THE PROPERTIES OF MAIN-SEQUENCE STARS FROM HIPPARCOS DATA

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ABSTRACT

We received a sample of 6840 Hipparcos stars south of declination −26° that (i) have MK spectral types in the Michigan catalogues and (ii) had spectroscopic parallaxes that placed them within 80 pc of the Sun. Of these, 3727 are well determined as luminosity class V and actually lie within 100 pc. From this subsample we can determine the distribution in M_V of main-sequence stars of given spectral type for spectral types that range from early F to early K. These distributions are significantly non-Gaussian, but when fitted to Gaussians they yield central values of M_V in good agreement with earlier estimates of the absolute magnitudes of main-sequence stars. We also determine anew the distribution of $B-V$ at each spectral type. We find that the dispersion in $B-V$ at given spectral type is very small.

Key words: Stars: main-sequence.

1. INTRODUCTION

During the last two decades of the nineteenth century, staff of the Harvard College Observatory defined and ordered the spectral classes O, B, A, etc., and, in the four years from 1911, Annie Cannon classified on this

one-dimensional system the ∼ 225 000 stars that are brighter than $m_{\rm pg} \simeq 10$ – these classifications were published as the classical *Henry Draper Catalogue.* Miss Antonia Maury of Harvard early recognized that a second parameter was needed to fully characterize the spectra, and astronomers at Mt Wilson further developed this concept. However, it was only in the 1940's and 1950's that Morgan et al. (1943) completed a two-dimensional classification system for stellar spectra by dividing stars into luminosity classes I – V. This 'MK classification system' was an important advance because it yielded reasonably accurate estimates for the luminosities of many stars. In a continuing programme at University of Michigan the Henry Draper stars are being reclassified on the two-dimensional MK system. To date four

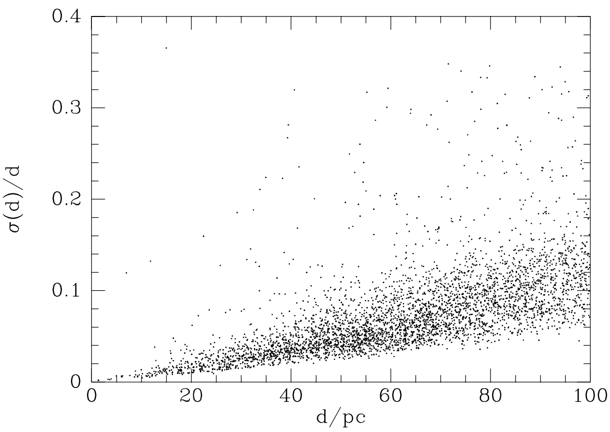

Figure 1. The distribution with respect to distance and its error of the stars that lie within d = 100 pc.

Michigan catalogues have been published that contain MK classifications for 130 000 stars with declinations $\delta < -12\,\mathrm{deg}$ (Houk & Cowley 1975, Houk 1978, 1982, Houk & Smith-Moore 1988).

By estimating the distance of stars from their HD apparent magnitudes, Michigan spectral types and assumed values for the absolute magnitude of each spectral type, Murray & Penston identified 6845 stars of luminosity classes IV-V and V that should lie within 80 pc of the Sun. The Hipparcos team was then asked to provide the astrometric parameters of these stars, which range in spectral type from B8 to K4. This paper examines the main sequence that is defined by the portion of these stars that lie within 100 pc (from their Hipparcos parallaxes) and have good two-dimensional spectral types.

