Astron. Astrophys. 341, 784–788 (1999)

ASTRONOMY AND ASTROPHYSICS

A comparison of different spectral classification systems for early type stars using Hipparcos parallaxes*

Ernst Paunzen

Institut für Astronomie der Universität Wien, Türkenschanzstrasse 17, A-1180 Wien, Austria (e-mail: Ernst.Paunzen@univie.ac.at)

Received 17 September 1998 / Accepted 29 October 1998

Abstract. An "inventory" of different classification systems were made. Two different surveys for B9 to F2 type stars were chosen in oder to get an unbiased sample of "normal" stars. Jaschek & Valbousquet (1997) and Jaschek & Gómez (1998) already investigated the intrinsic consistency of the MK spectral classification systems. But interesting enough their results contradict in some important points.

With the help of Hipparcos parallaxes, a comparison of the luminosity classes V, IV and III was performed using absolute magnitudes in order to find significant deviations from the "classical" picture ($M_{\rm V}({\rm III})$ brighter than $M_{\rm V}({\rm V})$ for the same spectral type).

The main result is that luminosity class IV is completely covered by luminosity class V and III, furthermore only the brightest luminosity class III objects are distinct from luminosity class V stars. This conclusion is based on a large sample of stars from different classification surveys. Otherwise these surveys give comparable intrinsic errors.

Key words: techniques: spectroscopic – stars: distances – stars: early-type – stars: fundamental parameters – stars: statistics

1. Introduction

The tool of spectral classification was first used in the second half of the nineteenth century. Even a brief history of its development would fill many pages. A whole zoo of different systems have been developed from which only the Harvard and Yerkes systems survived. Latter is associated with the work of Morgan et al. (1943) who used a prismatic spectrograph covering the region from 3900 to 4900 Å with a resolution of 115 Å$\rm mm^{-1}$ at Hγ. During the years new developments (e.g. grating spectrographs, CCD technology) made it necessary to check and revise the original system (Keenan 1985). Additional information about thousands of stars became available with the "invention" of photometric systems. Nowadays it would be desirable to include all possible information (spectra with higher resolutions than used in the original system, photometric indices and the projected rotational velocity) in order to derive precise astrophysical quantities such as the spectral type (or effective temperature) and the luminosity class (or surface gravity).

With the parallaxes measured by the Hipparcos satellite and thus accurate absolute magnitudes it should be possible to independently check the intrinsic consistency ($M_{\rm V}({\rm III})$ brighter than $M_{\rm V}({\rm V})$ for the same spectral type) of the MK classification system. Jaschek & Gómez (1998) analyzed early type (B1 - F5) MK standards and their absolute magnitude calibration. Their conclusions are very surprising:

- The intrinsic dispersion of the mean absolute magnitudes is about 0.7 mag
- There seems no clear separation between luminosity class V and III

Jaschek & Gómez (1998) therefore proposed to revise the MK standards in order to eliminate the most deviant cases and to secure the overall validity of the system.

Since the author of this article is involved in a spectroscopic survey for λ Bootis type stars (chemically peculiar A to F-type stars; Paunzen & Gray 1997) an "inventory" of the relevant spectral region (B9 to F2) was made. Fortunately, two recent independent classification surveys for these spectral types were performed (Abt & Morrell 1995; AM95 hereafter and Gray & Garrison 1987, 1989a,b; GG hereafter). Especially interesting is the fact that AM95 used the classical MK system, whereas GG refined it and introduced "high $v \sin i$ standards" as well as the additional use of Strömgren colours in the classification process.

Jaschek & Valbousquet (1997) already analyzed the precision of the luminosity classification for different spectroscopic surveys (beside AM95 and GG they also included Cowley et al. 1969). They concluded that the precision of the luminosity classes is ± 0.7 provided by all three references. This error estimation converts (based on standard relations) into $\sigma(M_{\rm V}) = \pm 0.4$ mag for A-type stars. These findings seem to contradict the results of Jaschek & Gómez (1998).

A comparison of the different classification systems was therefore made using Hipparcos data resulting in a complete new picture of the MK system.

