The Nearby Spectroscopic Binaries re–visited with Hipparcos

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Abstract

Some results of the Coravel survey of spectroscopic binaries among nearby stars are revised, using additional data coming from the Hipparcos satellite. The high precision Hipparcos parallaxes are used to select a sample of F7–K main sequence stars unaffected by the bias in favor of binaries with equally bright components. The Hipparcos astrometric measurements are combined with the elements of the spectroscopic orbits, providing important constraints on the mass ratios of the single–lined spectroscopic binaries. The distribution of the mass ratios of the binaries with periods shorter than 10 years is derived, taking into account the selection effects. This distribution is rising from $q = \mathcal{M}_2/\mathcal{M}_1 \approx 0.02$ to $q \approx 0.2$. It could be constant for $q > 0.2$. The distribution of logarithms of periods, P, is not constant, but rising. Finally, 11 % of the F7–K dwarf stars are binaries with periods shorter than 10 years.

1. The Coravel survey of late–type main sequence spectroscopic binaries

A search for spectroscopic binaries (SBs) was initiated about 20 years ago, with the Coravel spectrometer of the 1 meter Swiss telescope at the Haute–Provence Observatory. The goal of this programme was to study the binarity of nearby late–type dwarf stars. About 600 stars with spectral types F7 to K and declinations northern to $\delta = -15\,\mathrm{deg}$ were taken from the *Catalogue of Nearby Stars* (CNS2, Gliese 1969) and from its supplement (Gliese & Jahreiss 1979). In order to detect SBs, the radial velocities of these stars were measured during 9 years on average. 64 SBs with periods P shorter than 10 years were found. The spectroscopic orbits of these stars were obtained from additional observations performed until January 1999.

A statistical study of the solar–type stars of the sample was done by Duquennoy and Mayor (1991). Preliminary results about the K dwarfs were presented in Mayor et al. (1992). Statistical investigations about F7–K dwarfs were carried out by Halbwachs, Mayor and Udry (1998). However, all these works were based on presumed unbiased samples that were selected using trigonometric parallaxes derived from on–ground observations. When the Hipparcos catalogue (ESA, 1997) was published, it appeared that these parallaxes were affected by large errors and thus overestimated (Jahreiss & Wielen 1997). The conclusions of the papers cited above became then questionable.

2. An unbiased sample defined by the Hipparcos trigonometric parallaxes

The Hipparcos parallaxes are first used to select the dwarf stars. The position of the main sequence (MS) is derived in the $(B-V)$ vs M_V diagram, and the stars at less than 3 σ_{M_V} from the sequence are selected. Among the 64 SBs with $P < 10$ years, 57 are MS stars. This group of SBs is called the *extended sample* hereafter. It will be used to derive the distribution of mass ratios until $q = \mathcal{M}_2/\mathcal{M}_1 = 0.5$, since the contribution of the secondary components to the total luminosities of the systems is negligible in this range. An unbiased sample is requested to derive the upper part of the distribution.

The stars with companions as bright as themselves seem 0.75 mag brighter than the stars with faint secondary components; therefore, in a sample selected from a limit in apparent magnitude, they are taken from a volume that is 2.8 times larger than for the others. In order to avoid this effect, we need a sample selected on the basis of the trigonometric parallaxes. A comparison between our sample and the nearby stars in the Hipparcos catalogue leads to the conclusion that the selection in the CNS2+supplement is almost complete for $\pi \geq 65$ mas. A so drastic selection would provide a sample of only 8 SBs. Therefore, in place of a limit corresponding to complete selection, we prefere another solution: the distances of the stars from the MS are considered, and parallaxes smaller than the exhaustivity limit are accepted as long as the distribution of stars around the MS remains unchanged. It appears thus that the CNS2+supplement stars northern than -15 degrees constitute an unbiased (although uncomplete) sample as long as the parallaxes are larger than 46 mas. This sample is called the *unbiased sample*. It contains 250 programme stars including 26 SBs with $P < 10$ years. The frequency of binary stars with large mass ratios will be derived from this sample.

3. The mass ratios of the SB1s derived from Hipparcos astrometry

The mass ratios of the double–lined spectroscopic binaries (SB2s) are directly derived from the semi–amplitudes of radial velocity of the components: $q = K_1/K_2$. The treatment of the single–lined spectroscopic binaries (SB1s) is more complicated. The orbital elements provide the mass function, that is converted in the "mass ratio function", Y:

$$Y = f_{\mathcal{M}}/\mathcal{M}_1 = \frac{q^3 \sin^3 i}{(1+q)^2}. \qquad (1)$$

Since the inclination of the orbit, i, is unknown, q cannot be derived. Nevertheless, the probability distribution of q is calculated with an iterative inversion technique (Boffin et al. 1992, Mazeh & Goldberg 1992). It is assumed that q is less than 0.7, since the binary should be SB2 otherwise. Instead of being counted in one bin in a histogram, each star is then scattered over several bins. This procedure is greatly improved, however, when it is possible to compute the astrometric orbit of the binary, as explained hereafter.

