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ASTRONOMY AND ASTROPHYSICS

Barium stars, galactic populations and evolution⋆,⋆⋆

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Abstract. In this paper HIPPARCOS astrometric and kinematical data together with radial velocities from other sources are used to calibrate both luminosity and kinematics parameters of Ba stars and to classify them. We confirm the results of our previous paper (where we used data from the HIPPARCOS Input Catalogue), and show that Ba stars are an inhomogeneous group. Five distinct classes have been found i.e. some halo stars and four groups belonging to disk population: roughly supergiants, two groups of giants (one on the giant branch, the other at the clump location) and dwarfs, with a few subgiants mixed with them. The confirmed or suspected duplicity, the variability and the range of known orbital periods found in each group give coherent results supporting the scenario for Ba stars that are not too highly massive binary stars in any evolutionary stages but that all were previously enriched with Ba from a more evolved companion. The presence in the sample of a certain number of "false" Ba stars is confirmed. The estimates of age and mass are compatible with models for stars with a strong Ba anomaly. The mild Ba stars with an estimated mass higher than 3 $M_\odot$ may be either stars Ba enriched by themselves or "true" Ba stars, which imposes new constraints on models.

Key words: stars: abundances; distances; kinematics; evolution – galaxy: stellar content

1. Introduction

Ba stars spread out over a large range in luminosity: from class IV-V to class Ib, with most of the stars having luminosities of normal giants. In a previous paper, Gómez et al. (1997) [Paper 1] concluded that Ba stars do not constitute a homogeneous group. Four groups with different absolute magnitudes, kinematics and spatial distribution were identified: a halo group plus three disk groups, classified as supergiants, giants and dwarfs-subgiants. These results relied on the HIPPARCOS Input Catalog (HIC) data and the LM method (Luri, Mennessier et al., 1996) based on a Maximum Likelihood estimation.

In this paper we reassess the problem using the HIPPARCOS mission results (ESA 1997). High precision astrometric data are now available: proper motions as well as trigonometric parallaxes (see Sect. 2.1) that allow us to strongly refine our first results. With our method we can also estimate individual luminosities and distances for all Ba stars, substantially improving the HIPPARCOS parallaxes. On the other hand, we have also improved the LM method: we can parametrize the absolute magnitude. For instance, groups covering a wide range of spectral types are better modeled by a relation (absolute magnitude M versus a color index) than by using a mean magnitude and a dispersion.

Ba stars were defined as a group by Bidelman & Keenan (1951) based upon 80 Å/mm spectrograms. They are mainly G and K stars that show enhancements of many s-process elements, particularly BaII for which the abundance peculiarity is characterized from the λ4554 line strength, on a scale from 1 (mild Ba stars) to 5 (strong Ba stars). Many Ba stars belong to binary systems and the abundance anomalies are explained via the mass transfer, through either Roche lobe overflow (Webbink 1986) or wind accretion in a detached system (Boffin & Jorissen 1988;Jorissen & Boffin 1992), the companion being a white dwarf star (Böhm-Vitense 1980; Böhm-Vitense et al. 1984). Thus they can be a mixture of several galactic populations.

We first identify groups (see Sect. 2.3) based at the same time on the luminosity and kinematics, and relate them to the initial mass and age of the stars. On the basis of these results and the distribution of Ba abundance anomalies, metallicities, variability, duplicity and orbital periods inside the groups, new insights into the evolutionary status of theses stars are presented. Stars with peculiar properties are discussed and we argue that some may be not "true" Ba stars and rather AGB stars. (see Sect. 3).

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⋆ Based on data from the ESA HIPPARCOS astrometry satellite

⋆⋆ Table 4 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

Table 1. Mean errors for the photometric and astrometric data. The 'T' subindex in $(B-V)_T$ indicates Tycho photometry

	Paper 1	this paper
σ_{m_v} (m)	0.09	~ 0.01
$\sigma_{\mu_\alpha \cos(\delta)}$ $(arcsec/year)$	0.07	0.015
σ_{μ_δ} $(arcsec/year)$	0.07	0.015
$\sigma_{(B-V)_T}$ (m)	—	0.02

2. Classification from HIPPARCOS data

2.1. Sample and data

The sample used in this paper is essentially the same as that used in Paper 1, based on the Lü catalogue (1991). Ten stars contained in the list of Ba dwarfs by North et al. (1997) were added. In order to apply the LM method, positions, apparent magnitudes and proper motion components are required, and parallaxes and radial velocities are highly desirable (as well as the measurement errors for all these quantities). Astrometric and photometric data were taken exclusively from the HIPPARCOS Catalogue (ESA 1997) to provide a homogeneous data set, so the number of stars in the sample was reduced to 297. Radial velocity data come from different sources: McClure & Woodsworth (1990) and Griffin R. (1983, 1991) for stars with orbit determinations (about 20 stars), and Coravel data obtained by L. Prévot, A. Jorissen, P. North and M. Mayor, for about 250 stars. For the remaining stars, the radial velocities were taken from the catalogues of Wilson (1953), Evans (1978), Barbier-Brossat (1989), Barbier-Brossat et al. (1994) and Lü (1991). Some of the non-Coravel radial velocities used in Paper 1 were replaced by Coravel measurements which are of higher quality.

The quality of the new astrometric and photometric data is much higher than the sample used in Paper 1. The mean errors for $(m_v, \mu_\alpha \cos(\delta), \mu_\delta)$ are compared in Table 1. In addition the mean error on the Tycho (ESA, 1997) $(B-V)_T$ index is also listed in the table.

