42. PHOTOMETRIC DOUBLE STARS
(ÉTOILES DOUBLES PHOTOMÉTRIQUES)

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INTRODUCTION

This report differs from earlier ones because financial limitations require the length to be half that of the preceding one. Thus, bibliographical lists are severely limited and it has not been possible to refer to all published papers or to much of the unpublished work. It is hoped that a more extensive mimeographed report will be available to commission members and others interested by the time of the 1970 General Assembly.

For invaluable aid in preparing this report, I am deeply indebted to Drs. Batten, Herczeg, Katherine Kron, Larsson-Leander, Merrill, Plavec, and Cesevič. Most of these wrote sections of the report which appear only slightly altered to prevent duplication or to take account of very recent developments. Since it was necessary to review more than 1400 papers which appeared during the three-year interval, obviously this could not have been written without extensive collaboration. I am especially indebted to Drs. Merrill and Plavec for consultation in the difficult choice of matters to be eliminated.

The Commission continued to be active between sessions of the General Assembly. Symposia or colloquia sponsored or co-sponsored include:

Non-Periodic Phenomena in Variable Stars, Budapest, Hungary, 1968; Mass Loss from Stars, Trieste, Italy, 1968; Close Binaries and Stellar Evolution, Elsinore, Denmark, 1969.

The Bibliography and Program Notes on Eclipsing Variables continued to be issued semi-annually; the extensive amount of material contained therein substitutes for the omission of certain tables in this report. Numbers 12 through 16 were issued in the interval covered in this report. Contributors include Cester, Italy; Grygar, Central and Eastern Europe; Günther, Germany; Kitamura or Kiyokawa, Japan; Mrs. Kron, North America; Kwee, Western Europe; Sahade, Southern Hemisphere; Schulberg, U.S.S.R.; and Sinvhal, India and Indonesia. Larsson-Leander has borne the heavy burden of the compilation and distribution of these reports which are now of increased value. The heavy work of collating, editing, typing, and running stencils was done by the competent staff of the Lund Observatory.

The most notable feature of the past three years has been the tremendous increase in the number of theoretical investigations, especially those connected with evolution of close double stars. Mass exchange, once scarcely considered, is now accepted as commonplace at certain times of the post main sequence evolutionary stages. However, because of the great computational difficulties involved, detailed studies of the effects of mass loss to the system as a whole, have not yet been made. Further, the stars must somehow reach the main sequence and, while promising work is under way, the theory here is not in nearly as satisfactory a condition as are the more evolved states.

Continued efforts are being made to improve the rectification processes, both in the study of the ellipticity and the re-radiation effects. Merrill's work (*Vistas in Astronomy*, in press) in particular indicates the importance of the inclusion of higher order terms in the harmonic expansion than had previously been thought necessary. After a long period of neglect various observers are again turning their attention to the problem of apsidal motion. Details of these and other developments will be found in later sections.

The discovery that many objects previously thought single are in reality close doubles has added to the significance of our studies in many lines. The work of Mumford and others has shown that

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many cataclysmic variables are close doubles; it now seems clear that most if not all of the peculiar A stars are also double; R. E. Wilson's work on Cygnus X-2 supports earlier suggestions of its binary nature and describes the system in terms of a semi-detached binary in which the primary component is a white dwarf. However, it seems likely that the kind of systematic X-ray observation needed for significant results must await the establishment of a lunar station where a sustained program can replace the fragmentary results obtained from satellites.

The international collaborative programs have been continued and details are given in a later section. Another effort has been initiated to aid in keeping selected systems under continuous observation for extended intervals. Beginning in November 1968, a site testing program at the South Geographic Pole has been carried on under the joint auspices of the Bartol Foundation and the University of Florida. Preliminary indications are that there will be many successive hours of cloud-free weather during the polar night. The extremely small amount of water vapor pressure also makes infrared work desirable. There is at least the possibility that a 24-inch (61 cm) telescope of special design may be part of the new pole station planned for 1971.

Various review articles have appeared or are in the process of publication; the more specialized will be referred to in later sections. Here can be mentioned Batten's "On the Interpretation of Statistics of Double Stars" in Vol. 5 of the *Annual Review of Astronomy and Astrophysics* and Popper's "Determination of Masses of Eclipsing Binary Stars" in the same volume. Several of the papers in *Mass Loss from Stars* edited by M. Hack discussed close doubles. The Elsinore colloquium brought together a small group of specialists for general discussion; details are given in a later section. Šulberg has finished a monograph on *Close Eclipsing Variables with Spherical Components*, and a group of U.S.S.R. astronomers have completed a book which contains a complete review of methods of solution and a discussion of the statistical data from an evolutionary point of view.

The important work of cataloguing has not been neglected. The Card Catalogue of eclipsing variables formerly at the Flower and Cook Observatory has now been transferred to the University of Florida and information on individual systems is continuously supplied on request. For published work, Svečnikov and Lavrov have completed a catalogue of both relative and absolute elements of 197 systems and are preparing a more extensive catalogue of photometric elements. Batten's excellent catalogue of spectroscopic elements is soon to be supplemented by a critical catalogue of photometric solutions by Koch, Plavec, and Wood. The combination of these should make possible the preparation of a complete and critical catalogue of absolute dimensions.

Finally, attention should be called to the appearance as one of the series in *Vistas in Astronomy*, edited by Beer, of the Henry Norris Russell Memorial volume. It is appropriate that, while an effort was made to include many of Russell's varied interests, the majority of the papers are on photometric double stars, the field of Russell's earliest and latest significant contributions, and one that occupied his interest throughout his career.

OBSERVATIONAL TECHNIQUES AND NEW PHOTOMETRIC DATA

An extremely large number of photometric observations has been accumulated during the past three years. It is impossible to call attention in the alloted space even to the more important individual investigations. Fortunately, references to these are given in the Bibliography and Program Notes of Commission 42; the semi-annual distribution of this makes it essential to workers in the field. Astronomers not on the mailing list may apply to Larsson-Leander at the Lund Observatory. Detailed information concerning any individual system can be obtained by application to any of the three cataloguing centers at the Cracow Observatory, the Sternberg Institute, or the University of Florida.

Work has continued at an increasing rate at the observatories long active in the photometry of eclipsing variables. It is possible here to call attention only to newly established centers or to older institutions which are for the first time (or again after a lapse of many years) beginning the photometry of eclipsing variables; even here the list is probably not complete. Among those to be mentioned are the centers in Romania, especially those at the Universities of Timisoara and of Cluj which are now making photoelectric observations and carrying on theoretical work as well in the field of eclipsing binary stars, the Louisiana State University which now has its own telescope to supplement the observations its astronomers have been obtaining at Kitt Peak and Cerro Tololo, the joint program between Nürnberg (Germany) and the Ege University, Izmir, Turkey, the new Rosemary Hill Observatory at Florida, the apsidal motion program initiated at Yale University, and the Mount John Observatory in New Zealand (operated jointly by the Universities of Pennsylvania and Canterbury) where a new 24-inch (61 cm) telescope is being installed. Attention also should be called to the large number of photoelectric light curves observed at Catania, which has now become one of the leading contributors in this field. On the negative side, nothing whatever has been heard from the Purple Mountain Observatory which contributed to the 1959 β-Lyrae campaign and which until 1965 published in *Acta Astronomica Sinica*.

In instrumentation and techniques, the chief factor has been the increasing amount of two-color or three-color photoelectric photometry on standard color systems. Now, except for discovery purposes and timing of minima, almost all of the observations are made in this manner. An increased care in making extinction corrections and color standards is noted in the work of most observers. A small but increasing amount of polarization studies are being made. Attention should be called in particular to the work of Rucinski on the changes in polarization of β Lyrae; in the Southern Hemisphere, a polarizing photometer is being installed at Mt. John. Cristaldi and Rodono at Catania have constructed an ingenious photometer which permits simultaneous photometry in three colors and thus extremely precise color measures. Cester reports from Trieste that a new 40-inch (101 cm) reflector is under construction for spectrographic and photoelectric purposes and that a simultaneous three color photometer is in operation on existing telescopes. A prototype of an infrared photometer has also been tested.

NEW SPECTROGRAPHIC DATA

Considerable activity has been reported in this field during the past three years from several observatories. Much interest has again been shown in the supergiant systems of the ζ Aurigae and VV Cephei types. The former are the subject of a review by Wright (1970, *Vistas in Astronomy*, **12**, Ed. A. Beer, in press) and the latter of one by Cowley (1969, *Publ. astr. Soc. Pacific*, **81**, 297). Popper has continued his work on improving our knowledge of masses and absolute dimensions of many eclipsing binaries.

The *Sixth Catalogue of the Orbital Elements of Spectroscopic Binary Systems* has been published (1967, Batten, *Publ. Dom. astrophys. Obs., Victoria*, **13**, 119). Batten and Ovenden (1968, *Publ. astr. Soc. Pacific*, **80**, 85) have discussed the distribution of the element ω for the systems in that catalogue. They confirm the Barr effect and point out other anomalies. Batten has also discussed observational evidence for very large stellar masses (1968, *Astr. J.*, **73**, 551) and errors affecting the determination of orbital elements (1968, *J. R. astr. Soc. Can.*, **62**, 344).

Abt and his associates have continued their work on the incidence of close binaries in different stellar classes. Abt and Levy (1969, *Astr. J.*, **74**, 908) find that the incidence is probably low among high-velocity stars, although Eggen (1967, *Astrophys. J.*, **150**, L111) reports a possible high-velocity contact system. Abt and Bidelman (1969, *Astrophys. J.*, **158**, in press) have reclassified many known spectroscopic binaries of late A types. Their results seem to support Abt's earlier conclusions that short-period binaries in this spectral range have metallic-line spectra and few of them have normal A-type spectra.

Olson has published a list of spectral classifications and surface gravities, for bright early type eclipsing binaries (1968, *Astrophys. J.*, **153**, 187), and for Am stars (including many eclipsing systems (1969, *Publ. astr. Soc. Pacific*, **81**, 97). He has also discussed the rotation of components of eclipsing binaries (1968, *Publ. astr. Soc. Pacific*, **80**, 185).

Review articles by Kraft (1967, *Publ. astr. Soc. Pacific*, **79**, 395) on W Ursae Majoris systems and by Mumford (1967, *Publ. astr. Soc. Pacific*, **79**, 283) on Novae and Nova-like variables are also of importance. The suggestion has been made that the X-ray source Cyg X-2 is a spectroscopic and possibly eclipsing binary (1967, Burbidge *et al.*, *Astrophys. J.*, **150**, L95; 1967, Kristian *et al.*, *Astrophys. J.*, **150**, L99). Later work, however, has shown that the interpretation of this spectrum is far from simple (1967, Kraft and Demoulin, *Astrophys. J.*, **150**, L183).

A list is given below of all those systems known either to be under spectroscopic observation or for which unpublished analyses are well in hand. They are classified according to the observatory at which the observations were made and the investigator. Fuller information on most of this work can be found in the Bibliographies issued by the Commission since the last report.

WW Aur, δ Cap, 32 Cyg, RR Lyn, TU Mon (Kiyokawa, Kondo, Kitamura, and Saito; Okayama). BF Aur, IU Aur, RS CVn, BV 267, 447, 449, 544, HD35652, Boss 5481 (Mammano, Margoni, Catalano, Bartolini, Perinotto, and Stagni; Asiago). 32 Cyg, VV Cep, W UMa (Faraggiana, Hack, Cester; Trieste). AZ Cas (Tempesti; Teramo). R CMa, VV Ori (Beltrami and Galeotti; Milano). δ Lib, η Ori, ϕ Phe, δ Pic, V Pup (Buscombe; Mt. Stromlo). HD159441 (Chambliss; Siding Spring). V 1143 Cyg (Avery; Kitt Peak). u Her (Sobieski and Koch; Kitt Peak). BV 268 (Hilditch; Haute Provence). BV 143, XY UMa, PV Cas (Geyer; Bonn). β Per, BD 53° 323, 32 Cyg, AR Cas, TU Cam (Herczeg, Yavuz; Hamburg). BV 447 (Wachmann; Hamburg). 31 Cyg (Mayer; München). AR Cas, SX Cas, RX Cas, U Cep, VV Cep, 31 Cyg, 32 Cyg, β Lyrae, HD35652, HD35921 (Batten, Wright; Victoria). GF Car, BF Cen, V346 Cen (Landolt; Cerro Tololo). CG Cyg (Milone and McClurken; Kitt Peak).

