42. CLOSE BINARY STARS (ETOILES DOUBLES SERREES)

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1. Introduction

Studies of close binary stars were persued more vigorously than ever: about 3000 research papers and notes pertaining to the field were published during the triennium 1976 - 1978. Many major advances and spectacular discoveries were made, mostly due to increased observational efficiency and precision, especially in the X-ray, radio, and ultraviolet domains. The high activity is also shown by the number of conferences devoted to close-binary problems.

The proceedings of our 1975 Cambridge Symposium, IAU No. 73, appeared in print in 1976: *Structure and Evolution of Close Binary Systems*, eds. P. Eggleton, S. Mitton, and J. Whelan; Reidel Publ. Co. Likewise, IAU Symposium No. 70, dedicated to the memory of P.W. Merrill and D.B. McLaughlin, was printed by Reidel in 1976 (*Be and Shell Stars*, ed. A. Slettebak). At the Grenoble Meeting decision was taken to co-sponsor a symposium on "Mass-Loss and Evolution of O-type Stars". It was held, as IAU Symposium No. 83, at Qualicum Beach, Vancouver Island (Canada), in June 1978; many papers and much of the discussion dealt with close binaries. As will be known to all readers, the Commission is sponsoring IAU Symposium No. 88, "Close Binary Stars: Observation and Interpretation", to be held in Toronto, August 1979, with M. Plavec as Chairman of the Scientific Organizing Committee. Further, the Commission offered co-sponsorship for a symposium on "Fundamental Problems in the Theory of Stellar Evolution", planned for Kyoto, July 1980. IAU Colloquia of special interest were: No. 29, *Multiple Periodic Variable Stars*, ed. W.S. Fitch, published 1976 in two volumes by the Hungarian Academy of Sciences (Vol. 1, with the invited papers, was also issued by Reidel); No. 33, "Observational Parameters and Dynamical Evolution of Multiple Stars", published 1977 as Vol. 3 of *Rev. Mexicana Astron. Astrophys.*; No. 42, "The Interaction of Variable Stars with their Environment" appeared in book form 1977 (eds. R. Kippenhahn, J. Rahe, and W. Strohmeier, *Veröff. Remeis-Sternw. Bamberg*, No. 121) just a few months after the colloquium; No. 46, "Changing Trends in Variable Star Research", held at Hamilton, New Zealand, November 1978. The conference on "X-ray Binaries" at Goddard Space Flight Center in October 1975 was edited by E. Boldt and Y. Kondo and published early 1976 as *NASA SP*-389. Reidel printed 1977 *Novae and Related Stars* (ed. M. Friedjung), the proceedings of the September 1976 Paris conference. The 1974 Moscow conference on evolutionary problems was followed up by a second conference in Warsaw, June 1977 (*Non-stationary Evolution of Close Binaries*, ed. A.N. Zytkow, Polish Scientific Publ.,1978).

Two important monographs were published, *viz.*, Z. Kopal, *Dynamics of Close Binary Systems*, Reidel Publ. Co., 1978, and J. Sahade and F.B. Wood, *Interacting Binary Stars*, Pergamon Press, 1978. Of utmost importance for close-binary workers is the appearance 1978 of *Seventh Catalogue of the Orbital Elements of Spectroscopic Binary Systems*, by A.H. Batten, J.M. Fletcher and F.J. Mann (*Publ. Dominion Astrophys. Obs.* 15, No. 5). Also, we should mention that a new edition of the *Finding List for Observers of Eclipsing Variables* will soon be published by F.B. Wood, R.H. Koch, J.P. Oliver, and D.R. Florkowski. The *Bibliography and Program Notes on Close Binaries* continued to be issued from Lund Observatory, with G. Larsson-Leander as editor. Nos. 27 - 31 appeared during the triennium; regional contributors were B. Cester (Italy), M. de Groot and R.F. Sisteró (Southern Hemisphere), J. Grygar (Central and Eastern Europe), D.S. Hall and

G.W. Henry (USA, except the West Coast), M. Kitamura (Japan), H. Mauder (Germany and *IAU Circ.*), C.D. Scarfe (Canada, US West Coast, Mexico), A. Shulberg (USSR), S.D. Sinvhal and C.D. Kandpal (India and Indonesia), F. van't Veer (Western Europe).

The present Report is based on published literature and information from Commission members. Members of the Organizing Committee kindly consented to write specific Sections, and for reviewing radio observations I got the expert help of Dr. D.M. Gibson. The names of these contributors are indicated at proper places. In addition, on my request Dr. A.M. Cherepashchuk wrote an extensive summary of the work done in the USSR, excerpts of which were communicated to the contributors. However, to keep the Report at the prescribed length, make the presentation as homogeneous as possible, and take into account the most recent literature, the contributions were more or less heavily edited. Much material was especially added to Tables 1 - 4, in an attempt to make them as complete as possible. Lack of space made it necessary to omit names of authors in the tables. As it was realized that many details on work in progress could not be included in the Report, much of this information was given in No. 31 of the *Bibliography*. I am deeply thankful to all contributing authors and Commission members who have helped me so generously.

Key to the references:
AA = Acta Astron.
AAp = Astron. Astrophys.
AAp Sup = Astron. Astrophys., Suppl. Ser.
AASin = Acta Astron. Sinica
Af = Astrofizika
Af Issl = Astrofiz. Issled. Izv. Spets. Astrofiz. Obs.
AJ = Astron. J.
AmAf = Astrometr. Astrofiz., Kiev
AN = Astron. Nachr.
Ann Rev AAp = Annu. Rev. Astron. Astrophys.
Ann Tokyo = Ann. Tokyo Astron. Obs., Second Ser.
ApJ = Astrophys. J.
ApJ Sup = Astrophys. J., Suppl. Ser.
ApL = Astrophys. Lett.
ApSpSc = Astrophys. Space Sci.
ATs = Astron. Tsirk.
AZh = Astron. Zh. Akad. Nauk SSSR
BAAS = Bull. American Astron. Soc.
BAC = Bull. Astron. Inst. Czechoslovakia
Bamberg Ver = Veröff. Remeis-Sternw. Bamberg
BASI = Bull. Astron. Soc. India
Byull Abastuman = Byull. Abastuman. Astrofiz. Obs.
Com Ankara = Commun. Astron. Dep. Univ. Ankara
ComAp = Comments Astrophys.
Contr Cluj-Napoca = Contrib. Astron. Obs. Univ. "Babes-Bolyai", Cluj-Napoca
IAUC = IAU Circ.
IBVS = Inf. Bull. Variable Stars
Izv AN AzSSR = Izv. Akad. Nauk Azerb. SSR, Ser. fiz.-tekn. i mat. n.
Izv Ehngelg = Izv. Astron. Ehngel'gardt. Obs., Kazan
Izv Krym = Izv. Krymskoj Astrofiz. Obs.
JAAVSO = J. American Assoc. Variable Star Obs.
JRASC = J. R. Astron. Soc. Canada
Kodaikanal Bull = Kodaikanal Obs. Bull.
Liège Coll = Colloque Int. Astrophys. Liège
MittAG = Mitt. Astron. Ges.
MN = Mon. Not. R. Astron. Soc.
MRAS = Mem. R. Astron. Soc.
MSAI = Mem. Soc. Astron. Italiana
Obs = Observatory
PASP = Publ. Astron. Soc. Pacific
PerZv = Perem. Zvezdy, Byull.
PerZv Pril = Perem. Zvezdy, Prilozhenie
Pis AZh = Pis'ma v Astron. Zh.
Publ DAO = Publ. Dominion Astrophys. Obs.
Publ Tartu = Publ. Tartu Astrofiz. Obs.
QJRAS = Q. J. R. Astron. Soc.
Rep Ege = Sci. Rep. Fac. Sci. Ege Univ., Izmir
Rep Lund = Rep. Obs. Lund
Soob Zelenchuk = Soobshch. Spets. Astrofiz. Obs.
Stud Babes-Bolyai = Stud. Univ. Babes-Bolyai, Ser. Math.-phys.
Tokyo Bull = Tokyo Astron Bull., Second Ser.
Trudy Alma-Ata = Trudy Astrofiz. Inst. Alma-Ata
Trudy Kazan = Trudy Kazan. Gorod. Astron. Obs.
Ts Lvov = Tsirk. Astron. Obs., L'vov.
Ts Shemak = Tsirk. Shemakhinsk. Astrofiz. Obs.
Villanova Contr = Villanova Univ. Obs. Contrib.
Vistas = Vistas Astron.

2. Observational Techniques

(B. Warner)

A wide range of techniques are currently used for the study of close binary stars. The more conventional photometric and spectrographic observations, polarimetry, X-ray and radio observations are discussed in Section 4. Extraterrestrial observations, including those made with the IUE, are summarized in Section 10. In addition we mention here the ultraviolet satellite observations of β Lyr (Kondo *et al.*, *ApSpSc* 41,121), V1500 Cyg (Jenkins *et al.*, *ApJ* 212,198; Wu and Kester, *AAp* 58,331), W UMa (Rucinski, *AA* 26,227), and V Pup (York *et al.*, *ApJ* 210,143).

High-resolution spectroscopy of HR Del (Gallagher and Anderson, *ApJ* 203,625) used an Echelle system, in V1500 Cyg photoelectric scans gave good results for interstellar lines (Tomkin *et al.*, *AAp* 48,319). Infrared spectroscopy (2 - 3 μ) detected coronal lines in V1500 Cyg (Grasdalen and Joyce, *Nature* 259,187); 1 - 20 μ spectra of this nova were obtained by Ennis *et al.* (*ApJ* 214,478). An application of the surface-brightness technique to V1500 Cyg (Barnes, *MN* 177,53P) provided a new way of estimating distances to novae.

Rapid photometry was widely used for studies of dwarf and other novae (Nevo and Sadeh, *MN* 177,167, 182,595; Robinson and Nather, *PASP* 89,572; Szkody, *ApJ* 207,190; Warner and Brickhill, *MN* 182,777), quasi-periodic variations were found in VW Hyi (Haefner *et al.*, *AAp* 61,L37), RU Peg (Patterson *et al.*, *ApJ* 214,144), and WZ Sge (Robinson *et al.*, *ApJ* 219,168). Rapid flickering was detected in AM Her (Bailey *et al.*, *MN* 180,35P) and in the symbiotic variable CH Cyg at outburst (Slovak and Africano, *MN* 185,591). Optical pulsations were detected in HZ Her (Middleditch and Nelson, *ApJ* 208,567) and from 4U 1626-67 (Ilovaisky *et al.*, *AAp* 70,L19). Optical bursts were reported from MXB 1735-44 (McClintock *et al.*, *Nature* 274,567). Rapid variations in line profiles were seen in V1500 Cyg (Campbell, *ApJ* 207,L41), in EZ CMa (Vojkhanskaya *et al.*, *Af* 12,180), and in β Lyr (Sanyal, *ApJ* 210,853). Pulse-resolved spectrophotometry was obtained for DQ Her by Margon *et al.* (*ApJ* 208,L35), and possible pulsations in the spectral lines were reported (Margon *et al.*, *PASP* 89,300).

We note the increasing importance of speckle interferometry (Blazit *et al.*, *ApJ* 214,L79; McAlister, *ApJ* 215,159, 225,932; Morgan *et al.*, *MN* 183,701) for spectroscopic binaries. Detailed studies by McAlister include η Ori (*PASP* 88,957), 12 Per (*ApJ* 223,526), and 51 Tau (*ApJ* 212,459). Lunar occultations continue to furnish information on new and old systems (*e.g.*, Africano *et al.*, *AJ* 82,631, 83,1100). Long-focus astrometry by van de Kamp yielded parallaxes and orbital data for ε Aur (*AJ* 83,975) and VV Cep (*AJ* 82,750). New interferometric techniques (Currie *et al.*, *BAAS* 9,625) seem very promising.

3. Methods of Analyzing Light Curves

The methods of analyzing light changes in the frequency domain were further developed, primarily by Kopal and his collaborators in the long series of papers entitled "Fourier Analysis of the Light Curves of Eclipsing Variables" in *ApSpSc* (Vol. 34 - 57, 19 papers). Other contributions were given by Jurkevich *et al.* (*ApSpSc* 44,63), Rovithis-Livaniou (*ApSpSc* 51,77, 52,271), and by several investigators dealing with specific systems.

As outlined by Kopal (*ApSpSc* 34,431), one of the most suitable methods of transforming from the time to the frequency domain is to consider light loss to be a function of even powers of the sine of the phase angle and to evaluate certain integrals A_{2m}, called moments, from which the elements are determined. The relations between the A_{2m} and the geometrical elements, although simple for uniformly bright stars, were found complicated for limb-darkened stars. A simpler and more direct method to obtain these relations was indicated by Smith (*ApSpSc* 40,315). Kopal (*ApSpSc* 46,87) generalized the procedure, introducing the complete Fourier transform and considering also odd and non-linear moments. In Paper XI of the series, Kopal (*ApSpSc* 50,225) defined the light loss as the cross correlation of two apertures, representing the eclipsing and eclipsed disks. This new approach is shown to have considerable advantages compared to the geometrical one. The fractional light loss of arbitrarily limb-darkened stars, equal to the associated alpha-functions α_l^0, may be described as Hankel transforms of products of two Bessel functions, with orders depending on the physical characteristics of the components, while the geometry of the system enters only through their arguments. Kopal (*ApSpSc* 51,439) gave explicit forms for the α_l^0 for different types of eclipses together with the corresponding moments A_{2m}, and alternative forms of the α_l^0 were given by Demircan (*ApSpSc* 52,189). Kopal and Demircan (*ApSpSc* 55,241) described the practical procedures for deriving the geometrical elements for any type of eclipse, any proximity of components, and any limb-darkening. Demircan (*ApSpSc* 56,389) gave new general expressions for the moments A_{2m}, allowing an automated method of analysis, and discussed (*ApSpSc* 56,453) which moments should be chosen for best determinacy. Photometric perturbations were considered by Edalati and Budding (*ApSpSc* 57,181) and by Kopal (*ApSpSc* 57,439). All the above papers assume circular orbits. The generalization to excentric orbits was given by Kopal and Al-Naimiy in Paper XIX (*ApSpSc* 57,479). Several more papers of the series are in press. A book on the Fourier methods has already been completed by Kopal in manuscript form. It should be available as preprint to interested workers at the end of 1978, and will hopefully appear from the printer during 1979.

A computer program, based on Kopal's analytical method for solution in the time domain, was worked out by Söderhjelm (*Rep Lund* 10). Botsula (*Izv Ehngelg* 39,99) and the Peking Research Group (*AASin* 18,68) discussed the convergence of successive approximations in Kopal's method. Lanzano (*ApSpSc* 42,425, 45,419,483) discussed the J-integrals and derived recursion formulae useful for numerical computations.

