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DIVISION G
COMMISSION 42

CLOSE BINARY STARS
ÉTOILES DOUBLES SERRÉES

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1. Introduction: The beginnings

Commission 42 began life as Photometric Double Stars in 1948 at the 7th General Assembly in Zurich, under the presidency of Zdenek Kopal. As early as 1961, then General Secretary Lukas Plaut recommended a merger between C42 and C26, Double Stars, one of the original 32 commissions going back to 1919-22 (first president Aitken, assistant director at Lick). C42 became Close Binary Stars in 1970, at the 14th GA in Brighton (the first one I attended). Table 1 shows the presidents of C42, and vice presidents, from when the office started, through the history of the Commission.

The total membership of the Union was 207 from 19 member states at the end of the 1922 GA and 611 from 31 members in 1958. It is probably fair to say that binary (and double) stars accounted for a larger share of the membership and of astronomers' research then than now. Four presidents of the IUA have been at least partly binary star astronomers: W.W. Campbell (1922-25, who was also director of Lick Observatory and president of the University of California); Otto Struve (1952-55, who had fought first for Imperial Russia to 1917 and then against the Bolsheviks 1917-19); Jorge Sahade (1985-88, who solemnly asserted that his first name was pronounced "George"); and Robert Kraft (1997-2000, another director of Lick, who said that classifying spectra was an excellent pursuit for a director, because it could be done in small increments of time). The commission reports over the years make clear that there was a time when double/multiple/binary/eclipsing stars "lived" in at least three commissions, 26, 42 and 30, Stellar Radial Velocities, where for many years the Catalogues of Spectroscopic Binaries resided, with Campbell as its first president. There was briefly also C11, Spectroscopic Velocities (founding president H. Deslandres), though it disappeared in 1925. Over the triennia, there was a good deal of jostling of topics in subcommissions (later working groups) among the commissions interested in pairs of stars and in defending of territories. These can be followed in successive volumes of Transactions B, as can the scientific activities addressed in the next section.

2. Close binary stars in and out of the IAU: Some generalities

There have, so far, been three invited discourses in our territory: Josef Shklovsky on X-ray Binaries in Grenoble in 1976, Bohdan Paczyński on close binary evolution in Montreal in 1979, and Brian Warner on close binaries in Kyoto in 1997. As for symposia (1953 to present) and colloquia (1960s to 2005), typically one or two in or associated with the GAs have occurred each triennium, plus joint discussions, joint commission meetings, and so forth. In addition, the average of IAU binary events in non-GA years has been about one per year, with 1-2 major, non-IAU binary (etc.) meetings per year as well, including regular series on cataclysmic variables and held in Bamberg. Some of the non-IAU events asked for sponsorship and were refused; others never asked.

On average, the colloquia were more specialized than the symposia. For instance 1975 saw both S73 on Structure and Evolution of Close Binaries and C16 on analytical procedures for eclipsing binary light curves. Also on average topics have become more specialized over the years.

3. Close binary stars in and out of the IAU: Some specifics up to 1967

Before the formation of Commission 42 in 1948, close binaries (both spectroscopic and eclipsing) could turn up in Commission 26 (Double Stars), Commission 27 (Variable Stars), the short-lived Commission 11 (Spectroscopic Velocities) or Commission 30 (Stellar Radial Velocities). The topics gradually evolved at the same time as they flowed from Commission to Commission. Early on, a very large fraction of the work consisted of campaigns directed at particular, interesting systems and the assemblage of catalogues. The 3rd Catalogue of Spectroscopic Binaries already had, in 1925, 1054 stars and 248 orbits. Aitken, speaking for Lick, offered to host all double and binary star data. Technology was evolving, so that photographs were replacing filar micrometers for separation and angle of double stars, and, while photographs dominated photometry and spectroscopy, Joel Stebbins had obtained the first photoelectric light curve of an eclipsing binary as far back as 1910. It was Algol, the first variable star for which a dark, occulting companion had been suggested (by Pigott and Goodricke back in about 1786). Some of the "campaign" stars from the 1950s and early 60s included ϵ Aur, VV Ceph, β Lyrae (of which Henrietta Leavitt is supposed to have said "We shall never understand it until we find a way to send up a net and fetch the thing down!") 61 Cyg (to find a dark companion), and the white dwarf binaries, Sirius and Procyon for masses. There were studies of gas streams in AE Aqr, the Wolf-Rayet stars, and W Ser, and the folks reporting begin to be colleagues whom many of us knew, Crawford, Kraft, Sahade, and Popper (on absolute dimensions). The desirability of a new commission or subcommision on spectroscopic binaries was mentioned at both Rome (1952) and Moscow (1958), and there were attempts to classify the various sorts of eclipsing systems into an evolutionary sequence. And apsidal motions began to be used to constrain stellar interiors. Berkeley in 1961 witnessed more campaigns for W Ser, Zeta Aur, and the recognition of DQ Her, AE Aqr and U Gem as binaries (now called prototypes of cataclysmic variables or binaries). An IBM60 had been used for orbit computations. And Don Morton put forward his solution for the Algol paradox, in which a primary (more massive) star fills its Roche Lobe and mass is transferred to the secondary (less massive) star, until the mass ratios reverse. Perusing the next few Transaction volumes, one notes that, of our IAU binary presidents, both Kraft and Sahade had worked with Struve, the former at Berkeley and the latter at Yerkes.

