42. CLOSE BINARY STARS (ÉTOILES DOUBLES SERRÉES)

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1. INTRODUCTION
(T. Herczeg)

The previous report of the Commission, the last one published under the name 'Photometric Double Stars', closed on a note of high expectations: 'Great theoretical and observational advances may be anticipated'. Between 1973 and 1975, we had the opportunity to witness the occurrence of these great advances.

The progress has been most spectacular, naturally, in the field of the X-ray binaries. This concept was by no means new in 1973 yet the subsequent years brought an unusually interesting series of discoveries and identifications until we reached the state that a large fraction of hitherto identified galactic sources belong to this particular class of binaries. They always contain a collapsed object; in most cases the collapsed object is presumably a neutron star, in one case (SS Cygni) a white dwarf. Definitive proof has not yet been given for the existence of a very massive collapsed object in any of these systems, identifiable with a black hole; the most promising case is still Cygnus X-1, as it was three years ago. Thanks to new and in some cases quite sophisticated observing techniques and the emerging good cooperation between X-ray and optical (and also radio) observers we have now quantitative models at our disposal, for several of these objects. The first observational determinations of neutron star masses seem to be achieved: the range is about 1.3–1.6 solar masses, clearly above the values for white dwarfs. In the domain of radioastronomy, the remarkable discovery of a binary pulsar in 1974 was the starting point for many new considerations.

Studies of binaries with collapsed components still focused a great deal of interest on late phases of stellar evolution. As to the more classical cases of interacting binaries, like Algol systems, also novae and U Gem-stars, current research seems to turn from model computations to the study of the actual mechanism of close-binary interaction, to the hydrodynamical theory of disks and gas streams in the systems. We also see signs that the interest in the problems of binary origin and early evolution may be reviving, with added emphasis on the possibility of fission.

On the side of the theory of (eclipsing) binary orbits, the so-called synthesis method based on automated computational procedures became a 'main avenue' of research, to use a fashionable expression, at least so for the semi-detached and contact systems. Cases which seemed totally intractable a decade ago, can be handled now with impressive success. Returning to the observations, we have to mention here that many interesting systems have been investigated in the far or middle ultraviolet thanks to programs accommodated on satellite observatories. There is, in general, a noticeable concentration on 'crucial' objects, studied by all available techniques. It is comforting to recognize that this concentration of research does not mean necessarily that 'common' objects were neglected: in Table 3 of the spectroscopic investigations (without Table 3a), we find 152 papers listed, dealing with 134 systems. In the table of the previous report, roughly comparable in its degree of completeness, there were 57 papers on 59 systems.

Before we close this very short summary of main events and trends in our field and continue with questions of organization and information, let us consider for a moment the new name of Commission 42. What objects do we call 'close binary systems'? The definition which finally took shape after some discussions among Commission members, states the following: a binary system is to be considered 'close', if at any time during the evolution of the components, interaction takes place between them, strong enough to markedly influence their evolution. This is a somewhat cumbersome but clear and workable definition. There are a few loopholes, however. It is remarkable, for instance, that ζ Aurigae (as I think, Daniel M. Popper pointed out) may not be a *bona fide* close binary: one of the components presumably reached its maximum expansion yet there is no significant interaction between the two stars. Nevertheless, for all practical purposes, selection effects due to observational techniques provide us with a clear distinction between wide and close binaries, the line of demarcation being between visual binaries on one side, spectroscopic and eclipsing binaries on the other. The few cases of overlapping, resulting from astrometric or interferometric studies, present no serious problem.

This report contains, contrary to the previous ones, no section dealing with co-ordinated observing programs. At the General Assembly of the Union in 1973, no system was selected for co-ordinated optical studies; later on, the new experiment of a co-ordination program between optical and X-ray astronomers was making encouraging progress. Some of the programs of the proceeding triennium are not yet completed but the Commission should probably seek the adoption of new systems for coordinated study during the period 1976–79. One possible object has already been proposed for consideration: simultaneous X-ray and optical (photometric and spectroscopic) observations of Cyg X-1 (HDE 226868) in 1977, as suggested by T. Bolton.

A long awaited monograph by Alan H. Batten: *Binary and Multiple Systems of Stars*, has been published by Pergamon Press in 1973. A. Batten also edited the Proceedings of IAU Symposium No. 51 (Otto Struve Memorial Symposium) which was held in Parkesville, B.C. in 1972; the publisher was D. Reidel. V. P. Tsesevich edited a monograph on *Eclipsing Variable Stars*, which was translated from the Russian by R. Hardin and recently published by Halsted Press. The *Rocznik Astronomiczny* continued to be published yearly at Cracow; this very useful collection of ephemerides and predicted times of minima would certainly deserve a wider circulation. I wish to mention another helpful source of information: the Card Catalog of Eclipsing Variables, maintained at the University of Florida, Gainesville.

Restrictions imposed on the length of this report make it necessarily incomplete. A much more complete survey of current literature (including information concerning ongoing research) is being published semi-annually by G. Larsson-Leander at the Lund Observatory; the mimeographed issues are now entitled *Bibliography and Program Notes on Close Binaries.* Numbers 22 through 26 were published in the triennium covered by this report. Regional contributors to the Bibliography were: B. Cester (Italy), M. de Groot (Southern Hemisphere), J. Grygar (Central and Eastern Europe), D. S. Hall (U.S.A., except the West Coast), M. Kitamura (Japan), H. Mauder (Germany and the IAU Circulars), F. van't Veer (Western Europe), C. D. Scarfe (Canada, U.S. West Coast, Mexico), A. Shulberg (USSR), S. D. Sinvhal (India and Indonesia). The usefulness of this publication, coming out about a year before the corresponding volumes of the *Astronomy and Astrophysics Abstracts,* cannot be overestimated. The work of the Editor and the regional contributors is highly appreciated by all members of the Commission. Our thanks to them includes the editorial staff at the Lund Observatory too (Miss Gun Bergsten and Mr O. Ek).

A substantial part of the current literature – although in completeness not comparable to the *Bibliography* – is reviewed in the *Physics Abstracts*, published twice monthly by the Institution of Electrical Engineers. The Subject Index for January–June 1975 lists, for instance, nearly 200 references under the heading 'binaries'.

The Commission sponsored or co-sponsored three scientific meetings. IAU Symposium No. 73 (Structure and Evolution of Close Binary Stars) was held at Cambridge in July 1975 and sponsored together with Commission 35. This was the fourth of IAU sponsored meetings since 1969, dedicated exclusively to some aspect of our knowledge of close binary stars and was, according to *Nature* 'by general consent most successful'. The proceedings will be edited by J. Whelan and S. Mitton and published by D. Reidel; in our references, it will be abbreviated *Cambridge*. The Commission also co-sponsored IAU Symposium No. 70 (The Merrill-McLaughlin Memorial Symposium on Be and Shell Stars) held at Cape Cod, in September 1975.

A further successful meeting was organized under the title Symposium on X-ray Binaries, at Goddard Space Flight Center (Greenbelt, Maryland) in October 1975. This symposium was sponsored by Commissions 42 and 44 and was an outgrowth of a co-ordinated program directed by Y. Kondo (see his report below). The proceedings will be published as NASA special publication, edited by Y. Kondo and E. Boldt. Furthermore, two IAU Colloquia took place during the time considered here which, although not sponsored by Commission 42, contained some interesting contributions to close binary research. We refer to IAU Colloquium No. 29 (Multiple Periodic Variable Stars, Budapest, September 1975) and IAU Colloquium No. 33 (Observational Parameters and Dynamical Evolution of Multiple Stars, Oaxtepec, October 1975).

A conference on 'Close Binary Systems and their Evolution' took place in Moscow in the Sternberg Astronomical Institute (May, 1974). The proceedings of the conference were to be published at the end of 1975.

The Organizing Committee met at Cambridge and decided to prepare this report, similarly to the previous one, collectively, Changes were made mainly to reduce overlaps and to add some material in an effort to achieve a more balanced review. (A few important papers had to be quoted several times, in different sections of the report.) Contrasts in the style of presentation, from telegraphic brevity to an essay-like narrative, could not be completely eliminated. We kept the shorthand system of references and abbreviations adopted in the previous report and obvious to every specialist; see also the list below.

My thanks are due to all the authors and those colleagues who sent their reports.

ABBREVIATIONS

AA = Acta Astronomica
AC = Astronomicheskii Circular SSSR
Ann. Rev. A.A. = Annual Review of Astronomy and Astrophysics
Ast Aph = Astronomy and Astrophysics
AG Mitt = Mitteilungen der Astronomischen Gesellschaft
AJ = Astronomical Journal
Astr. Zh. = Astronomicheskii Zhurnal (English transl. = *Soviet AJ*)
Ap J = Astrophysical Journal
Aph Sp Sci = Astrophysics and Space Sciences
BAAS = Bulletin of the American Astronomical Society
BAC = Bulletin of the Astronomical Institutes of Czechoslovakia
IAUC = IAU Circular
IBVS = IAU Comm. 27 Information Bulletin on Variable Stars
JRASC = Journal of the Royal Astronomical Society of Canada
MSAIt = Memorie della Società Astronomica Italiana
MN = Monthly Notices of the Royal Astronomical Society
Observ. = The Observatory
Perem. Zv. = Peremennye Zvezdy
PASJ = Publications of the Astronomical Society of Japan
PASP = Publications of the Astronomical Society of the Pacific
PDAO Vict. = Publications of the Dominion Astrophysical Observatory
PDDO Toronto = Publications of the David Dunlap Observatory
Vistas = Vistas in Astronomy (ed. A. Beer)

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2. INSTRUMENTS AND TECHNIQUES
(B. Warner, T. Herczeg)

The triennium 1973–75 has witnessed the extension of studies of close binaries to cover the whole electromagnetic spectrum. At the one end, high frequency radio observations have been made of two RS CVn stars: AR Lac (Gibson and Hjellming, *PASP* **86**, 652) and UX Ari (Gibson *et al., ApJ* **200**, L99). At the other end cataclysmic variables have been held possibly responsible for gamma-ray bursts (Vidal and Wickramasinghe, *Ast Aph* **36**, 369). Simultaneous X-ray, optical and radio observations of Sco X-1, taken February–April 1971, have been discussed by Bradt *et al.* (*ApJ* **197**, 443); some correlation has been found between X-ray and optical activity, no correlation of these activities with radio flaring. Satellite ultraviolet observations by OAO-2 were made of several types of close binaries: Nova Ser 1970, after its maximum (Gallagher and Code, *ApJ* **189**, L123), the old novae V603 Aql and RR Pic (Gallagher and Holm, *ApJ* **189**, L23), SS Cyg (Holm and Gallagher, *ApJ* **192**, 425), VV Ori and MR Cyg (Eaton, *ApJ* **197**, 379). Soft X-ray surveys of cataclysmic variables have been made (Henry *et al., ApJ* 197, L117) with the positive detection of SS Cyg during outburst (Rappaport *et al., ApJ* **187**, L5).

In ground based photometry, the triennium has seen the further development of the high speed methods introduced in the early 1970's; a review has been given by Nather (*Vistas* **15**, 91). Principal results from application to cataclysmic variables appear in *MN* **168**, 235 (Warner, Z Cha), *MN* **170**, 219 (Warner, VW Hyi) and *Ast Aph* **36**, 369 (Vogt, VW Hyi). Pulsed emission lines were found in HZ Her (Davidsen *et al., ApJ* **198**, 653).

