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ASTRONOMY AND ASTROPHYSICS

Blue stragglers in open clusters

I. NGC 2632

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Abstract. We present the results of a spectroscopic study of four blue stragglers from old galactic open cluster NGC 2632 (Praesepe). The LTE analysis based on Kurucz's atmosphere models and synthetic spectra technique has shown that three stars, including the hottest star of the cluster HD73666, possess an uniform chemical composition: they show a solar-like abundance (or slight overabundance) of iron and an apparent deficiency of oxygen and silicon. Two stars exhibit a remarkable barium overabundance. The chemical composition of their atmospheres is typical for Am stars. One star of our sample does not share such uniform elemental distribution, being generally deficient in metals. For all stars T_{eff} and $log\ g$ values were estimated. A short discussion of the obtained results is given.

Key words: open clusters and associations: individual: NGC 2632 – stars: abundances – blue stragglers

1. Introduction

The phenomenon of blue straggler stars was described for the first time almost half a century ago. During this time a great number of stars, belonging to this stellar class, has been detected in different stellar systems.

At the present time, blue stragglers are found in young OB associations, open clusters of the different ages, old globular clusters and so they should be also present in the galactic field.

There is a rather extensive literature on this topic (see e.g. the review by Stryker, 1993), but nevertheless, there is not yet any definite answer on the main question: why some stars can have delayed evolution? Existing hypotheses cannot completely explain all the kinds of blue stragglers observed in various stellar systems.

As it was pointed out by Leonard and Linnell (1992) only 10% of blue stragglers observed in open clusters can be produced in physical collision involving binary stars.

Binary coalescence scenario proposed by Mateo et al. (1990) predicts that resulting blue straggler stars should be rapid rotators, while in some cases blue stragglers are found to be slower than average rotators for their spectral types ($\approx 150\,\mathrm{km\,s^{-1}}$ for A0V).

In the intermediate age stellar group blue stragglers are found to be Ap or Am stars. They could be magnetically mixed stars. An internal mixing within a single star was considered by Saio and Wheeler (1980) as a possible way to create a blue straggler. It should be noted that there are known several old open clusters ($log\ Age \approx 8.9$) having blue straggler stars (Hyades: 1 star; NGC 1817: 7 stars; King8: 5 stars; NGC 2194: 1 star; NGC 2254: 2 stars, NGC 2632: 5 stars, etc).

If internal mixing is the most plausible mechanism producing blue stragglers in such an old open cluster as Praesepe ($log\ Age$=8.82, Ahumada and Lapasset, 1995), then one could expect to detect some chemical anomalies in blue straggler atmospheres.

Up to now, no remarkable differences between blue stragglers and normal stars have been detected that could shed some light on the possible mechanism responsible for that phenomenon. These enigmatic stars deserve further investigation. Such an investigation can be divided into two different parts: 1) comparison of the elemental distributions between blue stragglers within a cluster and 2) comparison of the blue straggler elemental abundances with those of the cluster main-sequence stars. In this work we performed a first step of the investigation. The prime aim of this study is to search for possible evidences of the internal mixing that might be displayed in the surface elemental abundances.

A complete list of the blue stragglers in open clusters was published by Ahumada and Lapasset (1995). From this list we selected four targets which are members of old open cluster NGC 2632 (Praesepe). Their photometric characteristics are gathered in Table 1.

The position of investigated stars on the C-M diagram is shown on Fig. 1. In fact, only HD73666 could be considered as a true blue straggler star. It lies well outside of the bulk of the other brightest cluster stars – to the left of the turn-off point (Ahumada and Lapasset [1995] give for the turn-off point position $(B\text{-}V)_0$=0.15), while other investigated stars occupy a region which is very close to the turn-off point (see Fig. 1).

Characteristics of cluster stars were selected from Mermilliod's (1995) database by Robichon (1997). One sees that HD73666 is the hottest star of the cluster. It is known to be a bi-

