42. COMMISSION DES ETOILES DOUBLES PHOTOMETRIQUES

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The triennium which has elapsed since the eighth General Assembly of the I.A.U. in Rome 1952 witnessed further impressive growth and consolidation of our knowledge of eclipsing binary systems in all its aspects. In point of fact, the statement of our last report that in no comparable period of time in the past have such investigations been pursued with more vigour and led to more contributions—both observational and theoretical—to our subject has continued to hold true in full measure. As we proceed now, on the eve of the ninth General Assembly, to review the front lines of general advance, we cannot fail to note, on the way, certain sectors where exceptional progress has been achieved, and others where progress may have been relatively slow, or stalled, due to lack of manpower or technical resources. And yet, as we raise sights from the positions already won to more distant territory everywhere ahead, new problems are seen arising on the horizon in numbers which are certain to render this branch of astronomy full of fascination and promise of unexpected developments for many years to come.

The aim of our present report will, therefore, be both to survey, and comment on, the main feature of work accomplished in this field during the past three years, as well as to call attention to some, possibly promising, trends of further research—in brief, to summarize some of our hopes as well as accomplishments. For the sake of convenience, our survey will be divided into a number of individual sections, dealing with related subjects, which together should cover the entire field of our interest, and which will be treated in turn.

I. OBSERVATIONAL TECHNIQUES AND NEW PHOTOMETRIC DATA

The greatest single factor which contributed most to the rapid outgrowth of the observational knowledge of our subject in the past decade has been an effective application of photo-electric photometry to the study of eclipsing binary systems—or, more specifically, the introduction in astronomical practice of the photo-multiplier. The past three years have seen no new important instrumental advances (apart from a gradual penetration of photo-electric techniques in the infra-red domain of the spectrum, whose impact on the study of eclipsing systems has not yet made itself sufficiently felt), but rather a gradual widening of the circle of photo-electric observers of eclipsing variables. Thus, apart from a number of well-known centres (Lick, Washburn, etc.) which have been traditionally active in this field, we should welcome the Observatoire de Haute Provence (3), Hoher List (Bonn), Wien, Napoli (2), Engelhardt and Abastumani (U.S.S.R), Tokyo (Mitaka), and Canberra (Australia) joining in our work. A description of new equipment and general discussions of application of photo-electric techniques to our field of study can be found under (1–7) in the bibliography concluding this report.

As in our previous report, we open this section of our present report by Table 1, containing a list of all stars for which new photo-electric light curves (in one or more colours) have been secured in the past three years. This table should be regarded as a direct continuation of similar tables on pp. 633–4 and 651–2 of the *I.A.U. Trans.* **8**, and the number of additions which can now be reported is truly impressive: for it transpires that, since 1952, new light curves have been obtained for not less than ninety-seven eclipsing systems, many of which have been observed independently by several investigators:

Table 1. *New photo-electric observations*

Star	Reference*
RT And	Gordon (Lick Obs.; unpublished); Lenouvel (Observ. de Haute Provence; new observations).
XZ And	Blitzstein, *A.J.* **59**, 251, 1954.
BX And	Svolopoulos (Flower and Cook Observatories and National Observatory of Athens, two colours).
S Ant	Hogg (Mt Stromlo Obs.; new observations).
OO Aql	Kwee (Leiden Observatory).
V 805 Aql	Fresa, *Mem. Soc. Astr. Ital.* **25**, 105, 1954.
V 822 Aql	Nicolini (Obs. Capodimonte, Napoli).
FU Ara	Cillié and Lindsay (Armagh-Boyden).
BF Aur	Schneller and Daene (Berlin-Babelsberg).
ε Aur	Huffer (Washburn Obs.); Huruhata (Tokyo-Mitaka Obs., observing in six colours); Binnendijk (Flower and Cook Obs., observing in three colours and for polarization).
UW Boo	Bartlett (Chamberlin Obs., Denver, two colours).
UX Boo	von Socher (Univ. Sternwarte Wien).
ZZ Boo	von Socher (Univ. Sternwarte Wien).
44 i Boo	Binnendijk (Flower and Cook Obs.); Huruhata (Tokyo-Mitaka Obs., three colours); Kwee (Leiden Obs.); Schmidt (Univ. Sternwarte Bonn-Hoher List, three colours).
SV Cam	Kron and Gordon (Lick Obs., two colours); van Woerden (Leiden Obs.).
S Cnc	Huffer (Washburn Obs.).
RZ Cnc	Huruhata (Tokyo-Mitaka Obs.).
TW Cnc	Huffer (Washburn Obs.); Huruhata (Tokyo-Mitaka Obs.).
TX Cnc	Lenouvel (Obs. de Haute Provence, three colours).
UU Cnc	von Socher (Univ. Sternwarte Wien).
AD CMi	Fresa (Obs. Capodimonte, Napoli).
GM Car	Cillié and Lindsay (Armagh-Boyden).
RZ Cas	Huffer (Washburn Obs.); Lenouvel (Obs. de Haute Provence, three colours).
TW Cas	Huffer (Washburn and Lowell Obs.).
AR Cas	Huffer and Hardie (Washburn and Lowell Obs., three colours).
BM Cas	von Socher (Univ. Sternwarte Wien).
DO Cas	Kwee (Leiden Obs.).
U Cep	Miczaika, *Z. Ap.* **33**, 1, 1953 (three colours).
VW Cep	Hinderer (Obs. Berlin-Babelsberg); Kwee (Leiden Obs.); Moncibowycz and Walter, *Z. Ap.* **31**, 223, 1952; Schmidt (Univ. Sternwarte Bonn-Hoher List, two colours).
XX Cep	Fresa, *Mem. Soc. Astr. Ital.* **24**, 341, 1953; Kostylev and Botsula (Engelhardt Obs. Kazan).
AH Cep	Huffer (Washburn and Lowell Obs.); Nekrassova, *Publ. Crimean Obs.* (in the Press).
CW Cep	Abrami and Cester, *Trieste Ricerche*, no. 266, 1955.
TW Cet	Cillié and Bok, *Harv. Bull.* no. 920, 1952; Huruhata (Obs. Tokyo-Mitaka, three colours).
ε CrA	Cousins (Capetown Roy. Obs.).
U CrB	Bartlett (Chamberlin Obs., Denver, three colours).
α CrB	G. E. and K. C. Kron, *Ap. J.* **118**, 55, 1953.
AI Cru	Oosterhoff (Leiden Obs.).
Y Cyg	Magalashvili and Kumsishvili (Abastumani Obs., U.S.S.R.).
GO Cyg	Kwee (Leiden Obs.); Ovenden, *M.N.* **114**, 569, 1954 (two colours).
MR Cyg	Hardie (Lowell Obs., three colours); Kostylev and Botsula (Engelhardt Obs., Kazan).
V 380 Cyg	Huffer (Washburn Obs.).
V 548 Cyg	Fresa (Obs. Capodimonte, Napoli).
V 729 Cyg	Miczaika, *P.A.S.P.* **65**, 141, 1953.
32 Cyg	Kostylev and Botsula (Engelhardt Obs., Kazan).
RU Eri	Nakamura and Tanabe, *Ann. Tokyo Obs.* **3**, 175, 1953 (two colours).
UX Eri	Huruhata (Obs. Tokyo-Mitaka, three colours).
YY Eri	Cillié, *Harv. Bull.* no. 920, 1952; Huruhata, Dambara and Kitamura, *Ann. Tokyo Obs.* **3**, 227, 1953 (three colours); Kwee (Leiden Obs.).
YY Gem	Kron, *Ap. J.* **115**, 301, 1952.

* Unless specific quotation is given, observations are as yet unpublished.

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Table 1. *New photo-electric observations* (*continued*)

Star	Reference*
RX Her	Magalashvili, *Abastumani Obs. Bull.* no. 15, 1953; Miczaika (Heidelberg Obs., two colours).
SZ Her	Broglia, Masani, and Pestarino, *Mem. Soc. Astr. Ital.* **26**, 321, 1955 (two colours); Bartlett (Chamberlain Obs., Denver).
TT Her	Hogg and Kron, *A.J.* **60**, 100, 1955.
TX Her	Kostylev and Botsula (Engelhardt Obs., Kazan).
AK Her	Kwee (Leiden Obs.); Labs and Stock, *Z. Ap.* **33**, 132, 1953.
DQ Her	Walker, *P.A.S.P.* **66**, 230, 1954 (three colours).
u Her	Ruiz (Flower and Cook Obs.).
SW Lac	Brownlee (Goethe Link Observatory, three colours); Kwee (Leiden Obs.).
CM Lac	Hardie (Lowell Obs., three colours).
UV Leo	Wellmann, *Z. Ap.* **34**, 99, 1954.
UZ Leo	Hinderer (Berlin-Babelsberg).
δ Lib	Sczepanowska and Kolaczek (Krakow Obs.).
RR Lyn	Kostylev and Botsula (Engelhardt Obs., Kasan); Magalashvili and Kumsishvili (Abastumani Obs., U.S.S.R.).
RW Mon	Lenouvel (Obs. de Haute Provence).
V 451 Oph	Colacevich, *Mem. Soc. Astr. Ital.* **23**, 225; **24**, 121, 1953.
V 502 Oph	Kwee (Leiden Obs.).
V 566 Oph	Fresa, *Mem. Soc. Astr. Ital.* **25**, 127, 1954; Kwee (Leiden Obs.).
VV Ori	Huffer (Washburn and Lowell Obs.); Nekrassova, *Publ. Crimean Obs.* (in the Press).
ER Ori	Huruhata (Obs. Tokyo-Mitaka, three colours); Kwee (Leiden).
U Peg	Hinderer (Berlin-Babelsberg); Huruhata (Tokyo-Mitaka, three colours); Kwee (Leiden Obs.); La Fara, *Ap. J.* **115**, 14, 1952 (two colours).
AT Peg	Huruhata (Obs. Tokyo-Mitaka, three colours).
DK Peg	Bartlett (Chamberlin Obs., Denver, two colours).
EE Peg	Bakoš (David Dunlap Obs.); Wellmann, *Z. Ap.* **32**, 81, 1953.
AG Per	Huffer (Washburn and Lowell Obs.).
β Per	Lenouvel (Obs. de Haute Provence); Oberender (Sternwarte Sonneberg).
TY Pup	Huruhata (Tokyo-Mitaka Obs., three colours).
U Sge	Bartlett (Chamberlin Obs., Denver, four colours).
V 356 Sgr	Popper, *Ap. J.* **121**, 56, 1955 (two colours).
V 505 Sgr	Kwee, *B.A.N.* **12**, 35, 1953; Magalashvili (Abastumani Obs., U.S.S.R.); Sofronitski, Pulkova Izvestia, **19**, part 4, no. 151, 1953.
V 525 Sgr	Cillié and Lindsay, *M.N.* **113**, 515, 1953 (two colours).
V 499 Sco	Cillié and Lindsay (in the Press).
RT Scl	Wesselink (Radcliffe Obs., Pretoria, three colours); Cillié and Lindsay (in the Press).
RS Sct	Kwee (Leiden Obs.).
Y Sex	Huruhata (Tokyo-Mitaka Obs., three colours).
RZ Tau	Huruhata and Kitamura, *Publ. Astr. Soc. Japan*, **5**, 102, 1953 (three colours).
ET Tau	von Socher (Univ. Sternwarte Wien).
BL Tel	Cousins (Capetown Roy. Obs.).
W UMa	Kwee (Leiden Obs.)
UX UMa	Hiltner (Yerkes Obs., three colours); Walker and Herbig, *Ap. J.* **120**, 278, 1954.
ε UMi	Hinderer (Berlin-Babelsberg).
AL Vel	Cousins (Capetown Roy. Obs.).
AG Vir	Kwee (Leiden Obs.); Sczepanowska and Kolaczek (Krakow).
AH Vir	Huruhata (Tokyo-Mitaka Obs., three colours); Kwee (Leiden Obs.); Binnendijk (Flower and Cook Obs., two colours).
BF Vir	Kwee (Leiden Obs.).
BH Vir	Huruhata (Tokyo-Mitaka Obs., three colours).
α Vir	Magalashvili (Abastumani Obs.).
Z Vul	Wesselink (Leiden Station, Johannesburg, two colours).
RS Vul	Magalashvili, *Abastumani Obs. Bull.* no. 15, 1953.
DR Vul	Fresa (Obs. Capodimonte, Napoli).

* Unless specific quotation is given, observations are as yet unpublished.

and for thirty-seven of them photo-electric observations have been carried out in the light of two or more different spectral ranges. This does not mean that each new light curve reported in Table 1 is sufficiently complete, as it now stands, to serve for a definitive analysis for geometrical elements of the system; but the majority are indeed of this quality, and many of them are based on several thousand individual observations. The total number of photo-electric measures which went into the formation of all light curves reported in Table 1 is probably of the order of a hundred thousand. So large an increment of observations secured within three years bears an eloquent testimony to the rate at which our knowledge of the photometric behaviour of eclipsing binary systems keeps increasing at the present time.

A survey of the data compiled in the accompanying Table 1 lends itself to several interesting conclusions. First, the trend indicating a shift of the centre of gravity of photo-electric observation of eclipsing variables from America to Europe, notable since the end of the last decade, continued unabated throughout the past triennium. Of the American observatories, which were once almost the sole producers of photo-electric light curves, practically only Lick and Washburn have continued to remain active in this field; and the Washburn (i.e. Huffer's) observing activities have been gradually transferred to the McDonald and Lowell Observatories, blessed with a better photo-electric climate than Wisconsin. The majority of observatories in the East and Middle West of the United States appear to have been discouraged by their (photo-electrically) inferior climate and to have curtailed considerably their activities in this field. This is particularly true of Harvard and Princeton, whose traditional roles in the advancement of our subject have come—let us hope, only temporarily—largely to a standstill.

On the other side of the Atlantic, the Leiden Observatory, situated in a climate which is not better, in general, than that of the American East Coast, has of late become an important active centre of photo-electric observation, particularly of W UMa-type eclipsing systems—as the data collected in Table 1 bear witness in an impressive manner. The contributions of the Observatoire de Haute Provence (Lenouvel) and of Naples (Colacevich and Fresa), noted already at the time of our last meeting, continued throughout the triennium. We understand that Lenouvel's impending transfer from Haute Provence to the Observatoire de Pic-du-Midi will enable him to continue his photo-electric work in one of Europe's best observing sites: and that the tragic and premature passing of Prof. Colacevich, Director of the Capodimonte Observatory at Naples, on 24 August 1953* will not bring about any immediate change in the Observatory's eclipsing activities, which are being continued by Fresa.

Relatively little has been heard in the past three years of photo-electric work in Czechoslovakia or Poland. We welcome, however, the emergence of two new contributors to photo-electric photometry of short-period eclipsing variables at the Universitäts-Sternwarte, Bonn—Station Hoher List (H. Schmidt), and the Universitäts-Sternwarte, Wien (H. von Socher), who both have provided already significant contributions to the data collected in Table 1. We welcome, moreover, the come-back of the Berlin-Babelsberg Sternwarte (C. Hinderer) to its traditional field of study interrupted earlier by war. Anyone glancing through Table 1 will be impressed by the numerous contributions to the photo-electric study of eclipsing variables which we owe to several colleagues in the Soviet Union (R. A. Botsula, J. I. Kumsishvili, K. V. Kostylev, N. L. Magalashvili, S. V. Nekrassova) at the Abastumani, Crimean, and Engelhardt Observatories. Last but not least, we sincerely welcome an impressive outburst of activity in our field at the Tokyo (Mitaka) Observatory, where M. Huruhata, with his colleagues, has specialized (again on account of climate) in multi-colour photo-electric observations of W UMa-type variables. A co-operative programme between Tokyo and one of the West European (or East American) observing stations should be capable of furnishing a continuous record of light changes of many W UMa-type and other short-period eclipsing variables virtually 'round the clock'!

* A tribute to his memory can be found in an Obituary, by Righini, which appeared in the *Mem. Soc. Astr. Ital.* **25**, 87, 1954.

The foregoing remarks have been limited to a discussion of the *geographical distribution* of existing sources of observation. As to the *type* of the objects observed, anyone glancing at Table 1 and comparing it with its predecessors in our Report of three years ago* cannot fail to note an increasing preponderance of observations of variables of the W UMa-type. This is a significant development; for whereas up to (say) 1950 light curves of scarcely half a dozen variables of this type had been photo-electrically measured, by now more than thirty-six are available—and several in two or three colours. The reasons for this sudden turn of events are partly the mediocre climate at many observing stations (placing a premium on observation of stars for which significant variation can be expected in single clear nights), and also the fact that increasing sensitivity of photo-electric devices brought stars of the 9th–11th apparent magnitudes within the reach of the telescopes of moderate apertures. As the dwarf systems of W UMa-type represent probably by far the most common type of close binary systems, per unit volume, in the galactic system around us, a preponderance of their numbers with increasing apparent magnitude was eventually bound to make itself felt.

In the meantime, new eclipsing variables are being discovered among faint stars (14th–16th magnitudes) by photographic reconnaissance advancing in front of the main force of photo-electric photometrists; the latest supplements to the Kukarkin and Parenago's *Obschij Katalog* bear witness to their numbers. This does not mean that, among brighter stars, all eclipsing variables are already known. Pairs of small amplitudes, and some of the most interesting systems are found among them, cannot be detected otherwise than by photo-electric methods; and there are still doubts whether all such stars have already been discovered among naked-eye stars.

In this latter group, no major discoveries have been reported during the past triennium;† in particular, σ Scorpii, provisionally included in Table 1 of our Report three years ago, is no longer regarded as an eclipsing variable. It should, however, be emphasized in this connexion that several well-known eclipsing systems among naked-eye—nay, first and second magnitude—stars are greatly in need of photo-electric re-observation. A few of the most striking cases belonging to this group are listed in the following tabulation:

Star	Period	Amplitude	Reference
σ Aql	1^d·950	5·00–5·18	Wylie, *Ap. J.* **56**, 232, 1922
β Aur	3·960	2·07–2·16	Stebbins, *Ap. J.* **34**, 112, 1911
δ Lib	2·327	4·79–5·90	Stebbins, *Washb. Publ.* **15**, 33, 1928
δ Ori	5·733	2·40–2·55	Stebbins, *Ap. J.* **42**, 133, 1915
η Ori	7·989	3·20–3·35	Stebbins, *Publ. A.A.S.* **3**, 273, 1916
λ Tau	3·953	3·51–4·00	Stebbins, *Ap. J.* **51**, 193, 1920
α Vir	4·014	1·20–1·30	Stebbins, *Ap. J.* **39**, 475, 1914

A glance at its last column reveals that the existing light curves of all these stars are decades old and could no doubt be greatly improved by modern re-observation. Is it too much to hope that some master of photo-electric photometry accustomed to measure objects which are too faint to be seen through the guiding telescope, could be lured from his rich hunting grounds among faint stars to devote some attention to a few first and second magnitude variables?

* *Trans. I.A.U.* vol. **8** (Cambridge 1954), pp. 633–4 and 651–2.

† It may be of interest, in this connexion, to report that Magalashvili at Abastumani Observatory tested by photo-electric methods the constancy of light of the following spectroscopic binaries: BD +8° 19, 39° 811, +31° 2397, +43° 3755, +23° 4675, and +40° 4616, and established the non-variability of BD +31° 2397, +23° 4675, and +40° 4616.

