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Mass determination for visual binaries

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We consider a sample of 432 visual binaries having orbital elements and belonging to the Main Sequence. We calculate their total masses using the orbital elements and the new Hipparcos parallaxes by applying Kepler's third law. For the same pairs the total masses are also found by applying the mass-luminosity relation. The source for the apparent magnitudes is the Washington Double Star Catalog. The Keplerian total masses show a large scatter. Nevertheless, in a large number of cases the agreement between total masses obtained in these two different ways is quite satisfactory indicating that i) for many visual binaries, as a rule not too distant and with high-quality orbital elements, the Keplerian total masses can be reliable and ii) a correlation between the relative parallax error and orbit grade exists.

Keywords: Binaries: visual; Stars: fundamental parameters (apparent magnitudes, masses, parallaxes, spectral types)

1 Introduction

To obtain reliable total masses of binaries it is important to have both accurate distances and high-quality orbital elements. The most accurate distances follow from trigonometric parallaxes. For a large number of stars they were obtained as a result of the Hipparcos mission.

New measurements mostly due to various observational techniques of high angular resolution (speckle interferometry, lunar occultations, adaptive optics, eyepiece interferometry, etc.) are significantly more precise than earlier ones. They offer the possibility to calculate new orbits and recalculate previous orbits. The database for the orbital elements is the Sixth Catalog of Orbits of Visual Binary Stars† which is updated regularly.

All orbits are graded on a 1–5 scale (1 = definitive, 2 = good, 3 = reliable, 4 = preliminary and 5 = indeterminate). The best grade (1) characterizes a very low fraction (about 3% only). Many orbits were determined from low-precision measurements or from those covering a short orbital arc. Consequently, such orbits have worse grades and their improvement is necessary.

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†http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/orb6

In the case of many binaries photometric and spectroscopic data are also available such as apparent magnitudes of components m_A and m_B, as well as spectral types (Sp), which can be found in the Washington Double Star Catalog, WDS.*

The aim of the present examination is to reach a better insight into the quality and reliability of the data mentioned above. This may be useful in identifying those binaries for which some of the given data require a substantial improvement.

It is then of interest to compare the masses determined on the basis of the mass-luminosity relation (astrophysically) to the masses of binaries determined via Kepler's third law (dynamically).

The first version of this study [1] was published in 2007. The work was continued including new data: photometric data, orbital elements and trigonometric parallaxes. The full account has been already published [2]. It contains two approaches (details in [2]) which resulted in an insignificant difference. This is the reason why we present here the results based on one of the two approaches only.

Unlike the first version [1] where we used the old Hipparcos parallaxes [3] and the data from the Washington database, in [2] and here we use the new Hipparcos parallaxes [4] obtained in the framework of a new reduction of the Hipparcos astrometric data [5], new orbital elements, as well as the other data announced in the meantime. It should be expected that improved parallaxes will contribute, on the one hand, to obtaining more reliable masses of binaries from the orbital elements and, on the other hand, to estimating the reliability of the orbital elements themselves.

2 Procedure

In the Sixth Catalog of Orbits of Visual Binary Stars we find 432 pairs which, according to the data given in WDS, belong to the Main Sequence (MS). This sample is divided into two subsamples: one with 67 pairs where the spectral type is given for both components and another one with the remaining 365 pairs where only one spectral type is given. It is quite probable that it concerns either the primary in the case of wide pairs or both components in the case of close pairs. These two subsamples are examined separately.

With the orbital elements (period P and semimajor axis a) and the new trigonometric parallax we calculate the total masses applying Kepler's third law for the whole sample of 432 visual binaries. The input data can be found at website.†

For the purpose of calculating the total masses on the basis of mass-luminosity relation we need the photometric and spectroscopic data (m_A, m_B, Sp) and we take them from WDS. In calculating the absolute magnitudes the new trigonometric parallaxes are applied. The interstellar extinction is neglected since we deal with stars sufficiently close to the Sun.

