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COMMISSION 42 CLOSE BINARY STARS

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TRIENNIAL REPORT 2006 - 2009

1. Introduction

Two meetings of interest to close binaries took place during the reporting period: A full day session on short-period binary stars – mostly CV's – (Milone *et al.* 2008) during the 2006 AAS Spring meeting in Calgary and the very broadly designed IAU Symposium No. 240 on *Binary Stars as Critical Tools and Tests in Contemporary Astrophysics* in Prague, 2006, with many papers on close binaries Hartkopf *et al.* 2007. In addition, the book by Eggleton (2006), which is a comprehensive summary of evolutionary processes in binary and multiple stars, was published.

The report that follows consists of individual contributions of the Commission 42 Organizing Committee members. Its goal has been to give very personal views of a few individuals who are active in the field, so the report does not aim at covering the whole field of close binaries.

2. Close binary research from the perspective of BCB (C. D. Scarfe)

Some light can be thrown on the state of research on close binaries by considering the papers listed in the semi-annual Bibliography of Close Binaries (BCB). Since no similar summary appeared in the last few triennial reports of the Commission, we review here the patterns seen in the last 14 issues, since the most recent change of editorship in 2001, but with emphasis on the most recent six issues.

The total output of work on close binaries, appears to have decreased slightly during this decade. The two largest recent issues were those of December 2001 and June 2003, and the two smallest were those of December 2005 and December 2006. Part of this decline can be attributed to the editors' efforts to list only once, in the 'Collections of Data' section, papers giving the same kind of results for numerous binary systems. This avoids repetition of the listing for each system in the 'Individual Stars' section.

There is a slow trend toward larger numbers of authors per paper. The mean number of authors per paper has grown from 3.80 for the 420 entries in #72 to 4.88 for the 380 entries in #85. These means are affected by the few papers with very large numbers of authors – over 100 in rare cases – but the medians show the same trend. There is also a consistent systematic difference between 'Individual Star' (mostly observational) papers and those in the 'General' (mainly theoretical) category, the latter having about two fewer authors than the former, on average.

The literature of close binary stars, like that of other variables, suffers from a multiplicity of names for the objects of study. We have tried to follow the normal variable-star nomenclature of letters or numbers followed by constellation names, or their numbers in widely used catalogues such as the HD catalogue. Failing that, we prefer a coordinate-based nomenclature, and do our best to avoid other names. We encourage authors of papers to use standard nomenclature, making use of the SIMBAD identifier lists.

We turn now to the individual objects that are of abiding interest, or have attracted great temporary interest, based on the number of papers about them in the most recent 14 issues of BCB. Consistent with the preceding paragraph, we refer to each object by the name preferred for BCB, usually the standard variable-star designation. Papers have been listed in every issue for only two objects: V1357 Cyg (77 papers) and V1487 Aql (62 papers). Three other objects have more than 30 papers listed: KV UMa with 37 in 12 issues, V1343 Aql with 34 in 11, and HZ Her, with 33 in 12. However, PSR J0737–3039 was vigorously studied between 2004 and 2006, resulting in 29 papers in only 6 issues, including a record number of 12 in a single issue (#80). The remaining objects with at least 20 papers are V381 Nor (25 in 11), V615 Cas (24 in 9), V821 Ara (24 in 12), WZ Sge (23 in 10), V1033 Sco (23 in 9), V1521 Cyg and BR Cir (both 22 in 12), V818 Sco (21 in 10) and V4580 Sgr (20 in 11). Clearly, X-ray binaries dominate this list, but objects as the recurrent nova RS Oph, CH Cyg, AE Aqr and η Car are close behind (averaging > 1 paper per issue). All but RS Oph are of continuing interest, whereas that object's recent outburst has led to more papers in the latest three issues than for any other object.

