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COMMISSION 42 CLOSE BINARY STARS

ETOILES BINARIES SERREES

TRIENNIAL REPORT 2009-2012

1. Introduction

The present report covers the main developments in the field of close binaries during the triennium 2009-2012. In addition to scientific publications, there have been several opportunities for direct interaction of researchers working on close binaries. A number of meetings focused on more or less specific topics have taken place during this past years but the highlight for Commission 42 is arguably IAU Symposium 282 held in 2011 in Slovakia. The meeting exploited a strong connection in the methodology and tools used by close binary studies and the rapidly advancing field of exoplanet research. After all, exoplanetary systems are mostly discovered and studied using techniques employed by analyses of close binaries for decades. Modelling of exoplanet radial velocity curves and transiting planet light curves are just particular cases of single-lined and eclipsing binary systems, respectively, with very unequal component properties. As shown by IAU Symposium 282, the synergies between the two fields are strong and potentially very useful. Found below is a summary of the main scientific topics and conclusions from this very successful Symposium.

Meetings of interest to close binary research will continue to happen during 2012. We were very happy to see strong interest on the scientific aspects of our Commission through numerous sponsorship and support requests received for the IAU General Assembly in Beijing. Our Commission members will be glad to discover a broad range of Symposia, Joint Discussions, and Special Sessions in which close binaries play an important role in the science programme.

The present report includes an account of the activities of the Bibliography of Close Binaries publication. BCB gathers references to all publications containing results that are of interest to our Commission. Bringing BCB to light every six months entails significant work from the Editor-in-Chief (C. D. Scarfe) and a team of 10 editors. We have investigated the diffusion of this work and discovered with pleasure that the impact of BCB on close binary research is very significant, with a large number of downloads of every issue. This has given us all reasons to push forward with producing BCB twice yearly for the benefit of our community. In representation of C42, I would like to thank

the team of people who invest time and effort in making BCB a reality. Further details on BCB for the past triennium are provided below.

And, finally, this report includes contributions from C42 Organizing Committee members that have kindly accepted to provide brief reviews on topics they think can be of interest to the rest of the C42 community. This includes an analysis of the observations of a binary merger, a report on the impact of the Kepler space mission to studies on close binaries, an account of the current status of pulsating binary observations, and a description of the 2010 eruption of V407 Cyg. I am sure that many other events and developments took place during 2009–2012 that are of importance to our field, but the short contributions included here do provide an interesting view on a variety of aspects and demonstrate that close binary research is active and lively field.

2. Report on IAU Symposium 282 (M. T. Richards & I. Hubeny)

IAU Symposium 282 entitled "From Interacting Binaries to Exoplanets: Essential Modeling Tools" was held in Tatranská Lomnica, Slovakia, from July 18–22, 2011. This symposium was designed to build a bridge between the exoplanet and binary star communities to discuss the many techniques in common use. This was the first joint meeting between these groups and it is significant that 31 countries were represented. IAU S282 was sponsored by four divisions: V – Variable Stars, III – Planetary Systems, IV – Stars, and IX – Optical & IR Techniques, as well as 7 Commissions: C25, C27, C29, C36, C42, C53, and C54. Commission 42 played a central role in the planning of this meeting. There were 8 sessions with equal weight to interacting binaries and exoplanets, with less emphasis on brown dwarfs. The main topics were (1) Multiwavelength Photometry and Spectroscopy of Interacting Binaries, (2) Observations and Analysis of Exoplanets and Brown Dwarfs, (3), Imaging Techniques, (4) Model Atmosphere Codes, (5) Synthetic Light Curves, Velocity Curves, Spectra of Binary Stars, and Spectra of Binaries with Accretion Structures, (6) Techniques for Analysis and Disentangling of Spectra and Light Curves, (7) Formation and Evolution Models, and (8) Hydrodynamic Simulations (see `http://www.astro.sk/IB2E/`).