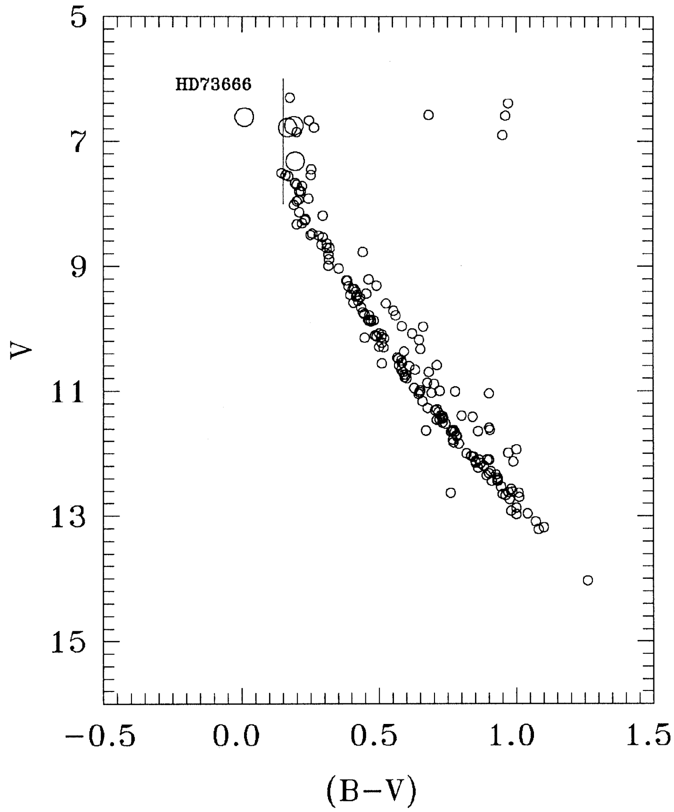

Fig. 1. Position of investigated stars on C-M diagram of NGC 2632. Investigated stars are indicated by large circles. Approximate position of the "turn-off point" is indicated by vertical line.

Table 1. Photometric characteristics of program stars

Star	Sp.	$(b-y)$	c_1
HD73666	A1V	-0.001	1.097
HD73819	A6Vn	0.091	1.075
HD73618	Am	0.104	0.965
HD73210	A5V	0.120	1.022

nary star, but the magnitude difference between the components is large (Mason et al., 1993).

$(b-y)$ and c_1 photometric data for program stars are from Gray and Garrison (1989), Stetson (1991), Maitzen and Pavlovski (1987), Henry et al. (1977).

2. Observations and reduction

Spectral observations were taken on 29 December 1996 at the AURELIE spectrograph (Gillet et al., 1994) of the 1.52-m telescope at the Haute-Provence Observatoire (France). The resolving power was about 11000, signal-to-noise ratio S/N $\approx$ 100. For each star we obtained a RETICON spectrum centered on 6000 Å, covering the region 5800 Å–6200 Å.

Reduction of the spectra has been done with software by Spite (1990) and Galazutdinov (1992).

Table 2. Adopted atmospheric parameters for program stars

Star	$T_{\rm eff}$,K	log *g*	V_t,km s^{-1}	*v sin i* ,km s^{-1}
HD73666	9600	3.8	3.0	30
HD73819	8000	3.7	3.0	150
HD73618	8050	4.0	3.0	60
HD73210	7800	3.7	3.0	80

3. Temperatures, gravities and microturbulence parameters

The effective temperatures and gravities for program stars were found using $(b-y)$ and c_1 values on the grid by Kurucz (1991). For all the stars we adopted a microturbulent velocity of $3\,{\rm km\,s^{-1}}$, which is appropriate for A-F main-sequence stars. Microturbulent velocity in the atmosphere of HD73618 (this star has a sufficient number of iron lines in the spectrum) was checked using the usual procedure of eliminating any dependence between abundances of individual iron lines and equivalent widths. Adopted atmospheric parameters are given in Table 2.

4. Method of the analysis

At the first step of spectroscopic analysis, WIDTH9 code and Kurucz's (1992) grid of atmosphere models were used to derive abundances. Obtained mean elemental abundances were then adopted as input information for STARSP code (Tsymbal, 1994, 1996) which performed the spectral synthesis. Calculated synthetic spectra were convolved using $v\ sin\ i$ values from Table 2.

In our synthetic spectrum analysis we used the original list of oscillator strengths (as well as damping constants and excitation potentials) of Kurucz (1995), but for selected lines $log\,gf$ values were corrected to reproduce their profiles in the solar spectrum (Kurucz et al., 1984) with currently adopted solar elemental abundances (Grevesse et al., 1996).

Final stellar abundances were found by means of optimal fitting of the synthetic spectrum to the observed one (see Figs. 2–9). One can visually estimate that observations are in very good agreement with theoretical spectra.

Note that, 1) not all the investigated lines are indicated on the figures (for some blends we indicate only the component which gives a maximal contribution in the corresponding absorption feature), 2) of course, there is no possibility to reach the full matching of the synthetic spectrum with the observed one for all available lines using mean abundances. There are a few lines (among them e.g., MgII, some FeII lines, etc) for which we did not perform the fitting procedure. These lines have usually high excitation potential. They are absent in the solar spectrum (or they are too weak) and this excludes the possibility of obtaining for them reliable oscillator strength values.

