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MULTI-COLOUR PHOTOGRAPHIC PHOTOMETRY OF ORION FLARE STARS

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SUMARIO

Se presenta la fotometría fotográfica de estrellas Ráfaga en el agregado de Orión, basándose en dos secuencias fotoeléctricas en el sistema *UBVR*. La precisión de la fotometría fuera de la nebulosa principal es suficiente como para discutir el exceso ultravioleta y azul encontrado por Haro, y examinar su efecto en el diagrama magnitud-color. De la evidencia derivada de una banda restringida en el diagrama *V—R/V*, debido probablemente al hecho de que las anomalías de color son mínimas en el visual y en el rojo, se concluye que seguramente la mayoría de las estrellas Ráfaga estudiadas son miembros del agregado de Orión.

ABSTRACT

Photographic photometry of flare stars in the Orion aggregate, based on two *UBVR* photoelectric sequences, is presented. The photometric accuracy outside the main nebulosity is sufficient to discuss the ultraviolet and blue excesses found by Haro, and to examine their effect on the colour-magnitude diagram. From the evidence of a restricted band in the *V—R/V* diagram, due probably to the fact that colour anomalies in the visual and red are minimal, it is concluded that by far the majority of flare stars are members of the Orion aggregate.

I. Introduction

The results of multi-colour photographic photometry of 68 Orion flare stars to $V = 16^m$ (Andrews 1969) in the standard *UBVR* system (Johnson et al. 1966) were briefly summarized at the I. A. U. Colloquium on "Non-Periodic Phenomena in Variable Stars", Budapest 1968. In the present paper the mean photometric results for 141 flare stars from Haro's list (1968) are presented to $V = 18^m$, and colour-magnitude and colour-colour diagrams are constructed. In Sections II and III the standdard photometric data upon which this work is based, and some details of the photographic material are given. The photometric accuracy of the mean results is sufficient to discuss the peculiar observed colours of the flare stars, as pointed out by Haro, particularly the scatter in the colour-magnitude diagrams and the appearance of many faint blue flare stars below the main sequence.

In common with a number of T Tauri-type variables, several flare stars within the Orion aggregate possess, outside flares, large and sometimes variable ultraviolet and blue colour-excesses (Joy 1949, Herbig 1952, Haro and Herbig 1955, Mendoza 1966). These may be attributed to variations of the observed line and continuum emission, usually veiling or obliterating underlying late-type spectra, and to the presence in some flare stars of an intense ultraviolet emission-feature shortward of λ 3750. Estimates of the effect of line emission upon the *B—V* colours of T Tauri-type stars and, subsequently, upon the position of these stars in the *H—R* diagram have been discussed (Herbig 1958, Varsavsky 1960, Smak 1964, Aveni 1966) but continuum emission will seriously complicate these correction procedures in the majority of flare stars. Least affected by emission in the present work is the *V—R* colour. The *V* and *R* plate-filter combinations used practically cut off longward and shortward of the H-alpha line, respectively. In Section IV the colour excesses of the flare stars are examined, and the stars classified according to their position in the colour-colour diagrams.

II. Standard Photometric Data

In two regions north and south of the Orion Nebula, standard UBVR photoelectric sequences were set up at 5^h27^m, $-4.^\circ4$ and 5^h35^m, $-6.^\circ0$ (Equinox 1900). Regions avoiding the main body of variables and clear of nebulosity were selected. The photometric equipment employed at the 60-inch reflector of the Boyden Observatory has been described previously (Andrews 1969). A large number of scattered photoelectric standards were also set in the region of the Orion aggregate to study the magnitude transfers across photographic plates each covering 2.9 × 2.9 sq. degs obtained at the 32/36-inch ADH Baker-Schmidt telescope. Excellent but non-linear transformations for the 60-inch from instrumental to standard magnitudes and colours in the Johnson *UBV* system were provided by C. J. Butler (private communication). For the red magnitude scale a 4-magnitude perforated aperture-screen was employed to first establish *V—R* colours for several primary standards within each sequence at about $V = 9^m$ using the Arizona-Tonantzintla Catalogue stars (Johnson et al. 1966). The transformations for 34 stars were linear to the red limit, $V-R = 1^m5$, to which the observations reached. The probable errors for the primary standards within the sequences in *V, U—B,*

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$B-V$ and $V-R$ were ±.014, ±.035, ±.007 and ±.018 magnitudes, respectively. The photoelectric sequences reached limiting magnitudes in U, B, V and R of 17.9, 17.2, 16.1 and 15.5, respectively. The magnitude scales finally adopted in the plate reductions were photographically smoothed and interpolated to a number of other stars in the region of the sequences. Six ADH plates in each spectral band were measured on the Sartorius iris-photometer at the Armagh Observatory. Since the above photo-electric sequences did not reach the faintest measurable star several objetive-grating plates were utilized to extend the B and V scales to 18th magnitude. The grating calibration by Butler and Wayman (1969), obtained from independent photoelectric measures over the entire photographic range of the ADH plates, gave very satisfactory results. A grating constant for the red plates ($G = 4^m42$) was derived separately by the author, and applied to give an extension of 0^m5 to the red scale to reach 16th magnitude. The plate-filter combinations are given in my previous paper, together with a discussion of the reduction procedures. Average internal standard deviations of the photographic measures within one degree of a sequence to the U, B, V and R magnitude

