BARIUM STARS: LUMINOSITY AND KINEMATICS FROM HIPPARCOS DATA

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ABSTRACT

Hipparcos astrometric data and Tycho photometry together with radial velocities (mainly from Coravel) are used to calibrate luminosity, kinematical parameters and scale height of Barium stars and to classify them. We improve the results of a 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, namely, 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 as moderately massive binary stars in any evolutionary stage but all previously enriched in Barium from a more evolved companion. The presence in the sample of a certain number of 'false' Barium stars (supergiants with Ba line enhanced by a gravity/luminosity effect or AGB stars with intrinsically strong barium lines) is confirmed.

Key words: barium stars; luminosity calibration; stellar kinematics.

1. BARIUM STARS: HISTORICAL REVIEW

1.1. Definition

Barium stars were defined as a group by Bidelman & Keenan (1951) based upon 80 Å/mm spectrograms. They are mainly G and K stars which show enhancements of many s-process elements, particularly BaII for which the abundance peculiarity is characterized from the $\lambda4554$ line strength, on a scale from 1 (mild Barium stars) to 5 (strong Barium stars).

1.2. Origin of the Barium Anomaly

Many barium stars belong to binary systems and the abundance anomalies are explained via the mass transfer, either through 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).

1.3. Luminosities

Previous determinations of absolute visual magnitudes of barium stars already showed that their luminosities are spread in a wide range, $-3.7 \leq M_v \leq +5$ mag (from class IV-V to class Ib, with most of the stars having luminosities of normal giants), so they constitute an inhomogeneous group.

In a previous work, Gómez et al. (1997), we confirmed this inhomogeneity and we identified four groups with different mean absolute magnitudes, kinematics and spatial distribution. This work was based on the LM method (see below) applied to the Hipparcos Input Catalogue (HIC) data.

2. THE LM METHOD

This work is based on the LM method (Luri 1995, Luri et al. 1996). Its mathematical foundations are presented in the above cited papers and a detailed description of its main properties and its adaptation to Ba stars can be found in Gómez et al. (1997) and Menessier et al. (1997). See also Luri et al. (1997) for a discussion of the utilisation of Hipparcos data for distance determinations.

2.1. Main Characteristics

- Based on a Maximum-Likelihood algorithm;
- Uses all the available information for the stars: $(V, \pi_t, \alpha, \delta, \mu_\alpha, \mu_\delta, v_r, (B-V))$;
- Takes into account the observational selection criteria; the results obtained are then bias-free (e.g. the Hipparcos magnitude limit is included in the method so the results are free of the Malmquist bias);

- Takes into account the effects of the observational errors; the results are not biased by them and even low-accuracy data (otherwise useless) can be included;
- The galactic rotation (Oort-Linblad model at first order) and the interstellar absorption (Arenou et al. (1992) model) are included.

2.2. Group Identification and Separation

An important feature of the LM method is its capability to identify and separate in the sample groups of stars with different physical characteristics (e.g. separation of population I and population II stars by its different kinematics).

Separate results are given for each group identified, so providing much more meaningful information than a global result for the mixture of all of them, that in some cases does not make much sense.

3. OUTPUT OF THE METHOD

The method provides for each of the groups identified:

- the absolute magnitude distribution: mean M_0 and dispersion σ_M or magnitude-color index relationship $M_v = M(0) + s(B-V)_{T0}$ plus dispersion around it;
- the velocity distribution: mean velocities (U_0, V_0, W_0) and dispersions $(\sigma_U, \sigma_V, \sigma_W)$;
- the spatial distribution: the disk scale height Z_0;
- the mean de-reddened color index and dispersion (in the cases where a mean color index versus absolute magnitude relationship was determined): $\overline{(B-V)_{T0}}$ and σ_{BV};
- the percentage of the sample in each group.

It also provides improved individual distance estimations that take into account all the available information for each star.

The trigonometric parallax π_t and other available measurements, $V, \alpha, \delta, \mu_\alpha, \mu\delta, v_r, (B_T - V_T)$, are taken into account to estimate the distance. This estimation is free of biases due to observational selection (because it is taken into account by the method).

4. THE SAMPLE

The sample used in this work has essentially been taken from the one used in Gómez et al. (1997), so it is based on the Lü (1991) list. Ten stars contained in the list of Barium dwarfs by North et al. (1997) have been added.

Astrometric data $(\pi_t, \alpha, \delta, \mu_\alpha, \mu_\delta)$ and photometric data $(V, (B-V))$ have been taken exclusively from the Hipparcos Catalogue (ESA 1997) in order to have a set of data as homogeneous as possible. The number of stars in the sample is 297.

