A&A 366, 490–497 (2001)
DOI: 10.1051/0004-6361:20000213

Astronomy & Astrophysics

Blue stragglers in open clusters*

III. NGC 7789

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Received 8 September 2000 / Accepted 7 November 2000

Abstract. We performed for the first time a detailed LTE spectroscopic study of a sample of blue straggler stars in the moderately old open cluster NGC 7789. For eight stars the parameters and abundances of several elements were determined. The cluster members show a remarkable surface magnesium deficiency which is quite unusual for late B - early A stars. Iron and titanium abundances are in agreement with other photometric and spectroscopic estimates of the NGC 7789 metallicity. All the confirmed blue stragglers have rather low projected rotational velocities (with one exception for K88, $v \sin i = 80$ km s^{-1}).

Key words. stars: open clusters and associations: individual: NGC 7789 – stars: blue stragglers – stars: abundances

1. Introduction

The moderately old open cluster NGC 7789 is among those having very rich blue-straggler populations. Ahumada & Lapasset (1995) give a cluster age of 1.6 Gyr, and the number of suspected blue-straggler candidates is reported to be 25. Despite this large blue-straggler population, no quantitative abundance analysis has been performed so far.

Twenty years ago NGC 7789 with its blue stragglers became a paradigm to explain the existence of such stars by assuming ad hoc additional internal mixing which extends the main sequence phase (Saio & Wheeler 1980). Such a putative mechanism was later discussed by Schönberner & Napiwotzki (1994) who determined accurate effective temperatures and gravities for several blue stragglers in NGC 7789. These authors have shown that the existence of blue stragglers does not result from internal mixing processes, but that they rather evolve like normal stars.

In recent years interest in the NGC 7789 blue stragglers (and in blue stragglers in general) has waned because of the failure to find any spectroscopic signature unique to this phenomenon.

Our third paper from this series is devoted to a detailed spectroscopic investigation of blue-straggler candidates in NGC 7789.

2. Program stars and observations

We have been able to secure spectrograms of a total of 8 blue-straggler candidates at two different observatories (Kitt Peak National Observatory – KPNO, and Calar Alto Observatory – CA). Some essential information about our targets and details of their observation are given in Table 1. Additional information about the stars listed in the table can be also found in the WEBDA data base (Mermilliod 1999). The well investigated star α Lyr (Vega) has been chosen as a reference star in order to control our method of the analysis.

KPNO spectra were obtained during October 1-3, 1985, with the 4-m telescope equipped with an echelle spectrograph and CCD camera (resolution 0.12 Å/px,

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* Based on the spectra collected at Kitt Peak National Observatory, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation, and at the German-Spanish Astronomical Center, Calar Alto, operated by the Max-Plank Institute for Astronomy, Heidelberg, jointly with the Spanish National Commission for Astronomy.

Table 1. Data for program stars

K	GET	V	$B-V$	MP	Region, Å	Instrument
K88	2873	13.10	0.38	0.98	4220-4525	KPNO
K316	5569	13.79	0.36	0.98	4220-4525	KPNO
K371	5951	12.95	0.36	0.98	4220-4525	KPNO
					Hγ, Hβ	CA
K409	6268	12.98	0.31	0.53	4220-4525	KPNO
					Hγ	CA
K677	8404	11.16	0.16	0.53	4220-4525	KPNO
					4450-4585, Hβ	CA
K746	8804	12.74	0.39	0.98	4220-4525	KPNO
					Hγ	CA
K1211	13 273	11.55	0.18	0.97	Hγ, Hβ	CA
					4450-4580	CA
K1270	14 054	13.46	0.46	0.98	4220-4525	KPNO
Vega		0.06			4220-4525	KPNO

K - Küstner (1923) number; GET - Gim et al. (1998a) number; MP - membership probability as determined by McNamara & Solomon (1981).

S/N ratio varying from approximately 30 to 80 at the continuum level, except for Vega). These spectrograms were extracted from the frames in the usual manner by using the IRAF package[1]. All spectra consisted of nine (not overlapping) orders, each covering approximately 30 Å. Because of the small sizes of the observed bands we met some problems with the correct continuum placement in the vicinity of the Hγ line. To avoid the problems that could be caused by the wrong continuum placement, the two adjacent orders from the spectrum of each star ranging from 4320 Å to 4390 Å were discarded in the further analysis.