2. NEW SPECTROGRAPHIC DATA

In contrast with the subject of the preceding section, the increase in our knowledge of spectrographic orbits during the past triennium has been relatively slow, and far out of line with the wealth of new photometric data acquired during the same time. The great work by Struve and his associates at the Yerkes and McDonald Observatories in this field between 1940–50, which more than doubled our previous knowledge of the subject and which was surveyed in our last report three years ago, spent its first momentum, and further additions to the list of new spectrographic orbits have been forthcoming at a much slower rate. The following Table 2 lists such additions, published or unpublished, in so far as they were known to the writer by the end of the year 1954.

A glance at the foregoing table reveals that the traditional three main contributors—Mt Wilson, Yerkes and McDonald, and the Dominion Astrophysical Observatories—have temporarily withdrawn from the field, the greatest single remaining contributor being the David Dunlap Observatory at Toronto under Dr Heard. May we therefore take this opportunity to appeal to our spectroscopic colleagues and to say that in general, in spite of their magnificent efforts of the past decade, the need for their continued co-operation remains as pressing as ever before. The immediate extent of this need is shown in the accompanying Table 3, which lists twenty-seven well-known eclipsing systems mostly of the Northern Hemisphere and brighter at maximum than the 10th apparent magnitude, for which no spectrographic orbits are so far available; and a similar survey of the Southern Hemisphere would reveal still more dark continents. Let us hope that these gaps in our present knowledge will be closed in the near future, both for the sake of a study of the respective individual systems, as well as for completion of the data on which statistical studies of the distribution of the different properties of close binary systems—such as the orientation of the semi-major axes of eccentric binaries in space, the frequency distribution of their eccentricities, the space motions of close binary systems, etc.—can be based. Specific attention should, in this connexion, be called to an examination of the systemic velocities deducible from the velocity curves of *both* components of two-spectra eclipsing systems, in view of the bearing of such results on certain problems possibly related to the general theory of relativity as pointed out recently by Freundlich.*

3. TIMES OF THE MINIMA AND PERIOD VARIATIONS

A determination of the times of the minima of eclipsing binary systems represents an important and necessary task—lacking perhaps some of the glamour of dramatic discoveries, but one which cannot be deferred to subsequent generations and whose aim is twofold: to provide the ephemerides for the immediate benefit of the observers, as well as (in the case of variable periods) fundamental data whose interpretation, by the theoreticians, is eventually bound to throw considerable light on the dynamics of close binary systems and the structure of their constituent components. When we stop to survey the work accomplished in this basic field of research during the past triennium, we have indeed reasons for satisfaction; for the amount of work on record is greater than has been accomplished ever before in a comparable period of time, and its accuracy is likewise on the increase.

A survey of the actual sources reveals that the work in this field is strongly geographically localized—in fact, most of it we owe to half a dozen specific observatories specializing in it—and it is being carried out still largely by photographic methods (though photoelectric techniques are being increasingly adopted). Of the observing centres active in this field, the primacy is no doubt held by the Krakow University Observatory, which for 25 years has been publishing (partly with the support of the International Astronomical Union) the well-known Ephemerides of Eclipsing Variables as a Supplement to their *Rocznyk Astronomiczny* and, as a part of this work, has undertaken a systematic

* Cf. Freundlich, *Phil. Mag.* (7) **45**, 303, 1954.

Table 2. *Eclipsing Systems with New Spectrographic Orbits*

Star	Reference
V 805 Aql	Heard (David Dunlap Obs., unpublished single-spectrum orbit).
SV Cam	Hiltner, *Ap. J.* **118**, 262, 1953.
TW Cnc	Popper (Lick Obs., unpublished).
V 548 Cyg	Heard (David Dunlap Obs., unpublished single-spectrum orbit).
YY Gem	Struve and Ebbighausen, *Ap. J.* **117**, 468, 1953.
RV Lib	Joy (Mt Wilson, unpublished).
V 451 Oph	Heard (David Dunlap Obs., unpublished two-spectra orbit).
V 566 Oph	Heard (David Dunlap Obs., unpublished).
δ Ori	Miczaika, *Z. Ap.* **30**, 299, 1952.
EE Peg	Bakoš (David Dunlap Obs., unpublished); Wellmann, *Z. Ap.* **32**, 81, 1953.
V 356 Sgr	Popper, *Ap. J.* **121**, 56, 1955.
V 449 Sco	Sahade, *P.A.S.P.* **65**, 88, 1953.
W Ser	Beer (Cambridge, unpublished).
UX UMa	Walker and Herbig, *Ap. J.* **120**, 278, 1954.
AL Vel	Wesselink (Radcliffe Obs., unpublished).
HD 121648* = ZZ Boo	Shajn, *Ann. Crimean Astr. Obs.* **5**, 105, 1950.
HD 200391†	Northcott (David Dunlap Obs., unpublished).

* Recognized as an eclipsing variable by Gaposchkin (*Harv. Bull.* no. 920, 1952).
† The spectrographic elements are such as to make it possible that this system eclipses; photoelectric observations are desirable.

Table 3. *Eclipsing Systems in Need of Spectrographic Orbits*

Star	Period	Spectrum	Magn.	Eclipse
RV Aqu	1·967	A3	8·8–10·1	Partial
ST Aqu	0·781	F0	9·2– 9·6	?
OO Aql	0·507	G5	9·2–10·1	?
V 337 Aql	2·734	B3	8·8– 9·5	?
V 346 Aql	1·106	A0	9·0–10·4	Partial
BF Aur	1·583	A0	8·5– 9·2	?
S Cnc	9·485	A0+G5	8·0–10·2	Total
RZ Cnc*	21·643	K2+K5	9·4–11·0	?
TU Cnc	5·562	A0	9·5–12·4	Partial
YY Cmi	1·094	F5	8·5– 9·1	?
TX Cas	2·927	B4	9·3– 9·8	?
XZ Cep	5·097	B5	8·2– 9·0	Partial
TV Cet	9·103	F0	8·6– 9·1	Partial
KR Cyg	0·845	A0	9·0– 9·7	Total
MY Cyg	2·003	A3	8·9– 9·5	?
V 488 Cyg	6·520	B3	7·9– 8·5	?
SX Dra	5·169	A7	9·8–11·9	Total
S Equ	3·436	A0	8·0–10·2	Total
TT Lyr	5·244	A0	9·2–10·3	Partial
RW Mon	1·906	A0	8·9–11·5	Total
RV Oph	3·687	A0	9·6–11·8	Total
AT Peg	1·146	A0	8·9– 9·7	Partial
DK Peg	1·632	A5	9·7–10·6	Total
AY Per	11·777	B9	9·3–10·1	Total
SZ Psc	3·966	G5	8·3– 9·8	Partial
RS Tri	1·909	A5	9·8–10·6	Total?

* Hiltner (*P.A.S.P.* **58**, 166, 1946) published some spectrophotometric results, but details of the orbit are still lacking.

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observation of the times of minima of very many eclipsing systems by visual as well as photo-electric methods. This work has been pursued by an enthusiastic group of Krakow observers under the direction of Prof. Thaddeusz Banachiewicz who, after a long and distinguished career, passed away, in the fullness of years, in November 1954. It is impossible to say how much we are hoping that the Krakow Observatory will be in a position to continue its meritorious work in the future; for its withdrawal from this field would confront our Commission with a real and acute problem.

Table 4. *Discussions of Periods of Eclipsing Binary Systems*

Star	Reference
XZ And	Odinskaya and Ustinov, *Per. Zvezdy*, **8**, 264, 1952.
RZ Cas	Parenago, *Per. Zvezdy*, **9**, 125, 1952.
RR Cen	O'Connell, *Acta Pontif. Acad. Sci.* **16**, 25, 1954.
U Cep	Miczaika, *Z. Ap.* **33**, 1, 1953.
XX Cep*	Fresa (unpublished).
W Crv*	Tsesevich (unpublished).
SW Cyg	Slovochotova, *Per. Zvezdy*, **10**, 21, 1954.
MR Cyg*	Kaminský, *Per. Zvezdy*, **9**, 285, 1953.
Z Dra	Taffara, *Mem. Soc. Astr. Ital.* **23**, 197, 1953.
TW Dra	Slovochotova, *Per. Zvezdy*, **10**, 21, 1954.
SW Lac*	Serkowski, *Sprav. Polskiego Tovarz. Astr.* Warsaw, 1953.
GN Nor*	de Kort, *Ricerche Astr.* (*Vatican*), **3**, 119, 1954.
SW Oph	Tsesevich (unpublished).
RT Per	Vasilieva, *Stalinabad Obs. Bull.* no. 4, 1952.
RS Vul	Martynov, *Per. Zvezdy*, **9**, 342, 1954.

* The orbit of this system is eccentric and the author discusses also the rate of apsidal advance.

Of other active centres of work we should mention (going from west to east) the activities of Dr Balfour S. Whitney at the University of Oklahoma (Norman, Okla., U.S.A.) who reports that '... my present photographic programme includes the determination of the times of minima for the following eclipsing systems with variable periods: RY Cnc, TY Cnc, SY Cyg, W Cyg, W Del, YY Del, TU Her, Y Leo, T LMi, RV Lyr, and EQ Ori.' During the next three years, new epochs will be obtained here (i.e. at the University of Oklahoma) 'for as many as possible of some 70 stars from Wood's latest Finding List fainter than 8·0 mag., which carry the notation "Var P" (or "Var. P?"), and which are not known to be observed elsewhere. Several others are being added to the programme for which no minima have been published in the past 15 years. A series of plates planned to provide new epochs for AW, AX, AZ, BF and BH Vir will be completed this summer' (i.e. 1954), reported Whitney in June 1954.

Whitney appears to be at present the only systematic observer of the times of the minima of eclipsing binary systems on the American continent. Crossing the Atlantic, we find, however (apart from Krakow), several centres active in this field. The most important one appears to be at Leiden where, according to a report by Dr Oosterhoff, Kwee is engaged in photo-electric observation of the times of the minima of 17 short-period eclipsing variables of the W UMa-type (OO Aql, 44 i Boo, DO Cas, VW Cep, GO Cyg, YY Eri, AK Her, SW Lac, V 502 Oph, V 566 Oph, ER Ori, U Peg, RS Sct, W UMa, AG Vir, AH Vir, BF Vir); and, in addition, Westerhout and Raimond have undertaken independent photographic observations of 53 W UMa-type variables for determination of the accurate epochs of the minima.

In Germany, two observatories appear to be engaged in extensive work on the epochs of eclipsing variables. According to a recent report by Hellerich,† Günther at Münster has taken several hundred plates of the variables SX Cas, TV Cas, DL Cas, U CrB,

† *Mitt. der A.G. für* 1953, p. 86.

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RX Her, V 451 Oph, and AU Peg. In addition, the Hoher List Station of the Bonn University Observatory has recently inaugurated a systematic programme by Schmidt of photo-electric observations of W UMa-type variables; and von Socher at the University Observatory at Vienna embarked in the past triennium on a similar photo-electric programme.

From Russia, Tsesevich reports the completion of reductions of over 40,000 visual observations of 250 eclipsing variables, secured by him between 1922 and 1953. The results will appear in the *Odessa Obs. Bull.* no. 4 (in the Press) and reveal—among other facts—a variable shift of the secondary minimum of W Crv, and the variability of the period of SW Oph.

Finally, the emergence of a vigorous group of photo-electric observers headed by Huruhata at the Tokyo (Mitaka) Observatory in Japan should be welcomed in this connexion; their activities (because of the changeable weather at Mitaka) appear to be directed predominantly towards variables of the W UMa-type.

In an attempt to summarize this part of our report, we cannot but rejoice at the amount of work accomplished as well as contemplated for the near future; but its centralization in a small number of places exposes it uncomfortably to weather vagaries. There is no doubt that there exists both room and need for additional observers in this field—particularly at sites blessed with good climates. Whitney's example shows what one can accomplish, under such circumstances, even with very modest instrumental equipment.

The second salient point which emerges from the present report is the amount of observational attention focused on the epochs (and periods) of variables of the W UMa type. This is undoubtedly a wise policy for observatories enjoying average climate, which cannot rely on many uninterrupted runs of clear nights; and it is also true that systems of W UMa type will run through many more cycles within a given span of time than the Algol variables, which facilitates detection of any possible variation of period. There is no doubt that the W UMa-type stars will amply repay the time and effort which is being expended at present in their observation. On the other hand, this fact should perhaps not be allowed to go too far to eclipse the need of observation of the epochs of variables with periods longer than a day—although the fruits of such observations might not ripen, generally speaking, until a later time.

4. Giant and Supergiant Eclipsing Systems

The eclipses of components surrounded by extended atmospheres in supergiant eclipsing systems have continued to attract considerable attention on the part of the photometric as well as spectroscopic observers; and many results of such studies have been published in the past triennium (8–25). The last minimum of 31 Cyg continues to give rise to new contributions (8, 9, 10), and of the more recent grazing eclipse of 32 Cyg preliminary results have been announced by Wellmann (11) and Weston (12) from David Dunlap Observatory. Another well-known variable of the group—ζ Aur—underwent eclipse in April and May of 1953; and new results pertaining to its minima as well as general discussions of various properties of this system have been published by several authors (13–17). Fuller details concerning the purely spectroscopic aspects of these objects will doubtless be found in the report of Commission 29 on Stellar Spectra. The famous system of ϵ Aur—perhaps the most remarkable and puzzling known eclipsing variable—has, during the past triennium, been steadily approaching, after a lapse of 27 years, the eve of another eclipse which is expected to commence some time in June 1955, and to last almost two years. This impending event has, in turn, revived interest in the nature of the eclipses of this unusual system which continues to present an outstanding problem. The reader may recall that, several years ago, Kuiper, Struve and Strömgren* advanced a hypothesis that the minima of ϵ Aur are due to the eclipses of its principal cF5 component by an ionized layer in the outer atmosphere of its (invisible) mate—

* *Ap. J.* **86**, 570, 1937.

ionized by an impact of the ultra-violet radiation of the F-star itself—and that the extinction of its light during minima is thus predominantly due to electron scattering. On the other hand, Schoenberg and Jung* have advanced reasons for concluding that the extinction-producing layer does not consist of free electrons, but of solid dust forming continuously at the periphery of an extremely cool star. Incidentally, observational search for an evidence of the light of this elusive secondary component by lead-sulphide photometry† or, more recently by infra-red spectroscopy (18), has so far proved fruitless (or, at best, inconclusive).

In recent years, these earlier views have been challenged by the writer of this report (19–21) on several grounds, and an alternative hypothesis proposed attributing the minima of ϵ Aur to eclipses of its cF 5 star by a semi-transparent flat ring surrounding the secondary component—a ring consisting of solid particles whose dimensions are large in comparison with the wave-length of visible light, and which is inclined to the plane of the eclipsing orbit. On the other hand, Gaposchkin revived recently the view that the minima of ϵ Aur might be due to annular eclipses of a heavily darkened star (22), whereas Kraft (23) proposed still more recently a fourth hypothesis for the explanation of the minima, which attributes their origin to the absorption of the negative hydrogen ion (H^-) in the outer layers of the secondary component, through which the cF 5 star shines during eclipses. Whether or not such a hypothesis could account for the frequency independence of the depth of the last minimum of ϵ Aur as observed in 1929–30, as well as for the flat bottom of its light curve, remains somewhat dubious; but judgement should no doubt be postponed till the new minimum forthcoming in 1955–57 will have revealed its story. This minimum is likely to prove the most important event of eclipsing-star astronomy in the next triennium; and an organization of its complete observational coverage—both photometric (on as wide a frequency baseline as possible) and spectrographic should be one of the main concerns of our Commission at the Dublin meetings.

Another well-known member of the group of supergiant eclipsing systems, VV Cep, has continued to keep out of eclipse during the past triennium and has made, in general, but little news, except for an isolated but highly intriguing fact, established by Babcock,‡ that its primary component has turned out to be a magnetic variable—the first such variable to be detected among eclipsing binary systems. According to Babcock, the magnetic field of VV Cep was found to oscillate in strength between -1200 and $+2000$ gauss in a period which does not appear to be known as yet, but which is doubtless very short in comparison with that of the eclipsing orbit (i.e., with 7430 days). How many other magnetic stars (or variables) there may be among the components of known eclipsing systems seems impossible even to surmise, since the near-parallelism of their equatorial plane with the line of sight (inherent in their eclipsing nature) is, in general, bound to widen their spectral lines beyond any possibility of measuring Zeeman shifts corresponding to magnetic fields of strength of the order of 10^3 or even 10^4 gauss. VV Cephei appears to be an exception in this respect; for a sharpness of its lines leaves no room for doubt that the axis of rotation of its principal component can make, at best, only a small angle with the plane of the binary orbit—an interesting and unique dynamical situation, inviting closer analysis.

In contrast to the amount of work devoted to the foregoing few bright super-giants, all other eclipsing systems of this class have attracted considerably less attention—in most cases, no doubt, because of their smaller apparent brightness, and also because of the fact that the interesting features of their light-curves are not limited to a relatively short time space of a few days or weeks, but are likely to be spread evenly over the entire cycle. Consider, for instance, the following ten eclipsing systems of this class, whose principal characteristics are compiled in the table as shown on p. 609. The long duration of the periods of all these systems alone is sufficient to indicate that their components must lie well above the Main Sequence. The spectral characteristics

* *A.N.* **265**, 221, 1938.

† Fellgett, *M.N.* **111**, 537, 1951; Kuiper (unpublished).

‡ As quoted by Chandrasekhar and Fermi, *Ap. J.* **118**, 116, 1953.

of RZ Oph, as well as the conspicuous ellipticity effects exhibited by W Cru and BM Cas (indicative of the fact that the fractional size of their components must be very large), leave little room for doubt that these stars are likely to be supergiants, and the same is probably true of μ and ν Sgr; while the remaining five apparently belong to 'ordinary' giants.

Star	Period	Amplitude	Spectrum
RZ Oph	$261^d \cdot 9$	10·0–10·9	cF9+cK5
W Cru	198·5	9·2– 9·9	Gop
BM Cas	197·4	9·1– 9·5	G+M
μ Sgr	180·5	4·0– 4·2	cB8e
ν Sgr	137·9	4·2– 4·4	B8p+F2p
UU Cnc	97	8·7– 9·2	?
TW Cnc	70·77	9·3–10·3	G5
GG Car	62·09	9·5–10·0	Bep
SX Cas	36·57	9·5–10·7	gA6+gG6
RX Cas	32·32	10·0–11·1	gG3+gA5

A detailed observational study of all systems listed above is likely to disclose a wealth of important results. In particular, W Cru is almost certain to prove a rich prize for the first observer who will turn onto it a spectrograph attached to one of the large reflectors of the Southern Hemisphere. Unfortunately, such spectroscopic observations are still almost completely lacking. On the photometric side, the light curve of BM Cas was recently studied (visually, with the aid of heterochromatic filters) by Beyer(24), and the system of TW Cnc was the subject of a note by Popper(25). Accurate photo-electric light curves are badly overdue for μ and ν Sgr—both naked-eye objects. The system of μ Sgr has, to be sure, already been observed photo-electrically by Morgan and Elvey* and by Hall,† but only fragmentary results are available so far; and the same is true of photo-electric observations of ν Sgr reported more recently by Eggen, Kron and Greenstein.‡ We are, moreover, still waiting for accurate photo-electric light curves of SX Cas which would clear up the disturbing discrepancy between the earlier visual§ and photographic|| light curves, which has been discussed by S. Gaposchkin in several papers ten years ago.¶ May we also call, in this connexion, the attention of the observers to a rather puzzling case of δ Cas (spectrum A4n), for which a small light variation in a period of about 760 days was reported, by Guthnick and Prager,** and whose radial velocity likewise appears to be variable.†† If this star were indeed to prove to constitute an eclipsing system, its more detailed study would be decidedly worthwhile.

