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Very red stars between the Magellanic Clouds: discovery of carbon stars in the outer LMC and SMC haloes

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ABSTRACT

We present a list of 57 very red stars, $B-V>1.75$, selected from $\sim 5\times 10^5$ stars in three UK Schmidt fields between the Magellanic Clouds. These stars have an apparent magnitude distribution compatible with LMC carbon stars. They are located between 5° and 15° from the centre of the LMC. Follow-up spectroscopy of most of the candidates shows that more than two-thirds of them are indeed carbon stars. These red stars should be useful to establish better the dynamics of the outer haloes of the Magellanic Clouds.

Key words: stars: carbon – Magellanic Clouds.

1 INTRODUCTION

It is now recognized that the Large Magellanic Cloud (LMC) is much larger than previously believed (Irwin, Demers & Kunkel 1990; Irwin 1991). Its halo extends, on the west side, as far as a right ascension of $03^{\rm h}40^{\rm m}$, some 9° from its optical centre. In this inter-Cloud region, one observes a series of young associations extending from the Small Magellanic Cloud (SMC) wing to the LMC halo. The space between the Magellanic Clouds is not, however, filled with Population II stars. Grondin, Demers & Kunkel (1992) have shown that the outer haloes of the Magellanic Clouds do not touch each other. In contrast to the H I envelope, the Magellanic Clouds are not embedded, at the present epoch, in a huge stellar envelope. The nature of inter-Cloud stars of unusual colours is, however, far from well established. Following our survey of blue stars, we present now a list of stars on the other side of the colour–magnitude diagram.

2 THE DATA

The photographic data presented here were obtained from three pairs of UK Schmidt plates (IIIaJ and IIIaF), centred on ($02^{\rm h}48^{\rm m}$, $-73°36'$), ($04^{\rm h}0^{\rm m}$, $-73°$) and ($02^{\rm h}00^{\rm m}$, $-68°$), used by Irwin, Demers & Kunkel (1990) to identify the young stellar population of the inter-Cloud region. These plates have been scanned by the APM in Cambridge. For the first two fields, the instrumental photographic magnitudes were calibrated and transformed into the B, V system using several CCD frames. The CCD data were those of Grondin et al. (1990), Demers et al. (1991) and Grondin et al. (1992), which represent observations of the young associations in the inter-Cloud region. These targets are distributed between $02^{\rm h}20^{\rm m}$ and $04^{\rm h}20^{\rm m}$, giving good cover of the first two fields. Nearly 100 stars are available for the calibration of each field. In order to check the constancy of the transformation equations across the plates, we calculated the V, $B-V$ of stars in one association using the coefficients obtained from the regression from stars in another association. The average residuals in V and in $B-V$ were ~ 0.06 mag. Details of the transformation coefficients are given by Demers & Irwin (1991). For the third field, the calibration was carried out by making use of the known properties of the foreground galactic stellar population. This procedure is relatively simple and stable when only coefficients corresponding to a linear fit are required, as in this case.

The first two plates cover a region of the sky roughly ranging from $02^{\rm h}0^{\rm m}$ to $04^{\rm h}40^{\rm m}$ in right ascension and from $-76°$ to $-70°$ in declination. This region stretches from the tip of the SMC wing to the LMC halo. We have magnitudes and colours for roughly 350 000 stars to $V\sim 20$. It is therefore quite easy to select subsets of stars based on given criteria. Looking at the extreme right of the colour–magnitude diagram, we present, in Table 1, a list of stars redder than $B-V=1.75$. These red objects have been classified 'stellar' by the APM; this is a condition needed to exclude non-stellar objects, which sometimes have abnormal colours. Their appearance on the blue and on the red plates is often quite different, leading to extreme colours. Stars 8 and 8a refer to the same star detected on both plates. The magnitude difference of these two sets of measures is somewhat larger than the value expected from the residual quoted above. This can be explained by the fact that star 8 is very close to the edge of the plate. Such a red star could be slightly variable. Along with the V magnitude and $B-V$ colour, we give, in the last two columns, the angular distance between the star and the dynamical centre of the LMC (Bessell, Freeman & Wood 1986) and of the SMC (Hindman 1967). The harvest from the third field is presented in Table 2. One must keep in mind that these magnitudes and colours are not as well calibrated as the ones in the previous table.

Computer-produced finding charts are presented in Figs 1, 2 and 3; they are displayed for the three UK Schmidt fields. Each chart corresponds to 5×5 arcmin^2.

