Tertiary Companions to Close Spectroscopic Binaries

A. Tokovinin[1], S. Thomas[1], M. Sterzik[2], S. Udry[3]

[1] Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile
atokovinin, sthomas@ctio.noao.edu
[2] European Southern Observatory, Casilla 19001, Santiago 19, Chile.
msterzik@eso.org
[3] Observatoire de Genève, CH-1290 Sauverny, Switzerland
Stephane.Udry@obs.unige.ch

Summary. Preliminary results of a survey of nearby solar-type spectroscopic binaries (SB) with orbital periods $1 < P_1 < 30$ days for tertiary companions are presented. Observations with adaptive optics and data from the 2MASS sky survey permitted to discover new tertiary components and to sharpen statistical limits on their frequency. We find that 0.86 ± 0.07 SBs with $P_1 < 5$ d have tertiaries, but this fraction drops to 0.49 ± 0.06 for $P_1 > 5$ d. The periods of tertiary companions are distributed in a wide range, from 2 to 10^5 yr, with most frequent periods of few thousand years.

1 The Goals and the Sample

All binaries were likely formed by fragmentation of molecular clouds with subsequent dynamical evolution. The formation of close binaries remains an unsolved problem, however [1]. It is believed that some mechanisms of angular momentum transport lead to shrinkage of their orbits. But were is that angular momentum deposited? Larson [4] argues that the momentum goes to a more distant tertiary component (or components). Current data indicate that almost half of spectroscopic binaries (SB) with periods below 10 d indeed have such companions [6], and it is possible that *all* close SBs are triple. Here we put this hypothesis to a stringent observational test.

We define a sample of SBs where the chance of discovering tertiary companion is maximized: nearby (within 100 pc) solar-type dwarfs with periods between 1 d and 30 d, selected from the catalogue of spectroscopic orbits, recent literature, and ongoing CORALIE survey. The sample contains 166 SBs belonging to 161 stellar systems. Some primaries turn out to be moderately evolved, despite their short orbital periods. The masses of spectroscopic components were estimated from spectral types and orbital parameters. Data on known wide components come from [5].

Using a combination of complementary observing techniques, it is possible to put strong constraints on potential tertiaries. Each method has its own detection range, depending on the tertiary period P_3 and the mass ratio q_3 (q_3

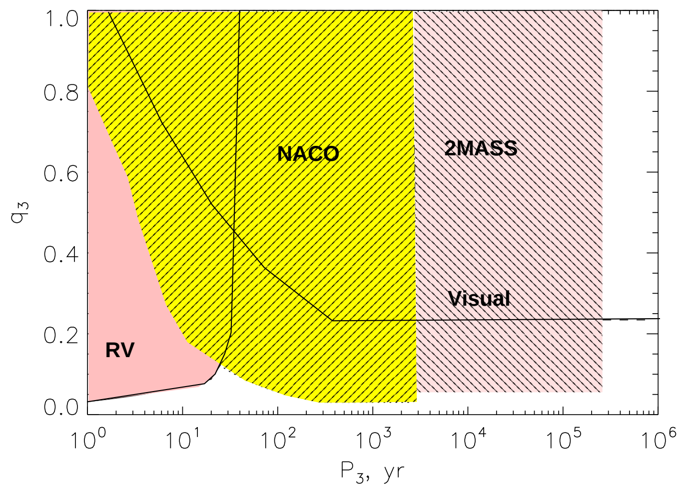

Fig. 1. Limits for detecting a tertiary component by different techniques as a function of tertiary period P_3 and its mass ratio q_3, for one target HIP 2790. Radial velocities (RV) cover short periods, adaptive-optics observations (NACO) probe companions with periods less than ∼3000 yr, still wider components can be detected with 2MASS, if not known already from historical visual and proper motion surveys.

is defined here with respect to the spectroscopic primary, rather than total mass of the SB). Figure 1 illustrates these limits for one specific system.

2 Adaptive Optics Observations

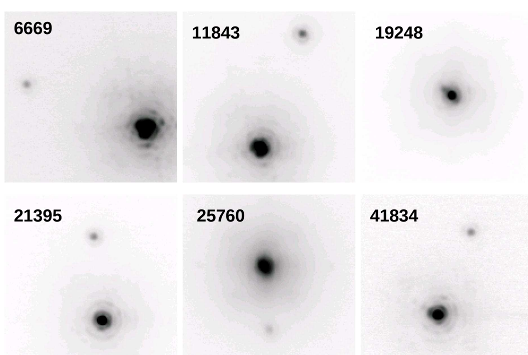

Fig. 2. Examples of new components detected with adaptive optics. The HIPPARCOS numbers of each target are given. The field size is $2'' \times 2''$.

