Astron. Astrophys. 330, 619–625 (1998)

ASTRONOMY
AND
ASTROPHYSICS

The absolute magnitude of the early type MK standards from Hipparcos parallaxes*

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Received 15 July 1997 / Accepted 22 September 1997

Abstract. We analyse the standards of the MK system with the help of Hipparcos parallaxes, using only stars for which the error of the absolute magnitude is $\leq$ 0.3 mag. We find that the main sequence is a wide band and that, although in general giants and dwarfs have different absolute magnitudes, the separation between luminosity classes V and III is not clear. Furthermore, there are a number of exceptions to the strict relation between luminosity class and absolute magnitude. We analyse similarly the system of standards defined by Garrison & Gray (1994) separating low and high rotational velocity standards. We find similar effects as in the original MK system.

We propose a revision of the MK standards, to eliminate the most deviant cases.

Key words: stars: early type MK standards – absolute magnitude

1. Introduction

The availability of parallaxes from the Hipparcos mission for a large number of MK standards permits to examine two fundamental questions, namely the accuracy of the MK luminosity calibrations and the validity of the spectroscopic approach.

It is well known that up to now, 90% of all the stellar distances known were based upon the spectroscopic method, which consists in using the MK luminosity class for obtaining the absolute magnitude. The calibration of the absolute magnitudes upon luminosity classes has been made through a combination of methods; for late type stars, mostly trigonometric parallaxes were used, whereas for the earlier types, use was made of both cluster sequences and statistical methods. The result of such methods are compiled in tabulations like the classical ones by Blaauw (1963) and by Schmidt-Kaler (1982). The sore point about these calibrations is that the uncertainties involved are seldomly known. Schmidt-Kaler says "The intrinsic (cosmic) dispersion (of the absolute magnitude) varies generally around σ = 0.7 mag; on the main sequence it is about 0.3 mag". The availability of the Hipparcos parallaxes makes it possible to extend the trigonometric calibrations well into early type stars, leaving aside use of the less certain statistical methods and the cluster sequences.

The second point which can also be examined is the relation between luminosity classes and absolute magnitudes. The authors of the MK system have always emphasized that the luminosity class is a description of the spectrum (for instance Morgan, 1984). Calibration is thus an independent step. At some intermediate step (never stated clearly), the assumption is then made that a strict relation exists between luminosity class and absolute magnitude. In practice this translates into the fact that the luminosity class is treated as if it were a coded absolute magnitude. To our knowledge, an examination of the relation between luminosity class and absolute magnitude has never been made for early type stars, probably because of the lack of a sufficient number of stars with both known luminosity classes and absolute magnitudes.

In what follows we shall consider the two questions successively, first the calibration and second the relation between luminosity class and absolute magnitude. In the last years another problem has appeared, which tends to complicate the problem. Several authors -for instance Slettebak (1975) and Gray & Garrison (1987)- have emphasized that when stars with higher dispersion than the original one of the MK system (125 Å/mm) are used, care must be taken to set up separate standards for high and low velocity rotating stars. We shall also consider what can be said concerning this point.

2. Material

We have used the list of MK standards collected by García (1989) and have sorted out all the stars of that list observed by Hipparcos. The selection by García was based upon specific recommendation of W.W. Morgan. Since we are interested only in early type stars we have stopped at F5. Of the resulting stars we have selected those belonging to the Hipparcos survey (Turon et al., 1992) and from these -203 stars- we have retained

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* Based on data from the ESA Hipparcos astrometry satellite

