THE LUMINOSITY CALIBRATION OF THE HR DIAGRAM REVISITED BY HIPPARCOS

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ABSTRACT

The HR diagram luminosity calibration basically relies on trigonometric parallaxes and kinematical data (proper motions and radial velocities). Hipparcos data allow to re-calibrate the absolute magnitude for groups of stars selected in the HR diagram according to spectroscopic criteria.

A new Maximum Likelihood luminosity calibration algorithm (the LM method) developed by Luri et al. (1996) has been applied to the Hipparcos survey stars. This algorithm uses all the available parallax and kinematical data and takes into account the sample biases and the observational errors. We have estimated the accuracy of the calibrations based on the MK classification and found that the relation between absolute magnitude and luminosity class has a large intrinsic dispersion. Given a sample, the LM method not only provides a luminosity calibration relationship but also an unbiased estimation of the individual absolute magnitude and distance for each star.

Key words: survey stars; luminosity calibration; MK classification.

1. INTRODUCTION

It is well known that up to now about 90 per cent of the stellar distances were obtained using absolute magnitudes estimated from spectroscopic criteria (spectral type and luminosity class). The methods used to calibrate the absolute magnitude made use of trigonometric parallaxes, kinematical data (proper motions and radial velocities) or cluster sequences. The most comprehensive luminosity calibration for groups of stars spectroscopically selected is the compilation of Schmidt-Kaler (1982). However, the quoted absolute magnitudes are inhomogeneous, the involved uncertainties are seldomly known and, very often, it is impossible to know how the sample biases were taken into account. The availability of Hipparcos parallaxes and proper motions for a large number of stars covering most of the parts of the HR diagram allows a reconsideration of the luminosity calibration problem on a new bases.

A short summary of the method used to obtain an unbiased estimate of the absolute magnitude and its dispersion (even for incomplete samples) is presented. The method has been applied to the Hipparcos survey stars. The precision of luminosity calibrations based on the MK spectral classification is evaluated and our results are compared with previous ones. The method used allows individual absolute magnitudes to be obtained. Moreover, for stars with low-accuracy parallax data, our method gives a better estimation of the individual absolute magnitude than the classical method which uses only the trigonometrical parallax.

2. METHOD

The most fundamental method to calculate the absolute magnitude is the use of the trigonometric parallax. Among the 120 000 stars measured by Hipparcos, the stars out of a sphere of about 150 pc around the sun have a relative error on the parallax > 20 per cent, corresponding to an error in the absolute magnitude greater than 0.4 mag. On the contrary, high accuracy proper motions are available for all the observed stars. In order to make full use of the Hipparcos data a method has been developed by Luri et al. (1996) (called the LM method in the following) allowing the use of trigonometric parallaxes as well as kinematical data (proper motions and all the available radial velocities). Given a selected sample and a model for the luminosity, kinematics and spatial distribution, the method (based on the Maximum Likelihood estimation) takes into account the sample selection and the observational errors on the input observed values. It makes use of all the available trigonometric parallaxes, including low-accuracy and negative ones. Finally, it allows separation of the groups in the sample with different absolute magnitudes, velocity or spatial density distributions. For details see Luri (1995), Luri & Arenou (1997), Luri et al. (1997). On the one hand, we are interested in the unbiased estimate of the absolute magnitude and its dispersion for different samples selected by spectral type and luminosity class. On the other hand, we also calibrate for G-K stars a linear relationship: visual absolute magnitude M_v versus de-reddened colour index $(B-V)_0$ whatever the luminosity class of the stars is.

The application of the LM method to a given sample not only provides a luminosity calibration relationship but also an individual absolute magnitude and distance estimate for each star. In the case of stars with accurate parallax data ($\frac{\sigma_\pi}{\pi} < 20$ per cent), the estimated absolute magnitude is very close to the one calculated directly from the observed trigonometric parallax. For stars with less accurate parallaxes, the method allows the improvement of the estimation of the absolute magnitude: on the one hand the estimate is not biased and on the other hand it has a smaller variance because the method makes use of all the available information for each star (see Brown et al. 1997, for a detailed discussion on this subject).