Lavrov (*PerZv Pril* 2,349) published a program suited to the rectifiable Russell-Merrill method, and coefficients for polynomials approximating the $\alpha(p,k)$ functions were tabulated by Lavrov and Sokolova (*BAC* 27,301). Horak (*BAC* 26,257) presented a modification of his iterative minimization method. Ureche (*Contr Cluj-Napoca*, p. 13; *Stud Babes-Bolyai*, in press) discussed the influence of the quadratic and a possible sine term in the limb-darkening law, and he extended his studies of the ellipsoid-ellipsoid approximation to the case of elliptic orbits (*BAC*, in press). Budding reports that a 16-parameter curve-fitting program was put in operation in Manchester.

Binnendijk in a lucid paper (*Vistas* 21,359) described a new method for computing light curves and deriving orbital parameters for contact binaries, assuming Roche potentials. A slightly more theoretical treatment was presented by Sapar (*Publ Tartu* 44,124). Eaton (*BAAS* 9,624) wrote a program for application on RS CVn systems, assuming unevenly distributed spots on one component. Eclipses by an elliptical torus were treated by Wilson (*AJ* 80,719).

Among the various existing programs for light-curve synthesis, especially those of D.B. Wood and Wilson and Devinney have been used extensively by many workers. For the benefit of users, Wood issued a number of *WINK Status Reports*, with improvements and amendments. In the Wilson-Devinney program, Wilson added an optional stellar-atmosphere provision, the capability of treating non-synchronous rotation, and the generation of radial-velocity curves. Accuracy-related improvements were described by Wilson and Biermann (*AAp* 48,349). The procedures are now being generalized to include effects of orbital excentricity, with proper accounting for the variable tidal field on the figures of the components. Wilson further intends to incorporate the effects of radiation pressure and to develop programs for simultaneous solution of light and radial-velocity curves.

Comparisons of various methods on specific systems have been made in a number of cases. Binnendijk, in his paper referred to above (*Vistas* 21,359), gave parameters for V566 Oph, RZ Tau, and AW UMa. Results of other methods for these and other stars were reduced to the same set of parameters, thus making direct comparisons possible. The Russell-Merrill, Kitamura, Wood, and Wilson-Devinney procedures were used on CW Cas by Burchi *et al.* (*ApSpSc* 47,35) and on RT Per by Mancuso *et al.* (*ApSpSc* 47,277). For RZ Cas, Chambliss (*PASP* 88,22) obtained with the Wood model elements which differ significantly from those found with the Russell-Merrill and Kopal-Jurkevich methods. Chambliss and Leung (preprint) comparing the Russell-Merrill, Kopal-Jurkevich, and Wilson-Devinney approaches on SX Aur found the third procedure to yield the most consistent solution.

4. Observational Data

A. Photometric Observations and Solutions (T. Herczeg)

Tables 1 and 2 list publications reporting new photoelectric observations and orbital solutions. Photoelectric work continued to increase; among observatories that recently became very active in this field, we mention Athens, Biruni, Ege, Helwan, and Villanova. Quite frequently the number of observations are so high that their detailed publication becomes impractical, and the observations are deposited with one of the established repositories or made available upon request to the observer. Also, there are cases where publication is postponed to some later time, and only the observed light curves or other results are published presently. Table 1 contains papers that are obviously based on a "considerable amount" of new photoelectric data, thus, in contrast to previous practice, not only papers presenting individual observations. Satellite UV-photometry is included.

Novae at outburst are not regarded as belonging to the field of this Commission. The papers on V1500 Cyg quoted in Table 1 deal more or less with the periodic fluctuations in the light curve; if interpreted as an orbital phenomenon similar to those found in cataclysmic variables, they would suggest a very strong change of orbital period (*cf.* Semeniuk *et al.*, *AA* 27,301).

Photographic studies are not listed in Table 1. Important ones are the optical histories of X-ray binaries: AM Her (Feigelson *et al.*, *ApJ* 222,263), X Per (Gottlieb *et al.*, *ApJ* 202,L13), V818 Sco (Wright *et al.*, *ApJ* 200,171), and HD 245770 (Stier and Liller, *ApJ* 206,257), all derived from Harvard plates.

B. Spectroscopic and Spectrophotometric Investigations (A. Batten)

Table 3 lists spectroscopic and spectrophotometric studies, including determinations of orbital elements (references indicated by an asterisk). To save space, papers already cited in the *Seventh Catalogue of the Orbital Elements of Spectroscopic Binary Systems* (Batten *et al.*, *Publ DAO* 15,121) are omitted.

Important fundamental work on detached main-sequence systems was continued by Popper and the Copenhagen group (especially Andersen). Popper extended his studies to include Algol-type systems, and reports the detection of the secondary D-lines in the spectra of a number of them, which should lead to better knowledge of their masses. A noteworthy individual achievement was the detection of the secondary spectrum of Algol itself by Tomkin and Lambert (*ApJ* 222,L119). Tomkin (*ApJ* 221,608) also detected the secondary spectrum of δ Lib. Early-type systems attracted considerable interest. Hutchings continues his work on mass loss and stellar winds. Conti and his associates published a number of critical re-investigations of systems containing O-type stars. Popper (*ApJ* 220,L11) indicated that masses of some early-type systems - especially that of V382 Cyg, one of the most massive known - should be revised downwards. Wolf-Rayet binaries were the subject of considerable discussion at IAU Symposium 83; among others, Niemela reported on her continued work. A new study of θ Mus by Moffat and Seggewiss (*AAp* 54,607) should be particularly noted. Van Blerkom (*ApJ* 225,175) found supporting evidence that HD 45166 is binary, containing a low-mass star in Wolf-Rayet clothing.

Table 1. Photoelectric Observations

RT And *IBVS* 1409, AB And *Com Ankara* 77, CN And *IBVS* 1087, ζ And *Izv Krym* 56,16, λ And *AJ* 83,176, DX Aqr *IBVS* 1199, V337 Aql *PerZv* 20,375, V822 Aql *ATs* 956, V889 Aql *AA* 28,221, RW Ara *AAp Sup* 26,227, SS Ari *ATs* 888, UX Ari *AA* 27,281, *AJ* 83,176, *ApJ* 225,919, SX Aur *PerZv Pril* 2,51, *IBVS* 1278, WW Aur *BAAS* 7,463, CQ Aur *RicA* 8,555, IU Aur *AA* 28,63, KR Aur *Pis AZh* 3,510, ε Aur *Publ Tartu* 45,284, TZ Boo *IBVS* 1086, 1487, *AAp Sup* 33,63, XY Boo *AJ* 82,648, AC Boo *AAp Sup* 29,57, 44i Boo *IBVS* 1353, 1374, 1497, *AAp Sup* 32,361, SZ Cam *PerZv* 20,473, AS Cam *IBVS* 1090, *ApSpSc* 38,87, TX Cnc *Obs* 98,205, WY Cnc *IBVS* 1484, *BAC* 27,335, RS CVn *BAAS* 10,418, VZ CVn *AAp* 56,75, *Rep Ege* 225, AM CVn *AA* 25,371, *BAAS* 10,419, R CMa *AJ* 82,51, UW CMa *IBVS* 1235, *ApJ* 220,582, CW CMa *AJ* 81,1134, HH Car *AAp Sup* 22,263, RZ Cas *PASP* 87,909, 88,22, TV Cas *AJ* 82,740, *BAC* 28,41, AO Cas *Publ Tartu* 43,103, BM Cas *IBVS* 1117, DO Cas *AAp Sup* 30,223, *IBVS* 1413, MN Cas *AJ* 81,665, SV Cen *IBVS* 1162, SZ Cen *AAp* 55,401, BH Cen *ApJ* 211,844, KT Cen *AAp Sup* 22,263, U Cep *ATs* 882, *BAAS* 9,352, *ApJ Sup* 31,1, *ApJ* 220,251, 222,635, VV Cep *Tokyo Bull* 247, 248, *PASP* 89,621, *IBVS* 1286, 1385, XY Cep *BASI* 4,83, CQ Cep *Pis AZh* 2,505, CW Cep *AAp Sup* 25,151, EM Cep *JRASC* 69,307, ER Cep *MN* 184,33, TX Cet *AAp* 70,355, XY Cet *ApSpSc* 38,79, RS Cha *AAp Sup* 33,87, RZ Cha *AAp* 44,343, RW Com *BAAS* 8,521, CC Com *PASP* 88,777, *ATs* 918, Y Cyg *RicA* 8,543, SS Cyg *Pis AZh* 2,116, CG Cyg *IBVS* 1458, *BAAS* 9,623, MR Cyg *AASin* 18,68, MY Cyg *AJ* 80,976, V367 Cyg *Publ Tartu* 43,114, V388 Cyg *AAp Sup* 27,435, V444 Cyg *PerZv* 20,1, *ApJ* 221,193, V470 Cyg *PASP* 87,923, V1073 Cyg *IBVS* 1116, V1329 Cyg *PerZv* 20,345, V1341 Cyg = Cyg X-2 *Pis AZh* 4,402, *AZh* 53,511, *Soob Zelenchuk* 15,5, V1357 Cyg = Cyg X-1 *MN* 173,15P, 177,63P, 182,315, *ApJ* 205,855, *BAAS* 9,645, *MittAG* 43,225, *PerZv* 19,305, *Nature* 263,393, V1500 Cyg *AZh* 54,583,592,600,620, *AA* 27,301, *PASP* 89,37,44, *ApJ* 211,L71, 225,954, *AAp* 55,171, 58,331, 31 Cyg *AAp Sup* 21,189, 32 Cyg *AAp Sup* 21,189, TW Dra *AAp Sup* 32,57, BS Dra *IBVS* 1079, 1100, BY Dra *ApJ* 214,140, CM Dra *ApJ* 218,444, 71 Dra *IBVS* 1104, RU Eri *BASI* 4,83, CW Eri *MittAG* 38,231, U Gem *ApJ* 206,790, YY Gem *Tokyo Bull* 240, *AJ* 83,618, X Gru *AAp Sup* 29,51, AK Her *ApSpSc* 52,387, AM Her *ApJ* 211,859, 212,L113, 215,166, 219,597, 225,542, 226,397, *PASP* 90,61, *MN* 183,73P, *AAp* 68,L1, *Pis AZh* 4,183, *Nature* 271,335, DQ Her *ApJ* 196,L113, 207,195, HZ Her = Her X-1 *PerZv* 19,305, *Pis AZh* 1 No7,27, 4,356, *ApJ* 208,567,L31, 4 Her *AA* 27,265, 88 Her *BAC* 29,278, TU Hor *AAp* 61,161, TT Hya *BASI* 5,105, VZ Hya *ApSpSc* 35,249, AI Hya *IBVS* 1118, *AAp Sup* 33,103, HS Hya *AAp* 42,303, χ^2 Hya *AAp Sup* 31,307, RT Lac *ApJ Sup* 31,93, *AJ* 82,998, AR Lac *PerZv* 19,461, *PASP* 88,762, *Ts Shemak* 37,9, XY Leo *Obs* 98,205, *AJ* 83,1452, AM Leo *MittAG* 43,186, T LMi *PASJ* 29,289, RR Lyn *Ann Tokyo* 16,1, SW Lyn *BAC* 28,120, β Lyr *JAAVSO* 4,18,80, 5,16, *AAp Sup* 30,231, *ApSpSc* 41,121, *BAC* 27,215, *MN* 174,217, TY Men *IBVS* 1013, 1149, *AAp* 47,315, UX Men *AAp* 48,49, AO Mon *ApSpSc* 40,3, AR Mon *ApJ* 208,142, AU Mon *IBVS* 1348, V616 Mon *AAp* 48,141, 50,445, *ApJ* 211,L15, *IBVS* 1173, *Pis AZh* 2,112,402, TU Mus *AAp* 45,107, θ Mus *AAp* 54,607, GM Nor *AAp Sup* 22,263, U Oph *ApJ* 214,423, *BAAS* 10,410, V502 Oph *PerZv Pril* 2,161, V566 Oph *AN* 298,117, *PASP* 88,473, 89,47, *IBVS* 1457, VV Ori *BAAS* 8,306, BM Ori *AA* 26,91, η Ori *IBVS* 1418, θ^1 Ori A *IBVS* 1238, 1274, *PASP* 89,530, σ Ori E *Nature* 262,116, *ApJ* 205,L87, MW Pav *ApSpSc* 46,155, U Peg *IBVS* 1010, X Per *MN* 176,217,225, *AAp* 61,47, *ApJ* 218,504, *IBVS* 1359, *BAAS* 9,349, RT Per *ApSpSc* 47,277, RW Per *AA* 28,207, ST Per *AA* 26,15, AG Per *ApSpSc* 57,17, *BAAS* 10,410, DM Per *AAp Sup* 25,291, IW Per *BAAS* 9,626, IZ Per *BAAS* 9,288, LX Per *IBVS* 1178, β Per *AJ* 81,57, 82,67, *MN* 172,235, 173,271, 180,461, 184,523, *PASP* 87,745, AE Phe *AAp Sup* 24,399, AI Phe *IBVS* 1419, ζ Phe *AAp Sup* 23,261, RR Pic *AAp* 41,15, SZ Psc *AJ* 81,250, *IBVS* 1297, UV Psc *IBVS* 1381, V Pup *AA* 28,63, KX Pup *AAp Sup* 22,263, NO Pup *AAp* 50,79, TY Pyx *AA* 28,231, *IBVS* 1489, U Sge *PASP* 88,688, UU Sge *ApJ* 223,252, WZ Sge *ApJ* 219,168, V1647 Sgr *AAp* 58,121, V523 Sco *PASP* 87,901, V818 Sco = Sco X-1 *Soob Zelenchuk* 15,5, *AZh* 53,511, *AAp Sup* 28,119, *MN* 176,91, σ Sco *IBVS* 1432, RT Scl *AAp Sup* 28,389, RY Sct *Bamberg Ver* 121,386, RZ Sct *PASP* 88,262, CV Ser *ApJ* 199,432, *Af* 11,49, *Obs* 97,76, *AA* 28,55, RW Tau *PASP* 89,533, CD Tau *ApSpSc* 40,15, *AJ* 81,855, V471 Tau *AAp* 46,197, *ApSpSc* 57,219, *BAAS* 10,410, V711 Tau *AJ* 82,47, 83,176, *ApJ* 225,919, *IBVS* 1394, 1411, *Obs* 98,207, X Tri *AAp Sup* 23,439, *Byull Abastuman* 48,13, RW Tri *IBVS* 1251, AQ Tuc *AAp Sup* 34,207, W UMa *AA* 26,227, *MSAI* 48,83, *Obs* 98,205, VV UMa *AAp Sup* 27,285,

Table 1. (Continued)

XY UMa *AA* 27,273, AN UMa *BAAS* 8,346, AW UMa *AA* 25,417, *IBVS* 1176, *BAAS* 10,410, RT UMi *AAp* 29,333, RU UMi *AA* 27,187, AO Vel *IBVS* 1111, CV Vel *AAp* 58,131, EO Vel *AAp Sup* 22,263, γ^2 Vel *AAp* 57,151, AH Vir *BAC* 28,157, *Obs* 98,205, BF Vir *AA* 26,253, DL Vir *AAp* 61,107, ER Vul *IBVS* 1481, HR 3827A *IBVS* 1440, HR 4665 *IBVS* 1432, HR 5110 *IBVS* 1459, HD 5980 *PASP* 90,101, HD 13970 *AAp* 70,105, HD 20301 *IBVS* 1317, *AAp Sup* 29,313, HD 38735 *AAp Sup* 29,313, HD 47732 *ApJ* 222,574, HD 60168A *AAp Sup* 29,313, HD 71581 *AAp Sup* 29,313, HD 77581 = Vel X-1 *AAp* 55,473, *AAp Sup* 27,433, *MN* 183,813, HD 86441 *IBVS* 1265, HD 93206 *IBVS* 1265, HD 128141 *PASP* 87,877, HD 152235 *IBVS* 1265, HD 153919 = 3U 1700-37 *AAp* 52,139, 54,543,683, 58,L5, HD 159176 *BAAS* 7,533, HD 162724 *ApJ* 201,792, HD 173198 *IBVS* 1041, 1306, HD 193793 *MN* 185,467, HD 199497 *IBVS* 1214, HD 224085 *PASP* 89,280, HDE 271213 *ApJ* 207,329, HDE 271227 *ApJ* 207,329, BD -3°5357 *PASP* 89,616, BD -7°3007 *PASP* 87,716, CD -33°12119 *PASP* 89,720, CD -42°14462 *ApJ* 214,471, LB 3459 *MN* 183,523, LS 55°-8 *PASP* 90,191, PG 1413+01 *ApJ* 224,892, NGC 2264 W92 *PASP* 89,874, Sk 160 = SMC X-1 *AAp* 54,307, *AAp Sup* 29,339, Wray 977 = 3U 1223-62 *ApJ* 203,689, *AAp* 49,321, 54,733, *MittAG* 43,227, Cir X-1 *MN* 183,335, Cyg X-3 *ApJ* 207,78, LMC X-4 *AAp* 59,L9, 4U 1626-67 *ApJ* 225,1001.