The spectrum of HD73819 shows all the signs of strong rotation and has severely blended lines. In this case there were no possibility to measure accurately the line equivalent widths and

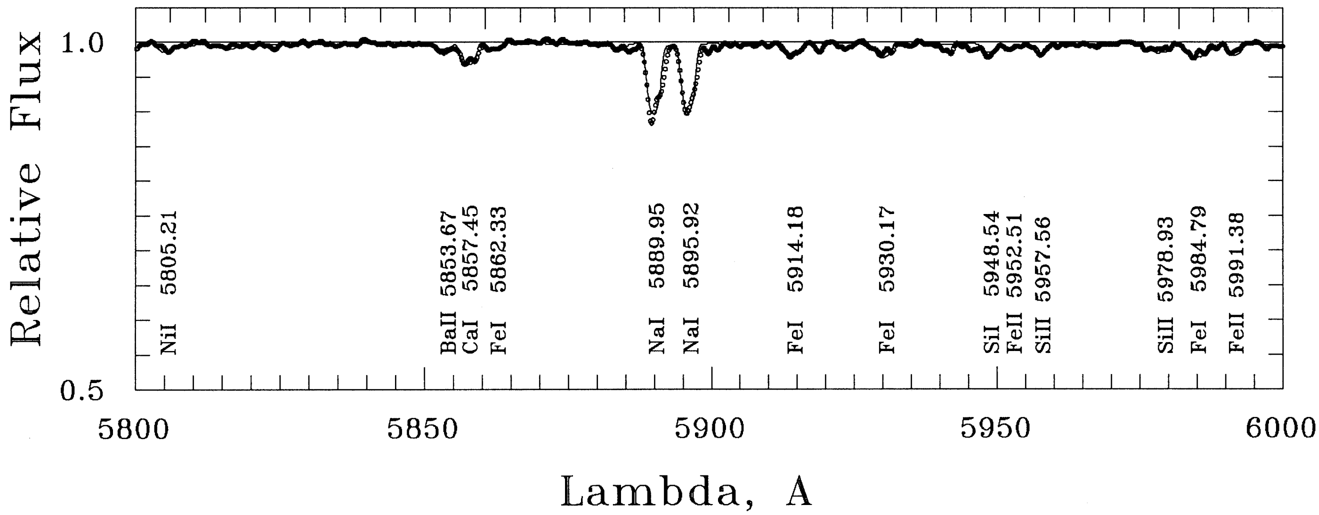

Fig. 2. Synthetic (solid line) and observed (dots) spectra for HD73210: region 5800Å–6000Å