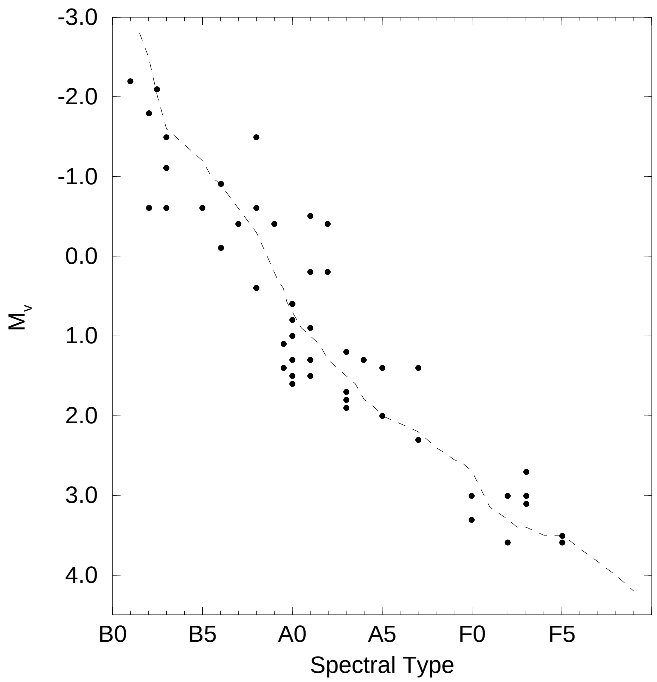

Fig. 1. The main sequence standards. Abscissa: spectral type. Ordinate: absolute magnitude M_v. The dashed curve represents Schmidt-Kaler's main sequence.

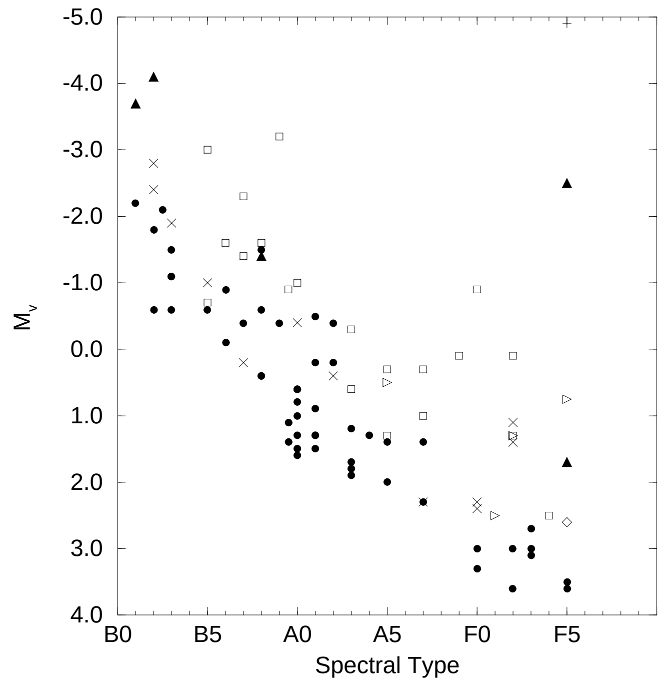

Fig. 2. All MK standards. Filled circle, class V; cross, class IV; empty diamond, class IV-V; empty square, class III; empty triangle right, class III-IV; filled triangle up, classes II and II-III; +, class I. Abscissa: spectral type. Ordinate: absolute magnitude M_v.

only those with absolute magnitude errors ≤ 0.3 mag, which leaves us with 96 standards for the interval B0-F5. What is apparent from the latter condition is that high luminosity stars will be underrepresented. The stars were then scrutinized for companions and for interstellar extinction. The correction for binarity is no problem in the case of visual binaries. In the case of double lined spectroscopic binaries, the correction can be derived through the mass ratio and the mass luminosity relation. For spectroscopic single lined binaries we have used a uniform correction of 0.2 mag, which corresponds to a magnitude difference between components of 1.7 mag. This correction has also been applied when The Bright Star Catalogue (Hoffleit & Jaschek, 1982) states "SB" but no orbit exists. It is clear that more undetected binaries exist and that the average correction of 0.2 mag is a rough approximation. This introduces an unavoidable uncertainty in the absolute magnitudes of the order of one or two tenths, the stars being brighter than they should be in reality. As for interstellar extinction we have used the common procedure to take the colour excess in (B-V) for the estimation of the extinction. Fortunately, most of the stars have small colour excesses. Since the spectral type-(B-V) relation has an intrinsic width by itself, we have corrected the extinction only when the colour excess is larger than 0.03 mag. The cases in which corrections for binarity and color excess have been applied are marked in Table 1.

