42. CLOSE BINARY STARS (ETOILES BINAIRES SERREES)

PRESIDENT: Y. Kondo
VICE PRESIDENT: M. Rodonò
SECRETARY: R. S. Polidan
ORGANIZING COMMITTEE: P. P. Eggleton, A. Gimenez, E. F. Guinan, R. W. Hilditch, G. Hill, R. H. Koch, R. L.Mutel, P. Szkody, A. V. Tutukov, R. F. Webbink, A. Yamasaki, D.-S. Zhai

1. INTRODUCTION

At the time of this report in September 1993, about a year before the next General Assembly in 1994, the membership of Commission 42 stands at 357, an increase of forty-two members since the time of the last report prepared in September 1990. This is an increase of more than 10 percent, indicating the continuing vitality of our Commission in astronomical research. Many – possibly even the majority – of astrophysically intriguing objects involve interacting binary stars, which probably accounts for the ever increasing vigor in this field of research.

Among the significant events of the last triennial period is IAU Symposium 151 on "Evolutionary Processes in Interacting Binary Stars", which was held in August 1991 in Cordova, Argentina. The meeting was dedicated to Jorge Sahade, the Past President of IAU, to honor his outstanding contributions to our field for more than half a century. The proceedings of this symposium, edited by Y. Kondo, R. Sistero, and R. S. Polidan, was published from Kluwer Academic Publishers in 1992.

We are pleased to announce that Commission 42 has joined Commission 27 as a sponsor of the Information Bulletin on Variable Stars, which is edited by L. Szabados and K. Olah and published by Konkoly Observatory in Budapest, Hungary. For further information on this important newsletter, please see the report of Commission 27 in this volume.

A. Yamasaki has continued to serve as editor in chief of another newsletter of our Commission "Bibliography and Program Notes on Close Binaries". O. Demircan, T. J. Herczeg, V. G. Karetnikov, H. L. Malasan, H. Mauder, J. Papousek and C. D. Scarfe are serving as editors of this important publication for Commission 42.

I would like to thank all the contributors for their report – especially Ronald Polidan, whose help has been invaluable in putting this report in a final form.

2. STATISTICAL INFORMATION (A. Yamasaki)

The importance of the studies of stellar duplicity has been reported by a number of authors. The frequency of multiplicity (binary and multiple systems) is closely related to many astrophysical issues, such as star formation; stability and evolution of disks and planetary systems; evolution and interaction of binary and multiple systems; dynamical evolution of stellar systems; the search for very low mass companions; and birth rates of peculiar stars, cataclysmic variables, X-ray binaries, and millisecond pulsars.

J. Bergeron (ed.), Reports on Astronomy, Vol. XXIIA, 463–488.

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

The most reliable, unbiased determination of binary frequency has been given by studies of the solar neighborhood stars.

Solar-type stars Based upon CORAVEL radial velocity database, Duquennoy and Mayor (*A&A*,**248**, 485) studied the stellar multiplicity in an unbiased sample of 164 G-dwarf primaries in the solar neighborhood. Their results are: *i*) one third of the G-dwarf primaries may be real single stars (significantly more single stars than in the study of Abt and Levy, *ApJS*,**30**,273), *ii*) the period distribution is unimodal with a median period of 180 yr, *iii*) the mass-ratio distribution shows no maximum for q=1, but an increase toward small q (up to q=0.23) with a possible drop off at q=0.1 or less, and *iv*) though negligible contribution to the local mass density, the brown dwarfs may not be as rare as quoted by Campbell *et al.* (*ApJ*,**331**, 902). Mazeh *et al.* (*ApJ*,**401**,265) studied short-period binaries (P< 3000d) using the Duquennoy and Mayor survey, and found that the mass-ratio distribution is uniform and might even rise toward large mass ratio, confirming the different distributions between the short- and long-period binaries of Abt and Levy.

K and M dwarfs The observations and analysis by Tokovinin (*A&A*,**256**,121) of the radial velocities of a homogeneous sample of 200 G9-M3 dwarfs from the solar neighborhood indicate *i*) the absence of substellar mass companions (0.02-0.08$M_\odot$) with P<3000d, *ii*) the frequency of spectroscopic binaries is 10% while the systems with q>0.5 are more frequent, and *iii*) a non-monotonic distribution of the companion masses with a gap at 0.2-0.3$M_\odot$. Examining various surveys of M dwarfs within 20pc, Fischer and Marcy (*ApJ*,**396**,178) found that the incidence of companions to M dwarf primaries is 42% (this agrees with Henry and McCarthy, *ApJ*,**350**,334) and that the mass distribution of companions is flat, similar to the field mass function at low masses, supporting capture as the dominant mechanism.

B main-sequence stars Abt *et al.* (*ApJS*,**74**,551) obtained spectra of 74 B2-B5 IV or V stars, and analyzed the sample (including the earlier sample, Abt and Levy *ApJS*,**36**,241) obtaining the following results: *i*) systems with P>3.6d have companions that fit the Salpeter luminosity function and were formed by capture, *ii*) observed binary frequency of 74%, or, after allowance for incompleteness, 0.8 companions with mass> $2M_\odot$ per primary or 1.9 companions with mass> $1M_\odot$ per primary.

The identification of pre-main-sequence binaries is particularly important to investigate binary formation as well as evolution of circumstellar disks in single and multiple systems. Simon *et al.* (*ApJ*,**384**,212) identified 11 binaries and 2 triples among 28 young stars in Taurus star-forming region. They found binaries have formed by the time stars are 1Myr and that the observed multiplicity and distribution of separations are similar to those of the solar-type stars.

To study the binary evolution off the main sequence and the formation scenario of peculiar red giants like barium stars, CH and S stars, one has to understand normal field binary giants as fundamental knowledge. Statistical analysis of a sample of 213 spectroscopic binaries containing G or K giants by Boffin *et al.* (*A&A*,**271**,125) indicates that *i*) a circularization cut-off period around 70d, *ii*) some long-period binaries with small eccentricity are systems made of a giant and a white dwarf resulting a previous mass transfer episode,

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

and *iii*) the observed mass function distribution fits a uniform mass-ratio distribution with giant mass of $1.5M_{\odot}$. Concerning S stars, the paradigm that binary S stars systematically lack Tc was furthermore confirmed by Jorissen *et al.* (*A&A*,**271**,463) with a CORAVEL monitoring.

The frequencies of binaries in clusters and associations have been studied by many workers. Morrell and Levato (*ApJS*,**75**,965) observed 96 brightest members of the Ori OB1 association and obtained the frequency of spectroscopic binaries with P<100d plus magnetic Ap-Bp stars to be 32%. Morrell and Abt (*ApJ*,**378**,157) measured the radial velocities of 15 bright B3-A2 members of IC 4665, giving a binary frequency of 27%, the smallest estimate to date. Kroupa and Tout (*MN*,**259**,223) found for Praesepe that the color-magnitude data are consistent with a large binary population and systems with B-V=0.8–1.0 prefer uncorrelated component masses. Radial velocities of red giants in five open clusters older than the Hyades allowed the overall percentage of binaries to be 27% (Mermilliod and Mayor *A&A*,**237**,61). Unusually low binary frequencies were confirmed for the Pleiades and the α Persei. Mermilliod *et al.* (*A&A*,**265**,513) obtained 13% for binaries with F5-K0, P<1000d in Pleiades (see also Rosvick *et al.*, *A&A*,**255**,130 and Steele *et al.* *MN*,**263**, 647). Morrell and Abt (*ApJ*,**393**,666) found the binary frequency of 14% for the α Persei cluster.

Since the discoveries of low-mass X-ray binaries and millisecond pulsars, binary stars in globular clusters have been studied extensively. Romani and Weinberg (*ApJ*,**372**, 487) derived the present main-sequence binary fraction in M92 and M30 to be less than 3%. Primordial binaries, low-mass X-ray binaries, and pulsars in globular clusters were discussed by Hut *et al.* (*A&A*,**241**,137), Taam and Lin (*ApJ*,**390**,440), Chen and Leonard (*ApJ*,**411**,L75), Wijers and van Paradijs (*A&A*,**241**,L37) and others.

Many important contribution papers on binary statistics appeared in "Complementary Approaches to Double and Multiple Star Research" (IAU Colloquium 135; eds. McAlister and Hartkopf) and in "Binaries as Tracers of Stellar Formation" (eds. Duquennoy and Mayor).

3. PERIOD CHANGES (T. J. Herczeg)

The number of period studies of various lengths and scopes, in the 3-year interval considered, can be estimated at 350 at least. This number does not include occasional short discussions in photometric and/or spectroscopic studies with the sole aim to fix the phases correctly but does include the published longer lists of times of minima (mostly photoelectric) with or without a short comment on the period. Perhaps the most active group in this work represents the decades-old Nurenberg- Izmir collaboration, now supplemented with a station at Eckental, Germany., Their latest list of minimum epochs has been published in *IBVS*, no. 3760. Photographic archival work of very great importance has been produced at the Sonneberg Observatory; other archives, such as at Harvard, Odessa, the Sternberg Observatory or at the Maria Mitchell Observatory have also contributed. Workers at the AAVSO increased their output, in particular concerning long-term behaviour of variables, among them several of cataclysmic type. The annual publication of the Cracow Observatory, Rocznik Astronomiczny, regularly publishes improved ephemerides for relatively less known eclipsing systems, based presumably on comprehensive period studies; the recent volumes

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

63 and 64 bring, respectively, 41 and 27 new photometric elements.

The following very restricted selection is oriented toward those types of objects which appear most important for current research.

Strictly periodic shifts in the observed orbital period are caused either by light-time effect or by apsidal rotation. Various cases of light-time effect, seldom definitely established owing to the small timing residuals, sometimes only 5 to 15 minutes, have been reviewed by Mayer (*BAC* **41**). Large amplitude light-time effects have been proposed for β Cep and σ Sco (Pigulski, Boratin, *A&A*,**253**; Pigulski, *A&A*,**261**). The corresponding orbital motions may explain most of the observed period changes of these β CMa-variables; the involved masses can be identified as close visual companions.

Among other methods of detecting additional members in a multiple system, the best approach is the spectroscopic one. Such a study has shown, for instance, that the symbiotic system CH Cyg is actually triple, with periods 14.5 and 2 years (Hinkle *et al.*, *AJ*,**105**). At the Toulouse Observatory, radial velocity work on stars with composite spectra also revealed several triple systems, see e.g. GINESTET *et al.* (*A&AS*,**91**).

A substantial number of systems with already known "classical" apsidal rotations have been revisited, some of them thoroughly rediscussed. Among them are CW Cep (Harvig, *Tartu Publ.* **53**, Stickland *et al.*, *Observ.* **112**, based on IUE spectra); Y Cyg (Stickland *et al.*, *Observ.* **111**, IUE spectra); V477 Cyg (Gimenez, Quintana, *A&A*,**260**, arriving at log k2 =-2.20±0.04); HS Her (Todoran, *AN* **313**, Khaliullina, *Astr. Circ.* **1552**); YY Sgr (Lacy, *AJ*,**105**); V523 Sgr (Lacy, *AJ*,**104**); V526 Sgr (Lacy, *AJ*,**105**). Further systems considered: CO Lac (Mosskovskaya, *Astr. Circ.* **1543**), ι Ori (Hilditch *et al.*, *Observ.* **111**), BD-1 1004 (Rao *et al.*, *JA&A*, **11**).