The HIPPARCOS parallaxes used in this work have small relative errors: about 15% of the stars in the sample have a relative error less than 0.1 and for 35% less than 0.2. However the LM method allows us to use all the parallaxes as explained in the next paragraph. The histogram of the distribution of relative errors in trigonometric parallax is shown in Fig. 1.

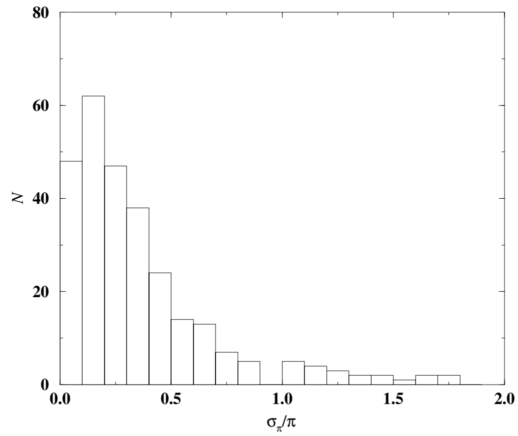

Fig. 1. Distribution of relative errors in trigonometric parallaxes (17 stars with $\sigma_\pi/\pi > 2$ are excluded).

2.2. The LM method

The main properties of the LM method and its application to Ba stars are shown in detail in Paper 1 and its mathematical foundations are presented in Luri, Mennessier et al. (1996). However, we have introduced two improvements with respect to the method presented in Paper 1.

On the one hand, we now use trigonometric parallaxes. This possibility is already outlined in Luri, Mennessier et al. (1996) and can now be applied using the HIPPARCOS parallaxes. As the individual errors are taken into account, even negative parallaxes or parallaxes with high relative errors can be used. Furthermore stars with such parallaxes should not be eliminated, otherwise the sample would be biased.

On the other hand, we now can parametrize the absolute magnitude. For instance, groups covering a wide enough range of spectral types can be better modeled using a relationship (M_v,one color index). To this end we use the $(B-V)_T$ Tycho color index. We have modeled the distribution of the different groups in the $[M_v, (B-V)_{T0}]$ plane (the subindex '0' indicating a dereddened color index) as being given by a mean linear relationship $M_v[(B-V)_{T0}]$ plus a gaussian dispersion of the individual absolute magnitudes around this mean line. The color index is assumed normally distributed. This rather simple model allows us to account for the large spread in absolute magnitude, for instance of the giant group (see 2.4). For more details about the LM method used with parametrization of the absolute magnitude see Luri (1995).

2.3. Number of groups and mean parameters

In accordance with our Paper 1 results, we first applied the LM method without using color indices to the total sample (297 stars). We separate a first group containing halo stars. During the process we noticed a peculiar star, HIC 102409=HD 197481, that was much fainter than the rest ($M_v \simeq 9^m$) so we eliminated it. The presence of a halo component among Ba stars is confirmed and the stars classified as halo members (Group H, 20 stars) were put in a separate sample, for which we estimated mean kinematic parameters. Let us remark that stars already known to belong to Population II like CH stars are in this group: HD 26, HD 107541, HD 148897 (Sleivyte and Bartkevicius, 1990). As seen later, the group is a mixture of subgiants and bright giants: an estimate of its mean luminosity has no meaning.

Then we applied the LM method twice to the remaining sample (containing 276 stars), not including and then including the $(B-V)_T$ color indices, and four groups were identified [1].

Our results for the halo group and the four disk groups are given in Table 2:

Luminosity parameters: the mean absolute magnitude and its dispersion (M_0, σ_M) for the groups without a color index-absolute magnitude relationship, and the absolute magnitude at $(B-V)_{T0} = 0$, slope and dispersion around the mean line $(M(0), s, \sigma_M^{BV})$ for the group where such a relationship holds.

Kinematical parameters: the mean velocities (U_0, V_0, W_0) and the dispersions $(\sigma_U, \sigma_V, \sigma_W)$ of the velocity ellipsoid.

Spatial parameters: scale height in the direction perpendicular to the galactic plane Z_0.

Color distribution parameters: the mean color index and dispersion of the group $[\overline{(B-V)}_{T0}, \sigma_{BV}]$ for all the groups except halo stars.

Percentage in the sample: percentage of the sample corresponding to the group.

The table is divided in two sections:

– The first section corresponds to the groups for which a color index-absolute magnitude relationship is not physically relevant (groups H and S) or the range of $(B-V)_{T0}$ values is so narrow that it is not worth using this relationship (groups D anc C).

– The second section corresponds to the group for which the color index-absolute magnitude relationship properly describes its distribution on the $[M_v, (B-V)_{T0}]$ plane (groups G). For this group the M_v at $(B-V)_{T0} = 0$ and the slope of the relationship are given.

2.4. Classification of stars and individual luminosities

The LM method can estimate the individual distance for each star. First each star is assigned to one group and then the parameters characterizing the group and the observational data of the star (including the trigonometric parallax) are used in the estimation of the most probable distance. This estimation is more refined than simply applying $r = 1/\pi_t$: all the bias due to the observational errors or observational selection effects are automatically corrected and the whole available observational information is used. A comparison of the distance estimates is given in Fig. 2 for stars with a relative error in π_t less than or equal to 1.0. We can see that there is no systematic error and that the agreement is better for stars with small values of $\frac{\sigma_{\pi_t}}{\pi_t}$ as it could be expected due to the procedure of estimation.

