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ON THE TOTAL MASSES OF VISUAL DOUBLE STARS

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SUMMARY: The subject of the study is a sample from the Gliese-Jahreiss catalogue containing 77 visual binaries. Their total masses are determined both statistically (by using the parallaxes, apparent magnitudes and spectra from the catalogue) and dynamically (by using the orbital data). The authors find that the agreement between the total masses determined in these two different ways is largely satisfactory.

1. INTRODUCTION

There is no doubt that the mass determination is very important in stellar astronomy. It is very well known that the mass of a stellar system can be estimated in two ways - statistically through the individual masses of stars concerned and dynamically, usually by applying the virial theorem.

This is also true of the most simple stellar systems - the double stars. The statistical estimate in their case is made clearly by the use of the mass-luminosity relation. The progress in astrophysics has enabled a relatively correct mass estimating for individual stars (above all for those from the main sequence) by applying this relation (e. g. Angelov, 1993a; Angelov, 1993b and the references therein). The corresponding dynamical estimate is, clearly, based on the Third Kepler Law (TKL) it being also a variant of the virial theorem.

The visual binaries are suitable for both approaches in the mass determination; if their spectra and distances are known, there are all prerequisites to try the individual-mass estimating. On the other hand for many of them the orbital data - period, semimajor axis and the rate of the B component in the total mass - are available (e. g. Popper, 1980). Unfortunately, the number of those pairs, where these elements are reliable enough, is really small as noticed in the same reference (Popper, 1980). Besides, the distance uncertainty appears as the additional complication since the TKL application requires the true semimajor axis to be known (not the angular one).

Among the reasons for this low reliability of the orbits may be the circumstance that visual binaries are, as a rule, wide pairs so that even for the nearby ones the periods can be very long (say, several centuries). Therefore, the importance of knowing the distances is clear enough. In such cases a sufficiently reliable estimate of the individual masses is possible. For this reason for the visual binaries with reliable distances a comparison of the values of their total masses obtained statistically to those obtained dynamically is important. In our opinion nearby visual double stars offer such a possibility. This time we apply some recent concepts of the mass-luminosity relation (e. g. Angelov, 1993b) which are compared with earlier ones (e. g. Popović and Angelov, 1970).

2. PROCEDURE

As the data source we use the Gliese-Jahreiss catalogue. This catalogue contains the data for 3803 nearby stars. All of them have known parallaxes whereat in most cases these parallaxes are trigonometric ones. This circumstance, certainly, contributes to their high accuracy. The other data, relevant for the present study (magnitudes, spectral types), are also given in the catalogue, usually with a sufficient accuracy (usually because not for all of them all the data are given with high accuracy). The catalogue has not been published; it is available on a diskette only. Thanks to the courtesy of our Russian colleagues (V. V. Orlov - St-Petersburg University and A. A. Müllari - University of Petrozavodsk) we have got such a diskette.

According to our finding there are 405 visual binaries in the catalogue where a third component has not been suspected. Since the spectra are not given for both components in all these cases, we cannot treat such pairs. Therefore, there are 217 systems with all data necessary to us. With regard to the distances being known and to our dealing with nearby stars, we can easily obtain the absolute magnitudes without taking into account the interstellar absorption. With these absolute magnitudes and spectral types we can construct the HR diagram (Fig. 1).

