42. CLOSE BINARY STARS (ETOILES BINAIRES SERREES)

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1. Introduction

Research on close binary systems has continued at a high level during the past triennium, although the rate of growth is noticeably slower - probably reflecting the cutbacks in funds to which many of us are subject. There have also been changes of emphasis within the field, which are commented on in the pages that follow. These reflect both changing opportunities for observation and the natural development of the subject. In many areas, the time is ripe for a more critical look at ideas that previously seemed adequate.

No large symposium devoted exclusively to close binary systems has been held in the past triennium. The Commission did sponsor IAU Colloquium 80, *Double Stars, Physical Properties and Generic Relations*, held at Lembang (Java), Indonesia, June 3-7, 1983, to commemorate the 60th anniversary of the Bosscha Observatory. The proceedings have been published in *Astrophysics and Space Science*, Vol. 99. The Commission was a co-sponsor of IAU Symposium No. 111, *Calibration of Fundamental Stellar Quantities* held in Como, Italy, May 24-29, 1984 (dedicated to D.M. Popper) and IAU Colloquium 88, *Stellar Radial Velocities*, held in Schenectady, N.Y., October 23-27, 1984. The proceedings of the first will be published by D. Reidel and of the second by L. Davis press.

Other meetings in our field have been arranged independently of our Commission and the following list is not guaranteed to be complete. Two workshops were held in 1983, one in Baton Rouge, Louisiana, in February, on cataclysmic variables, and one in Cambridge, England, in the summer, on close binaries and dedicated to the memory of J.A.J. Whelan. The Commission on "Physics and Evolution of Stars" of the multi-lateral cooperation of the Academies of Sciences of socialist countries organized two meetings: *Ejection and Accretion of Matter in Binary Systems* (Tatranska Lommica, Czechoslovakia, April 1980, published by VEDA in 1982, edited by J. Tremko) and *Relativistic Objects in Close Binary Systems* (Cluj-Napoca, Romania, Preprint No. 4, Faculty of Mathematics, Babeş-Bolyai University, edited by V. Ureche). A national workshop on binary stars, the first of its kind in the People's Republic of China, was held at the Xinglong observing station of Beijing Astronomical Observatory in September 1983. A Colloquium on *Astrometric Binaries and Related Problems* was held in Bamberg, F.R.G. in June 1984, to commemorate the 200th anniversary of the birth of F.W. Bessel. Proceedings of two meetings mentioned in our last report (*Binary and Multiple Stars as Tracers of Stellar Evolution* and IAU Colloquium 72, *Cataclysmic Variables and Related Objects*) have now been published. Your Organizing Committee hopes to submit a proposal, before the nineteenth General Assembly, for a symposium covering much the same ground as the 1972 Parksville symposium, to be held in 1986 or 1987.

During much of the triennium under review, many observers in our Commission have been interested in the eclipse of ε Aur. References to some preliminary results will be found in this report. A Joint Discussion in New Delhi will be partly devoted to this system, and a workshop on the subject will be held in Tucson, Arizona in January 1985. Most of the results of these observations must

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wait, however, for the next Commission report. Eleven campaign newsletters have been issued, edited by J. Hopkins and R. Stencel (who provided much of the information in this paragraph) with support from both the IAU and AAS. Collaboration between professional and amateur astronomers, through the International Amateur-Professional Photoelectric Photometry association, has greatly contributed to the completeness of photometric observations. Fourth contact of the eclipse was in May 1984. Reasonably well defined *UBV* light-curves were obtained. Red and near infrared photometric observations, as well as polarimetric (J. Kemp) observations, were also made. Spectroscopic and spectrophotometric observations, both from the ground and from space, are reported. The Mg II feature at 280 nm seems to have been unaffected by the eclipse. The time of egress determined from ultraviolet observations appears to have been several weeks later than that deduced from observations in the visual region of the spectrum.

During the Patras meetings, the Commission discussed the proposal by AAVSO to publish its accumulated observations of cataclysmic variables. We submitted a resolution of support to the General Assembly, which was endorsed. We note with gratitude that the IAU Executive has made a grant towards the cost of publication, which has stimulated private gifts. Although the AAVSO does not yet have all the funds it needs, it is proceeding with its plans for publication.

The Commission has continued to produce its *Bibliography and Program Notes on Close Binaries*. After the distribution of No. 37, Dr. Larsson-Leander relinquished the editorship which he had held since 1968. The high standard and usefulness of the *Bibliography* owes much to Dr. Larsson-Leander's work over 14 years, and to the support given him by Lund Observatory; we express our thanks to both for this important contribution to our work. We are fortunate that Dr. T. Herczeg (University of Oklahoma) has agreed to take over the editorship. Despite unexpected difficulties in financing the printing and distribution, Dr. Herczeg and his collaborators have produced (up to the time of writing) Nos. 38, 39 and 40. Contributors to the *Bibliography* during the last three years have been: K.D. Abhyankar, B. Cester, D.S. Hall, M. Kitamura, H. Mauder, C.D. Scarfe, A. Shul'berg, R.F. Sistero, F. Van't Veer and M. Vetesnik. Other help was given by R.P. Olowin and C. Jascheck (CDS Strasbourg).

In arrangement, this report is similar to previous ones, but some sections have been merged to reflect changing emphases. We propose to discuss further changes in New Delhi. The President acknowledges with thanks those members of the Organizing Committee (and others) who prepared various sections, as identified. Thanks are also due to those members of the Commission who submitted individual reports. Not everything thus submitted could be included, but members may be sure that their reports were helpful. As in previous years, we have found it convenient to use very abbreviated references to which we provide the key here:

AA = *Acta Astron.*
AAp = *Astron Astrophys.*
AAp Sup = *Astron. Astrophys. Suppl. Ser.*
AA Sin = *Acta Astron. Sinica*
AAp Sin = *Acta Astrophys. Sinica*
AJ = *Astron. J.*
AN = *Astron. Nachr.*
Ann Rev A Ap = *Ann. Rev. Astron. Astrophys.*
Ann. Tokyo = *Ann. Tokyo Astron. Obs. Second Ser.*
ApJ = *Astrophys. J.*
ApJSup = *Astrophys.J. Suppl. Ser.*
ApL = *Astrophys. Lett.*
Izv. Krym. = *Izv. Krymskoi Astrofiz. Obs.*
JAAVSO = *J. American Assoc. Variable Star Observers*
JApA = *J. Astrophys. Astron.*
JRASC = *J.R. Astron. Soc. Canada*
Mitt AG = *Mitt. Astron. Ges.*
MN = *Mon. Not. R. astr. Soc.*
MSAI = *Mem. Soc. Astron. Italiana*
Obs = *Observatory*
PASJ = *Publ. Astron. Soc. Japan*
PASP = *Publ. Astron. Soc. Pacific*
Per Zv = *Perem. Zvezdy Bull.*
PisAZh = *Pis'ma v Astron. Zh.*

ApSpSc = *Astrophys. Space Sci.*
ATs = *Astron. Tsirk*
AZh = *Astron. Zh. Akad. Nauk USSR*
BAAS = *Bull. American Astron. Soc.*
BAC = *Bull. Astron. Inst. Czechoslovakia*
BASI = *Bull. Astron. Soc. India*
Bull. Abas = *Bull. Abastamani Astrophys. Obs.*
IAUC = *IAU Circ.*
IBVS = *Inf. Bull. Variable Stars*
Publ. DAO = *Publ. Dominion Astrophys. Obs.*
Publ Tartu = *Publ. Tartu Astrofiz. Obs.*
Rev Mex = *Revista Mexicana Astron. Astrofis.*
Tartu Pub. = *Tartu Astrofiz. Obs. Publ.*
Trudy Kazan = *Trudy Kazan. Gorod. Astron. Obs.*

In addition *IAU* Symposium and Colloquium volumes are referred to by *IAU Sym* or *IAU Coll* and the appropriate number.

2. Methods of Light-Curve Analysis
(K-C. Leung)

There was an outburst of activity in the development of methods of analyzing light-curves in the early 1970s, when several groups developed methods of computation for high-speed computers. In the subsequent decade there seem to have been fewer astronomers participating in this important area of double-star astronomy. In the past triennium, only a few workers have been involved, but there have been significant developments.

R.E. Wilson has continued to make new contributions since the development of the Wilson-Devinney method in 1971. He has been generous in supplying his updated version on request; only recently has the University of Florida instituted a nominal charge for the reproduction of documentation and tapes. His method for simultaneous solution of light-curves and velocity-curves, developed in an earlier paper (*ApJ 234*,1054), is demonstrated for AS Eri and V1134 Cyg in a paper now in press (*AAp*). In another paper in press, Wilson identifies RZ Sct as a good example of a double-contact binary in the sense defined in the *ApJ* paper cited. He has now added to the Wilson-Devinney method a means of including star-spots (cold or hot) in the "light-curve" program. A star-spot is defined by four photoelectric parameters, namely, spot temperature, spot size and two coordinates (longitude and latitude of the spot). This required also a small modification in the differential-correction program.

Yamasaki (*ApSpSc 77*,75) has published 2,700 theoretical light-curves in tabular form, suggesting that they can be used for deriving preliminary parameters for contact systems. Linnell (*ApJSup 54*,17) has developed a program to synthesize light-curves and colour-curves of contact systems. He hopes to use this method to analyze W-type W UMa systems.

Cherepashchuk and Lipunova (*ApSpSc 86*,299, *AZh 599*, 73 *Pis AZh 8*, 242) have discussed methods of solving light-curves of Wolf-Rayet systems. Kopal (*ApSpSc 87*,149,*88*,313) has studied the theoretical light changes to be expected in a system with oscillating components.

3. Observational Data

A. PHOTOMETRIC OBSERVATIONS AND SOLUTIONS (R.H. Koch)

This section was written from materials with publication dates no later than June 30, 1984 and which were held at Pennsylvania by October 30, 1984. The format and content are intended to be consistent with the same section of the 1982 Report.

Table 1 shows that photoelectric observing has continued to increase from the

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Table 1. Photoelectric Observing Programs for the Past Three Triennia

	75-78	78-81	81-84
References for photoelectric data	346	564	713
Close binaries observed	209	342	455
Binaries not observed previous triennium	184	240	313
Northern systems ($\delta > +23°$)	88	120	197
Equatorial systems	50	77	135
Southern systems ($\delta < -23°$)	35	76	123

last triennium although at both absolute and relative rates slower than during the previous interval. The second and third entries demonstrate not only the accelerated pace of working on new (and in many cases very faint or very bright objects) but also the commitment to sustain observational coverage of systems that are intrinsically active.

The last three entries of the Table show that sky coverage is approaching uniformity. Naturally, this does not mean that we are yet free of selection bias even for Population I.

Part of the charge toward preparing this section was to include a listing of the light-curve analyses appearing in the last 3 years. The charge was construed in the same way as in 1981 and the list appears in Table 2. This enumeration of models and solutions is not complete. Several Argentine, Chinese, German, Indian, and Russian publications are not held in the Pennsylvania library. From the *Bibliography and Program Notes* it was evident that these journals and serials contain several analyses, but the published material could not be located in the vicinity of Philadelphia or at Goddard Space Flight Center. Additionally, for some of these papers the entries in *Astron. and Astrophys. Abstracts* were uninformative and it seemed best not to guess the contents and conclusions of the papers. In Table 2 the only unconventional abbreviation, *PSB*, refers to *Photometric and Spectroscopic Binary Systems* (E.B. Carling and Z. Kopal, D. Reidel 1981).