5. Dwarf and Sub-dwarf Eclipsing Systems

The yellow dwarf eclipsing systems—variables of the W UMa-type—have in the past triennium attracted more attention on the part of observers than any other group of objects in our field of study, for reasons already discussed. The wealth of the observational data which has so suddenly come into our possession, makes it, however, all the more embarrassing for us to realize that, so far, we are not in possession of any physically meaningful method for analysing the light curves of W UMa-type variables and ascertaining the true geometry of such systems. This fact deserves, perhaps, a particular emphasis; since attempts at solution of their light curves are currently pursued by many writers by methods devised for dealing with slightly distorted systems and extrapolated far outside the range within which their use could be physically justified. There seems but little room for doubt that the W UMa-type variables represent pairs of stars so close as

* *Ap. J.* **88**, 110, 1938.
† *Ap. J.* **94**, 550, 1941.
‡ *P.A.S.P.* **62**, 171, 1950.
§ Dugan, *Princ. Contr.* no. 13, 1933.
|| Gerasimovich, *Harv. Bull.* no. 852, 1927.
¶ *Ap. J.* **100**, 221, 1944; *Science*, **100**, 230, 1944, etc.
** *Veröff. Berlin-Babelsberg*, **2**, 112, 1918.
†† For a peculiar astrometric behaviour of this suspected eclipsing variable cf. Courvoisier, *A.N.* **204**, 329, 1917; or Orlov, *A.N.* **246**, 427, 1932.

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to be nearly (or actually) in contact, with a distribution of brightness over their apparent disks influenced profoundly by gravity-darkening. The proper model for approximating the geometry of such systems is obviously not a pair of prolate spheroids, but the well-known Roche model consisting of two mass-points surrounded by infinitesimally thin envelopes of arbitrary extent. The geometry of the configurations represented by such a model has only been recently investigated in some detail,* and a development of the methods of light-curve analysis based upon it represents one of the most important and pressing desiderata in the entire field of the computation of the elements of eclipsing binary systems.

Apart from the photometric photometry of W UMa-type variables, one other important piece of observational work on these systems should be mentioned here, namely, a series of photographic determinations of accurate positions by Kwee and Wolterbeek Muller at Leiden, aiming to provide data for the determination of the proper motions of a sufficient number of such variables.

Eclipsing systems consisting of pairs of sub-dwarfs are rare, but not unknown. The first discovered specie of this group—the system of UX UMa—was, in the past triennium, the subject of important investigations by Johnson, Perkins and Hiltner (26), and by Walker and Herbig (27) revealing that the intrinsic variations of light between eclipses, reported previously by Linnell,† are undoubtedly real and that their amplitude increases with diminishing wave-length.

Until 31 July 1954, UX UMa remained the only known sub-dwarf eclipsing system. On that night M. F. Walker, working with the 100-inch reflector at Mount Wilson, discovered that DQ Her—better known as Nova Herculis, 1934—was an eclipsing binary with the shortest known period of 4 hr. and 39 min. (28). The primary minima appear to be due to partial eclipses lasting approximately 1 hr., and their amplitudes are about 0·9 magn. in ultra-violet light, 1·1 magn. in the blue, and 1·3 magn. in the yellow. The secondary minima appear so far to be imperceptible.

Astronomers are still holding their breath while contemplating the implications of this discovery. The light curve of DQ Her is, at first sight, very similar to that of UX UMa: both curves show little or no evidence of ellipticity of the components, and exhibit also short-period intrinsic light fluctuation and, at least at times, an asymmetry of the ascending branch of the eclipse curve (as well as a bright 'shoulder' before the beginning of an eclipse). The orbital period of DQ Her is by only 4 min. shorter than that of UX UMa. Even prior to a detailed analysis of the observations, the brevity of the period and short fractional duration of the minima (coupled with an effective absence of any ellipticity effect) leaves no room for doubt that the components of DQ Her are, like those of UX UMa, absolutely very small and dense.

It may, as yet, be somewhat premature to conclude from these facts that UX UMa is also related to the Novae, though investigations relating the remnants of old Novae with sub-dwarfs‡ have, through Walker's discovery, received striking support. A discovery of the binary nature of DQ Her not only provides us with a possibility of obtaining direct and detailed information on the physical characteristics of a post-Nova, but raises also several crucial questions concerning their evolution: has, in particular, the present binary system of DQ Her existed an astronomically long time, or did a single star undergo fission during the Nova outburst in 1934; and if so, at what stage (secondary maximum?)? It is to be hoped that an examination of photographic plates taken before the 1934 outburst may establish whether or not the star was a binary at that time. Observations by Morgenroth on Sonneberg Observatory plates taken between 1930 and 1934 indicated no perceptible variation of the 15th magnitude pre-Nova. Harvard plates from the years 1894–1934, examined by Miss Boyd in 1934, show a possible variation of only a few tenths of a magnitude (the amplitude of the primary minima of DQ Her now appears to be, according to Walker, approximately 1·1 magn. in the blue,

* Kopal, *Jodrell Bank Annals*, **1**, 37, 1954.

† Harv. Obs. Circ. no. 455, 1950.

‡ Cf. e.g. McLaughlin, *Pop. Astr.* **49**, 268, 1941.

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and the minima last approximately 60 minutes). The balance of the available evidence would, therefore, seem to be slightly in favour of the hypothesis that the present binary system of DQ Her did come into being in 1934; and if so, the present views on the origin and circumstances of Nova explosions would take a decidedly new turn. Even if it is still advisable, at this stage of research, not to follow too far the speculations opening up in this direction, there seems no doubt that Walker's recent photo-electric work on DQ Her has led to one of the most important discoveries in the field of our Commission during the past triennium, and further details are being awaited with keenest interest.

White dwarfs represent, so far, the only group of the stellar population among which no eclipsing binaries have been detected. The discovery of close pairs consisting of white dwarfs would, to be sure, confront us with some outstanding observational difficulties: for their orbital periods would be likely to be of the order, not of hours as for UX UMa or DQ Her, but of *minutes* or *seconds*; and their hypothetical eclipses might last but fractions of a minute, or even of a second. Consider, for instance, that a pair of identical white dwarfs with the physical characteristics of Sirius B (i.e. mass $m = 0{\cdot}98\ \odot$ and radius $R = 13{\cdot}500$ km.) describe circular orbits around the common centre of gravity in a plane which is nearly parallel with the line of sight. If the separation of the components were four times their radii (as it is approximately in UX UMa or DQ Her) the orbital period of such a system would be 2 min. and 35 sec., and the duration of the eclipses would be less than 26 sec. If the two stars were to form a contact binary, its period would be only 55 sec., and the duration of eclipses between 9 and 10 sec. If, moreover, in place of Sirius B we consider stars of the type of AC 70°8247 for which, according to Kuiper, $R = 2900$ km. while the minimum mass, according to Chandrasekhar, proves to be 28 ⊙,* the orbital period of a hypothetical system consisting of the pair of such stars would be less than 2·86 sec. if the components are well-separated (orbital separation four times the radii of the stars), and less than 1·01 of a second for a contact binary system. The maximum duration of eclipses in such systems would be 0·48 sec. and 0·17 sec., respectively.

The foregoing figures represent certainly a far cry from the conventional situation facing the observers of eclipsing binary systems; and we are not at all sure that, in many cases, the situation may not turn out even more extreme. When, moreover, we consider also that a large majority of known white dwarfs—a hundred-odd objects all told—are stars fainter than 10th apparent magnitude, the observational problems connected with the discovery of hypothetical white dwarf eclipsing variables are indeed rather formidable. A photographic discovery of such variables would be possible only from plates containing multi-exposures of (say) 0·1 sec. duration—separated by at most a second—and reaching down to the requisite magnitudes. No photographic camera meeting such requirements has yet been used on this problem. Unless the amplitude of light changes were really large, direct visual observations would likewise be of little avail; and an observer who might have accidentally caught a momentary glimpse of such a variation would probably have been inclined to rub his eyes in distrust! In point of fact, the only practicable way for detecting such hypothetical pairs and proving their nature would be provided by a continuous record of light changes by means of special photo-electric photometers attached to telescopes of sufficiently large aperture.

First observational steps in this direction have already been taken. In response to the writer's earlier plea for a photo-electric check on white dwarfs,† the late Dr Frank S. Hogg embarked on observations of six objects of this class with the aid of the 74-inch reflector of the David Dunlap Observatory; but his work was soon to be interrupted by his premature death, and no specific results are known. In more recent years Kourganoff and Lenouvel returned to the same problem, using Lenouvel's photo-electric photometer attached to the 47-inch reflector of the Observatoire de Haute Provence at Saint Michel. Several white dwarfs were kept under continuous survey for varying intervals of time, but the present writer understands that no object examined so far has proved to be an eclipsing (or any other) variable.

* Cf. Chandrasekhar's *Introduction to the Study of Stellar Structure*, Chicago Univ. Press, 1939, p. 431.

† *Bull. of the Panel on Orbits of Eclipsing Binaries*, no. 6, October, 1947.

The number of known white dwarfs exceeds, however, one hundred already; and only a very small fraction of them could so far have been photometrically tested; moreover, most of the hypothetical close binaries among them would be bound to escape photometric detection on account of insufficient orbital inclination. It is, therefore, to be hoped that photometric search for close binary systems among white dwarfs will be continued until at least an appreciable fraction of known objects of this class have been sufficiently scrutinized. Walker's discovery of the eclipsing nature of DQ Her, referred to above, should act as a powerful incentive to observers in this field, having access to telescopes of sufficient light-gathering power. It may be added, in this connexion, that if any white dwarf is indeed a close binary system, its radial velocity should also be subject to large variation within very short intervals of time.* It would, of course, be hopeless to expect the discovery of such variation on ordinary spectrograms, since all known white dwarfs are faint stars, and the hypothetical system would be apt to complete many revolutions during an exposure time necessary even with a large telescope. If, however, the periods of white dwarf binaries were really of the order of minutes or even seconds, the resulting variation in radial velocity in the course of each cycle should be enormous, and sufficient to wash out all traces of absorption lines from the spectra by Doppler broadening.

For let us return to the hypothetical models of white dwarf systems we have considered before. If their components were objects like Sirius B, their orbital velocities would be approximately 2200 km./sec. for a well-separated system, and 3100 km./sec. for a contact binary. If, moreover, we should exchange Sirius B for stars with the properties of AC 70°8247, the corresponding figures would be 25,000 and 36,000 km./sec. In consequence, the radial velocity of such components would oscillate between ± 2200 or ± 3100 km./sec. in the first case, and between $\pm 25,000$ or $\pm 36,000$ km./sec. in the second; the corresponding Doppler displacements would amount to dozens, or hundreds, of angstroms.

Now spectra of white dwarfs with little or no traces of any absorption lines have indeed been observed, and several lines of physical argument have been adduced to account for their absence.† Enormous Doppler broadening caused by rapid orbital motion may perhaps be added to the list of such conjectures. It is, therefore, these objects—namely, white dwarfs exhibiting no line-spectra (such as AC 70°8247 or Wolf 219)—whose light should be tested for constancy by means of continuously recording photo-electric photometers in the first place; for if the absorption lines are relatively sharp (such as they are, for instance, in Sirius B), the star is certain to be single (or we may happen to view the orbit from the direction of its pole).

6. Absolute Dimensions of Eclipsing Binary Systems

As is well known, a combination of photometric and spectrographic elements of eclipsing binary systems offers a clue for the determination of their masses and absolute dimensions, which (apart from interferometric measurements) represents the only way in which the radii of stars other than the Sun can be obtained directly in absolute units. The number of systems which lend themselves for such use is increasing quite rapidly—certainly very much more so than the number of visual binaries with known parallaxes and absolute orbits—so that to secure and to codify the data on absolute properties of individual stars, on which so much of stellar astrophysics is based, comes logically within the purview of our Commission.

In order to meet a part of this responsibility, we have in the following Table 5 compiled a list of all close binary systems for which a combination of the photometric and spectroscopic data can result in a significant determination of their masses and absolute dimensions. The stars listed in this table are (with three isolated exceptions)‡ two-spectra

* Except for the cases of small inclination, this should be true regardless of whether or not the system happens to be an eclipsing variable.

† Cf. e.g. G. R. and E. M. Burbidge, *P.A.S.P.* **66**, 308, 1954.

‡ SZ Cam, β Lyr and β Per, where a determination of the mass-ratios was based on indirect dynamical evidence.

systems whose mass-ratios could be derived directly from the amplitudes of radial-velocity curves of both components. Anyone intending to use such data as a basis for any statistical investigations should be cautious, however, and warned that our reliance on two-spectra systems favours of necessity a selection of binaries in which the masses of the two components are comparable and their mass-ratios not far from unity. To this extent, therefore, the data compiled in Table 5 need not necessarily be representative of the stellar population at large. Altogether 156 components of 78 eclipsing systems are included in the Table (i.e. 23 systems more than in Table 6 of our last report); and arranged alphabetically according to their constellations. The list is believed to include all pertinent data known at the time of writing; though for some of them (marked with asterisks in the references) the observational data are uncertain or incomplete.

Table 5

Star	*m*	*R*	*Sp*	log *T*	*M*
RT And A	1·5	0·76	G0	3·78	5·1
RT And B	1·0	1·36	K1	3·65	5·1
AB And A	1·7	0·9	G5	3·74	5·1
AB And B	1·1	0·9	G4	3·75	5·0
S Ant A	0·76	1·4	A8	3·90	2·6
S Ant B	0·42	1·1	A3	3·96	2·5
V 599 Aql A	12	7·8	B4	4·20	−4·2
V 599 Aql B	6·4	4·4	B8	4·09	−1·8
σ Aql A	6·8	4·2	B8	4·09	−1·7
σ Aql B	5·4	3·3	B9	4·06	−0·9
SX Aur A	10·5	4·8	B3·5	4·21	−3·2
SX Aur B	5·6	4·3	B6	4·15	−2·4
TT Aur A	6·7	3·3	B3	4·22	−2·5
TT Aur B	5·3	3·2	B7	4·12	−1·4
WW Aur A	1·82	1·9	A7	3·91	1·8
WW Aur B	1·75	1·9	A8	3·90	1·9
AR Aur A	2·6	1·8	B9	4·06	0·4
AR Aur B	2·3	1·8	A0	4·03	0·7
EO Aur A	27	13	B3	4·22	−5·5
EO Aur B	27	16	B8	4·08	−4·5
β Aur A	2·4	2·49	A0	4·03	0·0
β Aur B	2·3	2·28	A0	4·03	0·2
ζ Aur A	22	205	cK4	3·50	−4·5
ζ Aur B	10	3·7	B7	4·08	−1·4
SS Boo A	1·2	1·9	dG5	3·74	3·5
SS Boo B	1·1	3·2	(dG5)	3·74	2·4
ZZ Boo A	1·8	1·8	A9·5	3·89	2·1
ZZ Boo B	1·7	1·7	F0·5	3·87	2·4
i Boo A	1·07	0·66	dG2	3·76	5·6
i Boo B	0·54	0·64	dG1	3·77	5·6
SZ Cam A	21	9·8	O9·5	4·31	−5·8
SZ Cam B	6·1	4·3	(B2)	4·25	−3·4
TX Cnc A	1·5	0·74	F8	3·79	5·0
TX Cnc B	0·8	0·78	F7	3·80	4·8
RS CVn A	1·9	1·8	F4	3·83	2·7
RS CVn B	1·7	5·1	gK4	3·60	2·8
TV Cas A	1·7	2·6	A0	4·03	−0·1
TV Cas B	1·0	2·4	(gF9*)	3·77	2·7
AO Cas A	30	14	O8·5	4·33	−6·7
AO Cas B	28	10	O9	4·32	−5·9
CC Cas A	21	9·3	O8	4·35	−6·0
CC Cas B	10	4·5	B0	4·30	−4·0

* Spectral type of the secondary component uncertain (cf. Sahade and Struve, *Ap. J.* **102**, 480, 1945).

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Table 5 (*cont.*)

Star	*m*	*R*	*Sp*	log *T*	*M*
U Cep A	2·9	2·4	B8	4·09	−0·5
U Cep B	1·4	3·9	gG8	3·67	2·6
VV Cep A	47	1200	cM2	3·48	−7·9
VV Cep B	33	13	B1	4·27	−6·0
VW Cep A	1·1	0·97	dK1	3·69	5·5
VW Cep B	0·35	0·58	G5	3·74	6·1
WX Cep A	1·0	2·0	A2	3·99	0·9
WX Cep B	1·0	2·0	A5	3·94	1·4
AH Cep A	16·5	6·1	B0	4·30	−4·6
AH Cep B	14·2	6·1	B0·5	4·28	−4·4
CW Cep A	10·0	4·5	B3	4·22	−3·2
CW Cep B	9·8	4·0	B3·5	4·22	−2·9
RZ Com A	1·6	0·9	K0	3·71	5·4
RZ Com B	0·8	0·9	G9	3·72	5·3
U CrB A	6·4	1·9	B5	4·17	−0·8
U CrB B	2·4	3·6	(gGo*)	3·76	1·9
Y Cyg A	17·4	5·9	O9·5	4·31	−4·6
Y Cyg B	17·2	5·9	O9·5	4·31	−4·6
GO Cyg A	1·12	1·8	B9	4·06	0·4
GO Cyg B	0·94	1·6	A0	4·03	0·9
MR Cyg A	3·0	3·4	A0	4·03	−0·6
MR Cyg B	2·6	2·6	F7	3·80	2·2
V 382 Cyg A	37	8·7	06·5	4·45	−6·9
V 382 Cyg B	33	7·9	07·5	4·38	−6·0
V 444 Cyg A	33	10·3	O6	4·48	−7·6
V 444 Cyg B	19	—	WN5	—	—
V 453 Cyg A	17·8	7·6	B2	4·25	−4·6
V 453 Cyg B	13·8	6·3	B3	4·22	−3·9
V 470 Cyg A	12·5	7	B2	4·25	−4·3
V 470 Cyg B	11·1	6	B4	4·20	−3·8
V 477 Cyg A	2·3	1·5	A3	3·96	1·8
V 477 Cyg B	1·6	1·2	F5	3·82	3·7
V 478 Cyg A	14·4	7·6	B0·5	4·29	−5·0
V 478 Cyg B	14·2	7·6	B0·5	4·29	−5·0
TW Dra A	2·2	3·5	A6	3·92	0·4
TW Dra B	0·62	5·1	K2	3·63	2·4
WW Dra A	3·9	3·0	gG2	3·73	2·6
WW Dra B	2·3	5·0	gK0	3·67	2·1
YY Eri A	0·97	0·89	G5	3·74	5·2
YY Eri B	0·57	0·81	G4	3·75	5·3
YY Gem A	0·64	0·62	dM1	3·56	7·8
YY Gem B	0·64	0·62	dM1	3·56	7·8
Z Her A	1·5	1·8	F2	3·85	2·4
Z Her B	1·3	2·8	dG4	3·74	2·7
RX Her A	2·1	2·2	A0	4·03	0·4
RX Her B	1·9	1·8	A1	4·01	0·8
TX Her A	2·1	1·8	A5	3·94	1·6
TX Her B	1·8	1·5	A7	3·91	2·2
DI Her A	3·7	2·1	B4	4·20	−1·3
DI Her B	3·3	2·4	B5	4·17	−1·3
u Her A	7·9	4·5	B3	4·22	−3·2
u Her B	2·8	4·3	B7	4·12	−2·1
VZ Hya A	1·2	1·5	F5	3·82	3·2
VZ Hya B	1·1	1·2	F6	3·81	3·8
RT Lac A	1·9	4·8	G9	3·72	1·7
RT Lac B	1·0	3·8	K1	3·69	2·5

* Spectral type of the secondary component uncertain (cf. Sahade and Struve, *Ap. J.* **102**, 480, 1945).

