Multiplicity of Contact Binary Stars

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Summary. We present results of a preliminary investigation of triple star incidence for contact binary stars. The goal is to shed light on the possible role of distant companions which may have acquired and/or absorbed AM during evolution of multiple systems facilitating or enabling formation of contact binaries. We used several techniques but mostly disregarded their detection biases in an attempt to establish a low limit to the frequency of triple systems. The result for the much better observed Northern-sky subsample is 56% ±8%, whereas subsamples of systems best observed using individual techniques indicate apparent frequencies as high as 60% to 67%; this is consistent with the hypothesis that all contact binary stars exist in multiple systems.

1 Introduction

Formation of binary stars is a fascinating subject [21]. Especially, formation of short-period binaries ($P <$ 3-5 days) is still not understood, because during the T Tauri stage the components would have to overlap. Formation in triple (or multiple) systems may alleviate the problem through the so called Kozai cycles [7, 6]. Confirmation of the triple body formation of very close binaries can only come through observations and careful statistical investigations. We limit our scope to contact binaries [15] with orbital periods shorter than 1 day, the most extreme objects in the sense of the lowest angular momentum content among all Main Sequence binary stars.

There are several known multiple systems containing contact binary stars, e.g., visual binary consisting of two contact binaries, BV Dra and BW Dra. Several new triple systems were detected during the David Dunlop Observatory (DDO) radial velocity program (see [19]). In the present study, we consider only systems brighter than $V = 10$ at light maximum. The contact binaries were selected from the updated version of the Catalogue of Contact Binary Stars (hereafter CCBS, [12]) currently containing 391 systems. We use new direct imaging and DDO spectroscopy and published astrometric, photometric and X-ray observations. In this preliminary contribution, we give just a short description of the data, techniques and results. A detailed study containing a final table of the detected triples has been submitted for publication [13].

2 Detection techniques

2.1 Direct imaging and astrometry

The most important data sources here are the Hipparcos Catalogue [4] and The Washington Double Star (WDS) Catalog [11]. 40 contact binaries from our sample are already listed in WDS as members of visual binaries.

The Hipparcos catalogue contains large number of apparently single stars which show astrometric perturbations due to unseen, but gravitationally bound companion(s). Six systems show enhanced scatter of positions indicating a third body orbiting a contact binary on a short-period orbit ($P_3 < 1$ year), two systems (ER Ori and V2388 Oph) required an acceleration term in their astrometric solution. 26 systems with a possible non-single astrometric solution are also listed. A good indicator of possible third-body astrometric or photometric perturbations is the Hipparcos parallax error. Contact binaries in most visual binaries have large parallax errors. Three systems not suspected before, but having parallax errors larger than 3σ relative to the error median, have been found: UX Eri, V1363 Eri and DY Cet. Another astrometric indicator is a large proper-motion error in the TYCHO-2 catalogue [5], which can indicate the presence of a third body on a relatively longer orbit (see Fig. 1).

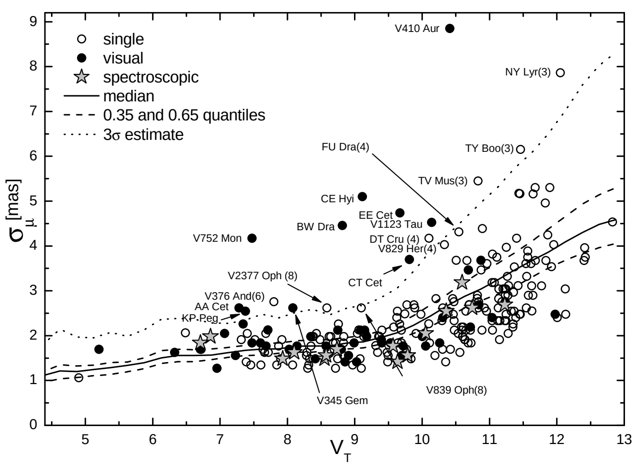

Fig. 1. Dependence of the combined proper motion error, σ_μ, on the median V_T magnitude for all contact binaries in the TYCHO-2 catalog. Numbers written in parentheses are given for systems currently not identified as multiple systems, they give the number of positions used for the proper-motion determination.