In order to check the nature of these very red stars, a number of them were observed, in 1991, with the MODular spectrograph attached to the duPont telescope on Las Campanas. The 1200/7500 grating, set for a central wavelength of 7730 Å (corresponding to 1.2 Å pixel^{-1}), was used. A 1-arcsec slit was used with exposure times of 900 or 1200 s. The identified spectral types are given in Tables 1 and 2. The spectrum of star 3 is displayed in Fig. 4. Fujita (1989) has identified the major features of carbon-star spectra, in this wavelength range, to be due to the CN red system ($A^2\Pi - X^2\Sigma$). The band heads are at $\lambda\lambda$7873, 8067, 8271 and 8485. As a comparison, we also obtained the spectra of star B-8, a known carbon star, from the list of Blanco, McCarthy & Blanco (1980). Its spectrum is quite similar to our carbon-star spectra.

Table 1. Very red stars between the Magellanic Clouds.

No.	RA	(1950)		Dec			V	B−V	Sp	θ_{LMC}	θ_{SMC}
1	2	2	41.62	−76	13	39.8	16.56	2.03	C	15.6	5.3
2	2	8	23.24	−75	15	23.4	16.39	2.25	C	15.3	5.1
3	2	25	36.91	−73	3	16.9	16.83	1.84	C	14.3	6.0
4	2	34	28.92	−72	57	41.2	18.00	1.80	–	13.6	6.7
5	2	50	27.35	−74	37	43.4	16.84	1.77	M	12.5	7.7
6	2	57	54.53	−73	51	46.4	18.23	1.78	–	12.0	8.2
7	3	22	34.58	−75	13	8.3	16.91	1.87	M	10.6	9.8
8	3	30	39.01	−75	12	51.4	17.00	2.23	C	10.1	10.3
8a	3	30	39.52	−75	12	52.0	16.83	2.30	C	10.1	10.3
9	3	54	2.49	−73	23	54.8	17.32	2.16	M	8.0	12.2
10	3	59	17.51	−73	20	32.3	16.82	2.46	C	7.6	12.6
11	3	59	36.54	−73	49	14.1	17.18	2.11	C	7.8	12.4
12	4	1	4.47	−72	8	14.6	16.14	2.37	M	7.1	13.1
13	4	8	30.15	−70	34	40.4	16.15	2.91	C	6.3	14.4
14	4	13	13.10	−72	56	23.7	17.45	2.18	C	6.5	13.7
15	4	17	50.84	−71	53	5.0	16.73	2.19	C	5.8	14.4
16	4	18	28.28	−71	1	8.0	17.78	2.02	–	5.6	14.9
17	4	19	41.39	−72	39	45.4	17.32	2.15	–	6.0	14.2
18	4	19	45.63	−72	29	8.5	16.77	1.90	C	5.9	14.3
19	4	20	42.33	−70	55	48.3	16.10	1.96	C	5.4	15.1
20	4	21	28.55	−75	1	36.8	16.73	2.05	–	7.3	13.5
21	4	21	57.95	−73	45	33.0	16.37	1.85	M	6.4	13.9
22	4	22	4.67	−72	50	18.5	16.29	1.94	M	5.9	14.3
23	4	22	35.64	−72	57	30.4	16.64	1.87	M	5.9	14.3
24	4	23	2.59	−72	28	15.8	16.23	2.17	M?	5.7	14.5
25	4	23	4.84	−74	54	13.7	15.61	1.86	C	7.1	13.7
26	4	23	15.41	−74	6	36.8	17.30	1.96	C	6.6	13.9
27	4	23	58.72	−72	25	49.2	16.58	1.86	M?	5.6	14.6
28	4	24	38.02	−72	42	11.8	16.74	1.86	–	5.7	14.5
29	4	24	58.81	−73	51	17.1	18.15	2.09	C	6.3	14.1
30	4	25	6.40	−71	49	39.7	17.13	1.87	–	5.3	14.9
31	4	26	19.43	−73	25	4.4	16.73	1.88	C	6.0	14.4
32	4	26	39.68	−72	23	1.5	16.75	2.10	C?	5.4	14.8
33	4	27	35.38	−72	1	35.4	16.89	2.84	C	5.2	15.0
34	4	28	5.31	−73	31	41.7	16.83	1.96	–	5.9	14.4
35	4	28	5.48	−73	24	59.4	16.53	1.87	–	5.9	14.5
36	4	29	35.18	−73	49	34.2	16.47	1.84	M	6.1	14.4
37	4	29	55.98	−72	11	48.5	16.73	2.68	C	5.1	15.1
38	4	30	7.65	−73	10	13.6	16.43	1.91	C	5.6	14.7
39	4	37	27.61	−75	25	17.8	17.09	1.84	M	6.9	14.4
40	4	38	29.15	−73	43	27.8	16.96	2.81	C	5.5	15.0
41	4	38	35.94	−75	5	13.5	17.32	2.24	C	6.6	14.6
42	4	39	25.36	−74	55	25.5	17.00	2.62	C	6.4	14.7
43	4	39	38.25	−74	8	59.4	16.47	2.50	C	5.8	14.9

Table 2. Very red stars in the north-east halo of the SMC.