Send offprint requests to: Ernst Paunzen

* Based on data obtained from the ESA Hipparcos astrometry satellite

Table 1. Classical classification criteria for different spectral resolutions of 125 $Å mm^{-1}$ (Morgan et al. 1977); 75 $Å mm^{-1}$ (Yamashita et al. 1978) and 40 $Å mm^{-1}$ (Landi et al. 1977)

	125 $Å mm^{-1}$
	Spectral Type
B9.5-F1:	Mn I 4030-34; Ca I 4226; Fe I 4271; Fe I,Ti II 4300
	Luminosity Class
A0:	hydrogen line profiles
A2:	$\frac{FeI,II4383-5}{MgII4481}$ stronger at high luminosity
A5:	$\frac{FeII,TiII4417}{MgII4481}$ stronger at high luminosity
	75 $Å mm^{-1}$
	Spectral Type
B9-A7:	Fe II 4233 has a maximum at A2
A3-F0:	$\frac{CaI4226}{MgII4481}$, $\frac{FeI4045}{FeII4173}$
	Luminosity Class
A0-A5:	$\frac{FeII,TiII4417}{MgII4481}$ stronger at high luminosity
A7-F0:	$\frac{SrII4215}{CaI4226}$ stronger at high luminosity
	40 $Å mm^{-1}$
	Spectral Type
B9-A7:	$\frac{MgII4481}{FeI4385}$, Ca I 4226=Fe II 4233 at A3
A5-A7:	$\frac{MgII4481}{FeII4416}$
A7-F1:	$\frac{CaI4226}{H\gamma4340}$
	Luminosity Class
B9-A3:	Fe II 4173-8, 4233 stronger at high luminosity
A3:	$\frac{FeII4416}{MgII4481}$ stronger at high luminosity
A5-A7:	$\frac{FeII4351}{MgII4481}$ stronger at high luminosity
A7-F1:	$\frac{SrII4215}{CaI4226}$ stronger at high luminosity

2. Used samples

Three independent lists of standards and classified B9 to F2 stars were used:

- Following Jaschek & Gómez (1998) the list of MK standards from Garcia (1989) was taken
- The stars classified by GG at a resolution of 120 $Å mm^{-1}$ and 67 $Å mm^{-1}$
- The extensive sample of A-type stars from AM95 classified at resolution of 39 $Å mm^{-1}$

GG tried to refine the MK classification system for late B to early F-types stars four decades after its introduction. They included the Strömgren $uvby\beta$ system and the information on the projected rotational velocity in order to provide new "high $v \sin i$ standards". It was shown that the line ratio $\frac{FeII,TiII4417}{MgII4481}$ is not very sensitive for stars later than A3. Based on spectra with resolutions of 120 $Å mm^{-1}$ and 67 $Å mm^{-1}$ they proposed to use the line ratio $\frac{FeII,TiII4172-9}{FeI4203}$ instead.

AM95 used photometric spectra with a resolution of 39 $Å mm^{-1}$ (for the estimation of $v \sin i$ values, CCD spectra with a resolution of 10 $Å mm^{-1}$ were taken) in order to apply the classical MK classification system as described by Morgan et al. (1978). Unfortunately, AM95 do not specify the spectral range of their spectra.

The obtained spectra were compared with MK standards using a binocular spectracomparator. The way of the classification seems problematic since Morgan et al. (1978) used a resolution of 125 $Å mm^{-1}$, but the lines used for higher resolutions (Table 1) differ significantly from those for 125 $Å mm^{-1}$. No details can be found in AM95 which spectral features have been used to classify their spectra. However it is surprising how many new peculiar stars not included in any other reference were discovered. Especially there seems an inflation of "4481-weak" stars which are often confused with members of the λ Bootis groups (Paunzen & Gray 1997). Since this strong blend of Mg II is sensitive to the effective temperature *and* luminosity (Table 1) even an estimation of the equivalent width (as done by AM95) does not prove an intrinsic peculiarity of this blend.

It has to be emphasized that there is an additional uncertainty introduced using "non-standard" stars because these objects might be incorrectly classified using "wrong" MK standards. But this does not affect the results because of two reasons:

- GG have used new and better (in their point of view) MK standards which should result in a better intrinsic consistency
- The intrinsic dispersion for all luminosity classes is about 0.7 mag (Jaschek & Gómez 1998) and should therefore affect all luminosity classifications uniformly

The Hipparcos catalog (Perryman 1997) was searched for entries of all included stars. As a next step the following stars were *not* considered in order to get an unbiased and homogeneous sample of "normal" stars:

- Spectroscopic and close visual binaries
- Peculiar stars (also including 4481-weak stars)
- Stars with $\frac{\sigma(\pi)}{\pi} > 0.18 \Longleftrightarrow \sigma(M_{\rm V}) > 0.3\,{\rm mag}$
- Stars without $uvby\beta$ measurements
- Stars with an ambiguous luminosity classification (e.g. A0 IV-V)

An estimate for the reddening of the individual stars was calculated using Strömgren indices (Hauck & Mermilliod 1998) and the "standard" calibration given by Crawford (1979). Since the

Table 2. Number of stars for the three samples

	V	IV	III
Sample 1	101	52	15
Sample 2	177	112	45
Sample 3	73	19	4

sample contains mainly bright stars it is not surprising that the reddening can be neglected for almost all objects. The Hipparcos parallaxes were directly converted into absolute magnitudes taking the reddening into account. A correction for the Lutz-Kelker effect (which is not very large because $\frac{\sigma(\pi)}{\pi} < 0.18$ was chosen as selection criterion) was applied following Koen (1992).