The opening lectures reviewed the modeling tools as well as several open problems in the field. As a result, an IAU Resolution will be drafted to adopt updated astrophysical parameters and constants to improve the accuracy of fundamental parameters. These include the use of GM(Sun) since this product is more accurate than the product of the separate quantities. Several review talks were presented about existing and future ground-based and space-based observational instruments devoted to a study of close binaries, with an overview of observational techniques and results. While the CoRoT and Kepler instruments were designed primarily for exoplanet studies, Kepler is already having an impact on close binary research. We also heard about the planned Gaia and LSST projects. Didier Queloz, a co-discoverer of the first exoplanet orbiting a solar-type star, summarized the present status of exoplanet search with an emphasis on the radial velocity techniques, and outlined the expected development of the field in the near future. The remaining talks concentrated both on exoplanets and brown dwarfs, emphasizing mostly the transiting planets observed by CoRoT and Kepler, including an introduction to brown dwarfs in binary systems. There were several reviews of imaging techniques: interferometry, Doppler tomography, polarimetry, vortex coronagraphy, nulling interferometry, adaptive optics, and direct imaging. Several talks summarized the predominant model atmospheres codes for computing LTE as well as non-LTE model atmospheres, model atmospheres of exoplanets, extended atmospheres with stellar winds, and 3-dimensional

hydrodynamic simulations of stellar atmospheres. Some interesting new results were presented, including a possible use of accurately determined limb darkening coefficients for constraining basic stellar parameters. The new variants of the classical methods and programs for solving light curves were discussed, as well as codes for computing the spectrum of a complex close binary system by modeling in detail both stars and the circumstellar accretion structures around them. We were delighted to see a statistical survey and analysis of the many close binaries already discovered by the Kepler mission.

There were talks on two independent methods of spectral disentangling of the components of the binary system with proposed applications to exoplanetary spectra. Other highlights included a talk on the history of the Rossiter-McLaughlin effect followed by applications of the technique to transiting planets and low mass eclipsing binaries. This method represents the closest methodological connection between close binary and exoplanetary research. The effect was used earlier to identify critical properties of close binary systems, and it is now providing an analogously rich source of information in the case of exoplanets. There were reviews of the stellar evolution of the components of a close binary system, as well as dynamical models of formation and evolution of exoplanets, a summary of non-conservative effects in the evolution of binaries, and a synthesis of simultaneous modeling of atmospheres and the global evolution of exoplanets. The final session dealt with close binary and exoplanet dynamics, including 3D hydrodynamic simulations of their atmospheres of these objects, and the mass transfer between them. We saw several simulations that showed the ever-increasing power of current numerical simulations to provide a detailed picture of mass transfer in the case of young binaries with low mass companions, common envelope binaries, and how magnetic fields influence cataclysmic variables and polars. One simulation also considered the meteorology of exoplanet atmospheres via models of global atmospheric circulations and transport of energy from the day to the night side for close-in giant exoplanets.

Panel discussions were held at the end of each day to summarize the lectures and to make proposals for enhancements to current techniques; this was a special feature of the symposium led by influential astronomers who have contributed to the development of important modeling tools or who have provided insightful reviews of these developments. There was a public outreach event on the last day of the conference.

3. Close Binary Research from the Perspective of BCB (C. D. Scarfe)

This report brings up to date the one that was included in C42's last triennial report, in 2008. It covers BCB issues 86 (June 2008) through 92 (June 2011), with reference to the 14 issues covered in 2008.

BCB has maintained its average size, but the lack of an increase can probably be attributed in part to the editors' careful attention to avoiding the inclusion of papers which are primarily within the purview of other Commissions, most frequently Commissions 26 and 53. We also continue to place papers which discuss similar work on four or more systems in the 'Collections of Data' section, to avoid as much as possible having multiple entries for the same paper in the 'Individual Stars' section, as we had begun to do three years ago.

We continue to try as much as possible to use variable star nomenclature, or names which involve equatorial co-ordinates, with cross-references to the names actually used by authors, when those differ from the above. And since there are now many extragalactic close binaries, several of them having co-ordinate-based names, we have abandoned the use of a separate sub-section of the 'Individual Stars' section for those distant objects.

