ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **136**, 313–331 (1999)

Spectroscopic observations of young open clusters: IC 1805, NGC 654 and NGC 6823

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Received September 30, 1998; accepted January 11, 1999

Abstract. Spectroscopic observations were made for a sample of 263 stars from three young open clusters IC 1805, NGC 654 and NGC 6823 with CCD detectors in the blue and yellow-red spectral regions. MKK types were properly determined for these stars by carefully comparing spectra of program stars with those of a complete grid of MKK standards, which were observed with the same instruments as the program stars. For most of the observed stars precise MKK types were assigned for the first time. A few of early-type emission-line stars were discovered or confirmed. The presence of Be stars in the studied clusters is discussed. Spectra of the observed MKK standards also reveal lots of features showing temperature or luminosity effect in the yellow-red region, which helped in our stellar spectral classification.

Key words: stars: fundamental parameters — stars: emission-line, Be — open clusters and associations: IC 1805, NGC 654 and NGC 6823

1. Introduction

Open clusters are natural laboratories for stellar evolution, because stars in clusters share a common origin from the same progenitor molecular cloud. Young open clusters are particularly suited to study the processes of star formation and early evolution of stars over a wide mass spectrum. Many questions related to young clusters and/or associations remain to be answered, e.g., the constancy of IMF (at higher masses), the coevality of star formation, the evolution of massive stars and its influence on the environment, and the presence of various peculiar stars (emission-line stars, for example) and their evolutionary status, to just cite a few. The study of clusters and associations deeply relies upon the accumulation of various kinds of precise data, be it astrometric, photometric or spectroscopic. While large efforts have been spent on obtaining magnitudes and colours in various systems such as UBV and $uvby$ for stars in clusters, the situation about spectroscopic data is still far from satisfactory. Reliable MKK spectral types, for example, are often available in published literature only to few brightest stars of a cluster (Mermilliod 1986).

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Table 1. Spectrographs and gratings

spectrograph name	grating lines/mm	dispersion Å/mm	Å/pixel	central wavelenth Å
UNIVERSAL	300	195	4.7	6000
OMR	300	200	4.8	6000
	600	100	2.4	5000
	1200	50	1.2	4375

Accurate two-dimensional spectral classification (temperature type and luminosity class) of stars is essential to the study of young open clusters. Differential reddenings often affect member stars in young clusters, causing scatters in color-magnitude diagrams. Spectroscopy provides the means of precisely detecting any differential reddening. By combination with photometric data (magnitudes and colors), spectral classification may be used to construct individually-dereddened high-quality H-R diagrams, from which the distances and evolutionary ages of clusters can be reliably determined and even the effects of binarity (usually indistinguishable from small diffential reddenings) may be examined. Spectral classification can also be used to investigate the nature of reddening and extinction, determining if any abnormality exists and if the differential reddening is caused by interstellar, intracluster or circumstellar extinction material (Sagar 1987; van den Ancker et al. 1997). Peculiar stars (e.g., emission-line stars) may also be discovered from spectral classification.

Traditionally spectral classification is made photographically in the blue spectral region of 3900 Å through 4900 Å. Reliable two-dimensional spectral types can be gained only for brighter stars due to the low sensitivity of photographic plates. With the use of CCDs spectroscopy can be done on much fainter objects and on a broader spectral coverage. The peak of the quantum efficiency of CCDs is usually in the yellow-red spectral region, which is advantageous to the observation of late type stars or highly-reddened early type stars such as those in young open clusters. With the spectral coverage extended from the blue into the yellow-red and even the near infrared, additional spectral features suitable for stellar classification also appear in these regions of longer wavelength (Jacoby et al. 1984; Turnshek et al. 1985; Torres-Dodgen & Weaver 1993; Danks & Dennefeld 1994; Shi & Hu 1999).

We have begun a project of systematically investigating the properties and stellar contents of young open clusters and/or associations, especially those with severe differential reddening. The study is to be based upon more complete and homogeneous sets of combined data. As a part of this program and the first step, we engage ourselves in making accurate two-dimensional spectral classification for large samples of stars in young clusters. The first three clusters selected by us are IC 1805 (C0228+612, $\alpha_{1950} = 02^{\rm h}28\overset{\rm m}{.}9$, $\delta_{1950} = 61°54'$), NGC 654 (C0140+616, $\alpha_{1950} = 01^{\rm h}40\overset{\rm m}{.}6$, $\delta_{1950} = 61°38'$) and NGC 6823 (C1941+231, $\alpha_{1950} = 19^{\rm h}41\overset{\rm m}{.}0$, $\delta_{1950} = 23°11'$). They are of very young ages and all showed differential reddenings according to earlier investigators (Moffat 1972; Turner 1979; Stone 1980; Sagar & Joshi 1981; Joshi & Sagar 1983a,b). Most of the cluster stars lack MKK types. In this work a total of 263 stars from these three clusters were spectroscopically observed by slit spectrograh and CCD detectors in the blue and yellow-red spectral regions. Results of the MKK classification are given in this paper. The presence of emission-line stars is discussed. Further studies upon these clusters are underway.

2. Observation and data reduction

Spectroscopic data were obtained during two observing runs, in 1995 and in 1997, with the 2.16 m telescope at Beijing Astronomical Observatory. In 1995 the telescope was equipped with a Tektronix 1024 CCD mounted at an UNIVASAL spectrograph, whereas in 1997 with another Tektronix 1024 CCD at an OMR (Optomechanics Research Inc.) spectrograph. The pixel size of the two Tektronix CCDs were both 24 μm. For the UNIVASAL spectrograph a grating of 300 lines/mm were used, and for the OMR spectrograph three gratings of 300 lines/mm, 600 lines/mm and 1200 lines/mm were used. The corresponding dispersion and central wavelength are given in Table 1. A slit with a width of about 2″ was used during all the observations.

A total of 263 program stars, 140 from IC 1805, 46 from NGC 654 and 77 from NGC 6823, were observed. They are mainly proper motion cluster members (See Sect. 3.2). The magnitude limit is around $V = 14^{\rm m}$. Spectra were taken with the 300 lines/mm grating for nearly all program stars. For the brighter stars spectra were also taken with the 600 lines/mm grating, and for the few brightest stars additional spectra were obtained with the 1200 lines/mm grating. The exposure times ranged from a few minutes to about an hour, depending on the magnitude of the object, the seeing, and the grating used. The resulting signal-to-noise (S/N) ratios usually exceeded 100. The observed cluster stars with their identifying numbers are listed in Tables 2, 3, and 4 for IC 1805, NGC 654 and NGC 6823 respectively.

We also observed a complete grid of MKK standards (up to 200) with the same instruments (telescope and spectrograph with same gratings) and under nearly identical observing conditions as our program stars. The S/N was kept comparable to that of the program stars. These standard stars are mainly from Keenan & McNeil (1976); Morgan et al. (1978) and Morgan & Keenan (1973). Reobserving MKK standards here is necessary for the spectral comparison and classification.

All the spectra were reduced using MIDAS. The raw CCD spectral images were corrected using average Bias and high S/N dome-flat frames. The dark current of the used CCDs was negligible. Sky subtraction was achieved by subtracting a third degree polynomial fitted to the spectrum in the spatial direction. This kind of sky subtraction proved to be effective in eliminating the emission from surrounding nebulosity. The sky-subtracted spectral images were then wavelength-calibrated using the comparison spectra (Fe-Ar or He-Ne-Ar lamps) and one-dimensional spectra were extracted. For the purpose of spectral classification all one-dimensional spectra were continuum-normalized instead of flux-calibrated. Data reduction for program stars and MKK standard stars were the same. Representative spectra of MKK standards are illustrated in Fig. **??** and Fig. **??**. Spectra of all the program stars from the three clusters are shown in Fig. **??** through Fig. **??**.

3. Spectral classification

3.1. Methods

To properly classify stellar spectra in the MKK system, the spectra of program stars have to be carefully compared with those of MKK standards. MKK standards should be observed with the same instrument and under the same conditions as the program stars. The reobservation of MKK standards is necessary to link the local instrumental system to the MKK system which is defined by its standards (Morgan & Keenan 1973; Morgan 1984).

Table 2. Spectral classification of stars in IC 1805

star No.	p (%)	spectral-type published	sources	spectral-type new	grating No.	notes
5	53			G8II-III	1	
8	75			G2V	1	
18	78			B1V	1	
21	75	O9.5V, B0III	a, b	B0III	1, 2	
23	83	B1V	b	B1V	1	
26	62			A3II-III	1	
29	8			A7V	1	
39	84			A3V	1	
42	62	B2.5V	a	B2.5V	1	
43	78			G2V	1	
49	72	B2.5V	a	B2V	1	
50	80			F3V	1	
52	73	B2.5V	a	B2V	1	
53	70			B1.5V	1	
55	83			F0III	1	
56	35			A0V	1	
57	75			F3III	1	
62	87			B2.5V	1	
63	80			F1V	1	
68	82			B2.5V	1	
69	82	B2.5V	a	B2V	1	
70	85	B0.5Ia	b	B0.5Iae	1, 2	
71	52			A3II	1	
72	80	B2.5V	a	B1V	1	
74	63	K0II	b	G8II	1, 2	
82	84	B2.5V	a	B1.5V	1	
85	73			B5V	1	
91	78			A3III	1	
94	62	B2V	a	B2.5V	1	
96	85			B4V	1	
99	86			A6V	1	
103	84	B1V, B0V	a, c	B1V	1, 2	
104	79	O7V((f))	a	O7V	1, 2	
105	76	A1II-III	b	A7III	1	
110	60			A8III	1	
111	87	B1V, B2V	a,	B1V	1, 2	
112	84	B0.2V, B0V, O9.5V	a, b, d	B0V	1, 2, 3	
113	85	Be, O9Ve	a, b	O9.5Ve	1, 2, 3	A
118	86	O9.5V((f)), O9V	a, b	O9V	1, 2, 3	
121	74	B1V	a	B1.5V	1, 2	
122	71			F8V	1	
123	70			B9.5V	1	
124	75			A5V	1	
128	83			A8V	1	
129	83			B5V	1	
130	40			B3V	1	
131	60			G3V	1	
134	85			B7V	1	
136	77	B1.5V, B1V	a, b	B1.5V	1, 2	
138	80	O7V((f)), O6.5V	a, d	O7V	1, 2, 3	
139	83			B4V	1	
143	86	B1V	a	B0.5V	1, 2	
146	30			B5V	1	
147	75			B6V	1	
148	6	O4III(f), O5f	a, d	O5III(f)	1, 2, 3	
149	86	B1.5V, B3V, B3V	a, b, c	B2.5IV	1	
152	77			B3V	1, 2	