The puzzling case of the anomalously slow relativistic apsidal rotation in the system DI Her still defies explanation; for a recent view, see Khaliullin *et al.* (*ApJ*,**375**, possible perturbations by a third body). The superior accuracy of pulsar timing, on the other hand, makes detection and study of relativistic apsidal rotation as well as other general relativistic effects possible. Since the early discussion by Taylor of the first binary pulsar PSR 1913+16, half a dozen cases of apsidal motion have been found in binary pulsars in in eccentric orbits, through the efforts of Bayles, Lyne, Prince, Ryba, Taylor, Wolszczan, and others. The latest detection yet is PSR B1802-7, a neutron star + low-mass white dwarf system (D'Amico *et al.*, *MN*,**260**, also Thorsett *et al.*, *ApJ*,**405**). The second paper quoted here gives a diagram summarizing all 17 neutron star masses, known as of March, 1993; the error bars for X-ray systems are sometimes considerable.

Among relativistic effects probed by pulsar timing, of greatest importance is the proof of orbital decay (decreasing period) of PSR 1913+16 due to quadrupole gravitational radiation as required by Einstein's relativity theory; a recent review is by Taylor (*Phil.Tr. Roy.Soc.* **A341**). In another study of the orbital period changes of PSR 1913+16, Damour and Taylor (*ApJ*,**366**) considered the effect of the accelerations in the galactic orbits of the pulsar and the Sun; they found a 0.8% confirmation of the relativistic prediction.

Precise timing of the pulse period led in the case of the ms-pulsar PSR 1257+12 to a truly amazing result: the probable existence of two planetary masses in orbit around the pulsar (Wolszczan, Frail, *Nature* **355**).

Concerning the orbital periods of X-ray binaries, the variations proved measurable only in three cases as of yet: Cen X-3, Her X-1 and EXO 0748-676 (see Asai *et al.*, *PASJ* **44**). The respective values of $\dot{P}/P$ are: -1.8×10^{-6}/year, -1.3×10^{-8}/year and -0.9×10^{-7}/year. It may be assumed that these variations are caused by tidal torques.

Among close binaries without compact components, W UMa systems, with their relatively short periods, have been studied extensively. With only a few exceptions such as UZ Leo or V401 Cyg, these systems show irregular period changes; moreover, a particular mode, abrupt, discontinuous variations of the order of $10^{-5}\times$ P seems to be characteristic, as proposed early by F.B. Wood, Binnendisk, and others. Alternative possibilities, however, have been put forward: long-term light curve disturbances, starspots, cyclic, magnetically induced structural variations. Merits and difficulties of such attempts can be seen in studies of AH Vir (Demircan *et al.*, *AJ*,**101**), V502 Oph (Derman, Demircan, *AJ*,**103**) or the "spotted" system AG Vir (Bell *et al.*, *MN*,247), to mention a few. The important triple system 44i Boo (ADS 9494) approaches its periastron and, although abrupt period changes are certainly present, an apparent increase of the period may reflect, at least partly, the orbital motion; see Rovithis (*A&AS*,**86**) and observations by Burke, Jones, Oprescu, Grobel and others in recent issues of the *IBVS*.

RS CVn stars usually show highly irregular O-C diagrams; a case in point is a recent discussion by Kim (*AJ*,**102**) of the characteristic system AR Lac. In these binaries with intense surface and magnetic activity and established light curve asymmetries (migrating distortion) seemingly irregular but actually spurious period variations of a time scale of a few years may arise as emphasized years ago by D.S. Hall, Rodonò and others.

There is slow progress concerning the period changes of cataclysmic variables where the timing residuals show wide scatter probably due to strong disturbances of the light curve. Yet it seems that most CVs have relatively stable periods. The spectroscopic determinations of the periods and orbits are far more reliable; however, in many cases there is a real or spurious multiplicity of the periods. Much work was done about these systems as well as deriving periods for newly identified CVs; in both cases at least half a dozen successful studies are to be noted. For the SU UMa stars, the "superhump timing" was reconsidered by Molnar and Kobulitzky (*ApJ*,**392**). They found a significant correlation between the superhump period excess (over the orbital period) and the mass ratio of the components. Statistics concerning the orbital period distribution of dwarf novae, with possible inferences about the evolution of these systems, was given by Shafter (*ApJ*,**394**) and for AM Her stars, Ritter and Kolb (*A&A*,**259**).

4. LIGHT CURVE MODELLING (G. Hill)

We have been fortunate in that within this triennium there has been an IAU Conference devoted to light curve modelling (*Light Curve Modeling of Eclipsing Binary Stars*; ed. Milone; Springer-Verlag, 1993, termed LCMEBS hereafter) and a related conference in

Korea (*New Frontiers in Binary Star Research*; ASP Conference Series,**38**,1993, NFBSR). Contained within these volumes are summaries of all of the major modelling codes. In both volumes, Wilson (LCMEBS, p7; NFBSR, p91) points the way to future developments, not only within the WD code but for any close binary modeling code. He includes the treatment of narrow and broad band indices as well as polarization. The ever more realistic atmospheres of Kurucz (LCMEBS, p93) will contribute to these endeavors even though their use will strain the computational facilities of most institutions. In this regard the work of Milone, Stagg and Kallrath (*e.g.*, *ApJ*,**389**,590,1992; LCMEBS, p75;NFBSR, p172) who have applied the simplex algorithm to a vectorized WDLC is very important. With a vectorized code and excellent atmospheres it will soon be possible to compute realistic photometric indices. All of the major codes now model spotted stars (see LCMEBS) but as ever the limitations of uniqueness still bedevil the analysis. Generally the available light curves are undersampled so that the growth and cycle time and the evolution of a spot system is rarely covered. An excellent example of what can be done given good observations is found in the study of RZ Eri (Burki *et al.*; *A&A*,**256**,463, 1992) using the EBOP code (Etzel,LCMEBS p113).

In addition another model, termed the geodesic distribution binary system (GDDSYN) method, has been developed specifically for analyzing surface features on eclipsing binaries (Hendry and Mochnacki *ApJ*,**388**,602,1992). Future developments include line profile synthesis and Doppler imaging. A simple method to get starting values for these more sophisticated codes is given by Riazi (*AJ*,**104**,228,1992). It assumes spherical stars, no limb darkening or proximity effects. A problem which persists in the field is the theoretical component of what is really going on over the surfaces of the stars in the presence of strong incident radiation and the circulation currents that probably result. All of the models contain gross simplifications as to the surface temperatures and the effects of incident radiation on the actual structure of the atmosphere. The models would all benefit if a rigorous means of accounting for these effects was developed. Other related developments which aid in the analysis process involve Doppler imaging, eclipse mapping, cross-correlation, speckle and interferometric observations.

5. OBSERVATIONAL DATA (M. Rodonò)

This section maintains the traditional subsection division essentially guided by the wavelength range or method of observations. Such a subsection arrangement, though not ideal, is quite convenient because, especially for practical reasons, many studies are primarily guided by specific methods (photometry, spectroscopy, spectrophotometry, polarimetry) and specific wavelength bands (X-rays, EUV, UV, optical, IR, radio), which have been set up by, or made available to observers. An increasing fraction of observational studies, however, are being done within collaborative programs aimed at multiwavelength, multisite studies of close binaries. This tendency is obviously more pronounced when the principal study purpose concerns the physical characteristics of the individual stellar companions, especially the structure of their outer atmospheres, more than the orbit or global stellar parameters.

5.A Ground-Based Photometry (M. Rodonò)

It is virtually impossible for reasons of limited space, nor it would be a useful service

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

to the general reader, to list here the huge amount of ground-based photometric papers published in the last triennium (July 1990 - June 1993), even by adopting the most sophisticated cryptic code. Actually, quite updated literature reference lists and databases are nowadays available or remotely accessible, such as the series of "Astr. & Astrophys. Abstracts" (Springer-Verlag) published every six months, the more specialized IAU Comm. 42 "Bibliography and Program Notes (BPN) on Close Binaries" (ed. A.Yamasaki), which is distributed to Comm. 42 members, the remotely accessible general literature database at Strasbourg Obs. (SIMBAD), the IUE archives at Goddard (NASA) and VILSPA (ESA), the high- energy database at Goddard (HEASARC, High Energy Astrophys. Science Archive Research Center), ESA's Space Science Department (SSD-ESTEC), and at the European Space Information System (ESIS-ESRIN). Any desired information on ground-based photometry and satellite data, sorted out by star name, subject, or author's name can be extracted from the above quoted literature sources. Hence, in the present report we will only try to illustrate general trends in ground-based photometry of close binaries that occurred in the past triennium.

Specific topics addressed by other sections of this report or by other IAU commissions (*e.g.*, novae and supernovae by Comm. 27) are disregarded, unless they have a vested close binary interest. Similarly, short notes or conference reports with preliminary results, that are or will appear in full papers, have been generally disregarded.

As usual, the most widely used photometric system has been the Johnson-Morgan UBVRI system (as well as the Cousins system), followed by the Stromgren uvby and the near-IR JHKLM systems, and by narrow-band Hα and Hβ photometry.

One of the highlights has been the increasing interest in the optical identification and study of CVs and low mass X-ray binaries discovered by the Einstein, Exosat, Rosat and Ginga X-ray observatories. A simple inspection of Comm. 42 BPN (Nos. 51 to 56) readily show the relatively large number of papers dealing with X-ray binaries and CVs with respect to classical close binaries. A fundamental reason for that has been the adoption of CCD detectors for photometry of faint sources down to about the 20th magnitude. Several close binaries and eclipsing binaries with periods of the order of 1-10 hours have been discovered (*IBVS*,**3489**; *MN*,248, 5p; *A&A*,242, 397; *PASP*,**103**, 300; see also papers presented at the 11th N.Am.Work. on Accretion-Powered Close Binaries), some of them in the central region of star clusters (M 15: *Nature* **351**,130; M 67: *IBVS*,**3586**; NGC 188: NATO-ASI on Active Close Binaries, p.891; NGC 288: *ApJS*,**82**,145; NGC 2004 and NGC 2100: *MN*,**260**,795; NGC 2346: *IBVS*,**3584**; NGC 5466: *AJ*,**100**,469 and *IAU Symposium 151*,483; NGC 6134: *A&AS*,**95**,429; Ton 2: *Acta A*,**42**,155; Pegasus: *AJ*,**100**,1151; Pleiades: *A&A*,**265**, 513; Praesepe: *ApJ*,**376**,514. The improved photometric accuracy, spatial resolution and limiting magnitude of CCD photometry have opened new research opportunities in the study of faint and cluster close binaries.

The binary nature of Nova Cyg 1978 = V 1668 Cyg (*MN*,**245**, 547) and of Nova Mon 1975 = A0620-00, the latter a black hole binary (*11th N. Am. Work. on Accretion-Powered Close Binaries*, p.7 and p.11), has also been discovered.