TABLE 1

ORION SEQUENCE I *Centre 5^h27^m, $-4°4$ (1900*

Chart Ident.	*U*	*B*	*V*	*R*	*Parenago Number*
1	11^m25	9^m99	8^m77	7^m88	866
2	8.57	8.77	8.81	8.77	908
3	12.15	9.99	8.21	6.77	857
4	10.53	10.67	10.10	9.61	878
5	11.51	11.29	10.77	10.25	784
6	11.59	11.61	10.92	10.36	824
7	11.93	12.02	11.29	10.82	917
8	14.25	13.16	11.73	10.56	895
9	13.60	12.94	11.84	10.97	930
10	12.68	12.61	11.96	11.40	804
11	13.89	13.33	12.40	11.55	952
12	13.29	13.26	12.69	12.08	767
13	13.56	13.45	12.77	12.05	793
14	15.08	14.82	13.99	12.97	924
15	17.35	16.01	14.50	13.02	
16	15.57	15.56	14.85	13.86	
17	17.50	16.71	15.53	14.32	
18	16.71	16.48	15.53	14.63	
19	16.64	16.56	15.71	14.85	
20	17.49	17.27	16.63	15.39	
21	17.28	16.90	15.90	15.09	
22	13.76	11.97	10.19	8.67	748
23	10.54	10.42	10.22	10.02	775
24	15.41	15.23	14.41	13.43	979
25	16.04	15.61	14.56	13.35	936
26	15.71	15.55	14.75	13.70	980
27	17.60	16.91	15.75	14.62	
29	omitted				
28	17.24	16.83	15.77	14.77	
30	17.81	17.15	16.05	15.02	
31	17.37	17.08	16.19	15.25	
32	17.86	17.31	16.32	15.50	
a	12.50	12.41	11.79	11.27	846
b	13.17	12.72	11.91	11.15	819
c	12.51	12.94	12.77	12.47	872
d	15.37	14.81	13.69	12.52	832
e	14.89	14.75	14.02	13.13	841
f	18.33	17.67	17.20	15.74	
g	17.95	17.60	17.25	15.74	
h		17.83	17.34		
k		17.96	17.79		
m		18.12	17.84		

limits, 17.9, 17.8, 17.1 and 15.0, were ±.14, ±.06 ±.05 and ±.07 magnitudes, respectively. These internal errors increase to ±.29, ±.15, ±.12 and ±.12 magnitudes in the overlapping-plate region at between about 1 and 1½ degrees from the two sequences, but they could only be studied to within 0^m5 of the above faint limits. Systematic deviations from the standard *UBVR* system at the faint end of the adopted sequences are not expected to be greater than 0^m3. See Tables 1 and 2 and visual finding charts, Figs. 1 and 2.

TABLE 2

ORION SEQUENCE II *Centre* 5^h33^m, $-6^\circ0$ *(1900)*

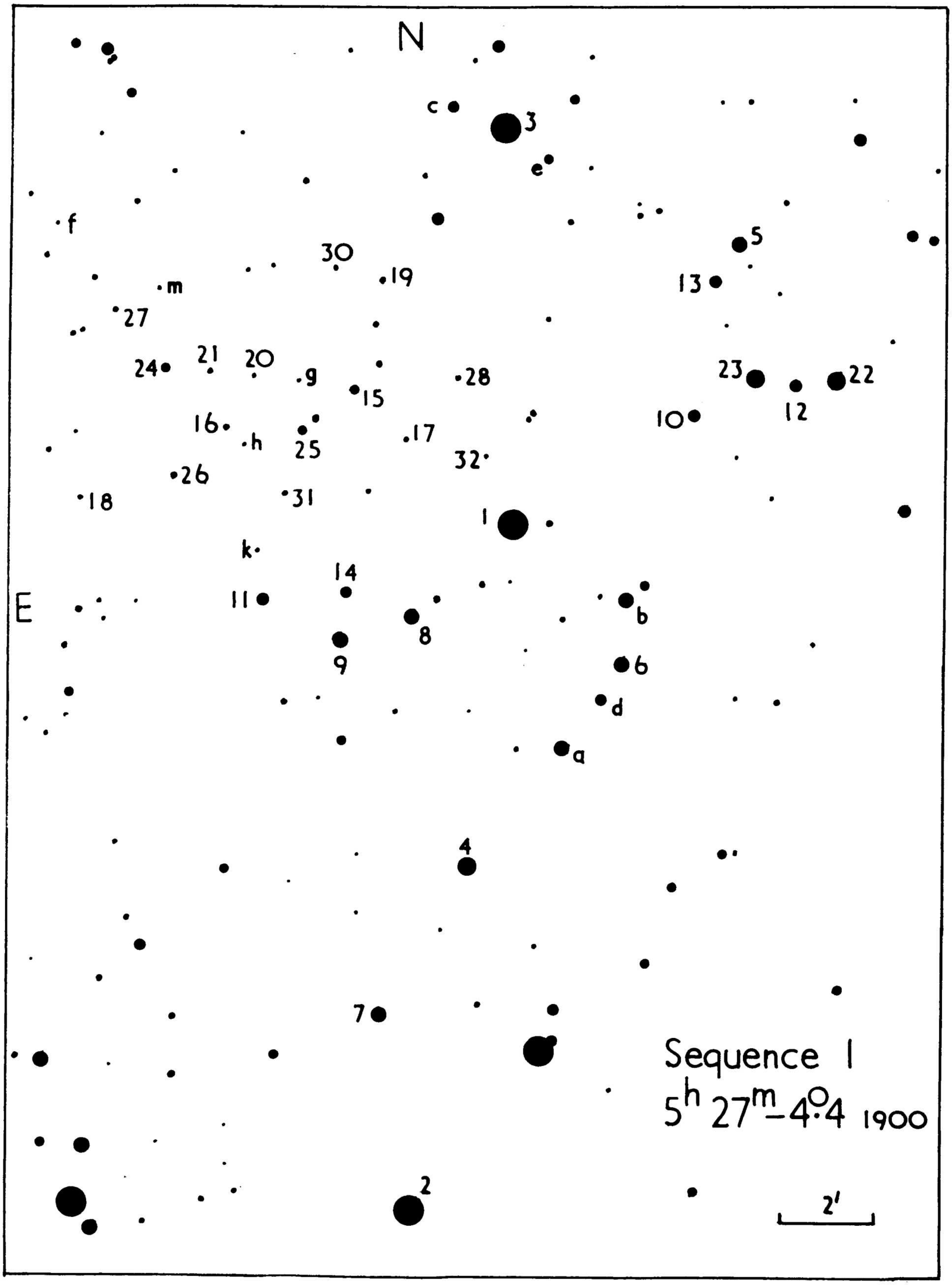
Chart Ident.	*U*	*B*	*V*	*R*	*Parenago Number*
A	9^m99	9^m91	9^m82	9^m66	2646
B	10.50	10.56	10.26	9.87	2687
C	11.39	11.21	10.89	10.51	2603
D	11.87	11.88	11.26	10.80	2571
E	11.92	11.80	11.28	10.71	2660
F	12.20	12.16	11.64	11.10	2605
G	16.35	14.99	12.59	10.66	2582
H	14.44	13.82	12.60	11.39	2597
I	13.33	13.25	12.62	12.00	2569
J	14.12	13.65	12.64	11.75	2651
K	14.98	14.59	13.25	12.15	2618
L	14.83	14.81	13.78	12.81	2714
M	15.24	15.36	14.31	13.05	2728
N		16.59	14.54	12.33	
O	17.88	16.40	14.73	12.92	
P		16.44	15.12	13.41	
Q	16.80	16.41	15.23	13.75	
R		17.32	16.25	14.85	
S		17.43	16.38	15.00	
T		17.74	16.51	14.70	
U		17.55	16.67	15.21	
V		18.17	17.15	15.48	
W		18.02	17.63		
X		18.24	17.95		

