42. PHOTOMETRIC DOUBLE STARS
(ÉTOILES DOUBLES PHOTOMÉTRIQUES)

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INTRODUCTION

M. Plavec

Extremely important developments occurred in the study of close binaries in recent years. The preceding triennium, 1967–69, witnessed the formulation of the theory of mass transfer between the components of a close binary. Evolutionary calculations using mainly Henyey's method explained – at least qualitatively – the existence of the semi-detached binaries, and predicted formation of white dwarfs and helium stars in certain close binary systems. In connection with these studies, a number of theoreticians working on stellar evolution contributed to the study of close binaries. In the triennium 1970–72, reviewed here, the interaction of our field with the theory of stellar structure and evolution continued, but mostly in another form. The intensive search for collapsed objects (black holes and neutron stars) – as the final stages of stellar evolution for more massive stars – naturally focused attention on binary systems, for a black hole can reveal its presence only by its gravitational field.

Another equally important development came as an outcome of new observing techniques. Radio waves coming from Algol and β Lyrae were detected. Also the other two known 'radio stars', Antares and Cyg X-1, are binary systems. These four systems, at first sight so dissimilar, may have one characteristic in common: gaseous material is likely to be transferred between the components. Cyg X-1 is also an X-ray source, and other X-ray sources were discovered some of which are eclipsing binaries while others – some certainly, others probably – are spectroscopic binaries. The first theoretical models attempting to explain the X-radiation locate its source in the interaction between a gas stream or disk and the mass-accreting star. Specific properties are required for this star: it may be a white dwarf, a neutron star, or even a black hole surrounded by a gaseous disk. Evidently peculiar and complicated systems will attract more attention in the future.

An effort to understand such peculiar binaries, or binaries harboring a collapsed object, will require a broader observational approach. But even in this respect the prospects are good thanks to an enormous improvement and expansion of observing techniques. Narrow-band and high time resolution photometry, image intensifiers in spectroscopy, increased access into the infrared, extraterrestrial observations in the far ultraviolet – all these techniques are beginning to make their impact on the study of binary stars.

On the theoretical side, the impact of high-speed computers is now much more felt in the computation of elements than a few years ago. The attempts to understand X-ray sources and to detect black holes temporarily focused attention on the present-day models of binary stars rather than on their evolution. However, once acceptable models are found and present character of some components clarified, the question will reappear about the ways by which the systems have arrived at their present stage.

A very surprising feature of theoretical work in the past triennium has been the very intense and successful work on contact binaries. For a long time, the W UMa systems were considered so hopelessly complicated that no serious attempt was made to understand them. The sudden breakthrough only shows how difficult it is to make predictions in science and how cautious one must be before using the word 'impossible'.

Both the new techniques and the theoretical studies make no fundamental distinction between eclipsing and non-eclipsing (spectroscopic) binaries. As a consequence of these developments, a majority of members of the Commission and all members of the Organizing Committee think that the present name of the Commission, referring specifically to one technique, is obsolete and should be replaced, probably by the name 'Commission on Close Binary Stars'.

This does not diminish the importance of eclipsing binaries as objects which furnish more fundamental data on stars than any other class of objects. Whenever a binary turns out to be eclipsing, our hopes to understand the system are immensely increased. But close binary stars as a whole have now become important cosmological objects, worth of being studied for the sake of themselves. A much wider spectrum of astrophysicists are now interested in close binaries, and their interaction with the 'old faithful' investigators will help us to understand better the nature, origin and evolution of binary stars.

Some of the new trends are already reflected in this report, but many astrophysicists whose interest in close binaries is transient or indirect did not report their results to us; therefore the reader is advised to read also reports of commissions 29, 30, 35, 36, 40 and 44.

Of common interest will be several compilations. M. G. Fracastoro published an *Atlas of Light Curves of Eclipsing Binaries*. The *Rocznik Astronomiczny*, published yearly at Cracow, now contains also predictions of minima of southern variables, as well as of bright eclipsing variables wih shallow minima. Landolt and Blondeau (Baton Rouge, Louisiana) recalculated Prager's tables of heliocentric corrections which are now out of print; a copy can be obtained on request from Professor Landolt. Lucy and Sweeney (*AJ*, **76**, 544) rediscussed some older spectroscopic solutions, which may improve grades *d* or *e* assigned in Batten's *Sixth Catalogue*.

Restrictions imposed on the length of this report make it naturally incomplete. A more complete survey of current bibliography has been published semi-annually by G. Larsson-Leander at the Lund Observatory, as a mimeographed publication entitled *Bibliography and Program Notes on Eclipsing Binaries*. Numbers 17 through 21 were issued in the triennium covered by this report. Regional contributors to the Bibliography were in particular: B. Cester (Italy), J. Grygar (Central and Eastern Europe), O. Günther (Germany), M. Kitamura (Japan), D. S. Hall (North America), G. F. G. Knipe (Southern Hemisphere), F. van't Veer (Western Europe), A. Shulberg (U.S.S.R.), S. D. Sinvhal (India and Indonesia). Their work is appreciated by all members of the Commission. The editorial work by G. Larsson-Leander and his staff at the Lund Observatory (in particular, Miss Gun Bergsten and Mr. O. Ek) deserves particular thanks of us all.

The Commission sponsored or co-sponsored three scientific meetings. The Bamberg Colloquium on Variable Stars was held in 1971 and its proceedings have already been published as *Veröff. Sternw. Bamberg*, Bd. **IX**, Nr. 100; we shall refer to it simply as *Bamberg*. IAU Colloquium No. 16 held at Philadelphia in November 1971 specialized on the methodology of the solution of light curves of eclipsing binaries. Its proceedings will soon appear as *Publ. Univ. of Pennsylvania, Astronomical Series*, Vol. **XII**, edited by R. Koch. We will refer to this publication as *Phila*. IAU Symposium No. 51, or the Otto Struve Memorial Symposium, was held in Parksville, B.C., in September 1972. The proceedings of this symposium, which dealt with circumstellar matter and extended atmospheres in binary systems, were edited by A. H. Batten and will be published by D. Reidel. In our references it will be abbreviated *Parksv*. Proceedings of two previous Colloquia, already published, will be frequently referred to in this report, therefore an abbreviation for them is also convenient. *Budap.* means *Non-Periodic Phenomena in Variable Stars*, ed. L. Detre, published by D. Reidel in 1969, and *Copenh.* means *Mass Loss and Evolution in Close Binaries*, ed. K. Gyldenkerne and R. M. West, a very neat and cheap book published by the University of Copenhagen in 1970. Some of our abbreviations of current astronomical journals will not please the General Secretary, but since he dislikes long reports even more, we saw no other solution.

The Organizing Committee met at Parksville and decided to prepare this report collectively. At the end of each section, the name of its author is given. Changes were made only where I felt that overlaps should be eliminated, or where the effort to have a fairly balanced report led me to include more material; therefore a few sections have two authors. My thanks are due to all the authors, to Dr Larsson-Leander who collected a good deal of the references, to all those who sent us their reports and to Ms. J. Kuebler who typed the manuscript.

INSTRUMENTS AND TECHNIQUES

T. Herczeg, M. G. Fracastoro

The greatest progress in ground-based observations was probably the high time-resolution photometry introduced by Nather and Warner (*MN*, **152**, 209), which already yielded excellent results on ultra-rapid variables. Basic limitation is imposed only by photon statistics, therefore use of a large telescope is desirable. Integration times longer than 4 s may already result in a loss of significant details in a light curve like that of U Gem ($P = 4^{h}.2$). For description and results, see also Warner, *Bamberg*, 144.

Increasing number is reported of multichannel and dual-beam photometers, enabling the observer to record several colors or the variable and the comparison star at the same time. A few examples are the photometer of University of Florida at Rosemary Hill (*BAAS*, **4**, 34), dual-channel photometer at the 30-in. at McDonald, Fernie's photometer at David Dunlap (*BAAS*, **4**, 292), Cester's photometer with rotating filter and analyser, designed for the Trieste 1 m-telescope.

Similar progress was made in spectroscopy. High resolution spectral scans are possible with the Isocon televison camera as used by Walker and Auman at Vancouver (Hutchings, Walker and Auman, *Bamberg*, 279); first results confirm earlier findings of Hutchings that the emission profiles in Be stars are rapidly variable. The high time-resolution spectrographic techniques using electronographic image-tubes will be invaluable for the study of rapid variables or of phases where the spectrum changes rapidly (and this is often the case with eclipses.)

Another extremely important development following from the introduction of image-tube techniqes into astronomical spectroscopy is the availability to observations of the infrared spectrum, where the lines of cool secondary components can be observed, and where it is also possible to find imprints of circumstellar shells.

Polarization techniques and results were reviewed by Serkowski (*Bamberg*, 11). Particularly important were the studies of polarization in β Lyr by Coyne (*ApJ*, **161**, 1011).

In this report, first results will be presented of radio and X-ray studies of close binary systems. The techniqes are described by the proper commissions. Here we only append the report of the committee entrusted with maintaining the links to teams who are in charge of extraterrestrial observations.

REPORT OF THE COMMITTEE FOR EXTRATERRESTRIAL OBSERVATIONS

Y. Kondo

The primary functions of the Committee are: (a) Coordination of space observations with terrestrial observations, (b) Disseminating information on the status of the space observations, (c) Channeling comments from the broad astronomical community concerning space observations.

The coordination of space and terrestrial programs was realized between the University of Wisconsin OAO-A2 investigators and the coordinators of campaigns on β Lyr and on 31 and 32 Cyg. Doherty (Wisconsin) reports that part of totality and egress was observed for 32 Cyg and ingress was observed for 31 Cyg. The balloon and rocket-borne experiments on β Lyr performed by Kondo *et al.* were similarly coordinated with Batten and Sobieski.

The variable stars observed with the OAO-A2 were reported by Kondo in a review paper (*Bamberg*, 298). Committee members and other interested members of Commission 42 were kept informed of the status of the observations obtained with OAO-A2. Much of the data have been deposited at the National Space Science Data Center at Greenbelt. Release of the data is pending subject to completion of 'the user's handbook' (hopefully within the next few months). Scientists desiring the data should write to the National Space Science Data Center, Code 601.4, Goddard Space Flight Center, Greenbelt, Maryland 20771. Scientists who are not U.S. citizens also have access to these by writing to World Data Center A, for Rockets and Satellites, Code 601, Goddard Space Flight Center, Greenbelt, Maryland 20771, U.S.A. Astronomers desiring these data need not wait until its availability is formally announced, but may write to one of the above addresses. Their names will be filed and they will be notified as soon as the data are released.

We are currently keeping an eye on OAO-C (Copernicus), for which a guest observer program may be initiated. Establishment of a standard procedure for flow of information from the Committee to the rest of the Commission is desirable; perhaps several people can act as 'regional disseminators of information'.

PHOTOMETRIC OBSERVATIONS AND SOLUTIONS

F. B. Wood

Conventional photoelectric observations of light curves and photometric solutions based on them continued on many observatories. Tables 1 and 2 summarize the published material received at the time of writing (November, 1972). In the case of newly observed light curves, we have followed the sense of previous resolutions passed by Commission 42 and included only those for which the individual observations were published; thus publications which included only a plot of the light curve or a list of normals have been omitted.