Polarimetric observations of binaries include studies of U Cep (Piirola, *IBVS* 1061) and YY Eri (Oshchepkov, *Abastumani Bull.* **45**, 51), and measurements of the white dwarf binary BD + 16°516 (Kemp and Rudy, *PASP* **87**, 301). Applications of narrow-band photometry include 6-filter photometry of β Lyr by Cester and Pucillo (*Ast Aph Suppl* **13**, 405), observations of WR-binaries by Cherepashchuk (*Astr Zh* **52**, 255, see also *Perem. Zv.* **20**, No. 1) and Hα photometry of Z Vul, Al Dra, and RZ Cas (Olson and Weis, *ApJ* **79**, 642). Hα observations of Algol simultaneous with radio observations were made by Walker *et al.* (*AJ* **78**, 681). The Wampler scanner was used for time-resolved spectra of HZ 29 (Robinson and Faulkner, *ApJ* **200**, L23) and the spectracon provided time-resolved spectra of some cataclysmic variables (Walker, *Bamberg Veröff.* No. 100, 243). Simultaneous photoelectric observations and time-resolved spectra of AE Aqr, taken earlier by the aid of the Lallemand tube, have been recently discussed by Chincarini and Walker (*Conference on Electrography* p. 249; in the same volume Walker gives a review of the astronomical applications of the spectracon, p. 221).

Griffin has successfully applied his radial-velocity spectrometer to the determination of orbital elements of single spectrum binaries (see a series of five papers in *Observ.* Vol. 95). As the rms residuals are $\leqslant 1.0$ km s^{-1}, the method holds great promise in this field, too.

High resolution radio interferometry (spacing 20 million wavelength) was applied to β Per by Clark *et al.* (*ApJ* **198**, L123). They found the emitting region about 0.1 AU in size, its mean brightness temperature 4×10^8 K; expansion of the region is compatible with the observed variation of fringe visibility. Speckle interferometry enabled the resolution of twelve binary systems (Labeyrie *et al., ApJ* **194**, L147), among them Capella and, for the first time, the triple system β Per AB–C. (With angular separations ranging from 0".05 to 0".29, most of these cases are actually no 'close binaries' in the sense we use the word in this review.) Astrometric investigations of close binaries directed toward the detection of possible distant companions led to positive results in the case of VW Cep (Hershey, *AJ* **80**, 662). The predicted third body has subsequently been observed visually by Heintz.

Radio, satellite ultraviolet and, in particular, X-ray studies of close binary systems were in rapid progress during the period covered in this report. The corresponding techniques are described in more detail by the proper commissions. Here we only mention an extensive review of instrumental technique in X-ray astronomy by Peterson (*Ann. Rev. A.A.* **13**, 423–509) and follow up with the report of the committee whose primary function is the coordination of space observations with ground-based observations.

3. REPORT OF THE COMMITTEE FOR EXTRATERRESTRIAL OBSERVATIONS
(Y. Kondo)

The Committee continued to perform its normal function of closely monitoring space experiments which are of potential interest to members of Commision 42. Four satellite observatories with experiments in the ultraviolet spectral region were either launched successfully or had continued their operations during this period. They are, with their launch dates:

TD1	1972	S59 and S2/68 UV Spectrometers
Copernicus (OAO-3)	1972	Princeton University Telescope Spectrometer
Skylab	1973	SO19 UV Spectrograph
ANS	1974	Groningen UV Photometer

X-ray observations of galactic sources have been carried out by the following scientific spacecraft:

Copernicus (OAO-3)	1972	University College London experiment
ANS	1974	Space Research Lab. Utrecht and SAO exps.
Ariel 5 (UK-5)	1974	Mullard Space Sci. Lab., Univ. Leicester, Imperial Coll., Goddard SFC, Appleton Lab.
SAS-3	1975	MIT experiments
OSO-8	1975	Columbia Univ., Goddard SFC, Lockhead, Univ. Wisconsin exps.

UHURU, OSO-7 and OAO-2 were already inactive for most part of the triennium considered.

Three of the ultraviolet experiments (the exception being SO19) have been open to guest-investigator participation. Also, it was announced by NASA that the results of the OAO-2 Wisconsin Experiment Package were available through World Space Science Data Center.

The major effort of the Committee was concentrated on the 'Coordinated Campaign to Observe X-Ray Binaries'. This program has been initiated jointly with the Committee for Coordinated Observations (Chairman K. Gyldenkerne), also in coordination with IAU Commission 44. The objectives of this campaign include, in addition to the usual ones, coordination of observing efforts between the ground-based observers and satellite experimenters. About one hundred ground-based observers, X-ray and ultraviolet experimenters and theorists are currently participating in this campaign; 17 circulars have been issued by the undersigned (Y. Kondo) who acted as coordinator of the program. As an outgrowth of this campaign, a Symposium on X-ray Binaries was organized at Goddard Space Flight Center; details are given in the introductory section of the report.

4. PHOTOMETRIC OBSERVATIONS AND SOLUTIONS
(F. B. Wood, T. Herczeg)

Tables 1 and 2 (p. 225) summarize the publications received by November 1, 1975. Again, we have in almost all cases of newly observed light curves followed previous resolutions of Commission 42 and included only those for which individual observations were published. Observations obtained by satellites are covered in other sections of this report and are not repeated here. High time-resolution observations are dealt with under 'Instruments and Techniques.' As in the previous report, space limitation forces us to omit all names and to give only the journal (abbreviated), volume and page.

Photometric work and, in particular, photoelectric studies continued to increase at a spectacular rate. A large part of the newly acquired material is coming from observatories where groups of dedicated specialists reserved relatively modest, 20–40-in. telescopes for systematic study of eclipsing binaries; Abastumani, Baton Rouge, Bonn (Hoher List), Bucharest, Catania, Cluj, Gainesville, Nashville, Moscow (Sternberg Institute), Philadelphia, Skalnate Pleso, Trieste, Utter Pradash State Observatory, Victoria, to name a few. There has been great progress in covering southern objects by using the smaller telescopes at La Silla (ESO) fairly regularly for close binaries; in this respect, contributions from several German and Swedish universities (Bochum, Bonn, Tübingen; Lund) and especially from the Copenhagen Observatory proved of great value. Similarly, Cerro Tololo, the Leiden Southern Station in South Africa, and Australian observatories continued binary work on the once neglected southern hemisphere.

Among the many investigations which were carried out by conventional equipment but where the object of study was of particular interest, we mention three: the photometry of the very massive 1.88-day binary V382 Cyg by Landolt (*PASP* **87**, 409), Broglia's study of Y Cam, an eclipsing system with δ Scu-type primary (*Ast Aph* **34**, 89), and the long series of observations of XY UMa by Geyer, showing unusually strong changes of the light curve (*Cambridge*). We may also mention an extensive infrared photometry of 14 eclipsing binaries, with variable light curves, carried out at Calgary (E. Milone). Kukarkin reported (*IBVS* 1039) that the nova-like variable AN UMa also shows eclipses with a period of 0.16 days.

In spite of the increased efforts, an urgent need of systematic observations of systems with periods roughly three days or longer still continues.

5. METHODS OF ANALYZING LIGHT CURVES
(F. B. Wood)

The work here has been extensive. In the difficult task of attempting to survey it, I have been greatly aided by comments from a number of members of the commission; some of them will recognize their remarks in the following summary.

After the important new developments of five or six years ago (covered in the 1973 Reports), the field settled into a stage of still rapid but relatively orderly development. Two of the main areas have been:

(a) Extensions of the capabilities of the various computer programs, and,

(b) Results which could not have been obtained with the older methods. (There is, of course, considerable overlap in these areas).

Developments under (a) include development of real as opposed to formal estimates of reliability and increasing facility in changing the basic program to allow for changing opinion as to parameter ranges. Söderhjelm, for example, has estimated the conditions under which certain approximations break down near contact (*Ast Aph* **34**, 59). In general, the new methods are now being applied on a routine basis to many binaries with the satisfying result that different people are getting essentially the same results for a given binary, and it is becoming necessary to invoke third light in fewer cases than formerly.

Under (a), Hutchings now treats eccentic orbits and computes spectral line profiles (Crampton and Hutchings, *ApJ* **191**, 483; Hutchings, *ApJ* **180**, 501); Wilson and Sofia compute radial velocity (*ApJ* **203**, 182). In this latter program, the radial velocities are printed routinely with the light curves and include automatically the effects of reflection, tides, eclipses, etc. Their differential corrections for semi-detached systems can be made to force the contact component to fill exactly its Roche or Jacobian (zero-velocity) limit. The same type of solutions for X-ray binaries enforce the constraint that the duration of the X-ray eclipse is that observed in the X-ray observations (Wilson and Wilson, in press, *ApJ* 1976). Hutchings and Hill have contined their studies of the synthesis of close binary light curves (see *e.g., ApJ* **179**, 539).

The adaptability of the differential correction process has been demonstrated by the β Lyr solution in which minor modifications make it possible even to solve for the properties of a circumstellar disk by least squares, and it is now being used by a number of workers in the field. One development is the use of optimization techniques, taken from operations research which is more realistic than conventional least squares (for example, see papers by Budding, *Aph Sp Sci* **22**, 87; **26**, 371). Ureche has published studies of the reflection effect and further developments of the ellipsoidal-ellipsoidal and the sphere-ellipsoidal models (*Studii Cerc. Astr.* **17**, 213; **19**, 67; *Studii Univ. Babes-Bolyai, Ser. Math-Mech, Fasc* 1, 89; Proceedings of the Second European Astr. Meeting, in press). Kwee is preparing D. B. Wood's program for the Leiden computer and has made minor revisions.

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Rucinski has continued his series of papers on the photometric proximity effects in close binary systems (*AA* **22**, 455; **23**, 301), and applied these to certain individual systems (*e.g.* HZ Her, *AA* **23**, 283). Mochnacki and Whelan (*Ast Aph* **25**, 249) also presented a model of the W group of W UMa systems, as did Mauder (*Ast Aph* **17**, 1).

Hall has tried to understand the nature of light curve distortions in 'pathological' systems, so that these can be removed properly and a meaningful solution obtained, see for instance, the discussion of RX Gem in *Ast Aph* **38**, 225 by Hall and Walter. Walter has also been engaged in an attempt to understand 'hot spots' and similar phenomena, and a number of joint papers have resulted.

Hutchings and Hill have applied their synthesis program to W UMa, AM Leo, V 566 Oph, and GK Cep (*ApJ* **179**, 539).

Kopal has started a series of papers on the Fourier analysis approach (see *Aph Sp Sci*, Vol. 34–36, several papers). Instead of the conventional Fourier transform, this depends on evaluation of integrals of the form

$$\int_0^{\theta'} (1 - l)\mathrm{d}(\sin^{2m} \theta), \text{ in which } \theta' \text{ is the angle of external contact.}$$

The elements are then derived from (usually complex) expressions involving the results of these integrations.

Other modification have been suggested in *Perem. Zv.* **18**, 529; **19**, 421, 431, 97; *AC* 754; *Soviet A J* **17**, 622; **16**, 442; **15**, 236; *Aph Sp Sci* **11**, 475; **21**, 7; **20**, 123; **26**, 215; *AA* **23**, 247; *PASP* **85**, 253.

Light curves for binaries with extensive atmospheres here have been discussed in *BAC* **24**, 243; *Soviet A J* **17**, 555; **19**, 227; *Perem. Zv.* **18**, 535.

Some, although not all, of the papers given at IAU Colloquium No. 16 have been published in *Astrophysics and Space Science.*

Under (b), the extent to which UMa systems are 'overcontact' has been reasonably well established. The W-type systems (primary eclipse occultation) are slightly overcontact, while the A-type systems are well overcontact (about 1/3 to 1/2 way between inner and outer contact surfaces). (See, for example, Lucy, Proc. IAU Coll. 16; Wilson and Devinney, *ApJ* **182**, 539; Mochnacki and Doughty, *MN* **156**, 51; **156**, 243; Wilson and Biermann, *Ast Aph*, in press).