No.	RA	(1950)		Dec			V	B−V	Sp	θ_{SMC}
44	1	24	15.38	−70	41	44.2	17.18	1.72	M?	2.6
45	1	26	25.81	−70	50	28.4	16.77	1.82	C	1.9
46	1	27	15.12	−69	42	26.9	17.33	1.77	C	3.6
47	1	28	57.17	−69	41	5.5	16.55	1.75	wkC	2.7
48	1	29	53.49	−70	42	53.8	16.83	1.74	C	2.2
49	1	30	18.01	−69	22	37.3	16.54	1.83	wkC	3.0
50	1	32	30.00	−69	56	22.0	17.69	2.77	C	2.8
51	1	34	31.04	−68	28	36.1	16.84	2.00	C	3.9
52	1	37	44.70	−70	28	34.6	16.76	1.82	C	3.5
53	1	40	33.92	−69	31	18.1	16.49	1.82	wkC	4.4
54	1	45	55.91	−70	46	3.4	17.09	2.01	C	3.9
55	1	51	08.90	−70	42	54.1	17.59	1.71	wkC?	4.0
56	2	21	33.44	−68	36	29.1	15.74	1.82	M	7.6
57	2	26	39.63	−68	00	31.8	15.52	2.28	M	8.4

3 DISCUSSION

Carbon stars are expected among the intermediate-age population (Mateo & Hodge 1986; Demers et al. 1991) of the LMC halo. The magnitude distribution of our spectroscopically confirmed carbon stars is similar to the distribution of apparent V magnitudes of LMC carbon stars observed by Richer (1981). The comparison is presented in Fig. 5.

A review of the carbon-star surveys in the Magellanic Clouds has recently been presented by Azzopardi & Rebeirot (1991); none of these surveys extends into the inter-Cloud region investigated here. On the LMC side, for example, the spatial overlap between our fields and the regions surveyed by Blanco & McCarthy (1990) is essentially nil. None of their stars coincides with our short list of candidates. The catalogue published by Westerlund et al. (1978) does not include stars in our regions. The survey of CH stars of Hartwick & Cowley (1988) overlaps a little with our fields. One star, their no. 004, is within our region. From our data base, we found that the nearest star to it is 36 arcsec from their published coordinates and has a magnitude $V = 15.67$ and $B-V = 1.37$. This colour is reasonable for a CH star, but it is not red enough to be included in our list. On the SMC side, the survey by Blanco et al. (1980) does not go far enough east into the wing to reach our region.

The break in the θ_{LMC} distribution at $\sim 8°$ (Table 1) roughly coincides with the western limit of the LMC halo in that direction. It is, then, reasonable to assume that the stars east of $03^h 54^m$ are members of the LMC halo. The origin of the other ones is more problematic. They could even be associated with the halo of the Galaxy. Bothun et al. (1991) have identified carbon stars in the galactic halo as far as 115 kpc. We intend to pursue spectroscopic follow-up observations; the radial velocity of these stars will be useful to understand better the kinematic properties of the outer haloes of the Clouds.