In spite of the apparent wealth of light curves (and their solutions) it appears that in particular for systems of longer period (4 days and more), more observations and analyses are urgently needed. These systems are extremely important for studies of evolution of the binary stars. Moreover, they often contain giants for which masses and other characteristics are very little known. Presently only D. S. Hall at Nashville is studying the binaries of longer period systematically, and has already made a number of important discoveries. More observers should be encouraged to shift attention to systems of longer periods, since there seems to be little point in continuing to repeat routine observations of the W UMa systems in broad-band wavelength regions.

The OAO-2 satellite took multicolor UV observations of β Lyr, LY Aur, VV Ori, U Oph, and CW Cep. So far the observations have not been made generally accessible, so that it is difficult to judge exactly their value; in principle, of course, these observations signal a new epoch. Preliminary results on β Lyr have been published (Kondo, McCluskey, Houck in *Bamberg* 308) and revealed unexpected behavior in the ultraviolet.

An Atlas of Light Curves of Eclipsing Binaries, prepared by M. G. Fracastoro and published by the Osservatorio di Torino, Italy, is extremely useful in showing at a glance the chief characteristics of the light curves as well as the precision and completeness of coverage. Koch (*PASP*, **84**, 5) published a valuable review of the photometric behavior of close binaries.

One of the observational highlights was the discovery of an eclipsing system containing a white dwarf, by Nelson and Young (*PASP*, **82**, 699; *ApJ*, **173**, 653). Warner *et al.* (*MN*, **154**, 455) derived a limb darkening coefficient for the white dwarf and discussed the system, as also did Vauclair (*Astr. Aph.*, **17**, 437).

The introduction of high time resolution photometry by Warner and Nather promises to reveal new phenomena in close binary stars. Studying the rapid blue variables with a time resolution of 3 s, they detected rapid flickering with an amplitude of up to 10% of the total light in WZ Sge, VV Pup, EX Hya, and AM CVn (*MN*, **156**, 297, 305; **158**, 425; **159**, 101).

Table 1. Published photoelectric light curves

AB And, *AJ*, **74**, 1078; ST Aqr, *MNASSA*, **30**, 157; V 535 Ara, *Bamberg Veröff.*, **8**, No. 88; V 539 Ara, *Astron. and Ap.*, **14**, 70; β Aur, *Astron. and Ap.*, **12**, 165; WW Aur, *Studii si Cercetari de Astronomie*, **14**, 69;

AR Aur, *Astron. and Ap.*, **4**, 1; IU Aur, *BAC*, **22**, 168; LY Aur, *BAC*, **22**, 237; TY Boo and TZ Boo, *Goodsell Pub.*, No. 16; XY Boo, *AJ*, **76**, 922; ZZ Boo, *PASP*, **83**, 192; AS Cam, *Mem. RAS*, **76**, 1; RZ Cas, *Pub. Tartu*, **38**, 144; *Mem. Soc. Astr. Ital.*, **41**, 395; SX Cas, *AJ*, **77**, 500; TW Cas, *AJ*, **76**, 449; AR Cas, *AJ*,**76**, 557; DO Cas, *AJ*, **74**, 1191; GG Cas, *BAC*, **21**, 353; RR Cen, *AJ*, **76**, 64; V 701 Cen, *AJ*, **76**, 52; V 747 Cen, *AJ*, **75**, 731; VW Cep, *Mem.Soc.Astron. Ital.*, **41**, 395; **43**, 1; WX Cep, *BAC*, **21**, 345; CQ Cep, *Perem. Zv.*, **16**, 488; EM Cep, *PASP*, **82**, 1093; GP Cep, *AA*, **20**, 117; R CMa, *PAS Japan*, **23**, 335; TX Cnc, *Tokyo Bull.*, No. 209; RS Col, *PASP*, **81**, 696; ε CrA, *AJ*, **74**, 533; *Studii si Cerc. de Astr.*, **15**, 65; *AJ*, **77**, 157; RW CrB, *AJ*, **77**, 239; *Goodsell Pub.*, No. 16; 31 Cyg, *Astron. and Ap.*, Supl. **1**, 129; 32 Cyg, *Astron. and Ap.*, Supl. **1**, 149; SW Cyg, *Astron. and Ap.*, **13**, 249; *PASP*, **84**, 552; WW Cyg, *PASP*, **84**, 541; MR Cyg, *PASP*, **81**, 754; V 444 Cyg, *Soobs. Sternberg*, No. 161; V 477 Cyg, *Studii si Cerc. de Astr.*, **14**, 69; *Vistas in Astronomy*, **12**, 271; W Del, *AN*, **292**, 145; AI Dra, *AA*, **21**, 517; RX Her, *Studii si Cerc. de Astr.*, **14**, 69; AK Her, *PASP*, **84**, 566; HS Her, *PASP*, **83**, 459; VZ Hya, *AJ*, **75**, 720; WY Hya, *Goodsell Pub.*, No. 16; SW Lac, *AA*, **21**, 49; TX Leo, *Astron. and Ap.*, Suppl. **1**, 165; UZ Leo, *AJ*, **77**, 246; β Lyr, *PASP*, **83**, 357; TT Lyr, *AN*, **291**, 89; RW Mon, *AA*, **19**, 257; TU Mus, *Republic Obs. Circ.*, **8**, 8; RV Oph, *Astron. and Ap.*, **5**, 140; V 566 Oph, *AJ*, **74**, 1197; BM Ori, *PASP*, **81**, 771; FT Ori, *Astron. and Ap.*, **5**, 228; U Peg, *Tokyo Astr. Bull.*, No. 211; *AJ*, **77**, 319; β Per, *Ap. J.*, **177**, 191; ST Per, *BAC*, **21**, 219; IQ Per, *PASP*, **82**, 219; ζ Phe, *Astron. and Ap.*, **12**, 286; UU Psc, *AJ*, **76**, 455; V Pup, *Bol. d. Tonantzintla y Tacubaya*, **6**, 89; XZ Pup, *Astron. and Ap.*, **11**, 20; RZ Sct, *Perem. Zv.*, **17**, 468; CV Ser, *Astr. Circ.*, No. 602; *Soviet AJ*, **48**, 1201; WZ Sge, *AA*, **21**, 133; EQ Tau, *Abastumani Bull.*, **40**, 11; HO Tel, *Notas Scientificas Obs. Nacional*, Brasil, No. 1; *Astron. and Ap.*, Suppl. 7, 83; W UMa, *Mem. Soc. Astr. Ital.*, **41**, 395; W UMi, *PASP*, **82**, 10; AG Vir, *AJ*, **74**, 1024; AH Vir, *Trudy Inst. Astr. Kazakstan*, **17**, 18; BF Vir, *Goodsell Pub.*, No. 16; BE Vul, *AA*, **20**, 123; BU Vul, *Republic Obs. Circ.*, **8**, 7; DR Vul, *Ric. Astr.*, **8**, 319.

Table 2. Photometric Solutions

AB And, *Studii si Cerc. de Astr.*, **16**, 197; FK Aql, *Perem. Zv.*, **17**, 81; *Soviet AJ*, **48**, 301; V 337 Aql, *Aph. Sp. Sci.*, **11**, 232; V 1182 Aql, *Izvestia Crimean Astroph. Obs.*, **40**, 82; V 535 Ara, *Bamberg Veröff.*, **8**, No. 88; V 539 Ara, *Astron. and Ap.*, **14**, 70; β Aur, *Astron. and Ap.*, **12**, 165; ε Aur, *Ap. J.*, **170**, 529; AR Aur, *Astron. and Ap.*, **4**, 1; LY Aur, *BAC*, **22**, 327; ZZ Boo, *PASP*, **83**, 192; SZ Cam, *Tokyo Bull.*, No. 220; AS Cam, *Mem. RAS*, **76**, 1; AY Cam, *Mem. Soc. Astr. Ital.*, **40**, 345; RZ Cas, *Tartu Pub.*, **38**, 171; SX Cas, *AJ*, **77**, 500; TW Cas, *AJ*, **76**, 449; AO Cas, *Ap. J.*, **167**, 137; DO Cas, *AJ*, **74**, 1191; GG Cas, *BAC*, **21**, 353; MN Cas, *Soviet AJ*, **48**, 301; RR Cen, *AJ*, **76**, 64; *MN*, **156**, 243; V 701 Cen, *AJ*, **76**, 52; V 747 Cen, *AJ*, **75**, 731; WX Cep, *BAC*, **21**, 353; EG Cep, *AJ*, **76**, 701; R CMa, *PAS Japan*, **23**, 355; FF CMa, *Veröff. Bamberg*, **VIII**, No. 83; S Cnc, *Ap. J.*, **164**, 131; TX Cnc, *PAS Japan*, **24**, 213; ε CrA, *Studii si Cerc. de Astr.*, **15**, 65; RW CrB, *AJ*, **77**, 239; *Perem. Zv.*, **17**, 647; 31 Cyg, *Astron. and Ap.*, **3**, 179; SW Cyg, *Astron. and Ap.*, **13**, 249; VW Cyg, *AJ*, **75**, 961; WW Cyg, *PASP*, **84**, 541; DK Cyg, *MN*, **156**, 243; MR Cyg, *PASP*, **81**, 754; *Ap. J.*, **166**, 605; *Ap. J.*, **171**, 413; *AJ*, **76**, 701; V 477 Cyg, *Vistas in Astronomy*, **12**, 271; V 1143 Cyg, *AJ*, **76**, 701; W Del, *AN*, **292**, 145; AI Dra, *Studii si Cerc. de Astr.*, **15**, 187; *AA*, **21**, 517; S Equ, *Perem. Zv.*, **17**, 76; AS Eri, *Ap. J.*, **166**, 373; U Gem, *AA*, **21**, 15, not a solution in the conventional sense; RX Her, *Studii si Cerc de Astr.*, **14**, 69; TX Her, *Ap. J.*, **162**, 925; AD Her, *AN*, **291**, 231; AK Her, *PASP*, **84**, 566; HS Her, *PASP*, **83**, MM Her, *Astron. and Ap.*, **12**, 155; χ^2 Hya, *Astron. and Ap.*, **1**, 147; VZ Hya, *AJ*, **75**, 720; *AJ*, 76, 701; FG Hya, *MN*, **156**, 243, SW Lac, *Studii si Cerc. de Astr.*, **16**, 55; TT Lyr, *AN*, **291**, 89; RW Mon, *AA*, **19**, 257; *AA*, **20**, 351; RV Oph, *Astron. and Ap.*, **5**, 140; V 566 Oph, *AJ*, **74**, 1197; *MN*, **156**, 243; ψ Ori, *Ap. J.*, **167**, 137; BM Ori, *PASP*, **81**, 771; FT Ori, *Astron. and Ap.*, **5**, 228; U Peg, *AJ*, **77**, 319; EE Peg, *Astron. and Ap.*, **4**, 173; *AJ*, **76**, 460; β Per, *Ap. J.*, **162**, 265; *Ap. J.*, **177**, 191; ST Per, *BAC*, **21**, 219; XZ Per, *Soviet AJ*, **48**, 301; IQ Per, *PASP*, **82**, 1077; IZ Per, *BAC*, **21**, 359; ζ Phe, *Ap. J.*, **162**, 925; *Astron. and Ap.*, **12**, 286; XZ Pup, *Astron. and Ap.*, **11**, 20; AU Pup, *Astron. and Ap.*, **17**, 362; RZ Sct, *Perem. Zv.*, **17**, 479; WZ Sge, *AA*, **21**, 133; λ Tau, *Ap. J.*, **166**, 373; RZ Tau, *MN*, **156**, 243; BD + 16° 516 Tau, *Ap. J.*, **173**, 653; HO Tel, *Notas Scientificas Obs. Nacional de Brasil*, No. 1; W UMa, *AJ*, **77**, 230; AW UMa, *MN*, **156**, 51; W UMi, *PASP*, **82**, 10; RU UMi, *PASP*, **83**, 286; AG Vir, *AJ*, **74**, 1024; *Mem. Soc. Astr. Ital.*, **41**, 343; Z Vul, *Studii si Cerc. de Astr.*, **16**, 45; RS Vul, *Ap. J.*, **166**, 373; BE Vul, *AA*, **20**, 123; DR Vul, *Ric. Astr.*, **8**, 319.