The following studies of orbits and/or absolute dimensions of eclipsing binaries have been published since the *Sixth Catalogue*:

β Aur (1968, Galeotti and Guerrero, *Mem. Soc. astr. ital.*, **39**, 269). AE Aqu (1969, Payne-Gaposchkin, *Astrophys. J.*, **158**, 429), AO Cas (1967, Galkina, *Izv. Krym. astrofiz. Obs.*, **36**, 175), 9RS Cha (1969, Chambliss, *M.N.R.A.S.*, **142**, 113; 1969, Jones, *Mon. Notes astr. Soc. Sth. Afr.*, **28**, 5), TV Ceti (1968, Popper, *Astrophys. J.*, **154**, 191), 31 Cyg (1968, Wright and Huffman, *Publ. Dominion astrophys. Obs. Victoria*, **13**, 275), V448 Cyg (1969, Cohen, *Publ. astr. Soc. Pacific*, **81**, 665), V 477 Cyg; CM Lac (1968, Popper, *Astrophys. J.*, **154**, 191), CM Lac (1968, Barnes *et al.*, *Publ. astr. Soc. Pacific*, **80**, 69), CO Lac (1967, Smak, *Acta Astr.*, **17**, 245), RR Lyn (1967, Botsula, *Astr. Zu.* **44**, 1253), TZ Men (1969, Jones, *Mon. Notes astr. Soc. Sth. Afr.*, **28**, 5), RW Mon (1969, Heard and Newton, *J. R. astr. Soc. Can.*, **63**, 208), TU Mon (1967, Popper, *Publ. astr. Soc. Pacific*, **79**, 493), IZ Per (1969, Yavuz, *Astr. Astrophys.*, **2**, 388), λ Tau (1968, Casini *et al.*, Comm. 27, *IAU Inf. Bull.*, Var. Stars, No. 257), TX UMa (1968, Swensen and McNamara, *Publ. astr. Soc. Pacific*, **80**, 192), BV 344 (HD178001) (1968, Yavuz, *Astr. Abh. Hamburg*, **8**, No. 5), HR 7484 (1969, Snowden and Koch, *Astrophys. J.*, **156**, 667), HD175514 (1967, Vitrichenko, *Astr. Circ. Izdav. bjuro astr. Soobsc. Kazan*, No. 448), HD193576 (1967, Ganesh *et al.*, *Kodaikanal Bull.*, Ser. A, No. 184).

Other spectrographic investigations of eclipsing binaries are presented in Table 1.

Table 1. Recent spectrographic work

Star	References	Remarks
o And	Passinetti, L. E., *Mem. Soc. astr. ital.*, **39**, 73, 1968.	Spectrophotometry of variable shell.
ε Aur	Ivanova, N. L., *Astrofiz.*, **3**, 223, 1967.	Spectrophotometry: atmospheric conditions.
ζ Aur	Kitamura, M., *Publ. astr. Soc. Japan*, **19**, 194, 1967.	K-line obs., 1963–64 eclipse.
	Farragiana, R., Hack, M., *Mass Loss from Stars* Ed. M. Hack, D. Reidel, Holland, 1969.	
RCMa	Kitamura, M., *Astrophys. Space Sci.*, **3**, 163, 1969.	Spectrophotometry: variation of line intensities during eclipse.
AO Cas	Galkina, T. S., *Izv. Krym. astrofiz. Obs.*, **37**, 205, 1967.	Spectrophotometry Δm, spectral-type variations.

Table 1 (continued)

Star	References	Remarks
RZ Cas	Ricard-Roux, M., Van 't Veer, F., *C.r.*, **266**, Ser. B, 1345, 1968.	Spectrophotometric measures of limb-darkening.
MN Cas	Lavrov, M. I., Lavrova, N. V., *Trudy Kazan astr. Obs.*, **35**.	
U Cep	Batten, A. H., Laskarides, P. G., *Publ. astr. Soc. Pacific*, **81**, 677, 1969.	Possible H emission outside eclipse.
	Batten, A. H. (in press).	Detection of H emission during eclipse.
VV Cep	Wright, K. O., Larson, S. J., *Mass Loss from Stars*, Ed. M. Hack, D. Reidel, Holland, p. 198, 1969.	Evidence from Hα for mass motions. Wright continuing work.
	Glebocki, R., Keenan, P. C., *Astrophys. J.*, **150**, 529, 1967.	Var. of O I lines at time of secondary eclipse.
31 Cyg	Faraggianna, R., Hack, M., *Mass Loss from Stars*, Ed. M. Hack, D. Reidel, Holland, 1969.	
	Wright, K. O., Morbey, C. L., *J. R. astr. Soc. Canada*, **63**, 213, 1969.	Duration of totality 1968: luminosity.
32 Cyg	Faraggianna, R., Hack, M., *Mass Loss from Stars*, Ed. M. Hack, D. Reidel, Holland, 1969.	
	Wright, K. O., Hesse, K. H., *Publ. Dom. astrophys. Obs. Victoria*, **13**, 301, 1969.	Measures of K-line at 1965 eclipse.
V444 Cyg	Guseinzade, A. A., *Astrofiz.*, **2**, 325, 1966; *Perem. Zvezdy*, **16**, 500, 1969.	Scanning spectrophotometry of emission lines.
	Kuhi, L. V., *Astrophys. J.*, **152**, 89, 1968.	Scanning of emission lines and continuum.
V453 Cyg	Cohen, H. L., Dissertation, unpublished.	
WY Gem	Martini, A., *Mem. Soc. astr. ital.*, **40**, 25, 1969.	Description of Spectrum VV Cephei-type system.
β Lyr	Svolopoulos, S. N., *Astr. Nachr.*, **290**, 155, 1967.	Spectrophotometry of line-profile variations.
	Knappenberger, P. H., Fredrick, L. W., *Publ. astr. Soc. Pacific*, **80**, 96, 1968.	Observations of He I λ10830.
AX Mon	Cowley, C. R., Marlborough, J. M., Cowley, A. P., *Publ. astr. Soc. Pacific*, **79**, 21, 1967.	Suppression of Hε component.
AG Peg	Boyarchuk, A. A., *Astr. Zu.*, **44**, 12, 1967.	Spectrophotometry, radial velocities, model.
β Persei	Glushneva, I. N., *Trudy gos. astr. Inst. Sternberga*, **34**, 81, 1966.	
	Glushneva, I. N., Esipov, V. F., *Astr. Zu.*, **44**, 1028, 1967.	Infrared spectrophotometry.
	Va'tts, I. E., Glushneva, I. N., *ibid.*, 728.	Spectrophotometry of K-line.
ν Sgr	Nariai, K., *Publ. astr. Soc. Japan*, **19**, 564, 1967.	Model for mass flow.
	Coyne, G. V., Kruszewski, A., *Astr. J.*, **74**, 528, 1969.	Polarization measurements.
RZ Scu	Karetnikov, V. G., *Astr. Zu.*, **44**, 22, 1967.	Spectrophotometry.
RW Tau	Plavec, M., *Bull. astr. Inst. Csl.*, **19**, 11, 1968.	Structure of emission ring.
BL Tel	Feast, M. W., *Mon. Not. R. astr. Soc.*, **135**, 287, 1967.	Thorough discussion: model.
HD 47129	Galkina, T. S., *Izv. Krym. astrofiz. Obs.*, **36**, 175, 1967.	Spectrophotometry.
HD 211853	Bracher, K., *Publ. astr. Soc. Pacific*, **80**, 165, 1968.	Spectrum variation.

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TIMES OF MINIMA AND PERIOD VARIATIONS

The triennium 1967–69 brought again a body of observations and a number of published papers comparable with those reported in the Transactions of the previous General Assembly. One outstanding feature of the period is the extensive use of photoelectric techniques; apart from the studies based on archives of patrol plates and observations by amateurs, photo-electrically observed times of minima became far superior in number to photographic or visual determinations.

In addition to existing centers of period studies, new series of regular photoelectric observations have been started at several places with considerable effort devoted to timing of minima: University of Florida; Ege University (Izmir), in collaboration with Nürnberg; Bamberg Observatory; Cluj University; Tartu Observatory; Ashchabad Observatory. Southern hemisphere work can be supplemented now by observations in New Zealand, by close cooperation between the University of Pennsylvania and the University of Canterbury. While the Bonn Observatory seems to have stopped its program on WUMa-stars, it is to be hoped that the Vienna group remains active and continues its systematic work on short period eclipsing binaries. Some important observations came from the Haute-Provence Observatory, mainly carried out by guest investigators.

There is a steep increase of systematic photoelectric work on times of minima, supplemented by discussion of the periods, in Poland and, especially, in Italy. In Poland, observational work is mainly centered at Cracow, theoretical studies at Warsaw, results being published almost exclusively in the *Acta Astronomica*. Italian observatories (Asiago, Bologna, Catania, Merate, Teramo, Torino, Trieste), benefited by relatively favourable weather conditions, keep some 60 bright eclipsing variables (mainly BD-stars) on their photoelectric observing schedule; a list of these stars was prepared by Cester and perhaps will be circulated privately. Observations and discussions concerning about one-third of these variables, have been already published, mostly in the *Memorie della Società Astronomica Italiana*. To the three groups of amateur observers mentioned in the previous Draft Report, there is now added a Swiss group (Locher *et al.*), regularly publishing visually determined minima in the periodical *Orion*.

Although the work of non-professional observers should be clearly encouraged, we do have to notice that these observations are of very uneven quality. Looking into the $O - C$ diagrams reveals immediately that the usually high standard of reliability, represented for instance by the group around *Sky and Telescope*, is not always matched by other observers. Besides, there are cases, stars under regular photoelectric surveillance, where visual estimates of minimum epochs convey virtually no additional information, owing to the mean errors 20 or 30 times higher than those of the photoelectric measurements. It could be of considerable value to find some form of coordinating the efforts of the amateur groups or, at least, to support them by professional advice while choosing the objects to be observed. It is to be welcomed that more and more amateur observers shift to photoelectric techniques.

As to the photographic observations, surveys aiming to discover new binaries and to derive periods for them, are still the main task. Some extended series of photographic observations of selected objects or discussions of individual binaries based on patrol plates, deserve mentioning: Whitney's investigations at the University of Oklahoma or studies of numerous less known variables at the Sonneberg Observatory, dealing with about 40 published light curves and periods during the time interval reported here. Other such programs, including the comprehensive Southern hemisphere survey co-ordinated by the Bamberg Observatory, are discussed in the report of Commission 27.

A very important contribution to this field is the systematic investigation into the periods and possible earlier period changes of recently discovered binaries. These studies are carried out by the Bamberg Observatory under the direction of Strohmeier and are based on the great plate collections at the Harvard Observatory, in Bamberg and in Sonneberg. The latest issue of the publications (1969, *Veröff. Remeis-Sternw. Bamberg*, **8**, Nr. 81) deals mainly with Harvard material.

The accuracy of individual minimum epochs is indicated by a scatter of perhaps $\pm 0\overset{d}{.}05$, as a mean. This prevents discussion of finer details in the $O - C$ diagram, but is sufficient to check the period and its constancy. Out of 48 systems, 16 show with certainty changes of the period.