3. Results

The results are given in Table 1 and are summarized in Figs. 1 and 2. Fig. 1 provides a graphical representation for the main sequence, whereas in Fig. 2 are plotted all the objects of classes V to I. An examination of Fig. 1 shows that the main sequence is not a line, but rather a wide band, whose width can be calculated from those spectral types where we have at least three dwarf standards of the same spectral type (B2, B3, B8, A0, A1, A3, F3). The respective widths are 1.2, 0.9, 1.9, 0.8, 1.9, 0.6 and 0.4 with an average of 1.1 magnitudes. In the figure we have plotted the Schmidt-Kaler main sequence. It can be seen that the mean calibration curve runs through widely scattered points, so that the assumption of a dispersion of 0.3 mag is an overoptimistic estimate. The scatter is especially large around A0. An examination of Fig. 2 shows that in general giants lie above dwarfs, as it should be. There is however no gap between class V and class III in the domain of B-type stars, but rather a continuum. From A2 on, the separation between classes III and V becomes clearer. To examine in more detail the situation, we have plotted in Fig. 3 the different absolute magnitudes for a given spectral type, specifying for each point its luminosity class. It can be seen that in general a sequence exists, although at some points the natural order is not kept. For instance at B5 the order is reversed (giant less luminous than the subgiant), at B7 the class IV falls below the V, in B8 the class II below the III. At A2, A7 and F2 we have abnormally positioned class IV objects. At F2 we have four points of class IV, IV-III and III,

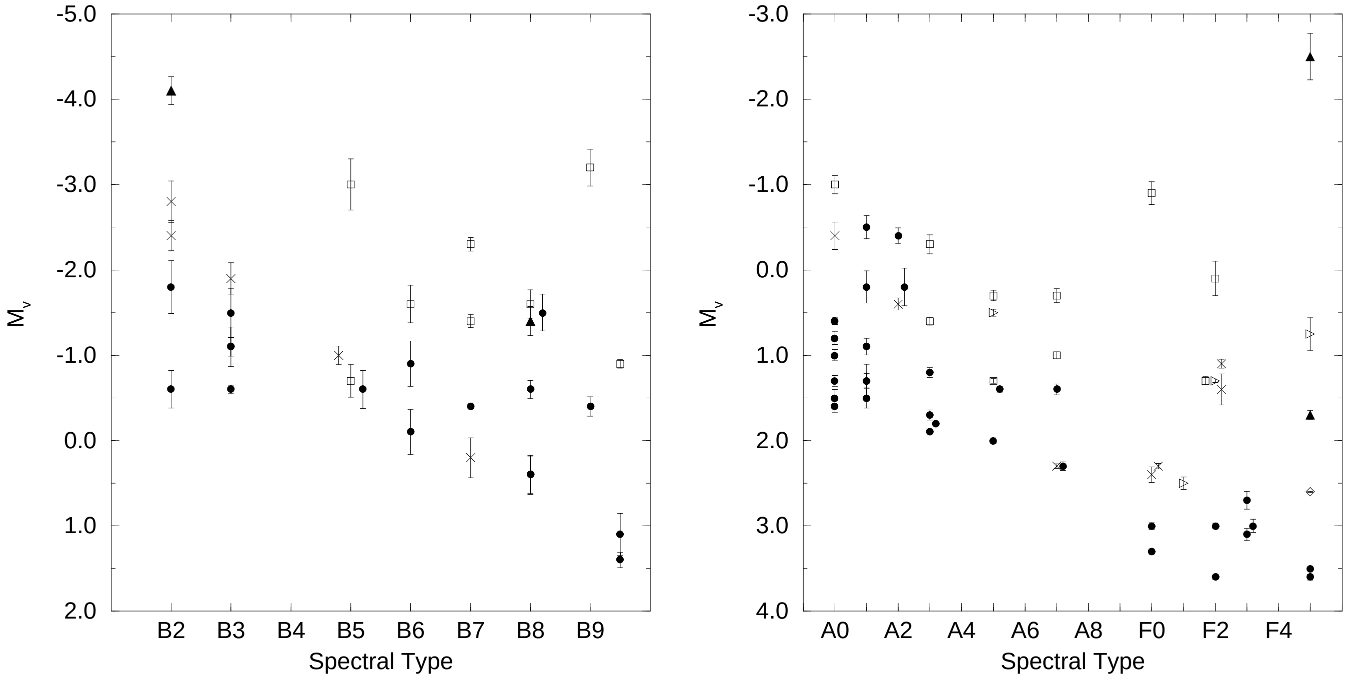

Fig. 3. Luminosity class and absolute magnitude. Relation between luminosity class and absolute magnitude M_v at a given spectral type. The symbols for luminosity class are: filled circle, class V; cross, class IV; empty diamond, class IV-V; empty square, class III; empty triangle right, class III-IV; filled triangle up, class II. The length of the vertical line at each point denotes the error of M_v.