Remarks on Tables 1 and 2

Photometric work continued on a scale so large that a complete table recording all observations and authors would outgrow the size of this report. Wanting to preserve at least the most important information, we had to omit the names of observers and authors, although we know that this is grossly unfair. Let us mention at least here the leading contributors to this field. Argentina: Hernandez (studied ε CrA in R, I), Mendez (both La Plata); Czechoslovakia: Mayer (Prague), Vetešník (Brno); Denmark: Gyldenkerne, Jørgensen (Copenhagen); Germany: Geyer (Hohe List), Walter (Tübingen); India: Sinvhal (Uttar Pradesh); Italy: Cester, Pucillo (Trieste), Blanco, Catalano, Rodono', Cristaldi (Catania); Japan: Kitamura, Saito, Sato and a number of other observers at Dodaira, Akita and Kanawaga; The Netherlands: Kwee, Van Houten (Leiden), de Kort (Nijmegen); Poland: Szafraniec (Cracow), Smak *et al.* (Warsaw) ; Roumania: Popovici, Minti (Bucarest), Chis, Todoran (Cluj); South Africa: Knipe (Johannesburg), Warner (Capetown); U.S.A.: many observers, reports received from Hall (Nashville), Landolt (Baton Rouge), F. B. Wood, Chen, Bloomer *et al.* (Gainesville), Binnendijk and Koch (Philadelphia); U.S.S.R.: Magalashvili, Kumsishvili (Abastumani) (report incomplete).

METHODS OF ANALYSING LIGHT CURVES

F. B. Wood

Developments in this field have been rapid; many were discussed at IAU Colloquium No. 16 (*Phila.*) which was devoted entirely to the methodology of the solution of light curves. For exploratory work, printed tables are still an extremely effective approach; Merrill has constructed via computer by appropriate interpolations in Princeton Contr. 23 tables for (1) ${}^x\psi\,(k,\alpha)$, (2)${}^x\alpha\,(k,p)$, (3) ${}^x\psi_c\,(\alpha)$, (4)${}^x\alpha_c\,(p)$. The valuable Princeton Contr. 26 is to be reprinted.

For more refined analysis, two basic philosophies have developed. One is the automation of the traditional (Russell-Merrill) methods as carried out by Linnell (e.g., Linnell and Proctor, *ApJ*, **161**, 1043; Proctor and Linnell, *ApJ Suppl.*, No. 211). This generates the light at any phase by automating the formal analytical expressions for light loss. This is a fast approach and hence is amenable to the use of individual observations in calculating a light curve. In its present state of development it works best on detached systems whose light curves are defined by a large number of observations. It is flexible and quite accurate insofar as representation of the light curve for an adopted model is concerned.

The other approach is the development of a new non-spherical model by what has become known as the 'synthesis' method. Chief contributors in this area have been Hill and Hutchings, Wilson and Devinney, and D. B. Wood, who first suggested the synthesis techniques (*Trans. IAU* **XIB**). Special purpose models, differing in detail but philosophically similar, have been computed by Horák, Lucy, Mochnacki and Doughty, Rucinski, and others. The most significant differences are in the figure of the star (ellipsoid *vs.* Roche or Jacobian surface) and in the treatment of the reflection effect. The models also vary widely in their computer techniques but the main intention has been to reduce systematic errors in the analyses of light curves by applying more realistic physics and eliminating rectification procedures. Some attention also has been paid to computation of line profiles.

Most of the work uses a model assuming point masses; the photospheres are considered equipotential surfaces in the rotating coordinate frame of the binary. For a given element of surface area, the basic equation for the modified potential in the 'Roche' model is used to compute limb darkening and gravity darkening, the 'reflection' effect and orientation effects. The flexibility (also characteristic of the Linnell models) permits such parameters as the limb and gravity darkening coefficients to differ for the two components.

In 1968, Lucy (*ApJ*, **153**, 877) developed a method for computing bolometric light curves for contact binaries neglecting, at this stage, reflection effect. The first detailed comparison with observation was by Hill and Hutchings (*ApJ*, **162**, 265) who in particular were interested in determining the physical parameters of systems for comparison with evolutionary calculations. These authors have now developed a number of special purpose programs in differential correction form for dealing with various types of close binaries – for example one with reflection for both components applied to ellipsoidal variables (*ApJ*, **167**, 137), and a contact binary system applied to four WUMa

Changes in the circumstellar matter are difficult to study since older spectrograms were not calibrated. Short-term changes have definitely been established in β Lyr (Kondo *et al.*, *ApJ*, **176,** 153; Batten; Hack), and in SX Cas (Andersen and Batten). Bopp and Moffet (*ApJ*, 168, L117) found flare-like phenomena in YY Gem.

While extraterrestrial observations have widened the observable extent of the spectrum, improvement of techniques for ground-based spectroscopy offer new opportunities. Spectral scanners with high time resolution permit to study short-term changes in line profiles. Image intensifiers enable us to penetrate further into the infra-red and study spectra of late-type components, as well as possible circumstellar shells around binaries.

The following Table 3 gives brief references to spectrographic work reported to the Commission in the triennium 1970–72.

Table 3. Published spectrographic observations

AE Aqr: Payne-Gaposchkin (*ApJ*, **158,** 429); IU Aur: Mayer (*BAC*, **22,** 168); β Aur: Popper and Carlos (*PASP*, **82,** 762), Toy (*ApJ*, **158,** 1099); SZ Cam: Murphy (*AJ*, **74,** 1085); AS Cam: Hilditch (*Mem RAS*, **76,** 1); TX Cnc: Kitamura, Yamasaki (*PASJ*, **24,** 213); RS CVn: Catalano, Rodonó (*Budap.*, 435); R CMa: Galeotti (*Aph. Sp. Sci.*, **7,** 87); SZ Cen: Popper (*ApJ*, **169,** 549); LR Cen: Bessell (*ApJ*, **175,** L133); U Cep: Batten (*PASP*, **81,** 904), Batten and Laskarides (*PASP*, **81,** 677); VV Cep: Hutchings and Wright (*MN*, **155,** 203), Wright (*PASP*, **82,** 1036; *JRASC*, **64,** 182; *JRASC*, **66,** 70); EI Cep: Popper (*ApJ*, **166,** 361); XY Cet: Popper (*ApJ*, **169,** 549); SS Cyg: Smak (*AA*, **19,** 287); MY Cyg: Popper (*ApJ*, **169,** 549); V 448 Cyg: Cohen (*PASP*, **81,** 665); 31 Cyg: Wright and Huffman (*PDAO Vict.*, **13,** 275); 32 Cyg: Griffiths and Stencel (*PASP*, **84,** 427); BS Dra: Popper (*ApJ*, **166,** 361); WY Gem: Cowley (*PASP*, **82,** 329); YY Gem: Moffett and Bopp (*ApJ*, **168,** L117); TX Her: Popper (*ApJ*, **162,** 925); MM Her: Imbert (*Astr. Aph.*, **12,** 155); 68 Her: Koch and Sobieski (*BAAS*, **1,** 350); 88 Her: Harmanec, Koubský and Krpata (*BAC*, **23,** 218); HS Hya: Popper (*ApJ*, **166,** 361); χ^2 Hya: Mauder (*Astr. Aph.*, **4,** 437); RR Lyn: Popper (*ApJ*, **169,** 549); β Lyr: Skulskyi (*Sov Astr.*, **15,** 606); U Oph: Popper and Carlos, (*PASP*, **82,** 762); V 451 Oph: Popper (*ApJ*, **166,** 361); V 566 Oph: Bookmyer (*AJ*, **74,** 1197); BM Ori: Doremus (*PASP*, **82,** 745); δ Ori: Murphy (*AJ*, **74,** 1085); AT Peg: Hill, Barnes (*PASP*, **84,** 430); DI Peg: Bidelman (*IBVS*, 629); EE Peg: Ebbighausen (*AJ*, **76,** 460); AG Per: Lopez and Sahade (*As. Arg. Astr. Bol.*, **14,** 68); IZ Per: Yavuz (*Astr. Aph.*, **2,** 388); β Per: Bolton (*IAUC* 2388), Ebbighausen (*PASP*, **82,** 349); Hill *et al.* (*ApJ*, **168,** 443); ζ Phe: Popper (*ApJ*, **162,** 925); υ Sgr: Sahade and Albano (*ApJ*, **162,** 905); W Ser: (*Inf. Bull. Sth. Hem.*, April 1970); CV Ser: Cowley, Hiltner and Berry (*Astr. Aph.*, **11,** 407), Kuhi and Schweizer (*ApJ*, **160,** L185); RW Tau: Battistini *et al.* (*Aph. Sp. Sci.*, **14,** 438); CD Tau: Popper (*ApJ*, **166,** 361); RW Tri; Walker (*Bamberg*, 243); S Vel: Sisteró (*BAC*, **22,** 188); γ_2 Vel: Conti and Smith (*ApJ*, **172,** 623); DM Vir: Popper (*ApJ*, **166,** 361); BD + 16°516: Nelson and Young (*PASP*, **82,** 699; *ApJ*, **173,** 653); HD 5514: Vitrichenko (*Izv. Krym*, **40,** 82); HD 72754: Thackeray (*MN*, **154,** 103); HD 209813: Heard (*JRASC*, **64,** 215); HD 211853: Guseinadze (*Astrofiz.* **5,** 502); HR 2902: Cowley (*PASP*, **83,** 213); HR 6773: Hube (*PASP*, **83,** 805); HZ 22: Young *et al.* (*ApJ*, **174,** 27).

ABSOLUTE DIMENSIONS

F. B. Wood, M. Plavec

A number of authors combined photometric and spectrographic observations from various sources to compute absolute dimensions. Those received at the time of writing are included in Table 4.

The number of solutions is high mainly thanks to the systematic work by Popper who reported on it in two recent review papers (*Ann. Rev. Astro.*, **5,** 85, 1967; *Copenh.*, 13). The principal aim of his present investigations is to determine the loci of unevolved stars (smallest radius for a given mass) in the mass-radius and mass-color planes, as well as the evolutionary vectors for stars of known mass. Another result is the determination of the domain of the Am stars in these planes and in the color-surface gravity plane (*ApJ*, **169,** 549).

Popper also systematically studies the so-called AR Lac or RS CVn-type eclipsing binaries, characterized by an emission reversal in the broad absorption lines H and K being visible in one or both components outside eclipse. New provisional masses for members of this group are (hotter type systems (*ApJ*, Jan. 15, 1973). R. E. Wilson *et al.* (*ApJ*, **177**, 191) discussed their solution for Algol and presented their own model.