2. CHARACTERIZING THE SAMPLE

Figure 1 shows the distribution with respect to Hipparcos distance d and its standard deviation $\sigma(d)$ of the 3727 stars in the sample that have luminosity class V, Hipparcos distance $d \leq 100\,\mathrm{pc}$ and high-

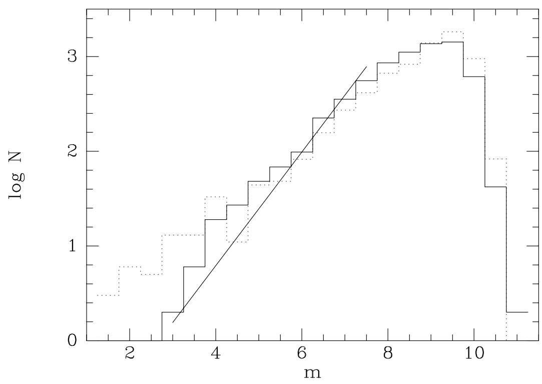

Figure 2. The full histogram shows the apparent-magnitude distributon of the 5992 stars in the sample that have high-quality spectral classifications. The dashed histogram shows a Monte-Carlo simulation of a sample selected from a spatially homogeneous poulation to have estimated distance d $\leq$ 80 pc and m $\leq$ 10, where the distance moduli employed have errors $\sigma(M-m)$ = 0.6 and apparent magnitudes have errors $\sigma(m)$ = 0.2. The full line shows the slope $\log N$ $\propto$ *0.6m that is characteristic of an infinite, homogeneous population.*

quality spectral classifications. As expected, the relative error in distance tends to be greater than 10 per cent for $d > 100\,$pc. Since a 10 per cent error in distance yields a 20 per cent error in luminosity, we decided to confine our analysis to those with $d \leq 100\,$pc. The median relative distance error of these stars is $\sigma(d)/d = 0.065$ in this group is great majority of these objects have distances accurate to better than 16 per cent.

The full histogram in Figure 2 shows the apparent-magnitude distribution of all the 5992 stars in the sample that had high-quality spectral classifications. For $m \lesssim 8$ this follows the plotted linear relationship, $\log N \propto 0.6m$, that is characteristic of a spatially uniform population. At fainter magnitudes the histogram falls below the straight line for the reasons given by Murray et al. (1997), whose equation (2) gives the probability $P(r)$ that a star that is at distance r would enter a sample that is limited by photometric parallax. The dotted histogram in Figure 2 shows the apparent-magnitude distribution of a Monte-Carlo simulation of the selection of our sample of 6840 stars from the luminosity function of Wielen et al. (1983) under the following asumptions: (i) the expression for $P(r)$ given by Murray et al. is correct; (ii) the distance moduli employed had dispersion $\sigma(M-m) = 0.6$ mag; (iii) the apparent magnitudes employed had dispersion $\sigma(m) = 0.2$ mag; (iv) the limiting apparent magnitude was 9.5 mag. (The limiting magnitude derived by Murray et al. was 0.5 mag brighter because they imposed the additional criterion $\sigma(\pi)/\pi \leq 0.125$.) The excellent agreement between the two histograms in Figure 2 inspires confidence in the completeness model of Murray et al. In the following we correct for incompleteness by weighting each star by $V_{\rm max}/V$, where V is the effective volume out to the star [equation (3) of Murray et al.] and $V_{\rm max}$ is the effective volume to the greatest distance at which the star could enter the sample. For the later spectral types the incompleteness correction $V_{\rm max}/V$ can be large, and it might be thought prudent to diminish the correction by decreasing the limiting distance from $d_{\rm lim} = 100\,$pc. It should be borne in mind, however, that the absolute value of $V_{\rm max}/V$ is immaterial for the present study; it is only the *variation* in $V_{\rm max}/V$ over the ~ 2 mag spread in absolute magnitude at given spectral type that matters, and for the latest spectral types, which have the largest values of $V_{\rm max}/V$, this variation is independent of $d_{\rm lim}$. Hence a large value of $d_{\rm lim}$ introduces no additional uncertainty as regards late spectral types, while reducing the uncertainties regarding early spectral types by bringing as many of these stars into our study as possible.