Table 2. continued

star No.	p (%)	spectral-type published	sources	spectral-type new	grating No.	notes
154	76			G2V	1	
155	40			A0V	1	
156	62	B1IV	a	B1V	1, 2	
157	77			B2.5V	1	
158	67			B1.5V	1, 2	
159	39			B3V	1	
160	64	O4If, O5Iaf, O4f	a, b, d	O4.5If	1	A
161	76	B1V, B1.5V	a, b	B1.5V	1, 2	
162	57			B2.5V	1	
163	84	B1.5V	a	B2V	1	
164	66			B5V	1	
165	79			B3V	1	
166	84	B2.5V, B3V	a, b	B2V	1, 2	
167	86	B1.5V	a	B1.5V	1	
168	65			B8V	1	
169	82	B1.5V, B2IV	a, b	B2III	1, 2	
170	75	B2.5V, A2II, A2II	a, b, e	A2III	1, 2, 3	
171	70			B5V	1	
172	82			B7V	1	
174	80	B2.5V, B2V	a, b	B2V	1, 2	
175	82			B2.5V	1	
177	78			B5V	1	
179	40			G2V	1	
180	75	B1V	a	B2V	1	
182	86			B4V	1	
183	80	B0.5V, B1IV, B0V	a, b, e	B1III	1, 2	
185	56	B1V, B2V	a, b	B1.5V	1, 2	
188	78			B2V	1	
189	78			B5V	1	
191	75	B2.5V	a	B2.5V	1	
192	67	O5V((f)), O5V	a, b	O5V((f))	1, 2, 3	
195	83			G9V	1	
198	73			G5III	1	
199	86			G7Ib	1	
200	24			B4V	1	B
208	69			A1V	1	
211	85	B1V, B1V	a, b	B2III	1, 2	
212	78	B2V	a	B3V	1	
213	72			B5V	1	B
214	63			F2V	1	
215	79			K5II-III	1	
218	84			B7V	1	
220	38			F8V	1	
221	86	B8II-III	b	B9.5V	1	
222	50			G3V	1	B
224	58			F0V	1	
225	87	B2V	a	B2V	1	
228	67			F3V	1	
229	76			B7V	1	
232	81	O8V((f)), O9V	a, b	O7V	1, 2, 3	
236	75			B8V	1	
240	83			B8V	1	
241	29			G5V	1	
244	75			F0V	1	

Table 2. continued

star No.	p (%)	spectral-type published	sources	spectral-type new	grating No.	notes
248	74			A1V	1	
250	77			G8II	1	
252	85			B3V	1	
255	84			A5III	1	
258	86			B8III	1	
259	81	B1V	a	B1V	1	
260	86	B2V, B2V	a, b	B3IV	1, 2	
262	85			B2V	1	
264	84			B4V	1	
266	86			B5V	1	
267	14			A1V	1	
276	83			B3V	1	
277	85			B3V	1	
278	83	A0II-III	b	A5III	1, 2	
279	46			B7V	1	
280	86			A3III	1	
288	83	B1V, B1.5V	a, b	B2III	1, 2	
290	76	F1V	b	F1III	1, 2	
298	37			A5V	1	
300	25			A3V	1	B
301	76			F5V	1	
303	44	A0II-III	b	A0II-III	1	
308	64	G5Ib-II	b	G5Ib-II	1	
310	84			A3V	1	
322	84			A5V	1	B
330	85			A7V	1	B
332	85			B3V	1	
339	77			A5V	1	
346	81			A3V	1	

Sources:
a: Massey et al. (1995).
b: Ishida (1970).
c: Hoag & Applequist (1965).
d: Conti & Alschuler (1971).
e: Hiltner (1956).

Notes:
A: showing Hα emission.
B: low S/N.

The spectra of a complete grid of MKK standards observed by us served as the basic frame for our spectral comparison and classification. Published atlases of grating spectra with similar resolution were also referenced. The main atlases used are those from Jacoby et al. (1984) and Turnshek et al. (1985).

Criteria of MKK classification in the classical region (3900 Å − 4900 Å) are described and illustrated in many sources (Keenan & McNeil 1976; Morgan et al 1978; Jaschek & Jaschek 1987). These criteria were used in our spectral classification. As our spectra also covered the yellow-red region (5000 Å − 8000 Å), all the spectral features present in the whole wavelength range from blue to red could be examined and compared. Many authors have been engaged in seeking suitable criteria for MKK classification in non-classical regions (Turnshek et al. 1985; Silva & Cornell 1992; Torres-Dodgen & Weaver 1993; Danks & Dennefeld 1994; Allen & Strom 1995; Shi & Hu 1999). As stated by these authors and illustrated by our spectra of observed MKK standards (Shi & Hu 1999), a lot of spectral features (lines, blends or bands) show temperature or luminosity effect in the yellow-red region. Among these, the intensity ratio of blend 6495/Hα is a very good

Table 3. Spectral classification of stars in NGC 654

star No.	p (%)	spectral-type published	sources	spectral-type new	grating No.	notes
5	95			B8V	1	
9	96			B1.5Ve	1, 2, 3	A
37	96			K4III	1	
52	80			B1.5Ie	1, 2	A
57	94			B9III	1, 2	
68	91	A2Ib, A2Ib, A0Ib	a, b, d	A0Ib-II	1, 2, 3	
71	96			B1V	1	
72	93			B3V	1	
76	95			B1.5V	1	B
78	94	B1.5IV, B6V	a, d	B1.5III-IV	1, 2	
79	94			B2V	1	
81	94			B3V	1	
84	91			B4V	1	
85	93			B2V	1	
86	93			B2V	1	
88	92	B1V	a	B1.5V	1, 2	
89	94			B2.5V	1	
90	94	B2IV	a	B1V	1	
94	94			B1V	1	B
96	93			B2V	1	B
97	94			B2V	1	
98	94			B1.5V	1	
100	95			B1V	1	
101	36			B1V	1	
102	93			B2V	1	
103	95			B2V	1	
104	92			B0Ve	1, 2	A
106	96			B3V	1	
108	96			B2V	1	
109	94	B2II	a	B2II	1, 2	
111	92	F5Ia, F2Ia, F5Ia	a, b, c	F5Ia	1, 2, 3	
112	91			B2.5V	1	
113	93			B1.5V	1	
114	89	B1V, B5V	a, d	B1.5V	1, 2	
119	95			B2V	1	
124	95			B1.5V	1	
125	95	B1.5V, B6V	a, d	B1.5V	1	
127	67			B3V	1	B
130	90			B1.5V	1	
131	87	B2IV	a	B1.5V	1, 2	
133	85			F3V	1	
135	96	B1V	a	B1Ve	1	A
147	64			F8IV	1	
154	88			B1.5V	1	
161	63			B9.5V	1, 2	
170	88			G8III	1	B

Sources:
a: Turnner (1976).
b: Sowell (1987).
c: Boulon et al. (1960).
d: Hoag & Applequist (1965).

Notes:
A: showing Hα emission.
B: low S/N.

Table 4. Spectral classification of stars in NGC 6823

star No.	p (%)	spectral-type published	sources	spectral-type new	grating No.	notes
1	79			A0V	1	
3	0			G2V	2	
4	91	B0IVe	a	B0.5IV	1, 2	
5	95			B2V	1	
8	97	O9.5III	a	O8V	1, 2, 3	
9	94			A2V	1, 2	
13	67			B7V	1, 2	
14	-			B2V	1	
17	-			B1.5V	1	
18	97			B2V	1, 2	
20	0			G7V	2	
21	0			K4V	2	
24	94	B1.5V	b	B1.5V	1, 2	
26	0			A9V	2	
30	88			B1.5V	1	
32	95			A0III	1, 2	
33	0			F5III	2	
36	96			G8III	1	
42	0			F3V	2	
46	85	B0.5Ib, B0.5Ia	b, c	B0.5Ib	1, 2, 3	
50	94			B4V	1	
52	-			B4V	1	A
53	0	G2V	d	G3V	2	
54	96	B1V, B1.5V, B2III	a, b, d	B1.5V	1, 2	
55	-			G8V	1	
56	0			G8V	2	
57	96	B1V, B2V, B2V	a, b, d	B2V	1, 2	
59	91	B2V, B5V	a, d	B3V	1	
60	0			K4III	2	
61	0			F1IV	2	
62	0			K0III	2	
63	-			G8II-III	1	
65	-			G5V	1	
66	-			B9V	1	
67	-			F2III-IV	1	
68	94	O9.5Ia, B0IV	b, c	B1III	1, 2, 3	
69	96	B2V	a	B3V	1	
71	-			B6V	1	
72	95	O7V((f)), O9.5Ia	a, b	O9.5III	1, 2, 3	
74	95	B1.5V, B0.5V	a, b	B1V	1, 2	
77	95	B1III, B1III	b, c	B1III	1, 2	
78	92	K8V	a	K4V	1, 2	
79	-			F9V	1	
80	96			B2.5V	1	
81	97	B1.5V, B0.5V	a	B1V	1, 2	
82	-			F0V	1	
83	96	O7V((f))	b	O7V((f))	1, 2, 3	
84	96	B0.5III, B0.5V	b, d	B1V	1, 2	
85	-			B4V	1, 2	
86	95	O9V, B0.5V	a, b	B0.5V	1, 2	
87	0			F8III	2	
88	96	B0:Vpe, B1.5V	a, b	B1V	1, 2	
89	76			F5V	1	
92	67			F8V	1	
93	93	O9.5V, B1V	a, b	B0V	1	
94	-			B8III	2	
95	0	G0V:	a	F7V	2	
96	67			F2IV	1, 2	
97	-			K3III	1	
98	0			G2III	2	

luminosity indicator for late-type stars, with the intensity of the blend significantly enhanced in supergiants. These new criteria did help in our stellar classification, especially in cases when good S/N could only be gained in the yellow-red wavelength range.