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4. Computational breakthrough: 1966-1970

Paczyński (1971) wrote: "Approximately 5 years ago, it became clear that the numerical techniques developed to study the evolution of single stars might be used to compute evolution of binaries. Such studies began almost simultaneously in 1966 in Göttingen, in Warsaw, and in Ondrejov. The first results were presented at the IAU Colloquium On the Evolution of Double Stars in Uccle in 1966. Rapid progress appeared at the Prague IAU Joint Discussion in 1967, a Trieste colloquium on mass loss from stars in 1968, and at IAU Colloquium 6, Mass loss and evolution in close binaries" in 1969 in Elsinore, Denmark. It quickly became clear that mass transfer in close binaries not only solved the Algol paradox of the less massive star being the more evolved but also accounted for the various sorts of detached, contact, and semi-contact systems, the origin of cataclysmic variables, the presence of gas streams, short and long-lived phases (reflected in statistics of types), and the hydrogen deficiency in binary Wolf-Rayet stars.

This last was vigorously debated at the Prague IAU General Assembly (1968), where Anne Underhill said that she had detailed data on some WRs that (a) were definitely single stars and (b) that were not hydrogen-deficient, but merely experiencing anomalous excitation (with the opposite effect of the same phenomenon mentioned in C.H. Payne's PhD thesis, where H lines could be strong without the element being very abundant). Her claim that "there are more models that are not stars than there are stars that are not models" deserves to be remembered; and also that stars can lose hydrogen envelopes in several ways, so that not all WRs are binaries. The ones that are, however, do display the Algol paradox, as she noted in 1968 (Underhill 1968). Her own view was then, and I think for the rest of her life, that the Wolf-Rayets were pre-main-sequence stars of normal composition.

The mass transfer (and loss) scenario, however, unquestionably triumphed and was ready to embrace X-ray binaries with neutron star and black hole primaries when these were discovered, and even binary pulsars. These developments led to close binary stars being a relatively hot topic for a decade or two. The names to remember are, from the Göttingen group, Kippenhahn and Weigert, from Warsaw Paczyński and Ziolkowski, and from Ondrejob Plavec, Horn, and Harmanec. All appear regularly at later IAU events, and Ziolkovski and Harmanec were in Honolulu. The C42 report by Wood (1970) is particularly interesting both because he was firmly an observer, slightly astounded by the rapid theoretical progress and because he "hoped that intensive work on the origin of close binaries may be a feature of the next three years." Work, yes. Progress not so much.

On the observational side, of the participants in Colloquium 6, Alan Batten, Al Linnell, Johannes Anderson, and the present writer were also at the 29th GA. In the interim, two of the young C6 folk, Andersen and Richard M. West, have served as IAU General Secretaries. This probably was an effect of statistics of small numbers.

5. The 1970s and 1980s

Here, in chronological order, are (most of) the IAU-sponsored symposia and colloquia at which binaries (etc.) were featured, with a very few exciting topics from each, or at least the titles of the meetings.

• S73, Structure and evolution of Close Binary Systems, UK July 1975. Dwarf novae, capture of neutron stars by red giants, hydro-dynamical studies of disk formation

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• C33, Observational Parameters and Dynamical Evolution of Multiple Stars, Mexico, October 1975
• S51, Extended Atmospheres and Circumstellar Matter in Spectroscopic Binary Systems, Canada
• C16, Analytical Procedures for Eclipsing Binary Light Curves
• C18, Orbital and Physical Parameters of Double Stars, Canada
• JD at GA 1976, X-ray Binaries and Compact Objects
• Novae and Related Stars, first international conference since 1963; France, September 1976
• S88, Close Binary Stars, Canada, August 1979, circumstellar matter, mass-streaming, binary radio sources and stellar winds, RS CVn stars, WR stars, radio, UV, and X-ray observations, binary nuclei of PNe, origins of binary stars
• C62, Current Techniques in Double and Multiple Star Research, USA, May 1981 new techniques for observing multiple and double star systems, interferometric and electronic; orbit determinations
• C70, The Nature of Symbiotic Stars, France, 1981, many are binaries
• C69, Binary and Multiple Stars as Tracers of Stellar Evolution, Germany, 1981, W UMas, systems in late stages of evolution; wide systems with Algol paradox
• S99, Wolf Rayet Stars, Mexico, 1981, both single and binary types occur
• C72, Cataclysmic Variables and Related Objects, Israel August 1982, Type I SNe, polars, X0ray bursters, accretion disks
• C80, Double Stars, Physical Properties and Generic Relations, June 1983, Indonesia, occurrence of binaries in different stellar populations, relations between wide and close systems.
• Bessel Conference on Astrometric Binaries, Germany (FR) September 1984.
• The Impact of IUE and EXOSAT Observations on our Understanding of CVs, FRG, April 1985
• C93, Cataclysmic Variables, FRG, June 1986, recent classical novae, DNe, related objects, future missions.

The appearance about this time of multiple meetings that had been proposed as IAU Symposia or Colloquia but went ahead without that sponsorship probably tracks the relative decline of the subject compared to high-energy astrophysics and extragalactic astronomy.

