27. COMMISSION DES ETOILES VARIABLES

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1. INTRODUCTION

It is obvious that there is no reason to give here an exhaustive listing of all the work in the field of variable stars over the past three years; that service is provided by the regular bibliographic publications such as the *Astronomischer Jahresbericht* or *Referatnyi Zhurnal* (*Astronomiya*). Some 500 references were examined during the preparation of this report, plus many citations of unpublished work furnished by members of the Commission, but I have made no attempt to cover everything. Semi-popular articles, short notes, lists of discoveries of new variables, and routine observations have in most cases not been mentioned unless I have seen something of particular interest in them. Since this must be a subjective judgment, not everyone will agree with my choice in every case. But I hope that no major contributions have been slighted.

This Report is in three parts: the first deals with variable stars in general, and was prepared by the President. Appendix I covers the Spectra of Variable Stars and was written by Dr M. W. Feast, Chairman of that Committee of Commission 27. Appendix II encompasses Variable Stars in Clusters, and was prepared by Dr Helen Sawyer Hogg, Chairman of that Committee. There is inevitably some small overlap between the three parts, and probably to some extent with Reports of other Commissions, but this seems inevitable if one is to present the various topics in proper perspective.

2. ACTIVITIES OF THE COMMISSION

Under the editorship of L. Detre, the very useful *Information Bulletin on Variable Stars* of Commission 27 has continued to appear; through October 1966, some 164 numbers have been distributed from the Konkoly Observatory, generally with a publication time of 2 to 3 weeks. The support of the *Bulletins* has been guaranteed by the Hungarian Academy of Sciences for a further 3-year period. A similar service for longer contributions is provided by the *Mitteilungen über veränderliche Sterne*, edited by W. Wenzel at Sonneberg. The time between receipt of a manuscript and its publication is about two months. Workers in the field of variable stars are invited to make use of either of these series, as appropriate.

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The Commission has recently established, through the cooperation of the Royal Astronomical Society, a depository of unpublished photoelectric observations of variable stars. It is located in the R.A.S. Library, Burlington House, London, W.1, England and meets a long-felt need for an archive in which large masses of data, too expensive to publish in detail, can be deposited. Authors are now free to publish only condensations of their observations, accompanied by a statement to the effect that the complete data are on file in the Commission 27 depository, from which a copy can be obtained at cost plus a small charge for postage and handling. This offers an advantage over the system in which the data are supposedly kept on file at the originating observatory, but cannot be found years later. The administrative details of the service will undoubtedly be modified with time and experience so for the present, interested observers are referred to the statement on procedures which appears in *IAU Information Bulletin* No. 18. Some idea of the type of material that is especially appropriate for deposit can be gained by referring to the first three lists of photoelectric data that were placed on file: 3400 observations in three colors of the peculiar rapid variable and short-period eclipsing binary V Sge (**1**); 2400 ultraviolet observations of the rapidly erratic star AE Aqr (**2**), and 990 observations in three colors of the somewhat similar object BD + 14° 341 (**3, 4**).

Since the Berkeley General Assembly in 1961, a working group of the Commission under the Chairmanship of A. J. Wesselink has been studying the problem of nomenclature and identification of variable stars in the Magellanic Clouds, both for those variables already known and those yet to be discovered. It is hoped that the recommendations of this working group can be considered by the full Commission in the near future.

3. MEETINGS AND SYMPOSIA

A large number of the papers presented at the Colloque International sur les Novae, Novoïdes et Supernovae held at Haute-Provence in September 1963 have now appeared in *Ann. Astrophys.*, **27**, 1964. The proceedings of a symposium on Clusters and Stellar Evolution held at Herstmonceux in August 1963, and containing much material on variable stars, have also been published (**5**). At the Hamburg General Assembly in August 1964, Commissions 27, 34, and 40 sponsored a Joint Discussion on 'The Orion Nebula', part of which dealt with problems of variable stars in the Nebula (**6**). Some problems of variable stars in the halo and of hot subluminous variables were discussed at the First Conference on Faint Blue Stars, held in Strasbourg in August 1964 (**7**). In Moscow in November 1964, the Variable Star Commission of the Astronomical Council (Academy of Sciences of U.S.S.R.) held a symposium on 'Variable Stars and Stellar Evolution' (**8**), and another in Odessa in September 1965, on observational problems of variable stars in the context of stellar evolution. A conference in Sverdlovsk in June-July 1966 dealt with variables in clusters and associations, and with eclipsing variables. An IAU Colloquium on 'Variable Stars in the Hertzsprung-Russell Diagram' was held at Bamberg in August 1965 (**9**), the third in the triennial series of Bamberg meetings on variable star topics. The fourth, also under the sponsorship of Commission 27, will convene in Budapest in 1968. The subject of magnetic variables, of interest to this Commission, was discussed at a symposium held in Washington in November 1965, sponsored by the American Astronomical Society and the U.S. National Aeronautics and Space Administration. The proceedings will appear as a special volume (**10**). *IAU Symposium* No. 30 on Radial Velocities, held in Toronto in June 1966, included one session on radial velocities of variable stars, organized on behalf of Commission 27 by J. D. Fernie. The symposium volume is being edited by J. F. Heard and A. H. Batten.

4. CATALOGUES AND BOOKS

The variable star bureau at the Astronomical Council, Academy of Sciences of the U.S.S.R., and Sternberg Institute (Moscow) continued with its indispensable work of systematizing variable star data. Under the authorship of B. V. Kukarkin, P. Kholopov, Yu. N. Efremov

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and N. Kurochkin, the *Second Catalogue of Suspected Variables* appeared in 1966, containing data on 3907 objects. Compilation of data on the *Second Supplement* to the *General Catalogue of the Variable Stars* (2nd ed., 1958) was completed in 1966 by Kukarkin, Kholopov, M. S. Frolov, *et al*. An index of the increasing magnitude of this task is provided by the number of annual references consulted: 5540 in 1962, 6060 in 1963, 7500 in 1964, 10 530 in 1965. In both instances, English translations of the introduction and remarks will be published with financial assistance by the IAU. All investigators of variable stars are indebted to the Moscow group for its thorough and painstaking work, and to the Astronomical Council for support of the program.

A very useful Atlas of finding charts for RR Lyrae and other types of variable star has been published by Tsesevich and Kazanasmas (**11**). Tsesevich has also written a monograph on RR Lyrae variables (**12**). Much detailed information on variable stars has been presented by Beyer in the new Landolt-Börnstein (**13**). A catalog of variables in double and multiple systems has been compiled by Perova (**14**). A festschrift dedicated to Professor C. Hoffmeister contains many papers on variable stars (**15**). An atlas of the Large Magellanic Cloud has been published by Hodge and Wright (**16**).

The books *Pulsation Theory of Variable Stars* by S. Rosseland, and *The Galactic Novae* by C. Payne-Gaposchkin have been reissued in paperback form by Dover Press, New York.

5. DEVELOPMENTS AND TRENDS IN VARIABLE STAR RESEARCH

Since the beginnings of the subject, the study of intrinsic variable stars has been essentially descriptive. Since there was no real understanding of the causes of variability, there was no real theory. But over the past two decades a new point of view has gradually emerged, namely that the key to intrinsic variability lies in the properties of stellar structure which come about from the predictable evolutionary movement of a star across the Hertzsprung-Russell Diagram. A recent exposition of this point of view is given by Kippenhahn (**9**, p. 7). The concept certainly provides a major simplification in the almost zoological diversity which existed in the classification of variable stars before about 1950. The idea that for example, an individual star in the course of its lifetime may successively become a variable of more than one type, such as at the beginning a T Tau star and much later a long-period variable, is a consequence that would not have been anticipated otherwise. This concept results in the now-familiar HR Diagrams in which strips and domains of specific instabilities are outlined, with the implicit assumption that every star falling therein must be a variable of that particular class. Whether this latter assumption is indeed true is not proven, but one will not be too surprised if it can be violated in special cases, since other parameters than are displayed in the conventional HR Diagram (initial chemical composition, previous history, degree of rotation) may be relevant.

The most convincing demonstration of this point of view is probably provided by recent investigations of the properties of pulsating stars. With large modern computers, the coupled partial differential equations which describe the time-dependent structure and motion of a spherically-symmetric stellar model can be integrated directly. The point of view is that the pulsation of an RR Lyrae or cepheid variable arises not from variation in the rate of energy generation in the core, but by a variable throttling action of layers near the surface upon a constant energy flux. Zhevakin (who reviews the subject as well as his own work in **17**) first pointed out the importance of the ionized helium convection zone for this process. Subsequent investigations by Kippenhahn, Baker, Cox, Iben, Christy, and their associates have extended the subject, which is reviewed thoroughly in the Report of Commission 35. The Munich group has considered simultaneously the evolution of stars of masses 5 to 9 $\odot$ across the upper part of the HR Diagram and the accompanying changes in their pulsation properties (**18**). This makes possible in principle a comparison with the observed behavior of individual cepheids.

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Christy (**19**; **9**, p. 77) has carried out detailed calculations of the pulsations of models having a variety of effective temperatures, masses and chemical compositions, with a somewhat more sophisticated consideration of non-linear effects. He has applied this approach to cepheids of intermediate period (**20**), to RR Lyrae stars (**21**), and to W Vir (**22**).

The details of such work do not fall in the domain of Commission 27, but only direct observations of variable stars can provide a basis for improving the theory and insuring that the calculations refer to real stars. It is not always clear from the published papers whether the observational information is adequate for a proper bridge between theory and observation. Dr Christy has very kindly written for inclusion here a brief statement of the present theoretical situation, pointing out especially those quantities which observations must provide.

Theory and Observation of Variable Stars

R. F. Christy

In the past few years there has been very considerable progress in our ability to calculate the behavior of a pulsationally unstable stellar envelope. (See report of Commission 35.) This progress brings the hope that we will be able to make detailed comparison of calculated models with observed variables and thereby determine additional parameters of these stars by observational means.

At present, calculations are being made of various types of variables in a generalized cepheid instability strip. We may hope in the near future to see this progress extended to the red variables. Separate attacks are being made on the β CMa variables. Irregular variables are excluded from this discussion.

Undoubtedly the most important contribution from observation on variable stars is their classification by physical groupings. This work of classification has been going on for a long time and much of our progress is attributable to it; but much more needs to be done. In the case of the variables of spectral type later than A, rotation and magnetic fields do not seem to be essential, so the significant parameters which affect the envelope are the composition (hydrogen, X; helium, Y; and metals, Z), the luminosity, the mass, and the effective temperature. Given these parameters, the structure and stability of the envelope can be calculated. In the early-type variables, rotation or magnetic fields may well be important and we must add these quantities to the list of physical quantities we wish to explore.

There are many different observational classes of variables in the region of $T_{\mathrm{eff}} < 10^4$ °K or of spectral type later than A. In the generalized cepheid instability strip there are, in addition to the classical cepheids, the W Vir variables, the RR Lyr variables, the δ Sct variables, the dwarf cepheids, and perhaps also the RV Tau variables. The physical bases for the distinctions between these classes is not always clear and, indeed, the systematics and location of some of these classes is still obscure. It is probable that the log g vs. log T_{eff} diagram is the most suitable one to demonstrate the relationship of these various classes and new information to order them in this diagram is needed.

In addition to the generalized cepheid instability strip, there are several classes of red variables. Among those, the physical distinctions are even more obscure and the delineation of an instability region in some suitable parameter space has hardly begun. There is much yet to be done in defining the various variable types by physical parameters. It is again likely that the log g vs. log T_{eff} diagram would be the most useful one to display these instabilities.

Perhaps the greatest need, from the viewpoint of theory, is for more information on the mean T_{eff} of the various variables of type later than A. The observational problems associated with determining T_{eff} from possible photometric data are different for different categories of variable. The corrections for reddening are very difficult and the blanketing

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corrections are apt to be important. Nevertheless, the envelope structure is very sensitive to T_{eff} because of the rapid variation of hydrogen opacity and therefore the instability problem is also sensitive to T_{eff}. It has been found that the high T_{eff} boundary of the cepheid instability strip is quite dependent on the helium abundance in the envelope. The accurate location of groups of cepheid-type variables in terms of T_{eff} will therefore determine their helium content. In the case of the various red variables, T_{eff} is very inadequately determined by $B-V$ and a more systematic use of red or infrared colors and a better knowledge of the red and infrared spectrum will be necessary to classify them in T_{eff}.

The accuracy with which T_{eff} and log g are needed is suggested by the approximate relation $\theta_{eff} = 1{\cdot}09 - 0{\cdot}11 \log g - 0{\cdot}20\ Y$ which governs the dependence of the value of T_{eff} at the high temperature boundary of cepheid instability on log g and Y, the helium abundance by mass. The table below shows the content of this expression:

log g	Y	θ_{eff}	T_{eff}
3·0	0·30	0·70	7200°
	0·0	0·76	6640°
2·0	0·30	0·81	6230°
	0·0	0·87	5800°
1·0	0·30	0·92	5480°
	0·0	0·98	5150°

In addition to T_{eff} the envelope structure is primarily determined by the surface gravity g. In some cases, measures of g can be made from the Balmer jump. In other cases, it can be determined from spectral lines. It is likely that the principal distinction between different classes of variables in the generalized cepheid instability region may lie in their differing g (which, of course, reflects their mass to luminosity ratio). The determination of g values, coupled with T_{eff}, may show these differences. Actually the period of the fundamental mode is primarily sensitive to g and only secondarily to the mass. It follows that the period can verify the determination of g by other means or, alternatively, may indicate that the pulsation is not in the fundamental mode.

When it is possible to locate the different variable classes in T_{eff} and g, it may become possible to distinguish additional effects associated with differing compositions or with rotation.

For the early-type variables (β CMa stars and magnetic or spectrum variables), the principal observational problems appear to lie in the acquisition of the basic data on variability rather than in classification of the variables.

In addition to information, discussed above, which could help in determining the basic envelope structure of various instable groups, there is, in many cases, additional detailed information on individual variables that would be of help in evaluating the physical nature of the variability.

In the β CMa variables, it is likely that the stellar surface displays a quite complicated motion that is responsible for the radial velocity and line width variations. It is almost certain that there must be associated variations in the shapes of the line profiles. These line profile shape variations will be, in turn, closely connected with the nature of the surface motions. The surface motions will in turn reflect the type of instability responsible for the variability. It is hoped that some detailed measures of line shape variations can be used to distinguish between different possible explanations of these variables.

In the case of cepheid variables, it is now becoming possible to calculate detailed surface dynamics. Some of these calculations show interesting sub-structure in the light curve and

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in the velocity curve which is reminiscent of observed bumps in these curves. It is likely that systematic study of this sub-structure (small variations which appear regularly in the light or velocity curves) will soon be interpretable in terms of additional detailed knowledge of the structure of the stellar envelope.

Another concept that has gained force in recent years is that some types of intrinsic variability may be restricted to binary systems, through the tidal effect of one star upon the other. One of the first suggestions of this kind was Meyer's (**23**) in the case of β CMa. It is now clear that many if not all U Gem variables and novae are close binaries. The symbiotic variables also are double, or at least exhibit two dissimilar spectra, which may come from the two nuclei within a common envelope, but how explosive activity is generated in such a system is obscure. Recently the binary hypothesis has been revived by Fitch to explain the long-period modulation in the β CMa variable σ Sco, in the δ Sct stars, and possibly in the RR Lyr stars having secondary periods. The possibility that a tidal instability can be stimulated in a magnetic variable by a close companion has been considered by Ledoux (**24**). The case for tidally-excited pulsation would be strengthened if such variability could be found in spectroscopic binaries of high eccentricity, such as σ Psc and 26 Aql. A possible development of this kind may be Preston's discovery that the δ Sct star δ Del is a double-line binary with a very eccentric orbit (see Sec. 14).

Consideration has also been given to the role played by axial rotation in stellar variability. The apparent preference of β CMa and δ Sct-type variability for slowly-rotating stars is well known, as is the fact that RR Lyr stars always have narrow lines. The relationship between rotation and variability in the Hertzsprung gap has been discussed by Preston (**9**, p. 155) and by Kraft (**25**) from the observational point of view. On theoretical grounds, however, Kippenhahn (**9**, p. 162) doubts that, in that part of the HR Diagram, rotation can affect pulsation to any significant degree.

We should mention a few surprises: quite unexpected observational discoveries made during the past few years in the field of variable stars. Certainly surprising, although the extent of their significance is not yet clear, are the discoveries by Lovell of radio emission from flare stars, by Mendoza of infrared excesses in Orion population stars, by Serkowski of strong polarization in some red variables. Each of these developments is discussed later in this Report.