Table 5 (*cont.*)

Star	*m*	*R*	*Sp*	log *T*	*M*
SW Lac A	1·08	0·82	G3	3·75	5·2
SW Lac B	0·93	0·89	G1	3·77	4·9
AR Lac A	1·32	1·54	G5	3·73	4·1
AR Lac B	1·31	2·86	K0	3·67	3·3
CM Lac A	2·0	1·8	A2	3·99	1·1
CM Lac B	1·5	1·3	F2	3·85	3·2
UV Leo A	1·36	1·21	G0	3·78	4·1
UV Leo B	1·25	1·22	G2	3·77	4·2
β Lyr A	52	47	cB9	4·13	−7·4
β Lyr B	43	31	(F1)	3·87	−3·9
TU Mon A	2·4	3·7	B5	4·17	−2·2
TU Mon B	1·0	4·3	A5	3·94	−0·3
UX Mon A	3·5	8·4	G1	3·76	0·1
UX Mon B	1·5	4·4	A5	3·94	−0·3
IM Mon A	9·0	3·8	B5	4·17	−2·3
IM Mon B	6·0	2·7	B8	4·09	−0·8
U Oph A	5·30	3·4	B5	4·17	−2·1
U Oph B	4·65	3·1	B6	4·15	−1·7
WZ Oph A	1·4	0·88	G0	3·78	4·8
WZ Oph B	1·35	0·86	G0	3·78	4·8
V 502 Oph A	1·2	1·51	G2	3·76	3·8
V 502 Oph B	0·49	1·04	F8	3·79	4·3
ER Ori A	0·58	0·72	G1	3·77	5·3
ER Ori B	0·35	0·72	G1	3·76	5·4
δ Ori A	26	17	B1	4·27	−6·5
δ Ori B	10	10	B2	4·25	−5·2
U Peg A	1·25	1·18	F3	3·84	3·6
U Peg B	1·00	1·18	F2	3·85	3·4
AG Per A	5·01	3·1	B3	4·22	−2·4
AG Per B	4·47	2·8	B4	4·20	−1·9
β Per A	4·7	3·4	B8	4·09	−1·3
β Per B	0·94	3·6	(gG0)	3·76	1·9
ζ Pho A	2·8	2·5	B7	4·12	−0·9
ζ Pho B	2·0	1·5	B9	4·06	0·8
V Pup A	16·6	6·0	B1	4·27	−4·3
V Pup B	9·8	5·3	B3	4·22	−3·5
U Sge A	6·7	4·1	B9	4·06	−1·4
U Sge B	2·0	5·4	gG6	3·70	1·6
V 356 Sgr A	12·1	4·9	B3	4·23	−3·4
V 356 Sgr B	4·7	12·7	A2	3·99	−3·2
μ^1 Sco A	14·0	4·8	B3	4·22	−3·3
μ^1 Sco B	9·2	5·3	B7	4·12	−2·5
RZ Tau A	2·2	1·4	F0	3·88	2·8
RZ Tau B	1·2	1·3	F1	3·87	3·0
W UMa A	1·29	1·1	dF8	3·79	4·2
W UMa B	0·65	0·61	dF6	3·80	5·4
RW UMa A	1·2	1·0	dF9	3·78	4·5
RW UMa B	1·2	3	dG9	3·72	3(?)
TX UMa A	2·9	2·16	B8	4·09	−0·3
TX UMa B	0·9	3·79	gG4	3·71	2·3
ε UMi A	13·5	12	gG1	3·74	−0·5
ε UMi B	3·4	0·8	A5	3·94	3·4
AH Vir A	1·36	1·3	dK0	3·71	4·6
AH Vir B	0·57	0·75	dG6	3·74	5·5
Z Vul A	5·25	4·7	B3	4·22	−3·3
Z Vul B	2·34	4·2	A2	3·99	−0·7
RS Vul A	4·6	4·2	B5	4·17	−2·5
RS Vul B	1·4	5·4	(F4)	3·83	0·3

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* The light curve on which the photometric solution is based is no longer adequate and should be re-observed (** indicates highly uncertain objects).

† The ratio of luminosities of both components has been determined spectroscopically by Petrie (*Publ. D.A.O.* **7**, 205, 1939; and **8**, 319, 1950).

‡ The ratio of luminosities of both components determined spectroscopically by Popper (*Ap. J.* **97**, 394, 1943).

§ Spectroscopic elements rediscussed by Luyten (*Ap. J.* **84**, 53, 1936).

Star	References
RT And	Payne-Gaposchkin, *Ap. J.* **103**, 291, 1946.
AB And	*Gaposchkin, *Veröff. Berl. Bab.* **9**, Heft 5, 1932.
	Struve *et al.* *Ap. J.* **111**, 658, 1950.
S Ant	Hogg and Bowe, *M.N.* **110**, 373, 1950.
	Joy, *Ap. J.* **64**, 287, 1926.
V 599 Aql	**Gaposchkin, *Harv. Bull.* no. 917, 1943.
	†Pearce, *Publ. D.A.O.* **4**, 75, 1927.
σ Aql	*Wylie, *Ap. J.* **56**, 232, 1922.
	†Luyten, Struve and Morgan, *Yerkes Publ.* VII, pt. 4, 1939.
SX Aur	*Oosterhoff, *B.A.N.* **7**, 107, 1933.
	‡Popper, *Ap. J.* **97**, 394, 1943.
TT Aur	Joy and Sitterly, *Ap. J.* **73**, 77, 1931.
WW Aur	Huffer and Kopal, *Ap. J.* **114**, 297, 1951.
	†Slocum, *Lick Bull.* **19**, 147, 1942.
AR Aur	Huffer and Eggen, *Ap. J.* **106**, 106, 1947.
	†Harper, *Publ. D.A.O.* **6**, 311, 1937.
EO Aur	*Gaposchkin, *P.A.S.P.* **55**, 193, 1943.
	†Pearce, *Journ. R.A.S.C.* **40**, 139, 1946.
β Aur	Piotrowski, *Ap. J.* **108**, 510, 1948.
	†Smith, *Ap. J.* **108**, 504, 1948.
ζ Aur	Kopal, *Ap. J.* **103**, 310, 1946.
	Wellmann, *A.N.* **279**, 257, 1951.
SS Boo	**Sitterly, *Pop. Astro.* **30**, 231, 1922.
	Struve, *Ap. J.* **102**, 74, 1945, and Sanford, *Ap. J.* **103**, 114, 1946.
ZZ Boo	*Gaposchkin, *A.J.* **59**, 196, 1954.
	Shajn, *Ann. Crimean Astro. Obs.* **5**, 105, 1950.
i Boo	Eggen, *Ap. J.* **108**, 15, 1948.
	‡Popper, *Ap. J.* **97**, 394, 1943.
SZ Cam	Wesselink, *Leiden Ann.* **17**, pt. 3, 1941 (rediscussed by Kopal).
TX Cnc	Haffner, *A.N.* **276**, 233, 1948.
	Popper, *Ap. J.* **108**, 490, 1948.
RS CVn	Keller and Limber, *Ap. J.* **113**, 637, 1951.
	Joy, *Ap. J.* **72**, 41, 1930.
TV Cas	Huffer and Kopal, *Ap. J.* **114**, 297, 1951.
	†Plaskett, *Publ. D.A.O.* **2**, 141, 1922; §
AO Cas	Wood, *Ap. J.* **108**, 28, 1948; Hiltner, *Ap. J.* **110**, 443, 1949.
	†Pearce, *Publ. D.A.O.* **3**, 283, 1926.
CC Cas	*Gaposchkin, *Publ. A.A.S.* **10**, 12, 1939.
	†Pearce, *Publ. D.A.O.* **4**, 67, 1927; §
U Cep	Dugan, *Princ. Contr.* no. 5, 1920.
	Hardie, *Ap. J.* **112**, 542, 1950.
VV Cep	Goedicke, *Michigan Obs. Publ.* **8**, 1, 1939.
VW Cep	Huffer, *Ap. J.* **103**, 1, 1946.
	†Popper, *Ap. J.* **108**, 490, 1948.
WX Cep	**Schneller, *Veröff. Berl. Bab.* **8**, Heft 6, 1931.
	Sahade and Cesco, *Ap. J.* **102**, 128, 1945.
AH Cep	Huffer and Eggen, *Ap. J.* **106**, 313, 1947.
	†Pearce, *Journ. R.A.S.C.* **29**, 411, 1935.
CW Cep	*Gaposchkin, *Per. Zvezdy*, **7**, 34, 1949. Abrami and Cester, *Trieste Contr.*, No. 266, 1955.
	†Petrie, *Publ. D.A.O.* **7**, 305, 1947.
RZ Com	**Gaposchkin, *Harv. Mono.* no. 5, 1946, p. 70.
	Struve and Gratton, *Ap. J.* **108**, 497, 1948.
U Cr B	*Baker, *Laws Bull.* no. 29, 1921.
	†Sahade and Struve, *Ap. J.* **102**, 480, 1945 (cf. also Pearce, *Publ. A.A.S.* **8**, 219, 1935).
Y Cyg	Dugan, *Princ. Contr.* no. 12, 1931.
	†Redman, *Publ. D.A.O.* **4**, 341, 1931.
GO Cyg	Ovenden, *M.N.* **114**, 569, 1954.
	Pearce, *Journ. R.A.S.C.* **27**, 62, 1933.
MR Cyg	Kaminský, *Per. Zvjozdy*, **9**, 285, 1953.
	Pearce, *Journ. R.A.S.C.* **29**, 411, 1935.
V 382 Cyg	**Petrov, *Per. Zvjozdy*, **6**, 72, 1948.
	Pearce, *P.A.S.P.* **64**, 219, 1952.
V 444 Cyg	†Keeping, *Publ. D.A.O.* **7**, 349, 1947.
V 453 Cyg	*Smirnov, *Per. Zvjozdy*, **6**, 13, 1946.
	†Pearce, *Publ. A.A.S.* **10**, 233, 1941.
V 470 Cyg	*Gaposchkin, *A.J.* **53**, 112, 1948.
	†Pearce, *P.A.S.P.* **58**, 247, 1946.
V 477 Cyg	Wallenquist, *Uppsala Medd.* no. 96, 1949.
	Pearce, *A.J.* **57**, 22, 1952.

Table 5 (*cont.*)

Star	References
V 478 Cyg	*Gaposchkin, *Harv. Bull.* no. 919, 1949. McDonald, *Publ. D.A.O.* **8**, 135, 1949.
TW Dra	Baglow, *Publ. David Dunlap Obs.* **2**, no. 1, 1952. Smith, *Ap. J.* **110**, 63, 1949.
WW Dra	Plaut, *B.A.N.* **9**, 121, 1940. Joy, *Ap. J.* **94**, 407, 1941.
YY Eri	Huruhata, Dambara and Kitamura, *Ann. Tokyo Obs.* (2), **3**, 227, 1953. Struve, *Ap. J.* **106**, 92, 1947.
YY Gem	Kron, *Ap. J.* **115**, 301, 1952. Struve, Herbig and Horak, *Ap. J.* **112**, 216, 1950.
Z Her	Baglow, *Publ. David Dunlap Obs.* **2**, no. 1, 1952. †Adams and Joy, *Ap. J.* **49**, 192, 1919.
RX Her	Wood, *Ap. J.* **110**, 465, 1949. †Sanford, *Ap. J.* **68**, 51, 1928.
TX Her	Plaut, *Groningen Publ.* no. 55, 1953. †Plaskett, *Publ. D.A.O.* **1**, 207, 1920; §
DI Her	Jacchia, *Harv. Bull.* no. 912, 1940. †McKellar, *Publ. D.A.O.* **8**, 235, 1950.
u Her	Kopal and Shapley (unpublished). †Smith, *Ap. J.* **102**, 500, 1945.
VZ Hya	Pierce, *Princ. Contr.* no. 21, 1946. Struve, *Ap. J.* **102**, 74, 1945.
RT Lac	*Krat and Nekrassova, *Acta Astr.* (a) **2**, 129, 1936. Joy, *Ap. J.* **74**, 101, 1931 (cf. also Wilson, *Ap. J.* **93**, 29, 1941).
SW Lac	*Schilt, *B.A.N.* **2**, 175, 1924. Struve, *Ap. J.* **109**, 436, 1949.
AR Lac	Wood, *Princ. Contr.* no. 21, 1946. Harper, *Journ. R.A.S.C.* **27**, 146, 1933; also Sanford, *Ap. J.* **113**, 299, 1951.
CM Lac	*Wachmann, *A.N.* **259**, 323, 1936. †Sanford, *Ap. J.* **79**, 95, 1934.
UV Leo	Wellmann, *Z. Ap.* **34**, 99, 1954. Gaposchkin, *Ap. J.* **104**, 370, 1946.
β Lyr	Kopal, *Ap. J.* **93**, 92, 1941. Rossiter, *Michigan Obs. Publ.* **5**, 69, 1933.
TU Mon	**Gaposchkin, *Veröff. Berl. Bab.* **9**, Heft 5, 1932. Deutsch, *Ap. J.* **102**, 433, 1945.
UX Mon	Hiltner, Struve and Jose, *Ap. J.* **112**, 504, 1950 (discussed by Nicholson). Struve, *Ap. J.* **106**, 255, 1947.
IM Mon	Gum, *M.N.* **111**, 634, 1951. †Pearce, *Publ. D.A.O.* **6**, 70, 1932; §
U Oph	Huffer and Kopal, *Ap. J.* **114**, 297, 1951. †Plaskett, *Publ. D.A.O.* **1**, 138, 1919.
WZ Oph	Gaposchkin, *Harv. Bull.* no. 907, 1938. Sanford, *Ap. J.* **86**, 157, 1937.
V 502 Oph	*Nekrassova, *Astr. Circ. U.S.S.R. Acad. Sci.* no. 21, 1943. Struve and Gratton, *Ap. J.* **108**, 497, 1948.
ER Ori	*Taylor, *P.A.S.P.* **56**, 112, 1944. Struve, *P.A.S.P.* **56**, 34, 1944.
δ Ori	*Stebbins, *Ap. J.* **42**, 133, 1915. Luyten, Struve and Morgan, *Yerkes Publ.* VII, pt. 4, 1939.
U Peg	*La Fara, *Ap. J.* **115**, 14, 1952. Struve *et al.* *Ap. J.* **111**, 658, 1950.
AG Per	Eggen (unpublished). †Plaskett, *Publ. D.A.O.* **3**, 184, 1925.
β Per	Kopal, *Ap. J.* **96**, 399, 1942. McLaughlin, *Michigan Obs. Publ.* **6**, 3, 1934.
ζ Pho	Hogg, *M.N.* **111**, 315, 1951. Colacevich, *P.A.S.P.* **47**, 84, 1935.
V Pup	van Gent, *B.A.N.* **8**, 319, 1939 (rediscussed by Kopal). ‡Popper, *Ap. J.* **97**, 394, 1943.
U Sge	Irwin (unpublished). Joy, *Ap. J.* **71**, 336, 1930; §
V 356 Sgr	Popper, *Ap. J.* **121**, 56, 1955.
μ^1 Sco	Stibbs, *M.N.* **108**, 398, 1948. Struve, *Strömgren Festschrift*, Copenhagen, 1940, p. 258.
RZ Tau	Huruhata and Kitamura, *Publ. Astr. Soc. Japan*, **5**, 102, 1953. Struve *et al.* *Ap. J.* **111**, 658, 1950.
W UMa	Plaut, *Groningen Publ.* no. 55, 1953. †Struve and Horak, *Ap. J.* **112**, 178, 1950.
RW UMa	**Fetlaar, *B.A.N.* **3**, 195, 1926. Struve, *Ap. J.* **102**, 74, 1945.
TX UMa	Piotrowski, *Ap. J.* **106**, 472, 1947. Hiltner, *Ap. J.* **101**, 108, 1945 (cf. also Pearce, *Publ. A.A.S.* **8**, 251, 1936).
ε UMi	*Guthnick, *Abh. Deutsch. Akad. Wiss.* no. 7, 1947.
AH Vir	**Chang, *Ap. J.* **107**, 96, 1948.
Z Vul	Baker, *Laws Obs. Bull.* no. 26, 1916. †Plaskett, *Publ. D.A.O.* **1**, 251, 1920.
RS Vul	Baglow, *Publ. David Dunlap Obs.* **2**, no. 1, 1952. †Plaskett, *Publ. D.A.O.* **1**, 141, 1919; §

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The headings of the individual columns of Table 5 are self-explanatory. The letters A, B in column 1 refer to the more massive and less massive component, respectively, though the former need not necessarily be the more luminous of the two. The masses m and radii R as given in columns 2 and 3 have been expressed in solar units. The spectra of column 4 adopted for the secondary components are in harmony with the observed ratios of surface brightnesses of the two components. Whenever direct reliable spectroscopic determination was not available (or was difficult to obtain if the disparity in luminosities of the two stars was too large) a determination of the secondary's spectral type from its relative surface brightness by a recourse to Planck's formula has been preferred. All spectra determined in this way have been placed in brackets.

The logarithms $\log_{10}T$ of the effective temperatures (in degrees K) of both components of each system, as given in column 5, have been adopted for spectral types of column 4 in accordance with the following procedure: for spectra later than A0 the corresponding temperatures can nowadays be regarded as well established, and a temperature scale (essentially Kuiper's*) as quoted by Keenan and Morgan in Hynek's *Astrophysics*† has been adopted. For spectral types earlier than A0, however, several lines of observational evidence based on eclipsing variables indicate that Kuiper's 1938 temperatures tend to be too high. The present writer has already discussed this evidence in an earlier investigation,‡ but certain supplementary data may be added here.

There exist three early-type eclipsing systems for which a determination of the effective temperatures of their principal components can be wholly based on empirical data,§ namely, β Aur, β Per, and μ^1 Sco, and the pertinent quantities are summarized in the following tabulation:

	β Aur A	β Per A	μ^1 Sco A
Spectrum	A0	B8	B3
Parallax	0".037 ± 0".005	0".042 ± 0".002	0".0053 ± 0".0004
Abs. vis. magn.	+0·6 ± 0·2	+0·3 ± 0·1	−1·6 ± 0·2
Bol. Corr.	−0·7	−1·0	−1·7
Radius	2·5 ± 0·1	2·7 ± 0·2	4·8 ± 0·2
Temperature	10,700° ± 500°	12,200° ± 500°	16,000° ± 700°

The parallax of β Aur was taken from Jenkins' *General Catalogue of Trigonometric Stellar Parallaxes* (no. 1373), while that of β Persei is due to van de Kamp, Smith and Thomas.‖ The absolute radius of Algol A is taken from Kopal.¶ The star μ^1 Sco A should be adjoined to the preceding two on the strength of Blaauw's recent group parallax** deduced from the membership of this system in the Scorpio-Centaurus stream.†† In view of the relatively high precision of the effective temperatures of the three early-type stars as determined from the foregoing data, it seems reasonable to adopt a temperature scale which coincides, at the respective spectra, with those determinations, namely,

Spectrum	Log T
O8	(4·35)
B0	(4·30)
B2	4·25
B3	4·22
B5	4·17
B8	4·09
A0	4·03

* *Ap. J.* **88**, 429, 1938.