'Photometric' mass ratios for contact binaries can now be determined with an accuracy which in many cases is better than that found from radial velocity curves. This is, of course, particularly valuable for single-line contact binaries (see references in preceding paragraph). It now seems clear that early type contact binaries do indeed exist (*e.g.*, Leung and Wilson, *Cambridge*). These include, but are not confined to, V 701 Sco, V 1010 Oph, and SV Cen. Some of the above papers also suggest that both classical (von Zeipel) and convective gravity darkening occur in W UMa systems, but that intermediate cases are rare or do not occur at all. The A-type systems seem to have convective darkening and the W-type, classical.

It now seems possible to detect differences of only a few hundred degrees between the components of contact binaries (Whelan, Worden, and Mochnacki, *ApJ* **183**, 133; Wilson and Biermann, *Ast Aph*, in press). Even these small differences have important implications for structural models.

For more unusual stars, various papers have presented parameters computed from the light curves of Cyg X-1, SMC X-1, and other X-ray binaries. At the moment, Cyg X-1 seems the strongest candidate for a system with a black hole as one component.

Rucinski has started a series of papers with running title, 'The W UMa Type Systems as Contact Binaries' (*AA* **23**, 79; **24**, 119).

Finally, in one of the newest branches of our field, we should mention the ultraviolet photometry from satellites and the theoretical treatment of the results. Examples are a paper by Eaton and Ward (*ApJ* **185**, 921) which analyzes seven simultaneous light curves of U Oph to determine limb and gravity darkening as well as geometrical elements, and a paper by Eaton (*ApJ* **197**, 379) which discusses VV Ori and MR Cyg. For U Oph, it is found that limb darkening increases toward the shorter wavelengths, and at the shortest approaches unity, as has been predicted by theory. For VV Ori, analysis using synthesis techniques gives a mass ratio consistent with radial velocity observations and limb darkening consistent with theory. For MR Cyg, the picture is less clear. For both, the wavelength dependence of the reflection effect is qualitatively that predicted by Rucinski.

6. SPECTROSCOPIC AND SPECTROPHOTOMETRIC INVESTIGATIONS (A. Batten, T. Herczeg)

This section of the report is the most directly affected by the enlargement of the Commission's scope to include non-eclipsing close binaries. Because it covers a triennium of transition (1973–75), however, it may not be complete with respect to spectroscopic binaries for the early part of the interval.

Much of the effort of spectroscopists who work on close binaries has, during the last three years, been directed to the study of binary X-ray objects. Indeed the period under review may have been the time of the most intense activity in that field. Although X-ray binaries will be dealt with elsewhere in this report, we have attempted to list in the accompanying table the strictly spectroscopic investigations of them (in the optical and UV spectral regions) that have been published, except for the several brief announcements in IAU Circulars.

The ex-novae and eruptive variables, also systems that are presumably in a late stage of stellar evolution, continue to attract attention. Massive binary systems are intensively studied, expecially by Hutchings (in several papers), *cf.* his review of basic data on very massive stars (*PASP* **87**, 529). The massive binary LY Aur was studied by several groups, partly as a result of a co-ordinated campaign organized by the Commission.

Old favourites are still being observed, sometimes in new ways. Important observations of β Lyr have been made in the far UV from the *Copernicus* satellite (Hack *et al., ApJ* **198**, 453) and other early-type systems are being observed in this way. In the far ultraviolet spectrum of β Lyr no stellar absorption lines but a number of strong emission lines of multiply ionized elements (up to N V) have been found. Ground based observations of β Lyr have also continued. Several of the papers listed in the Table are based on observations made during another of the Commission's coordinated campaigns in the summer of 1971. In particular many observations of the Hα emission have been made by Skulsky, Flora and Hack, and Batten and Sahade. The last-named investigators found evidence for a considerable range of variation in the strength of the emission, and this result has been confirmed and extended by Sanyal (see Table 3, pp. 225–227).

One main concern is still the nature of the secondary component in the β Lyr system. Earlier claims that the K-line from the secondary has been found seem to be discounted now (Batten *et al.*, see Table 3). Hack *et al.* mention the hypothesis that the secondary might be a mass-accreting black hole; in this case the system is in the second epoch of mass exchange, Type B. Another possible description is that the secondary is rendered invisible by a thick disk surrounding it, as was proposed by Huang already in 1963. A model of this type has been worked out by Wilson (*ApJ* **189**, 319) based mainly on a quantitative analysis of the light curve; he found $\mathfrak{M}_2/\mathfrak{M}_1 \approx 4$. Huang and Brown (*ApJ* **204**, 151) estimated from an analysis of light curves in different colours that the temperature of the disk surrounding the secondary is about the same as that of the primary. This leads to the assumption of an early B-type secondary. They suggest that the emission lines found in the far ultraviolet may originate in a corona around the entire system.

The outburst of U Cephei, discovered both photometrically and spectroscopically by several observers in the fall of 1974, seems likely to be of particular importance for studies of the evolution of Algol-type systems. The activity subsided by the end of the year, but observations in September 1975 show that it has since resumed. Preliminary papers have appeared, and a major interpretive one is in press, but most of the spectroscopic results are still being discussed and analyzed. The observations of this system and of β Lyr underline one area of progress since the last report. We now have established the reality of changes in circumstellar matter in several systems. Other examples are Algol (the continuing work of Bolton) and YY Gem in which Bopp (see table) has established the existence of 'flares' in the circumstellar matter. Our success in this field is partly the result of the application of new techniques that permit observations to be made with high time-resolution, and partly the result of systematic routine programmes such as those undertaken at Lick by Plavec and his associates, at Victoria by Baldwin, and at Toronto by Bolton.

Supergiant systems continue to attract interest. The next eclipse of VV Cep is due soon, and Wright has already announced the appearance of chromospheric features in the spectrum. The VV Cep class of systems has been discussed by Wawrukiewicz and Lee (*PASP* 86, 51). Spectroscopic results of the 1956–57 eclipse of AZ Cas, a somewhat neglected object of this type, have been published (Mêndez *et al.*, *PASP* 87, 305). The late component, earlier classified as K or M supergiant, displayed an F8Ib spectrum. This striking variation of the spectral type is tentatively interpreted as indicating changes in the optical thickness of the envelope surrounding the late type component. AZ Cas undergoes eclipse during the second half of 1975 and we may hope to gain some further, much needed information.

Among these binary systems which contain an intrinsic variable component, α Vir was subject of considerable attention; an extensive spectroscopic study of the β CMa nature of the primary was published by Dukes (*ApJ* **192**, 81).

The star HD 107325 has to be deleted from the list of spectroscopic binaries, as a study by Bolton *et al.* demonstrated (*PASP* 87, 259).

The active groups listed in the last report (Okayama, Ondrejov, Toronto, La Plata – Buenos Aires, Los Angeles, and Victoria) have continued their work. Other groups are Hack and her associates in Trieste, and various Soviet astronomers at the Crimean Astrophysical Observatory. Many other observers have contributed to the unspectacular but important task of improving our knowledge of orbital elements.

The following table of spectroscopic observations is arranged along the same lines as in the last report, except that for convenience, X-ray binaries and suspected X-ray binaries are listed separately. Nominally it covers 1973–75, but papers published in 1972 and not listed in the previous report have been included. On the other hand, the literature of 1975 is reasonably complete only for the first eight or nine months of the year. Abstracts have been listed unless a full paper has subsequently appeared. An asterisk following a reference indicates that new values for the orbital elements will be found in the paper.

7. ABSOLUTE DIMENSIONS
(F. B. Wood)

New determinations of absolute dimension are summarized in Table 4 (p. 227).

In this section we concentrate on a particular question, where progress has been promising. During the past three years the existence of the sub-group of RS CVn (or AR Lac) variables as a distinctly separate type of systems has become more clearly established chiefly through the work of D. M. Popper, of J. P. Oliver, of S. Catalano and M. Rodono, and of D. S. Hall. Questions of their origin were discussed by Hall and by Ulrich at the Cambridge Symposium and will be found in its proceedings.

The following have developed as characteristics of this class:

(a) Most close double stars with late-type primaries, which are not W UMa stars are RS CVn systems.

(b) Space density studies show RS CVn stars may be the most commonly occurring binary stars.

(c) Evolutionary status is unclear; sometimes the 'more evolved' star is the more massive and sometimes the less massive. In addition, the numbers suggests their current evolutionary state must be a long-lived one.

(d) As a class, these stars are radio emitters, although large scale mass flow is not evident.

(e) Period changes in some are among the largest seen in close binaries, although neither component fills its zero-velocity or Jacobian surface (Roche lobe).

(f) Light curve variations up to 0.3 mag. occur outside eclipse.

(g) In some cases, the entire light curve has shifted by up to 0.2 mag.

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(h) One component is normally a F or G star, on or a little above the main sequence, while the other is usually a K0 subgiant.

(i) The systems are detached with roughly equal masses for the components. The combined masses are in the range of 1.0 to 4.0 solar masses, and usually in the range of 1.75 to 3.0 solar masses.

(j) Apparently these systems are not found in regions of star formation; none are known in clusters.

(k) H and K emission reversals are seen in the spectra of one or both components.

Further investigation of this class offers a challenge and the problem of their evolution is particularly important. As to some other studies:

Giannone and Giannuzzi (*Aph Sp Sci* **26**, 289) have computed the absolute dimensions of 140 close binary systems by combining spectrographic and photometric elements with an assumed mass luminosity relation or an assumed Jacobian (Roche) lobe fitting.

Devinney (*PASP* **85**, 330) has discussed an apparent gap in the mass distribution occurring at 3.5 solar masses. Hutchings (*PASP* **87**, 529) has collected and tabulated the well-determined masses and radii of O and early B stars.

8. PERIOD CHANGES
(T. Herczeg)

There was great interest shown in period changes of all types of close binaries during the triennium reviewed here. The basis of this growing concern is, of course, the hope to obtain reliable information about the rate of mass exchange and mass loss and establish, ultimately, time scales for different stages of binary evolution. The observational coverage of the brighter objects and, in particular, the photoelectric work was comparable to that of the previous years, with a large part of the material published in the *IBVS*. There is a mounting suspicion that this 'mass production' of minimum epochs brings, indeed, a slow deterioration of accuracy, *cf.* Duerbeck, *IBVS* 1023. An improved way of computing minimum times was put forward by Van Dienst (*Ast Aph* **42**, 465).

Among the more important objects or group of objects much attention was paid to the novae and U Gem-stars. Here we have the great benefit of the long series of eclipse timings by Mumford, of practically all available objects of this class, and the intensive studies of individual variables by Warner and his colleagues; these observations form the basis of any major period study. An investigation of the periods of nine eruptive variables has been carried out by Pringle (*MN* **170**, 633). He concluded that the evidence is 'not clear cut'; only two of the systems investigated (T Aur and EM Cyg), show unquestionable variations of the period (in both cases the period is decreasing), see also Mumford, *IBVS* 1043. In an important paper dedicated to rapid oscillations in the related object UX UMa, Nather and Robinson discussed the well established long term variations of the period, too (*ApJ* **190**, 637). New eclipse timings fit very well an earlier suggestion by Mandel of a 29-year secondary period (third body?).

A number of important Algol-systems has been thoroughly investigated at Skalnate Pleso Observatory (Bakos and Tremko, several papers in the *BAC*). U Cep was the subject of a detailed period study by Hall (*AA* **25**, 1). His interpretation of the O-C diagram means that the period changes consisted of longer intervals of linear increase, interrupted by quite substantial discontinuous, practically instantaneous, decreases. In the case of RW Tau, a sudden increase of the period about 1960 seems well established (see, e.g. Ahnert, *IBVS* 1030). The interacting eclipsing system SZ Psc is under study at the David Dunlap Observatory improving earlier results by Bakos and Heard. All photometric and spectroscopic data can be satisfied by assuming a linear decrease of the period which leads to the mass transfer rate (from the K- to the F-component) of $10^{-6}\,\mathfrak{M}_{\odot}\,\mathrm{yr}^{-1}$.