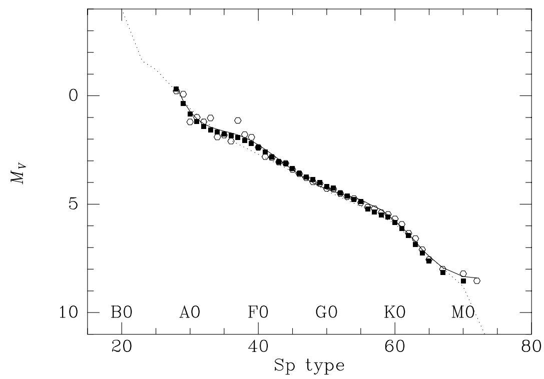

Figure 3. The open points show the median value of M_V for stars of each spectral type. The full curve is a polynomial fit to these points. The full points show the modal values from Table 1. The dotted curve shows the values of M_V given in Schaifers & Voigt (1982).

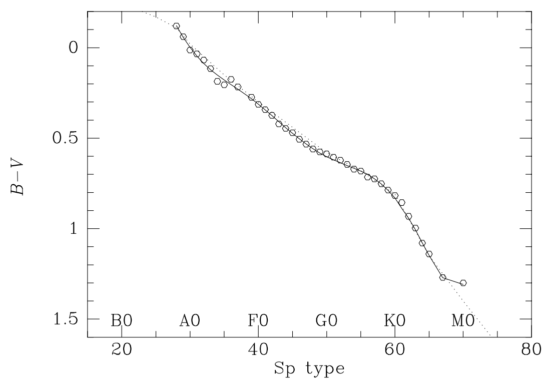

Figure 5. The points show the value of $B-V$ at each spectral type. The full curve is a polynomial fit to these points. The dotted curve shows the relation between $B-V$ and spectral type given in Schaifers & Voigt (1982).

3. THE HR DIAGRAM

Figure 3 gives an indication of the location of the stars within the HR diagram: the median absolute magnitude at a given spectral type is marked by a hexagon. The full curve is a polynomial that has been least-squares fitted to these hexagons. For com-

