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LETTER

Letter to the Editor

The barium stars in the Hertzsprung-Russell diagram⋆,⋆⋆,⋆⋆⋆

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Abstract. We present absolute magnitudes for a sample of 52 barium stars observed by the HIPPARCOS satellite, and their location in the HR diagram. Our plot (Fig. 1) is restricted to stars with parallax accuracies better than 22 %. The luminosity classes range from Ib supergiants down to V dwarfs on the main sequence, as expected from spectral classification. Discrepancies are however noted. No gap is observed in the region extending from the main sequence to the giant branch, exactly as shown by Perryman et al. (1995) for normal stars. This is also true for class II bright giants. A clump is however obvious at G8-K0 IIIb and Mv ≈ 0.85 which corresponds to the one noted at $(B - V) \approx 1.0$ and $M_{H_p} \approx 1.0$ by Perryman et al. It appears that barium stars on the main sequence are earlier than G4, upward evolution being noticeable for later types. They are also distributed in the subgiant zone following the locus of normal stars, i.e. increasing brightness for later types. A few stars in our sample are also classified as CH stars : four of them are definitely main sequence class V-dwarfs, one is a class IVb faint subgiant while two possible CH-stars are class III-giants. These results are consistent with the currently-admitted model of surface pollution of a normal star through mass transfer in a binary system whose primary has become a white dwarf (WD). HIPPARCOS data show perturbations of the astrometric solution which can be attributed to proved (or possible) binarity for 21 stars out of 121, and 8 of them were already quoted in the CCDM catalogue (not necessarily with a WD component). This low proportion can be explained by the 5-11 magnitudes differences predicted between the two components and/or low angular separations with periods close to one year.

Key words: stars: HR diagram; stars: chemically peculiar; stars: evolution

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⋆ This research has made use of the Simbad database operated at CDS, Strasbourg, France.

⋆⋆ Based on data from the ESA HIPPARCOS astrometry satellite

⋆⋆⋆ Table 2 is only available in electronic form at the CDS via anonymous ftp 130.79.128.5

1. Introduction

According to Bidelman & Keenan (1951), a barium star (Ba star) is a G2-K4 giant showing a very strong BaII λ4554 line in its spectrum. Following Keenan (1942), a CH star is a G5-K5 giant with very strong CH bands in its spectrum, and heavy elements (Sr, Ba..) are enhanced. Stars thermally pulsating on the asymptotic giant branch (TP-AGB) can produce the s-process elements (which is not the case for the much fainter stars discussed here), as confirmed by observation. McClure et al. (1980) found that the explanation could be mass transfer in a binary system where the former primary, now a white dwarf (WD), has been a TP-AGB star. Further observations (e.g. Jorissen & Boffin 1992) confirmed that all Ba stars should be members of binary systems, even if direct observation of the WD component is still missing. This is also the case of CH stars (McClure & Woodsworth 1990). Wind accretion in a detached binary may explain the systems with large periods (e.g. Han et al. 1995). We present here the first results of a programme on the HIPPARCOS satellite. A sample of 121 barium stars (Ba stars) was observed, some of which being also CH or CH-like stars and one star (HD 92626) being also a carbon star. They were selected from a list of about 240 known (in 1981) Ba stars, as candidates for measurable parallaxes, on the grounds of luminosity classes from spectra and apparent magnitudes. We derive equivalent spectral types from the available photometry and correct for interstellar extinction (Sect. 2), making use of the method developed by Knapik & Bergeat (1997). A dramatic improvement is observed when HIPPARCOS parallaxes are used to compute absolute visual magnitudes (Sect. 3). The results are given for 52 stars and the location of 37 stars with the best available parallaxes are shown in the HR diagram (Sect. 4), ranging in luminosity class from Ib to V. The subdivision in luminosity classes is briefly re-discussed, a rather continuous distribution being observed from the main sequence to the giant branch exactly as found for normal stars (Perryman et al. 1995).

2. Photometric classification and interstellar extinction

Spectral types from the literature do exhibit some scatter, e.g. G8, K0 and K2 for a given star. To pinpoint the classification and simultaneously evaluate the interstellar extinction, the approach developed by Knapik & Bergeat (1997) for carbon variables, was applied. The method, which makes use of the whole available photometry from UV to ir, is illustrated by their Fig. 4. Pecularities such as the Bond & Neff (1969) depression were taken into account. A linear relationship is obtained when the appropriate reference spectral energy distribution is selected while mismatch results in a curved one : a box or group is thus ascribed without ambiguity. The slope is the extinction A(J) at the wavelength λ = 1.25 μm and the intercept a dereddened magnitude. This choice was justified by the authors and the reader is referred to their paper for a detailed discussion.