Several W UMa-type binaries have been investigated in detail, among them VW Cep and W UMa itself. Hershey's astrometric study of VW Cep (see p. 210) brought the result that the third body cannot be responsible for more than a modest fraction of the observed time residuals. After substracting the orbital effect, only erratic changes of the period remain. In the case of

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W UMa, the existence of a third body is favored in a study by Whelan *et al.* (*MN*, **168**, 31), since it explains both the period variations and the apparent discrepancy between the spectroscopically and photometrically determined mass-ratios.

The enigmatic behavior of the period of β Lyr was discussed by Klimek and Kreiner (*AA* **23**, 331; see also **25**, 29). Nearly 2000 epochs of primary and secondary minimum were considered, practically the whole available material since Goodricke's time. The authors came to the remarkable conclusion that representation of the residuals by a single quadratic formula is possible.

The white dwarf binary BD + 16°516 enables rather accurate timings of the minima, to a few seconds or even less. The period undoubtedly shows (perhaps cyclic) variations but their interpretation must await further data (Lohsen, *Ast Aph* **36**, 459; Young and Lanning, *PASP* **87**, 461).

Evidence is not clear cut either if we consider the X-ray binaries. In the case of Cyg X-1, although a possible abrupt change was mentioned recently, no secular variation of the period has been found as yet. For investigations of this type the work of Liller and his collaborators on the Harvard plate archive is of great importance.

For a few eclipsing variables, a substantial revision of the catalogue value of the period has been proposed: KP Aql, period should be doubled (Ibanoglu and Gülmen, *Ast Aph* **35**, 478): PV Cas, period doubled (Ibanoglu, *Ast Aph* **35**, 483); Söderhjelm observed that the system AY Mus was no longer eclipsing (*Ast Aph Suppl.* **22**, 263).

On the side of the theoretical interpretation of period changes, Biermann and Hall (*Ast Aph* **27**, 243) give a mechanism which may explain in a satisfactory way the alternate decreases and increases of the period, characteristic for many Algol-type systems. Developing a model by Smak, Biermann and Hall calculated the alternating, back and forth exchange of angular momentum between rotation and orbital motion and its influence on the period, as the mass transfer progresses. The theory was applied to the test object U Cep.

9. APSIDAL MOTION
(T. Herczeg)

Theoretical apsidal motion coefficients involving evolutionary considerations were calculated by Petty (*Aph Sp Sci* **21**, 189), Stothers (*ApJ* **194**, 651) and, particularly for α Vir, by Mathis and Odell (*ApJ* **180**, 517; **192**, 417). In the case of α Vir the very low observed value of log k (−2.6 or even −2.7) appeared seriously discrepant; Stothers (*loc. cit.*) found that, under some assumptions, the predicted and observed apsidal motions can be matched for an evolved primary using new opacities based on the Thomas-Fermi atomic model.

Observationally, apsidal motion in the α Vir system is generally accepted now although its period is not well determined (see Dukes, *ApJ* **192**, 81 and further references there). Other additions to the list of apsidal motion binaries are:

V 453 Cyg	Wachmann, *Ast Aph* **25**, 157
CW Cep	Nha, *AJ* **80**, 232
FT Ori	Grønbeck, *Ast Aph* **37**, 435
b Per	cf. *Quart. J. RAS* **15**, 303
EO Vel, KT Cen	Söderhjelm, *Ast Aph Suppl* **22**, 263
HD 98088	Wolff, *PASP* **86**, 179

Some cases need further confirmation. Also, the reality of apsidal motion in the HS Her system, announced earlier, has been questioned (Scarfe and Barlow, *PASP* **86**, 181) and the apsidal motion in the XX Cep system remains unconfirmed (Lavrov and Lavrov, *AC* 756).

Martynov continued work on RU Mon (*Ast Zh* **51**, 107), Battistini *et al.* re-discussed V380 Cyg (*Aph Sp Sci* **30**, 163). In Nijmegen, work on V523 Sgr and similar systems of long apsidal period is continuing (de Kort); in Siding Spring, the important southern binaries GL Car and V346 Cen are on the current program (Kříž), HH Car and other systems at ESO. Thomas

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discussed the possibility of apsidal motion in Cen X-3 (*ApJ* **191**, L25), several authors the period of the binary pulsar PSR 1913+16, see also p. 223.

Todoran (*First European Ast. Meeting* **2**, 42) investigated the cases where the determination of apsidal motion may be affected by changes in the orbital period. He recommended the following objects for systematic observation of both primary and secondary minimum:

GL Car; Y, MR, V477 Cyg; HS Her; CO Lac; RU Mon; AG Per.

10. STRUCTURE AND MODELS
(M. Kitamura)

A certain amount of overlap is unavoidable between this section and the section dealing with evolutionary problems (see in particular the review of contact binaries and novae).

During the past three years much effort was directed toward the study of models of W UMa-type contact binaries. Vilhu (*Ast Aph* **26**, 260) calculated a series of evolving models for contact systems with Biermann and Thomas-type structure of $1.8\mathfrak{M}_\odot$ total mass. Mochnacki and Whelan (*Ast Aph* **26**, 149) presented a model, in which the energy exchange occurs largely through the superadiabatic part of the common convective envelope and the secondary component is a few hundred degrees hotter than the primary. A critical condition was given by Hazlehurst (*As Aph* **36**, 49) for the secular stability of a contact binary in which the components share a common convective envelope, and application revealed that the models of Biermann and Thomas, Moss and Whelan and Vilhu are all unstable. Difficulty of construction of contact binary models at age zero with unequal components was further discussed by Whelan (*MN* **160**, 63) from consideration of the effects of opacity and rotation. Using the common convective envelope model, Lucy (*Aph Sp Sci* **22**, 381) analysed the light curves of sixteen sytems of the W UMa-type with spectroscopic mass ratios and showed an indication that W-type systems have only shallow common envelopes which may be a cause of the difference between A- and W-type systems. Yamasaki (*PASJ* **27**, 469) presented a new model of unequal entropy between the components for A-type W UMa stars by considering the energy transfer through turbulent motion in the contact region. Properties of the A- and W-type W UMa stars were also discussed by Rucinski (*AA* **24**, 119). An interesting hypothesis that magnetic starspots may occur in W UMa stars was presented by Mullan (*ApJ* **138**, 563).

Models for cataclysmic binaries were a target of attack by several authors. From a hydrodynamical study of the components transfering mass in semi-detached close binaries, Bath (*MN* **171**, 311) suggested a quasi-periodic mass transfer as being responsible for dwarf nova eruptions. Biermann and Thomas (*Ast Aph* **23**, 55) also constructed numerical models for cataclysmic binaries, in which the components are a main-sequence star filling the Roche limit and a white dwarf. An interesting possibility in regard to the outbursts in U Gem stars was raised by Osaki (*PASJ* **26**, 429) who proposed a model in which the outbursts may be caused by sudden gravitational energy release due to intermittent accretion of material onto the white dwarf component from the surrounding disk. Losses of mass and angular momentum during the evolution towards cataclysmic binaries was also discussed by Ritter (*AG Mitt* **36**, 93). A model for post novae was studied by Finzi (*ApJ* **183**, 183); in this model the light originates in the central star after the explosion, not in the ejected envelope, and also the atmosphere of the central star is steadily flowing out, while in a deeper shell energy is largely carried by convection. Internal structure of uniformly rotating close binaries were also discussed with polytrope models by Naylor and Anand (*Aph Sp Sci* **18**, 59), by Naylor (*Aph Sp Sci* **18**, 85), and by Green and Kolchin (*Aph Sp Sci* **21**, 285).

11. LIMB DARKENING AND PROXIMITY EFFECTS
(M. Kitamura)

The non-linear effect of limb darkening has received much attention for these three years, but Shulberg's discussion (*Astr Zh* **50**, 981) has concluded that the direct finding of the effect from

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real eclipsing systems is impossible at present. A comparison between theoretical and empirical limb-darkening coefficients was presented by Choodnovskij and Shulberg (*AC* 754), and theoretical values of the coefficients were discussed by Rubashevskij (*AC* 851). A study of the limb-darkening law based on detailed non-grey LTE model atmospheres was presented by van Landingham (*BAAS* **5**, 43).

Following Rucinski's important earlier contribution (*AA* **19**, 245) on the bolometric reflection effect for stars with deep convective envelopes, he further gave the exact solution for the source function in monodirectional illumination of the grey atmosphere; he also discussed the convection efficiency for subgiant secondaries in semidetached systems showing the reflection effect. Along the same line, Ureche's discussion (*Studii Cerc. Astr.* **17**, 213) of the photometric reflection of AI Dra with some modified Napier's method confirmed that the albedo is considerably less than unity, being in agreement with Rucinski's result. The spectral types of the cool components with convective envelopes were considered (Koch, *AA* **23**, 301) by taking into account the radiative interaction between the components. The effect of reflection upon spectral lines was discussed by Chen and Rhein (*AA* **23**, 247) for W UMa-type binaries and also by Tomasson and Pustylnik (*Perem. Zv.* **19**, 279). Important articles by Binnendijk deal specifically with the reflection effect in very close eclipsing binary systems with distorted components (*Vistas* **16**, 85) and with the limb- and gravity-darkening in distorted components (*Vistas* **16**, 61). The amounts of gravity darkening for W UMa-type systems were discussed by Wilson and Devinney (*ApJ* **182**, 539) from differential correction analysis of their light curves. A photometric proximity effect was discussed by Shakura and Dmitrienko (*AC* 835), but a full investigation of the proximity effects in the light curves of close binaries was carried out by Budding (*Aph Sp Sci* **29**, 17) who used Kopal's *a*-functions and related integrals extensively in order to apply for SZ Cam. Wood (*MN* **164**, 53) presented a procedure of computation for the reflection effect which can reduce the computing time necessary for modeling eclipsing binaries.

12. SPECTRAL LINE PROFILES
(M. Kitamura)

The majority of papers are devoted to the variation of spectral line profiles with phase in close binary systems. Theoretical variations of line profiles of eclipsing binaries during eclipses were investigated by Sato (*PASJ* **26**, 65) and applied to discussions of observed asymmetric line profiles in R CMa, YZ Cas and RZ Sct; the conclusion was that some additional absorption by gaseous matter should affect the shapes of the profiles. Hutchings (*ApJ* **180**, 501) calculated distortion of line profiles and radial velocities in the spectra of W UMa systems and estimated the effect on values of mass ratios. Hydrogen profiles, helium strengths and surface gravities of eclipsing binaries were also discussed by Olsen (*ApJ Suppl* **29**, 43). Using spectrographic data of the 1971–72 Zeta Aur eclipse, Saito (IAU Symp No. 51, 213) detected definite satellite lines of Ca I (λ6572). Kim and Kitamura (*Ann Tokyo Obs* No. 16) studied a number of high-dispersion spectrograms of WW Aur and found that the amount of metallicity of this system changes within eclipses. The effect of gas streams (due to mass transfer) upon the line profiles was calculated by Sima (*Aph Sp Sci* **24**, 421) in detail for the case of $i = 90^\circ$.

13. GAS STREAMS AND MASS TRANSFER
(M. Kitamura)

Most work on mass transfer in close binaries continued to be based on the outflow of mass through the Lagrangian points due to dynamical instability. The gas dynamics of semidetached close binaries was treated by Lubow and Shu (*ApJ* **198**, 383) within the context of the Roche model, assuming that the contact component rotates synchronously and that the flow occurs isothermally with the thermal speed. Concerning mass exchange, Wilson (*MN* **170**, 497) considered the limiting efficiency with which orbital angular momentum can be converted into rotational angular momentum of the mass-gaining component. Plavec *et al.* (*PASP* **85**, 769) discussed the mass loss from convective envelopes of contact giant components; see also section 15 on evolutionary problems.

