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Determination of lg g of several variable Herbig Ae/Be stars

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Abstract. Echelle spectrogrammes of 19 variable Herbig Ae/Be stars were obtained in 1988–1992 in the wavelength interval 4000-7000Å with the spectral complex "Zebra" at the 6–m telescope of Special Astrophysical Observatory, Russian Academy of Sciences (SAO RAS). Kurucz's models were employed for the analysis of the hydrogen absorption line profiles. For all programme and standard stars lg g gravity parameters were obtained. The location of the stars on the "lg g-T_{eff}" diagram does not agree with the hypothesis that the studied objects are pre-main sequence stars.

Key words: stars: early type - stars: pre-main sequence - stars: variables - stars: emission line - stars: fundamental parameters

1. Introduction

In an effort to identify early-type stars in their pre-main sequence (PMS) stages of evolution, Herbig (1960) compiled a list of 26 Ae and Be stars, using the criteria of early spectral type and strong emission lines, location in an obscured region, and illumination of nearby nebulosity. Since then his selection criteria have been used to choose stars for spectroscopic and photometric study, and the term "Herbig Ae/Be star" (HAeBes) is employed to identify a possible PMS object of moderate mass. Individual HAeBes have been studied photometrically (Bastien et al. 1983; Cohen 1973a, 1973b, 1974; Cohen & Kuhi 1979; Herbst et al. 1982; Herbst et al. 1983;), spectroscopically (Böhm & Catala 1994; Finkenzeller & Mundt 1984; Finkenzeller & Jankovics 1984; Grinin et al. 1994; Grinin et al. 1996; Strom et al. 1972) and polarimetrically (Garrison & Anderson 1978; Grinin 1991).

However, after more than thirty years of investigations it is still difficult to define a unique set of observable quantities that can distinguish intermediate-mass PMS objects from more evolved stars. Moreover, some alternative hypotheses were suggested concerning the location of HAeBes on the Hertzsprung-Russell diagram (HRD). Herbst et al. (1982) have proposed that these objects are ordinary Be-stars associated with dark cloud material, rather than being PMS objects. Their location above the main sequence is commonly interpreted as due to rapid rotation, an effect which seems to explain the shift of Be-stars above the main sequence (Collins & Sonneborn 1977). Thé et al. (1994) also believed that a certain fraction of HAeBes is not PMS stars. This point of view is supported by Davies et al. (1990). Thus the validity of the assumption that all HAeBes as defined by Herbig are young stars is now questioned by some authors.

There is a small subgroup of variable Ae-stars with unpredicted Algol-like minima. Most of them demonstrate no obvious connection with bright or dark nebulosities, as well as star-formation regions, and part of them was previously called by Grinin "isolated HAeBes" (Grinin et al. 1994). We conventionally call them ALIVARS–Alfa Line (or Algol Like) Irregular VARiable Stars.

The object of our investigation is a small group of HAeBes with non-periodic light fadings. They are rapid irregular variables of Is(A)-type according to (Kholopov et al. 1985). Their light variations is expressed as algol-like minima of 1–2^m that last a few days. Owing to the specific form of their light curve they are sometimes called "anti-flare stars" and we will denote these stars hereafter as ALIVARS. Analysis of photometric UBVR observations has shown that on the HR-diagram ALIVARS occupy the region on the both sides of the giant branch (Pugach & Kovalchuk 1991). This fact as well as a photometric resemblance of ALIVARS and fairly evolved RCB stars support an assumption that ALIVARS are post-main sequence stars rather than pre-main sequence ones. The space distribution of the most of ALIVARS: VX Cas, BH Cep, BO Cep, SV Cep, V517 Cyg, BN Ori, UX Ori, EO Per, XY Per, DD Ser, CQ Tau - has revealed no obvious connection with star-formation regions, although some of them seem to be surrounded by nebulae (Thé et al. 1994). A small part of ALIVARS (UX Ori, WW Wul, BF Ori, CQ Tau) are considered to be the so-called "isolated HAeBes" (Grinin et al. 1994), or may be considered (V351 Ori, RZ Psc) as isolated ones. It remains to be shown whether the ALIVARS are young objects if most of them are located outside star formation regions?