We continue to keep up-to-date the coding system that appears on the inside cover of each issue, and welcome suggestions for its further improvement.

The average number of authors per paper continues to increase slowly, but much of the increase is due to an increase in the number of papers with very large numbers of listed 'authors'. In the most recent seven issues, there are nine entries with over 100, two of which have over 200. Apart from those papers the distribution of the number of authors per paper is roughly Poissonian, with every possible number represented up to 24, and few gaps up to 43. If the entries with over 50 'authors' are omitted, the mean number of authors per paper is just under 5, with the most frequently occurring number being 3. The 'Individual Stars' section continues to have a higher average number of authors and the 'General' section a lower number, while the 'Collections of Data' section averages the same as the combined total. The total number of entries in the last seven issues is 2557, an average of 365 per issue.

The list of objects discussed most frequently continues to evolve. V1357 Cyg and V1487 Aql continue their record of having at least one paper in every issue, and although the total number for V1487 Aql has decreased to 18 for the seven issues, V1357 Cyg again has more papers (26) than any other object. In the most recent 21 issues there are a total of 103 papers on V1357 Cyg; V1487 Aql is still in second place with 80, but others are gaining on it. In the past seven issues, there are 24 entries on η Car, 22 on V821 Ara, 21 on V1521 Cyg, 20 on V1343 Aql, and 19 on V615 Cas. RS Oph has 18 like V1487 Aql, and V4580 Sgr has 17. No other object has more than 13. Interest in KV UMa has declined from 37 papers in 14 issues to 5 in the most recent seven issues, and that in PSRJ0737-3039 has decreased from its peak of 12 papers in a single issue to none in any the most recent five issues.

Preparing each issue is time-consuming for all the editors, but we are advised by Andras Holl, who maintains the Commission web site, that each issue is downloaded about 500 times in the six months after it appears, so clearly our efforts are worthwhile. I would like to thank all the contributing editors for their work, in particular Yasuhisa Nakamura, whose home is in Fukushima, Japan, and who contributed as usual to the most recent issue despite the great earthquake of March 2011 and the events that followed it.

4. Observations of a binary merger: V1309 Sco (S. Rucinski)

Tylenda *et al.* (2011) collected very convincing evidence of a first ever observed contact-binary coalescence. In 2008, an inconspicuous ($I \simeq 17$) star in the direction of the Galactic Centre ($l = 359.8$, $b = -3.1$) exploded reaching $I \simeq 6.8$. Nova Sco 2008, also called V1309 Sco, showed rather unusual properties similar to "red-nova" or V838 Mon-type eruptions (Mason *et al.* 2010) which had been linked to possible mergers of binary components (Tylenda & Soker 2006).

Photometry collected by the OGLE project during 10 years starting in 2001 (Tylenda *et al.*) very clearly established that V1309 Sco looked originally like a contact binary with a period 1.44 days. Its orbital period shortened before the outburst by an incredibly large amount of 1.2% in five years $2002-2007$. Not only the relatively long period, but also the red colour very clearly indicated that it was not a W UMa binary: After accounting for the heavy reddening in this direction, its colour corresponded to that of a K1-2 red giant. During a few months in 2007, the light curve underwent a dramatic evolution: It lost its double-eclipse, contact-binary character progressively looking more like that of a single, spotted star. Within about half a year before the outburst by some 10 magnitudes, the

time-scale of the luminosity increase strongly shortened from the initially almost constant $\simeq 27$ days to single days when the OGLE project lost it due to detector saturation.

After the outburst, no periodicity was detected, but the star is now very red and probably shrouded in a dust envelope (Tylenda 2011) so that its photosphere is invisible. No observations exist to check if any periodicity is present in the infra-red.