† *Astrophysics*, Topical Symposium, ed. by J. A. Hynek, McGraw Hill, New York, 1951, p. 20.

‡ Z. Kopal and Ch. G. Treuenfels, *Harv. Circ.* no. 457, 1951.

§ The spectra of the secondary components in these systems have so far not been accurately classified.

‖ *A.J.* **55**, 251, 1951.

¶ *Ap. J.* **96**, 399, 1942.

** Blaauw, *Groningen Publ.* no. 52, 1946.

†† According to Blaauw (*Groningen Publ.* no. 52 (1946), μ^1 Sco is to be regarded as 'certain member of the cluster' (*op. cit.* p. 119).

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These temperatures are somewhat higher than those proposed earlier by the writer, but still significantly lower than Kuiper's.

With the aid of a temperature scale thus established the absolute bolometric magnitudes M of the individual components of systems included in Table 5 have been evaluated (by a recourse to Planck's law) as $M = 4\cdot 7 - 5 \log R - 10 \log (T/5730°)$, where $+4\cdot 7$ stands for the adopted bolometric absolute magnitude of the Sun, and 5730° (corresponding to $\log T_\odot = 3\cdot 76 \pm 0\cdot 01$) for its effective temperature. Such values of M are listed in the penultimate column 6 of Table 6, while the ultimate column 7 contains references to the basic observational data. Of the pairs of such references given in each case, the first pertains always to the source of photometric elements, and the second to that of the spectrographic data.

Anyone contemplating the use of the data compiled in Table 5 should be aware of the fact that the material collected in it does not represent a proper critical survey, and does not, in particular, undertake to guarantee the accuracy of the individual data—except that, in general, no decimals have been included which were regarded as wholly insignificant, and that the uncertainty of all entries is believed not to exceed a few units of the last place. A critical rediscussion of the whole material which should ascertain the degree of reliability of the individual pieces of information represents a timely and urgent task which cannot be met by casual compilations of data widely scattered in the literature and of very different weight. The importance of this task obviously transcends the field of our Commission, but must be regarded outside the scope of the present report.

The data compiled in the foregoing Table 5 exhaust the supply of eclipsing systems whose masses and absolute dimensions can at present be obtained by a combination of their photometric and spectroscopic elements. An assumption of synchronism between rotation and revolution would permit us to augment the list by an addition of half a dozen or more single-spectrum systems exhibiting conspicuous rotational effect. Good photometric elements are available for a great many other single-spectrum variables. However, it may be pertinent to point out here that no photometric elements are available for at least eight two-spectra eclipsing systems with known spectroscopic elements which represent potential additions to Table 5. These stars are listed in the following tabulation:

Star	Period	Amplitude	Spectra	Spectr. Elements
SW CMa	$10^d\cdot 092$	9·1– 9·6	A8+A8	Struve, *Ap. J.* **102**, 74, 1945.
ZZ Cep	2·149	9·3–10·0	B7+F0	Herbig, *Ap. J.* **106**, 112, 1947.
DH Cep	2·111	8·5– 8·6	O5+O5·5	Pearce, *A.J.* **54**, 135, 1949.
TW Cet	0·317	9·5–10·5	G5+(G5)	Struve *et al. Ap. J.* **111**, 658, 1950.
AO Mon	1·885	9·2– 9·9	B3+B5	Struve, *Ap. J.* **102**, 74, 1945.
UZ Pup	0·795	9·7–10·6	A6+A6	Struve, *Ap. J.* **102**, 74, 1945.
CV Ser	29·675	9·0– 9·1	WC7+B	Hiltner, *Ap. J.* **102**, 492, 1945.
α Vir	4·014	1·2– 1·3	B2+B3	Struve and Ebbighausen, *Ap. J.* **80**, 365, 1934.

For SW Cas, DH Cep, AO Mon, and UZ Pup no light curves or photometric elements are available at all, though Petrie* determined the ratio of luminosities of the two components of DH Cep (and also of α Vir) by his spectrophotometric method. Crude discovery light curves (but no photometric elements) are known for ZZ Cep,† CV Ser,‡ and α Vir,§ but all these systems will require re-observation by more accurate methods before a reliable solution for the elements can be attempted. For TW Cet a good photoelectric light curve was recently produced by Cillié and Bok,‖ though no photometric elements have as yet been deduced from it.

* *Publ. D.A.O.* **8**, 319, 1950.

† Schneller, *Veröff. Berl. Bab.* **8**, 49, 1931.

‡ Gaposchkin, *Per. Zvjozdy*, **7**, 36, 1949.

§ Stebbins, *Ap. J.* **39**, 459, 1914.

‖ *Harv. Bull.* no. 920, 1952.

7. Determination of Photometric Elements

The computation of the elements of eclipsing binary systems from an analysis of their light curves has witnessed relatively few methodological developments within the past three years. Russell and Merrill (29) published a comprehensive introduction to the computation of the elements by the classical Russell-Shapley method of 1912, and Merrill (30) completed subsequently a set of interesting nomographs facilitating the application of the underlying semigraphic procedures. Moreover, the work on the illustrative examples for preliminary solution of light curves of eclipsing variables by Merrill and Russell is under way, and should appear in the Princeton Contributions within a year or two. On the other hand, Schneller* prepared new 6D tables of the functions $q(k, \alpha)$ for coefficients of limb-darkening $u = 0(0{\cdot}2)1$ for the case of occultation as well as transit eclipses. Schulberg (31) prepared a set of the α-tables appropriate for eclipses of Algol-type (spherical) stars with extended atmospheres; and in a subsequent paper (32) he considered the problem of the computation of elements of such systems with the aid of the new tables, and carried out an application to V 444 Cyg as an illustrative example. Lastly, Huffer reports resumption of the work on mechanization of light-curve analysis with the aid of punched-card (I.B.M.) automatic computing machines at the Washburn Observatory at Madison.

The apparent variation of periods in triple systems containing an eclipsing variable was subject to a detailed study by Vasilieva (33), centred around an application to RT Per as an illustrative example. De Kort (34) discussed the upper and lower limits for the eccentricity and longitude of periastron of an eclipsing binary; and in another paper (35) he dealt with the determination of the periods of revolution of apsidal lines in eccentric eclipsing systems.

The systems for which new photometric elements have been determined in the past triennium are listed in the following Table 6, which continues Table 2 of our previous report (pp. 636 and 652 of *Trans. I.A.U.* **8**). The present table is not guaranteed for completeness; but a comparison of its extent with that of Table 1 reveals forcefully the disparity between the rate at which accurate light curves of eclipsing binary systems are at present being produced and analysed. This situation, which has been gradually developing in the past decade, has progressed sufficiently far to invite serious thought—and some frank discussion at Dublin! The reasons which have led to it seem little in doubt, for with the increasing accuracy as well as amount of the observational data obtainable by means of modern photo-electric photometers, the burden of numerical work involved in an appropriate analysis of the light curves is becoming prohibitive to the observer, and may widely overtax the facilities at his disposal. The situation in which the investigators of the elements of eclipsing binary systems are finding themselves may be comparable with that which confronted the computers of cometary or asteroidal orbits a quarter of a century ago. The example shown by these older branches of classical astronomy indicates, moreover, the direction which the future development of eclipsing orbit work is likely to follow, namely, towards an increasing specialization of the observational work and of its analysis. On the one hand, an accurate analysis of the light curves of eclipsing binary systems is rapidly becoming a rigorous and exacting branch of theoretical astronomy calling for as much skill and dexterity in numerical work as was traditionally expected of investigators in other branches of celestial mechanics. On the other hand, the observers of eclipsing systems in the future are likely to become primarily experts in intricate photo-electric techniques of light measurements, whose complexity may grow in proportion to the increasing accuracy of the results. As the pioneer days of the development of our subject are gradually receding into the past, the sheer weight of technicalities on both sides threatens already to convert a growing separation between the observer and the computer into a permanent divorce—whether for better or worse, only the future can tell.

Our concern about this situation at the present time arises mainly from the anticipated

* Cf. *Mitteilungen der Astr. Gesell. für* 1954, p. 88.

need of providing, in the near future, a comprehensive and homogeneous catalogue of the elements of eclipsing binary systems. While the number of known eclipsing systems is well over 3000, and with those for which light curves (of varying quality) are available running into several hundreds, the need of cataloguing their photometric elements is manifest, and the task of preparing such a catalogue cannot be deferred much longer without risking a disastrous accumulation of backlog. It should be stressed that what is needed is not a compilation of possibly heterogeneous elements widely scattered in literature, but a critical rediscussion of all observations by suitable methods which would guarantee the homogeneity of the results, the compatibility of their probable errors, and the absence of errors of the systematic type.

Table 6.

New Geometrical Elements of Eclipsing Binary Systems

Star	Reference
RT And	Gordon (Lick Obs., unpublished).
XZ And	Blitzstein, *A.J.* **59**, 251, 1954.
V 805 Aql	Fresa, *Mem. Soc. Astr. Ital.* **25**, 105, 1954.
ZZ Boo	Gaposchkin, *A.J.* **59**, 196, 1954.
SV Cam	van Woerden (Leiden, unpublished).
GL Car	van Wijk, Rogerson and Skumanich, *A.J.* **60**, 95, 1955.
V 495 Cen	O'Connell, *Ricerche Astr.* (*Vatican*), **3**, 81, 1954.
α CrB	Kron and Kron, *Ap. J.* **118**, 55, 1953.
AI Cru	Ollongren (Leiden, unpublished).
GO Cyg	Ovenden, *M.N.* **114**, 569, 1954.
MR Cyg	Kaminskÿ, *Per. Zvjozdy*, **9**, 285, 1953.
RU Eri	Nakamura and Tanabe, *Ann. Tokyo Astr. Obs.* (2), **3**, 175, 1953.
RZ Eri	Gaposchkin, *Harv. Bull.* no. 920, 1952.
YY Eri	Huruhata, Dambara and Kitamura, *Ann. Tokyo Astr. Obs.* (2), **3**, 227, 1953.
YY Gem	Kron, *Ap. J.* **115**, 301, 1952.
RX Her	Magalashvili, *Abastumani Bull.* no. 15, 1953.
SZ Her	Broglia, Masani and Pestarino, *Mem. Soc. Astr. Ital.* **26**, 321, 1955.
DH Her	Botsula, *Per. Zvjozdy*, **9**, 67, 1953.
u Her	Svolopoulos (Athens, unpublished).
AR Lac	Bolokadze, *Per. Zvjozdy*, **9**, 63, 1953.
UX Mon	Nicholson (St Andrews, unpublished).
GN Nor	de Kort, *Ricerche Astr.* (*Vatican*), **3**, 119, 1954.
V 451 Oph	Colacevich, *Mem. Soc. Astr. Ital.* **23**, 225; **24**, 121, 1953.
V 566 Oph	Fresa, *Mem. Soc. Astr. Ital.* **25**, 127, 1954.
VV Ori	Bolokadze, *Per. Zvjozdy*, **9**, 379, 1953.
U Peg	La Fara, *Ap. J.* **115**, 14, 1952.
EE Peg	Bakoš (David Dunlap Obs., unpublished); Wellmann, *Z. Ap.* **32**, 81, 1953.
U Sge	Irwin (Goethe Link Observatory, unpublished).
V 356 Sgr	Popper, *Ap. J.* **121**, 56, 1955.
V 505 Sgr	Kwee, *B.A.N.* **12**, 35, 1953; Sofronitski, *Pulkova Izvestia*, **19**, pt. 4, 1953.
RZ Tau	Huruhata and Kitamura, *Publ. Astr. Soc. Japan*, **5**, 102, 1953.
X Tri	Lenouvel (Obs. de Haute Provence, unpublished).
W UMa	Kwee (Leiden, unpublished).
S Vel	O'Connell, *Ricerche Astr.* (*Vatican*), **3**, 90, 1954.
RS Vul	Lavrov, *Per. Zvjozdy*, **10**, 9, 1954; Magalashvili, *Abastumani Bull.* no. 15, 1953.

When we look back on the literature of our subject in the past half century, we find only one such catalogue which, in its time, met very closely the requirements which we are now discussing: namely, Shapley's *Study of the Orbits of Eclipsing Binaries* (36), published in 1915, which culminated in a catalogue of the elements of ninety eclipsing variables. Most observational data at the basis of the catalogue would be regarded as deficient judged by modern standards, and the methods of analysis largely out of date, but the treatment of the whole material was systematic and the results possessed a degree of homogeneity never attained by any subsequent similar publication. The catalogues by Gaposchkin (37), or Payne-Gaposchkin and Gaposchkin (38), which appeared in 1939, were compilations making little or no attempt at a critical rediscussion of the underlying data, and reflecting the lack of homogeneity which such compilations are bound to entail.

In post-war years, three additional catalogues of a similar nature have made their appearance. That by Tchudovitchev (39) was again very largely a compilation including all the photometric and spectroscopic elements of eclipsing binary systems which were published by 1950, while in two subsequent catalogues Plaut (40) limited himself to a thorough discussion of all eclipsing binaries brighter than 8·50 phot. magn. at maximum. An attractive feature of Plaut's catalogues has been the explicit attention paid to the uncertainty within which the individual elements are defined by the available observational data. Since the observations of no system can be made infinitely numerous or accurate, such an uncertainty should always be regarded as an integral and indispensable part of any orbital solution; and it is gratifying to record that this has been respected in Plaut's catalogues.

In order to meet the need of a critical catalogue, Mrs Shapley and the present writer of this report embarked, in 1946 at Harvard, on the rediscussion of all first-class light curves then available, by rigorous analytical methods. This work, which has from the beginning enjoyed generous support on the part of the American Philosophical Society, was completed in its original outline by 1950, and the methods of analysis published in a separate monograph.* The catalogue itself has, however, not yet appeared—partly because of reasons connected with the writer's transfer from Cambridge, Mass., to Manchester in 1951, but largely because of an unexpected (though welcome) flux of new accurate light curves demanding analysis, but forthcoming much too rapidly for our ability to process them with the care they obviously deserve. At the time of the inception of our work in 1946, thirty to forty systems were believed to meet the standards sufficient to make an accurate analysis worthwhile, but now—barely ten years later—more than one hundred of them would be eligible on the same grounds, and there is but little doubt that, ten years from now, several hundred first-class light curves may be available for accurate analysis. Even now, it is well-nigh impossible for scattered efforts of individual investigators to cope properly with such an influx, and there is every indication that, in the future, this situation will be only aggravated. The only logical solution of this impasse would seem to lie in the creation of an International Bureau—similar to the one responsible for the orbits of asteroids—affiliated with some large observatory or astronomical institution, but operating under the auspices of the International Astronomical Union and possessing a small permanent staff. Such a Bureau should then be in a position to deal with incoming photometric (and spectrographic) data as well as with their arrears by mass-production methods—with the aid of automatic computing machinery which is available for scientific work—and to be responsible for keeping the critical Catalogue of the Elements of Eclipsing Binary Systems up to date. The forthcoming meetings of the I.A.U. at Dublin should afford a good opportunity for members of our Commission to discuss the situation in all aspects; and it is to be hoped that those colleagues who may not be able to be present will communicate their views in writing.

Any discussion of the large-scale analysis of the observational data is inseparably connected with the problem of their publication. In this connexion, many of us have for a considerable time been disturbed by the fact that individual observations are often not published in full, even when they are of high quality. An analysis of the circumstances would probably show that, in most cases, this arises not from reluctance on the part of

* Z. Kopal, *Computation of Elements of Eclipsing Binary Systems* (Harvard Obs. Monograph, no. 8), Cambridge, Mass., 1950.

the observer, but from pressure resulting from the cost of such publication. On behalf of certainly the majority of his colleagues, Wood would like to place on record that this is probably false economy, and that information of value is being lost because of it. Wood suggests that a useful purpose would be served if a resolution urging the importance of publication of individual observations were passed by our Commission, approved by the General Assembly, and then sent to the editors of professional journals and to directors of observatories concerned with publication budgets.

Another publication of great interest to investigators of eclipsing binaries which appeared during the past three years is Wood's new *Finding List for Observers of Eclipsing Variables* (41)—which continues in the tradition originally initiated in Princeton by the late Professors Dugan and Pierce. The present list incorporates all pertinent information available up to the end of 1952, and we should welcome an extension covering the objects of the whole Southern Hemisphere. On the other hand, the bibliographical references in this new edition continue to be so fragmentary and incomplete as to be of only limited use for anyone trying to locate the data (and impossible for use as a source of second-hand quotation). May we hope that so outstanding a defect of so useful a publication will be remedied in the next edition?

In 1952, at the Rome General Assembly, members of our Commission were informed that not less than three independent observatories—Engelhardt (Kazan), Krakow, and Flower and Cook (Philadelphia)—were keeping up-to-date independent card catalogues of all literature which concerns eclipsing binary systems, and in our session on 5 September 1952, our Commission approved a resolution requesting all investigators working in this field to send in reprints of all their publications to the three centres.* In the three years which have elapsed since that time, little specific news concerning the card catalogues has been heard from Krakow or Philadelphia. On the other hand, Prof. Martynov reports that the Engelhardt Bibliographical Catalogue contained (as of 1 October 1954) a transcript of the data of 3111 eclipsing variables (some of which are suspected variables). The catalogue includes 25,946 references and abstracts (i.e. an average of eight references per star; although for such well-known objects as β Lyr more than 400 summaries have been prepared). A yearly increment of bibliographical references is now in excess of one thousand titles—an eloquent testimony of the amount of work currently published in our field!

In addition to the card catalogue of eclipsing variables, Martynov reports also the existence, at the Engelhardt Observatory, of a similar catalogue of spectroscopic binary systems, containing (in October 1954) a total of 2098 objects with 15,873 summaries. The recent publication of Wood's *Finding List* (41) made it unnecessary for the Engelhardt Observatory to embark upon preparation of a similar publication as originally intended, but Martynov stresses the desirability that all members of our Commission should come to the Dublin Assembly with the latest data concerning their observing programmes, and studies that are being carried out. Such information is needed to prepare new lists of objects recommended for observation, which may be published from the Engelhardt Observatory early in 1956. 'It seems to me, besides,' writes Martynov in this connexion, 'that all members of Commission no. 42 did not follow sufficiently literally paragraph 1 of the resolutions taken at our meeting of 5 September 1952',† to which attention is again hereby invited.

8. Effects of Limb Darkening

A systematic work towards the formation of a critical Catalogue of the Elements of Eclipsing Binary Systems—which should play in our field the role of the *Boss General Catalogue* or of FK3 in positional astronomy—will require a considerable amount of

* See *Trans I.A.U.* **8**, p. 655, 1952.

† This particular method has been developed by the present writer and described in his *Computation of Orbits of Eclipsing Binary Systems* (Cambridge, Mass., 1950), sec. 3.12.

preparatory investigation to remove or lessen its possible systematic errors; and of such tasks, none is more serious and more important in its consequences than the establishment of proper correspondence between spectral type and the degree of limb darkening of apparent stellar disks in the light of different frequency.

As is well known, the degree of limb darkening of the star undergoing eclipse exerts a profound influence on the whole determination of photometric elements of an eclipsing binary from an analysis of its light curve. An empirical determination of the coefficient of limb darkening is, however, practicable only for special systems exhibiting total and annular eclipses which have been observed with a sufficiently high degree of precision. Eclipsing systems meeting such requirements are relatively few in number, and their list is given in the following Table 7. The data compiled in it represent the entire store of the empirical evidence available at the present time. The headings of its individual columns are largely self-explanatory. Column 3 lists the coefficients of limb darkening u together with the probable errors of their empirical determination in the light of effective wave-length $\lambda_{\text{eff.}}$ (col. 4) by a method indicated in column 5 where the numerals I–IV signify, respectively, a determination:

I: From an analysis of light changes during annular eclipses.
II: From an equalization of the 'shape' and 'depth' k in the course of orbital solution.
III: From the ellipticity exhibited between eclipses.
IV: From spectrophotometric measurement of the temperature distribution across the disk.