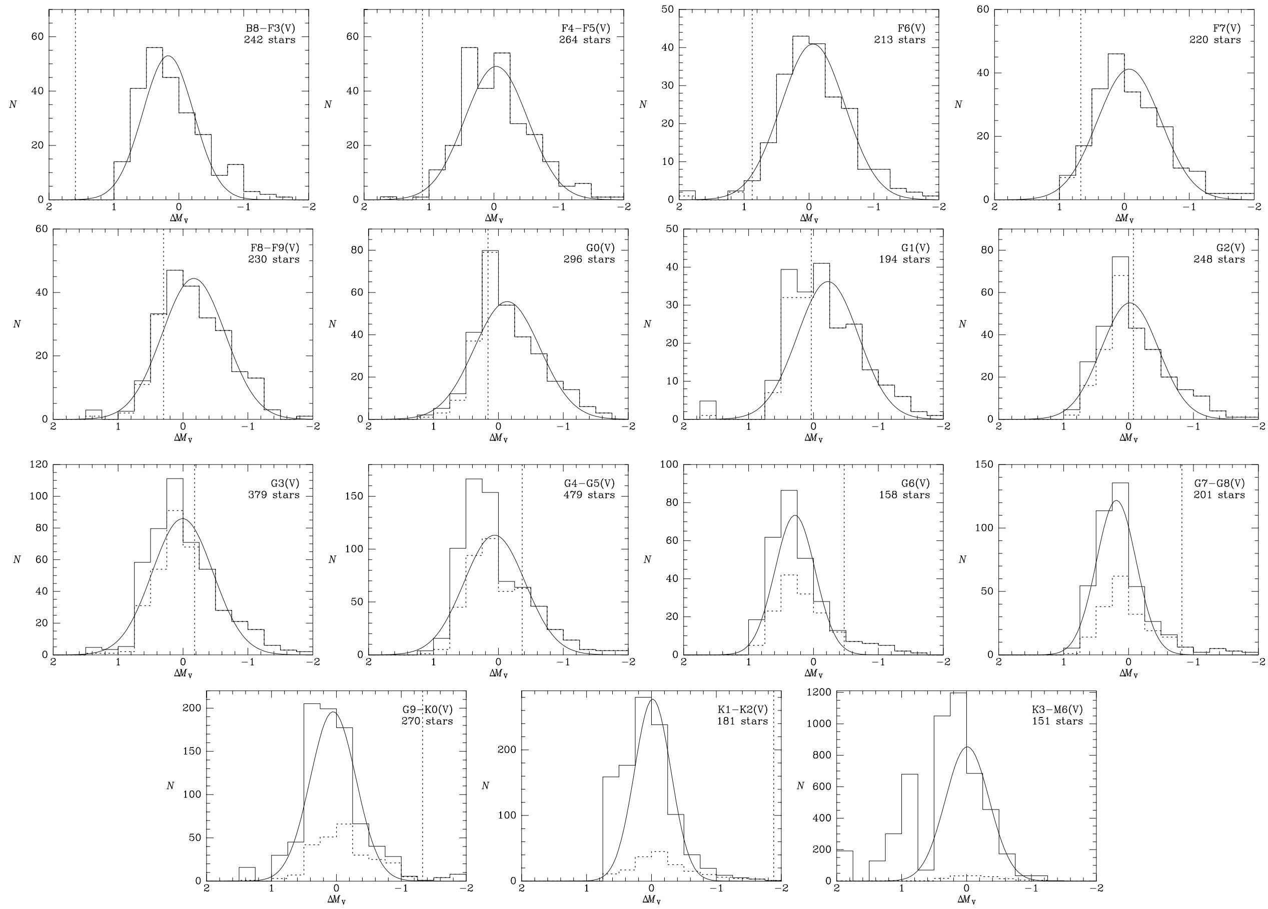

Figure 4. The distribution of absolute magnitudes of stars of similar spectral type.

Table 1. Gaussian fits to the distributions.

Sp type	$\langle M_V \rangle$	$\sigma(M_V)$	$\langle B-V \rangle$	$\sigma(B-V)$
B8	-0.25	0.39	-0.112	0.031
A0	0.82	0.39	0.008	0.031
A5	1.76	0.39	0.188	0.031
F0	2.40	0.39	0.321	0.031
F2	2.84	0.39	0.385	0.031
F4	3.11	0.49	0.440	0.029
F6	3.56	0.49	0.506	0.023
F8	3.87	0.49	0.553	0.025
G0	4.20	0.51	0.587	0.026
G1	4.24	0.47	0.606	0.030
G2	4.56	0.44	0.622	0.029
G3	4.69	0.47	0.642	0.033
G4	4.82	0.47	0.671	0.038
G5	4.93	0.47	0.687	0.038
G6	5.26	0.31	0.719	0.039
G7	5.32	0.31	0.724	0.041
G8	5.51	0.31	0.752	0.041
K0	5.88	0.35	0.828	0.053
K2	6.37	0.28	0.929	0.050
K4	7.12	0.34	1.091	0.049

parison the dotted curve shows the variation of M_V as a function of spectral type as given in Schaifers & Voigt (1982).

Figure 4 indicates the spread in luminosity of stars of similar spectral type. The vertical dotted lines show the faintest magnitude at which no correction for Malmquist bias is required. The full histograms show the data after correction for Malmquist as described in §2, while the dotted histograms show the raw data. Since some spectral types contain only a small number of stars, several of the histograms shown in Figure 4 have been obtained by aggregating stars from two or more spectral types. This aggegation has been done as follows: each star was assigned a value of $\Delta M_V \equiv M_V - M_{\rm poly}$, where M_V is the star's absolute magnitude and $M_{\rm poly}$ is the absolute magnitude at the star's spectral type of the polynomial fit of Figure 3. Then stars were binned by their values of ΔM_V.

In Figure 4 smooth curves show the Gaussians that best fit the histograms of the Malmquist-corrected data. Table 1 lists the mean absolute magnitude and the dispersion about it for each spectral class that one infers from these Gaussians and the polynomial fit to the median magnitude that is shown in Figure 3.

All the well-determined histograms of Figure 4 are significantly skew, having a longer tails on the bright than on the faint side.