To assign the stars, the bayesian rule is followed: we assign the star to the group with the largest probability given the realized observation of the star – i.e. the group for which the product of the probability of the star belonging to the group and the percentage of the group in the sample is the highest – (Lebart et al. 1995).

[1] the number of groups in the sample is decided using Wilks likelihood test, as described in Paper 1

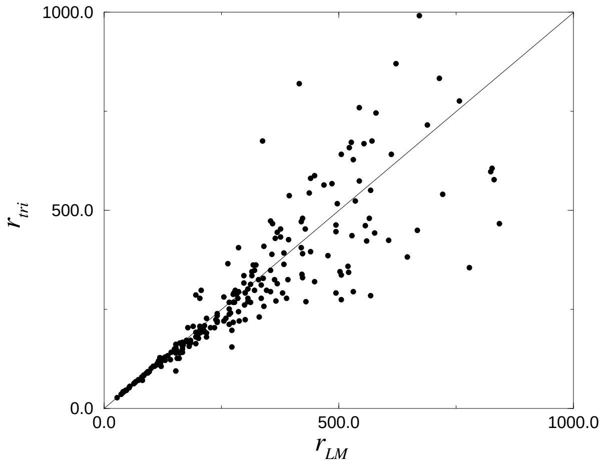

Fig. 2. Comparison of the LM distance estimator (r_{LM}) and the one obtained by inverting the trigonometric parallax $(r_\pi = 1/\pi)$ for stars with $\frac{\sigma_{\pi_t}}{\pi_t} \leq 1$.

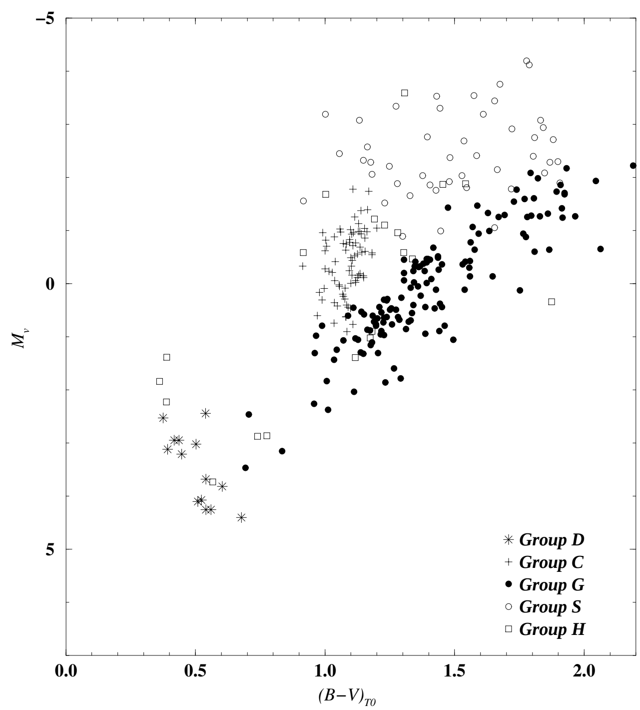

Fig. 3. Distribution of the stars in the $[M_v, (B-V)_{T0}]$ plane

Using the individual distance estimates we have calculated the absolute magnitudes and the de-reddened color index $(B-V)_{T0}$ of the stars. To de-redden this color index we first calculated the absorption A_v using the Arenou et al. (1992) model and then the color excess as $E[(B-V)_T] = A_v/(3.311 * 0.85)$ the factor 0.85 corresponding to the transformation from Johnson to Tycho photometry (Grenon, 1996). The results are presented in Fig. 3. The mean accuracy of estimated individual luminosities is 0.4 mag. as deduced from the distribution in Fig. 4.

Table 2. Estimated parameters of the different groups and percentage of the sample into each of them

	Group H		Group D		Group C		Group S			Group G	
	est.	σ	est.	σ	est.	σ	est.	σ		est.	σ
M_v	—	–	4.1	1	0.2	0.6	-1.2	1.6	$M_v(0)$	5.3	0.6
σ_M	—	–	0.7	0.3	0.8	0.3	1.0	1.1	s	-3.4	0.3
U_0	-20	39	-6	10	2	3	-9	4	σ_M^{BV}	0.7	0.2
σ_U	114	43	38	9	20	2	17	4	U_0	-14	4
V_0	-163	47	-18	7	-7	2	-5	2	σ_U	37	4
σ_V	94	52	13	5	13	2	10	3	V_0	-12	2
W_0	10	51	5	6	-8	2	-9	2	σ_V	20	2
σ_W	89	49	15	4	10	1	8	3	W_0	-6	2
Z_0	690	989	88	216	164	21	86	26	σ_W	16	2
$\overline{(B-V)_{T0}}$	—	-	0.51	0.03	1.08	0.01	1.40	0.09	Z_0	235	30
σ_{BV}	—	-	0.08	0.02	0.07	0.01	0.28	0.05	$\overline{(B-V)_{T0}}$	1.08	0.06
%	—	-	5.0	0.5	26.0	2.0	19.3	5.3	σ_{BV}	0.32	0.03
									%	49.7	4.4