By using high-speed photometric techniques, a number of studies have addressed the question of short-period oscillations, flickering and flaring (*ApJ*,**359**,197; *ApJ*,**374**,340; *A&A*,**266**,237; *IBVS*,**3806**; *Acta A* **40**,129; *IBVS*,**3567**; *11th North Am. Work. on Accretion-Powered Close Binaries*, p.243 and p.279). Jets or jet- like ejection have also been found (*ApJ*,**354**,231; *Nature* **346**,637; *ApJ*,**357**,231).

Only a few interferometric studies have been done (*e.g.*, *ApJS*,**177**,161). This research topic certainly deserves more attention, but it is easy to anticipate that the completion of new large telescopes with interferometric capability, such as the ESO VLT (Very Large Telescope) and the Arizona U.-Italy LBT (Large Binocular Telescope), will provide new momentum to interferometric studies.

An increasing number of multiwavelength, multisite studies have been carried out (*e.g.*, YY Gem: *A&A*,**230**,419; V803 Cen: *MN*,**245**,140; V834 Cen: *ApJ*,**374**,744; HR 4049: *A&A*,**242**,433; Cyg X-2: *ApJ*,**355**,468; LMC X-3: *ApJ*,**364**,266; Sco X-1: *ApJ*,**396**,201; V 471 Tau: *ApJ*,**391**,773; τ Per: *AJ*,**101**,1821; V 711 Tau = HR1099: *A&A*, in press). These programs generally include concurrent photometry and spectroscopy, from ground-based and space-born telescopes, and are aimed at probing the vertical structure of stellar atmospheres or the system environment by monitoring specific emission diagnostics along a complete orbital or stellar rotation period, in order to disentangle permanent from transient features. The multisite approach to achieve round-the-clock coverage is essential in the case of unfavourable variability period or to follow transient or long-duration flare-like events. The multisite, multiwavelength programs have proven to be fundamental for solar-like activity and CV studies (cf. MUSICOS project, IAU Coll. 137, p.662).

The discovery and study of photospheric activity cycles by photometric methods in different types of close binaries (cf. *AJ*,**99**,1941; *A&A*,**237**,395; *A&AS*,**95**,55; and references therein) have triggered systematic monitoring programs of several dozen systems, which are performed also by unmanned Automatic Photoelectric Telescopes (APT). The majority of APTs are located in USA (*e.g.*, JPL, Mt. Hopkins, Phoenix, Villanova). Recently, however, two APTs were installed at Catania (Italy) and Seoul (S.Korea) Observatories. The importance of systematic photometry by automated telescopes is now widely recognized (cf., Surf. Inhom. in *Late-type Stars*, p.201; *New Frontiers in Binary Star Research*, p.45).

In addition to increasingly accurate light curves of known close binaries, the of which provides fundamental stellar parameters, the contribution of ground-based photometry can be appreciated by a simple inspection of even a likely incomplete list of newly discovered photometric close binaries and CVs. The new systems listed below, in addition to those already quoted, certainly deserve additional and extensive observations:

FO Aqr (*ApJ*,391,295); FS CMa (*IBVS*,**3602**); V1776 Cyg = Lanning 90 (*ApJ*,365,696); V365 Lac (*AZ*, **67**,1010); DO Leo (*PASP*,**102**,558); S Mus (*PASP*,**102**,551); BD+33 4070 (*IBVS*,**3814**); HD 2680 (*MN*,**261**,1); HD 46407 (*A&A*,**253**,407 and IAU Symp. 151,411); HD 89499 (*A&A*,**244**,310); HD 101191 (*MN*,**254**,404); HD 135775 (*MN*,**254**,404); HD 197010 = 1E2038.3-0046 (*IBVS*,**3536**); HD 223971 (IAPPP Comm. **44**,82); GX 339-4 (*MN*,**259**,395); H1907+690 (*ApJ*,**379**,715); LB 1800 = 4U0608-49 (*ApJ*,**355**,617); MS1603.6+2600 (*ApJ*,

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

365,686); PG0027+260 (*AJ*,**102**,272); SVS2831 Cyg (*AZ* **1547**,21); SVS2874 Cyg (*AZ* **1547**,17); 1E1615.0+3114 (*IBVS*,**3547**); in Magellanic Clouds: (*MN*,**250**,119); in M15: AZ 211 = X2127+119 (*A&A*,**270**,139); in NGC 2346 (*IBVS*,**3584**); in 47 Tuc (*Nature*,**360**,46); in Virgo (*AZ* **1548**,27); near BX Peg (*IBVS*,**3579**); in multiple systems (*PASP*,**104**,663).

5B. Ground-Based Spectroscopy (R. W. Hilditch)

The past triennium has seen two main developments in spectroscopy which are of major importance for the study of close binary stars. Firstly, new echelle spectrographs equipped with larger format CCD detectors have been installed on the world's major telescopes, thereby permitting studies of spectra at high resolution (< 0.1 Å) over a wide wavelength range (3000Å). For a given source brightness, observers can now achieve time resolutions comparable with that attainable only at very much lower resolution and spectral coverage a few years ago. Secondly, much attention has been devoted to the analysis of spectra involving techniques of deconvolution, doppler tomography, cross-correlation and spectral-line broadening functions. Hill (*ASP Conf.Ser*, **38**,127, 1993) provided an excellent summary of the techniques or procedures which he and co-workers have developed to determine radial velocities via cross-correlation from the spectra of close binary stars. By careful attention to such procedures it is now possible to obtain reliable radial velocity curves for both components in binaries even when the luminosity ratio is quite extreme. Light ratios of 10:1 are now relatively easy, and the procedures have been success- fully applied at 20:1 (Khalesseh & Hill *A&A*,**257**,199,1992). The consequences for all areas of close binary research are very significant since it allows much more accurate specifications of masses and absolute parameters for many types of evolved systems as well as for main-sequence systems with dissimilar components. No longer are we confined to studying double-lined systems with light ratios of order unity to determine such absolute parameters with precision.

Bagnuolo & Gies (*ApJ*,**376**,266,1991) have described new techniques, borrowed from medical physics, of separating the spectra of the two components in binaries from the observed spectra. This tomographic separation procedure has allowed these authors and others to disentangle such spectra very effectively in a wide range of binaries - O stars with similar components and with added contributions from colliding stellar winds, to Algol-type binaries with light ratios of 10:1. Thus a complete set of spectra, obtained to determine radial velocities of both components by cross-correlation for example, may then be subjected to much further analysis. Co-adding all the observed spectra, with appropriate doppler-shifts for both components, then results in separate and high S/N spectra of each stellar component. Not only does this work result in improved spectral classifications, but also it provides the opportunity to conduct quantitative spectroscopic investigations of line profiles for equivalent widths, rotational velocities, temperatures, surface gravities and chemical abundances.

Eclipse mapping and doppler tomography techniques have also continued to be applied in extenso by a number of observers/data analysts to establishing the structure of accretion discs in cataclysmic variables, and the distribution of star spots or zones in RS CVn systems and WUMa-type contact binaries. Good examples of such work are to be found in Dhillon *et al.* (*MN*,**252**,342,1991) for accretion disc mapping, and Strassmeier *et al.* (*A&A*,**247**,130,1991) for star spots. Much of this work concentrates on monitoring detailed changes in profiles of individual lines, requiring the use of large telescopes to attain good S/N in short time intervals.

Rucinski (*AJ*,**104**,1968,1992) has returned to the subject of the spectral-line broadening function applied to contact binaries. In his new spectroscopic study of AW UMa, he demonstrates the effectiveness of the singular value decomposition (SVD) technique to establish broadening functions (doppler profiles) which describe the intensity distribution across the surfaces of both stars as a function of radial velocity. One then requires a model of the binary system with appropriate intensity distributions and rotation laws to establish how well a model function compares with those derived from observed spectra. Clearly such techniques will be used in future in combination with photometric studies to determine more accurate descriptions of stellar surfaces.

If much effort has been put into new procedures for analysing spectra, then certainly no less effort has been spared in continuing with well-established practices of determining radial velocities, spectral-line profile variations as a function of orbital phase etc. from (typically) medium-resolution spectroscopy. It has been the practice, in the past two decades, for the contributor of this section of the Commission Report to provide a list of all the binary systems observed spectroscopically in the triennium. But the various abstracting and data-base services now available render the value of that task somewhat obsolete. A survey of the literature over the last three years demonstrates that three main themes dominate the publications of ground-based spectroscopic or spectrophotometric results - *(i)* time-resolved spectra of faint sources via 4-m class telescopes which are later co-added into orbital-phase bins by means of precisely-known photometric or X-ray ephemerides for further study, *(ii)* the "main-stream" determinations of radial velocities from medium-resolution spectra with the best techniques to obtain spectroscopic orbits of high precision, and associated line profile studies, *(iii)* searches for the existence of binaries amongst particular stellar types or clusters/regions.

This reviewer has noted some 460 publications which present significant spectroscopic investigations - a testament to the hard work of many astronomers world-wide. It is interesting to note that about 40% of these publications are concerned with detached normal or RS CVn-type binaries, such a large proportion being due to continuing surveys of solar-neighbourhood stars for binarity, late-type stars observable via radial-velocity spectrometers, or surveys of open clusters and recent star formation regions. Useful references for much of this work may be found in the proceedings of the conference "Binaries as Tracers of Stellar Formation" (eds. Duquennoy & Mayor, Cambridge UP, 1992) held at Geneva in 1992. A few new, and precise (2%), masses and absolute dimensions for detached systems have been determined since the extensive review of such data by Andersen (*A&A*,*Review* **3**,91,1991) (cf. for example, Holmgren *et al.* *A&A*,**248**,129,1991).

Cataclysmic variables and low-mass X-ray binaries constitute the second most popular spectroscopic targets at 25%. The majority of these papers discuss the properties of the accretion discs, streams and columns deduced from time-resolved spectroscopy via doppler tomography. But several also report radial velocities for the faint secondary components in these systems, thereby substantially improving the physical models for these interacting binaries, (*e.g.*, Friend *et al.* (*MN*,**246**,637,1990). Of particular importance is the LMXB system V404 Cyg (Casares & Charles *MN*,**255**,7,1992), which, with a mass function of 6.2 solar masses, may contain a black-hole secondary; and UU Sge, the central star of a planetary nebula, which is an eclipsing binary with spectroscopic orbits for both components determined for the first time (Pollacco & Bell *MN*,**262**,377,1993).

Semi-detached (Algol-type) and contact binary studies contribute 20% of the total, with significant contributions of precise determinations (5%) of masses, radii etc. being made (*e.g.* Tomkin *ApJ*,**387**,631,1992; Lu *AJ*,**102**,262, 1991; Samec & Hube *AJ*,**102**,1171,1991). These data provide real tests of mass-exchange/loss evolution models, not just in the Milky Way galaxy but also for such systems in other galaxies with different chemical histories (Bell *et al.*, *MN*,**250**,119,1991).

The flurry of activity on WR binaries in the early part of the triennium seems to have been superseded by attention to symbiotic stars in the latter part, with a total of 12% of papers published, many on MWC 560 and CH Cyg. A few papers discuss specifically the chemical abundances of the components of binary stars. Notable by their paucity, there are less than 10 papers reporting spectroscopy of high-mass X-ray binaries. Nevertheless, much improved determinations of the masses of the neutron stars and their OB-type companions in SMC X-1 and QV Nor are presented by Reynolds *et al.* (*MN*,**256**,631,1992; **261**,337,1993).