High spatial resolution images of target stars have been obtained using the NAOS-Conica adaptive optics system[4] mounted at the VLT on November 8-9, 2004. We observed 52 targets and two astrometric calibrators in a narrow-band filter centered at the wavelength 2.12 μm, to avoid detector saturation. Only targets without known tertiary components (or with very distant tertiaries) were on this program. We detected 11 certain and 3 suspected tertiaries among 52 targets (Fig. 2). The observations were pursued in July 2005, but these data are not included in the present analysis.

3 Search of Companions in 2MASS

The SBs were examined for the presence of wide visual companions using Two Micron All-Sky Survey (2MASS) and Digital Sky Survey (DSS). The JHK_s photometry provided by 2MASS enabled us to construct $J_{\rm abs}, (J-K)$ color-magnitude diagrams for all stars within 2 arcmin. radius from each target. The standard main sequence (MS) was traced as well because the distance to each SB is known. All stars within 0.2^m from the MS were considered as photometric candidates, i.e. potential physical companions. We checked that this criterion selects known physical companions, but it cannot be made "sharper" without risk of losing companions.

Among 6079 point sources around our targets, 202 photometric candidates were selected. Most of these stars, of course, are optical, as can be inferred from their statistics (mostly faint and distant from targets). A chance of detecting a *real* physical component depends on the total number of point sources in each field, N_*. We abandoned 1/3 fields with $N_* > 40$ (near the Galactic plane) where confusion makes the companion search hopeless. For the remaining targets, we found 35 new candidates, in addition to those previously known. New candidates with separations above $20''$ were then checked for common proper motion by comparing their positions in 2MASS and DSS, on a time base ranging from 10 to 50 yr. We finally retrieved from 2MASS 22 known and 13 new companions (8 certain and 5 tentative, i.e. still unconfirmed).

4 Parameters of Tertiary Companions

Known and new tertiary companions are plotted in the (P_3, q_3) plane in Fig. 3. Their masses are estimated from magnitude difference with the help of standard MS relations, their orbital periods are evaluated statistically by the third Kelper's law from the separations, unless known from exact orbital solutions. Indicative detection limits for the whole sample are also shown.

[4] `http://www.eso.org/instruments/naco`

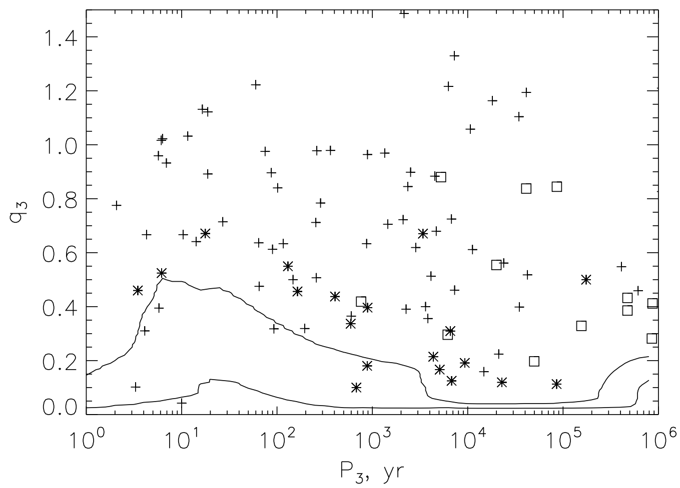

Fig. 3. Mass ratios and periods of tertiary companions. Known components are plotted as pluses, new components as asterisks. The squares denote components at the next hierarchical level, not considered in the main statistics. The lines trace detection probabilities of 10% and 50%.

For comparison, Fig. 3 shows even more distant, higher-level companions (squares) that dominate at the longest periods. Hence, the paucity of tertiaries with $P_3 > 10^5$ yr is real, not a selection effect. Similarly, we see only few tertiaries with $P_3 < 3$ yr (the shortest period is 2.1 yr), despite a good coverage of this region by spectroscopy. Discovering spectroscopic tertiaries with periods of few years is relatively straightforward, so that many more would have been known now if they were really abundant.

New components have, mostly, low mass ratios q_3. On the other hand, some previously known tertiaries are more massive than their respective spectroscopic primaries. The fraction of tertiaries with $q_3 > 1$ is 0.18 ± 0.04 – still smaller than 1/3 expected for a random choice of component masses. Thus, there is a tendency for the most massive companions of each system to belong to the SB.