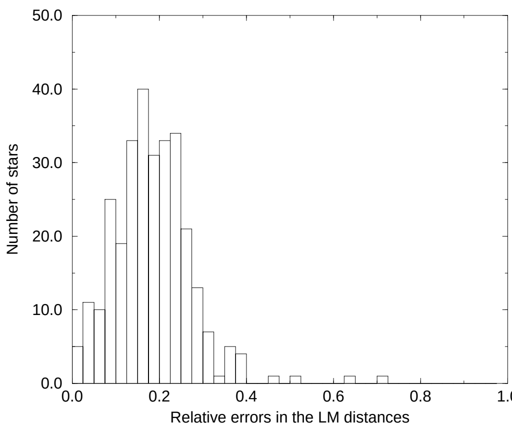

Fig. 4. Histogram of the relative errors in the LM distances

From the positions of the stars in the HR diagram and the kinematics and spatial distribution of the groups (see Table 2) a preliminary physical identification can be proposed as follows:

Group H: the halo stars. This group contains stars from several luminosity classes and should be further divided, but the sample is too small.
Group D: dwarf stars
Group C: giant stars in the "Clump" region i.e. having already undergone the Helium flash
Group G: subgiant and giant stars
Group S: supergiant stars

Table 4 gives the individual estimates of luminosities M_v and distances, the group at which the star has been assigned and the HIPPARCOS variability and duplicity flags as explained in the next sections 3.2 and 3.3.

We confirm one of the results of Paper 1, indicating that Ba stars are a mixture of different luminosity classes ranging from V to Ib. Indeed, if the Ba anomaly comes from an evolved companion and is not related to the star itself, as proposed by the binary scenario, then a Ba star can be in any evolutionary state, provided it is late enough to accommodate a contemporaneous but more massive and more evolved companion.

3. Discussion

In Paper 1 we argued that the binary scenario applied to both dwarfs and giants but that the identification of some AGB stars among the Ba supergiants should not be ruled out. Now, we improve the classification of Ba stars and discuss their evolutionary state from the obtained results on luminosity and kinematics combined with data on duplicity, variability and abundance anomaly.

3.1. Ages and masses

An estimate of the mean ages and masses of the disk groups was obtained using isochrones and tracks from stellar models. We used the Schaller et al. (1992) models which consider the mass loss and overshooting. The transformation of the theoretical HR diagram to the $[(B-V)_0, M_v]$ plane was performed following Meynet (1994). The $(B-V)_T$ color index was converted to the Johnson system following Grenon (1996) i.e. using the relationship $(B-V)_0 = 0.85(B-V)_{T0}$ for stars of late spectral types. This is not an accurate transformation but it is sufficient for our purpose.

In Figs. 5 and 6 we present these comparisons. We have depicted sets of isochrones and tracks for solar metallicity stars ($Z = 0.02$). It is known that metal deficient stars are up and left shifted but their locations are not precise enough to be used for our purpose. In each disk group the metallicity probably ranges from solar to more deficient for the oldest stars belonging to the group. Let us remark that we have computed the $[Fe/H]$ value of stars recognized as halo members from DDO photometry (Claria et al., 1993) and that they are in the range $(-0.41, -1.95)$ with a mean value $[Fe/H] = -1.01$.

The ranges of ages and masses are given in Table 3. These age ranges agree with the ages obtained from the age-velocity dispersion relationship given by Lacey (1992), also included in the table. The agreement between ages is fairly good taking

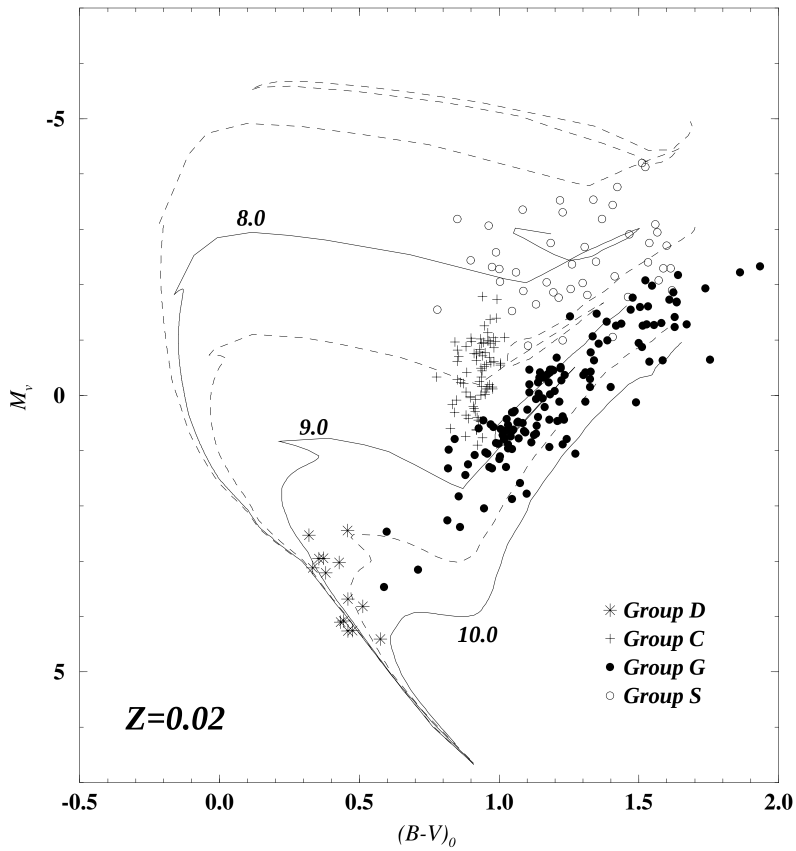

Fig. 5. Isochrones in the $[(B-V)_0, M_v]$ plane. The solid lines have their log(age) indicated. The dashed lines correspond to intermediate isochrones with increments of 0.5 in log(age). The horizontal axis corresponds to $(B-V)_0$ Johnson.