Table 2. Photometric Solutions

RT And *AAp 103*,57, *PSB* p313; AB And *PSB* p199, *MN 208*, 123; AD And *AApSup 45*,499; AN And *AAp 114*,74, *Ann Tokyo 19*,361; S Ant *AApSup 47*,211; AE Aqr *A Ap 104*,24; EE Aqr *AAp 107*,197; KO Aql *AApSup 45*,85; OO Aql *PSB* p199; V337 Aql *AApSup45*, 499; V346 Aql *AApSup 45*,85; V603 Aql *MN 195*,51P; V889 Aql *AAp 115*,321; V1182 Aql *AApSup 45*,499; V1343 Aql *AZh 61*,124; V535 Ara *PSB* p199, *ApSpSc 92*,99; SS Ari *ATs 1249*,5; SX Aur *PerZv 21*,445; EO Aur *JAAVSO 10*,13; KR Aur *PASP 95*,265, TY Boo *PSB* p199; VW Boo *PSB* p199; XY Boo *PSB* p199; AC Boo *PSB* p199, *ApSpSc 92*,99; AD Boo *AApSin 2*,232; 44 Boo *AApSup 45*,187; AO Cam *BAAS 13*,514, *JRASC 76*,90; AS Cam *ApSpSc 94*,115; AW Cam *AApSup 45*,85, *52*,311; TX Cnc *MN 196*,305; AC Cnc *PASJ 35*,423, *IAU Coll 72*,17; R CMa *ApSpSc 99*,229; FZ CMa *AAp 120*,278; XZ CMi *AAp 96*,415; X Car *ApSpSc 99*,191; ST Car *AAp 121*,271, *MN 206*,305; GW Car *ApSpSc 99*,191; OY Car *MN 207*,783, *AAp 128*,29, *128*,37; PX Car *MittAG 52*,169; QX Car *AAp 121*,271; TV Cas *AApSup 52*,213; YZ Cas *AApSup 53*,161; AZ Cas *AApSin 2*,143; CW Cas *PSB* p199; HT Cas *ApJ 244*,579, *245*,1035, *ApJSup 45*,517; V368 Cas *IBVS* 2517; V523 Cas *AJ 86*,98, *AApSup 49*,89; RR Cen *PSB* p199; ST Cen *AJ 86*,1546; SV Cen *AAp 110*,246, *IAU Coll 59*,487; BH Cen *AJ 89*,872; V757 Cen *PASP 94*,189; V779 Cen *AAp 124*,294; RS Cep *AJ 89*,562; VV Cep *MSAI 52*,275; VW Cep *PSB* p199; CQ Cep *AAp 134*,45; *244*, CX Cep *AZh 59*, 73, *ApJ 244*,169; EM Cep *IBVS* 2050; GT Cep *AApSup 49*,89, *55*,403; GW Cep *ApSpSc 83*,195; NN Cep *AApSup 51*,27; TV Cet *AJ 86*,102; TW Cet *AApSup 47*,211; Z Cha *ApJ 244*,579, *252*,653; RZ Com *ApSpSc 92*,99, *PSB* p199; CC Com *PSB* p199, *AApSup 49*,123; TZ CrA *AApSup 45*,85; RT CrB *AASin 23*,125; W Crv *BAAS 14*,979; RV Crv *AApSup 49*,89; UZ Cyg *ApSpSc 82*,189; VW Cyg *ApSpSc 82*,189; BR Cyg *AAp 96*,409; DK Cyg *ApSpSc 92*,

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99, *PSB* p199; EM Cyg *MN 195*,235; V388 Cyg *MN 203*,235; V444 Cyg *ApJ 281*,774; V463 Cyg *BAC 33*,187; V470 Cyg *AAp 109*,368; V478 Cyg *AApSup 53*,363; V1073 Cyg *PSB* p199, V1357 Cyg *AJ 86*,1259; V1727 Cyg *ApJ 243*,900; RZ Dra *AApSin 2*,144; UX Dra *BAC 35*,65; BH Dra *AApSup 45*,499; BS Dra *ApSpSc 79*,359, *AA 31*,505; BV Dra *AApSup 48*,85, *51*,435, *ApSpSc 88*,433; BW Dra *AApSup 51*,435, *ApSpSc 88*,433; RU Eri *ApSpSc 81*,209, *AApSup 49*,89; UX Eri *PSB* p199; WX Eri *AApSup 45*,85, *52*,311; YY Eri *AApSup 49*,123; BV Eri *ApSpSc 93*,69; BW Eri *ApSpSc 88*,197; EF Eri *MN 195*,155; U Gem *ApJ 246*,215, *258*,572, *MN 204*,1105; RY Gem *AA 32*,411, *Bull.Abas 55*,89; AF Gem *PASP 94*,926; GW Gem *AApSup 46*,185; SZ Her *AApSup 45*,85; TT Her *AAp 126*,94; AH Her *AAp 117*,283; AK Her *ApSpSc 92*,99, *PSB* p199; AM Her *ApJ 247*,984; DI Her *ApJ 254*,203; *ATs 1183*,5; DQ Her *ApJ 244*,579; HZ Her *ApJ 247*,1003, *275*,278; LT Her *AApSup 52*,311; MM Her *ApSpSc 90*,421; u Her *AN 304*,37; TT Hya *JApA 2*,119, *3*,93; WY Hya *AAp 103*,349; KM Hya *AAp 130*,102; RY Ind *PASP 94*,524, *MN 206*,305; SW Lac *AApSup 51*,435, *PSB* p199; AR Lac *ApSpSc 78*,123; AW Lac *AJ 88*,1679; CO Lac *ApSpSc 89*,5; EM Lac *AApSup 51*,435, *PSB* p199; EN Lac *AAp 122*,193; UV Leo *AN 304*,37; UZ Leo *PSB* p199; XY Leo *MN 196*,305; AM Leo *PSB* p199, *ApSpSc 92*,99; RS Lep *AApSup 45*,85; ES Lib *AN 302*,187; FT Lup *MittAG 55*,72, *MN 208*,135; RR Lyn *ATs 1165*,3; UU Lyn *PASJ 35*,131; UV Lyn *PASP 94*,350; MV Lyr *ApJ 245*,644; β Lyr *AAp 95*,328; TU Men *AAp 132*,187; AU Mon *AA 32*,431, *MN 199*, 131; BT Mon *ApJ 254*,646; UZ Oct *AAp 130*,97; RZ Oph *AAp 111*,372, *ApJ 264*,251; V502 Oph *AApSup 49*,123, *PSB* p199; V566 Oph *PSB* p199; V839 Oph *PSB* p199; V2051 Oph *MN 203*,909; VV Ori *ApSpSc 89*,15, *AApSup 51*,111, *ApJSup 49*,531; CN Ori *AAp 115*,190; ER Ori *AApSup 47*,211, *PSB* p199; δ Ori *ApJ 248*,249; θ^1Ori *PerZv 21*,227; BD Pav *AAp 124*,287; U Peg *AApSup 47*,211; *PSB* p199; AQ Peg *ApSpSc 82*,189; BB Peg *AN 302*,285, *AAp 101*,273; BX Peg *AA 32*,131; DI Peg *ApSpSc 81*,283; EE Peg *ApJ 281*,268; II Peg *ApJ 247*,975; RT Per *ApSpSc 75*,329; DM Per *AApSup 54*,193, *Obs 104*,83; β Per *ApSpSc 98*,163; 1 Per *IBVS* 2077; AE Phe *AApSup 45*,187, *PSB* p199; AG Phe *PASP 95*,347; AI Phe *BAAS 15*,877; δ Pic *PASP 95*,319; SZ Psc *ApSpSc 82*,289; UV Psc *AApSup 49*,89, *ApSpSc 99*,239; V Pup *AAp 128*,17; TY Pup *AAp 99*,182, *AApSup 49*,123; VV Pup *MN 201*, 521, *203*,749; PV Pup *AAp 132*,219; TY Pyx *AAp 101*,7, *PSB* p361; VV Pyx *AAp 134*,147; U Sge *PASP 94*,70; UU Sge *PSB* p405; WZ Sge *ApJ 248*,1067; V499 Sco *AApSup 49*,89; V861 Sco *MN 203*,1021, *IAU Coll 59*,481; V884 Sco *AZh 58*,1226; RT Scl *ApSpSc 100*, 117; VZ Scl *ApJ 244*,579; RS Sct *ApSpSc 99*,191; RY Sct *AAp 100*,59, *101*,138; RZ Tau *ApSpSc 92*,99, *PSB* p199; CD Tau *ApSpSc 79*,359; HU Tau *AAp 97*,410; V471 Tau *AA 31*, 37; HO Tel *AApSup 45*,499; RW Tri *ApJ 244*,579, *MN 195*,227, *195*,825; RR TrA *AApSup 45*,85; KZ TrA *ApJ 244*,1001; AQ Tuc *AApSup 45*,187; W UMa *PSB* p199, *ApSpSc 92*,99,*MN 196*,305; TX UMa *AJ 89*,126; TY UMa *AApSup 51*,97; UX UMa *ApJ 244*,579, *MN 195*,505; VV UMa *BAAS 14*,613; AW UMa *ApJ 260*,744; BE UMa *ApJ 272*,202, *PASJ 34*,141; RT UMi *ATs 1165*,1, *AAp 96*,328, *97*,206; RU UMi *BAAS 14*,613; AG Vir *ApSpSc 92*,99; AH Vir *PSB* p199, *ApSpSc 92*,99, *MN 196*,305, *AApSup 53*,13; AZ Vir *AN 303*,311; BF Vir *ApSpSc 78*,141; BH Vir *MN 206*,305; DM Vir *AJ 88*,535; HD5303 *MN 197*,769, *202*,427; HD90657 *ApJ 259*,213; HD 97152 *ApJ 244*,528; HD134518 *AAp 109*,366; HD155638 *ApJ 270*,L79; HR7442 *IBVS* 2552; HR7464 *AAp 135*,194; HR9049 *ApSpSc 74*,83, *MNASSA 40*,48; BV267 *BAAS 14*,613; BD+37°2356 *IBVS* 2191; 2A0311-227(=EF Eri) *MN 199*,801; E2003+225 *ApJ 277*,682; PG1012-029 *ApJ 276*,233; Lanning 10 *ApJ 252*,681.

Table 3 gives a breakdown of analytical procedures used for light-curve study. This is offered with the same caveats and apologies as in 1982. The Russell-Merrill formalisms still survive either as entry-level solutions or because some groups do not yet have available to them the more deeply and physically parameterized methods. The frequency-domain methods have been elaborated and used abundantly by workers affiliated with the Manchester group. Their work has raised anew the question of whether contact and over-contact binaries are really so. At this time, it seems fair to say that results indicating that such binaries are not in contact are not accepted by most students, nor are they construed as evidence that the cycling episodes of, e.g., the theory of thermal-relaxation oscillations have been found (see also section 5C). The past three years have continued the abundant productivity with Wilson's and Wood's codes. Applied retrospectively to many light curves, in the literature, these efforts have certainly removed false and satellite solutions of several binaries, but some confusions and unlikely interpretations do remain.

Table 3. Percentages of Light Curves Studied by Different Computational Methods

Budding	2
Kopal	15
Miscellaneous	22
Rucinski	3
Russell-Merrill	11
Spherical and Nelson-Davis-Etzel	3
Wilson-Devinney	22
Wood	22

From Table 4 it is possible to sense the changes of interest in binaries of different configurations. Except at the hottest and coolest ends, there are numerous light curves solved for systems on or near the main sequence and, without a judgment concerning evolution, it is possible to be satisfied with the sample of contact pairs except for the coolest temperatures. Because of their stellar and solar impacts, the RS CVn-like objects and spotted stars have great value but many more light curves are needed. Modelled systems associated with slow mass exchange are plentiful now but we are still limited by only a few showing fast mass transfer. The most obvious trend is associated with binaries having a degenerate component. These attract deserved attention for the light-curve studies support all other investigations and, in many cases, we can hardly believe that we have seen the entire repertoire of a system's photometric behaviour.

Table 4. Percentages of Configurations among Solutions of Binary Light Curves

	75-78	78-81	81-84
Numbers of binaries	173	211	215
Mostly non-contact, ZAMS to TAMS	33%	22%	16%
Near MS contact	21%	29%	37%
Slightly evolved, e.g. RS CVn-syndrome	4%	7%	6%
Substantially evolved but still non-degenerate	37%	34%	24%
Substantially evolved with collapsed component	5%	9%	17%

Space limitations have caused this section to concentrate on photoelectric work. Nonetheless, archival photographic and even visual studies continue to have value as is shown by the exemplary summary concerning GK Per = N Per 1901 in 1983, *AApSup 54*,p393.

B. SPECTROSCOPIC AND SPECTROPHOTOMETRIC OBSERVATIONS

Table 5 shows that spectroscopic observers have been very active. It includes ultraviolet observations, but not radio or X-ray studies, although spectroscopy of the optical counterparts of X-ray sources is included. References to IAU Circulars are not given, neither are references given to abstracts if the subsequent main paper can be identified. A few papers that give only a little information (e.g. spectral classification) about each of many systems have been deliberately omitted. An asterisk indicates that the paper cited contains new information about orbital elements.