5.C Polarization Studies (R. H. Koch)

Between the previous reporting interval and the current one two major changes have occurred. The first of these is the slowly increasing number of polarimetric data in the spacecraft UV. While very few of these measures refer to close binaries themselves, the new results (*e.g.*, *ApJ*,**385**,L53, *ApJ*,**386**,562) are establishing a longer baseline for evaluation of the interstellar components of all measures. The levels of intrinsic polarization for well–behaved, single stars corrected for their interstellar components will provide a better reference against which to judge close binary polarizations. The second change has been increased use of modern polarimeters on large–aperture telescopes. This technological marriage has greatly enhanced S/N with essentially no sacrifices of other requirements. Several effects have followed from this cause. (1) Shortened duty cycles of observing have resulted in very large data sets. (2) Because of briefer duty cycles, it is now useful to search for phase–locked periodicities shorter than has been feasible up to now. (3) It is now possible to observe objects hitherto too faint. (4) Narrowed bandpasses permit spectropolarimetry for many objects so as to overcome the dilution characteristic of broad–band instruments.

It is not only close binary stars which benefit from this happy situation, but these systems do create some requirements for polarization data sets which are not characteristic of those for constant stars. For example, as noted in (1) and (2) above, data sets for periodic variables are now commonly voluminous and authors have recourse to publishing only a precis of the journal of results. A good example of this practice occurs in *ApJ*,**401**,628 wherein Stockman *et al.*. report on their concentrated program observing many CV's. No tabulated data are available to guide the reader in the reasoning of the authors. Even if data show no periodicities, archival availability should be ensured so that later workers may

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

have access to them. This same practice underpins the extensive work of Donati, Semel, and Rees (*A&A*,**265**,669), whose paper powerfully illustrates item (4) above.

The past triennium has been characterized by extensive work on magnetic white dwarf CV's, Wolf–Rayet binaries, and symbiotic stars. By contrast, the familiar attention to conventional main sequence and giant pairs appears to have abated. It is not possible to refer here to all published studies; the observed systems are simply too numerous. Rather, citations will be confined to those available through June 30, 1993 and which have led to evaluations of binary magnetic, geometrical, or envelope parameters. For many of these objects, concurrent photometric and spectroscopic programs have been necessary. Below is a list of polarimetric analyses.

EZ CMa *ApJ*,**365**,L19, *ApJ*,**391**,L37, *ApJ*,**397**,277; V834 Cen *MN*,**256**,252; DH Cep *ApJ*, **366**,308; V444 Cyg *ApJ*,**359**,211, *ApJ*,**410**,342; V1500 Cyg *ApJ*,**371**,749; UZ For *MN*,**253**, 27; AM Her *MN*,**251**,28; θ Mus *ApJ*,**391**,L37; VV Pup *A&A*,**235**,245; Grus–V1 *MN*,**244**, 34P; H1907+690 *ApJ*,**379**,715; HD 226868/Cyg X–1 *ApJ*,**384**,249; Her X–1 *A&A*,**244**, L41; HR 1099 *A&A*,**232**,L1; LSS 3074 *IAU Symp. 151*,505; Sk–67D105 *IAU Symp. 151*,505.

Space limitation permits only a sampling summary of the large number of theoretical papers published over the last 3 years. The Glasgow methodology has advanced to the level that significant limitations in the original procedure have been removed in *ApJ*,**379**,663. This effort underpins those in *MN*,**260**,513 & 525 with specific application to Be stars. A generalization beyond the familiar evaluation of mass loss from expanding envelopes appears in *A&A*,**265**,663 and a more specific application to the energy supply in the jets of SS 433 is given in *A&A*,**259**,L43. Mention may also be made of the very ample treatment of polarized cyclotron emission from AM Her–type objects appearing in *ApJ*,**354**,625. Finally, the keV–band polarization signatures in emission lines from the disks of collapsed objects are treated in *ApJ*,**382**,125.

The only new review of current understanding of polarization in close binaries appears in *The Realm of Interacting Binary Stars*, p311. This is simply a statistical summary of the known incidence of polarized and unpolarized binaries in various evolutionary stages and the likely dominant polarizing mechanisms for each stage.

5.D X-Ray Observations (J. C. Raymond)

Extensive observations have been performed over the past few years with ROSAT, GINGA and SIGMA. ROSAT observations have been vital to X-ray source identifications, especially in crowded fields such as external galaxies or globular clusters. GINGA produces important X-ray timing results and studies of the iron line. SIGMA is important for observations of high energy X-ray tails. The ASCA satellite is just beginning to provide observations at higher spectral resolution.

Many exciting results have been obtained from observations of soft X-ray transients. J0422+32, discovered by GRO/BATSE, showed an X-ray spectrum similar to that of Cyg X-1, and it is likely to contain a black hole. Nova Muscae 1991 (GS 1124-683) also showed a luminous soft X-ray component with a high energy tail, and SIGMA observations showed

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

the 511 KeV positron-electron annihilation line (Sunyaev *et al.* 1992 *ApJ*,**399**, L145). It also has a mass function which strongly suggests a black hole (Remillard *et al.* 1992 *ApJ*,**389**, L75).

Another exciting discovery in the past few years was the existence of exceptionally soft sources in the Large Magellanic Cloud (Greiner 1991 *A&A*,**246**, L17). These objects have blackbody temperatures below 0.1 KeV and high luminosities. While the nature of these systems is still open to question, Van den Heuvel *et al.* 1992 (*A&A*,**262**, 97) present a strong case that these are white dwarfs burning accreted hydrogen.

One general area of recent accomplishments has been a series of multiwavelength campaigns covering X-ray through radio wavelengths. Among other results, the campaigns on Cyg X-2 and Sco X-1 have helped to pin down the relationship between the position of a 'Z' source on the X-ray color-color diagram and its accretion rate (*e.g.* Vrtilek *et al.*, 1991 *ApJ*,**370**, 717).

5.E UV and EUV (G. E. McCluskey, Jr. and R. S. Polidan)

The IUE continued its role as the mainstay of ultraviolet astronomy and provided essentially all of the UV data on interacting binaries. To date, HST has observed very few interacting binaries, a situation which will hopefully improve in the near future. The ROSAT has provided limited but promising observations in the EUV spectral region for a number of systems and with the successful launch of EUVE in June 1992 this spectral region is now open to investigation in far greater detail than ever before. In June 1993 the first CD-ROM from the EUVE Science Archive was published.

The IUE observed many cataclysmic variables (CV). la Dous (*A&A*,**252**, 100) made a detailed study of IUE spectra of numerous CV, analysing the effects of orbital inclination on the lines and continuum. Harlaftis (*MN*,**259**, 593) compared the UV spectrum of Z Cha in normal and super outburst finding the accretion rate, which is higher for superoutbursts, to be a crucial factor. Selvelli (*ApJ*,**393**, 289) found that the recurrent novae T CrB probably does contain a white dwarf accretor rather than the previously suggested main sequence accretor.

Other CV studied were TX Col and TW Pic (Moucher *A&A*,250, 99), V795 Her (Prinja and Rosen *MN*,262, L37), QU Vul (Saizar *et al.* *ApJ*,398, 651), RW Sex, RW Tri and V Sge (Vitello and Shlosman *ApJ*,410, 815) and SU UMa, RX And and 0623+71 (Woods and Drew *MN*,245, 323).

Other interacting binaries studied with IUE include VV Cep (Bauer *et al.* *A&AS*,**90**, 175), υ Sgr (Dudley and Jeffrey *MN*,**247**, 400), AL Vel (Eaton *et al.* *AJ*,**100**, 799), ζ Aur (Eaton *ApJ*,**404**, 305), UU Cnc (Eaton *MN*,**247**, 62), 32 Cyg (Eaton *AJ*,**105**, 1525), ι Ori (Gies *et al.* *ApJ*,**403**, 752), Algol (Gonzalez-Riestra *et al.* EPIBS p.285), U Sge (McCluskey *et al.* *ApJ*,**378**, 281), τ Per, HR 2554 and HR 6902 (Schroder *A&A*,**236**, 165), Cyg X-2 (Vrtilek *et al.* *A&A*,**235**, 162), UW UMa (Wiggs and Gies *ApJ*,**407**, 252) and HD 47129 (Wiggs and Gies *ApJ*,**396**, 238). Stickland *et al.* continued their UV radial velocity curve program (*Obs*, **111**, 23; **111**, 167; **112**, 150; **112**, 277).

Pounds *et al.* (*MN*,**260**, 77) published the results of the ROSAT EUV sky survey which detected about 30 RS CVn systems, 17 CV, several AM Her stars and Algol. Jeffries and Bromage (*MN*,**260**, 132) discovered the active chromosphere late-type binary Gliese 841A in the EUV with ROSAT. Buckley *et al.* (*MN*,**262**, 93) discovered an AM Her polar, RE1938-461, in the period gap with ROSAT. The EUVE obtained an EUVE light curve for the RS CVn binary V711 Tau (EUVE Tech. Bull. No. 20). Cheng *et al.* (*ApJ*,**397**, 664) observed X-ray nova Muscae with the FOS and FOC on HST. Long *et al.* (*ApJ*,**405**, 327) observed U Gem with the Hopkins UV Telescope.

5.F Radio Flux Modeling (B. Geldzahler)

The radio emission from the envelope of a binary star system can impart important information. This data is just as important as photospheric data for an understanding of the system. A combination of the two kinds of data leads to a holistic, more complete model of such systems.

Lestrade *et al.* (*ApJ*,**410**, 808, 1993) extended their VLBI astrometric studies of Algol. The less massive star of the binary (a K subgiant) emits nonthermal radio radiation; consistent with a view of from strong magnetic activity in the subgiant. The orbital motions of the long period and close binary systems are nearly orthogonal and counter-revolving; relevant for evolution and dynamical studies. The orientation and sense of the motion of the close binary are identical to early determinations made by optical polarization measurements.

Simultaneous VLA and VLBI observations of the T Tauri binary system.(Phillips *et al.* *ApJ*,**382**, 261, *ApJ*,**403**, L43 1993) detected no VLBI emission although there was sufficient sensitivity indicating a lower limit to the source size of about 1 AU = 70 stellar radii. 25-30% polarization was detected with the VLA and variations of the circular polarization were seen on time scales of 1 hour indicating a strong nonthermal component to the radio emission previously thought to be thermal free-free emission. T Tauri appears to be the first protostar system to show nonthermal radio emission.

11 years of VLA and VLBI astrometric data firmly established (Fomalont and Geldzahler *ApJ*,**383**, 289, 1991) that the "components" of the Sco X-1 system are unrelated; Sco X-1 is not a "microquasar." The collinear, triple source appearance of the source is another cosmic conspiracy. The proper motions of the NE and SW sources indicate these sources are probably extragalactic; the binary itself has a proper motion (along the line joining the three objects) of 15 mas/year. A parallax of 210±80 pc was measured indicating that Sco X-1 is a member of the Sco-Cen moving group. This is the first time the parallax and hence distance to an X- ray binary has been measured.