A program of direct detection of infrared companions using the adaptive optics system on the Canada France Hawaii Telescope was undertaken by one of the authors (SMR) in 1998. The observations were obtained with the PUEO instrument and KIR camera combination in the H and K infrared bands. The measured FWHM of corrected images was 0.143 arcsec in the K band. We used the PSF subtraction only for obvious companions at separations below 1 arcsec. In spite of this cursory treatment, we detected seven previously not identified companions at separations smaller than 5 arcsec to GZ And, AH Aur, CK Boo (separation only 0.12 arscec), SW Lac, V508 Oph, U Peg and RZ Tau. In all those cases, judging by the values of magnitude differences ΔK and ΔH, we suspect the companions to be M-type dwarfs.

2.2 Spectroscopy

Spectroscopy offers one of the most direct methods of discovery of companions to contact binaries. When a companion is present, extraction techniques utilizing deconvolution of spectra, such as the broadening functions (BF, see [17]), often show one sharp peak superimposed on a background of a broad and rapidly changing projection of the contact binary brightness onto the radial-velocity axis. The radial velocity program at the David Dunlap Observatory (see [19]) has led to the discovery of several new triple or multiple systems containing contact binaries: V899 Her and VZ Lib [9], V401 Cyg [18], as well as VW LMi, TV UMi and AG Vir (to be published).

The detection limit for third components, given by the ratio of the third component light to the total light of the eclipsing pair $\beta = L_3/(L_1 + L_2)$, is about 0.03 – 0.04. Averaging of individual spectra may show much fainter companions to the level of $\beta \simeq 0.01$ or even below (see [2]). We use all detections of [2] for our statistics.

Another spectroscopic technique are systemic-velocity changes. Because radial velocities usually come from different sources with different systematic errors and because contact binaries show large broadening of spectral lines, this is a relatively poor indicator of multiplicity. Available radial-velocity studies of contact binaries suggest only two suspect cases, W UMa and AW UMa.

2.3 The light-time effect "LITE"

Sinusoidal modulation of times of eclipses in binaries may result from the binary revolution on a wide orbit around a center of mass with a companion, the LITE or the LIght-Time Effect [1]. Because intrinsic period changes in close binaries are quite common due to their strong physical interaction, the presence of the LITE is usually not conclusive, but can prompt other observations. 129 systems having more than 15 CCD or *pe* minima in the Cracow database (the May 2004 version, [8]) were selected and analyzed. Only 18 out of 129 systems provided stable LITE solutions. The LITE interpretation was found for the first time for TY Boo, TZ Boo, CK Boo, GW Cep, UX Eri, V566 Oph and BB Peg. Predicted mean separations for several systems (e.g., AB And, CK Boo, V566 Oph) are accessible to speckle or direct detection. In fact, CK Boo was independently detected as visual double during CFHT observations (see Section 2). For the 20 best observed systems (with largest number of available minima), the multiplicity rate is 60% ± 5%.

2.4 The period–color relation

The period – color relation for contact binary stars was discovered observationally by [3]. The relation is a consequence of contact binaries being Main Sequence objects, with all implied correlations between the mass, effective temperature and radius, hence the size and thus the period. As pointed out before [16] the period – color relation must have a short-period, blue envelope (SPBE). Its locus corresponds to the Zero Age Main Sequence of least evolved stars. Evolution and expansion of components can lead to lengthening of the period and to reddening of the color index; reddening may be also caused by the interstellar matter. Thus, one does not expect contact binaries to appear blue-ward of the SPBE. Some blue outliers which do exist may be multiple systems with the color index peculiarity caused by a blue companion. The most deviating systems from our sample are V523 Cas, V1191 Cyg, XY Boo, V445 Cep and V758 Cen.