The CA spectral material was obtained during two runs in January and September 1986 with the 2.2-m telescope equipped with a Coudé spectrograph (resolution 0.26 Å/px, S/N ratio about 40–70). These observations were aimed at getting reliable profiles of the hydrogen lines Hγ and Hβ. The spectral regions cover approximately 130 Å each.

The final spectra were treated using the DECH20 spectra processing package (Galazutdinov 1992).

3. Stellar parameters

The effective temperatures were estimated using the Strömgren photometric indices (available for the program stars through the WEBDA data base, see Mermilliod 1999) by means of the numerical code written by T.T. Moon (based on the grid published in Moon & Dworetsky 1985) and modified by Napiwotzki (1994). In the WEBDA data base, however, the β-index is given for only two of our program stars. For the remaining ones we used either the measurements given in the paper of Schönberner & Napiwotzki (1994), or obtained by Schönberner (unpublished) with the same technique as explained in Schönberner & Napiwotzki (1994).

In cases where Hγ and Hβ profiles were available (cf. Table 1) the gravities were specified by matching observed and calculated profiles. The profiles of the hydrogen lines were calculated with the help of the SYNSPEC code (Hubeny et al. 1994). For K88, K316 and K1270 hydrogen profiles are not available, and we used gravities determined by photometry. However, for K316 and K1270 the photometrically determined gravities appeared to be inconsistent with their positions in the HR diagram (see Fig. 4 from Breger 1982). For the less evolved star, K316, we adopted $\log g = 4.0$, and for K1270 $\log\ g = 3.5$. Note that these adopted gravities differ ≈ 0.4 dex from the photometrically estimated ones, but this difference has a small influence on the derived abundances in the temperature region in question.

The finally adopted effective temperatures and gravities are collected in Table 2. Note that for K409, K677, K1211 and Vega the values given in Schönberner & Napiwotzki (1994) were used.

Projected rotational velocities were determined by matching observed and calculated profiles of the hydrogen and/or metallic lines (mainly Mg II) and are also listed in Table 2.

4. Elemental abundances

The atmosphere models of Kurucz (1991) and oscillator strengths for the lines of interest from the VALD data base were used to determine individual elemental abundances in conjunction with the LTE spectrum synthesis method (SYNSPEC, Hubeny et al. 1994). For all the program blue stragglers we adopted the microturbulent velocity

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Table 2. Parameters of program stars

Knum	$T_{\rm eff}$ (K)	$\log g$	$v \sin i$ ($\rm km\,s^{-1}$)
K88	8900	3.7	80
K316	8950	4.0	25
K371	8500	3.7	45
K409	9480	4.2	140
K677	10 680	3.6	40
K746	8600	3.5	20
K1211	12 630	3.6	30
K1270	8300	3.5	25
Vega	9500	4.0	22

Table 3. Elemental abundances for Vega

	Present Paper				Hill (1995)
	0.6 $\rm km\,s^{-1}$	2.0 $\rm km\,s^{-1}$			
El.	[El/H]	[El/H]	σ	N	[El/H]
Mg	−0.10	−0.26	-	1	−0.27
Ca	−0.63	−0.73	-	1	−0.47
Sc	−1.27	−1.41	-	1	-
Ti	−0.30	−0.64	0.09	7	−0.46
Cr	−0.25	−0.34	-	1	−0.48
Fe	−0.18	−0.46	0.11	7	−0.54

$V_{\rm t} = 3\ \rm km\,s^{-1}$ (the same value as adopted in Andrievsky et al. 2000 - Paper II), while for Vega we used the literature value $V_{\rm t} = 2\ \rm km\,s^{-1}$ (see, e.g. Sadakane & Nishimura 1981). For the sake of completeness, we also calculated the abundances with the smaller value of $V_{\rm t} = 0.6\ \rm km\,s^{-1}$ recommended by Adelman & Gulliver (1990). Note that our implementation of the SYNSPEC code enables one to calculate only the spectra of chemical elements with $Z \leq 30$, therefore, the lines of the heavier species (if observed) were ignored. The steps of the analysis mentioned above are described in more detail in Paper II.

There is much evidence that Vega is a mild metal deficient star, therefore, we used the atmosphere model selected from the grid with [A] = −0.5 for its spectrum synthesis.