6. GENERAL PROBLEMS OF STELLAR VARIABILITY

A perennial question is this: if one were able to determine apparent magnitudes to a much higher degree of accuracy, would there then be found a large number of new, intrinsic variable stars? A definite answer to this question may require observations from outside the Earth's atmosphere. Opinions of photoelectric observers have themselves varied. According to Nikonov (**26**), carefully selected standard stars are likely to be constant to at least 0·02 magnitude. Sharov (**27**) has pointed out how small spurious variability can arise as the result of inadequate allowance for atmospheric transparency. Jackisch (**28**) at Sonneberg studied photoelectrically about 156 stars brighter than $m = 4{\cdot}5$, and found that about 22% showed some suspicion of variability, in amount 0·03 to 0·10 magnitude. Some stars now known to be small-range variables were missed (β Cas) but at least one star now known to be a short-period variable was found (κ Boo). Öpik (**29**) has however criticized this work on the basis that, due to the size of the observational error (0·025 magnitude for one night), it is impossible to be certain of the reality of variations of less than about 0·10 magnitude. He recommended that the program be repeated in a better photometric climate. In 1965, Jackisch did make further observations at Kottamia (U.A.R.). Of 210 A-type stars in his program (**30**), 20% proved to be variable with ranges of 0·03–0·06 magnitude, with 2% showing ranges up to 0·15 magnitude.

It is well known that M-type giants are very susceptible to small light variations; a statistical study by Blanco and Plaut (**31**) of old observations by Stebbins and Huffer showed that the percentage of variables increases from 20% at K5 to 100% at M6. The majority have amplitudes less than 0·5 magnitude. A similar study of variability among M giants in Groningen-Palomar Field 2 is being made by Miss Houk and Plaut, and by Miss Houk in VSF 193 in Sagittarius. Small light and radial-velocity variations are common among high-luminosity stars. This was shown also in Jackisch's original investigation, and a new program to observe supergiants in *UBV* has been inaugurated at Sonneberg.

The linear polarization of the light from pulsating variables in general has been discussed by Shakhovskoy (**32**); polarization in magnetic variables and in long-period variables is described in Sections 13 and 11. Since the amount and direction of polarization varies in some stars, Shakhovskoy considers this component to be of stellar origin. The best cases are the RV Tau stars AC Her and R Sct, the M supergiant μ Cep, and the Mira variable RT Cyg. The mechanism suggested for the production of the polarization is Rayleigh scattering by neutral atoms in atmospheric inhomogeneities, and the reorganization of these inhomogeneities by the shock waves at successive maxima is perhaps responsible for the variations. The polarization of μ Cep and other M supergiants has been investigated also by Grigorian (**33**) who first found the effect, and by Vardanian (**34**), who also gives reasons for believing the polarization found in T Tau and RY Tau is intrinsic (**35**).

Theoretical questions of stability, although of course fundamental to the problem of stellar variability, are technically not within the province of Commission 27. Attention is only called here to a review of this subject (**36**) and remarks on the effects of neutrino loss upon stability (**37**), by Ledoux.

7. PHOTOGRAPHIC SURVEYS, SPECIAL FIELDS

A major study by Richter has been completed at Sonneberg on the distribution of variable stars of all types throughout the Galaxy (**38**). Color estimates from Palomar Sky Survey prints make it possible to eliminate erroneously classified stars, and the material collected at Sonneberg in course of the Felderplan is used to allow for incompleteness. The star density and logarithmic density gradients in the solar vicinity for various types of object are derived, as are the total number of each type in the Galaxy, their Population assignments, and the duration of that phase of evolution. Pending the appearance of these results, one of the most authoritative reviews of the distribution of (some kinds of) variable stars are those of Plaut (**39**, **40**). The Sonneberg surveys for new variable stars are being pressed with the new 400/1600 mm astrograph. About 50 areas are under investigation, the regions added most recently being at higher galactic latitudes because the areas at low latitudes are beginning to show signs of exhaustion (**9**, p. 299). The total number of new variables discovered at Sonneberg had reached 10 100 by mid-October 1966.

The very large Palomar-Groningen search for faint variables in four selected regions is continuing under Plaut's direction. The blinking has been finished, and estimates of brightness completed for Fields 1, 2, 4. The results for Field 1 have been published (**41**; see also **9**, p. 297). De Kort is collaborating on Field 4. The Lick survey of variables in high latitudes is discussed in Section 9.

Among the bright stars, a number of short lists of small-amplitude southern variables have been published by the Cape observers Cousins, Lake, Warren and Corben in *Mon. Not. R. astr. Soc. So. Africa*. More recently Cousins has published a list of variables found in his Fabry photometric program at the Cape (**42**). A report by Strohmeier (**9**, p. 302) on the results of the first two years' work at the Bamberg South African Station lists about 50 bright new southern variables. Further discoveries are announced from time to time in the *Inf. Bull. var. Stars*. The photographic program of Weber (at Mainterne) deserves commendation, both for the discovery of new variables and for attention to stars of special interest. Romano (at Asiago) has collected plates of ten high- and five low-latitude fields for the past five years, for the study of variables to $m_{pg} \approx 17{\cdot}5$.

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The Leiden work on variables in the southern Milky Way is represented by the work of Kooreman, Charlier, van Houten *et al.* in *Ann. Sterrew. Leiden*, **22**, 1965–66. Oosterhoff and his associates are working on variables in the two Sagittarius 'windows' (**43**). Hoffleit's significant work on faint variables in Sagittarius continues (**44**). This region is important since on account of the richness of the field, one finds here good examples of some types of rare and interesting variables. Wachmann's results on variables in SA 98 and the Cygnus cloud have been published (**45**), and Miller's work on faint variables in Cygnus has also been very fruitful (**46**). Miss Harwood and Mrs Swain continue work on the variables in the Scutum cloud. Investigation now is complete for over half of the new variables found at Nantucket (**47**); the majority are long-period stars.

Outside our Galaxy, the very comprehensive studies by the Gaposchkins and by Hodge and Wright of variable stars in the Magellanic Clouds is described in Section 10. Baade and Swope have published (**48**) their results on variables in three fields in Messier 31, and Tammann and Sandage (**49**) have reported on their study of variables in NGC 2403.

8. VISUAL OBSERVATIONS

The visual programs of the various amateur variable star groups have continued, with a heavy emphasis on observations of long-period variables. The Variable Star Section, R.A.S. of New Zealand, directed by Bateson, is following some 400 southern variables, including all types suitable for visual work. The observations are published in detail in the *Circular* of the Section, as well as occasional discussions of special objects. The Variable Star Section, British Astronomical Association, observes both eruptive and long-period variables; reports appear from time to time in the *J.B.A.A.* The Variable Star Section of the Danish Astronomical Society has continued its activity under the direction of O. Klinting. Its reports appear in *Nord. astr. Tidskr.* The summary reports of the Berliner Arbeitsgemeinschaft für veränderliche Sterne are published in the *Astr. Nachr.*, and give mainly times of maxima and minima of long-period, semiregular, and irregular variables. Mrs Mayall, Director of The American Association of Variable Star Observers, publishes a monthly article in *J. R. astr. Soc. Canada.* Condensed lists of observations are issued as *Quarterly Reports*, but the original observations are available on microfilm by request. The Swedish Astronomical Society, Variable Star Section, publishes its reports in *Gothenburg astr. Not.*

Several members of this Commission are very active visual observers. Beyer publishes much of his work in *Astr. Nachr.* including some observations through blue and red filters. Peltier participates in the AAVSO program, and during this Report period, was responsible for the detection of the flare-up of Nova (GK) Per 1901 in 1966. De Kock (at the Cape) is following some 175 stars, including irregular, semiregular, and Mira types, as well as UV Cet and AE Aqr.

9. RR LYRAE VARIABLES*

The subject of the RR Lyr stars has been reviewed in depth by Preston (**50**) and by Woolley (**51**). The two articles overlap only partially; one emphasizes the astrophysical approach wherein major attention is given to individual stars, while the other represents the statistical and kinematical point of view. A new book on the RR Lyr stars has been written by Tsesevich (**52**).

Systematic searches for RR Lyr stars in high galactic latitudes, to determine the dimensions of the Galaxy at right angles to the plane, are in progress at several institutions. At Sonneberg, Hoffmeister has found many faint RR Lyr stars (e.g. **53**) in the north galactic pole and in the anticenter. The observational work on the Sonneberg variables near the pole is nearing completion (by Löchel, Meinunger, Wenzel, Ziegler, and the Hartha workers). A catalog of these

*Stars with periods shorter than $0^{d}.25$, except those that are clearly Bailey type *c*'s are discussed under δ Sct stars and dwarf cepheids in Section 14.

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stars will appear in *Mitt. veränd. Sterne*, **4**. The very extensive Lick program directed by Kinman continues. The methods have been described by Kinman *et al.* (**54**), and results for a low-latitude field (**55**) and for three fields near the north galactic pole (**56**) have been published. An analysis of the latter results in terms of density gradient and force law was carried out. The faintest RR Lyr stars found at Lick near the pole have m_{pg} (mean) = 18·0 approximately. Still fainter variables in the same area, at magnitudes 19 and 20, have been reported by Luyten (**57**); according to Luyten and Erickson (**58**) three of these have colors appropriate to RR Lyr stars, but no periods were obtained. Some 51 faint RR Lyr stars were found by Plaut (**59**) in Field 1 of the Palomar-Groningen survey at $l^{II} = 0°$, $b^{II} = +29°$, and discussed by him in a determination of the density gradient in that direction. Many other new RR Lyr variables have been discovered in the general surveys for variables that are described in Section 7. Mention should be made of the study by Arp (**60**) of the properties and statistics of RR Lyr stars in the direction of the galactic bulge.

An extensive series of five-color photoelectric observations of pulsating stars (mostly RR Lyr variables) made by Ponsen (**61**) has been discussed by Oosterhoff and Walraven (**62**) and by Oosterhoff (**63**). They have considered particularly the cyclic motion of RR Lyr stars in several kinds of two-color diagram. Further five-color photometry of southern RR Lyr stars by Van Houten and Van Genderen is in process of reduction by Van Herk. A large program of multi-color observations of RR Lyr stars selected from Van Herk's list (**64**) is being carried out by Johnson, Wisniewski and Fitch. The first observational phase is completed, consisting of *UBV* measures at maximum and minimum for over 100 stars. The observations will appear shortly, and the analysis later. Observations of RR Lyr stars have been published by many observers. Space does not permit them all to be cited here; we mention here only the *UBV* studies of six stars (three in only *BV*) by Jones (**65**), of five southern variables by Warren (**66**), and of three southern stars by Breger (**67**). Miss Capelli (Padova) is observing a number of RR Lyr stars that seem to have ranges either abnormally small or large for their periods. This is part of a thesis study on the statistical properties of the RR Lyr stars. Programs of *UBV* work on RR Lyr variables are underway at Budapest, during which Kanyó (**68**) has found the very short secondary period of 22ᵈ75 for Z CVn, and Tremko believes that a secondary period of 28ᵈ8 is present (**69**) in RU Psc. At Edinburgh, an attempt is being made by Smyth to observe a number of brighter variables for which such data is lacking. SW Dra, KN Per, RV UMa have been observed, and W CVn, ST CVn, XZ Dra, CZ Lac, TU Per are on the program. Conventional photographic work has not been entirely neglected: at Toruń, a program for determination of photographic and photovisual light curves of RR Lyr stars is being carried out (**70**). Robinson (**71**) has studied the changing period of SZ Hya on Harvard patrol plates. With regard to such effects, Tsesevich pointed out that period variation appears to be a general property of the RR Lyr stars of Population II, while the much less common RR Lyr stars of Population I have constant periods. The same general phenomenon is exhibited in an investigation by Balázs-Detre and Detre (**72**). They have studied the possibility that the deviations of RR Lyr stars (as well as other types) from a linear ephemeris might be explained by the accumulation of small random errors. They show that this is indeed possible, the important parameter being the standard deviation of the random period noise, and tabulate mean values of this quantity for a number of types of variable star.

The *UBV* colors of RR Lyr stars were studied by Sturch (**73**). He found that in variables of Bailey types *a* and *b*, $B-V$ and $U-B$ are essentially constant between phases 0·5 and 0·8 (counted from maximum light). The observed $U-B$ is used to correct $B-V$ for line blanketing, which then gives (following allowance for its dependence on period) the interstellar reddening. Frolov (**74**) had earlier investigated the dependence of $B-V$, after a correction for line strength, upon period.

Preston *et al.* have demonstrated the advantages that come from a combination of time-resolved high-dispersion spectroscopy and simultaneous *UBV* photometry of both singly

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(**75**) and doubly-periodic (**76**) RR Lyr stars. The amount of detail that is missed by conventional observations is striking. Their results are discussed in Appendix I.

Fernie determined an empirical period-radius relation for intrinsic variables in general (**77**), and later included allowance for a mass dependence (**78**). It is essentially a substitute for the usual period-density law, and can be expressed as a *P*, *L*, color relationship for several kinds of pulsating stars. Since individual stars follow this relationship not only in the mean but even as they vary, Fernie has used this fact to develop a short method of determining distances and reddenings of RR Lyr stars (**79**) from 'instantaneous' observations. With a similar aim of lessening the amount of observational data required for statistical studies, Breger (**80**) has studied the question whether there is a definite phase in the cycles of all RR Lyr stars at which they have the mean luminosity, or the mean velocity. The answer appears affirmative in both cases, as long as one avoids stars having variable light curves. Demarque and Percy (**81**) have investigated the possibility of explaining Fernie's empirical relationships by studying the adiabatic pulsations of giant star models having a large mass range. Gough *et al.* (**82**) show that the *R*-dependence found by Fernie can be understood in terms of the travel-time of a wave through the atmosphere, but not the mass dependence. The *P*, *L* relation for RR Lyr stars was re-investigated by Frolov (**8**), who found the expression $M_v = -4.41 \log P - 0.66$. Van den Bergh found (**83**) that the scatter of the *P*, *L* relation in the Magellanic Clouds can be improved if $\langle V \rangle$ is corrected by $-3 \langle B-V \rangle$, which is possible since the constant-*P* and reddening lines are so nearly parallel in a color-magnitude diagram. Wesselink and Shuttleworth (**84**) in their study of 45 variables in the SMC found five variables of periods less than 1^d with $\langle m_{pg} \rangle \approx 18.0$. It was concluded that these are members of the cloud with $M_{pg} \approx -0.5$. The non-linear pulsation calculations for RR Lyr stars by Christy (**21**) now provide a consistent theoretical foundation with which to compare observational data, although Christy's models are subject to possible future refinement. Christy has already commented very briefly (**9**, p. 111) on the possibility of understanding Fernie's empirical *P*, *R*, *M* relationship in terms of these calculations.

A discussion of the absolute magnitudes of the RR Lyr stars was made by Woolley *et al.* (**85**) on the basis of a statistical comparison of proper motions with radial velocities. A similar discussion was carried out by Van Herk (**64**) who had, however, new proper motions for a large number of stars, from a Mt Wilson program begun by Van Maanen and from a comparison of new Leiden plates with Carte du Ciel positions. The results of the two investigations are therefore independent to some extent. It would be of interest to see if improved allowance for reddening, as is now possible if *UBV* data are available, would sharpen such results. Van Herk is now engaged in the determination of the proper motions of a large number of additional RR Lyr stars, using the Carte du Ciel catalogues or original plates as far as possible. In view of the impending availability of such data, it is very important that radial velocities for many more RR Lyr stars be measured. As Woolley *et al.* point out (**85**), the requirements on velocity precision are not high.

10. CEPHEIDS OF BOTH POPULATIONS

Recent theoretical calculations of stellar pulsation have been reviewed in Section 5, and will be referred to only incidentally here. Mention should be made of the general discussion of evolutionary tracks in the cepheid region by Kippenhahn (**86**) in his review of stellar evolution and variability. The detailed discussion has been published separately for masses of 5·0 and 7·0 ⊙ (**87, 88**) with the results for 9·0 ⊙ yet to appear. Iben has performed similar calculations for masses between 3 and 15 ⊙ (**89**). The correlation of these tracks and the speed of evolution along them with the observed properties of cepheid variables has been investigated by Miss Hofmeister (**90**), Kraft (**25**), Kopylov (**91**), Efremov and Kopylov (**121**), and Iben. Expectation and observation seem to be in acceptable agreement. Reference is made to the use of pulsation theory by Masani *et al.* (**92**) to estimate the mass of a cepheid variable; their procedure is to vary the mass until the fundamental theoretical period matches the observed one.

A very useful catalog of some 10 000 *UBV* observations of over 300 cepheids has been published by Mitchell, Iriarte, Steinmetz, and Johnson (**93**). Approximately 2000 of these observations are new, made by Mitchell *et al.*; the others are published data from a variety of sources, all re-reduced to the *UBV* system. Walraven, Tinbergen, and Walraven (**94**) have observed 24 southern cepheids with periods between 5^d and 79^d in the five-color *UBVWL* system. Breckenridge and Kron (**95**) have published observations in the Stebbins-Whitford six-color system of four southern cepheids, and Nielsen at Aarhus is observing ten bright cepheids photoelectrically in *BV*. Gouseva and Tsarevsky are also carrying out narrow-band photometry of a number of cepheids.