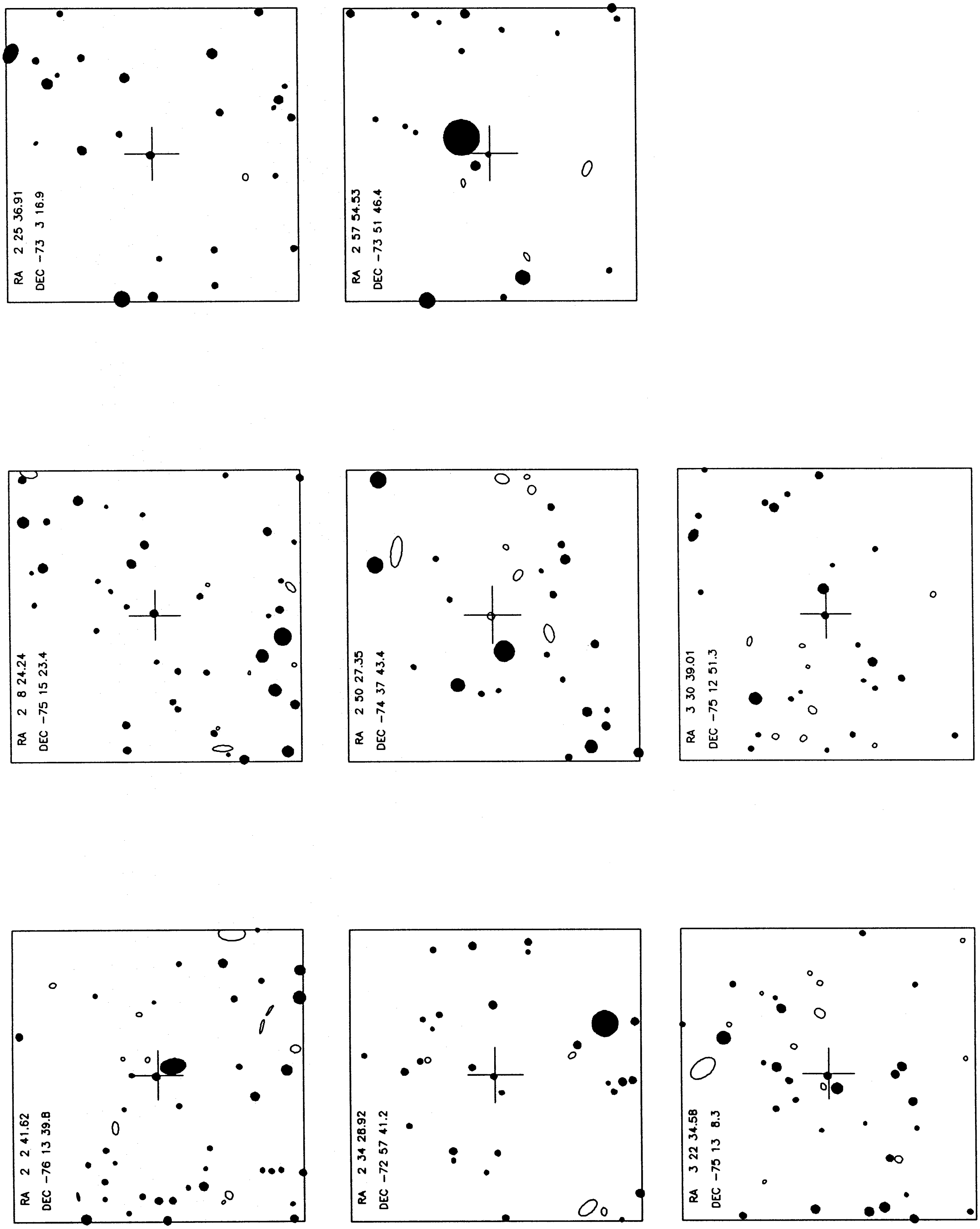

Figure 1. Finding charts for the field centred on 02^h28^m, $-73°36'$. The size is 5×5 arcmin^2. North is to the top and east to the left. The charts are displayed in order of right ascension. The cross in the middle is 1 arcmin across.