When classifying a stellar spectrum, we first figured out an approximate temperature type (e.g., early-B, mid-B or late-B). The second step was to determine its luminosity class. After that a more accurate temperature type was obtained. The last two steps were often performed several times before a final accurate MKK type

Table 4. continued

star No.	p (%)	spectral-type published	sources	spectral-type new	grating No.	notes
99	-			B2V	1	
101	45			A0V	1	
102	-			F4V	1	A
103	92			G8III	1	
104	96	B0.5V, B1V	a, b	B2III	1, 2	
105	0			K5V	2	
110	75	F8Ib	a	F8Ib	1, 2, 3	
113	75			A7III-IV	1	
115	96	B1V, B1.5III	a, b	B1.5III	1, 2	
116	-			B3V	1	
119	93	B1V, B2.5V	a, b	B1V	1, 2	
124	-			G8III	1	A
126	0			F3V	2	
135	-			B2.5V	1	
136	0			M6III	2	
141	0			K2V	1	
143	81			A2V	1	

Sources:
a: Turner (1979).
b: Massey et al. (1995).
c: Hiltner (1956).
d: Hoag & Applequist (1965).

Notes:
A: low S/N.

Table 5. Statistics of Be and B-type stars in the observed clusters

cluster	number of B-type stars	number of Be stars	frequency of Be stars (%)
IC 1805	33	1	3
NGC 654	30	3	10
NGC 6823	22	2	9
Total	85	6	7

could be fixed. When a program spectrum and a standard spectrum were compared, the whole spectrum as well as individual features corresponding to classification criteria were carefully examined. The program spectra were also compared with each other, to check that nothing went wrong during the process of spectral classification.

The errors in the MKK types classified by us have been estimated by: 1) comparing classification results of the two authors of this paper; 2) comparing results derived from spectra of different gratings (when existing); 3) comparing our results with those published in the literature for some brighter cluster stars; and 4) reclassifying the observed MKK standards; The errors of the resulting MKK types generally are smaller than 1 subclass in temperature types and about 1 subclass in luminosity classes. It should be pointed out that the luminosity class could be more easily determined using the spectra obtained with the grating of 600 lines/mm than the grating of 300 lines/mm. But even in the spectra of the lower dispersion luminosity classes I, III and V distinguished themselves from each other clearly.

3.2. Results

3.2.1. IC 1805

IC 1805 is the central cluster of the association Cas OB6. A proper motion survey was made by Vasilevskis et al. (1965) for 354 stars located in an area about two-thirds of a square degree and centered on BD +60°502 (HD 15558) which is the brightest star of IC 1805. Spectra of 140 stars from this survey list were obtained by us. Of these observed stars, 126 have proper motion membership probabilities $p \geq 50\%$ according to Zhao et al. (1985). Reduced spectra of all the program stars in IC 1805 are shown in Fig. **??** and Fig. **??**, for 600 lines/mm and 300 lines/mm grating respectively.

The results of the spectral classification on stars in IC 1805 are shown in Table 2. The star numbers from Vasilevskis et al. (1965) are listed in Col. 1. Proper motion membership probabilities from Zhao et al. (1985) are given in Col. 2. Spectral types published previously and their sources are presented in Cols. 3 and 4. MK types classified in this work are given in Col. 5. The grating(s) used in obtaining the spectra are listed in Col. 6, with “1” for the 300 lines/mm grating, “2” for 600 lines/mm and “3” for 1200 lines/mm.

IC 1805 contains a lot of massive stars, about forty from O4.5 through B2. These are most probable cluster members, judging from both their proper motion membership probabilities and early spectral types. The presence of very early O type stars indicates a very young cluster age and makes this cluster an desirable object for the study of the star formation process as well as for the determination of IMF at higher masses.

3.2.2. NGC 654

NGC 654 is a young cluster also located in the Cassiopeia region as IC 1805. Stone (1977) conducted a proper motion study for 186 stars in the cluster area. Spectra of 46 stars from this study were taken by us. This sample of observed stars corresponding to all the stars with membership probabilities $p \geq 50\%$ (Zhao et al. 1985) and brighter than $V = 14^{\rm m}_{.}0$. Only one exception is star No. 101 with $p = 36\%$. Reduced spectra of all the program stars in NGC 654 are shown in Fig. **??** and Fig. **??**.

The results of the spectral classification on stars in NGC 654 are shown in Table 3. The star numbers from Stone (1977) are listed in Col. 1. Proper motion membership probabilities from Zhao et al. (1985) are given in Col. 2. The other columns in Table 3 are similar to those in Table 2.

The earliest spectral type of around B0 means that NGC 654 is a more evolved young cluster than IC 1805. The presence of a few luminous stars, i.e., No. 111 (HD 10494, F5Ia), No. 68 (BD+61°315, A0Ib-II), No. 2 (B1.5Ie) and No. 109 (B2II) makes NGC 654 an interesting cluster for the study of the evolution of massive stars.

3.2.3. NGC 6823

NGC 6823 is the central cluster of the association Vul OB1. Erickson (1971) made a proper motion survey of a region about $30' \times 30'$ centred on the central Trapezium system of NGC 6823. 146 stars were listed in that survey, but membership probabilities were computed only for the 92 stars brighter than $V = 13^{\rm m}_{.}0$ whose proper motions were better determined (Erickson 1971; Zhao et al. 1985). Spectra of 77 Erickson’s stars were obtained by us. The observed stars went into three catagories: 1) 40 proper motion members, including all the stars with probability $p \geq 50\%$ except for star No. 73 which is too close to a bright star; 2) 19 proper motion non-members; and 3) 18 stars fainter than $V = 13^{\rm m}_{.}0$ to which no proper motion membership probabilities were assigned. Reduced spectra of all the program stars in NGC 6823 are shown in Fig. **??** and Fig. **??**.

The results of the spectral classification on stars in NGC 6823 are shown in Table 4. The star numbers from Erickson (1971) are listed in Col. 1. Proper motion membership probabilities from Zhao et al. (1985) are given in Col. 2. The other columns are similar to those in Table 2.

The earliest spectral type is O7, which suggests that the age of NGC 6823 may come between those of IC 1805 and NGC 654. The MKK types of two massive stars, No. 8 and No. 72, show some discrepancies among ours and other authors’. No. 8 is an O8V star here whereas it was classified as O9.5III by Turner (1979). No. 72 was assigned O7V((f)), O9Ia and O9.5III respectively by Turner (1979), Massey et al. (1995) and here. The spreads among spectral types for the above two stars(and maybe some others of similar cases in Table 2 through 4) as classified from time to time may indicate possible changes of spectral features due to some reason(s), rather than misclassification in the spectral types.

4. Early type emission-line stars

Quite a few stars showed at least Hα emission in our spectra. In IC 1805, the star No. 160 was confirmed as an Of star, and No. 113 an Be star (Ishida 1970; Massey et al. 1995). No. 70 is classified as an early type supergiant(B0.5Ia) with Hα emission. In NGC 654, four stars were found to have Hα emission. These include stars Nos. 9, 52, 104 and 135. No. 52 is classified as a supergiant, while the other three appear to be new Be stars from our spectral classification. In NGC 6823, The stars No. 4 and No. 88 were once classified as B0IVe and B0Vpe by Turner (1979). Both of them, however, did not show any distinct Hα emission in our spectra.

The frequency of Be stars has been discussed by many authors in the literature (Schild & Romanishin 1976; Mermilliod 1982; Jaschek & Jaschek 1983). Open clusters provide the desirable B-type parent population to which the Be stars can be compared. By definition, Be stars are non-supergiant B-type stars having at least once shown emission in one of the Balmer lines (Jaschek et al. 1981). Therefore, in IC 1805, NGC 6823 and NGC 654 respectively, one,two and three Be stars have been found as mentioned above. In Table 5, the number of all observed stars earlier than B2 (in Col. 2) and the number of Be stars ever found (in Col. 3) are given. All these Be stars also have types earlier than B2. According to both the proper motion surveys (mentioned in the previous section) and our spectral classification surveys over the three clusters, all of the cluster members earlier than B2 may well have been spectroscopically observed by us, on a statistical stand. The frequency of Be stars have been computed and given in Table 5. The averaged frequency of Be stars in these three clusters is 7%. For the sake of comparison, we just list the results of similar work from two other sources below. A frequency of about 7% was also obtained by Schild & Romanishin (1976) from a survey of 566 stars in 29 young open clusters, of which 41 Be stars were detected. By using the data of bright stars ($V \leq 6\overset{\mathrm{m}}{.}5$), Jaschek & Jaschek (1983) derived a frequency of about 17% and 11% of Be stars among B0 through B2 stars and among all B-type stars respectively. It should be pointed out that a Be star may not exhibit emissions at the time the observation was carried out, and the percentage of Be stars among B-type stars at a given moment is smaller than that when all stars which were once Be are included (Jaschek & Jaschek 1983). For a more reliable determination of the frequency of Be stars in open clusters, systematic detection of Be stars in more clusters should be made.