This investigation is devoted to determination the gravity prameter lg g - a fundamental physical characteristic of ALI-

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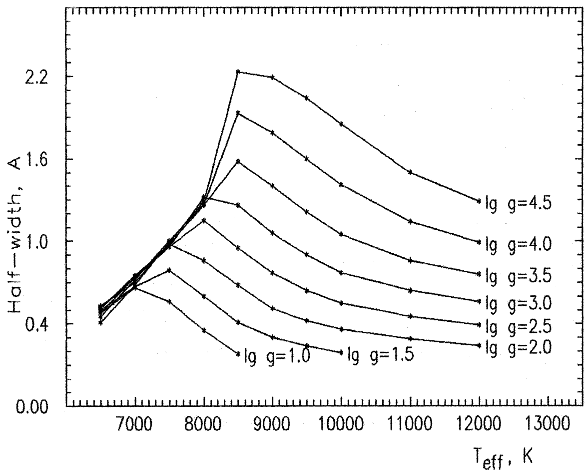

Fig. 1. Variation of H_δ half-width at intensity level 0.8 as a function of T_{eff}

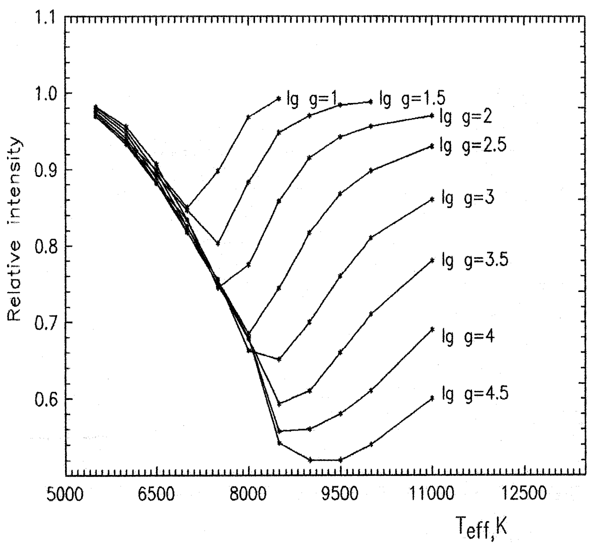

Fig. 2. Variation of relative intensity of H_δ at distant $\Delta\lambda$=8Å from the line center as a function of T_{eff}

VARS. The results of the investigation allow us to give some conclusions about the evolutionary status of ALIVARS.

2. Observations and data reduction

Spectral observations of 19 ALIVARS have been obtained during 1988–1992 using the spectral complex "Zebra" at the 6-m telescope of SAO RAS. "Zebra" consists of an echelle spectrograph located at the Nasmyth focus, and a quanta-counting system with a frame memory which gives the possibility to control the state of the spectrum being registered (Gazhur et al. 1990). The dispersion spanned a range of 1.2 Å/pixel (at H_α-line) to 0.6 Å/pixel (at H_δ-line). For control and calibration purposes some MK-standards of different luminosity classes were observed and processed in exactly the same way as the programme stars. The "Journal of observations" is given in Table 1.

Table 1. Journal of observations

Star	Spectral type	UT Date	Exposure time (min)
VX Cas	A0ea	01.25.1989	34
BH Cep	A/F5 Vea	01.24.1989	143
BO Cep	F2ea	01.24.1989	156
		02.23.1991	86
SV Cep	A0ea	01.24.1989	131
V517 Cyg	A5ea	01.23.1991	74
BN Ori	F2ea	01.22.1991	55
CO Ori	F8:e V	02.23.1992	90
EZ Ori	G0:n	01.21.1991	54
V346 Ori	A5 IIIe	01.23.1989	93
V351 Ori	A7 III	01.27.1989	69
		02.23.1991	80
V451 Ori	B9e	01.21.1991	51
V586 Ori	A2 Ve	01.21.1989	81
		02.22.1991	120
		02.23.1992	90
UX Ori	A2ea	02.24.1992	95
EO Per	B0ea	01.21.1991	54
IP Per	A3ea	11.24.1988	98
		02.22.1991	81
XY Per	B6/A5ea	01.27.1989	80
DD Ser	A5 III	02.23.1989	76
CQ Tau	A8vea	01.25.1989	104
RR Tau	B8ea	02.22.1991	11
		01.23.1991	90
	Standard stars		
HD 17	A3 III	01.24.1991	100
HD 23194	A5 V	01.22.1991	72
HD 32642	A7 III	01.22.1991	90
HD 82523	A3 III	02.23.1991	91

