ON THE MASS DISTRIBUTION OF STARS
IN THE SOLAR NEIGHBOURHOOD

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SUMMARY: The present authors analyse samples consisting of Hipparcos stars. Based on the corresponding HR diagrams they estimate masses of Main-Sequence stars from their visual magnitudes. They find that already beyond the heliocentric radius of 10 pc the effects of observational selection against K and M dwarfs become rather strong. For this reason the authors are inclined to think that the results concerning this heliocentric sphere appear as realistic, i.e. the fraction of low-mass stars (under half solar mass) is about 50% and, as a consequence, the mean star mass should be about 0.6 solar masses and Agekyan's factor about 1.2. That stars with masses higher than 5 $M_\odot$ are very rare is confirmed also from the data concerning more remote stars. It seems that white dwarfs near the Sun are not too frequent so that their presence cannot affect the main results of the present work significantly.

Key words. Stars: luminosity function, mass function – Hertzsprung-Russell (HR) and C-M diagrams

1. INTRODUCTION

It is very well known that for a star the mass is, practically, its most important physical property. There are two essential moments in this respect: the reliability of mass determination and the mass distribution of stars. As for the former one, recently the present authors (Ninković and Trajkovska 2005 - hereinafter referred to as Paper I) estimated the masses for a number of nearby stars. Since these stars were from the Hipparcos Catalogue they are expected to have good parallaxes and, automatically, reliable absolute magnitudes enabling us to apply successfully the mass-luminosity relation. Once the masses for a sufficiently large number of stars are available, it is possible to ask the question of their mass distribution.

It is also well known that stars are born with different masses. So one comes to the problem of initial mass function (IMF). Historically, Salpeter's attempt (1955) to explain the variety of star masses by introducing a suitable formula as description of "relative probability for the creation of stars of mass near M_* at a particular time", appears as the beginning of studies of this kind. Though sufficiently simple, Salpeter's formula was found to yield a too high rate of very massive stars (those exceeding 5 $M_\odot$). As a consequence, a number of alternative functions has been proposed (e.g. Miller and Scalo 1979, Lequeux 1979). Certainly, any sampling of stars aimed at throwing more light to the problem is welcome. However, it should be emphasized that IMF and the mass-distribution function for stars from the solar neighbourhood need not coincide. Simply, in the solar neighbourhood there are evolved stars (say, red giants and white dwarfs) and, also, the nearby stars are of different chemical composition. Nevertheless, the situation in the solar neighbourhood is especially important. For example Rana (1987) found a mass function for the solar neighbourhood which should have covered a mass interval between

$m = 0.08$ and $m = 100$ solar masses. With regard to the well known astrophysical conditions these limits seem very acceptable, but, nevertheless, they deserve comments. Namely, as will be seen below, the upper limit is rather a theoretical value since very massive stars, though easily detectable, are very rare indeed, or more precisely, extremely massive stars are extremely rare. This seems to be a well known fact. On the other hand, to establish the fraction of very low mass stars is difficult because they are usually very faint, a circumstance strongly diminishing their detectability. Since the masses of stars are usually estimated on the basis of their luminosity, it is not so easy to indicate any particular mass value under which the mass distribution becomes significantly uncertain. However, it may be said that some kind of general agreement, nevertheless, exists so that the value of $0.1 M_\odot$ is frequently considered as a practical lower limit to the mass of a star (here stars luminous enough to be detected are borne in mind). Of course, the obtained mass values depend on the mass-luminosity relation assumed in the mass calculation.

On the other hand, one should not forget that as a distinguishing criterion between a star and a planet (also a brown dwarf) appears the object's mass. Therefore, of importance is to estimate the mean star mass and the mass scatter. According to a concept developed by one of the present authors (Ninković 1995) the mass scatter for stars may be characterised by use of a dimensionless quantity named as Agekyan's factor (its definition given also in Paper I). Estimates of the mean star mass are not frequent in the literature, instead authors are generally satisfied to present the slope of the mass-distribution function proposed in a given article. No doubt, from the theoretical point of view the slope of a mass-distribution function is very important, but from a more practical view point it is quite convenient to present the mean star mass and the value of Agekyan's factor, especially when borne in mind that the modern results clearly indicate that the slope of the mass-distribution function cannot be the same over the entire mass interval covered by stars.

In Paper I a sufficiently large sample of nearby stars (Hipparcos stars with accurate parallaxes) was considered. However, there a thorough analysis missed. Hence, in this paper examine the mass distribution in more details. In accordance with what has been said above a special attention will be given to the questions concerning the local values for the mean star mass and Agekyan's factor.