A list of especially important binaries, selected by Plavec, was given in the last Draft Report. At least, four-fifths of these crucial objects were observed photoelectrically during the triennium 1967–69, this indicating the major role this list of desiderata has played in planning observing programs. The following gives a certainly incomplete list of unpublished observations, collected of these systems in various observatories: RT And; WW Aur; i Boo (Teramo, Victoria, Hamburg); RS CVn (Catania); R CMa; RZ Cas (Catania, Teramo); TV Cas (Cracow); U Cep; VW Cep (Bamberg, Teramo, Victoria); U CrB (Catania); Y Cyg (Teramo, Vatican; earlier obs. Bonn); V 477 Cyg (Bologna, Catania, Teramo); W Del (Catania); TW Dra; TX Her (Hamburg, Teramo); AR Lac (Bamberg, Teramo); βLyr (Hamburg; IAU campaign 1959); U Oph (Johannesburg, Teramo); V 451 Oph (Teramo); β Per; U Sge (Teramo, Trieste); RW Tau; X Tri (Teramo); TX UMa (Bologna, Hamburg); VV UMa (Merate). Very few of these binaries can be still considered photometrically neglected. Some proposed additions to this list, of more or less *ad hoc* character, will be added at the end of this chapter.

For a thorough discussion of possible mechanisms causing period changes in close binary systems, Kruszewski's review in Vol. 4 of *Advances in Astronomy and Astrophysics* is still the most comprehensive document to consult; cf. also his recent paper in Vol. 17 of *Acta Astronomica*. Though less directly addressed to the problem of period changes, review articles by Hadjidemetriou (1967, *Adv. Astr. Astrophys.*, **5**, 131), Plavec (1968, *Adv. Astr. Astrophys.*, **6**, 202), Piotrowski (1967, *Commun. Obs. r. Belgique*, Ser. B, No. 17, 133) contain additional information.

Calculations of the evolution of close binary systems, based on the assumption of extensive mass exchange between the components, as carried out with remarkable success in Göttingen, Munich, Warsaw or Ondřejov, have important bearings on the problem of period changes. The calculated traces of evolution require, at some evolutionary phases, substantial changes of the orbital period; these again could serve as support for the theories. There is, however, up to now no clear case known where observed period changes and theoretical predictions would lend themselves to a detailed comparison. It is to be hoped that series of accurate timings of minima, extended to perhaps the next 15–20 years, may clarify this question.

Close binaries attracted much attention as possible sources of gravitational radiation. Among others, Paczynski discussed this problem (1967, *Acta Astr.*, **17**, 287) and concluded that for binaries of short and very short period (like WZ Sge), gravitational radiation may turn out, indeed, to be an evolutionary factor.

In the following some results are summarized very briefly; among the systems considered, well above a hundred in number, we had to select – somewhat arbitrarily – those investigations which can possibly contribute to future understanding the general pattern of period changes.

In many cases, when checked against recent minimum epochs, the cubic ephemeris formulae derived by D. B. Wood and Forbes do not hold. The simple assumption of "accelerated" period changes probably does not do justice to the complicated phenomenon of changing periods.

Purgathofer and Prochazka discussed the ten short period binaries observed in Vienna (1966, *Wien, Mathemat.-nat. Klasse*: *Sber. öst. Akad. Wiss.*, Abt. 2, 175, 301). In more than half of the cases they found good representations of the $O - C$ values by sudden period changes; a highly convincing object of this type is AH Vir. Other authors likewise emphasize the importance of sudden, erratic changes of the period (bot positive and negative), amounting, to the order of magnitude, to a few 10^{-5} times the period. An intriguing case is W UMa, where possibly two such changes in rapid succession shifted the phase of minimum light by $+0\overset{d}{.}0045$ (Kristenson, 1967, *J. Observateurs*, **50**, 71); the event seems to coincide with the flare of the star observed by Kuhi in 1964.

Algol type binaries, like AR Lac show a similar behaviour, $\Delta P/P$ being of the same order of magnitude as in the case of W UMa-stars. An analysis of all photoelectrically observed minima of Algol strongly suggests two such "jumps" during the last decades (Herczeg, Frieboes-Conde, 1968, *Sky Telesc.*, **35**, 288; also *Adv. Astr. Astrophys.*, in press). Two WR eclipsing systems have been discussed by Semeniuk (1968, *Acta Astr.*, **18**, 313), without establishing definite evidence of a changing period.

Mumford has been observing several old novae and nova-like variables photoelectrically (1969, *Mass Loss from Stars*, Ed. M. Hack, pp. 202ff.). He found evidence of an increasing period for U Gem and DQ Her; changing period was also indicated in the case of V Sge, as proposed previously by Smak. The very shortest periods (EX Hye, WZ Sge) seem to be constant. The well-known short period binary UX UMa was observed by Kukarkin *et al.* (1969, *Perem. Zviozdy*, **16**, 599); changes of the period suggest cyclic, if not periodic nature, with a total amplitude of $0\overset{d}{.}003$.

A radical modification of the period derived for HZ 22 was proposed by Smak (1969, *Acta Astr.*, **19**, 165), from $3\overset{d}{.}6$ to possibly $0\overset{d}{.}43$. This would put the star, hitherto considered as a normal B-type binary, into the class of the close binaries with a hot subdwarf component.

As to the ultra-short periods, autocorrelation analysis revealed a period of 18 minutes for the white dwarf HZ 29 (Smak, 1967, *Acta Astr.*, **17**, 255). The light curve can be interpreted as due to orbital motion in a very close system, but other possible explanations (pulsation?) could not be dismissed entirely.

Concerning the early phases of stellar evolution, an interesting contribution by Meinunger (1966, *Mitt. Sternw. Sonneberg*), based on Sonneberg plates and dealing with eclipsing variables in T-associations, should be mentioned. He found numerous eclipsing binaries (with one exception, all Algol-type stars), part of them may turn out members and not merely background objects.

Finally, in the case of the much observed supergiant system ζ Aur, the favorable eclipse in 1963–64 made a new determination of the period possible. Kiyokawa (1967, *Publ. astr. Soc. Japan*, **19**, 209) discussed all the observed durations beginning with 1934 and found that they indicate a secular increase; a similar suggestion is also mentioned by Hardorp *et al.* (1966, *Z. Astrophys.*, **64**, 97), and was first suggested by Roach and Wood (1952, *Ann. Astrophys.*, **15**, 21).

Proposed supplement to Plavec's list

OO Aql	W UMa system with unusual deep eclipses. Sudden period changes?
SV Cam	Third body? Recent phe min scatter widely.
SW CMa	Displaced secondary, $e \approx 0{\cdot}5$.
CQ Cep	WR binary with possibly changing period.
CO Lac	Apsidal motion with $P' \approx 35^a$.
V 566 Oph	W UMa system showing constant period.
AG Per	Apsidal motion with $P' \approx 76^a$.
V 1647 Sgr	Displaced secondary, $P = 3\overset{d}{.}3$, apsidal motion possibly detectable.

Table 2. Investigations on apsidal motion

V 889 Aql	Long per. aps. motion indicated	Semeniuk (1)
HH Car	Long per. aps. motion indicated	O'Connell (2)
Y Cyg	More accurate data requested	Schneller (3)
V 380 Cyg	Long per. aps. motion indicated	Semeniuk (1)
V 453 Cyg	Evidence of aps. motion	Wachmann (4)
V 477 Cyg	Long per. aps. motion evident $P' \approx 349^a$, O'Connell, $P' \approx 349^a$ (5),	Semeniuk (1)
	$P' \approx 200^a$	Rodono (6)
DI Her	Relativistic aps. motion still undetectable	Semeniuk (1)
CO Lac	Rapid aps. motion evident	Semeniuk (7)
AG Per	Rapid aps. motion evident	Semeniuk (1)
	Jones (8)	Morley (9)
V 526 Sgr	Evidence of aps. motion	O'Connell (10)
DR Vul	Rapid aps. motion evident	Semeniuk (1)
CW Cep	Apparently rapid apsidal motion	Nha (11)

(1) *loc. cit.*; (2) 1968, *Ric. astr. Specola astr. Vatic.*, 7 (13) 399; (3) 1966, *Comm. 27 IAU, Inf. Bull. Var. Stars*, No. 145; (4) private communication; (5) in press, *Vistas in Astronomy*; (6) 1967, *Publ. Oss. astr. Catania*; (7) 1967, *Acta astr.*, **17**, 223; (8) 1969, *Acta astr.*, **19**, 53; (9) 1966, *Comm. 27 IAU, Inf. Bull. Var. Stars*, No. 163; (10) 1968, *Ric. astr. Specola astr. Vatic.*, 7 (11) 339; (11) private communication.

APSIDAL MOTION

A paper by Semeniuk examining six systems with apsidal motion and quoted in *Transactions*, **13B** as being in press, appeared in 1968 (*Acta Astr.*, **18**, 1). There is a concise summary of present-day observational evidence in this paper, too, giving lists of stars with (*a*) reliable apsidal coefficients; (*b*) determined apsidal period; (*c*) evidence of apsidal motion; (*d*) suspected in apsidal motion; (*e*) displaced secondary minima. Model computations related to apsidal motion have been carried out by Semeniuk and Paczynski (1968, *Acta Astr.* **18**, 33).

CO-ORDINATED OBSERVING PROGRAMS

At the 1967 meetings the committee on co-ordinated programs agreed to concentrate on two systems: GL Car in the south and AR Cas in the north.

Dr. Serkowski, who served as co-ordinator for GL Car, reports (as of September 1969): Photometric observations were made on several nights of 1968 by Quast (São Jose de Campos) in *BV* and by Tapia (Santiago de Chile) in *UBV*. *UBV* observations were also planned by Feinstein and Snowden. The main reason for including GL Car in the co-ordinated program was the lack of spectroscopic orbit for this star with the most pronounced and shortest period apsidal motion of all eclipsing binaries. Unfortunately the only spectroscopic observations reported were by Thackeray; they suggest a value of K greater than 200 km s^{-1} for both stars and a spectral class certainly earlier than the HDE value of B3. Miss Semeniuk of Warsaw University has offered to make any needed reductions and analyses.

Dr. Herczeg acted as co-ordinator for the AR Cas program and published four circulars, the last of which appeared in August 1969 at the start of the second observing season. AR Cas was chosen because the potential yield was so great. This B3V binary has total eclipses of relatively long duration ($D \simeq 10$ h), shallow minima, a displaced secondary minimum, and inconsistencies between photometric and spectroscopic observations. Third-body and apsidal-motion questions need to be settled. Specifically reported observations are: from Hamburg: BV obs of sec min by Wachmann on July 23, 1968 and 28 spectra obtained August 22–November 4, 1968 at 72Å mm^{-1} by Herczeg, Prölss, and Wehmeyer; from Kitt Peak, 4 spectra obtained by West (University of Florida) at 13 Å mm^{-1} November 29–December 1, 1968; from Cracow, pe obs. on 4 nights, July–August 1968, by Kreiner; from Catania, pe obs. on 33 nights up to December 1968, and a few pe observations by Chen and Gleim at Florida. The Catania results by Catalano and Rodono are particularly encouraging; they consist of 460 photoelectric observations in two colors, cover about 80 % of the light curve, and define both minima reasonably well. Geyer (Bonn) reports 30 medium dispersion spectra obtained at the Hoher List Observatory. Circular 4 presents Wachmann's individual observations and estimates of 3rd and 4th contact times.

Stars of earlier co-ordinated programs continued to be studied, SX Cas by Koch and epsilon and zeta Aurigae, 31 and 32 Cygni by Gyldenkerne. Gyldenkerne has called attention in particular to the importance of observing 32 Cygni between now and the favorable 1971 eclipse; observers of any of these four systems are urged to communicate with him. Various papers resulting from these co-ordinated programs are now appearing in the literature.

An excellent summary of the photometric results of the 1959 international campaign on β Lyrae has been published by Larsson-Leander (1969, *Ark. Astr.*, **5**, 253).