The individual masses are obtained from their luminosities by using the relation proposed by Angelov [6] where the absolute bolometric magnitudes are input data. Throughout this paper our source for the bolometric corrections (BC) is a table in [7], on page 110. In the case of the subsample of 67 binaries, BC is applied for each component according to the given Sp, whereas in the case of the subsample of 365

*http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/WDS
†http://saj.matf.bg.ac.yu/180/pdf/Table1.pdf

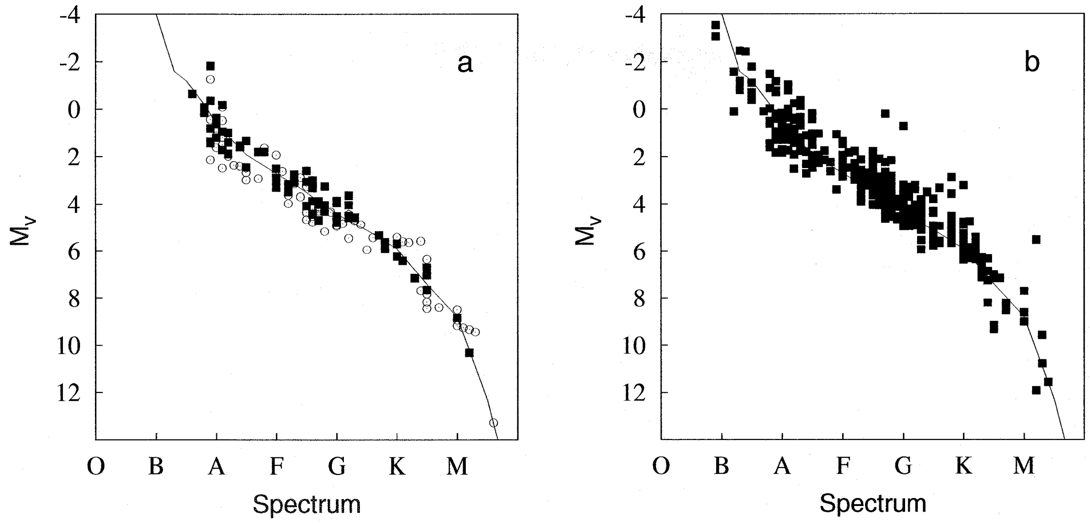

Figure 1 Absolute visual magnitudes versus spectral types: a) for the subsample of 67 binaries b) for the subsample of 365 binaries; filled squares – primary components, open circles - secondary components; the curve follows the dependence given in [7].

binaries, we assume BC according to our estimate of *Sp*. The sums of these individual masses are compared to the Keplerian masses.

3 Results

The application of the mass-luminosity relation requires the stars to belong to MS. Therefore, using the absolute visual magnitudes and spectral types we construct the corresponding HR diagram. In the case of the subsample of 67 binaries, since the spectral types are available for both components, HR contains both the primaries and the secondaries (Fig. 1a). The same is also presented in the case of the subsample of 365 binaries (Fig. 1b) containing the primaries only. The curve passing through the points is obtained by means of the dependence between the absolute visual magnitude and spectral type according to the table from [7]. The points are concentrated around the curve sufficiently closely. The scatter is affected, among others, by the errors in the trigonometric parallax. In this case, with reference to the fact that only one spectral type is given, we cannot be sure whether it concerns the primary indeed, or, perhaps, this is the integrated spectral type. This, combined with the parallax, contributes additionally to the scatter seen in Fig 1b.

The spectral type of the components can be also estimated on the basis of their visual absolute magnitudes. For about 40% of the binaries from the subsample containing 365 binaries the difference of the individual visual apparent magnitudes m_A and m_B is significant; in particular $\Delta m > 0.7$, which is also the difference between the corresponding absolute magnitudes. The spectral types of the components are found on the basis of the dependence visual absolute magnitude versus spectral type given in [7]. The results can be found at website.[‡] For a majority among the 365