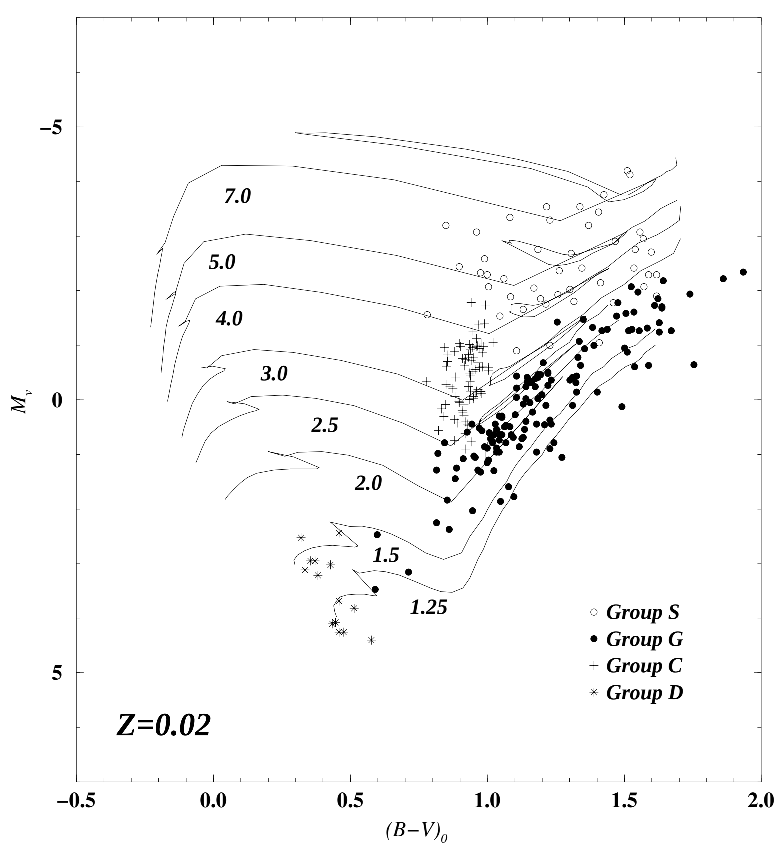

Fig. 6. Tracks in the $[(B-V)_0, M_v]$ plane. The mass of the tracks in solar masses is indicated in the figure. The horizontal axis corresponds to $(B-V)_0$ Johnson.

Table 3. Approximate ranges of ages and masses of disk groups

group	age isoch. (yr)	age Lacey (yr)	mass ($M_{\odot}$)
D	$2\ 10^9 - 10^{10}$	$3\ 10^9 - 5\ 10^9$	$1 - 1.6$
C	$3\ 10^8 - 10^9$	$7\ 10^8 - 1.6\ 10^9$	$2.5 - 4.5$
G	$10^9 - 10^{10}$	$3\ 10^9 - 5\ 10^9$	$1 - 3$
S	$4\ 10^7 - 3\ 10^8$	$2\ 10^8 - 5\ 10^8$	$3 - 7$

into account the inaccuracies involved in both methods. In the case of group S the range in age obtained using isochrones is larger than the one estimated from kinematics. This confirms the presence in this group of non "true" Ba stars (see 3.3).

3.2. Duplicity

The HIPPARCOS mission discovered new double or multiple systems and also detected some stars that may not be single. In Fig. 7 the distribution of HIPPARCOS duplicity flags for the disk groups in the $[(B-V)_{T0}, M_v]$ plane is presented. The symbols '+' are the stars not confirmed or denied as binaries. The other symbols are the stars with a duplicity/multiplicity flag: stars known beforehand as binary or multiple systems (INCA (I) or Miscellaneous (M)), stars for which acceleration terms are necessary in the data reduction process (G) (probably binary systems with a period greater than 10 years), double stars with at least one orbital element determined by HIPPARCOS (O) and stars with a "stochastic solution" used in the data reduction process (X) (probably binary systems with periods shorter than 3 years). In group H there is only one star with a duplicity (G) flag.

It is remarkable that the binary (or multiple) systems are mainly found in groups D, C and G while only a few are in group S composed of supergiants. None is at the right upper limit corresponding to the location of the Asymptotic Giant Branch. More comments about this last point will be given in the next paragraph.

Moreover G and X flags are essentially in D and G groups, very few in the clump and none in the group S, they correspond to systems for which the companion of the Ba star is not identified and could be a white dwarf. Stars with I and M flags (identified binary or multiple systems) are in groups C and S. For these stars we can estimate the absolute magnitude of the companion from the absolute magnitude of the Ba star and the apparent magnitude difference of the system. Examination of CCDM information for these stars allow us to evaluate the possibility that the companion could be a white dwarf (for all except perhaps 5 about which no sufficient data are given in CCDM: HIC 46390, HIC 49405, HIC 54059, HIC 94913, HIC 99874). Indeed a white dwarf is less luminous than M_v = 10, and on the contrary, the values deduced from the apparent magnitude of the Ba star and other identified stars in the system and from the estimated luminosity of the Ba star, indicate that the companions are always more luminous than 10. This allows us to suspect that stars into the groups C and S could show Ba characteristics as a result of a process other than the enrichment from an evolved companion. They are post He flash stars, with the possibility of