Cepheids that behave in some anomalous manner received attention. Fernie (**96**) pointed out that the LMC cepheid HV 953, of period 48^d, should change in $B-V$ at a rate of $+0{\cdot}26$ magnitude per century if the period change of one day per century reported by Oosterhoff were maintained. However, a subsequent study of HV 953 by Janes (**97**) on Harvard plates shows that the period fluctuates erratically rather than progressively. Fernie, Demers, and Marlborough (**98**) found that the period of the galactic 45^d cepheid SV Vul behaves in the same fashion. Oosterhoff (**99**) investigated the cepheid AP Vel, and found it to be a case like TU Cas and U TrA: a fundamental period of 2 to 3^d beating against a secondary period of 0·70 that length. In the case of AP Vel, the fundamental is $3^d{\cdot}13$, and the period of the beating $7^d{\cdot}4$. A photoelectric study of TU Cas was carried out by Vasilianovskaya (**100**). Kapko (**101**) and Huth (**102**) have studied the remarkable 10^d cepheid AP Her, whose period is subject to such large changes. Over the interval of observation, it has varied between $10^d{\cdot}35$ and $10^d{\cdot}42$. The period variations of PP Aql, AP Her, and MZ Cyg have been studied by Tsesevich. In this connection, attention is drawn again to the work of Balázs-Detre and Detre (**72** and Section 9) on the representation of such behavior as the result of the accumulation of a series of small random events. The problem has been discussed by Demers (**103**) in the case of three specific cepheids, among them RU Cam, which underwent a remarkable decrease in amplitude in 1965–66. This latter fact was discovered by Demers and Fernie (**104**), and further contributions were made by Wamsteker (**105**), Smak (**106**), and Nikolov (**107**). All the available photoelectric material was discussed by Detre (**108**), who showed that the range seems to vary cyclically with a period of about five years. On this basis, Detre suggests that an increase in the range is to be expected soon; in August 1966 the range was only $\Delta V = 0{\cdot}08$ magnitude as compared to about 1·6 magnitude two years before. RU Cam is being investigated in detail by Fernie.

Fernie has examined the properties of the sixth-magnitude B-type companion of δ Cep (**109**). Largely on the basis of its Hβ strength, he finds it to have an absolute magnitude which is 1·6 magnitude too faint for agreement with the presently-accepted M_v of the cepheid. Fernie therefore believes that the two do not constitute a physical system. In the case of the F-type visual companion of α UMi, Fernie (**110**) assumes the system to be physical and from the further assumption that the companion lies on the zero-age main sequence, finds that $\langle M_v \rangle = -3{\cdot}2$ for the cepheid, which appears reasonable. Fernie uses Miss Roemer's (**111**) data on the long-period spectroscopic orbit to estimate that the invisible spectroscopic companion is probably a main-sequence star of type near F0. Fernie also remarks on the curious fact that although α UMi lies near the center of the cepheid instability strip, it has the smallest known amplitude among cepheids.

As to cepheids in galactic clusters, Landolt has studied S Nor in NGC 6087 and U Sgr in Messier 25 (**112**). Preston (**113**) has obtained the spectral types of many stars in the field of CV Mon, and finds that there are difficulties in assigning the cepheid to cluster membership, if indeed the cluster itself is real. Malik (**114**) has observed the three-day cepheid BY Cas in *UBV*, but the question of its membership in NGC 663 remains unanswered. BQ Ser lies near the cluster IC 4756, but is not a member according to Wenzel, who has finished a discussion of the Sonneberg *UBV* observations. It is a cepheid with variable light curve and/or period, as recognized first by Meinunger (**115**). Smak (**116**) has obtained limited photometric material in *BV* on the cepheids CE*a* and CE*b* Cas, in NGC 7790. Comparison with CF Cas in the same cluster shows that the data on the three variables are internally consistent, and also are in accord with the mean *P*, *L*, color relations for cepheids at large. Efremov and Kholopov (**117**) have also studied CE*a*, *b* Cas, and drew similar conclusions. Westerlund (**118**) has published his investigation of the 41^d cepheid RS Pup and the OB association of which it is apparently a member. This cepheid is further remarkable in the fact that it illuminates a small reflection nebula. Efremov (**119**) has argued in favor of the membership of cepheids in the halos of some clusters and associations, including *h*, χ Per. He also found a dependence of the period of a cepheid upon the age of the cluster to which it belongs (**8, 120**). This is in accord with the production of cepheids from B stars, and provides an estimate of the duration of the cepheid stage. Efremov and Kopylov (**121**) revised the data on the 19 cepheids which possibly are members of 11 clusters and associations. They found that Kopylov's (**122**) calibration of the zero-age main sequence requires that the cepheids be 0·5 magnitude fainter than Kraft's estimate. They confirmed Efremov's earlier estimate of the duration of the cepheid stage, and regard this time (about 10^6 years) as compatible with the time that the star remains in the instability strip according to the tracks calculated by Kippenhahn and his associates. Since the same deviation follows from the relative numbers of B stars and cepheids, Efremov and Kopylov conclude that a majority of the B stars evolve into cepheids. Tsarevsky *et al.* (**123**) believe that as many as 40 cepheids can belong to clusters or their halos.

The Gaposchkins are engaged in a very large program involving all the known variables in both Magellanic Clouds. A discussion of the relationship of light curve to period for cepheids in the SMC has been published (**124**), as well as general accounts of the project (**125**). The complete SMC results will appear soon. Wesselink and Shuttleworth (**84**) have obtained photographic light curves for 39 cepheids in the SMC, and Van Genderen is working on cepheids in the central section of the SMC. Work on the LMC by the Gaposchkins is now underway; over 1000 cepheids alone are on the program. Wright and Hodge have published an Atlas (**16**) of over 2000 variables in the LMC, and are now engaged in an exhaustive study (in *BV*) of 80 variables in a small region north of the bar (**126**). They estimate that only 25% of the variables in the area have been discovered, so that the total number in the LMC to $M = 0$ is about 8000. They have also worked on Population II cepheids in the LMC (**127**). Dickens (**128**) has obtained light curves of ten bright cepheids in the LMC and finds, in accord with earlier work, that the LMC stars are bluer than galactic variables of the same period.

The *P*, *L* and *P*, color laws for W Vir stars in globular clusters have been investigated by Fernie (**129**), who finds that they can be extrapolated to include the RR Lyr stars. The W Vir cepheids occur in metal-poor globular clusters, yet Woolley has pointed out (**130**) that the kinematics of the field W Vir stars are such that they cannot be regarded as the halo analogues of the classical cepheids. Kholopov (**131**) suggested that the W Vir stars may actually be a product of the evolution of classical cepheids. An extensive investigation of the properties of the W Vir stars has been carried out by Demers (**132**). Michalowska-Smak and Smak have published *UBV* observations of eight cepheids considered to be Population II objects (**133**). Kwee is engaged in a photometric study of Population II cepheids. New five-color observations of W Vir have been discussed by Oosterhoff and Walraven (**62**) and narrow-band photometry of a large number of cepheids, including W Vir stars, has been carried out by Williams (**134**) in an effort to measure metal/hydrogen ratios in different parts of the Galaxy. The period variations of W and AL Vir have been investigated by Prikhodko and Chouprina (**135**). On the theoretical side, Christy (**22**) has carried out exploratory calculations on an unstable stellar model of mass 0·88 $\odot$ which exhibits some of the observed properties of W Vir.

The normal colors of cepheids have been reconsidered by Nikolov (136) and by Efremov (137), who finds from a discussion of the six-color data that in the period range 20 to 30^d the intrinsic colors are 0·15 to 0·20 magnitude redder than obtained by Kraft; Efremov gives the relation: $\langle B-V\rangle_0 = +0{\cdot}21 + 0{\cdot}56 \log P$. Reference has already been made to the work of Fernie (77, 78) on the empirical P, R, mass relationship for pulsating stars. The empirical data on the P, L relation has been summarized by Efremov (138). Both Efremov and Kopylov (121) and Genkin (139), the latter on the basis of cepheid proper motions, suggested that the zero-point of Kraft's P, L law requires a correction of $+$ 0·5 magnitude.

We only mention here the use that has been made of the cepheids for investigations of galactic structure. Kraft (140) has discussed their distribution in the Galaxy and their lack of concentration to spiral arms. Takase (141) has made a kinematical analysis of their motions, and Howard and Kirk (142) have determined galactic rotation parameters from the radial velocities.

II. SEMIREGULAR, LONG-PERIOD, AND RED VARIABLES

Smak has given (143) a thorough review of the observational problems of the Mira and long-period variables. A major advance in this area was provided by Smak's *UBV* and low-dispersion spectrophotometry of 29 Miras, 12 semiregular M's, and several miscellaneous M stars (144). These were accompanied by a rediscussion of radiometric data, and an analysis of the effect of the TiO bands. A later narrow-band photometric study (145) was directed toward classification on the basis of TiO strength, with the effect of H emission eliminated; this two-color system was shown to be useful for determination of reddening. Bolometric corrections and effective temperatures for M giants were obtained by Mendoza and Johnson (146) from their photometry to 9μ; a new scale of BC's has been established by Smak (147) on the basis of those results together with balloon observations from Stratoscope II. Tsesevitch has also studied the problem of BC's for Mira variables. The ubiquity of variability among M giants has again been emphasized by Blanco and Plaut; their results are discussed briefly in Section 6. Maffei (148) finds that there is a considerable advantage in searching for very long-period Miras by using the near infrared.

Mrs Mayall has published (149) a valuable series of light curves of long-period variables based on visual observations over a long time interval: R Lep, over the years 1854–1962; T Cas, 1889–1964; X Cam, 1904–64; RV Cas, 1906–65; V Hya, 1884–1965; χ Cyg, 1841–1966. Certainly such long series provide one of the best scientific justifications for the emphasis of the amateur associations upon observations of Mira and long-period stars. A good example of the use that can be made of such material is the study by Harrington (150) of cycle lengths and heights of maxima for some 165 stars. He finds that if a maximum is earlier than expected, it is likely to be brighter than the average. Miss Houk (151) has studied the light curve of the N-type Mira V1280 Sgr, with $P \approx 523^d$. The cycle lengths and the magnitude at maximum vary considerably, but their correlation may be in the opposite sense to that of Harrington. Houk points out that the departures of V1280 Sgr from strict periodicity can be explained formally as the effect of a long secondary period. In fact, if this secondary period were due to the beats between two nearly equal shorter P's, the sense of the correlation between spacings and heights of maxima would be understandable. In some well-studied Miras, the systematic deviations from a linear ephemeris are very large. Huth (152) and Schneller (153) have discussed the material on W Tau, R Aql and R Hya, in all of which a parabolic term is a clear necessity, although it may be that a limited number of straight-line segments would fit the $O-C$ curve as well. Superimposed upon these large-scale changes are more erratic deviations which may be identified with the accumulation of random errors, as discussed elsewhere (72). The dependence of range on period for Mira stars, and its interpretation in terms of age were investigated by Bredichin (154).

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The variability of M supergiants is of course of a different character than in M giants. Larsson-Leander (155) has reported on a five-year series of *P*, *V* observations of μ Cep, and Magalashvili and Kumsishvili (156) have made photoelectric observations of the supergiants RW Cyg and SU Per. Some tendencies toward cyclic behavior are apparent in these stars, but they are not striking. A periodogram analysis of the older observations of μ Cep by Sharpless *et al.* (157) does, however, reveal a considerable degree of 'hidden' regularity. No further optical information is available on the rapidly variable infrared (9μ) emission reported by Low (158) around μ Cep, α Ori, and α Tau.

Some general properties of the RV Tau stars have been reviewed by Stothers (159), with emphasis upon their galactic distribution. The light curves of two RV Tau stars, EZ Aql and EQ Cas, on the basis of about 18 years of visual observation, have been discussed by Beyer (160) with emphasis on the period changes. Questions of the nature of RV Tau stars, and of Mira and long-period variables with periods near 200^d soon involve the stars of these types in globular clusters. These matters are discussed by Mrs Sawyer Hogg in Appendix II; we only refer here to the useful paper by Stothers (161) on longer-period variables in clusters and the field, and to the remarks by Feast (162) on the same subject.

The kinematics of long-period and Mira stars have been studied by Smak and Preston (163) on the basis of new radial velocities for 270 variables; the discussion was directed toward galactic-dynamic ends so we do not consider it further here. Feast (164) has with new velocities for 53 Me and Se variables in the general direction of the galactic center, discussed the motions in terms of galactocentric orbits; an interesting comparison with the planetary nebulae in the same direction is made. Kreiken (165) has examined the question whether the velocity components in different directions are a function of *P* for stars with $140^d < P < 200^d$. Eskioğlu (166) earlier had obtained a positive correlation between *P* and the tangential component, but Kreiken's results were inconclusive. A major injection of fresh material in this field can be anticipated when the results of Van Herk's current proper motion program for 343 red variables become available.

The significance of the discovery by Serkowski (167) of large amounts (up to 6%) of plane polarization in some Mira stars, variable with phase, is not yet clear. Certainly the observations should be pressed vigorously to many more objects over their complete light cycles. Donn *et al.* (168) have suggested that aligned graphite flakes, condensed in the atmospheres of these stars, could be responsible through the angular dependence of their scattering. One would expect such an effect to be much greater in the carbon variables, but the two carbon stars for which data have been published appear no different in amount than the M stars.

The discovery by Neugebauer *et al.* (169) of a number of visually very faint stars that were of magnitude 0 or 1 at 2μ was most exciting, and for a time it appeared that possibly a new type of stellar object had been discovered. It now appears that that belief was premature. With the exception of one object in Cygnus near $20^h43^m, +40°$ (1900) which may be a heavily-reddened M supergiant, and an object in the Orion Nebula (see Section 15) the other 'infrared stars' appear to be no more than very late-type Mira variables of unusually long period. That such stars can be discovered by conventional infrared photography was demonstrated in the 1930's by Hetzler, and more recently by Haro and Luyten (170) and by Haro and Chavira (171). Reference has already been made to the finding of Maffei (148) that such long-period Miras become very conspicuous in surveys made in the near infrared. The literature on the subject of the 'infrared stars' is already fairly extensive, so that for spectroscopic information we refer to the discussion in Appendix I, and for a fairly complete discussion and bibliography to a review paper by Wing *et al.* (172).

12. β CANIS MAJORIS STARS AND OTHER EARLY-TYPE VARIABLES

Observational activity in the field of β CMa variables has slackened, due at least in part to the loss of the stimulus provided by O. Struve. The photometric program of van Hoof of southern β CMa stars has produced two- and three-color light curves of β CMa itself (**173**), 15 (AO) CMa (**174**), σ Sco (**175**), information on the beat period of τ^1 Lup (**176**). Miss Kupo (**177**) has published a spectrophotometric study of β CMa, and Milone (**178**) has studied the fundamental periods of β CMa as exhibited in the radial velocities. Klock (**179**) has observed KP Per (= HD 21803), and found in addition to the usual interfering fundamental periods near 0ᵈ20, evidence for a still shorter period of 10 to 15 minutes. Rossati (**180**) has observed the same star in two colors but since he regarded the light curve as containing two minima of unequal depth, interpreted it in terms of the double period of 0ᵈ40. Jerzykiewicz (**181**) has observed δ Cet in two colors and compared his results with the older radial velocity observations. From radial velocity observations, van Hoof and Blaauw (**182**) have obtained a provisional period of 0ᵈ153 for 53 Ari.

The origin of the beat phenomena in β CMa stars has generated some discussion. Theoretical studies by Chandrasekhar and Lebovitz (for references see **183**) showed how the effect of rotation could produce two normal modes of nonradial oscillation whose difference might account for the β CMa effect. Mrs Böhm-Vitense (**183**) actually computed the rotational velocities required to reproduce the observations; they were in the range 100–300 km s^{-1}, depending upon details. These velocities v_{rot} were so large as compared to the uniformly small values of $v_{rot} \sin i$ actually observed, that to save the explanation it was necessary to postulate that we observe all the known β CMa stars nearly pole-on (and also that they do not appear to vary appreciably if seen otherwise). However, van Hoof (**184**) pointed out that two of these β CMa stars were also single-line spectroscopic binaries, and if one assumed the orbital and rotational axes to be parallel, then the inclination requirement of the Chandrasekhar-Lebovitz theory led to impossibly high masses for the components, from Kepler's third law. Clement (**185**) has refined the original theory and finds that the required v_{rot}'s become somewhat smaller. It is possible that if all the contributing factors were now to lean in the same direction, the conflict would not be so decisive, but it is certainly not yet resolved. For the clarification of such questions, it is becoming ever clearer that photometric observers have an obligation to settle once and for all the issue: has there been some bias in the search for β CMa variables *against* broad-line stars? That is, are there any cases of rapidly rotating β CMa stars?