DETERMINATION OF PHOTOMETRIC ORBITS

These three years have seen a gratifying surge of interest in improving our knowledge of proximity effects in close pairs, probably the weakest part of our conventional solutions of light curves. Ruciński (*Acta Astr.*, in press) has derived albedoes (directly comparable with the reflection coefficient C_1, in the Russell Model) for stars having deep adiabatic convective envelopes. He finds the "reflected" light completely limb-darkened, as in the case of radiative equilibrium, and his numerical results follow much along the lines of Sobieski's earlier ones, in these not-too-close pairs. The known need for closer definition of temperature distributions across the facing sides of close spherical pairs has occupied the attention of Chen and Rhein (*Publ. astr. Soc. Pac.*, **81**, 387, 1969), using a method valid both for the regions of full illumination and for the penumbras. They trace the somewhat higher temperatures at large polar angles, yielded by their theory as compared to Sobieski's, to more effective inclusion in their geometry of the attenuated penumbral radiation, more an effect of difference of geometrical model than of physical theory.

Departures from spherical shape and from classical von Zeipel gravity darkening have received attention, with results helpful in establishing firmer rectification procedures. Pustyl'nik (Tartu) has found a new expression for the flux distribution over the surface of a non-spherical star, more rigorous than that from von Zeipel's theorem simply applied, and has formulated the radiation transfer in an explicit form adapted to a new approach to the light curve rectification problem. Ruciński has also presented (*Acta Astr.*, **19**, 125, 1969) a method of computing the light changes in cases of moderate distortions of the binary components; his results are given as the coefficients of a Fourier cosine series. In both these "rectification" studies just described, reflection has been neglected.

Reuning (*Am. phys. Soc.*, S. E. Section, Nov. 1969; abstract) has continued his valuable computerized study of the distorted polytrope model, with special attention to polytropes of index 3·5 in contradistinction to the algebraically simpler Roche model $n=5$. He finds not only that the distorted component will be some five percent or more larger than the Roche limiting surface before instability sets in, but also that the true limiting surface for the more realistic case $n=3{\cdot}5$ approximates a triaxial ellipsoid far more closely than it does the commonly used Roche surface. For his models leakage occurs from the essentially rounded vertex of the ellipsoid, not from a Rochelike "tip". Also working from the Chandrasekhar equations for distorted polytropes, Merrill (*Vistas in Astr.*, **12**, Ed. A. Beer, p. 43) finds that the distortion may in some very close systems produce a $\cos 3\theta$ term of significant size, and that neglect of a significant $\cos 3\theta$ term during the analysis (whatever its source) can completely vitiate the deduced coefficient of $\cos \theta$ as far as its use in rectifying for reflection is concerned.

It should be noticed particularly that all the foregoing items represent improvements in our understanding of the existent models and the concomitant desirable rectification procedures; they in no way represent "new" models. In view of this substantial theoretical and procedural progress, and in view of the vast improvements in light curves resulting from increased emphasis in recent years on "epochal" rather than "mean" curves to which to apply our more refined procedures, the "new W UMa – system model" being called for by Kopal (*Astrophys. Space Sci.*, **2**, 23, 1968) and Lucy (*Ap. J.*, **153**, 877, 1968) hardly seems as much a need for W UMa systems in general as it may have 15 years ago. A few years yet of patient comparison of really good modern curves with existing refined models should at least narrow down the range of systems for which the rather considerable labor of new model-building would be likely to be justified.

Tcherepaschuk (Sternberg) is well along on working out a new method for the determination of the elements of eclipsing binaries with ellipsoidal components, with arbitrary law of limb-darkening, while Šulberg (Odessa) has nearly completed work on a method specially aimed at early-type systems and with the assumption of non-linear darkening. Cohen (*Publ. astr. Soc. Pac.*, **81**, 60, 1969) and Cesevič (*Astr. Zu.*, **44**, 139) have both published "short-cut" methods for tabular solutions of rectified light curves on assumed linear limb-darkening. Computerized solutions have multiplied; West's program (*Publ. København*, No. 184, 1965), sketchily mentioned in our 1967 report, follows the Russell Model for rectification, then Kopal's for elements from the rectified curve. Tabachnik (*Astr. Zu.*, **42**, 3, 1965; **45**, 5, 1968; **45**, 6, 1968; *Problems of Cosmic Physics*, **2**, 1968) has an extended computer program to take into account the weights of the observations and equations for semi-detached systems.

Horak (*B.A.C.*, **17**, 27, 1966; **17**, 273, 1966) continued work on his "sphere-ellipsoid" model and followed it (*B.A.C.*, **19**, 149, 1967; **19**, 241, 1968) with an "ellipsoid-ellipsoid" one. In the first the rectification process implicity assumed similar and similarly brightened ellipsoids; the second is sharply restricted in applicability to cases of very small distortions. In both models sine terms are arbitrarily "added out" and the outer faces of the components are not brightened but instead only the difference in reflection on the two inner faces removed. A computerized integration over the eclipsed area (assumed bounded by elliptical segments) is then iterated to reduce the sum of the squares of residuals to a minimum. Publication of a much more detailed exposition of the model and the associated procedures would seem to be next in order if the differences he achieves in orbital parameters from different colors are to be accepted.

Mauder (*Kl. Veröff. Bamberg*, Nr. 39, 1966) has followed his paper on solutions from the Fourier transform of the light curve, with the tables requisite for the case of uniform disks and spherical components. The method is promising and we would hope for tables covering partial limb-darkening soon.

Two books should be mentioned here. Šulberg (Odessa) has a monograph in press on "Close Eclipsing Binaries with Spherical Components". Second, a team of investigators – Martynov and Tcherepaschuk (Sternberg); Šulberg, Tabachnik and Cesevič (Odessa); Svechnikov and Snejko (Sverdlovsk') have completed the manuscript of a treatise on eclipsing binaries containing, besides other matters, a complete and full review of all methods proposed for solution of light curves! The book is scheduled for publication in 1971. Further, the new photometric catalogue by Koch, Plavec, and Wood should be available in 1970.

We close this section with three lists of new solutions of photometric light curves.

First, for the following 62 systems new orbital solutions have been published based on new photometric observations which were in practically all cases made by the respective authors and published in the orbital-solution paper:

XZ And, AD And, BL And, V535 Ara, RX Ari, OO Aql, V599 Aql, AR Aur, HD 35652 Aur, TZ Boo, TU Cam, AW Cam = BV 412, VZ CVn = BV 332, HH Car, RZ Cas, SX Cas, GG Cas, V78 in ω Cen, VW Cep, WX Cep, EK Cep, RS Cha, W Crv, BR Cyg, CV Cyg, MR Cyg (2), V448 Cyg, V463 Cyg, V470 Cyg, V477 Cyg, V836 Cyg = BV 143, UX Eri, S Equ, RY Gem, AD Her, DQ Her, V338 Her (2), RT Lac, AM Leo, AP Leo, RR Lyn, SW Lyn, TT Lyr, TY Men, TV Mon, DI Peg, EE Peg, AU Pup, AG Vir, BH Vir, BV 241, BV 267, BV 357, BV 374, BV 366, BV 412 (2) BV 419, BV 430, BV 722, BD + 34°1051, S8 279 in NGC 188, S8 280 in NGC 188.

Several of these observational series merit attention by investigators who are specialists in intermediary or definitive solutions, and several by investigators interested in tracing time-dependent deviations from some fixed model.

For the following 28 systems new orbital solutions have been published which are based on photometric observations previously available and not in general made by the authors of the respective solutions:

AB And, SX Aur, TT Aur, YZ Cas, RR Cen, 9 Cha, TZ CrA, U CrB, KR Cyg, V453 Cyg, V548 Cyg, V809 Cyg, TW Dra, TX Her, AD Her, RR Lyn, TT Lyr, β Per, V505 Sgr (2), V499 Sco, RT Scl, RZ Sct (2), RW Tau, VV UMa, W UMa, XY UMa, HD 161 783.

In several cases orbital solutions from these same observations are already in the literature; new solutions therefore provide either confirmation of deduced elements or an opportunity to compare philosophies and procedures of different investigators. This latter is valuable because orbital solutions in so many cases are still an art rather than a mere technique.

For the following 27 systems, the persons named have informed the Commission (either through Program Notes to Dr Larsson-Leander or by a letter to Dr Wood) that new orbital solutions, based on new photometric data, are essentially completed:

RT And (Dean, Nelson, San Diego); V 337 Aql (Catalano, Catania); ST Aqr (Gleim, Rosemary Hill); GG Cas (Kandpal, Srivastava, Uttar Pradesh); V 701 Cen (Chen, Rosemary Hill); WX Cep (Kandpal, Srivastava, Uttar Pradesh); XX Cep (Angione, Nelson, San Diego); CQ Cep (Kartas-

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hova, U.S.S.R.); SW Cyg (Hall, Dyer); V 541 Cyg (Vetešnik, Brno); V 729 Cyg (Hall, Dyer); Z Dra (Devinney, Flower & Cook); RX Gem (Hall, Dyer); RY Gem (Hall, Dyer); AR Lac (Nelson, San Diego); V 1010 Oph (Guinan, Mt. John); TT Ori (Cristaldi, Catania); VV Ori (Marasso, Nelson, San Diego); BM Ori (Hall, Dyer); KZ Pav (Shaw, Mt. John); RW Per (Hall, Dyer); ST Per (Srivastava, Uttar Pradesh); β Per (Wilson, So. Florida); Y Psc (Hall, Dyer); AU Pup (Chambliss, Mt. Stromlo and Mt. John); BP Vul (Illès, Konkoly); BV 332 (Harris, Flower and Cook).

ABSOLUTE DIMENSIONS OF ECLIPSING SYSTEMS

While not quite as many determinations of absolute dimensions have been published in this triennium as in the previous one, the 49 determinations listed below include somewhat more systems for which no absolute dimensions at all were available before. This then is gratifying to report since such determinations are ultimately a principal reason for the existence of our field.

Three matters deserve particular mention in this connection. First, attention has been called before to Popper's long-term program; this continues to yield rich fruit both on the positive side in new determinations and on the negative side in his carefully reasoned decisions that certain stars originally on his program cannot be expected to yield, for one or another stated reason, reliable determinations of absolute dimensions. Second, special mention should be made of the study of 31 Cygni by Wright and Huffman; the depth of insight and the meticulous care employed in this investigation have provided a truly definitive work.

Third, one interesting though minor point resulting from Reuning's study, mentioned earlier, of highly distorted components of polytropic index 3·5. It appears that the geometrical center of a highly distorted component will be significantly (perhaps as much as 5%) nearer the companion than its center of mass. Since the photometric solution deals essentially with the geometrical surfaces but the spectroscopic one with (point) masses, direct combination of the two sets of elements in the conventional fashion can in cases of highly distorted components, result in a slight overestimate of the real sizes of the stars.

For the following 7 systems new determinations of absolute dimensions have been published which are based on photometric and spectroscopic observations previously available:

TV Cam, 31 Cyg, u Her, RR Lyn, AG Per, RZ Sct, BD $+53°323$.

It is an interesting commentary on the coordination of effort (or lack of it) that sometimes occurs, that it should be possible to find data for deriving such badly needed material as absolute dimensions, hitherto unused for the purpose, as in a couple of the cases listed above.

For the following 24 systems new determinations of absolute dimensions have been published which are based on new photometric observations but spectroscopic material already available:

Y Aql, ZZ Cep, EI Cep, MR Cyg, V 448 Cyg, V 453 Cyg, V 477 Cyg, χ^2 Hya, CM Lac, CO Lac, TX Leo, UV Leo, V 566 Oph, EE Peg, ST Per, V 526 Sgr, W UMa, ER Vul, BV 241, BV 342, BV 374, BV 382.

It is very satisfying to see evidence such as the above that photometrists are (presumably) taking the spectroscopic situation into account in planning their observational programs.