Radial velocity data (v_r) come from different sources:

- McClure & Woodsworth (1990), Griffin (1983) and Griffin (1991) for stars with orbit determinations (about 20 stars);
- Coravel data obtained by L. Prévot or kindly communicated by M. Mayor for about 250 stars;
- for the remaining stars, the radial velocities have been taken from the catalogues of Wilson (1953), Evans (1978), Barbier-Brossat (1989), Barbier-Brossat et al. (1994) and Lü (1991).

5. RESULTS

Five groups are identified in the sample:

Group H: 'Halo stars'. A small group with very extreme kinematics (typical of population II). This group contains stars from several luminosity classes (see Figure 1) and should be further divided, but it is too small to do so.

Group D: 'Dwarf stars'. A small group, much less luminous than the rest, lying around the main sequence (see Figure 2).

Group C: 'Clump stars'. A group with a narrow distribution in both absolute magnitude and color index, lying in the region of the giant clump (see Figure 2).

Group G: 'Giant stars'. A group with a wide distribution in color index lying in the giant branch (see Figure 2).

Group S: 'Supergiant stars'. A group with a wide distribution in color index, more luminous than the rest, lying in the supergiant region of the HR diagram (see Figure 2).

The results for these groups are given in Table 1. The table is divided in two sections:

- The first section corresponds to the groups for which a color index-absolute magnitude relationship has no physical meaning given its inhomogeneity (group H), the relationship found is not relevant (group S) or the range of $(B-V)_{T0}$ values is so narrow that it is not worth using this relationship (groups D and C).
- The second section corresponds to the group for which a color index-absolute magnitude relationship properly describes its distribution in the $[M_v, (B-V)_{T0}]$ plane (group G). For this group the M_v at $(B-V)_{T0} = 0$ and the slope of the relationship are given.

Table 1. Estimated parameters for the different groups and percentage of the sample in each of them. fit = LM results, σ = estimated error. $M_0, \sigma_M, \overline{(B-V)}_{T0}$ and σ_{BV} are given in magnitudes, $U_0, V_0, W_0, \sigma_U, \sigma_V$ and σ_W in km/s and Z_0 is given in pc.

	Group H		Group D		Group C		Group S		Group G		
	fit	σ	fit	σ	fit	σ	fit	σ		fit	σ
M_0	6	2	4.1	1	0.2	0.6	-1.2	26	$M_v(0)$	5.3	0.6
σ_M	2	0.5	0.7	0.3	0.8	0.3	1.0	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	44	38	9	20	2	17	4	U_0	-14	4
V_0	-163	46	-18	7	-7	2	-5	2	σ_U	37	4
σ_V	95	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	90	49	15	4	10	1	8	3	W_0	-6	2
Z_0	700	1000	88	220	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
%	8.0	2.5	4.6	0.5	24.0	1.8	17.7	4.9	σ_{BV}	0.32	0.03
									%	45.7	4.0

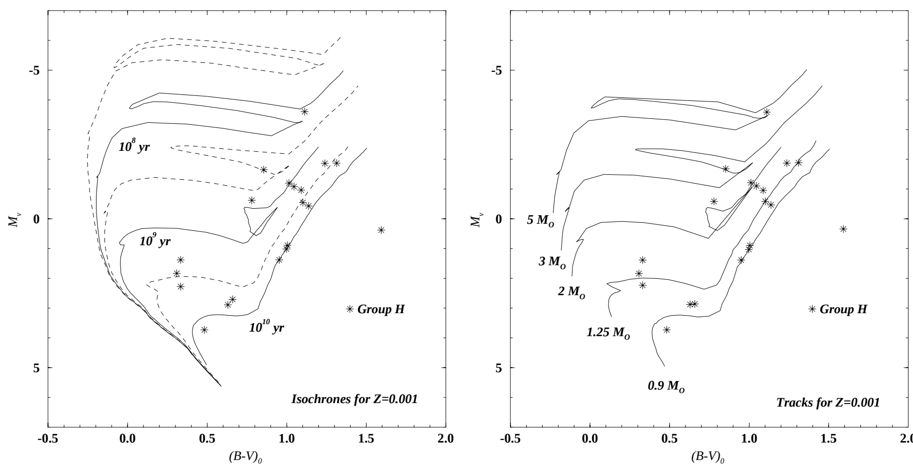

Figure 1. Group H with isochrones and tracks from Schaller et al. (1992) for low-metal content. Tycho (B-V)$_{T0}$ color index has been transformed to the Johnson system using Grenon (1996) transformations.