A characteristic of Table 5 is the increasing number of spectroscopic observations that are not primarily concerned with the determination or revision of orbital elements. Several studies of stellar rotation and of magnetic fields are included. This reflects the growing realization of the importance of these factors for the understanding of surface phenomena in some kinds of binary. Of particular interest is the application by Vogt and Penrod (*PASP 95*,p565) of Doppler imaging to the study of the distribution of luminous flux over the surfaces of components of RSCVn binaries. The results of this technique lend considerable support to the spot hypothesis as an explanation of the light variations of these stars.

Cross-correlation has been used to determine the velocities of binary components and has proved very useful. Good spectroscopic mass-ratios are at last being obtained for W UMa systems (see e.g. Maclean and Hilditch, *MN 203*,p1), which should help in the definitive solution of their light-curves. Hill (*Publ. DAO 16*,p59) has devised a cross-correlation program that has been found most effective for determining velocities from the spectral lines of weak early-type components, and may lead to more reliable determinations of absolute dimensions for such stars. It has also been used successfully in the measurements of components of composite spectra (see the reference for 93 Leo in Table 5).

The expanding nebulae around old novae have been studied spectroscopically by Williams (*ApJ 261*,p170). Oliversen and Anderson (*ApJ 268*,p250) have made observations of the visual and ultraviolet spectra of symbiotic stars that tend to confirm the binary nature of these objects, since they can be interpreted by a model in which a red-giant star surrounded by a nebula is eclipsed by a hot companion. In this context, Sahade's (*IAU Coll 70*,p1) useful review of symbiotic stars should be noted.

Reticons and similar detectors continue to be used successfully in the detection of faint secondaries of Algol-type systems. An important example is the system of λ Tau in which Fekel and Tomkin (*ApJ 263*,p289) detected the secondary spectrum and confirmed that the system is triple, with a remarkably small ratio of periods. Spectroscopy of the disk of RW Tau with high time-resolution by Kaitchuck and Honeycutt (*ApJ 258*,p224) is also an important development promising a much greater understanding of circumstellar disks in Algol systems. Plavec' (*ApJ 275*,p251) study of the UV spectrum of U Cep is discussed in section 5B.

Table 5. Spectroscopic and Spectrophotometric Studies

RX And *PASP 94*,102*, *BAAS 14*,981; AN And *Ann Tokyo 19*,361*; EG And *ApJ 262*,282, *BAAS 15*,927; KZ And *ApJ 269*,250; α And *AAp 118*,313; λ And *BAAS 15*,650, *ApJ 268*,L121; o And *IBVS 2125*,2284*, *ApSpSc 86*,179*; V337 Aql *ATs* 1212; V496 Aql *RevMex 6*,103; V603 Aql *AA 33*,149, V794 Aql *ApJ 260*,794; V822 Aql *Izv Krym 64*,81*; V882 Aql *ATs* 1212; V1343 Aql (SS433) *PASP 94*,80, *ApJ 256*,222; *BAAS 14*,880, *15*,927; ε Aql *Obs 102*,82*; AE Aqr *MittAG 57*,302*; FF Aqr *BAAS 14*,979; R Ara *ApSpSc 99*,281; AT Ara *MittAG 55*,77*; BF Ara *IBVS* 2286; V359 Ara *AAp 118*,255*; TT Ari *AAp 110*, 281, *BAAS 15*,663; AR Aur *AAp 118*,313; KR Aur *ApJ 267*,922, *PASP 95*,264*; α Aur *BAAS 14*,900*, *ApJ 272*,223,*277*,678, *AZh 60*,267; β Aur *ApJ 258*,369; ε Aur *BAAS 14*,979,*15*, 925, *IBVS* 2326,2534, *PASP 95*,1012, *ApSpSc 99*,269; ζ Aur *AAp 126*, L5,225, *BAAS 15*,925, *AApSup 53*,339; TZ and XY Boo *MN 203*,1*; ZZ Boo *AJ 88*,1242*; AO Cam *JRASC 76*,90; ζ Cap *PASP 96*,226; Y Car *Obs 103*,163*; YZ Car *MN 205*,1135*; QU Car *ApJ 261*,617*; QX Car *AAp 121*,271*; RX Cas *BAAS 15*,916; SX Cas *PASP 95*,364; TV Cas *AAp 127*,297; YZ Cas *AAp 127*,297, *ApJ 251*,291; AR Cas *MittAG 55*,163*; V425 Cas *BAAS 14*,880*; V635 Cas *ApJ 266*,806; MU Cen *MittAG 50*,77*; BV Cen *ApJ 263*,302*; V373 Cen *MittAG 50*,77*; V436 Cen *ibid**, *ApJ 254*,653, V442 *MittAG 50*,77*; Cen XR-3 *ApJ 278*, 266; Cen X-4 *ApJ 278*,270; U Cep *MN 203*,1063, *ApJ 275*,251; VV Cep *AApSup 53*,339; CQ Cep *ApJ 265*,961*; *AAp 134*,45*; EK Cep *ApJ 271*,717*; EM Cep *MN 200*,1153; π Cep *MN 203*,103*; 6 Cet *IBVS* 2313; R CMa *ApSpSc 99*,229*; UW CMa *BAAS 16*,473; CW CMa *ApJ 261*,612*; FZ CMa *AAp 120*,278*; HL CMa *AAp 125*,L1; ξ CMa *IBVS* 2330; TX Cnc *MN 203*,1*; AC Cnc *PASJ 35*,423, *ApJ 280*,235*, *PASP 94*,162,950, *IAU Coll 72*,17; 81 Cnc *Obs 102*,217*; RW Com *BAAS 15*,917*; RZ and CC Com *MN 203*,1*, V691 CrA *ApJ 255*,596*; θ CrB *BAC 34*,324*, *AAp 131*,210; σ CrB *MN 207*,809, *BAAS 15*,665, *16*,473; VY Cru *BAAS 16*,506; SS Cyg *BAAS 15*,982, *ApSpSc 98*,237, *AA 33*,219; BF Cyg *ApJ 268*,250; CH Cyg *PASP 95*,135,399,1006, *AAp 107*,200, *113*,250, *ApJ 262*,282, *Pis AZh 9*,421; CI Cyg *IBVS* 2126,2355,2356, *AAp 116*,210*, *ApJ 268*,250, *AA 33*,403; V367 Cyg *AAp 131*,147;

V386 Cyg *JApA 3*,233*; V1016 Cyg *AAp 122*,343, *133*,137, *ApJ 268*,250; V1341 Cyg (X2) *BAAS 14*,944, *15*,637,663, *AAp 130*,175; V1357 Cyg (X1) *ApJ 260*,240*, *270*,671, *Pis AZh 9*,606*, *AZh 60*,1041, *PASP 94*,149; V1727 Cyg (4U 2129+47) *ApJ 253*,756,*281*,751, *BAAS 15*,925, 31 and 32 Cyg *AAp 126*,225; HR Del *PASP 94*,916*; YY Dra *BAAS 14*,618; AG Dra *ApSpSc 91*,63, *BAAS 15*,665; υ Dra *JRASC 77*,73*; ω Dra *BAAS 15*,665; BM Eri *AAp 125*,391; BV Eri *ApSpSc 93*,69*; CW Eri *AJ 88*,1242*; EF Eri *BAAS 15*,663; U Gem *BAAS 15*,982, *ApJ 277*,700; WY Gem *ApJ 262*,282; χ and 81 Gem *MN 200*,1161*; RZ Gru *MN 206*,819; DI Her *ApJ 254*,203*; *BAAS 16*,505; HZ Her (X-1) *PASP 94*,149, *BAC 33*,122; V624 Her *AJ 89*,1057*; 105 Her *MN 203*,103*; ζ Her *JRASC 77*,126*; TT Hya *BAAS 15*,926, *16*,504; EX Hya *ApJ 258*,576; KM Hya *AAp 130*,102*; χ^2 Hya *PASP 95*,757*; VW and WX Hyi *MN 203*,865; SW Lac *MN 208*,309; AR Lac *AJ 89*,549; T Leo *ApJ 276*,305*; XY Leo *BAAS 15*,916; 93 Leo *PASP 95*,768*; Leo *IBVS* 2188; FT Lup *MN 208*,135; UU Lyn *PASJ 35*,131*, SZ Lyn *IBVS* 2417; MV Lyr *PASP 94*,328; β Lyr *PASP 94*,341, *AAp 126*, 115; TU Men *AAp 132*,187*; T Mon *MN 203*,925*; AU Mon *PASP 94*,113*; BM Mon *JAAVSO 10*,85; BT Mon *ApSpSc 99*,95*; V505 Mon *ApSpSc 88*,115; V616 Mon *PASP 95*,391, *ApJ 226*,L27; HP Nor *MittAG 55*,77*, V442 Oph *PASP 95*,509*; V566 Oph *MN 204*,817*; V1010 Oph *BAAS 15*,1926; V2051 Oph *MN 205*,465; Nova Oph (H1705-25) *ApJ 274*,717; 64 Ori *ApJ 266*, 732; δ Ori *ApSpSc 87*,269*; AR Pav *PASP 94*,107, *ApJ 275*,271; BD Pav *AAp 124*,287; AG Peg *ApJ 262*,282; AU Peg *AJ 89*,119*; BK Peg *AJ 88*,1242*; EE Peg *ApJ 281*,268*; II Peg *IAU Coll 71*, *AA 32*,315; ι Peg *PASP 95*,1000*; X Per *ApJ 256*,L13: AX Per *ApJ 268*,250; KT Per *BAAS 14*,981; 58 Per *MN 204*,927*; β Per *ApJ 259*,719, *AA 32*,379, *AAp 128*,429; AE Phe *ApSpSc 99*,157; AI Phe *BAAS 15*,877*; ζ Phe *AAp 118*, 255*; φ Phe *Obs 102*,145; SS Psc *ApSpSc 98*,237; SZ Psc *AJ 89*,549; UV Psc *BAAS 16*, 473; V Pup *AAp 128*,17*; VV Pup *ApJ 259*,730*, *BAAS 15*,663; CP Pup *ApJ 261*,170; KQ Pup *AApSup 49*,511; PV Pup *AAp 132*,219*; T Pyx *ApJ 261*,170; VV Pyx *AAp 134*,147*; V818 Sco (X-1) *BAAS 15*,663; V856 Sco *IBVS* 2234; V861 Sco *MN 206*,625; RY Scu *ATs* 1246, *AApSup 56*,17; FH Ser *BAC 33*,116; Y Sex *MN 203*,1*; RY Sex *ApJ 258*,209; U Sge *MN 203*,1063; WY Sge *ApJ 264*,560; WZ Sge *AZh 60*,938; HM Sge *BAAS 14*,982; *AAp 133*, 137; δ Sge *AAp 124*,241*; AP and V350 Sgr *Rev Mex 6*,103; V3885 Sgr *ApJ 258*,217; Nova Sgr (1982) *IBVS* 2283, *PASP 95*,506; ν^1 Sgr *PASP 94*,647; RW Tau *ApJ 258*,224, *272*,206; BU Tau *IBVS* 2148; GR Tau *PASJ 36*,175*; V471 Tau *IBVS* 2092*, *MN 202*,587*, *BAAS 15*, 917, *16*,516; V711 Tau *ApJ 254*,L41, *268*,274*, *PASP 95*,565; ζ Tau *ApSpSc 99*,139; λ Tau *ApJ 263*,289*; RR Tel *MN 202*,833; RW Tri *ApJ 267*,239*; R TrA *RevMex 6*,103; SU UMa *BAAS 14*,880*; SW UMa *IBVS* 2354; UX UMa *ApJSup 53*,397*; AN UMa *BAAS 15*,663, *ApJ 254*,232; AW UMa *ApJ 270*,200, *MN 208*,309; BE UMa *ApJ 272*,202*; ε UMi *ApJ 262*,682; Vel X-1 (4U0900-40) *AAp 135*,155*; γ^1 Vel *PASP 96*,88; γ^2 Vel *Obs 103*,154*, *ApJ 276*,281, *ApSpSc 99*,153; FO Vir *IBVS* 2527; α Vir *PASP 94*,143; ER Vul *MittAG 55*,164*; HR 96 *AApSup 53*,29; HR 362 *PASP 96*,179*; HR 753 *ApJ 269*,250; HR 1883 *MN 199*,303*; HR 2142 *PASP 95*,311*; HR 2577 *PASP 94*,169*; HR 2786,2859 *PASP 94*,642; HR 3084 *IBVS* 2242*; HR 3361 *Obs 104*,74*; HR 3626 *PASP 94*,356*; HR 4006 *PASP 94*,557*; HR 4668 *JApA 5*,181*; HR 4896 *Obs 103*,17*; HR 5553, 6524 *PASP 95*,79*; HR 7024 *Obs 102*,27*; HR 7578 *AJ 267*,682*; HR 8580 *Obs 102*,223*; HD 5980 *ApJ 257*, 116*; HD 13725 *Obs 103*,284*; HD 26337 *IBVS* 2110,2323; HD 27130 and 27149 *ApJ 254*, 606*; HD 28475 *JRASC 77*,142*; HD 31487 *ApJ 268*,264*; HD 33708 *Obs 102*,136*; HD 45088 *ApJ 269*,250*; HD 45166 *IAU Symp 99*,447; HD 46407 *ApJ 268*,264*; HD 47129 *ApSpSc 99*,153; HD 47415 *AApSup 52*,293*; HD 50896 *IAU Symp 99*,295; HD 57339 *Obs 103*,252*; HD 58368 *ApJ 268*,264*; HD 64704 *Obs 104*,69; HD 68244 *AJ 88*,1349; HD 69148 *AApSup 54*,187*; HD 77247 *ApJ 268*,264*; HD 80655 *Obs 103*,56*; HD 81817 *AAp 136*,L5; HD 85091 *AApSup 54*,187*; HD 86590 *AJ 89*,683*; HD 90524 *Obs 102*,136*; HD 90657 *ApJ 259*,213*; HD 94305 *ApJ 272*,190*; HD 104328 *AJ 88*,1349; HD 104451 *JRASC 77*,18*; HD 107742 *JApA 4*,19*; HD 116378 *JApA 4*,171*; HD 117064 *JApA 3*,107*; HD 120803 JApA 3,101*; HD 121844 *JApA 4*,171*; HD 123299 *AApSup 53*,215*; HD 128220 *AAp 121*,85; HD 136905 *IBVS* 2111; HD 141458 *JRASC 77*,18*; HD 143414 *AAp 126*,183*; HD 151910,152333,152570 *AApSup 49*,673*; HD 154791 *ApJ 267*,291; HD 157978 *ApSpSc 94*,1; HD 162085 *AApSup 54*,515*; HD 172865 *PASP 94*,860*; HD 177230 *ApJ 269*,596*; HD 181602 *Obs 102*,1*; HD 184467 *PASP 95*,201*; HD 185151 *AJ 87*,1035*; HD 185662 *Obs 103*,145*; HD 186943 *PASP 95*,151; HD 189178 *PASP 94*,515*; HD 190002 *RevMex 5*,285; HD 193077 *ApJ 253*,230*; HD 193793 *ApJ 277*,258*; HD 199547 *Obs 104*,6*; HD 199939 *ApJ 268*,264*; HD 207739 *ApSpSc 99*,281; HD 208095 *PASP 94*,76*; HD 210647 *Obs*