• Critical Observations vs. Physical Models for Close Binary Systems, China, Nov. 1985
• C97, Wide Components in Double and Multiple Stars: Problems of Observation and Interpretation, Belgium June 1987, selection effects, CPM stars, moving groups, statistics, origin and evolution.
• C103, The Symbiotic Phenomenon, Poland, August 1987, essentially all binaries with hot and cool components, specific interesting stars
• C107, Algols, Canada, August 1988, non-degenerate, semi-detached, interacting binaries
• Quasi-periodic Oscillations in Bright Galactic X-ray Sources, October 1988, USA (things are getting pretty specialized!)
• S143, Wolf Rayet stars and Interrelations with Other Massive Stars in Galaxies, Indonesia, June 1990, effects on ISM, enrichment, and galactic evolution

Table 1. History of the Leadership of Commission 42

TERM	PRESIDENT	VICE-PRESIDENT
1948-52	Kopal	—
1952-55	Kopal	—
1955-58	OConnell	—
1958-61	OConnell	—
1961-64	Merrill	Tsesevitch
1964-67	Tsesevitch	Wood
1967-70	Wood	Plavec
1970-73	Plavec	Herczeg
1973-76	Herczeg	Larssen-Leander
1976-79	Larssen-Leander	Warner
1979-82	Warner	Batten
1982-85	Batten	Smak
1985-88	Smak	Koch
1988-91	Koch	Kondo
1991-94	Kondo	Rodono
1994-97	Rodono	Guinan
1997-2000	Guinan	Szkody
2000-03	Szkody	Gimenez
2003-06	Gimenez	Rucinski
2003-06	Rucinski	Ribas
2006-09	Ribas	Richards
2009-12	Richards	Pribulla

• C122, Physics of Classical Novae, Spain, June 1989, basic data on quiescence, grains, outbursts, and ejecta, not all the same, generally non-solar, radiative transfer

• NATO Advanced Study Institute, Active Close Binaries, Turkey, September 1989, multiwavelength observations

• 11th North American Workshop on Cataclysmic Variables and Low-Mass X-ray Binaries, USA October 1989

• S151, Evolutionary Processes in Interacting Binaries, Argentina, August 1991 mass loss, accretion, pulsation, explosions, types: Algols, W UMa, CVs, X-ray binaries

• Pacific Rim Colloquium on New Frontiers in Binary Star Research, Korea, October 1990

• C135, Complementary Approaches to Double & Multiple Star Research USA, April 1992, HIPPARCOS & HST results, speckle, high precision radial velocities, multi-telescope array results, IR observations of young systems.

• Workshop on Cataclysmic Variable Stars, Easter Island, July 1991

In addition, many IAU sponsored regional meetings and symposia and colloquia with titles emphasizing stellar evolution, variable stars, and observational techniques also contained significant binary and double star information.

The information in this section comes from issues 31 to 66 of the IAU Information Bulletins, and is as accurate as your colleagues, and, especially, the sequence of outstanding General Secretaries (G. Contoupulos, Edith Müller, Patrick Wayman, Richard West, Jean Paul Swings, Derek McNally, and Jacqueline Bergeron, all very dear friends) could make them.

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6. The Noble Nineties and beyond

As astronomers (even binary star astronomers), telescopes, journals, and sensitive detectors all became more numerous, new kinds of systems, new ideas, and new members of old classes all also became more numerous. Here we meet just one example from each year, 1990-2006, with the citations run into the sentences, as they will be in the next section as well.

1990. Beech (EM&P 49, 177) put forward the most unlikely explanation ever of blue stragglers intervention by astroengineers anxious to prolong the lives of their host stars.

1991. Mathys (A&A 241, 467) made clear that no one of the more likely explanations (mass transfer, mergers, star exchange, extra mixing) could account for all observed blue stragglers, even those in a single cluster.

1992. Evidence for ongoing circularization of binary orbits to ages of at least 10 Gyr came from Latham *et al.* (AJ 104, 774) with a sample of halo systems circular out to periods of 19 days, vs. 12.4 days in M67 and 8.5 days among per-main-sequence systems (Mathieu *et al.* in Duquennoy & Mayor Eds., Binary Stars as Tracers of Stellar Evolution, CUP).

1993. The chemical peculiarities of barium stars, dwarf carbon stars, and Tc-poor S-type stars are most readily explained by mass transfer from companions now shrunk to white dwarfs, thus it was welcome news to read that some of them at least are confirmed binaries (Heber A&A 267, LL31; Johnson *et al.* Nature 361, 213, Groenewege A&A 271, 463).

1994. The first binary lenses turned up among the OGLE events (Udalski *et al.* ApJ 426, L69) and in the MACHO Survey toward the LMC (Axelrod *et al.* BAAS 26, 92).

1995. Novae do turn off, but sometimes rather slowly. Shara & Drissen ApJ 448, 203 recovered T Sco (Nova 1860), and Warner *et al.* (ASS, 226, 27) studied the flickering of the first 19th century nova V841 Oph (1848).

1996. GRO J1744-28 was the first binary X-ray source (P = 11.8 days) to show both pulsation and bursts (Kouveliotou *et al.* Nature 379, 799, Lewin *et al.* ApJ 462, L39, Finger *et al.* Nature 381, 291, Strickman *et al.* ApJ 464, L13).

1997. Sills *et al.* (ApJ 487, 296) and Sandquist *et al.* (ApJ 477, 335) modeled the mergers of binaries in a way that kept them from mixing, so that the products retain helium-rich cores.