which coincide within 0.3 mag. At F5 we also have an inversion of luminosity classes. It is clear that a (large) number of problems are related to class IV stars, so that the old saying that luminosity class IV is really well defined only for late-type stars regains its actuality. What will be needed is a careful cleaning up of the MK standards in this region. It is excellent that many standards were defined for the same type, so that it suffices to leave out some of them without having to redefine the whole system. We have looked into the question if the conflicting points come from a particular list of standards or can be attributed to high or low rotational velocities (vsini). The disagreeing objects are listed in Table 2, together with comments on their position in the HR diagram and with the name of the list of standards they came from and the rotational velocity. It can be seen that there exist stars with problems in all the three lists of standards (see Table 2), although C standards predominate. As far as rotation is concerned, nothing clear comes out either.

The number of stars listed in Table 2 seems large, but there are only 11 disagreeing stars in a list of about 100. Similar inconsistencies were found when we examined the infrared region -there we found among 110 standards observed, 13 stars which presented some discrepancies between the blue and the infrared (Jaschek & Andrillat, 1997). All this shows that the list of MK standards needs some cleaning, by rejecting standards which behave either abnormally in the infrared or in which the luminosity class disagrees with the absolute magnitude.

4. The recent system of the Garrison-Gray standards

In recent years Gray & Garrison (1987, 1989a, 1989b) and Garrison & Gray (1994) have proposed a calibration of B8-F2 stars with standards for both low and high rotational velocity. As remarked before this is a consequence of the use of higher dispersion than the one used originally in the MK system.

We have analysed their system, as we did with the original MK system, using only those stars for which the errors in absolute magnitudes were ≤ 0.3 mag. The additional stars are included as an appendix to Table 1. The procedure for corrections for binarity and for interstellar extinction were the same as for the previous sample.

Fig. 4 provides a plot of the standards recommended by the above mentioned authors, with different symbols for low and high rotational velocity standards. An inspection of the figure shows that we find again, as for the MK standards, a wide sequence. We find also no clear separation of giants and dwarfs before A2 and we find also a mixture and inversion of luminosity classes with absolute magnitude. In Fig. 5 we have plotted the absolute magnitudes for different spectral types, marking in each case the luminosity class. We find also now that in general giants lie above dwarfs, as it should be, but there are places where this relation is inverted. The B II standard has the same absolute magnitude as a B9 V and B9 III standard; at B9, among low rotation standards, classes V and IV are inverted. At A2 a class III high rotation standard lies between two class IV standards and at class A7 the standards IV and V practically coincide. One can also try to ascertain if low rotational velocity standards have lower or higher luminosity than high rotational

Table 1. Absolute magnitudes of the MK standards

Part a) MK standards used

HD	Sp. Type	π	e(π)	M_v	Notes
144470	B 1 V	7.70	0.86	-2.2	E
44743	B 1 II-III	6.53	0.66	-3.7	D
147934	B 2 V	8.27	1.18	-1.8	D,E
148605	B 2 V	8.30	0.84	-0.6	
886	B 2 IV	9.79	0.80	-2.4	D
3360	B 2 IV	5.46	0.61	-2.8	E
52089	B 2 II	7.57	0.57	-4.1	
175191	B 2.5 V	14.54	0.87	-2.1	
20365	B 3 V	6.18	0.66	-1.1	D, E
32630	B 3 V	14.87	0.74	-1.1	E
74280	B 3 V	6.99	0.92	-1.5	
120315	B 3 V	32.39	0.74	-0.6	
160762	B 3 IV	6.58	0.56	-1.9	D
219688	B 5 V	10.13	1.03	-0.6	
147394	B 5 IV	10.37	0.52	-1.0	
22928	B 5 III	6.18	0.85	-3.0	D, E
184930	B 5 III	10.61	0.93	-0.7	D, E
23338	B 6 V	8.75	1.07	-0.9	D, E
90994	B 6 V	9.46	1.15	-0.1	
23302	B 6 III	8.80	0.89	-1.6	E
87901	B 7 V	42.09	0.80	-0.4	D, E
23288	B 7 IV	9.75	1.05	0.2	E
23630	B 7 III	8.87	0.32	-2.3	D, E
35497	B 7 III	24.89	0.87	-1.4	
23324	B 8 V	8.87	0.89	0.4	D, E
23432	B 8 V	8.43	0.89	0.4	D, E
214923	B 8 V	15.64	0.75	-0.6	
222173	B 8 V	6.49	0.65	-1.5	D
23850	B 8 III	8.57	0.66	-1.6	D, E
53244	B 8 II	8.11	0.63	-1.4	
196867	B 9 V	13.55	0.70	-0.4	D
176437	B 9 III	5.14	0.51	-3.2	
23873	B 9.5 V	8.02	0.91	1.1	
222661	B 9.5 V	21.16	0.87	1.4	D
186882	B 9.5 III	19.07	0.44	-0.9	D, E
31647	A 0 V	20.50	0.94	1.5	D
71155	A 0 V	26.09	0.78	1.0	
103287	A 0 V	38.99	0.66	0.6	D
130109	A 0 V	25.35	0.86	0.8	
139006	A 0 V	43.65	0.78	0.6	D
146624	A 0 V	23.23	0.79	1.6	
161868	A 0 V	34.42	1.00	1.3	E
172167	A 0 V	128.93	0.52	0.6	
47105	A 0 IV	31.12	2.33	-0.4	D
123299	A 0 III	10.56	0.52	-1.0	D
18331	A 1 V	17.28	0.93	1.5	D
21447	A 1 V	17.07	0.68	1.3	
140159	A 1 V	16.97	0.76	0.9	D
140775	A 1 V	8.49	0.73	0.2	
193702	A 1 V	9.18	0.83	1.3	D, E
198001	A 1 V	14.21	0.89	-0.5	
1280	A 2 V	12.88	1.30	0.2	
97633	A 2 V	18.36	0.77	-0.4	
89021	A 2 IV	24.27	0.78	0.4	
56537	A 3 V	34.59	0.93	1.7	D
102647	A 3 V	90.16	0.90	1.9	