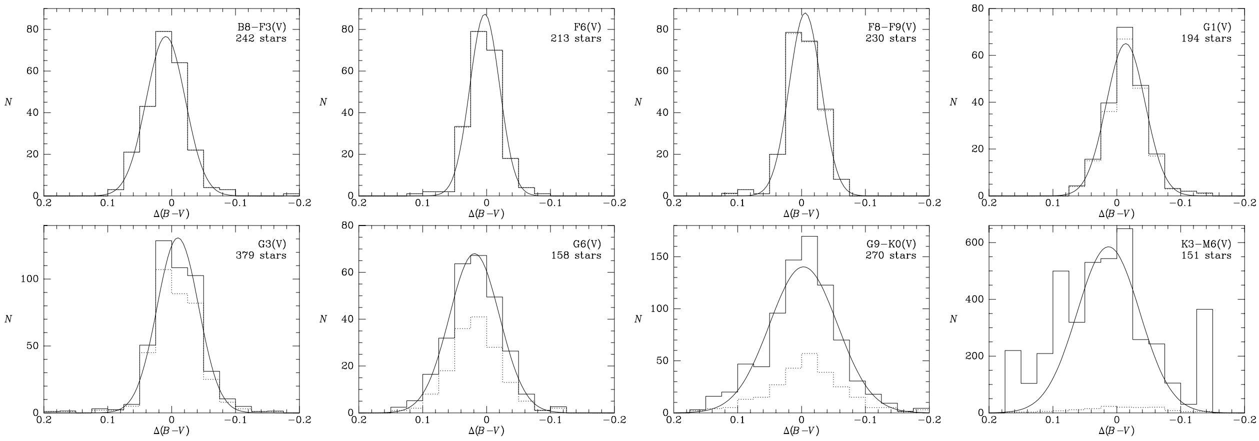

Figure 6. The distribution of $B-V$ for stars of similar spectral type.

4. COLOURS

The Hipparcos Catalogues give $B-V$ for each programme star. Since these colours are from the literature rather than measured by Hipparcos, they will be subject to significant observational error (unlike our values of m_V). Nonetheless, it is interesting to study the colour distribution at fixed spectral type because our sample is completely free of giant contamination, which probably cannot be said with such confidence of the samples from which the classical color-spectral type relations derive.

The analysis of the distribution over $B-V$ proceeds in close analogy with the analysis of the absolute-magnitide distribution. The points in Figure 5 show the median colour for each spectral type, while the full curve in Figure 5 is a polynomial fitted to these points. The dotted curve in Figure 5 shows the relation between $B-V$ and spectral type that is given in Schaifers & Voigt (1982). This can be seen to be in excellent agreement with our results.

Figure 6 shows the spread in colour at fixed spectral type by plotting histograms of the differences $\Delta(B-V)$ between the actual colour of each star and the colour that is assigned to its type by the polynomial fit of Figure 5. Again the full histograms show the data after correction for Malmquist bias, while the dashed histograms show the raw data. Since there is not a strong correlation between $\Delta(B-V)$ and M_V, the dashed and full histograms in Figure 6, in contrast to those of Figure 4, do not differ systematically in shape.

Figure 6 also shows Gaussian fits to the full histograms. These fits have been used to derive the parameters of the colour distributions at fixed spectral type that are listed in Table 1. Since the colours we are using are from the literature rather than from Hipparcos, a significant portion of the dispersions $\sigma(B-V) \sim 0.03$ mag will come from observational scatter. Hence the intrinsic dispersion in $B-V$ at given spectral type must be extremely small.

5. CONCLUSIONS

We have determined the distributions of absolute-magnitude and $B-V$ colour for solar-neighbourhood main-sequence stars that lie within 100 pc of the Sun and have accurate trigonometric parallaxes from the Hipparcos satellite and reliable spectral types in the first three volumes of the Michigan catalogue. When Gaussians are fitted to the data for each spectral type, we derive central values that are in excellent agreement with the classical values tabulated in Schaifers & Voigt (1982). The scatter in M_V at fixed spectral type is significantly non-Gaussian, having a tail towards high luminosity. The corresponding scatter in $B-V$ is very small and probably largely dominated by observational errors.

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