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SPACE DISTRIBUTION OF STARS IN THE DIRECTION OF THE ASSOCIATION CAM OB3

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Abstract. The space distribution of stars of various types is investigated in a 1.5 square degree area at the Galactic equator ($\ell = 146°$, $b = +2.6°$) in Camelopardalis, in the direction of the association Cam OB3. The study is based on photometric classification, interstellar extinction and distance determination of 1303 stars down to 15.5 mag (in the violet). The limiting distance of the study is about 5 kpc, thus our line of sight crosses the Perseus and the Outer spiral arms. The space density of stars of different spectral types and the luminosity function are determined.

Key words: Galaxy: stellar content, structure, spiral arms – associations: individual (Cam OB3)

1. INTRODUCTION

Within the past quarter of century a number of Galactic structure models have been developed by Bahcall & Soneira (1980, 1981, 1984), Bahcall (1986), Robin & Crézé (1986a,b), Reid & Majewski (1993), Peiris (2000), Larsen & Humphreys (2003), Robin et al. (2003). For the calculation of Galaxy models mean luminosity functions are used for the included population types. Since disk stars are most numerous in the Galaxy, the luminosity function for the disk is most important. Although this function usually is considered to be applicable everywhere in the disk, in reality its considerable variations are expected, especially for O-B stars. It is obvious that star distributions in spectral types in spiral arms are different from the interarm regions. Significant variations of the luminosity function are expected in star-forming regions and clusters.

Methods for the determination of luminosity functions are described in detail by van Rhijn (1965), McCuskey (1966) and Bessell & Stringfellow (1993). The accuracy of the luminosity function depends mainly on the accuracy of absolute magnitudes of stars and interstellar extinction. In the solar vicinity up to 100 pc interstellar extinction may be neglected, and the distances can be determined by the ground-based or the orbital *Hipparcos* trigonometric parallaxes (Jahreiss & Wielen 1997).

At larger distances the method of “spectroscopic parallaxes” may be used. This method for the determination of luminosity functions was successfully used by S. W. McCuskey in 1947–1955 (LF areas). For the determination of distances of stars two-dimensional spectral classification was combined with two-color photographic photometry. Spectral and luminosity classes were used to estimate the absolute magnitude and color indices – interstellar reddening and extinction. The results of the investigation of nine LF areas, selected in the relatively transparent and uniform Milky Way places, were published in a series of papers with a summary in McCuskey (1956, 1965). The distribution of stars of most luminous stars up to 2.5 kpc was found. Luminosity functions for a wider sample of spectral classes were given up to 600 pc. However, since for the spectral classification objective-prism spectra of low-dispersion (280 Å/mm at Hγ) were used, McCuskey was not able to determine luminosity classes for B- and A-type stars, and the luminosity classes of F- and G-type stars were of low accuracy. As a result, the dispersion of absolute magnitudes, prescribed to these stars, was quite large. Also, in these works the accepted interstellar extinction was taken into account only approximately.

The method of determination of spectral classes and absolute magnitudes from multicolor photometry offers much greater possibilities in limiting distances, in the accuracy of classification and absolute magnitudes and in the account of interstellar extinction. In the *Vilnius* seven-color photometric system (Straižys 1977, 1992) the expected accuracy of classification and physical parameters is: ±1 decimal subclass for spectral classes, ±0.3–0.5 mag for M_V, ±0.02–0.03 mag for E_{Y-V}, ±0.1 mag for A_V and 15–25 % for distances. For each star absolute magnitude and interstellar extinction are determined individually. Similar accuracies are expected in the *Strömvil* photometric system combined from passbands of the *Vilnius* and *Strömgren* photometric systems (Straižys, Crawford & Philip 1996).

In the present paper the method is tested for the first time for the determination of space density of stars of various types using CCD photometry and classification of about 1300 stars down to 15.5 mag in a Camelopardalis area. The investigated area is centered at $\alpha(2000) = 3^{\rm h}56^{\rm m}$ and $\delta(2000) = +56°57'(\ell = 146°, b = +2.6°)$, its angular size is 1.26°×1.22°. The results of photometry and two-dimensional classification are given in Zdanavičius & Zdanavičius (2005), the interstellar extinction in the area is investigated in Zdanavičius et al. (2005). This area is at the central part of the larger LF6 area investigated by McCuskey (1952, 1956a). Also it coincides with the direction towards the Cam OB3 association.