Detailed study on individual Be stars in open clusters such as those found in this work is of special interest, since the distances, ages and intrinsic colours can be inferred from the well-determined cluster parameters (Mermilliod 1982; Slettebak 1985). It will help in understanding the evolutionary status of Be stars and the origin of the envelops around them.

5. Summary

Three young open clusters with differential reddenings were selected as targets of a comprehensive spectral classification study. MKK types were obtained for 140, 46 and 77 stars in IC 1805, NGC 654 and NGC 6823 respectively. As these clusters are very young, most of the proper motion members are found to be early-type stars. Seven stars showed at least Hα emission in our spectra. Among these, three Be stars in NGC 654 were discovered by us. One Be and one Of star in IC 1805 were confirmed by our spectra. The other two were appropriately classified as early-type supergiants showing Hα emission.

The spectral classification work is just the first step to the systematical investigation of stellar contents and cluster properties (e.g., reddening, distance and age) of young open clusters and/or associations. Further study will be followed, based upon homogeneously combined data from spectroscopy, photometry, astrometry and so on.

Acknowledgements. The authors gratefully acknowledge Xinglong Observation-Station of the Joint Laboratories for Optical Astronomy for providing all the needed observing time. They also wish to express their sincere gratitude to Dr. Ram Sagar for his valuable comments on improving the paper. This research has made use of the BDA database, kindly offered by Dr. Jean-Claude Mermilliod, for bibliography information on MKK classification of stars in the clusters studied.

References

Allen L.E., Strom K.A., 1995, AJ 109, 1379
Boulon J., et al., 1960, Publ. Obs. Haute-Provence 4, No. 34
Conti P.S., Alschuler W.R., 1971, ApJ 170, 325
Danks A.C., Dennefeld M., 1994, PASP 106, 382
Erickson R.R., 1971, A&A 10, 270
Hiltner W.A., 1956, ApJS 12, 215
Hoag A.A., Applequist L., 1965, ApJS 12, 215
Ishida K., 1970, Publ. Astr. Soc. Japan 22, 277
Jacoby G.H., Hunter D.A., Christian C.A., 1984, ApJS 56, 257
Jaschek C., Jaschek M., 1983, A&A 117, 357
Jaschek C., Jaschek M., 1987, The claasification of Stars. Cambridge University Press, Cambridge
Jaschek M., Slettebak A., Jaschek C., 1981, Be Newslett. 4, 9
Joshi U.C., Sagar R., 1983a, J. R. Astr. Soc. Can. 77, 40
Joshi U.C., Sagar R., 1983b, MNRAS 202, 961
Keenan P.C., McNeil R.C., 1976, An atlas of spectra of the cooler stars. Ohio State University Press
Massey P., Johnson K.E., DeGioia-Eastwood K., 1995, ApJ 454, 151
Mermilliod J.C., 1982, A&A 109, 48
Mermilliod J.C., 1986, BIC DS 31, 175
Moffat A.F.J., 1972, A&AS 7, 355
Morgan W.W., 1984, in: Garrison R.F. (ed.) The MK Process and Stellar Classification, p. 18
Morgan H.L., Keenan P.C., 1973, ARA&A 11, 29
Morgan W.W., Abt H.A., Tapscott S.W., 1978, Revised MK spectral atlas for stars earlier than the sun. Yerkes Observatory and Kitt Peak National Observatory
Sagar R., 1987, MNRAS 228, 483
Sagar R., Joshi U.C., 1981, ApSS 75, 465
Sanders W.L., 1972, A&A 16, 58
Schild R.E., Romanishin W., 1976, ApJ 204, 493
Shi H.M., Hu J.Y., 1999, Acta Astrophys. Sin. (in press)
Silva D.R., Cornell M.E., 1992, ApJS 81, 865
Slettebak A., 1985, ApJS 59, 769
Sowell J.R., 1987, ApJS 64, 241
Stone R.C., 1977, A&A 54, 803
Stone R.C., 1980, PASP 92, 426
Torres-Dodgen A.V., Weaver W.B., 1995, PASP 105, 693
Turner D.G., 1976, AJ 81, 87
Turner D.G., 1979, J. R. Astro. Soc. Can. 73, 74
Turnshek D.E., Turnshek D.A., Craine E., Boeshaar P.C., 1985, An atlas of digital spectra of the cool stars. Tucson: Western Reasearch Co.
van den Ancker M.E., The P.S., Feinstein A., Vazquez R.A., der Winter D., Perez M.R., 1997, A&AS 123, 63
Vasilevskis S., Sanders W.L., Van Altena F., 1965, AJ 70, 806
Zhao J., Tian K, Jing J., Yin M., 1985, Special Issue for Tables of Membership for 42 Open Clusters. Shanghai Astronomical Observatory, Chinese Academy of Sciences