Apart from providing high–precision parallaxes, the astrometric measurements of Hipparcos may be used to obtain astrometric orbits. When the period of a binary is not excessively short, but also not too much larger than the duration of the mission of Hipparcos (3 years), the semi–major axis of the astrometric orbit, a_0, is derived from the *Hipparcos Intermediate Astrometric Data*, taking into account the elements of the spectroscopic orbit. a_0 and its uncertainty, σ_{a_0}, are important constraints to q (Halbwachs et al. 2000). Among the 57 SBs of the extended sample, 32 are SB1s; it was possible to get astrometric orbital elements for 22 of them, and, for 11, the resulting precision of the mass ratio was even better than 10 %. An example is shown in Figure 1. When an astrometric orbit is obtained, its elements are introduced in the calculation of the probability distributions of q. As a consequence, the rather flat distribution originally derived for a star with a small Y may be changed in a sharp peak, more especially as σ_{a_0}/a_0 is small.

The astrometric orbits may also be computed for some SB2s of our sample. It is then possible to derive the individual masses of the components, as explained in Arenou et al. (2000).

4. Correction of the selection effects

The first step of the selection of SBs was the detection of the variability of the radial velocity. The method was based on the probability to obtain measurements with a scatter at least as large as the actual one. The detection criterium was $P(\chi^2) < 1$ %. When a candidate SB was detected, it was still observed during several years, and, for some stars with small amplitude variations, high–precision radial velocity measurements were performed with the Elodie spectrometer of the 1.93 meter telescope of the Haute–Provence Observatory. Therefore, the conditions for obtaining the orbit of a detected SB are $K_1 > 1$ km/s if $P < 1000$ days, and $K_1 > 1.5$ km/s if P is between 1000 days and 10 years.

The detection procedure and the conditions above are taken into account for evalutating the number of binaries that were missed in our survey. For each value of q, i.e. for the actual mass ratio of a SB2, or for each part of the probability distribution of q of a SB1, we compute by Monte Carlo simulation the proportion of stars that were selected. We use in this calculation the distribution of the periods derived from the sample, and the distribution of eccentricities used by Duquennoy & Mayor (1991, see the formulae in Künzli & North 1998).

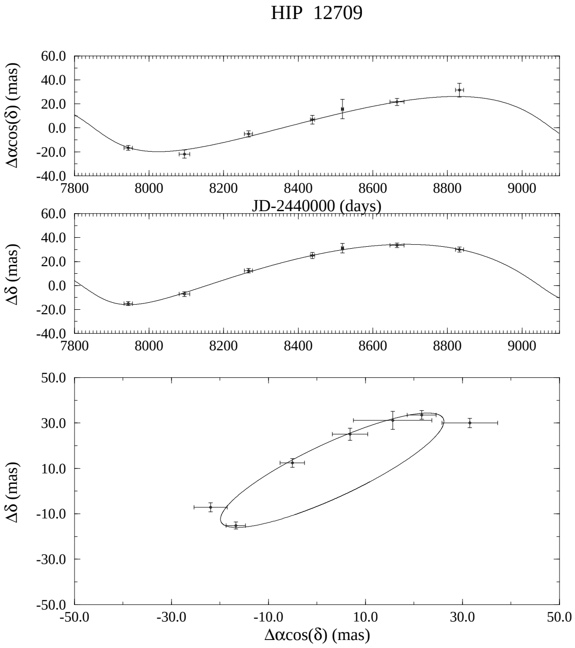

Fig. 1.— The astrometric orbit of GJ 106 = HIP 12709, derived from the Hipparcos data taking into account the elements of the spectroscopic orbit. When the primary mass $\mathcal{M}_1 = 0.69\mathcal{M}_\odot$ is assumed, the mass of the secondary component is $\mathcal{M}_2 = 0.291 \pm 0.011\mathcal{M}_\odot$.

Virtual binaries are generated and they are observed with the same uncertainties and the same observation dates as the actual stars. $P(\chi^2)$ is computed, and the proportion of binaries for which the orbits are obtained is finally derived for a given q. The inverse of this proportion is the correction factor that is applied to the distribution of q. The number of binaries that were not detected in our survey is also derived from this calculation.

5. The distribution of mass ratios

The distribution of mass ratios is derived from the unbiased sample, and it is corrected for the selection effects. However, the bias toward bright secondary components is negligible for q smaller than 0.5: the difference in magnitude between the components is then less than 3 mag, and the contribution of the secondary to the total brightness of the system is at the most 0.07 mag. In the worth case, when the sample is completely delimited on the basis of the apparent magnitude, this lead to an excess of 10 % for $q = 0.5$. This is very small when compared to the uncertainties coming from the small counts in the bins. Therefore, the distribution of q below 0.5 is derived from the extended sample, that contains twice more stars than the unbiased one. The resulting distribution is plotted in Figure 2. It is defined from $q = 0.023$, since this is the minimum mass ratio found in the sample. The uncertainties were derived with the method of the Jackknife. The distribution of q for the SBs of the sample, without correction for selection effects, is also represented for comparison.