3. THE SAMPLE

In this work, the Hipparcos survey stars are used. The survey constitutes a basic list of about 50 000 stars complete up to a limiting visual apparent magnitude (V), function of the spectral type and of the galactic latitude (Turon et al. 1992a). For instance, in the survey all the stars brighter than $V = 7.9$ mag with spectral types $\leq$G5 and brighter than $V = 7.3$ mag with spectral types later than G5 were included. About 30 per cent of the stars have a parallax relative error $\frac{\sigma_\pi}{\pi} \leq 0.1$ and for 91 per cent $\frac{\sigma_\pi}{\pi} \leq 0.5$.

Among the survey stars, about 22 per cent belong to double or multiple systems and 7.5 per cent are variables. The stars known as binaries, the variables with a variability range in Hp magnitude $> 0.06^m$ and the stars with peculiarities in the spectral type were eliminated from the original sample. First, in order to evaluate the precision of the luminosity calibration based on the MK spectral classification, only stars with known luminosity class were kept. The resulting sample contains 22 054 stars and its distribution in spectral type and luminosity class is given in Table 1. Then, the LM method was applied to all the survey non-binary and non-variable G-K stars whatever the luminosity class was. The resulting sample contains 16 880 stars, instead of only 6832 with known luminosity class.

Table 1. Number of stars by spectral type and luminosity class.

	I	II	III	IV	V	Total
B	177	225	802	590	1412	3206
A	54	48	541	918	2305	3866
F	57	104	451	1030	3708	5350
G	73	117	1375	548	1449	3562
K	36	122	5457	299	138	6070
Total	397	616	8626	3385	9012	22054

Astrometric and photometric data have been taken from the Hipparcos Catalogue (ESA 1997). Radial velocity data come from the following sources: Hipparcos Input Catalogue (Turon et al. 1992b), Duflot et al. (1995) and Barbier-Brossat (1997). MK spectral classification has been taken from the Hipparcos Input Catalogue (locally cited).

4. RESULTS

4.1. Survey Stars With MK Classification

The results of the application of the LM method to the samples given in Table 1 are displayed in Figure 4 and 5 which represent the HR diagrams (M_v versus colour index $(B-V)_0$) for the different luminosity classes. The isochrones of Schaller et al. (1992) for solar metallicity are indicated. The algorithm identified and separated in each sample groups of stars differing in luminosity and/or in kinematical or spatial properties. The groups called 'main' are those containing the largest number of stars. The continuous solid lines represent the resulting mean absolute magnitude calibrations for the main groups. The plotted absolute magnitude for each star of a group corresponds to the unbiased estimate obtained.

Notice that the main sequence (luminosity class V stars) is a wide band, its width reaching up to 2 mag. This result contrasts with the value of 0.3 mag given by Schmidt-Kaler for the main sequence. Moreover, some stars are out of the main sequence; this is well seen in the case of late type stars. For early type stars (B to F), there is no clear separation on the HR diagrams between luminosity classes V, IV and III. The luminosity classes I, II and III stars spread over a large range in absolute magnitudes which implies that a mean absolute magnitude for these groups does not provide valuable information. In Figures 1 and 2 the intrinsic dispersion in absolute magnitude is given, respectively for classes III and V.

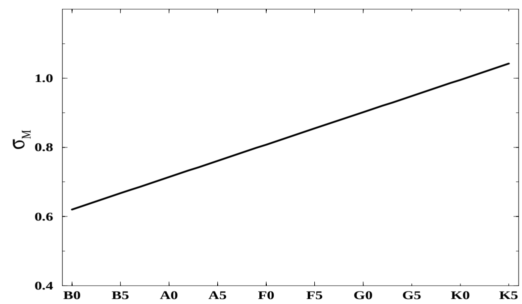

Figure 1. Absolute magnitude dispersion for Class III main groups.