Two favorable circumstances were met here. First of all, the stars of this program are essentially non variable (constant to the accuracy of the available photometry) with few exceptions. Observations secured at various epochs obtained over different spectral ranges, can be consistently used. Then, the unredenned spectral distributions of these oxygen stars are known and grouping according to spectral types and luminosity classes were derived. A few exceptions are hot carbon stars such as the Ba star HD 92626 = C 2829 entry in Stephenson's (1989) catalogue to which the K2g-type is attributed hereafter, as the nearest "oxygen" spectral distribution. We compiled data from Johnson (1966), Johnson et al. (1968), Bessell (1979), Bessell & Brett (1986) and Koornneef (1983). Tables of indices were constructed for reference, the V-filter being used for zero point instead of the near infrared one adopted in Knapik & Bergeat (1997). We kept three boxes, namely supergiants (sg : here the Ib-class), giants (g : II, III & IV-classes) and dwarfs (d : V & IV-classes). We have then compiled the available photometry. Our main sources were Lü (1991), Watanabe et al. (1993), Catchpole et al. (1977), and Eggen (1972, 1975) for UBVRI photometry. Infrared photometry was found for part of our stars in Mendoza & Johnson (1965), Johnson et al. (1966), Feast & Catchpole (1977), Dominy et al. (1986), Hakkila & McNamara (1987) and Hakkila (1989). The results are given in Table 1, where [K2g] means, for instance, the spectral distribution of the g-box for "spectral type" K2. Good consistency is found when these photometric types are compared to spectral ones (i.e. they fall in the range of published spectral types as quoted by various authors), and they are used in Fig. 1.

3. The absolute magnitudes

Very accurate apparent magnitudes Hp are provided in the HIPPARCOS Catalogue (ESA, 1997). They are visual magnitude observed through a bandpass larger than the standard V-one. They may be converted accurately to V-magnitudes and, to do this, we have used tables or formulae from the draft version (release 2 : 1 December 1996) of Volume 1 of the HIPPARCOS & TYCHO Catalogues. The reason for this choice is that Hp-values are the mean of many (usually 100 and more, and at least, say, 40) spatial observations. The data were also corrected for interstellar extinction as derived in Sect. 2.

Then, we computed absolute visual magnitudes, making use of the trigonometric parallaxes as quoted in the HIPPARCOS catalog. Also given in Table 1 are the lower (faint) estimate (Mvl) and upper (bright) estimate (Mvu), applying the standard deviation of the parallax as given in the catalog. We have restricted Fig. 1 data to stars with $\sigma_{\varpi}/\varpi \leq 0.22$. Assuming that the error on absolute magnitudes solely results from error on the distance, the maximum error amounts to nearly ± 0.5 mag. In addition, Smith & Eichhorn (1996) emphasize that overestimated distances and brighter absolute magnitudes should be expected on statistical grounds, when larger relative errors on parallaxes are allowed. In Table 1, the overestimate should be less than 3% on distances and -0.07 mag on the absolute magnitudes. An additional sample of 15 stars with $0.22 \leq \sigma_{\varpi}/\varpi \leq 0.30$ is given in Table 2. The overestimate may reach there 12 % on the distances and -0.25 mag. on the absolute magnitude. Amongst the 52 stars presented here, only 14 had ground- based parallaxes compiled in the HIPPARCOS Input Catalogue (Turon et al. 1992) with 5-11 mas quoted accuracies, while HIPPARCOS ones range from 0.5 to 1.7 mas. Eight of them are either negative or quite inaccurate while five other parallaxes fall anomalously far from the new data. The only confirmed value is (21 ± 7) mas, now (21.6 ± 0.6) mas, as given for HD 202109.

4. The distribution of Ba stars in the HR diagram

Thirty-seven Ba stars from Table 1 are shown in the HR diagram (Fig. 1) together with mean sequences for various classes taken from Lanz (1992) and also from Allen (1973) for the Ib and II classes. It is seen that the barium star phenomenon do spread over five luminosity classes (I to V). Low luminosities were previously deduced through high surface gravities (Luck & Bond 1982). There is however a tendency for concentration in the region of class-III giants where 21 stars out of 37 are found (i.e. 57 %). This is consistent with the original definition of Ba stars (Bidelman & Keenan 1951). A clump is especially obvious in the G8-K0, $M_V \approx 0.6 - 1$(IIIb) region. It has been observed in the diagram of normal stars by Perryman et al. (1995) at $(B - V) \approx 1.0$ and $M_{H_p} \approx 1.0$. Six or seven stars in our sample are located on (or close to) the main sequence (class V). Three of them (HD 50264, 123585 and 127392) were classified as subgiant CH stars by Bond (1974). They are clearly the pre-Ba/CH stars in the models of Han et al. (1995), i.e. stars polluted by a TP-AGB companion when on the main sequence. They are to evolve into Ba/CH (giant) stars. From Fig. 1 and additional data in Table 2 as well, a transition appears at G4, evolution away from the main sequence being observed in this type and later ones. A few stars are distributed in the subgiant (class IV) zone. Presumably Ba/CH stars do populate the whole branch which can be seen in the diagrams of Perryman et al. (1995). Stars within one magnitude above the class V-sequence like HD 87080 and HD 207585 should be classified either as Va or IVb, taking due account of the error bars. Conversely, four stars (HD 65584, 51959, Lu 139 = COD $-61^{\circ}1024$ and HD