Elemental abundances for Vega and our program blue stragglers are given in Tables 3 and 4. For Vega we also give a comparison with the most recent study by Hill (1995) also based on the spectrum synthesis technique. It should be stressed that with this study we did not aim to enlarge the number of precise and detailed spectroscopic investigations of Vega. Our main reason was to have some external indication of the reliability of the analysis based on our homogeneous spectroscopic material. Although the number of lines used is limited, the agreement in the derived abundances with Hill (1995) is satisfactory.

All of our high-probability proper-motion members show a strong deficiency of magnesium and scandium. For example, in Figs. 1 and 2 the synthetic and observed spectra for program stars in the vicinity of the Mg II 4481 Å line are shown. The synthetic spectra were calculated with the parameters listed in Table 2 and magnesium abundances for individual stars from Tables 3 and 4.

The detected magnesium deficiency for blue straggler stars cannot be removed by any reasonable changes in the atmospheric parameters, because within the temperature region 8 000 K–10 000 K, the magnesium line 4481 Å appears to be practically insensitive to temperature and gravity variations. This was also mentioned by Holweger, Gigas & Steffen (1986) who performed a qualitative search for abundance indicators in early A stars which are both temperature and gravity insensitive. As an example, we have calculated the magnesium abundance for K1270 assuming temperature and gravity uncertainties of about ±500 K and ±0.5 dex respectively. The resulting changes in the abundance appeared to be negligible, and even smaller for temperatures higher than 8 500 K. The response of the magnesium abundance (as derived from the Mg II 4481 Å line) caused by the parameter variations is given in Table 5. The Δ means the difference between the magnesium abundance [Mg/H] derived for K1270 with its basic model parameters (see Table 2) and with varied parameters (e.g., 7 750/4.0/3.0 denotes model with $T_{\rm eff}$ = 7 750 K, $\log g = 4.0$ and $V_{\rm t} = 3.0\ \rm km\ s^{-1}$).

For the iron-group (Ti, Fe), the abundances for the blue stragglers do not differ from those determined for other stars in NGC 7789. Tiede et al. (1997) estimated the metallicity of NGC 7789 by IR photometry of the giant branch to be [Fe/H] = −0.62. Recently, Vallenary et al. (2000) revised this value by an improved method using new IR photometry and found [Fe/H] = −0.25 ± 0.11. Friel & Janes (1993) carried out low-resolution spectroscopy for several giants and obtained a mean metallicity of [Fe/H] = −0.26 ± 0.06. Pilachowski (1985) performed a high-resolution spectroscopic investigation of six giant stars and found [Fe/H] = −0.1 ± 0.2, in excellent agreement with our mean iron abundance (−0.16 dex).

As to other elements, there is only one indication in the literature that the relative-to-solar abundances of atomic species like Ca, Sc, Ti, etc. scatter only slightly about that of iron (Pilachowski 1985). Our results for titanium and chromium agree very well with those of Pilachowski, that of calcium only marginally. The only really discrepant case is for scandium where our blue stragglers appear to be deficient between a factor of 10 to 100. It is known, however, that A-type stars very often show peculiarities of certain elements (see Sect. 5.2).

5. Discussion

5.1. Cluster membership

The membership probabilities for our blue-straggler candidates in NGC 7789 have been determined by several investigations:

Photometry, polarimetry and proper motion:
Pendl (1975), McNamara (1980), Twarog & Tyson (1985), Manteiga et al. (1991), Breger (1982).

Table 4. Relative elemental abundances [El/H] for program stars in the field of NGC 7789

Star	He	Mg	Ca	Sc	Ti	Cr	Fe
K88		−0.70 (–, 1)	−0.25 (–, 1)	−1.11 (–, 1)	−0.28 (0.18, 5)		−0.12 (0.20, 5)
K316		−1.04 (–, 1)	−0.53 (–, 1)	−1.31 (0.18, 4)	−0.41 (0.19, 3)	+0.09 (–, 2)	−0.23 (0.19, 11)
K371		−0.20 (–, 1)		−0.77 (–, 1)			−0.13 (0.23, 4)
K409		+0.00 (–, 1)					
K677	+0.07 (–, 1)	+0.16 (0.18, 5)			−0.24 (0.22, 6)		−0.08 (0.17, 7)
K746		−0.64 (–, 1)	−0.14 (0.17, 4)	−0.92 (0.25, 5)	−0.23 (0.19, 15)	+0.03 (0.16, 4)	−0.13 (0.19, 13)
K1211	−1.00 (–, 1)	−1.04 (–, 1)					−0.10 (0.23, 4)
K1270		−1.14 (–, 1)	−0.71 (0.29, 4)	−2.03 (0.19, 5)	−0.39 (0.24, 11)	+0.00 (0.18, 4)	−0.20 (0.18, 15)

Given in the brackets are s.d. and number of used lines respectively.