104,148*; HD 210763 *AApSup 52*,293*; HD 211853 *Tartu Pub 49*,84, *PASP 95*,151; HD 224118 *Obs 104*,80*; HDE 245770 (A0535+26) *PASP 95*,391, *96*,312*; HDE 320156 (LSS 4300) *ApJ 276*,229; BD 45°3310 (ADS 14396) *Obs 104*,143*; BD 26°730 *ApJ 269*,250; CPD-48° 1577 *BAAS 14*,978, *ApSpSc 99*,145*; HZ 22 *PASP 94*,815; Case 1 *ApJ 253*,752*; *279*,758; SMC AB6 *ApJ 257*,110*; NGC 1851 UV5 *PASP 94*,769; MWC 17 *IBVS* 2135; 209 BAC *AAp 114*,135*; PS 74 *AAp 114*,L11; PSR 0921-63 *ApJ 256*,605*; H1-36 *MN 204*,113*; Lanning 90 *PASP 95*,206; P2 *ApJ 269*,229*; Abell 41 *ApJ 280*,177; 2S 0114+650 *PisAZh 9*,603; H0139-68 *BAAS 14*,633; 2A0526-238 (TV Col) *MN 200*,1039; A0538-66 *MN 202*,657, *205*,1117, *207*,287; LMC X1 *ApJ 275*,L43*; LMC X3 *ApJ 272*,118*; *281*,354; PG 1012-029 *ApJ 276*, 233*; PG 1030+590 *BAAS 16*,505; CW 1103+254 *PASP 94*,682, *ApJ 271*,725, *BAAS 14*,980; 4U 1223-62 *PASP 94*,541*; 1329-294 *MN 205*,559; E1405-401 *ApJ 264*,575, *BAAS 14*,633; 3A 1431-409 *MN 201*,25P,32P; PG 1550+191 *ApJ 256*,594*; *BAAS 15*,663; MXB 1735-44 *PASP 95*,23; 4U 1735-44 *MN 207*,29P; 2A 1822-371 *MN 200*,793*; E 2003+225 *ApJ 277*,682, *BAAS 14*,980; H2215-086 *AJ 87*,655*; H 2252-035 *ApJ 265*,363, *267*,726.

C. POLARIMETRIC STUDIES (A.M. Cherepashchuk)

The most important results are the discovery of the 294-day photometric and polarimetric period of Cyg X-1 (Kemp *et al. ApJ 271*,pL65), the discovery of polarization during the eclipse of Algol (Kemp *et al. ApJ 273*,pL85) and the study of circular polarization of the light of white-dwarf pulsars (Krzeminski *et al. IAU Coll 69*,p399).

Polarimetric work has been in two directions: the study of circular and linear polarization in individual stars (many of them of the AM Her type) and theoretical studies of the variations in polarization to be expected in a binary system. Work published in the report period includes the following: *MN 194*, pp187, 283; *AZh 58*,p146; *MN 196*,p275; *AAp Sup. 44*,p461; *ApJ 247*,p984, *MN 198*, p787, *199*,p601; *ApJ 256*,p594; *IAU Coll 70*, p139; *PASP 94*,pp692,695; *IAU Coll 72*,pp205,211,217; *ApJ 264*,p237; *Rep. radio Lab. Helsinki Univ. Technol. No. 129*, p46; *ApJ 275*,p709; *BAAS 15*,p665.

D. X-RAY OBSERVATIONS (Y. Kondo)

During the report period, three X-ray satellites have been in operation: the Japanese satellites Hakucha (launched 1979 February) and Tenma (1983 March) and the European satellite EXOSAT (1983 May 26). The American X-ray satellite *Einstein* (HEAO-2) ceased operating on 1981 June 17, before the triennium under review; nevertheless, a brief report on it is included.

Einstein

When the operation of this satellite was terminated by the exhaustion of its gas, a few hundred binaries, including "normal" interacting binaries (e.g. R. Ara, 31 Cyg), RS CVn systems (e.g. ζ And, UX Ari), novae (e.g. U gem, SY Cnc), X-ray binaries containing compact objects (e.g. AM Her, SMC X-1) and pulsars (e.g. PSR 0740-28, PSR 1055-52) had been observed. A complete list can be found in the booklet *A Listing of all Targets Observed by the Einstein Observatory*, available from: Dr. Frederick D. Seward, Head, Einstein Guest Observer Program, Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, U.S.A., who can slso provide other information about *Einstein* archival data.

Hakucho and Tenma

These two satellites were still in operation at the end of 1984. The X-ray pulsars observed include Her X-1, Cen X-3, 4U 1626-67, OAO 1657-415, 4U 1700-377, A0535 + 26, Vela X-1, 4U 1907 + 09, 4U 1538-52 and GX 301-2. They have also observed the X-ray binaries Sco X-1, 1608-522, GX 349 + 2, GX5 - 1, Cyg X-1 and Cyg X-3, as well as the RS CVn binary HR 1099. The project scientists, both located at the Institute of Space and Astronautical Science, 4-6-1 Komaba,

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Meguro-ku, Tokyo 153, Japan, are Dr. Minoru Oda (Hakucho) and Dr. Yasuo Tanaka (Tenma).

EXOSAT

A large number of interesting binaries has been observed with EXOSAT. Amongst the X-ray binaries with compact objects that have been observed are: Cyg X-1, Cyg X-2, Cyg X-3, Her X-1, Sco X-1, LMC X-1, LMC X-4, AM Her and Vela X-1. Cataclysmic binaries observed include U Gem, SS Cyg, SU UMa, WZ Sge and GK Per. Other binaries observed include Algol, W UMa and the RSCVn systems AR Lac and λ And.

The targets observed with this satellite are listed in the newsletter *EXOSAT Express*, available from: Dr. David Andrews, EXOSAT Observatory Manager, ESOC, Robert-Bosch Strasse 5, 61 Darmstadt, Germany, F.R. There is a guest-observer programme and observing proposals are evaluated every three months. Further information may be obtained from EXOSAT Observatory.

E. RADIO OBSERVATIONS (D.M. Gibson)

The interval July 1981 - June 1984 was characterized by solidification of the picture which emerged in the previous decade. Only three new (single-member) classes of objects were detected: AM Her (Chanmugan and Dulk, *ApJ 255*,pL107), YY Gem (Gary, Linsky, and Dulk, *Solar and Stellar Magnetic Fields: Origins and Effects* p387), and W UMa (Hughes and McLean, *ApJ 278*,p716). The latter two exhibit emission similar to that observed in the dMe flare stars (cf. review by Gibson, in *IAU Coll 71*,p273) and the RS CVn binaries (cf. Feldman, *IAU Coll 71*,p429), respectively. In neither case is it believed that the binary nature is important to the observed activity other than through the enforcement of rapid rotation of the active component(s) by synchronization. In the case of AM Her, Dulk *et al.* (*ApJ 273*,p249) interpreted the rapidly-variable, highly-circularly polarized emission as an electron-cyclotron maser associated with the dMe component. For the quiescent emission they propose a new mechanism. The electrons captured and heated during mass transfer radiate thermal gyro-resonance emission in the strong magnetic field of the white dwarf.

Mutel, Lestrade, and their collaborators (cf. Mutel *et al.* *ApJ 278*,p220; Lestrade *et al.* *ApJ 279*,p194) made first reports on an ongoing effort to *map* the structure of RS CVn radio sources with the VLBI. They found the stars UX Ari, HR 1099, and HR 5110 to be unresolved within measurement uncertainties, implying that the emission arises from a region of at most a few stellar radii in diameter. The inferred brightness temperatures 10^{10} K and mild circular polarizations ($\pi_c < 10$) are consistent with the working model of a coronal radio source wherein a power-law distribution of mildly relativistic electrons radiates gyrosynchrotron emission in magnetic fields $5 < B < 80$ Gauss. Doiron and Mutel (*AJ 89*,p430) made similar inferences when they did not detect radio eclipses from AR lac. A number of new (primarily southern) RS CVn systems have been detected by Collier *et al.* (*MN 200*, p869) and Slee *et al.* (*MN 208*,p865).

The peculiar Galactic object SS433, a stellar binary displaying twin collimated jets which precess with a period of 164 days, has been the subject of continued systematic monitoring by a number of groups (Johnston *et al.* *AJ 86*, p1377; Niell *et al.* *ApJ 250*,p248; Seaquist, *Vistas Astron. 25*,p79; Bonsignori *et al.* *Vistas Astron. 25*,p91; Johnston *et al.* *AJ 89*,p509). The radio observations are consistent with continuous injection of relativistic electrons into the optically-thin jets and show no evidence of the periodicities, other than precession, seen at other bands. The bright radio knots seen in VLA (cf. Hjellming and Johnston *IAU Symp. 97*,p187) and *VLBI* (cf. Schilizzi *et al.* *IAU Symp 97*,p205) are thought to result from synchrotron emission produced by relativistic electrons accelerated in the jets through resonant cyclotron interaction with turbulent waves which arise due to Kelvin-Helmholtz instabilities in the ordered

0.26*c* flow (Bodo *et al.* *AA 133*,p247). *VLBI* observations of Cyg X-3 (Geldzahler *et al.* *ApJ 273*,pL65) have revealed that it too is a twin jet source with a jet velocity near 0.25*c*. The peculiar Be-star LSI+61°303, a binary X-ray and γ-ray source, has been detected (Taylor and Gregory, *ApJ 255*,p210) and confirmed (Coe *et al.* *MN 203*,p791) to have radio outbursts at intervals of 26.52 days. The object is probably similar to Cir X-1.