Sco X-1 is a quasi-periodic oscillating X-ray source; one of 6 known QPO Z-sources. Hjellming *et al.* (*ApJ*,**365**, 681, 1990) found that Sco X-1 has two emission states: radio-quiet when Sco X-1 was on the flaring branch of the x-ray color-color diagram, and radio-loud when the x-ray emission was on the normal branch. The same radio-x-ray correlation is seen in the QPO Z-sources GX 17+2 and Cyg X-2. The variability indicates a multicomponent radio source whose high frequency component is variable on time scales of 2-3 hours.

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

Hollis and Michalitsianos (*ApJ*,**411**, 235, 1993) observed R Aquarii with both HST and the VLA and found evidence for precession of the jets and showed that the optical and radio emission are not co- spatial. Proper motion analysis of the discrete radio components in the jets indicates a 44 year period for the binary.

Ivison *et al.* (*MN*,**249**, 374, 1991) made nearly simultaneous optical and radio observations of a sample of 17 symbiotic stars and estimated physical parameters, including mass loss rates They confirmed the suggestion of Seaquist *et al.* (*ApJ*,**284**, 202, 1984) that ionized regions of D-type (dust, infrared emitters) symbiotics are much more extensive than those of S-type ("stellar," no infrared emission). This strengthens the hypothesis that S-types are more likely than D-types to be undergoing Roche equipotential surface overflow.

Drake *et al.* (in PASP Conference Series, Cool Stars, Stellar Systems, and the Sun, 1992) observed radio emission from rapidly rotating cool giant stars. They surmised that there are two subclasses of this group: (1) Late F and early G giants that are in or near the Hertzsprung gap, stars of moderate mass that had a radiative envelope on the main sequence and have only recently developed convective envelopes with resultant chromospheres and coronae. They have not had time to lose angular momentum through a magnetic wind. The levels of UV, radio, and x-ray emission are similar to single mid-G to mid-K normal giants. (2) mid-G to early-K giants that are a bit more evolved, and which have retained or acquired more angular momentum than the majority of stars in this region of the HR diagram. These stars have UV, radio and x-ray emission levels similar to RS CVn stars of similar rotation rates.

Williams *et al.* (*MN*,**243**, 662, 1990) observed the O-star/Wolf-Rayet system HD 193793 over a ten year period. They found the radio emission is well represented by a two component model: a constant free-free emission from the stellar wind and a strong non-thermal source which undergoes variable extinction as it moves through the WC7's wind along the orbit of the O-star.

6. STELLAR PHYSICAL PARAMETERS (A. Gimenez)

The obtaining of accurate stellar dimensions from detached binaries is well covered in the review by Andersen (*AAR*, **3**, 91) which includes the best available data on stellar masses and radii, using members of double-lined eclipsing systems with errors below 2%, to reproduce the parameters of normal stars. Further discussions are given in IAU Symp. 151, p.31, IAU Coll. 137 p.347 & 361, and Bin. as Tracers of Stellar Form. p.18. Some statistical studies have been made about the mass-ratio distribution in spectroscopic binaries (*ApSpSc*, **194**, 143 & **196**, 299; *ApJ*,**394**, 592 & **401**, 265) and short-period systems (IAU Coll. 137, p.119; *Astrop*, **30**, 323). Relations between masses, radii, temperatures and luminosities of stars in eclipsing binaries of various types are given by Karetnikov (*SovA*, **35**,437)

At the same time, a complete revision of standard theoretical models has taken place from the point of view of the radiative opacities as well as the theory of convection. These new studies are discussed in Comm. 35 report where new grids of stellar evolutionary models are also mentioned. Among them, models using Rogers & Iglesias (*ApJ*,**371**, 408) opacities have been specifically computed for comparison with parameters derived from the study of

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

binary systems (*A&AS*,**96**, 255), including internal structure constants for the interpretation of observed apsidal motion rates (*A&A*,**244**, 319). Accurate binary star data around the TAMS seem to favour the existence of some amount of overshooting, at least within the mass range between around 1.5 and 2.5 solar masses (*ApJ*,**363**, L33). Below that value, convection in the core is too small and above it, the effect of overshooting may be negligible. A detailed study of Procyon indicated that no convective overshooting was necessary (*ApJ*,**405**, 298) and similar results were pointed out by Stothers & Chin using different tests (*ApJ*,**381**, L67; *ApJ*,**383**, 820). On the contrary, BW Aqr was shown by Clausen (*A&A*,**246**,397) to be better understood with overshooting models and Napiwotzki *et al.* (IAU Coll. 137, p.461) obtained similar indications from the width of the main sequence. The new opacities provide better agreement with observations, adopting smaller amounts of convective overshooting, but new observational data about actual metal abundances for well-detached binaries are still badly needed to perform a detailed comparison (IAU Coll. 137, p.177).

The importance of obtaining accurate dimensions for early-type stars and the involved difficulties have been emphasized (*Messenger*, **64**, 26; *Observ*, **111**, 14). Popper and Hill (*AJ*,**101**, 600) rediscussed several spectroscopic orbits of OB systems using cross-correlation techniques and warned against some systematic effects. A revision of the early-type systems BF Aur (*A&A*,**265**, 613) and NY Cep, with no secondary eclipse due to its high eccentricity (*ApSpSc*, **198**, 137) have been published. Accurate absolute dimensions have been obtained for the early-type binaries AH Cep (*A&A*,**236**, 409), V3903 Sgr (IAU Coll. 137, p.371), CW Cep (*A&A*,**241**, 98) and U Oph (*A&A*,**248**, 129), the two latter showing apsidal motion. Further, new radial velocity curves have been published using IUE measurements for the systems Y Cyg (*Observ*, **112**, 150; *BAAS*,**22**, 1292) and CW Cep (*Observ*, **112**, 277). Less massive detached binaries like EG Ser (*AJ*,**105**, 2291), HD 174853 (*AJ*,**102**, 1777) or RX Her (IAU Symp. 151, p.281; *IBVS*,**3403**) were also analysed.

The relatively unexplored region of the HR diagram around main sequence G-K stars is still being scrutinized spectroscopically by Popper (*ApJ*,**404**, L67). RU UMi is a late-type binary which may be a result of extensive mass transfer (*MN*,**260**, 478) and the orbit and physical parameters of V1073 Cyg (*A&A*,**265**, 597) and WX Cnc (*Ch.A&A*,**14**, 397; **15**, 214) have also been determined. A particularly interesting case is TZ For (*A&A*,**246**, 99), a fully-fledged red giant binary allowing accurate comparison with stellar models and a detailed tidal evolution analysis. Another interesting case, the system AI Phe, has been revisited (*ApJS*,**79**, 123). Many late-type eclipsing binaries are found to be active due to enhanced rotation induced by tidal synchronization. Three more papers by Popper of a series devoted to study spectroscopic orbits of close binaries with Ca II H and K emission have been published (*AJ*,**100**, 247; **101**, 220; **102**, 699), adding 15 binaries to the existing list. On the other hand, fundamental data for stars like V792 Her (*AJ*,**101**, 1489; see also *ApSpSc*, **182**, 1) and short-period binaries, like BH Vir (*A&A*,**237**, 148), RT And (*Ch.A&A*,**16**, 162) and ER Vul (*A&A*,**238**, 145) have been obtained. A second edition of the catalogue of chromospheric active binary stars by Strassmeier *et al.* (*A&AS*,**100**, 173) was published, including revised masses and radii. In some cases, these values are only estimations using methods like that by Hall (*AJ*,**100**, 554). Activity in the cool components of totally eclipsing Algol binaries was studied by Olson and Etzel (*AJ*,**106**, 342) and wind driven mass transfer, with special attention to the system Z Her, was discussed by Tout and

Hall (*MN*,**253**, 9).

Photometry and spectroscopy of very close early-type binaries, like SV Cen (*AJ*,**103**, 573) and LZ Cep (*Ir. Astron.J*, **20**, 32) or early-type Algols, like TV Cas (*A&A*,**257**, 199) has also been analyzed. To try to understand these and other interacting binaries, De Greve and De Loore have computed a series of evolutionary sequences (*A&AS*,**94**, 453; **96**, 653; **97**, 527). β Lyr has been revisited (*PisAZh*, **18**, 711; *A&A*,**266**, 307) as well as the evolutionary status of Algol (*MN*,**262**, 534) from a non-conservative point of view. The chemical evolution of mass exchanging binary systems was discussed (IAU Coll. 137, p.792; *MN*,**259**, 17) and absolute dimensions of Algol-type semidetached binaries were obtained for systems like TX UMa (*ApSpSc*, **201**, 177), RT Per (*Ch.A&A*,**14**, 437), RS Sgr (*BolAsArgAstr*, **36**, 28), U Cep (*ApJ*,**377**,278; *BAAS*,**22**, 1292) or V505 Sgr (*A&A*,244, 75; *ApJ*,387, 631). The system GO Cyg was found to be a reverse Algol (*ApSpSc*, **203**, 121) and CG Vir was suggested as a post-Algol phase system (*Ch.A&A*,**14**, 273). It was studied the effect of irradiation in the cool components of Algol-type binaries (*A&A*,**256**, 572) and other effects of proximity (NATO ASI, p.7). On the other hand, a classification survey has been started for classical Algol binaries (*BAAS*,**22**, 1334) while the various methods to estimate dimensions in this type of systems have been discussed (NATO ASI, p.121) and applied to compile a catalogue of the best available data (IAU Symp. 151, p.295). Cool Algols are introduced and discussed by Popper (IAU Symp. 151, p.395). Absolute dimensions of W UMa-type binaries have been obtained for the systems V781 Tau (*AJ*,**105**, 646), AA UMa (*Ch.A&A*,**14**, 389), SS Ari (*AJ*,**102**, 262), and RW Dor (*MN*,**255**, 285). With respect to cataclysmic binaries, Webbink (*11th NAmerWork CataclVar.*, p.117) has presented a spectroscopic and photometric survey with the objective of deriving absolute dimensions.

One of the areas of research showing important advances during the past triennium was the determination of stellar dimensions in binaries of the Magellanic Clouds (NATO ASI, p.61). Absolute dimensions were published for the semidetached system HV 2226 (*MN*,**250**, 119; IAU Symp. 151, p.501) and CCD light curves have been obtained for systems like HV 12484 (*MN*,**260**, 777), HV 2208 and HV 12634 (*MN*,**254**, 419). Specially interesting systems were found to be HV 2274 (*MN*,**258**, 527; IAU Symp. 151, p.509), a well-detached eccentric binary with apsidal motion, and the eccentric Wolf-Rayet eclipsing binary HD 5980 in the SMC (IAU Symp. 143, p.229). Some massive close binaries in the Magellanic Clouds were studied by Niemela and Bassino (IAU Symp. 151, p.497)

Another area of interest has been the study of binary members of open clusters. This is a promising research area due to the combination of isochrone and extinction determinations with stellar masses and radii (102 Summ. Sci. Meet. of the ASP, p.427 and p.433). Binary systems in clusters and associations which have been studied include H235 in NGC 752 (*BAAS*,**23**, 881; IAU Symp. 151, p.487), SS Lac in NGC 7209 (IAU Symp. 151, p.483; *BAAS*, **23**, 879) which is no longer eclipsing (!) or CW Cep, a member of Cep OB2 like NY Cep. Known eclipsing binaries in the old cluster NGC 188 have been re-analyzed (NATO ASI, p.891) and the population in M67 has been studied (*BAAS*,**22**, 1293) as well as some spectroscopic systems in the halo (IAU Coll. 137, p.158; *PASP*,**104**, 1108). A CCD study has discovered 12 short-period eclipsing binaries in the old cluster Be39 (*MN*,**262**, 49) supporting the theory of formation of W UMa binaries through magnetic braking. Moreover, several

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

papers have pointed out that a larger amount of eclipsing binaries are found in globular clusters, and Pop II stars in general, than previously reported (*PASP*,**104**, 981; *ComAp*, **16**, 61; *A&A*,**244**, 310; IAU Symp. 151, p.483; *ApJ*,**389**, 590).