1998. AE Lyncis is the same star as 54 Cam, and one might suppose that it had been singled out as a star of very large proper motion, but in fact it is an example (Fekel AJ 115 1153) of pseudo synchronous rotation in a close binary. Many pulsars and X-ray binaries really do display large proper motions, and Tauris & Takens (A&A 330, 1047) conclude that unbinding of close binaries by supernova explosions is part of, but not the whole, story.

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2000. Triples also belong to us, even the triple white dwarf called 1704+481, Sanduleak B, and GR 577 (Maxted *et al.* MNRAS 314, 334). At least one of the pulsating WDs, GW Lib, has a companion (Hubrig *et al.* A&A 355, 1031). This will, I promise, be the only year with three topics, but it is not possible to pass in silence the last (at least in this world)study by Popper (AJ 119, 2291), of HS Aqr.

2001. Binary systems actually form that way, at least in the sense that star pairs with separations of 10-1000 AU in the Taurus-Aurigae star formation region are more nearly the same age than pairs selected at random (White & Ghez ApJ 556, 265) and the distribution of system periods (from 1 to 10^{10} days) is in place at birth according to Kroupa & Burkert (ApJ 555, 945).

2002. The supersoft X-ray binaries are generally systems in which the accretor is a white dwarf rather than a neutron star or black hole (Kitabatake *et al.* PASJ 54, 235, not the discovery of this factoid). Emission lines rather like those of Seyfert 1 galaxies and the presence of radio jets led to the name nanoquasars (Zamanov & Marziani ApJ 571, L77). Indeed you can pick them out by radio properties (Bond *et al.* PASP 14, 1359).

2003. Type Ia supernovae are now strongly suspected of having two or more types of progenitors, but here is a good place to note arguments in favor of double degenerates (Napiwotzki *et al.* ESO Messenger 112, 25, Livio & Reiss ApJ 594, L93). Eta Carinae is a binary non-supernova, but may just possibly have been bright enough to be recorded in a thousand year old Bolivian rock carving (Teames JAAVSO 31, 54).

2004. A long-standing problem with the W UMa stars has been their ability to maintain contact, despite having two stars of different masses and the same temperature. Kahler's (A&A 414, 317) solution is mass flow in both directions but at higher levels from the more massive to the less massive star. That both stars can be spotted (Barnes *et al.* MNRAS 348, 1321) and share a common chromosphere (Gurzadyan Ap&SS 286, 515), may or may not help. In globular clusters, they perhaps end up as blue stragglers (Tutukov *et al.* Astron. Rep. 48, 119).
better than 3.

2005. The best numbers we have for current star properties of course come from binaries (that's a major reason we were all in C42), but, in addition, Liebert *et al.* ApJ 630, L69) were able to show, by the convergence of several different lines of thought, that Sirius B began life as a $5M_{\odot}$ star. The pair of Wolf-Rayet stars with both masses about $80M_{\odot}$ (Rauw *et al.* A&A 432, 985) promise us a couple of nice galactic supernovae in the not-too-distant future. Mass ratios near one are actually fairly common (Fisher *et al.* MNRAS 361, 495).

2006. Putting binaries explicitly into models is one of the last frontiers in galactic evolution and nucleosynthesis, though not a completely unexplored one (about like Pike's Peak lots of people have been there before, but you can still get yourself killed, Zhand & Li MNRAS 370, 118). An interesting step forward, perhaps, is to focus on the evolutionary phase that will dominate light at various times after a burst of star formation (Mucciarelli *et al.* ApJ 646, 939), perhaps just the earliest phases (Dionne & Robert ApJ 641, 252).

These items were extracted from the 16-year series Astrophysics in 1991 to Astrophysics in 2006 (ending with Trimble, Aschwanden, & Hansen 2006, Sp. Sci. Rev. 132, 1) and are a totally inadequate representation even of the 2 or 3 to 20 or 30 binary star items that appeared each year and which, in turn, were selected from the full contents of more than 25 journals.

7. To each his or her own

With the knowledge that this is our last opportunity to shine together as Commission 42, the rapporteur, with help from New Commission G.1 president, Andrej Prsa, asked all C42 members with available e-dresses to send one-sentence descriptions of what they regarded as their single most important contribution to close binary research. After a single reminder and a window of about 3 weeks, 69 responses arrived. These follow, in chronological order of publication of the contributions. A few colleagues who have been in the field more than 30 or 35 years appear more than once or have two or three closely related contributions listed by the year of either the first or the last. First names are included where they were clear from what was sent. Otherwise just initials, or surnames. (VT = items added by Rapporteur).

1949. Albert Linnell (Sky and Telescope 8, 166) discovered the remarkable light curve of UX UMa, the prototype for cataclysmic variables.

1959. Zdenek Kopal, founding president of C42, was also the author of Close Binary Systems (Chapman Hall), a vital reference for decades (VT).

1968. The definitive Sixth, Seventh, and Eighth Catalogues of Spectroscopic binaries with critical notes and bibliographies came from Alan Batten (Publ. Dom. Astrophys. Obs. 13, 119) and Batten *et al.* (PDAO 15, 121, 1978; PDAO 17, 1, 1989)

1969. Virginia Trimble and Kip Thorne's (ApJ 156, 1013) search for neutron stars and black holes in close binaries (using the immediately-preceding catalogue) didn't find any, but the method, suggested by Yakov B. Zel'dovich & O.H. Guseinov (identification of X-ray sources with massive SB1's) led to the discovery of Cygnus X-1 = HD226868 = black hole, enabling Trimble *et al.* (MNRAS 162, 1p, 1972) to write the last fundamentally wrong paper about the source.