Two objects continuing to attract much attention are β Lyr and VV Cep. Hack *et al.* (*ApJ Sup* 34,565) presented evidence for the secondary spectrum in the far UV that would set an upper limit of 3:1 (secondary:primary) for the mass-ratio. On the other hand, Dadaev (*Izv Pulkovo* 193,41, 194,18) claims to have found the secondary spectrum in the photographic region and gives the mass-ratio 1.1:1. Dadaev (*Izv Pulkovo* 195,98, and subsequent papers) is now studying the emission-line spectrum and relating it to the pattern of gas streams. Batten, Ringuelet, and Sahade continue their studies of emission lines. The other system, VV Cep, underwent eclipse during the triennium. Wright now has high-dispersion spectrograms covering a complete orbital cycle. He published orbital elements and a discussion of gas streams (*JRASC* 71,152), and continued observations through eclipse. For a third famous star, ε Aur, IUE observations indicated the presence of a hot companion (Hack and Selvelli, *Nature* 276,376).

Binaries containing intrinsic variables were studied by several groups. Abt and Levy (*PASP* 90,188) drew attention to the probable duplicity of the cepheid Y Oph; and the dwarf cepheid RS Gru was shown to have a companion by Balona and Martin (*MN* 184,1). Rodonò (*AAp* 66,175) studied flare-active systems. The RS CVn group of binaries naturally attracted much attention, because of the discovery that they are radio sources. The study of optical counterparts of X-ray binaries continued. New identifications were made and attempted, and orbital elements of known binaries were refined (Conti, *AAp* 63,225; Hutchings, *ApJ* 226,264).

Orbital elements of several multiple systems were determined, especially by Fekel, who is continuing his work. Geyer and Patkos report that ADS 12019 is quadruple (component A is the eclipsing variable BH Dra). Morbey *et al.* (*PASP* 89,851) showed that one component of ADS 11060 is a close binary. The visual pair has now been followed through periastron and is the spectroscopic binary with the most excentric orbit known (e=0.96). Radial velocities of other visual binaries have been measured, especially δ Equ (Popper and Dworetzky, *PASP* 90,71; Scarfe *et al.*, in press).

C. Polarimetric Studies (A.M. Cherepashchuk)

"Ordinary" close binaries show variable linear polarization due to scattering from circumstellar matter, and possibly to some degree also from other mechanisms. Pfeiffer and Koch (*PASP* 89,147), reviewing existing data (in many cases obtained by the authors themselves) found that, with the exception of U Oph, unevolved binaries do not show intrinsic polarization. Phase-locked polarization was detected in AO Cas (Pfeiffer, *AJ* 81,1000; Rudy and Kemp, *ApJ* 207,L125), u Her (Rudy and Kemp, *ApJ* 216,767), HD 47129 (Rudy and Herman, *PASP* 90,163), and in Algol, U Sge and V444 Cyg

Table 2. Photometric Solutions

RT And *AAp Sup* 32,351, FK Aql *Trudy Kazan* 41,3, V805 Aql *AAp Sup* 32,351, σ Aql *AAp Sup* 33,91, RW Ara *AAp Sup* 26,227, V535 Ara *ApJ* 222,917, RX Ari *BAC* 26,257, RZ Aur *Trudy Kazan* 41,3, TT Aur *AAp Sup* 33,91, WW Aur *BAAS* 7,463, *AAp Sup* 33,91, AR Aur *AAp Sup* 33,91, IU Aur *AA* 28,63, LY Aur *AAp* 62,291, ZZ Boo *AAp Sup* 32,351, AC Boo *ApSpSc* 29,57, *AAp* 63,193, 44i Boo *AAp Sup* 32,361, SZ Cam *ApSpSc* 46,407, AS Cam *ApSpSc* 38,87, AY Cam *ApSpSc* 46,261, S Cnc *Trudy Kazan* 39,42, *ApSpSc* 47,375, RZ Cnc *ApJ* 208,142, *AAp* 61,469,809, TX Cnc *Obs* 98,205, RS CVn *BAAS* 10,418, VZ CVn *AAp* 56,75, *Rep Ege* 225, R CMa *AJ* 82,51, UW CMa *ApJ* 220,582, 222,924, *MN* 185,485, CW CMa *AJ* 81,1134, HH Car *AAp Sup* 22,263, RZ Cas *PASP* 88,22, TV Cas *ATs* 881, *BAC* 28,41, YZ Cas *ApSpSc* 56,389, 57,71, AO Cas *ApJ* 223,202, CW Cas *ApSpSc* 47,35, DO Cas *AAp Sup* 30,223, MN Cas *AJ* 82,290, V523 Cas *ATs* 873, RR Cen *MittAG* 38,225, SV Cen *PASP* 88,244, *MN* 176,625, SZ Cen *AAp* 55,401, BH Cen *ApJ* 211,844, KT Cen *AAp Sup* 22,263, U Cep *BAAS* 9,352, *AAp* 61,469, VW Cep *Publ Tartu* 43,130,176, WX Cep *AAp Sup* 32,351, XY Cep *BASI* 4,83, ZZ Cep *AAp Sup* 33,91, AH Cep *AAp Sup* 33,91, CW Cep *AAp Sup* 25,151, 33,91, EI Cep *Ann Tokyo* 16,37, *AAp Sup* 32,351, EK Cep *ATs* 971, ER Cep *MN* 184,33, SS Cet *Trudy Kazan* 41,3, TX Cet *AAp* 70,355, XY Cet *ApSpSc* 38,79, 56,293, RS Cha *BAC* 26,257, *AAp* 44,459, RZ Cha *AAp* 44,343, CC Com *PASP* 88,777, U CrB *AAp* 61,469, RV Crt *IBVS* 1272, SW Cyg *Trudy Kazan* 41,3, GG Cyg *BAAS* 9,623, MR Cyg *AASin* 18,68, *AAp* 66,161, *AAp Sup* 33,91, *Villanova Contr* 1, MY Cyg *BAC* 27,125, *AJ* 80,976, V367 Cyg *Publ Tartu* 43,114, V382 Cyg *AAp Sup* 33,91, V388 Cyg *AAp Sup* 27,435, V444 Cyg *ApJ* 221,193, V453 Cyg *BAAS* 9,352, *AAp Sup* 33,91, V729 Cyg *ApJ* 224,565, V1073 Cyg *ApJ* 222,917, V1357 Cyg = Cyg X-1 *MittAG* 43,225, *ApJ* 226,264, RR Dra *Trudy Kazan* 41,3, TW Dra *AAp Sup* 32,57, CM Dra *ApJ* 218,444, 71 Dra *IBVS* 1104, RU Eri *BASI* 4,83, AS Eri *AAp* 62,291, CW Eri *MittAG* 38,231, RW Gem *ApSpSc* 46,261, YY Gem *Tokyo Bull* 240, *AJ* 83,618, X Gru *AAp Sup* 29,51, RX Her *AAp Sup* 33,91, TX Her *AAp Sup* 32,351, AK Her *ApSpSc* 47,79, 52,387, *BAAS* 10,411, HZ Her = Her X-1 *ApJ* 208,567, V338 Her *BAC* 26,257, u Her *AAp* 61,469, 66,161, VZ Hya *ApSpSc* 35,249, *AAp Sup* 32,351, AI Hya *AAp* 66,377, HS Hya *AAp* 42,303, χ^2 Hya *AAp* 67,15, RT Lac *ApJ Sup* 31,93, *AJ* 82,998, AR Lac *PASP* 88,762, *ApSpSc* 52,213, *Ts Shemak* 51-52,20, CM Lac *BAAS* 8,305, *AAp Sup* 32,351, UV Leo *BAC* 26,257, *AAp Sup* 32,351, XY Leo *Obs* 98,205, *AJ* 83,1452, T LMi *PASJ* 29,289, RS Lep *PerZv Pril* 3,149, RR Lyn *Ann Tokyo* 16,1, SW Lyn *BAC* 28,120, β Lyr *ApSpSc* 41,121, UX Men *AAp* 48,49, RW Mon *Trudy Kazan* 41,3, TU Mon *AAp* 61,469, AO Mon *ApSpSc* 40,3, AR Mon *ApJ* 208,142, *AAp* 61,809, IM Mon *AAp Sup* 33,91, V616 Mon *AAp* 50,445, TU Mus *AAp* 45,107, GM Nor *AAp Sup* 22,263, U Oph *ApJ* 214,423, *AAp Sup* 33,91, *BAAS* 10,410, WZ Oph *AAp Sup* 32,351, V566 Oph *Vistas* 21,359, *PASP* 88,473, 89,366, V1010 Oph *ApJ* 211,853, VV Ori *AAp Sup* 33,91, θ^1 Ori A *IBVS* 1129, MW Pav *ApSpSc* 46,155, AW Peg *AAp* 62,291, RT Per *ApSpSc* 47,277, 58,3, RW Per *AA* 28,207, RY Per *Trudy Kazan* 41,3, ST Per *AA* 26,15, AG Per *ApSpSc* 57,17, *BAAS* 10,410, DM Per *AAp Sup* 25,291, IZ Per *BAAS* 9,288, β Per *PASP* 87,745, *AJ* 81,57, 82,67, *ApSpSc* 47,459, 51,265, ζ Phe *AAp* 46,205, SZ Psc *AJ* 81,250, V Pup *AAp* 61,275,469, *AA* 28,63, AU Pup *ApJ* 222,917, KX Pup *AAp Sup* 22,263, NO Pup *AAp* 50,79, U Sge *PASP* 88,688, *ApSpSc* 47,361, 56,219, *AAp* 61,469, UU Sge *ApJ* 223,252, WZ Sge *ApJ* 219,168, V356 Sgr *AAp* 61,469, V1647 Sgr *AAp* 58,121, V523 Sco *PASP* 87,901, V701 Sco *AAp* 61,137, μ^1 Sco *AAp* 61,469, RZ Sct *PASP* 88,262, RW Tau *Izv Ehngelg* 41-42,196, *ApSpSc* 47,361, RZ Tau *Vistas* 21,359, CD Tau *AJ* 81,855, *ApSpSc* 40,15, V471 Tau *AAp* 46,197, λ Tau *AAp* 62,291, X Tri *AAp Sup* 23,439, *Byull Abastuman* 48,13, AQ Tuc *AAp Sup* 34,207, W UMa *Obs* 98,205, TX UMa *Villanova Contr* 1, *ApSpSc* 47,375, *AAp* 61,469, VV UMa *AAp Sup* 27,285, AW UMa *Vistas* 21,359, *ApSpSc* 56,219, *BAAS* 10,410, RT UMi *AAp Sup* 29,333, RU UMi *AA* 27,187, CV Vel *AAp* 58,131, EO Vel *AAp Sup* 22,263, AH Vir *Obs* 98,205, BF Vir *AA* 26,253, DL Vir *AAp* 61,107, Z Vul *AAp* 61,469, RS Vul *AAp* 61,469, BV845 *PASP* 90,97, HD 47732 *ApJ* 222,574, HD 77581 = Vel X-1 *Pis AZh* 1 No12,13, *ApJ* 202,L131, 226,264, *AAp* 54,167, HD 101799 *PASP* 88,936, HD 153919 = 3U 1700-37 *ApJ* 226,264, HD 159176 *BAAS* 7,533, HD 162724 *ApJ* 201,792, HD 173198 *IBVS* 1306, LB 3459 *MN* 183,523, PG 1413+01 *ApJ* 224,892, Sk 160 = SMC X-1 *ApJ* 204,551.