2. SOME STATISTICAL DATA

The following figures give some statistical view to the observational data which we use. The numbers of stars are plotted against the apparent magnitude V, the spectral class, the absolute magnitude M_V and the distance r.

1. Figure 1 shows the distribution of stars in apparent magnitudes V. Spectral classes are shown by different colors. It is evident that the limiting magnitude, to which the stars are complete, is close to V = 15 mag. However, for B and A stars this limit is fainter at least by 0.5 mag.

2. Figure 2 shows the distribution of stars in spectral classes. The bin widths of spectral classes are 2 decimal spectral subclasses. For the cool stars starting at G4 the plot shows luminosity V and luminosity IV–III stars separately. The observed distribution pattern is the result of differences of the real number densities and the apparent density differences caused by the limiting magnitude and interstellar extinction effects. The most outstanding feature of the diagram is the deficiency of A6–F0 stars in comparison with hotter and cooler stars. This deficiency is either

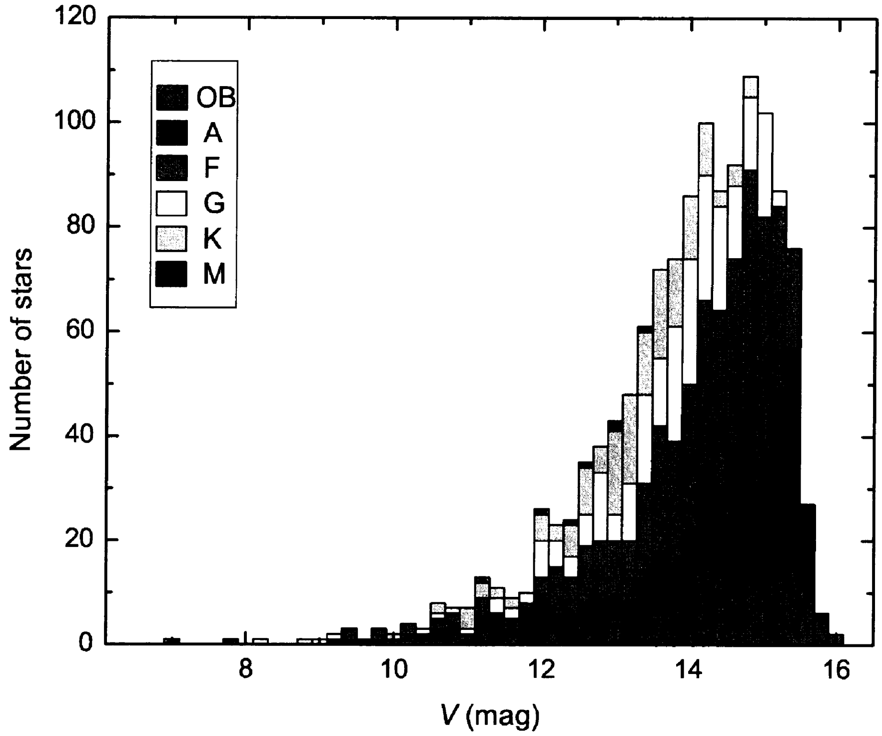

Fig. 1. Distribution of stars of the area in apparent magnitudes V.

