27. VARIABLE STARS (ÉTOILES VARIABLES)

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1. INTRODUCTION

This report has been written by the President ad interim and others whose names appear at the heads of the sections for which they are responsible. The President a.i. is responsible for some slight editorial changes in these latter reports. In the sections written by the President a.i. at least, the view has been taken that the best use of the available space would be to give an extremely concise account of each topic with plenty of references. It is hoped that in this way the report is made a useful work of reference. Extensive use of *Astronomy and Astrophysics Abstracts* by the writer strongly suggests that despite the vast help they give the working astronomer, some survey such as the present is needed by workers in this and related fields.

References are given according to their numbers in *Astronomy and Astrophysics Abstracts* or else in another obvious form. Some common abbreviations are in the last report. In addition; a number preceded by IAU indicates an IAU Circular; *IB* indicates Information Bulletin for variable stars; Bamberg 1971 denotes the 1971 Bamberg Colloquium No 15; a name plus a journal name indicates a paper in press; a name alone indicates an unpublished observation. During the period under review this Commission co-sponsored IAU Colloquium No 15 on 'New Direction and New Frontiers in Variable Star Research' (Bamberg 1971), and IAU Colloquium No 21 on 'Variable Stars in Globular Clusters and in Related systems' (Toronto 1972).

2. PREDICTING THE FUTURE

The IAU Executive require a report on the priorities and expected developments in the field of each commission. This will be used in a report to a 'Panel of Scientific Priorities' of the International Council of Scientific Unions presumably for use in influencing policy making and fund granting bodies. The president a.i. has prepared this section (as a basis for discussion) with great reluctance. First, because the unexpected is generally the most significant. Secondly, because the primary function of those who administer funds for pure science (as distinct possibly from applied science) should be to support high quality scientists in the work the *latter* have chosen to do. Attempts by administrators and committees to lay down objectives and to carry out research by proxy can be disastrous.

Inevitably some of the most interesting recent results have come from the application of new techniques to variable star research, e.g.; Infrared excesses and Microwave (OH etc.) emission; Very Rapid Optical Variations; Stellar XR sources (and possible optical identifications); Spectra of very faint objects using image tubes; Observations from space platforms. Sound technical advances seem almost always to uncover the unexpected. In several of the new fields progress now requires well planned, systematic programmes, e.g. how do infrared excesses in variables change with time? Significant advances seem most probable from concerted attacks on specific problems by many different techniques simultaneously.

Nearly all variable star programmes will presumably be aimed at making some contribution, however small, to the following basic aims.

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1. *The physical study of stars and the causes of variability*

Variables offer an unrivalled opportunity to study physical conditions in stars. Some lines of investigation which will no doubt be actively pursued are as follows.

(a) *Confrontation of pulsation theories with observations.* We are at the exciting stage when theories are becoming sufficiently realistic and observations sufficiently numerous and accurate that a comparison of the two becomes meaningful. Problems have arisen in such comparisons for cepheids. Their resolution theoretically and observationally (including improved absolute magnitudes) must deepen our understanding of the cepheid phenomenon. Similar remarks apply to βCMa stars, variable white dwarfs and other stars with multiple periodicities where extensive observations are needed to unravel the complexities involved. Such work contributes fundamentally to studies of stellar structure.

(b) *Mass loss and circumstellar material. Relation of pulsation to mass loss.* In some variables (e.g. red variables, RV Tauri and RCB stars) the ejection of shells (often containing solids) results from, or co-exists with, pulsation. Concerted efforts (photometric, polarimetric and spectroscopic) at many wavelengths should reveal the mechanisms at work in the stars and show how the solid particles are formed (a problem of great general astronomical significance). Similar considerations apply to circumstellar matter around premain sequence variables. All planning should be sufficiently flexible to allow studies of important rare phenomena when they occur (e.g. the recent outburst of V 1057 Cyg). The nova phenomenon is an example of how established studies (e.g. light curves and spectra) become vastly more significant if carried out in conjunction with UV, infra-red and radio work. XR variables, eruptive binaries, pulsars, flare stars, magnetic variable, symbiotic stars, are some examples of variable stars whose nature is now barely understood but is within reach.

2. *The place of variables in stellar evolution*

Variables stand in the forefront of modern evolutionary work, partly because many lie at very advanced or very early evolutionary stages which are hardly understood. (e.g. T Tauri stars, RV Tauri stars, U Gem stars, RCB stars). Some of these groups are small. Discoveries of new objects in these groups are important. Despite much work, understanding of RR Lyrae variables is far from complete. Red variables offer an opportunity to study evolution off the red end of giant evolutionary tracks. The destination of these stars (? planetary nebulae) is a matter for speculation at present. Much work remains, to divide the heterogeneous red variable group into physically related subgroups. Studies of red variables in clusters are of great significance in this work.

3. *Variables in galactic and extra galactic work*

Variables will remain in the forefront of research on galactic structure and dynamics, e.g. problems of spiral structure and the constitution of the galactic nuclear bulge. The importance of cepheids, variable supergiants and supernovae in extragalactic astronomy remains. Increased effort is expected on the accurate study of variables in the Magellanic Clouds. This should provide badly needed data both on the absolute magnitudes of the variables and on the composition of the Magellanic Clouds including possible differences from our own Galaxy.

3. GENERALITIES

One of the most important functions of Commission 27 is the sponsoring of the *Information Bulletin* for variable stars (*IB*). This is edited by Professor Detre and supported by the Konkoly Observatory. Professor Detre writes that the Konkoly Observatory has renewed its support for a further three-year period. The third edition of the indispensable *General Catalogue of Variable Stars* prepared by Professors B. V. Kukarkin and P. N. Kholopov and their colleagues appeared during this period in three volumes. In addition the first supplement was published. Extensive work in compiling the material for the successor of *Geschichte und Literatur des Lichtwechsels der Veranderlichen Sterne* has been done by H. Huth (up to 1972.8 for constellations And to Car) including the computation of (B-R) curves for nearly all periodically varying stars. The RASNZ has continued publication of charts and sequences for southern variables. Observers of the RASNZ, the AAVSO, BAA etc. continue their extensive observations of variable stars. A number of these observations are now photoelectric. AAVSO reports now contain computer plotted light curves (05.122.069).

An important facility is the depository of unpublished photoelectric photometry of variable stars (IAU (27)RAS). (cf. *IB* 510). The following information is supplied by Dr. W. S. Fitch.

Astronomers who wish to obtain unpublished photoelectric measurements on variable stars may do so by requesting at cost copies of whole files (not partial files) from *either*

Dr. E. W. Maddison, Librarian	*or*	Dr. V. P. Tsessevich
Royal Astronomical Society		Astronomical Observatory
Burlington House		Shevchenko Park
London, WIV ONL, England.		Odessa GSP 714, U.S.S.R.

At present, the depositories contain 22 files briefly described here as files IAU(27). RAS—

1. 3433 *UBV* measures of V Sge by Herbig, Preston Smak, and Paczynski.
2. About 2390 *U* measures of AE Aqr by Walker.
3. About 990 uby measures of BD $+14°431$ By Smak.
4. 2726 *U* measures of Nova WZ Sge by Krzeminski.
5. 508 *UBV* measures of HD 116994 by Chambliss.
6. About 6500 *UBV* measures of Nova Z Cam by Krzeminski and Mumford.
7. About 3370 yellow and white measures of EX Hya by Krzeminski.
8. 1191 *BV* measures of AU Pup by Chambliss.
9. About 1200 uby measures of HR 7484 by Koch.
10. 1167 blue measures of 16 Lac by Walker.
11. Measures of EM Cyg by Mumford and Krzeminski.
12. UBV measures of SX Ari, CU Vir, HD 173650, and χPsc by Blanco Catalano, and Godoli
13. 964 *BV* measures of TT Lyr, AD Her, and RV Oph by Walter.
14. 630 *UBV* measures of HD 199757 by Chambliss.
15. About 660 *ubv*, Hγ measures of δ Cet, ν Eri, β CMa, ξ' CMa, 15 CMa, β Cru, τ' Lup, σ Sco, and θ Oph by Watson.
16. About 517 *UBV* and 197 intermediate band measures of SX Cas by various observers, edited by Koch.
17. *UBV* measures of RZ Cnc by Broglia and Conconi.
18. 471 *UBV* measures of V505 Sgr by Chambliss.
19. About 2400 *ubv* measures of QS Aql, EG Cyg, FZ Del, AK Her, LS Her, and EW Lyr by van der Wal.
20. About 2535 *bv* measures of CW Cep and RU UMi by Nha.
21. About 4800 *UBV* measures of SU Cep, UV Lyn and RU UMi by Bossen.
22. About 240 *UBV* measures of HDE 302013 by Cannon and others.

Astronomers who wish to contribute photoelectric observations to these archives should send duplicate copies of tables with a descriptive cover sheet to: Dr. W. S. Fitch, Steward Observatory, The University of Arizona, Tucson, Arizona 85721, U.S.A., for assignment of file numbers and forwarding. New files must be printed or handwritten in black ink on sheets smaller than 10×15 inches ($25{\cdot}4 \times 38{\cdot}1$ cm).

4. VARIABLES OF THE ORION POPULATION (T. TAURI STARS ETC.)

The Orion population includes the T Tauri variables and other stars which are probably related to them. These stars are thought to be young, pre-main sequence objects. A new catalogue of emission line stars of the Orion population (*Ap. J.*, **174**, 401) contains many variables. The Ae and Be variables of this population have been much studied. Several are bright in the infrared (05.114.039; 06.114.102) and appear to be pre-main sequence objects surrounded by circumstellar material (*Ap. J.*, **171**, 267, **173**, 353, *BAAS*, **4**, 325). The variability of Lk Hα 224 and 225 in the young stellar group near BD +40°4124 was confirmed (*IB* 713). Quasiperiodic minima not accompanied by colour changes are found in SV Cep and may be due to the effects of cm-size particles in a circumstellar shell (02.122.170; *A.N.*, **292**, 221, c.f. WW Vul *A.N.*, **294**, 29). Power spectrum analysis of RR Tau suggests periods of 80, 200 and 533 days (06.122.068). A statistical analysis was carried out of possible variables in the Ori T2 association (03.122.013). Other work on young variables includes studies of $U-V$ excesses, UBV photometry and polarization (*Ap. J.*, **175**, 89; 06.122.145 +016). In NGC 2264, 25% of pre-main sequence stars are short period irregular variables. Two appear to be pre-main sequence δ Scuti stars. Strong polarization is present in a T Tauri member which lies below the main sequence confirming the hypothesis that this and other young objects are surrounded by circumstellar shells (*Ap. J.*, **171**, 539, **175**, 127 and Bamberg 1971, pp. 40, 85). Flare activity in VY Tau has been further studied (05.123.049).

The Liège 1969 colloquium volume contains a collection of papers on T Tauri and related stars (05.122.046, etc.). A summary (mainly spectroscopic) of T Tauri work is given by Kuhi (02.122.091). $UBVRI$ measures of various T Tauri stars (04.113.021) and V, R of some in the Orion nebula (05.122.037) have appeared. Six faint new T Tauri stars were found in the Orion nebula (05.122.037). For T Tauri itself the light variations seem to contain three components; (1) nightly variations ($A \leqslant 0\overset{m}{.}1$); (2) seasonal variations ($A \leqslant 0\overset{m}{.}2$); (3) outbursts ($A \sim 1\overset{m}{.}8$ in U or $0\overset{m}{.}3$ in V) of not more than a few days duration (04.122.135). The light curve of RY Tau was interpreted as showing a component due to obscuration by neutral clouds and another due to variations in the short wavelength tail of the IR excess (04.122.013). See also (05.122.088). OH emission at 1667 MHz was detected in the region of SU Aw and RY Aur and may come from small dust clouds around these stars (06.131.005). It was suggested that RS CVn is a T Tauri-like star in an eclipsing system (*PASP*, **84**, 323).

Much work has been done on the T Tauri variable V 1057 Cyg which in 1970 brightened from 16^m to 10^m and showed an early type spectrum (B or A with strong lithium absorption) (05.122.087 +045) and a large infrared excess. It behaved very similarly to FU Ori except that the rise time (250 days) (05.122.120) was longer. No such previous brightening (back to 1889) has been detected (06.122.064 + 066). The IR excess is probably due to a dust shell at ~110°K (06.114.098). The polarization is probably interstellar and the recently observed changes probably involve effects in the star itself rather than the clearing of a circumstellar cloud. During the second half of 1971 the star was declining slightly in brightness (at all observed wavelengths) and becoming later in spectral type (*AA*, **20**, 99; *PASP*, **84**, 34). (See also *Ap. J.*, **169**, L117, **172**, L77; 06.122.137; *IB* 722.) Summaries of the observations including a list of possibly similar objects have been given (05.122.102; *IB* 714). A bright filament became visible near the star presumably due to reflection of star light (05.122.045 + 087). One proposed model involves the fast readjustment of mass distribution in the star and the consequent release of potential energy as radiation (06.122.136). Hopefully, this object will clarify some of the uncertainties surrounding our knowledge of pre-main sequence evolution.

The nebula near FU Ori is radially polarized (04.132.038). A theory of FU Ori type stars (FUORS) has been given (06.122.042). R Mon shows variable optical polarization (03.131.013). No polarization of comparable strength to that in R Mon was detected in nine other objects in cometary nebulae. A general description of the spectra of eight stars in cometary nebulae including cases of emission line variability has been given. Photoelectric observations place some of these stars above the main sequence (02.114.030). Observations of other Orion population stars are given in 02.122.011, 03.122.003, 04.122.056 + 057.

The Sonneberg Group have remained particularly active in work on the variability of extremely young stars and related objects. Their work combines photoelectric and spectroscopic observations (partly in collaboration with the Tautenburg Karl-Schwarzschild-Observatorium). Some of their work is referred to above. Additional problems studied include the group properties of variables in young clusters and associations (*AN*, **239**, 81; **294**, 9 + 23; *MVS* **6**, 24; **6**, no. 3) and theoretical work on the physical processes in circumstellar gas (Thänert).

5. FLARE STARS

A useful collection of papers on various aspects of flare stars is given in the Bamberg 1971 volume and in Lovell's review (*QJRAS*, **12**, 98). Collaborative programmes on flare stars are dealt with by a working group (see Appendix IV). Extensive work (fostered by the group) has been done and large amounts of data have been published on individual flares, mainly in *IB* but also elsewhere. The Catania Observatory for instance has a large programme of photoelectric observations of flare stars, partly in collaboration with the working group. A number of new flare stars have been detected (05.122.031, 03.122.054 + 101, *IB* 623, 624, 724, Sanders (Uccle)). Amongst these is Ross 128 which is probably an evolutionarily 'old' object (*IB* 707). Flare-like activity is suggested for the Be Star 66 Oph (03.122.065 + 069 + 107). Much effort has gone into searches for more flare stars in clusters and associations: Orion (02.122.172, 03.132.032, 03.122.028 + 029, 02.122.111, *IB* 670); Pleiades (05.153.016, 05.122.124, 03.153.021 + 022, 04.122.124, 02.122.111 + 145 + 144, *IB* 715, 716, 688); Hyades (02.122.146); Coal Sack (06.122.140); NGC 7023 (02.122.010, 05.153.019).