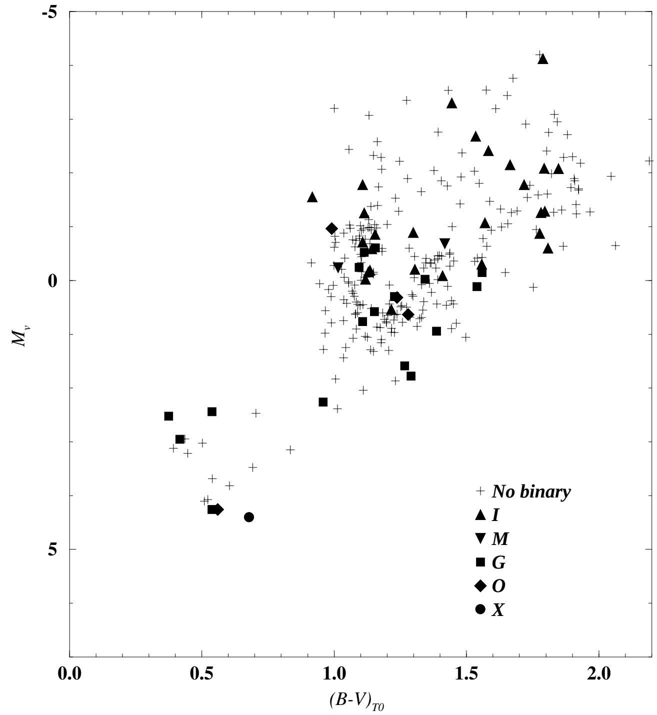

Fig. 7. Duplicity flags from HIPPARCOS data in the $[(B-V)_{T0}, M_v]$ plane for the disk groups

convection and s-process and so could produce Ba themselves. However the possibility remains that the observed companion is just a third body, leaving room for an as yet undetected white dwarf.

A further source of information about the duplicity is the radial velocity survey for Ba stars carried out by A.Jorissen, M.Mayor and P.North over several years to confirm the duplicity and to determine the orbital periods. The histograms of these orbital periods known to date are shown in Fig. 8 for each group. We have separated the histograms according to the intensity of the Ba line (strong or mild) determined from spectra by the same authors.

We observe again that there are few binaries in group S. The stars in group C have longer periods than those in groups D and G in which the stars are older.

Another interesting point is that almost all group C stars are classified as "mild", while in group G the "strong" stars prevail. Finally we can notice that the strong Ba Halo stars observed by North et al (1994 and 1997) and Jorissen et al. (1997), have any values of periods and are found mainly in the subgiant region and giant branch. One mild Ba star, according to Lu et al. (1983), is located in the dwarf region (HIC 10119) whereas the others are in the giant branch. A high resolution spectra of HIC 10119 taken in the lambda 5100 Åregion with the ESO CAT telescope, by P. North in July 1996, clearly shows enhanced lines of the s-process elements YII, ZrII, NdII and LaII, confirming its Ba nature.