Another suggestion as to the origin of the pulsations in β CMa stars has been made by Oleinik and Porfiriev (**186**). They believe that as a result of evolutionary change in the star's structure, meridional circulation will force a drastic equatorial deceleration of the rotation, which in turn will set up radial oscillations of the entire star. This proposal has not yet been explained in detail, although Porfiriev (**187**) has computed the line profiles expected for a star undergoing both pulsation and meridional circulation. Hitotuyanagi and Takeuti (**188**) have obtained a pulsation constant near 0·02 for the β CMa stars from a theoretical mass, L relationship.

Fitch has suggested that all β CMa stars showing beat phenomena do so as the result of the effects of tidal deformation by a faint companion, and not as the result of interference by multiple periods. In the case of σ Sco, a known binary, in which the orbital elements are known, he finds that the periodic phase changes in the 0ᵈ25 β CMa-type cycle do correlate well with the calculated variation of the tide-raising potential.

There is general agreement that the β CMa stars are former B-type dwarfs that have evolved off the main sequence but opinions differ as to their precise location on the theoretical evolutionary tracks. Stothers (**189**) has developed in detail the thesis that they are non-rotators in radial oscillation, evolving across an instability strip in the HR Diagram. Some of the observational issues involved are discussed by van Hoof (**9**, p. 149) and by Odgers (**9**, p. 145). The only safe conclusion at the present time is a familiar one: the information is still inadequate for a decision.

There are, of course other types of intrinsic variability among early-type stars. Feinstein has observed about 70 southern Be stars in *UBV*, and some in *RI* as well. About half of these objects show variations in both V and $U-B$. Jackisch has observed the Be stars 48 and 53 Per.

13. MAGNETIC AND PECULIAR A-TYPE VARIABLES

The general subject of magnetic variables has been reviewed at length by Ledoux and Renson (**190**), while the theories devised for their explanation have been discussed by Cowling (**191**). Observational aspects, and in particular the location of the magnetic variables in the HR Diagram have been considered by Jarzebowski (**9**, p. 25).

Ledoux (**10**) has suggested a new 'pulsation theory' of magnetic variables, based on the excitation in the presence of rotation of special non-radial modes in an external slightly super-adiabatic layer. This suggestion eliminates the difficulties concerning the excitation mechanism and the order of magnitude of the period (which is of the same order as that of rotation), but the excitation of the low-degree harmonics seems to require the presence of a binary companion in an eccentric orbit. The details of the magnetic variation have not been worked out. Renson has pointed out that the distribution of the periods for about 30 magnetic variables is very much like that of the periods of spectroscopic binaries (with $P < 11^d$), which reinforces the binary hypothesis of the magnetic variables. Renson believes that the invisible companions must be highly evolved degenerate stars, originally of higher mass that have transferred much of their material to the present magnetic star. Steinitz however regards the oblique rotator hypothesis as still the most promising explanation, and has reviewed the relevant observational information (**192**).

Renson has given special attention to the reconciliation of the magnetic and photometric observations. Some of his results both published and as yet unpublished are as follows: *HD 10783*: both magnetic field and radial velocity vary with the light period of $4^d.1565$, although erratic fluctuations are superimposed. The same period was found also by Van Genderen (**193**). *HR 8861*: The photometric observations of Rakos can be represented by a period of $0^d.723$, which is consistent with the period-line width relation (**194**). *HD 8441*: According to Renson the magnetic field varies with the period of the spectroscopic binary, $106^d.27$ (**195, 196**). Steinitz however believes (**197**) that the field period is $2^d.9632$. *21 Per*: Renson finds that the magnetic period is $1^d.728$, in agreement with the light variation. *HR 7058*: There is some difficulty in fitting the magnetic observations to the light period of $10^d.1$. γ *Equ*: a magnetic period of $314^d \pm 3^d$ has been obtained. *HD 32633*: The magnetic observations can be fitted with a period of $6^d.4289$, which is compatible with the light variation. *HR 5597*: both the magnetic and photometric data can be represented with a (slightly variable) period of about $1^d.054$. Babcock (**198**) has discussed the case of *53 Cam*, in which the phase difference of light and magnetic field appears to violate a general relationship suggested by Rakos. A new photoelectric light curve and improved period of ι *Cas* have been obtained by Klock (**199**). The rather unusual Ap star HD 221 568 has been found to be variable by Osawa *et al.* (**200**), apparently with a period of about 160 days.

HD 215441 (GL Lac) the magnetic variable of largest known field, has been studied both polarimetrically and photometrically by Polosuhina and Lebedeva (**201, 202**); they find that there is a linear correlation between the percentage polarization and the magnitude in the $9^d.5$ photometric period. At Uppsala, A. Elvius and Engberg are attempting to detect variable polarization in magnetic variables. No strong polarization has been found in any of the stars studied, but in 21 Per polarization changes are indicated that might have a period slightly shorter than the photometric period of Rakos.

14. δ SCUTI VARIABLES AND DWARF CEPHEIDS ($P < 0^d.2$)

An investigation by McNamara (**9**, p. 111) of dwarf cepheids and RR Lyr variables in a narrow-band three-color system has enabled him to determine, under certain assumptions, the luminosities and intrinsic colors. Empirical adjustment of these luminosities makes possible the location of these variables (together with the δ Sct stars, from an earlier investigation) and their constant-*P* lines on a HR Diagram. A discussion of the relative space densities is also included. One of the distinctive features of the δ Sct stars is that they possess a significant amount of axial rotation, which has long been recognized as an exception among the intrinsic variables. Preston (**9**, p. 155) has developed the idea that pulsation and rapid rotation are incompatible, and specifically that only those stars with sufficiently low rotational velocities are able to pulsate as δ Sct stars. Statistics then available on line widths seemed to support this thesis, but it has recently been discovered that some rapid rotators (such as β Cas (**204**)) are variable. Kraft has considered the similar problem for cepheids (**25**).

Since so many δ Sct variables and dwarf cepheids have been detected accidentally among the bright stars, it is obvious that many more await discovery. A short, rather general program directed to this question by McCullough (**205**) produced no new examples, however. Eggen has suggested a number of possible δ Sct stars on the basis of location in color-luminosity arrays. A considerable number of new short-period variables whose precise classification is not yet certain have been found recently, as the result of specific photoelectric observation of plausible candidates. A list of those announced through November 1966 as certainly variable is as follows:

HR	Name	Period	References
21	β Cas	$0^d.104$	Millis (**203**) (**204**)
1287	44 Tau	·134	Danziger and Dickens (**211**)
1706	14 Aur	·122	(**211**)
2107	1 Mon	·137	(**211**)
3265	—	·13	(**211**)
3888	υ UMa	·13	(**211**)
4715	4 CVn	·1707	Jones and Haslam (**206**), Wachmann (**207**), Smyth (**208**), (**211**)
5005	—	·14	(**211**)
5017	20 CVn	·14	Wehlau *et al.* (**210**), (**211**)
—	HD 116994	·104	Chen (**209**)
5329	κ^2 Boo A	·069	(**203, 28**)
5435	γ Boo	·2903	Magalashvili and Kumsishvili (**212**)

Possibly to be included are HR2539 (59 Aur) and HR3889 (20 Leo) (**211**). As in the case of flare stars and β CMa variables, those concerned with statistical properties of variable stars must be very careful that such lists of discoveries are not biased in some way, as if for example the stars examined were only those having sharp lines, or luminosities above the main sequence. It is an unfortunate fact that by such observational selectivity, an initial bias or prejudice can become hopelessly enshrined in the literature.

Photometric observations of the well-known δ Sct star DQ Cep have been published by Fitch and Wehlau (**213**), and reported by Jenks *et al.* (**214**). The multiple periodicity of δ Del has been studied by Wehlau and Leung (**215**) on the basis of Fourier analysis of new observations on 25 nights. They represented the variation of period $0^d.134$ by superimposing six short-period waves. Jerzykiewicz (**216**) reported that the variation on four nights in 1965 followed

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a period of $0^d.1363$, but that this could be equally well represented as the beat between Eggen's discovery period of $0^d.1350$ and a period of 14^d, which latter Preston had suspected to be the interval associated with the occasional line-doubling which he had discovered in δ Del. The idea that a tidal resonance effect in a close binary with an eccentric orbit could stimulate a component in the light variation is attractive (see below) but in this case it is not convincing since more recent work by Preston indicates that the period of δ Del is actually about 41 days. In the case of the δ Sct star CC And, Fitch has detected a $10^d.5$ modulation of the fundamental period for whose explanation he proposes the tidal effect of a close companion. He makes the same proposal for those β CMa stars with long-period modulations. Such an explanation will be most convincing if a photometric term can be found that is clearly identifiable with an orbital period. No one can argue against an orbital interpretation of a radial velocity variation if *two* spectra are visible. Since this is the case for δ Del, this star will be a crucial test for such proposals.

An analysis has been made by Oosterhoff (**217**) of Ponsen's photoelectric observations of the dwarf cepheid V 703 Sco. The high maxima are separated by an interval of $0^d.1152$, but the light curve is subject to major short-period fluctuations which Oosterhoff has now disentangled into primary and beat periods, together with a short period of about $0^d.042$ that is also subject to beat phenomena. The dwarf cepheid SZ Lyn ($0^d.1205$) has been observed in *UBVR* by Van Genderen (**218**). The probably similar stars YZ Boo ($0^d.1041$) and VZ Cnc ($0^d.1784$) have been observed by Heiser and Hardie (**219**) and by Wildey (**220**), respectively. The complex photometric behavior of the dwarf cepheid VX Hya has been studied by Fitch (**221**), who compares it to AI Vel. A double harmonic series with slowly changing coefficients fits the variation in *V* quite accurately; a fundamental period of $0^d.2234$ and an overtone of $0^d.1727$ was found. Notni (**222**) has studied the rapidly-changing light-curve of AC And, and points out similarities to the dwarf cepheids in its luminosity and color-magnitude variation. The period (sometimes represented as the sum of two variations with periods of $0^d.52$ and $0^d.71$) is however much longer than the generally accepted upper boundary for that class.

15. ORION POPULATION VARIABLES: T TAURI AND RW AURIGAE STARS, ETC.

Survey work and studies of variable stars occurring in young clusters and associations that have been published in the last three years will be found listed in Appendix II, the Report of the Committee on Variables in Clusters. Non-technical reviews of the present state of the subject have been presented by Kuhi (**223**) and by Hunger (**224**).

Götz (**225**) has made a very important study of the relationship of emission Hα stars to interstellar material, including a thorough examination of the systematics of the known variables in the major associations. One interesting result is that the intensity of Hα emission in individual stars is strongly correlated with the opacity of the dark material upon which they are seen projected. This is certainly connected with the finding by Herbig and Peimbert (**226**) that the number of such stars per unit projected area of the nebulae is also proportional to the opacity. It will be noted that this does not necessarily contradict the earlier belief that such stars prefer the edges of observed areas; obviously the edge regions occupy more square degrees than do the dense centres.

Garzoli and Varsavsky (**227**) have observed, in agreement with an earlier result by Burke, that 21-cm observations of the Taurus dark nebulae indicate no excess or deficiency of neutral H in those regions where emission-line stars are concentrated. Whatever the explanation for this apparent conflict—H_2 formation, very low H I temperature, or some other—it is apparent that direct observation is beginning to provide some useful boundary conditions for theories of star formation.

For such purposes however, the data must be trustworthy. Meinunger has begun a systematic examination of the variations of the rapidly irregular RW Aur stars. His first results (**228**) indicate that a number of T associations must be spurious, since most of their members belong to some other class of variables. Hoffmeister (**229**) has analyzed the light curves of four southern RW Aur variables (T Cha, RU Lup, RY Lup, AK Sco) and finds that quasi-periods of lengths three to five days persist. Hoffmeister proposes that these are due to axial rotation combined with variable, non-uniform distribution of brightness over the stellar surfaces. It is interesting that the rotational velocities implied by Hoffmeister's results are of the same order as the velocities inferred from the line widths observed in a number of other T Tau stars.

Much new data on the variations in color of RW Aur itself have appeared, especially as the result of an intensive campaign carried out in 1962–63 in the U.S.S.R. At Abastumani, spectrophotometric observations were made by Kharadse and Bartaya (**230**), while it was observed in three colors by Mosidze (**231**), and photoelectrically in two colors by Kumsishvili, Magalashvili, and Abuladze (**232**). Observations of RW Aur were also reported by Chugainov and Zaitseva (**233**), by Alksnis and Daube (**234**), by Mirzoian and Kazaryan (**235**) and by Ishchenko and Shevchenko (**236**). An extensive program of three-color photoelectric observations of this and similar stars continue at Sonneberg; the first results for RW Aur were published by Fürtig and Wenzel (**15**, p. 64). A limited series of *UBV* observations of RW Aur were made at Lick by Taylor. Despite all this attention, the star still lacks a firm physical model. The photometric activity proceeds on time scales from a few hours upward, the colors being correlated with the light variation. Efimov (**237**) suspects that there may be a change in the degree of polarization that varies with the $B-V$ color.

Three-color observations of some 26 T Tau stars have been carried out by Smak (**238**), together with a narrow-band substitute for the *B* color that avoids the strongest emission lines in that spectral region. Even with this refinement, the colors are quite anomalous in the sense that the emission-line stars are too bright in the blue, and of course in the ultraviolet. Spectrophotometric observations of T Tau and RW Aur by Aveni (**239**) indicate that the emission lines contribute about 0·1 magnitude to the *B* color in those stars. Smak's data indicate that $H\beta$ and $H\gamma$ alone can brighten *B* by 0·3 to 0·4 magnitude in extreme cases. One anticipates that *continuous* emission will add more energy to *B* and especially to *U* than do the lines, but no estimates of those amounts have been attempted. Kuhi's (**240**) scanner observations show that the *continuum* ultraviolet excess is well correlated with the intensity of $H\alpha$ emission; if the proportionality can be determined, perhaps the necessary corrections can be made to the observed colors. Until that is possible, the colors of these objects cannot be placed on theoretical evolutionary tracks with any degree of confidence.

The veiling of the absorption spectra of the T Tauri stars and the excess energy in the near ultraviolet could be reproduced formally by the superposition of a hot continuous spectrum. Gurzadian (**241**) has shown how a blanket of electrons, of appreciable optical thickness, could do just this by, in effect, simply transferring energy from the infrared into the blue and ultraviolet. The sudden appearance of such an electron cloud would then lead to a sudden flare-up in blue-ultraviolet light. But whether this suggestion is compatible with the simultaneous existence of infrared excesses in T Tauri stars is not clear. Kolesnik and Frank-Kamenetsky (**242, 243**) have indicated how the emission of dense, nonequilibrium plasma clouds ejected into the atmospheres of these stars would have the same effect. Kolesnik (**8**) has applied this idea to a sequence of stars in gravitational contraction. Gershberg (**263**) has applied similar considerations (i.e., that the spectrum is a composite one) to flare stars in some detail.

It is probably too much to expect at the present time that observations can differentiate between mechanisms whose end effects are qualitatively so similar. It is even less hopeful that observations can tell us anything directly about the forces which drive such phenomena. Schatzman (**9**, p. 17) has demonstrated how useful is the concept of surface electromagnetic activity in very young stars, in inducing light variations, mass ejection, nuclear reactions, and in affecting the axial rotation. But the hard facts at our disposal, for testing such proposals, are very few.

The all-too-sparse astrometric information on young stars above the main sequence increased substantially by the astrometric study of NGC 2264 by Vasilevskis, Sanders, and Balz (**244**). This serves to remove a certain number of non-members from the familiar color-magnitude diagram of this important cluster. The motions of 24 emission-Hα stars were measured; two of these stars (unfortunately with motions not of high weight) seem not to be cluster members. A somewhat similar situation exists for several variables in the Orion Nebula, as pointed out by Van Schewick (**245**). In the case of Orion, however, it is not completely certain that two of the three stars in question are truly variable. If a single unquestioned case could be established, it would be of considerable importance. New proper motions for 35 T Tauri stars are being measured by Van Herk. The difficulties with radial velocities make proper motions especially important in studies of the T Tauri stars.