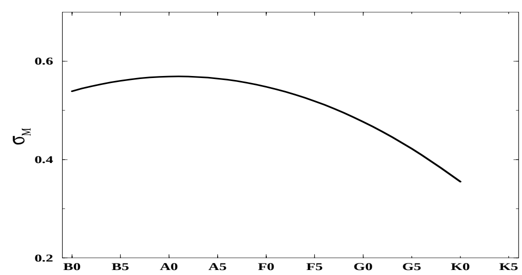

Figure 2. Absolute magnitude dispersion for Class V main groups.

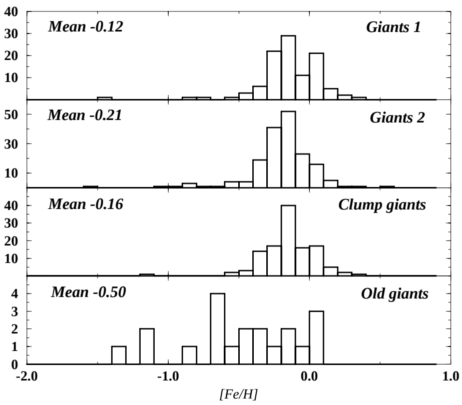

Figure 3. Histograms of metallicities for G-K giant groups. The [Fe/H] values were taken from Cayrel de Strobel et al. (1997).

4.2. Survey G-K Type Stars

Now we consider all the survey G-K stars with and without known luminosity class. A linear relationship between M_v and the colour index $(B-V)_0$ has been assumed. Seven groups have been identified and separated. The stars of each group are shown on the HR diagram (M_v versus colour index $(B-V)_0$), Figure 6. In addition to the groups containing dwarfs and subgiants, the remaining five groups on the giant branch correspond to: supergiants and bright giants, three groups of normal giants (clump stars rather concentrated in absolute magnitude and colour index, and two groups separated in absolute magnitude and colour index differing not only in luminosity but also in the kinematical behaviour) and old giants belonging to the thick disk and halo. The [Fe/H] distribution of the groups, excepting the supergiants-bright giants, is shown in Figure 3. As expected, the group of old giants contains the more metal deficient stars.

5. DISCUSSION

The results obtained show that the relation between absolute magnitude and luminosity class has a large intrinsic dispersion. In some cases the order of the luminosity classes is inversed with respect to the order in absolute magnitude (dwarfs brighter than giants). Similar results were obtained by Jaschek & Gómez (1997) from the analysis of about one hundred early type MK standards with the help of Hipparcos parallaxes. Furthermore, the conclusions do not change whether one separates low and high rotational velocity standards.

It can be concluded that the calibrations based on the luminosity class have a low accuracy, specially in certain regions of the HR diagram (giants and supergiants). The assignation of the mean absolute magnitude given by such a calibration to an individual star of the group is a rough procedure because of the large intrinsic dispersion of the different sequences. The use of these assignations should be restricted to the cases where the only available information for the star is its MK classification.

The application of the LM algorithm allowed to estimate individual absolute magnitudes for mixed groups. For example, in the case of G-K stars, seven groups characterised by different mean absolute magnitude relationships, kinematics and spatial distribution were obtained. Notice again that for the stars with less accurate parallaxes, the estimation of the absolute magnitude has been improved. Moreover, the density distribution laws adopted for the absolute magnitude, the spatial and the velocity components can be changed and adapted to the considered sample. Finally, the LM method is well adapted to calibrate the star luminosity as a function of spectroscopic and photometric data related to its physical parameters ($T_{\rm eff}$, gravity, metallicity, etc.).

6. CONCLUSION

The LM method has been applied to the non-binary and non-variable survey stars. The availability of Hipparcos data allowed to estimate the accuracy of the calibrations based on the MK classification. The different luminosity sequences show an intrinsic dispersion larger than estimated in previous works. The obtained dispersion of the absolute magnitude σ_M varies from about 0.5 mag on the main sequence, 1 mag on the giant branch to more than 1 mag for bright giants and supergiants. The assignation to a star of the mean absolute magnitude given by a calibration for a group is highly questionable. Our method takes into account all the available data and furnishes a non-biased estimation of individual absolute magnitudes.