Of particular interest for tidal evolution theories is the study of late-type binaries, like the eccentric case of HD 212280 (*AJ*,**105**, 2265), the circular orbit of the above mentioned TZ For, the nearby Capella (*PASP*,**105**, 476) or the active RZ Eri (*A&A*,256, 463). From a theoretical point of view, the Tassouls continued with their effort to explain synchronization and circularization in close binaries (*ApJ*,**395**, 259). Observational and theoretical data are presented by Mathews and Mathieu (IAU Coll. 135, p, 244), Mazeh *et al.* (NATO ASI, p.145) and Claret and Gimenez (IAU Symp. 151, p.269) for well detached binaries, and by Hall (NATO ASI, p.287) for chromospherically active binaries. Tidal circularization among close binaries in the halo (IAU Symp. 151, p.491) and in M67 (p.471) has also been studied. Zahn (*A&A*,**252**, 179) has provided new insight into the still schematic treatment of overshooting as well as a general review (Bin. as Tracers of Stellar Form. p.253), while Maceroni and van't Veer (*A&A*,**246**, 91) contributed to the evolutionary study of angular-momentum-losing G-type binaries. The dynamical theory of viscous tides in binary systems (*A&A*,**257**, 783; IAU Coll. 137, p.374; *A&A*,**257**, 783) has been analyzed, while the effect of dynamic tides on variations of the orbit was analysed by Ruymaekers (*A&A*,**259**, 349).

During the past triennium, important advances have been produced in the study of apsidal motions of eclipsing binaries. A review of the status at the beginning of it was given by Gimenez (NATO ASI, p.137) and several systems have been added to the list of eccentric binaries with accurate dimensions and well determined apsidal motion rates, like CO Lac (*BAAS*,**23**, 835; ATs 1543), BW Aqr (*A&A*,**246**, 397), V477 Cyg (*A&A*,**260**, 227), U Oph (*A&A*,**248**, 129) or CW Cep (*A&A*,**241**, 98). Moreover some evolved, more difficult, systems have been revised like V1765 (*BAC*, **42**, 230) and V380 Cyg (*BAAS*,**22**, 1223). Photometric studies have been presented for YY Sgr (*AJ*,**104**, 796), HS Her (*ATs*, **1552**; *AN*, **313**, 183), BF Dra (*IBVS*,**3867**), GR Car (*IBVS*,**3835**), and α CrB (*IBVS*,**3876**). Many observers have contributed to the data base of eclipse timings for systems showing apsidal motion (*IBVS*,**3408**. 3494, 3495, 3552, 3900 or BBSAG Bulletins, in particular, No. 99). A new list has been produced (*BAC*, **42**, 98) of eccentric binary systems deserving further attention as potential apsidal motion candidates and Lacy has proposed a new method to solve for apsidal motion variations (*AJ*,**104**, 2213) which was applied to analyse YY Sgr (*AJ*,, **105**, 637), V523 Sgr (*AJ*,**105**, 630) and V526 Sgr (*AJ*,**105**, 1096). A preliminary comparison with models was presented (IAU Symp. 151, 277; IAU Coll. 137, p.469) showing a much better global picture than only a few years ago. The effects of dynamical tides on the rate of apsidal motion was studied by Smeyers *et al.* (*A&A*,**248**, 94) showing a possible way to explain some anomalous cases. From the point of view of the relativistic apsidal motion term, new studies have been made of DI Her (*ApJ*,**375**, 314) and AS Cam (*AJ*,**102**, 256; *BAAS*,**23**, 879) which still show important discrepancies with predicted values.

Reflection and limb-darkening has been studied by Hadrava (*A&A*,**257**, 218) and Rubashevskij (*SovA*, **35**, 626) who provides a method for determining nonlinear limb-darkening coefficients from model atmospheres and light curves while a new nonlinear limb-darkening law was proposed by Diaz-Cordoves and Gimenez (*A&A*,**259**, 227). For these studies, new model atmospheres produced by Kurucz (in Light Curve Modeling of Eclipsing Binary Stars, p.93) are now available. Discussions about brightness distribution on highly distorted stars were made by Barman (*BASIndia*, **19**, 59) and by Nakamura and Kitamura (*ApSpSc*, **191**, 267). A revision of the effective gravity-darkening in different types of binary systems was presented by Kitamura (NATO ASI, p.69).

7. EVOLUTIONARY PROCESSES

7.A Origin of Binary Stars (A. P. Boss)

The last three years have seen a strong growth in interest in the formation of binary stars, driven by events on four fronts: (i) improved understanding of the statistical properties of main-sequence (MS) binary stars, (ii) emerging statistics for the properties of binary pre-main-sequence (PMS) stars, (iii) probable detection of binary protostellar objects, and (iv) theoretical advances in understanding the classical as well as newly advanced hypotheses of binary star formation. Several volumes have appeared that focus directly on binary stars (*Binaries as Tracers of Stellar Formation* = *BTSF*; *Interacting Binary Stars* = *IBS*; *The Realm of Interacting Binary Stars* = *RIBS*; and *Complementary Approaches to Double and Multiple Star Research* = *CADMSR*); the latter in particular contains important papers too numerous to list in this short report. Reviews of the theories of binary star formation are given by Pringle (in *The Physics of Star Formation and Early Stellar Evolution*), Bodenheimer, Ruzmaikina, and Mathieu (in *Protostars & Planets III* = *PPIII*), Clarke (in *BTSF*), and Boss (in *RIBS*).

It has long been recognized that the dynamical properties of MS binary stars place crucial constraints on any theory of their origin (*e.g.*, Tout *MN*,**250**, 701). Duquennoy and Mayor (DM, *A&A*,**248**, 485) surveyed all G-type stars within 22 pc of the Sun and found a unimodal period distribution and a secondary mass distribution rising toward low ratios; a similar unimodal distribution was found by Fischer and Marcy (*ApJ*,**396**, 178) for M dwarfs. When analyzed according to the improved mass ratio algorithm of Mazeh and Goldberg (in *BTSF* and *ApJ*,**394**, 592), the short period binaries in the DM sample show a mass ratio distribution that rises toward high $q = M_2/M_1$ values (Mazeh *et al.* *ApJ*,**401**, 265), implying a different distribution for long and short period binaries. Abt, Gomez, and Levy (*ApJS*,**74**, 551) found that B stars have a secondary mass distribution that rises toward lower masses, excepting the short period systems.

Brosch (*MN*,**253**, 545) found a five star system in the shape of a diamond that appears to be an evaporating small cluster. McCarthy *et al.* (*AJ*,**101**, 214) used an infrared speckle camera to image a triple system (Gleise 22ABC) where both secondaries (0.12 and 0.18 $M_\odot$) appear to orbit stably about the primary (0.36 $M_\odot$) at distances of 5 and 40 AU, respectively.

PMS binaries also are yielding dynamical properties of great interest for origins. Binary PMS stars have been detected by Reipurth *et al.* (*A&A*,**235**, 197), Moneti and Zinnecker (*A&A*,**242**, 428), Chen *et al.* (*ApJ*,**357**, 224), Simon *et al.* (*ApJ*,**384**, 212), Koresko *et al.* (*AJ*,**102**, 2073), Haas *et al.* (*A&A*,**269**, 282), and Casey *et al.* (*AJ*, in press). Amazingly, the binary frequency appears to be *higher* for PMS stars than on the MS (Ghez, Neugebauer, and Matthews, in *CADMSR*; Leinert *et al.*, in *CADMSR*; Zinnecker, Brandner, and

https://doi.org/10.1017/S0251107X00008245 Published online by Cambridge University Press

Reipurth, in *CADMSR*; Reipurth and Zinnecker, *A&A*,, in press). This seems to require significant orbital evolution between the PMS and MS phases, and that the great majority of stars form in binary or multiple systems. The eccentricity distribution of PMS binaries covers the same wide range (e = 0.0 to 0.8) as on the MS (Mathieu, in *BTSF*).

Candidate binary protostars are beginning to proliferate, detected both through molecular line emission (Harjunpää, Liljeström, and Mattila *A&A*,**249**, 493) and infrared emission (Sandell *et al.* *ApJ*,, **376**, L17; Mundy *et al.* *ApJ*,, **385**, 306). About 10% of PMS binaries contain an infrared-bright companion with a separation of about 200 AU (Zinnecker and Wilking, in *BTSF*). The existence of binary protostars places the tightest constraint yet on the epoch of binary formation – evidently binary formation occurs during or immediately prior to star formation itself.

Theoretical work on binary formation has concentrated on the fragmentation mechanism, that is, on break-up during the protostellar collapse phase prior to the PMS phase. Finite-difference 3D hydro codes (Boss and Myhill *ApJS*,**83**, 311) have been used to calculate tidally-induced fragmentation into binaries (de Felice and Sigalotti *MN*,**249**, 248; Sigalotti and Klapp *MN*,**254**, 111) and fragmentation of initially prolate clouds into binaries (Boss *ApJ*,**410**, 157). Myhill and Kaula (*ApJ*,**386**, 578) found that clouds with initial power law density distributions will fragment if they are in rapid differential rotation. Initial conditions leading to hierarchical fragmentation and multiple system formation were found by Boss (*Nature*, **351**,298), Klapp, Sigalotti, and de Felice (*A&A*,**273**, 175), and Sigalotti (*A&A*, in press). Fragmentation during the standard isothermal test case continues to be a useful test for 3D hydro codes (Myhill and Boss, *ApJS*, in press).

Smoothed particle hydro (SPH) calculations by Bastien *et al.* (*ApJ*,**378**, 255), Arcoragi *et al.* (*ApJ*,**380**, 476), Bonnell *et al.* (*ApJ*,**377**, 553; *ApJ*,**400**, 579) and Bonnell and Bastien (*ApJ*,**401**, 654) have examined in great detail the processes through which initially cylindrical clouds can fragment into binary and multiple systems. Monaghan and Lattanzio (*ApJ*,**375**, 177) demonstrated multiple system formation in a strongly cooled SPH cloud, while Chapman *et al.* (*Nature*, **359** 207) showed that binaries could result from the collision of interstellar clouds.

Given that PMS binaries have a range of eccentricities, the question of generating high eccentricities becomes important. N-body simulations of the evolution of open star clusters show that cluster evolution is unlikely to excite initially small eccentricities to large values (Aarseth, in *BTSF*), so high eccentricities must be primordial. Binary formation is likely to occur inside protostellar disks, and the interactions between companion objects and protostellar disks have been studied by Lin and Papaloizou (in *PP III*), Artymowicz *et al.* (*ApJ*,**370**, L35), and Artymowicz (*PASP*,**104**, 769). Mathieu (in *IBS*) discusses observational evidence for both circumprimary and circumbinary disks. Lubow and Artymowicz (in *BTSF*) find that initially small eccentricities should grow to e = 0.5 or so for binaries embedded in disks. If the binary is still accreting mass from the disk, however, Bonnell and Bastien (*ApJ*, in press) find that the binary eccentricity decreases. The net effect on binary eccentricities remains to be determined.