The following reductions of the observational material were performed:

1. The spectral sensitivity of the equipment was determined by observing the white dwarfs G 191B2B, HZ 44, Feige 67 and Feige 110 with the known energy distribution in their spectra (Massey et al. 1988) and necessary corrections were introduced.
2. The scattered light was taken into account by introducing an 8% correction.
3. The instrumental profile $\phi(\Delta\lambda)$ was determined using argon spectra lines (their own widths are negligible). Averaged profiles $\phi_i(\Delta\lambda)$ were drawn for every spectral region from all unblended argon lines. Within the limits of the 5% level of statistical significance, real instrumental profile can be well represented by a Gaussian frequency curve with the parameters a_0=0, σ=2.15 pixels.

3. Results and discussion

The hydrogen lines are one of the main source of information about gravity parameter lg g in the atmosphere of B and A stars. For the lg g determination both equivalent width and form of

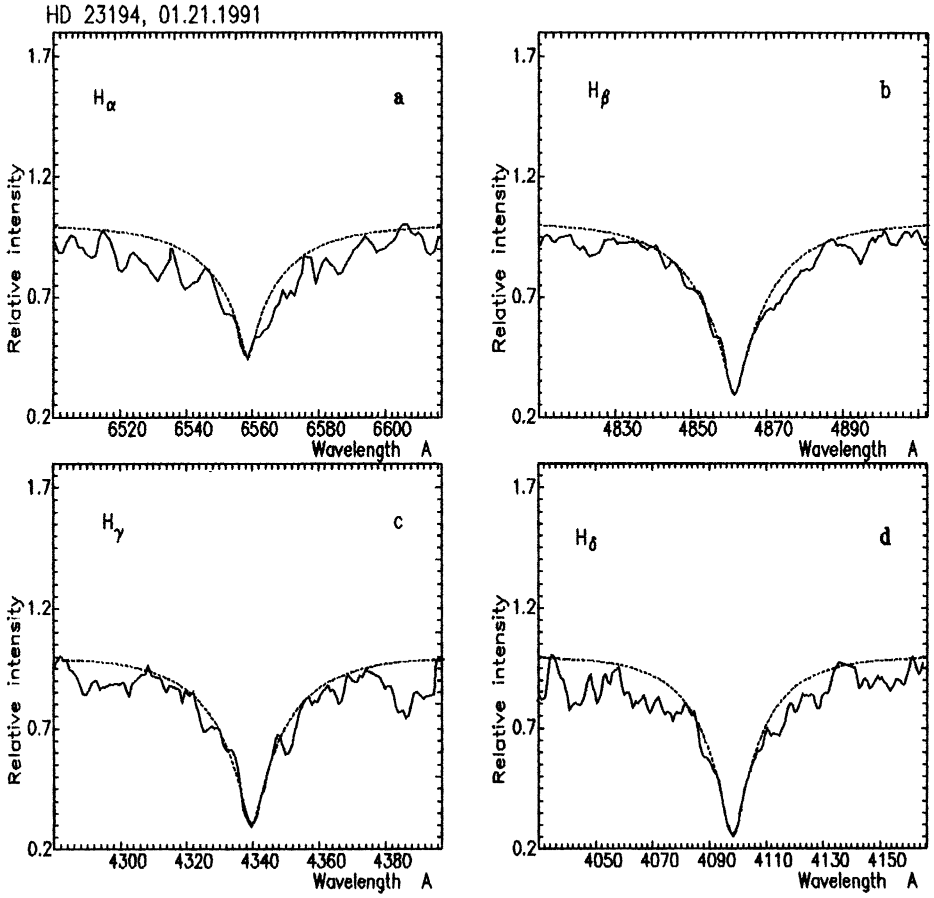

Fig. 3a–d. Comparison of observed (solid line) and calculated (dashed line) profiles of hydrogen lines for standard stars HD 23194