A glance at the data compiled in Table 7 reveals that the stars included in it do not cover the entire range of known spectral classes. No direct information is as yet available on the limb darkening of stars of the O-type, nor of stars whose spectra are later than K0. Between these two extremes (and this group includes a large majority of known eclipsing systems) the behaviour of stellar limb darkening can, however, be deduced from the empirical data alone with some degree of confidence.

An inspection of these data reveals that, in the visual-photographic range, *the observed degree of darkening of all stars of spectral types B0–K0 appears to lie between* 0·4 *and* 0·8, possibly between 0·5 and 0·8. Moreover, if we restrict our attention to stars of spectra between (say) early B and late A the range of variation of u will be diminished to $0{\cdot}4<u<0{\cdot}6$; with $u=0{\cdot}5$ representing a fair average. Limb darkenings in excess of 0·6 (between 0·6 and 0·8) have so far been encountered only among stars of spectral types between F0 and K0. In addition, the data compiled in Table 7 reveal that the degree of darkening varies appreciably with the effective wave-length of observation; but, whereas for stars of spectral types B8–A3 (U Sge, YZ Cas) the observations between 4500–6800 Å indicate a moderate *increase* of u with diminishing wave-length (as is also true for the Sun); recent observations (as yet unpublished), by Huffer, of AR Cas indicate unmistakably that the limb darkening of its principal component of spectral type B3 is *greater* in the yellow than in the blue or ultra-violet.

How do these results agree with theoretical expectations? While a more detailed discussion of a comparison between theory and observations is outside the scope of this report, and is being prepared for publication elsewhere, it must be said that the agreement between the data collected in Table 7 on the one hand, and the deductions from the theory of non-grey stellar atmospheres on the other,* is rather poor and qualitative rather than quantitative. In certain respects, theory and observations are still completely at variance. Consider, for instance, the problem of the limb darkening of early-type stars. Until relevant observational data became available, it was generally believed on the basis of theoretical considerations† that the limb darkening of O- and early B-type stars was quite small, corresponding to $u<0{\cdot}2$. When the present writer established in 1946 that the limb darkening of the principal component of SZ Cam (spectrum B0)

* For the latest theoretical data cf. Münch and Chandrasekhar, *Harv. Bull.* no. 453, 1949.

† Cf. e.g. Pannekoek, *M.N.* **95**, 725, 1935.

Table 7

Star	Spectrum	u	$\lambda_{eff.}$	Method
SZ Cam A	B0	$0{\cdot}49 \pm 0{\cdot}03$	4230 Å	II
VV Ori A	B2	$0{\cdot}54 \pm 0{\cdot}10$	4500	II
AR Cas A	B3	$0{\cdot}85 \pm 0{\cdot}03$	5400	I
		$0{\cdot}51 \pm 0{\cdot}04$	4200	I
		$0{\cdot}58 \pm 0{\cdot}03$	3500	I
U Sge A	B8	$0{\cdot}37 \pm 0{\cdot}04$	6800	I
		$0{\cdot}57 \pm 0{\cdot}04$	4500	I
β Per A	B8*	$0{\cdot}76 \pm$	4340	IV
AR Aur AB	B9+A0	$0{\cdot}50 \pm 0{\cdot}05$	4500	II
β Aur AB	A0+A0	$0{\cdot}6 \pm 0{\cdot}2$	7000	III
α CrB A	A0	$0{\cdot}5 \pm 0{\cdot}2$	4500	I
YZ Cas A	A3	$0{\cdot}33 \pm 0{\cdot}03$	6700	I
		$0{\cdot}49 \pm 0{\cdot}04$	4500	I
TW And A	dF0	$0{\cdot}80 \pm 0{\cdot}07$	5300	II
YZ Cas B	(F5)†	$0{\cdot}48 \pm 0{\cdot}11$	6700	I
		$0{\cdot}45 \pm 0{\cdot}11$	4500	I
Sun	dG2	$0{\cdot}43 \pm 0{\cdot}02$	8660	
		$0{\cdot}66 \pm 0{\cdot}02$	5340	
		$0{\cdot}74 \pm 0{\cdot}03$	4500	
		$0{\cdot}85 \pm 0{\cdot}03$	3860	
AR Lac A	gG5	$0{\cdot}6 \pm 0{\cdot}1$	4500	II
TW And B	(gG6)†	$0{\cdot}8 \pm 0{\cdot}1$	5300	II
AR Lac B	(gK0)†	$0{\cdot}55 \pm 0{\cdot}12$	4500	II

Star	Reference
SZ Cam A	Kopal's rediscussion (unpublished) of a light curve by Wesselink, *Leiden Ann.* **17**, pt. 3, 1941.
VV Ori A	Huffer and Kopal, *A.J.* **57**, 160, 1952.
AR Cas A	Huffer and Kopal, *A.J.* **60**, 164, 1955.
U Sge A	Irwin (*Bull. of the Panel on Orbits of Ecl. Var.* no. 3, 1946).
β Per A	Chalonge, Divan and de Strobel, *C.R.* (*Paris*), **238**, 1868, 1954.
AR Aur AB	Huffer and Eggen, *Ap. J.* **106**, 106, 1947.
β Aur AB	Russell, *Ap. J.* **102**, 1, 1945.
α CrB A	Kopal's rediscussion (*Proc. Amer. Phil. Soc.* **86**, 349, 1943) of a light curve by Stebbins, *Washburn Publ.* **15**, 41, 1928.
YZ Cas A	Kron, *Ap. J.* **96**, 173, 1942.
	Kron, *Lick Bull.* **19**, 59, 1939.
TW And A	Kopal and Shapley's (unpublished) rediscussion of a light curve by Dugan, *Princ. Contr.* no. 14, 1933.
YZ Cas B	Kron, *loc. cit. supra.*
	Kron, *loc. cit. supra.*
Sun	Determinations based on direct measurements of intensity distribution across the apparent solar disk by Abbot, *Annals Smithson Inst.* **3**, 157, 1913; and **4**, 221, 1922.
AR Lac A	Kopal's rediscussion (unpublished) of a light curve by Wood, *Princ. Contr.* no. 21, 1946.
TW And B	Kopal and Shapley, *loc. cit. supra.*
AR Lac B	Kopal, *loc. cit. supra.*

* Chalonge and his associates (*op. cit.*) have re-classified the spectrum of Algol A as B7V.
† Spectral class estimated from the observed ratio of surface brightnesses of the two stars.

could not be very much less than 0·5,* this result was interpreted as indicating that the opacity in the atmospheres of the early-type stars is governed by electron scattering—in which case the theoretical coefficient of limb darkening should be, according to Chandrasekhar,† slightly more than 0·6 in the light of any frequency (since electron scattering represents a frequency-independent process). Now the recent result by Huffer for AR Cas A (spectrum B3) indicating a distinct decrease of u between the yellow and the blue is plainly at variance with the hypothesis of electron scattering as well as of atomic absorption, for the latter should be expected to produce an *increase* of u with diminishing wave-length. There exists but little room for doubt that the discrepancy between theory and observation is genuine, and that its solution is as yet nowhere in sight. Huffer's recent observations of AR Cas are so numerous and accurate that a very great effort would be needed to improve upon his data. However, it is very much to be hoped that corroborative evidence may soon be secured for V 380 Cyg—a system resembling AR Cas in spectrum as well as geometry—and that observations of SZ Cam may be repeated in the light of several colours, in order to check on the relative importance of electron scattering in the atmospheres of early-type stars (B0–B3).

On the theoretical side, improved data on the behaviour of the absorption coefficient in stellar atmospheres and its dependence on the frequency as well as temperature will be required before theoretical predictions can claim confidence and stand comparison with the observations. 'Slightly non-grey' model-atmospheres of latest versions may still be too far from the actual reality. Apart from the possible variation of the ratio of $\kappa_\lambda/\bar{\kappa}$ with the temperature, there remains still the more basic question as to whether or not theory and observations can ever be reconciled on the basis of any *linear* law of darkening. From the theoretical point of view, a linear (i.e. cosine) law of darkening represents at best a crude approximation to the expected distribution of light over stellar apparent disks; and its use in practice has so far been justified solely on grounds of simplicity. There seems little doubt that the cosine law becomes a poor approximation near the star's limb—and it should be emphasized that its empirical determination (by any method) rests largely on the analysis of light changes during advanced stages of the eclipse (i.e. of that part of the light curve which is most affected by the detailed distribution of brightness near the star's limb). The use of non-linear laws of darkening in the analysis of light curves of eclipsing binary systems represents another important and timely task of the theory of close binary systems which awaits investigation; and provides possibly the only basis on which theory and observation of stellar limb darkening can properly be reconciled.

Such being the situation, what should be the present policy of an investigator aiming to solve for the photometric elements of an eclipsing system whose light curve does not lend itself for an empirical determination of limb darkening (as is true, for instance, of most partially eclipsing systems)? The old practice of meeting the situation half-way by a determination of two limiting sets of elements evaluated on the assumption of uniformly bright ('U') and totally darkened ('D') disks should nowadays be regarded as completely out of date, for no real stellar disks are likely to appear uniformly bright, or again completely darkened at limb, and an interpolation between the two limiting sets of elements for intermediate degrees of darkening represents a non-linear process. Even in routine solutions for preliminary or intermediary elements, the availability of detailed tables (Merrill, Tsesevich) for $u = 0{\cdot}2$, 0·4, 0·6 and 0·8 leaves no excuse for not computing such elements on the assumption of the most likely degree of darkening for stars of given spectral type and observed in the light of any particular frequency, and these can be bracketed more closely than between 0 and 1.

Our earlier discussion in this section should have made it sufficiently clear that there still exists a considerable latitude in our views as to what this most probable degree of

* This result has not yet been published in full, but details of it have been quoted by Russell in *Harvard Centennial Symposia* (*Harv. Obs. Mono.* no. 7, 1946, p. 193) and elsewhere.

† *Ap. J.* **103**, 351, 1946, and **105**, 435, 1947.

darkening should be. It is, however, fairly certain already now that if limiting solutions are to be attempted (bracketing the most probable value of limb darkening), the values of $u=0{\cdot}4$ and $0{\cdot}6$ should replace the old 'U' and 'D' solutions for stars of spectral classes B and A, observed in the visual or photographic range, and these limits should be increased to $0{\cdot}6$ and $0{\cdot}8$ for stars of spectral types F and G. The values of $u=0{\cdot}5$ for O and B stars, $0{\cdot}6$ for A and $0{\cdot}7$ for F–G stars represent probably the best averages that can be recommended for use at the present time, and their uncertainty is not likely to exceed $\pm 0{\cdot}1$. Detailed tables to facilitate solutions for $u=0{\cdot}5$ and $0{\cdot}7$ are as yet not available (those corresponding to $u=0{\cdot}5$ would probably turn out most useful of all), but the respective entries can, of course, be obtained by interpolation between the neighbouring tables which is (over the major part of such tables) reasonably linear. Unlike an interpolation between the conventional 'U' and 'D' sets of the elements, those computed on the assumption of two values of u differing by $0{\cdot}2$, are likewise linearly interpolable, at least the errors entailed in linear interpolation do not exceed those within which such elements are usually defined by the available photometric data.

A further refinement and improvement of the foregoing crude system of the values of u recommended for stars of different spectra represents an urgent auxiliary task whose importance for our field of research can scarcely be overestimated. In the absence of an effective contact between observers and theoreticians still prevailing in this sector, the values recommended at present are based predominantly on the observational evidence. We do so, however, only tentatively and in the hope that, before too long, the theoreticians will be able to give us a more helpful hand than has been possible so far in setting up a more complete and detailed correspondence between spectral type and stellar limb darkening.

9. Theoretical and Dynamical Investigations

A theory of the light (and radial-velocity) curves of eclipsing binary systems constitutes a subject which has already been investigated in the past in such detail that future contributions are likely to represent major contributions. Theoretical light or velocity curves—between minima as well as within eclipses—of close binaries whose components can be represented by equilibrium models (i.e. are mutually distorted in accordance with the equilibrium theory of tides) are at present known completely to quantities of the first order in superficial distortion. For well-separated systems (of the fractional size of the components being, say, less than $0{\cdot}25$) this first-order theory offers a satisfactory approximation, whose errors are of the same order of magnitude as the errors of contemporary photo-electric measurement of the light changes. For closer systems, the errors of the first-order theory are, however, apt to become intolerably large, and their neglect can systematically vitiate all results of the first approximation.

In order to meet the needs arising in this connexion, the present writer embarked in 1949 on an extension of the study of theoretical light and radial-velocity curves of eclipsing binary systems to terms of the *second* order in superficial distortion—i.e. completely to *seventh* spherical harmonic effects—on the basis of centrally condensed stellar models. Owing to the inherent complexity of its task, this investigation took several years to complete. At the time of writing full explicit results are, however, already available and will be gladly communicated to any colleague who may desire to have them in advance of publication.

It may be added in this connexion, that the convergence of the underlying expansions is found to become, in general, the slower, the larger the fractional size of the components. For very close binaries—whose components are nearly (or actually) in contact—even the second approximation becomes insufficient for present-day needs. This has led the writer recently to resort to the closed geometrical properties of the Roche model as a basis for light curve interpretation. A detailed investigation of the relevant geometrical properties of such a model has already been published(42), and its application to an analysis of the light and velocity curves of contact binary systems is expected to follow in the near future.

In addition, within the past two years, the writer has investigated the effects on light and velocity curves of close binary systems, of *tesseral* harmonic distortion of the order of P_j^i ($0 < i < j$), which may arise in nature, for instance, if the equatorial planes of rotating components are inclined to the plane of their orbit. Tesseral harmonics arising from this source have been found capable of exciting sine terms in the theoretical light curves, and may thus be partly (or perhaps wholly) responsible for the notorious asymmetries of light curves of so many eclipsing systems.

All the foregoing remarks refer to the *ellipticity effects* upon light or velocity curves arising from the mutual distortion of both components. As to the *reflexion effect*—which represents an additive contribution to the light of a system—Huang (43) has recently produced new solutions of the underlying transfer problem of reflected radiation, obtained by variational methods in continuation of similar earlier work by Menzel and Sen (44).* Quite recently, the present writer (45) succeeded also at last in deriving a general phase-law, which governs the variation of the amount of reflected light with the phase, taking account of the finite angular size of the illuminating component. His results are exact for Lambert's law of reflexion, and to the order of accuracy to which both components can be regarded as spheres.

Attention should be called, further, to a recent investigation by Kitamura (46) of the effects of reflexion on the observed amplitudes of radial-velocity curves of close binary systems, which tend spuriously to equalize the actual mass-ratios. Such effects have been known to affect the relevant observational data for some time, and have already been the subject of an earlier study by the writer.† Kitamura's work goes, however, far beyond the earlier treatment of the problems, and is to be followed by an application of the theoretical results to practical cases. Discussing the deformations of the radial-velocity curves in close binary systems, we must also refer to a recent study by Hosokawa (47), of the influence upon rotational effect, of a variable angular velocity of rotation of the component undergoing eclipse. Hosokawa assumes the angular velocity between the equator and the pole to follow Faye's law (established empirically for the Sun) and gives explicit expressions for the corresponding deformation of the radial-velocity curves from the Keplerian motion during eclipses. Lastly, it may be mentioned in this way that the present writer investigated also the theoretical deformation of the profiles of spectral lines which originate in stars undergoing eclipse.‡ This has been invoked to account for the rotationally distorted profiles of the B8-component of Algol as observed by Struve and Elvey§ several years ago, with satisfactory results.

Problems associated with the dynamics of close binary systems have provided material for many investigations in the past few years. The present writer has for a considerable time been engaged in an extension of Clairaut's theory of the figures of equilibrium of stellar configurations of arbitrary structure to terms of second order (i.e. including the effects of the squares of axial rotation, of tidal harmonic distortion of orders up to the seventh, as well as of the cross-terms between first-order rotational and tidal distortion). All earlier investigations of the second-order terms,|| limited themselves, it may be recalled, to a study of second-order rotational distortion and its geophysical applications. An investigation of all second-order terms of purely tidal origin was recently completed by Olle (48), but the second-order cross-terms of mixed rotational and tidal origin—giving rise to the most complicated part of the whole second-order theory—remain yet to be investigated.

A particular application of Clairaut's theory is represented by a determination of the apsidal-motion constants k_j, whose empirical evaluation from the observed rates of apsidal advance affords, in principle, an insight into the internal structure of the constituent components and, as such, is of general importance transcending the field

* Cf. also Chandrasekhar's *Radiative Transfer*, Oxford, 1950, pp. 80–7.

† Cf. Z. Kopal, *Proc. Amer. Phil. Soc.* **86**, 351, 1943.

‡ Cf. *The Observatory*, **74**, 103, 1954.

§ *M.N.* **91**, 664, 1931.

|| Cf. Callandreau, *Ann. Paris Obs.* **19**(E), 1889; or Darwin, *M.N.* **60**, 82, 1900. Cf. also Véronnet, *Journ. de Math.* (6) **8**, 331, 1912.

of our Commission. During the past triennium, Motz (49) pointed out the existence of an empirical calculation between k_2 and the radius of gyration of the respective configuration. Subsequently, the present writer (50) gave a theoretical justification of such a relation, and formulated generally an approximate dependence of all the k_j's on successively higher moments of inertia. Epstein and Motz (51) published also an outcome of numerical integrations leading to a determination of the value of k_2 for the solar model;* while, more recently, Brooker and Olle (52) completed an extensive and accurate redetermination of the k_j's ($j=2, 3, \ldots, 7$) for the polytropic model with the aid of the Manchester University Electronic Computer. Their work revealed several inaccuracies in the widely accepted values of these constants, and established their correct values to 4–5 significant figures.

The dynamics of gas streams in close binary systems, which have been observationally studied by Struve and his associates in the past decade with such success, have provided a renewed interest and incentive for a systematic study of the form of trajectories of the restricted problem of three bodies—in which the finite masses represent the two components of our binary, and the infinitesimal mass stands for that of a gas particle which moves in the gravitational field of the rotating pair. Numerical integrations sufficient to reveal the essential topological properties of such orbits and their classification would have required a prohibitive amount of labour in the days of desk-type computation, but have become feasible with the advent of modern automatic computers working at electronic speeds. In the past year, the writer of this report embarked at Manchester upon an extensive programme of integrations of this type, in collaboration with Mr R. A. Brooker and Miss Vera Hewison, with the aid of the University of Manchester's Electronic Computers Marks I and II, designed and built at the University's Department of Electrical Engineering by Prof. F. C. Williams and Dr Kilburn. These machines belong certainly to the world's most powerful computers for this type of work, and within less than one year of part-time operation, an amount of computation equivalent to at least 50,000 man-hours with desk-type machines has already been accomplished, and several times that amount will be performed in the relatively near future. A part of the results is already being prepared for publication, and may be exhibited at the Dublin meetings.