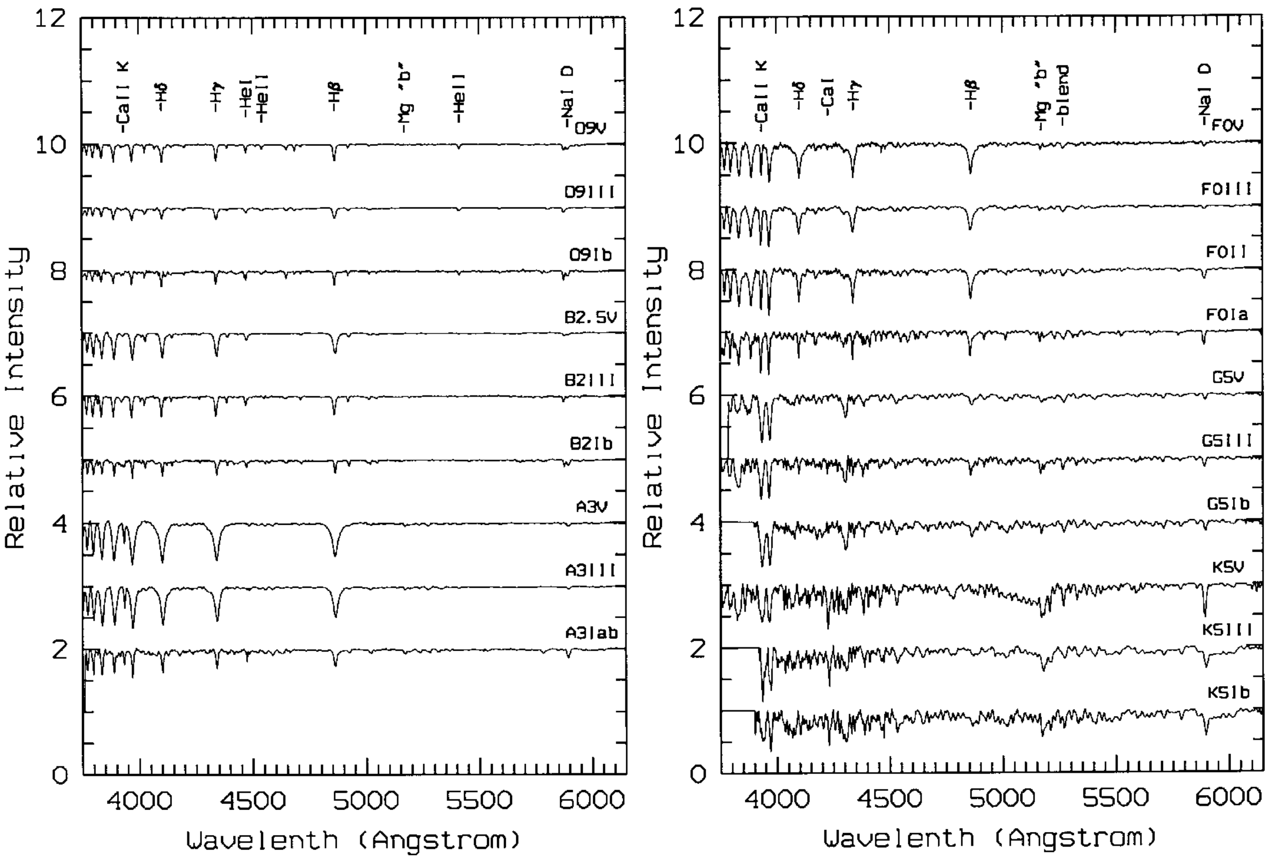


Fig. 1. Representative spectra of MK standards taken with 600 lines/mm grating

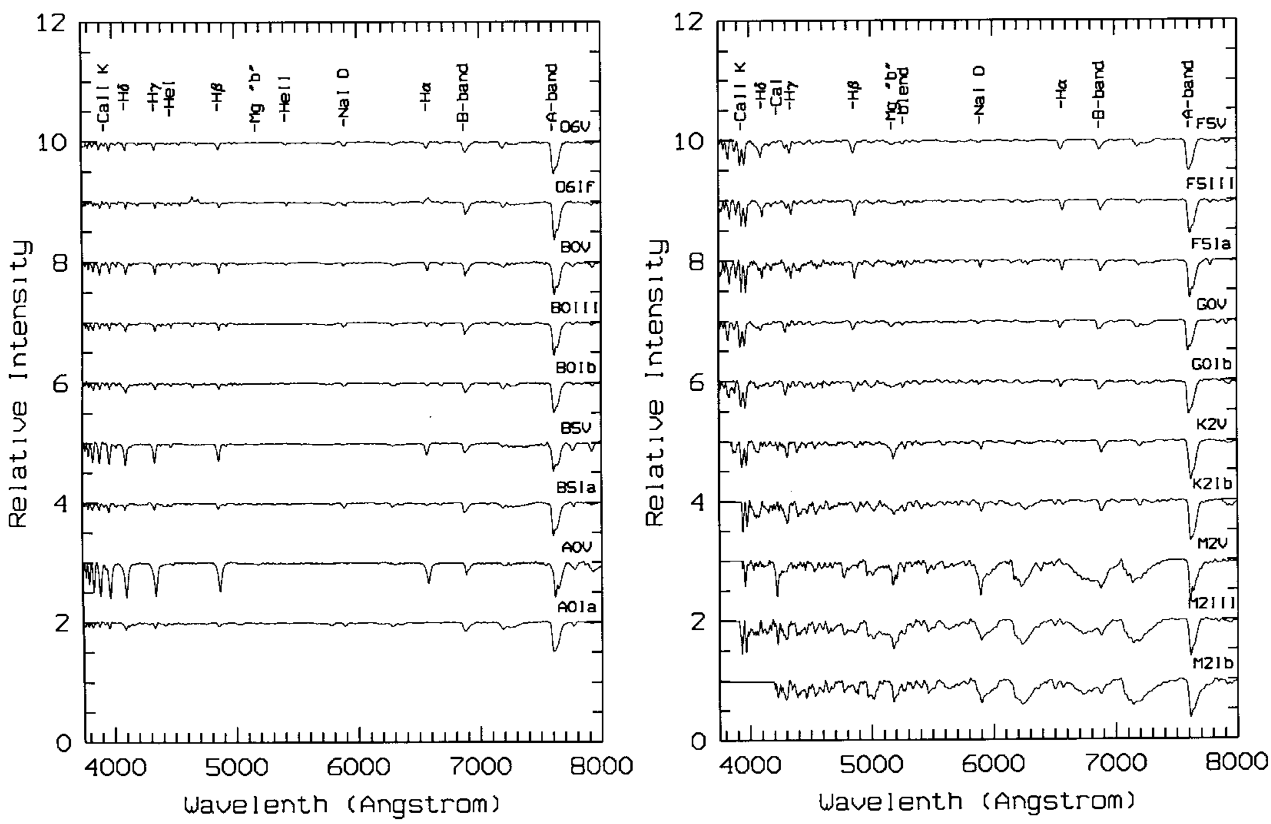


Fig. 2. Representative spectra of MK standards taken with 300 lines/mm grating

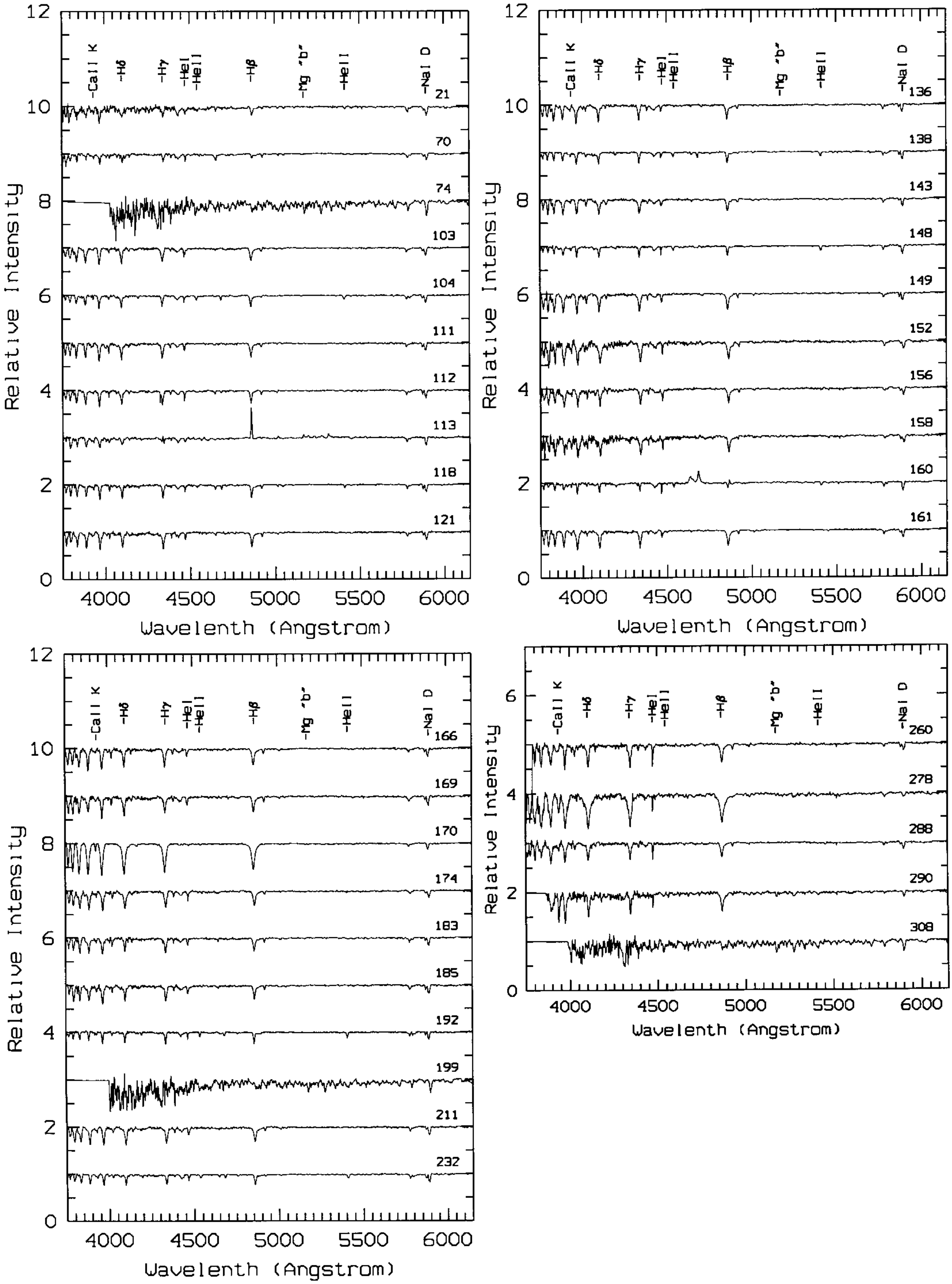


Fig. 3. Spectra of program stars in IC 1805 taken with 600 lines/mm grating