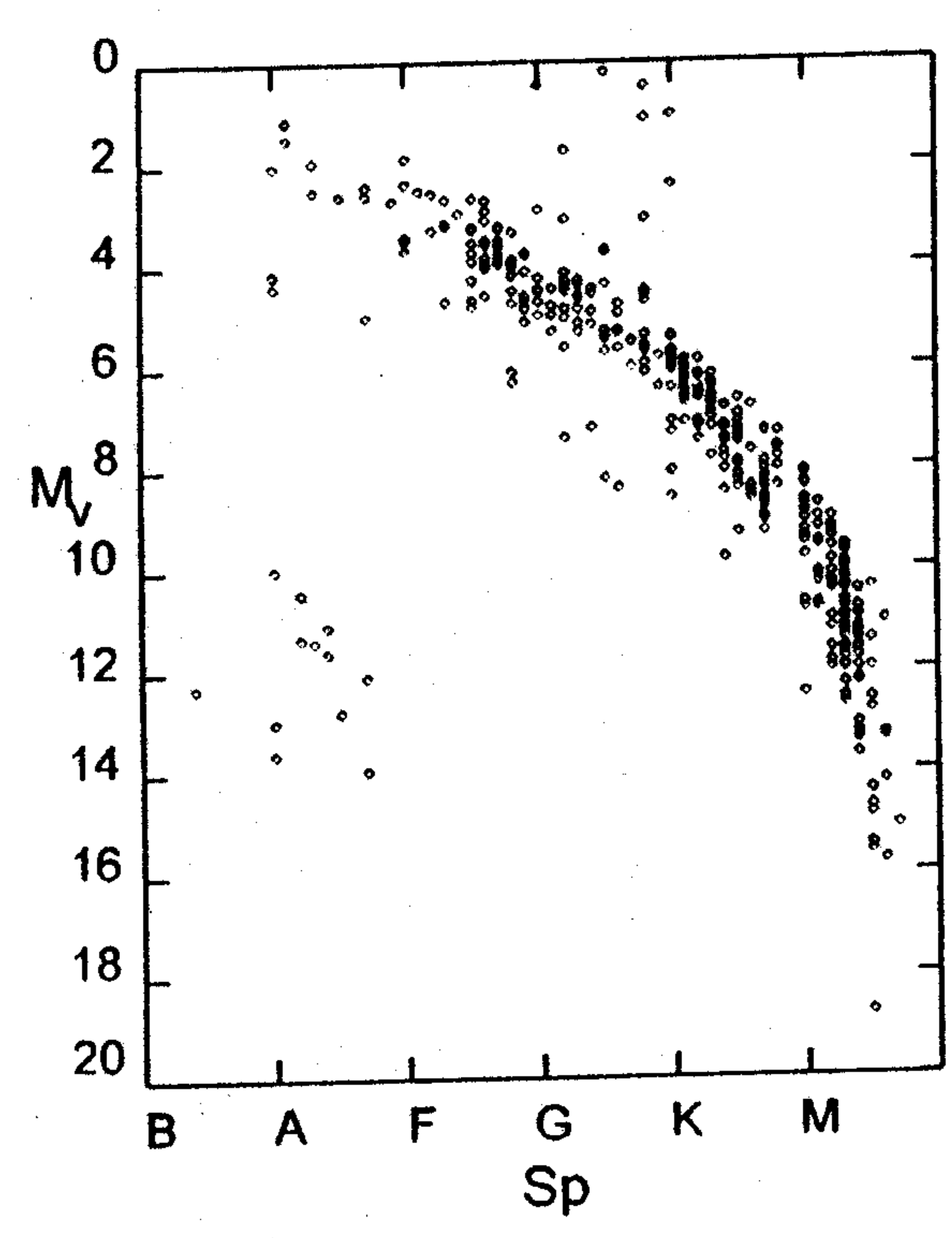

Fig. 1. The HR diagram for the visual-binary components from Gliese-Jahreiss Catalogue; explanations: 1.0 - O0, 2.0 - B0, 3.0 - A0, 4.0 - F0, 5.0 - G0, 6.0 - K0 and 7.0 - M0.

It is seen from Fig.1 that there are 31 systems for which at least one component is not on the main sequence (MS). All of them are eliminated from the further study so that finally we have 186 pairs with both components on the MS. As for the distribution of their spectral types, it is seen that there is none earlier than A and that a vast majority belong to F-M the types, especially to the region around K - the so-called "knee" of the main sequence. This is not surpising since we deal with nearby stars and also in most cases the components within a given system are mutually similar as to their spectral types and absolute magnitudes.

In the case of these pairs the mass of each component is estimated on the basis of the mass-luminosity relation. We use two particular forms of this relation. One of them (Popović and Angelov, 1970) connects the masses with the absolute magnitudes, but this is rather a set of such relations (each one for a different MS part). The other one (Angelov, 1993b) yields a (nonlinear) connexion between the mass and bolometric magnitude valid for the entire MS. The bolometric corrections are found on the basis of the spectra by using the data given in Kulikovskij, (1985) and Popper, (1980).

Both relations yield almost identical mass values. By simple adding we obtain the total masses of all 186 systems. These are the masses obtained statistically.

In order to verify the reliability of these masses their values should be obtained also dynamically, by means of TKL. For this purpose we need their orbits. We find such data from three main sources: the Gliese-Jahreiss Catalogue, Gliese's (1969) catalogue and the list of Worley and Heintz (1983). We have the orbital data for only 77 pairs out of our total containing 186 ones.

3. RESULTS

The comparison of the total masses obtained statistically with those obtained dynamically is presented in Fig. 2. Though a significant scatter is no-

