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The Short-period Multiplicity Among the T-Tauri Stars

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Abstract. We present in this paper the results of high-resolution spectroscopic observations carried out during three years aiming to estimate the short-period (P_{orb} < 100 days) binary frequency of a sample of T-Tauri stars in Oph-Sco, Cha, Lup, CrA star forming regions (SFRs) already observed with high angular resolution techniques by Ghez et al. (1993) and by Ghez et al. (1997) to detect more wider components. When combining all four SFRs, the short-period binary frequency is indistinguishable of that found by Duquennoy & Mayor (1991) for the solar-type field stars which is also consistent with the previous result obtained by Mathieu (1992, 1994). When Oph-Sco is analyzed separately, it seems that there is an excess of short-period binaries of a factor 2-2.5, on the opposite, short-period binary systems seem to be absent in the sample containing stars in Cha/Lup/CrA. Such a trend was equally found by Mathieu (1992). However, the small size of the sample avoid drawing any robust conclusion about a possible excess (lack) of short-period binaries in Oph (Cha/Lup/CrA).

1. Introduction

High-angular resolution techniques were widely used in this last decade to measure the binary frequency among the low-mass pre-main sequence populations (e.g. Ghez et al. 1993, 1997, Leinert et al. 1993, Richichi et al. 1994, Brandner & Köhler 1998) in the nearby star-forming regions and among the low-mass solar-type stars in young clusters (e.g., Bouvier et al. 1997, Patience et al. 1998, Duchêne et al. 1998, Patience & Duchêne 2001 and references therein).

Patience & Duchêne (2001) normalized the companion star fractions (CSF, $csf = \frac{B+2T+3Q}{S+B+T+Q}$ where S, B, T and Q is the number of single, binary, triple and quadruple systems, respectively) measured by several high-angular resolution studies by the CSF obtained by Duquennoy & Mayor (1991) in the same range of separation. They concluded that these normalized CSFs (csf/csf_{MS}) are greater or nearly equal to one (i.e., the binary frequency is greater or equal to that found among the solar-type stars). In addition, the normalized CSFs were better correlated with the density of SFR/cluster than with age which could indicate that the binary frequency of a given population might be set by the physical conditions of its parental cloud (Patience & Duchêne 2001).

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However, a direct comparison of the results of different surveys is somewhat hard to do mainly for two reasons. First, differences in the sample composition and detectability limits of each survey can lead us to derive a biased binary frequency. In principle, this problem can be surmounted if a careful analysis of the detection limits is performed (see e.g. Duchêne 1999). The second reason has to do with the shape of the binary frequency distribution curve. The high-angular resolution surveys are sensitive to binary systems having an orbital period within $\sim 10^{3.5}$ to $\sim 10^{7.5}$ days, which is a narrow strip if we compare with the binary frequency distribution determined by Duquennoy & Mayor which covers a range of orbital period from 1 to 10^{10} days. Thus, all conclusions regarding a possible excess of binaries in a given cluster or star-forming region with respect to the MS binary frequency is drawn taking in account only this narrow strip of orbital period where the PMS and the MS data overlap. If we further assume that all distributions of binary frequency as a function of separation between the components or orbital period are gaussians and that they peak at the same place as for the MS G and K-dwarfs, then the procedure of Duchêne (1999) can be used to answer the question of whether the binary frequency is higher among a given population. In this case, the overall binary frequency is just an extrapolation of the local binary frequency derived by a small range of orbital period.

If however these two assumptions are not necessarily true then the whole binary frequency distribution as a function of orbital period must be known in order to assess the overall binary frequency. Indeed, the results of Brandner & Köhler (1998) support the non-validity of these two assumptions. They carried out K-band speckle observations in two sub-regions of Scorpious-Centaurus OB association, namely, Upper-Scorpious A and B. In the US-A, the T-Tauri stars are associated with B-type stars whereas in US-B, only a few early-type stars are present. Their results give a similar binary frequency for both sub-regions (about 31%±7% for US-A and 39%±9%), nevertheless the closer binaries are much more numerous in US-A than in US-B. Their conclusion is that the same physical conditions that facilitate the formation of massive stars also facilitate the formation of closer binaries among low-mass stars.

How to discern a real overall excess and a difference in the shape of the binary frequency distribution? The answer lies on the determination of the PMS binary frequency distribution for a large range of orbital period as was done by Duquennoy & Mayor (1991) for MS stars. While higher-angular-resolution facilities like VLT-I are not available yet, the short-period part of the PMS binary frequency distribution can only be assessed with the help of spectroscopic observations. With this goal, we started, in June 1998, a spectroscopic monitoring of the southern part of the sample of Ghez et al. (1993, GMN93), i.e., Oph-Sco stars, and entire sample of Ghez et al. (1997, GMPB97). The survey was carried out with the high-resolution spectrograph CORALIE mounted at the Euler Swiss Telescope and FEROS mounted at the 1.5-m ESO, both at La Silla, Chile.