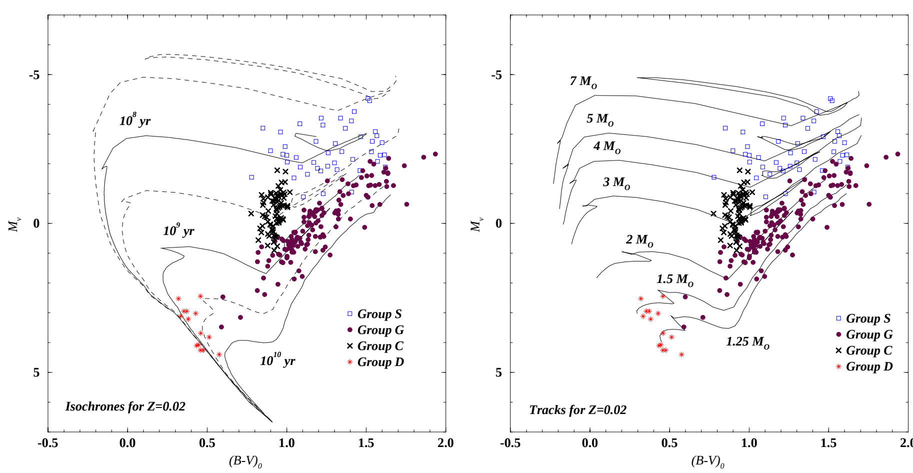

Figure 2. Non-halo groups with isochrones and tracks from Schaller et al. (1992) for solar metal content. Tycho (B-V)$_{T0}$ color index has been transformed to the Johnson system using Grenon (1996) transformations.

Table 2. Approximate ranges of ages and masses of non-halo groups.

group	age isoch. ($\times 10^9$ yr)	age Lacey ($\times 10^9$ yr)	mass ($M_\odot$)
D	$2 - 10$	$3 - 5$	$1 - 1.6$
C	$0.3 - 1$	$0.7 - 1.6$	$2.5 - 4.5$
G	$1 - 10$	$3 - 5$	$1 - 3$
S	$0.04 - 0.3$	$0.2 - 0.5$	$3 - 7$

The ranges of ages and masses for the non-halo groups estimated from the figures are presented in Table 2. The ages derived from the kinematic-age relationship given by Lacey (1992) are also given.

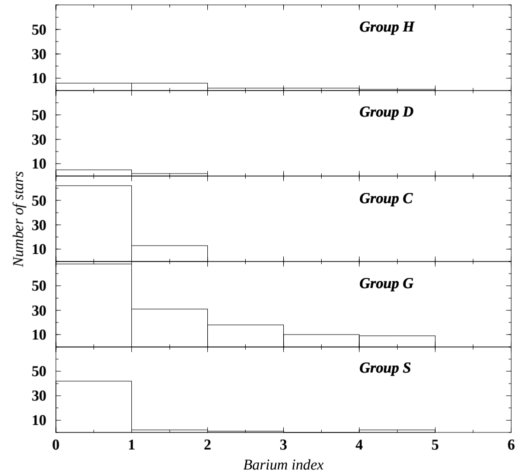

Figure 3. Histograms of barium index values by group.

6. DISCUSSION

The stars in group G are the ones that fit most nicely the current model of barium star formation via binary interaction of Han et al. (1995): they are giant stars, with a high percentage of binaries, the highest barium intensities are found among them (see Figure 3) and its range of masses ($1 - 3\ M_\odot$) is compatible with the model predictions.

Stars in group C fit less nicely in the current model: they have milder barium indices (see also Figure 3) and its range of masses ($2.5 - 4.5\ M_\odot$) exceeds the upper limit of the Han et al. (1995) model. This mass range implies either that a part of the group are 'false' barium stars or that a revised model is needed.

The classification of the stars in group S as barium stars is, on the contrary, less clear. The stars in this group show low barium intensities (Figure 3) and a high number of variables is found among them. They could be supergiants developing s-processes, and so with naturally intense barium lines, instead of 'true' barium stars.

Stars in group D are the 'barium dwarfs' whose existence is suggested in the literature. An evolutionary link with group G or C can not be ruled out, but the group is too small for any conclusive result.

Finally, group H is very likely the halo counterpart of the disk population of Barium stars. However, as it is too small, we were not able to further divide the group (as we did with the disk stars) and its content is then not homogeneous.

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