III. Photographic Data on Orion Flare Stars

From Haro's list of 172 flare stars in Orion (Haro 1968), discovered mainly at the Tonantzintla Observatory and the Asiago Observatory, a total of 141 were measurable on ADH plates using two plate centres. Sets of *UBVR* plates were generally taken on a single night, requiring a total exposure time of 2 hours to reach a reasonable number of flare stars in each spectral band. From an examination of nightly magnitudes it would appear that no flares occurred in the present material, and it is fairly safe to presume that the mean magnitudes and colours refer to the quiescent state of the flare stars. In the case of stars with known irregular variability and classified by Parenago (1954), or with published magnitude ranges, an indication of their position within the brightness range is given in the footnotes to Table 3. A fuller photometric study of the variability of the remaining flare stars is being prepared using more plate material.

Mean photometric results derived from a 2-month observing period in 1966-67 are given in Table 3. The "mean epoch" for the 6 sets of *UBVR* plates is J. D. 2439472 ± 29 days. Flare stars are listed according to their Tonantzintla serial number (column 1), with their mean magnitudes and colours (columns 2-5), and the number of plates or pair of plates used in their respective determinations (column 6). A provisional colour classification is given in column 7, based on the flare star's position in the colour-colour diagrams (discussed in the following section). An asterisk in the last column indicates a note under 'Remarks to Table 3'.

Figure 1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Sequence I
5h 27m −4°4 1900
2′