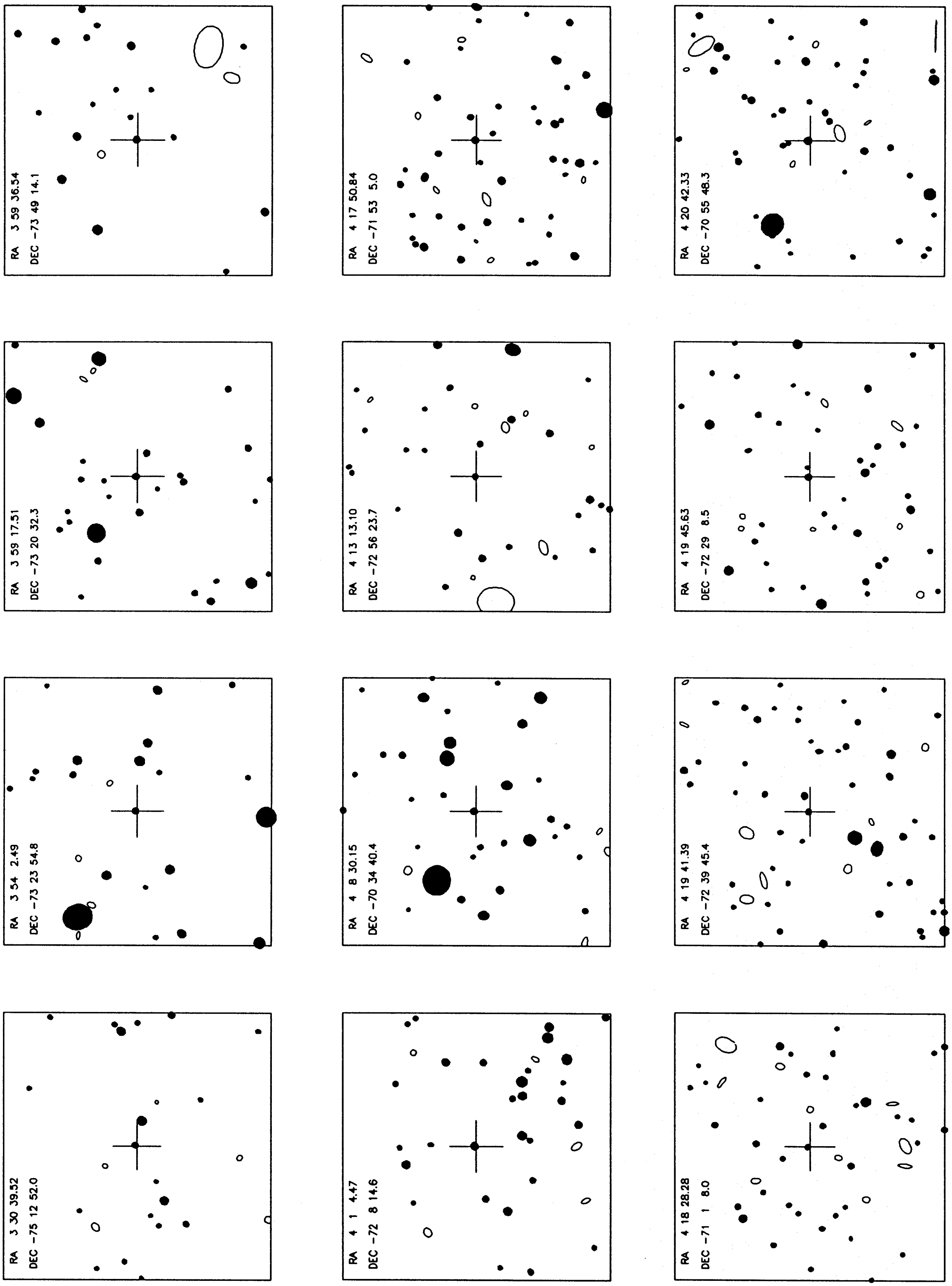

Figure 2. Finding charts for the field centred on 04^h0^m, $-73°$.