An entirely unexpected development was the discovery by Mendoza (**246**) that many Orion population variables, especially T Tauri stars, have a major excess of radiation in the infrared (0·9 to 5μ) as compared to normal stars of the same spectral types. The most extreme case, R Mon, has been observed also by Low and Smith at 20μ, confirming Mendoza's result that in that case the brightness curve peaks (on a wavelength scale) near 3μ. An obvious explanation is that we are seeing in these stars the contribution from an unresolved source of low temperature and large area. Before Mendoza's discovery, Poveda had suggested (**247**) that such very young stars might be surrounded by very small, dense, dust nebulae. Possibly the infrared excess is due to the thermal emission of such a circumstellar cloud. Indeed this may be supported by the fact that the objects with the largest excesses are just those involved in bright nebulosity (R Mon, T Tau, V 380 Ori). But the effect could also be produced by a 'window' in the continuous absorption coefficient of the stellar photosphere. A decision between these two possibilities could be made, at least in principle, by observation of the degree of veiling of the stellar absorption spectrum in the infrared. It is odd that only in our own visual region do the T Tau stars radiate according to our tastes: toward both shorter and longer wavelengths, they behave in a completely surprising fashion. It is not yet clear whether the discovery by Becklin and Neugebauer (**248**) of an infrared star in the Orion Nebula that is very bright at 2μ yet undetected at 0·8μ, is related to the infrared excess phenomenon.

R Mon has received attention not only on account of its infrared excess, but also because it lies at the apex of Hubble's Variable Nebula NGC 2261 which has itself been observed extensively in recent years. We only refer here to the work of Johnson (**249**) and of Hall (**250**) which concern R Mon to some extent, and to the suggestion by Dibai (**251**) that the formation of such nebulae and their associated stars might be due to the focussing of shock waves generated at an H I–H II boundary.

Finally, the 1936 flareup of FU Ori has been interpreted by Herbig (**252**) in terms of the rapid transit of the forbidden region on the right side of the HR Diagram by a contracting star, which is expected theoretically just prior to its appearance at the top of the vertical branch of its evolutionary track. A refinement of this suggestion has been advanced by Hayashi (**253**), and another interpretation altogether by Poveda (**247**).

16. FLARE AND FLASH VARIABLES

There is reason to suspect that the flare stars are connected with the Orion population variables in the evolutionary sense, and that the so-called flash variables constitute the bridge. (The presently-held distinction between flare and flash stars is explained in **254**). The major observational contributors to this concept have been Haro and his associates, who have given a summary of their recent work (**255**), although full details are still to be published. The entire

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subject has been reviewed by Haro (**256**). That review also gives an excellent account of the Tonantzintla work. Rosino and his co-workers also continue their program for the discovery of flash variables. In the Orion Trapezium region 14 have been discovered, 13 in the Pleiades, and two in Praesepe. The critical question in these studies is that of the physical membership of these faint variables in the galactic associations and cluster against which they are seen. When the cluster is projected on heavy, relatively nearby obscuration (Orion, NGC 2264) the problem of membership is much simpler than in older clusters (Pleiades, Praesepe), unless proper motions can be used. The best example of the latter is the case of the Hyades, where an astrometric study by van Altena (**257**) demonstrates the possibilities.

The problems of the classical flare stars have been discussed by Andrews (**258**). Photographic observations of UV Cet, YZ CMi, and V 371 Ori were made in 1963–64 by Mosidze and Chuadze (**259**) as part of a photometric campaign to support radio observations of flare stars (see below); they observed no actual flares, but did suspect some small variations. Gershberg and Chugainov (**260**) have observed five flares of AD Leo and six of UV Cet simultaneously with spectrograph and photoelectric photometer. Chugainov (**261**) has followed EV Lac through four flares in BV, and continues observations of flare stars with an interference filter centered on Hβ. At Odessa, visual observations of flare stars were carried out by Mandel, Migach, *et al.* In early 1966, Andrews (**262**) found YZ CMi to be extraordinarily active: in 26 days he observed nine flares. There was a suggestion that the time spacings of the flares were not random. Such extended intervals of high activity have been observed in other flare stars, but nothing is known of their systematics. Possibly these intervals of high flare activity bear some analogy to the renewal of flare activity in the Sun with the solar cycle.

Gershberg (**263**), as part of two more general papers on the representation of several kinds of variables as a quasi-normal star plus a volume of hot, optically thin gas, has analyzed quantitatively the light and color curves of several flares. These results have been displayed as movement of the star in the $U-B$, $B-V$ plane, and the decay of the flare as fitted to a recombination law. Mirzoian (**264**) has however questioned this interpretation.

One of the most significant developments in this field is the discovery by Lovell (**265, 266**) that the flares of dMe stars are accompanied by bursts of radio emission; the Sydney observations by Slee *et al.* (**267**) show that the radio flares are detectable over the frequency range from 20 to 1410 MHz. A very critical requirement, the coordination of radio and optical observations, was made possible by arrangements between the Jodrell Bank and Sydney radio observatories on the one hand, and the Crimean, Abastumani, and Odessa observatories in the U.S.S.R., the Belgrade Observatory, the Smithsonian satellite-tracking network, and a group of Australian amateurs on the other. The implication is, of course, that these are surface events like solar flares, although the radio energy radiated in the stellar flares is 10^4 to 10^6 times that of a typical large solar event. Shlysh (**268**) finds that it is possible to explain the radio bursts from flare stars by stimulated emission of 20 MeV electrons at densities of the order of 10^6 cm^{-3}. Vardya (**269**) finds that the alternative explanations of flares in M dwarfs are unacceptable or unlikely, and favors a hydromagnetic mechanism. Lortet-Zuckermann (**270**) has considered the observable consequence of the emission of particles with energies of 10^{-2} to 10 MeV from a flare star. If the star were accidentally immersed in a dense interstellar cloud, then the ejected protons would produce a small H II region of calculable surface brightness around the star, whose Hα emission might be detectable under favorable circumstances. The fact that she has been unable to find nebulae around any known flare stars indicates however that the required conditions are somehow not satisfied.

A new flare star (S 9537) has been announced by Hoffmeister (**271**), who has also discovered two others, as yet unpublished. Eggen (**272**) reported a flare of the short-period visual binary BD − 8° 4352 AB. Flare-like activity has been reported in a number of other stars of various spectral types. Andrews (**273**) found that the bright B 8 star HR 1938 (= + 31° 1048) was about three magnitudes brighter than normal on one plate in March 1964; a lesser variation was observed on one night about two weeks later. No further variation has been reported, nor did Mendoza (**274**) find any activity (photoelectrically) on 19 nights in early 1965. The color of the star is normal (**274**) as is the spectrum (Mammano, **275**; Herbig unpublished). Nielsen (**276**) has called attention to an apparently similar event observed spectroscopically in the case of the type A2 binary ζ Boo in 1905. Kuhi (**277**) observed a flare of amplitude about 1·5 magnitude at 3300Å in the type F8 contact binary W UMa. Butler (**278**) observed a $\Delta B = 0{\cdot}1$ magnitude flare in an early G-type star projected on the Small Magellanic Cloud, and a second flare of amplitude $\Delta B = 0{\cdot}8$ magnitude was followed more completely five nights later (**279**). To say the least, this extension of flare-like activity to earlier spectral types than M raises serious problems, if a general explanation is to be found. One is reminded of the lengthening list of stars in which K I emission lines have appeared temporarily (Andrillat and Morguleff, **280**).

17. LATE-TYPE DWARFS, NOT FLARE STARS

Flare stars aside, single M-type dwarfs give the impression that as a class, they are quite constant in light. The fact that this is not true of M giants at the same spectral class indicates that this difference in behavior is a structural characteristic, and has nothing to do with the low temperature or the properties of molecular bands. K- and M-type dwarfs in close binaries are however subject to intrinsic variation. The best documented cases are the eclipsing binary YY Gem (Kron, **281**) and the spectroscopic binary CC Eri (Evans, **282, 283**). A third example has been discovered by Chugainov (**284**): HD 234677, which subsequently has been found by Kraft and Krzeminski (**285**) to be a double line spectroscopic binary. These variations may be due to non-uniform surface brightness of the components, and apparently change with time. One expects that they will probably be detectable in systems of any orbital inclination, and thus in stars that cannot otherwise be shown to be binaries. An example of a variable M dwarf not known to be binary is Ross 248, found by Kron (**286**) to vary in a manner resembling the secondary variation of YY Gem, and with a period of approximately 120 days.

The three examples of known binaries mentioned above are of types M 0·5 V, K7 V and K6 V. This concentration to early spectral type may reflect nothing more than the fact that these stars are brighter than later M dwarfs, and hence have received more attention. Yet the dM2e spectroscopic binary BD −21° 6267 A (Herbig and Moorhead, **287**; Paczynski, **288**; Chugainov, **289**) has not been found to be variable. The solution of such problems depends upon the detailed examination of more M dwarfs. A very promising beginning has been made by Kraft and Krzeminski (**285**) on the basis of both photoelectric and spectroscopic observations. In any such program, it is recommended that the stars chosen for study be selected from among both emission and non-emission objects, in order that no observational bias arise such as is present in lists of the known flare stars. Although Gabriel (**290**) has found that M dwarfs are vibrationally unstable with respect to the fundamental mode of radial pulsation (in the case of Krüger 60A, type dM4, mass 0·27 ⊙, with a pulsation period of about 10^3 seconds) there is as yet no connection of this result to the kinds of variability actually observed in the M dwarfs. It seems safe to say that for the moment, observers must proceed without theoretical guidance.

18. R CORONAE BOREALIS VARIABLES

R CrB itself has been below maximum light since mid-1962, but with major fluctuations. Miskin observed a rapid oscillation of about 40 minutes in length just before the minimum. The star reached $m_{vis} \approx 14$, and both *UBV* and spectroscopic observations were made at Lick as opportunity permitted. At such deep minima, the lines of [O II] appear in the spectrum, indicating that very low-density envelope is present near the star. Direct photographs obtained with the 120-inch (305 cm) telescope in fairly good seeing, in an attempt to photograph the

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nebula directly, were not conclusive. Schmidt (**9**, p. 295) has studied a situation in which density fluctuations occur in the outward mass flow from a carbon-rich supergiant. If sporadic density enhancements by a factor of 200 do occur as Schmidt's arguments require, the precipitation of solid carbon particles in them could explain the variations of R CrB-like stars. One problem with the hypothesis of soot formation in R CrB variables is why this characteristic form of light activity is possible in very hot carbon stars like MV Sgr and in stars of intermediate temperature, as R CrB itself, but not in the cool N variables in which one would expect the formation of solids to be easiest.

The light curve of the far southern R CrB star S Aps has been studied by Waters (**291**), who finds indication of a cyclic variation of range about 0·3 magnitude and period 120^d, superimposed upon the R CrB-type activity. Furthermore, there is a tendency for major minima to recur at intervals of about 1300^d. Cyclic activity with length of the order of a few months is known in other R CrB stars, but no suggestion of any periodicity in their minima has been made. In fact, R CrB itself was found by Sterne (**292**) to be an ideally irregular variable star.

The already small number of known R CrB variables has been diminished by one: RZ Vul is believed by Meinunger (**293**) to be a nova-like object with cycle length of about 1500^d. CT Vul is likewise to be withdrawn from the list of possible R CrB stars. In this connection, attention should be drawn to Wenzel's (**294**) photometric investigation of four hydrogen-deficient carbon stars.

The light variation of the hot, hydrogen-deficient carbon star HD 30353, which is also a spectroscopic binary with a period of 360^d, has been studied in *UBV* by Osawa *et al.* (**295**). They find a roughly sinusoidal light curve of amplitude 0·14 magnitude and period $30–40^d$, which length is reminiscent of some R CrB stars, as mentioned before. The fact that HD 30353 is a single-line binary (although not a R CrB star) is perhaps relevant to the question of duplicity in H-deficient stars raised by McCrea. However, according to Hill (**296**), there is no evidence for duplicity in a number of other H-deficient objects.

The collection of spectroscopic material on R CrB stars assembled at Lick Observatory over the period 1950–60 is now being studied by J. Moorhead. The spectral type and radial velocity results are supplemented by *UBV* observations of as many stars as can be reached from Mt Hamilton.

19. SYMBIOTIC VARIABLES

The most direct approach to the problems of the symbiotic stars is through their spectra, which aspect is considered in Appendix I. Nevertheless, the stars do vary, in some cases in a rather spectacular fashion. The subject is reviewed by Sahade (**9**, p. 140) from the point of view of the binary hypothesis. Boyarchuk (**297**) has provided a physical model for AG Dra in terms of a K3 III star, an invisible hot star, and a cloud of ionized gas with $T_{eff} = 17\,000°$ and $n_e \geqslant 10^7$ cm^{-3}. Luud and Ilmas provided (**298**) a composite model for AG Peg consisting of a dense planetary nebula with a double nucleus, of types WN6 and M1–3 II–III. Belyakina (**299**) interpreted her three-color photometry of the star, which varied only in the ultraviolet over the period of observation, in terms of this model. A preliminary light curve for AG Dra for the period 1890–1952 was derived by Robinson (**300**) from Harvard plates. The light curve of AS 373 (= MHα 328 − 116) has been extended by Fitzgerald *et al.* (**301**) back to 1920. The star was fainter than $m_{pg} = 15·6$ prior to 1948, when it brightened to about 15·0, and then faded slightly before rising to $m_{pg} \approx 12$ in 1964. The object is being followed by Bertaud and at Asiago. Z And became bright in August 1966. The light curve of V407 Cyg has been obtained by Meinunger (**302**), who finds Mira-like behavior with a cycle length of 745^d. Lick spectrograms in 1966 confirm the earlier classification as type Me; perhaps, as Meinunger suggests, the star is similar to RR Tel. It is possible that a study of the object M1–2 studied by O'Dell (**303**) might show it to be a variable of this rather poorly defined (in the photometric sense) family of variables.

20. NOVAE DURING OUTBURST

The distribution of novae in the Galaxy and other systems has been reviewed by Plaut (**304**). During the report period, papers have appeared on the outburst activity of a few older novae, as well as on those which were bright during the triennium. The photometric investigations are listed here; the spectroscopic work is covered by Dr Feast in Appendix I of this Report.

Nova (*RS*) *Oph 1898, 1933, 1958*. Six-color photoelectric observations made during the outburst were reported by Svolopoulos (**305**), while the light curve as well as that of *Nova* (*WZ*)*Sge 1913, 1946* have been compared by Eskioğlu (**306**) with those of other recurrent novae. The spectrum as well as the reddening of RS Oph have been studied by Dufay and Bloch (**307**).

Nova Cet 1963 was discovered by Strohmeier (**308**). It reached $m = 10$ in September 1963, but no further information on the light curve is available. The star is of some interest because of its high galactic latitude (− 79°).

Nova Her 1963 was observed extensively. *UBV* observations by Chincarini (**309**), by Van Genderen (**310**). and by Almár and Illés-Almár (**311**). Six-color observations of the Nova were made by Breckenridge (**312**). An extensive investigation of the light curve in narrow spectral bands was carried out by Götz (**313**). A light curve has been published by Busch (**314**), and photographic observations by Weber (**315**) and by Bertaud are continuing. A small, possibly interstellar polarization of the Nova was reported by Clarke (**316**).

Nova Pup 1963–1 was discovered by Hoffmeister who also derived the light curve (**317**).

Nova Pup 1963–2 was found by Strohmeier (**318**). It attained magnitude 8 in December 1963. The early photometric history has been investigated by Huth and Hoffmeister (**319**).

Nova Sco 1964 was discovered by Przybylski, who also reported several *UBV* observations (**320**). The only other published data seem to be that on the spectrum, by Wilde (**321**).

S5420 Aur has been described by Hoffmeister (**322**) and Popova (**323**), and classified as either a slow nova like RT Ser with maxima in 1960 and 1964, or as a blue variable of new type. In support of the latter, Popova notes that six maxima have been observed since 1900. Additional observations have been reported by Weber (**324**). The spectrum has been observed by Preston.

Nova (*T*) *Pyx 1890, 1902, 1920, 1944* recurred again in December 1966; the flareup was detected first by Jones.

Friedjung (**325**) has attempted to construct physical models of novae that would represent characteristic features of the light curves and of the spectroscopic evolution. His first paper considers various alternatives for the nature of the ejection, the second deals with the temperature and radius variation, while the third deals with the interpretation of the various absorption systems. Pecker (**326**) has shown how the oscillatory phases of declining novae can be represented by an extension of Grotrian's explanation of the deep minimum of Nova (DQ) Her 1934, through allowance for a time-dependent opacity. Schatzman (**327**) has reviewed in considerable detail the current hypotheses of nova and supernova outbursts, and has presented there some of his own ideas on the subject as well.

21. OLD NOVAE AND HOT SUBLUMINOUS VARIABLES

The discovery that at least some of the quasi-stellar radio sources are variable in light raises the possibility that extraneous objects of this kind may appear in lists of faint variable stars, especially in higher galactic latitudes. Hopefully, such intruders can be recognized once radial velocities and/or radio observations become available.

Except for this future and probably minor complication, the general outline of this subject has not changed over the past three years, so we subdivide it in the same way as in the last Report.

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(i) Novae near minimum light

Nova (V528) Aql 1945 was observed photographically by Taffara (**328**) during 1945–63, as it declined to $m = 18$.