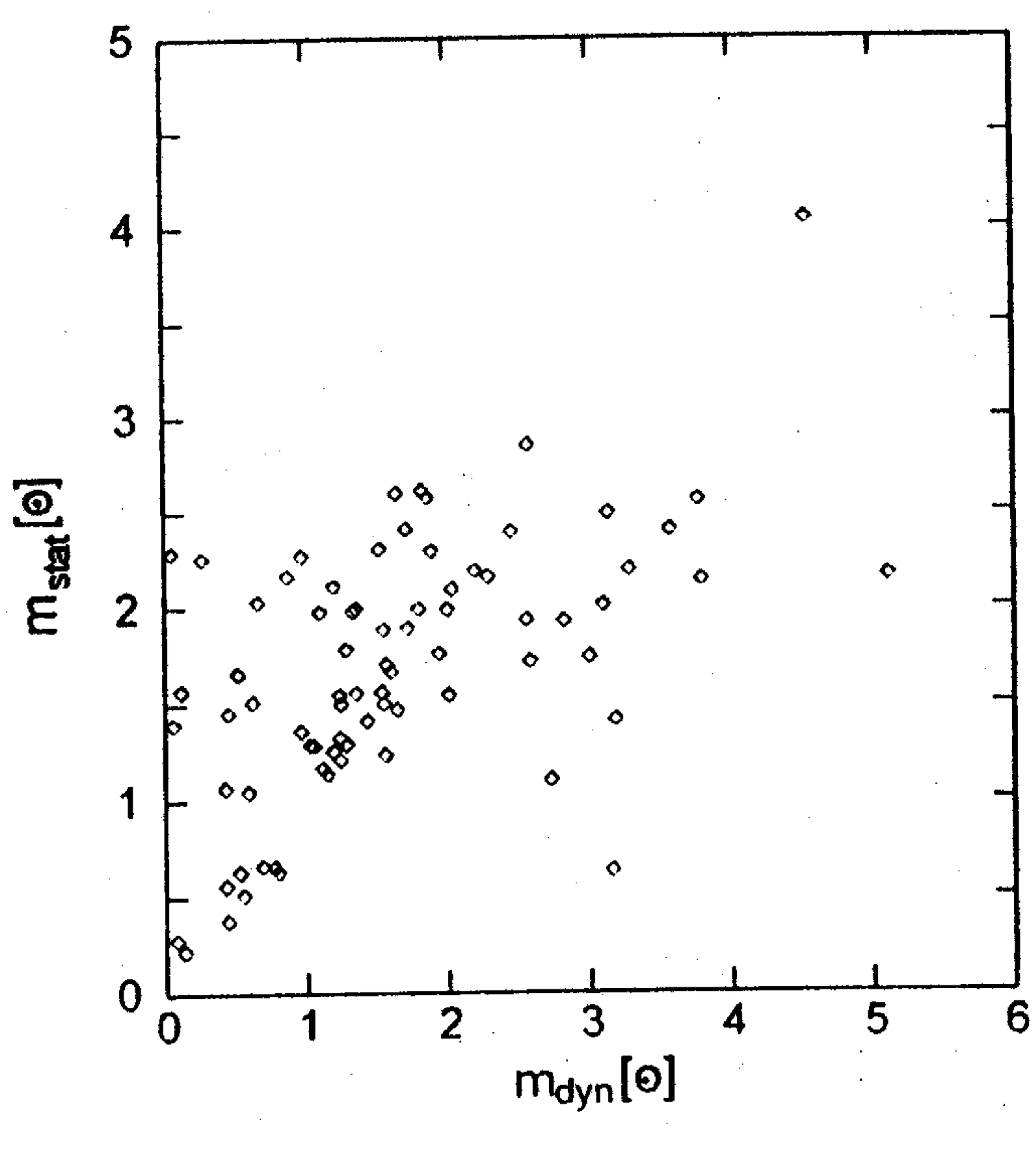

Fig. 2. The dependence of the "statistical" total mass on the "dynamical" one; mass unit $\mathcal{M}_\odot$.

ticeable, the agreement is, nevertheless, satisfactory. In favour to this is the distribution of the mass differences presented in Fig. 3. As seen from this Figure, the majority of mass differences is within 1 $\mathcal{M}_\odot$ and both signs are practically equally frequent. In order to establish whether the scatter from Fig. 2 is realistic or it is rather due to the errors we undertake a more thorough examination; here it should be commented that the concentration towards small mass differences is even more prominent if the intervals (the width unchanged - 0.5 $\mathcal{M}_\odot$) are centred on 0, ± 0.5, ± 1, ..., instead of ± 0.25, ± 0.75, ... (in solar masses) as in Fig. 3. The mean values for the total masses calculated in two different ways are rather similar: 1.68 $\mathcal{M}_\odot$ for the "statistical" masses and 1.62 $\mathcal{M}_\odot$ for the "dynamical" ones.

Fig. 4 presents the dependence of the differ ences in the total masses on the parallaxes. It i seen that for the case of small parallaxes (distanc exceeding 10 *pc*) the mass differences tend to be mor prominent. A similar situation is with their depen dence on the periods (Fig. 5). Considering that ou sample contains visual binaries, even in the case o nearby ones as already said above, we have a selec tion against those with short periods. On the othe hand, long periods, as a rule, mean unreliable orbits This is more clearly seen from Fig. 6 which give the period-parallax dependence; the long periods are characteristic of small parallaxes.