The magnitude and temporal development of the V1309 Sco outburst can be very well explained by energy released in a merger of a small mass-ratio binary, $q \leqslant 0.1$, with a helium core of mass $0.12M_\odot$ and radius $0.05R_\odot$ spiralling in the envelope of a $1.5M_\odot$ K-type giant (Tylenda 2011). Such a scenario is well described by evolutionary models of Stępień (2011). He proposes that in this particular case, a close binary (period $2.2 - 3.3$ days, original masses $1.1 - 1.3$ and $0.5 - 0.9M_\odot$) progressively lost mass and angular momentum, to enter after a few Gyr into a dynamical mass exchange and a strong mass-ratio reversal. In the last stages before coalescence the binary may have looked like a contact one, but its primary was a red giant and the contact stage lasted very short.

The long period of the progenitor binary corresponds very well to an abrupt discontinuity in the period distribution of contact binaries which was observed in the same direction before (Rucinski 1998). Some of the "long-period contact" binaries beyond the 1.5 day edge may be in fact not contact systems, but semi-detached binaries with red giants and small companions.

The excellent coverage of the whole event is to a large extent due to the persistence and dedication of the OGLE team. It very clearly shows how useful are surveys continuing in time and retaining high systematic consistence.

Most sincere thanks are due to Drs. R. Tylenda and K. Stępień for their detailed comments and suggestions.

5. Impact of the Kepler Mission on close binary studies (G. Torres & K. Oláh)

In March of 2009 NASA launched the Kepler Mission (Borucki *et al.* 2010) in an effort to detect, characterize, and determine the frequency of Earth-size planets around other stars, using the transit method. In its 3.5-year mission the spacecraft has been monitoring about 160,000 stars almost continuously in a 115 square degree field in the direction of the constellation Cygnus, with a photometric precision that is measured in *parts per million* rather than milli-magnitudes. In addition to the many planetary transit signals detected, a large number of eclipsing binaries have turned up, of which only a fraction were previously known. At the time of this writing the latest catalogue released by the Mission contains 2177 systems detected during the first four months of observation (Slawson *et al.* 2011, online version), and includes a morphological classification of the light curves (detached, semi-detached, overcontact, ellipsoidal) as well as estimates of the orbital parameters for each binary. A total of 1273 systems are detached, 152 are semi-detached, 469 are overcontact, 139 are ellipsoidal variables, and 144 are uncertain or unclassified systems. The database is available online at `http://keplerebs.villanova.edu/`. This wealth of information is likely to keep interested astronomers busy for years to come.

Because of the long duration of the observations, the nearly continuous coverage, and the high photometric precision afforded by the spacecraft, a number of unusual binaries have been detected that have merited special study. One rather spectacular example is KOI-54 (HD 187091), a pair of A stars in very eccentric ($e = 0.8335$) 41-day orbit oriented nearly face-on ($i = 5.5\,\mathrm{deg}$) that shows periodic *brightenings* caused by the tidal

distortions of the stars during each periastron passage (Welsh *et al.* 2010). Additionally, the light curve shows clear evidence of pulsations in one or both objects excited by the dynamical tides at periastron (Fuller & Lai 2011). Several other unusual systems have been uncovered by Kepler in which the relative eclipse depths show that the more compact, less luminous object is hotter than its stellar host (KOI-71, KOI-84, KIC 10657664, KOI-1224; Rowe *et al.* 2010, van Kerkwijk *et al.* 2010, Carter *et al.* 2011, Breton *et al.* 2011). These have turned out to be low-mass hot white dwarfs that are thermally bloated (up to ∼10 times their degenerate radii). In all cases the extremely high precision of the observations makes it possible to detect and measure the effects of Doppler beaming in the light curves, which provides valuable additional information on the physical parameters.