We looked for correlations between orbital parameters of SBs and those of tertiaries and found that SBs with tertiaries have, on average, shorter orbital periods P_1 (Fig. 4). The difference of period distributions between SBs within triple (or higher-order) multiples and "simple" SBs is highly significant. Considering that there are still undiscovered triple stars in the sample, this difference is in fact even larger. If all SBs were triple, no such difference of their period distributions would be expected. We consider Fig. 4 as a strong (although indirect) proof that *SBs without tertiary companions do exist.* On the other hand, the distributions of the mass ratio of SBs with and without

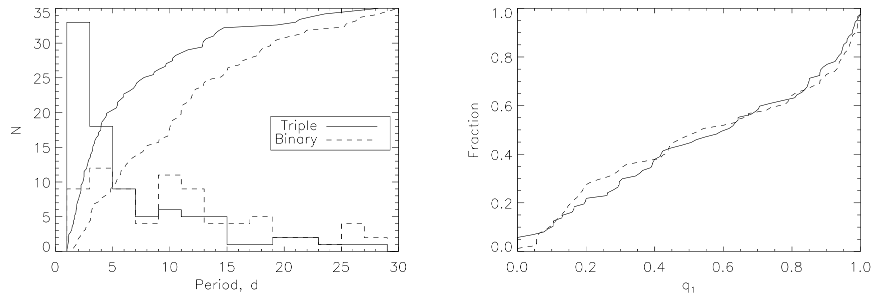

Fig. 4. Distributions of periods (left) and mass ratios (right) of spectroscopic binaries with (full lines) and without (dashed lines) tertiary components.

tertiaries are indistinguishable. No correlation between the periods of SBs and tertiaries is apparent in Fig. 5. Unlike visual triples, all systems in our sample are quite far from the dynamical stability limit $P_3/P_1 \sim 5$.

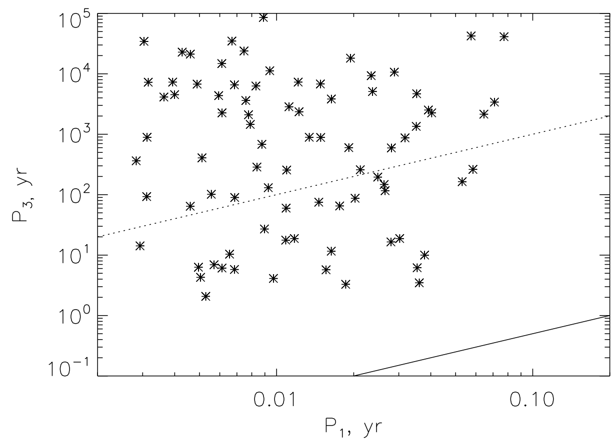

Fig. 5. Comparison of tertiary periods P_3 with the SB periods P_1. The full line denotes the stability limit $P_1 = 5P_3$, the dotted line corresponds to the period ratio of 10 000.

The true frequency of tertiary components in our sample has been determined by taking into account known selection effects. We used the maximum likelihood technique for estimating unbiased distribution of tertiaries in (P_3, q_3) coordinates, and for deriving the errors of such estimates. The analysis of the whole sample has been complemented by the analysis of subsamples, split accordingly to SB periods. It could be anticipated from Fig. 4

Table 1. Frequency of Tertiary Components

Sample	N	f
$P_1 < 5$d	72	0.86 ± 0.07
$P_1 > 5$d	94	0.49 ± 0.06
All	166	0.66 ± 0.05

that short-period SBs have a higher fraction of tertiary components, and the actual numbers in Table 1 confirm this.

The frequency of tertiaries can be compared to the frequency of wide binary companions to field dwarfs with periods above 1 yr, which is about 50% [2]. It is indistinguishable from the observed proportion of tertiaries among long-period SBs. On the other hand, almost all short-period SBs are triple. However, even in this group the existence of pure binaries cannot be excluded: we estimate their fraction as 14% ± 7%.

5 Discussion

We establish that the frequency of tertiary companions to close ($P_1 < 5$ d) SBs is higher than for wider SBs. In other terms, the period distributions of SBs with and without tertiaries are different. This points to the mechanism of Kozai cycles with tidal friction (KCTF) [3] as a way of creating SBs with periods of few days. The KCTF process works even for very wide and low-mass tertiaries, although it may take a long time to act.

Some SBs could have had wide companions that were later stripped away by dynamical interactions with members of their primordial clusters, preventing or restricting KCTF evolution. These SBs have, on average, longer orbital periods than SBs within multiple systems. These periods are still too short to be explained by fragmentation, however. We speculate that the period distribution of "pure" binaries (Fig. 4, dashed line) may be close to the initial period distribution, unmodified by the KCTF. The origin of these short periods can be tentatively related to processes like disk braking and accretion.

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