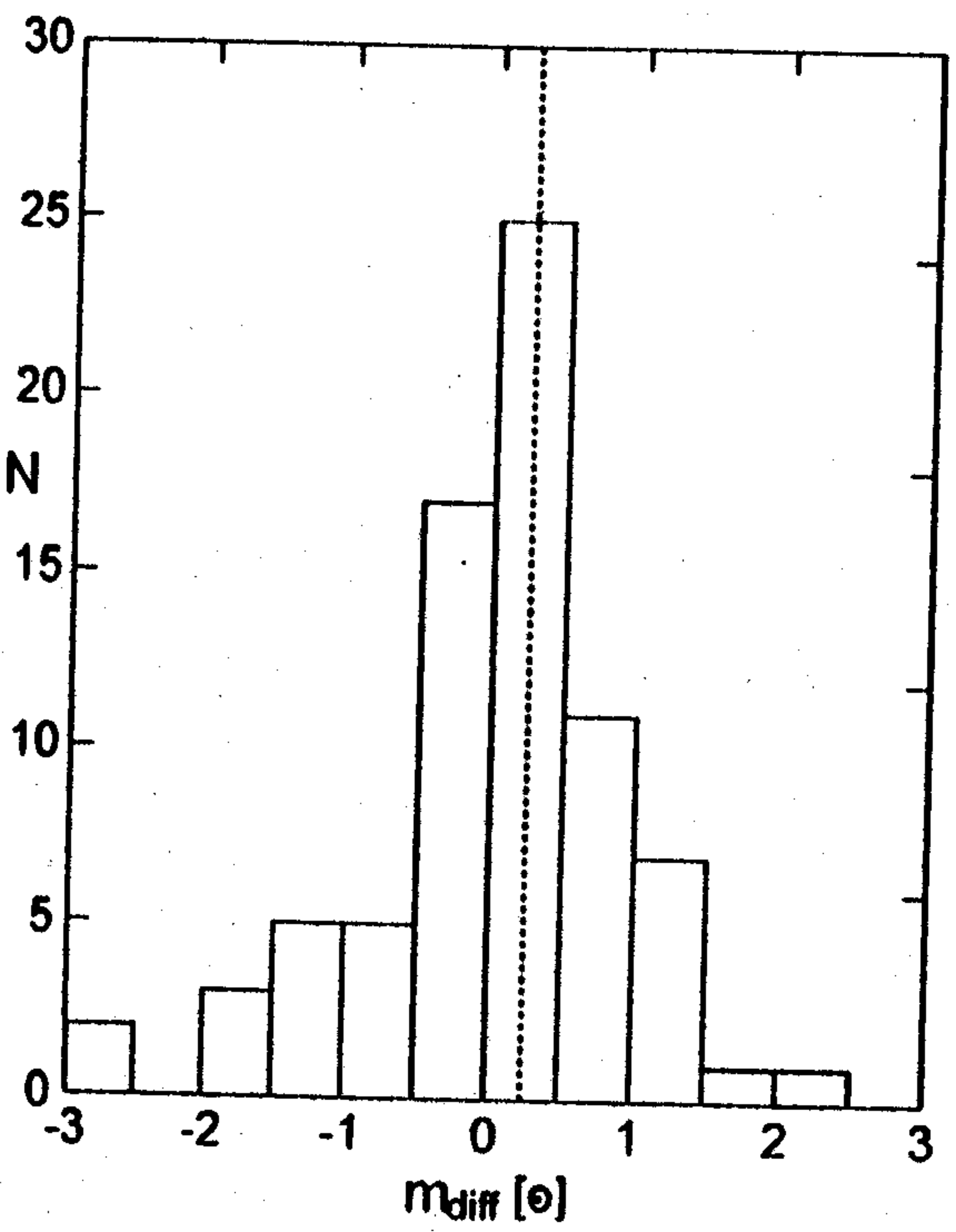

Fig. 3. The histogram of the mass differences - $\mathcal{M}_{stat} - \mathcal{M}_{dyn}$.

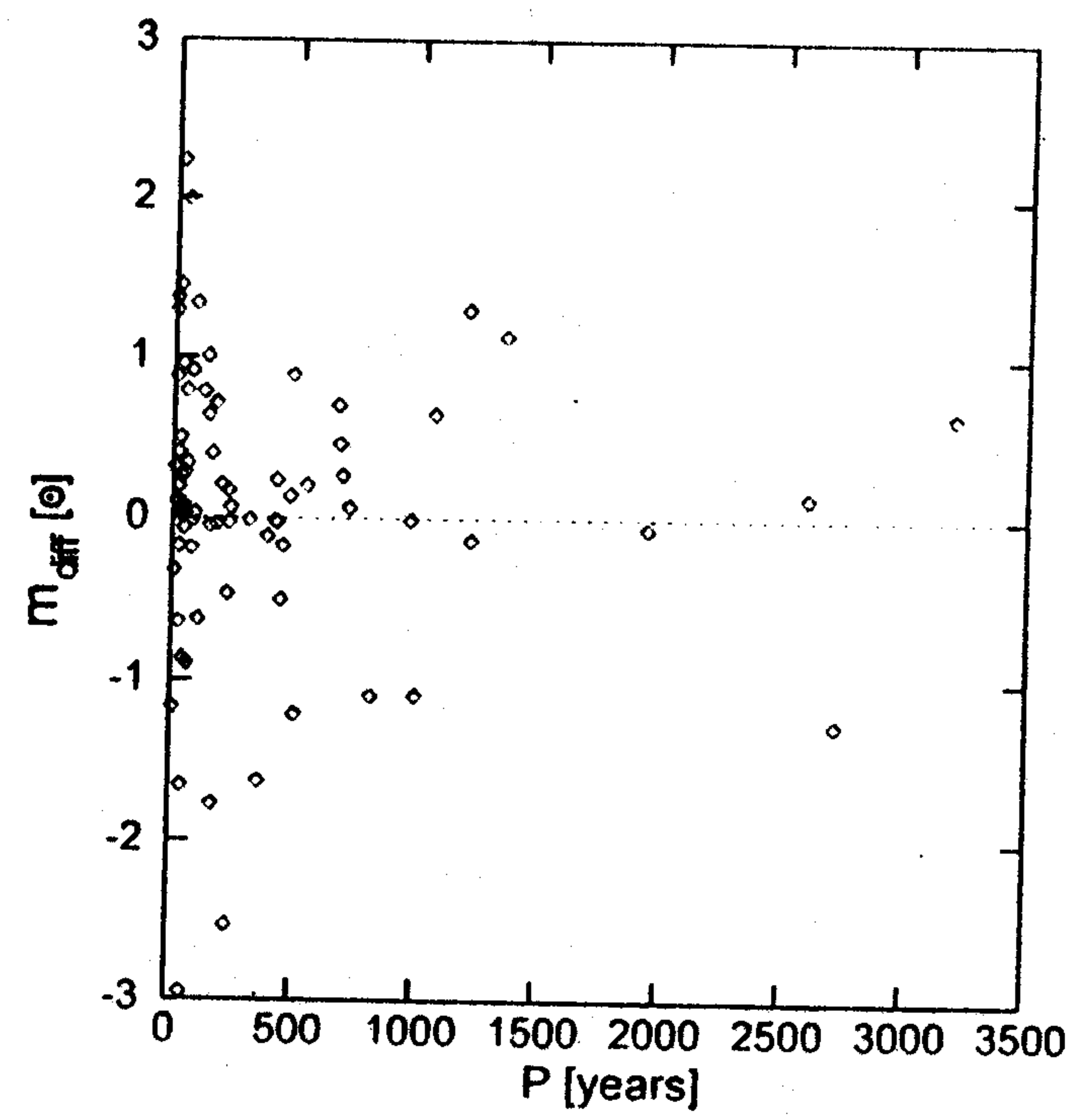

Fig. 5. The mass difference versus period (in years).