A number of "wide" binaries have nevertheless been shown to be "interacting" by radio observations. Symbiotic stars (cf. Kwok, *IAU Coll 70*,p17) and related objects such as Antares (Hjellming and Newell, *ApJ 275*,p704) and HM Sge (Kwok *et al.* *ApJ 279*,p188) evidently produce their emission when the hot companion to a late-type giant or supergiant ionizes a portion of its wind. The unusual shapes and symmetries of these circumstellar H II regions, from ellipsoidal cavities to quasi-cones, cause spectral variations significantly different from those expected to be exhibited by early-type mass-loss stars.

Although it falls outside the prescribed interval for this review, I must mention the *Workshop on Stellar Continuum Radio Emission* which was held in Boulder, Colorado, 8-10 August 1984. A wide range of observations and theories on radio-stars in general and binary radio-stars in particular was presented. Members may wish to obtain a copy of the *Proceedings* (ed. R.M. Hjellming and D.M. Gibson, Reidel) when it becomes available in mid-1985.

F. ULTRAVIOLET OBSERVATIONS (G.E. McCluskey Jr.)

High-resolution ($\sim$ 0.02nm) and low resolution ($\sim$0.6nm) spectrometers on the International Ultraviolet Explorer (*IUE*) satellite, operating in the wavelength range 115nm - 320nm, were used for nearly all the ultraviolet observations of close binaries. Important exceptions are the ultraviolet spectrometers on-board *Voyagers* 1 and 2, that have been used in the regions 55nm - 17nm and 50nm - 120nm, respectively. They have obtained spectrophotometric data, at about 2.5nm resolution, for a number of hot stars, including several interacting binaries. In addition, papers based on data obtained by *Copernicus* and *ANS* are still being published.

The *IUE* has provided 37,000 ultraviolet spectra to date and many of these are of close binaries. Important reviews of this work have been published by Dupree (*IAU Symp. 88*,p39), Hack (*2nd Goddard IUE Symp p89*), *McCluskey* (*ibid.* p102), Plavec (*IAU Coll 69*,p159) and Rahe (*3rd Goddard IUE Symp.*).

Selected studies of particular systems or classes of systems based at least partly on ultraviolet observations can be found in the following references.

Cataclysmic Variables

AAp 108,p243, *112*,p355, *113*,p76; *ApJ 247*,p577, *258*,p217, *271*,p754, *277*,p700, *281*,p194; *MN 203*,p865, *210*,p197.

ε Aur

AAp 130,*p419*; *ApSup 50*,p233; *ApJ 269*,pL97.

Interacting Systems

ApJ 247,p702, *256*,p206, *264*,pL19, *266*,p755, *275*,p251, *283*,p745; *ApJ Sup 47* p333; *ApSpSc 99*,p281; *MN 202*,p1221; *PASP 93*,p621, *94*,p113.

Symbiotic Stars

AAp 126,p407; *AApSup 56*,p17; *ApJ 253*,p735, *257*,p204, *268*,p250, *275*,p271, *283*, p226.

Wolf-Rayet Stars

AApSup 47,p257, *54*,p229; *ApJ 276*,p281, *MN 198*,p897.

X-Ray Binaries

AAp 106,p339; *ApJ 265*,p354, *278*,p270, *283*,p249; *MN 204*,p1091.

ζ-Aurigae Stars

AAp 126,p225; *ApJ 248*,p1043, *281*,p751.

Voyager Extreme UV Spectrophotometry

ApJ 257,p656; *BAAS 15*,p982.

4. Derived Physical Data

A. ABSOLUTE DIMENSIONS AND APSIDAL MOTION (D.M. Popper and A.H. Batten)

Masses in Wolf-Rayet binaries have been reviewed by Massey *IAU Symp 99*,p251) and in cataclysmic binaries by Shafter (*PhD dissertation, UCLA*) and by Wargau and Vogt (*MittAG 55*,p77). LMC X-3 may be the most promising Black-hole candidate yet proposed (Cowley *et al. ApJ 272*,p118). Controversy over the possible super-massiveness of R136 in 30 Dor is reviewed by Edwards (*Nature 306*,p5945). Application of a radial-velocity spectrometer may at last give us definitive masses of the components of Capella (Shen *et al. BAAS 14*,p900), while speckle interferometry, by providing the missing inclination for φ Cyg (McAlister *AJ 87*, p563), leads to rare masses of cool giants. Infrared speckle interferometry has found the faint companion of the famous halo astrometric binary μ Cas (McCarthy, *AJ 89*,p433), but the astrometric orbit of μ Cas A is so uncertain that its mass, and consequently the "primordial" helium abundance cannot be evaluated. Use of a radial-velocity spectrometer has also led to the masses of the Hyades eclipsing binary HD 27130 (McClure, *ApJ 254*,p606) and confirmed the larger distance modulus for the cluster. Fekel and Beavers (*Ap.J 267*,p682) have reviewed the evidence on the masses of K-type main-sequence spectroscopic binaries and conclude that they are more massive than given in "standard" tables. An excellent example among the bright stars of the detection of a faint secondary component with a low-noise detector is provided by ι Peg (Fekel and Tomkin *PASP 95*,p1000). Drechsel *et al.* (*AAp 110*,p246) have obtained rough values of the masses in SV Cen, the one-of-a-kind contact B-type binary with rapid period decrease. Popper has removed 2 more B-type binaries, HD 208095 (*PASP 94*,p76) and NY Cep (*ApJ 262*,p641), from the nearly non-existent list of over-massive binaries, and LY Aur (*ApJ 262*,p641) has been elevated to the status of the eclipsing system with the largest directly determined mass (32 $m_\odot$).

Following is a selected list of binaries with absolute dimensions determined directly, with a minimum of hypotheses, during the triennium: V539 Ara, ZZ Boo, CW CMa, QX Car, YZ Cas, EK Cep, U CrB, CW Eri, DI Her, V624 Her, KM Hya, BK Peg, ζ Phe PV Pup, VV Pyx and λ Tau. References for all but U CrB (*Publ. DAO 15*, p419) may be found in Table 5. Three systems (U CrB, V Pup and λTau are semi-detached, all the others detached.)

Apsidal motion in DI Her has proved to be of considerable interest. The relativistic component should dominate in this system but neither spectroscopic observations collected by Popper (*ApJ 254*,p203) nor eclipse timings since 1898, collected by Guinan *et al.* (*BAAS 16*,p505) show any certain evidence of apsidal motion. This result is consistent with a non-symmetric gravity theory recently proposed by J.W. Moffat (*Phys. Rev. Let. 50*,p709). While it may be too early to hail the result as confirmation of a new theory, it does underline the importance of apsidal-motion studies.

An important discussion of apsidal motion in 27 systems has been published by Jeffery (*MN 207*,p323). He has recalculated values of the apsidal constant k, using Carson's values of opacities, and has greatly improved the agreement between theory and observation (confirming earlier results by Giménez and García-Pelayo *IAU Coll 69*,p37). Only the system CO Lac still shows a significant difference from theoretical expectations. Jeffery also devised a method for estimating the mass and age of a system from the spectral type of the primary and the observed apsidal motion.

Individual systems for which studies of apsidal motion have been published include the following: V889 Aql (*AAp 115*,p221), PV Cas (*AJ 87*,p1233), EK Cep (*AZh 60*,p72), CI Cyg (*JAAVSO 10*,p92), and δ Ori (*ApSpSc 87*,p269). No evidence has been found for apsidal motion in V1347 Cyg (*ApJ 260*, p240) and its presence in β Per has been questioned (*JAAVSO 11*,p1). A new method for computing apsidal constants was published by Giménez and García-Pelayo (*ApSpSc 92*,p203).

B. PROXIMITY EFFECTS AND LIMB-DARKENING (M. Kitamura)

Within the last few years, considerable efforts have been directed towards the study of tidal evolution in close binary systems. Scharlemann (*ApJ 246*,p292; *253*,p298) studied the effect of tidal coupling with particular reference to RS CVn stars with differentially rotating convective envelopes. Hut (*AAp 99*,126; *110*,37) and Verbunt and Hut (*AAp 127*,p161) discussed the problem as applied to X-ray binaries. The tidal evolution of X-ray binaries was fully investigated by Savonije and Papaloizou (*MN 203*,p581; *207*,685) who calculated the response of non-rotating massive stars to a periodic perpurbing tidal potential (see also section 7). Tidally driven circulation in close binaries was also studied by Smith and Smith (*MN 194*,p583) who showed that it can not be responsible for energy transfer between the components.

Saio (*ApJ 244*,p299) investigated the effect of tidal force on the periods of non-radial oscillations with application to β-Cephei binaries. Tidal effects in twin-degenerate binaries were studied by Campbell (*MN 207*,p433) who showed that tidal excitation of non-radial oscillatory modes on the secondary may significantly shorten the synchronization time. Further comments on the importance of tidal effects and magnetic braking are in sections 5C and 7.

Koch and Hrivnak (*AJ 86*,438) examined the sensitivities of Zahn's theory of tidal friction in actual close binaries and statistically concluded that the theory is generally adequate for binaries whose periods are less than about twenty days.

Mathematically thorough investigations of the effects of rotation and tidal distortions on the orbital elements of a close binary system were presented by Zafiropoulos and Zafiropoulos (*ApSpSc 88*,p401). Mohan and Saxena (*ApSpSc 95*,p369) calculated the effect of rotation and tidal distortions on the structure of polytropic components of close binaries by evaluating various parameters on the Roche equipotentials.

The gravity-darkening of highly distorted stars in close binaries was studied by Kitamura and Nakamura (*Ann.Tokyo19*,p413) with second-order treatment, in order to compare with the result previously obtained in the first order. They found serious differences between these treatments in some actual close binaries. Kitamura and Yamasaki (*Ann.Tokyo 20*,p51) calculated photometric proximity effects by taking into account multiple reflections. Their result indicates that the effect of secondary reflection is quite appreciable and should be considered in

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almost all actual close binaries. The influence of tidal effects upon the structure of accretion disk in dwarf novae was also discussed by Kříž (*MN 199*, p725).

There has been very little work on limb-darkening problems during these three years, but Bogdovov (*A Zh 60*,p529) studied the source function from the limb-darkening of a star with an extended atmosphere in a close binary system, and Zhu *AASin 25*,p118) treated the limb-darkening effect in accretion disks.

C. ATMOSPHERIC ABUNDANCES (M. Kitamura)

One of the most important results on chemical abundances of close binary stars was obtained by Williams (*ApJ 257*,p672; *IAU Coll 72*) who detected spectroscopically a huge over-abundance of He,C,O,N in the accretion disks of cataclysmic variables. Such over-abundance has already been known in the ejecta of a number of classical novae. William's observations of quiescent novae revealed that the similar over-abundance of He,O,N,C definitely exists in the accretion disk as well.

IUE observations of close binaries have offered a number of new physical data for study of their circumstellar and chromospheric structures: e.g., for W UMa stars by Eaton (*ApJ 268*,p800), Capella by Ayres (*ApJ 284*,p784) and symbiotic binaries by Friedjung *et al.* (*AAp 126*,p407). By analysing *IUE* spectra of Ba stars, Dominy and Lambert (*ApJ 270*,p180) studied the current hypothesis that the Ba stars are produced by mass transfer from a companion now present as a white dwarf. McClure (*ApJ 268*,p264) measured radial velocities of such stars and concluded that all Ba II stars should be binaries. A bipolar nebulosity of NGC 2346 has been suggested by Walsh (*MN 202*,p303) to have been formed by mass-loss from a binary.

Luck and Bond (*ApJ 259*,792) determined C and O abundance in giant CH stars from abundance analysis, on the basis of which they also discussed a hypothesis of mass-transfer from a carbon-star binary companion that is now an invisible white dwarf.