Table 1. (continued)

Part a) MK standards used

HD	Sp. Type	π	e(π)	M_v	Notes
170073	A 3 V	17.31	0.48	1.2	D
216956	A 3 V	130.08	0.91	1.8	
33111	A 3 III	36.71	0.77	0.6	
50019	A 3 III	16.59	0.85	-0.3	
97603	A 4 V	56.52	0.85	1.3	
11636	A 5 V	54.74	0.77	1.4	
116842	A 5 V	40.19	0.56	2.0	
8538	A 5 III-IV	32.81	0.62	0.5	D
13161	A 5 III	26.24	0.76	0.3	D
159561	A 5 III	69.84	0.91	1.3	
6961	A 7 V	23.73	0.69	1.4	D
87696	A 7 V	35.78	0.82	2.3	
76644	A 7 IV	68.32	0.82	2.3	
28319	A 7 III	21.89	0.83	0.3	D
127762	A 7 III	38.29	0.73	1.0	
147547	A 9 III	16.69	0.73	0.1	D
58946	F 0 V	54.06	0.97	3.0	D
110379-80	F 0 V	84.53	1.18	3.3	D
211336	F 0 IV	38.86	0.54	2.3	D
27397	F 0 IV	22.31	0.91	2.4	
89025	F 0 III	12.56	0.78	-0.9	D
17094	F 1 III-IV	38.71	1.31	2.5	D
113139	F 2 V	40.06	0.60	3.0	
128167	F 2 V	64.66	0.71	3.6	
40535	F 2 IV	10.32	0.86	1.4	D
84999	F 2 IV	28.35	0.68	1.1	
432	F 2 III-IV	59.89	0.54	1.3	D
13174	F 2 III	10.19	0.95	0.1	
17584	F 2 III	25.54	0.56	1.3	
26015	F 3 V	21.27	1.02	2.7	D
26690	F 3 V	27.04	0.89	3.1	D
26911	F 3 V	22.51	0.81	3.0	E
21770	F 4 III	27.46	0.69	2.5	
134083	F 5 V	50.70	0.76	3.6	D
210027	F 5 V	85.06	0.68	3.5	
61421	F 5 IV-V	285.93	0.86	2.6	
55052	F 5 III-IV	9.34	0.82	0.75	
186155	F 5 II	20.51	0.49	1.7	
23230	F 5 II	5.86	0.74	-2.5	
20902	F 5 Ib	5.51	0.66	-4.9	E