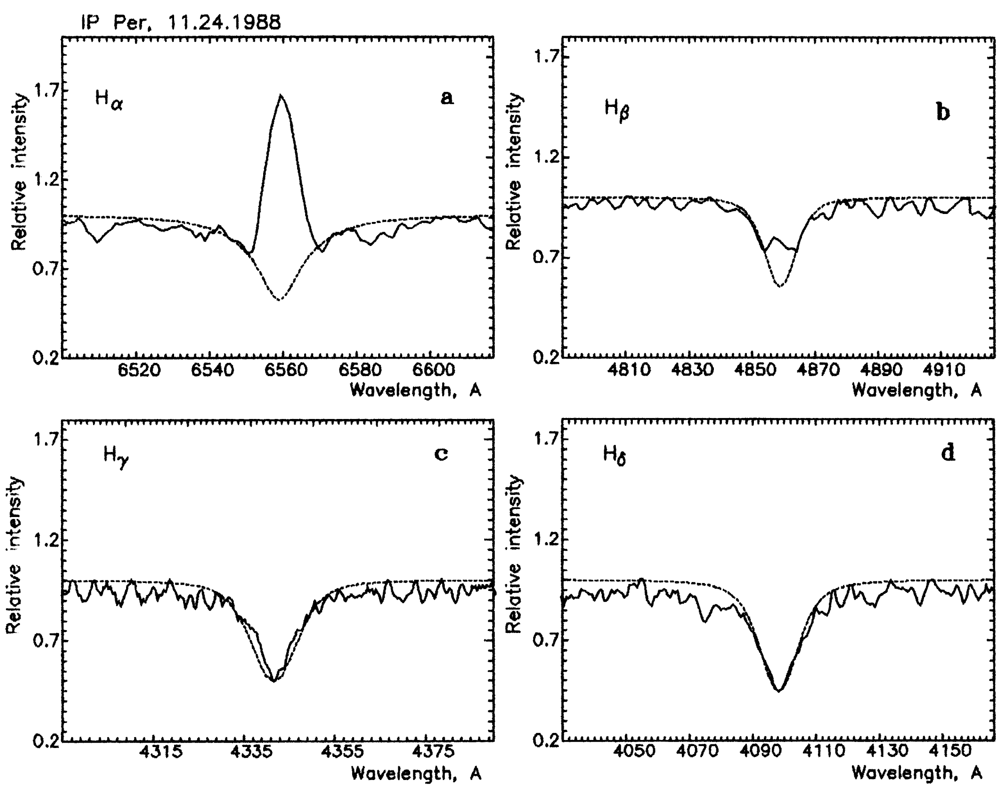

Fig. 4a–d. Same as Fig. 3, for programme star IP Per

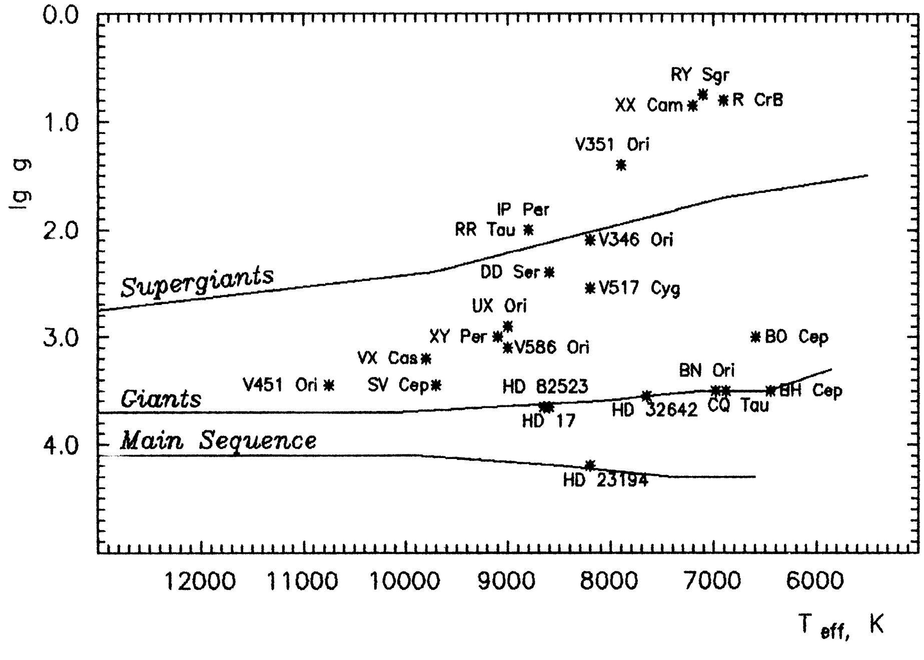

Fig. 5. Position of stars studied in the (lg g-T_{eff}) diagram

the hydrogen lines profiles were independently employed. The method applied was as follows. The observed H_β, H_γ and H_δ profiles were compared with theoretical profiles calculated by Kurucz (1979) for a set of parameters T_{eff} and lg g. This technique is especially efficient for A0-A3 stars, is admissible for A5-A7 stars and yields rather uncertain values of lg g for F0 and later spectral types. For obtaining the parameter lg g the correct value of T_{eff} should be known. As original value of T_{eff} we took a mean value of T_{sp} corresponding to the two-dimensional MK classification, and the temperature T_{BV} found from the colour index $(B-V)_0$ corrected for interstellar reddening. In cases when the interstellar absorption A_v was not known we set T_{eff}=T_{BV} for luminosity class III.

The error of the T_{eff} thus adopted cannot distort substantially the final result. The temperatures of most ALIVARS fall over the range where the equivalent widths of hydrogen lines depend very little on T_{eff}. Thus, in the interval 7600 K$\leq T_{eff} \leq$9200 K the H_γ equivalent width varies within the limits EW_γ=13.7±1.7Å, i.e. less than 13% for a certain fixed value lg g=3. Then, the theoretical (model) profiles were chosen from Kurucz's model (1979) for given value of T_{eff} and for the observed value of the equivalent width. It was convoluted with the instrumental profile and compared with the observed profile corrected for scattered light. The Balmer lines H_β, H_γ and H_δ were analysed in that way and the values of lg g were found. The values of lg g are listed in Table 2, first line for every programme star.