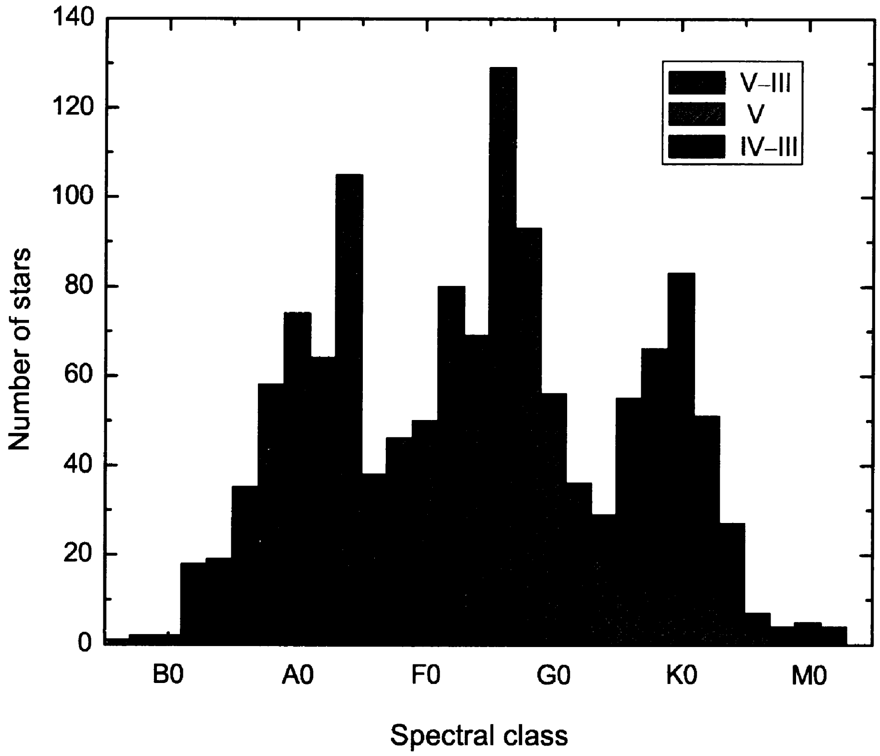

Fig. 2. Distribution of stars of the area in spectral classes.

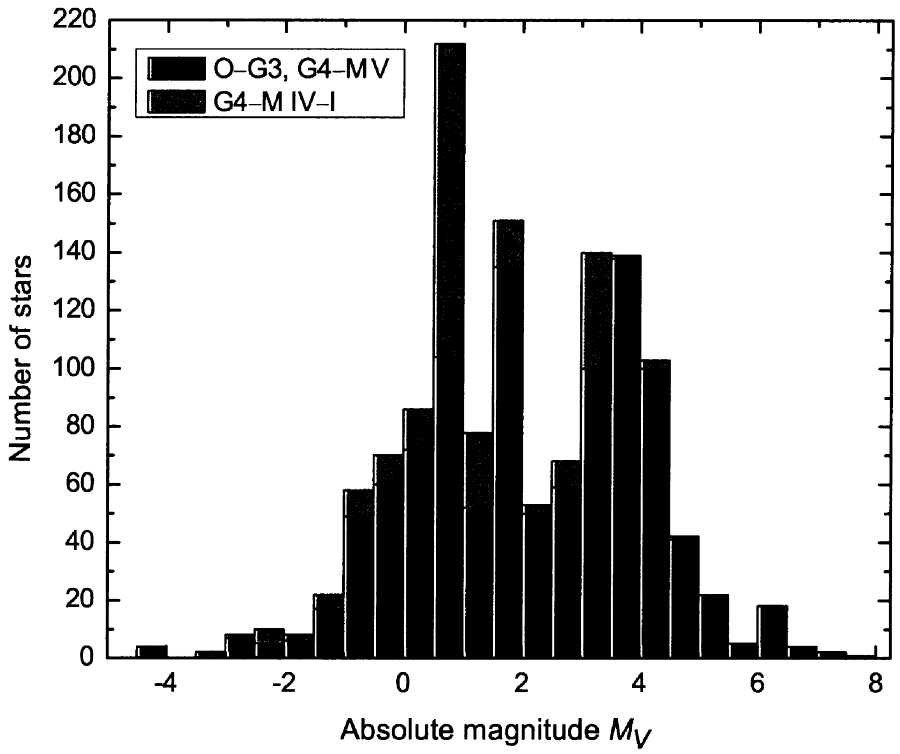

Fig. 3. Distribution of stars of the area in absolute magnitudes M_V.