5. Structure and Models of Close Binaries

A. EARLY-TYPE SYSTEMS (K.D. Abhyankar)

Evolution of close binary systems has been reviewed by Yungelson and Masevich in *Astrophysics and Space Physics Reviews* Vol. 2, pp29-74, 1983. It is also covered in *IAU Coll 69* and in *IAU Coll 80*.

W-R Binaries

There has been continued interest in the effects of mass loss in early type systems. Vanbeveren (*AAp 105*, p260) showed that mass loss by stellar wind is marginal for stars with $< 40\ M_{\odot}$ which give rise to OBN stars while stars with $> 40\ m_{\odot}$ lose 30 per cent of mass by stellar wind and Roche-lobe overflow to produce WR stars. Deloore (*IAU Coll 80*) found that 50 per cent loss of mass and angular momentum is required for bringing observations into agreement with theory. Hidayat *et al.* (*IAU Coll 80*, p175) studied the distribution of WR Stars in the Galaxy and concluded that in the regions where stars are of low metallicity, WR stars can evolve only in binary systems. Doome and De Greve (*ApSpSc 87*,p357) indicated the possible evolution scheme: OB+OB→WR+OB→C+OB→C+WR→WR+WR. Vanbeveren (*AAp 119*,p239) and Doome and De Greve (*AAp 120*,p97) considered the effect of overshooting on the evolution of massive close binaries.

Several binaries with WR components were observed:
(i) For CQ Cep Leung *et al.* (*ApJ 265*,p961) found 50 per cent overcontact: Kreiner and Tremko (*BAC 34*,p341) as well as Antokhina *et al.* (*AZh 59*,p704) interpreted period changes by the process of mass loss and mass transfer while

Walker (*AAp 128*,p394) doubted the period change. (ii) For γ^2 Vel Pike *et al.* (*Obs 103*,p154) derived a new orbit from archival plates and Kondo *et al.* (*ApJ 252*,p208) found that the temperature of the stellar wind increases outward, indicating an additional source of energy for mass flow in all directions, particularly toward L_3. The spectrum of the binary was analyzed by Sahade *et al.* (*ApJ 276*,p281). (iii) Low-mass companions were found in: HD 143414 by Isserstedt (*AAp 126*,p183) and HD 193077 by Lamontagne *et al.* (*ApJ 253*,p230). (iv) WR stars in Magellanic clouds were studied by Moffat (*ApJ 257*,*p110*) *and by Breysacher et al.* (*ApJ 257*,p116). (v) Other systems included HD 94305 in which Niemela *et al.* (*ApJ 272*,p190) found the minimum masses of 15 and 32 $m_\odot$; CX Cep in which Lipunova and Cherepaschak (*AZh 59*,p73) found the WN5 component to have a core radius of 4.5 ± 2.5 $R_\odot$ and T_h = 750,000; HD 45166 in which Willis and Stickland (*MN 203*,p619) found a stellar wind of 1200 km s^{-1} from UV Spectra; HD 186943 and HD 211853 for which *IUE* observations are reported by Hutchings and Massey (*PASP 95*,p151).

OB Binaries

Popper (*ApJ 262*,p641) found that luminosities of double-line O-type binaries are almost equal and, therefore, published mass-ratios will need revision toward equality of masses. While studying the massive contact system LY Aur Margoni *et al.* (*ApSpSc 79*,p145) found that 11 out of 14 early-type systems are of contact type. Leung (*IAU Coll 80*) found most contact systems to have been in contact at zero age. Contact systems observed during the period of the report include: BH Cen by Sistero *et al.* (*ApSpSc 91*,p427); RY Sct by Milano *et al.* (*AAp 100*,p59); AW Lac by Jiang *et al.* (*AJ 88*,p1679); HR 4975 by Waelkins and Bartholdi (*AAp 108*, p51); SV Cen by Nakamura and Nakamura (*ApSpSc 83*,p103); VV Ori by Chambliss and Leung (*ApJ 49*,p531); V 861 Sco by Howarth (*MN 203*,p1021); V 539 Ara, ζ Phe and QX Car by Andersen (*AAp 118*,p255) and *AAp 121*,p271); and FZ CMa by Moffet (*AAp 120*,p278), who found it to be a massive triple system. Sybesma and Deloore (*AAp 111*,p229) found that the runaway OB stars HD 108 and HD 53975 may have measurable light variations indicating the presence of compact companions.

β Lyrae

A structural model of the disk around the more massive component was given by Wilson (*IAU Coll 69*, p261). Plavec, Weiland and Dobias (*BAAS 13*,p803) found that the flux of the primary agrees with Kurucz's model in the optical region only and shows an excess in UV region. In the BUSS spectrum of the star Hack *et al.* (*AAp 126*,p115) discovered [N II] lines at 214.3nm and 213.9nm; they have suggested a model for the location of the regions of formation of [Si III] and [N II].

Be Stars

There were several studies of Be stars as interacting binaries. Peters (*PASP 95*,p311) has interpreted measurements of broad wings of Balmer and He lines in HR 2142 as binary motion of a 11 $m_\odot$ + 1 $m_\odot$ system, attributing periodic shell phenomena to mass transfer. Charles *et al.* (*MN 202*,p657) find the periodic recurrent X-ray transient A 0538-66 to be an interacting binary (12 $m_\odot$ + 1 $m_\odot$) with Balmer and He I lines in emission and a highly eccentric (e = 0.7) orbit. Antonello *et al.* (*ApSpSc 83*,p381) find evidence for the binary nature of the Be Stars EW Lac, 28 Tau and ζ Tau. Singh (*IBVS* 2284) gives evidence for a short-period and high-eccentricity orbit for the Be star o And.

B. ALGOLS AND RELATED SYSTEMS

Continued observations of the UV spectrum, and other new techniques, have contributed to our understanding of Algol-type systems. Plavec (*ApJ 275*,p251) has found emission lines in the UV spectrum of U Cep, which undergo eclipse. This observation rules out the chromosphere of the late-type component as the place of

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origin of these emissions. The strengths of the emission lines suggests anomalous abundances of C, N and O which are consistent with at least partial processing of the matter inside a star. Similar results are reported for U Sge and V356 Sgr (Plavec, *JRASC 77*,p283; Plavec and Dobias, *BAAS 15*,p915), and some confirmation is supplied by the synthetic spectra published by Parthasarathy *et al.* (*MN 203*, p1063). This provides important evidence in favour of mass transfer. Kondo *et al.* (*ApJ 247*,p202), also observing in the UV, found further evidence for mass loss from U Cep.

Plavec and Dobias (*ApJ 272*,p206) have also found weak emission lines in the UV spectrum of RW Tau, an observation that tends to confirm the relationship believed to exist between Algols and Serpentids. Spectroscopy of Balmer lines arising in the disk in this system by Kaitchuck and Honeycutt is mentioned in section 3B. They confirm the variability of the emission lines, already suspected by Joy and now known in other systems. They find that the disk is smaller than formerly believed - rarely exceeding 1.5 times the radius of the central star - and the emission lines are about twice as broad as expected from the rotation of the disk. This leads them to question determinations of the masses of stars from observationally measured rotations of accretion disks. Similar spectroscopy of other Algol-type systems should be valuable.

In Algol itself, Sahade and Hernández (*3rd IAU Latin American Regional Meeting*, in press) find evidence from *IUE* observations for two distinct regions of high electron temperature in the system: a suggestion they had already made for AU Mon (also of Algol-type) and for the very different system γ^1 Vel (*PASP 96*, 88). The successful detection of polarization during eclipses of Algol is mentioned in section 3C. Cugier (*AA 32*, p379) and Cugier and Molaro (*AAp 128*, p429) have constructed a stream model for the system, to explain extra components of the UV lines of Mg II. Harrington (*ApJ 277*,pL69) has discussed the relative inclination of the two orbital planes.

Olson (*ApJ 257*,p198; *258*,p702) has examined the light curves of 16 Algol-type systems for transient disturbances. He found evidence of such disturbances in 4 systems, and of non-stellar sources of flux in two. He has also studied the rotation of primaries of Algol systems (*KRTK 58*,p376) finding evidence for possible changes that might be linked with variable rates of mass transfer. McCluskey and Kondo (*ApJ 266*,p755) have found significant variations in the UV continuum level (outside eclipse) of the spectrum of R Ara which indicate that the volume of gas producing continuous radiation is changing. They also report (in press) X-rays from this system. A similarly variable UV continuum is reported in the spectrum of HD 207739 (Parsons *et al.* *ApJ 264*,pL19).

Young and Snyder (*ApJ 262*,p259) have made four-colour photometric and infrared spectroscopic observations of several Serpentids that they believe indicate both accretion within and variable mass loss from the systems. Similar results are reported by Guinan *et al.* (*PASP 95*,p364) for SX Cas. Kondo *et al.* (*ApJ Sup 47*, p33) confirm the presence of hot gases in this system, as well as in RX Cas and TT Hya. Plavec *et al.* (*ApJ 256*,p206) have found emission lines in the UV spectrum of SX Cas and have revised the spectral types of its components, making more obvious its similarity to Algol-type systems. On the other hand, Weiland and Plavec (*BAAS 15*, p916) reclassify both components of RX Cas as late-type giants - a conclusion to some extent confirmed by Taranova and Shenavrin (*PisAZh 9*,p291). In the visual region of the spectrum, RX Cas and SX Cas appear very similar, but these results from the UV make the former look more like RZ Oph, whose 1981 eclipse was studied by Forbes and Scarfe (*PASP 96*,p737) and by van Paradijs *et al.* (*AAp 111*,p372). The system 93 Leonis (Batten *et al.* *PASP 95*,p768), with a period of 72 days, provides an example of a system containing a late-type giant free to expand without yet encountering its Roche lobe.

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Apart from ε Aur, the ζ Aur systems have also been studied. With the help of *IUE* observations, the rates of mass loss from ζ Aur, 31 and 32 Cyg have been estimated by Che *et al.* (*AAp 126*,p225) and for δ Sge by Reimers and Schröder (*AAp 124*,p241). In all four systems the rate of mass loss is estimated to be of the order of 10^{-8} $m_{\odot}$ y^{-1}. From *IUE* observations of the 1979-80 eclipse of ζ Aur, Chapman (*BAAS 15*,p925) found evidence for a temperature gradient increasing outwards, reaching values as high as 14,000 K. Hempe (*AAp 115*,p133) and Hempe and Reimers (*AAp 107*,p36) have studied mechanism for the formation of lines in the UV spectra of these systems. Koch and Pfeiffer (*AJ 87*, p1409) found residual polarization in the light of ζ Aur, during the 1979-80 eclipse, which they ascribe to the effects of inhomogeneities in the atmosphere of the late-type component.

Amongst the RS CVn systems HR 1099 (V711 Tau) and AR Lac have probably attracted most attention. In a number of these systems, the migration of the distortion wave of the light curve appears not to be constant, and may be reversible (SS Boo, Wilson *et al.* *AJ 88*,257, UX Ari, Zeilik *et al.* *IBVS* 2168 - but see also Sarma *et al.* *IBVS* 2357, SZ Psc, Eaton *et al.* *ApSpSc 82*,p289 and possibly RS CVn itself, Blanco *et al.* *AAp 106*,p311). Several reviews of these systems, up to the beginning of the triennium under review, can be found in *IAU Coll. 71*. Agreement that the basic cause of their phenomena is starspots now seems general and, as mentioned in section 3B, the hypothesis has received considerable support from the results of Doppler imaging. For a dissenting opinion, however, see Kopal (*ApSpSc 87*,149). Middelkoop (*AAp 107*, p31, *113*,p1) has developed a theory of dynamo action in the envelopes of late-type stars, in which the emission flux in the H and K lines is dependent on rotational velocity. Vilhu and Rucinski, in various papers (*AAp 127*,*p5*, *133*, p117, *MN 202*,p1221 and *Physica Scripta T7*,p70) have applied this both to W UMa and RS CVn systems. Dorren and Guinan (*ApJ 252*, p296) have constructed a model for HR 1099 which simulates the light variations by the rotation of two spots on one of the stars. Nha and Kang (*PASP 94*,p496) however, find that neither a spot model nor a shell model fits their photometric observations of AR Lac. This system is known to be exceptional; Kiziloglu *et al.* (*AAp 123*,p17), from their studies of its UV spectrum conclude that both stars are active, about 70 per cent of the activity being on the secondary. The period is known to be decreasing (Evren *et al.* *ApSpSc 95*,p401; Erten *et al.* *87*,p255). The former authors find evidence for long-term photometric variations, and the latter suggest that mass is being transferred by stellar winds. A similar conclusion is reached by Svristava (*BASI 12*,p52).