Orion Association. A new 'slow' flare star (rise time > 30^{m}) was found (02.122.147). Radio emission has probably been detected from Orion flare stars. Coherent plasma oscillations or amplified gyro or synchrotron emission seems necessary to explain the large amounts of energy involved (02.122.124, 05.122.068). The flare activity increases with increasing distance from the centre of the association (04.122.114).

Pleiades. A possible 'cavity' in the frequency of flare stars at the centre of the cluster has been disputed (*IB* 604). Haro 18 flares at the high rate of 1 flare/13 hours (06.122.097). Two other stars also have very high flare rates (02.122.123). All or almost all Pleiades stars with $V > 13{\cdot}3$ are flare stars. The average frequency of flares with $A > 0^{m}_{\cdot}6$ is $\sim 4 \times 10^{-4}\ h^{-1}$. The distribution of flare frequencies is characterized by two Poisson distributions (03.153.010). There is evidence for large but slow variations in activity in some Pleiades flare stars (06.122.094).

Flares have been detected from both components of YY Gem and EQ Peg (06.119.006; *Ast. Let.*, **10**, 37). Thus it is not invariable that only the fainter component flares in binaries containing flare stars. Flares have been observed from the peculiar spectroscopic binary CC Eri (*IAU* 2434). HD 197481 is a periodic dMe star apparently similar to CC Eri (*Ap. Let.*, **11**, 13). BD −7° 3646 may also be a similar star and other possible examples are being investigated, or need investigating (06.120.013, 05.122.084). Various models for these (CC Eri) stars have been discussed (06.119.007, *IB* 431). The possibility that long period variations are present in them needs further investigation. For UV Cet and YZ CMi the flares are distributed approximately according to a Poisson distribution (05.122.116, see also 06.122.052, 04.122.021). Flare stars do not have IR excesses (06.122.138; *PASP*, **84**, 581) nor have X-rays been detected from them during flares (02.122.120). However a number of calculations of possible XR emission intensities have been made (e.g. *Nature P.S.* **237**, 101 and references given there) and the probable magnitude of integrated XR emission from flare stars in the galactic disc estimated. Changes of optical polarization during flares have been reported (05.122.021, also 02.122.116, 05.122.008, 06.122.053 + 051) and it is possible that the changes in polarization last longer than the optical flare (06.122.108). The flare incidence for 21 dMe stars near the sun indicates that the time averaged energy radiated by the flare is $\leqslant 1\%$ of the energy radiated by the quiescent photosphere (04.122.115). A flare appears to cover only a few percent of the stellar disc (04.122.018). The frequency of flares increases with decreasing luminosity of the flare stars. The mean flare amplitude is larger for lower luminosity stars but the absolute energy radiated is greater for the higher luminosity stars (06.122.012). Further discussions have been given of radio-optical correlations (04.122.022). Gurzadyan discusses the theoretical interpretation of the light curves (02.122.122, see also 03.122.081). Photometry of EV Lac appears consistent with an optically thin model (04.122.023). There may be an excess of flare stars in the solar neighbourhood (04.122.002).

6. RED VARIABLES (INCLUDING OH/IR SOURCES)

1. *General*

Eggen has continued his extensive work on red variables of various population groups mainly using *UBVRI* photometry (05.113.003 + 011 + 019, 06.113.032, *Ap. J.*, **172**, 639). Instability generally sets in near $(R\text{-}I) \sim +0^{m}.8$. The fraction of variable M stars rises from 14–33% in the Ma's to 72–80% in the Mb's (see also 05.113.017). Extensive observations of Mira's in Wing's narrow band system (out to 1·04 μ) show that at a given spectral type Miras with $P < 300^{d}$ are significantly hotter than normal M Giants (05.113.042, 06.122.083, *Ap. J. Sup.*, 209). The SR variable R Dor may be the nearest M giant later than M6, it is a very bright infrared object (05.114.050 + 110). NML Tau (= IK Tau) has an abnormally large infrared amplitude (*BAAS*, **4**, 322). Red variables occur in several lists of infrared stars (05.113.021, *A. J.*, **77**, 374). Reviews of infrared work include 06.144.062, 06.113.010. The silicate emission at 10 μ has been observed in detail in some variables (*Ap. J.*, **175**, 687). A number of papers give *UBV* photometry of red variables (03.113.047, 05.122.029, *AA*, **19**, 164, *PASP*, **81**, 381).

Revised spectral types of Mira variables in the region of the galactic centre show that these are not abnormal for their periods (*QJRAS*, **13**, 191), contrary to earlier work. Lloyd Evans finds Miras with periods up to 450^{d} to be common in the region of the centre. The problem of the proper subdivision of Mira variables into different population groups has received further attention (04.122.125 + 104) but there is not full agreement yet on this matter. The kinematics of SR variables was discussed on the basis of many new radial velocity determinations. They belong to the old disc population (*MN*, **158**, 23). Some new proper motions of long period variables were published (03.112.018, 04.112.007). Infrared absolute magnitudes of Miras were derived (05.122.066, and Toronto Thesis (Barnes)), based on extensive *VRI* photometry. Also of importance for absolute magnitude determination is membership of red variables in clusters and double stars (*IB* 606, 03.122.025). The considerable influence of underestimated distances (due to statistical effects) on discussions of Mira kinematics was pointed out (*Vistas*, **13**, 207). Work has been done on changes of period and other problems of the light curves and a monographic treatment of all observations of Mira itself published (02.122.136 + 100, 04.122.078, 05.122.117). Infrared excesses have been observed in Ic variables (*Ap. J.*, **161**, L219).

A large effort has gone into observing the polarization of red variables at a wide range of wavelengths. Collections of papers appear in *Kitt Peak Contrib.* 554 and Bamberg 1971. Various papers cover supergiant red variables (04.122.001 + 076 + 126, 05.114.035, 05.122.020, 06.122.045) and lower luminosity variables (03.122.046). In late type irregular giants and supergiants the polarization seems to be correlated with the infrared excess and the presence of Ca II and other emission lines (05.131.105). Polarization is generally present in variables having large infrared excesses (06.131.008) but it is quite small at 10 μ (*Ap. J.*, **175**, 693). In the Miras (05.122.018, see also *Proc. Aust. Ast. Soc.* **2**, 108) the observations suggest that the polarization arises in a circumstellar shell and not in the stellar atmosphere. The alignment of the dust particles by a magnetic field has been suggested (06.131.037).

The appearance of a strong blue continuum in the SR (M6 III) variable CH Cyg led to much photometric work. Rapid fluctuations in *U* on a time scale of minutes were observed (02.122.085, 03.122.044, 06.122.047). These died out in mid-1970 and reappeared in mid-1971 (04.123.045, 06.122.063). It seems likely that the blue radiation comes from a hot subdwarf companion which underwent an eclipse in 1970–71 (orbital period ~ 5 years). Spectroscopic observations have been discussed (06.122.058 + 096). V462 Cyg may be a similar object (*IB* 626). HD 5963, a carbon star, also showed a transitory blue continuum (*Ap. J.*, **163**, 309) and is slightly variable in light (*IB* 643).

VW Eri and QT CrA have been added to the small number of known SRd variables (03.122.096, 05.122.033). The G0 Iab star BD + 63°141 is a 134^{d} variable (03.122.055). Some of the red variables in the Magellanic Clouds may be SRd variables (Bamberg 1971, p. 90). Others are supergiant variables similar to S Per (05.122.107). In addition what are probably true Mira variables have been detected in the LMC with periods between 126^{d} and 420^{d} (06.159.022). Extensive *UBVRI* photometry of N and S and related objects has been made and used to classify these objects and to divide them into different population groups (*Ap. J.*, **174**, 45; *MN*, **159**, 403 and in press (Eggen)). Se variables generally belong to a disc population but one halo (high velocity) object has been found (05.122.106). The SC star Henize 120 has a light curve like R Cen (*IB* 679).

2. *OH/IR sources*

Extensive work on the detection of IR radiation and OH and H_2O microwave emission from stars, most of which are red variables, has been carried out (cf. summaries to 1970 in *Kitt Peak Contrib.* 554 and Bamberg 1971). The results indicate three main groupings of objects.

(1) Type II OH/IR stars. 1612 MHz is the strongest OH line and has two sharp components. These stars have large IR excesses (*AA*, **17**, 385; *AA*, **16**, 204; 03.114.073)

(2) Type I OH/IR stars. These are main line (1665 and 1667 MHz) OH emitters with H_2O emission but little or no infrared excess (05.122.003, 06.131.006). Both Types I and II are mainly late type Mira Variables.

(3) Supergiant OH/IR stars: The 1612 MHz double emission components are broad (e.g. VY CMa, NML Cyg) and large IR excesses and H_2O emission are also found (02.114.009, 05.114.028). Much of the work has been of a survey nature. Only a small proportion of Mira or SR variables are OH/IR stars (e.g. 06.122.041). Monitoring of stars for variability in IR, OH and H_2O is in progress (e.g. *BAAS*, **4**, 232; *BAAS*, **3**, 380). The strength of H_2O microwave emission seems anti-correlated with 1·9 μ H_2O absorption (04.122.063). Optical identification should be aided by recent accurate radio positions (5″–15″ accuracy) (06.114.099, *Ap. J.*, **172**, 583). Several 1612 MHz emitters remain unidentified optically. OH 338.5 + 0.1 seems to be a very red early M Type star (Glass, Feast, *Ap. Let.*). Observations suggest that IR colours correlate well with the velocity separation of the OH peaks and that the integrated OH emission is not critically dependant on the dust shell character but that the thickness of the shell affects the OH line ratios (main line emitters have optically thin dust shells) (*Ap. Let.* **11**, 7). The Maser theory of OH/IR objects has been further developed leading to an estimate of the mass loss of $\sim 10^{-6} M_\odot yr^{-1}$ (*Ap. Let.* **12**, 113). For NML Cyg very detailed observations (*Nature P.S.*, **237**, 21) give the distribution of many small OH components of different velocities in an elongated region 3·2 × 2·3 arc secs. The results suggest a model in which the rear of the shell is obscured by dust. There is evidence for rotation and for mass loss at the very high rate of $3{\cdot}5 \times 10^{-3} M_\odot yr^{-1}$.

A detailed model for VY CMa based on the energy distribution has been worked out (05.122.005) and radial optical polarization (up to 70%) has been found in the surrounding nebulosity. Other papers give the wavelength dependence of polarization for the whole object and discuss models (02.122.007, 04.122.039, 05.114.061, 06.131.086). A small amount of infrared circular polarization has been found (*Ap. J.*, **173**, L23). The intensity of OH and H_2O emission and the polarization of OH are variable (02.114.068, 04.131.052, 06.131.061). Long base line work in H_2O emission fails to resolve the object down to 0″003. A tentative detection of V YCMa at 3·5 mm has been made (05.114.064). Spectroscopic work includes photographic monitoring and infrared work (including the possible detection of SiO absorption) (02.113.027, 03.122.079, 04.122.094, 06.122.084). The unique light curve of the object over 60 years and evidence for a secular decrease in brightness over 170 years as well as the history of the variable as a multiple star have been published (04.123.051, 06.122.112, *Ap. J.*, **175**, L93). VX Sgr has some similarities to VY CMa in OH and spectral characteristics. Its light variations resemble Miras but it is of considerably higher luminosity (04.122.040, 05.122.004, 05.131.094, *Ap.J.*, **172**, L59).

7. THE R CORONAE BOREALIS (RCB) VARIABLES

An extensive investigation of RY Sgr, during and following a light minimum has been published (*MN*, **158**, 305). During initial decline the photospheric light fades rapidly (time scale ⩽ 5 days) and the chromospheric emission more slowly (time scale ~ 22 days). Evidence of pulsations in light colour and radial velocity with a period of 38·6 days was obtained. The observations strongly support the hypothesis of obscuration of the star by a circumstellar dust shell and yield $A_v/E_{B-V} = 4{\cdot}3$ and $E_{U-B}/E_{B-V} = 1{\cdot}3$ for the shell. The observations require the ejection of a dust cloud from the star rather than eclipses of the star by pre-existing clouds at a distance from the star. Some *UBVRI* observations of RY Sgr were published (04.122.042). UW Cen appears to be another pulsating RCB star (period ~42 days) (*IB* 661). There is also evidence for small amplitude pulsations of R CrB itself in about the same period (*Ap.J.*, **172**, 383).

Also in the H-deficient class of stars, HD 30353 has been shown to have semi-regular variations of period ~30 days (02.122.003). A number of workers have observed RCB stars in *UBV* and other photometric systems (e.g. Pels (Leiden) Andrews (Pretoria) Sherwood (Bochum) Eggen (Stromlo)). More, accurate, work is desirable to increase our scant knowledge of the stars.

Several RCB stars have been active during this period, e.g. R CrB (05.122.048) RY Sgr (05.123.034), S Aps (05.123.035 and 036) and SU Tau (05.123.031 and 032). In the latter case a drop in visual light was accompanied by a brightening at 5 μ as expected if the decline was accompanied by the formation of a circumstellar shell. It appears that the initial hypothesis of constant total bolometric magnitude (star + shell) may be too simple a view (06.122.101 and Wing *et al.*, *PASP*). Presumably this implies non-uniformities in the shell. However large departures from uniformity might be expected to affect the ratio A_v/E_{B-V} and there was no indication of this for RY Sgr (*MN*, **158**, 305). Infrared excesses are a normal feature of RCB stars including the hot object MV Sgr, but not of the spectroscopically related (but constant) HdC and Helium stars (Feast, Glass, *MN*). The peculiar C II emission object V 348 Sgr has a large infrared excess strengthening its similarities to the RCB stars (see 02.123.040 for a light curve of this star).

Four RCB stars are now known in the Large Magellanic Cloud (06.159.010). Two of them have C_2 band strengths similar to R CrB itself and have M_V's of −5 and −4. Another has very strong C_2 bands (like S Aps) and $M_V \sim -4$ (04.122.098 and *MN*, **158**, 11p). One new galactic RCB has been discovered (*IB* 617) and one removed from the class (*Ap.J.*, **174**, L89).

On the theoretical side, dust envelopes for RCB stars have been studied (03.122.119 and *PASP*, **84**, 64). Suitable stellar models have also been investigated (06.065.010, Trieste 1971, p. 383, Bamberg 1971, p. 54, *MN*, **158**, 385, 05.065.025, 05.065.039). The observed pulsation characteristics of RY Sgr (*MN*, **158**, 305) are broadly consistent with the pulsational characteristics of model helium stars (*MN*, **156**, 411).