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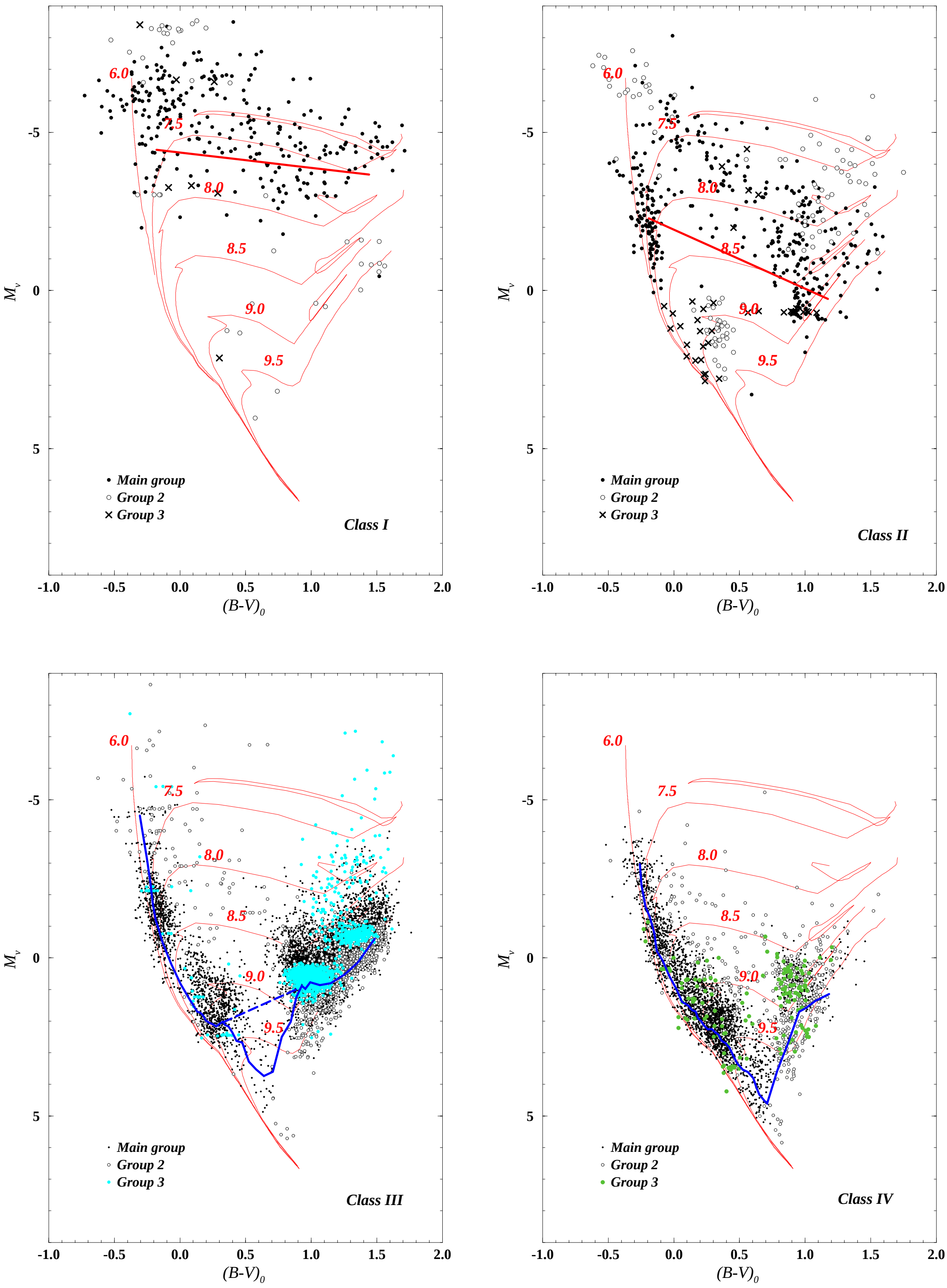

Figure 4. *Calibration and individual absolute magnitudes for luminosity classes I–IV. For class III the dashed line indicates a region where the calibration is uncertain due to the small number of stars.*