A good review of the arguments about envelopes in eclipsing binaries was presented by Huang (*Aph Sp Sci* **21**, 263). Dimensions of gaseous rings surrounding the brighter components in semidetached binaries were deduced hydrodynamically by Kitamura (*IAU Symp* **51**, 107) using Roche coordinates. The radius of the gaseous disc in close binaries was examined by Piotrowski (*AA* **25**, 21) and he concluded that the disc radius should increase with the mass of the parent component. Kříž (*BAC* **23**, 328) pointed out that in Algol-type binaries gaseous rings should be generated during mass transfer in Case B rather than Case A. Formation of a gaseous shell around the whole system was further studied by Bielicki *et al.* (*Aph Sp Sci* **26**, 173) for the case of slow outflow of gas through the external Lagrangian point. The ejection of mass to interstellar space was estimated by Svechnikov (*Perem. Zv.* **18**, 525).

During the reviewed period several authors attempted to get a better understanding of the 'hot spot' problem in close binaries. Such work was reported by Warner and Peters (*MN* **160**, 15) and by Flannery (*MN* **170**, 325), using a somewhat different approach. They mainly dealt with the location and size of the hot spot in cataclysmic binaries while Walter (*Aph Sp Sci* **21**, 289) considered the existence of luminous regions created by impact of gas streams in Algol-type systems. Walter's discussion was based upon photometric effects of gas streams, causing distortions of the light curves. Asymmetric light variations outside eclipses in W Uma-type systems were investigated by Breinhorst and Reinhardt (*AA* **24**, 377). An interesting report has come from image tube study of spectra of early-type stars in the region of the infrared Ca-triplet by Polidan, *et al.* (*BAAS* **5**, 413), suggesting that the presence of the Ca-triplet in emission in such stars is indicative of a binary star with mass exchange.

14. STATISTICAL WORKS
(T. Herczeg)

An investigation of multiplicity among solar-type stars has been carried out by Abt and Levy (in press, *ApJ*). Twenty-five new spectroscopic binaries has been detected in the spectral range F3-G2 (IV or V) and the combination of these results with data of known binaries gives the observed frequencies of singles: doubles: multiples as 42:46:12%. Their results suggest that in the solar neighbourhood single stars may be rare. Bettis and Branch (*PASP* **87**, 895) pointed out that the equivalent width of the D-line is a sensitive criterium in detecting faint companions of late main-sequence stars. The binary frequency among OB stars with anomalous N and C absorption lines was considered by Rogers and Bolton (*BAAS* **6**, 488).

Kříž and Harmanec discussed the possible binary origin of Be stars in *BAC* **26**, 65.

A study by Conti and Burnichon (*Ast Aph* **38**, 467) led to the conclusion that a substantial fraction of O stars have masses higher than 60. The mass determination was indirect, based on the positions in the HR-diagram and evolutionary tracks calculated by Stothers. It seems therefore particularly important that a study by Hutchings of the most massive, early type spectroscopic binaries (*PASP* **87**, 529) gave results consistent with those of Conti and Burnichon.

The distribution of binary mass ratios was discussed by Trimble (*AJ* **79**, 969), based on the 'Sixth Catalogue'. The sample suggests a bimodal distribution with peaks near mass ratios 0.3 and 1.0 (two populations of binaries formed in a different way?).

The question of coplanarity of orbits in open clusters was taken up again, by Ferrer and Jaschek (*PASP* **85**, 207) extending an earlier study by Kraft. They suggest for IC 4665 an average inclination of 45°, with a fairly small dispersion.

The rotation in binary stars and the problem of synchronism was again discussed by Levato using new observational material (*Ast Aph* **35**, 259). Borst and Troche-Boggino (*BAAS* **6**, 335) also considered this problem.

Blue CN-absorption was measured for 97 close binaries by Koch (*AJ* **79**, 34). Anomalous indices were found for certain types of binaries by more observations are necessary before conclusion can be reached.

The effect of stellar encounters on binary orbits was the subject of an interesting study by Hills (*AJ* **80**, 809, 1075) a problem which was considered earlier by van Albada and others. Hills' computer-simulated encounters strongly suggest the existence of a 'well defined' critical value of the pre-encounter velocity; below this velocity, the encounter tends to shrink the binary orbit, above, the orbit increases and eventually the binary breaks apart. In clusters, shrinking orbits feed kinetic energy in the system and can influence its structure significantly.

Wide pairs should be almost completely eliminated from globular clusters by encounters. On the other hand, tidal capture in dense stellar systems may play a role in the origin of binaries, even very close systems, see Fabian *et al.* (*MN* **172**, 15P).

Several other studies of statistical nature, like for instance the binary character of the blue stragglers, are mentioned elsewhere in this report. For a review of the field of binary statistics, see Jaschek, *AG Mitt.* **36**, 45.

15. EVOLUTION OF CLOSE BINARY SYSTEMS
(M. Plavec)

The following section of the Report will only deal with the evolution of 'ordinary' close binaries – a summary of recent work done on the evolution of contact binaries and novae is given in Sec. 16.

Very good agreement for AS Eri between observations (Popper, *ApJ* **185**, 265) and theory (Refsdal, Roth, and Weigert, *Ast Aph* **36**, 113) shows that the mass transfer models for Algols are essentially correct. Nevertheless, critical confrontation of models and observed systems shows that refinements are needed (Plavec, *IAU Symp.* **51**, 216; Koch, *AJ* **78** 410; Hall, *AA* **25**, 1). It is agreed that even massive Algols evolve according to mode B. Mass loss from the system may be required, and recent studies of gas streaming and disk formation promise to supply some necessary clues (Lubow and Shu, *ApJ* **198**, 383; Flannery, Pringle, and Shu, all in *Cambridge*; Prendergast and Taam, *ApJ* **189**, 125; Bielicki, Piotrowski, and Ziółkowski, *Aph Sp Sci* **26**, 173; Huang, *Aph Sp Sci* **21**, 263; Wilson and Stothers, *MN* **170**, 497). Equally important is the behavior of the mass-accreting component. Ulrich and Burger (*Cambridge*) find that at higher rates of mass transfer, this star may become greatly overluminous and eventually expand.

The process of mass transfer in Algols appears to be discontinuous and variable on a short time scale, thereby possibly causing the observed fluctuations of the periods (Biermann and Hall, *Ast Aph* **27**, 249; Hall, *AA* **25**, and *Cambridge*). They suggest that there may be instability on a dynamical time scale as put forward by Bath (*MN* **171**, 311; Papaloizou and Bath, *MN* **172**, 339).

Extensive model calculations with mass transfer and mass loss, in certain cases including also magnetic fields, were carried out by Drobyshevski and Rezhikov (*AA* **24**, 29, 189).

Naftilan (*BAAS* **7**, 476) finds that the subgiant in U Sge has anomalous metal abundances.

It was noted several years ago that mass transfer in case B leads to the formation of a disk around the accreting component, so that the star may appear as a Be or shell star (Plavec, *IAU Coll.* **4**, 133; Plavec *et al. BAAS* **5**, 398 and *Cambridge*). Křiž and Harmanec (*BAC* **26**, 65 and *Cambridge*) suggest that all Be stars are interacting binaries. On the other hand, it seems that some blue stragglers are not binaries (Hintzen *et al.*, *ApJ* **194**, 657).

The puzzling problem of undersize subgiants seems to have been solved by Hall (*AA* **24**, 215) who claims that their existence was due to inaccurate observations and that the only real group of undersize subgiants are the stars of the RS CVn (or AR Lac) type. These have been systematically studied by Popper who considers as the main characteristics the H and K emission (Ulrich and Popper, *BAAS* **6**, 461). Origin of these systems was discussed by Biermann and Hall (*Cambridge*) who prefer explanation in terms of post-main-sequence fission of a single star. On the contrary, Ulrich (*Cambridge*) suggests mass loss through stellar wind in the post-main-sequence stage. Stellar winds in binary systems tend to gain in importance in various aspects, and some theoretical work has been done (Siscoe and Heinemann, *Aph Sp Sci* **31**, 363).

The peculiar emission spectrum of β Lyr observed in the far ultraviolet (Hack *et al.*, *ApJ* **198**, 453) revived the discussion of the evolution of this systems. Of the two alternations proposed in the above article, i.e. an accreting black hole or a case B Algol-type mass transfer in the first epoch, the consensus is more in favor of the latter explanation (Kříž, *Nature* **245**, 36 and *BAC* **25**, 1 and 6; Ziółkowski, *ApJ* **204**, 512).

The problem of evolution of massive binaries, with various scenarios leading to collapsed objects, pulsars, supernovae, and X-ray sources, has been studied by a number of investigators, perhaps most systematically by van den Heuvel, de Loore, and associates (see, e.g., *Ast Aph* **25**, 387; *Aph Sp Sci* **35**, 241 and **36**, 219, and *Cambridge*).

Evolution of close binaries of low mass was studied extensively by Webbink (*Cambridge*). For moderate masses and near the main sequence, mass transfer proceeds on thermal time scales, but for stars on the giant branch (Plavec *et al. PASP* **85**, 769) or for stars of low mass, the event may be catastrophic, and the system may be drastically altered. Webbink suggests that the second mass transfer in Algols will form the low-mass ultrashort-period double white dwarf binaries, and that case C may generate the cataclysmic variables of the U Gem and Z Cam type. Webbink (*MN* **171**, 555) also studied the further evolution of helium white dwarfs generated by the first mass transfer in close binaries.

Various hypotheses were proposed connecting different types of binaries. Thus Huang (*BAAS* **5**, 41) suggests that the RS CVn stars ultimately develop into the W UMa systems. Warner (*MN* **167**, 61P) thinks that the W UMa systems evolve into cataclysmic variables, and these in turn become Type I supernovae. Whelan and Iben (*ApJ* **186**, 1007) suggest that, on the contrary, progenitors of Type I supernovae in elliptical galaxies are wide binary systems undergoing second mass transfer. Gorbatsky (*Aph Sp Sci* **33**, 325) believes that the W UMa systems originate by fission of a rapidly rotating helium core in a giant. Then the contraction of the more massive component leads to the transformation of the W UMa system to a nova-like variable.

The very short periods observed in close binaries of various types (Cyg X-3, the binary pulsar PSR 1913+16, the cataclysmic variables, the quiet white dwarf binary BD+16°516, and another dwarf binary recently discovered by M. Schmidt) pose a serious problem, for these systems must have passed through a stage of common envelope. One aspect of the motion of one star inside another was already studied by Sparks and Stecher (*ApJ* **188**, 149) who propose that a white dwarf spiraling into a red giant will cause a supernova explosion. Paczynski and Ostriker (*Cambridge*) find a less drastic scenario in which the giant gradually loses envelope, a planetary may be formed, and in the end one is left with the two cores moving in a very close orbit.

Hydrodynamic models of novae were studied by Starrfield, Sparks and Truran in a series of papers (see, for instance, *ApJ* **192**, 647 and references therein, also *Cambridge*). From a broader point of view, Faulkner, Eggleton and Webbink (*BAAS* **5**, 441) studied the response to mass loss of the radii of low-mass stars. They find that outbursts of dwarf novae cannot be caused by convective envelope instability of the red component, if this star is near the main sequence.

Various aspects of the tidal evolution of close binary systems were studied by Haymes (*Aph Sp Sci* **22**, 166) and by Alexander (*Aph Sp Sci* **23**, 459). From a more empirical point of view, Stothers (*PASP* **85**, 363) studied the role of rotation in the structure and evolution of massive binaries.