Figure 2

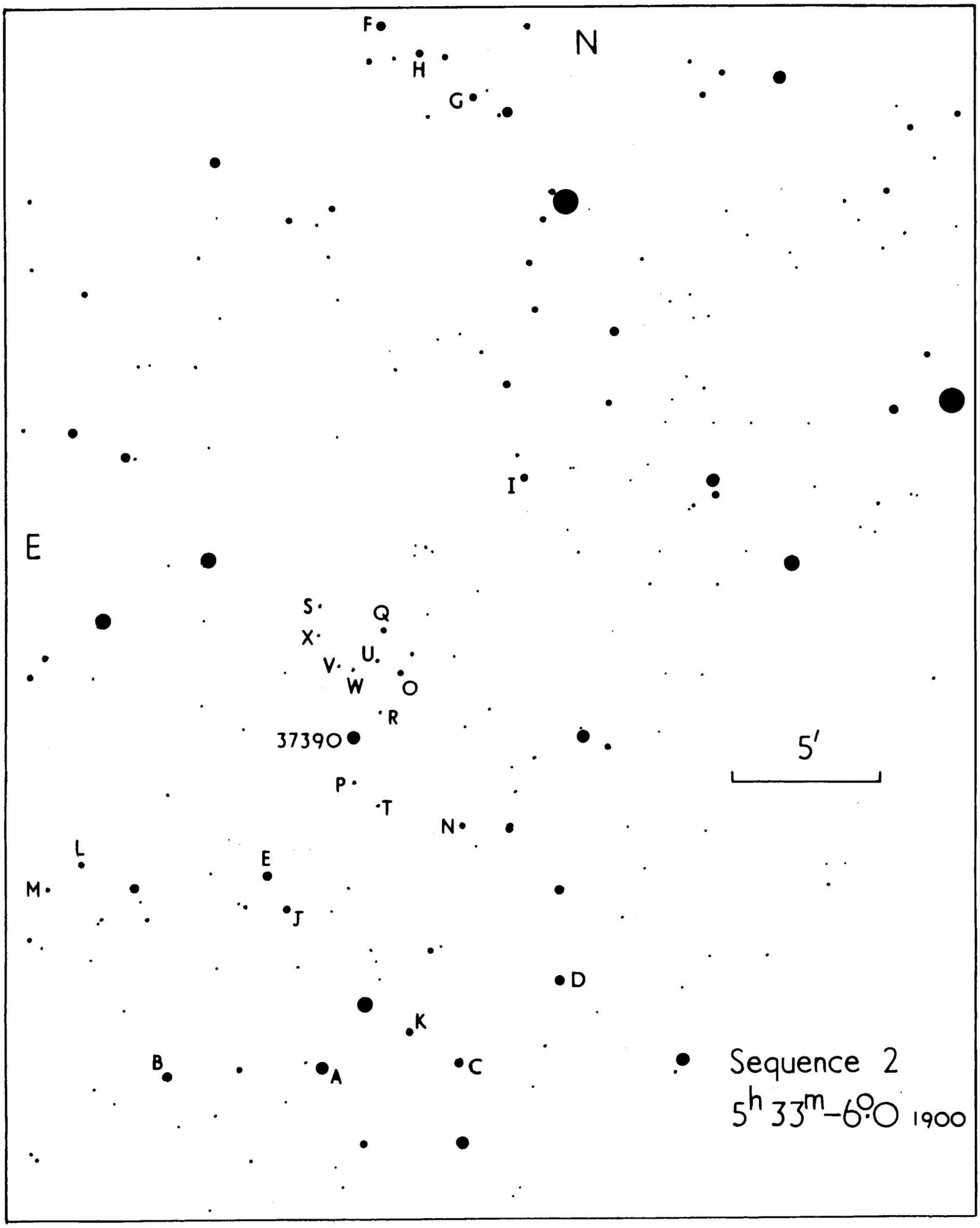

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TABLE 3

Mean Photometric Data of Orion Flare Stars

Ton. No.	*V*	*V–R*	*B–V*	*U–B*	*n*	*Class*
2	17.26		0.54		2-0-2-0	
4	13.72	1.12	1.24	0.28	2-2-2-2	A
5	15.95	1.29	1.65		4-4-4-0	?
6	14.75	1.41	1.52	1.14	3-3-3-1	A
8	16.84	2.17	1.00		2-2-2-0	C
10	15.46	1.51	1.65	0.61	6-6-6-4	A *
12	17.10	1.53	0.54	–0.68	3-3-3-3	D *
13	16.91	1.84	0.94		2-2-2-0	C
14	15.40	1.62	1.44	–0.32	6-6-6-4	B *
15	15.93	1.46	1.39		2-2-2-0	A
16	15.85	1.79	1.36	0.27	5-5-5-1	A *
17	15.66	1.86	1.40		3-3-3-0	A
18	15.01	1.45	0.89	–1.31	3-3-3-3	D *
19	16.22	1.75	1.20	0.92	3-3-3-1	B.
20	16.08	1.81	1.22	–0.24	6-6-6-1	B *
22	15.06	1.56	1.32		6-6-6-0	A *
23	14.87	1.38	1.50	0.49	6-6-6-5	A
24	14.43	1.34	1.32	0.75	3-3-3-3	A
25	13.36	1.05	0.98	–0.53	6-6-6-5	D? *
26	16.86	1.96	0.87	0.33	3-3-3-1	B
28	16.95	1.78	0.94		2-2-2-0	C
29	16.21	1.78	1.29		2-2-2-0	B?
30	16.17	1.66	1.20		5-5-5-0	B
31	15.23	1.48	1.52	0.63	3-3-3-2	A
32	15.84	1.72	1.37		4-4-4-0	A
33	18.18				1-0-0-0	
34	14.08	1.33	1.37	0.18	6-5-6-5	A
35	17.05	2.01	1.35		3-3-3-0	B
36	16.95	1.75	0.77		4-4-4-0	C
37	16.59	2.12	1.15		3-3-3-0	B
38	16.16	1.55	1.26		3-3-3-0	A *
39	16.30	1.58	0.30	–1.66	5-5-5-4	D *
40	15.79	1.66	1.36		4-4-4-0	A
41	16.43	1.80	0.82		4-4-4-0	C *
42	14.73	1.61	1.14	–0.73	6-6-6-5	D *
43	12.76	1.03	0.71	–0.12	6-6-6-5	B
45	14.69	1.31	1.11	–0.37	4-4-4-4	B *
46	16.64	1.69	1.05		3-3-3-0	B
48	16.30	1.58	1.07		5-5-5-0	B *
49	16.76	1.98	0.81		3-3-3-0	C
50	16.12	1.69	1.22		5-5-5-0	B
51	13.74	1.02	1.46	–1.13	2-2-2-2	D? *
55	15.79	1.54	0.90		3-3-3-0	C
56	15.74	1.68	1.34	0.88	3-3-3-2	A
57	16.06	1.74	1.15	0.03	5-5-5-1	B
58	13.65	1.29	1.10	–0.23	4-4-4-4	B *
59	16.42	1.19			1-1-0-0	
60	15.80	1.43	1.25		4-4-4-0	A
62	15.47	1.47	1.43		2-1-2-0	A *
63	13.76	1.36	1.29	0.22	5-5-5-5	A *
65	16.80	1.57	0.60	–0.86	3-3-3-1	D
66	15.00	1.52	1.35		3-3-3-0	A *
67	13.83	1.50	0.73		2-2-2-0	C *
68	15.46	1.33	0.34		2-2-2-0	C *
69	16.52	1.50	0.52	–1.31	3-3-3-3	D
70	14.68	1.71	1.55	0.35	3-3-3-2	A
71	14.80	1.29	0.90	–0.72	6-6-5-2	D *
72	13.86	1.24	1.01	–0.58	6-6-6-5	D *

TABLE 3 (cont.)