8. RV TAURI STARS

Large infrared excesses have been detected for several RV Tauri stars. This is probably explained by the condensation into grains of material ejected from the star by shock waves (04.122.046). Dust probably explains the large and variable polarization observed in some RV Tauri stars (03.122.077). Gross long-term changes in the circumstellar absorption spectrum of U Mon were observed (*Ap.J.*, **172**, L105). Extensive *UBVR* photometry of RV Tauri stars shows the variability of their light curves. Statistical parallaxes were estimated and evidence found for a period-luminosity relation. There is some evidence for circumstellar reddening and absorption in line with the dust shells inferred from other data (*BAAS*, **4**, 217 and Toronto Thesis (Du Puy)). The period instabilities are less for RV Tauris of the spectroscopic group B of Preston *et al.* than for Group A (06.122.017). The SRb variable TW Del has some of the characteristics of an RV Tauri star (*AN*, **293**, 171).

9. OPTICAL WORK ON PULSARS

A number of general reviews on pulsars are available (04.141.121, 05.141.045, 06.141.217, *Rep. Prog. Phys.*, **35**, 399). Here we deal only with optical observations.

The Crab pulsar NP 0532 remains the only one identified optically. Several papers on optical observations appear in the proceedings of symposia on the Crab (*PASP*, **82**, 375 *et seq.* and *IAU* **46**). The times of arrival of the optical pulses at four observatories are in good agreement showing that reported departures from a simple slowing-down law are intrinsic to the pulsar (05.141.127). Optical timing over a two year period indicates that there are three components to frequency changes: (1) (the major component) a cubic braking function; (2) glitches (e.g. Sept 1969); (3) a noise component (*Ap.J.*, **175**, 217, see also 04.141.066 + 125, 05.141.157). Changes in wisps of the nebulosity seem to have originated near the pulsar at the time of the Sept. 1969 glitch (03.134.005). One model predicts a high frequency modulation of light from NP 0532 (05.141.113). An unsuccessful search was carried out for nanosecond optical flashes (02.141.150). Observers now seem agreed that the main features of the optical polarization are that it is high ($\sim 20\%$) in the wings of both pulses but near zero at the pulse centres, and that in both pulses the polarization angle rotates in the same sense with a total rotation of $\sim 150°$ (04.141.183 + 019). There is no evidence for secular changes of total intensity or colour. The optical observations fit the Radhakrishnan-Cooke Model (proposed for the Vela Pulsar) well (06.141.114, see also 04.141.068, 06.141.212). There is no evidence for optical circular polarization (05.134.005, 06.141.187).

No other pulsar has yet been detected optically despite extensive searches (04.141.201, 05.141.150 + 174 + 173 + 002). Searches for the Vela pulsar have been the most intensive. These have so far been unsuccessful to a limit of $\sim 27^m$ (*BAAS*, **4**, 320, see also 02.141.004, 04.141.174 + 175). A magnitude of $\sim 27^m$ had been predicted (05.141.004). A variable optical object near the nucleus of M 99 may be an optical pulsar (05.141.175).

10. EX-NOVAE, ERUPTIVE BINARIES, ULTRA-SHORT PERIOD BINARIES AND OTHER RAPID VARIABLES

Considerable progess has been made in understanding this group of stars, partly as a result of the application of high time resolution equipment to this problem (Bamberg 1971, p. 144 and 160). An agreed model seems to be emerging in which a, (cool) low mass star loses mass to form a ring round a white dwarf. A hot spot is formed where the stream meets the ring (e.g. 04.122.100). The diversities observed in this group of stars are due to the differing masses and brightness of the two stars and the differing relative importance of light from the stars, from the ring and from the hot spot. Outbursts may be due to the infall of matter from the ring onto the white dwarf (05.121.026) but other possibilities have been considered (04.122.096, 06.122.010).

U Gem. (05.121.017 and 026) shows flickering on a time scale of from seconds to minutes associated with the hot spot which also undergoes total eclipses. Present models differ from earlier ones in that the hot spot is now situated on the ring not on the surface of the white dwarf. M_2/M_1 is $\sim 0{\cdot}6$.

SS Cyg. (05.119.008) An earlier ambiguity in the period has been resolved and it is concluded that the outbursts are associated with the hot component.

WZ Sge. Extensive photometry (05.124.107) as well as high time resolution studies (*MN*, **156**, 297) lead to a model somewhat similar to U Gem but with $M_1 = 0{\cdot}35\ M_\odot$ and $M_2 = 0{\cdot}025\ M_\odot$. Gravitational radiation losses are likely to be of importance for this and related objects (04.124.111 05.121.022, 06,117.023). The system might have originated from a star-planet configuration (03.121.035).

EX Hya. (*MN*, **158**, 425) is a similar system with only a partial eclipse of the bright spot. The star may be the X-ray source 2ASE 1253-28.

AE Aqr. The period is probably $0^d\!.4$ rather than $0^d\!.7$ as previously supposed (02.119.008).

WY Sge. Short time scale fluctuations confirm the supposition that this is ex-Nova Sge 1783 (d'Agelet) (06.124.106).

V Sge. New elements of the eclipsing system and a study of the eruptive behaviour have been published (*A.N.*, **293**, 167).

DQ Her. An estimate has been made of the rate of mass exchange (04.124.100).

VW Hyi. Warner reports the star to eclipse with a period of $\sim 108^m$. The spectrum shows wide H emission (Feast).

AM CVn. (HZ 29) is apparently an 18 min eclipsing binary consisting of two white dwarfs (and circumstellar matter). The object seems to have entirely depleted its hydrogen and to be therfore in a post-eruptive stage (*MN*, **159**, 101; *Ap.J.*, **175**, L79).Extensive photoelectric observations of this object indicate period variations which are interpreted as the motion of the close double round a third star (period 2·015 years). The third star is a low mass red dwarf and the mass of the whole system is less than 0·4 $M_\odot$ (Krzeminski, *Ac.A.*, **22**, no 4, see also Bamberg 1971, p. 178).

G61–29 is another hydrogen-poor rapid variable in this class (06.114.100, *MN*, **159**, 315).

WX Hyi formerly considered a Mira variable may be a U Gem star (05.114.097, 05.123.033, 06.122.062).

Additional photometric data on eruptive variables are given in 04.121.026 and 05.121.027. In addition extensive visual observations have been made, e.g. by the AAVSO and RAS N.Z. Some useful papers on eruptive binaries and related objects appear in the Bamberg 1971 volume.

Short time scale fluctuations have been observed in *o* Cet B which is interpreted as a white dwarf accreting matter from *o* Cet A (Mira) (*MN*, **159**, 95). Several new eruptive objects, probably U Gem stars have been reported (*I.A.U.* 2408,2267, *IB* 687, 692, 663, Romano). K3П 5235 Pav, V 1709 Sgr and V 2032 Sgr are *not* U Gem stars (*IB* 726; 02.122.176). A catalogue of U Gem stars (03.122.060) and some proper motions (02.112.019 and 021) have appeared. A fourth outburst of AL Com (Rosino's Object) was observed (*IB* 696). The object may be a U Gem star. Three-colour observations of several U Gem stars were made at the Auckland Observatory. Autocorrelation techniques have been further applied to eruptive variables (03.122.094, 04.121.059).

In ten systems short period oscillations have been detected and interpreted as due to non-radial pulsations of the white dwarf component (see *Nature P.S.*, **239**, 2 and references listed there, also 03.122.093 and 017, 03.114.053, *Nature P.S.* **236**, 83). For one of these objects Haro-Luyten Tau-76, Fitch has obtained an extensive set of observations showing extremely complicated (but periodic) light variations. He is engaged on a detailed analysis of these results. A possibly similar object is −42°14462 (*I.A.U.* 2407). The possibility that some of these objects may be radially pulsating pre-white dwarfs has also been suggested (*Ap.J.*, **172**, 181). HDE 310376 may be related to the eruptive variables (or to Sco X-1) (05.122.041, 02.122.035).

11. X-RAY SOURCES

Many XR Sources appear to be stellar objects variable at XR, radio or optical wavelengths. Here the main concentration is on the optical work. Radio and improved XR positions have helped enormously in the optical identification problem. Some reviews (04.142.026 + 027 + 071) cover optical observations till 1969 or 1970. *IB* 674 gives a general comparison of Uhuru positions with GCVS positions. Comparison of Uhuru positions with the SAO catalogue yields 10 relatively bright stars as possible candidates (*Ap.J.*, **175**, L141). Correlations with other types of objects have been examined (05.142.040). Theoretical work depends mainly on mass exchange in binaries e.g. *BAAS*, **4**, 219; *A.A.*, **21**, 1; *Ap.L.*, **11**, 191).

Sco X-1. Very extensive photometry has been carried out (06.142.065 and 092, *Tokyo Bull.* 195, 04.142.007 and 074, 03.142. 030, *IB* 667, *BAAS*, **4**, 227, Pels and Van Genderen (Leiden)). There now seems good evidence for a correlation of XR and optical variations (especially flaring) (*Nature P.S.*, **236**, 53, 06.142.048, 04.142.073 and 093, 03.142 + 033 + 009 + 005). Variations in the far *UV* (OAO) appear to be correlated with variations observed in *UBV* (04.142.029). Radio variations are found with a time scale of hours but these are uncorrelated with optical variations (05.142.024). It is not certain whether two non-variable radio sources close to Sco X-1 are related to it or not (05.141.060). Power spectrum analyses reveal in general no (rapid) periodic variations (04.142.086, 02.142.024) though some repeating pattern in the variations (on a longer time scale) has been suggested (03.142.039). A periodicity of ~170 s for a short while following a series of flares has been found (03.142.035, *MN* **157**, 85 and **159**, 1p). On one occasion simultaneous XR and optical observations both showed oscillations of 20 s period lasting for 2 m (06.142.061). The strength of the interstellar Ca II line suggests that Sco X-1 lies beyond the Sco-Cen association (02.142.017, 03.142.001). Other discussions (*Ap.J.*, **158**, L31, *A.J.*, **74** L20) make the star a Sco-Cen member on proper motion grounds. The linear polarization of Sco X-1 is probably of interstellar origin and there is no evidence of circular polarization (*ApJ.*, **172**, 443 and **173**, L113). No nebulosities connected with Sco X-1 have been found (03.142.032). The spectrum changes (sometimes in minutes) (05.142.002, *BAAS*, **4**, 227) in a manner not fully understood. Models proposed include neutron stars and white dwarfs, possibly in a binary system (03.142.041, 04.142.031, 05.142.054 + + 036, 06.142.006 + 081).

Cyg X-2 λ 4650 emission has been detected in the candidate star (*Ap.J.*, **148** L129, *PASP*, **84**, 68) (*B-V*) reddens with increasing brightness (04.142.030) contrary to the behaviour of Sco X-1. Doubt has however been cast on the optical identification by the discovery of a variable radio source close to the XR position but not coincident with the candidate star (05.142.043). A red variable appears near the radio position (*I.A.U.* 2344).

Cen X-4. S5003 Cen has been suggested (02.142.034 + 067) as an identification for this XR nova (e.g. *Ap.J.*, **171**, L87). The spectrum is peculiar and variable (02.142.069, 03.142.045, 05.114.101). The object is possibly an unusual shell star but the light curve has been classed as RCB type (03.123.033). It has a large infra-red excess (Glass, Feast). Cet X-2 may be similar to Cen X-4 (06.142.078).

2U 0352 + 30. May be identified with X Per which shows spectral changes similar to Be stars (*Nature*, **237**, 92). There is no circular (optical) polarization (*Nature* **237**, 29) and attempted radio observations gave negative results (*Nature* **235**, 273). A series of photometric measures of X Per has been published (02.122.038).

Cen X-2. The candidate star WX Cen is not a member of the Sco-Cen association (06. 142.034, *MN*, **155**, 415). (*B-V*) increases with brightness contrary to the case of Sco X-1 (04.142.030).

Cen X-3. This is an XR eclipsing system, period 2ᵈ087, with pulsations of period 4ˢ8. Occasional anomalously prolonged XR minima have been observed (06.142.005, *Nature P.S.* **237**, 104, *Ap.J.*, **172**, L79, *Ap.J.*, **173** L151). No 5s optical variable or unusual blue object has been found (06.142.023, *P. Aust. A.S.* **2**, 110). The eclipsing binary LR Cen which seemed a likely candidate has a slightly different period (2ᵈ095) and is 15σ away from the most recent XR position (*I.A.U.* 2412, 2395, *Nature*, **237**, 508, **238**, 448, *Ap.J.*, **175**, L137). It must thus apparently be rejected as an identification despite spectroscopic observations of the primary (rapidly rotating B8 III + shell) indicating a likely XR emitting system (*Ap.J.*, **175**, L133). The Be star Wray 795 is a possible though uncertain identification (*Ap.J.*, **174**, L141). Marked spectroscopic variability was not found on two nights at Los Campanos (*Ap.J.*, **175**, L137) or on 8 nights in Pretoria (Feast) despite early reports of variability. The mass of the XR source deduced from the binary system is low($< 0.5\, M_{\odot}$) (*PAS Jap.*, **24**, 419, *Ap.J.*, **174**, L27 + 31). Models suggested involve white dwarfs, neutron stars and black holes (*Nature P.S.*, **239**, 67, **233**, 18, *Nature*, **234**, 450, 237. 329 + 448, *Ap.J.*, **173**, 213).

Cyg X-1. This object is an XR variable on a rapid time scale with no evident regularities (06.142.072, 06.143.018, *Ap.J.*, **170**, L21, *BAAS*, **4**, 261 + 336, *Nature P.S.*, **238**, 22, *Ap.J.*, **175**, L73). A strongly variable radio source has been identified with it (05.142.074, 06.142.090, *BAAS*, **4**, 256). The radio emission has no pulsar-like component or variability in a period of days (as from a binary) (*Ap.J.*, **172**, L17, *Nature P.S.*, **235**, 147). XR eclipses have been suggested (03.142.019). The spectroscopic binary star HDE 226868 (period 5ᵈ6 primary B0Ib, He II emission from secondary or gas strems) is close to the radio position. Despite some doubt (*Ap.J.*, **168** L91) this appears the correct optical identification (06.142.044 + 037, *Nature*, **235**, 37 + 271, *I.A.U.* 2421, 2424). The mass of the secondary is likely to be several solar masses possibly indicating a black hole. Optical eclipses, have been reported (*I.A.U.* 2395, *MN*, **160**, 1p). The binary nature has been used in some models (06.142.040, *Nature P.S.*, **236**, 39, see also *Nature*, **235**, 97).

Sco X-2 may be identified with HD 152667, a P Cygni-like spectroscopic binary having some similarities to HDE 226868 (= Cyg X-1) (*MN*, **159**, 253).