New determinations of absolute dimensions, from earlier photometric solutions but new radial velocity material, have been published for the following 13 systems:

SS Boo, 44 i Boo, VW Cep, 9 Cha, V 477 Cyg, 31 Cyg, WW Dra, AS Eri, CM Lac, CO Lac, TX UMa, BV 267, BV 412.

It is clear that spectroscopists have been paying heed to the progress of photometric orbital solutions.

For 7 systems, determinations of absolute dimensions have been made from new photometric and new spectroscopic observations, by the observers themselves:

V448 Cyg, S Equ, TV Mon, W UMa, BV 344, HD197406, HR 7484.

ASTROPHYSICAL AND DYNAMICAL INVESTIGATIONS

During the past triennium our ideas on the origin of binary stars have not developed very much. In particular, Roxburgh's version of the fission theory has not met with general approval. Mammano (1967, *Mem. Soc. astr. ital.*, **38**, 425) pointed out that there are contact systems that violate the upper mass limit of $4M_{\odot}$, predicted by Roxburgh, and he found from the statistics of angular momenta that the fission origin cannot be of much relevance. Hall (1968, *Publ. astr. Soc. Pacific*, **80**, 477) remarked that in Kopal's list of eclipsing binaries there are several detached Algol systems similar to KO Aql, which is considered by Roxburgh to be a system in pre-main-sequence contraction. From the galactic *z*-distribution of these systems, as compared with the distributions of semi-detached Algol systems and stellar associations, Hall concluded that the detached and semi-detached systems are of about the same age and certainly much older than the associations.

The various theories were reviewed by Huang (1967, *Sky Telesc.*, **34**, 368), and reference was made to a theory of contact binaries that he has developed in detail in another paper (1966, *Ann. Astrophys.*, **29**, 331). It is assumed that the components originate with larger separation and that orbital angular momentum is dissipated through mass ejection along magnetic lines of force, as suggested by Schatzman. In this way W UMa systems may be formed with subsequent mass transfer to the less massive component. Huang found the observational data in favor of the proposed theory.

Worrall (1967, *Mon. Not. R. astr. Soc.*, **133**, 83) considered the few-body problem, arising after formation of a small group of proto-stars from a cloud. Stars are ejected from the group, and the remaining objects form close binaries. Numerical integrations were made for the three-body case with various initial conditions.

At the Colloquium on the Evolution of Double Stars in Uccle 1966, one session was devoted to the genesis of binaries. The introductory review was given by Lippincott (1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17, 55). Among the contributions we mention a paper by Roxburgh (1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17, 60), describing his theory for double star formation, including effects of a magnetic field, a paper by van Albada (1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17, 75), on the *N*-body problem and the formation of binaries by the escape process.

On the other hand, the theory of evolution of double stars has advanced in the most remarkable way. The detailed theoretical computations of the evolution of close binaries are summarized in the subsequent section. Here we mainly deal with the more general aspects of the theory and its confrontation with observations. General reviews were published by several authors, including Cester (1967, *Nuovo Cim. Suppl.*, **5**, 1089), Paczyński (1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17, 111, 122), Plavec (1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17, 83), Snezhko (1967, *Perem. Zvezdy*, **16**, 253), and Weigert (1968, *Mitt. astr. Ges.*, No. 25, 19).

Intimately connected with the evolution of close binaries are the effects of transfer of mass and angular momentum between the components and the losses occurring to the systems. The mass loss from stars in general was chosen as the topic of the second Trieste colloquium in astrophysics in 1968. As a sequel to this colloquium a smaller group of theoreticians and observers of close binaries met in 1969 at Elsinore, Denmark, for a more informal discussion. At this meeting introductory talks were given by Popper, on the knowledge of masses and their accuracy, by Koch, on observational facts, and by Paczynski, on the theoretical computations. Sahade gave a summary of the papers and the discussion. The proceedings of this meeting including the taped discussions are expected to be published in the near future as a Copenhagen publication.

Popper (1967, *Ann. Rev. Astr. Astrophys.*, **5**, 85) has given a comprehensive review on mass determinations. Batten and Ovenden (1968, *Mon. Not. R. astr. Soc.*, **140**, 81) computed masses for the objects in Sixth Catalogue of spectroscopic binary stars, for which the inclination can be found from visual or eclipsing orbits, and for which absolute magnitudes can be derived from visual orbits, trigonometric parallaxes or Hγ measurements. For $-6 < M_v < +2$ the relation between absolute magnitude and log mass is linear, and no systematic differences appear between Hγ magnitudes and dynamical or trigonometrical ones. For $M_v > +4$ there is a slight evidence for a dual relation. The observed relation is in good agreement with main-sequence models with $X=0{\cdot}68$, $Y=0{\cdot}30$. Kříž (1969, *Bull. astr. Inst. Csl.*, **20**, 202) summarized spectroscopic and photometric data for 26 main-sequence eclipsing binaries with two spectra and re-computed absolute dimensions and masses. Comparisons with main-sequence models show good agreement for masses smaller than $5M_\odot$, but the theoretical models are overluminous for larger masses. Popov (1968, *Astr. Zu.*, **45**, 804 = 1969, *Soviet Astr.*, **12**, 640) computed absolute dimensions for 34 eclipsing-binary systems having both components near the main sequence. In the H-R diagram the components with reliable data fall along lines of equal age. The derived mass-luminosity, mass-spectrum, and other relations show good agreement with corresponding theoretical relations for homogeneous models. The properties of the primary components of double-line Algol-like binaries were discussed by Plavec (1967, *Bull. astr. Inst. Csl.*, **18**, 334). The mass-luminosity and mass-spectrum relations agree with those for single stars. The latter relation may be used for determining masses and absolute dimensions when only one spectrum is measurable, but a certain range of masses is obtained, rather than a single definite value. In some cases the range may be narrowed because of the existence of the Roche limit. All available masses for Wolf-Rayet stars were collected by Smith (1967, *Publ. astr. Soc. Pacific*, **79**, 347). The presence of severe anomalies was emphasized, and the conslusion is that the value $10M_\odot$, commonly assumed for W-R stars, should be regarded with considerable suspicion. Batten (1968, *Astr. J.*, **73**, 551) discussed binaries with large masses. The largest reasonably well-determined masses are 30 to 35 $M_\odot$, but systematic errors have the effect to make the observed mass values too small. Considering this, it appears that no reliable mass values exceed 65 $M_\odot$, the limit set for a stable, normal star by the theory of stellar structure. A large number of visual binaries and 29 eclipsing binaries were used by Stephenson and Sawal (1969, *Astr. J.*, **74**, 689) to determine mean masses of stars above the main sequence as a function of the position in the H-R diagram. It was concluded that for non-interacting stars from B0 to K0, post-main-sequence evolution proceeds without dramatic mass loss. Absolute dimensions and masses for 18 interesting eclipsing binaries were discussed by Popov (1968, *Astr. Zu.*, **45**, 1309 = 1968, *Soviet Astr.*, **12**, 1033). Supergiants, like 31 Cyg, were found to be underluminous with respect to the evolutionary tracks corresponding to their masses. In his re-discussion of eclipsing binaries Popper (1968, *Astrophys. J.*, **154**, 191) has recently dealt with CM Lac, V477 Cyg and TV Cet. The first two systems appear to be unevolved, with components on the Sun-Sirius mass-luminosity relation. Popper (1967, *Publ. astr. Soc. Pacific*, **79**, 493) also announced that new spectrograms of TU Mon, considered to be of the R CMa class, does not show the supposed R CMa anomaly: the masses of the components are not small compared with their position in the H-R diagram. For the system RZ Sct, Kitamura and Sato (1967, *Publ. astr. Soc. Japan*, **19**, 575) found the luminosity of the primary component normal for its mass as a super-giant, while the secondary component is overluminous. Heard and Bakos (1968, *J. R. astr. Soc. Can.*, **62**, 67) reported that SZ Psc appears to be a unique example of a binary of the semi-detached type with the sub-giant component being the more massive. Burnashov and Vitrichenko (1969, *Non-periodic Phenomena in Variable Stars* (Ed. Detre), p. 427, Academic Press, Budapest) stated that the recently discovered young system HD 17514 has the large masses 48 $M_\odot + 13{\cdot}5$ $M_\odot$. The components almost fill their Roche lobes, but yet the system appears to be remarkably free of complications.

The angular momenta of 126 close binaries were calculated by Gianuzzi (1967, *Commun. Obs. R. Belgique*, Ser. B, 17, 152 = 1968, *Oss. astr. Roma Mte. Mario Contr. scient.*, No. 63), according to formulae given by Eggen for visual binaries. It was found that under certain conditions detached systems of early spectral type may evolve into contact binaries through mass exchange. A general review concerning the problems of close binary systems that involve transfer of angular momentum was given by Huang (1966, *Ann. Rev. Astr. Astrophys.*, **4**, 35).

The problems of mass transfer were reviewed in great detail by Hadjidemetriou (1967, *Adv. Astr.*

Astrophys., **5**, 131) and in abridged form by Piotrowski (1967, *Astr. Zu.*, **44**, 241 = 1967, *Soviet Astr.*, **11**, 191; 1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17, 133). A classification of particle orbits through L_1 was made by Hadjidemetriou (1968, *Astr. J.*, **73**, 104) according to their first minimum distance from either primary. Hadjidemetriou (1968, *Astrophys. Space Sci.*, **1**, 336) studied the effects on the orbital elements of repeated mass ejections from either component of a close binary. More frequent ejections at periastron will in most cases give larger eccentricity. In another paper Hadjidemetriou (1969, *Astrophys. Space Sci.*, **3**, 31) investigated the effects of non-isotropic ejections of mass, when all ejected mass is falling on the other component. In still another paper Hadjidemetriou (1969, *Astrophys. Space Sci.*, **3**, 330) considered the case occurring when one component has expanded to fill its Roche lobe and is losing mass to the other component. If mass is transferred from the more massive component, the semi-major axis will increase in most cases.

Plavec (1968, *Adv. Astr. Astrophys.*, **6**, 201) gave an extensive review of the mass exchange in close binaries considered in connection with the computations of stellar models. Detailed comparisons of the mass-exchange theory and the model computations with the observational data were made by Plavec (1967, *Bull. astr. Inst. Csl.*, **18**, 253), by Plavec and Horn (1969, *Mass Loss from Stars*, (Ed. Hack, p. 242, D. Reidel Publ. Co.) and by Ziołkowski (1969, *Astrophys. Space Sci.*, **3**, 14; 1969, *Mass Loss from Stars*, Ed. Hack, p. 231, D. Reidel Publ. Co).

The evolutionary effects due to emission of gravitational waves were considered by Paczyński (1967, *Acta Astr.*, **17**, 287). For W UMa stars the time scale of collapse is of the same order of magnitude as the time scale of nuclear evolution. The influence of gravitational radiation on the evolution of novae, U Gem stars and pair of white dwarfs was discussed. Mironovskii (1965, *Astr. Zu.*, **42**, 977 = 1966, *Soviet Astr.*, **9**, 752) gave a lower limit to the density of gravitational radiation from the space density of the W UMa stars, which were considered the most efficient source.

The properties of tides in close binaries and the importance of tides for the evolution of the systems were studied extensively by Zahn (1966, *Ann. Astrophys.*, **29**, 313, 489, 565; 1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17, 108, 124; 1969, *Mass Loss from Stars*, Ed. Hack, p. 267, D. Reidel Publ. Co). The adiabatic tide, in phase with the perturbing potential, and the dissipative tide, in quadrature, are defined. These two dissipative tides produce a torque on each component, and one effect of this is a change of orbital eccentricity. One of the predictions made is that orbits for systems, having at least one component with an external convective zone, should be rapidly transformed to circular form. Another extensive study of the dynamical tides was made by Kopal (1968, *Astrophys. Space Sci.*, **1**, 179, 284, 411; **2**, 48) in a series of papers. Quantitative aspects of the tidal lag were investigated by Roach (1968, *Astrophys. Space Sci.*, **1**, 32) for components in non-synchronous rotation. The equilibrium structure was assumed polytropic, and the viscosity was taken as the 2·5th power of local temperature. Tidal friction in radiative envelopes of massive main-sequence stars was studied by Dziembowski (1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17, 105).