2. MASS DETERMINATION

As already said in the Introduction, the source of the observational material is the Hipparcos Catalogue which contains many nearby stars with accurate astrometric data. For the purposes of both Paper I and the present one astrometric data of interest are (trigonometric) parallaxes. Combined with the apparent magnitudes of stars they enable to deter-

mine the absolute magnitudes without taking into account the interstellar absorption due to the very small heliocentric distances of the stars under examination. The particular mass-luminosity relation is that proposed by Angelov (1993). This relation has been regularly used by Belgrade astronomers for the purpose of mass estimation in the case of components of binary stars (e.g. Trajkovska and Ninković 1997). As binaries also allow to check the results by using the masses determined dynamically, it has been possible to test Angelov's relation intensively and these tests have given very satisfactory results. Since the main objective of the present paper is to offer a sufficiently good estimate for the average star mass, we choose single Hipparcos stars belonging to the Main Sequence, because Angelov's relation, as generally relations of such kind, is valid for the Main-Sequence stars only.

In this way we have obtained the mass values for a number of nearby stars. For these stars the mean mass and the value of Agekyan's factor were calculated and the results can be found in Paper I (Table 1). The circumstance deserving to be commented is, certainly, that in the case of very close stars both the mean mass and Agekyan's factor have significantly different values from those found for the whole sample (Main-Sequence stars within a heliocentric sphere of 100 pc). This especially affects the mean mass because for the subsample containing stars within 10 pc the mean mass is more than twice as small as the corresponding value for the whole sample - to compare $0.602 \ M_\odot$ to $1.288 \ M_\odot$. In addition, if the stars situated between the two heliocentric spheres - the radii are 10 pc and 100 pc, respectively - are concerned, the mean star mass tends to be even higher, closely approaching the value of $1.3 \ M_\odot$. The situation concerning Agekyan's factor is almost the same; whereas for the subsample of close stars its value exceeds 1.2, in the case of stars situated between the two heliocentric spheres mentioned above its value is about 1.07. As can be seen from Paper I, the fraction of close stars (Sample 2 in Paper I) is hardly over 1%. Therefore, it can be understood why there is, practically, no difference in the values of both mean star mass and Agekyan's factor for the whole sample and for the sample of stars situated between the two heliocentric spheres. Finally, Agekyan's factor, as a dimensionless quantity, cannot be less than 1 and the higher its value is, the stars within a given sample are more distant from having equal masses all. Therefore, we are inclined to think that the present study is heavily affected by observational selection. In what follows we shall try to corroborate this standpoint as strongly as possible.

3. ANALYSIS

Table 1 shows the numbers of stars within given mass intervals with the corresponding fraction in the total number for each interval. It is clearly seen that the interval between 0.1 $M_\odot$ and 0.5 $M_\odot$

has a very high fraction for the close stars, but after including the stars between 10 pc and 100 pc its fraction drops abruptly to about 4%. Bearing in mind the mass dependence on absolute magnitude (Fig. 1) we conclude straightforwardly that this mass interval contains dwarf stars (spectra K and M).
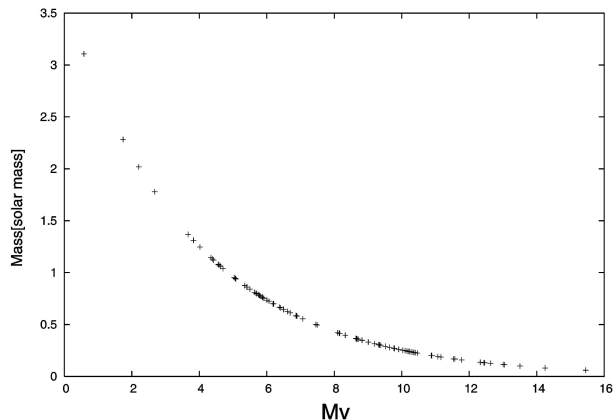
Fig. 1. *Mass versus absolute magnitude for MS stars within 10 pc.*

Their low brightness appears as a serious obstacle in their detection, but it seems to be clear that they are numerous, resulting, therefore, in a mean star mass definitively less than one solar mass; as a consequence Agekyan's factor is also expected to be about 1.2. In other words, in our opinion the whole sample is strongly affected by observational selection and, therefore, we tend to accept the values of 0.6 and 1.2 as final for the mean star mass and Agekyan's factor, respectively.

Table 1. Mass distribution of stars studied in the present paper: a) all stars b) stars within 10 pc.

a)

Mass interval	Number of stars	Fraction
0.1 - 0.5	368	0.0400
0.5 - 1.0	2531	0.2700
1.0 - 5.0	6588	0.6900
≥ 5.0	7	0.0007

b)

Mass interval	Number of stars	Fraction
0.1 - 0.5	47	0.50
0.5 - 1.0	32	0.34
1.0 - 5.0	15	0.16

4. DISCUSSION AND CONCLUSIONS

After accepting the final results one meets the question how reliable they are. Here we have three main items to consider. The first concerns the fraction of low-mass stars because if it is not so high, as found in this paper, then the present results become doubtful. A comparison can be done with IMF present in the literature. For example, Salpeter's law yields approximate values of $2M_\odot$ and 1.5 for the mean mass and Agekyan's factor, respectively. In all more recent papers dealing with the same subject (e.g. Miller and Scalo 1979, Lequeux 1979) it has been pointed out that the IMF slope introduced by Salpeter yields a very large fraction of massive stars, much larger than what can be based on the observational data.