Table 5. Parameter variation and Mg abundance changes for K1270

	7750/3.0/3.0	7750/4.0/3.0	8750/3.0/3.0	8750/4.0/3.0	8300/3.6/2.5	8300/3.6/3.5
Δ	−0.12	+0.18	−0.05	+0.05	+0.09	−0.05

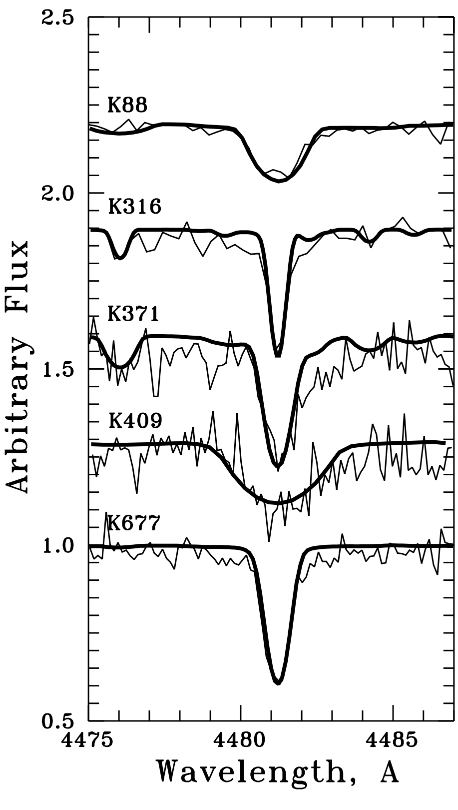

Fig. 1. Observed (**thin line**) and calculated (**thick line**) fragment of the spectra in the vicinity of Mg II 4481 Å line

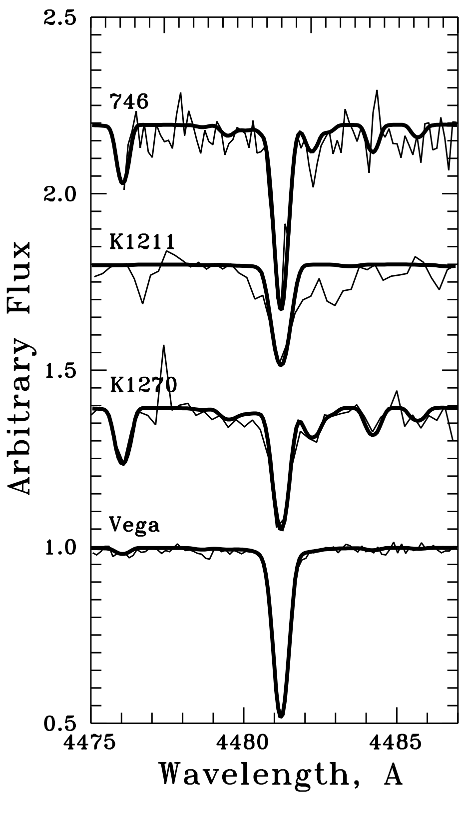

Fig. 2. Same as Fig. 1

Radial velocities: Strom & Strom (1970), Stryker & Hrivnak (1984), Drilling & Schönberner (1987), Manteiga et al. (1989), Milone & Latham (1994).
Spectroscopy: Schönberner & Napiwotzki (1994).

In discussing the cluster membership problem we exclusively rely only on the most stringent criteria, viz. proper motion, radial velocity and spectroscopy. Based on the proper motion study of McNamara (1980) and Pendl (1975) we selected those objects from McNamara's lists of blue straggler candidates with at least one measurement of the radial velocity. Instead of reporting the qualitative judgements of the respective authors, we retrieved the original data and listed them in Table 6.

We also revised the radial velocities for several blue stragglers previously analysed by Drilling & Schönberner (1987). We used the KPNO spectra and applied the very accurate method of line mirroring. The results are given in the corresponding column of Table 6. We checked the method by applying it to our reference star Vega. From 14 lines of its KPNO spectrum we derived the mean value of $V_r = -12.7 \pm 0.6$ km s^{-1}, in good agreement with the recommended value of -13.9 km s^{-1} (SIMBAD data base).