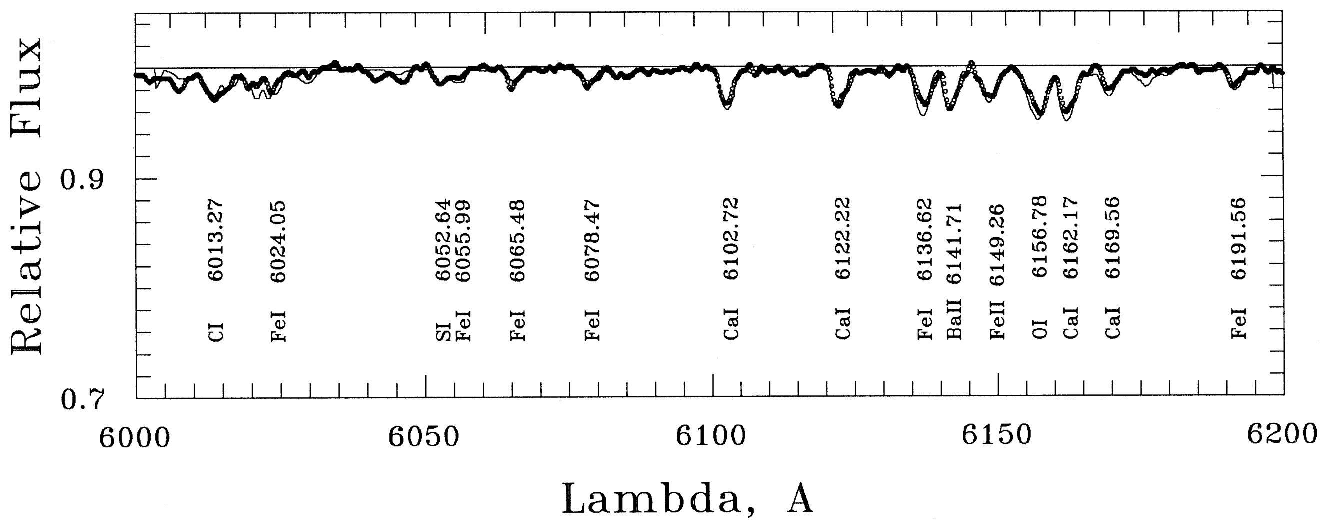

Fig. 3. Same as Fig. 2 but for region 6000Å–6200Å

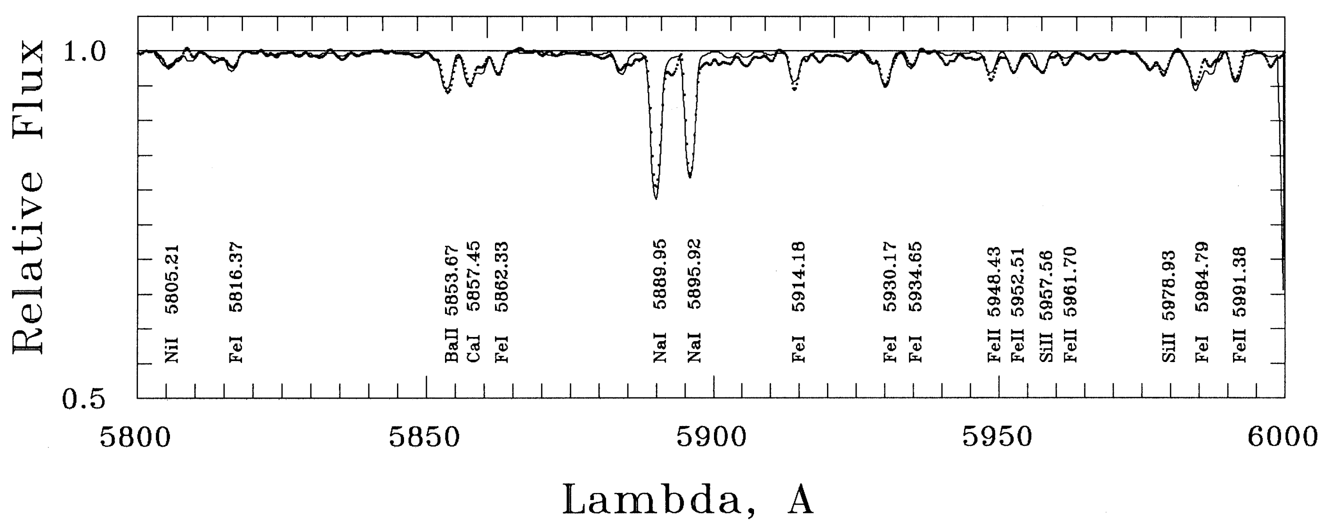

Fig. 4. Synthetic and observed spectra for HD73618: region 5800Å–6000Å

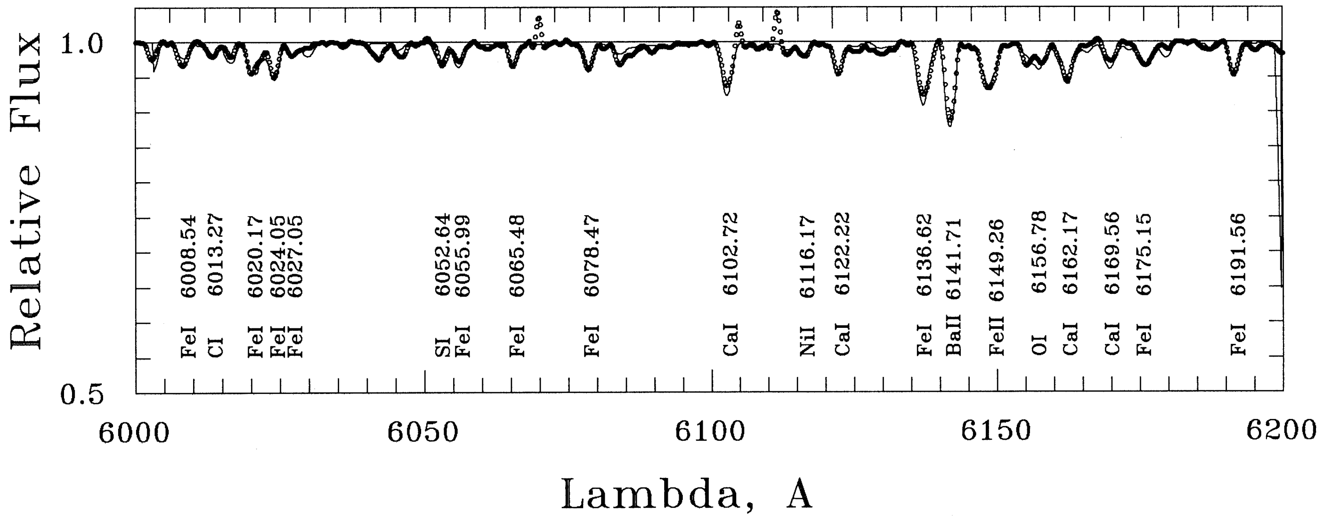

Fig. 5. Same as Fig. 4 but for region 6000Å–6200Å

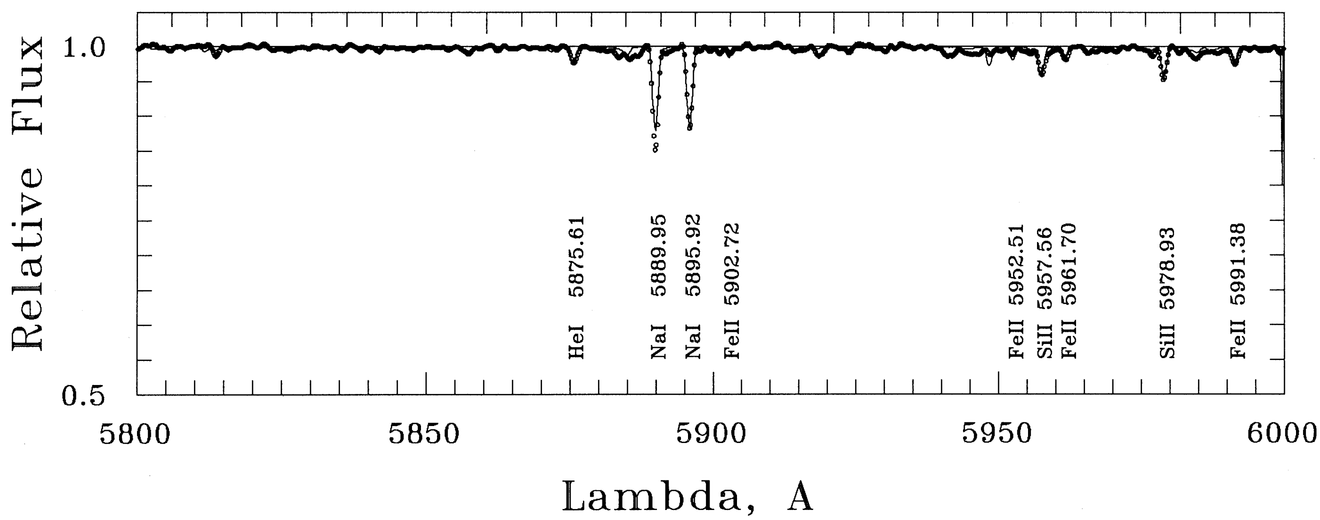

Fig. 6. Synthetic and observed spectra for HD73666: region 5800Å–6000Å

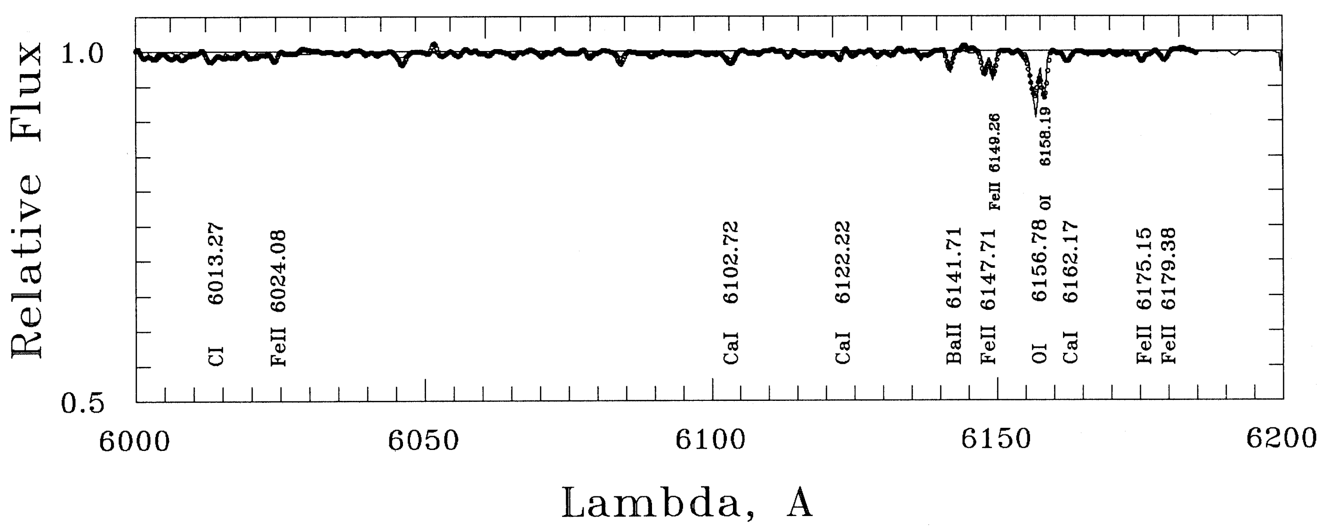

Fig. 7. Same as Fig. 6 but for region 6000Å–6200Å

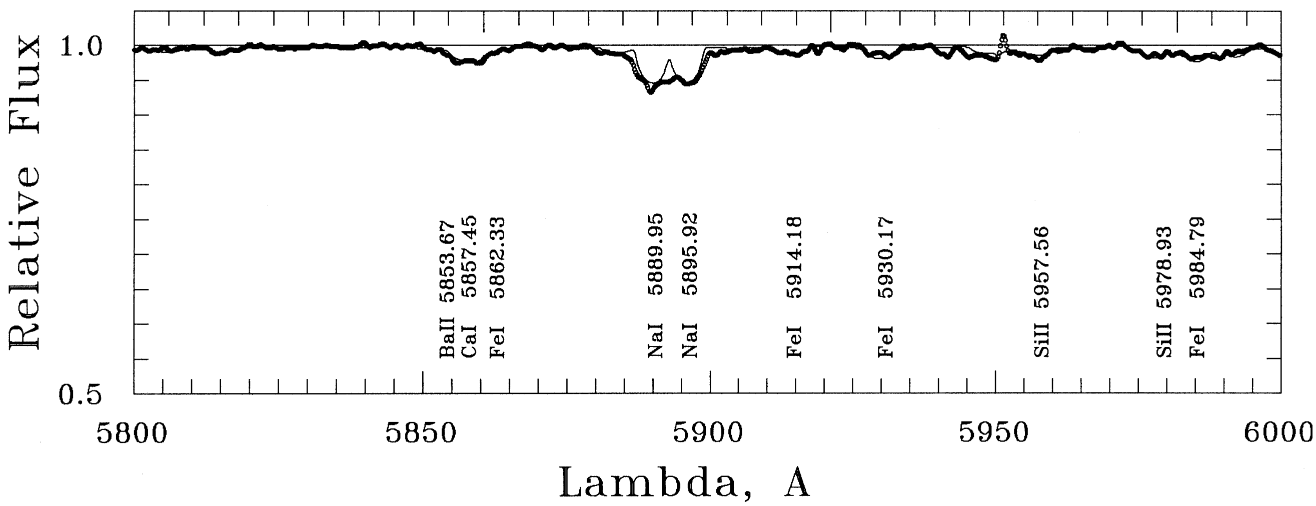

Fig. 8. Synthetic and observed spectra for HD73819: region 5800Å–6000Å

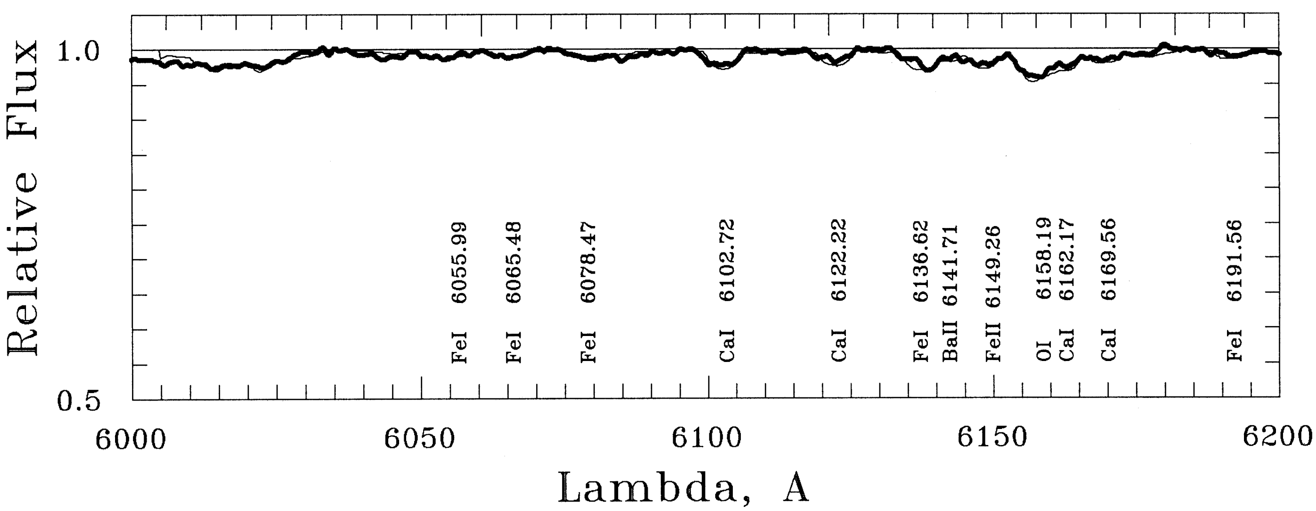

Fig. 9. Same as Fig. 8 but for region 6000Å–6200Å

to use WIDTH9 code for preliminary abundance determination. Therefore, for this star investigation we applied only a synthetic spectrum technique.

5. Results