As a by-product of this programme, Britton (53) completed recently a dynamical study of the gaseous ring surrounding the A o-component of the eclipsing system of RW Tau, and obtained a tentative estimate of the mass-ratio (and thus of absolute dimensions) of this single-spectrum system from the observed velocity of rotation of the ring. Using the same Manchester Electronic Computer, Dodd (54) published recently an interesting study of the mechanism of accretion of interstellar matter by binary systems. Batten (55) at St Andrews undertook a study of the systemic velocities of two-spectra binary systems, aiming to ascertain whether the γ's as deduced from the velocity curves of each component are significantly the same. Lastly, attention should be called to a recent investigation by Takase (56) in which its author has extended an earlier work by Chandrasekhar† on the dissolution time of binary systems taking account of the fluctuating density of the field of interstellar matter according to a model of Chandrasekhar and Münch.‡

10. Statistical and Spectrophotometric Investigations

Statistical studies of diverse properties of eclipsing binary systems have enjoyed considerable attention in the past few years. In addition to an extensive statistical study of eclipsing variables brighter than 8·5 apparent photographic magnitude at maximum by Plaut (40 a), to which reference has already been made, we should call attention to three recent papers by Fracastoro (57–59) and by Wood (60). Similar, as yet unpublished, studies by Lavrov, based on the Engelhardt Observatory bibliographical Catalogue and dealing with the statistics of period, amplitudes, spectra, etc., are to appear in the

* Cf. Epstein and Motz, *Ap. J.* **117**, 311, 1953; and **120**, 156, 1954.

† *Ap. J.* **99**, 54, 1944.

‡ *Ap. J.* **115**, 103, 1952.

Bulletin of the Engelhardt Observatory some time in 1955. Sakarian (61) investigated the probability aspects of the discovery of different types of eclipsing variables.* Miss Scott has brought the power of modern statistical analysis to bear on a study of the distribution of the longitudes of periastra in spectroscopic binary systems (62), and on general studies relating to the distribution of other orbital elements of such pairs (63). Miss Kurzemniece has continued her statistical studies of the distribution of mass ratios of close binary systems (64). Finally, Miss Bradley (65) has investigated the kinematic properties of different spectral groups of close binary systems, and ascertained the space velocities of all eclipsing variables for which the requisite data are known from the observations. Similar kinematic problems are reported to have been the subject of a Moscow (1953) thesis by Miss Kurzemniece.

Of special spectrographic studies of different eclipsing systems which have appeared in the past three years, Struve (66) investigated the variation in profile in Mg II 4481 at different phases of the eclipse, on the basis of spectra secured in 1952 with the aid of the 100-inch reflector at Mount Wilson, and attempted to explain them in terms of a postulated stratification of magnesium with latitude in the atmosphere of Algol's principal component. Beer and the present writer (67) studied Algol's spectrum in the near infra-red on plates secured with the 47-inch reflector at the Observatoire de Haute Provence in 1952, and established evidence of the spectrum of Algol's secondary component in the region near the head of the hydrogen Paschen series. The other famous eclipsing variable, β Lyrae, was also the subject of several investigations in the past triennium. Thus, Barocas and Righini (68) studied for the first time its spectrum beyond 10,000 Å, and found that the He I 10,830 is by far the strongest emission line of the whole spectrum—a result confirmed subsequently by Miller (69). Miss Böhm-Vitense (70) studied the absorption component of the B5 spectrum of β Lyr. Mitchell (71) showed that the observed profiles of Mg II 4481 in β Lyr do not exhibit any ellipticity effect, and indicate only a moderate rotational velocity of some 40 km./sec. at the equator of the cB9 component. Unpublished spectrophotometric observations of β Lyr are reported also from the Odessa Observatory by Saydov, who employed a Cooke apochromate of 150 mm. aperture and 2000 mm. focal length, in connexion with an 18°-objective prism. A new solution of Stebbins' light curve for the photometric elements of β Lyr was obtained by Dadaev (72). Circumstellar lines of Ca II absorbed by a medium enveloping the famous system of ϵ Aurigae were reported by Struve (73), and, more recently, Miss Pillans (74) reported the spectroscopic evidence for a CH^+ absorption. The eclipsing variable V 367 Cyg exhibiting a shell spectrum has been the subject of two notes by Abt (75) and Miss Underhill (76). Goldberg at Poulkovo reports the completion of a series of spectrophotometric observations of RS Vul. Dombrovsky's spectrophotometric observations of VV Ori at Abastumani Observatory were recently used by Bolokadze (77) to study the frequency-dependence of the photometric ellipticity of this system, which was found to increase with increasing wave-length. The same result was found by Amstislavsky for YZ Cas, and for RS Vul by Lavrov (78). Dadaev's extensive and thorough spectrophotometric study of AO Cas in the light of five effective wave-lengths should be especially pointed out in this connexion (72). Another young Russian astronomer, Miss Lukatskaya, undertook a spectrophotometry of AW Peg, of which only preliminary results have so far been published (79). Sofronitski's spectrophotometric investigation of V 505 Sgr in two colours has already been referred to (80). Ovenden (81) discussed general photometric effects of gaseous envelopes in close eclipsing systems.

* See also an extensive review of this paper by Scigolev in *Per. Zvjozdy*, **9**, 346, 1954.

11. Classification. Evolutionary Trends

Problems connected with the classification of close binary systems and its evolutionary implications have been very much alive in recent times. It has been customary, for many years, to divide the eclipsing variables into three principal groups—with Algol, β Lyrae, and W UMa as their respective prototypes. It is, however, easy to show that any such classification—still current in most catalogues today—lacks proper physical basis and can be justified, if at all, only on historical grounds. Its principal characteristics—the presence or absence of the photometric ellipticity effect between minima—is the natural resultant of a combination of the fractional dimensions, masses, and relative luminosities of the two components, and can be predicted from them on the basis of a reliable theory. Statistical investigations reveal, however, no apparent break in the frequency distribution of fractional radii, or mass—and luminosity—ratios in eclipsing binary systems. As a result, with increasing separation of the component, stars of the β Lyr type are found to merge gradually with the Algol systems; any dividing line between them being essentially a matter of observational precision with which the amount of photometric ellipticity can be ascertained. Moreover, the dependence of the mean photometric ellipticity of a system on the relative luminosities of the respective components (which are generally of different spectral types) renders this ellipticity dependent also on the effective wave-length of observation. In consequence, any classification based on photometric ellipticity becomes not only inexact but ambiguous as well.

It has already been pointed out by previous investigators* that a simple classification of eclipsing binaries in two or three groups is insufficient to reveal any physical or evolutionary connexion between them, and more complex systems have been elaborated from time to time. Thus, Krat† proposed a classification of eclipsing variables into eight groups (A, A1, B, C, ..., G) according to their spectral type, the form of the light curve and the orbital period. More recently, Struve‡ has worked out a different classification consisting of five groups (I, II, ..., V) for systems whose primary components were of spectrum earlier than F0. In so far as Krat's classification is based on the form of the light curve, it suffers from the same ambiguities as the simple two- or three-group classifications used formerly, and a closer scrutiny reveals that there are indeed continuous transitions between Krat's groups. On the other hand, Struve's criteria are based largely on spectroscopic phenomena which are, so far, known only for a limited number of systems, and pertain to the motions of gas streams between the two components rather than to the properties of the constituent stars themselves.

Quite recently, Plaut (40a) pointed out, on the basis of a statistical study of eclipsing variables brighter than 8·5 apparent photographic magnitude, at maximum that most such binaries can be naturally divided into the following three groups:

(1) systems with both components on the Main Sequence (excluding the W UMa-type stars);
(2) systems with one component outside the Main Sequence; and
(3) systems of the W UMa-type.

Plaut notices, moreover, that almost all well-observed systems of group (2) show spectral peculiarities, that variable periods occur more frequently in group (2) than in group (1), and that 'all W UMa-type systems probably will show variable periods, variable light curves, and peculiar spectra, if observed accurately'.

The present writer re-opened the problem of classification of eclipsing binary systems *de novo*, in an attempt to ascertain whether or not a suitable system of classification can be devised which may enable us to discern some evolutionary trends among close binaries possibly throwing some light on their origin. The main results of this investigation (as yet unpublished) can be summarized as follows: an analysis of the observational data pertaining to two-spectra eclipsing variables reveals that all such systems possessing at

* Cf., e.g., Struve, *Stellar Evolution*, Princeton Univ. Press, 1950, pp. 169 ff.

† *Russian Astr. Zhurnal*, **21**, 20, 1944.

‡ *The Observatory*, **71**, 197, 1951.

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least one (the primary) component on the Main Sequence can be divided into three groups with the following characteristics:

(1) *Main Sequence Systems*. Both components do not deviate appreciably from the Main Sequence, and obey a statistical mass-luminosity relation as well as a statistical mass-radius relation discussed already in Section 6 of this report. The primary (more massive) component is invariably the *larger* of the two, and of *earlier* spectral type. The primary (deeper) minima are, therefore, due to *transit* eclipses.

The volumes of both components are distinctly smaller than those of the largest closed equipotential capable of containing the whole mass of the system (hereafter called the Roche limit) for a given value of their mass-ratio. *The values of the potential over free surfaces of both detached components are*, however, *sensibly equal*—in spite of the fact that the absolute values of such potentials vary from system to system by a factor in excess of ten.

(2) *Semi-detached Systems* (Algol type). The secondary component lies invariably *above* the Main Sequence, and while the primary (Main Sequence) star in such pairs continues to obey the same statistical mass-luminosity and mass-radius relations as other stars of group (1), the secondary (sub-giant) components possess masses which are as a rule too small for their observed luminosities. The primary (more massive) component is the *smaller* of the two, and of *earlier* spectral type. The primary (deeper) minima of such systems are, therefore, due to *occultation* eclipses.

The values of the potential over surfaces of the primary components appear to be normal for stars of their spectra; but the potentials characteristic of the *secondaries* are abnormally *low*. Moreover, in the majority of known cases, the secondary components appear to fill *exactly* the largest closed equipotentials capable of containing the whole mass of the respective star.

(3) *Contact Systems* (W UMa-type). Perhaps the most numerous type of close binary systems in stellar population. Both the primary and secondary components are scattered loosely along the Main Sequence, their spectral types exhibiting a marked concentration from the late A's to early K's. They show, however—individually or statistically—no vestige of any relation between mass and luminosity.

The primary components are the *larger* of the two, but as a rule of *later* spectral type than those of their mates, and quite frequently also of *lesser* luminosity. The primary minima in eclipsing systems of this type are, therefore, likely to be due to *occultations*.

The potentials over free surfaces of the two components are sensibly equal, with each component just about filling completely the respective branch of the maximum Roche equipotential. Both components are, therefore, probably in bodily contact at the inner Lagrangian point L_1, and may actually exchange mass through the conical end of the critical equipotential.

The bearing of the above-enumerated characteristics of the different groups on evolutionary trends of close binary systems can be but briefly discussed in this place. The equality of potentials over free surfaces of the contact components of group III, or detached components of group I, is scarcely the result of a chance. In particular, this property of group I (which does not seem to have been noticed by any previous investigator) suggests that even their now detached components must once have been parts of the *same* body. Of all the hypotheses of the origin of close binary systems which have so far been advanced, only the fission theory would seem to account logically for this fact.

It is true that, in the original form given to it by Darwin and Jeans several decades ago, the fission theory has become the target of grave criticisms discussed, in recent years, particularly by Lyttleton.* The original Darwin-Jeans theory involved, however, several simplifying assumptions (the stars to consist of homogeneous liquid, possessing no internal energy sources, etc.) which were made for the sake of mathematical tractability,

* R. A. Lyttleton, *The Stability of Rotating Liquid Masses*, Cambridge University Press, 1953; cf. also his paper in *Trans. I.A.U.* vol. **8**, pp. 717–21.

but which are quite unacceptable today as a basis for any physically realistic discussion of the subject. So extreme a case of stellar hydrodynamics as a fission, under stress, of an originally single star in two components of comparable masses has never so far been properly formulated—let alone solved. As long as this is true, it seems unwise to rule out the possibility of fission from the arena of the theories contesting for the explanation of the origin of close binary systems. The empirical evidence now available suggests that the fission theory may indeed deserve further consideration (difficult as it may prove from the mathematical point of view), but this is not the place to follow it in any more detail.

Eclipsing systems of group II, whose secondary components are of the type generally known as *sub-giants*, have in the past two or three years given rise to some of the most interesting and revealing investigations in the whole field of our Commission. The problem of the sub-giants has been attracting increased attention of several investigators for some time—as is demonstrated by recent notes by Struve (82), or Struve and Gould (83). Extensive remarks concerning various properties of sub-giant components are contained in a memoir by Sofronitski (80) already quoted. Martynov discussed the significance of sub-giants at the recent 4th All-Union conference on problems on cosmogony in Moscow. It was, however, left to the present writer (84) and—independently—to Crawford (85) to prove, by different methods converging to the same result, the most interesting property of such sub-giants: namely, their *secular expansion*.

As was already mentioned, an analysis of the fractional dimensions of sub-giant components in systems of given mass-ratios has revealed that, in the large majority of such cases, the secondaries are found to fill exactly (or, rather, within the limits of observational errors) the largest closed Roche equipotential capable of containing their whole mass. The significance of this fact is not in doubt, and the observed clustering of the secondaries at their Roche limits demonstrates that these stars must be secularly expanding. It is, moreover, quite clear that the reason of this expansion must be sought in the internal constitution of the respective star, whose deep interior (unlike its surface) is influenced but little by the tides due to its mate. It is tempting to surmise that the tendency to expand is operative in all sub-giants—irrespective of whether or not they are single or constitute components of wide (ζ Her) or close binary systems. In the former case, the expansion could presumably go on unchecked for a long time. The presence of the primary component in a close binary system imposes merely an intangible upper limit (i.e. the Roche equipotential) which the secondary cannot exceed on dynamical grounds; and if many such secondaries are found actually to attain this limit, the expanding tendency of such stars is clearly revealed. The sub-giant components of such well-known systems as U Cep, u Her, U Sge, TX UMa (probably) Algol, etc., can be regarded as typical examples of this class of stars, and Crawford adduced several other more or less probable cases on statistical grounds.

The relative scarcity of intermediate cases (i.e. of sub-giant components occupying volumes smaller than their Roche limits—such as RS CVn B, for instance) indicates, moreover, that their secular expansion may proceed at a relatively rapid rate. Once the maximum distention permissible on dynamical grounds has been attained, a continuing tendency to expand is bound to bring about a *secular loss of mass*, through the conical end of the critical equipotential. The observed abnormally small masses of the secondary components* (leading to abnormally large mass-ratios m_1/m_2) in many systems of group (2) are probably a consequence of this fact.

The loss of mass in such systems leads one naturally to speculate concerning a possible connexion of this fact with the period changes which are only too well known in many eclipsing systems. This is indeed an intriguing possibility,† but we should be careful not to jump to conclusions which, attractive on first sight, may not stand the light of closer scrutiny. The known facts disclose that, among the systems with sub-giant secondaries

* For their discussion cf., e.g., Struve, *Ann. Ap.* **11**, 117, 1948.

† Cf. Wood, *Ap. J.* **112**, 196, 1950.

at their maximum size limit, there are some which exhibit indeed complex period changes (such as U Cep or Algol). But it is also true that for several other similar and well-known systems (u Her, U Sge, TX UMa) the variations of period are altogether small—if any. Lastly, we should not forget that curious variations of period are also known by other systems (U Oph, for instance) both of whose components are much smaller than their Roche limits, and should, therefore, be completely stable. Besides, a secular loss of mass would always bring about a *lengthening* of the period, while the actual period fluctuations in such systems as U Cep or Algol are manifestly very much more complex. Whether or not there is a significant connexion between the loss of mass due to a secular expansion of sub-giant components of close binary systems and their period changes constitutes a question admitting probably of no simple answer.

What is the evolutionary significance of the secular expansion of sub-giants? Sandage and Schwarzschild* pointed out some time ago that the secular expansion of a star is likely to begin in response to a diminishing hydrogen content. The sub-giant components in close binary systems accompany, however, as a rule late B- or early A-type Main Sequence stars, and as both components are no doubt of equal age (as well as initially of equal composition) the sub-giant secondaries cannot manifestly be 'old'. Crawford (85) proposed a hypothesis that the present sub-giant secondaries are erstwhile primaries which have, in the course of time, lost enough mass to reverse the balance of the mass-ratio. The (initially) more massive primary component is, according to Crawford, likely to run its evolutionary course more rapidly than its mate, and deplete its hydrogen supply which will cause expansion. In the course of such expansion enough mass will eventually be lost to reverse the original role of the two stars—the former primary now becoming the secondary component, and vice versa. Crawford's suggestion is ingenious, but so far fails to carry conviction. The objections are empirical, namely, first, a complete lack of sub-giants at their Roche limits whose masses are equal (or nearly so) to those of their mate (and such systems should be at least as frequent as those characterized by very unequal mass-ratios), and, secondly, the existence of sub-giants (RS CVn B, for example) whose dimensions are well inferior to those of the Roche limits. In particular, in all conspicuous cases on record the expanding star at the Roche limit is very much less massive than its mate, and the simplest tentative assumption may be that this has always been the case. The actual reason which compels such stars to expand is probably still unknown.

In conclusion of this section we may perhaps return with a few words to the 'problem of R CMa-stars' discussed briefly in the last report of our Commission.† This problem concerns a small group of single-spectrum eclipsing systems whose mass-functions are so minute as to necessitate very large mass-ratios. Whatever may have been the uncertainty arising in this connexion in the past, there seems now but little room for doubt that systems like R CMa or XZ Sgr exhibit extreme cases of sub-giant components at their Roche limits. The mass-ratios deduced from the fractional dimensions of the secondary components, combined with the respective mass-functions lead, it is true, to the masses and absolute dimensions which render *both* components quite abnormal with respect to mass and luminosity. This, however, is probably the consequence of a really old age, for the expansion must have been operative a very long time to render a disparity in masses of the two components as large as indicated by a ratio 5:1 (R CMa) or 10:1 (YZ Sgr). Both components of such systems as R CMa, YZ Sgr (or, to a lesser extent, T LMi or S Vel) are, therefore, probably very old stars; and their present characteristics may be indicative of the direction of evolutionary trends of Main Sequence stars of really great age.

* *Ap. J.* **116**, 463, 1952.
† *Trans. I.A.U.* **8**, 641, 1954.

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Report of Meetings. Wednesday, 31 August 1955, 9.00–11.10

PRESIDENT: Prof. Zdeněk Kopal.

SECRETARIES: Prof. C. M. Huffer, Dr J. L. Rigal.

The meeting was called to order at 9.00 a.m., and was opened with a tribute to the memory of two distinguished colleagues who have left us since our last reunion at Rome: Prof. Thaddeusz Banachiewicz, who passed away in November 1954 in the fullness of years, and Prof. Attilio Colacevich who preceded him in August 1953 in the prime of his life. Although neither of them was formally a member of our Commission at any time, their interest in our field was deep and lasting. To Prof. Banachiewicz we owe, in particular, the well-known yearly *Ephemerides of Eclipsing Variables*, which have appeared under his editorship for 26 years; and Prof. Colacevich—apart from his earlier spectroscopic work on close binary systems—was largely instrumental in initiating the photo-electric photometry of eclipsing variables at the Capodimonte Observatory in

Naples, from which several important contributions have come out in the past few years. Members of our Commission who attended our last session in Rome will recall the part which Prof. Banachiewicz took in our proceedings at that time, and remember the vacant place in the front row in which he is so sadly missed today.