The rotating emission rings in binary systems were discussed by Huang (1967, *Astrophys. J.*, **148**, 793). Periodic orbits around the more massive component in the restricted three-body problem were taken to represent the rings. Orbits were obtained and further improved by series expansion. A radius-velocity relation is derived and mass-ratios of the components may be deduced from this. Kruszewski (1967, *Acta Astr.*, **17**, 297; 1967, *Commun. R. Obs. Belgique*, Ser. B, No. 17, 146) considered the rings to originate from the angular momentum carried by matter travelling between the components. The smaller component may gain a large amount of angular momentum, resulting in ring formation. The theoretical ratio K/v_{em} is compared with observations. The observations show the predicted shape of velocity dependence on mass-ratio, but observed velocities are systematically smaller. It was, however, shown by Smak (1969, *Acta Astr.*, **19**, 155) that the observed velocities, derived from the emission lines, are smaller than the true velocities of ring rotation. The K/v_{em} relation was re-discussed. The discrepancy between theory and observations may be due to non-Keplerian motion in large rings and underestimated rotational velocity of rings of finite widths.

At the Trieste colloquium Wood (1969, *Mass Loss from Stars*, Ed. Hack, p. 149, D. Reidel Publ. Co.) summarized how our ideas concerning mass loss from close binaries have developed since 1941, and Sahade (1969, *ibid.*, p. 156) reviewed the spectroscopic evidence for mass loss. A new

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interpretation of the gaseous streams was given by Van Houten (1969, *ibid.*), who considered the streams caused by the tidal bulges. Milone (1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 457, Academic Press, Budapest) advanced the idea that unequal maxima, the so-called O'Connell effect, is partly due to gas streams, and not a periastron effect as formerly thought. Batten (1968, *J. R. astr. Soc. Can.*, **62**, 344) reviewed the statistics of ω, and its connection with gas streams. Gorbatsky (1967, *Astrofiz.*, **3**, 245; 1968, *Astrofiz.*, **4**, 504; 1969, *Astrophys. Space Sci.*, **3**, 179 = *Mass Loss from Stars*, Ed. Hack, p. 271, D. Reidel Publ. Co.; 1969, *Non-periodic phenomena in Variable Stars*, Ed. Detre, p. 391, Academic Press, Budapest) investigated the effects of gas streams from the secondary on the disk-like envelope of the primary. The envelope is supposed to be shock-heated, and the spectral index of the emitted radiation is determined, as well as $U-B$ and $B-V$ colours. It is implied that "hot spots" may be explained by this shock-heating.

The gaseous ring of RW Tau was studied by Plavec (1968, *Bull. astr. Inst. Csl.*, **19**, 11). A geometrical model is constructed and Sobolev's theory of moving envelopes is applied to derive the population of the higher energy levels. Swenssen and McNamara (1968, *Publ. astr. Soc. Pacific*, **80**, 192) found variable hydrogen absorption cores in high-dispersion spectrograms of TX UMa, indicating gas streams similar to those of U Cep and U Sge. Kitamura (1969, *Astrophys. Space Sci.*, **3**, 163 = *Mass Loss from Stars*, Ed. Hack, p. 159, D. Reidel Publ. Co.) from a spectrophotometric study of R CMa found evidence for gaseous matter surrounding the components. Nariai (1967, *Publ. astr. Soc. Japan*, **19**, 564) explained the displaced Hα absorption, which appears periodically in the spectrum of υ Sgr, as due to supersonic flow from a stellar corona, starting around L_1. Andrews (1967, *Astrophys. J.*, **147**, 1183) has measured the Hα emission strength of Algol at a variety of phases. It remains constant except during primary and secondary eclipses, when the emission region is eclipsed. The emission region is situated at L_1 and originates in a gas stream from the secondary component. Korsch and Walter (1969, *Astr. Nachr.*, **291**, 231) and Walter (1969, *Mass Loss from Stars*, Ed. Hack, p. 211, D. Reidel Publ. Co.) from photoelectric observations of AD Her found evidence for a gas stream from the secondary component. The density and mass-flow of the stream are calculated. Another star showing photometric evidence for gas streams is V448 Cyg, which, together with V453 Cyg, appears to be associated with the young cluster NGC 6871. Both stars have been observed by Cohen (1968, *Astr. J.*, **73**, S8; 1969, *Publ. astr. Soc. Pacific*, **81**, 665; 1969, *Astr. J.*, in press) and by Wachmann (1967, *Astr. Abh. Hamburg. Sternw. Bergedorf*, **8**, 89). Kumsiashvili (*Abastumani astrophys. Obs.*, unpublished) also reports photoelectric observations showing effects of gaseous streams around V448 Cyg as well as around RY Gem.

Free electrons in gaseous rings or disks are evidently responsible for intrinsic polarization of light from close double stars. This interpretation is in accord with observations of the wavelength dependence of polarization for Be-type stars, made by Coyne and Kruszewski (1969, *Astr. J.*, **74**, 528). Shakhovskoy (1969, *Astr. Zu.*, **46**, 386 = 1969, *Soviet Astr.*, **13**, 303) reported polarization measurements for 9 eclipsing variables giving the positions of the lines of nodes of their orbits and the inclinations of their orbital planes to the galactic plane. The results indicate random orientations. Shulov (1967, *Trudy astr. Obs. Leningr. gos. Univ.*, **24**, 38) published polarimetric observations of 13 eclipsing binaries. Variable polarization is found for RY Per, β Lyr, V444 Cyg, U Sge and Z Vul. Reference to further polarization observations of β Lyr are found below.

The problem of determining the type of rotation from a radial-velocity curve was treated by Porfirijev and Kalenichenko (1966, *Astr. Zu.*, **43**, 793 = 1967, *Soviet Astr.*, **10**, 631), by Porfirijev (1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17, 202) and by Plavec (1967, *Bull. astr. Inst. Csl.*, **18**, 93). In an extensive study of Stellar rotation Van den Heuvel (1968, *Bull. astr. Inst. Netherl.*, **19**, 326) argued that Ap and Am stars were probably originally the less massive members of spectroscopic binaries, in which the primary components after mass-transfer have evolved into white dwarfs. Olsen (1968, *Publ. astr. Soc. Pacific*, **80**, 185) reported upon measurements of rotational velocities, $v \sin i$, for 40 components in 29 early-type binaries. Small departures from axial-orbital synchronism were revealed, which are discussed in terms of angular-momentum transfer between components and evolution away from the main sequence.

Photometric peculiarities in general were described by Fracastoro (1965, *Oss. astrofis. Catania*

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Pubbl., Nuov. Ser., No. 77), and by Wood (1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 429, Academic Press, Budapest). Kozyrev (1967, *Commun. Obs. R. Belgique*, Ser. B, No. 17; 1968, *Izv. glav. astr. Obs. Pulkove*, No. 184, 108) stressed the important effects that the primary must have on the physics of the secondary component. Several photometric peculiarities of RS CVn were analyzed by Catalano and Rodono (1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 435, Academic Press, Budapest). Koch (1967, *Astr. J.*, **72**, 306) argued, with u Her as an example, that peculiarities, like transient $\cos\theta$ terms, should be removed before attempting light-curve solutions. Hall (1969, *Mass Loss from Stars*, Ed. Hack, p. 171, D. Reidel Publ. Co.) reported upon a strange secular expansion of the primary of RW Per.

Rucinski (1969, *Acta Astr.*, **19**, 125) developed a method for computing the photometric proximity effects in close binaries of early type. The brightness variation is computed by numerical integration of the emerging intensities over the visible surface, neglecting the reflection effects. Monochromatic light curves are obtained in terms of relative dimensions of components, mass ratio, inclination, average effective temperature, average gravity, frequency and mass concentration to centre. Rucinski (1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 361, Academic Press, Budapest) has also made similar computations for highly distorted white-dwarf secondaries. Another paper by Ruciński (1969, *Acta Astr.*, **19**) deals with the bolometric reflection effects for stars with deep convective envelopes. Pustylnik (1967, *Astrofiz.*, **3**, 69; 1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 423, Academic Press, Budapest) used Chandrasekhar's iterative technique to solve the transfer equation for an idealized plane-parallel atmosphere with H^- absorption. The monochromatic reflection amplitude was evaluated for the surface being that of the Roche lobe. McNapier (1968, *Astrophys. Space Sci.*, **2**, 61) developed a method for evaluating the reflection effects from light curves of high precision, except for cases when the components are in contact or nearly so. There is no restriction on the extent of the penumbra. Cester (1969, *Mem. Soc. astr. Ital.*, **40**, 169) calculated fluxes and luminous efficiency factors for main-sequence and sub-giant stars according to Chandrasekhar's model of a non-grey atmosphere, as proposed by Hosokawa, but using improved values for temperature and other parameters. The results are applied to 76 systems and a comparison is made between observed and theoretical coefficients of cosine terms. The agreement is satisfactory for all stars except for those of the earliest types. Here the choice of a lower temperature will reduce the negative trend in $O-C$, but does not eliminate it completely.

Van 't Veer (1968, *C. r. Acad. Sci. Paris*, Ser. B, **266**, 1245) studied the information that may be obtained from differential limb-darkening, deduced from multicolour observations of eclipsing binaries. Ricard-Roux and Van 't Veer (1968, *C. r. Acad. Sci. Paris*, Ser. B, **266**, 1345) specifically discussed RZ Cas using 8-band photometry. The observed differential limb-darkening is in agreement with theory if $u_{4950} = 0{\cdot}55$, which is the value predicted from stellar model atmospheres. A statistical discussion of limb- and gravity-darkening coefficients was published by Hosokawa (1968, *Sendai astr. Rap.*, No. 101). Chen and Rhein (1969, *Publ. astr. Soc. Pacific*, **81**, 387) calculated the temperature distribution on the stellar surfaces, assuming that close double stars are opaque black-bodies with limb-darkening. The increase of temperature due to radiative transfer between the components is calculated employing geometry of spheres.

Lucy (1967, *Z. Astrophys.* **65**, 89) derived a modification of von Zeipel's gravity-darkening law, valid for stars with convective envelopes. This modification is important for the theory of the light curves of W UMa stars. The gravity darkening of the W UMa systems was also considered by Kopal (1968, *Astrophys. Space Sci.*, **2**, 23). Pustylnik (*Tartu. astr. Obs.* (unpublished)) has found a new expression for the flux distribution over the surface of a non-spherical rotating star, which is more rigorous than that following from von Zeipel's theorem. The radiative transfer problem is formulated in explicit form, permitting also a new approach to the light-curve rectification problem.