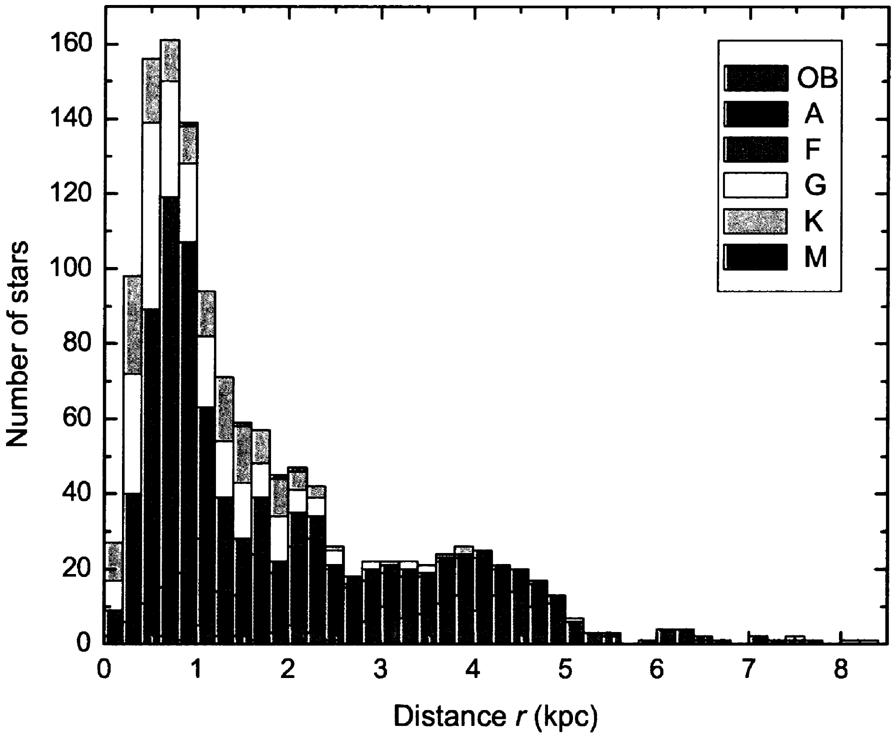

Fig. 4. Distribution of stars of the area in distances.