3. Low-mass binaries and model discrepancies (G. Torres)

The properties of short-period double-lined eclipsing binaries (EBs) with M-type components have long been known to present disagreements compared to predictions from stellar evolution models (e.g., Popper 1997), particularly in their radii and effective temperatures. Since mid-2006 there have been considerable efforts to find additional low-mass systems in order to test theory, such as the Monitor Project that focuses on young open clusters (Aigrain *et al.* 2007). A number of other discoveries of potentially useful systems have occurred serendipitously or as a result of searching existing photometric databases (e.g., Bayless & Orosz 2006; Young *et al.* 2006; López-Morales & Shaw 2007; Vaccaro *et al.* 2007; Becker *et al.* 2008). Most of these systems continue to indicate that the sizes of M dwarfs are larger than predicted by theory, and their temperatures are lower. A few single-lined F+M systems resulting from searches for transiting planets have also provided useful comparisons (e.g., Beatty *et al.* 2007). The discrepancies with models are not confined to low-mass systems, however, and have been shown to extend up to masses almost as large as the Sun (Torres *et al.* 2006).

Chromospheric activity that is common in late-type and tidally locked binaries has long been suspected to be the culprit, as pointed out by many of the above investigators, and observational evidence for this has been mounting recently (see López-Morales 2007; Reiners *et al.* 2007, Morales *et al.* 2008). Both heavy spot coverage and reduced convective efficiency due to strong magnetic fields may play a role. The problem has been reviewed, e.g., by Ribas *et al.* (2007). Although much remains to be done both observationally and on the theoretical side, recent modelling studies of the evolution of low-mass stars under the influence of chromospheric activity are very encouraging. They appear to be able to explain the observed effects quite well with reasonable magnetic field strengths and typical spot filling factors (Chabrier *et al.* 2007). Similar progress has been made in our understanding of the origin and strength of magnetic fields in fully convective stars that lack a tachocline (Browning 2008).

4. W UMa-type binaries (S. M. Rucinski)

Although numbers of publications remain high, the field of contact binaries does not enjoy any obvious progress. The literature is still abundant in single-object photometric solutions of dubious usefulness (is anybody going ever to combine them?), with unrealistically small parameter uncertainties; they contribute little and just inflate citation lists. While very few new theoretical studies have been done – with some notable exceptions, e.g., the model of AW UMa (Paczyński *et al.* 2007), a model of evolution including the mass reversal (Stępień 2006a) – most efforts concentrate on observations and their interpretation.

New, shallow but extensive surveys of variability such as ASAS (Paczyński *et al.* 2006) have resulted in large numbers of contact binaries to about $V \simeq 12$ mag. W UMa type binaries are not very common, with one per about 500 late-type dwarfs ($\simeq 1.0 \times 10^{-5}$ pc^{-3}; Rucinski 2006), but they are easy to discover, hence their strong representation in variable star catalogues. The catalogues are biased in terms of physical properties: an elementary correction for the sample volume shifts the peak of the period distribution from 0.35 d to 0.27 d (Rucinski 2007). This is not far from the sharp cut-off at 0.22 d, where CC Comae is accompanied by the new shortest-period record holder discovered by ASAS, GSC 01387–00475 (Rucinski & Pribulla 2008). Stępień (2006b) explains the cut-off by the strong dependence of the angular-momentum-loss efficiency on mass, $-dH/dt \propto M^3$, so that low-mass objects simply have had no time to evolve beyond it.

We know now that W UMa binaries almost certainly have companions (Rucinski *et al.* 2007; and citations therein), in full confirmation of the work of Tokovinin *et al.* (2006) of the increasing multiplicity at short binary periods.

Only AW UMa is worth mentioning as an individual object: This flagship contact binary, when analyzed spectroscopically in detail, appears not to be in contact at all, but is a complex and hard to interpret semi-detached binary (Pribulla & Rucinski 2008). This teaches us a lesson that light curve fits even with most elaborate synthesis codes may yield an entirely incorrect picture. There is also a major question if the contact model applies to W UMa binaries at all … .

Spectroscopy of bright contact binaries is essential for progress. Faint, accidentally discovered systems continue to be observed photometrically because this is easy, but usefulness of this is questionable. Note that hundreds W UMa's still remain to be detected to $V = 10$ mag, but most of them have small amplitudes because of low inclinations and/or dilution by the light of companions.

5. Cataclysmic Variables (E. M. Sion)

Since the discovery of the first CV containing a pulsating white dwarf with ZZ Ceti-like non-radial g-mode oscillations, the list of such cataclysmic white dwarf pulsators has grown to 12 (Gaensicke *et al.* 2006; Mukadam *et al.* 2007). These objects are being probed with asteroseismological techniques to address the extent to which accretion affects the white dwarf mass, temperature, and composition and how efficiently angular momentum is transferred into the core.