Her X-1. This object is similar at XR wavelengths to Cen X-3 pulsating with a period of 1ˢ2 and being in a 1ᵈ7 binary orbit (*Ap.J.*, **174**, L143). It is identified with HZ Her an A or B type star containing high excitation emission lines and with a variable radial velocity. The 1ᵈ7 period is present in the light and is stable over at least 65 years. The 1ˢ2 period has been detected optically but is frequently absent (*I.A.U.* 2415, 2422, 2424, 2427, 2428, 2430, 2431, 2433, 2434, 2436, 2441, 2454, *IB* 720). A precessing binary pulsar model has been suggested (*Nature*, **239**, 325).

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Cyg X-3 is an XR variable (period $4^h.8$) and also a radio variable (including a large outburst apparently uncorrelated with XR activity) (*Nature*, **237**, 506 + 507, *I.A.U.* 2440, 2442, 2446, 2447, *Nature P.S.*, **239**, 114 *et seq.*). There has been no convincing optical identification (*I.A.U.* 2401, 2424, 2444) but an infra-red object (which may be a highly reddened star) has recently been found near the radio position (*Nature P.S.*, **239**, 130).

2U 0900-40. HD 77581, within the XR error box, is a B0.5 Ib (Hα, P Cygni profile) spectroscopic binary (period $7^d.0$). It is similar to HDE 226868 (=Cyg X-1) and seems a likely identification (*Ap.J.*, **175**, L19, *Ap.J.*, **173**, L105).

*2U 1536-52.*The ex-nova IM Nor is a promising optical candidate (*Ap.J.*, **175**, L69).

GX 3 + 1. The prime optical candidate (as determined from an XR lunar occultation, *Nature*, **235**, 152) appears to be a normal late type star (*Nature*, **237**, 273, Feast) making the identification doubtful.

GX 5 − 1 An optical candidate (star '3') (*Nature*, **236**, 392) has no large radial velocity variations and the spectrum and colours of a normal A0 V star (Webster).

GX 9 + 1. No optical object has been found near the position of the variable radio source (*Nature*, **235**, 378).

2U 1543-47 is another XR nova, probably similar to Cen X-4. It may be identical to HDE 330036 (06.142.047) which is a peculiar emission object showing a large infra-red excess (Glass, Webster). However an extragalactic (supernova) origin for this and other XR novae has been suggested (*Ap.J.*, **175**, L113).

2U 1639-62. A suggested identification (*IAU* 2406) is the peculiar emission object Henize 177, which has been further investigated spectroscopically and shows a large infrared excess (Glass Webster).

2U 1700-37 is a three day XR binary. HD 153919 (type Of) appears a promising optical candidate (*BAAS*, **4**, 329).

SMC X-1. This is an XR eclipsing binary period $3^d.8927$ (Schreier *et al.*, *Ap.J. Let*). A likely candidate is Sanduleak 160 (Webster *et al.* (Pretoria)) which would make this a system like Cyg X-1.

Radio emission has been detected from three binary systems in each of which one component is a B star and there is evidence of gas around or between the two components: Antares B (*Ap.J.*, **163** L105, **168**, L115), β Lyrae and β Per (Algol) (*Nature*, **235**, 270, *Nature P.S.*, **236**, 42 + 43, **238**, 52, *IAU* 2388). In the case of β Per optical activity (e.g. P Cygni structure at K (Ca II) and rapid variation in Balmer lines) seemed to coincide with a burst of radio flare activity. The possible similarity of these systems to XR objects like Cyg X-1 has been stressed.

12. NOVAE

Since Novae have a section to themselves in Astronomy and Astrophysics Abstracts there is no need to list here the many photometric and spectroscopic investigations that have been made during the current period. Mention should however be made of the detection of Nova Del 1967 and Nov Ser 1970 at radio wavelengths (04.124.101, 05.124.100). Nova Ser 1970 was also observed from OAO from near outburst and for about 60 days afterwards. Over this period the total flux between 1000 Å and 6000 Å is approximately constant, the decrease in visual light being due to a shift of the energy curve towards the violet with time (NASA SP-310, p.535). In this nova an infrared excess developed some 50 days after outburst (04.124.001). Infra-red excesses were also found in Nova Del 1967, Nova Aql 1970 and RS Oph. Variable polarization was found in Nova Del 1967 and Nova Ser 1970. In the case of Nova Del 1967 the polarization observations seem to require grains of size $\sim 0{\cdot}10\ \mu$ which may serve as condensation nuclei for the later formation of larger particles which are responsible for the IR excess (06.124.001 + 002). Proper motions of four nova were derived (05.112.003). An attempt has been made to identify pre-outburst images of four novae and a supernova on the Palomar Sky Atlas (*Tokyo Bul.* 214, *I.B.* 472). Further work has been done on the theory of the nova outburst and nova hydrodynamics (*MN*, **155**, 129, *Ap.J.*, **172**, 699). Recent

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work shows that V 605 Aql was probably a peculiar slow nova at the centre of an old planetary nebula, despite a suggested extragalactic origin (05.122.040, 06.122.110, 06.124.107).

13. Am, Ap MAGNETIC VARIABLES

There is evidence that in general pulsation (δ Scuti type) and Am character are mutually exclusive (04.153.040) at least amongst classical Am stars. HR 5491 appears to be an exception to this rule (*PASP*, **84**, 72) though its variability has been contested (*PASP*, **84**, 443). 32 Vir appears to be another pulsating Am star (*I.B.* 704). 28 And (HR 114) also shows pulsations (e.g. 02.122.004) but recent spectroscopic work suggests (contrary to earlier work) that it is not an Am star (04.153.040).

Surveys of Magnetic stars are given in *PASP*, **83**, 571–593 and *Comments*, **3**, 190. A considerable effort has gone into the detection and detailed study of light variations of Ap stars (04.122.117, 03.116.010, 06.113.004, 06.116.004, 03.116.435 + 019, 02.116.024, 03.116.004, 02.116.025, 02.122.001, 02.116.019, *PASP*, **83**, 610, *Ast. Let.*, **11**, 113, 03.116.017). The Catania observatory has a large programme for observing magnetic stars photoelectrically. Generally regular variations with the same period as the magnetic and spectral variations have been found. In the case of HD 125248 there is a double minima in photometry longward of 4600 Å but not at shorter wavelengths (03.116.018, 03.122.074, Bamberg 1971, p. 59, *AA*, **16**, 385). Rakos believes in general all Ap stars have secondary minima in their light curves but that the wavelength regions in which this is observed varies from star to star (e.g. HD 71866 shows secondary minima only in V whereas α And shows secondary minima in U, B and V). 53 Cam (Ap) may be a spectroscopic binary (*I.B.* 618). In γ Equ the magnetic variations favour a period of $1785^{d}.7$ whilst the photometry is better fitted with 314^{d} (05.116.001, *AA*, **20**, 173). Magnetic Field Variations have been discussed for HD 126515, HD 153882, HD 188041, 53 Cam and β CrB. (03.116.014, 02.116.014, 06.116.001, 02.116.003, 02.116.015, 05.116.003, 03.116.015). A reversal of the field has been detected for the first time in γ Equ (06.116.002). The very short period of $0^{d}.168$ has been deduced for the magnetic variations of HD 133029 and this appears inconsistent with the oblique rotator hypothesis (05.116.008). Searches for long period Ap stars have continued (06.113.041, 04.122.043). HD 9996 has magnetic, spectroscopic and photometric variations in a period of ~23 years (03.119.013). Contrary to earlier suggestions it appears that most Ap stars have constant periods (*AA* **18**, 159). For stars later than B9 large light amplitudes are present only for stars with pronounced spectral variations (05.113.047). A reanalysis of the observations of period and line width shows that they are consistent with the rigid rotator model but that a strong decelerating mechanism must operate in at least some Ap stars, primarily Sr Cr Eu stars (04.116.014). Mean surface magnetic fields have been measured for 28 Ap Sr Cr Eu stars with $v \sin i \leqslant 10$ km s^{-1}. There appears to be no correlation of these fields with *UBV* colours, Eu II strengths or rotational velocities as inferred from periods (05.116.002, *BAC*, **23**, 297). The wavelength dependence of polarization for several Ap stars indicates that this polarization is intrinsic (03.116.020). No radio (6 cm) emission has been detected from Ap stars (04.116.025 + 004), ruling out synchrotron radiation as a source of light variations. The visual orbit of HR 3724 (Ap) is consistent with masses similar to early A main sequence stars (*AA*, **21**, 155). A good deal of progress has been made in understanding the effect of magnetic fields on stellar atmospheres and seeing how this explains the Ap phenomenon (*Ap.J.*, **171**, 569, *AA*, **15**, 239). Variations of abundances, and corresponding changes in opacity, over the stellar surface may account for light variations of Ap stars (04.113.018, 05.113.047, *AA*, **16**, 385). This interpretation is supported by observations of α^2 CnV from OAO-2 (NASA SP-310, p. 449, Bamberg 1971, p. 307). Alternatively, regions of different temperatures have been postulated (06.116.011) and possibly also non-spherical stars (05.116.010). The formulae necessary for a harmonic analysis of observations of Ap stars have been given (03.116.007) and the basic theory of magnetic stars reviewed (06.116.010). Coupling between radial and non-radial models in the presence of a magnetic field to explain long period modulation in some types of variable stars generally requires greater magnetic fields than are observed (05.110.013).

Purely spectroscopic work on Magnetic stars is dealt with by Commission 29.

14. SYMBIOTIC STARS AND PECULIAR VARIABLES

Several symbiotic stars in the galactic bulge were observed for variability and one with a period of 243 days found (04.122.145). AG Peg shows a periodicity of 800 days (03.122.045) whilst the irregular variations of AG Dra are attributed to the hot component (04.122.024). HV 13055 may be a symbiotic variable in the LMC (03.122.008). An outburst of CI Cyg was observed (*IAU* 2335, 2336). The relative importance in the infrared of free-free radiation and radiation from dust has been examined for symbiotic objects (05.114.077). Extensive observations of FN Sgr were discussed (*RASNZ Cir.* 164).

HBV 475 was found to be $\sim 2^m$ brighter in 1969 than on the Palomar sky survey plates and to have a complex emission spectrum (02.123.042). The photometric history back to 1891 (03.122.041, 04.133.003, 05.114.019, see also *I.B.* 708) shows a number of outbursts. The light curve is not unlike that of symbiotic objects but the range, $\Delta m > 6^m.5$ is larger than any other such stars. The object has an infrared excess (*Ap. Let.*, **11**, 201). The complex line structures, $u-v$ continuum and broad WR features have all been discussed (*IAU* 2174, 2176, 2182, 04.114.048, 03.133.022, 03.114.110 + 030, Bamberg 1971) and suggestions made that it is a symbiotic object similar to V 1016 Cyg and/or the early stage in the development of a planetary nebula. The detection of TiO absorption in the near infrared reinforces the similarity to symbiotic variables (Andrillat, *C.R.* **270**, 1066). Monitoring of V 1016 Cyg has continued (Philip) (see also 03.114.034, etc). MHα 208-92 (=AS 299) is an emission line object (probably symbiotic) with a light curve like a slow nova (06.114.061 + 060).

FG Sge which appears to be the central star of an old planetary nebula, is in the course of ejecting a new shell (e.g. 04.133.030). The star has been brightening steadily since 1894. However this brightening ceased in 1967–69 (05.123.022, 05.122.118). *B*, *V* measures suggest a periodicity of $\sim$ 60 days besides a shorter period one (*IB* 646). The object has no infrared excess (05.132.003).

Spectroscopic work on η Car has concentrated mainly on the interpretation of the emission line intensities in terms of possible internal reddening (02.122.088 + 090, 05.114.060, 03.114.038, 06.114.064). There is no evidence for short period oscillations (*Nature P.S.*, **237**, 73) but long term small scale variability is present (*IB* 549). The interpretation of X-rays from η Car was discussed (*Nature*, **236**, 46). HD 45677 is a hot emission line star with an infrared excess which is also a light variable (*AA*, **17**, 142, *Ap.J.*, **167**, L41).

15. BETA CANIS MAJORIS VARIABLES

The several investigations aimed at finding new β CMa stars and defining more clearly the region of the HR diagram occupied by these stars should help in understanding the basic cause of their instability about which there is as yet no general agreement. In addition the various interacting pulsational modes which are excited can only be disentangled and interpreted on the basis of extensive high quality data. Extensive programmes along these lines have been carried out or are planned.

A number of new β CMa stars have been discovered (04.122.025, *AA*, **18**, 51, *MN*, **157**, 5p, *MN* **156**, 181) several with broad lines. One possibility is that these broad lines indicate velocity fields in the stellar atmosphere rather than rotation (04.122.009). After α Vir has been shown to be a (broad-lined) β CMa star from photometry the old radial velocities were found to be in accord with this inter pretation (03.119.012). The 4^h period of this star appears unstable and likely to be a first overtone, an observed 6^h period may be the fundamental (*MN*, **156**, 165). A combination of spectroscopic and intensity interferometer data yield 84 ± 4pc for the distancs of α Vir. OAO-2 observation of β CMa and β Cep have been made. In β Cep the equivalent width of the 1550 Å C IV line varies in a period of $\sim$ 6 days. (NASA SP-310, p. 475, Bamberg 1971, p. 97). Fitch plans an extensive photometric investigation of β Cep. This variable is now known to be an astrometric triple (*Ap.J.*, **173**, L1). The Stothers-Simon binary μ mechanism for β CMa stars was much discussed (04.119.004, 06.122.157, 05.121.040). Spectroscopic studies of β CMa stars (06.122.087) show normal composi-

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tions which thus do not support the μ mechanism. Other data also do not support it (Bamberg 1971, p. 197). HD 193516 a possible β CMa star with strong N lines (a prediction of the μ mechanism) has been found to show no significant light variations (06.122.104). There is evidence that the β CMa phenomena is restricted to the range $-6{\cdot}0 < M_v < -3{\cdot}0$ (06.122.135, *AJ*, **77**, 381). There has been further work on defining the position of the β CMa instability strip above the main sequence and determining the pulsation constant Q (03.122.001, *BAAS*, **4**, 218, *Ap.J. Sup.* 204, Balona (Pretoria)). The ranges of light, colours and periods seem consistent with a radial pulsation model (06.122.107, see also 06.122.156). Detailed spectroscopic studies have been made of ν Eri, BW Vul and some other variables (05.122.060, *BAAS*, **4**, 218, 04.122.007). A detailed *UBV* study was made of δ Cet (05.122.103). Radial velocities confirm the period of EN Lac (03.122.010). The period of β Cep is constant (04.122.026) whilst that of BW Vul is changing at +3.7 sec/century (with fluctuations) (06.122.054). Besides the $3^h\,38^m$ period in γ Peg the B magnitude varies by $0\overset{m}{.}005$ in a 44^m period (03.122.071). In KP Per there is a 10^d periodicity in B (06.122.119). o Per is not a member of the II Per association (*AA*, **16**, 108). Additional evidence has been found for the long period variation of ν Eri (02.122.029). Further work on this star is planned by Fitch. Two probably β CMa stars were found in h and χ Per as well as five stars showing evidence for longer period variations (*PASP*, **84**, 420).