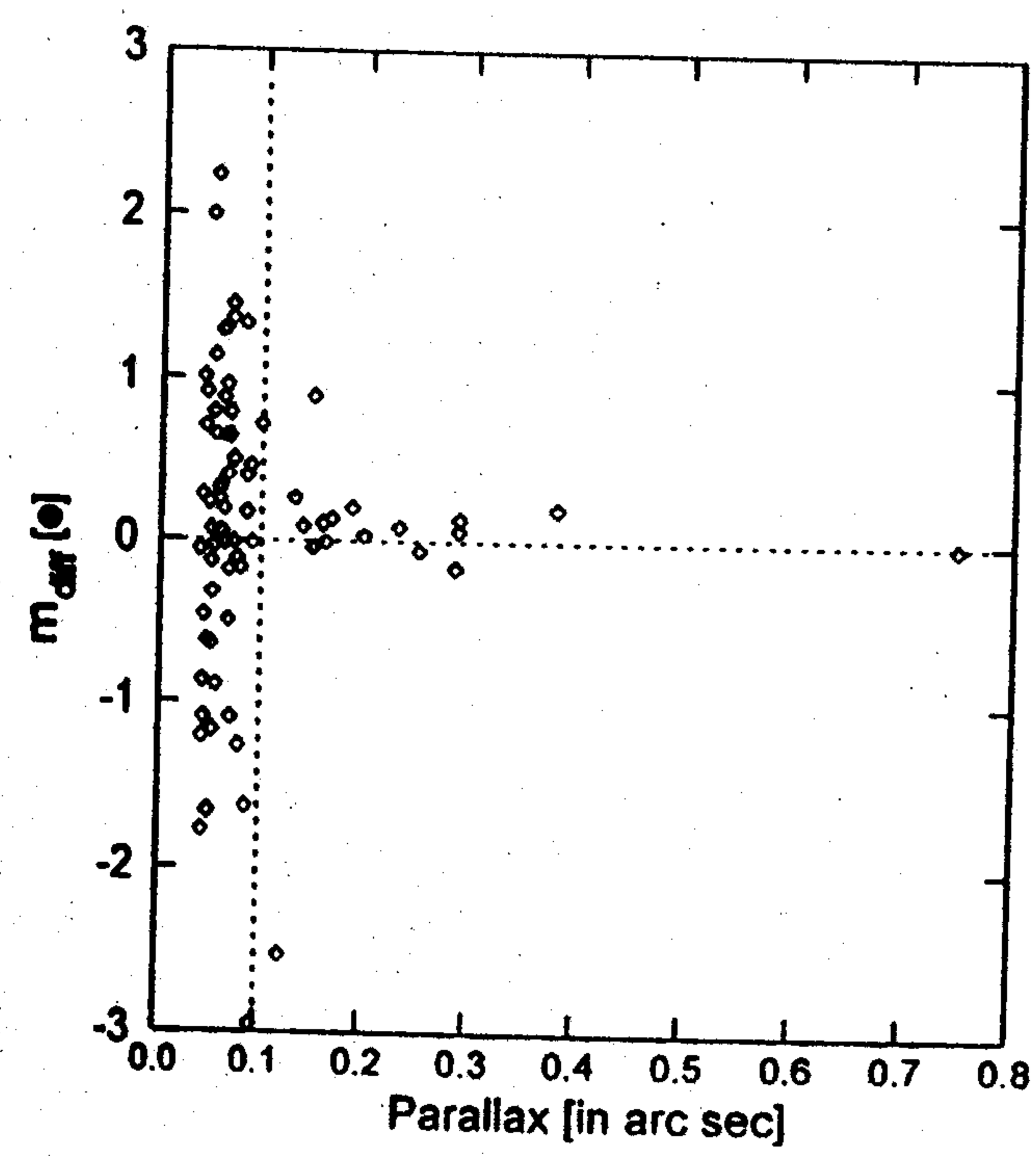

Fig. 4. The mass difference versus parallax (in arc seconds).