Other formation mechanisms have been studied as well. Adams and Benz (*CADMSR*) present SPH calculations of the growth of $m = 1$ instabilities in disks with central stars, leading to companions containing about 1% of the disk mass. Savonije, Papaloizou, and Heemskerk (in *Astrophysical Disks, Ann. N.Y. Acad. Sci. 675*) also studied the growth of $m = 1$ modes (also Heemskerk, Papaloizou, and Savonije *A&A*,**260**, 161), but were unable to reproduce the rapidly growing modes found by Adams, Ruden and Shu (*ApJ*,**347**, 959) and hypothesized to lead to the formation of binary companions.

Clarke and Pringle (*MN*,**249**, 584 and 588) modeled the ability of stars with protostellar disks to interact and become gravitationally bound, and found that capture rates are likely to be too low for capture to be an important mechanism. McDonald and Clarke (*MN*,**262**, 800) showed that very low mass companions should be rare in systems formed by capture. Hills (*AJ*,**103**, 1955) studied the formation of transient triple systems resulting from encounters between close binaries and single stars, while Anosova and Orlov (*A&A*,**260**, 473) integrated trajectories for three-body systems and delineated systems leading to immediate escape.

7.B Mass Flow and Evolution (G. E. McCluskey, Jr. & E. F. Guinan)

The observational and theoretical investigation of evolution and mass flow in non-degenerate binaries continues at a rapid rate. Major publications are IAU Symposium 151, "Evolutionary Processes in Interacting Binary Stars" (EPBIS) ed. by Kondo *et al.*, "The Realm of Interacting Binary Stars" RIBS) ed. by Sahade *et al.* and "Structure and Evolution of Single and Binary Stars" (SESBS) by de Loore and Doom.

The evolution of massive interacting binaries continues to attract great interest, stimulated in part by the difficulties presented by the blue supergiant progenitor of SN 1987A. General reviews include Iben (*ApJS*,76, 55), de Loore and Doom (SESBS), and Vanbeveren (*SpScRev* **56**, 249). De Greve and de Loore (*A&AS*,**96**, 653) and de Loore and De Greve (*A&AS*,**94**, 453) calculated extensive evolutionary sequences for stars with initial masses from 9 to 40 solar masses. Case B evolution was adopted and it was assumed that 50% of the mass lost by the stars was lost to the system. Initial masses greater than 20 - 25 solar masses lead to Wolf - Rayet stars and then to massive X-ray binaries. Some lower mass systems become He-rich binaries. Vanbeveren (*A&A*,**252**, 159) calculated a series of models carefully accounting for stellar wind mass loss during hydrogen and helium core burning. For initial masses greater than about 50 solar masses, a powerful stellar wind during the luminous blue variable stage of H-shell burning prevents a dynamic phase of mass loss due to binary interaction. All primaries of more than 10 solar masses (initial) begin He-core burning as bare helium cores and evolve thereafter as single stars. Dynamic mass loss rates of 10^{-3} are reached. de Loore and vanbeveren (*A&A*,**260**, 273) investigated a binary model for SN 1987A. The B3 supergiant evolved from the original secondary star with an initial mass of 9 - 15 solar masses and mass ratio near unity. When the progenitor was in the H-shell burning phase, it accreted 8 - 10 solar masses from its evolving companion and eventually became SN 1987A. Extensive pre-supernovae scenarios were investigated by Podsiadlowski *et al.* (*ApJ*,**391**, 246). Progenitors of SN of types Ib, II and 1987A were produced. Hubeny and Plavec (*AJ*,**102**, 1156) studied a thick disk model for β Lyr and Mazzali (*A&A*,**254**, 241) proposed a two wind model. As shown by Kondo *et al.* (*ApJ*, in press) who survey

OAO-2, Copernicus, IUE, and Voyager observations of β Lyr, no existing model can explain the bizarre behavior of β Lyr across the electromagnetic spectrum.

The Algol-type and closely related interacting binaries have drawn considerable effort. A wide range of phenomena are encompassed by the term Algol-type interacting binary. McCluskey (RIBS, p.39) divides the Algols into three classes: low activity systems, *e.g.*, S Cnc or U Sge; active systems, *e.g.*, U Cep or TT Hya; and dynamic systems, *e.g.*, SX Cas or V367 Cyg, if the latter two are semi-detached systems.

Algol itself has been the subject of recent research. Using the VLBI to observe the radio emitting plasma in the system, Lestrade *et al.* (*ApJ*,**410**, 808) find that the K-star's corona is responsible for the non-thermal radio emission which, along with X-ray emission from Algol (*e.g.*, Stern *et al.* *ApJ*,**400**, 321) demonstrates the importance of magnetic activity. Richards (*ApJS*,**86**, 255) made a detailed study of Hα profiles in Algol and finds evidence for a low-density, transient, asymmetric, rotating accretion disk which contains a turbulent high-velocity substructure. Gas extends some distance out of the orbital plane between the close components near the hot star where the gas stream interacts with the disk and/or the stellar surface. Evolutionary calculations by Sarna (*MN*,**262**, 534) indicate that about 15% of the total initial mass and 30% of the total initial angular momentum have been lost to the system. Edalati *et al.* (EPBIS p.303) find that the low mass, short period Algol system R CMa underwent far more systemic mass and angular momentum loss than most Algols.

Polidan and Wade (EPBIS p.351) studied the carbon abundance of 5 massive Algols showing UV emission lines during primary eclipse. Four systems showed no detectable carbon while one did have carbon emission indicative of roughly normal carbon abundance.

Unama *et al.* (*A&A*,**249**, 217; *A&A*,**267**, 126) observed a number of Algols at microwave wavelengths. Algol, RZ Cas, TW Dra, RT Lac, V505 Sgr and HR 5110 have radio spectra similar to the RS CVn systems. This emission is probably gyrosynchrotron emission from mildly relativistic electrons. Olson and Etzel (*AJ*,**106**, 342) attribute the increase in observed photometric variations of Algol secondaries with increasing rotational velocity and decreasing orbital period to rotationally induced magnetic activity in part. Guinan (EPBIS p.245) notes the importance of MHD effects on cool components of all classes of interacting binaries. Elias and Mutel (RIBS p.335) review the radio observations of late-type components in binaries. A wide class of binaries have been detected with magnetic fields of roughly 100-1000 G or higher associated with Algol secondaries.

With regard to low-mass systems, Rucinski (RIBS p.111) comments that angular momentum loss via magnetic winds may rival or dominate nuclear evolution in the W UMa systems. Mass and energy flow between the two stars is still very poorly understood. Vilhu (EPIBS p.61) postulates that W UMa systems have detached systems with periods of 1-4 days as progenitors and that they evolve into FK Comae stars or blue stragglers (single stars). Eggleton (EPIBS p.167) discusses the increase in cool star activity with increasing rotation rate which is critical for mass and angular momentum loss.

Important problems remain for investigators of interacting binaries. The "accretion disk" concept is used to explain a wide variety of phenomena and is undoubtedly a simplistic model (Sahade RIBS p.17). The use of the Roche model for hot stars with powerful winds or for systems in the dynamical phase of mass loss is very questionable at best (McCluskey RIBS p.381; Sahade RIBS p.17; Sahade *et al.* RIBS p.399). Greatly improved models for systemic mass and angular momentum loss are required. Guinan and Gimenez (RIBS p.51) review the great importance oh MHD effects for cool binary components, effects almost invariably neglected in interpreting and modeling interacting binary observations. Herczeg (EPIBS p.307) finds that irregular, often abrupt, period variations play a substantial role in the overall observed period changes. An explanation still eludes us.

Progress in resolving these issues will be stimulated by multiwavelength studies and new technology and methods, *e.g.*, Doppler tomography (Kaitchuk EPIBS p.175), but primarily in the old-fashioned way - hard work!

7.C Eruptive Phenomena (P. Szkody and S. Starrfield)

The last three years have seen major advances in the understanding of the structure and eruptive phenomena associated with cataclysmic variables. Three detailed reviews of the entire field were recently produced (Livio and Shore each had an article in the Proceedings of the 22nd Saas Fee Advanced Course, 1993 in press; Cordova, in X-Ray Binaries, 1993 in press; Starrfield, in Reviews in Modern Astronomy, Klare, ed., 1992, p.73). Highlights of results on the accretion disk, the white dwarf, the secondary star, LMC novae, recurrent novae, novae abundances, and the outburst of Nova V1974 Cyg 1992 are presented here. A poster and oral session were devoted to the observations of V1974 Cyg at the January 1993 meeting of the AAS (*BAAS*,1992, **24**, 1189).

The most promising results on understanding the accretion disk have emerged from time-resolved studies of eclipsing systems, such as Z Cha (Harlaftis *et al.*, 1992, *MN*,**257**, 607; Wood, in CVs and Related Physics, 1993, in press), HT Cas (Wood, Horne and Vennes, 1992, *ApJ*,**385**, 294) and U Gem (Marsh *et al.*, 1990, *ApJ*,**364**, 637). Some of these studies involved using IUE or HST spacecraft to obtain ultraviolet data in conjunction with optical coverage in order to derive the spectrum of the white dwarf and the disk. Eclipse mapping procedures (comparison to computed models or maximum entropy mapping, reviewed in Horne, IAU Coll. 129, 1991, 3) were then used to derive the temperature and surface density structures of disks. The results all show that observed disks at quiescence have a flatter temperature distribution with radius than predicted by steady state models but the outburst disks are close to predicted models (T proportional to $R^{-3/4}$). At superoutburst, the Z Cha results indicate an extended vertical structure with a cool bulge on the disk edge at the position of the intersection of the mass transfer stream. Doppler tomography using the emission lines of U Gem at quiescence indicate an outer rim of disk emission, with the bulk of the S-wave emission from the stream impact area, but with velocities suggestive of a mixture of disk and stream material. In the non-eclipsing old nova system, GK Per, modelling of the IUE and optical light curves of its dwarf nova like outbursts with disk instability models determined a large inner disk, indicating that a magnetic field greater than 10 MG disrupts the inner portion (Kim, Wheeler and Mineshige, 1992, *ApJ*,**384**, 269).

Besides information on the disk, the above techniques have resulted in new information about the stellar components. The eclipse studies provide a temperature for the white dwarf and allow a study of its heating as a result of the outburst scenario. The Wood HST results on Z Cha at quiescence and outburst show that the white dwarf is only heated by 2000K during outburst and cools within 16 days. This result is surprising in that it implies no extensive boundary layer develops during outburst (standard accretion disk theory predicts the boundary layer luminosity should be roughly equal to the disk luminosity unless the white dwarf is rotating very rapidly). The lack of a prominent boundary layer luminosity was also concluded from the X-ray and UV observations of VW Hyi (Mauche *et al.*, 1991, *ApJ*,**372**, 659; Belloni *et al.*, 1991, *A&A*,**246**, L44). Further puzzles about the interaction of this boundary layer and the heating of the white dwarf during a dwarf nova eruption are evident in the two component temperature structure determined in the studies of the white dwarf in U Gem (Kiplinger, Sion and Szkody, 1991, *ApJ*,**366**, 569; Long *et al.*, 1993, *ApJ*,**405**, 327).