Part b) Gray-Garrison standards

HD	Sp. Type	π	e(π)	M_v	Notes
76728	B8 II L	10.45	0.47	-1.1	
16046	B9 V L	7.19	0.78	-0.8	D
45380	B9 V H	7.97	1.12	0.8	D
38899	B9 IV L	12.99	0.81	0.5	D
107832	B9 III L	7.98	0.72	-0.2	
224686	B9 III H	8.71	0.57	-0.8	
210419	A0 IV H	9.00	0.82	1.05	
10939	A1 Va L	17.54	0.62	1.3	
45320	A1 Va H	14.26	0.89	1.6	
216735	A1 IV L	11.55	0.95	0.2	
73262	A1 IV H	18.21	0.88	0.7	D
135382	A1 III H	17.85	0.52	-0.9	
88955	A 2 Va L	31.72	0.55	1.5	D

Table 1. (continued)

Part b) Gray-Garrison standards

HD	Sp. Type	π	e(π)	M_v	Notes
56405	A 2 Va H	11.79	0.85	0.8	
97277	A 2 IV L	12.26	0.75	0.1	D
141003	A 2 IV H	21.31	0.86	0.3	
56169	A 2 III H	10.97	0.76	0.2	
135379	A 3 Vb L	33.75	0.75	1.7	
33111	A 3 IV H	36.71	0.76	0.6	
71297	A 7 V L	18.83	0.80	2.0	
70060	A 7 IV L	35.06	0.53	2.2	
8511	A 9 III H	14.83	0.77	2.1	
58923	F 0 IIIb L	9.28	0.95	0.1	
24740	F 2 IV L	22.31	0.92	2.4	

First column: HD number
Second column: spectral classification (L and H stand for low and high rotation, respectively)
Third column: parallax in mas
Fourth column: standard error on the parallax in mas
Fifth column: absolute visual magnitude in mag, rounded off to the nearest tenth of a magnitude
Sixth column: Notes (E stands for M_v corrected for interstellar extinction and D stands for M_v corrected for binarity)

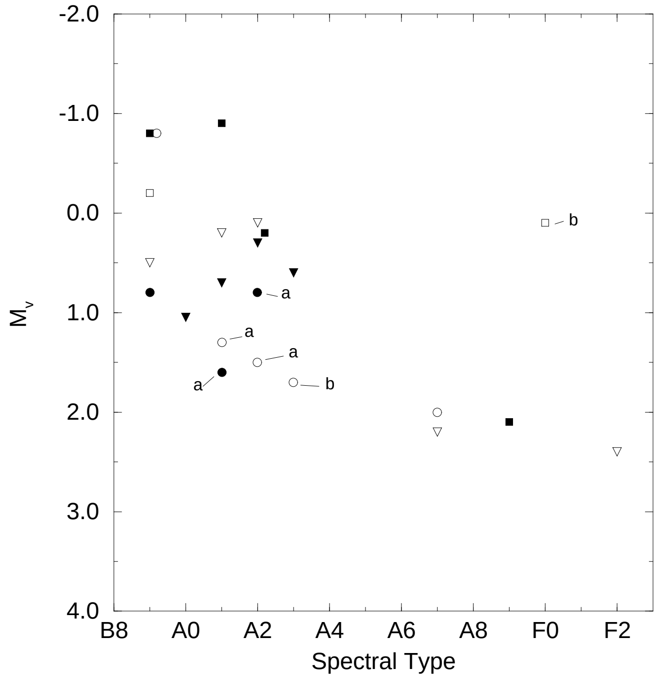

Fig. 4. All Gray-Garrison standards. Abscissa: spectral type. Ordinate: absolute magnitude M_v. Empty and full circles stand for class V, low and high vsini standards, empty and full triangles down for class IV low and high vsini standards and empty and full squares for class III low and high vsini standards.

Table 2. List of early type MK standards whose absolute magnitude disagrees with the luminosity class

HD	Sp. Type	Note	List	vsini
184930	B 5 III	too faint	C	95
23288	B 7 IV	too faint	C	246
53244	B 8 II	too faint	C	27
222173	B 8 V	too bright	C	84
89021	A 2 IV	too faint	J	48
159561	A 5 III	too faint	C	219
76644	A 7 IV	too faint	E	151
17094	F 1 III-IV	too faint	C	54
432	F2 III-IV	too faint	E,J	70
17584	F 2 III	too faint	C	149
23230	F 5 II	too faint	C	44

C: Johnson & Morgan (1953)
E: Morgan & Keenan (1973)
J: Morgan et al. (1978)
vsini is given in kmsec^{-1}

velocity standards and the answer is that there is no clear tendency - sometimes they go in one sense, sometimes in the other. We have also looked into the matter of a possible influence of rotation for standards earlier than B0 and we have found no evidence. One could notice in by-passing that although we have fewer disagreements than with the MK system (where we found 11 cases -see Table 2), this is partly due to the fact that we have only 24 new standards, because the authors retained a number of old standards for their new system. The conclusion is thus that the new list of standards has improved the description of the spectral features, but that this does not show up the same way in the luminosities.