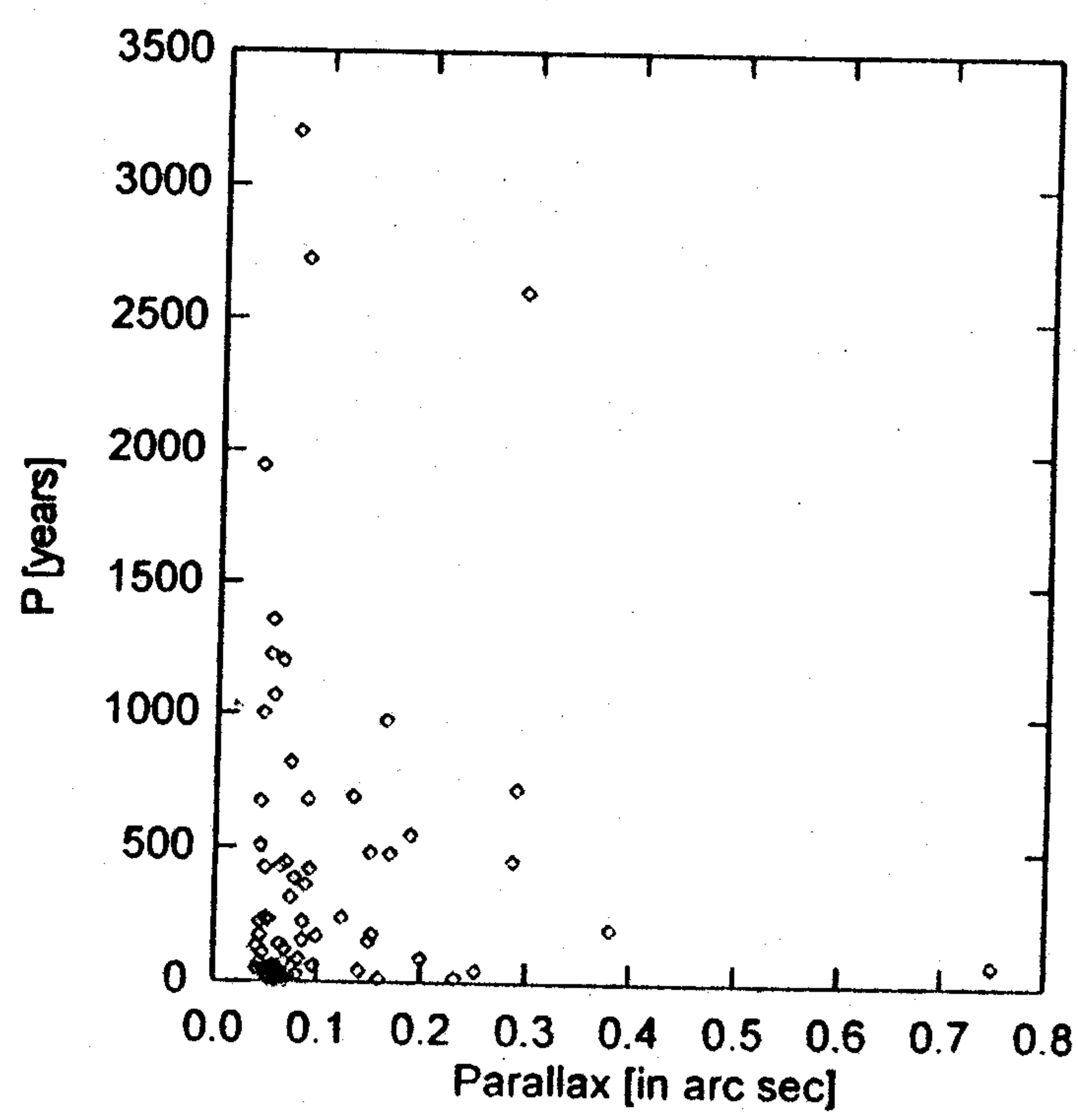

Fig. 6. Period (years) versus parallax (arc seconds).

4. DISCUSSION AND CONCLUSIONS

Based on the preceding section we conclude that the agreement between the total masses of visual binaries from our sample calculated in two different ways - statistically (mass-luminosity relation) and dynamically (TKL) - is satisfactory. The large deviations found in some cases can be largely attributed to the observational errors. In our opinion the "statistical" total masses seem more reliable, first of all, because the orbital data are very uncertain. This is confirmed by the fact that in many cases the periods have been estimated at several centuries (Fig. 7). Such periods clearly exceed the time intervals accessible to modern measurements.

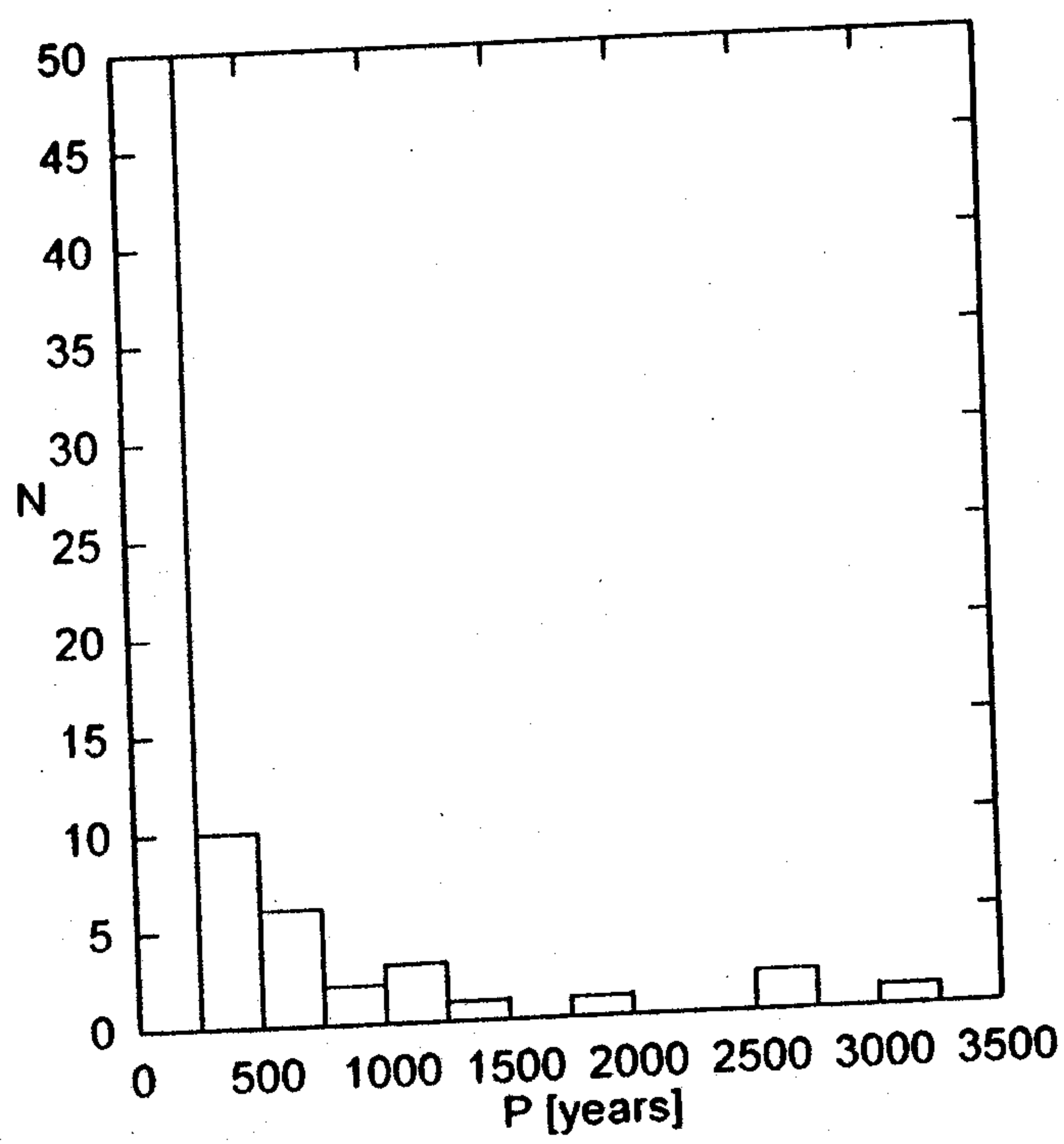

Fig. 7. The histogram of periods (years).