16. EVOLUTION OF CONTACT BINARIES AND NOVAE
(J. Smak)

Efforts have continued to modify the original common convective envelope model (Lucy, *ApJ* **151**, 1123) for contact binaries, to reproduce the observed period-color relation. Several authors (e.g. Biermann and Thomas, *Ast Aph* **16**, 60; Hazlehurst, *Ast Aph* **36**, 49; Moss and Whelan, *MN* **149**, 147; Vilhu, *Ast Aph* **26**, 267; Whelan, *MN* **156**, 115; **160**, 63) attempted to

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modify either the assumption of identical entropy or that of the chemical homogeneity (zero-age vs. evolved models). The most promising in this respect, however, is the idea advanced independently by Luch and Flannery (in press) to relax the assumption of thermal stability. It appears, in particular, that the properties of at least the W-type systems can be understood in terms of a model in which the components of a contact binary undergo thermal relaxation oscillations around the state of marginal contact. An extensive discussion of these problems (Flannery, Hazlehurst, Whelan) was presented at Cambridge (IAU Symposium No. 73).

The evolutionary problems of contact systems and nova-type binaries have been discussed in a number of papers (cf. Gorbatsky, Warner, for references, see Sec. 15. Van 't Veer, *Ast Aph* **40**, 167). But it appears that a major progress in this field (as well as in many other fields) is likely to be made by developing the concept of 'binaries in common envelopes' discussed by Ostriker and Paczyński at the Cambridge Symposium.

17. COLLAPSED OBJECTS IN CLOSE BINARY SYSTEMS
(E. P. J. van den Heuvel)

(See also the report of Commission 44)

In the last three years this subject underwent an explosive development, due to the many discoveries made with the Uhuru and other X-ray satellites, followed by optical identifications and ground based optical studies of X-ray binaries by a rapidly increasing number of observers.

So far ten X-ray binaries have been discovered, one of which is in the Small Magellanic Cloud. Six of these systems consist of a massive early-type star and a compact star; in three of these massive systems (Cen X-3, Vela X-1, X Per) the compact star is an X-ray pulsar, presumably a neutron star. The discovery of the rapid binary radio pulsar, PSR 1913+16 (Hulse and Taylor, *ApJ* **195**, L51) provided an unambiguous proof that the formation of a neutron star in a close binary does not necessarily disrupt the system, a fact already anticipated by theoretical investigations. The binary pulsar may become an important test object for general relativity (Esposito and Harrison, *ApJ* **196**, L1; Will, *ibid.* L3). Clearly, with all these results, the two centuries old field of close binary astronomy has moved into the very forefront of modern astrophysics. New results were presented at many meetings as well as in review articles. We mention *'X- and Gamma-Ray Astronomy' IAU Symp.* **55**, (eds. H. Bradt and R. Giacconi Reidel, 1973); *X-Ray Astronomy* (eds. R. Giacconi and H. Gursky, Reidel, 1974): *Astrophysics and Gravitation* (Proc. XVIth Internat. Solvay Conf. on Physics, Editions Univ. Bruxelles, 1974); *Neutron Stars, Black Holes and Binary X-Ray Sources* (eds. H. Gursky and R. Ruffini, Reidel, 1975); *Workshop Papers for a Symposium on X-ray Binaries* (eds. Y. Kondo and E. Boldt, NASA, preliminary edition); *Compact X-ray Sources* (Blumenthal and Tucker, *Ann. Rev. A.A.* **12**, 23); *Gravitational Radiation and Gravitational Collapse* (ed. C. DeWitt-Morette; Reidel, 1975).

Important work on the analysis of optical lightcurves of X-ray binaries was done by Lyutiy *et al.* (*Astr Zh* **50**, 3), Bahcall and co-workers, several papers, Hutchings (*e.g. ApJ* **192**, 677) and Mauder (*ApJ* **195**, L27). Together with radial velocity studies and X-ray eclipse data, these studies enable the determination of limits on the masses of X-ray sources. Thus the accurate radial velocity data (Bolton, *ApJ* **200**, 269) and photometric data for HDE 226868 lead to a minimum mass of around $9\mathfrak{M}_\odot$ for Cyg X-1 (Avni and Bahcall, *ApJ* **197**, 675), suggesting that this object is a black hole. Optical pulses from HZ Her were detected by Davidson *et al.* (*ApJ* **198**, 653) and allow a determination of the shape of this star. With the help of a Roche model, this leads to a mass estimate for the neutron star of around $1.3\mathfrak{M}_\odot$ (Nelson, *Seventh Texas Symp. on Relativistic Astrophys., N.Y. Acad. Sci.* **262**, Bergmann *et al.* edit.)

Other highlights of the past years were: The discovery of the optical counterparts of Vela X-1 (Jones and Liller, *ApJ* **184**, L65), 3U 1700-37 (Jones *et al., ApJ* **181**, L43) and Cen X-3 (Krzeminski, *IAUC* 2569); the discovery by Gottlieb *et al* (*ApJ* **195**, L33) of a 0.78-day photometric periodicity of Sco X-1, confirmed by radial velocity observations by Cowley and Crampton (*ApJ* **201**, L65); the discovery of a 283-sec periodicity in the X-ray emission of the eclipsing source Vela X-1 (Rappaport *et al.*, *IAUC* 2833). The doppler variations of this pulsation period together with the radial velocity curve of the optical companion HD 77581 lead to a direct determination of the mass of the pulsar, *viz*. $1.62 \pm 0.21\mathfrak{M}_\odot$ (van Paradijs *et al.*, *Symposium on X-ray Binaries*); the discovery of a 22-hour and a 13.924-min periodicity in the X-ray emission of X-Per (White *et al.*, *IAUC* 2855) suggesting this source to be another pulsating X-ray binary. Important contributions to the physics of accretion in X-ray binaries came, among others, from Shakura and Sunyaev (*Ast Aph* **24**, 337), Thorne and Price (*ApJ* **195**, L101) and McCray and co-workers (*cf.* McCray and Hatchett, *ApJ* **199**, 196). For the massive X-ray binaries accretion must be due to stellar wind (Davidson and Ostriker, *ApJ* **179**, 585), in the low-mass systems (Her X-1, Sco X-1). Roche-lobe overflow seems the most likely mechanism (van den Heuvel, *ApJ* **198**, L109). The evolutionary history of massive X-ray binaries was considered in detail by Tutukov and Yungelson (*Nauchnie Inform*. **27**, 70) and De Loore *et al.* (*Mem. Soc. Roy. Liège*, **6** (VIII), 399); case B evolution of massive close systems seems to account well for the origin of the massive X-ray binaries. The origin of the low-mass systems is not yet well understood. The orbital effects of the supernova explosion of the most evolved component in a case B system were studied in detail by Sutantyo (*Ast Aph* **31**, 339; 41, 47), Wheeler *et al.* (*ApJ* **192**, L71; **200**, 145), Cheng (*Aph Sp Sci* **31**, 49) and De Loore *et al.* (*Aph Sp Sci* **36**, 219). Neither the effects of mass loss and impact of the supernova shell on the companion, nor slight asymmetries in the explosion seem, in general, to be able to disrupt such systems; this is mainly due to the fact that in case B systems the exploding star is always less massive than its companion, due to preceeding mass exchange.

The final evolution of massive X-ray binaries seems to lead to the spiralling down of the compact star into the envelope of its companion wither due to tidal effects (Sparks and Stecher, *ApJ* **188**, 149; Sutantyo, *Ast Aph* **35**, 251; Chevalier, *ApJ* **199**, 189; Wheeler *et al.*, *ApJ* **192**, L71) or to other effects involving large loss of mass and angular momentum from the system (De Loore and van den Heuvel, *Ast Aph* **25**, 387). These effects were discussed extensively by Paczynski and Ostriker at IAU Symposium No. 73 in Cambridge; see also p. 222 of this report. After the spiraling in the second supernova explosion, this might lead to the formation of two runaway collapsed stars or of a close binary consisting of two collapsed stars. So far this seems to provide the only consistent scenario for the formation of the binary radio pulsar PSR 1913+16 (*cf.* Webbink, *Ast Aph* **41**, 1).

Recent developments in the field of X-ray binaries and collapsed objects are still of an almost incredibly rapid pace. During the few weeks when this report was 'finalized', X-ray sources appeared nine times in the IAU *Circulars* and fifteen papers on X-ray binaries were offered on the Chicago Meeting of the AAS. Thus the discussion of these objects had to be restricted to the apparently most important and best founded results. The spectacular event of the appearance of an intense transient X-ray source in August 1975 (A0620-00) was not mentioned above: although the source has been optically identified with an object resembling a recurrent nova, no direct evidence for its binary nature is available yet; nonetheless, several models have been worked out along the line of its possible close binary structure. Nor did the report mention other transient sources which may well be binaries but their relationship to the other, less variable X-ray sources is not yet clear. It has also been suggested that X-ray sources in globular clusters were binaries, although this possibility may be more remote. We are looking forward to further great advances.

Table 1. Published Photoelectric Observations (F. B. Wood)

RT And, *Ast Aph Suppl.* **12**, 313; TW And, *Ast Aph* **24**, 131; AB And, *Ast Aph Suppl.* **12**, 313; Aur, *PASP* **85**, 131; *Tokyo Obs. Bull.* **2**, 2577; *Ast Aph Sp Sci* **22**, 127, *Tokyo Obs. Ann.* XIII, 243, *Observ.* **93**, 30; WW Aur, *Tokyo Obs. Ann.* XV, 117; IM Aur, *IBVS* 916; LY Aur, *PASP* **84**, 33, 394; *ApJ* **186**, 939; VW Boo, *AJ* **78**, 103; BW Boo, *IBVS* 1007; SZ Cam, *Tokyo Obs. Bull.* No. 220; RZ Cas, *AJ* **79**, 642; TV Cas, *BAC* **24**, 305; AR Cas, *Aph Sp Sci* **23**, 403; DN Cas, *PASP* **86**, 661; DO Cas, *Tartu Pub.* XLI, 165; OX Cas, *AA* **25**, 117; SV Cen, *PASP* **84**, 686; HD 101799 Cen, *AJ* **78**, 413; U Cep, *Ast Aph Suppl.* **19**, 337, *BAC* **24**, 298; VW Cep, *MSAIt* **41**, 395, 43, 1, *Tartu Pub.* XLII, 103; WX Cep, *PASP* **87**, 795; CQ Cep, *Perem. Zv.* **18**, 459; CW Cep *AJ* **80**, 232; NY Cep, *PASP* **85**, 319, *JRAS* Canada **68**, 96; Z Cha, *MN* **168**, 235; TX Cnc, *PASJ* **24**, 213; RZ Com, *Aph Sp Sci* **22**, 381; W Cru, *MNASSA* **31**, 25; RV CrV, *Ast Aph Suppl.* **13**, 101; HD 110139 Crv, *Ast Aph Suppl.* **13**, 81; AM CVn, *MN* **159**, 101; *AA* **22**, 387; 31 Cyg, *PASP* **85**, 348, *IBVS* 757, 892, *ApJ* **195**, 121; 32 Cyg, *Tokyo Obs. Bull.* Nos. 219, 227, 237, *Ast Aph* **20**, 165; *ApJ* **187**, 521, *Abastumani Bull.* Nos. 37, 45, *PASP* **86**, 689, 947; Y Cyg, *Akita Mem.* No. 24; WW Cyg, *PASP* **84**, 541; ZZ Cyg, *AA* **24**, 79; BR Cyg, *BAC* **24**, 311; MR Cyg, *Aph Sp Sci* **19**, 395; V 382 Cyg, *PASP* **87**, 409; V 444 Cyg, *Perem. Zv.* **18**, 321, **19**, 73, *Soviet AJ* (transl.) **17**, 330; V 453 Cyg, *Ast Aph* **34**, 317 and *Suppl.* **15**, 181; V 729 Cyg, *AA* **24**, 69; CW Eri, *AA* **25**, 89; RX Gem, *Ast Aph* **38**, 335 and *Suppl.* **20**, 227; AK Her, *PASP* **84**, 566, V 624 Her *AJ* **77**, 610; SW Lac, *Ast Aph Suppl.* **13**, 127; β Lyr, *AA* **22**, 305, **25**, 29, *Rosemary Hill Contr.* No. 39, *PASP* **85**, 133, *IBVS* **805**, *JAAVSO* **2**, 67, *Tokyo Obs. Bull.* 233, *Ast Aph Suppl.* **13**, 405; TZ Lyr, *AJ* **77**, 595; RU Mon, *Sternberg Contr.* No. 185; VV Ori, *Ast Aph Suppl.* **22**, 19; U Oph, *ApJ* **185**, 921; AR Pav, *MN* **167**, 635; DI Peg, *AJ* **78**, 97; AE Phe, *AJ* **80**, 140; Y Psc, *Aph Sp Sci* **21**, 289; VZ Scl, *MN* **172**, 433; V 701 Sco, *Ast Aph Suppl.* **13**, 315; CV Ser, *Soviet AJ* (transl.) **15**, 955; CU Tau, *Abastumani Bull.* No. 45, 45; UX UMa, *MN* **159**, 429, *ApJ* **190**, 637.