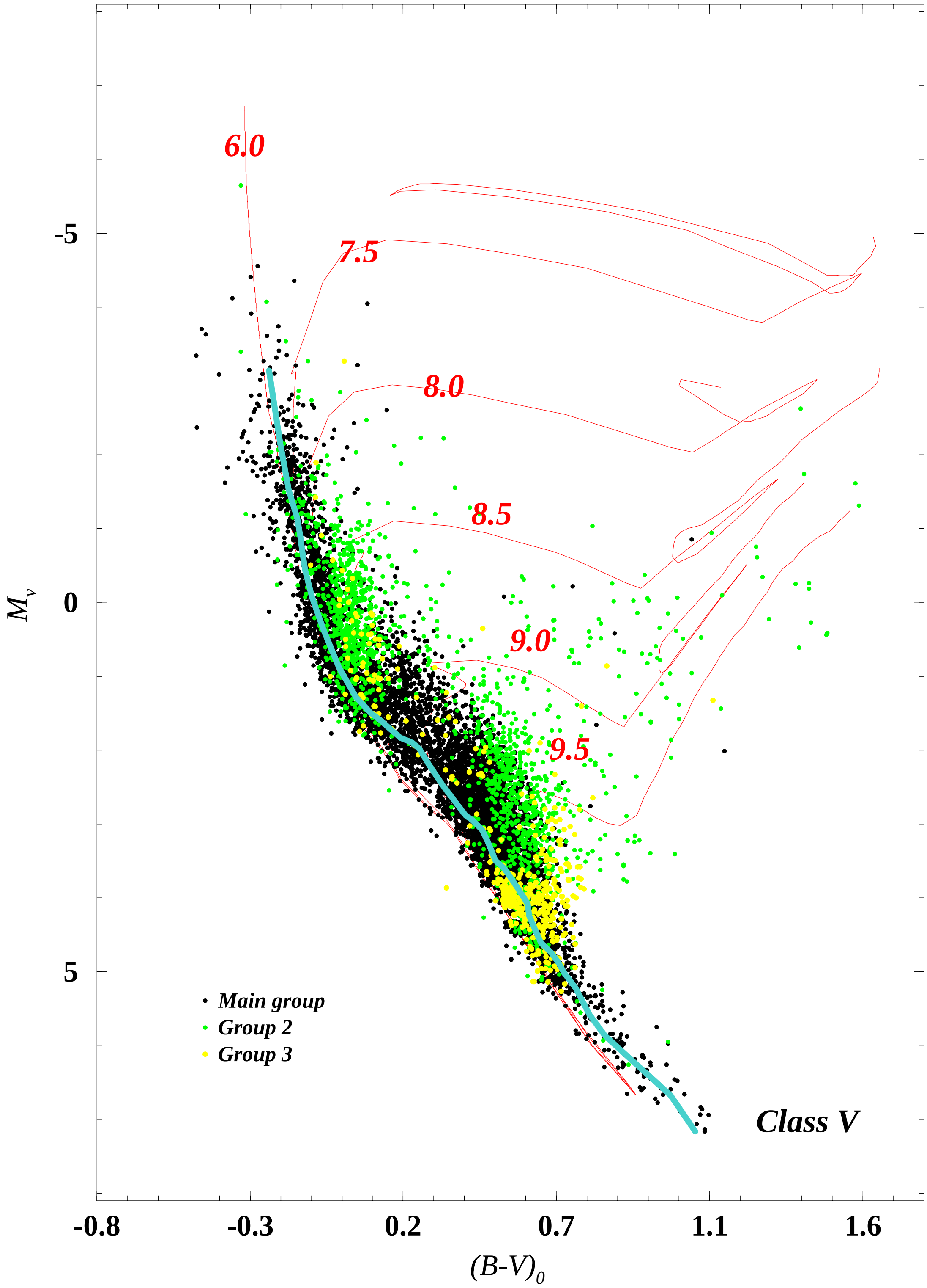

Figure 5. Calibration and individual absolute magnitudes for luminosity class V.