As a last point one should be aware that our absolute magnitudes need a systematic correction. If one wishes to apply the so called Lutz-Kelker correction (Lutz & Kelker, 1973), for 90% of the stars the absolute magnitudes should be brightened by less than 0.11 mag and for the remaining 10% the correction ranges between -0.11 and -0.24 mag. A more realistic correction has been derived by means of a complex simulation; the obtained systematic correction was of about -0.08 mag. Full details on the simulation will be provided in a forthcoming paper by Jaschek & Valbousquet (1997). This correction has not been applied in Table 2, since we were interested only in relative positioning.

5. Discussion

The obvious conclusion from the foregoing examination of both the MK and the Garrison-Gray standards is that we have to reconsider one of the byproducts of the MK system - namely the link between luminosity class and absolute magnitude. The luminosity class itself is a summary of the description of certain spectral features. The luminosity - as expressed by the absolute magnitude - refers to the whole star and not just to its superficial layers where the spectrum is produced. As remarked above, the implicit assumption up to now has been that the luminosity class translates directly into the absolute magnitude, in a unique way. The preceding discussion shows that this is not so, because the order of luminosity classes is not always the same as the order in absolute magnitude. One is thus led either to conclude that

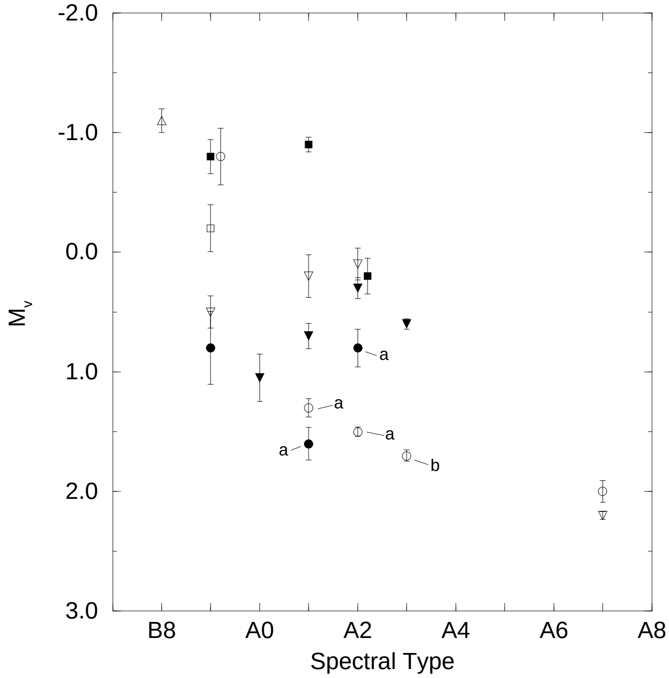

Fig. 5. Luminosity class and absolute magnitude. Relation between luminosity class and absolute magnitude M_v at a given spectral type. Empty and full symbols denote low and high vsini: circle, class V; triangle down, class IV; square, class III; triangle up, class II. The vertical lines denote the error in M_v.

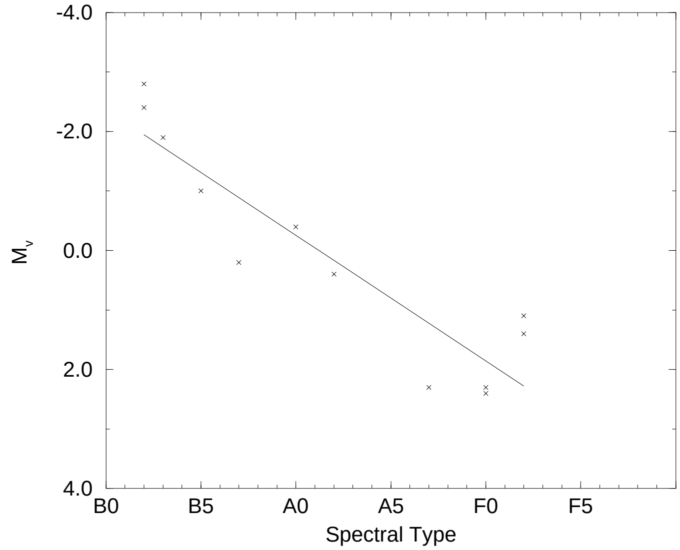

Fig. 6. Absolute magnitude as a function of spectral type for luminosity class IV MK standards. The straight line represents the average relation adopted.