1971. Beginning in 1971, Robert E. Wilson and collaborators developed logical relations and other mathematical astrophysics that are utilized in most of today's binary system computer models and associated analytic programs for light and velocity curves, the latest being ApJ 780, 151.

1971. Peter P. Eggelton's unique stellar evolution code (MNRAS 151, 351) applied first to single stars, then binary evolution (MNRAS 179, 359, 1977, with Robertson), and then on to triple evolution (ApJ 345, 489, 1989, with Tout & Bailyn), and will grow to encompass Galactic evolution in about a Hubble time.

1972. Summer Starrfield *et al.* (ApJ 176, 169) showed that a thermonuclear runaway in the accreted envelope of a white dwarf was the probable cause of the Classical Nova Outburst, and later (ApJ 222, 600, 1978) predicted ^{7}Li production in the explosion.

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1972. Edward P.J. van den Heuvel & J. Heise (Nature PhS, 67) formed high-mass X-ray binaries, which further evolved, leading to a spiral-in, producing a very close system consisting of a helium star plus compact star (van den Heuvel & De Loore 1973 A&A 25, 387), finally leading to the formation of a close double neutron star (B.P. Flannery & van den Heuvel 1975, A&A 39, 61).

1972. Stefan Mochnacki & Doughty's (MNRAS 156, 51) novel method of binary synthesis produced the first accurate fit of Lucy's common convective envelope model for contact binaries to light curves, at the same time finding AW UMa Paczyński's star) to have the extremely low mass ratio of 0.08, which Mochnacki later showed could be the result of evolution accompanied by angular momentum loss due to magnetic braking.

1973. Alan Batten's masterful monograph, Binary and Multiple systems of Stars (Pergamon Press) introduced the subject to a grateful generation of astronomers. (VT)

1974. Yojc Osaki (PASJ 26, 429) proposed a working model in which the outbursts of dwarf novae could be due to some instabilities in the accretion disk, the physical mechanisms for which were later found in the 1980s, so that this model is now generally accepted as the correct explanation, called the disk instability model, as reviewed by Osaki (1996, PASP 108, 39). The competing model was an instability in the donor star, largely associated with the name of Geoffrey T. Bath (e.g. Nature PhS 246, 84, 1969). (VT)

1974. V. Trimble's claim that close binary stars include a population of early-type systems with mass ratios near unity survived a referee's description of "the incorrect methods of Trimble" to publication (AJ 79, 967) but had been forgotten by the time others with cleaner samples and more rigorous statistics found the same result.

1975. Kriz & Peter Harmanec (BAICz 26, 65 and later modifications) suggested that duplicity is a key factor in understanding the nature and time variability of Be stars, and although there has been some resistance to the idea, recent years have brought plentiful evidence that, not only for emission-line stars, but for OB stars in general, their duplicity and multiplicity is very important for their understanding (see, e.g. the Proceedings of the 2013 conference Massive Stars from Alpha to Omega, http://a2omega-conference.net)

The absence of favorite papers from 1976 to 1983 may or may not mean anything.

1984. Ronald W. Webbink (ApJ 277, 355) deduced that a very large fraction of close binary systems ultimately evolve through common envelope evolution into close double white dwarfs; formulated a simple energetic argument (still commonly used) to characterize the outcome of a CEB; concluded that the resultant systems consist primarily of very short-period He/He, He/CO, and CO/CO pairs that decay through gravitational radiation to interaction; estimated the birthrate of each of these types and their contributions to the local surface brightness of the galactic disk in gravitational waves; examined the stability of mass transfer in these close double WD systems when the less massive components filled their Roche lobes, and concluded that the He/He pairs merge to sdO stars, He/CO pairs to He ignition and R CrB stars, and CO/CO pairs to Type Ia supernovae, for which they are still a leading candidate.

1986. In addition to summarizing more than 100 years of history, Scott Kenyon's book, *The Symbiotic Stars* (Cambridge Univ. Press) laid the observational and theoretical foundation for studying the structure and evolution of these long period systems.

1986. Important studies of massive binaries in the Magellanic Clouds were carried out by Virpi Niemela and Nadia Morrell (ApJ 301, 295), Morrell *et al.* (ApJ 789, 139, 2014), and Koenigsberger *et al.* (AJ 148, 62, 2014).

1986. The numerical simulations by Richard Durisen *et al.* (ApJ 305, 281) showed that, for compressible fluids, rotational fission of a single star into a binary does not occur via a dynamic bar-like instability, because fission into two pieces is aborted by outward transport of angular momentum in spiral arms.

1986. J.B. Rafert and Norman L. Markworth's investigation (AJ 92, 678) of "solution convergence characteristics of the Wilson-Devinney Program" set the stage for future investigations of solution space.

1988. Edward Guinan & Bradstreet (ASIC 241, 345) asserted that, because of relatively high average space velocities of W UMa systems indicate an average age of 8 Gyr, these overcontact systems must consist of formerly detached binaries that have come together by angular momentum loss via magnetic torques from stellar winds.

1989. Hall (Sp Sci Rev 50, 219) proposed that cyclic changes in periods of close binaries arose from magnetic activity in "The relation between RS CVn and Algol".