The derived abundances are given in Table 3. For three stars of our sample the abundances were derived spectroscopically for the first time. One star (HD73666) was previously investigated by several authors (Conti et al., 1965; Strom and Strom, 1966; Conti and Strom, 1968), but the differences in their results on iron abundance reach one order of magnitude ([Fe/H]= -0.5, +0.6 and +0.1 respectively). It is not surprising because those analyses were performed using photoplates and less reliable methods based on out-of-date methods and unreliable oscillator strength values.

We recalculated elemental abundances using the equivalent widths measured by above mentioned authors. From the work by Conti et al. (1965) we used only reliable lines having equivalent width less than 160 mÅ and $\lambda \geq 4800$ Å (because abundances derived from the analysis of individual lines show a slight dependence upon the wavelength, that is probably connected with wrong continuum location in the blue part of the spectra).

Conti and Strom (1968) observed HD73666 only in the blue spectral region from 3900 Å to 4900 Å. Therefore, from their list we selected only lines with $\lambda \geq 4500$ Å.

The mean abundances, resulting from our recalculation, are presented in Table 4. (The number of used lines and σ-values are indicated in brackets). It should be also noted, that simultaneously with abundance recalculating, we checked also the microturbulence parameter and the temperature choice. With the adopted parameters ($T_{\rm eff}$, log g and V_t) for HD73666 we achieve an ionization balance for FeI/FeII and the abundances derived from the individual TiII and FeII lines do not depend upon the equivalent widths or on excitation potentials.

Comparing the results from Table 3 and Table 4, we can conclude that generally there is an agreement between the results based on the investigations of different spectral material. Especially one can emphasise the confirmation of the silicon