Wilson and Devinney (*ApJ*, **166**, 605) introduced an automated computational procedure intended to be as general as reasonably possible. Detached and contact systems may be treated by the same program which accounts for all conventional proximity effects except penumbral effects in reflection. Wilson and Devinney believe the computational accuracy for their approach is significantly better than for other synthesis methods, except that by D. B. Wood (*AJ*, **76**, 701). They further point out that refining solutions can be made by the method of differential corrections and have given the results of such solutions for two binaries (*ApJ*, **166**, 605; **177**, 191). A more limited differential correction program, adjusting two parameters in one pass band, has been applied by Lucy to 16 W UMa binaries (*Phila.*) and some of the other groups are developing differential corrections programs. An important question concerns the high accuracy achieved in the calculation of partial derivatives compared to the saving of computer time by calculations of moderate accuracy believed in some cases to be sufficient.

For contact binaries, Mochnacki and Doughty (*MN*, **156**, 51, 243) used a program specifically for such binaries to do the first actual fitting. Their geometrical treatment of the reflection effect is quite detailed as are those of most synthesis systems. They have applied their program to W U Ma; the requirement is that the secondary, less massive, star must have the higher temperature; this is in accord with theoretical work by Whelan (*MN*, **156**, 115). They also computed line profiles for several systems, but found poor agreement with those observed.

D. B. Wood (*AJ*, **76**, 701) used a model of tri-axial ellipsoids of adjustable shape which treats the variation of local brightness over the photosphere with an accuracy better than that of the Russell model but less than in other computing schemes or contact or nearly contact systems. Wood's method has two distinct advantages: the orbital eccentricity need not be zero, and the precision achieved in a fixed computing time is considerably better than in other synthesis programs. This model can also approximate rapidly rotating components by making the stars oblate spheroids. Other work along these general lines has been done by Cochran (*Bull. AAS*, **2**, 309) and by Rucinski (*AA*, **21**, 455) who has also (*AA*, in press) confirmed by a photometric method Lucy's results on the shallowness of W UMa envelopes for 13 systems and shown this also to be true for 14 systems without spectrographic mass ratios.

In application of these programs, some of the results were the demonstration by Mochnacki and Doughty and by Wilson and Devinney that, in at least some of the W UMa binaries, the components have a common envelope. In addition, the latter two have found least squares values for the gravity exponent close to that predicted by Lucy for stars with convective envelopes; Hill and Hutchings have also found excellent fits using this gravity darkening in cool stars. Wilson *et al.* (*ApJ*, previously cited) have found a value of the bolometric albedo for the secondary component of Algol which agrees with that predicted theoretically by Rucinski (*AA*, **19**, 245) following an earlier suggestion by Lucy (*ApJ*, **153**, 877); Hill and Hutchings have done the same for TX UMa. A rather extreme but apparently well determined mass ratio ($\sim 0{\cdot}07$) has been found by Mochnacki and Doughty and confirmed by Wilson and Devinney and by Lucy for the contact system AW UMa. Hill and Hutchings have applied their techniques successfully to Algol systems, ζ Aur, and even X-ray binaries (*ApJ*, **162**, 265; **166**, 373; **167**, 136; *MN*, **155**, 203; *Astrophys. Space Sci.*, in press; *ApJ. Letters*, in press). Wilson, (*ApJ*, **174**, L27) has also applied programs to X-ray binaires.

Ureche produced a number of papers on the interpretation of light curves; references to all are found in the latest (*Studii si Cerc. de Astron.*, Bucharest, **15**, 9). Similarly, Lavrov in Kazan worked systematically on the problem of analysis of light curves (*Russ. AJ*, **48**, 301 and 951; *AC*, 559, 656, 663) and published also a new fast code for computing the functions ${}^{x}\alpha\,(k,p)$ (*AC*, 631, 677). Nelson and Davis developed a simplified method of solution using small computers (*ApJ*, **174**, 617). The same problem was attacked by Minti (*Stud. si Cerce.*, **17**, 45). Methods of solution were also studied by Tabachnik (*Russ. AJ*, **49**, 544) and Schulberg (*AC*, 691). Horák (*BAC*, **23**, 178) investigated determination of elements of synthetic close binaries. Mauder (*Bamberg*, 290) discussed light variability of contact configurations.

Huang calculated theoretical light curves for eclipsing binaries with scattering envelopes, and applied these to V 444 Cyg (*ApJ*, **161**, 1033). He is continuing calculations of light curves of eclipsing binaries whose components possess semi-transparent disks of finite thickness in the hope of understanding ε Aur.

SPECTROGRAPHIC AND SPECTROPHOTOMETRIC INVESTIGATIONS

A. H. Batten, M. Plavec

The past triennium withnessed the first description of some features in the far UV spectrum of β Lyr (Kondo *et al.*, *ApJ*, **176**, 153) obtained from a balloon. Spectrographic observations became extremely important in the identification of some X-ray sources with optically observable binary systems, and in the interpretation of their nature. A similar cooperation developed in radio observations. Bolton (*IAU Circ.*, 2388) suggested that a transient appearance of weak emission lines in the optical spectrum of Algol may be related to its radio outbursts (Hjellming, Wade and Webster, *Nat. Phys. Sci.*, **236**, 43; Hughes and Woodsworth, *Nat. Phys. Sci.*, **236**, 42).

More conventional spectroscopic work on eclipsing binaries continued. Hill and Hilditch (Victoria) report good progress with classification spectra of all the eclipsing binaires north of the equator listed in the *Graded Catalog* by Koch, Plavec and Wood.

Most spectrographic work was aimed at obtaining absolute dimensions of eclipsing binaries (see next Section). In the course of his systematic work, Popper tested the reliability of older published orbits of some early-type binaries. The results for U Oph and AG Per show that little improvement can be made on Plaskett's work, while moderate revision is indicated for CW Cep.

Currently under Popper's spectrographic observation are the following main-sequence systems: V 805 Aql, PV Cas, VZ CVn, V 624 Her, AI Hya, χ^2 Hya, BK Peg, HD 19115 = BV 1000, HD 214686. The period of HD 19115 is found to be 2ᵈ73 rather than the published value of 2ᵈ16.

Valuable spectrographic observations of eclipsing binaries have been made in Japan at Okayama by Kitamura, Okazaki and others; at Ondřejov by Grygar, Kříž, Harmanec, Horn; at Toronto by Heard and Gorza; at La Plata by Sahade, Mendez; at Victoria by Batten, Hill, Hutchings, Wright and others; at Lick by Popper and Plavec.

Following the idea that some shell stars may actually be close binaries at some stage of mass transfer between components, two groups began to study shell stars systematically: Harmanec, Koubský and Krpata at Ondřejov, Plavec, Polidan and Peters at Los Angeles. Harmanec *et al.* discovered an 87-day period in 88 Her (*BAC*, **23**, 178; *Astrophys. L.*, **11**, 119) and a 46-day period in 4 Her (*Astr. Aph.*, **22**, 337).

The Balmer discontinuity and other spectrophotometric parameteors have been studied in β Per, RW Tau and other stars by Fracassini, Passinetti and Battistini (Milan) (*MSAI*, **41**, 311; **42**, 7; *Astroph. Sp. Sci.*, **14**, 438).

Wright and his collaborators at Victoria have continued to study the supergiant eclipsing binaires. A detailed study of the Hα line in VV Cep reveals interesting features, among them a sharp absorption arising in the circumstellar envelope and a weak emission originating possibly in the gas streaming from the M star towards the B star. Satellite lines in the Ca II K line in 31 Cyg and 32 Cyg indicate prominence activity in the chromospheres of the supergiant components of these systems.

Relatively little progress has been made in the study of circumstellar matter in close binaries (see review by Batten in *Parksv.*) Hutchings and Wright (*MN*, **155**, 203) attempted to reproduce the observed emission-line profiles in the spectrum of VV Cep by means of geometrical models of the emitting region. Sahade and Albano (*ApJ*, **162**, 905) offered a new interpretation of circumstellar matter in ν Sgr. Thackeray (*Parksv.*) revised his model of AR Pav. Greenstein *et al.* (*Inf. Bull. Sth. Hemisph.*, No. 16) revised orbital elements of W Ser since they detected emission even in the Mg II λ 4481 line.

Table 4. Absolute dimensions

V 1182 Aql (*Izv. Krym*, **40**, 82); V 539 Ara (*Astr. Aph.*, **14**, 70); β Aur (*Astr. Aph.*, **12**, 165; *PASP*, **82**, 762); LY Aur (*BAC*, 22, 168); ZZ Boo (*PASP*, **83**, 192); SZ Cam (*Tokyo Bull.*, No. 220); AS Cam (*PASP*, **84**, 519); TW Cas (*AJ*, **76**, 449); AO Cas (*APJ*, **167**, 137); SZ Cen (*ApJ*, **169**, 549); WX Cep (*BAC*, **21**, 353); EI Cep (*ApJ*, **166**, 361); XY Cet (*ApJ*, **169**, 549); RS Cha (*MNASSA*, **28**, 5); R CMa (*PASJ*, **23**, 335); TX Cnc (*PASJ*, **24**, 213); 31 Cyg (*Astr. Aph.*, **3**, 179); 32 Cyg (*ApJ*, **175**, 809); WW Cyg (*PASP*, **84**, 541); MR Cyg (*PASP*, **81**, 754); MY Cyg (*ApJ*, **169**, 549); AI Dra (*Stud. Cerc. Astr.*, **15**, 187); BS Dra (*ApJ*, **166**, 361); δ Equ (*PASP*, **83**, 207); TX Her (*ApJ*, **162**, 925); HS Her (*PASP*, **83**, 459); MM Her (*Astr. Aph.*, **12**, 155); χ^2 Hya (*Astr. Aph.*, **4**, 437); VZ Hya (*AJ*, **75**, 720); HS Hya (*ApJ*, **166**, 361); RR Lyn (*ApJ*, **169**, 549); RW Mon (*AA*, **19**, 257); U Oph (*PASP*, **82**, 762); V 451 Oph (*ApJ*, **166**, 361); BM Ori (*PASP*, **81**, 771); AT Peg (*PASP*, **84**, 430); EE Peg (*Astr. Aph.*, **4**, 173); β Per (*ApJ*, **168**, 443; *ApJ*, **177**, 191); ST Per (*BAC*, **21**, 219); ζ Phe (*ApJ*, **162**, 925; *Astr. Aph.*, **12**, 286); XZ Pup (*Astr. Aph.*, **11**, 20); AU Pup (*Astr. Aph.*, **17**, 362); RZ Sct (*Per. Zv.*, **17**, 468); WZ Sge (*AA*, **21**, 133); CD Tau (*ApJ*, **166**, 361); W UMi (*PASP*, **82**, 10); RU UMi (*PASP*, **83**, 286); α Vir (*MN*, **151**, 161); AG Vir (*MSAI*, **43**, 291); DM Vir (*ApJ*, **166**, 361); RS Vul (*ApJ*, **167**, 137); HD 21242 (*PASP*, **83**, 504).

component first): RZ Eri (2·2, 1·7 $m_\odot$); AW Her (1·3, 1·3); MM Her (1·2, 1·2); PW Her (1·4, 1·6); RT Lac (0·8, 1·7); LX Per (1·2, 1·3); SZ Psc (1·3, 1·7); TY Pyx (1·2, 1·2). GK Hya and RT CrB are newly found members of this group, while HD 21242 is a non-eclipsing counterpart. Some of these systems are known to undergo period changes of considerable magnitude (SZ Psc, RT Lac). AD Cap, a probable member, appears to undergo phase shifts of as much as $0\overset{P}{.}05$ in one year.