The mentioned method of lg g determination using equivalent widths gives overestimated values of the gravity parameter, because the observed equivalent widths of hydrogen lines comprise equivalent widths of many weak metal lines superposed on the hydrogen lines. For this reason we employed the form of wings of the hydrogen lines together with the equivalent widths method to obtain independent evaluations of lg g. Firstly, we have used the dependence of line half-width at the intensity level 0.8 on the temperature T_{eff}. Some examples of such a dependence are shown in Fig. 1, for wnich the data were taken from Kurucz (1979).

Secondly, we have used the dependence of the relative intensity of the line, at the distance $\Delta\lambda$ from its center, on the temperature T_{eff} (the $\Delta\lambda$'s are equal 7, 8 and 9 Å). These relationships are shown in Fig. 2.

The lg g values determined using these two additional methods are also listed in Table 2, at the second and third lines for each programme star correspondingly. The mean square root error of the lg g determination, determined using programme and standard stars, equals 0.08 dex. All lg g values obtained using the three mentioned methods are in good agreement. Mean values of lg g for individual stars are given in the last column of Table 2 (the statistical weight of each method employed equals to 1).

Standard stars of different luminosity classes were employed to test the validity of the approach used. The lg g values obtained for 4 standard stars (see Table 3) are consistent with that for stars of luminosity classes V and III.

A comparison of the observed profiles of HD 23194 and the theoretical ones for T_{eff}=8800 K and lg g=4.1 is shown in Fig. 3 to illustrate the suitability of the method used. It seemed to give fairly reliable results.