Ton. No.	V	V–R	B–V	U–B	n	Class
73	16.61	1.87	0.99		3-3-3-0	C
75	16.54	1.63	0.80		4-4-4-0	C
76	15.75	1.51	1.24		3-3-3-0	A *
77	13.32	1.30	1.09	0.41	6-6-5-5	A *
78	17.80	1.74	0.02		4-1-3-0	C *
79	14.49	1.47	1.43	0.48	5-5-5-4	A *
80	15.35	1.33	0.94	−0.88	5-5-5-4	D *
81	17.12	2.11	0.87		2-2-2-0	C
82	15.98	1.81	1.24		3-3-3-0	B *
83	14.90	1.40	1.25	1.32	3-3-3-3	A
84	16.71	1.65	0.75		4-4-4-0	C
85	15.02	1.25	1.16	0.51	6-6-6-3	A *
86	13.97	1.29	0.99	−0.08	6-6-6-5	B *
87	16.06	1.77	0.94	−0.32	6-6-6-4	B
89	15.03	1.34	1.17	0.21	6-6-6-4	A
90	14.72	1.43	1.46	0.68	3-3-3-2	A
91	17.26	2.50	0.59		2-2-2-0	C
92	15.86	1.64	1.31		3-3-3-0	A *
93	15.80	1.63	1.11	0.25	3-3-3-2	B *
94	16.67	1.88	0.91		1-1-1-0	C
97	15.14	1.67	1.39	0.20	5-5-5-3	A *
98	17.90	1.96	−0.03		2-1-1-0	C
99	15.25	1.43	1.55	0.66	3-3-3-3	A *
100	16.38	1.87	1.05	−0.08	3-3-3-2	B *
101	15.75	1.53	1.17	−0.08	5-5-5-4	B *
102	14.34	2.01	1.59	0.83	3-3-3-2	A *
103	17.87	2.26	0.18		2-1-2-0	C
104	14.80	1.58	1.20	−0.09	6-6-6-6	B *
105	16.67	2.09	0.85	−1.07	5-5-5-1	D *
107	16.59	2.03	0.91		5-5-5-0	C
109	15.60	1.79	1.46	0.66	3-3-3-1	A
111	16.51	1.61	0.87	0.11	5-5-5-4	B *
112	17.64	2.00	0.56		2-2-2-0	C
113	15.40	1.45	1.25	0.69	6-6-6-4	A
114	15.98	1.48	1.21	0.49	5-4-5-1	A
115	15.09	1.38	0.91	−0.75	3-3-3-3	D *
116	15.77	1.59	1.33	0.18	5-5-5-2	A
117	17.43	2.11	0.49		5-4-5-0	C
118	15.17	1.35	1.39	0.66	3-3-3-2	A *
119	17.07	2.07	0.83		3-3-3-0	C
124	15.22	1.83	1.64		3-2-3-0	A *
125	15.07	1.60	1.51		3-2-3-0	A
126	14.62	0.53	0.92	−0.50	2-2-2-2	D? *
127	15.26	1.61	1.47	1.13	3-3-3-2	A
128	17.02	1.69	0.85		2-2-2-0	C
129	16.26	2.06	1.19	0.77	3-3-3-1	B
130	14.41	1.55	1.52	0.69	6-6-5-5	A
131	16.31	1.90	1.49	−0.24	4-4-4-1	B
132	15.82	1.56	1.41		2-2-2-0	A
133	17.01	2.10	0.63		3-3-3-0	C
134	14.91	1.11	1.28	0.21	6-6-6-5	A
135	17.43	1.87	0.44		2-2-2-0	C
136	15.68	1.72	1.49		3-3-3-0	A
137	17.38	1.86	0.76		4-4-4-0	C
138	16.12	1.61	1.15	−0.37	3-3-3-1	B
139	14.97	1.70	1.39	0.65	6-6-6-5	A
140	17.06	2.04	0.77		2-2-2-0	C
141	14.63	1.50	1.45	0.80	5-5-5-4	A *
142	15.92	1.49	1.38		3-3-3-0	A

TABLE 3 (cont.)

Ton. No.	*V*	*V–R*	*B–V*	*U–B*	*n*	*Class*
143	14.49	1.26	1.43	0.66	3-3-3-3	A
144	15.38	1.24	0.92	–1.05	6-6-6-5	D *
146	12.60	1.12	0.90	–0.54	6-6-6-5	D *
147	14.87	1.76	1.41		4-4-4-0	A
148	15.29	1.47	1.62		2-2-2-0	A *
149	16.61	1.64	1.14		1-1-1-0	B *
150	16.28	1.55	1.24		3-3-3-0	A
151	15.85	1.65	0.90	–1.26	5-5-5-5	D *
152	14.86	1.40	1.18	–0.18	5-5-5-3	B
153	15.56	1.32	1.32		6-6-6-0	A *
155	16.11	1.80	1.06	–0.32	5-5-5-1	B
157	16.43	1.40	0.20	–1.22	5-5-5-5	D *
158	15.03	1.37	1.23	0.94	3-3-3-2	A
161	17.07	1.71	0.57		5-4-5-0	C
162	17.37	2.27	0.35		3-3-3-0	C *
163	15.88	1.88	1.12		5-5-5-0	B
164	16.51	2.23	0.97		5-5-5-0	C
166	15.95	1.62	1.15	0.15	3-3-3-2	B
167	15.92	1.58	1.37	0.45	3-3-3-1	A *
168	17.96		0.09	–0.46	1-0-1-1	D
169	13.54	1.14	1.15	0.29	6-6-6-6	A *
170	17.29	1.98	0.79		2-2-2-0	C
171	15.75	1.79	1.18	–0.08	3-3-3-1	B
172	15.33	1.29	1.32	0.73	3-3-3-2	A

REMARKS TO TABLE 3

Identification of the Orion flare stars in the General Catalogue of Variable Stars (Kukarkin et al. 1958) and its Supplements is given below. The classification of light curves of irregular variables (outside flares), according to Parenago (1954), and described by Herbig (1962), allows some indication to be given as to relative brightness of the stars within their range during our observations. Spectral types, when available, and general remarks on peculiar spectral features (mainly due to Herbig, 1950, 1962a) and the presence of H-alpha line emission (e), including its temporary appearance (Haro 1953, 1968), are noted. Spectral classification is by no means easy as reference to the original papers show. Multi-colour photometric results of other authors are quoted as mean magnitudes and colours. The extensive surveys of Orion variables made at Asiago Observatory are frequently referred to and allow further assessment of the mean brightnesses during our observations. In nearly every case the variables appeared faint, the exceptions being Ton. Nos. 22, 25, 71 and 72. Furthermore, a few further flare stars were suspected as variable, e. g. Ton. Nos. 62, 118, 124, 153 and 167. Flare stars of particular interest such as those observed by Haro and others to have flared on more than 3 occasions, and those in which the rare "slow" flares (Haro 1969) have been detected are noted.