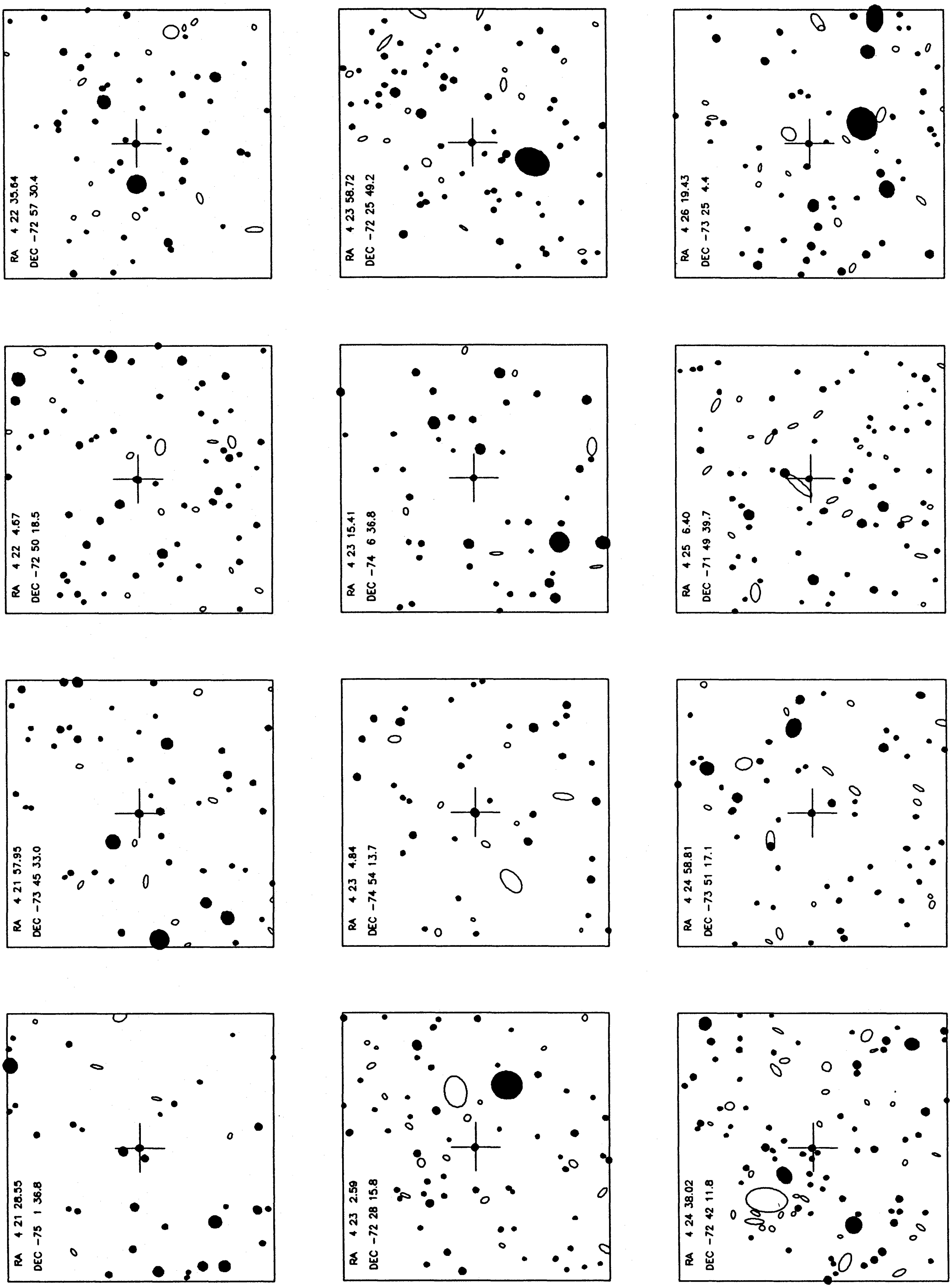

Figure 2 – *continued*

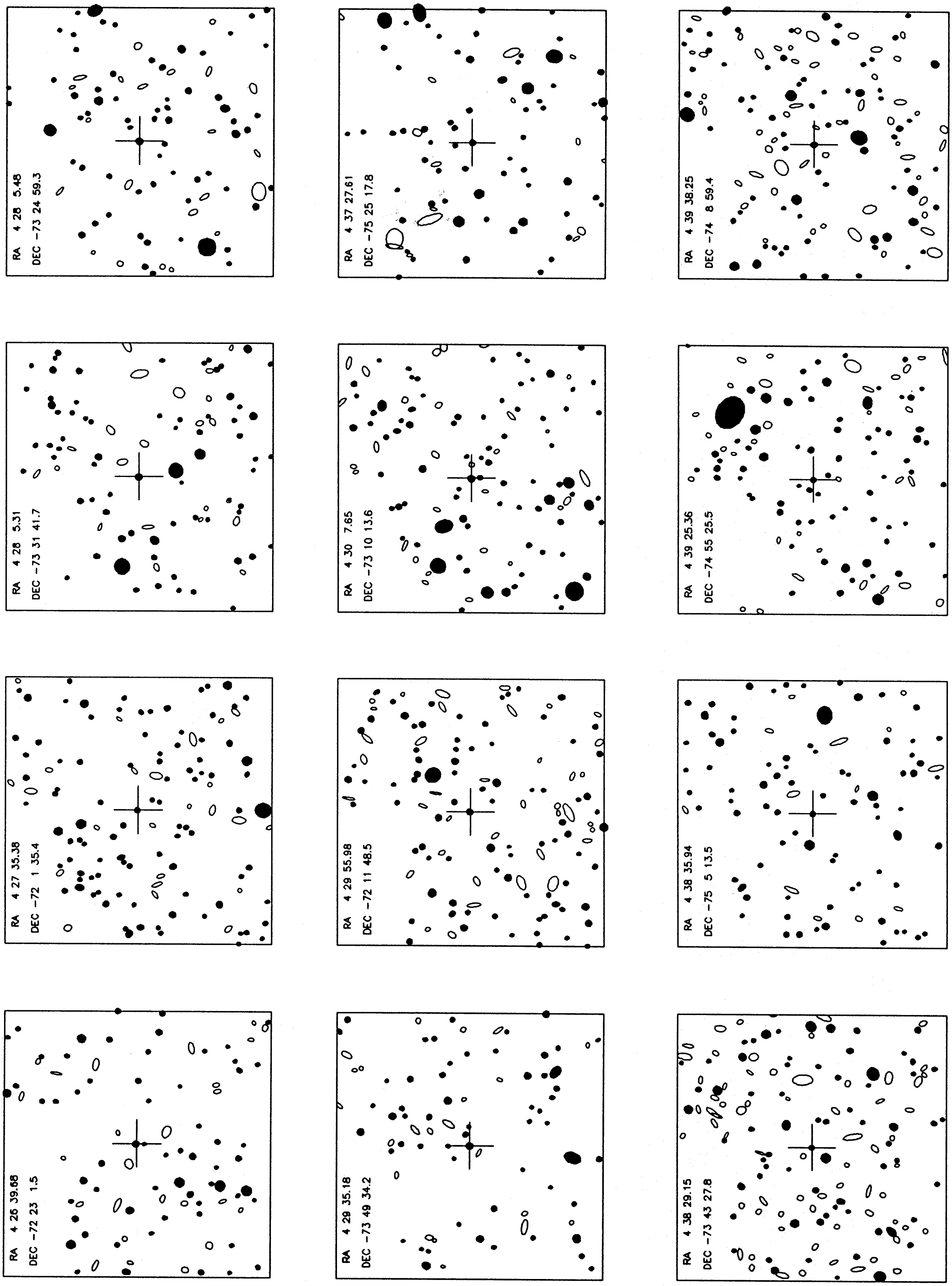

Figure 2 – *continued*

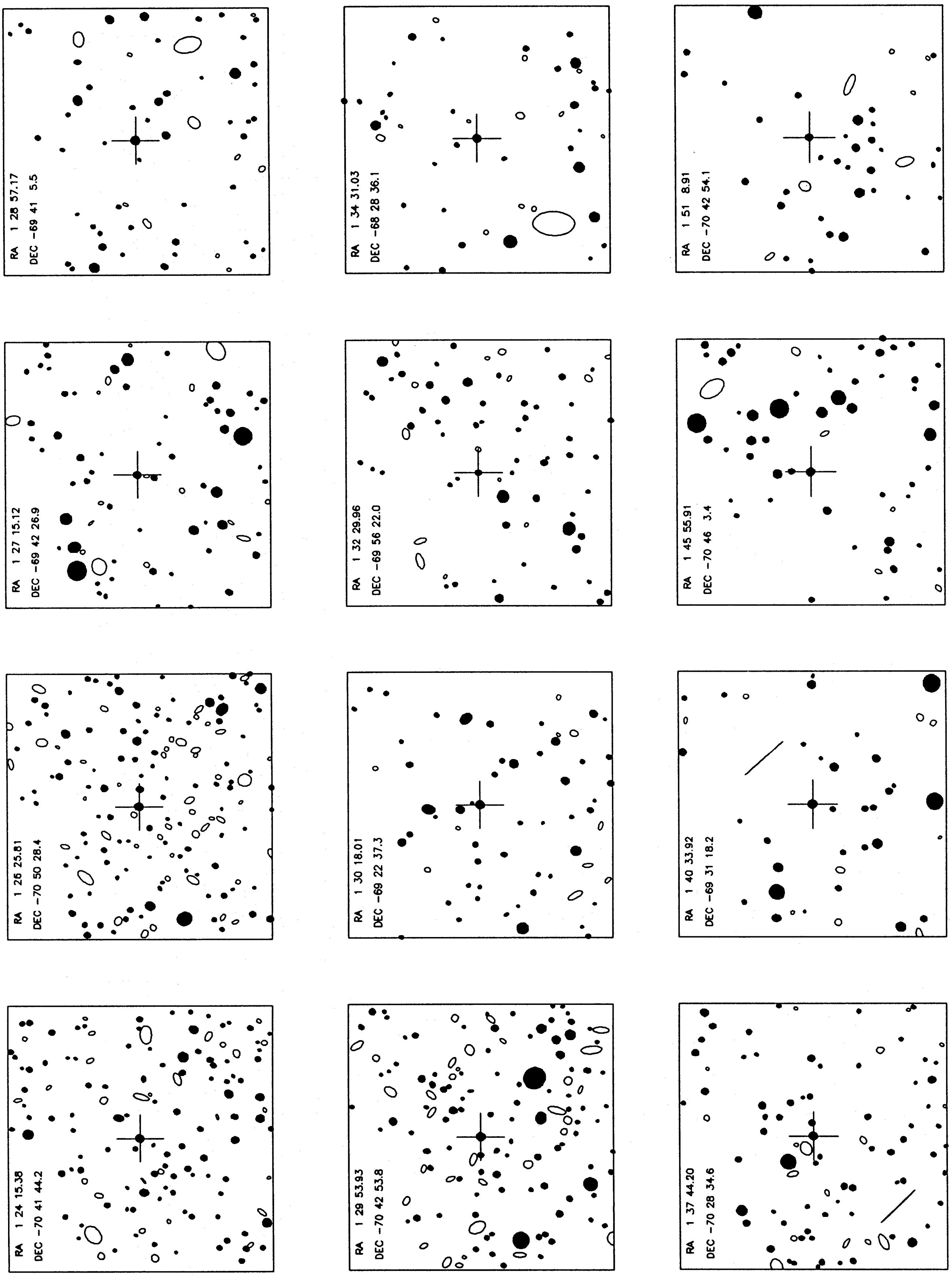

Figure 3. Finding charts for the field centred on 02^h0^m, $-68°$.