We now turn to the various groups of binaries and start with the Wolf-Rayet systems. V 444 Cyg has been extensively studied by several observers. Kuhi (1968, *Astrophys. J.*, **152**, 89; 1968, *Astr. Soc. Pacific*, Leafl. No. 468) made photoelectric spectrum-scanner observations of emission-line and continuum intensities, especially around secondary minimum, for the purpose of determining atmospheric stratification. Interpretation of data in terms of purely geometric effects proved

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impossible. Erratic fluctuations point to a random process of ejection, perhaps some type of large-scale prominence activity. Similar observations of the He II lines λλ4686 and 5411 and of the continuum were made by Guseinzade (1966, *Astrofiz.*, **2**, 325; 1969, *Perem. Zvezdy*, **16**, 500). Line variability was found rare compared to the changes of the continuum. It is supposed that the main mechanism of the formation of emission lines is not a recombination, and that the upper layers of the envelope are transparent for radiation from lower layers. Tcherepashchuk (1967, *Astr. Circ.*, No. 413; 1967, *Perem. Zvezdy*, **16**, 226) discussed *U, B, V* light curves, obtained from narrow-band photometry in the continuum, and the intensity of He II 4686. The physical fluctuations in the continuum are almost independent of the fluctuations of the He II 4686 emission. The mean light curves in the continuum are of the Algol type, while in the λ4686 region they are almost of the β Lyr type. The size of the envelope emitting He II 4686 is at least twice that of the region responsible for the continuous spectrum. Bracher (1967, *Astr. J.*, **72**, 787) investigated the spectrum variation of HD 211 853. There is an absorption feature at λ3870, which is almost absent at phases 0·4 to 0·6 but increases to a very prominent absorption at phases 0·85 to 0·19, when the W-R star is in front. Tcherepashchuk (*Gos. astr. Inst. Sternberga* (unpublished)) has made narrow-band photometry of CV Ser and CQ Cep, both in emission lines and in the continuum. Narrow-band emission-line observations of some spectroscopic W-R binaries are planned to check the possibility of eclipses.

The physical conditions in the atmospheres of both components of the early type binary HD 47 129 (Plaskett's star) were analyzed by Galkina (1967, *Izv. Krym. astrofiz. Obs.*, **36**, 175). The line intensities of the secondary vary appreciably with phase and wavelength. The behaviour of He II 4686 and N III 4641–4634 emissions as well as the Hβ, Hγ line profiles were studied. Galkina (1967, *Izv. Krym. astrofiz. Obs.*, **37**, 205) also made a similar analysis of the components of AO Cas. The equivalent line widths of both components show considerable variations at elongations.The primary varies from O9·1 to O8·0, the secondary is estimated as O7·2. The components are situated on the lower boundary of the main sequence. Olson (1968, *Astrophys. J.*, **153**, 187) derived line profiles for 20 eclipsing binaries between O9 and A2. Surface gravities were determined by fitting these to theoretical profiles, calculated by Strom and Peterson using the latest Griem broadening theory and a modification by Edmonds, Schluter and Wells. Comparisons with gravities found from the binary solutions indicate that the latter broadening theory is the more nearly correct one.

Knappenberger and Fredrick (1968, *Publ. astr. Soc. Pacific*, **80**, 96) reported upon the first successful observations of the He I 10 830 emission line in the spectrum of β Lyr. This is the first member of the principal series of triplets, the second member of which is λ3889. The line is a broad emission, cut by a sharp absorption. Alduseva (1969, *Astr. Zu.*, **46**, 363 = 1969, *Soviet Astr.*, **13**, 286) obtained 1961–63 absolute spectrographic gradients for β Lyr in the photographic region and monochromatic light curves at λλ4000 and 4500. Differences between the 1961–62 and 1963 results are found in the gradients as a function of phase, in the shape of the light curve, and in the integrated brightness. Larsson-Leander (1969, *Ark. Astr.*, **5**, 253; 1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 443, Academic Press, Budapest) published the photometric results from the 1959 international campaign on β Lyr. A comparison with the 1958 Lick observations reveals changes in integrated light, colour, and asymmetry of minima. The central parts of the primary minima show changing asymmetry, and there appears to be a gradual decline of total light during the campaign. The color curve shows evidence of a "blue top" at zero phase and a "red dip" at phase 0·37. The Huang disk-model is regarded as most promising for explaining the various peculiarities. Changes in the polarization were reported by Ruciński (1966, *Acta Astr.*, **16**, 127; 1967, *Acta Astr.*, **17**, 207), and Shulov (1966, *Astrofiz.*, **2**, 339; 1967, *Astrofiz.*, **3**, 233), and by Appenzeller and Hiltner (1967, *Astrophys. J.*, **149**, 353). All the authors explain the variable polarization component as due to scattering by free electrons in a flat disc in the orbital plane. Ruciński finds that the shift of secondary maxima confirm that the orbital inclination can be about 75°. Shulov determines the electron density and finds that the mass of the disc is $1{\cdot}5 \times 10^{-7}\ M_{\odot}$. Sculsky (*Lwow Univ.* and *Krym. astrofiz. Obs.* (unpublished)) has investigated the physical conditions in the envelope by means of curves-of-growth. He concludes from high-dispersion spectrograms that there is a third body with a period of about 30 years.

The measurements of radial velocities of Algol-type stars were discussed by Plavec (1967, *Determination of Radial Velocities and their Application, IAU Symposium, No. 30*, Eds. Batten and Heard, p. 229, Academic Press), using S Equ as an example. Yavuz (1968, *Astr. Abh. Hamburg. Sternw. Bergedorf*, **8**, No. 5) made a detailed spectrographic and photometric investigation of BV 344. The Roche model indicates that it is a detached system. The spectrally invisible secondary is probably an F-type sub-giant. Azimov (*Shemaha Obs.* (unpublished)) determined absolute spectrophotometric gradients for RS Ari, S Cnc, RS CVn, SX Cas, GG Cas, U Cep, AR Lac, UX Mon, RY Per, and U Sge. The variation of the gradient with phase was studied in the case of UY Vir. A similar study of AW Peg by Azimov and Babaev (*Shemaha Obs.* (unpublished)) included also the variation of hydrogen-line intensities. Jones (1969, *Acta Astr.*, **19**, 53) determined the effective temperature of AG Per from $(B-V)_0$ using the *Q*-method. Svolopoulos (1968, *Z. Astrophys.*, **69**, 296) derived an empirical relation between $B-V$ colour and radiation temperature from variables with total eclipses. The relation is compared with a similar empirical relation obtained by Becker (1948). Hall (1967, *Astr. J.*, **72**, 301) used narrow-band photometry on sub-giant components of Algol-type binaries to search for a possible anomalous abundance of heavy elements. The measurements revealed an apparent under-abundance of CN. McNamara (1967, *Astrophys. J.*, **149**, 723) commented upon the apparent metal deficiency of the secondary component of U Cep. Sistero (1968, *Publ. astr. Soc. Pacific*, **80**, 474) reported that *UBV* observations of S Vel during primary eclipse show an ultraviolet excess, similar to those found for some other sub-giant components. Surkova and Skatova (unpublished) investigated the period variations of 13 binaries and evaluated the rate of mass loss among binaries with sub-giant components.

A spectrophotometric investigation of Algol in the region λλ4700–3000 was made by Glushneva (1966, *Izv. gos. astr. Inst. Sternberga*, **34**, 81). Equivalent widths and depths of Balmer lines were determined at primary minimum and at maxima. The influence of Algol B and Algol C on the line shape was investigated. The Algol A Balmer lines increase during primary minimum, which can be connected with the limb-darkening. Valts and Glushneva (1967, *Astr. Zu.*, **44**, 728 = 1968, *Soviet Astr.*, **11**, 585) studied the behaviour of Ca II K from 195 spectrograms of Algol. The equivalent width is 2·4 times as large at minimum as at other phases, which confirms that the darker component is a K0 star. A doubling of the K line was observed in three spectrograms at primary minimum. Fracassini and Pasinetti (1968, *Mem. Soc. astr. ital.*, **39**, 653) determined sizes of the non-eclipsed area of Algol by means of the Balmer discontinuity, slightly modifying Chalonge and Divan's method. If the blue spectral gradient is assumed constant during eclipse the results are in agreement with McLaughlin's elements. Herczeg (1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 465, Academic Press, Budapest) and Friboes Conde, Herczeg and Høg (*Astr. Astrophys.* (in press)) discussed the Algol system, combining available astrometric, spectrographic, and photometric observations. It is concluded that the so-called great inequality, of "period" about 190 years, is in reality well represented by two sudden period-changes in the system AB, in about 1944 and 1952. The 32-year variation is probably due to apsidal motion. No further bodies beside *A*, *B*, *C* are present. The astrometric observations at primary minimum show effects of the light of Algol C.

The very interesting system BL Tel has been studied by Feast (1967, *Mon. Not. R. astr. Soc.*, **135**, 287). High-dispersion spectrograms show that the *F* super-giant primary has normal (solar) abundances. The secondary fills its Roche lobe and is slightly smaller and much fainter than the primary. It may be a cool super-giant or a hot sub-dwarf, ionizing a small and dense H II region, which produces the eclipse. High velocity and large *z*-coordinate (= 3·3 kpc) makes it a run-away system. The present state may be explained by the assumption that the secondary component was once a very massive star (about 400 $M_\odot$), which at some 10^7 years ago lost most of its mass very rapidly, probably as a result of a type II supernova outburst.

A general review on the W UMa stars was given by Kraft (1967, *Publ. astr. Soc. Pacific*, **79**, 395). He concludes, from statistical evidence, that the W UMa systems cannot now be transferring mass from one component to the other and cannot have descended from close-but-not-contact binaries, satisfying the mass luminosity relation. According to Lucy (1968, *Astrophys. J.*, **151**, 1123) the W

UMa systems are contact binaries, in the sense that the components have a common convective envelope. On the basis of this theory, Lucy (1968, *Astrophys. J.*, **153**, 877) proposed a model for calculating the light curves. It explains the anomalous luminosity ratios and correctly predicts the major characteristics of the light curves. A maximum of 1·28 mag. for the depth of primary minimum in integrated light is predicted and shown to be consistent with observational data. However, the asymmetries of the light curves cannot be explained, and the primary minimum for the theoretical light curves is due to the eclipse of the more massive component, which is not true for the majority of observed systems. Mauder (1968, *Mitt. astr. Ges.*, No. 25, 139; 1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 419, Academic Press, Budapest) developed a method for deriving the elements of W UMa systems by a Fourier transform of the whole light curve. Three parameters are basic: inclination, luminosity-ratio and mass-ratio, which fix the geometrical situation completely. Numerical work along these lines is in progress. Koch (1968, *Astr. J.*, **73**, S102) pointed out that theoretical models of W UMa stars give contact systems, while photometric analysis of light curves give semi-detached systems. A program with narrow-band filters has been started at Flower and Cook Observatory, to investigate if this is a band-pass effect, and if the W UMa stars show the CN-absorption strength expected for main-sequence stars. Herczeg (1969, *Mass Loss from Stars*, Ed. Hack, p. 213, D. Reidel Publ. Co.) summarized our knowledge on the period changes of the W UMa stars. It was emphasized that almost all changes are of abrupt nature, and that both positive and negative changes occur.

A monograph on the binary systems of the ζ Aur type was written by Botsula (1968, *Binary Systems with Atmospheric Eclipses* (in Russian), "Nauka", Moscow). Magnan (1965, *Ann. Astrophys.*, **28**, 512) applied the theory of deviations from local thermodynamic equilibrium for a study of the chromosphere of the K component of 31 Cyg. The case of Ca II was examined with a three-level atom and a continuum. A model atmosphere with homogeneous density-distribution was obtained. Saito (1965, *Publ. astr. Soc. Japan*, **17**, 107) used the theory of shock-pulse propagation on the K components of ζ Aur and 31 Cyg. The inferred chromospheric condensations are taken to represent shock-pulses and the turbulent velocity field originates from these pulses. Tatum (1966, *Publ. Dom. astrophys. Obs. Victoria*, **12**, 425) discussed the problem of interpreting the equivalent widths of absorption lines produced during the atmospheric eclipse. A computer programme for obtaining the radial density-distribution was applied to 32 Cyg. Wright (1968, *J. R. astr. Soc. Can.*, **62**, 67) summarized recent Victoria spectrographic results on ζ Aur and 31 Cyg. Kitamura (1967, *Publ. astr. Soc. Japan*, **19**, 194) published a study of the chromospheric K line of ζ Aur in the 1963–64 eclipse and made comparisons with theoretical profiles. Doherty (1967, *Astr. J.*, **72**, 296) analyzed photoelectric spectral scans from the 1965 eclipse 32 Cyg. The spectral type of the secondary was determined as B3. Comparisons with previous eclipses give some evidence for a decrease of the radius of the K4 I component. Mayer (*Sternw. München* (unpublished)) is reported to be working on spectrograms of 31 Cyg obtained during the 1961 eclipse.