On the question of duplicity, several flare stars have been examined by F. Holden using the 69 cm refractor at Lamont-Hussey Observatory (S. Africa). Apart from the known wide doubles (Ton. Nos. 18, 25 and 105), the following stars, Tons. Nos. 10, 16, 22, 34, 42, 43, 45, 58, 63, 70, 71, 72, 77, 79, 85, 86, 89, 102, 104, 130, 134, 141, 146, 147, 152 and 169, all appeared single, although for those at about 15th magnitude a companion $0^{m}5$ fainter would not have been detected. Holden notes, however, for No. 42 "image not sharp" and for No. 86 "faint and fuzzy" (private communication). Several faint close companions were noted during our plate examination. See below. The latter may have interfered with our photometric results.

10. V 383.
12. (e).
14. V 384, Ke6 (Herbig 1962a), observed faint (Rosino 1956).
16. V 394, (e).
18. VY Ori, Parenago class II, observed faint (Rosino 1962), V = 15.22, B–V = 0.79, U–B = –1.32 (Walker 1969), (e).
20. V 385, observed faint (Rosino 1956).
25. WX Ori = V 395, Ge (Dall'Olmo 1958), Parenago class Ia, observed bright (Rosino 1956), V = 14.33, V–R = 1.14, B–V = 0.95, U–B = –0.21 (Mendoza 1968).
38. Observed faint (Rosino 1969).
39. IZ Ori, (e), Parenago class III, observed faint (Rosino 1956).
41. Peculiar elongated image on long-exposure ADH plates in the red.
42. KK Ori, (e), Parenago class IIab, observed faint (Rosino 1956), companion or nebulosity to E confusing image.
45. YZ, G–Ke (Herbig 1950), Parenago class IV, observed faint (Rosino 1956).
48. Possible companion on visual ADH plates.

51. BW Ori, (e), Parenago class IIb, observed near mean brightness, close companion on visual and red plates.
58. V 498, K2 (Herbig 1962a), nebulous region, V = 13.74, V–R = 1.21, B–V = 1.01, U–B = –0.27 (Mendoza 1968).
62. Variable or misidentification since Haro (1968) gives vis. mag. 18.2.
63. V 569, V = 13.92 V–R = 1.34, B–V = 1.34, U–B = 0.72 (Mendoza 1968), V = 13.74, B–V = 1.23, U–B = 0.24 (Walker 1969).
66. V 389, K7e (Herbig 1962a), "slow and fast" flares (Haro 1969).
67. V 427, nebulous region.
68. V 378, in nebulous filament, observed faint (Rosino 1969).
71. V 379, K7 (Herbig 1962a), nebulous region, observed bright (Rosino 1969).
72. OT Ori, Ke (Herbig 1962a), Parenago class III, nebulous region, observed fairly bright (Rosino 1956).
76. V 390, K3e (Herbig 1962a), observed faint (Rosino 1956).
77. Nebulous region, V = 13.53, V–R = 1.20, B–V = 1.32, U–B = 1.18 (Mendoza 1968).
78. (e), "appears below main sequence", 7 flares observed (Haro 1968).
79. (e).
80. V 393, dK6?e given in General Catalogue (Kukarkin et al. 1958) only surmised, (e).
82. (e).
85. 3 flares observed (Haro 1968).
86. (e) var., "fuzzy image" (Holden 1969), V = 13.97, V–R = 1.14, B–V = 1.06, U–B = 0.34 (Mendoza 1968).
92. (e) max., "slow and fast" flares (Haro 1969).
93. (e) var.
97. (e) var.
99. Possible companion on visual ADH plates.
100. 3 flares (Haro 1968).
101. (e) var.
102. M2 (Blanco 1963), V = 14.40, V–R = 1.89, B–V = 1.69, U–B = 1.32 (Mendoza 1968).
104. PW Ori, (e), Parenago class Ia, observed faint (Rosino 1956).
105. Wide double but another faint companion to E on visual ADH plates.
111. (e) var.
115. (e).
118. Suspected variable since much fainter than given by Haro (1968).
124. Variable or misidentification since brighter than given by Haro (1968).
126. Peculiar position in V–R/B–V diagram.
141. V = 14.83, B–V = 1.26, U–B = 1.36 (Walker 1969).
144. XX Ori, (e), Parenago class Ib, observed faint.
146. (e), V = 12.86, V–R = 1.12, B–V = 1.16, U–B = 0.43 (Mendoza 1968).
148. (e), close companion.
149. "Slow and fast" flares (Haro 1969).
151. (e).
153. "Slow and fast" flares (Haro 1969), observed much fainter than given by Haro (1968) or Parenago (1954).
157. NS Ori, (e). Parenago class III, observed faint (Rosino 1969) but star observed much fainter by Haro (1968).
162. (e).
167. Possibly variable on blue ADH plates.
169. K1 (Haro 1968).

Note added by the Editor (G. H.)

Flare star No. 25 – Parenago 1353, by mistake appears in Haro's original list as Parenago 1352. Dr. Andrews took Parenago's star No. 1218 (VY Ori) as Haro's flare star No. 18. This is due to an error in Haro's original flare star lists.

IV. Colour-Magnitude and Colour-Colour Diagrams

Haro has stated that many flare stars observed by him possess large ultraviolet excesses (Haro and Herbig 1955, and subsequent papers). Photoelectric measures of the brighter Orion flare stars (Mendoza 1966, 1968, Walker 1969a) confirm the peculiar colours of these stars. As also pointed out by Haro, the present results show that the flare stars scatter not only above but also below the main sequence. The unusual brightness in the ultraviolet of T Tauri stars (Joy 1949) and T Tauri-type objects has led a number of authors to spectroscopic studies of this phenomenon (Böhm 1957, Herbig 1958, Walker 1964, 1969, Anderson and Kuhi 1969). Several Orion flare stars are amongst those studied, e. g. VY Ori (= Ton. No. 18) and XX Ori (= Ton. No. 144) by Böhm and Walker. The problem of interpreting colour-magnitude diagrams in evolutionary terms certainly cannot be attacked for stars of this type until these emission continua are understood. It is with this in mind that an attempt is now made to classify the Orion flare stars according to their observed colours.