The problem of the determination of true, i.e. physical, cluster memberships is somewhat delicate and prone to personal opinions. The necessary condition for an object to be a (physical) cluster member is the agreement of its proper motion *and* radial velocity with those of the cluster.

Spectroscopy, as performed by Schönberner & Napiwotzki (1994), serves as a final criterion because it provides a distance information. If, however, spectroscopy indicates membership, it *must* be supplemented by the proper motion *and* radial velocity data in order to distinguish between the physical members and field interlopers (see the case of K677 in Table 6).

The membership assignments of Table 6 are based on the philosophy outlined above. Note that in the two cases (K409 and K1211) where spectroscopy indicates non-membership, this statement is supported by the radial velocity measurements. Altogether we consider 11 of the 26 blue-straggler candidates to be the members of NGC 7789.

5.2. Abundance peculiarities

The fact that the blue stragglers in NGC 7789 display abundance anomalies for some chemical elements, which are not seen in the convectively well-mixed cluster giants, indicates that these anomalies are purely surface phenomena. All investigated blue stragglers fall in the domain of late B – early/mid A-type stars. It is well known that stars of these spectral types demonstrate a great variety of chemical peculiarities. Our investigated blue stragglers possess projected rotational velocities which are lower than is expected for their spectral classes. It is therefore interesting to compare their abundance anomalies (for the confirmed cluster members only, see Sect. 5.1) with those of chemically peculiar stars.

Normal A-type stars. Numerous studies of sharp-lined late B – early A-type stars were performed by Adelman with co-authors (see, e.g. Caliskan & Adelman 1997 and references therein). They showed that some of these stars have solar-like elemental distributions. For example, Caliskan & Adelman (1997) and Adelman (1999) provide elemental abundances for 17 stars (without Vega and the λ Boo type star 29 Cyg). From this sample one can derive a mean magnesium abundance (from the Mg II lines only) of [Mg/H] $= -0.11 \pm 0.19$. This value is significantly larger than the magnesium abundance of our blue stragglers. In Fig. 3 we compare their abundance distribution (that of Vega from Table 3 included) with data from the literature on A stars possessing small projected rotational velocities. As one can see from Fig. 3 the blue straggler abundance distribution follows the general trend, with the exception of Mg and Sc which appear to be depleted.

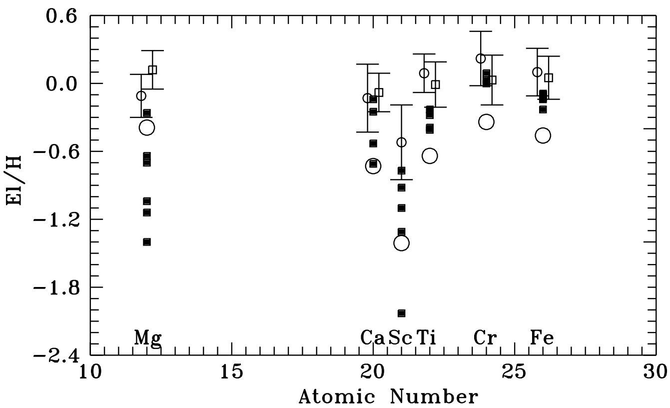

Fig. 3. Comparison of different abundance distributions. **Open circles:** mean values of "normal" A-type stars from Caliskan & Adelman (1997) and Adelman (1999); **open squares:** mean values from Hill (1995); **filled squares:** individual values of the blue stragglers investigated in this paper; **large open circles:** our data for Vega. Note that the literature values are horizontally shifted by ± 0.2, and that the typical error (2σ) is indicated

Am stars. According to the classical definition, Am stars have apparent surface underabundances of Ca and Sc (see Cayrel et al. 1991). This is also the case for the blue stragglers studied here. Am stars are, however, also characterized by a moderate overabundance of the iron-group and heavier elements, but this is not seen in NGC 7789 (we recall that we did not investigate elements heavier than iron). Also, the remarkable magnesium deficiency of the NGC 7789 blue stragglers is not reported for Am stars.