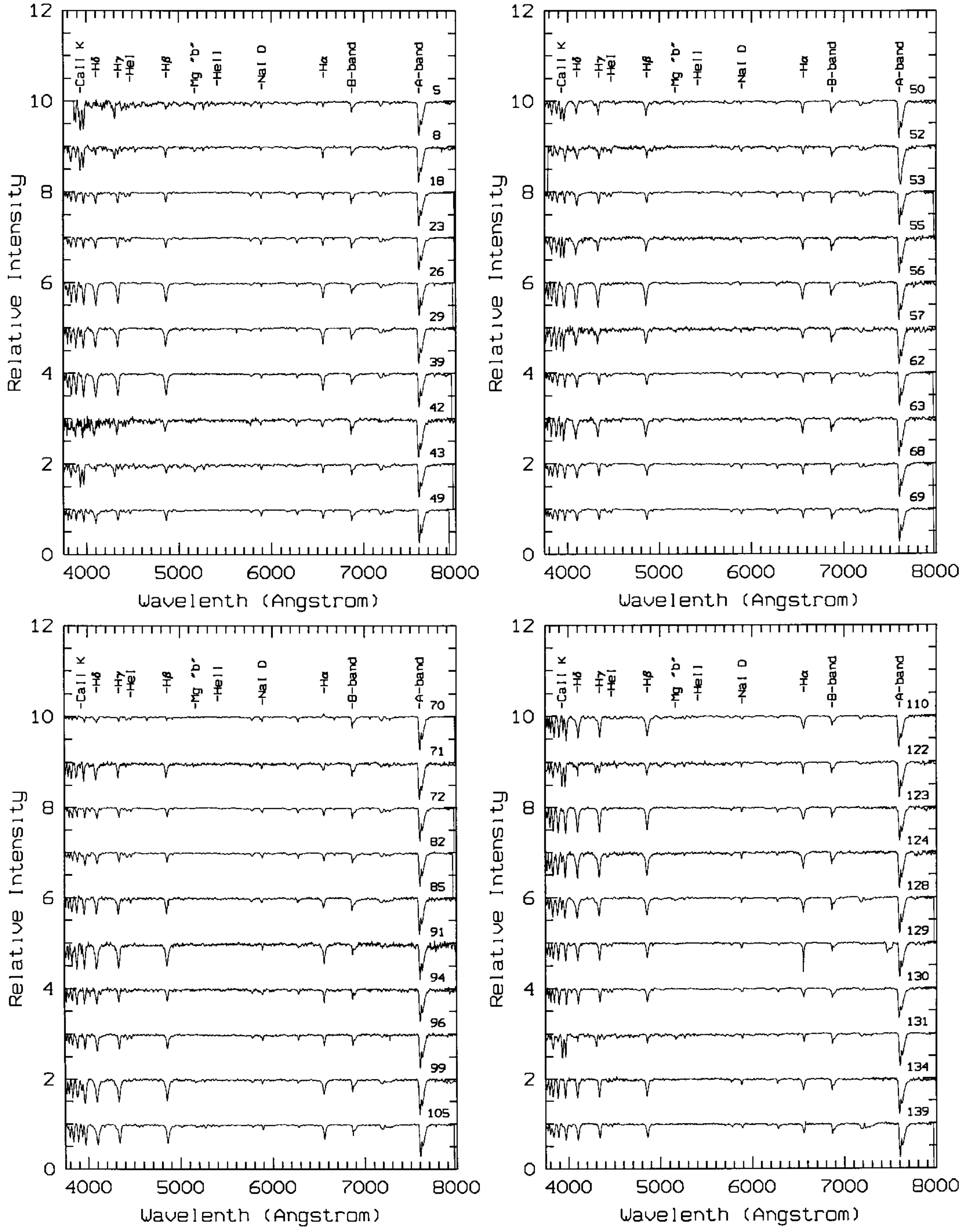


Fig. 4. Spectra of program stars in IC 1805 taken with 300 lines/mm grating

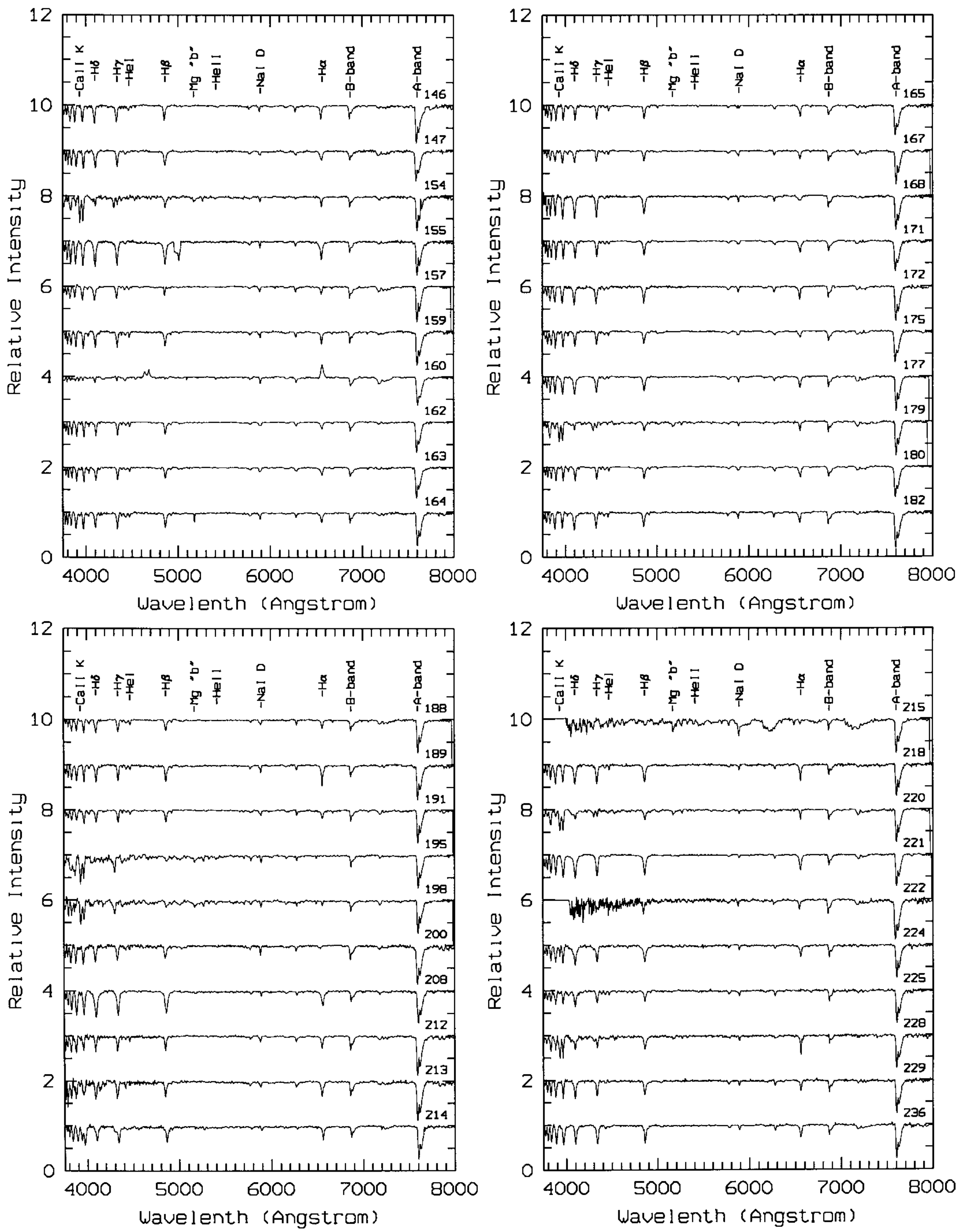
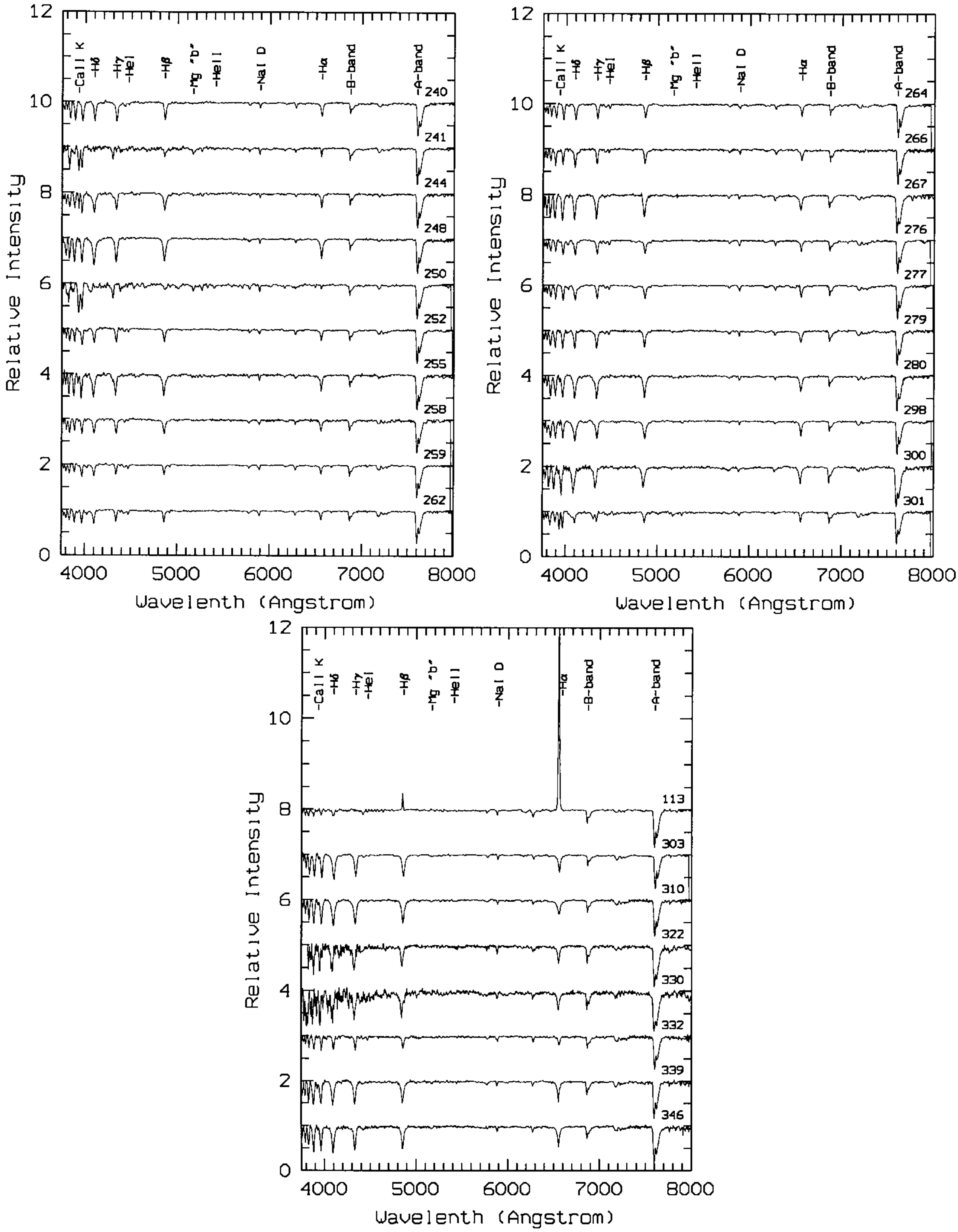


Fig. 4. continued



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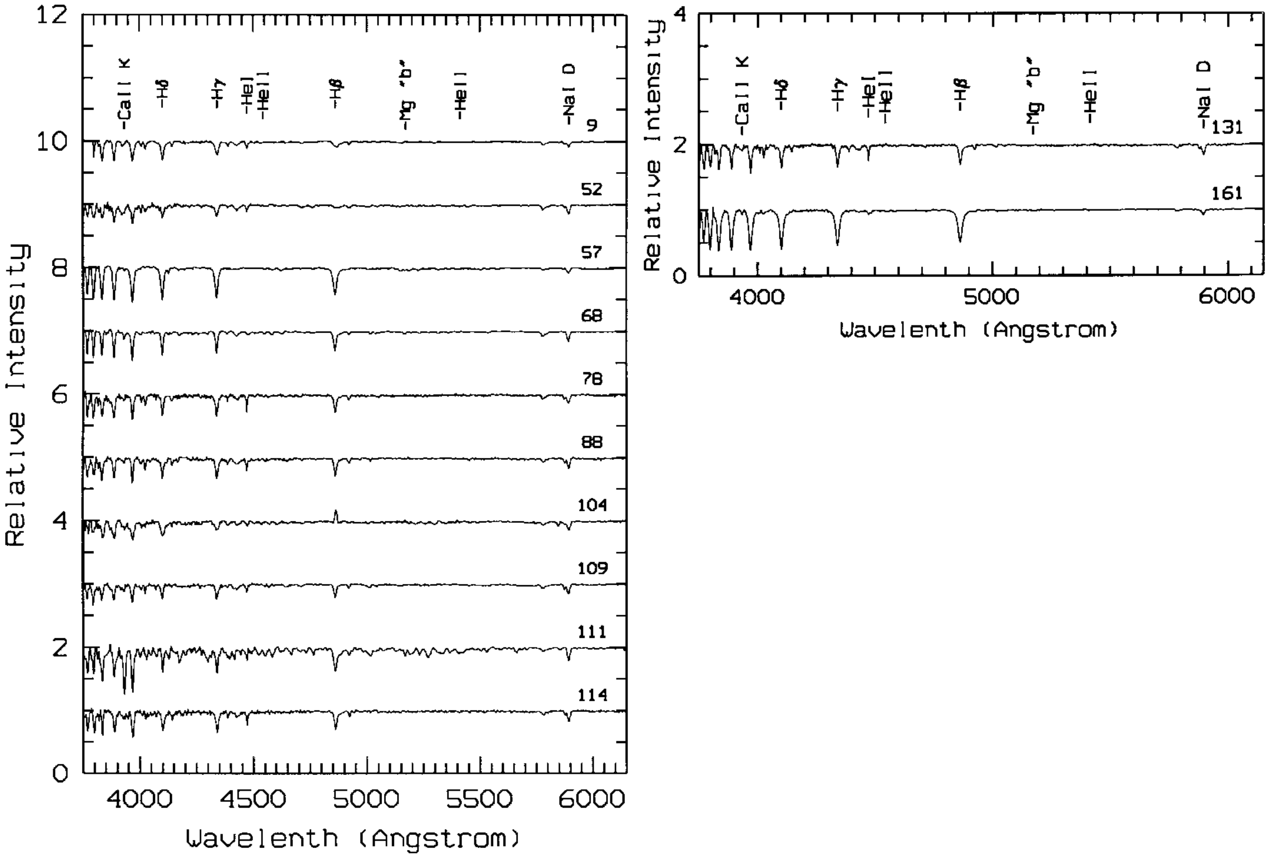