[‡]http://saj.matf.bg.ac.yu/180/pdf/Table2.pdf

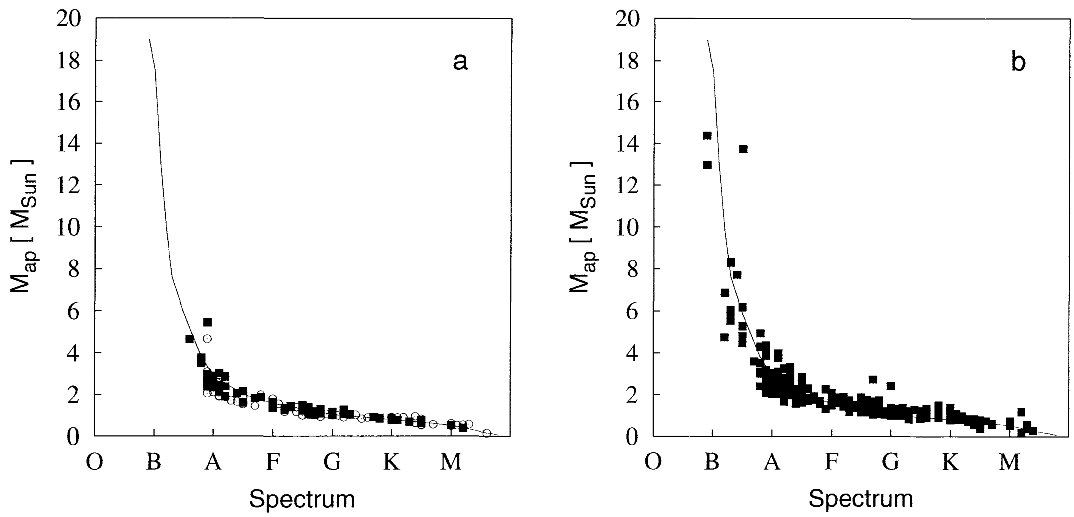

Figure 2 Astrophysical mass versus spectral types: a) for the subsample of 67 binaries b) for the subsample of 365 binaries; filled squares – primary components, open circles - secondary components; the curve follows the dependence given in [7].

pairs the spectral type of the primary found by us and that given in WDS are very close to each other.

In order to examine the values of the astrophysical masses we plot them versus the spectral type. In the case of the subsample containing 67 binaries, the mass of each component is given (Fig. 2a). In the case of the subsample containing 365 binaries only the masses of the primaries are presented (Fig. 2b). It is seen that the dependence of the mass on the spectral type also follows closely the trend presented by the curve drawn on the basis of the corresponding dependence given in [7].

The component masses and the total mass for the binaries from the whole sample can be found at website.[§]

The comparison of the total masses obtained astrophysically and dynamically for both subsamples is seen in Fig. 3. There are only a few cases where the dynamical mass exceeds 100 solar masses, a value which is very unrealistic. They are out of the plot boundaries.

In the case of the subsample of 67 binaries (Fig. 3a) we have almost a straight line with very few outliers. In the case of the subsample of 365 binaries (Fig. 3b) the scatter is apparently larger which is contributed more by dynamical masses. The large deviations of the dynamical total masses from the astrophysical ones appear in cases when such a binary belongs to a multiple star, has a low parallax (generally unreliable), its orbit is of a low quality (grade $G = 3$, 4, 5), or a combination of these influences takes place.

A correlation between the orbit grade and relative error of the parallax is found. This correlation is shown in Fig. 4. It is clearly seen that, on the average, for orbits of low quality the relative parallax error is high. Now, the scatter of dynamical masses in Fig. 3 can be more easily understood. It is largely a consequence of low quality of both orbits and parallaxes.

[§] http://saj.matf.bg.ac.yu/180/pdf/Table3.pdf

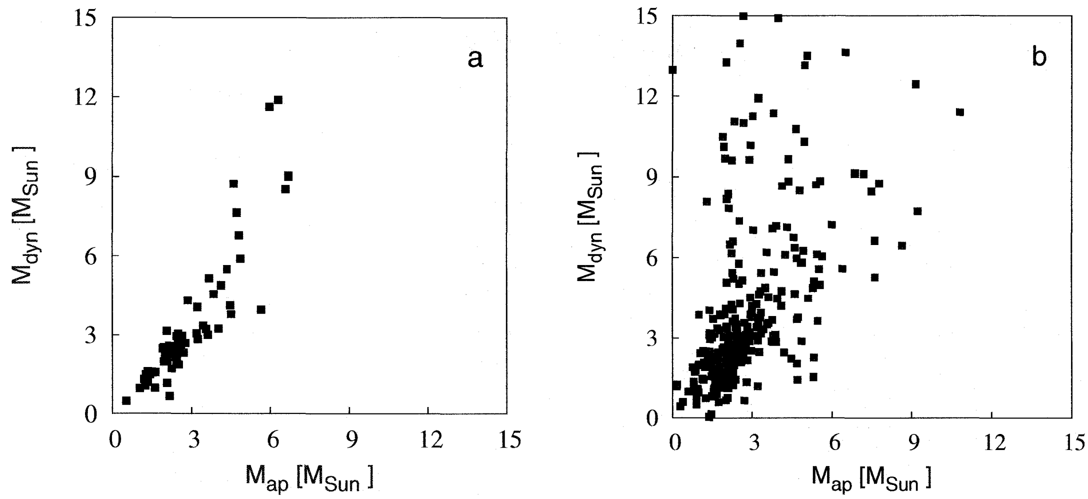

Figure 3 Dynamical mass versus astrophysical mass: a) for the subsample of 67 binaries; b) for the subsample of 365 binaries.