Ap stars. Ap stars show even more pronounced abundance anomalies, especially for heavy species. On the other side, magnesium, calcium and scandium can often be substantially depleted. With the spectral material at our disposal we are not able to decide whether our blue-straggler sample contains Ap stars. For example, the Sr II 4215 Å classification feature is not covered by the observed spectral region, although the rather strong lines of Zr II 4496.96 Å and Y II 4398.02 Å are seen in the spectra of K746 and K1270. It should be also mentioned that Stryker & Hrivnak (1984) noted that K1211 shows relatively strong Si II lines and an absence of the helium lines (the latter is in agreement with our result on helium abundance in this star). The above mentioned authors classified K1211 as Ap(Si) star.

Mg II 4481 Å weak stars. The weak Mg II 4481 Å line is an inherent feature of some A stars, as described by Abt & Morrell (1995). These authors consider them as a mild version of the λ Boo-type stars (see the next item). Using the data of Abt & Morrell (1995) we plot the equivalent widths of the magnesium line vs. spectral class for normal A-type stars,

Table 6. Radial velocities (in $\mathrm{km\,s^{-1}}$) and memberships of blue stragglers in NGC 7789. The cluster velocity based on red giants is $V_{\rm r} = -55\ \mathrm{km\,s^{-1}}$ (Gim et al. 1998b)

Star number		Radial velocity							Spectroscopy	Membership
M	K	SS70	SH84	DS87(CA)	DS87(KPNO)	MPMR89	ML94	This work	SN94	
257	2	–	–	–	–	–	N	–	–	N
317	68	–	–	–	–	–	N	–	–	N
325	88	–	–	–	–	–	Y	$-58 \pm 4(6)$	–	M*
377	168	−21	–	–	–	–	U	–	–	U
389	192	–	–	–	–	–	U	–	–	U
396	197	−31	–	–	–	–	N	–	–	N
419	234	−26	–	–	–	–	–	–	–	N
460	282	–	−47	−54	–	−43	M	–	M	U
482	316	–	–	–	−58	–	Y	$-59 \pm 3(15)$	–	M
502	342	−45	−51	−56	–	−51	U	–	M	M
500	349	−34	–	–	–	–	–	–	–	N
518	371	−56	−56	−55	−65	−58	Y	$-56 \pm 5(6)$	–	M
543	409	−20	−45	−27	−29	–	N	−28(1)	N	N
574	453	−41	−52	−41	–	−71	U	–	M	M
747	677	–	−37	−27	−23	−18	N	$-17 \pm 4(14)$	M	N
752	696	–	–	–	–	–	U	–	–	U
789	746	–	–	−53	−52	–	Y	$-43 \pm 2(14)$	–	M
913	934	–	–	–	–	–	N	–	–	N
1011	1095	–	–	–	–	–	Y	–	–	M
1054	1168	−49	–	–	–	–	Y	–	–	M
1088	1211	−33	−41	−31	–	–	N	–	N	N
1133	1270	–	–	–	−61	–	Y	$-55 \pm 3(15)$	–	M
144	–	–	–				U	–	–	U
459	–	–	–	−44	–	–	U	–	M	M
808	–	–	–	–	–	–	U	–	–	U
1060	–	–	–	–	–	–	U	–	–	U

M – McNamara (1980) number.
K – Küstner (1923) number.
M, N, U – denotes the members, non-members and stars with an uncertain membership respectively.
SS70 – Strom & Strom (1970).
SH84 – Stryker & Hrivnak (1984).
DS87(CA) – Drilling & Schönberner (1987), Calar Alto spectra.
DS87(KPNO) – Drilling & Schönberner (1987), Kitt Peak spectra.
MPMR89 – Manteiga et al. (1989).
ML94 – Milone & Latham (1994).
SN94 – Schönberner & Napiwotzki (1994).
* – Based on the study of Milone & Latham (1994), Gim et al. (1998a) considered the membership of K88 to be uncertain. However, by looking at the original data of Milone & Latham (Table 2 therein), it became evident that Gim et al. used erroneously the data of K68 instead, which is a radial-velocity non-member.

Mg II 4481 Å-weak stars, and NGC 7789 blue stragglers (see Table 7 for the spectral class assignments for program stars). As can be seen, several of the stragglers resemble the most extreme Mg II 4481 Å-weak stars. In spite of this, the stragglers have rather low projected rotational velocities (cf. Table 2) as compared with the Mg II 4481 Å-weak stars for which a mean of more than 100 $\mathrm{km\,s^{-1}}$ appears to be appropriate (Abt & Morrell 1995). Interestingly, the two certain non-members, K409 and K677, show virtually solar magnesium abundances, thereby giving additional evidence for their non-membership.