The first item of business concerned a matter which was brought to a head by Prof. Banachiewicz's passing away: the continuation of the Kraków *Ephemerides* in which so many observers are deeply interested. Our Polish colleagues, Profs. S. L. Piotrowski and J. Witkowski, brought with them the welcome news that the Kraków Observatory intends to continue with the yearly publication of these *Ephemerides*, and is not in need of any financial support from the I.A.U. to this end. The Polish Academy of Sciences (under whose auspices the publication is to continue its existence) would, however, appreciate a statement of the extent of the interest in these *Ephemerides* by the astronomical community at large. After a lively discussion in which several members and guests of our Commission participated, the following resolution was unanimously adopted:

Commission 42 of the I.A.U. recommends that the publication of the *Ephemerides of Eclipsing Binaries*—edited hitherto by the late Prof. Th. Banachiewicz—be continued by the Kraków Observatory. This publication is of highest interest to all observers of eclipsing variables.

Dr K. Kordylewski, who will be the editor of the *Ephemerides* from now on, sent a message announcing that, beginning with the volume no. 27, English and Russian texts will replace the 'latine sine flexione' formerly used. The members and guests taking part in our meeting unanimously welcomed this change and instructed, moreover, the Chairman to approach the Kraków astronomers with regard to the possibility of reverting also to the ordinary Julian calendar in place of the 'nova era astronomica' used hitherto. The Commission would, furthermore, welcome it if the *Ephemerides* for a given calendar year could appear so as to be in the hands of the users not later than by mid-December of the preceding year.

The next item on our agenda was individual reports by different colleagues present on recent work in the field of our Commission carried out since the Draft Report was written. Prof. M. G. Fracastoro reports the inauguration of photo-electric observations of eclipsing variables at Catania (Sicily), and Prof. J. F. Heard informed us that a new photo-electric photometer with a Brown recorder has been attached to the 19-inch reflector of David Dunlap Observatory for observation of eclipsing stars in two colours. Dr Heard reported, in this connexion, that the star HD 200391, suspected by Miss Ruth J. Northcott as a possible eclipsing system on the basis of her double-line spectrographic orbit, has been confirmed as an eclipsing variable by Bakoš at Toronto; the depth of the primary minimum being about 0·1 magn.

Dr F. B. Wood (Flower and Cook Observatories), in a letter circulated among members of the Commission after the Draft Report was completed, reported new photo-electric observations of BX And (Svolopoulos), AH Vir (Binnendijk), and XY Leo (Koch and Blitzstein) being made at Philadelphia. Wood also informed us of a systematic observation of the times of the minima of eclipsing variables, now under way at Steward Observatory in Tucson (Arizona) under Dr E. F. Carpenter. A motion-picture camera has been installed to this end to a 7-inch telescope, and successive exposures automatically record the star's passage through minimum. The entire assemblage was designed specifically for observation of the times of the minima of eclipsing variables, and during the first few months of the operation more than 6000 exposures of 100 systems were made. A further contribution to the study of period changes of eclipsing systems is reported from Pulkovo. Svechnikov discussed recently the period variability of RZ Cas, AO Cas, U Cep, CQ Cep (which is a Wolf-Rayet eclipsing system)—the periods of all these systems undergo abrupt, rather than periodic, changes.

From Capodimonte (Napoli) Observatory Dr A. Fresa reports the completion of photo-electric light curves of XX Cep and V 548 Cyg. A total of 438 individual observations has revealed XX Cephei to be an Algol-like variable (amplitudes 1·13 magn. pri. min., 0·13 magn. sec. min.) exhibiting appreciable reflexion effect between minima. The orbit of this pair is eccentric, and oscillating position of the secondary minimum suggests a revolution of the apsidal line in a period of approximately 20 years. V 548 Cygni (428 observations) is a short-period close binary ($P = 1{\cdot}805$ days) exhibiting conspicuous ellipticity effect. Fresa reports, moreover, continued observation of DR Vul, while V 822 Aql continues to be observed by Dr T. Nicolini.

Dr C. M. Huffer (Washburn Observatory) exhibited the results of his three-colour photo-electric observations of AR Cas secured at the Lowell Observatory last year, which were subsequently analysed for the geometrical elements by Huffer and Kopal. The most interesting result of this analysis appears to be the fact that the limb darkening of the principal component of AR Cas (spectrum B3) is greater in the yellow than in the blue (cf. Huffer and Kopal, *A.J.* **60**, 164, 1955). Dr P. G. Kulikovsky (Moscow) described briefly the principal results of his investigation of V 541 Cyg—a system exhibiting two minima of equal depth and extremely short fractional duration, and relatively displaced owing to large orbital eccentricity (cf. *Per. Zvjozdy*, **9**, 169, 1953). Dr H. Schneller (Berlin-Babelsberg) reported (by letter) the completion of an analysis of his light curve of BF Aur for orbital elements.

On the spectroscopic side, Dr Heard reported new spectrographic orbits for HD 200391 (spectra G2+G7, period $0^{d}{\cdot}7$; eclipsing variable), two-spectra orbits of V 805 Aql and V 451 Oph, and a single-spectrum orbit of V 548 Cyg. The variable V 566 Oph continues to be under observation at David Dunlap, but no orbit is as yet available.

In this connexion, members of Commission 42 should note a 'List of Stars of Variable Radial Velocity under Observation', prepared on behalf of sub-commission (*c*) of Commission 30 (Radial Velocities) by Dr D. B. McLaughlin and his colleagues, which reveals that several other well-known eclipsing systems are on active observing programmes of many institutions. Thus, Cordoba Observatory reports current observations of S Ant, RR Cen, SS Cen, V 346 Cen, TT Hya, TU Mus, V 566 Oph, V Pup, FV Sco, V 393 Sco, V 453 Sco, and HD 163930, with the aim of determining their orbits, Dominion Astrophysical Observatory (Victoria) reports S Equ, RX Gem, and β Lyr to be under observation, while Ann Arbor (Michigan) reports current work on the long-period binaries of ϵ and ζ Aur and VV Cep. The system of ϵ Aur is also being observed at Lick (Struve) and Victoria, while Struve continues his spectrographic work on Algol. Lastly, mention should also be made of the fact that, according to Strömgren (*A.J.* **58**, 276, 1953), Miss Nancy Roman at the Yerkes Observatory plans to observe the spectra of the secondary components of all northern eclipsing variables which are brighter than 10th magnitude.

On the spectrophotometric side, Mme Giusa Cayrel—de Strobel (Institut d'Astrophysique, Paris) studied recently the variation in depth of the Balmer hydrogen lines and of calcium K line in the spectra of Algol and RZ Cas during the minima (cf. *Mem. Soc. Astr. Ital.* **26**, 267, 1955). Attention should also be called, in this connexion, to a study of the distribution of monochromatic brightness and surface temperature over the disk of the primary component of Algol by Mme Cayrel, D. Chalonge, and Mlle L. Divan, which has also recently been published in the *Mem. Soc. Astr. Ital.* **26**, 257, 1955.

Among the long-period eclipsing binaries, none is currently attracting greater attention than the famous system of ϵ Aurigae which is due to exhibit eclipse in 1955–57. According to the ephemeris, the present eclipse should have started in the middle of this summer, at a time of the star's lower passage through the meridian, rendering observation very difficult except at latitudes above which ϵ Aur becomes circumpolar. According to the information available at the meeting, the only observer who has successfully covered this critical opening phase of the eclipse is Dr K. Gyldenkerne (Copenhagen), who has been observing ϵ Aur for several months photo-electrically at Tølløse (Denmark) through two interference filters with passbands centred at 4120 Å and 5575 Å. Dr Gyldenkerne was present at our session, and exhibited his recent observations revealing that the first contact of the eclipse probably took place in the last week of June 1955 (J.D. 2 435 280 ±). The colour of the systems seems to have undergone no change during the first two months of the eclipse—an important fact (if it continues to be true) for any theory trying to explain the origin of the observed light changes. Apart from Dr Gyldenkerne, the only other colleague whose observing station is situated sufficiently far north to enable effective observation during the summer was Dr Gunnar Larsson-Leander in Stockholm. He was reported observing ϵ Aur as well, though no details were available at the time of the Dublin meeting. Dr Thirring (Hamburg-Bergedorf) showed some of his recent results on another giant eclipsing system of BM Cas, which are awaiting publication.

If giant and supergiant eclipsing systems have recently attracted considerable attention, dwarf and sub-dwarf systems did even more so. Eclipsing systems of W UMa-type are being studied extensively at the Observatory Bonn-Hoher List (cf. H. Schmidt and K.W. Schrick, *Z. Ap.* **37**, 73, 1955), and at the Institut d'Astrophysique in Paris (cf. E. Schatzman and J. L. Rigal, *C.R. Acad. Sci.*, Paris, **238**, 2392, 1954; J. L. Rigal, *op. cit.* **240**, 50, 1955). Dr Rigal gave a verbal account of his investigations of the kinematic properties of the close binaries of W UMa-type, and of other aspects of related problems now under investigation in Paris. Furthermore, Kaltchajev at Pulkovo studied also recently the physical characteristics of the dwarf eclipsing systems of RW CrB, AK Her, and AG Vir. For AK Her he secured new photographic and photovisual light curves, while for RW CrB and AG Vir light curves of other authors have been used. The results are still awaiting publication.

A most important communication—which by itself contributed perhaps the highlight of the meeting—was made by Dr M. G. Walker (Mt Wilson) concerning the binary nature of Nova (DQ) Herculis 1934. The essential facts of Walker's remarkable discovery last year have already been described in the Draft Report. The new (and as yet unpublished) result presented by Dr Walker at this session concerned his discovery of a high-frequency oscillation ($P = 1{\cdot}17$ minutes!) of brightness, superimposed upon the major part of the cycle caused by the eclipse phenomena*. This astonishing and unique fact gave rise to a lively discussion, in the course of which Dr A. Masani (Brera-Milano) proposed a hypothesis that one component of DQ Herculis consists of a pair of mutually-eclipsing white dwarfs, revolving around their common centre of gravity in 70 seconds. If so, Walker's new result would represent the first (and long overdue) discovery of a white-dwarf eclipsing binary system.

The remarkable new facts emerging from the study of DQ Her go hand-in-hand with several other lines of new evidence converging to the view that close binary systems may be intrinsically much more important links in the framework of stellar evolution in post-Main Sequence stage than has been realized hitherto. Thus most stars with composite spectra are now regarded as close binaries (cf., e.g., M. Johnson, *Vistas in Astronomy* (ed. A. Beer), vol. II, London 1955; or Tcheng Mao-Lin and M. Bloch, *op. cit.*), and it also appears that eclipsing systems like V 444 Cyg, CQ Cep or CV Ser represent a rule rather than exceptions among Wolf-Rayet stars. Among the Novae, DQ Her and (probably) T CrB are now known to be close binaries; and on the heels of Walker's demonstration that DQ Her consists of a pair of sub-dwarfs came Joy's discovery that SS Cyg, a prototype of sub-dwarf explosive variables, is a spectroscopic binary as well. How many other post-Novae or explosive variables of SS Cyg or U Gem type may prove to be close (and possible eclipsing) variables remains to be seen,† but if we consider the effects of observational selection hampering their discovery, the possibility that many—and perhaps the majority of—such stars are close binary systems cannot be ruled out. If so, the field of study of our Commission is going to widen greatly and becomes literally pregnant with the possibilities of other exciting discoveries which may equal those of Walker or Joy and which, in turn, will confront the theoreticians among us with a wholly new class of problems. In fact, perhaps at no other time in the past thirty or forty years has our subject been fuller of fascination and promise. Would anyone venture to guess how much of it may already be realized before we meet again in three years time?

ZDENĚK KOPAL
President of the Commission

* Dr Walker advised, however, the writer since that when he re-observed DQ Her with the 100 in. reflector in September 1955, the 70 sec. variation was no longer present.

† Grant (*Ap. J.* **122**, 566, 1955) has since reported the absence of eclipsing variability for SS Cyg.

Joint Session of Commissions 27 and 42. Tuesday, 30 August 1955, 4.30–5.35 p.m.

PRESIDENT: Prof. Zdeněk Kopal.

SECRETARY: Prof. C. M. Huffer.

The meeting was called to order at 4.30 p.m.; Drs F. Lenouvel and F. B. Wood acted as French interpreters, and Dr S. Gaposchkin as Russian interpreter.

The first item for discussion at this joint session was a question of the desirability of more explicit publication of photo-electric observations of regular variables than has been done in recent years. The subject was introduced by the Chairman, who pointed out that the current practice of publishing only the 'normal points' to represent the light changes of eclipsing variables is likely to withhold a significant part of the information, stored in the original observations, from general circulation and makes it effectively impossible to rediscuss properly such data at a later date, when new methods of reduction may become available. The present brevity of publication of photo-electric data may no doubt stem largely from economic reasons, for the cost of publication of tabular matter by ordinary letterpress in scientific journals is relatively high. The question arises, however, whether economy has not been carried too far to do injustice to the efforts of the observers, and whether letterpress printing cannot be superseded by other, and more economic, means for making such observations available to future generations.

Several members and guests of both Commissions took part in the discussion which followed, and expressed their views. Dr Fracastoro (Catania) asked why we should limit the requirements of fuller publication to photo-electric measures, and Mrs Gaposchkin (Harvard) asked to include all regular variables (cepheids, β CMa-type) in our recommendation. Her opinion was seconded by Dr Merrill (Princeton). Miss Underhill (Victoria) raised the question of desirability to publish the original data (brightness and time) as recorded directly at the telescope, but Dr Huffer (Madison) pointed out that the corrections (extinction, clock, etc.) which must be applied to the original records had better be done by the observer before publishing the data. Merrill objected, in particular, against the vicious habit (slowly gaining ground) of publishing only the 'reflected' normals of the light curves of eclipsing variables—which may conceal any indication of asymmetry—and his view was shared by all colleagues present in the session.

In order to formulate a specific recommendation in which members of both Commissions may wish to place on record the views expressed in discussion, an *ad hoc* subcommittee consisting of P. N. Kholopov, C. M. Huffer, F. Lenouvel, and F. B. Wood was asked to formulate the corresponding resolution, the text of which follows:

Resolved that Commissions 27 and 42, meeting jointly, emphasize the importance of the publication of the original photo-electric observations of regular variables *in full* (i.e. the instantaneous brightness at the corresponding times), instead of mere normal points at given phases, or graphical representation, as is frequently done at present.

It is further resolved that the Presidents of Commissions 27 and 42 be instructed to inform the editors of astronomical journals and directors of observatories of this resolution, and to request their co-operation.

The resolution was moved by the Chairman, seconded by Merrill, and passed by unanimous vote.

The next subject to be discussed at this joint session was the extent to which recent observational studies have contributed to an identification of the stars of Populations I and II among eclipsing binary systems. There seems but little room for doubt that the large majority of eclipsing variables in the spiral arm around us are Population I objects, as evidenced by their relatively high luminosities and low space velocities. On the other hand, the presence of an appreciable proportion of eclipsing binaries among the Population II stars in the central bulge of our Galaxy was established in recent years by the work of Baade and Gaposchkin (though the populations of stars in the globular clusters

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are again completely devoid of them). Certain investigations carried out since throw further light on two important questions, namely, the presence of Population II objects among nearby eclipsing stars, and the distribution and properties of eclipsing variables in at least two neighbouring galaxies.

In the past three years, eclipsing variables have been detected, in considerable numbers, in both Andromeda nebula (M 31) and the Large Magellanic Cloud. Mrs Virginia Nail-McKibben, who has been associated in the investigation of the Magellanic variables with Dr Shapley at Harvard, reports that light curves have now been established for at least 50 such variables (cf. H. Shapley and V. McKibben-Nail, *Proc. Nat. Acad. Sci.* **41**, 185, 1955), and the geometrical elements for some of them have been determined by Russell (cf. his forthcoming paper, entitled 'Eclipsing Variables in the Magellanic Clouds, in the second volume of *Vistas in Astronomy*). The concentration of known variables in the Magellanic Cloud rules out any possibility of their being foreground objects, they must be regarded as genuine members of the population of this neighbouring galaxy.

In addition, Baade and Miss Swope established, in recent years, the first crop of eclipsing variables in M 31 on 48-inch Palomar Schmidt plates. A preliminary account of their discovery was given by them in *A.J.* **60**, 151, 1955. Miss H. H. Swope reported that both Algol and β Lyrae-type variables have been found, with periods longer than about 2·5 days, and (to her recollection) these objects did not exhibit the same concentration towards the dust lanes in spiral arms as the O stars or the H II regions. The apparent magnitudes of the eclipsing objects would place them on the upper part of the Main Sequence.

Of relatively rare Population II binary stars in our neighbourhood, a most significant addition to known objects of this type was made by Walker's recent discovery of DQ Her as an eclipsing system. The foremost question arising in this connexion is whether or not any evidence exists which could confirm the binary nature of the system prior to its outburst in 1934. An examination by Morgenroth of the Sonneberg Observatory plates taken between 1930–34 indicated no perceptible variation, but Dr Hoffmeister pointed out that most of these plates were exposed for two hours, and are thus ill-suited for detecting any variability with 4-hour period. Moreover, Mrs Gaposchkin added that fifteen Harvard plates taken over an interval of 50 years disclose a variability by about 0·4 magn. amplitude, but with no detectable regularity. As no single observatory appears to be in possession of a sufficient series of plates, taken prior to 1934, to verify the variability due to the eclipses, the Chairman suggested that a compilation of occasional plates of this region which may have been taken with fast telescopes at different observatories of the world would represent a very worthwhile task, for its outcome might enable us to verify whether or not DQ Her was an eclipsing variable, of amplitude about 1·0 magn., before its 1934 outburst. With regard to a frequency-dependence of this amplitude as reported originally by Walker, Prof. Rosino (Padua) remarked that it may be due to the contribution of the surrounding nebulosity to the light admitted through the pinhole of the photometer (which would be frequency-dependent), and Dr Walker agreed with this suggestion. Walker was also asked as to the number of other post-Novae which he may have scrutinized for short-period variability of eclipsing nature. He replied that the only other old Nova for which no such variation was found to exist is T CrB (although its composite spectrum indicates that it is probably a double star). If, however, other post-Novae are close binaries, and the fractional dimensions of their components are about the same as for DQ Her, only 10–15% of them should be expected to be eclipsing variables by accident of orientation of their orbital planes.

The only class of Population II dwarf stars among which no close binaries have as yet been detected are white dwarfs, though this fact may be largely the result of observational selection, and their ultimate discovery only a matter of time. Dr Lenouvel (Observatoire du Pic-du-Midi) reported, in this connexion, that he observed with the aid of a photoelectric photometer attached to the 47-inch reflector of the Observatoire de Haute Provence 13 selected white dwarfs continuously for periods of the order of 30 minutes, in two colours, and failed to record any light variation. Dr Heard (David Dunlap Observatory) recalled that, prior to 1950, six white dwarfs were tested for variability by photographic methods, likewise with negative results.*

In conclusion of the meeting, Dr Huffer made a plea in the interest of one additional aspect of our work which calls for international collaboration, namely, the observation of eclipsing variables whose periods are so close to an integral multiple of one day that many years would be necessary for a complete coverage of their light curves from any single observing station. As typical examples of such stars he quoted Y Cyg ($P=2{\cdot}9963$ days), Z Her (3·9928 days) or η Ori (7·789 days), though many others could be added to the list. The co-operation of at least two observatories at widely different longitudes is necessary, in such cases, to obtain complete results.

ZDENĚK KOPAL

* The writer has since been informed that Broglia and Masani, working at Brera-Milano, established photo-electrically the non-variability of the following white dwarfs: Grw +70°8247, L 1244–26, LDS 678 A, Wolf 1346 and 1516, and have further objects of this class under observation.