1990. Johannes Andersen, Birgitta Nordstrom, & J.V. Clausen (ApJ 363, L63) gave clear observational evidence (from accurate mass, radius, luminosity, and abundance data for eclipsing binaries) that stellar evolution models must include convective overshooting, with the result, among others, that ages for stars younger than roughly 4 Gyr will increase by up to 50-100%.

1991. Johannes Andersen summarized and codified the use of binaries to determine "Accurate masses and radii of normal stars" (A&A Rev. 3, 91; updated in A&A Rev 18, 67, 2010).

1992. Davey & Robert C. Smith (MNRAS 257, 476) published the first set of maps of the irradiation patterns on the surfaces of the secondary stars in 11 dwarf novae and one polar, using a simple one-spot model, the work having been subsequently greatly improved by others using maximum entropy techniques, albeit on rather fewer stars.

1994. Shahbaz, Timothy Naylor *et al.* (MN 209, 756; MN 221, L10) used the ellipsoidal variations of the secondary star to obtain masses for the black holes in A0620-00 and V404 Cygni, showing that they were far over the maximum mass for neutron stars, unlike neutron stars themselves, which are normally only just larger than the white dwarf maximum mass.

1994. Shay Zucker & Mazeh (ApJ 420, 806) introduced the technique of TwO-Dimensional Correlations - - TODCOR - - which is still widely used to derive radial

velocities of double-lined spectroscopic binaries in cases of small flux ratios, thus contributing to increase the sample of known mass ratios.

1995. Petr Hadrava (A&AS 114, 393) introduced the method of Fourier disentangling for simultaneous separation of spectra of multiple stars and fitting their parameters which enabled many applications in the physics of stellar evolution and distance determinations e.g. for Algols, HMXRBs, CP stars, and long period variables.

1995. Horst Dreschel *et al.* (A&A 294, 723) developed a method to account for deviations of component shapes from pure Roche geometry due to radiation pressure so as to get more realistic solutions for close, early-type systems.

1996. Fred Ringwald (MNRAS 281, 192) addressed "The optical spectra of old novae."

1997. Chris Tout *et al.* (MNRAS 329, 897, 2002) combined binary star population synthesis with N-body simulations of clusters, leading to the now widely used binary star evolution package, BSE (Hurley *et al.* MNRAS 329, 897, 2002).

2001. In the 1990s, Robert Mathieu (IAUS 200, 419) contributed to opening the field of pre-main-sequence binaries through systemic discovery and characterization of PMS spectroscopic binaries and study of their associated accretion disks.

2001. Colin Scarfe began editing the Bibliography of Close Binaries, has done so longer than anyone else except the founding editor Gunnar Larsson-Leander, and has been contributing to it since the founder's time; Tibor Herczeg had been the intermediate editor, and the handover issue was No. 72.

2002. Robert Zavala *et al.* (AJ 123, 450) showed the use of photometry to understand cyclic period changes in close binaries via the magnetic activity method proposed on empirical grounds by Hall and theoretically by Applegate.

2003. David Pooley *et al.* (ApJ 591, L131) showed conclusively that close binary systems are formed in globular clusters by establishing a strong correlation between the number of low mass XRBs (almost all of which are CBSs or their progeny) in a globular cluster and the stellar encounter frequency in the cluster.

2003. Ronald Mennickent *et al.* (A&A 399, L47) found a sample of close interacting binaries with long photometric cycles about 33 times the orbit period in the OGLE-II catalog of variable stars in the Magellanic Clouds and described them as Double Periodic Variables, similar to Algols, but with a more massive and hotter primary, possibly experiencing mild cycles of mass loss.

2004. David Bradstreet and Steelman's (AAS 201, 7502) release of Binary Maker 3.0 introduced light curve analysis to a whole new generation, making the complicated techniques accessible to anyone with a computer.

2004. Jan Budaj & Mercedes Richards (Contrib. Astron. Obs. Skalnate Pleso 34, 167) developed a new computer code SHELLSPEC which calculates spectra and light curves of interacting binaries immersed in a moving circumstellar environment with

update (Budaj, AJ 141, 59, 2011) to account for reflection effects with scattering, heating, and heat redistribution over the stellar surface.

2005. Andrej Prsa & Tomaz Zwitter (ApJ 628, 426) upgraded the well-proven Wilson-Devinney binary modeling program with scientific extensions and numerical innovations to call it the first version of PHOEBE, which by luck largely conforms with the Bayesian approach (a word then unknown to the authors).

2005. Dirk Terrell & Wilson (ApSpSci 296, 221) used synthetic eclipsing binary star light curves to clear up longstanding confusion about photometric mass ratios, showing that the nature of the eclipses (total vs. partial) was the key to accurate values, not, as commonly claimed, the light variation outside eclipse.

2006. Francesca D'Antona *et al.* (ApJ 653, 1429) showed that mass transfer from a degenerate dwarf in very short period interacting helium WD binaries, en route to becoming AM CVn stars causes the period to decrease, not increase as expected, because of a thin remaining H-burning envelope that shrinks as mass is lost for the first million years of mass transfer, applying their model specifically to the case of the 5.4 min system RX J0806.3+1527.

2006. Konstantin Postnos & Lev Yungelson (LRR 96) since the 1980s have developed a population synthesis code for close binary evolution, used to evaluate (among other things) the rate of bursts of gravitational waves expected from coalescence of double neutron stars and black holes, important for the ground-based detectors.