λ **Boo and Vega-like stars.** Chemically peculiar A stars of the λ Boo type occur at various rotational velocities with a typical $v \sin i$ value of $\approx$100 $\mathrm{km\,s^{-1}}$. Several recent studies of the λ Boo-type stars (see, Andrievsky et al. 1998; Paunzen et al. 1999) have shown that in their atmospheres many metals have significantly reduced abundances. In particular, magnesium, calcium and scandium may be depleted by a factor of about 10–100. Similar underabundances are also detected for titanium and iron. At present, there is accumulating evidence that there should be a link between the λ Boo phenomenon (extreme abundance

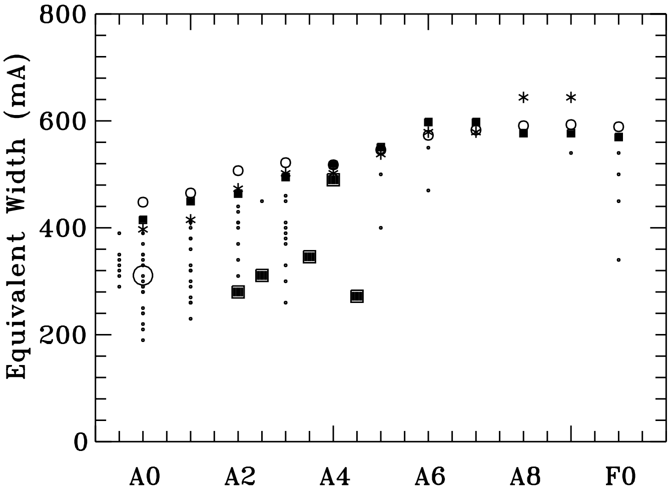

Fig. 4. Equivalent width of the Mg II 4481 Å line vs. spectral class: **small circles** - class V, **small filled squares** - class IV, **asterisks** - class III, **large filled squares** - program blue stragglers, **large open circle** - Vega, **dots** - Mg II 4481 Å-weak stars

anomalies) and Vega-like stars characterized by a milder metal deficiency. Dunkin et al. (1997) recently analysed several Vega-like stars and found in some cases relatively strong depletion of magnesium and calcium, while the abundances of iron-group elements are solar within 0.25 dex.

Summarizing, the abundance peculiarities found in the NGC 7789 blue straggler are difficult to attribute to any chemical peculiarity known among A-type stars. This peculiarity is also in contrast with the results reported in our Paper II. None of the straggler stars from three open clusters exhibits, for instance, such a profound magnesium deficiency as found in the present study. The only distinct feature which unites the blue stragglers from the present and previous studies is a low projected rotational velocity.

Concluding this investigation of the blue stragglers in the NGC 7789 field we state that:

a) All the confirmed cluster members show a remarkably superficial magnesium deficiency, while the nonmembers possess a nearly normal abundance;
b) The iron and titanium abundances in all blue stragglers agree with the mean cluster metallicity as derived from red giant stars;
c) The (projected) rotational velocities of the confirmed blue stragglers are significanly lower than normal for their spectral types.

The present study was hampered by the fact that the most powerful telescopes available when the observations were made did not allow us to perform a high-resolution study of the *total* blue-straggler population of NGC 7789 relative to that cluster's turn-off stars. Such an ambitious project would certainly require the use of 8–10 m class telescopes in order to get spectra of sufficient resolution, signal-to-noise ratio and wavelength coverage. Only then might we be able to answer the fundamental questions on the origin and evolution of blue straggler stars in open clusters.

Table 7. Mg II 4481 Å line in program stars

Star	$T_{\rm eff}$ (K)	Sp*	EW(4481) (mÅ)
K88	8900	A2-A3	320
K316	8950	A2	280
K371	8500	A4	490
K746	8600	A3-A4	353
K1270	8300	A4-A5	270
K409	9480	A0	640
K677	10 680	B9	460
K1211	12 630	B7-B8	280
Vega	9500	A0	311

* - spectral types are roughly estimated by us between III-V luminosity classes using Lang (1992).

Acknowledgements. Authors are thankful to the referee, Dr. S. J. Adelman, for his valuable comments. SMA is also grateful to the Astrophysikalisches Institut of Potsdam (Germany) for the financial support and the opportunity to perform this work using its institutional facilities. The necessary information has been obtained through the SIMBAD and VALD data bases.

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