Provisional masses are announced by Popper for two late-type giant systems: AR Mon (G8 III + K2 III) has masses 2·6 and 0·8 $m_\odot$, while RZ Cnc (Kl III + K4 III) has 3·1 and 0·6 $m_\odot$, respectively. Provisional data by Batten and Popper indicate that the components of the O 9·5 III binary LY Aur have very different masses, 22 $m_\odot$ and 9 $m_\odot$, although the difference in brightness is less than one magnitude.

A critically important problem is to determine masses of systems with one late-type component, such as the Algol systems with subgiants. For these attempts, it is important to know about systems in which attempts have been already made to find suitable lines of the secondary component in the visual region of the spectrum, but these attempts failed. Popper reports that no suitable lines were found in the following systems: RT And, AN And, BX And, CD And, SU Aqr, DV Aqr, DX Aqr, RX Ari, BW Boo, S Cnc, UU Cnc, WY Cnc, ZZ Cnc, R CMa, YY CMi, YZ Cas, BR Cyg, V 788 Cyg, AI Dra, BH Dra, S Equ, SZ Her, HK Lac, ES Lib, RZ Oph, V 1010 Oph, DI Peg, EE Peg, IQ Per, TX UMa, UY Vir, CX Vir.

CO-ORDINATED OBSERVING PROGRAMS

K. Gyldenkerne

At the Brighton meeting seven systems were adopted for co-ordinated campaigns. The results are summarized as follows according to the reports from the co-ordinators (whose names are given in parenthesis).

LY Aurigae (Mayer), has a spectral type of O 9·5 III, double spectral lines, deep minima and a period very close to four days ($4\overset{d}{.}0025$). Several spectroscopic and photometric observations were obtained in the years 1967–1971. During the 1970/71 season it was found that the minima are complete, but that the light curve possesses strong proximity effects and that probably intrinsic variations are present. The campaign was planned for the season 1971/72, and about a dozen observers from Europe, Japan and North America participated. Nevertheless, the light curve is still not sufficiently well covered in all phases, and the co-ordinator has recommended to the photometrists to keep this star on their observing program. Two independent series of spectroscopic observations cover the phases reasonably well.

The systems *32 Cygni, ζ Aurigae, 31 Cygni* (K. O. Wright), being of similar types with a primary supergiant K star and a secondary B type main sequence star and with periods of 3·1, 10·4 and 2·6 yr respectively, had been observed in co-ordinated programs at previous minima. The eclipses are particularly interesting for the study of the structure of the extended atmospheres of the K-type components. Minima for the three systems, and especially well observable for 32 Cygni and ζ Aurigae, happened to occur within a year (mid-eclipses: 1st Nobember 1971 for 32 Cygni, 17th December 1971 for ζ Aurigae, 1st June 1972 for 31 Cygni), and it was natural to have a common campaign for these stars. In addition to *UBV* photometry it was attempted to obtain photometric observations in a common narrow-band system (nb), which would be especially important for this kind of eclipses. A set of three interference filters with peaks at 3530 Å, 4240 Å and 5000 Å were offered to observers being interested and able to use them in the campaign. The transmission bands were close to those used by some observers in previous campaigns for these stars. For 32 Cygni photometry has been reported from Japan (Dodaira *UBV* nb, Okayama *UBV*, Atika *UBV*, Kanagawa *BV*) from Abastumani (nb), Gainsville (nb), Victoria (nb), Cracow, Pine Bluff of U. of Wisconsin (20 Å band monchromator). Spectroscopy was made at Haute Provence (12 Å mm)$^{-1}$ and at Victoria (2 and 6 Å mm^{-1}). For 32 Cygni the shape of the curve was then determined for the first time; however, it may change at future minima. For ζ Aurigae photometry was made at Cracow, Tampa, Gainsville and particularly extensively at the Japanese observatories. Spectroscopy was made at Okayama (10 Å mm^{-1}) and at Mauna Kea. 31 Cygni was difficult to observe during the first part of the minimum; only a few photometric observations have been reported. A summary of the campaign for the three systems is given by K. O. Wright (*JRASC*, in press).

For the 2nd *β Lyrae* campaign (Batten) the observing periods were set at July 17th–August 2nd and August 10th–23rd, 1971, covering rather more than two complete cycles. Three kinds of observations were planned: (1) Narrow-band photometry (nb) in six selected regions: emission at Hα, emission at the He 6678 singlet, emission at the He 4471 triplet, and three neighbouring regions of the continuum). (2) *UBV* photometry. (3) High-dispersion spectroscopy. The nb light curves should provide better time resolution than conventional spectroscopy and be helpful in interpretation of the spectroscopic-results. nb data are reported from five observers, *UBV* from four, and spectroscopy from three observers. The observations were obtained from Europe, North America and Japan. In addition to the ground based results, rocket and OAO observations were obtained for *β* Lyrae a little before the capaign period.

γ_2 *Velorum* (Sahade)at declination − 60° and with a period of 78 days was recommended for a coordinated program of photometric observations in 6 narrow-band regions, 3 emission-rich, emission-poor. *Y Cygni* (O'Connell, Fracastoro) was adopted because this system is one of the best known cases of apsidal motion. The period is very close to three days, and it is difficult for a single observer to obtain a complete light curve. Very limited information on the results of the campaigns for the two latter system has been reported (by the end of October 1972).

The participants in the campaigns were asked to publish their results as quickly as possible in order to make the combination and synthesis to appear sooner than in previous cases; already several papers have appeared in the literature or are known to be in manuscript. In this connection it may be mentioned that Koch has recently published his work on the SX Cas capaign from 1964–1967 (*AJ*, 77, 500).

At one of the campaigns (for the long-period binaries) the chairman of the co-ordination programs committee asked directors of observatories in important geographic locations for help in making telescope time available and in encouraging qualified staff members to participate. Actions like this might improve and homogenize the contributions in future campaigns.

PERIOD CHANGES

T. Herczeg

During the reviewed period, besides the established centers of investigation of eclipsing binary periods, several institutions joined them by stepping up their programs in the field and contributing a substantial part of current results. Among them one should mention the Bonn Observatory (Hoher List Station), Bucharest, Cluj, U. of Florida (Rosemary Hill Station), Louisiana State U., Nashville (Dyer Obs.) and also U. of Texas (McDonald Obs.), in this particular case by using high time-resolution photometry. Observers at Cerro Tololo (AURA) as well as at La Silla (ESO) increased their engagement in eclipsing binary programs; the hemispheric gap is narrowing, thanks also to the efforts made at the Republic Observatory and in New Zealand.

Cooperation between the photoelectric observers in Izmir and in Nurenberg (Kizilirmak, Pohl *et al.*), concentrating almost exclusively on the timing of minima, resulted in an astonishing amount of information: in 1970–71, these groups produced 165 photoelectrically determined minimum epochs, more than one-third of the whole observational material secured during this time! As the individual measurements are not published, it is difficult to judge the accuracy of these epochs but even if it turns out to be only about $\pm 0\overset{d}{.}002$, the gain is very considerable.

Among the most active amateurs are the Swiss observers around the periodical 'Orion' (now publishing their own Bulletin), while the group connected wtih the Brno Planetarium recently started photoelectric observations.

The number of eclipsing systems which have been followed photoelectrically during the years 1970–71 may be around 120, objects of co-ordinated observing programs not counted; many more systems have been observed photographically. For the best observed systems (usually short-period variables like i Boo or VW Cep) there may be ten or more minima, determined photoelectrically, per year. Thus the coverage is not unsatisfactory and should be maintained at this level. It also should be emphasized that for most of these stars visual observations (and in particular, visual estimates) lose much of their value if simultaneous photoelectric measurements are available. Visual timings of minima of W UMa-stars, for instance, have very little importance, since these systems are under rather systematic photoelectric surveillance now (at least the 15–20 brightest objects of this class). Among those cases where visual observations still pay higher dividends, are the relatively bright, deep-eclipse Algol-systems like W Del, Z Dra, RW Tau or RT Per. Photographic work, on the other hand, should be primarily concentrated on variables fainter than, say, 12^m, beyond the usual reach of photoelectric programs.

General problems

Breinhorst *et al.* (*As. Ap.* **22**, 239) discussed the numerical determination of minimum times, especially the method of Kwee and van Woerden in the case of asymmetric light curves; they propose a leastsquare fit by a third degree polynomial. Van't Veer (*AA*, **20**, 131) worked out a statistical method to evaluate the rate dP/dt and the duration of the period change in the case of a rapid transition from one value of the eclipsing period to another. Evolutionary aspects of period changes in close binary systems are treated in considerable detail in three review articles: Paczynski (*Ann. Rev. Ast. Aph.*, **9**, 183), Batten (*PASP*, **82**, 514), Plavec (*PASP*, **82**, 957). See also: Van't Veer (*AA*, **19**, 337). A general review of period changes (including intrinsic variables) was given by Detre (*Ann. Sternwarte Wien*, **29**, No. 2). Szafraniec discussed some problems of period changes in connection with H. N. Russell's work in this field (*Vistas Ast.*, **12**, 13–16). Kreiner (*AA*. **21**, 365) collected and reproduced O–C diagrams for 137 eclipsing variables. Although the small-scale diagrams do not seem suitable for detailed investigations, they may be very useful to a first information or to statistical purposes. The primary aim of this study was to decide about the question whether a dependence can be found of the period changes on the spherical position of the stars, ascribable to a radial acceleration of the Sun in the galactic system'. Kreiner's result was negative. Frieboes-Conde and Herczeg (in press) assembled and discussed all available minimum epochs for 14 eclipsing binaries with possible light-time effect. No definitely positive case has been found although seven of the variables should be kept on the list of possible candidates. However, as Chen pointed out (*AJ*, **76**, 52) for *V701 Cen*, in some cases the photometric solutions require a 'third light' in the system.

Some special objects

A rather arbitrary selection of some more interesting systems follows, investigated during the triennium 1970–72. Eclipses of eruptive binaries (old novae and U Gem-stars) have recently been followed by several observers (Mumford, Walker, Warner and Nather); a survey of the periods of these objects was given by Smak (*AA*, **22**, 1). His conclusion was that period variations were more complicated than previously anticipated. While *DQ Her* probably shows monotonous increase of the period, *U Gem*, *UX UMa* and *RW Tri* seem to exhibit alternating, roughly sine-like period variations. Smak discussed this possibility in the light of current models of eruptive binaries; see also Starrfield, *ApJ*, **161**, 361. Mumford (*ApJ*, **165**, 369) found that *EX Hya* and *WZ Sge* still show constant periods. In the case of the (non-eclipsing) eruptive binary *SS Cyg*, Walker and Reagan (*IBVS*, No. 544) found fairly large, unexplained phase shifts, indicating perhaps short-term changes of the period. They confirmed the period and its linear increase found earlier by Walker and Chincarini.