Table 3. Spectrographic Observations

ζ And *Izv Krym* 56,16, λ And *BAAS* 8,353, *PASP* 88,137, *Nature* 275,389, ν And *ApJ Sup* 36,241*, ο And *ApSpSc* 46,379, V599 Aql *Izv Krym* 58,56, V603 Aql *BAAS* 9,627, UX Ari *IBVS* 1075, *ApJ* 216,503, 225,919, *AJ* 83,795, *MN* 182,77, κ Ari *AAp Sup* 27,35, 35 Ari *ApJ Sup* 36,241*, EO Aur *ApJ* 220,L11, KR Aur *Pis AZh* 3,271,510, α Aur *Nature* 275,389, ε Aur *ApSpSc* 49,179, *Nature* 276,376, ζ Aur *ApSpSc* 36,273, TZ Boo *AAp Sup* 33,63, ZZ Boo *AAp Sup* 32,347*, α Cam *ApJ* 223,908, S Cnc *Obs* 96,9, RS CVn *AA* 26,301, *ApJ* 216,503, *MN* 182,77, TX CVn *AAp Sup* 34,211, UW CMa *ApJ* 208,760, EZ CMa *Af* 12,180, SX Cas *ApJ* 209,821, ξ Cas *ApJ Sup* 36,241*, ο Cas *ApJ Sup* 36,241*, β Cen *MN* 172,639, U Cep *ApJ* 209,821, 212,446, VV Cep *AAp* 46,317, 64,253, EM Cep *Izv Krym* 56,11, α CrB *ApSpSc* 46,379, SS Cyg *Af Issl* 8,3, *Nature* 275,385, V367 Cyg *ApSpSc* 53,345, V382 Cyg *ApJ* 220,L11, V389 Cyg *AAp* 68,437*, V453 Cyg *ApJ* 220,L11, V478 Cyg *ApJ* 220,L11, V1329 Cyg *Bamberg Ver* 121,383, V1341 Cyg = Cyg X-2 *Pis AZh* 2,534, *ApJ* 207,L171, V1357 Cyg = Cyg X-1 *ApJ* 213,815, *BAAS* 9,645, *Nature* 275,400, V1500 Cyg *PASP* 89,37, *ApJ* 207,L41, 211,184, 217,775, 224,899, *AAp* 56,181, 9 Cyg *AJ* 83,615*, 57 Cyg *ApJ Sup* 36,241*, AI Dra *AA* 28,41*, BY Dra *PASP* 89,69, CM Dra *AA* 28,167, α Equ *MN* 184,265*, δ Equ *JRASC* 71,408*, *PASP* 90,71*, YY Gem *PASP* 88,451, RS Gru *MN* 184,1, Z Her *MN* 182,77, AD Her *PASP* 90,312*, AM Her *ApJ* 212,L117, 218,L121, *PASP* 89,374, HZ Her = Her X-1 *AAp* 59,441, *ApJ* 209,547, 222,L33, *PASP* 89,285, *Nature* 275,400, V600 Her *AAp* 51,1, ι Her *ApJ Sup* 36,241, 88 Her *IBVS* 1496, TU Hor *AAp* 61,161, RT Lac *IBVS* 1130, AR Lac *PerZv* 19,377, 20,207, *Ts Shemak* 35,8,11, 36,11, *ApJ* 216,503,508, *MN* 182,77, 5 Lac *PASP* 90,184*, T LMi *PASJ* 29,289, FX Lib *AAp Sup* 34,51, δ Lib *ApJ* 221,608*, RR Lyn *Ann Tokyo* 16,1, β Lyr *Izv Pulkovo* 193,41, 194,18, *AZh* 52,710, *Ts Lvov* 51,20, *ApSpSc* 38,353, *ApJ* 206,777, 208,468, 210,853, *AAp* 50,335, *Af Issl* 9,3, *PASP* 88,899, *ATs* 966, *Izv Krym* 58,75, η Lyr *ApJ Sup* 36,241*, VV Mon *AAp Sup* 33,323*, V616 Mon *ApJ* 206,260, 211,872, 217,181, *AAp* 56,311, *MN* 180,657, U Oph *ApJ* 220,L11, Y Oph *PASP* 90,188*, κ Oph *ApJ Sup* 36,241*, BM Ori *PerZv* 20,361, δ Ori *Izv Krym* 54,128, η Ori A *ApSpSc* 46,379, θ^1 Ori A *IBVS* 1211*, ξ Ori *ApJ Sup* 36,241*, σ Ori E *ApJ* 205,L87, ψ Ori *ApJ Sup* 36,241*, 22 Ori *ApJ Sup* 36,241*, 64 Ori *BAAS* 9,623*, AG Peg *BAAS* 10,410, κ Peg *PASP* 89,857, X Per *PASP* 88,754, *MN* 176,233, 181,685, *Izv Krym* 57,45, *IBVS* 1461, LX Per *MN* 182,77, β Per *MN* 176,5P, *IBVS* 1312, *ApJ* 222,L119*, 20 Per *PASP* 90,297, AE Phe *AA* 28,49*, RR Pic *BAAS* 9,627, SZ Psc *MN* 182,77, V Pup *ApJ* 210,143, VV Pup *ApJ* 225,201, U Sge *ApJ* 209,821, 41 Sex A *AJ* 83,303*, V818 Sco = Sco X-1 *ApJ* 206,L49, *BAAS* 9,627, RY Sct *Bamberg Ver* 121,386, W Ser *IBVS* 1482, V711 Tau *AJ* 81,771*, 83,795, *ApJ* 225,919, *BAAS* 9,624, *Nature* 275,389, δ Tau *AJ* 82,176*, θ^1 Tau *AJ* 82,176, τ Tau *ApJ Sup* 36,241*, 51 Tau *BAAS* 9,600*, RR Tel *MN* 182,57P, RW Tri *BAAS* 9,556, α Tri *AA* 28,235*, γ^2 Vel *MN* 176,29P, *ApJ Sup* 36,217, α Vir *ApSpSc* 46,379, 1 Vul *ApJ Sup* 36,241*, 15 Vul *Obs* 97,2, HR 1034 *ApJ Sup* 36,241*, HR 1970 *Obs* 98,122*, HR 2013 *Obs* 96,54, HR 2172 *AAp Sup* 27,31, HR 2317 *Obs* 98,232*, HR 3080 *ApJ* 203,435, HR 4665 *BAAS* 10,419, HR 5049 *AAp* 58,93, HR 6388 *Obs* 98,14*, HR 6902 *AJ* 83,615*, HR 7083 *Obs* 97,235*, HD 698 *PASP* 90,179*, HD 5303 *IBVS* 1342, HD 28033 *AJ* 83,1114*, HD 30738 *AJ* 83,1114*, HD 47732 *ApJ* 222,570*, HD 50896 *ApJ Sup* 36,217, HD 67084 *PASP* 90,204*, HD 67198 *PASP* 90,204, HD 77581 = Vel X-1 *AAp Sup* 30,195*, *MittAG* 43,219, HD 92740 *ApJ Sup* 36,217, *AAp* 70,69, HD 135774-5 *AJ* 83,615*, HD 137569 *BAAS* 9,351*, HD 147508 *Obs* 98,47*, HD 150958 *ApJ* 225,165, HD 152270 *MittAG* 43,148, HD 153919 = 3U 1700-37 *AAp* 47,19, 56,433, 64,399*, *AAp Sup* 32,375, *ApJ* 217,L35, *Nature* 275,400, HD 155989 *Obs* 98,158*, HD 165052 *ApJ* 224,558*, HD 167771 *ApJ* 224,558*, HD 183030 *Obs* 98,118*, HD 187399 *Af* 12,623, HD 188753 *Obs* 98,122*, HD 190918 *JRASC* 71,407*, HD 204934 *Obs* 98,122*, HD 214419 *Kodaikanal Bull* 2,89, HDE 245770 *AAp* 56,311, *ApJ* 215,568, 223,530, BD +27°4642 *Izv Krym* 57,31, BD +24°692 *AJ* 83,1114*, BD -3°5357 *PASP* 89,616, BD -7°3007 *PASP* 89,716*, ADS 14893 B *ApJ* 205,194*, Feige 24 *ApJ* 223,260*, Gliese 815 *AJ* 83,1445*, Wray 977 = 3U 1223-62 *MittAG* 43,227*, G 61-29 *AA* 25,227, CRL 2104 *MN* 185,47, CRL 2179 *MN* 185,47, ω Cen V78 *BAAS* 10,411, NGC 1851 UV5 *AAp* 59,L23, SMC X-2 *ApJ* 223,L79, SMC X-3 *ApJ* 223,L79, LMC X-4 *AAp* 59,L9, *ApJ* 225,548*, 4U 1538-52 *ApJ* 225,L63, 3U 1728-24 *ApJ* 211,866.

(Rudy and Kemp, *ApJ* 221,200). These observations allow determinations of orbital inclinations (Rudy and Kemp, *ApJ* 221,200; McLean, *Obs* 98,205). Tapia (*ApJ* 212,L125) made the exciting discovery that the radiation from AM Her exhibited high linear and circular polarization in the *V* and *B* wave-length bands, indicating a magnetic field of about 2×10^8 gauss for the white-dwarf component. Further observations were published by Michalsky *et al.* (*ApJ* 216,L35), Stockman *et al.* (*ApJ* 217,815), Bailey *et al.* (*MN* 183,73P), and Priedhorsky *et al.* (*ApJ* 225,542). Similar polarization properties were found for AN UMa (Krzeminski and Serkowski, *ApJ* 216,L45; Downes and Urbanski, *PASP* 90,458) and for VV Pup (Tapia, *IAUC* 3054). In a search for other "polars", Vojkhanskaya *et al.* (*Pis AZh* 4,272) picked out MV Lyr as a promising candidate. X-ray binaries with harder spectra than AM Her show only weak intrinsic polarization in the optical region. For Cyg X-1 Michalsky and Swedlund (*ApJ* 212,221) reported slight variations of the circular polarization synchronous with the orbital period, 5.6 d, but this periodicity was not apparent in 1977 (Michalsky *et al.*, *ApJ* 225,599). For the linear polarization Kemp *et al.* found a period of 39.2 d from UV-data (*Nature* 270,227) and, from an extensive set of observations, orbital synchronism at long wave-lenghts (*ApJ* 220,L123). Long-term variations are probably present.

D. X-ray Observations (Y. Kondo)

X-ray satellites that have been operational during the triennium and used for observations of close binaries are listed below (with launch dates and experimenters):

Copernicus	1972	University College London
Ariel-5 (UK-5)	1974	Mullard Space Sci. Lab., Univ. of Leicester, Imperial College, Goddard Space Flt. Ctr., Appleton Lab.
SAS-3	1975	M.I.T.
OSO-8	1975	Columbia Univ., Goddard Space Flt. Ctr., Lockhead, Univ. of Wisconsin
HEAO-1	1977	Goddard Space Flt. Ctr., C.I.T., Univ. of Calif. Berkeley, Naval Res. Lab., Ctr. for Astrophysics, M.I.T., Univ. of Calif. San Diego
HEAO-2	1978	Goddard Space Flt. Ctr., Ctr for Astrophysics, M.I.T., Columbia Univ.

In addition, rocket experiments were flown to observe selected X-ray binaries, *e.g.* by Boldt and co-workers. Balloon-borne experiments also produced interesting new results, *e.g.*, Trümper and co-workers.

Some 40 galactic X-ray sources have now been identified with optical counterparts, the great majority being close binaries. An informative review on positions and identifications was given by Bradt *et al.* at the COSPAR/IAU Symposium on X-ray Astronomy, held at Innsbruck 1978. Reference may also be made to the series of letters to *Nature* (269,112, 270,586, 271,225, 272,701, 273,364) by the SAS-3 team. As the number of optical identifications increases, it is possible to segregate different classes of objects. One classification scheme is the following:

A. Sources comprising compact object (white dwarf, neutron star, black hole) and early-type star (often supergiants). Examples: SMC X-1, Vel X-1, Cen X-3, Cyg X-1, V861 Sco, 4U 1700-37.
B. Compact object with late-type companion: HZ Her, AM Her, Sco X-1, Cyg X-3.
C. Dwarf novae: SS Cyg, U Gem, EX Hya.
D. RS CVn systems: V711 Tau, UX Ari, RS CVn.
E. Other transient X-ray sources - novae, X-ray novae, etc.: V616 Mon, A 0535+26.
F. Other binaries identified as X-ray sources: Algol, Sirius, Capella, γ Cas.
G. X-ray bursters: Several bursters have been identified with stellar objects, making close-binary models most probable. Many bursters appear associated with globular clusters.

There are additional optically identified objects that can be fitted into some of these categories; the ones above are merely examples. As more optical identifications are made, additional classes of sources may be found. Of course, a variety of other classification schemes are possible.

Publications on X-ray emitting binaries are very numerous, and only some few items can be mentioned within the limited space available. New binary orbits from pulse-phase data were determined for Cen X-3 (Fabbiano and Schreier, *ApJ* 214,235), Vel X-1 (Rappaport *et al.*, *ApJ* 206,L103; Charles *et al.*, *MN* 183,813), SMC X-1 (Primini *et al.*, *ApJ* 210,L71, 217,543), 4U 0115+63 (Rappaport *et al.*, *ApJ* 224,L1), 3U 1223-62 (White *et al.*, *MN* 184,67P), and 3U 1538-52 (Davison *et al.*, *MN* 181,73P). Trümper and his co-workers (*ApJ* 219,L105) discovered in the spectrum of Her X-1 a line feature at about 58 keV, interpreted as cyclotron emission. Iron lines are reported by many groups in the spectra of several X-ray binaries. Observations of the γ-ray flux from Cyg X-3 were discussed by Vladimirsky *et al.* (*Izv Krym* 58,44).

E. Radio Observations (D.M. Gibson)

Radio surveys of binaries from one or more of the classes below were reported by Altenhoff *et al.* (*AAp* 46,11), Feldman (*BAAS* 10,418), Gibson (Thesis, UVa), Owen and Gibson (*AJ* Dec. 1978), Spangler *et al.* (*AJ* 82,989), Woodsworth and Hughes (*AAp* 58,105), and Wright and Allen (*MN* 184,893).

RS CVn and related binaries. Detected RS CVn systems include UX Ari, RT Lac, AR Lac, SZ Psc, TY Pyx (probable), V711 Tau (HR 1099), HD 224085 (Owen and Gibson, *AJ* Dec. 1978), and HR 5110 (Feldman, pri. com.). Emission from the related long-period systems λ And (Bath and Wallerstein, *PASP* 88,759), and σ Gem, σ CrB, HD 216489, and the short-period system UV Psc (Spangler *et al.*, *AJ* 82,989) was also reported. Algol and b Per can probably be regarded as similar objects. The above sources are highly variable - from about 10^{16} to 10^{19} erg s^{-1} Hz^{-1} (Gibson *et al.*, *AJ* Dec. 1978; Feldman *et al.*, *AJ* Dec. 1978; Gibson *et al.*, *PASP* Nov. 1978) - as befits their compact size (few $R_\odot$; Clark *et al.*, *ApJ* 206,L107; Owen and Spangler, *ApJ* 217,L41). The gyrosynchrotron emission (Owen *et al.*, *ApJ* 210,L27) arises just beyond the X-ray coronae (Gibson *et al.*, *AJ* Dec. 1978), and thus their spectra can be affected by either self-absorption (Owen *et al.*, *ApJ* 210,L27) or thermal absorption (Spangler, *AJ* 82,169). The circular polarization can be quite large (74%; Mutel and Weisberg, *AJ* Dec. 1978) and has been observed to be rapidly variable (Brown and Crane, *AJ* Dec. 1978). The emission is associated with "super solar-flare" phenomena intrinsic to one of the late-type (subgiant) components (Weiler *et al.*, *ApJ* 225,919), *not* with mass exchange. However, binarity - particularly faster rotation, larger differential rotation, and smaller surface gravity relative to single stars (Hall and Shore, *BAAS* 10,418) - seems to enhance their radio emissivity relative to their single counterparts (Gibson, *BAAS* 9,600).