16. BL LAC AND SIMILAR OBJECTS

Variable galaxies and quasars are not reported on here. However there are a group of objects which should be mentioned. These are probably extragalactic though in several cases (e.g. BL Lac, OJ 287) they have stellar images and continuous spectra so that an extragalactic nature has not been conclusively demonstrated. In any case Commission 27 and in particular the Information Bulletin is a suitable place for planning of collaborative efforts on these objects (e.g. *IB* 728).

BL Lac. This has been extensively monitored. There are variations up to $0\overset{m}{.}7$ in a few hours, long term variations (13^m–16^m) and small amplitude fluctuations on a scale of minutes (05.122.062, 04.122.121, 03.122.002 + 076, 02.122.042 + 097). No regular pattern has yet emerged.

OJ 287. This object varies on a time scale of days at wavelengths from the cm range to the ultraviolet. A range greater than $3\overset{m}{.}5$ has been reported. Some regularity in a period of 26 days has been found and polarimetric observations suggest a similar period. A longer term variation may be superimposed (*IAU* 2389, 2365, 2366 06.141.173, 06.113.045, *Nature P.S.* **237**, 48, *IB* 621, *Ap.J.*, **174**, L63, *BAAS*, **4**, 314, 06.123.037).

ON 325 is a rapid optical variable (*Nature*, **231**, 515, *Nature*, **232**, 622).

W Com is identified with a radio source (*Nature*, **231**, 515). Optical observations of W Com and B1215 + 30 from 1962 to 1971 are in *Mem. Ast. Soc. Ital.*, **43**, 309.

AP Lib is a nonstellar object (*Nature*, **232**, 178, 06.141.023, *Nature*, **233**, 401, 06.122.098).

BW Tau is the Seyfert galaxy 3C 120.

V395 Her is apparently a compact galaxy which is not known as a radio source. It is a very rapid variable ($\Delta m \sim 0\overset{m}{.}7$ in 48 min) (*Ap.J.*, **174**, L163).

17. CEPHEIDS OF ALL POPULATION TYPES

K. K. Kwee

That not all stars lying in the cepheid instability strip are variable is shown by Fernie and Hube (*Ap.J.*, **168**, 437), who have examined 48 G0 Ib stars for light variability. They found only five suspected variables with possible amplitudes of 0·1 mag, and the rest appeared to be stable to within a few hundredths of a magnitude. Schmidt (*Ap.J.*, **172**, 679) came to a similar conclusion by investigating 11 supergiants of spectral types F and G in the instability strip. Here it is found that the four stars lying more than two standard errors within the instability strip are constant in light.

Difficulties and problems on classifications of cepheids were still encountered. An attempt to divide cepheids into two population types according to their galactic position and motion has been undertaken by Boenigk (*Bull. Astr. Obs. Torun* No. **44**, 1). A different classification system was introduced by Kolesnik (*IB* 470, 471) based on light gradients. With this system different types of pulsating variables can be distinguished. Petit (*IB* 455) published a list of 69 cepheids with periods of about 2 days or longer, which are characterized by small amplitudes (ΔB less than 0·7 mag) and nearly sinusoidal lightcurves. The peculiar characteristics of the cepheid SZ Mon are discussed by Lloyd Evans (*Obs.*, **90**, 254, **91**, 159) in relation to the population type of this variable. The variable DI Car, previously classified as a RW Aurigae variable, according to Seggewiss (*Astr. J.*, **75**, 345), is a cepheid possibly of population II. The cepheid IU Cyg, by some classified as population II and by others as population I, has according to Tammann (*IB* 366) probably a strong variation of the lightcurve. Formerly classified as a W UMa star, the variable EU Tau, according to Guinan (*PAS Pacific*, **84**, 56), is a classical cepheid with a period of 2·105 day. One other dubious case of classification has been S Vul. Fernie (*Astr. J.*, **75**, 244) now came to the conclusion that this 67 day periodic variable is not a semi-regular nor an RV Tauri variable, but a cepheid of possibly population I. If this is correct, it is the longest known period among the population I cepheids.

Since Blaauw and Morgan made an attempt in 1954 to determine the zero-point of the period-luminosity relation of classical cepheids from the proper motion of only 18 nearby variables, the number of cepheids with accurate proper motions has been increased considerably. Geyer (*Astr. Ap.*, **5**, 116) made a new determination using more than a hundred population I cepheids. Using Kraft's slope of the period-luminosity relation Geyer found: $\langle M_V \rangle = -1{\cdot}88 - 2{\cdot}54 \log P$, while using Fernie's slope with the additional quadratic term in log P, he found: $\langle M_V \rangle = -2{\cdot}05 - 1{\cdot}89 \log P - 0{\cdot}38 (\log P)^2$. Another attempt to check the zero-point of the period-luminosity relation is made by Jung (*Astr. Ap.*, **6** 130). Using 33 population I cepheids within a distance of 1 kpc around the sun he found a systematic correction to the period-luminosity relation of Sandage and Tammann of about 0·4 mag; however the accuracy of this determination is so low that it is doubtful whether this correction is really significant.

Takase (*PAS Japan*, **22**, 255) made a new kinematical analysis of 146 galactic population I cepheids for which accurate photometric and radial velocity measurements were available. Using Kraft's period-luminosity relation he found for the distance of the galactic centre 10 kpc; with Geyer's corrections for the zero-point this distance turned out to be 10 or 20% larger.

The age of population I cepheids has been estimated by Tammann (*IAU Symp.* **38**, 236). For practically all of them having periods longer than 15 days, it is found that they are as young or younger than b 2–3 clusters. Tammann also derived a period-luminosity-colour relation with the *U-B* colour instead of the *B-V*: $\langle M_V \rangle = -3{\cdot}382 \log P + 1{\cdot}834 (\langle U \rangle - \langle B \rangle) - 1{\cdot}700$.

Schaltenbrand and Tammann (*Astr. Ap. Suppl.*, **4**, 265) derived light curve parameters of 323 photoelectrically observed galactic cepheids by making use of Fourier analysis of the lightcurves. So they got quantitative determinations of lightcurve parameters in a homogeneous system. The results of this analysis can now be used to derive accurate relations such as the period-luminosity, period-colour or colour-amplitude relations.

It is now generally accepted that in the period-luminosity-colour relations the amplitude plays an important role. Fernie (*Ap.J.*, **161**, 679) found relations between the amplitude, period and colours of population I cepheids: $(B-V)_{max} = 0{\cdot}297 + 0{\cdot}307 \log P - 0{\cdot}194 \Delta V$ and $(B-V)_{min} = 0{\cdot}238 + 0{\cdot}373 \log P + 0{\cdot}373 \Delta V$. Sandage and Tammann (*Ap.J.*, **167**, 293) discussed a period-luminosity-amplitude relation for galactic cepheids. It is found that for cepheids with periods between $0{\cdot}40 < \log P < 0{\cdot}86$ and for $\log P > 1{\cdot}3$, the maximum amplitudes belong to those cepheids which are located at the blue edge of the instability strip, and that the amplitudes decreased monotonically to the red. Such a correlation has also been found with the RR Lyrae variables. For cepheids with log P between 0·86 and 1·3, the behaviour is reversed. So the amplitude as a function of strip position leads to the formulation of a period-luminosity-amplitude relation which is equivalent to the usual period-luminosity-colour relation. Its advantage is that no colours are needed.

Relations including the light-amplitude and radial velocity amplitude have been studied by Leung (*Ap. Space Sci.* **8**, 222) for classical cepheids, RR Lyrae stars, δ Scuti stars and dwarf cepheids. It is found that the ratio of these two amplitudes form a sequential series for these groups of pulsating variables.

In connection with the universality of the lightcurve-parameter relations it is unavoidable to make comparative studies between different extra-galactic systems and our galaxy. A study of the appearance and position of bumps in the lightcurve of cepheids was made by Van Genderen (*Astr. Ap.*, **7**, 244). He compared these characteristics for cepheids found in the galaxy, M 31 and the two Magellanic clouds and found a slight difference in the behaviour of the bumps between the cepheids of the galaxy and M 31, on the one hand, and of the Small Magellanic Cloud on the other. Schaltenbrand and Tammann (*Astr. Ap.*, **7**, 289) discussed the period-amplitude relation for cepheids in the galaxy and in the Magellanic clouds. They concluded that for log P between 0·5 and 1·7, there existed no differences between the galaxy and the Small Magellanic Cloud. Outside this period interval the differences are only apparent, because of the different period-frequency distribution. Van Genderen disputes this latter point and argues that there are real differences between the two relations. Van Genderen also made an attempt to explain the dip seen in the upper envelope of the period-amplitude relation between log $P = 0{\cdot}85$ and 1·05. Meanwhile Sandage and Tammann (*Ap.J.*, **167**, 293) found that most of the fundamental differences between the galactic cepheids and those in the Small Magellanic Cloud disappear when one takes into account that the amplitude is a function of the position in the instability strip, and that it is largest at the blue edge of the strip instead of in the middle as assumed before.

It is of considerable interest for theoretical investigators if something is known of the physical properties of cepheids. Based on Stebbins, Whitford and Kron's six-colour photometry Parsons (*MNRAS*, **152**, 121, 133) compared effective temperatures, intrinsic colours, surface gravities, radii, luminosities and masses between galactic cepheids and yellow non-variable supergiants. For the classical cepheid β Dor, for which large differences exist in the reported values of the range in effective temperature and of the mean radius, Parsons (*Astr. J.*, **76**, 562) concludes that the range in T_{eff} is about 950°, the mean radius about 80 $R_{\odot}$ and $\langle M_V \rangle = -4{\cdot}7$. From actual calculations of line-profiles appropriate to classical cepheids Parsons (*Ap.J.*, **174**, 57) found that the conversion factor from radial to pulsational velocity of a stellar atmosphere should be 1·31 instead of the commonly adopted $24/17 = 1{\cdot}41$. Takeuti (*Sendai Astr. Rap.*, No. 113) discussed Opolski's new method (*Acta Astr.*, **18**, 515) to determine radii of cepheids. He also applied the theoretical period-mass-radius relation to 13 population I cepheids in galactic clusters and five cepheids with beat periods. Assuming Stobie's transition periods obtained from his non-linear calculations of pulsation, Takeuti found that the mass-luminosity relation is: $\log L = 1{\cdot}57 \log M + 2{\cdot}60$. The masses of these variables are less than the masses predicted from the evolutionary tracks without substantial mass loss, especially for the short period cepheids. For cepheids with modulated lightcurves it is possible, through the fundamental-mode pulsation constant Q_0 and an observationally determined radius, to derive another mass, here called beat mass (Fitch, *Ap.J.*, **161**, 669). For the well-known beat cepheid TU Cas such a determination has been carried out by E. G. Schmidt (*Ap.J.*, **176**, 165). He found a value which compared well with the so called evolution mass, but is larger than the so-called pulsation mass computed for this star. See also Section 21.

Studies of period variations are still of interest to several astronomers. Bauernfeind (*Veröff. Remeis Sternw. Bamberg* **8**, No. 85) discussed the periods of 9 cepheids. Two of them, BV 458 and 505, appeared to have a variable period. Stobie (*MNRAS*, **148**, 1), also discussed the periods of 29 mostly classical bright southern cepheids, based on new *UBV* observations. Except for SZ Mon and RY Sco, he found no evidence of variable periods. The periods of DT Cyg and T Vul have been studied by Johansen (*Astr. Ap.*, **15**, 311). The period variability of DT Cyg was confirmed, while T Vul showed no period variability. A period variation of DL Cas, an 8-day cepheid in the galactic cluster NGC 129 was detected by Hoffleit (*IB* 607).

Beat periods have been found in the population I cepheids; Y Car (*MNRAS*, **157**, 167), VX Pup (*Obs.*, **90**, 20) and AX Vel (*MNRAS*, **157**, 157). The short-period cepheid CS Mon, which was suspected to have a peculiar behaviour of the period, according to Tammann (*IB* 366), had a wrongly determined period; the right period should be about 4·16915 day.

In the past three years quite a number of publications and reports of photometric observations have appeared. Steiner (*Astr. Ap.* **2**, 195, **14**, 128) investigated 19 bright cepheids in the new spectro-

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photometric classification system of Barbier-Chalonge-Divan (BCD-classification). E. G. Schmidt (*Ap.J.*, **165**, 335) made an extensive photometric study of four bright cepheids, U Sgr, Eta Aql, S Nor and Y Oph, based on spectral scans and broad-band photometry in the *UBV* and *VRI* colour systems.

At the David Dunlap Observatory Mrs Evans has obtained simultaneous *UBVR* photometric and radial velocity observations of about a dozen bright northern classical cepheids. The observations are insufficient to define complete light-, colour-and velocity-curves, but with the shapes of the curves taken from previous work, the observations do allow accurate phase-matching of the various curves. These data form the basis of an observational study of Wesselink's method for determining stellar radii which Mrs Evans is currently undertaking. At the same observatory, Fernie has obtained new radial velocity and *UBVR* photometric observations of the classical cepheid binary HR 8157. An improved determination can be made of the pulsation period of this cepheid of 3·3336 day. The available evidence on the nature of the secondary star, however, seems contradictory, and further observations are still being undertaken.

At the Leiden Southern Station Pel has made five-colour observations of about 150 southern population I cepheids during 1970 and 1971. These observations, which were made in Walraven's colour system, were aimed to obtain light- and colour-curves as complete as possible in order to study the intrinsic colours of these stars. The reduction is now still in progress.

Bahner and Mavridis (*Contr. Dept. Geodetic Astr. Univ. Thessaloniki*, No. 3) published two colour lightcurves of 5 bright galactic population I cepheids. The same stars have been re-observed in three colours by Asteriadis, Mavridis and Tsioumis. Bahner and Mavridis also published numerous *BV* observations of TU Cas made during the time interval 1956–59. Wamsteker (*IB* 690) published photo-electric observations of 13 galactic cepheids of which two belong to population type II. Landolt (*PAS Pacific*, **83**, 43) published three colour observations of three southern cepheids: 1 Car, AG Cru and ST Pup.

Dawe (*Obs.*, **89**, 67, *MNRAS*, **145**, 377) made an extensive investigation of the classical cepheid 1 Car. Its position in the HR diagram is discussed, and from spectroscopic observations it was possible to establish a definitive radial-velocity curve, which in conjunction with earlier photometric observations and by application of Wesselink's method resulted in a mean radius of about 133 million km. For the classical cepheid S Nor, which is situated in the galactic cluster NGC 6087, Breger (*Astr. J.*, **75**, 239) found on the basis of new photometric and radial-velocity measurements, a mean radius of about 60 $R_{\odot}$ with an uncertainty of about 10%.

The classical cepheid BX Del was observed in three colours by Basu (*PAS Pacific*, **81**, 834). The two-colour diagram confirms that this classical cepheid with the shortest period known is a strong-lined star with no spectral pecularities. Cousins and Lagerwey (*Mon. Not. Astr. Soc. S. Africa*, **30**, 76) published photo-electric observations of the cepheid 35 Cru. Stobie (*Obs.*, **92**, 12) published three colour observations of the small amplitude cepheid HR 2957 = HD 61715.