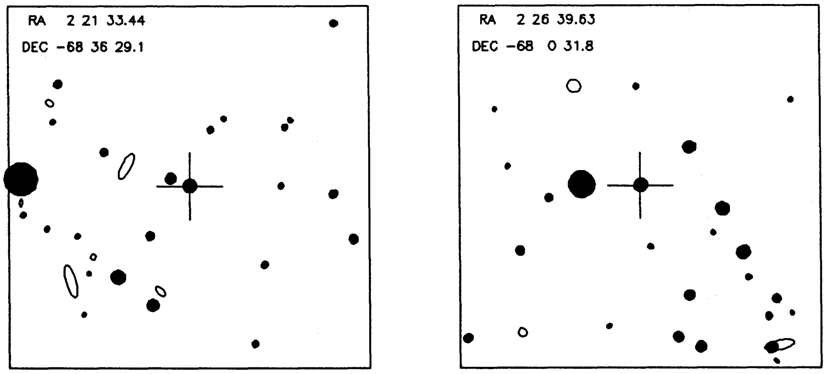

Figure 3 – *continued*

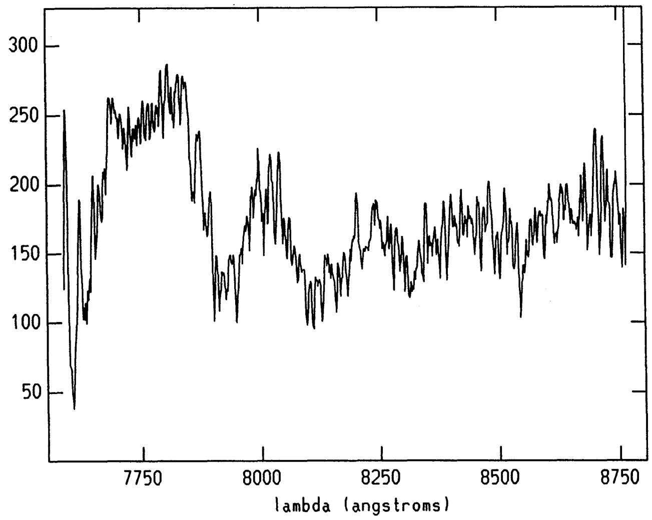

Figure 4. Spectrum of one of the newly identified carbon stars, star no. 3 in Table 1.

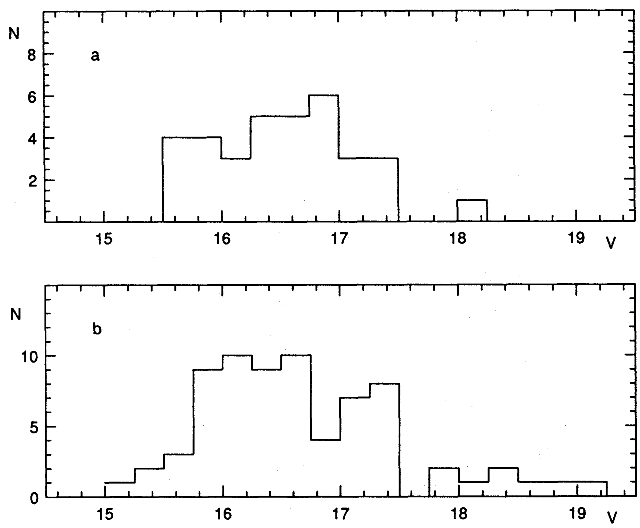

Figure 5. (a) Magnitude distribution of the spectroscopically confirmed C stars. (b) Apparent magnitude of a sample of LMC carbon stars.

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