of IC 342 is high, and since our measurement is very near to the center of the IC 342 field it is probably representative of the average (albeit highly variable) reddening for this galaxy as a whole.

4. CONCLUSIONS

From direct BV photometry of the brightest stars in IC 342 we derive a reddening of $E(B-V) = 0.79 \pm 0.05$ mag. This confirms the large reddening to IC 342 based on Balmer-decrement observations of four H II regions in IC 342 as discussed by McCall (1989). These observations also support the Galactic extinction model for the region around IC 342 as given by Burstein and Heiles (1984). The large reddening value suggests that an accurate distance determination to this galaxy is important to test the assertion by McCall that the dynamical influence of IC 342 on the Local Group is significant.

The referee has rightly pointed out that a discussion of the adopted value of the ratio of total to selective absorption $R_B = A_B/E(B-V)$ is also in order when assigning an uncertainty to the extinction derived here from a reddening. We have adopted a value of $R_B = 4.2$. This base value as determined for normal regions in our own galaxy has an uncertainty of ± 0.1 (as reviewed by Crawford and Mandwewala 1976); however, the systematic variation of R_B with reddening itself is perhaps of more concern in the present context of large $E(B-V)$ (i.e., the reddening trajectory becomes nonlinear at large reddenings). However, according to Schmidt-Kaler (1982 and references therein) $R_B = 4.30 + 0.28(B-V)_0 + 0.04E(B-V)$. Inputting the values appropriate to the IC 342 stars we find that our adopted value of R_B is 0.06 too small, but it is still well within the quoted uncertainty ascribed to R_B initially. In any case this added uncertainty is still only a 2% effect as compared to the factor-of-5 controversy originally surrounding the value of the extinction, as discussed in the Introduction.

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