Classical novae and dwarf novae are powered by two entirely different outburst mechanisms and have never been seen closely spaced in time. However, Sokoloski *et al.* (2006) discovered the first example (Z And) of an accretion disk instability depositing enough material that a 2 magnitude flare was triggered, followed by a thermonuclear explosion on an accreting white dwarf which brightened the system to $10^4\,L_\odot$, accompanied by a mass ejection. The two closely spaced events occurred in a symbiotic variable, but this so-called 'combination nova' holds potential implications for CVs as well. A likely classical nova shell has been detected around the prototype dwarf nova Z Cam by Shara *et al.* (2007). This would be one of the first direct links between classical novae and dwarf novae.

Darnley *et al.* (2006) estimate that if recent X-ray surveys of the galactic plane are correct in predicting more than $> 2 \times 10^4$ CVs with X-ray luminosity $< 2 \times 10^{33}$ erg/s, then each must undergo a nova explosion once per millennium to keep up the expected nova rate of 34 per year. Shara & Hurley (2006) reported a new class of CVs, found exclusively in globular clusters, whose members never went through a common envelope binary phase. They predict that their distribution of orbital periods should not have the standard CV period gap at 2-3 hr. Pretorius & Knigge (2008) presented an independent new sample of CVs, selected by $H\alpha$ emission. They cannot reconcile the large ratio of short- to long-period CVs predicted by standard CV evolution theory with their sample unless the rate of angular momentum loss below the period gap is increased by a factor of at least 3. Schmidtobreick & Tappert (2006) reported that there are now 11 known CVs in the period gap, but a shortage of expected dwarf novae that have evolved past the turn-around in orbital period. This again suggests that a mechanism of angular momentum loss in addition to gravitational radiation is required. Recent studies of the temperature distribution of CV white dwarfs versus orbital period below the period gap also suggest additional angular momentum loss.

Knigge (2007) has introduced a valuable method for determining the distances to cataclysmic variables using 2MASS JHK photometry and a semi-empirical relationship between donor absolute magnitude in the K-band and orbital period. The long sought-after and controversial mass of the white dwarf in WZ Sge was determined by Steeghs *et al.* (2007) in 2004. The WD mass is $0.85 \pm 0.03\,M_\odot$. Finally, Kromer *et al.* (2007) have succeeded in constructing model accretion disks with emission lines formed through irradiation of the inner disk by the hot white dwarf. This is a significant breakthrough since these accretion disk models enable emission line modelling *ab initio*.

6. Algol-type binaries (M. T. Richards)

The important fundamental light curve and spectroscopic analyses of several systems has continued (e.g., Angione & Sievers 2006; Soydugan *et al.* 2007) We also need additional studies of infrared light curves like those of Lázaro *et al.* (2006). Analyses that include a third body (e.g., Li 2006; Hoffman *et al.* 2006) suggest that many Algols have a companion in a long-period orbit and that the third body has a non-negligible effect on the binary through long-term variations in the binary orbital period. Both light curves and spectra have been combined by Van Hamme & Wilson (2007) to refine the derivation of third-body parameters and to challenge the existence of a third body in VV Ori. The six largest coronal X-ray flares ever detected by Chandra were studied by Nordon &

Behar (2007) to derive the flare properties. Flare size and position have been constrained by studying eclipsed X-ray flares on Algol and VW Cep (Sanz-Forcada *et al.* 2007).

The angular momentum evolution of 74 detached binaries and 61 semidetached binaries was studied by Ibanoğlu *et al.* (2006). Evolutionary models suggest that a circumbinary disk could extract angular momentum from the binary, thereby causing the orbit to shrink. This disk may explain the low mass ratio systems undergoing rapid mass transfer (Chen *et al.* 2006). Conservative Roche Lobe overflow explains the observed range of orbital periods in systems with B-type primaries but not for those with high mass ratios (van Rensbergen *et al.* 2006). However, hot spots and the spin-up of the primary may lead to significant mass loss.