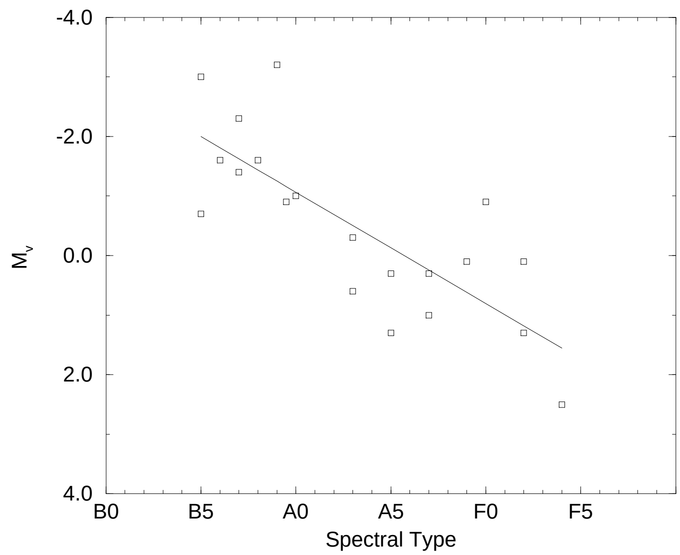

Fig. 7. Absolute magnitude as a function of spectral type for luminosity class III MK standards. The straight line represents the average relation adopted.

a) the relation is only a statistical one or that b) there exist one or more other parameters which influence the relation.

As remarked before, there exists an overall agreement of luminosity classes with absolute magnitude, in the sense that giants are on the average brighter than dwarfs, so it seems that the relation is a statistical one. With the accuracy of the individual Hipparcos parallaxes one can be sure that the scatter does not come from the absolute magnitudes.

To examine this possibility in more detail, we have plotted in Figs. 6 and 7 the spectral-type absolute magnitude relations for subgiants and giants respectively (for class V see Fig. 1). One can then draw average curves through the points or segments of straight lines, to establish the scatter around the mean relations. For dwarfs we have fitted two straight lines, one through the B-type stars and the other through the A and F-type stars. The dispersion of the points around these straight lines is of the order of 0.7 mag. For giants we have adopted one straight line. Leaving aside two very deviating points, the dispersion is again of 0.7 mag. Such large dispersions explain easily the occasional misplacement of giants below dwarfs, or of dwarfs above giants. For subgiants the dispersion is also of the order of 0.7 mag.

As remarked above the large dispersion is not due to the absolute magnitudes, because they have very small errors - the cause must lie with the luminosity classes. In principle this is understandable, because absolute magnitude and its correlated spectroscopic characteristics are continuous variables, whereas luminosity classes are discrete variables. On top of this, luminosity classes are estimated by eye, not measured. It is therefore hard to imagine that classifiers have chosen always as standards those stars which fall just in the middle of the range of the continuous variable which correlates strongly with absolute magnitude. This fact alone may be responsible for the scatter. Obviously it will be desirable that stars which deviate very much from the average should be eliminated, and this implies a critical revision of the list of standards.

If one accepts the opposite point of view, namely that the relation is strict, the cause of the deviations has to be sougth in other factors. One of the possible explanations - rotation - seems not the cause, as we have shown in the discussion of the

Gray-Garrison standards. A second possibility is (undetected) binarity. The fact that some standards are close binaries (spectroscopic or interferometric) can not be excluded, even it is not very plausible, because the standards belong to the group of the most observed stars. However the number of ”problem” stars seems too large to be explained this way.

6. Conclusions

We have analysed the absolute magnitude of about one hundrerd MK standards in the B0-F5 spectral region. We conclude that there is no strict relation between luminosity class and absolute magnitude, because in a number of cases inversions in absolute magnitude appear (for instance dwarfs brighter than giants). We also show that the new system of standards of Gray and Garrison shows the same effects.

We conclude that the relation between absolute magnitude and luminosity class is only a statistical one, which has a large intrinsic dispersion. It would seem advisable to eliminate some of the standards which cause problems.

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