2. Sample and Spectroscopic Observations

As we have pointed out above, the main aim of this study is to search for close companions which could not be detected by the speckle studies of GMN93 and GMPB97. Thus we chose the very same sample as in GMPB97 and the southern sample of GMN93, i.e., the Oph-Sco objects. Our initial sample counts 88 stars. 12 of these 88 stars were too faint to be observed with the Swiss Telescope. Some of these faint stars was observed with the ESO 1.5m telescope, but due to time restrictions, some of them could not be observed. The sample studied in GMPB97 counts 3 Herbig Ae/Be stars which were not observed, as we were interested only on the T-Tauri stars. In order to save telescope time, the 9 NTTS (Walter et al. 1994) previously studied by Mathieu et al.(1989) were not observed either, since the potential spectroscopic companions were already found. Our final sample which counts 59 stars as well as the individual radial velocities for each targets are given in Melo (2001).

The CORALIE spectra were collected in three different seasons, namely, Jul/98, May/99 and Apr/00. A few observations were performed with the two-fiber-fed spectrograph FEROS ($\lambda/\Delta\lambda \sim 50,000$) attached to 1.5-m/ESO. The FEROS observations were collected in only one run in May/99.

Radial velocities were derived from the CCF which is computed by convolving the observed spectrum with a K0V CORAVEL-type numerical mask (Queloz 1995). For our program stars the internal error on the radial velocity measurement is about 0.2 km.s^{-1}.

3. Results

In Figure 1 we present the spectroscopic companion star fraction (CSF) for the present Oph plus Cha/Lup/CrA combined sample (first two open bins with $0 \leq \log P_{orb} \leq 2$) along with the high-angular resolution (speckle, adaptive optics, direct imaging) CSF (last two open bins) from other studies. For each bin, the respective CSF of the G- and K-dwarfs of the solar neighborhood is shown as a hatched bin.

The spectroscopic CSF was computed by considered the 59 observed in our survey plus 6 other stars in Oph already observed for radial velocities (Mathieu et al. 1989, Mathieu 1992, Walter et al. 1994). We fail to find any new binary besides those known a priori from Mathieu (1992, 1994). Within the interval $0 \leq \log P_{orb} \leq 1$ we count one triple system (NTTS155913-2233), thus the CSF in this interval of orbital period is of 0.03 (2/65). Applying the correction due to missed companions we have a corrected CSF (the corrected CSF is found dividing the CSF by the probability of detection of a binary with a solar mass primary and a secondary of mass M_2 and an orbital period P_{orb} within a given bin of orbital period, details are given in Duquennoy & Mayor 1991 and in Melo 2001) of 0.04 (2/0.75/65). One binary (ROXs 43A) and one triple system (ROXs 42C) lie within the interval $1 \leq \log P_{orb} \leq 2$, the respective CSF is thus of 0.05 (3/65) and of 0.07 (3/.65/65) if a correction is applied.

For the domain of separation of 15-150 AU (i.e, $0''.1$ up to $1''.2$), we have taken the corrected companion star fractions (CSF') computed in GMPB97 for Cha/Lup/CrA. For Oph, the CSF' computed from the union of the results from

GMN93 and Simon et al. (1995) was taken. The CSFs for the domain of separation of 150-1800 AU (i.e., $1''.2$ up to $12''.0$) for Cha/Lup/CrA and for Oph were taken respectively from GMPB97 and from Simon et al. (1995). All aforementioned values of CSF and CSF' are compiled in Table 5 of GMPB97. In each respective bin of separation the final value of CSF for Cha/Lup/CrA+Oph was computed by simply averaging the values taken from GMPB97.

The equivalent orbital period domain for each domain of separation was computed by assuming a total mass of $1M_\odot$ and that the semi major-axis a relates to the apparent separation ρ as $\overline{\log a} = \overline{\log \rho} + 0.1$ (Reipurth & Zinnecker 1993). For the same interval of orbital period, the respective CSF for the MS was estimated by integrating the the analytical expression given by Duquennoy & Mayor (1991). Errors are calculated following the Poisson counting statistics, i.e., $\sigma \sim \sqrt{N}$, where N is the number of detections.

As we can see from Figure 1, the PMS short period binary frequency within the errors is indistinguishable from that observed among the field G- and K-dwarfs. In contrast to the visual binary domain where the data are in abundance, little has been done to measure the PMS short period ($P_{orb} < 100$ days) binary frequency. In fact, the only estimations up to now of the PMS short period binary frequency comes from Mathieu (1992, 1994). This lack of new results in this short range of period is likely due to the difficult in measuring the spectroscopic binary frequency. While in the visual binaries domain, a few exposures per object generally taken in one observing run are enough to assess their binary nature, in the spectroscopic domain, unless we are dealing with a double-lined spectroscopic binary, several epochs are needed. Another important point is that the short period binary frequency is expected to be low (about 10%), thus large samples are needed to be able to unambiguously detect any possible excess between different populations.