Physical companions and other objects near cepheids can in favourable cases give an estimate of the luminosity of the variable. The nebulosity surrounding the galactic cepheid RS Pup has been investigated by Havlen. (*BAAS*, **3**, 13). Lloyd Evans and Stobie (*Obs.*, **91**, 160) reported their results of observations of the visual components of BB Sgr and RY Sco which according to them are probably not related physically to the variables themselves.

The peculiar behaviour of the galactic population II cepheid RU Cam has been followed closely by investigators in Trieste and in Merate (*Publ. Oss. Astr. Trieste*, No. 405, *Contr. Oss. Astr. Milano-Merate, Nuova Ser.* 318, 326, *IB* 511, *Astr. Ap.*, **18**, 201). After the considerable reduction in the light-amplitude of this variable around 1965, the expectations were that the amplitude would grow again till the original values were regained. In 1968, however, and also in the middle of 1970, the light-variation again reduced to only 0·1 mag. In their last paper, Broglia and Guerrero found that the period is oscillating continuously. The residuals of the minimum and maximum epochs show an abrupt change from a linear to an almost sinusoidal trend at the end of 1965, about one year after the quasi-cancellation of the light-pulsation started. According to these authors an erratic component of the light-variation is superimposed on a periodic one, however, the mean luminosity

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and colour of the variable remained constant during the past 20 years. The latter confirms the hypothesis put forward by Wallerstein (*Ap.J.*, **151**, 1011, 1968), that RU Cam is probably in a transitory stage for which the pulsations have stopped because of strong modifications occurring in the outer layers of the star.

A new type of cepheid is suggested by Lloyd Evans, Wisse and Wisse (*MNRAS*, **159**, 67). Characteristics are: short periods (about 2 days), over-abundance of carbon, radial velocities and strong-lined spectra consistent with disk-population stars, light- and colour-curves characteristic of globular cluster cepheids with the same period, mean intrinsic colours which are probably redder and absolute magnitudes which are probably 1 mag brighter than those of the corresponding globular cluster cepheids, Examples of this type of cepheid are V 553 Cen and RT TrA. No counterpart seems to exist among the population II cepheids with longer periods. They are probably related to the cepheids found in dwarf spheroidal galaxies, which are also confined only to the shorter periods.

Kwee started an observing programme to study light- and colour-curves of about 15 galactic population II cepheids with periods between 1 and 3 days. The observations have been made and will be continued with the 1-m photometric telescope of the European Southern Observatory in Chile.

18. DELTA SCUTI VARIABLES

K. K. Kwee

δ Scuti variables are short-period pulsating variables with periods between 0·05 and 0·20 days, spectral types from A to F and with small amplitudes in the light- as well as in the radial velocity curves. For most of these variables the lightcurve does not repeat itself from cycle to cycle. They differ from the dwarf cepheids (RRs) in the amplitude of their lightvariation which does not exceed 0·10 mag and is often only a few hundredths of a magnitude. In the HR diagram they occupy a position in the lower extention of the cepheid instability strip, between the RR Lyrae variables and the dwarf cepheids (Leung, *Ap. Space Sci.*, **8**, 222). A condensed and excellent summary of our present knowledge about the δ Scuti stars has been given by Seeds and Yanchak in a report of the Bartol Research Foundation (*IB* 625). In this report 58 known δ Scuti stars and 97 suspected variables of this type are also listed.

In the past three years the search for δ Scuti variables has been continued extensively. Hall and Mallama (*PAS Pacific*, **82**, 830) published photoelectric observations of BD $-$ 6° 4932 = HD 174553, which appeared to be a δ Scuti variable with a varying period of about 0·2 day and an amplitude also varying from 0·08 to 0·16 mag. Percy (*PAS Pacific*, **82**, 126) confirmed the suspicion made earlier by Fernie (*J. Roy. Astr. Soc. Canada*, **63**, 133) that γ CrB = HD 140436 is a δ Scuti variable. In blue and yellow light this star showed variations of about 0·05 mag with a time scale of 0·03 day. The star is a member of a visual binary with a known orbit, so that a mass of 1·9 $M_\odot$ can be derived for this δ Scuti star with the earliest spectral type known. One other bright star, HR 2989 = HD 62437, appears to be a δ Scuti variable according to Percy (*IB* 444, *PAS Pacific*, **83**, 335). This star has a period of 0·09526 day and amplitudes of 0·055, 0·075 and 0·076 mag in *V*, *B*, and *U*, respectively. Two new δ Scuti variables were also found by Demers (*PAS Pacific*, **81**, 861). They are HD 9065 and HD 9133; the latter has a period of only 66 min and is therefore one of the shortest periods known of this class. Millis and Thompson (*PAS Pacific*, **82**, 352) made photo-electric observations of HR 8880 = HD 220061, which indicate that this star, previously reported not to be variable, indeed shows small variations in brightness with a variable amplitude of a few hundredths of a mag and with a period of about 80 min. Tempesti (*IB* 596) found brightness fluctuations in the lightcurve of the eclipsing binary AB Cas, which he ascribes to a δ Scuti-type of variability of the A3 component with a mass of 2 $M_\odot$ and an absolute visual magnitude of $+2{\cdot}2$. The period and amplitude of this δ Scuti variable are 0·058 day and 0·05 mag, respectively. Finally HD 34409 is found to be a suspected δ Scuti variable (*IB* 569). Breger (*Astr. J.*, 74, 166) in a survey of 300 field and cluster stars of spectral types A and F found 15 new δ Scuti stars. A study in NGC 2264 resulted in two new δ Scuti variables (*Veröff. Remeis Sternw. Bamberg*, **9**, No. 100, 85). Large numbers of δ Scuti variables have been discovered in the Pleiades, Praesepe, Hyades and Coma clusters by Breger (*Ap.J.*, **162**, 597, *Ap.J.*, **171**, 539, *Ap.J.*, **176**, 367 + 373). About 30% of main sequence cluster stars inside the instability strip show detectable variability with amplitudes greater than 0ᵐ008 mag. An investigation of the galactic cluster NGC 7789 by Danziger (*PAS Pacific*, **83**, 84) led to the discovery of one suspected δ Scuti star in this cluster. Jørgensen, Johansen and Olsen (*Astr. Ap.*, **12**, 223) tested 94 bright stars mostly of spectral types A and F in the southern sky for short-period variability. They found three new δ Scuti stars (HR 401, HR 1225 and HR 1298), confirm the variability of HR 2707 found earlier by Eggen, and indicate 6 other stars as suspected variables of this type. A spectroscopic search for southern δ Scuti stars was made by Jones (*R.O.Bul.* 163). Radial velocities of 8 stars have been studied; two new variables were found among them.

Apart from Seed's and Yanchak's catalogue, Frolov (*IB* 427) published a list of probable δ Scuti stars. Two of these stars appeared to be constant within an observational scatter of 0·03 mag (*IB* 630).

Besides the search for new δ Scuti stars, a number of investigators made new observations of already known variables. Valtier (*IB* 556) made photo-electric photometry of 1 Mon = HR 2107 = = HD 40535 and of HR 5005 = HD 115308; the latter showed no variability above the observational scatter. Hudson, Chiu, Moran, Stuart and Vokac (*Ap.J.* **165**, 573) obtained observations of 14 Aur = HR 1706 = HD 33959. Penfold (*PAS Pacific*, 83, 497) made radial velocity and photometric measurements of 20 CVn = HD 155604. An abundance analysis of this variable (*MNRAS*, **153**, 1) showed that the star has a metal abundance greater than that of the sun and similar to that of the Hyades. Reimers (*Astr. Ap.*, **3**, 94) made an extensive quantitative analysis of δ Del = HD 197461 based on high dispersion spectra. He used model atmospheres in non-grey radiative equilibrium and obtained predicted values for the metal abundance. According to Reimers the effective temperature is about 7100° and the surface gravity: log $g = 3{\cdot}8$. Five colour photo-electric observations of δ Del were made by Van Genderen. (*Astr. Ap.*). Heiser reported having some unpublished *UBV* data of 20 CVn, ε Cep and δ Ser, and also uvby data of ε Cep and HR 4684. Fitch has set up an observing programme on 14 Aur and δ Sct itself.

From a study of 30 δ Scuti variables, which have been measured in the Geneva photometric system, Hauck (*Astr. Ap.*, **11**, 79) came to the conclusion that δ Scuti variables have more resemblance of the giants than of Am stars. Eggen (*PAS Pacific*, 82, 274) investigated nine δ Scuti stars and dwarf cepheids which he believed to be members of the Hyades. He concluded that these variables occur in young as well as in old disk populations. Leung (*Astr. J.*, **75**, 643) made an interesting study of Strömgren's intermediate-band colours of 41 δ Scuti variables. He found a period-colour-luminosity relation for these variables and, because the spread in colour is small, also a period-luminosity relation. Plotting the HR-diagram he found that these variables are placed in two regions which coincides with the extension of the cepheid instability strip to the fainter side. In between these two regions there appeared to be a definite zone of avoidance. The fainter region, which is located just above the zero-age main sequence, contains the variables with the shorter periods (0·04 to 0·08 days), while the upper box contains the variables with periods ranging from 0·07 to 0·19 days. Finally he made the suggestion that the variables with the shorter periods are stars with masses of about 1.7 $M_\odot$ which are probably in the hydrogen-burning evolution phase, and the long-period δ Scuti stars are stars with masses of about 2 $M_\odot$ in the post-main-sequence core-contraction phase or in the post-helium-flash helium-burning phase of evolution.

By a corrected method to determine masses, Breger and Kuhi (*Ap.J.*, **160**, 1129) found masses of about 2 $M_\odot$ for δ Scuti variables. They also felt that this indicates that pulsation in a higher harmonic is not necessary to explain the δ Scuti stars. Valtier (*Astr. Ap.*, **16**, 38) developed a method to analyse lightcurves built up from non equi-spaced observations made in short intervals of time. For about 30 δ Scuti stars he gives new periods and amplitudes.

Baglin (*Astr. Ap.*, **19**, 45) analysed the rotation of A stars. This analysis led to the conclusion that δ Scuti stars distinguished themselves from the Am stars in their rotational velocities: δ Scuti stars are normal rotators (of the order of 90 km/sec), while Am stars are rotating with velocities smaller than 60 km/sec. This difference in rotational velocities resulted in the mutual exclusion of

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Am- and δ Scuti-characters. Because of the faster rotations the δ Scuti stars in the instability strip could develop oscillations driven by the opacity mechanism. Breger (*Ap.J.*, **176**, 373) made an integral study of the occurrence of pulsation in nearby open clusters where stellar distances are known. He summed up all the established and statistically significant correlations between slow rotation, metallicity and pulsational stability for the different clusters and deduced that it is not the low rotation, but the metallic-line characteristics, which are often associated with low rotation, that inhibit pulsation.

Fitch continued his investigations on δ Scuti variables. An analysis of some additional data on CC And now allows a very accurate definition of the behaviour of the primary pulsation ($P_0 = 0{\cdot}1249$ day) of the light-variation during the 10·466 days modulation period. Fitch is trying to invert the data in order to get a detailed surface brightness variation. He thinks that it will be possible to utilize some simple model calculations to obtain the actual radial, angular and time distribution of the light. Meanwhile Fitch is now engaged in some observational work on 14 Aur and δ Sct in order to determine the nature and extent of possible tidal pertubations affecting the radial pulsational instability of these stars.

19. RR LYRAE VARIABLES AND DWARF CEPHEIDS (RRs STARS)

L. Detre

The work directed toward the determination of the absolute magnitudes of the RR Lyr variables was intensively continued. On this theme a joint meeting of Commissions 24, 27, 30, 33 and 37 was organized by the Steward Observatory at the Brighton General Assembly of the IAU with Bart Bok as chairman and Sir Richard Woolley, Christy, van Herk, Clube and Klemola as speakers (*Highlights of Astr.* **3**). It seems now we must be prepared to accept fainter absolute magnitudes for the RR Lyr variables than previously supposed. A mean absolute magnitude of $M_v = +1{\cdot}3$ was proposed by Clube (*MN*, **151**, 231). But it is most likely that the M depends on the chemical composition of the stars. In order to separate variables of different chemical composition, van Herk and van Genderen continue their work on accurate 5 colour photometry in the Walraven system of about 90 southern RR Lyr variables for determining photometrically ΔS values. Willis published ΔS values for 21 (*Obs.*, **92**, 14), Alania for 20 variables (*IB* 702).

At present we are not yet in a position to consider the whole subject as finished. The number of stars should substantially be increased in order to get a better statistical discussion possible, i.e. we have to go to fainter stars. A paper by Clube, Aslan, Russo and Clements (*ROB*, **161**) brings the total of nearby RR Lyraes whose proper motions have been determined to 260. There is now good reason to suppose that the mean parallaxes of the reference stars to these variables have been systematically underestimated (*Obs.*, **91**, 11 and 14). Van Herk is engaged in the determination of the proper motions of some 600 variable stars, among which there are about 280 RR Lyr stars. Klemola published absolute proper motions for 41 RR Lyraes in 16 fields lying outside the zone of avoidance (*PASP*, **83**, 277; *Lick B.*, 613). Radial velocities are known for about 200 RR Lyraes.

The masses, radii and luminosities of RR Lyrae variables and dwarf cepheids were investigated in an important paper by Woolley and Savage (*ROB*, **170**). A modified Baade-Wesselink method was applied appealing to proper motions to establish mean absolute magnitudes, to a pulsation constant supposed known from theory, or in one case to trigonometrical parallax.

Frolov (*PZ*, **16**, 615), also using a modified Wesselink method, determined mean radii, absolute and relative amplitudes of the radial variations for five RR Lyrae stars. This work was extended later to 113 stars (*PZ*, **17**, 3).

Mandel (*A. Cir. USSR*, 515, 3) determined reddening lines for RR Lyraes. Kanishva discussed partly the correlation between brightness and colour amplitudes (ib.6) partly between colour and light amplitude (*A. Cir. USSR* 559) for the same stars. Frolov (*A. Cir. USSR* 619, 4) investigated the period-luminosity and period-radius relation for dwarf cepheids. Iwaniszewska published statistical population indices for RR Lyraes (*Torun Bull.* **46**/II). Leung (*Ap. Space Sc.* **8**, 222) determined the ratio of radial velocity amplitude to light amplitude for pulsation variables.

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Eggen published important papers on the population characteristics of ultrashort-period variables (*PASP*, **82**, 274, **83**, 741). He suggested (*PASP*, **83**, 762) that there is more evidence for the presence of dwarf cepheids than of close binaries among the blue stragglers of the old disk population. The possibility that the RRs star SX Phe is a variable blue straggler in the halo population should be examined.