2008. Tsantillas & Eleni Rovithis-Livaniou (AN 329, 59) have determined the gravity and effective temperature distributions on the surfaces of contact binary systems.

2008. Albert Linnell *et al.* (ApJ 688, 568) have provided BINSYS the only current package capable of calculating and iteratively improving multiwavelength light curves and spectra of cataclysmic variables with hot spots on their accretion disks as well as simple systems.

2008. The discovery of the precessing circumbinary disk around the precessing, jet-launching black hole binary SS 433 (Catherine Blundell *et al.* ApJ 678, L47) led to the Global Jet Watch project (http://www. GlobalJetWatch.net), which follows spectroscopically, on myriad timescales, close binaries via observatories separated in longitude around the world.

2009. Sirotkin & Woong-Tae Kim (ApJ 698, 715) semi-analytically calculate the internal structures and apsidal motion rates of circular-orbit binaries as well as the mass loss rates of CVs as a function of orbit period, finding (ApJ 721, 1356, 2010) that the classical linear theory underestimates the real apsidal motion rates by as much as 50% for critical configurations.

2009. J. Kallrath & Eugene F. Milone's useful little book, Eclipsing Binary Stars; Modeling and Analysis, 2nd Ed. (Springer) provides both details of methods and advances in the field that have come from using them.

2009. A dynamical mass measurement by Sandro Mereghetti *et al.* (Science 325, 1022) obtained through X-ray pulse timing with XMM-Newton has shown that the long sought companion of the SB1 HD 49798 (a luminous sdO) is most likely a massive (1.28 $M_{\odot}$), fast rotating (13.2 sec) white dwarf, confirming the existence of compact objects accreting from hot subdwarfs as predicted e.g. by Iben & Tutukov 1985 ApJSS 58, 661.

2009. Costa & Claudia Vilega Rodrigues (MNRAS 398, 240) and Silva *et al.* (MNRAS 432, 1587) have developed the only 3D code that simulates the emission from magnetic accretion columns in CVs by including cyclotron and bremsstrahlung emission from the post-shock region and absorption from the pre-shock column, appropriate for modeling optical and X-ray observations of some polars.

2010. Kloppenborg, Robert Stencel, *et al.* have carried out interferometric imaging of the disk in Epsilon Aurigae (Nature 464, 870).

2010. The compilations of mass and radius determinations accurate to better than 3%, mostly from eclipsing binaries, provided by G. Torres *et al.* (A&A Rev 18, 67) more than doubled the number of systems in the previous catalogue (Andersen 1991 A&A Rev 3, 91).

2011. The series of papers identifying 285 CVs from SDSS (Paula Szkody *et al.* AJ 142, 181) and hundreds of hours of follow-up by dozens of astronomers at observatories around the world have finally eliminated selection biases due to magnitude limits and have led to a close alignment of observations with close binary evolution models (Gaensicke *et al.* 2009 MNRAS 397, 1270).

2011. Large scale photometric surveys help enormously in using eclipsing binaries to calibrate properties of normal stars, including physical properties accurate to 2% for XY Cet (John Southworth *et al.* MNRAS 414, 3740) using SuperWASP photometry and eclipse modeling plus identification of 55 Delta Scuti pulsation frequencies in Kepler observations of KIC 10661783 (Southworth *et al.* MNRAS 414, 2413).

2011. Carter, Andrej Prsa, *et al.* (Science 331, 562), working on a hierarchical triple system KOI-126, introduced photodynamics, a method that can provide masses and radii to 0.1% or better, and have done so for the first circumbinary planet, Kepler-16 (Doyle *et al.*) Science 333, 1602) and for the bright quintuple system KIC 415611 (Prsa *et al.* 2015 in preparation).

2011. Gordon Sarty *et al.*'s (MNRAS 411, 1293) MOST satellite observations of the gamma-ray binary LS 5039 have helped to constrain detailed models of the system to ones that favor gamma-ray emission driven by pulsar winds as opposed to emission from accretion onto a black hole.

8. The last triennium of Commission 42

Fifteen of "my best works" answers received in response to the aforementioned request pertained to papers from 2012-15, which might reasonably have appeared in an ordinary commission report. These follow, and this section ends with a very brief summary of C42's presence in a splinter meeting, where most of the participants were a bit sad, but

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nevertheless comforted to realize that C42 and C26 (Double and Multiple Stars) had come through the restructuring in much better shape (merged as G1) than many of the other old units. This is due almost entirely to the hard work of past presidents Mercedes Richards and Brian Mason and on-going president Andrej Prsa with a bit of help from the rapporteur.

2012. Stephane Vennes *et al.* (ApJ 759, L25) have shown that the hot subdwarf in the ultra-short period binary CD-30 11223 will, in approximately 25 Myr, transfer part of its helium-rich envelope onto the massive white dwarf companion and help detonate the degenerate C-0 core.

2012. Mercedes T. Richards *et al.* (ApJ 760, 8) used 3D tomography of Beta Per and RS Vul to demonstrate magnetic interactions, and related 2D back-projection Doppler tomography of interacting binary stars (Richards *et al.* 2014, ApJ 795, 160) has yielded images of gravitational and magnetic phenomena.