The distribution in Figure 2 exhibits 3 peaks, but, since the errors are rather large, the reality of these fea-

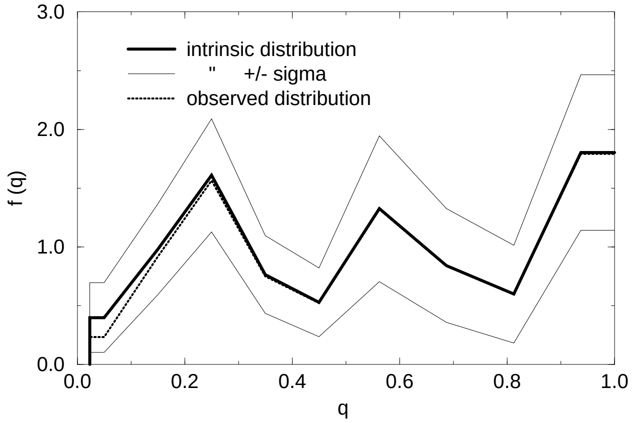

Fig. 2.— Distribution of mass ratios for the binaries with periods shorter than 10 years. The interval $q \in [0.023, 0.5]$ was derived from the extended sample, and the distribution of large mass ratio comes from the unbiased sample. The thick line is the distribution corrected for selection effects. The uncorrected distribution of q is represented by the dotted line.

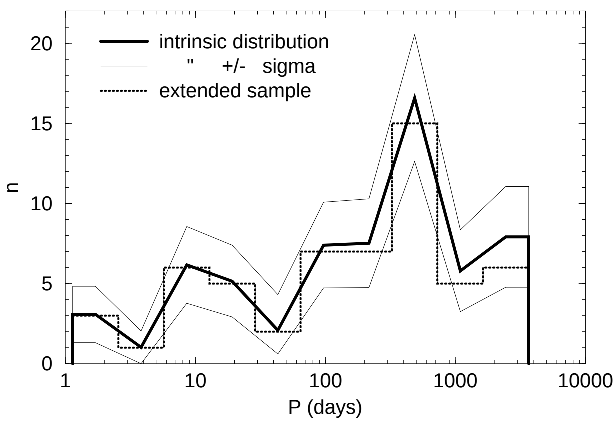

Fig. 3.— Distribution of periods as derived from the extended sample. The thick line is the distribution corrected for selection effects. The thin lines mark the error intervals. The dotted line is the uncorrected histogram of the periods in the sample.

tures must be verified. The rising part, from $q = 0.02$ to $q \simeq 0.25$ seems to exist in fact, since it includes the "brown dwarf desert" that was found from a sample containing more low–mass ratio stars (Halbwachs et al. 2000). This peak was already visible in Heacox (1998), but the selection effects were not corrected in his figure. In our sample, it appears only when the astrometric elements coming from Hipparcos are taken into account: otherwise, the distribution is constant from $q = 0.023$ to $q = 0.25$. At the opposite side of the distribution, the peak around $q = 1$ is triggering. A large frequency of close binaries with similar components was already found in other studies, but it was usually an artefact generated by a biased sample. In order to check if it is significant, the Kolmogorov–Smirnov test was applied to the hypothesis "the distribution of q of the SB2s is constant on the interval [0.7 , 1]". It was found that the rejection threshold of this hypothesis was 48 %. That means that, if the distribution of q is actually constant, the probability to have discrepancies at least as large as those observed is 48 %. Therefore, this peak may be due to statistical noise in small counts only. In conclusion, the distribution of q may be constant from about 0.2 to 1.

6. The distribution of periods and the frequency of binaries

The distribution of periods of binaries, corrected for selection effects, is a by–product of the calculation of the distribution of mass ratios. Since the bias toward equal brightness components should not affect the distribution of periods, the extended sample is considered here. The histogram of the periods of the SBs is plotted in Figure 3, with the distribution corrected for selection effects. The distribution of $\log P$ is not constant, but rising. This property is verified on the basis of the SBs of the extended sample. Although the selection effects are neglected in the Kolmogorov–Smirnov test, the constant distribution is rejected with the 0.2 % level of significance.

Contrarely to the distribution of periods, the frequency of binaries is derived from the unbiased sample. We count 26 SBs among 250 F7–K MS stars. We estimate that, due to selection effects, the average number of SBs that were omitted is 0.83 ± 0.48. Therefore, the frequency of binary stars with $q > 0.023$ and $P < 10$ years is finally 10.9 ± 1.9 % among F7–K MS stars.

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