Hartwick, Hesser and Hill (*Ap.J.*, **174**, 573) obtained on Cerro Tololo new plate material with the 60-inch telescope for Baade's field near the galactic centre around NGC 6522 ($l = 1°$, $b = -4°$) in order to obtain correct periods for a larger number of RR Lyrae stars. From the period-frequency and period-amplitude distribution they found that the variables in this direction, belonging to the galactic bulge, are metal-rich with an estimated $\Delta S \sim 3$–4. Using Christy's theoretical relation for the transition period from type *c* to type *a* light-curves, they estimated the absolute magnitudes of the RR Lyraes. In accordance with the above mentioned papers, they have obtained similar low values for the luminosity.

Borzov determined the *Z*-coordinate distribution for RR Lyr variables in Harvard fields (*PZ*, **17**, 570, **18**, 141). The results are in good accordance with Kinman (*Ap.J. Sup.*, 119).

With the 2·1 m KPNO telescope many plates of three galactic anticenter fields were obtained. About 4000 measures of 60 RR Lyr stars are finished. At Lick Kinman's survey of RR Lyr stars at high galactic latitudes is being continued (*QJRAS*, **13**, 258).

Fitch and his collaborators, Brookmeyer, Lee, Wisniewski and H. L. Johnson have finished their *IUBV* photometry program on about 170 RR Lyr field stars. The measures obtained in the first portion of the program have already been published (*Com. Lunar Plan. Lab. Arizona*, **71**). Observations on the concluding portion of the program were obtained up to the spring of 1970 and will soon be published. On the basis of the Arizona observations Wisniewski (*AcA*, **21**, 307) suggested that the RRc star RW Ari is a component of an eclipsing system, with elements $P = 3^{d}.1754$, primary minima depth $A_v = 0^{m}.8$ after correction for the pulsation effect. Radial velocities obtained by Abt and Wisniewski (*IB* 697) at the 84-inch KPNO telescope confirm this suggestion.

Jones (Canberra-Herstmonceux) has modified Stromgren's *u-v-b-y-β* system to include a *k* index at λ 3933. Colours of 102 RR Lyrae, δ Scuti and dwarf cepheids on this system are in press. Indices strongly dependent on temperature, metal abundance, gravity and interstellar reddening can be formed from these colours. The system has also been applied to RR Lyraes in 47 Tuc and ω Cen.

During 1970, Fitch and Duke obtained simultaneous radial velocity and photometric measures of AC And (RRa? RRs?) and VZ Cnc (RRs), which are pulsating in two modes simultaneously. In collaboration with the Konkoly Observatory Fitch is analysing the complex pulsation of AC And, utilizing about 4000 photoelectric measures obtained by the Hungarian observers as a joint project between Steward and Konkoly Observatories (*BAAS*, **4**, 298).

On Cerro Tololo, considerable work has been devoted to the RRs star SX Phe (Stock, Tapia, *AA*, **10**, 134, 147). The radial velocity variations were derived from 497 spectra, simultaneously photoelectric observations were obtained. An analysis of the data shows that the observations cannot be reconciled with the model of a single pulsating star. This conclusion is confirmed by the behaviour of the absorption line profiles. In addition, the intensities and profiles of the absorption lines vary rapidly, often within minutes. SX Phe is possibly a binary, or even a multiple system. ESO participated in these observations with *UBV*, Hβ measures. A pre-study of the polarization of the star was done by Wood with negative results.

At the ESO Plaut observed photoelectrically RR Lyraes in Field 3 ($l = 0°$, $b = -10°$) of the Palomar-Groningen survey, Elst (*AA*, **17**, 148) published new *UBV*-measurements of CY Aqr. He claimed to reveal a beat period which is exactly the double of the primary period. He studied also KU Cen. High speed *UBV* observations were obtained of DY Her, YZ Boo and RS Boo to look for period changes and rapid variations (Moffett, Texas).

Epstein published his (ubvy) study of RR Lyr field stars (*AJ*, **74**, 1131, *Cont. KPNO*, 493). Observations at minimum light of 38 variables are used to find interstellar absorption corrections. The low metal-content variables show a *P-L* relation in the sense of increasing *L* with increasing *P*.

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D. H. P. Jones (*PASP* **83**, 471) studied DK Vel which is substantially redder than any known RR Lyr star, moreover it has also other peculiarities.

At the Leiden Southern Station Pel made 5 colour observations of the peculiar RR Lyr variable UZ Lib. De Bruyn (*AA*, **16**, 478) published 5 colour observations of the RRs star V576 Oph. Wisse (*AA*, **4**, 419) discussed Graham's observations of the RRs star DT Vel.

At the Hale Observatories (*Ann. Rep.* 1970–1, 434) McNamara secured spectrograms with the 100-inch telescope coudé spectrograph (20 Å mm^{-1}) of the dwarf cepheids SZ Lyn, DY Her, AD CMi and EH Lib for the purpose of determining rotational and radial velocities. The spectra indicate that the stars have rotational velocities less than the resolution of the plate ($v < 20$ km sec^{-1}). Mrs Penston has used the 20-inch telescope to obtain light curves in UBV for the RRc variables RW Ari, AE Boo and TV Lyn. In addition, radial velocities were given for AE Boo (*MN*, **156**, 103).

The interstellar reddening of RR Lyr was determined by McNamara and Langford as at most 0·03 mag in *B-V*. *UBV* observations of RR Lyr stars indicate that the average reddening near the north galactic pole is extremely small (*PASP* **81**, 141, **82**, 293).

Binnendijk on a visit to KPNO has shown that LS Her is not an eclipsing binary but an RR Lyr variable with $P = 0\overset{d}{.}2316$ (*BAAS*, **4**, 37).

At the Dyer Observatory *UBV* light curves were obtained for the RRc variables DE Lac and U Com. On the dwarf ceptheid EH Lib ubvy data will be published in *PASP* **84**.

At Mt. Stromlo and the Mt. Bingar Field Station in a spectroscopic and photometric survey of prospective high velocity stars HD 16456 was discovered by Przybylski (*MN*, **151**, 197) as an RRc variable. It is the second brightest known *c*-type variable.

Photometry at the Cape by Alexander an Radcliffe spectra by Thackeray show CPD − 72°214 (BV 1041) to be an RRc star. It has the high radial velocity of + 304 km s^{-1} and $\Delta S \sim 7$ (*MN*, **149**, 59).

RR Lyr stars are intensively studied photographically and photoelectrically in Roumania at Bucharest and Cluj. Photoelectric maxima of XZ Dra, VZ Cnc and SZ Lyn were published (Popovici, Dumitrescu, Minti, *IB* 419 and 508). New photoelectric light curves were obtained for BE Eri by Pop and Todoran, and for UX Cet by Chis. Also RZ Cap and XZ Cyg are observed photoelectrically. Ureche found a secondary period $P' = 34\overset{d}{.}5$ for SW Psc (*IB* 532).

At the Konkoly Observatory, in Hungary, *UBV* observations are continued chiefly for RR Lyraes with secondary periods XZ Cyg, RW Dra, XZ Dra, RR Lyr, RZ Lyr, AR Ser, RV UMa. Kanyó, during a stay at the Catania Observatory, determined the secondary period of SZ Hya as $P' = 25\overset{d}{.}8$ (*IB* 490) and the correct value of the secondary period of RV Cap as $P' = 138\overset{d}{.}3$ *IB*. Detre and Szeidl have shown that the Blashko-effect in RR Lyr undergoes cyclic variations with cycles between 3·8 to 4·8 years. A new cycle generally begins with a large phase shift in the 41-day period (*IAU Coll.* **21**, Toronto, 1972). Szeidl and his collaborators observe the following dwarf cepheids: GP And, CY Aqr, RV Ari, XX Cyg, DY Her, EH Lib, SZ Lyn, V 567 Oph, DY Peg.

In Slovakia, at Skalnate Pleso, Tremko obtained *UBV* observations for W CVn, TT Lyn and VY Ser (*Contr. Skalnate Pleso V*).

Visual and photographic observations have been published by Mandel (*PZ*, **16**, 628) for V773, V778, V822 and V829 Oph. by Kanishcheva (*PZ*, **18**, 105) for DX Del, by Lange and Chuprina for TV Lyn (*A. Cir.USSR* 634). Pochinok (*ib.* 690, 7) observed DL Com. Lange and Gussev published O-C's for RV CrB, XZ Cyg and AR Her (*ib.* 695, 7). Old visual observations were published by Kanishcheva and Lange (*PZ Suppl.*, **1**, 107) Karanish *et al.* (*Ib.* 175) and Tsesevich (*Ib.* 227).

20. SURVEY WORK, SPECIAL FIELDS

W. Wenzel

P. Maffei has completed the collection of the plates for the blue-infrared comparison of variable stars in 6 fields, started in the summer 1967 with both Schmidt telescopes of the Astrophysical Observatory of Asiago. The processing of the first field, including the nebulae M 16 and M 17, is in progress. The most important preliminary result has been the discovery of the dramatic increase of

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the number of new variable stars by means of the infrared techniques. In the field of M 16–M 17 in which 28 variable stars are known from the *General Catalogue*, 200 new variables have been discovered on some 50 infrared plates. The search on an equal number of blue plates obtained at the same time led to the discovery of only 6 new variable stars. Most of them appear to be of Mira type. The determination of the periods and the comparison between the behaviour of the blue and infrared light curves are in progress but are not yet sufficient to formulate statistical results.

The photographic discovery, patrol and processing of variable stars of the sourthern sky has been continued by the staff of the Bamberg Remeis Observatory. A number of guest investigators took part in measuring the plates. The results appeared partly in *IBVS*, partly in *Veröff. Sternw. Bamberg*, Vol. VIII. The number of Bamberg variable stars (BV) now lies near 1500.

W. J. Miller of the Fordham University Astronomical Laboratory continued in publishing details of his study of variables in the Cygnus cloud on thousands of Vatican, Hamburg, Heidelberg, Harvard, and Hale Observatory plates (VV 251–280, *Ric. Astr.* **8**, nos. 8 to 10). The second field, the center of which is at BD +53°3167, is now treated jointly by W. J. Miller and A. A. Wachmann, the first paper on this subject being *Ric. Astr.* **8**, no. 12 and dealing with VV 281–427. In preparation is a further article containing data on at least 60 variable stars of the same field, some 17 of which are already known objects with hitherto unknown light elements, the remainder being new discoveries by Wachmann on Vatican plates.

At the observatory Hoher List of the University of Bonn the patrol program on the associations Cyg T 1, Cep OB 2, and Per OB 2 are in progress (Gieseking). In Cyg T 1 the light curves of 34 variables similar to T Tauri are observed. The other two areas are being worked on. (Limiting *B* of the Durchmusterung: $17^{m}_{\cdot}5$.) Numerous *UBV* plates of all fields of the program, taken with the 35/50/138 cm Schmidt camera, also exist. Geyer and Seggewiss began a patrol of SMC and LMC with the aid of the ESO Schmidt telescope in order mainly to search for RR Lyrae field stars in these star systems. Photographic *UBV* series are planned to start at the end of 1972.

At the Maria Mitchell Observatory Miss Hoffleit and her associates prepared and published identification charts and tables for 275 variables of suspected stars in VSF 193 of Sagittarius (as announced in the Report 1970), together with a summary of the work thus far accomplished in this field (*IBVS* 660).

Results from fields 1, 2 and 3 of the Palomar-Groningen Variable Star Survey (*BAN Suppl.* **1**, 105; **2**, 293; **3**, 1; *Astr. Astrophys.* **8**, 341 and *Suppl.* **4**, 75). A discussion of the results is given in *Astr. Astrophys.* **8**, 341 and in *Veröff. Bamberg* 100, 317. From the spatial distribution of the RR Lyrae stars a distance to the galactic center much smaller than the usually adopted value of $R_0 = 10$ kpc is obtained. For a discussion of this, reference is made to *QJ RAS* **13**, 271. Recently Plaut checked the magnitude scale in the three fields by B and V observations of standard stars and of 20 RR Lyraes and confirmed the original values. It is planned to recompute the spatial distribution by dividing the RR Lyraes into two groups according to the metallicity parameter ΔS. Without further confirmation the smaller value of R_0 should not be adopted at present.

At Sonneberg observatory detailed results on the variables in the fields ϕ Cas, β Del, α Pav, ε Pav and χ Lyr are to be published by H. Gessner, I. Meinunger and Ch. Thänert (*Ver. Sternw. Sonneberg* **7**, no. 6; **6**, no. 5; **8**, no. 2, in press). The work is in good progress on the areas β Her (H. Busch), η Ara (I. Meinunger, *MVS*, **5**, 156, **6**, 11) and β Aps (H. Gessner, *MVS*, **5**, 158, **6**, 12, **6**, 34) and has begun in the areas ϱ Per (K.-H. Muller) and 20 Vir (E. Splittgerber). On plates of the Tautenburg 52-inch Schmidt telescope with centres near M 31 and M 3 Meinunger searched for new faint variables (*MVS*, **5**, 177, **6**, no. 4, 1973 in preparation); among other objects he found 4 novae of the halo of M 31. The spurious variability of the so-called 'blue objects' was investigated thoroughly on Tautenburg plates by L. Richter, N. B. Richter and W. Wenzel (*AN*, **293**, 119). New variables in a number of Sonneberg fields were announced by G. Richter (*MVS*, **5**, 99). The Bamberg work on new variables was supported by observations of H. Gessner. The program on objective prism spectra of variable stars (W. Götz, W. Wenzel) was stopped for the time being (see MVS for a number of lists; concluding remarks in *MVS*, **6**, no. 3). A large number of papers appeared in *MVS* concerning work on single variables by observations on plates of Sonneberg fields and of the Sonneberg Sky Patrol, or resulting from visual observations (P. Ahnert, H. Huth and others).

G. Romano at Treviso has continued his photographic program using also Asiago Schmidt plates. Results on the fields of γ Cygni, of IC 1848, of η Cygni, and, with M. Perissinotto, on the field of Lac and Lyr are published in *Pubb. Padova* No. 156, no. 158, No. 162, *MAI* **48**, 319. 127 new variable stars have been discovered (see also *MAI*, **42**, 639, *IB* 522, 645).

Ward and Welch, of the Variable Star Section RASNZ have continued their photographic surveys for the detection of novae and variable stars under the supervision of F. M. Bateson, The areas cover the Magellanic Clouds, the galactic centre and about 250 square degrees near Crux, Musca and β Cen. Some results have been published (*Circ.* 151, 163, *IB* 389, 475).

The extensive survey work on variables in the Scutum Cloud at Harvard (Harwood, Robinson *et al.*) is continuing. Some 300 stars were measured on 24-inch photographs. 200 of these have periods in the range 42–490 days. For RR Lyrae and eclipsing systems 50 plates taken on five consecutive nights with the Palomar Schmidt have been loaned by Sandage. A considerable effort has been put into the problem of magnitude sequences.