Nova (T) CrB 1866, 1946 was observed to undergo a very brief flare by Ianna (**329**). The range was about a magnitude in *U*, and the duration probably less than one hour.

Nova Her 1963 has not yet returned to pre-outburst minimum light. The light is subject to short-period fluctuations; Almár (**330**) also observed a minimum rather like a partial eclipse, of depth 0·1 magnitude. Further observations reported by Chincarini and Howard (**331**) showed no clear evidence of eclipses, although there was some suggestion of repetition after an interval 6^h.

Nova (DI) Lac 1910 has been observed by Mumford (**332**). Erratic fluctuations with a range of 0·26 magnitude were found, but no eclipses.

Nova (V529) Ori 1677, 1740, 1894? has been discussed by Ashbrook (**333**) who concludes that in view of the dubious nature of the evidence, the Nova is non-existent. However, Eggen (**334**) has reported briefly on his photoelectric observations of a magnitude 14 object identified with the Nova which is not variable in *B* and *V*, but fluctuates irregularly in *U*. This conflict should be resolved.

Nova (GK) Per 1901 has been found to 'flicker' with a range of 0·2 to 0·4 magnitude by Mumford (**332**). The star was usually bright in August 1966, according to Peltier (**335**) and Huth (**336**), becoming at least two magnitudes brighter (visually) than usual.

Nova (RR) Pic 1925 was discovered by Van Houten (**337**) to be variable with a period of $0^d.145$. The light curve is quite unlike those of conventional eclipsing stars, but does resemble those increasingly familiar curves such as VV Pup.

Nova (WZ) Sge 1913, 1946 has been studied in detail by Krzeminski and Kraft (**338**). The system differs from others that have been studied thus far in that the spectrum of what appears to be a o^2 Eri-type white dwarf is present. The fact that primary minimum occurs at elongation, according to the velocity curve, makes necessary a rather complicated model of the system.

Nova (CK) Vul 1670 probably still has not been identified. Observations by Walker (**339**) of a variable discovered by Wachmann in this area show none of the characteristics of old novae.

(ii) Hot variables, and short-period eclipsing systems with additional activity.

BD + 14° 341 is the brightest known member of this class. Unpublished photoelectric observations by Smak have now been analyzed by Williams (**4**). There is evidence for a periodicity of $0^d.117$ superimposed on more rapid activity. Smak has recently obtained more extensive observations of the star at Haute-Provence, and a thorough analysis of the object is anticipated.

EM Cyg has been found to eclipse; Mumford (**340**) has determined an accurate period (about $0^d.291$).

A bright, blue irregular variable very near the position of the Scorpius X-ray source was discovered by Osawa and Jugaku (**341**) and independently by Johnson and Stephenson (**342**). The color, irregular variability and spectrum of this object are much like those of other hot subluminous variables, and one does not hesitate in adding this to the class. Why only this particular member should apparently be a strong X-ray emitter is an unanswered question.

V Sge has been discussed in detail by Herbig, Preston, Smak and Paczynski (**1**); it is a double-line eclipsing binary having a period of $0^d.514$, and showing much non-periodic activity. Romano (**343**) has reexamined his photographic observations of 1956–58, recovered the short-period light curve, detected a number of primary minima, and obtained a slightly improved period. Smak (**344**) has made new photoelectric observations that, if combined with Romano's, suggest that the period may be decreasing slightly. Smak points out the importance of the investigation of times of minima of V Sge on collections of old photographic plates, to determine if this period change is real. It would also be of interest to examine the great number of visual observations of V Sge that have been made by the amateur associations over the past years, to see if significant information on the period length could be obtained.

Ton S 120 (a notation used by Greenstein for entry no. 120 in the list of blue stars found in the south galactic cap by Chavira (**345**)) was observed by Greenstein (**346**) to have a spectrum like that of an old nova or U Gem star. Krzeminski (**347**) found that the star is an eclipsing binary with a period of $0^d.145$.

UX UMa was observed by Bretz through four minima in 1965 in a four-color system.

(*iii*) *U Gem and Z Cam stars*

AE Aqr has been observed photoelectrically and spectroscopically by Walker (**348**), who states that contrary to earlier belief, the spectrum of the secondary star is not visible. Furthermore, the binary period is not $0^d.71$, but near $0^d.4$.

Z Cam is discussed by Mayall (**349**), who shows the very interesting AAVSO light curve for 1945–65.

2·1937 Cet = HV 8002 was observed by Paczynski (**350**) in *UBV*. The familiar rapid flickering was found, as well as two outbursts. According to Kraft (**351**), the star is a single-line binary of type sdBe and period $0^d.160$.

SS Cyg has been studied statistically by Lortet-Zuckermann (**352**) in order to classify both the major outbursts and the smaller oscillations observed at minimum light. These data were then analyzed from the point of view of the Markov chain theory of successive events (**353**) but it was found that the theory did not represent at all well the succession of outbursts and oscillations actually observed in SS Cyg. A few *UBV* observations of SS Cyg are given by Eggen and Sandage (**354**). Observations of the star in *UBV* were also made by Mirzoian and Bretz during the descent from a maximum in September 1966.

U Gem, an eclipsing binary with period of $0^d.177$, was observed by Mumford (**355**) about a day before the beginning of a major outburst, but a physical interpretation of the changes that he found was not possible. Krzeminski (**356**), from more extensive data, was able to discuss the system in some detail. One interesting feature of his model is that the eruptions occur not on the hotter star but on the larger, cooler component of the system.

EX Hya was observed in *UBV* by Mumford (**357**), and the variations compared by him to those of Nova (WZ) Sge. The star is an eclipsing binary with period of $0^d.0682$; according to Mumford (**340**), the period is quite constant.

Mumford (**358**) has reported the results of extended photoelectric runs on a number of other U Gem or Z Cam stars, all of which were found to 'flicker': AB Dra, RX And, CN Ori, TZ Per, RU Peg, SU UMa, AH Her, and YZ Cnc. The last two stars also have been observed by Miss Bretz (**9**, p. 244); her observations of YZ Cnc continue. Mumford also studied SS Aur, but found no eclipses; this star is a single-lined sdBe binary of period $0^d.180$, according to Kraft (**351**).

A number of new U Gem and Z Cam variables, some of them fairly bright, have been discovered or recognized in the last few years. The brightest are DX And, *11–16* (Weber, **359**); GR 102, *10·9–17·5* (Romano, **360**); GR 91, *10·9– < 15·0* (Löchel, **361**); and Wr 160, *12·5–17*: (Weber, **362**). Fainter members of the same types have been announced by Hoffmeister (**363**) and by Meinunger (**364**).

The mean absolute magnitudes of the U Gem variables have been redetermined by Kraft and Luyten (**351**) from new proper motions of 25 members, and radial velocities of 11. A mean

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value of $M_v = +7{\cdot}5$ at minimum light is found, with some evidence for a period-luminosity dependence. An earlier proposal by Kraft on an evolutionary relationship between binaries of the W UMa and U Gem types had been criticized by Popov (**365**) on the basis of dissimilarities in the space distributions and kinematics. Kraft replied to these criticisms (**366**) taking advantage of the newer distance scale, and allowance for the effect of incompleteness upon the space distributions; he believes that his original proposal is substantiated. Kopal, on the other hand, believes that the masses require that these stars were not binary at the time they were on the main sequence (**9**, p. 52).

(*iv*) *Variable nuclei of planetary nebulae*

The outstanding example of this class is FG = 377·1943 Sge. Three-color photoelectric observations by Wenzel (**367**) show that in *B* and *V* the star continues to brighten at about 0·05 magnitude per year, but that the star is becoming fainter in *U*. Lick spectrograms show that this is due to an increase in the Balmer jump. The star is also being observed photometrically by Bertaud. Kohoutek (**368**) has discovered that the nucleus of the (presumed) planetary nebula K1–2 is variable. The secular change in the emission-line spectrum of the bright planetary nubula IC 4997 has been interpreted by Aller and Liller (**369**) as due to the change in electron temperature and density of the gas resulting from expansion. There is some evidence that the radial velocity has also changed (Smak and Preston, **163**), and it might be asked if variability of the exciting star may not also be a contributing factor. The assumption that the hot stars which illuminate planetary nebula are constant, despite the fact that rapid variability is widespread among other subluminous blue stars, should be re-examined.

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APPENDIX I

REPORT OF THE COMMITTEE ON THE SPECTRA OF VARIABLE STARS

(Prepared by M. W. Feast, Chairman)

In the following report purely radial velocity work has generally been omitted as has spectroscopic work on eclipsing binaries (except old novae and U Gem stars). For work published in Russian I have relied heavily on a report prepared by Professor B. V. Kukarkin and Dr Yu. N. Efremov. I am extremely grateful to them for their help. As far as possible titles of papers have been included in the bibliography.

1. *The Mira and Semi-Regular Variables*

Keenan (1) has published an important catalogue of the spectra of Me and Se variables. His work covers 253 stars and is based on observations made by many observers over a 50-year period. It is of great value to have this large body of data classified on a uniform system. The data refer almost entirely to Miras north of $-35°$ and it is to be hoped that Keenan will be able to extend this work to southern Miras, possibly using existing material. Keenan shows that considerable caution is necessary in applying normal luminosity criteria to the spectra of Mira variables. This is a problem of very considerable importance especially since the dispersion in absolute magnitude at a given period remains almost entirely a matter of conjecture. Further studies will probably require combined spectroscopic and photometric observations throughout the light cycle for a representative selection of Mira variables. Some of the complications found in the study of Mira variables may well be due to the fact that most

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observations refer to epochs near light maximum, especially since there is a wide range of amplitudes at any given period. Before spectroscopic luminosity criteria of Mira variables can be adequately calibrated more work will be necessary on the absolute magnitudes of these stars by other methods (statistical parallaxes, membership of Mira variables in clusters and in extragalactic systems (e.g. Magellanic Clouds)).

Of considerable importance is the progress that has been made by Smak in applying multicolor photometry to Mira variables. From combined photometry and spectrophotometry (**2**) he has been able to establish the effects of both the TiO bands and the emission lines on *U B V* colours. In another paper (**3**) he showed how the spectral types of long period variables can be derived from narrow-band photometry (centred on TiO, 4955 Å). He also showed that these results may be combined with a further colour to obtain interstellar reddening for these stars. Coupled with this type of work is the problem of the bolometric corrections for the Mira stars (**2, 4, 5**).

The recent increase in work in infrared stellar spectroscopy both from ground-based telescopes and balloons has provided much new information about the brighter Mira variables. Spinrad (**6**) has succeeded in detecting the quadrupole rotation-vibration bands of H_2 in some Mira variables. The lines are in the 1μ region and he has detected the $S(2)$, $S(3)$ and possibly the $S(5)$ lines of the (2, 0) band. The H_2 lines appear strongest in *o* Cet near minimum light and have also been detected in W Hya and R Aql. The amount of H_2 detected is less than theoretical prediction though additional opacity (such as the pseudo-continuum of H_2O suggested by Auman) may resolve the discrepancy. H_2O in the infrared spectra of Mira variables and other stars has been studied by a number of workers (**7–12**). The bands become extremely strong in certain of the variables. For instance Woolf *et al.* (**12**) note that in *o* Cet the bands absorb about 1/4 of the total energy emitted by the star. They point out that these bands are likely to have a marked effect on the structure of the star's atmosphere while no other bands will have any significant effects. Spinrad and Newburn (**10**) find that the amount of H_2O detected in o Cet is a factor of about 60 less than the theoretical predictions. The amount detected varies with phase in the predicted manner (**7**). Spinrad *et al.* (**7**) included Miras of types M, MS and S in their survey. There is an H_2O deficiency in the S stars relative to the M types which they interpret in terms of a reduced *O*/*C* ratio in the S types. Spinrad and Younkin (**13**) also consider that a change in the *O*/*C* ratio may explain the weakness of the infrared *VO* bands in χ Cyg (MS) relative to *o* Cet and R Leo (M types) in which they are very strong. Keenan (**14**) has discussed the strength of YO bands in variables of spectral types M and S. He indicates that YO may be a good index of heavy metal abundance and also that the abundances of Y and Zr may not be completely correlated in these stars. Fredrick (**15**) reports that an unidentified feature at 11 028 Å appears rather abruptly in the spectrum of the Mira variable R Leo as the star approaches minimum light. There is a possibility that the band is due to TiO. For spectroscopic work on Mira variables the computations by Dolan (**16**) of the abundances of polyatomic molecules will be of value.

Detailed quantitative work on the spectra of Mira variables has, in the past, been limited by difficulties in locating the true continuum level even at very high dispersion. Preston (**17**) has however shown how the excitation temperature and level of ionization may be estimated from the spectra without an exact knowledge of the continuum level. He finds for *o* Cet near maximum light that $\theta_{exc} = 1{\cdot}98 \pm 0{\cdot}14$ (p.e.) and log $P_e \sim -4$. From this he deduces that H^- is not a major source of opacity in the violet region near maximum light. The study of the physical and chemical state of the atmospheres of the cool carbon variables has been continued by Fujita and his colleagues (**18–23**) and by Wyller (**29**). Further progress has also been made with the determination of the C^{12}/C^{13} ratio in these stars (**24**) (**25**). The high C^{12}/C^{13} ratio ($\sim 2:1$) in some semiregular carbon variables (e.g. Y CVn and WZ Cas) constitutes a serious problem, possibly indicating spallation processes in the atmospheres of these stars (now or at some time in the past) (25). The high lithium abundance of some carbon variables (and also some S stars) (26, 27, 28) also raises considerable theoretical problems.

From combined spectroscopic and photometric work Wing, Spinrad and Kuhi (30) have been able to reach the important conclusion that the majority of 'infra-red' stars are Mira variables with periods longer than a year. The Mira sequence as usually considered is therefore now extended at the long period end by the infrared stars and at the short-period end by the SRd variables (31). Amongst the infrared Mira variables, TX Cam appears to have a normal composition whilst the Taurus object is believed to have a low *O/C* ratio like the S star R And but without, however, any appreciable enrichment of *s*-process elements (30).

Several papers (32–35) give new spectral classifications for long-period variables. Stephenson (35) lists five stars which may belong to the group of stars like the semiregular variable GP Orionis which seem to combine S- and C-type characteristics. Several additional members of this class have been found by Feast as a result of slit spectroscopy of stars in Henize's unpublished catalogue of S-type stars. UY Cen and other members of this group are being studied at coudé dispersion in Pretoria. A number of other spectral classification studies of late-type variables are in progress at the Warner and Swasey Observatory. Terrill and Stephenson are studying spectral changes in 20 S-type and 40 M-type variables using objective prism spectra in the near infrared whilst Miss Houk is obtaining similar data for long period variables in the Groningen-Palomar Field 2 (approx. 120 stars). Miss Houk is also studying magnitude and spectral variability of giant M stars in VSF 193 (Sagittarius) also using objective prism spectra. About 440 stars are included in her survey and the frequency of occurrence of variability as a function of spectral type is under study. Also at Warner and Swasey, Miss Wycoff and Stephenson are obtaining slit spectra of about 80 late-type variables in the near infrared (390 Å/mm). Stars to $m_v = 14{\cdot}2$ can be observed by their technique.

Herbig (36) searched spectroscopically for physical companions to long-period variables. Several new companions were found but they all appeared to be normal F–G stars. Surprisingly no new hot peculiar companions like *o* Cet B were found. Stephenson and Blanco (37) have shown that the double BD + 15°4134 (A 7 III + Me) is probably optical.

Amongst individual stars observed the following may be mentioned: Spectral changes in R Cam have been discussed by Nassau (40). The star resembles an S-type at maximum and an M-type at minimum. Some work on the spectrum of L_2 Pup was published by Janes and Gaposchkin (39). Z Cir which has been classified as an eclipsing system or a peculiar R CrB variable on the basis of its light curve was found to have the spectrum of a normal Me variable (42).

There are still many unsolved problems connected with the emission lines in long period variables. For instance Preston (cf. 38) has deduced that the difference $(A-E)$ between the velocities given by the absorption and emission lines is a function of space velocity for Mira variables with $150^d < P < 200^d$. On the other hand the possibility that the strengths of the Balmer emission lines is different in semiregular variables of high and low velocity is raised by the work of Keenan and Young (41). Wing (43) has shown that some emission lines give evidence of being fluorescent emissions excited by Balmer lines. The large and variable polarization found in the integrated light of Mira variables (e.g. (44, 45)) suggests that tests should be made to see whether or not the polarization is confined to the continuum or whether the emission lines also show polarization effects. Herbig (see (6)) has suggested that H_2 in Mira variables might be detected by Raman-scattered Mg II 2795·5, 2802·7 Å. These lines would be well worth searching for in suitable stars. A number of years ago an unpublished survey by Feast of all unidentified emission lines in the spectra of Mira variables indicated that none of these were likely to be due to Raman scattering by H_2 or by any of several other molecules which were expected to be abundant in these stars.