Table 2. Photometric Solutions (F. B. Wood)

RT And, *IBVS* No. 830, *PASP* **86**, 912; TW And, *Ast Aph* **24**, 131; AB And, *AA* **23**, 131; AB And, *AA* **23**, 79, *Ast Aph Suppl.* **12**, 313; KO Aql, *PASP* **86**, 187; KP Aql, *Ast Aph* **35**, 487; V539 Ara, *Bamberg Veröff.* X, 126; WW Aur, *Tokyo Obs. Ann.* XV, 117, *Aph Sp Sci* **22**, 87, LY Aur, *ApJ* **187**, 93; 44i Boo, *AA* **23**, 79; TZ Boo, *AA* **23**, 79; VW Boo, *AJ* **78**, 103; AY Boo, *AA* **23**, 79; AC Boo, *AA* **23**, 79; SZ Cam, *Aph Sp Sci* **22**, 87, **29** 17; TW Cas, *Aph Sp Sci* **32**, 291; YZ Cas, *Aph Sp Sci* **22**, 87; DO Cas, *Tartu Pub.* XLI, 165; PV Cas, *Ast Aph* **35**, 483; RR Cen, *AA* **23**, 79; SV Cen, *PASP* **84**, 686; HD 101799 Cen, *AJ* **78**, 413; U Cep, *Asp Aph* **37**, 263; VW Cep, *AA* **23**, 79, *Aph Sp Sci* **22**, 381; WX Cep, *PASP* **87**, 795; CQ Cep, *Ast Issledov.* **6**, 11, *Perem. Zv.* **19**, 441; CW Cep, *AJ* **80**, 132, EI Cep, *Aph Sp Sci* **32**, 285, GK Cep, *ApJ* **179**, 539; TW Cet, *AA* **23**, 79, *Aph Sp Sci* **22**, 381; S Cnc, *Perem. Zv.* **19**, 97; RV Cnc, *Perem. Zv.* **19**, 431; TX Cnc, *PASJ* **24**, 213, *ApJ* **183**, 133, *AA* **23**, 79; RZ Com, *AA* **23**, 79, *ApJ* **182**, 539, *Aph Sp Sci* **22**, 381; α CrB, *Aph Sp Sci* **26**, 371; RS Crv, *Ast Sph Suppl.* **13**, 101; RV Crv, *Ast Aph Suppl.* **13**, 101; HD 110139 Crv, *Ast Aph Suppl.* **13**, 8; VZ CVn, *Ast Aph Suppl.* **13**, 119; UZ Cyg, *Perem. Zv.* **19**, 431; VW Cyg, *Perem. Zv.* **19**, 431; WW Cyg, *PASP* **84**, 541; ZZ Cyg, *AA* **24**, 79; DK Cyg, *AA* **23**, 79; MR Cyg, *Aph Sp Sci* **19**, 395, *Ast Aph* **34**, 59; V 444 Cyg, *BAC* **24**, 243; V 453 Cyg, *Ast Aph* **34**, 317, and *Suppl.* **15**, 181; V 477 Cyg, *Aph Sp Sci* **26**, 371; V 729 Cyg, *AA* **24**, 69; HD 187399 Cyg, *ApJ* **188**, 341; UX Eri, *AA* **23**, 79; YYEri, *AA* **23**, 79; CW Eri, *AA* **25**, 89; RX Gem, *Ast Aph* **38**, 225; YY Gem, *Aph Sp Sci* **22**, 87; TU Her, *Perem. Zv.* **19**, 431, TX Her, *BAC* **24**, 57; AK Her, *AA* **23**, 79; *PASP* **84**, 566; HS Her, *Perem. Zv.* **18**, 269; V 624 Her, *AJ* **77**, 610; VZ Hya, *Aph Sp Sci* **33**, 256; FG Hya, *AA* **23**, 79; SW Lac, *AA* **23**, 79, *Aph Sp Sci* **22**, 381; CM Lac, *Aph Sp Sci* **22**, 13; UZ Leo, *AA* **23**, 79; XY Leo, *Aph Sp Sci* **22**, 381; AM Leo, *ApJ* **179**, 539 *AA* **23**, 79; UZ Lib, *MN* **161**, 331; β Lyr, *Bamberg Veröff.* IX, 308, *ApJ* **189**, 319; TZ Lyr, *AJ* **77**, 595; XZ Lyr, *MN* **167**, 369; U Oph *ApJ* **185**, 921; V 502 Oph, *AA* **23**, 79, *Aph Sp Sci* **22**, 381, V 566 Oph, *ApJ* **179**, 539, *AA* **23**, 79, *Aph Sp Sci* **22**, 381; V 839 Oph, *AA* **23**, 79; VV Ori, *Ast Aph Suppl.* **22**, 19; BM Ori, *ApJ* **195**, 127; ER Ori, *Aph Sp Sci* **22**, 81; U Peg, *AA* **23**, 79, *Aph Sp Sci* **22**, 381, EE Peg, *Aph Sp Sci* **22**, 13; GH Peg, *Aph Sp Sci* **29**, 435; AE Phe, *AJ* **80**, 140; Y Psc, *Aph Sp Sci* **24**, 189; V 701 Sco, *Ast Aph Suppl.* **13**, 315; AU Ser, *AA* **23**, 79; U Sge, *MSAIt* **43**, 510; V 505 Sgr, *AJ* **77**, 672; V 2283 Sgr, *Ricerche Ast.* **8**, 491; RZ Tau, *ApJ* **182**, 539, *AA* **23**, 79, *Aph Sp Sci* **22**, 381; HO Tel, *Studii Cerc. Astr.* **18**, 193; W UMa, *ApJ* **179**, 539, *AA* **23**, 79, *Aph Sp Sci* **22**, 381; TX UMa, *Aph Sp Sci* **20**, 123; AW UMA, *AA* **23**, 79, *ApJ* **182**, 539; RU UMi, *PASP* **83**, 286; AG Vir, *AA* **23**, 79; AH Vir, *Aph Sp Sci* **22**, 381.

Table 3. Published Spectrographic Observations (A. Batten)

AN And: Young (*PASP* **86**, 63); TT Ari: Cowley *et al.* (*ApJ* **195**, 483*); β Ari: Gorza and Heard (*PDDO Toronto* **3**, No. 4*); BF Aur: Mammano *et al.* (*Ast Aph* **35**, 143*); LY Aur: Anderson *et al.* (*Ast Aph* **31**, 1*), Heap (*ApJ* **186**, 939); α Aur: Batten and Erceg (*MN* **171**, 47P*), Dupree (*ApJ* **200**, L27); β Aur: Wright