On the other hand, the result of Reid et al. (2002), who obtain a value of about 0.03 $M_\odot$ pc^{-3} for the mass density of the MS stars at the Sun, can be in accordance with our estimate for the mean star mass because the corresponding number density of the MS stars seems to be realistic. Therefore, we conclude that on the basis of the subsample of stars closer than 10 pc it is possible to get a realistic information concerning the rate of K and M dwarfs among MS stars.

In Ninković's (1995) analysis the mean star mass was found to be about 0.59 $M_\odot$, in excellent agreement with the present result, but the corresponding value of Agekyan's factor was about 2.0, significantly higher than the one found here. This discrepancy can be explained by the mass distribution assumed there, which differs from what we obtain here. However, in our opinion this merely indicates how still uncertain the mass distribution of stars is and that a lot of future work is required for the purpose of answering this important question. In addition, the mean value for the total mass of a double star, of 1.6-1.7 $M_\odot$, found by Trajkovska and Ninković (1997) is also in a fair agreement with the present result for the mean star mass.

Some very recent results (e.g. Kroupa 2001, Reid et al. 2002) indicate that stars with masses greater than 5 $M_\odot$ are very rare, almost extremely rare in accordance with what we find here (Table 1).

The second item concerns the relation used by the present authors for the purpose of obtaining mass values. To the comments given above we may add that in the sample studied here we find only two cases with masses less than 0.1 $M_\odot$. Both stars are, of course, among those within 10 pc. However, bearing in mind that stars of such low masses are expected to be very faint we do not think that these two mass values are realistic. For this reason they are rejected and not analysed. On the other hand, the mere circumstance that we have only two such cases, in our opinion, is in favour of the satisfactory quality of the mass-luminosity relation used in the present paper.

Finally, in estimating the mean star mass and Agekyan's factor one, certainly, must take into account the presence of non-MS stars in each of our samples because for them there is no reliable mass-

luminosity relation. In order to indicate the rate of non-MS stars we present the HR diagram for the Hipparcos stars within 10 pc (Fig. 2).
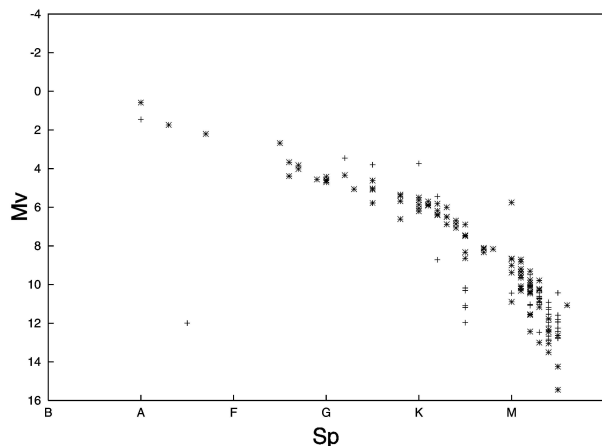

Fig. 2. *HR diagram for all stars within 10 pc.*

According to this figure they seem not to be very numerous. Here one should be cautious because of white dwarfs. They are quite faint and, consequently, not easily detectable. However, Fig. 2 shows a very poorly populated WD branch among these very close stars (within 10 pc). In addition Reid et al. (2002) write that the contribution of white dwarfs to the mass density at the Sun is not higher than 4×10^{-3} $M_\odot$ per cubic parsec. With regard to the

mass values which could be expected for them this might mean that the contribution of white dwarfs to the local number density is rather small.

Based on all of this the present authors are ready to conclude that the mean star mass, at least in the solar neighbourhood, is very probably about 0.6 $M_\odot$ and Agekyan's factor about 1.22, in accordance with the preliminary values given in Paper I.

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О РАСПОДЕЛИ МАСА ЗВЕЗДА У СУНЧЕВОЈ ОКОЛИНИ

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Анализирају се узорци који се састоје од звезда из каталога "Хипаркос". Масе звезда са главног низа се процењују према одговарајућем ХР дијаграму из њихових визуалних апсолутних величина. Установљује се да већ изван хелиоцентричне сфере полупречника 10 рс ефекти посматрачке селекције у односу на К и М патуљке постају веома јаки. Из тог разлога аутори рада сматрају да су резултати у вези са овом сфером реални, тј. да

је удео звезда малих маса (мање од половине Сунчеве масе) око 50%, па стога средња маса једне звезде треба да износи око 0,6 Сунчевих маса, а Агекјанов чинилац око 1,2. Такође из података који се односе на удаљеније звезде потврђује се да су звезде масе веће од 5 $M_\odot$ врло ретке. Изгледа да бели патуљци нису сувише чести у близини Сунца тако да њихово присуство не може да има већи утицај на главне резултате овог рада.