Error estimations carried out by us are in favour of this statement. In the case of the "statistical masses" the input data are the apparent magnitudes, the spectra and the distances. The accuracy level of the former two is high indeed so that the main effect is due to the distance. Without taking into account the quality of a mass-luminosity relation it may be said that the relative errors of the total mass and the distance are approximately equal. Bearing in mind that here we deal with a sample of nearby double stars, their distances are known to a few percent of accuracy so that we estimate the relative error in the total mass determined statistically to at most 10%. On the other hand, the distance enters in the total mass determined dynamically with its third power, a circumstance diminishing the accuracy of the mass determination significantly compared to that of the statistical determination on the basis of the distance alone. The inclusion of the accuracies of the angular semimajor axis and the period acts on the reliability as an additional diminishing. Therefore, we estimate the relative errors of the total masses determined dynamically to some 10%, thus as significantly exceeding the corresponding errors in the case of the statistical determination. Of course, such a statement does not involve any consideration of the reliability question concerning the mass-luminosity relation itself.

As for the particular type of this relation used here, it has been tested on ten examples (Angelov, 1993b) and it is seen that the deviations, except in one case, do not exceed $|0.15|\ \mathcal{M}_{\odot}$. Such an amount is quite within the error limits specified by Popper (1980) for the same systems. However, it seems to us that the error amounts given by Popper are too conservative, i. e. that the real mass errors are higher bearing in mind that among the ten systems analysed by Angelov (1993b) there are four with periods exceeding a century. Therefore, one can expect the "statistical" masses to be reliable enough, though the correctness of the mass-luminosity relation cannot be equal to that of TKL.

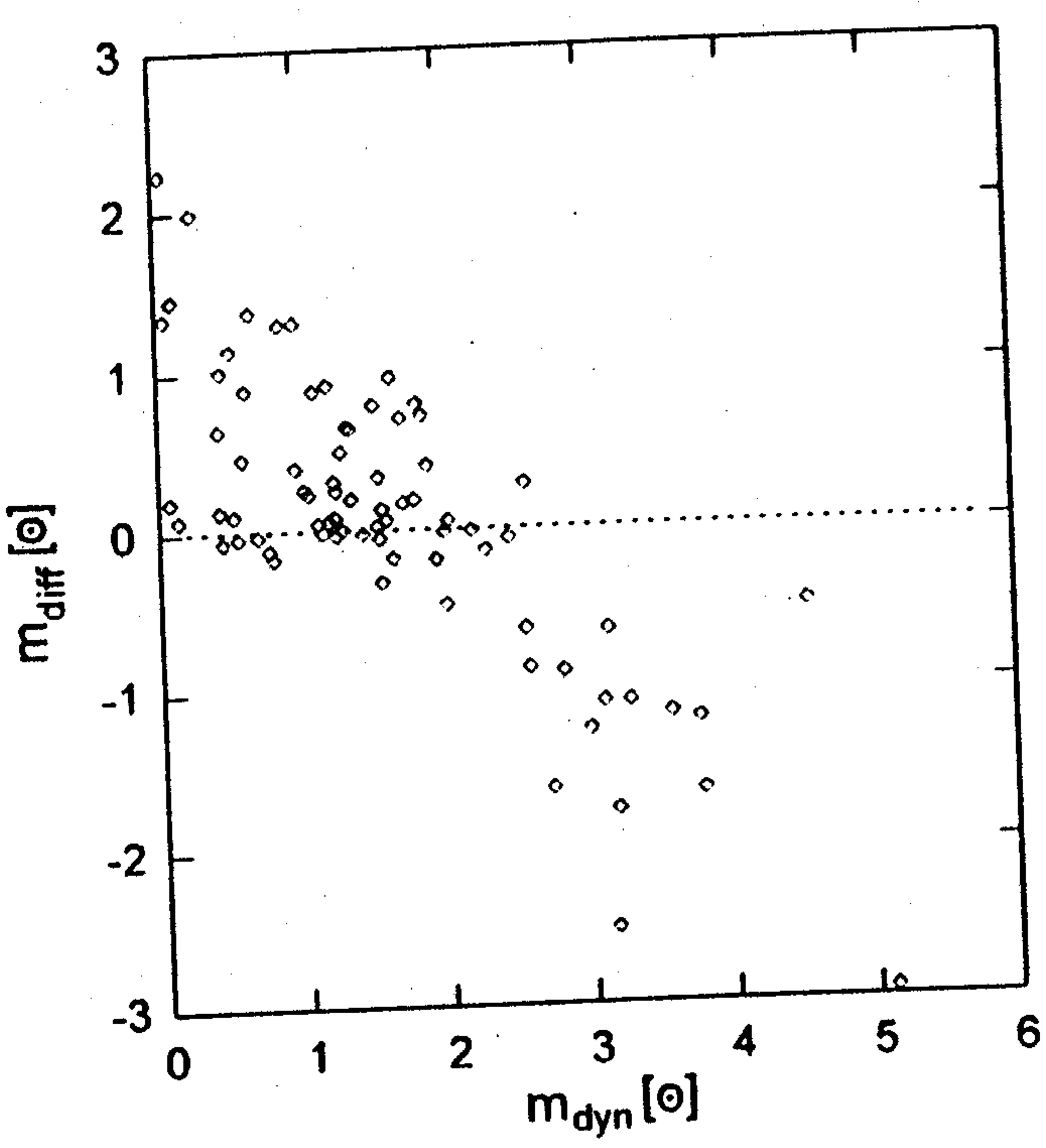

Fig. 8. The mass difference (as in Fig. 3) versus total "dynamical" mass.