2. *RV Tauri Stars*

Preston (46) made a spectroscopic study of the RV Tau star U Mon. He finds metallic emission lines during rising light. He I 5876 Å emission is also present during rising light whilst Hα emission is found at all phases. The absorption line velocities indicate a velocity gradient in the atmosphere. The slow radial velocity changes have a period of 1560 days. Further work is required to determine definitely whether the long-period variations are due to binary motion or not. Preston finds evidence from the H and K lines for two expanding circumstellar shells. A. Piev (unpublished) has discussed the shock wave interpretation of U Mon. A spectroscopic survey of southern semi-regular variables is being carried out in Pretoria and this has already revealed one or two stars which are probably RV Tau stars.

Spectra and photometry of two irregular variable F-type supergiants are discussed by Smak (125). They are *not* RV Tau stars.

3. *Cepheids*

In two papers Rodgers and Bell (47, 48) have discussed the atmosphere of the southern cepheid β Dor in some detail. The star has approximately solar abundances but the abundance derived from Eu II lines in anomalous and varies with phase (the element is found to be over-abundant at all phases except maximum light). It would be very important to discover the cause of this anomaly especially since Eu is an important element in some discussions of nucleogenesis. In their second paper Rodgers and Bell study the macroturbulence in β Dor as a function of phase and interpret the results in terms of a running wave in the atmosphere.

Some years ago Bahner, Hiltner and Kraft (49) noticed some spectral peculiarities in a few distant cepheids with large light amplitudes. A detailed analysis of one of these stars (TV Cam) has now been published (50). Abt, Osmer and Kraft found that this star has a normal chemical composition and that the marked line weakening is due to exceptionally low atmospheric turbulence. It would be interesting to know whether there is any general correlation between atmospheric turbulence and light amplitude.

The peculiar carbon variable RU Cam which is often grouped with the type II cepheids is being studied at coudé dispersion by Hack. Ahnert (51) has reinvestigated the period-spectrum relationship for cepheids. A number of the stars discussed by him which have anomalous spectra types for their periods would be worth further investigation. Schneider at the Institut d'Astrophysique has classified eight cepheids (in the IAP spectral system) throughout their light cycle. He has been searching for line intensity parameters associated with chemical composition in order to discriminate reddening effects from evolutionary effects.

4. *RR Lyrae Stars, Dwarf Cepheids, δ Scuti Stars*

Preston and Paczynski (52) have made a very detailed study of the atmospheres of singly-periodic RR Lyr variables based on simultaneous spectroscopic and photometric work. This is a continuation of work discussed in the last report. The relation between the hydrogen emission, the Bailey type and the $(U-B)$ excess is discussed. Excitation temperatures are derived from Hγ profiles and equivalent widths. Preston and Paczynski discuss the relationship between the light range and the radial velocity range. RR Lyr stars of all Bailey types seem to define a single relation. The slope of the relation as derived from the metal lines is smaller than that from the hydrogen lines although it exceeds the value derived for classical cepheids. In this connection it may be mentioned that there appears to be considerably more scatter in the light range-velocity range relationship for classical cepheids than was at one time thought (cf. Eggen, Gascoigne and Burr (53)).

Preston, Smak and Paczynski (54) have discussed simultaneous photometry and spectroscopy of RR Lyr itself. They particularly discuss the long period (41^d) variations. In 1962 and 1964

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most parameters varied in this long-period cycle. However, in 1963 the long-period variations were not present. A model is advanced based on the observed emission and doubling of the H lines. A critical level of shock wave formation is believed to move up and down in the atmosphere of RR Lyr during the 41-day cycle. Metallic line doubling has also been detected. The effects of Balmer emission, metal line blanketing and effective gravity on the $(U-B)$ colour has been discussed. Preston, Smak and Paczynski also discuss problems of temperature determination in RR Lyr. Mlle Fringant observed spectrophotometrically one total secondary cycle of RR Lyr in 1963. She will investigate the blue and ultraviolet gradients, and the Balmer discontinuity. A detailed study of the RR Lyr variable X Ari has been published by Oke (**55**). This work follows the general lines of his previous studies of RR Lyrae stars and cepheids, and combines photoelectric spectrum scans with accurate radial velocities and $H\gamma$ profiles. He finds that the interstellar reddening is somewhat greater than had previously been supposed. This increases the metal abundance as compared with earlier estimates although the star is still metal deficient by a factor of about 100. Oke deduces from his data a mean radius of $4{\cdot}8\ R_{\odot}$, a mean absolute visual magnitude $< M_v >$ of $+ 0{\cdot}8 \pm 0{\cdot}4$ and a mass of $0{\cdot}4\ M_{\odot}$.

The type *a* RR Lyr variable Su Dra with a well-marked $(U-B)$ excess was at one time thought to be anomalous in that, unlike similar stars, no H emission had been detected during rising light. Preston (**56**) has, however, been able to show that strong H emission is present in this star when adequate dispersion and time-resolution are employed. Preston notes that the effects of Balmer continuum radiation must be taken into account in discussing observations obtained by photoelectric scanning techniques. Spectrophotometry of some RR Lyr stars has been carried out by Alania (**57**).

There is considerable current activity in the photometry and spectroscopy of δ Sct itself, and of suspected δ Sct-type variables. Work at Mt Wilson has been reported by Danziger and Dickens (**58**) and spectroscopic work has been carried out at Herstmonceux (**59**) and Pretoria (**59a**) by Jones. Simultaneous spectroscopy and phtotelectric scans are being made of the dwarf cepheids AI Vel, SX Phe and of ρ Pup by Rodgers, Searle and Bessell.

5. *β Canis Majoris Stars*

Milone (**60**) has discussed radial velocity variations in β CMa itself. He is at present working on a kinematic study of the stars atmosphere using Mt Wilson spectra. Van Hoof (**61**) has discussed theories of the multiperiodicity of β CMa stars in the light of the observed axial rotations. Koupo (**62, 63**) has carried out a spectrophotometric study of β CMa on the basis of 60 slitless spectra. She determined the physical parameters of the atmosphere and established that their variations are related to the period P_2. She interpretes the connection of the light variations with each period of radial velocity variations as an effect due to different oscillation periods at different levels in the stellar atmosphere.

6. *R CrB Variables, Symbiotic Variables and Nova-like Variables*

The R CrB variable MV Sgr has been studied by Herbig (**64**). The object is of great interest since it is much hotter than the general run of R CrB stars. Herbig suggests that its spectrum is much like that to be expected if R CrB itself were to be raised to a temperature of about 20 000°. The spectrum is in fact rather similar to that of the helium star BD + 10°2179 although some emission lines (He I 5875, 6678 and possibly also $H\alpha$, [S II] and [O I] are found in the yellow-red region. Herbig points out the importance of investigating whether or not the other known helium-rich stars are variable in light.

A detailed high dispersion analysis of the R CrB star RY Sgr has been carried out by Danziger (**132**). The star is generally similar to R CrB itself. The C/H ratio is found to be 25 : 1 and the C/Fe ratio is 35 times normal.

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Dossin has given a summary (**65**) of his spectroscopic investigations of a number of symbiotic stars. Between 3300 Å and 5000 Å more than 850 lines have been measured in the spectrum of Z And including many new lines of Fe II and Cr II. The profiles of hydrogen emission lines indicate that the star is surrounded by a slowly expanding atmosphere. Evidence is found for some effects due to fluorescence. BF Cyg and other stars have been studied by Dossin in the photographic infra-red (6000–9000 Å). New emission lines have been observed and the behaviour of the infra-red O I lines has been particularly discussed. The spectra of the symbiotic stars AG Peg, AG Dra and AX Mon were investigated by Boyarchuk and Pronik (**66, 67, 68**). They found that AG Peg is a double star with components WN6 and M 3 III. The character of the WN6 component coincides with that of the nuclei of planetary nebulae. Both components are immersed in a nebula the mass of which is $10^{-3} M_{\odot}$. The light and spectrum variations of AG Peg are explained by the flares of the hot component. In AG Dra the cool component has the spectral class K 3 III; the hot component is invisible, its luminosity is probably + 4·5. The parameters of the nebula surrounding the star were determined. Evidence for mass loss by the hot component of AX Mon is found. E. Vanderkerkhove reports that he also has carried out spectrophotometric work on AG Peg. Boyarchuk (**69**) studied the spectra of Z And obtained with a dispersion of 16 Å/mm at the Lick Observatory and estimated a number of parameters of the star's envelope. He suggested that symbiotic stars may be related to the stage of evolution of double stars at which the more massive component becomes a planetary nebula, the less massive component still being in the red giant stage. Changes in the spectrum of Z And since 1959 have been discussed by Bloch (**116**). Mlle Bloch has a number of other symbiotic stars under study. Sahade (**70**) reviewed the data on symbiotic variables and discussed the problem of eruptive variability. Wilde (**99**) reports that AS 210 (an Hα emission object) is possibly a symbiotic object. He finds emission lines of H, He I, He II, [O III] and [Ne III]. Absorption by TiO is not seen although the G band may be present. A spectrogram of 1964 May 10, gives evidence for a flare-up of this star.

There is every hope that a full understanding of the unique object η Car will provide important clues to problems of stellar evolution. Thackeray (**71**) has continued his work on this object which has extended over many years. His most recent paper discusses the spectroscopic complexities of this object. Many new [Fe II] and [Ni II] lines have been identified and an excitation temperature of about 8500° has been derived. Thackeray has identified [N I] 3466 in η Car and has noted various temporal changes in the spectrum. For instance [Ne III] disappeared temporarily in 1965 whilst He I emission weakened. Furthermore the structures of the displaced absorption line varies with time. This work emphasises the need for continued detailed spectroscopic work on this object. Photoelectric spectrophotometry of η Car has been carried out by Rodgers and Searle (**72**). They are able to estimate physical parameters for the emitting volume. Thackeray (**74**) had originally pointed out that O was almost certainly underabundant in η Car. Rodgers and Searle show that in addition, N and S are also underabundant. These workers also discuss in some detail the possible origin of the optical continuum. Photoelectric spectrophotometry of η Car has also been carried out by Aller (**73**). Both Rodgers and Searle, and Aller reach the very interesting conclusion that the gaseous mass associated with η Car is less than one solar mass.

The variable RR Tel which is generally referred to as a slow nova has been studied quantitatively by Friedjung (**75**) on the basis of Thackeray's spectrograms. Half-intensity widths were measured for emission lines and interpreted in terms of a deceleration in the gaseous envelope. Electron temperatures were also discussed.

McCuskey discovered in July 1965 that MHα 328–116 had brightened by about three magnitudes during the preceding three years. The spectrum at maximum has been investigated by Bloch (**76**), FitzGerald *et al.* (**77**) and Rosino (**78**). The object shows affinities to both the slow novae (e.g. RR Tel) and to the symbiotic stars. Many forbidden and permitted emission lines have been detected. The object will undoubtedly be extensively investigated by spectroscopists. Mlle Bloch draws attention to the fact that accurate photoelectric photometry should be carried out on this star to facilitate the discussions of the spectroscopy. She also points out the dearth of photoelectric observations of several other stars she is studying spectroscopically (e.g. 377·1943 Sge which has brightened practically linearly from magnitude 13·5 in 1890 to 10 at present and shows Balmer emission lines (of P Cygni type)). Webster (**124**) has given an account of a number of interesting emission line stars in the southern Milky Way which were originally classified as planetaries. Some of these objects warrant further study. For instance work at Canberra and Pretoria has shown (Henize, 177) to have a rich emission spectrum including [Fe II], [Fe III] and [Fe V]. It is not clear whether this object should be classified with slow novae of the RR Tel type or as a symbiotic object. Studies for possible light variations would be of interest.

Amongst miscellaneous variable stars that have been studied spectroscopically mention should be made of the very luminous irregular variable S Dor in the LMC. Thackeray (**126**) studied spectra at a recent faint phase when [Fe II] was prominent. Spectroscopic resemblances to η Car are noted. Barbon *et al.* (**127**) have obtained a long series of spectra of the Wolf Rayet star HD 50896. Although they find marked radial velocity changes to occur they have been unable to understand them in terms of binary motion. They suggest the possibility that the velocity effects are due to activity in the W-R star's atmosphere. Further work on this star is clearly desirable. Vanderkerkhove is measuring line intensities and gradients in γ Cas whilst Herman (**128**) has discussed variations in the hydrogen profiles in P Cyg.

7. *Flare Stars, T Tauri Stars and Related Variables*

The detailed spectroscopic investigation of mass loss from T Tau stars by Kuhi mentioned in the last report has now been published (**80**). This work has been supplemented by a spectroscopic study of two additional T Tau stars (**81**). The early conclusions have been strengthened by this work. Kuhi has also shown that the Wilson-Bappu relation (on Ca II reversals) does not apply to T Tau stars (**82**). The effect of line emission on $(B-V)$ colours of T Tau stars was studied by Aveni (**83**) who concluded that the effect was sufficient to significantly affect the computed contraction times for some stars.

Simultaneous photoelectric and spectral observations of flare stars was carried out by Gershberg and Chugainov (**84**). Five flares of AD Leo and six of UV Cet were observed. The spectra were obtained with the 2·6-meter Shajn telescope using a grating spectrograph (50Å/mm) and an image converter. The variations of intensity of hydrogen and helium emission lines and the intensity jumps near the limits of TiO bands were obtained for different phases of flares. Shevchenko (**85, 86**) has investigated the relationship between the amplitudes and spectra of RW Aur stars in certain stellar aggregates. He interprets the results as a relation between the light variations and the relative age of the star during its gravitational contraction. Rachkovskaya (Bartash)((**87, 88**) carried out a spectrophotometric investigation of RW Aur stars of early spectral type. There appeared to be no differences from normal stars. Mirzoyan and Kazaryan investigated the variations in the continuous spectrum of RW Aur in November 1962. An emission at short wavelengths was observed at times of decreasing light. The emission shifted towards the red as it increased its intensity. Shevchenko (**89**) has investigated the distribution of axial velocities of early-type stars in the Orion aggregate. He finds that these stars are intermediate between the Oe and Be stars and the normal OB stars. He has suggested that Be stars could be an early stage of B star evolution and that the Orion Nebula could be formed by the matter thrown off by rapidly rotating Be stars. Bartaya and Kharadze (**90**) found that the ultraviolet continuous emission in RW Aur was always present.

The emission line spectrum (Balmer lines + Ca II, K) of the flare star YZ CMi which has shown some recent activity, has been described by Chincarini and Mammano (**91**). Mammano

(**92**) has confirmed the conclusions reached by observers at Herstmonceux and Edinburgh that BD + 31° 1048 has a normal B8 absorption spectrum despite its recent identification as a flare star by Andrews (**93**).

An important paper on the variable FU Ori has been published by Herbig (**94**). He considers that the most satisfactory explanation of the 1936 flare-up of this star is that it represents a pre-main sequence collapse. Some further discussion of this interpretation is given by Hayashi (**95**). Herbig's investigation includes some detailed spectroscopic work. The low-dispersion spectra of FU Ori resemble a G-type supergiant with abnormally strong hydrogen lines. However, Herbig's work at coudé dispersion shows the spectrum to be quite peculiar. There are two components to the spectra, a high luminosity F type spectrum (F2:p I–II) with a shell spectrum displaced 80 km s^{-1} to the blue. The Li/Ca ratio in FU Ori is found to be about 80 times the solar value (as in the T Tauri stars).

8. *Novae*

A large number of papers dealing with the spectra of novae were presented at the 1963 Haute-Provence Colloquium. These papers have now appeared in print (**95a**) and are not listed separately. Besides this there have been a considerable number of papers published elsewhere—most of these (and many at the Colloquium) refer to the bright Nova Her 1963. Most such papers on this and other novae are relatively brief accounts dealing with the spectral changes over a limited period. No attempt will be made to summarize the individual papers. In the case of Nova Her 1963 in particular, it is to be hoped that someone will undertake the task of bringing together all the data obtained for this star and will make a definitive study of the results. Although strictly the province of Commission 28, it is of interest to note here that the search for Novae in M 31 is being continued by Rosino (**95a**) and that a start has been made in a systematic nova survey in the Magellanic Clouds.

General. Pecker-Wimel discusses (**95a**) the theoretical interpretation of the presence of coronal lines in novae spectra whilst Swings (**95a**) indicates the possibilities in the study of novae spectra that will result from orbiting telescopes. A general discussion of the various absorption systems in the spectra of novae has been given by McLaughlin (**95a**). Andrillat compares the near infrared spectra of Novae Her 1960 and 1963; some features in common with Wolf-Rayet star spectra are noted. Underhill (**95a**) also compares the spectra of Wolf-Rayet stars and novae.

Nova Pup 1963. Short accounts of the spectrum have been published (**97, 98**).