The spectroscopic binary frequency and the errors computed in the present work are quite the same as reported by Mathieu (1992, 1994). Indeed, the two samples in question have approximately the same size (65 for this work against 55 in Mathieu 1992), consequently the statistical significance of the spectroscopic binary frequency estimations remains the same.

While the combined spectroscopic binary frequency for Cha/Lup/CrA+Oph are indistinguishable from that observed for the field solar-type stars the spectroscopic binary frequency for Oph-Sco alone is very high. In fact all confirmed binaries in our sample come from Oph-Sco which yields an uncorrected multiple star fraction (MSF, which is defined as $msf = \frac{B+T+Q}{S+B+T+Q}$) of 16%±9% (3/19) against 9.7%±2 (16/164) for the MS field stars. In contrast to Oph-Sco, no spectroscopic binary was found when only the stars in Cha/Lup/CrA were considered. Interesting enough, Mathieu (1992) also found evidence for an excess by a factor 2.5 of binaries in Oph (given the MS frequency, they should find 2 short-period binaries in a sample of 24 stars, instead they found 5) while in Taurus, the number of short-period binaries expected in a sample containing 62 stars was of 4-5, instead only one binary was found, similarly to what is observed here in Cha/Lup/CrA.

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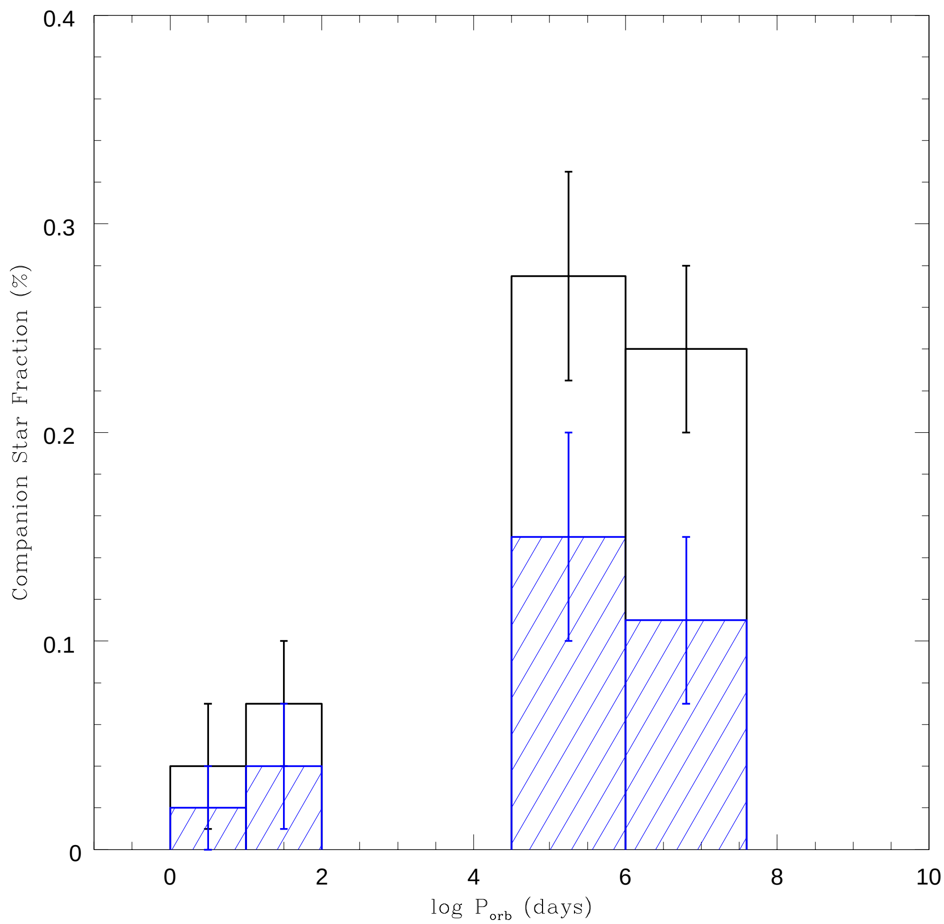

Figure 1. The combined companion star fraction as a function of the orbital period for the sample of Cha/Lup/CrA+Oph. The first two open bins ($\log P_{orb} \leq 2$) correspond to the spectroscopic binary frequency estimated in this paper, while the two left most ones come from a combination of the results of the high-angular resolution survey presented in GMN93, GMPB97 and Simon et al. (1995), as explained in the text. The equivalent orbital period domain for each domain of separation was computed by assuming a total mass of $1M_{\odot}$ and that the semi major-axis a relates to the apparent separation ρ as $\overline{\log a} = \overline{\log \rho} + 0.1$ (Reipurth & Zinnecker 1993). For the same interval of orbital period, the respective CSF for the MS, which is shown as hatched bins, was estimated by integrate the the analytical expression given by Duquennoy & Mayor (1991).

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