The heating effects on the secondary also invoke theoretical challenges. Doppler tomography on U Gem revealed a source of Balmer emission on the secondary star which was offset from the line of centers. Further study of the irradiation of the secondary in CH UMa, IP Peg and YY Dra (Davey and Smith, 1992, *MN*,**257**, 476) confirmed the same effect, which could not be explained by straightforward irradiation from a hot white dwarf plus a hot spot. Furthermore, detailed spectroscopy of the secondary in the long period dwarf nova DX And (Drew, Jones and Woods, 1993, *MN*,**260**, 803) revealed spectral abnormalities which may be related to prior evolution through the common envelope phase or large scale mass transfer from the companion.

Successful searches of the LMC for novae since 1990 have resulted in studies of LMC 1990 No. 1 (a fast ONeMg nova: Dopita *et al.* IAU Circular 5262), LMC 1990 No. 2 (a recurrent nova: Shore *et al.* 1991 *ApJ*,**370**, 193), LMC 1991 (a fast CO nova; it reached a V$\sim$ 9 making it one of the most luminous novae studied: Della Valle 1991, *A&A*,**252**, L9), and LMC 1992 (a moderate speed CO nova with an ultraviolet spectral development similar to OS And 1986: Shore *et al.* 1993, in prep.). Novae in the Clouds are all at the same distance with small reddening, so they are useful as fiducials for studies of Galactic novae. For example, a comparison of U Sco to LMC 1990 No. 2 shows that U Sco must be a Halo object (Shore *et al.* 1991, *ApJ*,370, 193) and it was possible to compare the outburst of Nova Her 1991 to that of LMC 1990 No. 1 and obtain the distance and reddening to Her 91 (Starrfield *et al.* 1992, *ApJ*,**391**, L71). A review of LMC Novae can be found in Starrfield *et al.* (1993; in New Aspects of Magellanic Cloud Research ed. Baschek, Klare, and Lequeux, p.181).

The studies of recurrent novae indicate that there are at least two classes of RN, those with giant secondaries such as V3890 Sgr (Gonzalez-Riestra 1992, *A&A*,**265**, 71; Harrison *et al.* 1993, *AJ*,, **105**, 320; Shore and Aufdenberg 1993, *ApJ*, in press), V745 Sco (Sekiguchi *et al.* 1990, *MN*,**246**, 78), RS Oph, and T CrB and those with evolved but compact secondaries such as U Sco, V394 CrA, and LMC 1990 No. 2. In both cases, however, theoretical calculations require that the white dwarf be very massive in order for the outbursts to occur with very short inter-outburst times. Schaefer (1990, *ApJ*,**355**, L39) has determined orbital periods for U Sco and V394 CrA and Johnston and Kulkarni (1992, *ApJ*,**396**, 267) obtained a very low mass for the white dwarf in U Sco. Duerbeck *et al.* (1993, ESO Messenger, No. 71, 19) redid the study and report a high mass for the white dwarf. A similar problem with a possible low mass white dwarf exists for Nova V838 Her 1991 (Szkody and Ingram 1993, *ApJ*, in press). A study of T Pyx was inconclusive about the structure of the system (Schaefer *et al.* 1992, *ApJS*,**81**, 321).

Abundance studies have demonstrated that there are two compositional classes of novae: those that occur on carbon-oxygen white dwarfs and those that occur on oxygen-neon-magnesium white dwarfs. Theoretical studies of thermonuclear runaways on ONeMg white dwarfs show that such novae can produce important amounts of ^{22}Na and ^{26}Al (Weiss and Truran 1990, *A&A*,**238**, 178; Nofar *et al.* 1991, *ApJ*,**369**, 440; Starrfield *et al.* 1992, *ApJ*,, **391**, L71; Politano *et al.* 1993, in preparation). Observational studies of recent nova outbursts have shown that the following were ONeMg novae: Her 1991 (t_3 = 2.8days; Matheson *et al.* 1992, *BAAS*, **24**, 1260; Vanlandingham *et al.* 1992; *BAAS*, **24**, 1284; Harrison and Stringfellow 1992, *BAAS*, **24**, 1284), Pup 1991 (Shore *et al.* 1993; in preparation), and Nova Cyg 1992 (Hayward *et al.* 1992, *ApJ*,**401**, L101). Andreä *et al.* (1993, *A&A*,submitted) determined nebular abundances for 10 nova outbursts. Saizar *et al.* (1991, *ApJ*,**367**, 310) and Andreä *et al.* (*A&A*,**244**, 111, 1991) reported abundances for the very slow CO nova PW Vul and Saizar *et al.* (1992, *ApJ*,**398**, 651) reported abundances for QU Vul a slow ONeMg nova. Abundances for LMC 1990 No. 1 were reported by Dopita *et al.* (1993, in "New Aspects of Magellanic Cloud Research", ed Baschek, Klare, and Lequeux, Springer-Verlag, p.195). Analyses of GQ Mus (Pèquignot *et al.* 1993, *A&A*,**219**) and V443 Scuti 1989 (Anupama *et al.* 1992, *A&A*,**263**, 87) have appeared. GQ Mus was detected in the ROSAT Survey (Ögelman *et al.* 1993, *Nature*,**361**,331) which implies that it is still in outburst.

Hayward *et al.* (1992, *ApJ*,**401**, L101) reported the detection of Ne II 12.8μm in V1974 Cyg 1992 and showed that the line profile was produced by a very asymmetric ejection. Dinerstein *et al.* (1992, *BAAS* **24**, 1189) reported on the transition to the IR coronal phase, Elias *et al.* (1992, *BAAS*,**24**, 1189) used an optical interferometer to resolve the expanding shell 8 days into outburst ($\sim$ 5 mas). Garnavich (1992, *BAAS*,**24**, 1189), Bjorkman et al. (1992, *BAAS*,**24**, 1190), Gallagher *et al.* (1992, *BAAS*,**24**, 1189), Taylor *et al.* (1992, *BAAS*,**24**, 1189), and Austin *et al.* (1992, *BAAS*,**24**, 1284) all reported optical studies. Polidan *et al.* (1992, *BAAS*,**24**, 1191) reported on Voyager observations, Shore *et al.* (1992, *BAAS*,**24**, 1191) described the IUE and HST data, Shore *et al.* (1993a, *ApJ*, in press) showed that this nova emitted at a constant bolometric luminosity for at least the first 100 days of the outburst, and Shore *et al.* (1993b, *AJ*,submitted) described the kinematics of the ejecta using both IUE high dispersion data and two HST visits. Hauschildt *et al.* (1993, *ApJ*,submitted) described a non- LTE, spherical, expanding stellar atmosphere analysis of the early spectra and showed that there was a major structural change in the ejecta early in the outburst. Gehrz *et al.* (1993, *ApJ*, in press) described their KAO observations of the nova and provided an estimate of the neon and sodium abundances in the ejecta.

7.D Close Binaries with Collapsed Components (R. F. Webbink)

A startling new development of the past triennium has been the discovery of a possible planetary system surrounding a millisecond pulsar. Although the discovery first announced (PSR 1829-10: Bailes *et al.* 1991, *Nature*,**352**, 311) was subsequently retracted

(Lyne & Bailes 1992, *Nature*,**355**, 213), it set in motion a flurry of model-building which was subsequently vindicated by the discovery of a second, more compelling example (PSR 1257+12: Wolszczan & Frail 1992, *Nature*,**355**, 145). A rich variety of hypotheses have been put forward: simple survival of a prior planetary system (Bailes *et al.* 1991, *Nature*,**352**, 311); cannibalization of the central star in a solar-type system (Podsiadlowski *et al.* 1991, *Nature*,**352**, 783); spiral-in of a primordial planetary system in the merger remnant of a massive X-ray binary (Wijers *et al.* 1992, *Nature*,**355**, 393); formation from the supernova ejecta (Bailes *et al.* 1991; Lin *et al.* 1991, *Nature*,**353**, 827); condensation in the thick disk remnant of a close double white dwarf (or white dwarf/neutron star) merger (Podsiadlowski *et al.* 1991), or in a disk formed by accretion from the wind of a distant (now extinct) Be star companion (Fabian & Podsiadlowski 1991, *Nature*,**353**, 801), by deflation of the envelope of a Thorne-Zytkow object (Podsiadlowski *et al.* 1991), by tidal disruption of a low-mass stellar companion (Stevens *et al.* 1992, *MN*,**252**, 19P), or by the systemic outflow from an evaporating companion (Tavani & Brookshaw 1992, *Nature*,**356**, 320; Banit *et al.* 1993, Planets around Pulsars, p.167); evaporation of a stellar companion to planetary mass (Bailes *et al.* 1991; Krolik 1991, *Nature*,**353**, 829; Rasio *et al.* 1992, *A&A*,**256**, L35); and more. A wide range of issues raised by this discovery are encompassed in Planets around Pulsars (1993, ASP Conf. Ser. 36), in which the comprehensive review and critique of these scenarios by Podsiadlowski, and the discussion of the physics of planetary formation in a disk around a pulsar by Phinney and Hansen will be of interest to students of close binary evolution.

Uncertainties over the formation channel for low-mass X-ray binaries and their putative connection with binary millisecond pulsars continue to preoccupy theorists. These issues are surveyed in X-Ray Binaries and Recycled Pulsars (1992, Kluwer), and have been thoroughly reviewed by Bhattacharya and van den Heuvel (1991, *Phys. Rep.*, **203**, 1). Recent population synthesis studies by Romani (1992, *ApJ*,**399**, 621) lead to a very high space density of black hole X-ray transient sources with low-mass donors, in comparison with their neutron star counterparts.

The process of pulsar companion evaporation observed first in PSR 1957+20 continues to stimulate many investigations into the evolutionary implications of this phenomenon (Podsiadlowski 1991, *Nature*,**350**, 136; Fedorova & Ergma 1991, *Pis'ma AZh*, **17**, 999; Tavani 1991, *Nature*,**351**, 39; Ergma & Fedorova 1991, *A&A*,**242**, 125 and 1992, *A&A*,**265**, 65; Shaham & Tavani, 1991, *ApJ*,**377**, 588; Harpaz & Rappaport 1991, *ApJ*,**383**, 766; D'Antona & Ergma 1993, *A&A*,**269**, 219).

Questions of the frequency and *Nature*,of neutron star-neutron star and neutron star-black hole mergers have received new attention as sources of gravitational waves (Hils *et al.* 1990, *ApJ*,**360**, 75; Hils 1991, *ApJ*,**381**, 484) and possibly of gamma-ray bursts (Narayan *et al.* 1992, *ApJ*,**395**, L83; Mészáros and Rees 1992, *ApJ*,**397**, 570). Several significant efforts at modeling the merger process have been published (Kochanek 1992, *ApJ*,**398**, 234; Bildsten & Cutler 1992, *ApJ*,**400**, 175; Rasio & Shapiro 1992, *ApJ*,**401**, 226), and Tutukov and Yungelson (1993, *MN*,**260**, 675) have derived new estimates for the frequency of these events.