Cowley (1969, *Publ. astr. Soc. Pacific*, **81**, 297) has given a concise summary of the photometric and spectrographic studies of the VV Cep stars. The number of objects in this group is now 14, including the related object α Sco. Besides VV Cep and AZ Cas, showing photometric eclipses, several others are suspected to show atmospheric eclipses. Spectrograms of VV Cep from the interval 1956–68 were analyzed by Wright and Larson (1969, *Mass Loss from Stars*, Ed Hack, p. 198, D. Reidel Publ. Co.) for mass motions within the system. The mass ratio of the components is found closer to 1 than to 2. Additional absorption lines may be interpreted as due to gas moving from the M-type star towards the secondary. Faraggiana and Hack (1969, *Mem. Soc. R. Sci. Liège*, Ser. 5, **17**, 317) discussed intensities and radial velocities of the forbidden lines of VV Cep. Glebocki and Keenan (1967, *Astrophys. J.*, **150**, 529) reported upon observations of the O I lines λλ7774 and 8446. These lines, which were seen in the spectrum of VV Cas in 1944, but had disappeared in 1945, reappeared in 1964 and persisted until spring or summer 1965. Both apparitions coincide with predicted times of secondary minima, and it is probable that they originate in gas surrounding the B-component. Mammano and Martini (1969, *Mass Loss from Stars*, Ed. Hack, p. 184, D. Reidel Publ. Co.) described the spectrum of Boss 5481 during the 1965–67 shell episode, which may be an eclipse phenomenon. In another paper Mammano and Martini (1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 415, Academic Press, Budapest) described changes in the spectra of three other VV Cep stars, including WY Gem. Cowley (1969, *Publ. astr. Soc. Pacific*, **81**, 297) reported that this star exhibited a shell spectrum 1968–69, probably due to an atmospheric eclipse.

The related object ε Aur was studied by Ivanova (1967, *Astrofiz.*, **3**, 223) with spectrophotometric methods during the 1955–57 minimum and also out of minimum. A comprehensive and critical review of observations and theories concerning this star has been completed by Jesse (*Sternw. München* (unpublished)).

The spectroscopic and photoelectric observations of novae and nova-like variables, pertaining to the binary nature of these stars, were reviewed by Mumford (1967, *Publ. astr. Soc. Pacific*, **79**, 283, 500). The outstanding questions are: Where did the short periods originate, and how can the varying degree of explosive activity be explained among systems constructed on approximately the same model? In a later article Mumford (1969, *Mass Loss from Stars*, Ed. Hack, p. 204, D. Reidel Publ. Co.) discussed the periods of T Aur, EM Cyg, U Gem, DQ Her, EX Hya, V Sge, and WZ Sge. Period changes are indicated for U Gem, DQ Her, and V Sge. Another review of the problems of the eruptive binaries was given by Smak (1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 345, Academic Press, Budapest). He dealt especially with period changes, as indicating mass loss or mass transfer, with colours and "hot spots", and with the origin of outbursts. Previous photometric evidence from U Gem seemed to indicate that the eruptions occur in the late type component. Recent spectroscopic observations of the non-eclipsing SS Cyg by Walker and Chincarini (1968, *Astrophys. J.*, **154**, 157) indicate, however, that the outbursts occur in the blue component. Paczyński, Ziółkowski, and Zytkow (1969, *Mass Loss from Stars*, Ed. Hack, p. 237, D. Reidel Publ. Co.) suggested that the outbursts of U Gem systems might be related to mass outflow from the late type components. These components are the more massive ones, and they fill their Roche lobes. The authors show that under these circumstances the mass outflow will occur on a dynamic time-scale, if there is a deep convective envelope. A model for nova outbursts has been developed by Rose (1968, *Astrophys. J.*, **152**, 245; 1969, *Mass Loss from Stars*, Ed. Hack, p. 77, D. Reidel Publ. Co.) on the basis of the binary nature of novae. The hydrogen-exhausted hot component is supposed to accrete small amounts of hydrogen-rich mass. A non-degenerate hydrogen-burning shell is formed, which may become thermally unstable, and pulsational instability is found to develop.

New important observations were reported on DQ Her. Dibai and Shakhovskoi (1966, *Astr. Zu.*, **43**, 1319 = 1967, *Soviet Astr.*, **10**, 1059) found that the polarization parameters vary substantially during eclipse. The polarization measurements give for the orbital plane the same position angle as that of the major axis of the envelope visible after the 1934 outburst. Nather and Warner (1969, *Mon. Not. R. astr. Soc.*, **143**, 145) have used their synchronous photometer, constructed for pulsar work, to obtain an accurate light curve for the 71·1 second-pulsation of the white dwarf component. This component does not contribute more than 2 or 3 % of the total light of the system, thus the true amplitude of the pulsation is above 1 mag. The shoulders on the light curve, preceding and following eclipse, cannot be due to a "hot spot" on the white dwarf. The nebula surrounding this component is suggested to be optically thick, and the eclipse of a bright region in the nebulosity by the larger component is considered responsible for the shoulders.

Krzeminski and Smak (1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 371, Academic Press, Budapest) proposed a new model for WZ Sge, in which the secondary contributes 20 % of the total light. The W UMa-type light curve is, except for the primary eclipse, explained as a result of the aspherical shape of the secondary. Both stars are degenerate, with effective temperatures of 20000 K and 8000 K respectively. Smak and Stepien (1969, *Non-periodic Phenomena in Variable Stars*, Ed. Detre, p. 355, Academic Press, Budapest) reported extensive photoelectric observations of TT Ari, which indicate that this star is a hot, sub-luminous close binary with $P = 0{\cdot}2658$ days. It also shows quasi-periodic fluctuations with periods between 14 and 20 min, and flickering with a time scale of about 1 min. Smak (1969, *Acta astr.*, **19**, 165) presented arguments in favour of the view that HZ 22 is not a normal B-type binary with $P = 3{\cdot}58$ days but rather a hot sub-dwarf binary with $P < 1$ day.

THEORETICAL AND STATISTICAL INVESTIGATIONS

A new feature in the past triennium was the introduction of the technique of computing time-dependent evolutionary model sequences. The integration method devised by Henyey and collaborators was adapted (first by Kippenhahn and Weigert, *Z. Astrophys.*, **65**, 251, 1967) to include mass loss due to thermal instability of the more massive component when it reaches its Roche limit. Rapid progress in this field can best be surveyed from the proceedings of four recent conferences: (1) Uccle Colloquium in 1966 (On the Evolution of Double Stars, *Comm. Obs. R. Belg. Uccle*, **B17**), (2) Joint Discussion in Prague, 1967 (section F of *Highlights of Astronomy*, Ed. L. Perek), (3) Trieste Colloquium in 1968 (*Mass Loss from Stars*, Ed. M. Hack), (4) Copenhagen Colloquium in 1969, Ed. K. Gyldenkerne. Original papers were published mainly in *Z. Astrophys.*, **65–67** by Kippenhahn, Weigert, Kohl, Thomas, Giannone, Refsdal etc., in *Acta astr.*, **17** by Paczyński and Ziółkowski, and in *Bull. astr. Csl.* (*B.A.C.*), **18–20** by Plavec, Kriz, Harmanec and Horn. See also the review papers by Plavec (*Adv. Astron. Astrophys.*, **6**, 201, 1968) and Paczyński (*Ann. Rev. Astron. Astrophys.*, in press).

Originally the purpose was to explain the evolutionary paradox of the Algol-like semidetached binaries, where the less massive component appears more advanced in evolution. It appears that the above-described theory can explain not only this but also other properties of these systems like overluminosity of the subgiant secondaries, their contact nature, and presence of gas streams. It appears that semidetached binaries are generated by mass exchange of type A (the initially more massive component reaches its Roche limit when hydrogen is still burning in its core) in case of more massive systems, while case B (hydrogen shell burning) applies to low-mass binaries, although a mixed case AB can be important, too. (Kippenhahn *et al.*, *Z. Astrophys.*, **65**, 251, **66**, 58; Refsdal, Weigert, *Astron. Astrophys.*, **1**, 167; Plavec, *Astrophys. Space Sci.*, **1**, 239, 1968; Plavec *et al.*, *B.A.C.*, **20**, 41, 1969; Ziólkowski, *Astrophys. Space Sci.*, **3**, 14, 1969).

Quantitative comparison with observed systems will probably have to take into account deviations from sphericity, possible escape of material from the system, and conversion of orbital angular momentum into that of axial rotation. The latter may explain the excess rotation of some primaries like U Cep or RZ Sct (Plavec, Van den Heuvel, 1969, Columbus Colloquium on Stellar Rotation).

Connected with the problem of angular momentum is the formation of gaseous rings around primaries (Kruszewski, *Acta astr.*, **17**, 297, 1967; Huang, *Ap. J.*, **148**, 793, 1967; Plavec, *B.A.C.*, **19**, 11, 1968; Smak, *Acta astr.*, **19**, 155, 1969; Gorbackij, *Astrofiz.*, **3**, 245).

Huang suggested that massive and opaque rings may be formed in systems like β Lyr (*Ap. J.*, **138**, 342, 1963) or ε Aur (*Ap. J.*, **141**, 976, 1965). β Lyr is likely to be in the phase of rapid mass transfer of type B. But in the supergiant systems like ε Aur or VV Cep the components apparently do not fill critical lobes and yet they lose mass. This superficial instability may in fact not be restricted to supergiants, as indicated by the erratic period changes and intermittent ring formation in some systems with giants (SX Cas, UX Mon) or subgiants (U Cep, RS CVn).

Case B of mass exchange is generally of greater importance, in particular practically all spectroscopic binaries will at one time be subject to it. The transformation is even more drastic, and mass losses as high as 80 % occur (Kippenhahn, Weigert, *Z. Astrophys.*, **65**, 251, **66**, 58; Kriz, *B.A.C.*, **20**, 127, 1969). Suggestions have been put forward that this process (or case C and higher) could explain various objects like: the Sirius-like visual binaries (Lauterborn, Trieste and Copenhagen), Wolf-Rayet stars (Paczyński, *Acta Astr.*, **17**, 355, 1967), some shell stars (Křiž, Plavec, Horn, Trieste), blue stragglers and even Am and Ap stars (Van den Heuvel, *B.A.N.*, **19**, 326, 1968 and Prague meeting), helium-rich and hydrogen-poor stars, etc. Many more detailed studies are needed, including the problem whether and how the mass-gaining component accommodates the in-flowing material. Certainly much depends on the star's nature. If it is already a degenerate star, thermal instability and violent pulses are expected (Kippenhahn *et al.*, *Z. Astrophys.*, **69**, 258, 1968; Giannone, Weigert, *ibid.*, **67**, 41, Rose, *Ap. J.*, **150**, 193, 1967), the study of which may throw new light on the problem of novae and U Gem stars.

The evolution of the W UMa systems appears to be more complex, and Huang (*Ann. Astrophys.*,

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29, 331, 1966) invokes magnetic fields besides mass exchange. However, we do not even understand the character of these systems fully, since the interpretation by Lucy (*Ap. J.*, **151**, 1123, 1968) in terms of a contact binary is not in agreement with the observational evidence that they are actually semi-detached systems.

Another open problem is whether we can and do observe some binaries still at the phase of pre-main-sequence contraction (cf. Wood, Prague and Trieste). A single system of this kind would be very interesting.

Relatively little progress can be reported in the problem of the origin of binary stars. From a statistical study, Huang (*Ann. Astrophys.*, **31**, 379, 1968, and Prague meeting) found support for the contention about star formation in groups; it is hoped that intensive work on the origin of close binaries may be a feature of the next three years.

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