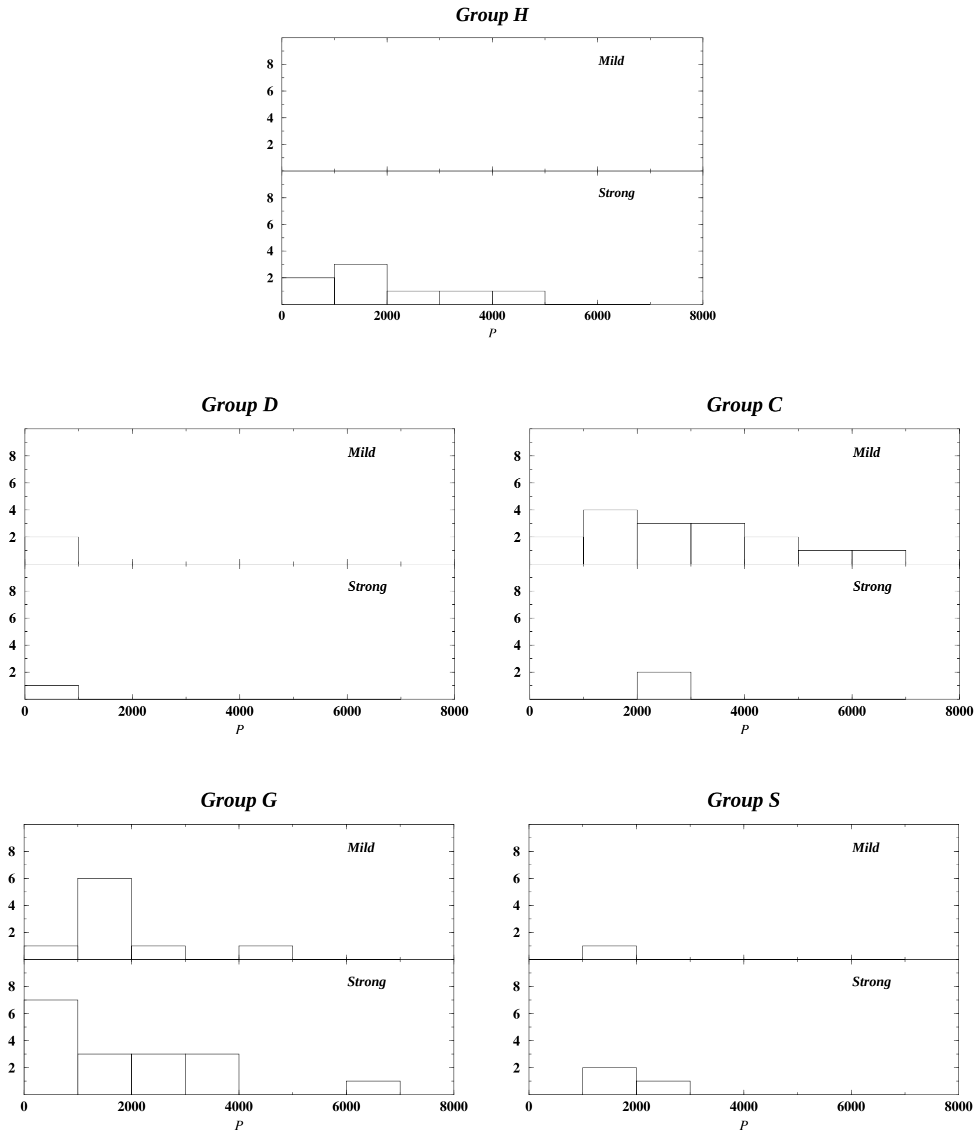

Fig. 8. Histograms of the known orbital periods by group

3.3. Variability

The high number of photometric observations per star during the HIPPARCOS mission led to the discovery of new confirmed or putative variable stars. In Fig. 9 the distribution of HIPPARCOS variability flags in the $[(B-V)_{T0}, M_v]$ plane is given. The C flag corresponds to stars without any detected variability. The D, M and U flags correspond to variability induced by duplicity, microvariability and other types of variability respectively.

Confirming the results of the previous section, the duplicity-induced variability (D flag) is found exclusively in groups D, C and G. In contrary, most "true" variability flags (U and M) are found in group S and are concentrated in the rightmost part of the diagram, in the region of the Asymptotic Giant Branch. The classification of these stars as Ba stars is questionable. It is probable that most of these stars are giants or supergiants that are developing s-processes and thus are "false" Ba stars in contrast to the "true" Ba stars for which the Ba anomaly comes from enrichment by a previously evolved companion. The masses deduced from the tracks in Fig. 6, $1-7M_{\odot}$, are compatible with the values expected for AGB stars. Moreover the effective temperatures of 6 of our stars with a flag M (HD 20644, HD 30504, HD 81797, HD 131873, HD 168532, HD 198542) were estimated by McWilliam (1990) and they are in the range 3900-4100 K. The fact that all M giants and the S stars in our sample have a variability flag confirms our conclusion.

3.4. Ba intensities

The Lü (1991) catalogue gives a "Ba index" I(Ba) for the stars, ranging from 0 to 5, indicating the relative intensity of the Ba line. This index, obtained from objective prism spectra, is not very accurate but it can be used to check the Ba abundances in our groups.

The distribution of values of this index for the disk groups in the $[(B-V)_{T0}, M_v]$ plane is given in Fig. 10.

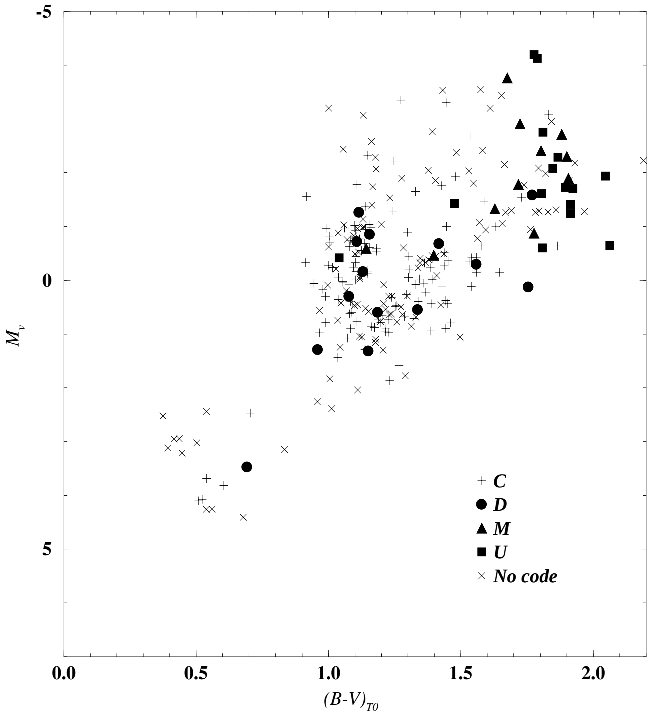

Fig. 9. Distribution of variability flags from HIPPARCOS data in the $[(B-V)_{T0}, M_v]$ plane

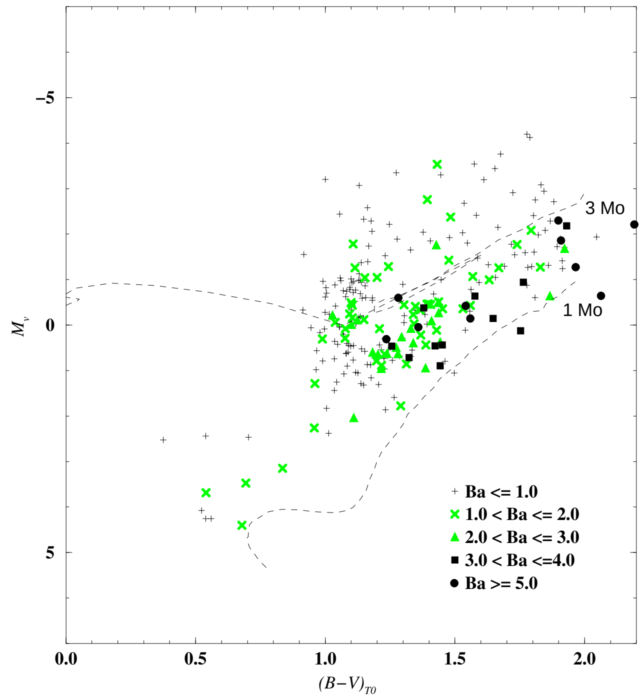

Fig. 10. Distribution of Lü (1991) Ba intensities in the $[(B-V)_{T0}, M_v]$ plane. Dashed lines are evolutionary tracks at Z=0.02 for 1 and 3 $M_\odot$