Table 3. Elemental abundances for blue stragglers

Element	HD73210	HD73618	HD73666	HD73819
He			0.0	
C	-0.3	-0.4	-0.1	
O	-0.3	-0.6	-0.2	-0.1
Na	0.0	0.0	+0.3	0.0
Si	-0.4	-0.2	-0.4	-0.2
S	-0.1	+0.2		
Ca	-0.3	-0.1	0.0	0.0
Mn	-0.3	-0.1		
Fe	-0.3	+0.3	+0.1	0.0
Ni	-0.1	+0.3		
Ba	-0.5	+0.7	+0.6	-0.5

Table 4. Recalculated abundances for HD73666

Element	W_λ from CWW	W_λ from CS
C	-0.2 (1,0.00)	
Na	+0.9 (1,0.00)	
Mg	-0.5 (1,0.00)	-0.4 (1,0.00)
Si	-0.5 (3,0.35)	
Ca	+0.5 (1,0.00)	
Ti	-0.4 (3,0.02)	+0.1 (10,0.13)
Cr	+0.3 (3,0.30)	
Fe	+0.0 (12,0.25)	-0.1 (9,0.25)
Zn	+0.5 (1,0.00)	
Ba	+0.5 (2,0.03)	+0.2 (1,0.00)

deficiency, the normal iron abundance and the barium overabundance. The overabundance of sodium must be taken into account with caution, because only one strong line was available for the analysis.