Among the W UMa-stars, *TX Cnc* (in Praesepe) has been investigated by Kitamura and Yamasaki (*Tokyo Ast. Bull.*, 2nd Series, No. 209). An abrupt change of the perriod is clearly indicated. The period of *W UMa* has likewise been interpreted in terms of several abrupt changes by Cester (*MSAI*, **40**, 489 and **42**, 61). Presently, the period is decreasing again after the very manifest change in 1963–64 (Cester and Pucillo, *IBVS*, *No.* 659); see also Rigterink (*AJ*, **77**, 230). Herczeg and Frieboes-Conde calculated a light-time orbit for both *W UMa* and *VW Cep* (unpublished); the abrupt period variations seem to be superposed on this effect. In the case of *VW Cep*, Tempesti and deCarlo (*MSAI*, **43**, 1), also found a periodic term in the O–C diagram, its interpretation as light-time effect is, however, in their opinion rather improbable.

An explanation for the very enigmatic, apparently irregular O-C curve of *RS CVn* was put forward by Hall (*PASP*, **84**, 323). His model of the perturbations of the light-curve (a differentially rotating zone of very strong sunspot activity) may account for the observed alternating changes of the period, too.

The intriguing system *SV Cen* was studied in detail by Irwin and Landolt (*PASP*, **84**, 686). This binary shows a very rapid decrease of the period amounting to $3^{m}27^{s}$ in 75 yr; this rate of decrease leads to a characteristic life-time $P(\mathrm{d}P/\mathrm{d}t)^{-1} \simeq 50000$ yr only, thus the phenomenon may correspond to an accelerated phase of evolution. The decrease is not exactly linear, a secondary period of about 35 yr is possible.

The eclipsing binary *QS Aql* is member of the visual pair Ku 93. Knipe (*PASP*, **83**, 352) followed the period near the recent periastron passage. The observed rapid period changes seem to correspond to the motion in the visual orbit.

In a few cases earlier published values of the period have been revised and substantially modified: *MV Pav* (Williamon, *IBVS*, No. 574) *TY Pup* (van Houten, *As. Ap.*, **14**, 487) *EQ Tau* (Whitney, *IBVS*, No. 633).

APSIDAL MOTION

T. Herczeg

Theoretical work

Cisneros-Parra (*Astr. Aph.*, **8**, 141) calculated apsidal motion coefficients for homogeneous main-sequence models, and found that mass loss from a subgiant component can decrease k_2 by a factor of 100, which is below the value observed in semidetached close binaries. The apsidal-motion test for late-type stellar models was investigated by Heasley (*Ap. J.*, **163**, 345), giving theoretical apsidal-motion coefficients for 1 $M_{\odot}$ models and a series of subgiant models. Heasley discussed the agreement between observed and calculated coefficients for the subgiant secondaries in six semi-detached systems (although some of them are rather doubtful cases from the observational point of view!); it has been pointed out that 10% error in the photometric radius can change the apsidal-motion coefficient by a factor of 2. Dinescu (unpublished) also has calculated theoretical apsidal-motion coefficients. A general review of the question was given by Martynov (in the textbook *Eclipsing Variables*, in Russian).

Observed apsidal motions

HS Her was added to the list of stars with probable apsidal motion, $P' = 15{\cdot}5$ yr (Hall and Hubbard, *PASP*, **83**, 459). The apsidal motion of *V477* Cygni was studied by O'Connell (*Vistas in Ast.*, **12**, 271). Long period apsidal motion was considered by Todoran, with a practical application to *RU Mon* (*Stud. Cerc. Astron.*, **16**, 177). The most important photometric series of observations taken during the 1968–69 *AR Cas* campaign was published (Catalano and Rodono', *AJ*, **76**, 557). The occurrence of apsidal motion appears certain, P' may be as long as 10^3 yr. Recent spectroscopic orbits: Gorza and Heard (*Publ. David Dunlap*, **3**, 99), Herczeg (unpublished).

At ESO Jørgensen has recently initiated a program for ubvy photometry of close binaries having apsidal motion.

Displaced secondary minima

PV Cas, $\phi_2 = 0{\cdot}52$ (Ibanoglu, *IBVS*, No. 555); V 453 Cyg, $\phi_2 = 0{\cdot}508$ (Cohen, *PASP*, **83**, 677); FT Ori, $\phi_2 = 0{\cdot}746$ (Cristaldi, *As.Ap.*, **5**, 228); IQ Per, $\phi_2 = 0{\cdot}542$ (Hall, Gertken and Burke, *PASP*, **82**, 1077); HR 3327, $\phi_2 = 0{\cdot}528$ (Jørgensen, *IBVS*, No. 641); VV 399, $\phi_2 = 0{\cdot}71$ (discovered by Miller and Wachmann, see *Sky & Tel.* **44**, 157).

As Milone and Wesselink pointed out (*IBVS*, No. 611), contrary to earlier descriptions *RW CrB* has no displaced secondary minimum. See also Johnston (*AJ*, **76**, 455) for a possibly eccentric orbit of *UU Psc*.

STRUCTURE AND MODELS

M. Kitamura

A new polytropic model for the structure of rapidly rotating close binary systems was presented by Martin (*Aph. Sp. Sci.*, **7**, 119) by dividing the interior of each star into an inner region (corresponding to the interior of the Emden sphere), and an outer region. Polytropic models of close and contact binaries were also constructed by Durney and Roxburgh (*MN*, **148**, 239) using a combination of perturbation techniques and a Laplacian approximation, and it was shown that when the two stars are built on the same polytropic model, a contact binary with mass ratio different from unity is not possible.

The structure of a synchronously rotating close binary system was discussed by Jackson (*ApJ*, **160**, 685) with a double-approximation method of Roxburgh, Griffiths, and Sweet. Theory of the internal structure of synchronously rotating close binary polytropes was further developed by Naylor and Anand (*Aph. Sp. Sci.*, **16**, 137) with a modified double-approximation technique.

Various attempts were made to study models of contact systems which would represent the W UMa stars. Various modifications of the Lucy model have been proposed, although observationally it is still not clear what the actual character of the W UMa systems is (Robinson, *PASP*, **84**, 51; Binnendijk, *Vistas*, **12**, 217). Assuming a common convective envelope with equal adiabatic constants as done by Lucy, Moss and Whelan (*MN*, **149**, 147) showed that contact configuration at zero age could be produced with extreme population I compositions only if the ordinary nuclear reaction rates and more recent opacities are adopted. Hazlehurst (*MN*, **149**, 129) showed that the observed characteristics of W UMa systems of low mass are found to be consistent with the primaries being evolved stars and the secondaries being of age zero. From the observational side, Mauder (*Astr. Aph.*, **17**, 1) carefully tested the Lucy model with result of recalculations of the photometric elements of 34 selected W UMa stars and showed that the postulating of a common convective envelope in the sense of Lucy's model is in contradiction to the observation. A new development was made by Biermann and Thomas (*Astr. Aph.*, **16**, 60) with a method that allows for different entropy constants in the convective envelopes of both stars. They calculated models of W UMa stars with normal chemical compositions and for age zero of both components and showed that these models are able to reproduce most properties of the observation. However, Hazlehurst and Mayer-Hofmeister (*Bamberg*, 288) used models of nearly equal entropies for both components for studying the evolution of a contact binary with a primary of 1·5 $m_{\odot}$. In order to explain the fact that the secondary components are hotter in most cases, Whelan (*MN*, **156**, 115) studied the property of energy transfer occurring in the superdiabatic part of the convective envelope. Models for cataclysmic binaries consisting of a main-sequence star filling its Roche limit and a white dwarf were calculated by Biermann and Thomas (*Bamberg*, 285). Osaki (*ApJ*, **162**, 621) calculated models for U Gem stars including shear-flow turbulence as a mechanism of energy transport in the convection zone. According to Osaki's calculation, maximum light occurs when the cool component overflows the Roche limit by a large amount in qualitative agreement with some small-amplitude U Gem stars. Faulkner (*ApJ*, **170**, L99) also presented a model for U Gem stars, in which gravitational-radiation losses, by reducing the scale size of the system, induce mass transfer. For a periodic varying gravitational field, the forced oscillations of a star as one component in a close binary system was discussed by Zahn (*Aph. Sp. Sci.*, **4**, 452).

On the assumption of the hot spot, Smak (*AA*, **21**, 13) analysed the observational data of U Gem. A similar hot-spot model was investigated for WZ Sge by Krzeminski and Smak (*AA*, **21**, 133), in which the source of the S-wave emission lines should be a hot spot located in the disk surrounding the primary white-dwarf component. They estimated the distance of the spot from the parent star surface, its temperature, its density and the mass-transfer rate etc.

Warner and Robinson (*Nat. Phys. Sci.*, **239**, 2) gave a short review of the observed non-radial pulsation in white dwarf components of novae and dwarf novae, in which they suggest that the observed oscillations can be explained in terms of g-mode pulsations.

PROXIMITY EFFECTS

M. Kitamura

Napier and Ovenden (*Aph. Sp. Sci.*, **11**, 475) investigated the reflection effect on spectral lines of 57 Cyg and showed that the observed spectral features due to the reflection can not be explained in terms of its conventional theory. They suggested that the high-temperature lines would be formed in a chromosphere and might arise from the dissipation of turbulence, as expected from the mutual heating, over the heated hemispheres. Ovenden (*Vistas in Astr.*, **12**, 135) pointed out that the existence of hot spot conditions is indicated over an area of the reflecting star and circulating currents should be generated in its atmosphere. Successive investigations on the proximity effects in close binary systems have been made by Rucinski. He discussed the photometric distortion effect in the β CMa-component of α Vir (*AA*, **20**, 249) and computed the LTE radiative equilibrium model atmospheres for the illuminated and un-illuminated sides of the secondary component of μ' Sco (*AA*, **20**, 325). The non-gray model atmosphere for the illuminated early-type component (*BAAS*, **3**, 14) and the average gravity and effective temperature at the outward surface of distorted components (*AA*, **21**, 455) were also studied by Rucinski. From a statistical study of the observed reflection effect, Napier (*Aph. Sp. Sci.*, **11**, 475) confirmed Rucinski's previous prediction that cool secondary components have deep convection envelopes whose structure is altered by the incident radiation. Chen and Rhein (*PASP*, **81**, 387) calculated the temperature distribution on the inward faces of the components from radiative transfer between the facing sides of both components on the assumption that close binaries are opaque black bodies with limb-darkening, and they presented the resulting monochromatic reflection effect (*PASP*, **83**, 449). From an analysis of the infrared light curve of the secondary minimum of Algol, Budding and Kopal (*Aph. Sp. Sci.*, **9**, 343) concluded that the gravity-darkening of the distorted secondary component is some three to four times larger than that resulting from von Zeipel's theory.