Two more stars - CO Ori and EZ Ori - were added to our observing programme, both being classified as HAeBes (Herbig & Bell 1988) located on the main sequence. Their photosphere temperatures are lower than that for typical ALIVARS and, in addition, CO Ori is considered to be an object of the T Tau group (Herbst et al. 1983). Unfortunately, the method of lg g determination, which have been used, failed to give a proper value of the

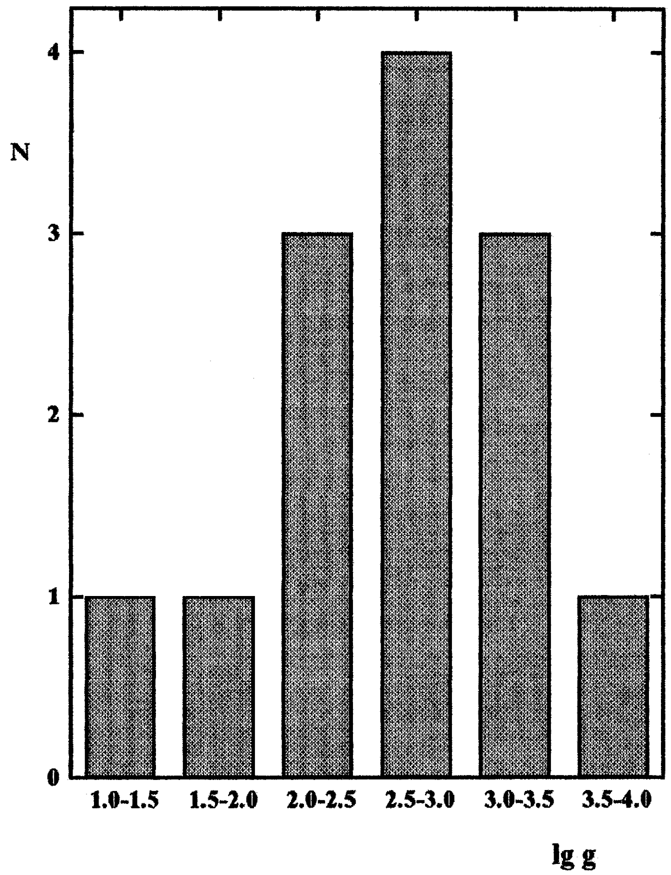

Fig. 6. Histogram of lg g for programme stars

gravity parameter for temperatures less than 7500 K. However we succeeded to obtain certain values of temperatures of these cool stars using equivalent widths of hydrogen lines.

In those cases where the lg g determinations are not possible we have substituted it by the determination of the luminosity classes. A well known criterium based on the ratio of the specific absorption line intensities was used (Seiter 1970). The following pairs of metal lines were chosen: SrII λ4215 Å/FeI λ4250 Å; CaI λ4456 Å/FeI λ4462 Å; CrI λ4344 Å/FeI λ4415 Å.

The criteria used unambiguously point out that the ALIVARS BH Cep, BO Cep and BN Ori are more luminous stars than CO Ori and EZ Ori. For this reason proper values of lg g have been assigned to BH Cep, BO Cep and BN Ori which in our opinion correspond with ratios of the chosen line pairs. These values are labeled in Table 2 with the letter "c".

In Fig. 4 the results of the comparison of the observed hydrogen line profiles with theoretical ones for the variable IP Per are shown for illustration. Emissions in H_α and H_β are well observable here.

Data obtained allow us to state that the ALIVARS studied here are neither main sequence nor pre-main sequence stars. On the "T_{eff}-lg g" diagram (see Fig. 5) they occupy a region bounded by giants and stars of higher luminosity. Their parameters of gravity lg g range from 3.8 to 1.4, the mean value being near lg g≅3.0 (see Fig. 6).