Mekkaden *et al.* (*JApA 3*,p27) believe that the amplitude of the wave distortion in the light-curve of HR 1099 changes cyclically, increasing sharply and decaying slowly in intervals of 5-6 years. Fraquelli (*ApJ 254*,pL41, *276*, p243) has studied the Hα emission associated with both components and finds that its intensity is correlated with radio flux, but not with the phase of the distortion wave. The Hα emission appears to arise from localized regions and the line profiles are broader than expected from either the orbital motion or the rotation of the stars. Fekel (*ApJ 268*,p274) has derived an excellent set of orbital elements and (different) rotational velocities for each star. He also detected the asymmetries in the line profiles of the more active star which were made the basis of Doppler imaging. Three years of cooperative photometry (Bartolini *et al.* *AAp 117*,p149) support the spot interpretation and suggest that the spots are migrating on a differentially rotating star. Ayres and Linsky (*ApJ 254*, p18) have detected high-excitation emission lines (e.g. C II, C IV) at quadratures, whose structure changes in about a week. Radial velocities derived from these lines are similar to that of the primary stars; the secondary components are weak or absent. Ayres and Linsky interpret these results as support for the hypothesis of a connection between the rotational activity and the magnetic behaviour of these stars. Both HR 1099 and UX Ari have been observed with the VLBI by Mutel *et al.* (*ApJ 278*,p220) with results that are discussed in section 3E.

Ramsey and Nations (*AJ 89*,p15) find changes in the phase dependence of the Hα intensity in the spectrum of II Peg, and that the flux has decreased. Udalski and Rucinski (*AA 32*,p315) have published a study of the *IUE* spectrum, in which Marstad and Linsky (*BAAS 14*,p866) find enhanced emission between phases 0.45 and 0.95. They ascribe this enhancement to a plage area overlying the spots. Huenemoerder *et al.* (*BAAS 15*,p663) have observed Hα emission in both components of SZ Psc, a system that was very active in 1982-3. There is evidence that the emission is concentrated at particular longitudes of the primary. Giampapa *et al.* (*ApJ 268*,pL121) measured a magnetic field of close to 1300 gauss in the system λ And.

Scaltriti and Busso, together with other colleagues (*AAp 135*,p23,p.255, *139*, p25 and others in press, *IAU Coll 77*,p395 and *Proc. Statistical Methods in Astron. Strasbourg* Symposium, p13) have devised and applied statistical methods for extracting the information contained in the photometric observations of RS CVn stars and are working on detailed models for individual systems. Amongst others reporting observations are Hearnshaw (New Zealand) and Hu (Peoples' Republic of China).

C. W URSAE MAJORIS SYSTEMS (K-C. Leung)

The last decade has been an extremely active period in the development of theoretical models of the structure of contact and near-contact systems. Many papers were published, including Benson's discussion of the possibility of the mass-gaining component swelling into contact, and important advances made by two groups (Lucy, Flannery, Robertson and Eggleton, on the one hand and Shu, Lubow and Anderson on the other). Shu and Lubow (*Ann Rev A Ap 19*,p277) gave a good summary of these developments (up to 1981) and the controversy engendered by them. They questioned whether or not we should accept the swelling into a contact configuration predicted for mass-gaining stars by several investigators. Theories produced by both groups of workers require refinement, and a high level of precision is needed in both theories and computations to solve many problems in this field. Fundamental advances have become much more difficult and more theorists are leaving the field than are attracted to it. It is to be hoped that this situation will change. Nevertheless, theoretical work has been published in the past triennium on e.g., the stability of zero-age contact binaries (Hazlehurst and Refsdal *AAp 113*,p63; Rahunen *AAp 109*,p66) and on magnetic braking in close binary systems (Rappaport *et al. ApJ 275*,p713; Mochnacki *BAAS 13*,p513; Vilhu *ApSpSc 99*, p287 - see also references given in section 7).

Many photoelectric observations of short-period close binary systems have been published and photometric solutions based on the Roche model have been derived from them. References can be found in the *Bibliography and Program Notes on Close Binaries*. More reliable data are now being accumulated for contact and semi-detached systems, which - no doubt - will help us to understand their structure and evolution. It is becoming apparent that there are systems that cannot be readily classified as either contact or semi-detached. There is evidence for two new configurations: almost-contact systems and closely detached systems. In the former, the component of lower mass is in contact with its Roche lobe, and that of higher mass is extremely close to its Roche surface. These systems may be at an evolutionary phase immediately following the evolution into contact. In systems of the latter type, both components are close to their Roche surfaces, but not in contact with them. Some investigators identified these systems with a type described by Lucy that goes in and out of contact. Absolute dimensions are known for some of these systems, however, and the radii of the components of lower mass are considerably larger than those expected for zero-age stars of similar mass. These systems, therefore, are presumably evolved, while those described by Lucy are of zero-age. The closely detached systems, therefore, are not the in-and-out-of-contact systems predicted by thermal-oscillation theory, but, probably, evolved close binary systems. Perhaps they have completed the

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Algol phase and the mass-losing components have just detached from their Roche lobes.

While spectroscopic observations of W UMa systems have not been published in the same quantity as photometric ones, important results have been obtained by cross-correlation, as described in section 3B, by McLean and Hilditch (St Andrews) and by Milone, Hrivnak, Hill and Fisher (Calgary and Victoria). Spectroscopically and photometrically determined mass-ratios now agree more closely.

D. NOVAE AND RELATED SYSTEMS (J. Smak)

Many meetings were held devoted entirely or partly to the field of cataclysmic variables (CV's): *IAU Coll Nos. 69* (Bamberg), *72* (Haifa), and *80* (Bandung), three North American Workshops on CV's and related objects (Santa Cruz, 1981; Cambridge, 1983; Baton Rouge, 1984), *Coll. on Pulsations in Classical and Cataclysmic Var. Stars* (Boulder, 1982), *Nato Symp.* on *Interacting Binaries* (Cambridge, England, 1983), Frascati Workshop on *Galactic Accreting Sources* (Vulcano Island, 1984), and the American and European *IUE* Conferences. Their proceedings contain excellent reviews of observational and theoretical aspects. Reviews are also contained in *The Classical Novae* (ed. Bode and Evans, J. Wiley, 1984). Other, individual reviews included: Pringle, (*Ann Rev AAp 19*,p137) and Verbunt (*SpSc Rev 32,p379)* on accretion disks, Smak (*PASP 96*,p5) on dwarf novae, and Truran (in *Essays in Nuclear Astrophysics*, eds. Barnes *et al.*, Cambridge U. Press, 1982) on THR models of nova outbursts. Several useful catalogues of objects and lists of literature were published (e.g. Duerbeck, *ApSpSc 99*,p93; Patterson, *ApJ Sup 54,p443; Ritter, AAp Sup,* in press).

There was a large number of papers based on observations in the visual and UV regions. Particularly important are new results of extensive observations of selected objects; examples are: photometry of Z Cha (Cook and Warner, *MN 207*, p705), photometric and spectroscopic study of OY Car (Vogt, *AAp 128*,p29; Schoembs and Hartmann, *AAp 128*,p37; Krzemínski and Vogt, *AAp* in press), spectroscopic coverage of SS Cyg over outburst cycle (Clarke *et al. ApJ* in press), extensive observations of several dwarf novae in the ultraviolet and visual regions by Cambridge observers (cf. Pringle and Verbunt, and Hassall, *Proc. 4th European IUE Conf.*), and observations of recent novae. Ultraviolet photometry of SS Cyg and U Gem was extended into the extreme UV by Polidan and Holmberg (*Nature 309*,p528). Disk eclipses were analysed by Schwarzenberg-Czerny (MN 208,p57) and Horne (Ph.D. Thesis, Caltech). Studies of CV's belonging to the VY Scl group have shown (Robinson *et al. ApJ 251*,p611; Shafter *et al. ApJ* (in press) that their "low" states are due to considerably reduced mass-transfer rates. The SU UMa subtype was reviewed by Warner (*NATO Symp.*) who finds that all earlier explanations of superhumps are inconsistent with observations and proposes a new, intermediate polar model in which the superhumps result from illumination of asymmetries in the disk.

CV's continue to be favoured targets of X-ray observers. Results of the *Einstein* survey were summarized by Cordova and Mason (*MN 206*,p879) and new data are coming from EXOSAT. The X-ray fluxes provide important constraints on models of the boundary layer; most recent discussions range from nearly alarmist, about the "missing boundary layer" (Ferland *et al. ApJ 262*,pL53) to fairly optimistic, showing reasonable agreement between theory and observations (Patterson and Raymond *ApJ* in press). See also section 5E. The X-ray emission from polar columns in the case of magnetic white dwarfs was discussed by several authors (cf. King, *IAU Coll 72*, p181).

The number of CV's known to contain magnetic white dwarfs is growing. The subtype of intermediate polars (Lamb and Patterson, *IAU Coll 72*, p229; Warner, *IAU Coll 72*,p155; *7th N.American Workshop; NATO Symp)* includes objects ranging from strong X-ray emitters and rapid rotators to (probably) less extreme cases such as the SU UMa variables.

A major breakthrough was achieved in the field of dwarf novae following a pioneering work by Meyer and Meyer-Hofmeister (*AAp 104*,pL10). First time-dependent accretion-disk models, including effects of thermal instability due to hydrogen ionization (Meyer and Meyer-Hofmeister, *AAp 132*,p143; Mineshige and Osaki, *PASJ*, in press; Papaloizou *et al. MN 205*,p487; Smak, *AA 34*,p161) reproduce quite well the light-curves and other properties of dwarf novae and demonstrate that their outbursts are due to non-stationary accretion behaviour. There is obvious need to include additional effects, such as the heating of the secondary by radiation from the boundary layer, which appears crucial for the Z Cam (Meyer and Meyer-Hofmeister *AAp 121*,p29) and SU UMa (Osaki, *AAp*, in press) behaviour. Heating effects have already been detected in some dwarf novae (Szkody *et al. ApJ 282*,p236; Hessman, *ApJ*, in press). Superoutbursts of SU UMa variables represent a different case. Vogt (*AAp 118*,p95) finds that supermaxima of VW Hyi always develop from immediately preceeding normal maxima and are likely due to increased mass-transfer rate. Time-dependent disk models with mass-transfer bursts (Bath *et al. MN 205*,p171; Mantle and Bath, *MN 202*,p151) may be applicable to this case. Dwarf novae, with their outbursts being due to accretion phenomena, are also vulnerable, on a longer time scale, to the TNR phenomena leading to nova type outbursts. Three recorded novae, GK Per, WY Sge, and V3890 Sgr, are indeed showing also the dwarf nova behaviour (Duerbeck, *ApSpSc 99*,p363).

The theory of nova outbursts has reached a new turning point. The TNR models, calculated in spherical case explain satisfactorily many observed properties of fast and slow novae and also of some recurrent novae (Starrfield *et al. ApJ*, in press). The predicted CNO overabundance (cf. McDonald, *IAU Coll 72*,77), which was confirmed by observations, can be understood in terms of mixing with the deeper layers of the C-O white dwarf; in the special case of Nova CrA 1981 (Williams *et al. MN* in press) observations suggest an O-Ne-Mg white dwarf. The most promising explanation involves mixing due to shear instabilities in the equatorial belt (McDonald, *ApJ 273*,p289); there is obvious need for further work along these lines.

E. X-RAY BINARIES (CATACLYSMIC VARIABLES) (G. Shaviv)

The most important event concerning observations of X-rays from cataclysmic variables is the publication of a catalogue of such variables that are X-ray sources and have been observed by *Einstein* (Cordova and Mason *MN 206*,p879). The catalogue is accompanied with a few detailed studies of particular sources. The 18 close binaries in the catalogue have luminosities in the 1 Kev band of between 10^{30} erg s^{-1} and 10^{32} erg s^{-1}. Most of them show hard spectra (kT > 2 Kev) independently of whether or not they are undergoing an outburst. Of seven dwarf novae observed during optical outbursts, only U Gem exhibits enhanced ultra-soft X-ray emission (kT 10 ev) in addition to weak, hard X-ray emission. The observed X-rays are highly variable on time-scales ranging from tens of seconds to hours.