For the further analysis three samples were generated (the number of stars included in each sample is listed in Table 2):

- Sample 1: stars taken only from AM95
- Sample 2: stars taken only from GG
- Sample 3: stars from AM95 and GG with the luminosity classification in agreement

These three samples (the tables of all samples are only available at Simbad, CDS and/or from the author upon request) were statistically tested taking the Hipparcos absolute magnitudes and apparent spectral classifications.

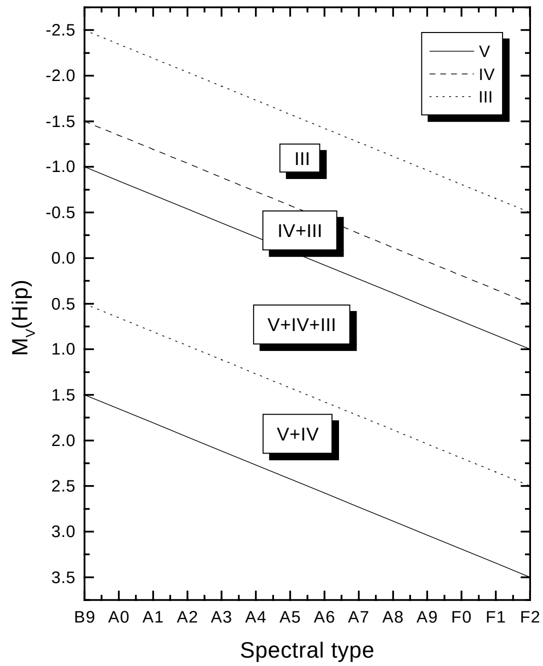

Fig. 1. The different bandwidths according to Table 3 for the three luminosity classes, the lower limit of the luminosity class IV is the same as for class V

3. Analysis and conclusions

A comparison of the derived spectral classifications and absolute magnitudes from Hipparcos parallaxes should answer the following questions:

- Are the different classification surveys intrinsically consistent for the luminosity types?
- Is the MK classification system supported by Hipparcos data?
- What is the natural bandwidth of the main sequence and is it compatible with theoretical ones?

All three samples *give the same* results. This means that the classical MK system and the refined one by GG result in a comparable intrinsic error. The inclusion of the projected rotational velocity and colour indices does, therefore, *not* improve the accuracy.

Fig. 1 summarizes the found $M_{\rm V}$-ranges for the luminosity classes V, IV and III. For clarity only the lower and upper limits are shown. The intrinsic dispersion is *constant* throughout the investigated spectral range and is not affected by known uncertainties such as at the spectral type A0 (see Gerbaldi et al. 1998 for a discussion). Table 3 lists the borders for different spectral types and compares them with the values from Schmidt-Kaler (1982). The apparent bandwidth of luminosity class V is about 2.5 mag for the whole relevant spectral range. There is *no* separation between luminosity class V and IV, there is even a wide band (1.5 mag) where all three luminosity classes are found. The bandwidth of the luminosity class III is especially broad (3 mag).

These results are *not* biased by the selected spectral types since the number of stars for each luminosity class is almost constant throughout the whole investigated spectral region. Furthermore no influence of the projected rotational velocity on the $M_{\rm V}$ values was detected. This means that for example the $\bar{M}_{\rm V}(Hip)$ of high-$v\sin i$ A0 V stars is not statistically significant different from those of low-$v\sin i$ A0 V stars.

Still, the question about the frequency of apparent undetected binary systems remains open. In the process of the sample evaluation about 30 percent of all a priori selected candidates turned out to be visual or spectroscopic binary systems (see Sect. 2). The "standard" rate of binarity among normal B0 to M-type stars is almost 50 percent (Jaschek & Gómez 1970; Aikman 1976). This would imply that 20 percent (or approximately 100 stars) of the chosen sample are still undetected binary systems introducing incorrect absolute magnitudes. But one has to keep in mind that AM95 and GG have mainly used the Bright Star Catalogue and its Supplement (Hoffleit & Jaschek 1982) as primary source for their target selection. These (bright) stars have often been investigated and binarity should have been detected before. Another valuable database for new binary systems is the Hipparcos data compilation. Due to incorrect space motion solutions, binary systems could be detected (Lindegren 1997). But only 15 percent of all Hipparcos catalogue entries had to be treated as non-single objects. Taking into account that only certain spectroscopic binary systems (e.g. short enough orbital period) were suitable for detection (Lindegren 1997), the number of new A-type binary systems cannot be very numerous hence not affecting significantly the results of this work.