Fig. 5. Spectra of program stars in NGC 654 taken with 600 lines/mm grating

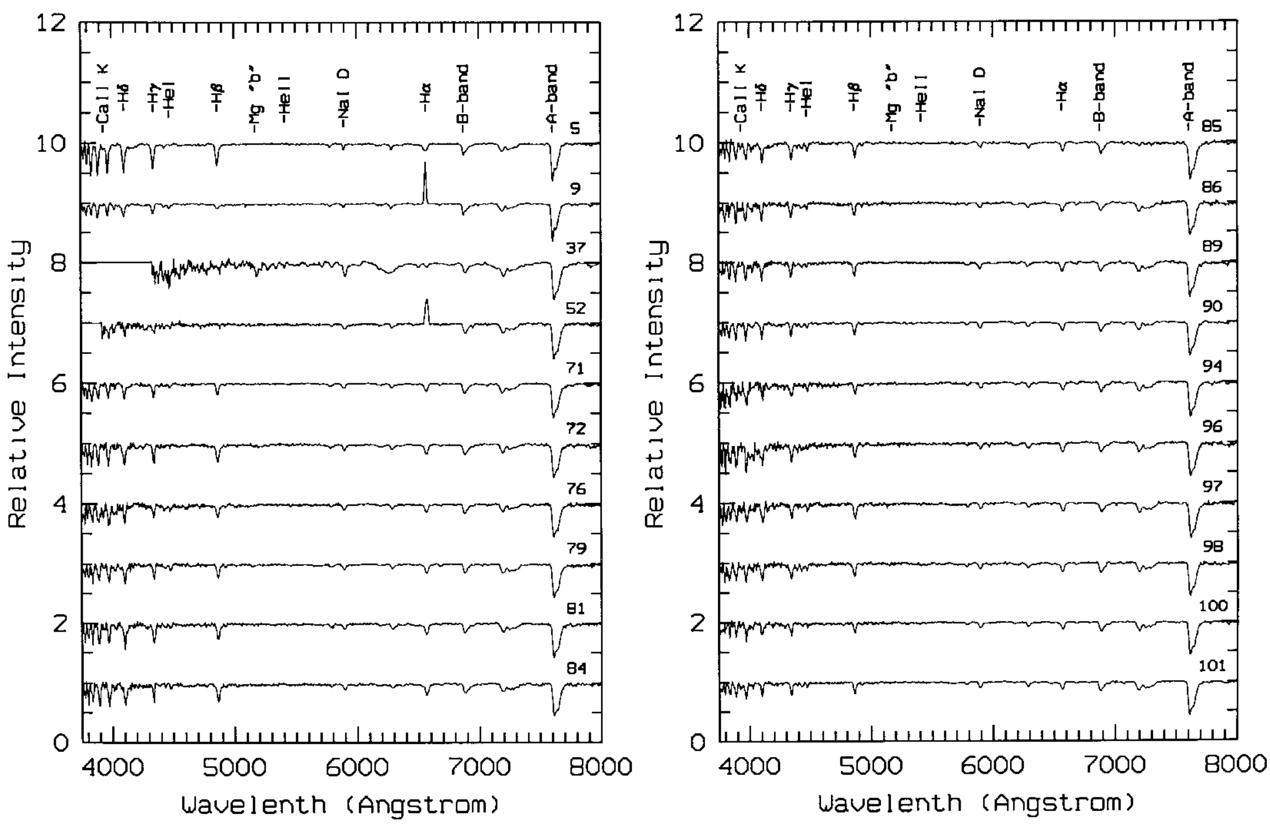
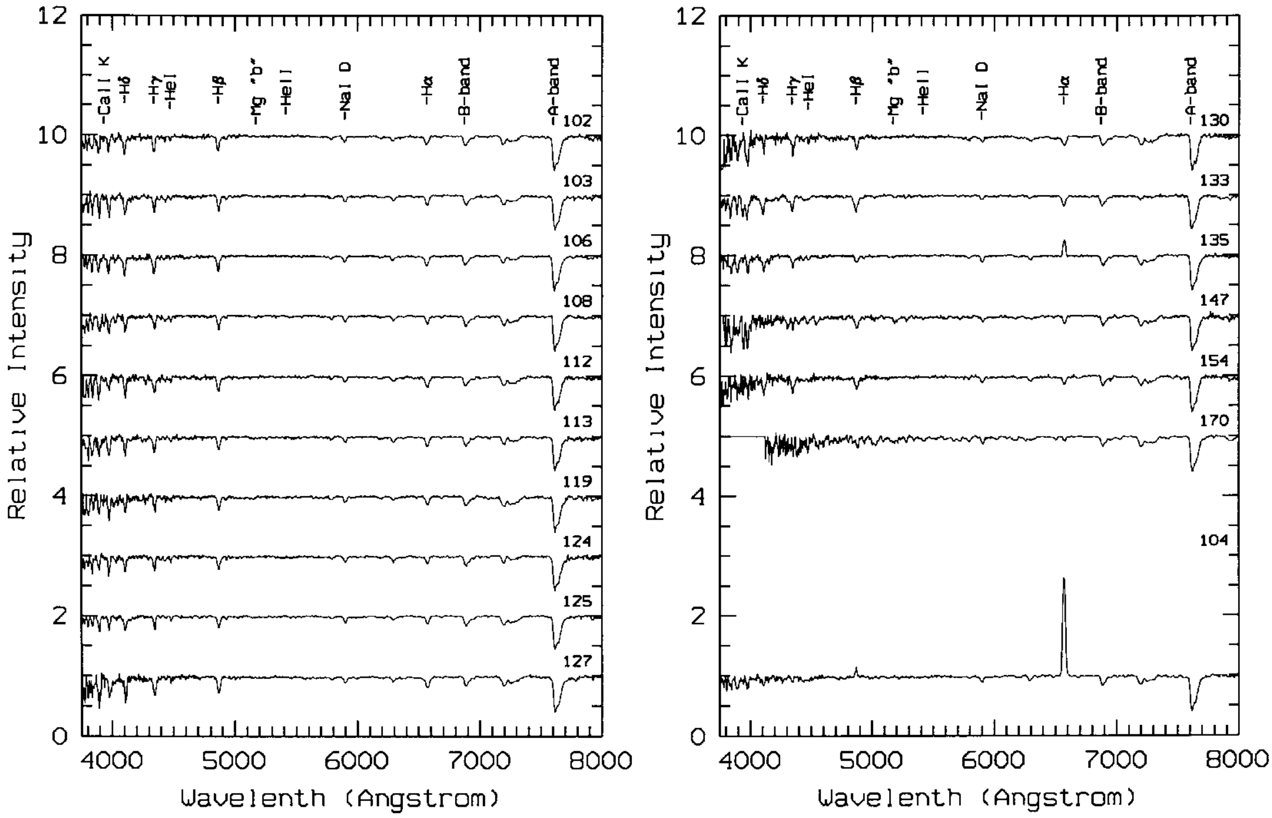