(*JRASC* **66**, 289), Saito (*Aph Sp Sci* **22**, 133); AS Cam: Hilditch (*PASP* **84**, 519*); TX Cnc: Whelan *et al.* (*ApJ* **183**, 133*); UW CMa: McCluskey *et al.* (*ApJ* **201**, 607); EZ CMa: Irvine and Irvine (*PASP* **85**, 403); SX Cas: Koch (*AJ* **77**, 500), Andersen (*PASP* **85**, 191); AR Cas: Gorza and Heard (*PDDO Toronto* **3**, No. 4*), Herczeg (*BAAS* **6**, 233); U Cep: Baldwin (*PASP* **85**, 714); Batten (*PDAO Vict.* **14**, 191*), Plavec and Polidan (*Nature* **253**, 173), Batten *et al.* (*Nature* **253**, 174); VV Cep: Wright (*BASS* **5**, 43, *JRASC* **68**, 262): CW Cep: Popper (*ApJ* **188**, 559*); 14 Cep: Hilditch (*MN* **169**, 323*); 17 Com B: Conti and Barker (*ApJ* **186**, 185*); ϵ CrA: Tapia and Whelan (*ApJ* **200**, 98*); α Cru: Thackeray and Hill (*MN* **168**, 55*); CH Cyg: Deutsch *et al.* (*PASP* **86**, 233); CI Cyg: Stienon (*BAAS* **5**, 17); EM Cyg: Robinson (*ApJ* **193**, 191*); MR Cyg: Hill and Hutchings (*Ast Aph* **23**, 357*); V729 Cyg: Walborn (*ApJ* **180**, L35); 31 Cyg: Wright (*JRASC* **66**, 289); 32 Cyg: Wright (*JRASC* **66**, 289), Bisiacchi *et al.* (*Ast Aph Suppl.* **13**, 109); 57 Cyg: Hilditch (*MN* **164**, 101*); BY Dra: Bopp and Evans (*MN* **164**, 343*); AS Eri: Popper (*ApJ* **185**, 265*); S Equ: Polidan and Plavec (*BAAS* **6**, 465); SY For: Feast (*Observ.* **95**, 19); YY Gem: Bopp (*ApJ* **193**, 389); W Gru: Imbert (*Ast Aph* **32**, 429*); AH Her: Robinson (*ApJ* **181**, 531); DQ Her: Beer (*Vistas* **16**, 254); LT Her: Ebbighansen and Penegor (*PASP* **86**, 203); u Her: Kovachev (*AG Mitt* **35**, 189), Kowachev and Seggewiss (*Ast Aph Suppl.* **19**, 395*), Kovachev and Reinhardt (*AA* **25**, 133), Hilditch and Hill (*MN* **172**,29P); 4 Her: Heard *et al.* (*Ast Aph* **42**, 47*); 88 Her: Harmenec *et al.* (*Ast Aph* **33**, 117*); 21 Hya: Chaville (*Ast Aph* **40**, 207*); 2 Lac: Hilditch (*MN* **169**, 323*); ES Lib: Bartolini *et al.* (*MSAIt* **44**, 231*); β Lyr: Batten and Sahade (*PASP* **85**, 599), Skulsky (*Izv. Krim A O* **45**, 135, *Perem. Zv.* **18**, 609, *AC* 827), Hack *et al.* (*Nature* **294**, 534, *ApJ* **198**, 453), Batten *et al.* (*PASP* **86**, 237), Kondo and McCluskey (*ApJ* **188**, L63), Křiž and Zdárský (*BAC* **25**, 1), Morgan *et al.* (*ApJ* **190**, 349), Wolf *et al.* (*PASP* **85**, 718), Dadaev (*AC* 839), Flora and Hack (*Ast Aph Suppl.* **19**, 57), Hack (*Ast Aph* **36**, 321), Sanyal (*BAAS* **6**, 466), Batten and Fletcher (*PASP* **87**, 237*); UX Men: Imbert (*Ast Aph* **32**, 429*); AX Mon: Peton (*Aph Sp Sci* **30**, 481); V566 Oph: Babaev (*Perem. Zv.* **18**, 389); VV Ori: Duerbeck (*Ast Aph Suppl.* **22**, 19*); BM Ori: Popper and Plavec (*BAAS* **6**, 334); δ Ori: Conti (*ApJ* **187**, 539); Θ^2 Ori A: Conti (*ApJ* **187**, 539), Aikman and Goldberg (*JRASC* **68**, 205*); σ Ori AB: Bolton (*ApJ* **192**, L7); AR Pav: Thackeray and Hutchings (*MN* **167**, 319*); AG Peg: Cowley and Stencel (*ApJ* **184**, 687*), Stienon (*BAAS* **5**, 49); AW Peg: Polidan and Plavec (*BAAS* **6**, 465); AG Per: Popper (*ApJ* **188**, 559*); GK Per: Gallagher and Oinas (*PASP* **86** 952); IQ Per: Young (*PASP* **87**, 717*); LX Per: Weiler (*PASP* **86**, 56*); β Per: Bolton (*JRASC* **66**, 219), Walker *et al.* (*AJ* **78**, 681), Chen and Wood (*ApJ* **195**, L73); 2 Per: Heard and Krautter (*JRASC* **69**, 22*); 43 Per: Wallerstein (*PASP* **85**, 115*); b Per: Wolf and Wolf (*PASP* **86**, 176*); 16 Psc: Cayrel de Strobel *et al.* (*Ast Aph* **37**, 179*); TY Pyx: Andersen and Popper (*Ast Aph* **39**, 131*); U Sge: Polidan and Plavec (*BAAS* **6**, 465); V 453 Sco: Walborn (*ApJ* **176**, L119), Hutchings (*PASP* **87**, 245); RZ Sct: Karetnikov (*Ast. Zh.* **49**, 1188); BS Sct: Hall and Mallama (*AA* **24**, 359); CV Ser: Cowley (*PASP* **84**, 772); ζ Tau: Bolton and Hurkens (*JRASC* **68**, 262); W UMa: Worden and Whelan (*MN* **163**, 391*); S Vel: Bond (*PASP* **84**, 839); γ^2 Vel: Bahng (*BAAS* **5**, 412; **6**, 455), Barnes *et al.* (*ApJ* **187**, 73), Burton *et al.* (*Nature Phys. Sci.* **246**, 37), Jeffers *et al.* (*Nature Phys. Sci.* **243**, 109), Sanyal *et al.* (*ApJ* **187**, L31), van den Hucht and Lamers (*ApJ* **181**, 537), Henize *et al.* (*BAAS* **6**, 447); DL Vir: Schoffel and Popper (*PASP* **86**, 267*); α Vir: Meisel and Berg (*ApJ* **198**, 551); HR 4072: Octken and Orwert (*AN* **294**, 261*); HR 5361: Scarfe and Alers (*PASP* **87**, 285*) HR 6611: Zissell (*AJ* **77**, 610*); HR 6773: Young and Etzel (*PASP* **87**, 471*); HR 7694: Dworetsky (*PASP* **86**, 173*); HR 7955: Spite and Spite (*Ast Aph* **25**, 352); HR 8035: Redford and Griffin (*Observ.* **95**, 143); HR 8281: Crampton and Redman (*AJ* **80**, 454*); HR 8704: Wolff (*PASP* **86**, 173*); HD 108: Hutchings (*ApJ* **200**, 122*); HD 9313: Griffin and Emerson (*Observ.* **95**, 98*); HD 11860: Batten and Szeidl (*PDAO Vict.* **14**, 97*); HD 16246, 23848: Morbey and Brosterhus (*PASP* **86**, 456*); HD 22637, 23805, 23964, 24769: Pearce and Hill (*PDAO Vict.* **14**, 319); HD 27149: Batten and Wallerstein (*PDAO Vict.* **14**, 135*); HD 28052, 31109, 37507, 56986, 104321, 110951: Guseinov *et al.* (*Ast. Zh.* **51**, 782); HD 45088: Griffin and Emerson (*Observ.* **95**, 23*); HD 52942: Moffat and Vogt (*Ast Aph* **30**, 381); HD 82191: Heard and Hurkens (*JRASC* **67**, 306*); HD 90707: Lloyd Evans (*MN* **161**, 15*); HD 92168: Ginestet *et al.* (*Ast Aph Suppl.* **15**, 133*); HD 92740: Niemela (*PASP* **85**, 220*); HD 98088: Wolff (*PASP* **86**, 179*); HD 101799: Sisteró and Sisteró (*AJ* **79**, 391*); HD 107325: Bolton *et al.* (*PASP* **87**, 259); HD 126983: Kaufmann and Klippel (*Ast Aph* **27**, 469*); HD 128661: Gorza and Heard (*PDDO Toronto* **3**, No. 4*); HD 151564, 152219, 152667, 152218, 152248, 152270, CPD–41°7733, –41°7742: Hill *et al.* (*AJ* **79**, 1271*); HD 152667: Hill and Crawford (*PASP* **86**, 477*); HD 152270: Seggewiss (*Ast Aph* **31**, 211*); HD 159976: Conti *et al.* (*PASP* **87**, 327*); HD 166181: Nadal *et al.* (*Ast Aph* **37**, 191*); HD 173219: Hutchings and Redman (*MN* **163**, 219*); HD 180553: Hube (*Ast Aph Suppl.* **10**, 267*); HD 187399: Hutchings and Redman (*MN* **163**, 209*); HD 193964: Hube (*JRASC* **67**, 161*); HD 209813: Gorza and Heard (*PDDO Toronto* **3**, No. 4*); HDE 235679: Rogers and Bolton: (*BAAS* **6**, 488); HDE 228766: Walborn (*ApJ* **186**, 611); BD + 24°692: Young (*PASP* **86**, 59); BD + 47°781: FitzGerald (*JRASC* **68**, 23*); BD 48° 1958: Bopp and Fekel (*PASP* **86**, 978*); BD 56° 2190: Burke and Abt (*PASP* **86**, 677*); HBV 475: Mammano and Righini (*MSAIt* **44**, 23).

Table 3a. Spectrographic Observations of Binary X-ray Sources (A. Batten)

Cen X-3: Richard (*ApJ* **189**, L113), Vidal *et al.* (*ApJ* **191**, L23), Osmer *et al.* *ApJ* **195**, 705); Cyg X-1: Bolton (*ApJ* **200**, 269*), Hutchings *et al.* (*ApJ* **182**, 549), Brucato and Zappala (*ApJ* **189**, L71), Hutchings *et al.* (*ApJ* **191**, 743); Cyg X-2: Bopp (*Nature* **247**, 139); Her X-1: Bopp *et al.* (*ApJ* **178**, L5), Crampton and Hutchings (*ApJ* **178**, L65), Davidson *et al.* (*ApJ* **177**, L97), Canizares and McClintock (*BAAS* **5**, 394), Barbon *et al.* (*Ast Aph* **31**, 237), Bopp *et al.* (*ApJ* **186**, L123), Crampton (*ApJ* **187**, 345), Crampton and Hutchings (*ApJ* **191**, 483*), Sco X-1: Crampton and Cowley (*ApJ* **197**, 467, **201**, L65*), Lyntyi *et al.* (*Ast Zh.* **51**, 905), SMC X-1: Osmer and Hiltner (*ApJ* **188**, L5); V748 Cen (Cen X-4?): van Genderen *et al.* (*MN* **167**, 283); X Per: Hutchings *et al.* (*ApJ* **191**, L101, *MN* **170**, 313*); HD 77581: Angel *et al.* (*ApJ* **184**, L79); Jones *et al.* (*BAAS* **5**, 381); Mook and Boley (*BAAS* **6**, 264); Petro and Hiltner (*ApJ* **190**, 661*); Wickramasinghe *et al.* (*ApJ* **188**, 167*), Bessell *et al.* (*ApJ* **195**, L117), Hutchings (*ApJ* **192**, 685*), Wallerstein (*ApJ* **194**, 451*), Zuiderwijk *et al.* (*Ast Aph* **35**, 353); HD 153919: Angel *et al.* (*ApJ* **184**, L79), Canizares and McClintock (*BAAS* **5**, 394), Hensberge *et al.* (*Ast Aph* **29**, 69), Hutchings *et al.* (*MN* **163**, 13P*), Walker (*MN* **162**, 15P), Jones *et al.* (*BAAS* **5**, 381), Boley and Mook (*BAAS* **6**, 264), Bopp *et al.* (*BAAS* **6**, 276) Kondo *et al.* (*BAAS* **6**, 223), Dachs and Schober (*Ast Aph* **33**, 49), Wolff and Morrison (*ApJ* **187**, 69), Conti and Cowley (*ApJ* **200**, 133), Hutchings (*ApJ* **192**, 677*); HD 158320 (3U1727−33?): Penny *et al.* (*MN* **171**, 387*).

Table 4. Absolute Dimensions (F. B. Wood)

KO Aql, *PASP* **86**, 187; QY Aql *PASP* **86**, 195; V 539 Ara, *Bamberg Veröff.* X, 126; SX Aur, *Ast Aph* **35**, 259; LY Aur, *Ast Aph* **31**, 1, *ApJ* **187**, 93; TW Cas *Aph Sp Sci* **32**, 291; YZ Cas, *Ast Aph* **35**, 259; SV Cen, *PASP* **84**, 686; HD 101799 Cen, *AJ* **79**, 391; VW Cep, *Aph Sp Sci* **22**, 381; RS Cep, *PASP* **86**, 195; CQ Cep, *Ast. Issledov.* **6**, 11, *Perem. Zv.* **19**, 441; CW Cep, *ApJ* **188**, 559, *AJ* **80**, 232; EI Cep, *Aph Sp Sci* **32**, 285; TW Cet, *Aph Sp Sci* **22**, 381; S Cnc, *PASP* **86**, 195; TX Cnc, *PASJ* **24**, 213, *ApJ* **183**, 133; ε CrA, *ApJ* **200**, 98; SW Cyg, *PASP* **86**, 195; VW Cyg, *PASP* **86**, 195; *Studia Univ. Babes-Bolyai*, ser. Math-Mech., fasc. 1, 87; WW Cyg, *PASP* **84**, 541; MR Cyg, *Ast Aph* **23**, 357; V 453 Cyg, *Ast Aph* **34**, 317 and *Suppl.* **15**, 181; V 729 Cyg, *AA* **24**, 69; YY Eri, *Aph Sp Sci* **22**, 381; AS Eri, *ApJ* **185**, 265, *Ast Aph* **35**, 259; HS Her, *Sternberg Contr.* No. 185; V 624 Her, *AJ* **77**, 610; VZ Hya, *Aph Sp Sci* **33**, 256; SW Lac, *Aph Sp Sci* **22**, 381; XY Leo, *Aph Sp Sci* **22**, 381; β Lyr, *Bamberg Veröff.* IX, 308; XZ Lyr, *MN* **167**, 369; V 502 Oph, *Aph Sp Sci* **22**, 381; V 566 Oph, *Aph Sp Sci* **22**, 381; VV Ori, *Ast Aph Suppl.* **22**, 19; ER Ori, *Aph Sp Sci* **22**, 381; AR Pav, *MN* **167**, 319, 635; U Peg, *Aph Sp Sci* **22**, 381; AQ Peg, *PASP* **86**, 195; RW Per, *PASP* **86**, 195; RY Per, *Ast Aph* **35**, 259; AG Per *ApJ* **188**, 559; δ Pic, *MN* **167**, 517; TY Pyx, *Ast Aph* **39**, 131; BS Sct, *AA* **24**, 359; V 505 Sgr, *AJ* **77**, 672; λ Tau, *Ast Aph* **35**, 259; RZ Tau, *Aph Sp Sci* **22**, 381; V 471 Tau, *Ast Aph* **17**, 437, *ApJ* **173**, 653; W UMa, *MN* **163**, 391, *Aph Sp Sci* **22**, 381; AW UMa, *ApJ* **182**, 539; RU UMi, *PASP* 83, 286; AG Vir, *PASP* **84**, 382; AH Vir, *Aph Sp Sci* **22**, 381.

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