Table 2. The results of the lg g determination of the programme stars

	H_δ	H_γ	H_β	Mean	
Star	lg g	lg g	lg g	T_{eff},K	lg g
VX Cas	3.25	3.25	em	9800	3.20
	3.25	3.15	3.30		
	3.10	3.20	3.25		
SV Cep	3.50	3.50	em	9800	3.45
	3.40	3.35	3.45		
	3.45	3.45	3.45		
V517 Cyg	2.55	2.50	em	8200	2.50
	2.60	2.40	2.55		
	2.55	2.45	2.40		
UX Ori	2.85	2.90	-	9000	2.90
	2.95	2.90	-		
	3.00	2.90	-		
V346 Ori	1.95	2.05	2.25	8200	2.10
	2.25	2.15	2.15		
	1.95	1.95	2.05		
V351 Ori	1.35	1.30	1.25	7900	1.40^a
	1.50	1.35	1.45		
	1.45	1.40	1.40		
V451 Ori	3.50	em	em	10750	3.45
	3.35	3.65	-		
	3.50	3.30	-		
V586 Ori	3.10	3.10	em	9000	3.10^b
	3.15	3.05	3.30		
	2.95	3.25	3.05		
EO Per	3.75	3.65	3.70	29700	3.70
IP Per	2.00	em	em	8800	2.00^a
	2.10	1.95	-		
	2.05	1.90	-		
XY Per	3.15	3.20	3.05	9100	3.00
	2.95	2.90	3.00		
	2.90	2.95	2.90		
DD Ser	2.25	2.40	em	8600	2.40
	2.35	2.40	-		
	2.45	2.50	-		
RR Tau	2.00	2.00	em	8800	2.05^a
	1.95	2.05			
	2.10	2.10			
	Cool stars				
BH Cep	-	-	-	6450±50	$\leq 3.50^c$
BO Cep	-	-		6590±50	$\leq 2.5 - 3.5^c$
BN Ori	-	-	-	6950±150	$\leq 3.5^c$
CO Ori	-	-	-	6250±50	MS?
EZ Ori	-	-	em	5850±150	MS?
CQ Tau	-	-	-	6860±150	≤ 3.5

Notes: "a" - mean for two nights; "b"-mean for three nights; "c" - more luminous than MS stars. The luminosity is evaluated by means of the line intensity ratio; "em" - denotes the presence of emission in the lines; MS? - main sequence

This conclusion should not be regarded as a result of the erroneous method applied, because for the standard stars reasonable values of lg g were obtained. It might well be that ALIVARS are evolved rather than young stars, especially those lying far away from star-formation regions.

Some ALIVARS on the "T_{eff}-lg g" diagram have reached a region which neighbours that of the well evolved RCB-type

Table 3. The results of the lg g determination of the standard stars

	H_δ	H_γ	H_β	H_α	Mean	
Star	lg g	lg g	lg g	lg g	T_{eff}	lg g
HD 17	3.60	3.60	3.50	3.65	8600	3.65
	3.65	3.65	3.65	3.65		
	3.70	3.60	3.60	3.70		
HD23194	4.20	4.00	4.10	3.95	8300	4.10
	4.15	4.15	3.95	4.10		
	4.15	4.15	3.95	4.15		
HD32642	3.65	3.70	3.65	3.70	7850	3.70
HD82523	3.65	3.60	-	3.65	8650	3.65
	3.65	3.55	-	3.85		
	3.60	3.55	-	3.75		

variable stars (R CrB, RY Sgr, XX Cam). It is a very serious argument in favour of the hypothesis of the post-main sequence status of ALIVARS. One of the programme stars, V351 Ori, was shown to be an Ae/Be star which has left the main sequence and in the past was never connected with the Orion star-formation region (Pugach & Kovalchuk 1997). The rotation velocity of V351 Ori is near $87 \pm 5 km/s$.

We can't help but agree with Filkenzeller's (Finkenzeller 1985) remark that the locus of HAeBes on the HRD should not be regarded as a final reference of the evolutionary status of the stars. Values of the rotation velocities are needed before a definite conclusion can be drawn. Unfortunately reliable *v* sin *i* data are absent at present. However, it is notable that no fast rotators have been found among ALIVARS.

4. Conclusions

According to the parameters of lg g a small subgroup of HAeBes, the so-called "anti-flare stars" or ALIVARS, with unpredictable light fadings is located on the "T_{eff}-lg g" diagram between branches of giants and supergiants. We interpret this behaviour as being due to the fact that ALIVARS are evolved rather than young stars and have at present left the main sequence. Probably ALIVARS form an isolated subgroup of HAeBes with specific observational properties and evolutionary status. If so, the structure of the HAeBes group is not so homogenuous as it was previously thought. There is a substantial number of A-spectral type emission stars having an infrared excess which is not pre-main sequence (Davies et al. 1990). This idea has been stressed by some authors on the last "International Meeting on the Nature and Evolutionary Status of Herbig Ae/Be Stars"(Imhoff 1993; Herbig 1993).

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