X-ray/radio binaries. Continued observations of Cyg X-1 (Hjellming and Gibson, in prep.), including some correlated with X-ray bursts (Hjellming, *X-ray Binaries*, NASA SP-389, p. 495; Braes and Miley, *Nature* 264,731), now indicate the emission is non-thermal, but the spectrum is probably affected by the O-star's wind (Johnson *et al.*, in prep.). Hjellming and Helfand (in prep.) and Hjellming (*ApJ* 221,225) reconfirmed the identifications of Cyg X-2 and GX 17+2 with G-type stars. Further observations of Cyg X-3 (McEllin, *MN* 175,5P; Mason *et al.*, *ApJ* 207,78; Ledden *et al.*, *Nature* 252,669) were useful in determining conditions in the emission region both during outbursts (Seaquist, *ApJ* 207,88; Shields and Wheeler, *ApL* 17,69; Woodsworth and Hughes, *ApJ* 208,863) and quiscent periods (Seaquist and Gregory, *ApL* 18,65). Several new types of X-ray/radio binaries were detected, including the highly unusual counterpart to Cir X-1 (Whelan *et al.*, *MN* 181,259; Thomas *et al.*, *MN* 185,29P). Non-thermal radio counterparts to the transient sources A 0620-00 (Owen *et al.*, *ApJ* 203,L15; Little *et al.*, *Nature* 261,113) and one near the galactic centre (Davies *et al.*, *Nature* 261,476) were also detected. The controversy over the nature of the globular-cluster transients (*cf.*, Smith, *Nature* 261,453) or whether they have even been detected at radio frequencies (Johnson, *ApJ* 208,706) remains unresolved.

Novae. While radio emission from V1500 Cyg was apparently weak and short-lived (Pynzar *et al.*, *ATs* 893; Altunin, *Pis AZh* 2,299; Hjellming, *Bamberg Ver* 121,279), emission from FH Ser and HR Del is still being monitored (Hjellming and Vandenberg, in prep.). A thick inhomogeneous shell model for FH Ser was developed by Seaquist and Palimaka (*ApJ* 217,781).

Wolf-Rayet binaries and symbiotic stars. Variable thermal emission from WR-binaries was detected (Florkowski and Gottesman, *IBVS* 1101), with γ^2 Vel (Seaquist, *ApJ* 203,L35) and HD 193793 (Florkowski and Gottesman, *MN* 179,105) receiving continuing monitoring, the latter in conjunction with a recent IR-outburst. Variable thermal emission associated with recent outbusts was monitored for the symbiotic objects V1016 Cyg (FitzGerald *et al.*, *BAAS* 8,372), AG Peg (Gregory *et al.*, *ApJ* 211,429), and HM Sge (Feldman, *JRASC* 71,386).

Monitoring of the thermal-type, compact stellar-wind binaries CC Cas and β Lyr continued (Gibson and Newell, in prep.). Monitoring of α Sco resulted in detection of both A and B components (Gibson, in prep.). The latter's spectrum, while non-thermal, is varying, which suggests it is either a coherent emitter or has an unusual particle-acceleration mechanism. Observations of the binary pulsar, PSR 1913+16, continued; a recent progress report was given by Fowler and Taylor (*BAAS* 10,447).

5. Physical Data

A. Absolute Dimensions (T. Herczeg)

New determinations of absolute dimensions are listed in Table 4. A novel feature here is the fairly extensive rediscussion of earlier light-curves by applying modern programs of analysis and then using existing spectrographic data to obtain revised absolute dimensions. A considerable part of this work was done by Cester and his collaborators with Wood's WINK program. Leung, Schneider, and Wilson, in several papers, systematically rediscussed the "W UMa-like" light-curves of early, massive contact (or near-contact) systems. Here the Russell-Merrill method is clearly inadequate; they used the Wilson-Devinney code and found in several cases various degrees of over-contact between the components.

B. Period Changes (T. Herczeg)

Some few theoretical investigations continued the work toward establishing a relationship between period changes and the modes and rates of mass transfer and mass loss (Amnuel and Guseinov, *AAp* 54,23; Chau, *ApJ* 219,1038; Mukhametkalieva and Omarov, *Trudy Alma-Ata* 28,24; Piotrowski and Ziolkowski, *AA* 28,295). Several detailed evolutionary studies touched upon period changes in connection with the time scales involved. In general, however, we are still rather far from being able to use observed period changes as checks on evolution theories. One reason may be the apparently erratic behaviour of the periods, short-term fluctuations exhibited by a surprising number of systems. Also, the time scale is in most cases perhaps too long for the only 30 - 40 years of more systematic and accurate observations, with the possible exception of a few objects in rapid evolution, such as β Lyr and SV Cen. This, of course, emphasizes the importance of collecting as many well-defined minimum epochs as possible, for the benefit of future studies.

At IAU Colloquium 42, Kreiner (*Bamberg Ver* 121,393) reviewed period changes of W UMa stars, and Smak (*Bamberg Ver* 121,365) discussed secular mass-loss and period changes of cataclysmic variables. Of the many individual systems observed and discussed during the triennium, only a few particularly interesting ones will be mentioned. In the case of XY UMa, Geyer (*ApSpSc* 48,137) demonstrated the occurrence of spurious changes due to light-curve anomalies. Hall *et al.*, *AJ* 81,1138) discussed the "migrating wave" in the light curve of AR Lac and its relation to observed period changes; they concluded that although a correlation exists, the period changes are almost certainly real. Other studies of AR Lac are by Babaev (*Izv AN AzSSR* 4,3), Chambliss (*PASP* 88,762), and Theokas (*ApSpSc* 52,213). A detailed study of U Oph by

Table 4. Absolute Dimensions

RT And *AAp Sup* 32,351, V805 Aql *AAp Sup* 32,351, σ Aql *AAp Sup* 33,91, TT Aur *AAp Sup* 33,91, WW Aur *BAAS* 7,463, *AAp Sup* 33,91, AR Aur *AAp Sup* 33,91, IU Aur *AAp* 59,9, LY Aur *AAp* 62,291, ε Aur *AAp* 69,23, ZZ Boo *AAp Sup* 32,347, 33,91, WX Cep *AAp Sup* 32,351, AH Cep *AAp Sup* 33,91, CW Cep *AAp Sup* 33,91, EI Cep *AAp Sup* 32,351, SZ Cam *ApSpSc* 36,329, AS Cam *ApSpSc* 38,87, RZ Cnc *ApJ* 208,142, *AAp* 61,469, UX CVn *AAp* 70,451, UW CMa *PASP* 89,668, *ApJ* 220,582, 222,924, *MN* 185,485, RZ Cas *PASP* 88,22, TV Cas *ATs* 881, *BAC* 28,41, AO Cas *ApJ* 223,202, AZ Cas *PASP* 89,882, V523 Cas *ATs* 873, SV Cen *PASP* 88,244, *MN* 176,625, SZ Cen *AAp* 45,203, 55,401, BH Cen *ApJ* 211,844, U Cep *AAp* 61,469, VV Cep *JRASC* 71,152, CW Cep *AAp Sup* 25,151, EI Cep *Ann Tokyo* 16,37, EK Cep *ATs* 971, ER Cep *MN* 184,33, ξ Cep *PASP* 88,944, XY Cet *ApSpSc* 38,79, 56,293, 13 Cet *PASP* 88,50, RS Cha *AAp* 44,445, RZ Cha *AAp* 44,343,349, CC Com *PASP* 89,684, U CrB *AAp* 61,469, MR Cyg *AAp* 66,161, *AAp Sup* 33,91, MY Cyg *BAC* 27,125, V382 Cyg *AAp Sup* 33,91, V444 Cyg *ApJ* 221,193, V453 Cyg *AAp Sup* 33,91, V729 Cyg *ApJ* 224,565, V1073 Cyg *ApJ* 222,917, AI Dra *AA* 28,41, CM Dra *ApJ* 218,444, δ Equ *PASP* 90,71, AS Eri *AAp* 62,291, CW Eri *MittAG* 38,231, U Gem *AA* 26,277, YY Gem *AJ* 83,618, RX Her *AAp Sup* 33,91, TX Her *AAp Sup* 32,351, AD Her *PASP* 90,312, HZ Her = Her X-1 *ApJ* 208,567, 215,L21, V600 Her *AAp* 51,1, u Her *AAp* 61,469, 66,161, VZ Hya *ApSpSc* 35,249, *AAp Sup* 32,351, HS Hya *AAp* 42,303, χ^2 Hya *AAp* 44,445, 67,15, AR Lac *Ts Shemak* 44,3, *PASP* 88,762, CM Lac *AAp Sup* 32,351, UV Leo *AAp Sup* 32,351, XY Leo *AJ* 83,1452, T LMi *PASJ* 29,289, δ Lib *ApJ* 221,608, RR Lyn *Ann Tokyo* 16,1, SW Lyn *BAC* 28,120, β Lyr *AZh* 52,710, *Izv Pulkovo* 195,98, *ApSpSc* 41,121, UX Men *AAp* 48,49, TU Mon *AAp* 61,469, VV Mon *AAp Sup* 33,323, AO Mon *ApSpSc* 40,3, AR Mon *ApJ* 208,142, IM Mon *AAp Sup* 33,91, V616 Mon *AAp* 50,445, TU Mus *AAp* 45,107, U Oph *AAp Sup* 33,91, WZ Oph *AAp Sup* 32,351, V1010 Oph *ApJ* 211,853, VV Ori *AAp Sup* 33,91, BM Ori *ApJ* 205,462, AG Peg *ApJ* 201,404, AW Peg *AAp* 62,291, X Per *AAp* 54,817, RT Per *ApSpSc* 47,277, β Per *PASP* 87,745, *AJ* 80,836, *ApJ* 222,L119, ϕ Per *ApSpSc* 39,495, b Per *ApJ* 208,152, ζ Phe *AAp* 46,205, SZ Psc *AJ* 81,250, V Pup *AAp* 61,275,469, U Sge *PASP* 88,688, *AAp* 61,469, UU Sge *ApJ* 223,252, WZ Sge *ApJ* 219,168, V356 Sgr *AAp* 61,469, V523 Sco *PASP* 87,901, V818 Sco = Sco X-1 *ApJ* 207,907, μ^1 Sco *AAp* 61,469, RY Sct *PASP* 88,456, RZ Sct *PASP* 88,262, CV Ser *Af* 11,49, CD Tau *ApSpSc* 40,15, *AJ* 81,855, V471 Tau *AAp* 46,197, V711 Tau *AJ* 81,771, λ Tau *AAp* 62,291, X Tri *Byull Abastuman* 48,13, TX UMa *AAp* 61,469, VV UMa *AAp Sup* 27,285, CV Vel *AAp* 44,355, 58,131, BF Vir *AA* 26,253, DL Vir *AAp* 61,107, Z Vul *AAp* 61,469, RS Vul *AAp* 61,469, HD 698 *PASP* 90,179, HD 47732 *ApJ* 222,574, HD 77581 = Vel X-1 *ApJ* 202,L131, 206,L103, *Pis AZh* 1 No12,13, HD 93205 *ApJ* 207,502, HD 101799 *PASP* 88,936, HD 159176 *BAAS* 7,533, HD 160861 *AAp Sup* 23,277, HD 162724 *ApJ* 201,792, HD 165052 *ApJ* 224,558, HD 167771 *ApJ* 224,558, HD 173198 *IBVS* 1306, HDE 228766 *ApJ* 218,431, BD -3°5357 *PASP* 89,616, Gliese 815 *AJ* 83,1445, PG 1413+01 *ApJ* 224,892, Sk 160 = SMC X-1 *MN* 174,29, *ApJ* 210,L71, 217,186,543, LMC X-4 *ApJ* 225,548, 4U 1538-52 *ApJ* 225,L63.

Koch and Koegler (*ApJ* 214,423) illustrated the complicated nature of this system and the great difficulties in its interpretation. For SV Cam, Hilditch reports supporting evidence for a third body with $P \approx 64$ y, while for the white-dwarf binary V471 Tau, Oliver and Rucinski (*IBVS* 1444) brought strong arguments against light-time interpretation. A somewhat similar case may be UX UMa, discussed by Quigley and Africano (*PASP* 90,445); here some doubt was already cast on the triple-system interpretation by Kukarkin (*MN* 180,5P). The system is of great interest, because the period changes are markedly different from those of any other star of this class.

C. Apsidal Motion (T. Herczeg)

Several important studies concentrated on the somewhat neglected topic of relativistic periastron advance. A programme of systematic observations of five eccentric systems with relatively long periods, EK Cyg, α CrB, V1143 Cyg, DI Her, and RR Lyn, is being carried out by Koch (*AJ* 82,653). DI Her was also studied by Martynov and

Khalioullin; they report a marked discrepancy between observed and theoretically predicted rates of relativistic apsidal motion. Koch's value is apparently much closer to theoretical prediction; however, he does not consider the observed magnitude of the effect statistically significant, as yet. V1143 Cyg is also observed by Ebbighausen. Among the cases of "classical" apsidal motion, Y Cyg was discussed by O'Connell (*RicA* 8,543), including results of the Commission campaign, V477 Cyg and DR Vul were re-examined by Todoran (*AA* 27,59). Apsidal motion was detected for the systems KX Pup and GM Nor (Söderhjelm, *AAp Sup* 22,263) and for V1647 Sgr (Clausen *et al.*, *AAp* 58,121). Several X-ray binaries were considered (Tanzi and Treves, *AAp* 60,431), and for X Per, apsidal motion was discussed as possible explanation of the 581-d periodicity (Henrichs and van den Heuvel, *AAp* 54,817). Theoretical apsidal-motion coefficients were calculated by Vila (*ApJ* 213,464) for highly evolved objects, such as helium main-sequence and pre-white-dwarf stars.

D. Proximity Effects and Limb Darkening (M. Kitamura)

Considerable work was directed towards the theoretical study of tides and related problems. Seguin (*ApJ* 207,848) investigated the effects of tidal distortion on the stability of components against development of turbulence and convection. Horedt (*AAp* 44,461) studied synchronization of rotation, and Press *et al.*, *ApJ* 202,L135) circularization of orbits as well, due to tidally induced turbulence. In a comprehensive study, Zahn (*AAp* 41,329) dealt with the dynamical tide produced by non-adiabatic oscillations of components in the rotating gravitational field. For stars with convective envelopes, Zahn (*AAp* 57,383) found that the most efficient tidal-friction mechanism is turbulent viscosity retarding the equilibrium tide, while for radiative envelopes the action of radiative damping on the dynamical tide is most efficient. Effects of tidal distortion on velocity curves and ellipsoidal light-variations were considered by Wilson and Sofia (*ApJ* 203,182) for extreme mass-ratios. Gravity-darkening of W UMa stars was discussed by Ivanov (*PerZv* 20,99). Eaton (*BAAS* 9,433) noted that not all stars with radiative envelopes obey the von Zeipel law.