Although circumbinary planets were suggested in a few cases from stellar eclipse timings, the first direct evidence of such a system was discovered by Doyle *et al.* (2011). The star KIC 12644769 was first found to be an eclipsing binary, later tertiary eclipses were detected by Doyle *et al.* (2011) indicating a third body in the system. From the depth of the tertiary eclipses and on the magnitude of the eclipsing timing variation, the third body proved to have 0.333±0.016 Jupiter massses and 0.754±0.003 Jupiter radii, i.e., a planet. The host binary is on an eccentric orbit of 41 deays, with components of 0.690 and 0.203 solar masses. The circumbinary planet is thus named as Kepler 16(AB)-b. Winn *et al.* (2011) determined the rotation period of Kepler 16A as 35.1±1 days, and found that the stellar orbit, the planetary orbit and the rotation of the primary are closely aligned. To reach this configuration two alternative scenarios are suggested. The system is about 2–4 Gyr old, and the stars agree with the evolutionary models of low-mass stars.

Aside from individual studies of such systems, other interesting areas of research made possible by this remarkable data set include the search for eclipse timing variations, which may reveal the presence of third bodies or other astrophysical effects.

6. Pulsating binaries (or oEA stars) (P. G. Niarchos)

Mkrtichian *et al.* (2004) introduced the oEA (oscillating EA) stars as the (B)A-F spectral type mass-accreting main-sequence pulsating stars in semi-detached Algol-type eclipsing binary systems. The oEA stars are the former secondaries of evolved, semi-detached eclipsing binaries which are (still) undergoing mass transfer and form a newly detected class of pulsators close to the main-sequence. The study of a pulsating star (e.g., δ Scuti star) in a binary system provides the possibility to accurately measure its fundamental stellar parameters, greatly helping mode identifications and thus the application of asteroseismology. Several papers have been published during the last 2–3 years on oEA stars. Some of them are mentioned below.

Mkrtichian (2010), gave a review of the present status of the pulsation studies of close binary systems, focusing on pulsating gainers of semi-detached Algol type eclipsing binaries. Zhou (2010) published a catalogue containing 89 systems and distinguished them according to their pulsational properties. This catalog is intended to be a collection of pulsating binary stars across the Hertzsprung-Russell diagram. Soydugan *et al.* (2011) published also a similar list including 43 cases of systems including a δ Scuti component. Although few pulsating EBs are known (Mkrtichian *et al.* 2007), Kepler will lead to a major increase in this number.

The following oEA systems were studied: RZ Cas (Tkachenko *et al.* 2009), Y Cam (a three-continent multi-site photometric campaign by Rodr-guez et al. 2010), CoRoT 102931335 (Damiani *et al.* 2010), CT Her (multi-site, multi-year photometric monitoring,

by Lampens *et al.* 2011), KIC10661783 (Kepler photometry, by Southworth *et al.* 2011), sdB KPD 1930+2752 (Reed *et al.* 2011). New discoveries of oEA systems were reported by Soydugan *et al.* (2009), Soydugan *et al.* (2010), Liakos & Niarchos (2009), Liakos & Niarchos (2011).

7. The 2010 eruption of V407 Cyg (U. Munari)

The symbiotic binary Mira V407 Cyg erupted into a spectacular nova outburst in March 2010, which was happily detected and eagerly studied at any wavelength, from Fermi-LAT gamma-rays at energies >100 MeV, through X-rays (Swift) and UV/optical/IT, down to radio range (single dish, E-VLA, VLBI, maser). In normal novae, the initial high energy flash goes undetected and the subsequent expansion of the ejecta follows a simple ballistic path. In V407 Cyg, the dense wind of the Mira was instantaneously ionized by the initial flash and begun glowing following recombining with a time-scale of 4 days, while the underlying fast expanding nova ejecta were progressively decelerated by the collision with the Mira's wind, from an initial >1500 km s^{-1} velocity to ∼100 km s^{-1} in less than 200 days. Something similar, but at lower energies given the thinner circumstellar medium, had been observed only once before, the 2006 outburst of the symbiotic recurrent nova RS Oph. This outburst is triggering a far-reaching modeling effort that, considering the current strong momentum, will takes year to complete.

A selection among the >30 already published papers includes Orlando et al. (2011), Munari *et al.* (2011), Razzaque *et al.* (2011), Deguchi *et al.* (2011), Lü *et al.* (2011) and Abdo *et al.* (2010).

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