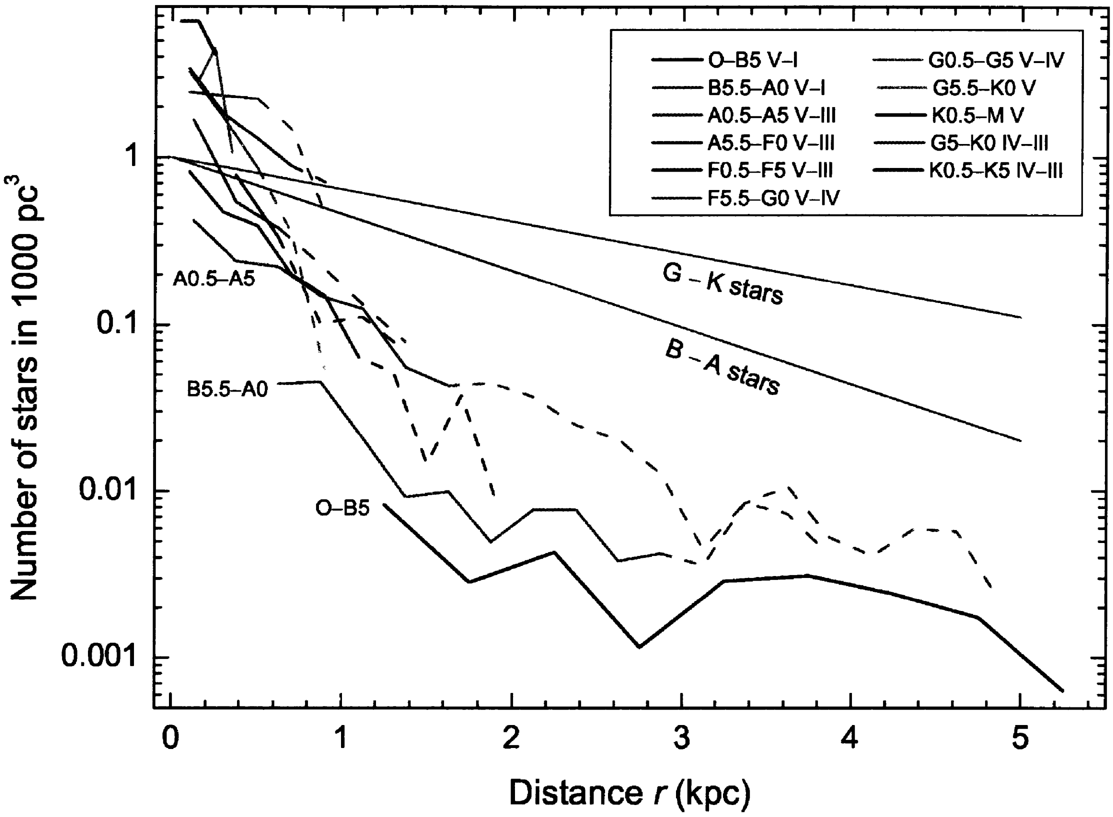

Fig. 5. Space densities of stars of different spectral and luminosity groups. The two straight lines show the fall of density of B–A and G–K stars due to increase of the galactocentric distance and the distance from the Galactic plane.

real or it is partly caused by some systematic errors in photometric spectral classification due to uncorrect calibration. The minimum of number density of late A- and early F-type stars has been noted also by other authors in the star samples classified in the MK system (see, e.g., Vereshchagin & Chupina 1995).

3. Figure 3 shows the distribution of stars in absolute magnitudes M_V. The bin widths of the magnitudes are 0.5 mag. G4–M IV–III stars are shown separately. Here we see the minimum of stars between 2.0 and 3.0 mag which is the reflection of the same effect of deficiency of A5–F0 stars discussed in item 2.

4. Figure 4 shows the distribution of stars in distances. The distance bin is 200 pc. Overwhelming majority of stars closer than 1 kpc are F and G main-sequence stars. Majority of B-type stars are at the distances larger than 3 kpc.

3. SPACE DENSITIES

Space densities as a function of distance were calculated for the following spectral groups: O–B5 of all luminosities, B5.5–A0 V–III, A0.5–A5 V–III, A5.5–F0 V–III, F0.5–F5 V–III, F5.5–G0 V–IV, G0.5–G5 V–IV, G5.5–K0 V, K0.5–M V, G5–K0 IV–III and K0.5–K5 IV–III. Distance binning was 500 pc for O–B5 stars, 250 pc for B5.5–A0 and A0.5–A5 stars and 200 pc for the remaining. Figure 5 shows the plot of the density functions (in a log scale) for these spectral ranges. Space density of stars is given for 1000 pc^3.