LIMB DARKENING

M. Kitamura

The limb darkening of a star is a very important quantity which enables us to check the model stellar atmosphere and, excepting the Sun, it can be obtained only from precise analysis of light curves of eclipsing binary systems. During the past three years many discussions on the limb darkening from light curves of eclipsing variables applied nonlinear laws. Heintze and Crygar (*BAC*, **121**, 77) discussed Wesselink's photographic light curve of SZ Cam for the orbital solution and the limb darkening with a nonlinear term under the assumption that both components can be represented as ellipsoids. A useful review was presented by Grygar, Cooper and Jurkevich (*BAC*, **23**, 147) of recent development bearing on precise determinations of limb darkening. They presented a comparison of linear and nonlinear laws of limb darkening and a critical comparison between theory and observations. Crygar (*BAC*, **23**, 175) calculated the limb darkening for B-type main sequence stars in the infrared spectral region from 14588 to 58353 Å which should be useful for analysis of the anticipated infrared observations of eclipsing binaries. Theoretical values of non-linear limb darkening coefficients were computed by Klinglesmith and Sobieski (*AJ*, **75**, 175) from a grid of hydrogen line-blanketed model atmospheres. They presented a set of coefficients for the ordinary linear law and compared with previous theoretical values by Grygar and Hosokawa. The limb darkening of the white dwarf eclipsing binary BD + 16°516 B has been determined by Warner, Robinson and Nather (*MN*, **154**, 455) to be $u = 0{\cdot}366 \pm 0{\cdot}037$, which is an excellent agreement with that for a gray atmosphere. Kopal (*Aph. Sp. Sci.*, **12**, 147) pointed out that in determing nonlinear effects of limb darkening from light curves of eclipsing variables the quadratic terms of limb darkening can not generally separated from the first-order effects of the gravity darkening of distorted components undergoing eclipse. Parsons (*ApJ*, **164**, 355) computed the limb darkening data from model atmospheres for yellow giants with $T_e = 5400° \sim 6600°$ and $\log g = 1{\cdot}2 \sim 2{\cdot}4$. Limb darkening coefficients for the components of YZ Cas (*AC*, **588**, 4) and S Cnc (*Russ. AJ*, **48**, 301; **48**, 951) were derived by Lavrov. The effect of non-linearity of limb darkening when calculating the elements of eclipsing variables was also discussed by Schulberg (*AC*, No. 691, 1).

RADIATIVE TRANSFER AND SPECTRAL LINES

M. Kitamura

Buerger (*ApJ*, **158**, 1151) computed theoretical continuum and line spectra of stars in a close binary system for rotationally and tidally distorted models with gray atmospheres with radiation incident at the surface and found that for a system of similar early-type components, large variations in the UV flux can be predicted as function of separation, orbital inclination and phase. Buerger and Collins (*ApJ*, **161**, 1025) studied the polarization resulting from Thomson scattering which can arise in the distorted gray atmospheres of the components of close binary systems in and out of eclipse. Their results indicate that the intrinsic polarization varies with phase by up to several tenths of a percent. Transfer problem of radiation in circumstellar dust envelopes was discussed by Huang (*ApJ*, **164**, 91) for the case of distant envelopes and a point-source central star, in which the continuous conversion of optical radiation to infrared radiation as well as of directional flow of radiation to the diffused radiation fields are treated. A good review on the problem of radiative transfer in atmospheres of close binaries was presented by Pustylnik (*Publ. W. Struve Obs.*, 1971). Hydrogen line profiles in eclipsing binary systems were generally discussed by Neff (*Theo. and Obs. Stellar Atmos.*, ed. Gingerich, p. 293). Šíma (*BAC*, **22**, 334) calculated the line profiles due to the absorption in the rotating gaseous rings in close binaries for outside eclipse and for half-eclipse phases, and established that these profiles are deeper in some parts which may cause an illusory shift of the line. The rotationally broadened line profiles for W UMa stars were also studied by Rucinski (*BAAS*, **3**, 237). Wilson's transit-time effect known as a lag of the emission line velocity curve from the actual velocity curve of the Wolf-Rayet star was examined by Castor (*ApJ*, **160**, 1187) by calculating the exact motion of particles ejected from the Wolf-Rayet component and the transit time effect is found to be actually negligible. On the assumption that the envelope of the Wolf-Rayet component accelerates outwards, Limber (*ApJ*, **163**, 337) made estimates on the dynamical and geometrical asymmetries in the envelope.

GAS STREAMS AND MASS TRANSFER

M. Kitamura

A good review of arguments pointing to the location of a hot spot in the disk around the primary blue component rather than on its surface in the U Gem stars was presented by Smak (*AA*, **20**, 311). He gave a simple method of finding the correct amplitude of the radial velocity curve with application to VV Pup and Z Cam. Gorbatzky (*Astrofizika*, **7**, 57) studied some effects of gaseous streams in close binaries of dwarf stars on the observed light curves and calculated the profile of hump on light curve preceding the primary minimum. He estimated optical densites of the radiating layers of disk-like envelopes of VV Pup and U Gem from comparison with the observation. Gorbatzky showed that brightness fluctuations in these systems may be caused by inhomogeneity of turbulent gaseous jet which collides with the envelope.

Piotrowki and Ziólkowski (*Aph. Sp. Sci.*, **8**, 66) estimated the dimensions of gaseous rings in close binary systems with the aid of particle dynamics, and they showed that the observational data seem to indicate that the upper limit coincides with the upper boundary of the stability domain of singly periodic orbits around the parent star. Three-dimensional trajectories for gaseous streams were calculated by Korovyakovsky (*Astrofizika*, **7**, 71) for VV Pup and UX UM UMa by taking into account some dynamical effects. Formation of gaseous rings was also discussed by Kříž (*BAC*, **22**, 108) who combined particle trajectories with some simple hydrodynamic considerations.

The outflow of matter from the companion in a close binary star was discussed for the case of asynchronous rotation by Korovyakovsky (*AC*, **662**, 5). The collision between the gas streams and the envelope of the parent star was further studied by Korovyakovsky (*Astrofizika*, **5**, 67) in order to explain the hot spot. The behaviour of the shock wave front in the gaseous streams was studied by Tarnov (*Astrofizika*, **7**, 295) and he treated the case that there is a loss of the radiative energy behind the shock wave's front. The fronts are found to make oscillatory motion and the dependence of period and amplitude of the oscillation on the system's physical parameters was found.

Observational evidence of circumstellar matter in close binary stars was best summarized by Batten (*PASP*, **82**, 574) and a model consisting of cloud, disk and streams was proposed which is acceptable on dynamical ground. Biermann (*Astr. Aph.*, **10**, 205) calculated the motion of gas streams for stationary supersonic flow and showed that the gas streams have a tendency to form a ring around the star receiving mass that rotates in the same sense as the orbital revolution. The tendency is bound to be more pronounced for cases in which the star receiving mass is the more massive component of the system. For general treatment of gas motions in binary systems by hydrodynamics, Kopal pointed out the importance of the use of a new system of orthogonal coordinates with the zero-velocity surfaces as one of them – the Roche coordinates (*Aph. Sp. Sci.*, **5**, 360; **8**, 149; **10**, 328). The topological properties of the Roche coordinates in three-dimensional space were revealed by extensive numerical calculations by Kitamura (*Aph. Sp. Sci.*, **7**, 272). Kopal and Ali (*Aph. Sp. Sci.*, **11**, 423) further proved that the Roche coordinates can be obtained only numerically in an asymptotic manner. The nature of stream lines of the gas flow was discussed by Sobouti (*Astr. Aph.*, **5**, 145). He also discussed Bernoulli's integral supplemented by the equation of continuity in treating the motion of gas surrounding a binary system and found that there exist two velocity modes whose streamlines are confined within appropriate zero-velocity surfaces (*Aph. Sp. Sci.*, **12**, 408).

Saito (*PASJ*, **22**, 455) presented a model for the HI chromosphere of the K-type component of

Zeta Aur from hydrodynamic consideration on motion of chromospheric gases and he showed that the observed radial velocity features can be explained as being caused by the rotation of the undisturbed chromosphere and non-steady motion of the chromospheric gas clouds. The chromospheric structure of the K-type component of 32 Cyg was further studied from the light variation in the 1968 and 1971 eclipses by Saito and Sato (*PASJ*, **24**, 503).

STATISTICAL WORKS

M. Kitamura

From a discussion of the observed dispersion of radial velocity measurments, Jaschek and Gomez (*PASP*, **82**, 809) showed that the percentage of spectroscopic binaries is constant along the main-sequence stars and that it is smaller for giants. Scarfe (*PASP*, **82**, 1119) statistically discussed the mass-functions of spectroscopic binaries with giant primaries. The distribution of the mass-function was also examined by Jaschek and Ferrer (*PASP*, **84**, 292). From a statistical consideration, Popov (*Perem. Zv.*, **17**, 209) discussed the discovery probability and observational conditions of close binaries. The dependence of probability of eclipsing binary discovery on the periastron longitude was studied by Radzievsky, Surkova and Tolstijch (*Perem. Zv.*, **18**, 31). Brazhnikova (*Russ. AJ*, **47**, 149) studied the selection effect in discovery of spectroscopic binaries moving relative to cosmic dust. Criteria were proposed by Stothers and Simon (*PASP*, **82**, 707) for the discovery of β Cep stars in close binary systems according to the mu-mechanism theory; the published list of stars was criticized by Plavec (*PASP*, **83**, 144).

A group of close binary systems with both components lying near the main-sequence was statistically compared with a group of close binaries with subgiants by Popov (*Perem. Zv.*, **17**, 412). in order to clear the question of the genetical relation between both groups of binaries. Kukarkin and Mironov (*Russ AJ*, **47**, 1211) discussed close binary systems belonging to the globular and old open clusters. The binary nature of the blue stragglers in the open cluster NGC 7789 was studied from radial-velocity variations by Strom and Strom (*ApJ*, **162**, 523) and it was shown that blue stragglers are members of binary systems in which mass exchange has taken place. From a study of the nature of the field blue stragglers, Bond and MacConnell (*ApJ*, **165**, 51) supported McCrea's suggestion that the blue stragglers are the secondaries of close binary stars which have moved up the main sequence as mass was transferred to them from the evolved primaries. Strom (*PASP*, **83**, 768) further discussed the blue stars above het evolutionary turn-off point in M67 and suggested that these stars are analogs of the blue stragglers.

The luminosity-radius relation for eclipsing binaries was statistically discussed by Popovici and Dumitrescu (*Stud. Cerc. de Astr.*, **16**, 123). The mass-luminosity relation for eclipsing and visual binaries consisting of main-sequence components was carefully discussed by McClusky and Kondo (*Aph. Sp. Sci.*, **17**, 134). Nariai (*PASJ*, **23**, 529) discussed the period-rotational velocity relation for double-line spectroscopic binaries and eclipsing binaries and concluded that the deviation from synchronism is larger for normal main sequence stars although the synchronism holds for Am stars and Hg-Mn type Ap stars with periods less than 10 days.

Castor (*ApJ*, **160**, 1187) calculated the exact motion of particles ejected from the Wolf-Rayet component and showed that the transit-time effect in Wolf-Rayet binaries is negligible in all cases of interest.

The probability of discovery as eclipsing binaries was studied for models of detached systems by Giannone and Giannuzzi (*Astr. Aph.*, **18**, 111). The frequency of spectroscopic binaries was investigated for members of NGC 6475 by Abt *et al.* (*ApJ*, **159**, 919), for members of Perseus arm by Abt, Jennings, Lee and Villere (*ApJ*, **161**, 477), and for members of the open cluster IC 4665 by Abt, Bolton and Levy (*ApJ*, **171**, 259). In particular, they discovered a clustering of binaries in IC 4665. The distribution of semi-major axes and eccentricities of binary systems after rapid mass losses was discussed by Seidov (*BAC*, **23**, 123).