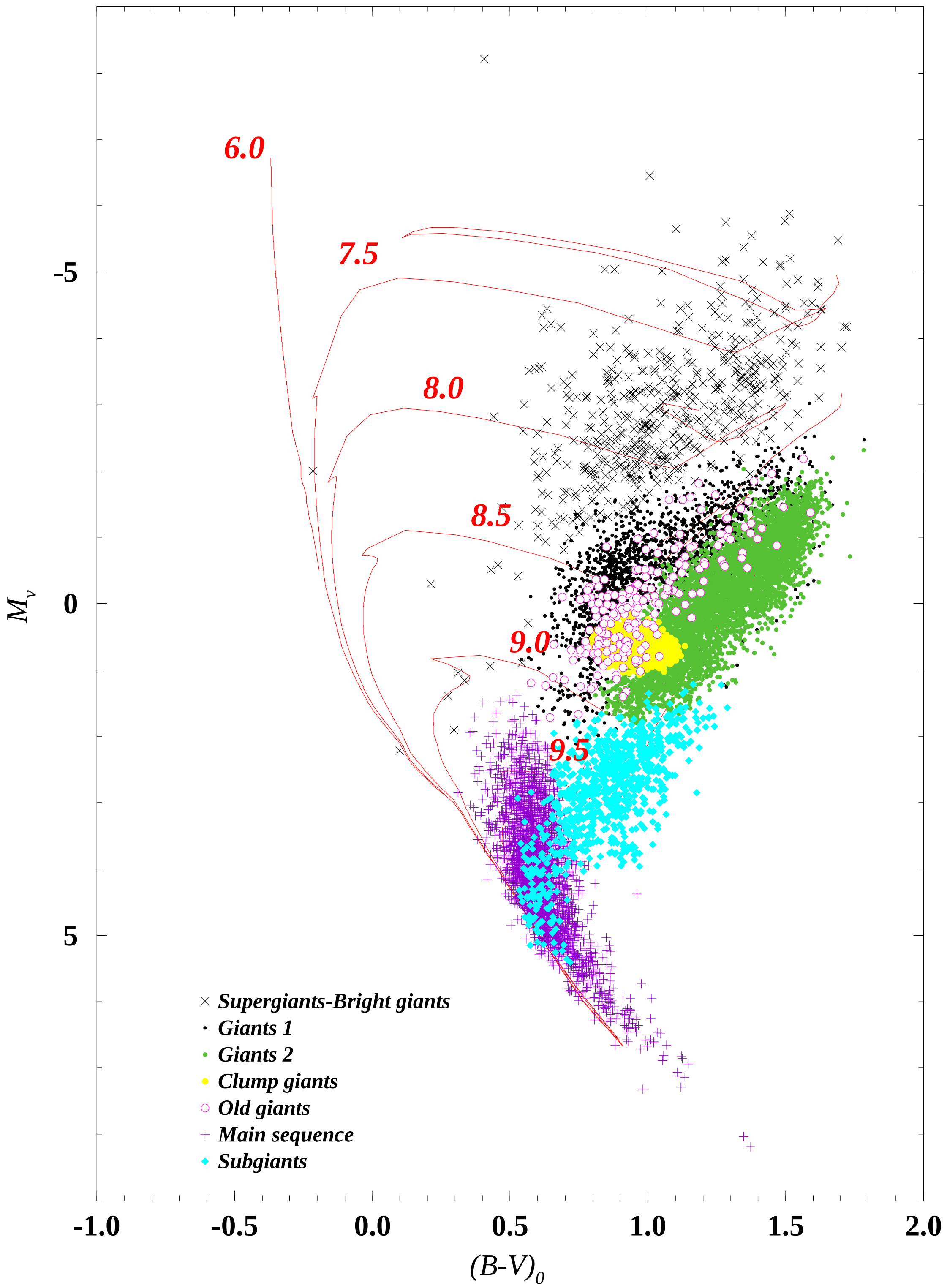

Figure 6. Groups resulting from the $[(B-V)_0, M_v]$ calibration for all G-K stars (without taking into account the luminosity class).