The mass difference distribution (Fig. 3) resembles a gaussian curve, i. e. most likely the scatter in Fig. 2 is due to the measuring errors. However, the "statistical" masses are on the average higher. It is curious to note that in the very small sample of visual binaries with reliable orbits discussed by Angelov (1993b) the same effect occurs. Perhaps, his relation yields systematically higher masses (in general, or at least for some MS parts)? In order to examine this question more thoroughly we study the dependence of the mass differences on the total masses themselves. Fig. 8 presents their dependence on the "dynamical" total masses, Fig. 9 gives the same thing for the case of the "statistical" ones. Different trends are noticeable. Fig. 8 indicates a systematic trend, whereas the other one indicates a random situation. Our opinion is that this circumstance is in favour of our conclusion reached above that the dynamical masses are less accurate and therefore the sign of the mass difference is correlated with the total-mass amount determined dynamically.

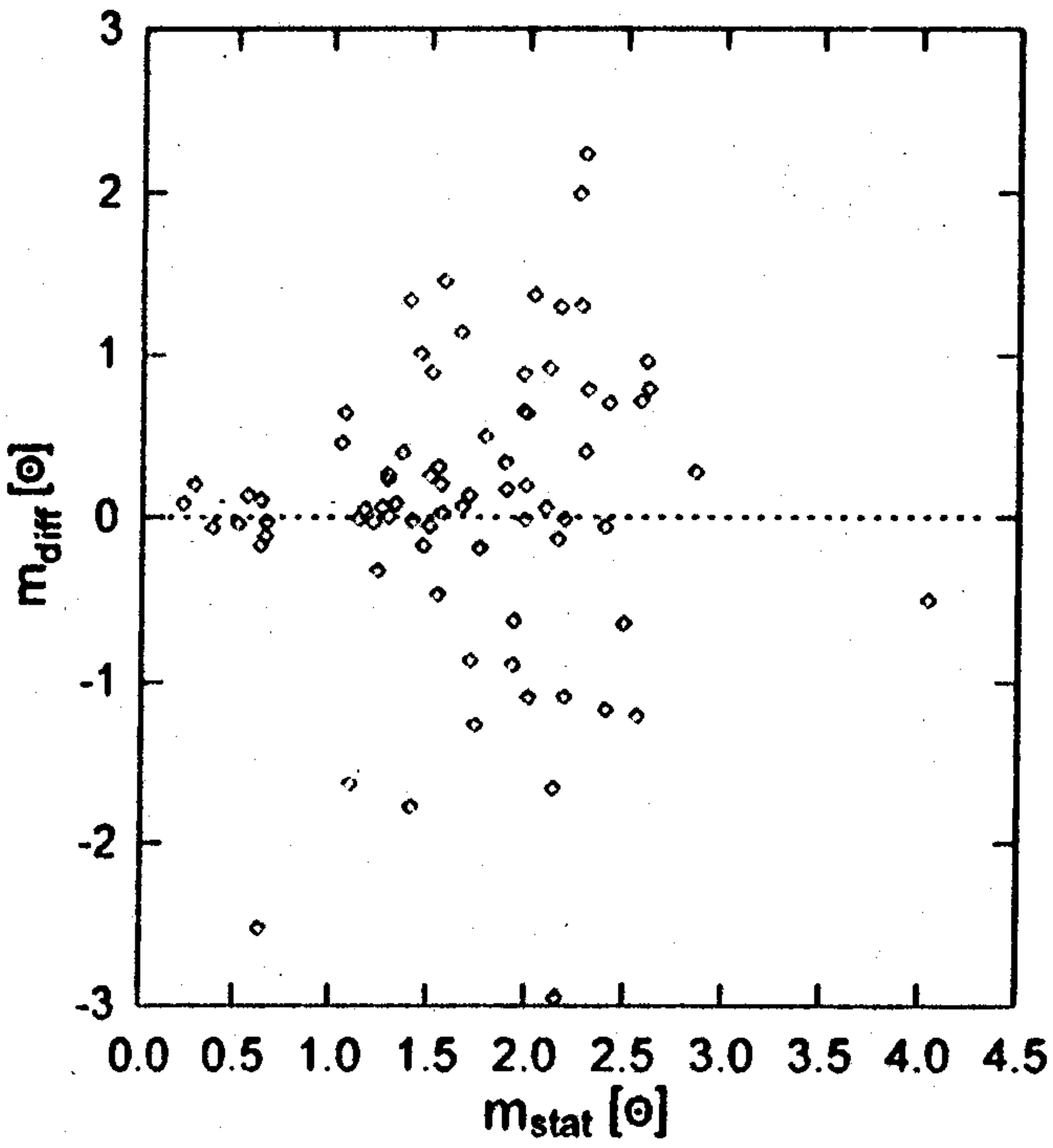

Fig. 9. The mass difference (as in Fig. 3) versus total "statistical" mass.

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О УКУПНИМ МАСАМА ВИЗУАЛНО ДВОЈНИХ ЗВЕЗДА

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Оригинални научни рад

Предмет овог проучавања је узорак из Глизе-Јарајсовог каталога који садржи 77 визуално двојних звезда. Њихове укупне масе су одређене и статистички (коришћењем паралакси, привидних величина и спектара из каталога) и динамички (коришћењем података о орбитама). По мишљењу аутора слагање између укупних маса одређених на ова два начина је углавном задовољавајуће.