COLLAPSED OBJECTS IN BINARY SYSTEMS

M. Plavec, M. Kitamura

Since a black hole can be detected only by its gravitational field, binary stars are naturally the most important objects in which to search for black holes. Already in 1966, Zeldovich and Guseynov (*ApJ*, **144**, 840) listed seven spectroscopic binaries in which only one spectrum is observed but the mass function indicates that the mass of the invisible object is at least equal to the mass of the visible component. They suggested that some of the invisible components may be collapsed stars (neutron stars for $m \leqslant 1{\cdot}5\ m_\odot$, black holes for larger masses). Trimble and Thorne (*ApJ*, **156**, 1013) much extended this list using Batten's Sixth Catalogue. They suggested that some of the systems like ε Aur, β Lyr, W Ser, or V 367 Cyg may harbor a collapsed star, but on the whole concluded that such a case would be rare. In this they are probably right since efforts to find evidence for collapsars from statistical surveys met little success. Gibbon and Hawkins (*Nat.*, **232**, 465) suggested that there is an excessive number of eccentric orbits among single-spectrum spectroscopic binaries which may be due to explosive collapse of their components. Batten and Olowin (*Nat.*, **234**, 341) and Evans and Bath (*Nat.*, **283**, 7) questioned the validity of their arguements. Gott (*Nat.*, **234**, 342) advanced arguments similar to those of Gibbon and Hawkins.

More promising is a detailed study of individual systems. When Kopal (*Aph. Sp. Sci.*, **10**, 332) called attention to ε Aur, Cameron (*Nat.*, **229**, 178) and Stothers (*Nat.*, **229**, 180) suggested that its invisible component is a black hole. Wilson (*ApJ*, **170**, 529) offered a variant of this model, which is in better agreement with observations. However, Demarque and Morris (*Nat.*, **230**, 516) maintain that the black hole hypothesis disagrees with observations. The peculiar combination of an apparently total minimum, large mass and invisibility of the eclipsing body led Wilson to interpret BM Ori (Hall, *Bamberg*, 217) as harboring a black hole, although the systems is apparently very young (being the faintest star in Trapezium) and rather close, $P = 6^{\rm d}\!.5$. Similar suggestion about β Lyr (Devinney, *Nat.*, **233**, 110; Wilson, *Nat.*, **234**, 406), stimulated also by the strange behavior of its ultraviolet light curves (Kondo *et al.*, *Bamberg*, 308), started a very vivid discussion on the evolutionary stage of the system and on the nature of the invisible component (Stothers and Lucy, *Nat.*, **236**, 218; Stothers, *Nat. Phys. Sci.* **238**, 5).

Another candidate for a black hole is the radio and X-ray source Cyg X-1, identified with the spectroscopic binary HDE 226868. If the optically visible component has a mass corresponding to its spectrum BO Ib, the X-ray source is too massive for a white dwarf or a neutron star (Bolton, *Nat.*, **235**, 271; Webster and Murdin, *Nat.*, **235**, 37).

In other binaries which are X-ray sources, the mass-accreting component seems to be either a white dwarf or a neutron star. Prendergast and Burbidge (*ApJ*, **151**, L83) developed a model in which X-rays are generated in a disk surrounding a white dwarf; this model was further developed by Kraft (*Lick Contr.*, No. 368). On the other hand, van den Heuvel and Heise (*Nat. Phys. Sci.*, **239**, 67) interpreted the eclipsing binary Cen X-3 as harboring an old neutron star. Models of this system were proposed by Osaki (*PASJ*, **24**, 419), Wilson (*ApJ*, **174**, L30), Sofia (*ApJ*, **174**, L31) and Gratton (*Nat.*, **237**, 329). In any case, Cen X-3 is the first eclisping binary whose elements were derived from X-ray observations (Schreier *et al.*, *ApJ*, **172**, L79). Other X-ray eclipsing binaries are Her X-1 (Tananbaum *et al.*, *ApJ*, **174**, L143), SMCX-1, and Vela X-1. Binary nature is indicated in some other X-ray sources like Cyg X-2 (Wilson, in *Non-Solar X- and Gamma Ray Astro.*, 242) or Sco X-1, but their complexity is discouraging.

Short periods of the binary X-ray sources rise some problems about their past evolution. Perhaps mass transfer of mode B played an important role (Plavec, *Parksv.*). McCluskey and Kondo (*Aph. Sp, Sci.*, **10**, 464) argue that in many cases a type I supernova explosion does not disrupt the binary, therefore neutron stars and black holes may exist in close binaries; cf. also van den Heuvel and Heise (*Nat. Phys. Sci.*, **239**, 567). Shvartsman (*Sov. Astr. -AJ*, **15**, 377) argues that accretion can make a black hole in a binary system 'visible' and distinguishable from a neutron star. Accretion disk models for compact X-ray sources were studied by Pringle and Rees (*Astr. Aph.*, **21**, 1).

BINARY SYSTEMS AS RADIO STARS

M. Plavec

The first four radio stars discovered are binaries. The Antares radio source (Wade and Hjellming, *ApJ*, **163**, L105) is associated with its blue companion (Hjellming and Wade, *ApJ*, **168**, L115). Cyg X-1 which 'turned on' on radio waves in April 1971 is probably the spectroscopic binary HDE 226868 (Wade and Hjellming, *Nat.*, **235**, 271). β Lyr and β Per (Algol) were detected as radio sources by the same observers (*Nat.*, **235**, 270). Variability of the radio flux is quite outstanding in the case of Algol which flares up apparently independently of its orbital phase (Hughes and Woodsworth, *Nat. Phys. Sci.*, **236**, 42; Hjellming *et al.*, *ibid.*, 43). Bolton (*IAU Circ.*, 2388) suggested that a temporary appearance of weak emission lines in the optical spectrum of Algol is related to these flares. In all four cases, radio emission may be associated with gas streaming between and around the components, hence also related to X-ray activity (Hjellming, *Nat.*, **238**, 52).

EVOLUTION OF CLOSE BINARY SYSTEMS

M. Plavec

Most work on evolution continued to be based on the idea that the existence of the limit of dynaical stability (the Roche limit) around each component profoundly affects the evolution of close binary systems, and that a large-scale mass transfer sets in when a component fills its critical lobe. Many new papers continued to assume conservative mass transfer, i.e. no mass lost from the system. Thus, Ziólkowski (*AA*, **20**, 59) described the Warsaw computing code and applied it (*AA*, **20**, 213) to binaries of low and moderate mass. Similar problem was investigated by Giannone, Refsdal and Weigert (*Astr. Aph.*, **4**, 428); the latter two derived formulae to predict the properties of the final systems (*Astr. Aph.*, **13**, 367). Horn, Kříž and Plavec tabulated results of rapid mass loss in case A (*BAC*, **21**, 45). Case AB, whose importance was suggested by Ziólkowski, was studied by Horn (*BAC*, **22**, 37). Computations for case B were made by Harmanec (*BAC*, **21**, 113 and 316), for case C by Lauterborn (*Astr. Aph.*, **7**, 150). A wider variety of models were computed by Giannone and Giannuzzi (*Astr. Aph.*, **6**, 309; **19**, 298). Plavec (*PASP*, **82**, 957) reviewed all the computed models for the conservative case. A more recent review by Paczyński (*Ann. Rev. Astr. Astroph.*, **9**, 183) covers a wider range of problems, including the cataclysmic variables, and the origin and final stages of close binaries.

Considerable attention was paid to mass loss from convective envelopes. Eearlier work (Paczyński, *AA*, **15**, 89; Paczyński *et al.*, *Mass Loss from Stars*, 237; Refdsal and Weigert, *Astr. Aph.*, **18**, 294) indicated that mass loss may be very rapid in this case, perhaps even proceed on the dynamical time scale. Recent work progressed along two lines. Bath assumed that all the material crossing the Roche limit is immediately lost, and found that this assumption indeed leads to dynamical instabilities (*ApJ*, **158**, 571; **173**, 121), which might perhaps explain the outbursts of the U Gem stars (if their seat is in the red component, which is doubtful). The paper by Osaki (*ApJ*, **162**, 26), who suggests shear turbulence as the source of energy for flares, should be read jointly with Bath's papers. The other way of approach assumes that material flows away from the mass-losing component in a steady laminar flow, and was developed mainly by Paczyński and Sienkiewicz (*AA*, **22**, 73) on the basis of a formula derived by Jendrzejec. The time scale is then longer than the dynamical time scale but much shorter than the thermal time scale, and very high rates of mass loss were found for a giant originally of 1·8 $m_\odot$. Similar high rates were obtained for a giant originally of 7 $m_\odot$, studied by Harmanec and Plavec in an attempt to interpret the peculiar shell star and binary, AX Mon. Using Ulrich's theory of convection, Plavec and Polidan (cf. Plavec, *Parksv.*) took into account convective overshoot, but the principal conclusion remains unchanged. Mass loss from system and ring formation may modify the mass transfer; a number of cases are being studied by Plavec and Polidan. Lauterborn and Weigert (*Astr. Aph.*, **18**, 294) studied the physics of mass-losing envelopes.

Evidence has gradually accumulated that the conservative case is too oversimplified. Plavec (*Parksv.*) showed that massive Algol systems cannot be formed by conservative case A. Benson (*BAAS*, **2**, 295) found that the mass-receiving component may very soon become contact. In Algol systems, we must probably admit loss of mass and angular momentum from system, or/and transient contact phases in which exchange of energy may be more important than exchange of mass.

This only emphasizes the general importance of models of contact binaries, originally invented to explain primarily the W UMa systems (Moss, *MN*, **153**, 41; **157**, 433; Whelan, *MN*, **156**, 115; Thomas, *Bamberg*, 285; Hazlehurst and Meyer-Hoffmeister, *Bamberg*, 289). The formation of W UMa stars was considered by Okamoto and Sato (*PASJ*, **22**, 317) on the basis of the theory of magnetic braking of orbital motion in the pre-main-sequence phase. Whelan (*MN*, **149**, 167) and Yamasaki (*PASJ*, **23**, 33) showed that contact binaries in the pre-main-sequence phase are unstable to mass transfer or mass loss.

The role of gravitational radiation in the evolution of the U Gem stars and ultrashort-period variables was studied by Vila (*ApJ*, **168**, 217), Faulkner (*ApJ*, **170**, L99) and Faulkner, Flannery and Warner (*ApJ*, **175**, L79).

Plavec (*Parksv.*) confronted theoretical models with actually observed systems and concluded that the theory of mass transfer must be generalized to include the effect of loss of mass and of angular momentum from the system, and the interaction between the gas stream and the mass-accreting star. He suggested that helium rich binaries like *v* Sgr and the symbiotic objects like AG Peg as well as some X-ray sources may be systems in the phase of a second mass transfer. The first mass transfer, usually of type B (or AB), may create a shortcut in stellar evolution circumventing the supergiant stage and making it possible for collapsed objects to form in very close binaries.

From a different point of view, Kopal (*PASP*, **83**, 521) criticized the theory of mass transfer and suggested that, if anything, mass loss must be dominant. In a series of papers (see *Aph. Sp. Sci.*, **17**, 161 also for further references), Kopal studied the effect of tidal friction on the evolution of detached binaries.

The paper by Lebovitz (*ApJ*, **175**, 171) on the fission theory of formation of binary systems stands practically isolated. Attention is currently focused on the late stages of evolution when collapsed objects may occur in binaries, and when binary stars may become radio and X-ray sources. Great theoretical and observational advances may be anticipated. In an editorial article entitled 'Binary Stars as Astronomical Accelerators', *Nature* (**235**, 247) writes: "... binary systems provide excellent opportunities to come to grips with the physics involved in high energy processes. So although binary stars have never been ignored by astronomers, it may be that their study is entering a new and profitable phase".

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