The high Ba intensities (index 3-5) are found almost exclusively in group G, while medium-high intensities are mainly found in groups D, C and G. In contrary, low Ba intensities prevail (index ≤ 1) in the group S. Some of these stars could just be supergiants with Ba line enhanced by a gravity/luminosity effect and so simulate Ba stars. This segregation of Ba intensities among the groups is seen more clearly in the histograms presented in Fig. 11. This result is in agreement with the previous section.

Han et al (1995) who modeled the formation of Ba stars via binary interaction, estimated the average mass of strong Ba stars to be 1.8 $M_\odot$ with a range of 1 to 3 $M_\odot$. This result is in excellent agreement with our mass estimates for group G, the only group containing high Ba intensity stars. In Fig. 10 we have drawn tracks for 1 and $3M_\odot$ with solar metallicity. All Ba stars with I(Ba) larger than 2 have masses less than $3M_\odot$. However the milder Ba stars can have larger masses. This conflicts with the model by Han et al (1995) and we will examine this point in detail in the conclusions.

4. Conclusion

Our powerful LM algorithm has been applied to improve the luminosity calibration of Ba stars using newly available HIPPARCOS data.

Our results confirm that the Ba stars should be understood as an inhomogeneous sample containing halo and disk populations stars. They are found among dwarfs, giants or supergiants as well as in the clump. This is consistent with the most widely accepted model: Ba stars are "normal" stars in different evolutionary stages depending on their initial mass but the Ba enrichment is only due to a close and initially more massive companion that has already produced s-elements. The enrichment comes from a mass transfer phenomenon.

Nevertheless, examination of HIPPARCOS variability flags reveals that some stars may have been classified erroneously as Ba stars. We argue that they are "false Ba" and their characteristics suggest that they are "true AGB" stars.

From the estimated mass and age ranges of Ba stars in the different groups no evolutionary link has been found between supergiants (the youngest and most massive group), the clump stars and the giants (oldest and least massive group). On other hand an evolutionary link between the dwarfs and the giants groups cannot be ruled out. However the sample of dwarf Ba stars is too small to conclude on this point.

The distribution of the Ba intensities among the different groups shows that strong Ba stars are mainly among giants. Our estimated age range for giants $(1-3M_\odot)$ agrees with the distribution of masses of strong Ba stars $(1-3M_\odot)$ found by Han et al (1995) from their model of formation via binary interactions. However a discrepancy appears between our estimates of masses up to $7M_\odot$ for group S and $4.5M_\odot$ for group C in which there are mild Ba stars, whereas these authors assigned masses of less than $3M_\odot$ for all Ba stars.

We can remark that:

- The I(Ba) should be checked when it is less than or equal to 1: this is the case for the most part of the members of the group S and for about half of those in the clump.

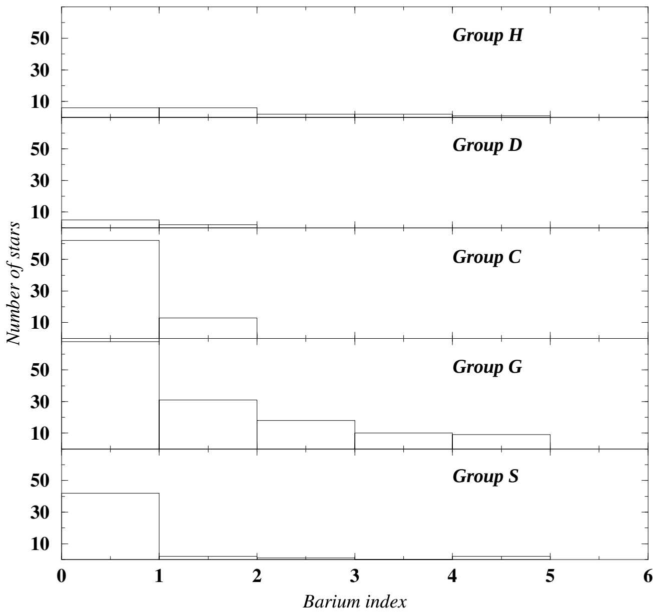

Fig. 11. Histograms of the distribution of Lü (1991) Ba index among the groups

- The stars in the lower right part of group C can have an age close to 10^9 years and so are metal deficient and have a mass between 2.5 and $3M_{\odot}$. Most of the stars with I(Ba) between 1 and 2 are seen at this location.
- Some stars in group S could simulate Ba stars but only be supergiants in which Ba line is enhanced by a gravity/luminosity effect.
- Some stars in these groups could be enriched in Ba generated by the star itself and so be "false" Ba stars: "true" AGB's (see 3.3) or lower luminosity, post He-flash stars where the s-process has taken place for some unknown reason (see 3.2).

After a detailed examination of stars of groups C and S, the presence of mild Ba stars with masses larger than $3M_{\odot}$ seems proven by our kinematical study. This fact should constrain future evolutionary models.

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