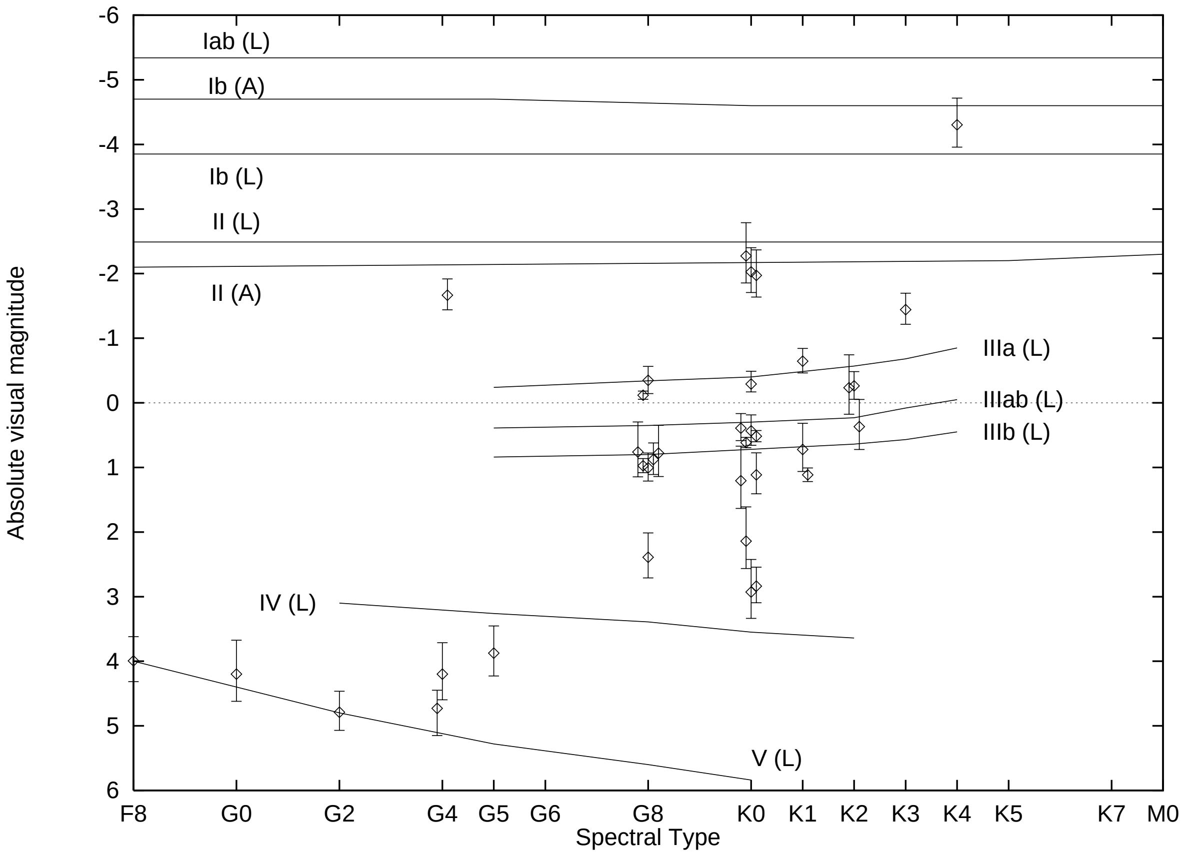

Fig. 1. The Ba stars in the HR diagram as obtained from HIPPARCOS data with error bars as deduced from the parallax errors. For comparison purposes, the curves given by Allen (1973) and Lanz (1992) (A and L respectively) are also given for various luminosity classes. See text for details.