2.5 X-ray emission

Contact binary stars consist of solar-type stars spun into very rapid rotation by the tidal forces. As a consequence, they are very active and show elevated chromospheric and coronal activity [20]. X-ray coronal emission correlates with the effective temperature, T_{eff}, and the orbital period, P. A convenient distance independent quantity is the ratio of the apparent X-ray and bolometric fluxes, f_X/f_{bol}. X-ray fluxes were estimated from RASS counts by the procedure described in [20]. The scatter in f_X/f_{bol} reaches factors of 10 or 100 times from the average. We argue that companions to contact binaries may be the cause of these large deviations and that the deviations may go both ways: (i) When an early-type contact binary has an M-dwarf companion or even a binary M-dwarf companion then f_X/f_{bol} can be strongly elevated, but (ii) when the contact binary is of solar or later spectral type, its inactive early-type companion may reduce the value of f_X/f_{bol}. In fact we detected several early-type, long-period contact systems, showing enhanced X-ray flux (V335 Peg, DO Cha or RS Col) which may indicate that they host a late-type, active companion.

2.6 Other possible methods

There are other feasible methods and indicators of multiplicity which were not applied in the present investigation: (i) lunar occultations [14]: from among

391 contact binary stars in the electronic version of CCBS, 26 lie within the path of the Moon; (ii) the third light in light curve solutions: usually not reliable due to correlations with other photometric elements; (iii) precession of the orbital plane: a close and massive third body orbiting a binary system can cause precession of the orbital plane resulting in the changes of its orbital inclination and thus changes of the photometric amplitude of the eclipses [10].

3 Statistics and results

We have carefully inspected our list of contact binaries brighter than $V = 10$ with periods shorter than one day to establish all cases which appear to indicate multiplicity. We see 58 triple systems among 138 objects of our sample, giving the nominal lower limit to the frequency of triple systems of $42\% \pm 5\%$. While on the Northern sky ($\delta > 0$), using all available techniques, we see 47 triple systems among 84 objects, giving the frequency of $56\% \pm 8\%$, the Southern sky yields only 11 systems out of 54, corresponding to $20\% \pm 6\%$. Our estimate for the Northern hemisphere may be taken as a confirmation of the multiplicity hypothesis in production of close binary stars.

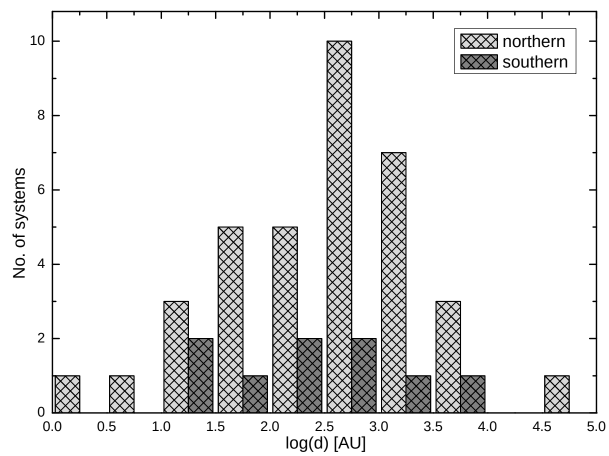

Fig. 2. The projected separations (in AU) shown for all systems with astrometric data, separately for both hemispheres (relative to the celestial equator). EM Cep (the only system in the bin with $4.5 < \log d < 5$), previously considered to be in a visual binary with a very large separation, is probably not a physically bound system.

The visual technique, combined with the parallax data permits to evaluate projected physical separations between the companions. The projected separations are moderate and distributed in the range between 3 and 5,700

AU, or 1.4×10^{-5} pc and 0.027 pc. Fig. 2 shows a histogram of the projected separations. The distribution may in fact reflect observational biases, but it does show that the separations are much smaller than typical distances between stars in the solar neighborhood of about one parsec. Thus, even the widest pairs with angular separations of several tens of arcsec can be regarded as gravitationally bound. But – physically – can these stars be evolutionary connected to the contact binaries? Can the Kozai cycle work at such large distances or do we see now only the results of it acting well in the past? Answers to these exciting questions are beyond the scope of this paper.

Acknowledgement. The conference participation of TP was supported by the Slovak Science and Technology Assistance Agency under the contract No. APVT-20-014402. The research made use of the SIMBAD database and the Washington Double Star (WDS) Catalog.

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