Observations with EXOSAT have allowed better exploration of possible correlations and predictions. Watson *et al.* (*MN* in press) have discovered a definite X-ray period of 351s in the old nova GK Per. Accompanying ground-based observations (Mazeh *et al. AAp* in press) show a bit signal at 380s caused by a long-term transient in the system, observable also in X-rays with a quasi-period of 3000s. These observations confirm the suggestion by King and Shaviv (*MN* in press) that GK Per is an "intermediate polar" - that is, a magnetic white dwarf with a field in the range of 10^5 gauss. The X-ray pulse profile is remarkably constant and has a quasi-sinusoidal shape. The spectrum of the dominant hard X-rays is of a flatness unprecedented among cataclysmic variables. Another important discovery by King *et al.* (*Nature*, in press) is the existence of a correlation between the hard X-ray luminosity L and the temperature T of the

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bremsstrahlung-emitting plasma.

The first theoretical predictions of X-rays from cataclysmic variables were that they must have a high luminosity in hard X-rays, as a result of either shock or viscous dissipation at the boundary layer. The low observed X-ray flux from cataclysmic variables, however, has led people to look for the "missing boundary layer" or to suspect that the X-rays come from the M-type dwarf or a disk corona. Obviously, the process by which X-rays are formed must be different in each case, as shown by differing properties from one system to another. Recent discoveries by EXOSAT help to clarify the problem. It is natural to suppose that the white-dwarf corona is the hottest source, since it is in the deepest gravitational well. Recent theory by King and Shaviv (*Nature 308*,p519) predicts that boundary-layer instability leads to the formation of a corona at low accretion rates (thus hard X-rays are expected for low masses). For high masses, the boundary layer is stable and only soft X-rays are observed. Exactly this behaviour is observed in SS Cyg. During optical outbursts the hard X-rays decay, while the soft ones increase.

The puzzle of the soft X-rays from AM Her has not yet been settled observationally. Recent observations reported by Heisse at the 1984 North American workshop on cataclysmic variables, seem to indicate that hard X-rays emerge from one pole and soft X-rays from a second pole, since radiations in the two X-ray bands are out of phase. It is not clear how this can happen.

6. Statistical Investigations

A number of wide-ranging statistical studies has been published by Guiricin *et al.* (*AApSup 54*,p211, *ApJSup 54*,p421, *AAp 119*,p218, and *ApJSup 52*,p35) based on samples of up to 1,000 systems. The authors find an underabundance of short-period systems (relative to the numbers of longer periods) and especially of early-type contact systems. Their studies of the angular momentum of Algol-type systems lead them to conclude that considerable amounts of mass and angular momentum must have been lost during the formation of these systems.

The frequency of binaries in both globular and galactic clusters, and among Population II field stars has continued to attract attention. A possible cataclysmic variable has been identified in M30 (*ApJ 274*,pL31). Harris and McClure (*ApJ 265*,pL77) argue from their study of binary incidence amongst late-type giants that it does not necessarily follow from the presently available evidence that M3 is deficient in binaries, while Irwin and Trimble have found some possible W UMa systems in the globular cluster NGC 6809. Krolik (*Nature 305*, p506) published estimates of the number of binaries to be expected in globular clusters; similarly, Herz and Grindley (*ApJ 267*,pL83) predict that an average globular cluster should contain about 200 white-dwarf binaries. Four W UMa systems have been found in NGC 188 (Baluinas and Guinan *BAAS 15*,p924) while Stefanik *et al.* (*ibid*) find that about half the stars in the Hyades are binaries. Levato and Malaroda (*PASP 94*,p807) have identified possible binaries in Trumpler 16. On the other hand, Stryker and Hrivnak (*ApJ 278*, p215) believe that not *all* the blue stragglers in NGC 7789 are binaries. Stryker (*BAAS 16*,p507) also advances arguments for supposing that the binary frequency of Population II stars may be higher than some investigations have suggested, while Carney (*AJ 88*,p623) believes that 20 to 25 per cent of a sample of 71 halo dwarfs may be binaries.

Griffin (*Obs 103*,p280) has published an interesting synopsis of his first 50 orbits from photoelectrically determined radial velocities which indicates how the distribution of (e.g.) orbital periods in a sample can be influenced by selection factors dependent on the method of observation. Halbwachs (*AAp 128*,p399) studied the distribution of binaries in the new edition of the *Bright Star Catalogue* and concluded that 60 per cent of the stars are in binary or multiple systems with a

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separation greater than 3 A.U. Fofi *et al.* (*AAp 124*,p313) from a multivariate statistical analysis confirm the existence of a period-eccentricity relation and of bimodality in the distribution of mass-ratios (the latter is also confirmed in *AAp 119*,p218). Mezzetti *et al.* (*AAp 122*,p333) have studied the effects of duplicity on estimates of the local luminosity function. Echeverría (*Rev Mex 8*, p109) finds a period-spectral-type relation for cataclysmic variables and deduces that the secondaries are not normal main-sequence stars. Trimble (*Obs 102*,p133) has considered the binary systems likely to produce cataclysmic variables and type I supernovae. She concludes that there is an ample supply for the former but not for the latter. Kenyon and Gallagher (*AJ 88*,p666) have studied a sample of symbiotic stars and conclude that not all the giant components of such stars fill their Roche lobes. Russo (*IAU Coll 69*,p23) believes that upto 25 per cent of Cepheids have companions while Panchatsaram and Abhyankar (*ibid* p.47) have studied period changes in 22 binaries.

Garrison *et al.* (*ApJ 276*,pL13) report the discovery of a probable cataclysmic variable that is, if its nature is confirmed, the brightest member of its class ($V = 9.4$). From the results of a survey of stars to $B = 10.0$, they are able to estimate the space density of cataclysmic variables as 1.3×10^{-6} per cubic parsec.

Popova *et al.* (*ApSpSc 88*,p55) have published a discussion of the properties of 1041 known spectroscopic binaries. Amongst the bright stars, they find a duplicity rate of 40 to 45 per cent and, allowing for selection effects, they estimate that almost all stars belong to binary systems. Related investigations of 482 eclipsing binaries and 333 two-spectra binaries have been published by Kraicheva *et al.* (*PisAZh 7*,p488) and by Popova *et al.* (*PisAZh 8*,p297). From the frequency distributions with respect to mass and separation, the last-named authors are led to postulate the coalescence of some binaries into single stars (see also section 7).

Two useful catalogues are in press: the 14th *Catalogue Complementaire (Binaries Spectroscopiques)* - Pedoussaut *et al.* *AApSup* - and Budding's *Catalogue of Classical (Evolved) Algol-Type Binary Candidate Stars*, to be published by CDS Strasbourg.

7. Origin and Evolution

A review of the evolution of close binaries has been published by Yungelson and Massevich (*Soviet Scientific Review 21*,p27). No attempt will be made to review more than a few of the many papers that discuss the evolutionary status of individual systems. McClure's (*ApJ 268*,p264) discovery of the binary nature of barium stars is clearly of evolutionary interest.

Most of the effort in theoretical studies of evolution seems directed towards understanding systems containing collapsed objects. Kornilov and Lipunov (*AZh 60*, p284,p574) have studied the evolution of close binaries, taking into account the evolution of a rotating neutron-star component. Tutukov *et al.* (*Pis.AZh 8*,p365) have discussed the evolution of dwarf novae, with particular reference to gravitational radiation. Webbink and collaborators (*ApJ 254*,p616) have developed theoretical models of low-mass X-ray binaries, again taking into account gravitational radiation which explains the minimum period found for cataclysmic binaries - a conclusion reached independently by Paczynksi and Sienkiewicz (*ApJ 248*,pL27), *268*,p825). Webbink *et al.* (*ApJ 270*,p678) find that mass-transferring subgiant stars, driven by nuclear evolution, provide a satisfactory explanation for bright-bulge sources and fit very closely the observed parameters of Cyg X-2 and 2S 0921-630. Webbink (*ApJ 277*,p355) has also explored the origin and evolution of close double white dwarfs, suggesting that they may be progenitors of R CrB stars and type I supernovae. The latter suggestion was also made by Iben and Tutukov (*ApJSup 54*,p335), but see the reference to Trimble's work in section 6. Some work by Bath and his collaborators is mentioned in section 5D. Bath and Pringle (*MN 194*,p967, *199*,p267, *201*,p345) have also studied the evolution of viscous accretion disks, finding excellent agreement between predicted outburst evolution and observed photometric and spectroscopic behaviour of dwarf novae and symbiotic systems. A statistical study of outbursts of SS Cyg since 1897 (Bath and van Paradijs *Nature 305*, p33) shows a clear correlation between the structure of the outburst and the light level in the quiescent state.

Campbell (*MN 205*, p1031) has found that the white-dwarf component of AM Her systems cannot be completely synchronized with the orbit while mass is being transferred. As mentioned in section 4B, however, he found that tidal torque can synchronize the white dwarf in a twin-degenerate binary within the lifetime of the system (*MN 207*, p433). Campbell and Papaloizu (*MN 204*, p433) find that synchronization times for convective secondaries can approach the lifetime of the system. Chau and Nelson (*ApSpSc 90*, p245) have discussed non-conservative mass transfer and gravitational radiation in low-mass binaries. Other evolutionary studies of cataclysmic variables have been published by Anzer and Borner (*AAp 122*, p73), Law and Ritter (*AAp 123*, p33), and Miyaji (*IAU Coll 72*, p263). Vilhu (*ApSpSc 99*, p287) has considered magnetic braking of the red star in a cataclysmic variable as a mechanism to drive mass transfer. Ureche (e.g. *IAU Coll 69*, p73) has published several studies of relativistic objects in close binaries.

Studies, by the research group at the Free University of Brussels, on the formation of Wolf-Rayet binaries are reported in section 5A. The same group of authors has studied the structure of early-type contact stars and the origin of Algol-type systems (De Greve and Packet *ApSpSci 99*, p313 and papers in press). Chaubey (*ApSpSc 73*, p503) finds that all semi-detached systems are results of Case B evolution, provided allowance is made for loss of mass and angular momentum. From data for 333 unevolved double-line systems, he deduces that Case A evolution is rare. Guiricin *et al.* (*AAp 125*, p388) find no satisfactory agreement between theoretical calculations and the observed properties of Algols. Kenyon and Gallagher (*AJ 88*, p666) find that the late-type components of many symbiotic stars do not fill their Roche lobes, even though it appears that mass is being transferred. This may have implications for all theories of binary evolution. Other work by Kenyon and his collaborators on symbiotic stars is to be found in *AAp 106*, p109 and *ApJ 273*, p280, *279*, p252.

Vilhu (*AAp 109*, p17) has discussed the formation of W UMa stars by angular-momentum loss from detached systems. See, however, Rucinski's (*Obs 103*, p280) comments. Verbunt and Hut (*AAp 127*, p161) also discuss magnetic braking as an evolutionary mechanism, as mentioned in section 4b. An alternative origin for W UMa systems is proposed by Budding (*AAp 130*, 324), who suggests that they are formed from detached systems with small mass-ratio, by Case B mass transfer. Van Hamme (*AAp 116*, p27) has studied the absolute dimensions and lifetimes of W UMa systems.

Van't Veer (Paris preprint No. 26) has postulated that the components of a binary can coalesce into single stars. Walter and Basri (*ApJ 260*, p735) have suggested that this is happening in FK Com.

Artymowicz (*AA 33*, 233) has studied the formation of binaries by accretion on to protostars from a molecular cloud. Numerical simulations show that the mass-ratio of neighbouring nuclei of condensation tends to equalize during this process, which can thus explain the observed preponderance of binaries with mass-ratios near unity. The possible evolutionary connection between planetary systems and low-mass cataclysmic variables has been discussed by Livio and Soker (*AAp 125*, L12).

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Lebovitz (*ApJ* 275,316) has extended his earlier investigation of the possibility of binary and multiple systems being formed by the fission of a single proto-star. When changes in internal energy - ignored in classical treatments in fission theory - are taken into account, it appears that binary systems may be able to be formed by this process.

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