6. Short discussion

Three stars of our sample (HD73666, HD73819 and HD73618) have practically uniform metallicity. They show solar-like abundance (or slight overabundance) of sodium, calcium and iron and also moderate (or slight) carbon, oxygen and silicon deficiency. In the atmosphere of HD73618 sulphur is also overabundant. For the hottest star HD73666 one can estimate the helium content as being normal. Two stars of our sample HD73618 and HD73666 display a remarkable barium overabundance, while this element is apparently deficient in the atmosphere of HD73819.

One star of our sample (HD73210) does not follow this tendency, being deficient in the α-, iron-group elements and barium.

Taking into account the results on elemental distribution in two program stars HD73618 and HD73666, one can state that it is reminiscent of that of the ordinary Am stars: i.e. underabundance of the light elements, solar-like abundance (or slight overabundance) of iron-group elements and apparent overabundance of the heavier species (see e.g. Fig. 5.6 from review by Lyubimkov, 1995).

Thus, the present subtle analysis gives us some argumentation that not only HD73618, but also the hottest star of the cluster HD73666 could be Am star, although the latter has not been before classified as a star of that type.

It is interesting to note, that in 1991 Mathys published the work devoted to spectroscopic analysis of several blue stragglers from M67. Two of them appeared to be Am stars. Mathys claimed that there should be a connection between the blue straggler characteristics in old open clusters and the Am phenomenon. He based this on the following observational results: blue stragglers appear to rotate slowly for their spectral class, they do not have a large-scale organized magnetic field as e.g. Ap stars, they show an elemental distribution typical for Am stars (see Fig. 7 from that work).

In our case, HD73618 and HD73666 possess the elemental abundances which are similar to those of Am stars and they are also slow rotators (*v sin i* =60 $\mathrm{km\,s^{-1}}$and 30 $\mathrm{km\,s^{-1}}$respectively).

If internal mixing is the mechanism producing blue straggler stars in open clusters, then probably one should expect to detect the signs of such a mechanism by investigating their atmospheric chemical composition. At least, He, C and N abundances might be somewhat changed (e.g. due to the turbulent diffusion of the CNO-processed material or some kind of rotational mixing). For example, similar situations take place for blue stragglers in young OB associations. Mathys (1987) has investigated surface elemental abundances for several blue stragglers and found that they are quasi-homogeneously evolved stars with products of the CNO cycle which have become observable at the surface.

Nevertheless, in the case of Am stars, we cannot detect any specific anomalies apart from those, which being purely superficial are caused by selective radiative diffusion.

It would be also of interest to compare the blue straggler abundances to those of the main-sequence stars in NGC 2632. Very reliable iron abundances for three FV stars were provided by Boesgaard (1989). Having analysed five iron lines in the spectra of three program stars, she obtained the mean iron content [Fe/H]= +0.09. As one can see, three of our program stars show similar iron abundance. In a later investigation, Friel and Boesgaard (1992) confirmed the slight iron overabundance in F-dwarfs and also found that carbon abundance in their sample of stars is solar-like. Unfortunately, in the literature on NGC 2632 there is no information on abundances of such elements as Si, Ca, etc, in the atmospheres of main-sequence stars: it is therefore impossible to compare more completely the elemental distribution in blue stragglers and in the ordinary members of the cluster.

Finally, one can also make an additional remark. The hottest blue straggler HD73666 was classified by Abt (1985) as a Si-star. Nevertheless, present detailed investigation of the silicon lines based on RETICON spectrum and equivalent widths measured by CWW, does not support this classification. Silicon is apparently deficient in the atmosphere of this blue straggler.

7. Conclusion

Spectroscopic analysis of four stars from NGC 2632, which are regarded by Ahumada and Lapasset (1995) to be blue stragglers, reveals the following features:

1. Two stars (HD73618 and HD73666) demonstrate the chemical composition typical for Am stars. Note that HD73666 has not been before classified as a star of that type.
2. HD73819 possesses the solar-like elemental abundances (and moderate barium deficiency), while HD73210 appeared to be a metal deficient star.
3. Spectroscopic analysis did not reveal any abundance anomalies that could appear due to some kind of internal mixing changing surface abundances. Nevertheless, this statement should be reconsidered after the detailed investigation of the NGC 2632 main-sequence stars' chemical composition and comparison with elemental abundances of blue stragglers.
4. The hottest blue straggler HD73666 is probably not a Si-star. Silicon is apparently deficient in the atmosphere of this blue straggler.

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