Perrenod (*ApJ* 206,876) and Efremov *et al.* (*PerZv* 19,407), among others, discussed reflection effects in X-ray binaries. With an application to the bolometric effect in W UMa stars, Pustylnik (*AA* 27,251) studied non-radial energy transport. Kirbiyik and Smith (*MN* 176,103) modeled circulation currents in irradiated atmospheres; Budding and Ardabili (*ApSpSc* 59,19) gave a generalized approach to evaluation of the reflection effect.

Lavrov derived linear limb-darkening coefficients for nine systems (*ATs* 971) and non-linear coefficients for four systems (*ATs* 990). Discussing the limb-darkening law, Rubashevsky (*AmAf* 27,94) found a two-parameter representation as best approximation. Theoretical limb-darkening coefficients were computed by Al-Naimiy (*ApSpSc* 53,181) for wide ranges of T, g, and λ, and by Manduca *et al.* (*AAp* 61,809), who give *UBV* and *uvby* coefficients for late-type giants.

E. Atmospheric Abundances (M. Kitamura)

Determinations of chemical abundances for double-line binaries were made by several investigators. Heacox (*BAAS* 8,522) reported LTE analyses for components of the Hg-Mn type, including 49 Dra and 66 Eri. The system δ Del, consisting of two nearly identical δ Sct variables, was analysed in detail by Reimers (*AAp* 53,377), who concluded that both components are hybrids between Am and δ Sct stars. Kitamura *et al.* (*Ann Tokyo* 16,22) found intensity variations for characteristic lines of WW Aur during eclipses, indicating that the distribution of metallic-line features is non-uniform over the surface of either component of this Am binary. κ Ari, also with two Am components, was analysed by Mitton (*ApA Sup* 27,35). Naftilan (*ApJ* 206,785) found mild metal deficiency for the secondary of U Sge, abundances relative to iron resemble those of Am stars. Contrary to this, Parthasarathy *et al.* (preprint) report quite normal abundances in U Cep B. More data on abundances in Algol-type secondaries are expected from this Texas group and from Plavec. In AR Lac, Naftilan and Drake (*ApJ* 216,508) found the secondary show high chromospheric activity (strong H and K emission) and be under-abundant in most metals, while the primary has solar-type abundances. Fine-analysis of the F-component of ε Aur (Castelli, *AAp* 69,23) gave normal abundances. From spectrophotometry and model-atmosphere calculations, Leushin *et al.* (*Af Issl* 9,3) found for the visible component of β Lyr the value 1.55 for the He/H number-ratio. The Copenhagen group derived He abundances for a number of systems, by combining *uvby* photometry with stellar-model calculations (*e.g.*, Jørgensen and Gyldenkerne, *AAp* 44,343). Model atmospheres, illuminated from a companion star, were computed by Muthsam (*AA* 28,281).

F. Circumstellar Matter (M. Kitamura)

Observational evidence for circumstellar matter: gaseous disks or rings, streams between components, expanding shells, stellar-wind outflow, etc., continued to increase. In addition to all kind of optical observations, important contributions came from X-ray, satellite UV, and radio data. Thus, for instance, observations with the Copernicus satellite confirmed the existance of a gas stream flowing from Algol B in the direction of A (Cugier and Chen, *ApSpSc* 52,169), detected mass-flow in UW CMa (McCluskey and Kondo, *ApJ* 208,760), a stationary H II-region around V Pup (York *et al.*, *ApJ* 210,143), and variations in the stellar wind from δ Ori A (Snow and Hayes, *ApJ* 226,897). Among optical results we note studies of gas expanding from ζ Aur and 31 Cyg (Saito and Kawabata, *ApSpSc* 45,63), evidence for an expanding shell around δ Ori (Galkina, *Izv Krym* 54,128), and IR-photometry indicating that a thin shell of graphite grains condensed around the WR binary HD 193793 (Williams *et al.*, *MN* 185,467).

Wu (*ApSpSc* 36,407) proposed that double-component emission lines in RW Tau and other binaries primarily originate from gas accumulated at the Lagrangian triangular points. Profiles of lines from disks or rings around one component are computed by Kříž (*BAC* 30, in press), using a refined theory. Nariai (*PASJ* 28,587) studied circulation currents in the common envelope of a contact binary, taking energy transfer into account. Stability against mass overflow in contact binaries was discussed by Nariai and Sugimoto (*PASJ* 28,593); they showed that a binary filling the outer Roche-lobe should be unstable against mass loss through L_2. Particle motions from L_2 were calculated by Nariai (*PASJ* 29,263). The interaction with the environment of gas outflowing from young W UMa-stars was studied by Van't Veer (*Bamberg Ver* 121,388). Particle mechanics was used by Angeletti (*ApSpSc* 44,23) and by Piotrowski and Ziolkowski (*AA* 28,295) to elucidate gas flow in semi-detached binaries. The vertical structure of the flow was studied hydrodynamically by Lubow and Shu (*ApJ* 207,L53). Opaque rings or disks, pictured to surround one component of unusual binaries, such as β Lyr, were approximated by Wilson (*AJ* 80,719) with a torus having elliptical meridian-sections. This geometry for the eclipsing body was used with success to explain the light curve of V356 Sgr (Wilson and Caldwell, *ApJ* 221,917). Apsidal motion of rings was treated by Castle (*PASP* 89,862).

The properties of accretion disks, formed around components with small radii, were discussed in a large number of studies, only some of which can be mentioned. Warner (*Obs* 96,49) reviewed relevant observations. Theoretical studies of gas flow leading to formation of disks were made by Flannery (*ApJ* 201,661), Lin and Pringle (*IAU Symp* 73,237), Shu (*IAU Symp* 73,253). Models were discussed by Paczynski (*ApJ* 216,822, *AA* 28,91,241), Paczynski and Jaroszynski (*AA* 28,111), and Tylenda (*AA* 27,235); theoretical *UBV* colours were computed by Schwarzenberg-Czerny and Rozyczka (*AA* 27,429). Among papers treating structure and stability of disks, we mention Lin (*Obs* 98,208), Livio and Shaviv (*AAp* 55,95), Paczynski (*AA* 28,253), Papaloizou and Pringle (*MN* 181,441), Piran (*ApJ* 221,652), Pringle (*MN* 177,65), Kato (*MN* 185,629), Shakura *et al.* (*AAp* 62,179), Shulikowskij (*Pis AZh* 4,134), Stewart (*AAp* 42,95, 49,39), Stoeger (*MN* 182,647), Weber (*BAAS* 9,632). Accretion onto stars was discussed by Inoue (*PASJ* 28,293), Kippenhahn and Thomas (*AAp* 63,265), Neo *et al.* (*PASJ* 29,249), Nomoto *et al.* (preprint), Ulrich and Burger (*ApJ* 206,509). Of the many papers dealing with disk accretion onto magnetic neutron stars and black holes, we quote a few: Aarons and Lea (*ApJ* 207,914), Bisnovatyi-Kogan and Blinnikov (*AAp* 59,111), Ghosh *et al.* (*ApJ* 217,578), Lamb *et al.* (*ApJ* 224,969, 225,582), Liang (*ApJ* 218,243), Mytrophanov and Tsygan (*AAp* 70,133), Petterson (*ApJ* 214,550, 216,827, 226,253), Shakura and Sunyaev (*MN* 175,613).

6. Structure and Models of Close Binaries

A. Early-Type Systems

The structure of the extended atmospheres of Wolf-Rayet stars was studied using eclipses of especially V444 Cyg (Khaliullin and Cherepashchuk, *Af* 11,593; Limber and Corbin, *BAAS* 9,305; Hartmann, *ApJ* 221,193). Hartmann found that the stellar wind from the WN5 component expands at a nearly constant velocity deep in the atmosphere, in contrast to theories of O-star winds driven by radiation pressure in the lines. An extensive set of UV observations, including three WC+O binaries, were obtained with the TD-1 satellite and analysed in terms of model atmospheres (Willis and Wilson, *MN* 182,559). Ultraviolet variability was discussed by Burton *et al.* (*MN* 183,605). Spectrophotometry of γ^2 Vel by Moffat (*AAp* 57,151) revealed variations with time-scales 13 - 19 d of certain emission features. Schild and Liller (*ApJ* 199,432) found no eclipses in CV Ser. Cherepashchuk (*Pis AZh* 2,356) and Prilutskii and Usov (*AZh* 53,6) drew attention to WR-binaries as potential X-ray sources.

Among the O-type binaries, especially UW CMa has been the subject of several studies (Hutchings, *PASP* 89,668; Eaton, *ApJ* 220,582; Leung and Schneider, *ApJ* 222,924; Parthasarathy, *MN* 185,485). Eaton, using OAO light-curves, found a surprisingly sharp limb for the Of primary, while the expanding low-density region above is uniform. All three photometric studies agree in that the primary fills or over-flows its Roche-lobe. Leung and Schneider found UW CMa a system in over-contact with mass-ratio m_2/m_1 less than unity, contrary to Hutchings' spectrographic data; the masses suggested are 46 and 34 $M_\odot$. For V729 Cyg, Leung and Schneider (*ApJ* 224,565) found the same degree of over-contact (about 30%) and about 60 $M_\odot$ for the primary mass, making it one of the most massive stars known. Bohannan and Conti (*ApJ* 204,797) suggest this system is on the way becoming a WR-binary. For AO Cas, a third evolved system, only small over-contact was found and masses 25 and 29 $M_\odot$ (Schneider and Leung, *ApJ* 223,202). Another system of somewhat later type but thought to be very massive, *viz.* RY Sct, was discussed preliminarily by Ciatti *et al.* (*Bamberg Ver* 121,386). IU Aur, for which Mayer (*BAC* 27,308) found the eclipse depths increasing, was studied by Eaton (*AA* 28,63). The depths of minima continue to increase, and the only realistic explanation is a change of orbital inclination due to perturbations from the third body. Nakamura *et al.* (preprint) computed an evolutionary sequence for SV Cen. The rate of mass transfer for this contact system is believed to be 4×10^{-4} $M_\odot$/y, which may be 50 times higher than in β Lyr. Numerous studies were made of β Lyr itself, some of which have been mentioned earlier in this Report. Huang and Brown completed their investigations with three papers (*ApJ* 208,780, 218,461, 222,627). The emission spectrum in satellite UV was interpreted by Hack *et al.* (*ApJ Sup* 34,565) and Kondo *et al.* (*ApJ* 208,468) in terms of a "super-corona" concentrated towards the invisible component but enveloping the whole system. While the possibility that the secondary component is a black hole must still be seriously considered, Jameson and King (*AAp* 63,285) from radio observations argued strongly in favour of a B-star. β Lyr was believed to be a unique object for its UV spectrum, but Plavec and Koch (*IBVS* 1482) discovered quite similar spectra in W Ser and some other early-type systems.

We end with a few notes on various kinds of other early-type objects. Several β Cep stars are confirmed binaries; for a recent review, see Lesh and Aizenman *Ann Rev AAp* 16,215. For one of these binaries, α Vir, the pulsation has decreased so that it is now almost undetectable (Lomb, *MN* 185,325). LB 3459, a foreground star in the LMC field, has been shown (Kilkenny *et al.* (*MN* 183,523) to be a short-period eclipsing system of two O-type sub-dwarfs. UU Sge, central star of a faint planetary nebula (Bond, *PASP* 88,192) was confirmed to be an eclipsing binary (Miller *et al.*, *IAUC* 2974; Tsessevich, *IBVS* 1320). Méndez and Niemela report velocity variations for the central stars of the planetaries NGC 1360 and 2346, indicating that also these objects are close binaries.

B. Algols and Related Systems (M. Plavec)

Significant progress was accomplished in accumulation of important observational data on semi-detached binaries. The concept of "R CMa systems" (both components grossly undermassive for their luminosities), although almost certainly quite fallacious, continued to stimulate observers to efforts to eliminate the few remaining members of this spurious group. Okazaki (*PASJ* 29,289) found that T LMi is an ordinary Algol-system with a normal main-sequence primary. Very important is RZ Sct, studied by Wilcken *et al.* (*PASP* 88,262); here the primary is a B2 II giant. Most important for confrontation with evolutionary calculations are systems where masses of both components can be determined directly from the radial-velocity curves. Most new results come from Popper, using the Varo image-tube at Lick to observe the D-lines of the secondaries; he will soon have complete orbits for the secondaries in 12 new systems. Peculiar is the secondary of the pre-main-sequence system BM Ori in the Trapezium (Popper and Plavec, *ApJ* 205,462): it appears to be the first observed star to be greatly flattened by differential rotation. While the velocity curves of the secondaries now become increasingly more accessible, some of the primaries are found to give very poor curves. It appears that a circumstellar shell and/or a stream distort the line profiles more or less seriously. Very distorted are S Cnc, AW Peg, TT Hya, RY Per, moderate cases are RY Gem, AD Her, AU Mon, XX Pup, while TW And, TW Dra, RS Vul probably have good photospheric spectra (after Popper). The eccentric orbit of AD Her reported by Batten and Fletcher (*PASP* 90,312) may be a test case. On the photometric side, Walter reports indications of gas streams and polar-region hot-spots in RW Ara (*AAp Sup* 26,227), X Gru (*AAp Sup* 29,51), TW Dra (*AAp Sup* 32,57), and XZ Sgr. He also found long-period variations of light curves for TV Cas and U Cep and interprets them as precession (*AAp* 42,135, 69,437).

Ultraviolet excesses in U Cep, U Sge, SX Cas, and several RS CVn systems were studied by Rhombs and Fix (*ApJ* 209,821, 212,446, 216,503) with spectrum scanner. They suggest the excess is due to free-free and bound-free emission associated with the hotter component in the Algols; however, in the RS CVn stars, the excess seems to be associated with the cooler sub-giant. Rucinski observed the spectrum of Algol with the Copernicus satellite and found that the primary rotates as a solid body and in synchronism with orbital motion. Prilutskij *et al.* (*Pis AZh* 2,294) explained the X-ray emission of Algol in terms of an emitting hot spot formed at the surface of the primary by an impinging gas jet.

The idea that at least some Be-stars may be interacting binaries was further followed mainly at Ondřejov. Harmanec *et al.* announced the binary nature of 4 Her (*BAC* 27,47), found a period of 87 d in 88 Her (*BAC* 29,278), and 39 d in HD 218393. Periodicity and duplicity of o And remain controversial (Fracassini *et al.*, *ApSpSc* 49,145; Harmanec *et al.*, *IBVS* 1296). Binary nature of the periodic shell star HR 2142 was confirmed by Peters.