Table 3. Derived upper and lower M_V-boundaries as shown in Fig. 1 for the different luminosity classes; the last two columns are the "standard" values from Schmidt-Kaler (1982)

	V		IV		III		V	III
	lower	upper	lower	upper	lower	upper		
B9	+1.50	−1.00	+1.50	−1.50	+0.50	−2.50	+0.20	−0.60
A0	+1.65	−0.85	+1.65	−1.35	+0.65	−2.35	+0.60	0.00
A1	+1.81	−0.69	+1.81	−1.19	+0.81	−2.19	+1.00	+0.20
A2	+1.96	−0.54	+1.96	−1.04	+0.96	−2.04	+1.30	+0.30
A3	+2.12	−0.38	+2.12	−0.88	+1.12	−1.88	+1.50	+0.50
A4	+2.27	−0.23	+2.27	−0.73	+1.27	−1.73		
A5	+2.42	−0.08	+2.42	−0.58	+1.42	−1.58	+1.90	+0.70
A6	+2.58	+0.08	+2.58	−0.42	+1.58	−1.42		
A7	+2.73	+0.23	+2.73	−0.27	+1.73	−1.27	+2.20	+1.10
A8	+2.88	+0.38	+2.88	−0.12	+1.88	−1.12	+2.40	+1.20
A9	+3.04	+0.54	+3.04	+0.04	+2.04	−0.96		
F0	+3.19	+0.69	+3.19	+0.19	+2.19	−0.81	+2.70	+1.50
F1	+3.35	+0.85	+3.35	+0.35	+2.35	−0.65		
F2	+3.50	+1.00	+3.50	+0.50	+2.50	−0.50	+3.60	+1.70

It is interesting to compare the derived results for the bandwidth of the main sequence with previous one from the literature. Reliable absolute magnitude determinations in the Pre-Hipparcos era were only possible for star clusters (problems: differential reddening, membership of stars and the distance) and via ground based parallaxes (problems: error estimation and limited sample). The bandwidths for a sample of star clusters were estimated as about 2 mag (Jaschek & Mermilliod 1984) whereas the other method resulted in a significant less broader one.

Recent model calculations (Claret 1995) predict a bandwidth for the main sequence (defined as the region from the zero age main sequence to the terminal age main sequence) of about 1.2 mag (taking a solar chemical composition). If one takes the original concept of luminosity class V stars being hydrogen burning, main sequence objects, the result of this investigation clearly *does not fit* into this picture. Expanding the possible chemical composition of nearby stars to $[Z] = \pm 0.5 [Z]_{\odot}$ (optimistic values which are not confirmed by observations) does not solve the problem because the bandwidth of the main sequence is only broaded by 0.1 mag (A. Claret, private communication). Other "free parameters" such as overshooting and the conservation of angular momentum can only account for additional 0.1 mag. A first conclusion can therefore be drawn:

– Compared with the most optimistic theoretical models ($[Z] = \pm 0.5 [Z]_{\odot}$, different overshooting values and taking the rotation into account), the observed main sequence for B9 to F2-type stars is 1.1 mag to broad

The controversial status of the luminosity class IV in the relevant spectral region was described before (Keenan 1985). This most unsatisfying status is independently supported by the Hipparcos data:

– No distinction between luminosity class IV and V as well as III can be found

But most surprising:

– Only the brightest luminosity class III objects are clearly separated from luminosity class V ones

This is in line with the result of Jaschek & Gómez (1998) but is based on a much larger sample of stars from independent surveys.

If one assumes that the absolute Hipparcos parallaxes do no show any significant error, these findings have an major impact on the classification systems. Since no other calibrations than the dereddening procedure and the Lutz-Kelker correction (minor effects for almost all stars) have been applied, this means that the selected classification criteria (mainly blends of different metallic lines) for the luminosity classes are *not* able to distinguish between main sequence (V) and evolved giant (III) stars. This naturally implies that the luminosity class IV should be rejected.

To overcome this situation the material of AM95 and/or GG should be reclassified starting with absolute magnitudes from Hipparcos parallaxes and using new/refined luminosity indicators. The final results should then be checked with theoretical models in order to improve the MK classification system.

Acknowledgements. This project was partly supported by the Fonds zur Förderung der wissenschaftlichen Forschung (project *S7303-AST*, Asteroseismology-AMS). The author is indebted to Dr. Claret and Dr. Jaschek for helpful comments. Use was made of the Simbad database, operated at CDS, Strasbourg, France.

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