21. THEORY

N. Baker

Following earlier work by Christy and especially by Stobie (*MNRAS*, **144**, 485,511) which suggested, on the basis of nonlinear pulsation theory, that *cepheid masses* might be as much as 50% smaller than those derived from fitting to evolutionary tracks, a great deal has been written on this problem. There are essentially three ways of determining cepheid masses: (1) From evolutionary tracks; (2) From the periods, based on the theoretical pulsation constants, Q ('Q-masses'); and (3) From nonlinear computations, by matching the phases of secondary humps in the computed light or radial velocity curves with those seen in some cepheids ('hump masses'). All of these methods depend on having good absolute magnitudes for the observed objects, and the latter two, especially, are also very sensitive to the estimate of the mean effective temperature. On the theoretical side, the Q-masses are probably the most reliable, as they are very insensitive to changes in physical assumptions, and the hump-masses are probably least reliable, with evolutionary masses somewhere between.

Cogen (*Ap.J.*, **162**, 139) and Rodgers (*MNRAS*, **151**, 133) independently computed Q-masses for well observed galactic cepheids and both concluded that the Q-masses are smaller than evolutionary masses by 20-40%. The possibility that the discrepancy might be due to mass loss in the red-giant phase preceding the cepheid phase was discussed in detail by Tayler (*MNRAS*, **149**, 17). All three methods were considered by Fricke, Stobie, and Strittmatter (*MNRAS*, **154**, 23) who confirmed the discrepancy and felt it could be explained by errors in physical and empirical data. The Q-masses were rediscussed on the basis of new models by Cox, King, and Stellingwerf (*Ap.J.*, **171**, 93), who found a deficiency in the same sense as that of Cogan and of Rogers, but concluded that it is, on average, only about 15%. They questioned the significance of this discrepancy. Iben and Tuggle (*Ap.J.*, **173**, 135) who also discussed Q-masses and the effect of errors in the empirical parameters, concluded that the discrepancy could well be due to errors in the empirical luminosity and temperature calibrations. In a rediscussion, Fricke, Strittmatter, and Stobie (*Ap.J.*, **171**, 593) show that hump-masses are smaller than Q-masses, which are, in turn, smaller than evolutionary masses, The discrepancy between the two types of pulsation masses cannot be caused by mass loss or empirical errors and points to some problem in the nonlinear pulsation theory.

The consensus is that there is a real discrepancy between evolutionary masses and Q-masses, and that both errors in evolutionary model tracks and problems in empirical calibration of absolute luminosities and effective temperatures play a role. Mass loss seems less likely, especially since, according to Lauterborn, Refsdal, and Weigert (*Astron. Ap.*, **10**, 97), mass loss of more than 10% at the start of the He burning causes a stellar model to stay on the Hayas hiline and not make the loops required to carry it through the cepheid strip.

Several authors have attempted to get a better agreement between non-linear cepheid models

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and the observed properties of cepheids by including *radiative transfer effects* in the outer layers of the models. Such work has been reported by Keller and Mutschlecner (*Ap.J.*, **167**, 127), and (using a somewhat different approach) by Bendt and Davis (*Ap.J.*, **169**, 333) and, (for a W Vir model) by Davis (*Ap.J.*, **172**, 419). Davis (*J. Quant. Spect. Rad. Trans.*, **11**, 647) also discussed radiative transfer generally in cepheid atmospheres and Kalkofen and Whitney (*J. Quant. Spect. Rad. Trans.*, **11**, 531) studied line formation.

An interesting possibility in regard to the evolutionary state of *Population II cepheids* was raised by Schwarzschild and Härm (*Ap.J.*, **160** 341) who found that some models of globular cluster stars at the beginning of the helium shell burning phase make rapid loops in the HR diagram that pass through the region of the Population II cepheids. A possible objection is that very rapid period changes would be predicted, which are not observed. The suggestion has stimulated further work now in progress by several groups.

Linear nonadiabatic theory of radial oscillation was the tool used by several authors to investigate *RR Lyrae* stars, as there are several outstanding problems in this field which do not, or may not, require the difficult and expensive nonlinear calculations previously developed by Christy. The most important result of linear nonadiabatic theory is the location of the blue edge of the instability strip, and Iben and Huchra (*Ap.J.*, **162**, L43) Castor (*Ap.J.*, **166**, 109) and Iben (*Ap.J.*, **166**, 131) showed that the inclusion of radiative pressure, which had been omitted by Christy, may change the position of this edge and hence some of the predictions (such as He content, etc.) that may be made on the basis of this location. Castor pointed out that the complete omission of convection in the models on the blue side of the strip leads even in linear theory to very good agreement of the luminosity phase lag with that observed. This is in contrast to earlier results of Baker and Kippenhahn, who had partially included convection. Iben also showed that the particular boundary conditions used by Baker and Kippenhahn have a significant effect on the location of their blue edge. Iben's paper presents several series of models, and additional models are contained in a second paper by the same author (*Ap.J.*, **168**, 225) in which he established a relation between period and luminosity of certain linearized models of RR Lyrae stars. He conjectured that this relation is identical, or closely analogous, to one found earlier by Christy, which connects the luminosity of RR Lyrae stars with the period at which the transition from first-overtone to fundamental-mode pulsation occurs. If such a relation could be found by linear theory, it would be very convenient and useful. The conjecture was further developed in a paper by Iben and Huchra (*Astron. Ap.*, **14**, 293) which also contains extensive comparisons between theory and observation. Cox, Castor and King (*Ap.J.*, **172**, 423) proposed a physical interpretation for the period-luminosity relation conjectured by Iben and Huchra, but note that the point can be cleared up only by further non-linear models. It may be noted that the Christy period-luminosity relation has been questioned on observational grounds by von Albada and Baker (*Dudley Obs. Reps.*, No. 4, p. 193) and on theoretical grounds by Baker and von Sengbusch (*IAU Coll.* **21**). A review of theoretical evolution and pulsation studies of globular cluster stars and a comparison with observations has been presented by Iben (*PAS Pac.*, **83**, 697).

The *δ Scuti* and *AI Velorum* variables lie in the lower part of the cepheid instability strip. Chevalier (*Ap. Lett.*, **8**, 179, *Astron. Ap.*, **14**, 24) computed evolutionary tracks through the instability strip and compared pulsation constants with observations. For one model he computed growth rates using linear nonadiabatic theory and found the fundamental and first-overtone modes to be unstable. Peterson and Jørgensen (*Astron. Ap.*, **17**. 367) made an extensive comparison of pulsation constants and period ratios with observations for both δ Sct and AI Vel stars. They inferred masses for the AI Vel stars which are too small for them to be of Population I. They concluded that the fundamental mode as well as several overtones may be present in δ Sct variables.

Further theoretical work has been done on β CMa stars, but the puzzle posed by these objects remains unsolved. Observational data were analyzed by Percy (*Ap.J.*, **159**, 172) who confirmed that β CMa stars lie above the main sequence, near the locus in the H-R diagram of the final stage of H-burning. This might favour the semi-convection hypothesis. The problem with the latter is that semi-convection seems to be rather unimportant in stars having $M \leqslant 15\,M_{\odot}$; at least one

β CMa star (α Vir) of estimated mass $9M_\odot$ has been studied (Smak, *Acta Astron.* **20**, 75). Auré (*Astron. Ap.*, **11**, 345) investigated linear nonradial oscillations of a very simplified 2-zone model. The excitation in the lower, semi-convective zone was very small, much smaller than the damping in the overlying radiative layer. Davey (Thesis, Univ. of Colorado, Boulder, 1971) computed linear nonadiabatic radial pulsation of β CMa models and found no instability. This is perhaps not surprising, since there seems to be no cepheid-type mechanism in such stars. Furthermore, Osaki (*PAS Japan*, **23**, 485) extending earlier work by Ledoux showed that the hypothesis of nonradial oscillation can account for many of the observed properties of such stars. No new theoretical work work on the Stothers-Simon 'μ-mechanism' (*Ap.J.*, **157**, 673, *PASP*, **82**, 707) has been reported, but Watson's (*Ap.J.*, **169**, 343.) analysis of atmospheric abundances in β CMa stars, yielding normal composition, does not support the 'μ-mechanism' hypothesis. Smak also rejects it on the basis of his observations of α Vir.

Little work has been reported recently on the non-linear pulsations of cepheids (except for the models which include radiative transfer effects), but several authors have studied nonlinear pulsations of *massive* (10^2–10^4 $M_\odot$) *main-sequence stars*, and possible subsequent mass loss. These include Appenzeller (*Astron. Ap.* **5**, 355, **9**, 216) Ziebarth (*Ap.J.*, **162**, 947) and Talbot (*Ap.J.*, **163**, 17, **165**, 121). Techniques used by different authors differed slightly, but there is general agreement that the well known pulsational instability in these stars is not disruptive but leads to finite-amplitude pulsation with moderate rates of mass loss. The calculation of the rate of mass loss is very delicate – it is very difficult to treat the outer layers in enough detail to get an accurate answer. If such objects exist, as seems plausible, it is not easy to say what the observer will see. Some possibilities are summarized in Talbot's second paper. A much different approach was taken by Simon and Stothers (*Astron. Ap.*, **6**, 183) who used a simple recipe to estimate mass loss for stars in the range 60–115 $M_\odot$, which they argue can be identified with very luminous Wolf-Rayet stars.

Although nonadiabatic theory has been used for some years to test the vibrational stability of realistic stellar models, this has hardly been done at all for *nonradial* modes. In several cases it seems quite plausible that nonradial modes might be excited. Now Dziembowski (*Acta Astron.*, **21**, 289) has studied a cepheid model of $7M_\odot$ and found its nonradial modes to be stable. Robe, Ledoux, and Noels (*Astron. Ap.*, **18**, 424) tested the vibrational stability of an $0{\cdot}5M_\odot$ main sequence star and found the nonradial modes to be stable. They conjectured, however, that more massive stars in late evolutionary stages, which have extensive convective envelopes, might exhibit vibrationally unstable nonradial modes.

Several models of *long-period variable* stars were computed by Keeley (*Ap.J.*, **161**, 643, 657). He made realistic models of static red giants and then followed their pulsational behavior with a nonlinear code. He found strong excitation in the region just outside the hydrogen ionization zone and weak dissipation within it. Convection was included in a crude way.

Vibrational instability due to *deuterium burning* in nearly fully convective pre-main sequence models was found by Toma (*Astron. Ap.*, **19**, 76). He computed evolutionary tracks and used the quasi-adiabatic approximation to find growth rates of radial modes. It is suggested that some T-Tauri stars might be in this phase of evolution.

Linear and nonlinear pulsation calculations were made for *helium stars* by Trimble (*MNRAS*, **156**, 411). Convection was neglected, even though some of the models were quite cool. It was suggested these models might be identified with R Corona Borealis variables.

Pulsational instability of some stars on the helium main sequence was formed by Hansen and Spangenberg (*Ap.J.*, **163**, 653, **168**, 71). Similar behaviour on part of the carbon-burning main sequence seen in computations by Mariska and Hansen (*Ap.J.*, **171**, 317). It is not clear that such objects can actually be formed nor, if they can be, how they might be related to observed objects.

22. MISCELLANEOUS

The mathematical apparatus necessary for the interpretation of random variability in stars has been given and the pitfalls in attempting to see periodicities in all types of variability stressed

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(03.122.080, 04.122.091, *Ast. Sp. Sci.*, **16**, 437). The gradients dU/dB and dV/dB have been used to distinguish between different classes of variable stars (04.122.069 + 070 + 146 + 147). The Bamberg 1971 volume contains general reviews of the distribution of variables in the galaxy and the prospects for variable star observations from outside the atmosphere.

B3–B8 supergiants generally show small amplitude photometric variations and OB stars frequently do (*AA*, **20**, 437, also *AJ*, **75**, 337). Variations in the bright supergiant S Dor (LMC) have been discussed (05.122.105). *UBV* observations of Be stars over a 17 year period show 60% to be variable in V and $(B-V)$ [$\Delta V \sim 0^m1 - 0^m2$] (05.113.051). Large photometric variations in the Be star θ CrB were found in 1970 (06.122.035) and a possibly variable companion to the star was reported (06.117.014 + 015 + 016, *IB* 619). Photometry was published of Pleione and AX Mon (*IB* 698, 693, 613) and also of the P Cygni variables AG and HR Car (03.122.050, 05.122.030). P Cygni itself may belong to the Schmidt-Kaler-Isserstedt Ring 274 (*AA*, **8**, 168). The K supergiant ε Peg was reported to have brightened $\sim 1^m7$ for several minutes on 1972 Sept 26 (*IAU* 2450). A search for small amplitude variability amongst bright stars is being made at the Tokyo Gakugei University; ε Per (possibly eclipsing) and ν Aur have $\Delta V \sim 0^m1$. HD 209813 may be an intrinsically variable K star (period 25^d98) in a spectroscopic binary of period 24^d431 (03.119.009). During a search for δ Scuti stars a number of small amplitude variables which may be of other types were found (05.122.059). A B2V member of the open cluster NGC 7128 was found to be variable (*IB* 683). A considerable programme is underway at the Catania Observatory to search for light variations in late type stars showing variable H and K emission. First results suggest light variability in α Tau (*PASP*, **82**, 1293).

The area-scanner technique (Rakos) is being used to observe several visual double stars, one or both components of which are variables, e.g. the eclipsing systems BX And, BH Dra, AM Leo, BM Ori, the double cepheid CE Cas and the peculiar variable V389 Cyg (Geyer, Dürseck).

Extensive proper motion studies of variable stars are of great basic importance. Van Herk (Leiden) is engaged on such a programme involving 244 Miras, 12 RV Tauri's, 282 RR Lyrae's, 24 T Tauri's and 38 W UMa stars.

M. W. FEAST

President ad interim of the Commission

APPENDIX I

REPORT ON VARIABLE STARS IN GLOBULAR CLUSTERS

Mrs H. B. Sawyer Hogg

IAU Colloquium No. 21, on 'Variable Stars in Globular Clusters and in Related Systems', was held at the University of Toronto, Canada, August 29–31, 1972 with Dr. M. W. Feast as chairman of the scientific organizing committee. The papers presented will appear in a colloquium volume edited by J. D. Fernie and published by D. Reidel, which will constitute a voluminous report on this subject. (This is hereinafter referenced as *Coll.* **21.**) Probably because of all the material sent in for the colloquium, very few communications have been submitted directly to the writer for this IAU report.

1. *Catalogues*

A draft copy of the *Third Catalogue of Variable Stars in Globular Clusters* by H. Sawyer Hogg was circulated at the colloquium, for corrections and additions. The revised version will appear as *Publ. David Dunlap Obs.*, **4**, no. 6. This gives all observational references to variables in globular clusters published since the *Second Catalogue* in 1955. The material in this IAU report cannot include all references, but gives the broad outlines of work in this field since the last IAU.

Of approximately 130 clusters considered to be globular in and around our galaxy, 108 have now been examined to some degree. In these, more than 2000 variables have been found, but 13 of these clusters have no variables.

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