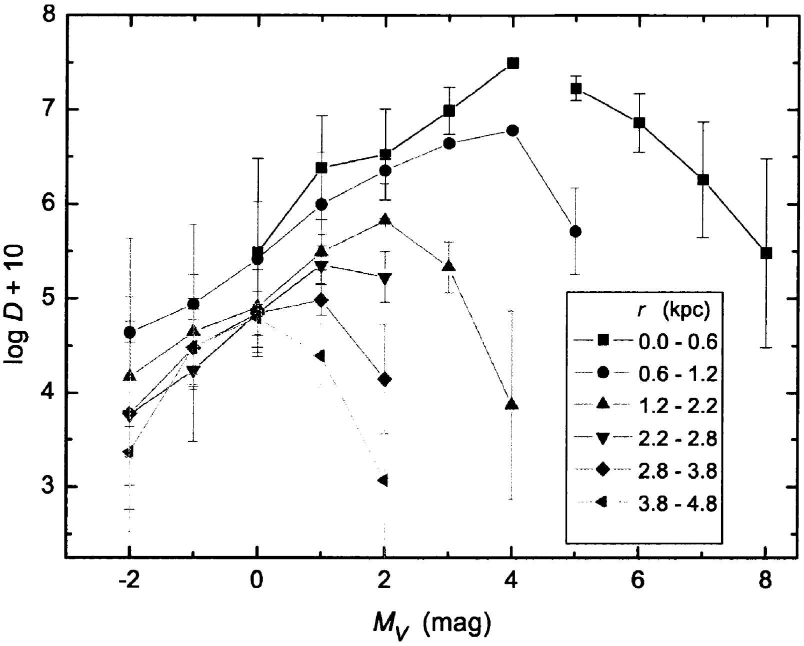

Fig. 6. The distribution of stars in absolute magnitudes of all observed stars of the main-sequence belt for various distance intervals. The fall of density at a certain distance is the result of the limiting magnitude and interstellar extinction.

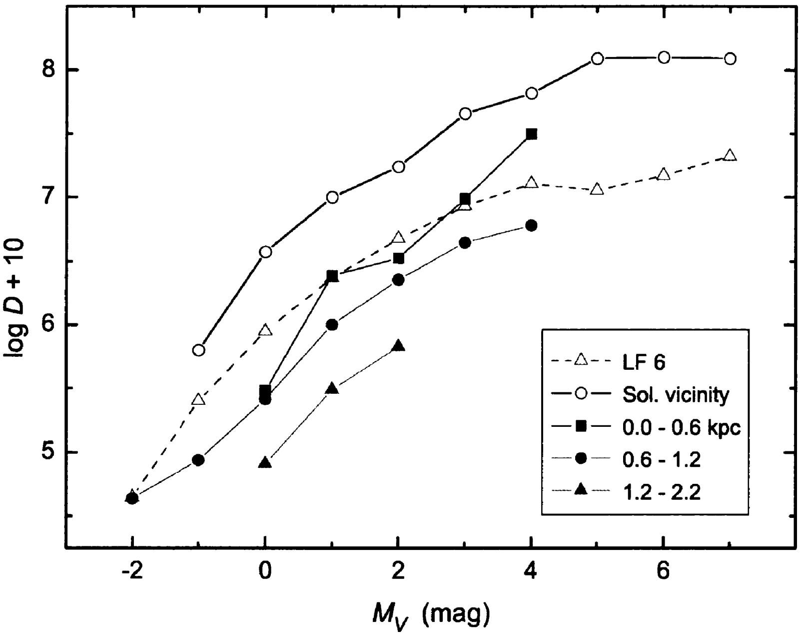

Fig. 7. Luminosity functions of stars of the main-sequence belt for three distance intervals, compared with the luminosity functions of McCuskey (1956b) for LF 6 and Jahreiss & Wielen (1997) for solar vicinity.

To avoid the limiting magnitude effect, we rejected the bins with distances larger than $5 \log r_{\rm lim} = V_{\rm lim} - M_V + A_V$ with $V_{\rm lim} = 15.5$ for B and A stars and 15.0 for the remaining, M_V is the absolutely brightest star in the bin and A_V is the extinction close to the maximum for this distance range according to the A_V vs. r dependence from Zdanavičius et al. (2005). The parts of density functions corresponding to M_V between the absolutely brightest and the faintest star in the bin are shown by dashed lines. At these distance intervals the star numbers are slightly affected by some selection.

Up to 1 kpc the density values are complete for all spectral classes of the main sequence belt (including luminosity V–IV–III stars in the B–A–F–G3 range and luminosity V class in the G4–K range) and for G4–K giants and subgiants (luminosity classes III and IV). At larger distances only B and A stars of the main sequence belt give realistic densities while cooler stars are affected by the limiting magnitude. On the other hand, the number of B-type stars at the distances less than 500 pc from the Sun is insufficient to get statistically meaningful densities.

It would be interesting to compare our values of space density with the values obtained many years ago by McCuskey (1952, 1956b) in his LF 6 area using a different techniques. A direct comparison is impossible since McCuskey has used different bins of spectral classes. However, the results are similar at least within an order of magnitude. On the other hand, spectral classification in the LF survey is not very accurate (see the Introduction). McCuskey (1952, 1956b, 1965) directs attention to rapidly diminishing density of F0–F5 stars with increasing distance. We find the same phenomenon in our star sample. A similar behavior is exhibited also by some other spectral groups, for example, by all G-type main-sequence stars.