The 76 flare stars for which $U-B$ was available were plotted firstly in a $U-B/B-V$ diagram (See top of Fig. 3). No account can, of course, be taken of interstellar reddening at this stage. Stars with extreme ultraviolet colours, arbitrarily set at $U-B < -0^{m}5$, are marked by triangles, whereas stars with $U-B > 0^{m}2$ (and generally redder $B-V$) are marked with circles. Due to the

Figure 3

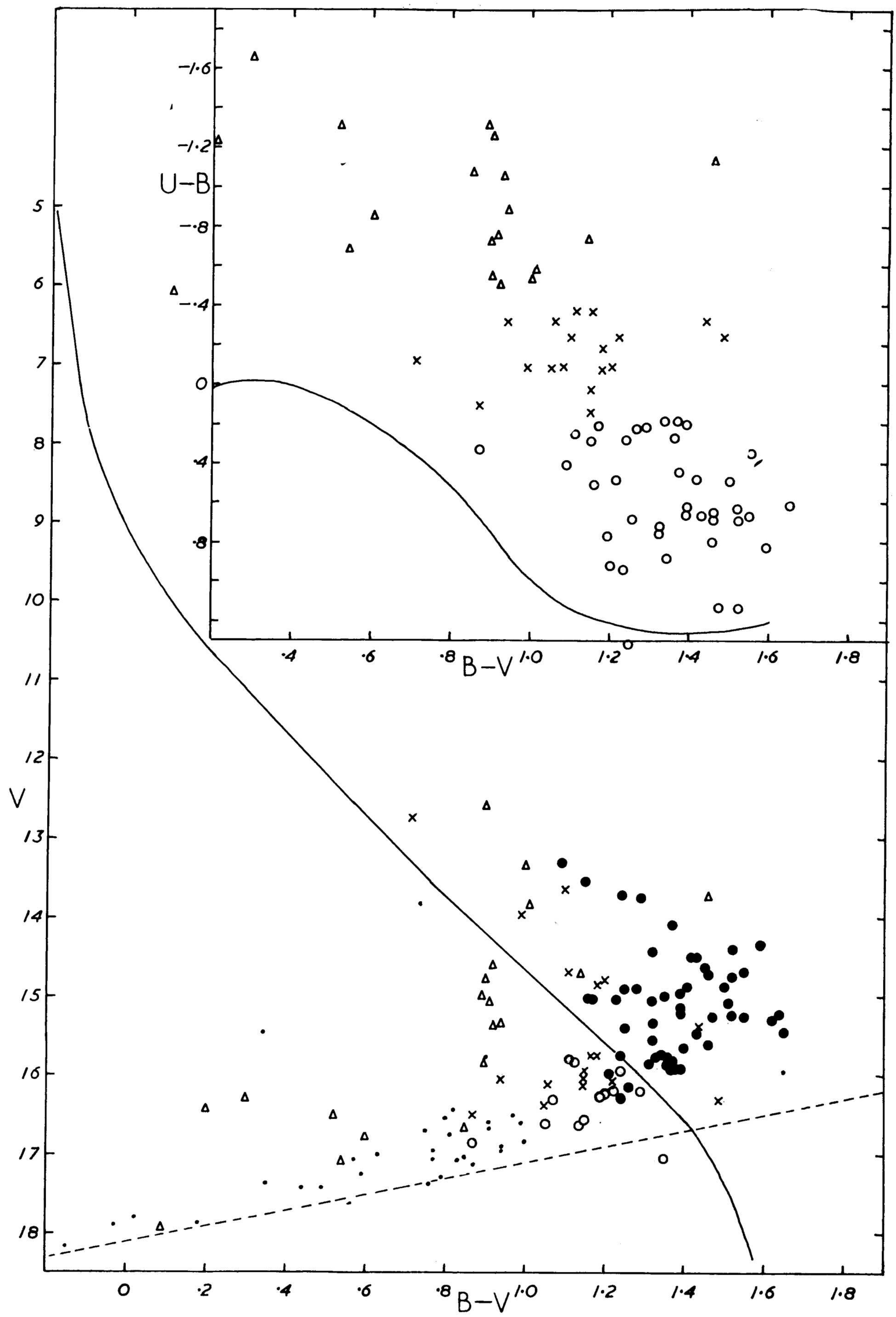
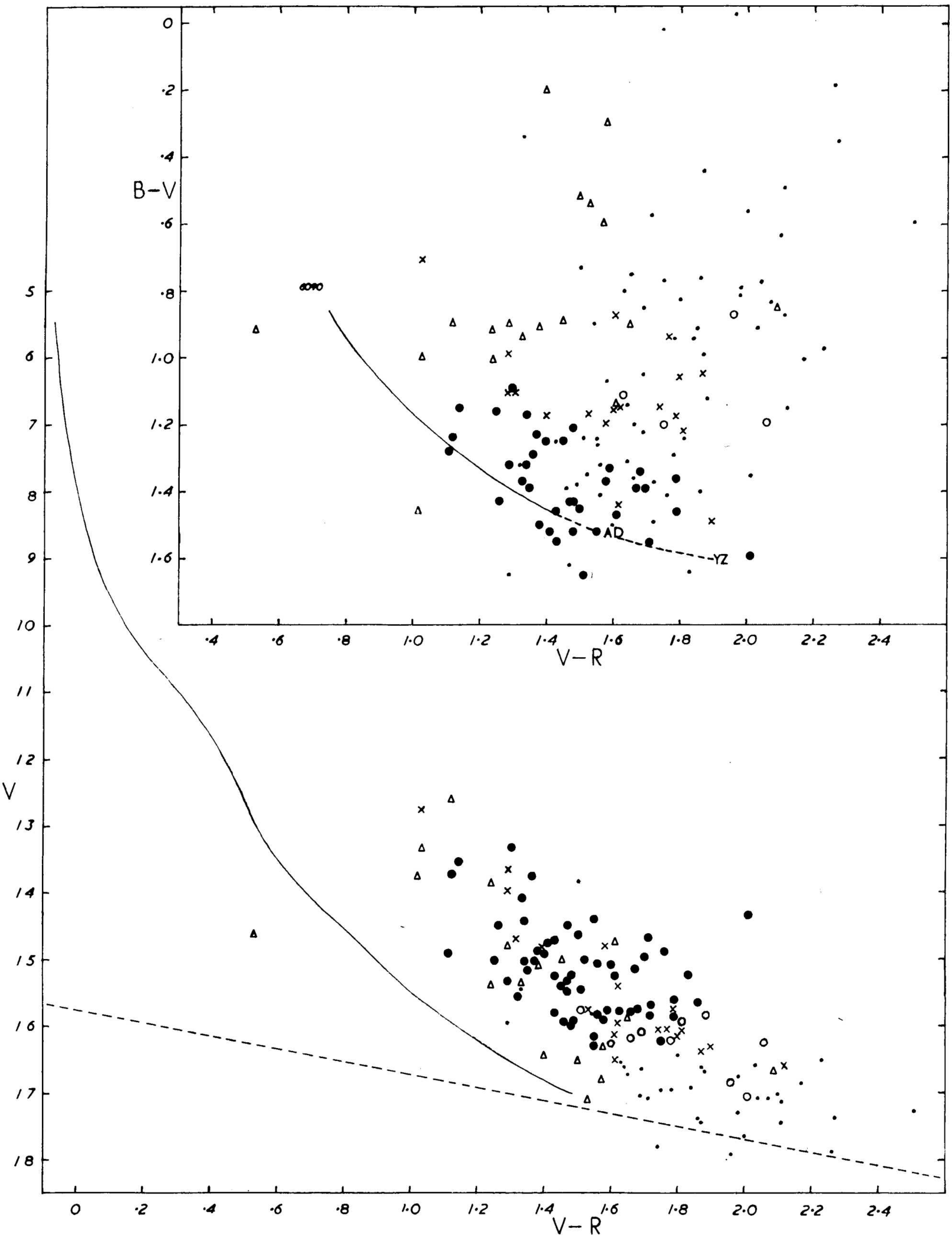