Fig. 6. Spectra of program stars in NGC 654 taken with 300 lines/mm grating



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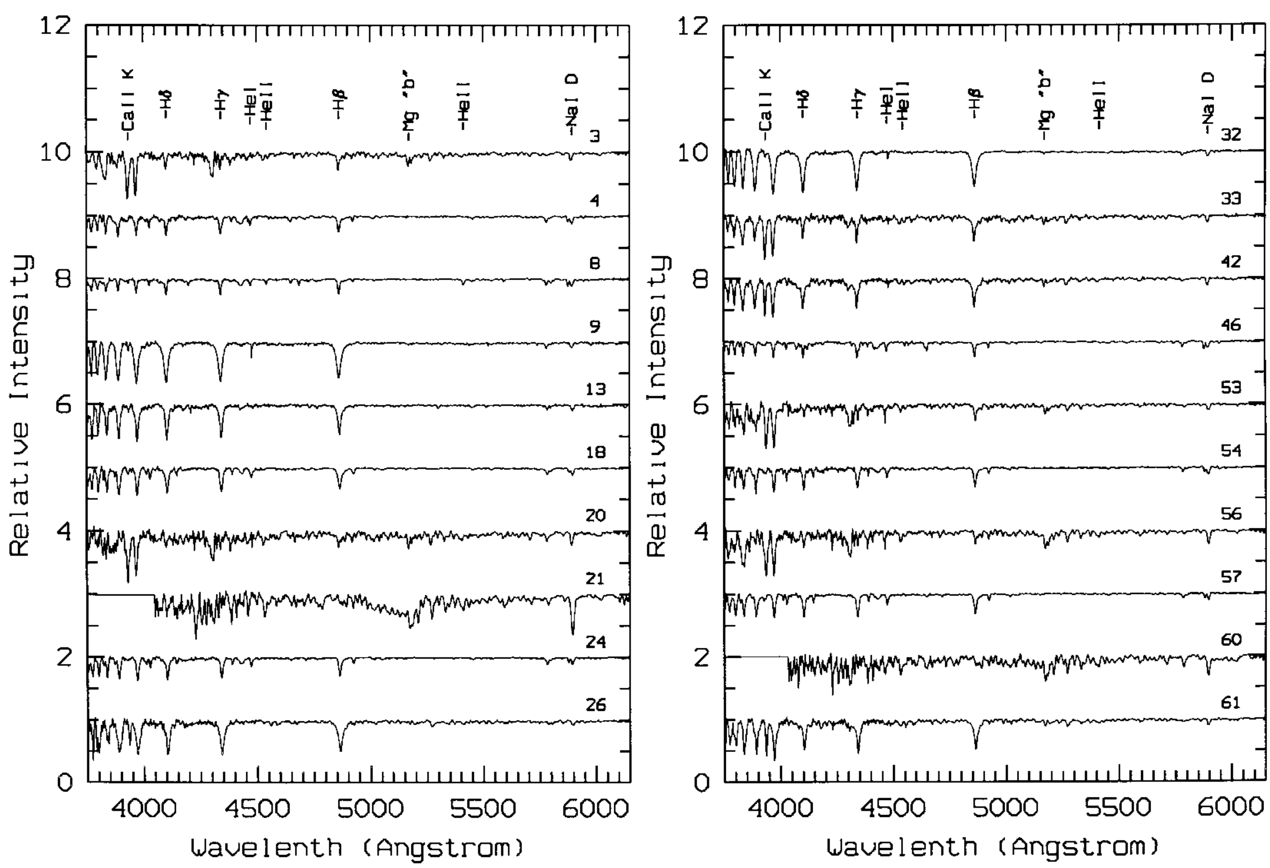
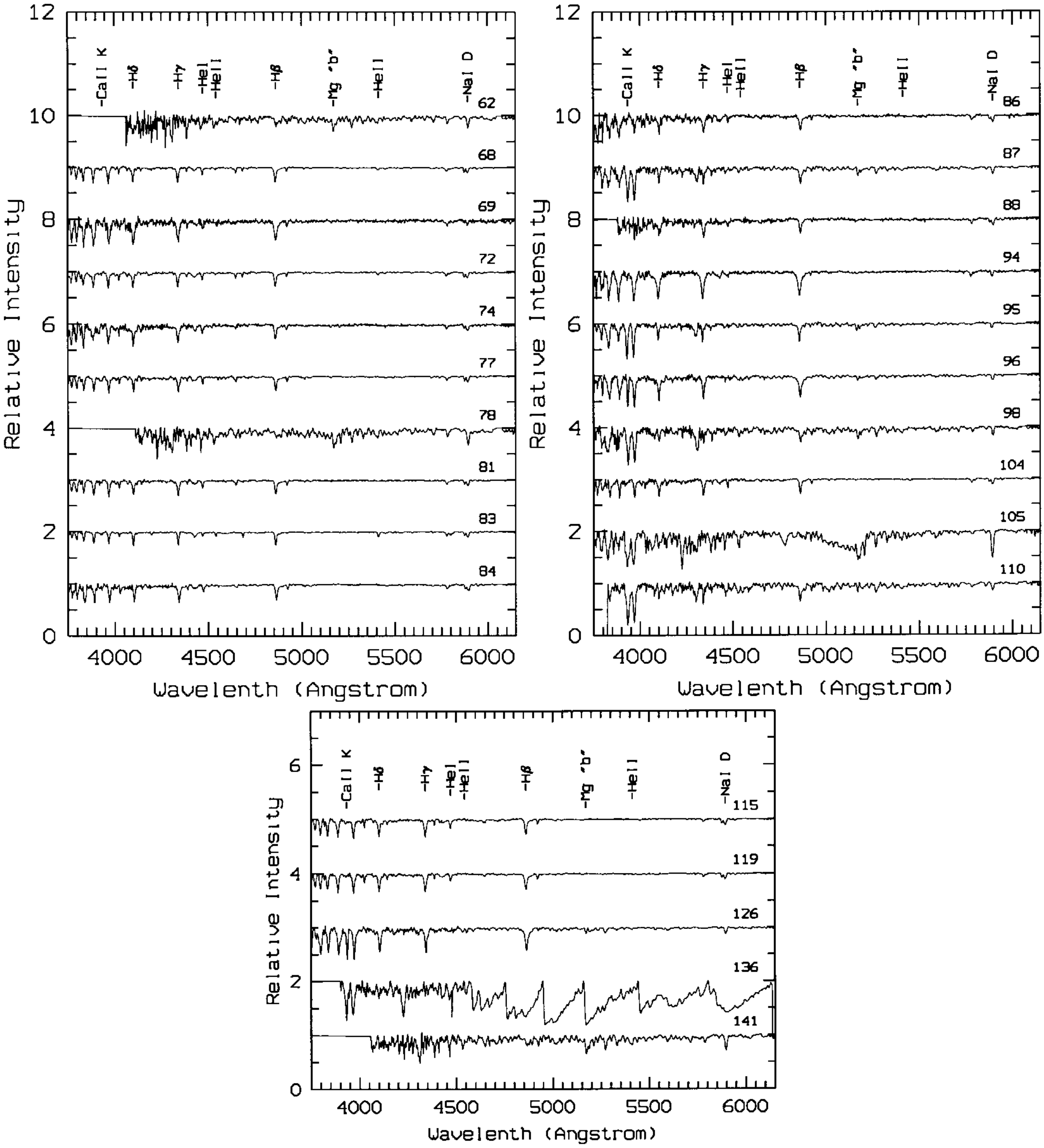


Fig. 7. Spectra of program stars in NGC 6823 taken with 600 lines/mm grating



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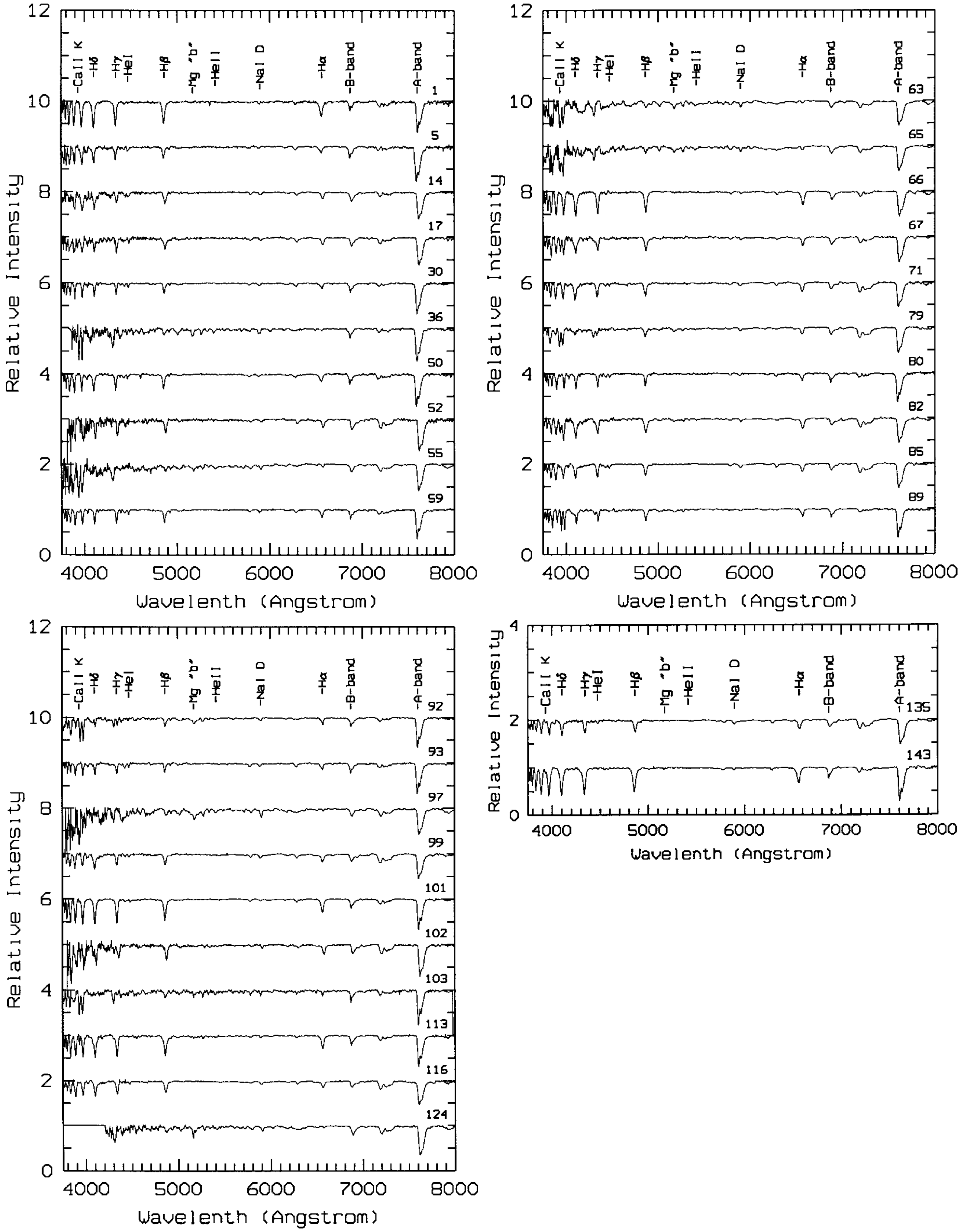

Fig. 8. Spectra of program stars in NGC 6823 taken with 300 lines/mm grating