Table 1. The data for 37 Ba stars. In the seven columns are quoted the HD or Lü (1991) entry, the spectral group and extinction as obtained in Sect. 2, the absolute visual magnitude between the lower and upper estimates as derived in Sect. 3, and the proposed luminosity class (Sect. 4). Note III = IIIab; II- : possibly IIIa and IVb- : possibly Va

HD	G	E(B-V)	Mvl	Mv	Mvu	LC	HD	G	E(B-V)	Mvl	Mv	Mvu	LC
5395	K0g	0.00	0.69	0.62	0.54	IIIb	11658	K1g	0.00	1.06	0.72	0.32	IIIb
16458	K0g	0.06	-0.17	-0.29	-0.49	IIIa	30554	K0g	0.05	1.41	1.11	0.77	IIIb
36650	K0g	0.07	1.64	1.21	0.67	IIIb	46407	G8g	0.00	1.11	0.88	0.62	IIIb
50082	G8g	0.02	1.15	0.76	0.30	IIIb	50264	G2d	0.00	5.07	4.79	4.46	V
51959	K0g	0.02	3.34	2.93	2.42	IVa	65699	K0g	0.04	-1.64	-1.97	-2.37	II
65854	G8g	0.01	2.71	2.39	2.01	IVa	67447	K0g	0.01	-1.86	-2.27	-2.79	II
Lu 139	K0g	0.10	2.57	2.14	1.61	IVa	77912	K0g	0.00	-1.71	-2.03	-2.40	II
83548	G8g	0.00	-0.14	-0.35	-0.56	IIIa	87080	G5d	0.00	4.23	3.87	3.45	IVb-
89175	G8g	0.05	1.14	0.78	0.35	IIIb	92626	K2g	0.00	0.18	-0.24	-0.74	IIIa
95345	K2g	0.00	-0.05	-0.26	-0.48	IIIa	101013	K0g	0.00	0.58	0.39	0.17	III
104059	F2d	0.00	3.80	3.49	3.13	V	104979	K0g	0.00	0.60	0.52	0.43	III
111315	K1g	0.04	-0.46	-0.64	-0.84	IIIa	116713	K1g	0.00	1.22	1.12	1.10	IIIb
123585	F8d	0.00	3.62	4.00	4.32	V	127392	G4d	0.00	4.45	4.73	5.15	V
139195	G8g	0.00	1.08	0.97	0.86	IIIb	Lu 262	G0d	0.06	4.62	4.20	3.67	V
168214	K0d	0.00	3.10	2.84	2.55	IV	175674	K2g	0.00	0.72	0.37	-0.05	III
199394	G8g	0.00	1.21	1.01	0.78	IIIa	202109	G8g	0.00	-0.05	-0.12	-0.18	IIIa
204075	G4sg	0.00	-1.44	-1.67	-1.92	II	205011	K0g	0.00	0.66	0.44	0.19	III
206778	K4sg	0.04	-3.96	-4.30	-4.72	Ib	207585	G4d	0.00	4.60	4.20	3.71	IVb-
218356	K3g	0.03	-1.22	-1.44	-1.70	II-							

168214) are located above the class-IV locus of Lanz (1992), close to the bottom (IIIb) of the giant branch. We tentatively classify these four stars as IVa. We found four Fig. 1 stars (HD 204075, 65699, 67447 and 77912) close to the curve given by Lanz (1992), or better by Allen (1973), for bright (class II) giants. The star HD 218356 located halfway between the IIIa and II curves, is attributed both types. Finally, the brighter star in our sample is HD 206778, a class-Ib supergiant.

5. Conclusion

We have presented direct absolute visual magnitudes from HIPPARCOS parallaxes and accurate spectral grouping for a sample of 52 barium stars (including CH stars), making use of the accurate photometry secured aboard the satellite. With unprecedented accuracy, the location of these stars in the HR diagram is shown for 37 stars (Fig. 1) and given for 15 additional stars in Table 2. The barium stars are observed from the main sequence up to the Ib-class supergiant, with a marked clump in the G8-K0 IIIb region. These results are consistent with the models of mass transfer or wind accretion in a binary system (Han et al. 1995 and references therein). The formerly more massive component, now a white dwarf star, polluted its companion while a mass loosing TP-AGB star. Main sequence and subgiant Ba/CH stars might be the progenitors of a majority of the barium giants (Smith et al. 1993). In our initial sample of 121 barium stars, only 21 are non single according to HIPPARCOS data, with 8 of them already in the CCDM. Four stars were studied as spectroscopic binaries by McClure & Woodsworth (1990). According to the HIPPARCOS Catalogue (ESA, 1997), 2 stars have new components solutions, 9 are unresolved systems, 1 has a stochastic orbital solution and 1 is suspected non single. This low proportion of detection might be expected since a 5-11 mag. difference is estimated between the components (HIPPARCOS is limited to about 4 mag.). Also photocenters deviations are unlikely to be detected when separation is low and period close to one year.

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