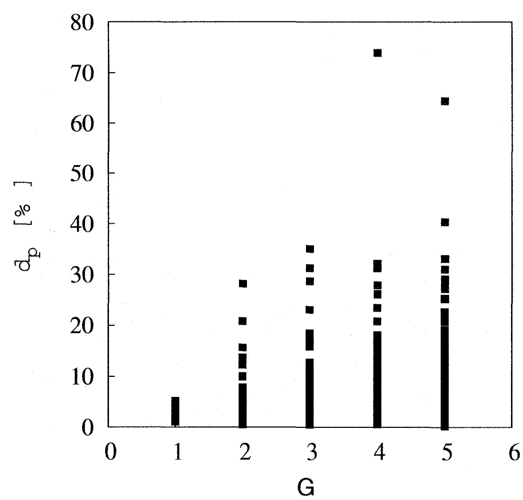

Figure 4 Relative parallax error versus orbit grade.

In the cases where we have orbits of high quality (grade 1, 2) and reliable parallaxes, the agreement between the astrophysical and dynamical total mass of a pair is generally very good. Therefore, the mass-luminosity relation assumed here appears sufficiently correct.

4 Discussion and conclusions

The dynamical total masses found here for the whole sample, show a very high dispersion attaining in some, though rare, cases either extremely high or extremely low values. In almost all these cases the orbital elements are classified with bad grades,

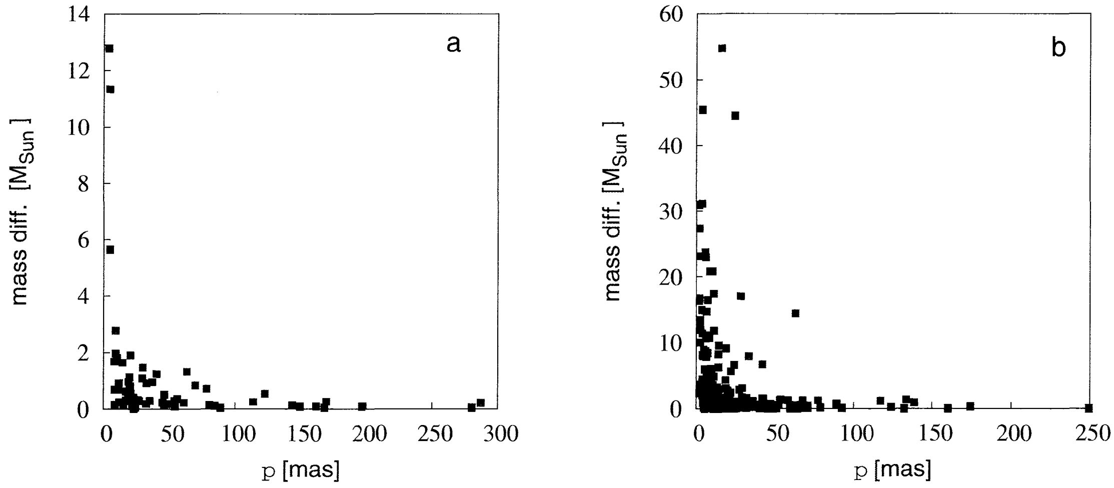

Figure 5 Mass difference versus parallax: a) for subsample of 67 binaries; b) for subsample of 365 binaries.

and the trigonometric parallaxes are very small, near the observational accuracy limit. A correlation is found between the orbit grade and relative parallax error. Taking also into account the well-known fact that the determination of the total mass via Kepler's third law is very sensitive to the inaccuracy of the parallax, as well as to that of the orbital elements, it becomes quite clear why the mass interval, covered by the dynamical total masses, is so wide to include sometimes unrealistic values. The parallax influence on the mass determination is examined also by plotting the modulus of the mass difference (dynamical and astrophysical) versus parallax (Fig. 5). As seen from Fig. 5, very high mass differences are typical for low parallaxes.

One may infer that the trigonometric parallaxes are generally sufficiently reliable inside of about 100 pc from the Sun. The spectral types estimated by us for the 365 pairs are more or less close to the spectral type given in WDS.

A general conclusion is that the astrophysical data (photometry and spectroscopy) are subject to significant noise, especially in the case of the secondaries where as a rule both apparent magnitudes and spectral types are much less certain than in the case of the primaries.

Besides, such comparisons of the total masses, as presented here, may help in distinguishing the visual binaries with sufficiently reliable parallaxes, and orbital elements of sufficiently high quality. They can then be used in further statistical analyses.

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