Sub-giant systems with H and K emission, more often called RS CVn stars, received broad attention. They appear to evolve from normal main-sequence systems with components of nearly equal mass. Only low rates of mass loss and/or mass transfer are probably required. The many instabilities appear to develop as the components cross the Hertzsprung gap (Popper and Ulrich, *ApJ* 212,L131). Weiler (*MN* 182,77) suggests, from a survey of H, K, and Hα emissions, an extensive chromospheric activity on the later-type component. Naftilan and Drake (*ApJ* 216,508) add to it a disk or shell surrounding the secondary in AR Lac. Related to the RS CVn stars are several interesting objects. HD 224085 was shown by Rucinsky (*PASP* 89,280) to be a strongly spotted, cool but probably young object. CM Dra is the eclipsing binary with the smallest and faintest known red-dwarf components; it is probably a population II system (Lacy, *ApJ* 218,444; Rucinski, *AA* 28,167). Dworetsky *et al.* (*MN* 181,13P) discovered a 9-d eclipsing binary, BD -3°5357, containing a red sub-giant and a hot OB sub-dwarf; the evolution of this system poses a problem. Mengel *et al.* (*ApJ* 204,488) suggested that in general the sdB stars are produced by mass transfer and mass loss in close binary systems. Great potential significance for our understanding of the helium-rich stars has the discovery (Hesser *et al.*, *Nature* 262,116; Groote and Hunger, *AAp* 56,129) that one of the classical objects of this kind, σ Ori E, is most likely an interacting binary with ring.

C. W Ursae Majoris Systems (J.A.J. Whelan)

Further modifications were made to the basic Lucy (*ApJ* 151,1123) common convective envelope model of W UMa contact systems. Lucy (*ApJ* 205,208), Flannery (*ApJ* 205,217), Robertson and Eggleton (*MN* 179,359) discussed a model in which the component stars are not in thermal equilibrium. The system oscillates about a state of marginal contact and spends substantial part of the cycle out of contact with components of very unequal temperatures. Since few, if any such systems are known at the characteristic periods of the models, efforts were made to reduce the out-of-contact part of the cycle. Robertson and Eggleton were able to construct models, with low total angular momentum, which spend only 5% of the cycle out of contact. The paradoxical possibility arises that as cycling models are constructed which approach 100% of the cycle in contact, their average properties might formally approach those of the "equilibrium" contact models, which are known to exist only with equal-mass components at the chemical compositions considered. A crucial factor in the cycling-model calculations is the detailed way in which the energy transfer is switched off as the degree of contact is decreased. Not only is some physical picture of energy transfer necessary, but also a very short time-step must be used, since the relative changes of contact depth occur very rapidly and the stellar reaction-times to changing rates of energy and mass flows are very short. The time-step required for accurate computation is probably much shorter than that used so far, and thus the conclusions of Lucy, Flannery, and Robertson and Eggleton must possibly be re-appraised. To cope with short time-steps in a feasible way, Hazlehurst and Refsdal introduced the "response-function method". The stellar response functions (Hazlehurst *et al.*, *AAp* 58,47) are calculated with the necessary "time resolution" to permit very rapid changes to be followed. Further detailed work is in progress along these lines (Hazlehurst, *Obs* 98,204).

A new, "contact discontinuity" model was introduced by Shu *et al.* (*ApJ* 209,536, 214,798, 216,517, 221,926). A discontinuity in the run of physical variables is maintained by fluid flow; the discontinuity provides an extra degree of freedom, which enables models with surface properties in agreement with observations to be constructed. Hazlehurst and Refsdal (*AAp* 62,L9) showed that in its first specific form the contact discontinuity would be smoothed out on a very short timescale, thus invalidating Shu *et al.*'s original model. Shu *et al.* (*ApJ* in press) have re-cast somewhat their model; they argue that a contact discontinuity is necessary for the existence of a dynamically stable configuration with unequal-mass components and that fluid flow may maintain a contact discontinuity. Various kinds of observational tests of the theories were collected and discussed by Lucy and Wilson (preprint). The conclusion is that the contact-discontinuity models are in substantial disagreement with observational data, but as several disagreements may no longer apply when the theory has reached its final form, it should not yet be regarded as contradicted.

Several attempts were made to attack the difficult problem of the details of the energy transfer between components of a contact binary (Moses, *MN* 176,161; Moses and Smith, *IAU Symp* 73,333; Nariai, *PASJ* 28,587; Ivanov, *Af* 12,475; Webbink, *ApJ* 215,851; Shu *et al.*, *ApJ* in press). There is not yet agreement about appropriate length-scales, dominant forces, etc. The large-scale circulation model (Webbink), driven by rotation and involving mass motions along the entropy gradients which generate or absorb thermal energy, ties up with the absence of thermal equilibrium in the cycling models. However, Shu *et al.* argue the mechanism is insufficient.

The question of which component of a W-type W UMa system is hotter was discussed in detail by Wilson and Biermann (*AAp* 48,349). It was concluded, for TX Cnc, that nearly radiative gravity-darkening, with a continuous temperature variation over the components, could account for the light curve as well, or better, than convective gravity-darkening and a hotter secondary. Further work on this subject is in progress by Hilditch (*Obs* 98,205). Rucinski (*AA* 26,227) showed how UV-observations are relevant to the gravity-darkening problem. Woodward and Wilson (*ApSpSc* 52,387) found that AK Her is in geometrical contact but with $\Delta T \approx 1000$ K between the components. Wilson (*ApJ* 224,885) discussed A-type systems selected for having accurately known parameters, and showed that the radii are larger than those of zero-age main-sequence stars.

D. Novae and Dwarf Novae (B. Warner)

The continued increase in observational data on cataclysmic variables, and their similarities to many X-ray objects, has generated much interest and attempts at understanding their structure and mechanisms. The three principal reviews on dwarf novae are those by Warner (*IAU Symp* 73,85), dealing with observations, Bath (*IAU Symp* 73,173), on theories, and Robinson (*Ann Rev AAp* 14,119). Classical novae were reviewed by Gallagher and Starrfield (*Ann Rev AAp* 16,171), and two recent semi-popular reviews concern explosions of novae (Bath, *QJRAS* 19,442) and the problem of novae *versus* dwarf novae (Mallama and Trimble, *QJRAS* 19,430).

Theoretical studies of gas flow between components were quoted in Section 5F; among these, Flannery (*ApJ* 201,661) confirmed the empirical hot-spot model. Nelson and Olson (*ApJ* 207,195) reported changes in DQ Her that indicate variations in the rate of mass flow; this was considered further by Nelson (*ApJ* 209,165). Works on accretion-disk structure were also mentioned in Section 5F; here we add the study of U Gem by Madej and Paczynski (*Bamberg Ver* 121,313). The structure of dwarf novae at minimum light was elucidated by discussion of multi-colour photometry by Szkody (*ApJ* 207,824, 217,140) and refinement of the U Gem model by Smak (*AA* 26,277). Masses of cataclysmic variables were deduced by Robinson (*ApJ* 203,485) and Ritter (*MN* 175,279). Interpretations of the rapid oscillations in DQ Her (Katz, *ApJ* 200,298; Patterson *et al.*, *ApJ* 224,570) and in dwarf novae during outburst were assisted by study of r-modes (Papaloizou and Pringle, *MN* 182,423).

Dwarf-nova outbursts and their relationship to binary properties were discussed by Sparks and Starrfield (*Liège Coll* 19,407) and Bath (*MSAI* 45,793). Photometric observations of short and long eruptions of VW Hyi (Haefner *et al.*, *AAp* in press) provided additional clues. However, there is still no consensus on the nature of the outbursts. Dynamical instabilities of the secondary were further studied by Papaloizou and Bath (*MN* 172,339). The most convincing application of the suggestion of dynamical instabilities was made by Webbink (*Nature* 262,271) to the recurrent nova T CrB.

Much work was performed in studies of classical novae; most of this concerns mechanism of ejection and properties of shells, but there are also results relevant to the binary nature. V1500 Cyg provided a wealth of information. Rapid variations in emission-line profiles indicated rapid changes in the central star (Rush and Thompson, *ApJ* 211,184). Rapid flickering and the presence of a 0.14-d (or 0.28-d) periodic light-variation (Kemp *et al.*, *ApJ* 211,L71; Kupo and Leibowitz, *AAp* 56,181; Young *et al.*, *PASP* 89,37; Patterson, *ApJ* 225,954) provided clues to binary nature. Interpretation of infrared and other observations (Ennis *et al.*, *ApJ* 214,478; Boyarchuk *et al.*, *AZh* 54,477; Vrba *et al.*, *ApJ* 211,480) gave an ejected mass of about $7\times10^{-5}\ M_\odot$. A search-light model was proposed by Hutchings and McCall (*ApJ* 217,775) and further elaborated by Hutchings *et al.* (*ApJ* 224,899). Models for ejection from novae (Bath and Shaviv, *MN* 175,305; Friedjung, *MSAI* 45,757; Gallagher and Ney, *ApJ* 204,L35; Clayton and Wickramasinghe, *ApSpSc* 42,463) were deduced partly from infrared observations; continouos-ejection models are in general favoured. This type of model was also proposed for the slow nova RR Tel by Thackeray (*MRAS* 83,1).

Finally we note that the discovery of magnetic close binaries, AM Her, AN UMa, and VV Pup (Section 4C), has closed the gap between conventional cataclysmic variables and X-ray binaries of the Sco X-1 type. In addition to references given already in Section 4C, we mention Chanmugam and Wagner (*ApJ* 222,641), Cowley and Crampton (*ApJ* 212,L121), Fabian *et al.* (*MN* 179,9P), Greenstein *et al.* (*ApJ* 218,L121), Liebert *et al.* (*ApJ* 225,201), and Stockman (*ApJ* 218,L57). The properties of the AM Her variables were recently used by Papaloizou and Pringle (*AAp* 70,L65) for explaining the different "hump"-periods of VW Hyi.

X-ray Binaries (E.P.J. van den Heuvel)

For recent reviews of the field, see (1) *Proceedings 8th Texas Conference on Relativistic Astrophysics* (ed. G. Papagiannis), 1977, *Ann. New York Acad. Sci.* 302 (especially the papers by Lamb, Rappaport and Joss, Cowley, Flannery, Schreier, Gursky, Ziolkowski, Sanford, Giacconi, Lewin, Ostriker, and van den Heuvel; each paper contains an extensive list of up-to-date references), (2) *Physics of Neutron Stars and Black Holes, Proc. 46th Enrico Fermi School of Physics* (eds. R. Giacconi and R. Ruffini), North Holland Publ. Co., Amsterdam, 1978. In this Report we only summarize the highlights of the last three years.

Massive X-ray Binaries. The most important discoveries concerning the massive X-ray binaries were probably those enumerated and described below.

1. A large number of slow X-ray pulsators with periods in the order of several minutes were recognized. These appear to be more common than the short-period pulsators, such as Her X-1 (1.24 s), Cen X-3 (4.84 s), and SMC X-1 (0.71 s). Only two more short-period pulsators were discovered: 3U 1626-67 (P = 7.7 s), probably in a low-mass close binary (Joss *et al.*, *ApJ* 221,645), and 4U 0115+63 (P = 3.6 s), in an eccentric massive system ($P_{\rm orb}$ = 24.3 d; Rappaport *et al.*, *ApJ* 224,L1). Presently 11 slow pulsators are known, most of them associated with massive early-type companions, either super-giants (*e.g.* 4U 0900-40, P = 383 s, $P_{\rm orb}$ = 8.96 d) or B-type emission stars (3U 0352+30 = X Per, P = 835 s). In one case, 3U 1728-24 (P = 138 s), the companion seems to be an M-giant (Davidsen *et al.*, *ApJ* 211,866).

2. An important characteristic of all X-ray pulsators is that they spin up rapidly; the timescales are in some cases (3U 1728-24) as short as decades, in others (Cen X-3, SMC X-1) of the order of 10^3 to 10^4 y, in Her X-1 about 3×10^5 y (see papers by Schreier and Rappaport and Joss in ref. 1). These large spin-up rates are a clear manifestation of the accretion process, which supplies the compact star with mass and angular momentum. The combination of X-ray luminosity (yielding accretion rate) with spin-up rate (proportional to the mass-transfer rate divided by stellar moment of inertia) provided unambiguous proof that the X-ray pulsators are neutron stars and not white dwarfs (Rappaport and Joss, *Nature* 266,683).

3. The discovery of the X-ray source OAO 1653-40 and its positional agreement with V861 Sco (P = 7.848 d) provided a second black-hole candidate; the mass function suggests a mass of at least 5 $M_\odot$ for the compact star (Polidan *et al.*, *IAUC* 3234). The third black-hole candidate, Cir X-1, was identified with a very faint red star, at least at a distance of 10 kpc (Whelan *et al.*, *MN* 181,259).

4. The discovery of an orbital period of 1.41 d in LMC X-4 by Chevalier and Ilovaisky (*AAp* 59,L9) is the first case of a massive binary where binary character was discovered photometrically before it was found in the X-rays.

5. The derivation of good optical and X-ray orbits proved to be more complicated than was hoped originally (see Bahcall, *Ann Rev AAp* 16,241). Much accurate optical photometric and spectroscopic information is required - together with accurate X-ray data - in order to derive accurate masses of compact stars. So far a complete analysis has been carried out only for the system 4U 0900-40 = HD 77581, by van Paradijs *et al.*

(*AAp Sup* 30,195), yielding a neutron-star mass of 1.74±0.25 $M_\odot$. A second system, where such an analysis seems possible, is SMC X-1 (Hutchings *et al.*, *ApJ* 217,186); here, however, due to the presence of an extra lightsource in the system near conjunction (*cf.* van Paradijs and Zuiderwijk, *AAp* 61,L19), the errors are considerably larger.

6. The Her X-1 system was studied extensively by Boynton and co-workers and by Nelson and Middleditch (see their contributions in ref. 2). In a beautiful analysis Boynton *et al.* found unambiguous evidence for the presence of a large precessing disk in the system, which causes the 35-d X-ray and optical variations.

7. The rather low rate of mass transfer by Roche-lobe overflow in the Her X-1 system inspired a detailed study of the effects of hydrodynamics and of angular-momentum transfer on the details of the mass-transfer process. Savonije (*AAp* 62,317) showed that especially the effects of hydrodynamics may extend the duration of the phase of very slow mass-transfer ($M < 10^{-8}$ $M_\odot$/y) by Roche overflow to $\geq 10^4$ y in massive systems, provided the massive star is in the phase of hydrogen burning. Therefore, in the short-period massive binaries such as Cen X-3 and SMC X-1, Roche-lobe overflow, probably mixed with wind, may be the main source of mass accretion (see also: Conti, *AAp* 63,225; Ziolkowski, ref. 1).