Synthetic spectra of cool Algol secondaries can now be calculated with the LinBrod code (Bitner & Robinson 2006). In addition, synthetic spectra of the accretion disk and gas stream were calculated for TT Hya using the shellspec code (Miller *et al.* 2007). The physical properties of the accretion disk and stream were derived from the direct comparison between the observed and synthetic spectra of the system and also by using Doppler tomography to demonstrate visually that the accretion structures have been properly modelled.

K-band direct imaging of SS Lep with VINCI/VLTI and photometry from the UV to far-IR has been used by Verhoelst *et al.* (2007) to reveal the stars and a dust shell or disk. Indirect images of W Cru based on the eclipse mapping method identified a clumpy disk structure (Pavlovski *et al.* 2006). Finally, new 3D Doppler tomograms of the U CrB binary demonstrate that the alternating accretion disk and stream structures have significant flow velocities beyond the central 2D velocity plane and there is evidence of a gas jet at the star-stream impact site Agafonov *et al.* (2006).

7. The oEA stars (P. G. Niarchos)

Following the introduction of the name 'oEA' (oscillating EA) for (B)A-F spectral type, mass-accreting, main-sequence, pulsating stars in semi-detached Algol-type EBs by Mkrtichian *et al.* (2004), several studies having been published in the recent years. The oEA stars are the former secondaries of evolved, semi-detached EBs which are (still) undergoing mass transfer and form a class of pulsators close to the main-sequence.

Soydugan *et al.* (2006a), considering a sample of 20 EBs with δ Sct primaries, discovered that there is a possible relation among the pulsational periods of the primaries and the orbital periods of the systems. An important contribution was made by Soydugan *et al.* (2006b), who presented a catalogue of close binaries (25 known and 197 candidate binaries with pulsating components) located in the δ Sct region of the instability strip. A status report on the search for pulsations in primary components of Algol-type systems was presented by Mkrtichian *et al.* (2006), while a revised list of presently known oEA stars and a discussion on the pulsation mode visibility and strategies of mode identification was published by Mkrtichian *et al.* (2007).

Studies of individual systems: The following oEA systems were studied: AB Per, QU Sge, RZ Cas, IV Cas, Y Cam, and CT Her. Moreover, Pigulski & Michalska (2007) and Michalska & Pigulski (2007) detected pulsating components in 25 EBs in the ASAS-3 database.

8. Effects of binarity on stellar activity (K. Oláh)

Kővári *et al.* (2007) present a detailed spot modeling analysis and Doppler images for the primary stars of the RS CVn-type binary ζ And. The photometric light modulation originates in the distorted geometry of the primary, and additionally, comes from spots, which preferably appear on the stellar surface towards the companion star and opposite to it. Doppler maps also show low latitude spots with a temperature contrast of about 1000 K, and some weak polar features. Weak solar-type differential rotation was derived from the cross-correlation of the consecutive Doppler maps.

Massi *et al.* (2008) reported observational evidence of interacting coronae of the two components of the young binary system V773 Tau A. The VLBA and Effelsberg radio images show two distinctive structures, which are associated with each star. In one image the two features are extended up to $18\,R_\star$ each and are nearly parallel revealing the presence of two interacting helmet streamers, observed for the first time in stars other than the Sun. During the stellar rotation, these helmet streamers come into collision producing periodical flares. This is the first evidence that even if the flare origin is magnetic reconnection due to inter-binary collision, both stars independently emit in the radio range with structures of their own. The helmet streamers appear to interact throughout the whole orbit, although the radio flares become stronger when the stars approach. Around periastron the stellar separation is only $30\,R_\star$, where the two streamers overlap producing the observed giant flares.

Dunstone *et al.* (2008) present the first measurements of surface differential rotation of the young, pre-main sequence binary system HD 155555. Both components are found to have high rates of differential rotation, similar to those of the same spectral type Main Sequence single stars. The results for HD 155555 are therefore in contrast to those found in other, more evolved binary systems where negligible or weak differential rotation has been discovered. The rotation of both stars of HD 155555 is synchronous and the system is tidally locked. The authors found that more likely the convection zone depth is the cause of the low differential rotation rates of evolved giants, rather than the effects of tidal forces. The strong differential rotation provides extra stresses on the fields, and the reconnection of these long binary field loops significantly contribute to the X-ray luminosity of the system and to the elevated frequency of large flares.

Slavek M. Rucinski & Ignasi Ribas
president & vice-president of the Commission

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