U−B
−1·6
−1·2
−·8
−·4
0
·4
·8
·4
·6
·8
B−V
1·0
1·2
1·4
1·6
1·8
V
5
6
7
8
9
10
11
12
13
14
15
16
17
18
0
·2
·4
·6
·8
B−V
1·0
1·2
1·4
1·6
1·8

Figure 4



arbitrary nature of this colour division an intermediate group was introduced and marked by crosses. The general appearance of this two-colour diagram is similar to that previously found for the

H-alpha emission stars in Orion (Walker 1969a), and in Taurus (Varsavsky 1960), and for many of the faint stars in NGC 2264 (Walker 1954).

The $B-V/V-R$ diagram was plotted using the same designation (top of Fig. 4), and the remaining stars without $U-B$ measures added, marked as small dots. We see that the same segregation is present as in the previous diagram. The relation between unreddened (Hyades) stars derived by Mendoza (1967) is shown as a solid line. This line is extended through the position of the two red dwarfs, AD Leo and YZ CMi, both classical flare stars, measured in the standard photometric system (Andrews 1967). Mendoza's relation is also seen to satisfy the flare star, HD 6090 (Butler 1967, Andrews 1967a) at the blueward limit of the line. Since it is found that the effect of normal interstellar reddening in the $B-V/V-R$ diagram (Mendoza 1968) is to shift stars practically along the downward direction of Mendoza's line, the fact that we find the flare stars with fairly normal $U-V$ ($> 0^m2$) scattered near this line suggests that they are not grossly affected by colour excesses in $B-V$. The scatter is of the same order as the photographic mean errors in $B-V$. All but four of the stars originally designated by open circles are 'promoted' to filled circles. On the other hand, the extreme ultraviolet stars (triangles) appear generally well above Mendoza's relation, i. e. blueward, and this may be interpreted as a blue excess in these stars. In the classification that follows the remaining stars for which $U-B$ was not available were interpreted in the same sense.

Colour-magnitude diagrams were now drawn (Figs. 3 and 4) for all stars with their final colour designation as summarized in Table 4. The classification of the flare stars, using a notation

TABLE 4

Classification (Table 3, Col. 7)	*Designation in Col/Mag Diagrams*	*Colour Excesses Present*
A	filled circles	Small ultraviolet excess and probably no blue excess No U—B available but no blue excess indicated in B—V/V—R
B	open circles or crosses	Intermediate ultraviolet excess and/or small blue excess
C	small dots	Large blue excess, no U—B available
D	triangles	Large ultraviolet excess and large or intermediate blue excess

A — D, indicates the ultraviolet and blue excesses that are present. A zero-age main sequence, using Mendoza's (1967) distance modulus for the Orion aggregate of 7^m9, is shown as a solid line. No corrections for interstellar absorption or reddening are attempted. The dashed lines indicate the limits of our photometric sequences. Out of 19 flare stars with large ultraviolet and blue excesses 14 lie below the main sequence in the $B-V/V$ diagram, and the general blueward scatter of the fainter stars is large. This confirms Walker's opinion that spectroscopic observations are essential for a definitive study of extremely young clusters (1969a). In the $V-R/V$ diagram no clear segregation according to colour excess is present. A band is found 1 or 2 magnitudes above the main sequence extending to the limit of our observations. This strongly suggests that the majority of Orion flare stars are indeed members of the Orion aggregate. Furthermore, in view of the large infrared excesses recently found by Mendoza (1968) in T Tauri-type objects, it appears that the smallest colour anomalies occur in the visual and red spectral regions.

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