Low-Mass X-ray Sources, X-ray Bursters, Galactic-Bulge Sources and Globular-Cluster X-ray Sources. After the discovery of the first X-ray burst-source, 3U 1820-30 (in the globular cluster NGC 6624), with the ANS satellite (Grindlay *et al.*, *ApJ* 205,L127), the SAS-3 team discovered more than 30 new burst-sources. Not more than five of them are in globular clusters. They show a galactic distribution probably characteristic for an old galactic-bulge population (see review by Lewin in ref. 1). At least four bursters have been optically identified, all of them with blue intrinsically faint stars. The spectrum of one of these (4U 1735-44), obtained by McClintock *et al.* (*ApJ* 223,L75) is almost identical to that of Sco X-1, suggesting that we are dealing with a low-mass binary system. The time-integrated burst luminosities of all bursters are such that the bursts can be satisfactorily explained by helium-burning flashes on the surface of an accreting neutron star (Joss, *ApJ* 225,L123). The steady luminosities of the sources, which are about 100 times larger, would, in this model, be due to the accretion process itself. Using all observational evidence, Joss and Rappaport (*AAp* 71, in press) argue that many of the galactic-bulge sources (including bursters and globular-cluster sources) are short-period binaries, consisting of a low-mass normal star ($M \lesssim 0.5$ $M_\odot$) together with a compact star. The analysis of various capture processes in globular clusters suggests that compact binaries of this type can be formed in sufficient quantities by means of two or three-body captures (Hills and Day, *ApL* 17,87; Finzi, *AAp* 62,149; *cf.* Heggie, *ComAp* 7,43).

7. Statistical Investigations

The frequency of binaries and multiples in various stellar samples was studied by several authors mainly by means of new radial velocities. Abt and Levy found among solar-type stars (F3-G2 IV or V) 46% binaries and 11% multiples (*ApJ Sup* 30,273) and for B2-B5 IV or V (including Be) respectively 36% and 13% (*ApJ Sup* 36,241). For late B-stars (B7-B9) Wolff (*ApJ* 222,556) obtained a binary frequency of about 45%. In a sample of 18 O-type stars, Bohannan and Garmany (*ApJ* 223,908) found only two which might be binaries, while several previously considered to be binaries proved to have constant velocities. For OB-stars with enhanced N or C lines, Bolton and Rogers (*ApJ* 222,234) estimated the binary frequency to 50-100%. Binary frequency in IC 4665 was brought down to about 50% by Crampton *et al.* (*ApJ* 204,502): previously reported very high frequency is suggested spurious. Among other open clusters searched for binaries we have NGC 6475 (Gieseking, *AAp* 60,9) and NGC 2516 (Gieseking, *AAp Sup* 32,17). The use of colour-magnitude diagrams of open clusters for obtaining binary frequencies and mass ratios was discussed by Dabrowski and Beardsley (*PASP* 89,225), Jaschek (*AAp* 50,185), and by Trimble and Ostriker (*AAp* 63,433), who especially point to the influence of stellar rotation. With reference to globular-cluster X-ray sources, Trimble searched for close binaries in NGC 6809 (*BAAS* 8,443) and discussed the incidence of close binaries in globular clusters (*MN* 178,335). The relation of mass-ratio *versus* period for eclipsing binaries with $P < 5$ d was studied by Sinvhal and Srivastava (*ApSpSc* 54,239). Trimble (*Obs* 98,163) discussed the mass-ratio distribution of spectroscopic binaries and found peaks at $M_2/M_1 = 0.2$ to 0.3 and 0.9 to 1.0. Van't Veer (*AAp* 70,91) studied the distribution of mass-ratios for W UMa systems.

8. Origin and Evolution of Close Binaries

There are three main theoretical avenues for the formation of binary and multiple stars: (1) collapse and fragmentation of an interstellar cloud into protostars, some of which forming gravitationally bound systems, (2) dynamical evolution of small clusters may as end products have a binary or multiple star, (3) fission may produce very close binaries. Exept perhaps for the very close pairs, the first mechanism is a most promising one, and much work was done in this field (*e.g.*, Larson, *IAU Symp* 75,255; Mouschovias, *ApJ* 211,147; Horedt, *ApSpSc* 54,253; Bodenheimer, *ApJ* 224,488; Norman and Wilson, *ApJ* 224,497). Numerical studies of cluster dynamics have generally assumed that all stars were single at the outset. If binaries already exist in the cluster, much of the *N*-body computations may not be applicable. This is especially so, if a sufficient number of strongly bound pairs exist (Dokuchaev and Ozernoy, *AZh* 55,27; Heggie, *Obs* 98,206). In globular clusters such pairs are likely to form by tidal captures, and they may also be present primordially. Fabian *et al.* (*MN* 172,15P) and Sutantyo (*AAp* 44,227) suggested that cluster X-ray sources are close binaries formed from tidal capture of compact objects by ordinary stars. This mechanism was worked out in detail by Press and Teukolsky (*ApJ* 213,183). Work on the modern versions of the fission theory (Lebovitz, *Liège Coll* 19,47) has been limited. Gingold and Monaghan (*MN* 184,481) studied fission of damped, differentially-rotating polytrops, and Lucy (*AJ* 82,1013) made a successful numerical demonstration of the fission hypothesis, applied to optically thick protostars.

The consequences of mass transfer on the evolution of close binaries were reviewed by Thomas (*Ann Rev AAp* 15,127), to which we refer for work mainly prior to 1977. Evolutionary sequences for massive binaries with conservative mass-exchange were pursued further by De Grève and de Loore. They found (*ApSpSc* 50,75) that the sequences bifurcate at an initial primary mass of about 14 $M_\odot$: larger masses are progenitors to neutron stars, lower masses end as white dwarfs. In a comparison with observations (De Grève *et al.*, *ApSpSc* 53,105), it is concluded that conservative mass-exchange, with low initial mass-ratio ($q_i < 0.5$), leads to acceptable first-order models of W-R and massive X-ray binaries. Evolutionary sequences, taking into account mass loss by stellar winds, were calculated by Vanbeveren *et al.* (*AAp* in press) for initial masses 30+50, 40+20, and 60+30 $M_\odot$. The restrictive condition $q_i < 0.5$ for the W-R systems disappears in these more refined computations. De Grève (preprint) studied similarly a still more massive system, 100+60 $M_\odot$, which after lobe overflow turns into a helium star with a massive O-type companion.

Very serious for the theory of Algol systems were the papers by Ulrich and Burger (*ApJ* 206,509), Flannery and Ulrich (*ApJ* 212,533), Kippenhahn and Meyer-Hofmeister (*AAp* 54,539), and Neo *et al.* (*PASJ* 29,249). All these authors agree that at the phase of rapid mass-transfer, the originally less massive component is uncapable of accomodating the high rate of mass influx, begins to swell and a contact system forms. This is illustrated, for instance, by the model sequence computed by Packet and De Grève (*AAp* in press) for a 10+3 $M_\odot$ system, similar to that assumed by Ziolkowski (*ApJ* 204,512) for constructing an evolution model for β Lyr. Instead of a system matching β Lyr, Packet and De Grève obtain a contact binary. The evolution subsequent to established contact is less clear, but it is probably rapid mass-loss from the system.

For a low-mass binary (1.50+0.75 $M_\odot$), Webbink (*ApJ Sup* 32,583) followed evolution from an original detached state to contact. Evolution, when already in contact (Webbink, *ApJ* 211,881; Rahunen and Vilhu, *AAp* 56,99) and a possible end-point of contact-binary evolution, namely coalescence (Webbink, *ApJ* 209,829) were also considered. The possibility of an absence of thermal equilibrium during the contact phase ties up with the cycling models of W UMa systems (Section 6C).

Besides other evolutionary studies, many papers discussed changes of orbital elements due to regular, slow evolution or to catastrophic mass-loss from symmetric or asymmetric supernova explosions. Lack of space prohibits us to enter these fields.

9. Report of the Coordinated Programs Committee

(K. Gyldenkerne)

At the Grenoble IAU Meeting it was recommended to carry out coordinated observing campaigns for RX Cas and VV Cep. For RX Cas, the coordinator, D.Ya. Martynov, reports successful *UBV*-photometry in the USSR: by Zaitseva at the Pulkovo Crimean Station, by Kalv in Tallinn, and by Kumsiashvili at Abastumani; nothing has been reported concerning spectroscopy. From the photometric series, confirmation was obtained for the lengthening of the period. For VV Cep, A. Galatola acted as coordinator and got photometric contributions from observers in USA and Japan, but probably the system has also been observed elsewhere. Wright, Faraggiana and others obtained spectrographic observations; Faraggiana and observers in USA also made IUE spectroscopy. It is suggested to have a discussion on the VV Cep problems at the Montreal Meeting.

Concerning X-ray binaries, Y. Kondo reports on three coordinated campaigns in 1977. The systems observed and the coordinators are: HDE 226868 (V1357 Cyg) = Cyg X-1 (T. Bolton), HZ Her = Her X-1 (J. Nelson), and X Per = 4U 0352+30 (C. de Loore). About a dozen groups or individual observers participated in each campaign. The X-ray observations of Cyg X-1 and Her X-1 were performed with SAS-3; the X Per ground-based observations were timed simultaneous with OSO-8 X-ray observations.

10. Report of the Committee for Extra-Terrestrial Observations

(Y. Kondo)

The Committee continued its usual task of monitoring space experiments that are of interest to the Commission members. In coordination with the Coordinated Programs Committee and IAU Commission 44, we have been involved in various campaigns to observe X-ray binaries; a summary of these activities is given in Section 9. For information on satellites that have been active for X-ray observations of close binaries and for some observational results, reference is made to Section 4D. We add here that the satellite HEAO-B was successfully launched on 1978 November 13. Those interested in observations coordinated with HEAO X-ray observations may contact Dr. J. Swank at Code 661, Goddard Space Flt. Ctr., Greenbelt, MD 20771, USA.

During the three-year period since 1976, the following two satellites were used to observe close binaries in the ultraviolet (launch dates and organizations/experimenters are indicated):

Copernicus	1972	Princeton University
IUE	1978	NASA (Goddard Space Flt. Ctr.), ESA, British Science Res. Council.

In addition, a balloon-borne ultraviolet stellar spectrometer (BUSS) was flown four times to obtain spectra in the mid-ultraviolet. Among binaries observed are β Lyr, ε Aur, υ Sgr, and μ Sgr (de Jager, Kondo and co-workers).

A large number of close binaries are being investigated with the two satellites. Copernicus was effective in observing at high resolutions (0.2 and 0.05 Å) in the spectral region 1000 - 1400 Å. IUE has the capability to observe at slightly lower resolutions (0.1 to 0.2 Å in the far-ultraviolet and 0.2 to 0.3 Å in the mid-ultraviolet), alternatively, it can observe much fainter objects at a resolution of 6 to 7 Å in the range 1200 - 3100 Å.

The results already published from Copernicus data include papers on β Lyr, β Per, UW CMa, and HD 153919 (4U 1700-37). R. Polidan prepared the following list of close binaries observed with Copernicus since 1976 January 1: λ And, UX Ari, 54 Cam, R CMa, AO Cas, AR Lac, HK Lac, 17 Lep, δ Lib, θ Mus, X Per, β Per, V Pup, μ Sgr, υ Sgr, V861 Sco, V 711 Tau, λ Tau, ε UMi, γ^2 Vel, HR 2142, 4665, 5110, 7275, 8703, HD 72754, 77581, 153919; and a list of observed, possibly interacting binaries: ζ And, π Aqr, α Aur, α CMa, τ CMa, υ Cyg, 66 Oph, δ Ori, η Ori, θ Ori, ι Ori, λ Ori, π^5 Ori, σ Ori, ε Per, ο Per, ψ Per, δ Pic, α Sco, β^1 Sco, μ Sco, π Sco, α Vir, HR 4830, 7084, HD 50896. B. Perry compiled the following list of examples of mostly non-X-ray eclipsing binaries observed with the IUE by guest observers, Hack: ε Aur, VV Cep, CH Cyg, β Lyr, υ Sgr, HD 192909; Koch: RX Cas, RW Cas, SX Cas, V382 Cyg, V1073 Cyg, TT Hya, AR Pav, RW Per, V Sgr, υ Sgr, V453 Sco; Kondo: UW CMa, AO Cas, U Cep, 31 Cyg, 32 Cyg, β Lyr, θ Mus, η Ori, δ Pic, μ Sgr, υ Sgr, V861 Sco, γ Vel, HD 153919; Plavec: RX Cas, W Cru, V367 Cyg, 17 Lep, χ Oph, AG Peg, RW Per, 3 Pup, μ Sgr, V356 Sgr, RZ Sct, W Ser, HD 161114, 163296, 206773. Additional interacting binaries, such as SS Cyg, were also observed with the IUE in other guest-observer programs but are not included here. X-ray emitting binaries observed with the IUE in a collaborative program between USA and Europe are given as follows (list prepared by R. Davis): good phase-coverage for the systems HZ Her, V1357 Cyg, V818 Sco, HD 77581, HD 153919, and varying degrees of phase-coverage for SS Cyg, AM Her, X Per, Sk 160, HD 152667, LMC X-4.

Highlights of X-ray binary observations obtained during the initial high-priority period of the IUE are presented in an article by Dupree *et al.* in a special issue of *Nature* (1978 October 5). Among preliminary reports is Hack's detection of the hot companion in ε Aur. Plavec reports detection of strong emission lines of hot plasma in W Ser, V367 Cyg, and W Cru. Most prominent lines in the region 1200 - 2000 Å are due to N V, Si IV, C IV, Si III, Al III, and He II. On the whole the spectra are similar to that of β Lyr. Koch and Sobieski detected similar spectra in RX Cas and SX Cas. Thus, it is established that a whole class of interacting binaries shows this type of spectrum. Plavec speculates on several possible explanations, including the presence of black holes. Kondo and McCluskey observed spectral profiles indicating mass flow in a number of cases, including υ Sgr, μ Sgr, V861 Sco, β Lyr, UW CMa, and U Cep. Those interested in learning more about these satellites' observations may contact Dr. R. Polidan (Copernicus), Code 410, and Dr. R. Perry (IUE), Code 685, both at Goddard Space Flt. Ctr., Greenbelt, MD 20771, USA.

11. Report of the Working Group on RS CVn Binaries

(D.S. Hall)

This Working Group was conceived at the end of the Grenoble Meeting to stimulate interest in RS CVn systems, make it known which astronomers are involved, define some of the important problems, minimize unnecessary duplication, and help with cooperative observing programs. To date 11 Circulars have been distributed to about 35 members in the Western Hemisphere and (with the help of M. Rodonò) to about 15 in the Eastern Hemisphere. Members are encouraged to announce research-in-progress and look for published results in the *Bibliography and Program Notes on Close Binaries*. We still need one light curve per year outside eclipse for the about 20 most important systems in order to follow the wave migration continuously; with less frequent observations, the phasing can become ambiguous. The "First RS CVn Workshop" was held 1978 April 6 and 7 at New Mexico Institute of Mining and Technology, Socorro, NM, with D.S. Hall scientific chairman, D.M. Gibson local chairman, and 27 participants. A summary of the discussions was distributed as Circular No. 9. There we arranged to have a special issue of the *Astron. J.* (December 1978) devoted to the large 1978 February 20 radio outburst of V711 Tau (HR 1099) and arranged to have a "Second RS CVn Workshop" at the Montreal Meeting, with P. Feldman local chairman.

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President of the Commission