This effect partly may be the result of the negative density gradient along the disk with increasing galactocentric distance and perpendicularly to the disk with increasing the distance from the Galactic plane. This effect can be estimated by the equation:

$$n = n(R_0) \exp(-z/H) \exp(-(x - R_0)/h), \tag{1}$$

where n is the star density at the galactocentric distance x, R_0 is the galactocentric distance of the Sun, z is the distance from the Galactic plane, H is the disk scale-height and h is the disk scale-length. Most authors of the Galaxy models use a value of scale-length $h = 3.5$ kpc for all types of stars (Bahcall 1986; Larsen & Humphreys 2003). The scale-height H depends on the age of star population: the values of 90 pc for B–A stars, 325 pc for G–K main sequence stars and 250 pc for G–K giants are usually recommended (see the above mentioned sources).

The average Galactic latitude of our area is 2.5°. For this line-of-sight at a distance of 5 kpc the height above the Galactic plane is 218 pc. Equation (1) for these distances from the Sun and from the plane for B–A stars, G–K dwarfs and G–K giants gives the densities 0.02, 0.12 and 0.10 of the value around the Sun. In Figure 5 the density gradient lines for early- and late-type stars in our area are shown as two solid lines starting from the 1.0 tick. It is evident, that the predicted density gradient can explain the decline of lines, corresponding to O–B5 and B5.5–A0 stars, up to 3 kpc, i.e., in the interarm and the Perseus arm regions. However, there is an increase of space density of B stars at the 3–5 kpc distance which may be related to the Outer spiral arm.

For A-type and cooler stars the slope of the model gradient line is too small to be responsible for the observed fall of the space density up to 1.5 kpc from the

Sun. This fall may mean that the density of stars in the Local spiral arm is larger in comparison with the interarm region which begins at about 1 kpc.

4. THE LUMINOSITY FUNCTION

For the determination of the luminosity function the numbers of stars in the main-sequence belt have been calculated in the consecutive 1 mag bins of absolute magnitudes for different 1 kpc distance intervals. The main-sequence belt in the B–A–F–G3 range includes the stars of luminosity classes V–IV–III, while in the G4–K–M range it includes only luminosity V stars. Space densities of all observed stars D (number of stars for 1 kpc^3) were calculated and plotted in Figure 6 in the form $\log D + 10$ vs. M_V. This form of presentation of the luminosity function was used by van Rhijn (1925, 1936) and McCuskey.

The density is the largest in the first distance interval between the Sun and 600 pc for all absolute magnitudes (between 0.0 and +5.0). The number of B-type stars in this distance range is not sufficient for the density determination. The falling parts of the curves correspond to the absolute magnitude bins which are affected by the limiting magnitude and interstellar extinction. These bins should be neglected in the luminosity function determination.

Our luminosity function using only bins on the rising part of the curve is shown in Figure 7. Only three distance intervals of 0–0.6, 0.6–1.2 and 1.2–2.2 kpc are used, since at larger distances most of the absolute magnitude bins are affected by the limiting magnitude. In the same figure we plot the luminosity function determined by McCuskey (1956b) for the LF 6 area which overlaps our area. McCuskey's function is obtained by taking the average values of space density for the distances 200, 400 and 600 pc. It is evident that both investigations are in satisfactory agreement.

Figure 7 also shows the luminosity function for the main-sequence stars in the solar vicinity according to Jahreiss & Wielen (1997). Although the slope of this function is similar to the slope of our functions, the shift of about 0.5 dex is present. We should expect that the solar vicinity luminosity function is more complete than ours, since we have rejected some number of close stars which could not be measured separately and some number of peculiar stars which could not be classified photometrically. However, it is hard to believe that we have taken into account only 1/3 of all stars in the space volume up to 600 pc distance. Probably this difference reflects the real difference of space densities of stars in both samples.

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