2012. Liakos, Panos Niarchos, *et al.* (MNRAS 422, 1250) surveyed 68 eclipsing binaries for Delta Scuti-type oscillations, with a yield of 8 new systems which were characterized and analyzed for connections between orbital and pulsation periods and pulsation frequency with evolutionary status.

2012. Soria, William Blair, *et al.* (ApJ 750, 152; Science 343, 1330, 2014) have found two black hole binaries in Chandra data for M83, a new ultraluminous X-ray source and a microquasar.

2012. M. Montgomery (ApJ 745, L25; ApJ 753; L27) discovered via numerical simulations that accretion disks in close binaries tilt naturally on their own, and thus precess in the retrograde direction, creating negative superhumps in the light curves that have periods and shapes like those observed, and that (ApJ 705, 603, 2009) the physics of retrograde precession in BH, NS, CV, and protostar accretion disk systems is the same as that which causes the earth's 26,000 year retrograde precession, uniting and connecting them with the Earth, Moon, and Sun triple system.

2013. Sylvain Chaty (Adv. Space Res. 52, 2132) has reviewed ten years of discoveries and multi-wavelength studies of the most obscured population of high mass X-ray binaries, constituted of NS or BH hosting supergiant stars, including those called supergiant FastX-ray Transients, with unusually rapid and intense X-ray flares.

2013. Robert Williams (AJ 146, 55) has explained the simultaneous presence of hard X-ray emission and dust in nova ejecta in terms of the strong density and temperature gradients in adiabatically expanding globules of gas ejected from the WD by the nova outburst.

2013. Natasha Ivanova *et al.* (Science 339, 433) have described the observational features that would accompany a common envelope event in close binaries and proposed a link between common envelope events and the mysterious Luminous Red Novae, changing thereby the status of common envelope events from "non-observable" to "observed."

2013. Biping Gong and Li (arXiv 1302.6299) have compared models for spin-orbit coupling in ultra-compact binaries with observations of PSR B0919+06 and conclude

that tide-contaminated Roemer delay is responsible for the quasi-periodic time residual, which suggests the possibility of orbit periods much shorter than the current observed limit of 90 minutes.

2014. Solen Balman (A&A 572, 114) has suggested that the recurrent nova T Pyx has an optically thin boundary layer merged with an advection-dominated accretion flow and/or X-ray corona in the inner disk, which can heat the WD, influencing a thermonuclear runaway and producing recurrent nova events in a new way.

2014. Avvakumova & Oleg Malkov (MNRAS 444, 1982) developed a procedure for classification of eclipsing binaries from their light curve parameters and spectral types, tested on more than 1000 systems with known classification to evaluate its efficiency, and then applied to 4700 new systems, classifying the vast majority of them successfully.

2014. Carla Maceroni *et al.* (A&A 563, A39) analyzed the Kepler photometry and follow-up spectroscopy for KIC 385884, a highly eccentric eclipsing binary with a multi-period, non-radial, Delta Scuti type pulsator and found that the combined data allowed validating the best model of the binary components, including the interpretation of the pulsational properties.

2014. A recent combined spectroscopic and photometric investigation of the O-type eclipsing system Y Cyg by Harmanec, David Holmgren, et. Al. (A&A 563, A12) produced the most precise absolute dimensions and apsidal motion period for the system to date.

2014. James R. Sowell with R.M. Williamson and/or F.C. Fekel has introduced many undergraduate astronomy students to basic research and to co-authorship of peer-reviewed papers with orbital analysis of photometric and spectroscopic data, using the Wilson-Devinney program (Cabrera *et al.* PASP 126, 121).

2014. Luciana Bianchi (ApSS 354, 112; J. Adv. Sp. Res. 53, 900) has combined the GALEX UV sky survey with SDSS & Pan-STARRS data to compile an enormous catalogue of hot white dwarfs, including binaries with cooler companions, extending out into the halo of the Milky Way, which will help clarify late evolution of intermediate mass stars and their contributions of C, N, and other important elements for Galactic chemical evolution, though follow-up HST and Gaia data are still needed.

2015. The symbiotic recurrent nova RS Oph shows a correlation between the flickering amplitude and the average flux of the hot component similar to the rms-flux relation found in accreting black holes (Radoslav Zamanov *et al.* MNRAS 450, 3958), the techniques being similar to those used by Zamanov *et al.* (A&A 561, 2, 2014) to find relationships between the Fermi-LAT gamma ray flux of LSI+61303 and its V band and H alpha emission.

2015 August 11. Old Commissions 42 and 26 joined with New Commission 14 (now G.1) in a splinter session to say farewell to the former and hello to the latter. The six presentations in the territory of close binary stars were:

- Andrej Prsa: The Final Kepler EB Catalog

- Eugene Milone: Direct distance estimation applied to eclipsing binaries in star clusters: Case study of DS And in NGC 752

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• Christine Allen: Theta-1 Ori B: a quintuple (sextuple?) system less than 30,000 year old

• Rafael Costero: Two bright eclipsing binaries in the Orion Trapezium (BM and V1016 Ori)

• David Soderblom: Advances in spectroscopy and implications for stellar research

• Dimitri Pourbaix: The 9th Catalogue of Orbits of Spectroscopic Binaries

• Virginia Trimble: History of C42 (material like the first couple of sections of this report)

DEDICATION: The members and officers of the late C42 wish to present this report in honor of Mercedes T. Richards, our president during this last, difficult triennium and transition period.

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