Nova Sco 1964. The spectrum is described by Wilde (**99**).

Nova (RS) Oph 1958. Folkart, Pecker and Pottasch (**95a**) have determined the profiles of Balmer lines. The narrow emission and absorption lines in the nova are also being investigated. Dufay and Bloch (**95a**) discuss the corrections to the colour temperature necessitated by the existence of considerable interstellar reddening. They note the presence of the diffuse interstellar bands in the spectrum. Dufay *et al.* (**95a**) give a very detailed discussion of the evolution of the spectrum. They also discuss the possibility that two lines in the red region are a permitted doublet of Ca x (the doublet is observed in the corona).

Nova Her 1960. The spectral evolution was described by Dufay, Bloch and Chalonge (**95a**).

Nova Gem 1912. McLaughlin (**96**) has given a summary of his work on the early stages of the nova.

Nova Her 1963. Papers in (**95a**) deal with, amongst other things (1) Distribution of light in the continuum; (2) Evolution of the various spectral systems; (3) Infrared spectrophotometry. Some idea of the contents of other papers on this nova (**100–111, 130**) may be obtained from their titles. Boyarchuk and Bartash (**112**) report that the abundance of both H and He is down (relative to Sun) by a factor of about ten compared with N and O. Another spectroscopic investigation covering the period 1963–66 was made by Doroshenko. Other spectroscopic investigations of this nova in the U.S.S.R. are (**113, 114**) (**115**).

Nova (DQ) Her 1934. High-dispersion spectra of this nova taken at Mount Wilson soon after outburst are being studied by Larsson-Leander (**95a**). An analysis of the chemical abundance in the envelope of this nova has been made by Mustel and Baranova (**129**).

9. *Hot Subluminous Variables and Ex-Novae*

Since many variables of this type have been shown to be eclipsing binaries they are now the province of Commission 42. However, some mention should be made of them here.

Krzeminski and Kraft (**116a**) have made a detailed study of the ultra-short period ex-nova WZ Sge based on photoelectric and spectroscopic observations. They find that the W UMa type of eclipse curves and the Hα emission velocities are about 90° out of phase. Maximum velocity of recession occurs near principal minimum. They propose a new model for the system which attributes this effect to a rapidly receding stream ejected from the dark star towards the primary. The properties of the radiation field of the white dwarf primary are derived from the Hγ absorption and are shown to be consistent with the observed geometrical extent of the line emitting region. Krzeminski and Kraft also discuss the geometrical and dynamical parameters of the system.

Van Houten (**117**) has shown that the light of the bright ex-nova RR Pic varies with a period of about 3·5 hours. A series of spectra of this object with short exposures has been obtained in Pretoria to examine for spectral and radial velocity changes in this period. Earlier spectroscopic work (**118**) integrated over a considerable fraction of van Houten's period. Boyarchuk and Mustel (**131**) have investigated Nova Aql 1918 spectroscopically. They find that at present $T = 30\,000°$ and $R = 3 \times 10^{10}$ cm. They have determined the physical characteristics of the envelope.

Kraft and Luyten (**118a**) found the statistical parallaxes of U Gem variables give $M_v = +7{\cdot}5$ whilst spectral classifications of four of the stars give $M_v \sim +5{\cdot}4$ for the red components ($+4^m{\cdot}8$ for the total light). They interpret this to mean that the stars have a considerable range in absolute magnitudes with the stars of longest orbital period being the brightest. Bretz (**119**) has obtained spectroscopic observations of the U Gem stars YZ Cnc and AH Her. She has not been able so far to find evidence of binary nature for these two stars. Work on SS Cyg was carried out by Mirzoyan and Kalloglyan (**120**) who discuss a non-thermal continuum present near light minimum. Chuvaev has been studying this star spectroscopically with a time resolution of two minutes. Spectroscopic work on Rosino's variable near M 88 (= AL Com) has been carred out by Bertola (**121**) and by Moorhead (**122**). A nearly featureless spectrum is reported with shallow Balmer absorptions. The variable is probably a U Gem star. Efremov and Kholopov (**123**) also reach this conclusion on the grounds of the light variations.

To conclude this section especial mention should be made of the very detailed study of the nova-like object V Sge by Herbig *et al.* (**79**) on the basis of spectroscopic and photometric observations. The object is apparently an eclipsing variable with a period of 1/2 day which undergoes various small- and large-scale fluctuations in light. The spectrum of V Sge resembles a WN5 star but it contains sharp fluorescent O III lines arising in both components of the binary. Most of the emission features are broadened and strengthened during a major outburst. Herbig *et al.* have been able to estimate various physical parameters for the system which they believe to represent an advanced stage in the evolution of a close binary system.

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APPENDIX II

REPORT OF THE COMMITTEE ON VARIABLE STARS IN CLUSTERS

(prepared by Mrs H. B. Sawyer Hogg, Chairman)

This report will follow the outline adopted for the last IAU report (1). Researches now in progress or published since the preparation of the last report will be considered under the following sections. 1. Variables in globular clusters. 2. Variables in galactic clusters and associations, with a separate subsection by Dr G. H. Herbig on irregular variables in young clusters and associations. 3. Variables in star clusters of external galaxies.

As this report shows, researches on variables in clusters are being carried out at more observatories than formerly participated. However, a large proportion of the contributions still come from Rosino and his colleagues in Italy, and from a group of Soviet astronomers.

1. *Variables in Globular Clusters*

(*a*) *Discovery of new variables and derivation of periods*.

There are now 121 clusters catalogued as globular in and around our galaxy. In these, more than 1700 variables have been published, with about 88 clusters examined; four of these clusters have no variables.

Table 1 lists those clusters, with references, in which data on new variables and their positions, and new or revised periods, have actually been published. In some cases, the variables published are in the field surrounding the cluster and this is indicated by an F. If the manuscript is in

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the hands of this compiler, the data is included in this published section. Information on clusters under investigation, in which data are not yet available for periods or positions of new variables will be found in Section 1(*j*).

Clusters which are now on record for the first time as searched for variables are NGC 1261, IC 4499, 6352 and 6624 while NGC 5286, formerly recorded as without variables, now has seven. All these clusters are the work of Laborde and Fourcade at Cordoba, as shown in Table 1.

Table 1. Published Data on Individual Variables and Periods

Cluster NGC	New Variables	New Periods	Revised Periods	Investigator	Ref.
1261	6			Laborde and Fourcade	2
1904	2			Tsoo	3
3201	3 + 7F			Wilkens	4
5024	3	3		Cuffey	5, 6
	1	1	19	Margoni	7, 8, 9
5139			47	Belserene	10
	8 + 7F			Wilkens	4
			54	Geyer and Szeidl	11, 12, 13
5272			113	Szeidl	14
5286	7			Fourcade and Laborde	15
5466			17	Bartolini, Biolchini, Mannino	16
IC 4499	6			Fourcade and Laborde	17
6121			30	Wilkens	18
6205	2 susp.			Tsoo	3
6341			10	Kheylo	19, 20
6352	2 + 10F			Fourcade and Laborde	15
OHP 1	1 + F			Terzan	21, 22
6402	4	37	3	Sawyer Hogg and Wehlau	23, 24
6522			6	Clube	25
6624	3 + 10F			Laborde and Fourcade	2
6626	1	1		Hoffleit	26
6656	2	2		Hoffleit	27, 28
6712	3	7	4	Sandage, Smith, Norton, Rosino	29, 30, 31, 32
7078			35	Makarova and Akimova	33
Pal 13		4		Ciatti, Rosino, and Sussi	34

Note: Periods classed as 'new' are for those variables which have never had a published period. Some of the 'revised' periods are so different from the original that they are in a sense, new.

The number of periods of variables determined for the first time increases rather slowly, while the redetermination or revision of periods in this interval runs to several hundred.

(*b*) *Clusters of special importance.*

Several globular clusters deserve to be singled out in this report because of the very extensive work which has been carried out on them in the last several years. These include the two richest in variable stars.

(1) *Omega Centauri.* This cluster has been under intensive investigation by the Herstmonceux observers with plates taken at the Cape and Radcliffe observatories in South Africa, for positions, motions, radial velocities and magnitudes. In one of the series of publications on this cluster, Dickens and Saunders (35) describe the photometry of 45 RR Lyrae variables in *B* and *V*. They compare the relations between colour, amplitude, period and luminosity with those in

M 3 from the observations of Roberts and Sandage (**36**). Uncertainty in the reddening of ω Cen precludes an exact comparison, but they conclude that apparently the variables in ω Cen are consistently bluer at a given period than those in M 3. If the pulsation theory is correct, the absolute magnitude of the variables in ω Cen is 0·2 magnitude brighter than those of M 3.

Belserene (**10**) studied the phase shifts of 47 RR*ab* variables, see Section 1(*d*).

Wilkens (**4**) has published eight new variables in this cluster, and seven in the nearby field, and continues his work on the periods of 130 variables in the cluster.

Geyer and Szeidl (**12**) reported at the Bamberg Colloquium first results on 45 RR Lyrae stars in this cluster from 38 *B* and 38 *V* plates taken with the ADH telescope of the Boyden Observatory. Their independent investigation proved to have 25 stars in common with that of Dickens and Saunders. In general the agreement between the two results is good. The visual mean intensity by Geyer and Szeidl is brighter, on the average by 0·06 magnitude and the colour bluer by 0·08, though larger deviations occur. Geyer and Szeidl believe that their series of observations double in number those of Saunders and Dickens, and obtained in a shorter period of time, are more homogeneous. They consider that the interstellar absorption in front of this cluster is practically zero. The instability zone of the RR Lyrae stars is sharp, at $B-V = 0{\cdot}15$ and $B-V = 0{\cdot}43$. The paper is in press (**13**).

(2) In *Messier* 3, Szeidl (**14**) has continued work started by Ozsvath, with 214 plates taken at Budapest and 17 supplied by Hamburg. On most plates 117 RR Lyrae stars were measurable. He has investigated 112 variables, of which 36 or 32% show well pronounced light curve changes. These periods have the highest relative abundance in the period interval $0^d_{\cdot}47$–$0^d_{\cdot}56$. In the period-amplitude relation their greatest amplitudes fit the relation of regular RR Lyrae stars as noted by Preston. In the period-amplitude relation for ordinary RR Lyrae stars outside the centre, a phenomenon found earlier by Belserene, the separation of the RR*ab* stars into a short and long period sequence, is clearly shown.

(3) *NGC* 6712 in the Scutum Cloud is the subject of a consecutive series of three papers by Sandage and Smith (**29**), Sandage, Smith and Norton (**30**), and Rosino (**31, 32**), in which the variables are investigated and placed on the colour-magnitude diagram of the cluster. Three new variables are discovered, which with those found earlier by Sawyer (**37**) and Harwood (**38**) brings the total to 20 (though one may not vary). Of these, at least five have periods over one day. This is proving to be a very interesting cluster. Rosino finds that the period distribution of the RR*a* in this cluster of intermediate metal content is that of Oosterhoff group I, with a mean value $P = 0^d_{\cdot}548$.

Recently Feast (**39**) has determined the radial velocity of the Mira-type star CH Scuti, period 190·6 days, and shows it to be a member of the cluster. For it, Feast derives a mean emission velocity of -124 km s^{-1}, an absorption velocity of -115 km s^{-1}, compared with the cluster velocity of -131 ± 22 km s^{-1}.

Worthy of special mention too, is Pal 13, where work on the four variables and the C–M diagram by Ciatti, Rosino, and Sussi (**34**) have shown this to be the faintest ($M_v = -2{\cdot}6$) and least massive ($\mathfrak{M} = 10^3\ \mathfrak{M}_\odot$) globular cluster known.

(*c*) *Long Period Variables in Globular Clusters*.

The radial velocity work of Feast is a major contribution in clearing up the problem of cluster membership of long period variables. Feast (**40**) considers it unlikely that there are any known long period variables in globular clusters with $P > 220^d$. From kinematic reasons he thinks these variables are too young to occur in globular clusters. Var. 6 in M 80 and Var. 4 in M 22 were earlier eliminated from cluster membership by radial velocity determination.

Now Feast (**39**) has studied radial velocities for two variables which were left with doubtful standing. He finds that Var. 2 in NGC 4833 is absolutely ruled out as a cluster member, and he considers Var. 1 in NGC 6397 improbable as a member.

His placing of CH Scuti in NGC 6712 adds another Mira star to the very few which exist in globular clusters. Feast notes that the three variables of 200-day period in 47 Tucanae are of normal luminosity.

(*d*) *Period Changes.*

As the observational material on these clusters accumulates over decades and at observatories with different longitudes, it is becoming easier to detect period changes in the variables in clusters. Such changes appear to be present in most of the clusters thoroughly investigated. In some of the clusters such as M 53, variables with changing periods may outnumber those with constant period.

In ω Cen Belserene (**10**) has studied phase shifts of 47 RR*ab* variables relative to older observations. Of these, 34 have increased in period during the past 70 years, eight have decreased and four have changed in both directions. The median rate of change is + 0·11 day per million years. In M 4 Wilkens (**18**) has determined 30 periods more accurately. Of these, 11 RR*a* have constant period, 12 have variable periods equally divided between increasing and decreasing. The six RR*c* have practically constant periods. In M 53 Margoni (**7, 8, 9**) finds 13 of the variables he has investigated have changing periods.

(*e*) *Photoelectric Photometry and Colours of Variables.*

Some investigations now are not concerned with periods of variables, but rather with getting highly accurate magnitudes at various wavelengths for sample variables in a cluster. Five colour photoelectric photometry has been carried out for some variables in ω Cen and M 4 by Oosterhoff and Walraven (**41**) and Ponsen and Oosterhoff (**42**). Sturch (**43**) has obtained colours on the U, B, V system for several RR Lyrae stars near minimum light in the clusters M3, M 5, M 92 and NGC 6171, with the 84-inch (213 cm) Kitt Peak reflector. The values found for $\delta(U-B)$, a metallic line strength indicator, are well correlated with the population types assigned by previous investigators.

Barbon (**44**) has drawn conclusions about the membership of six variables in M 56 by their position on the colour-magnitude diagram he has determined for the cluster. He finds the cepheid, Var. 1, the semiregulars Vars. 3 and 5, Var. 6, an RV Tauri type to be cluster members, while Var. 10, an RR Lyrae star, and Var. 11 a dwarf cepheid, seem to be excluded from membership.

Demers (**45**) in his study of the population II cepheids has determined new B, V data for two variables in M 2, Var. 1, a W Vir star, and Var. 11, an RV Tauri star.

(*f*) *Variables in the Surroundings of Globular Clusters.*

NGC 6171 is the centre of an area 10° by 10° in which Kurochkin (**46**) has catalogued 16 variable stars, of which 13 are new variables. He finds some excess of space density of RR Lyrae stars in the vicinity of the cluster.

Clusters set in variable-rich regions near the galactic nucleus have been studied by several investigators. Terzan (**21, 22**) has found over a hundred new variables from plates in the red and infrared at Haute-Provence in the region around the globular cluster Haute-Provence No. 1, the galactic cluster Trumpler 26, and 45 Ophiuchi. Other work includes that in the direction of NGC 6522 by Arp (**47**) and Clube (**25**).

(*g*) *Theoretical Papers and General Relationships.*

Review papers and general articles on variables frequently include much useful information on variables in clusters. Among such works on RR Lyrae variables Preston (**48**) finds a dispersion in M_v of $\pm$ 0·3 or 0·4 magnitudes for the RR Lyrae stars in different clusters. He discusses the subgroups of RR Lyrae stars in ω Cen. Three disk clusters, 47 Tuc, NGC 6356 and 6838 have a strong concentration of stars at the red end of the horizontal branch, indicating a small RR Lyrae population. The long period boundary of the RR Lyrae's in M 3 is 0·9, but shorter in ω Cen. There are no criteria to define an RR Lyrae star with a period near 1·0 day. Variables with $P <$ 0·2 are a distinct family, dwarf cepheids.

Rosino (**49**) gives a comprehensive discussion of the relation of variables to the metal content of the cluster, the distribution of RR Lyrae periods, and the values of the absolute magnitude of the RR Lyrae stars in various clusters. He finds no correlation of the absolute magnitude of the RR Lyrae variables with the metal class or the age of the cluster.

Kukarkin reports that Frolov (**50**) determined with the help of his version of Wesselink's method the luminosities of RR Lyrae variables in a number of globular clusters.

Woolley (**51**) in his comprehensive paper on the RR Lyrae variables discusses some of those in clusters, especially ω Cen. He notes that the amplitude of variation of Bailey type *a* increases from ½ magnitude to 1½ magnitude as the period decreases. Then a break occurs, and all variables with periods below a certain limit have more or less sinusoidal light curves. Type *c* has a low amplitude of ½ magnitude. The mean absolute magnitude of the two groups is nearly the same.

Christy (**52, 53**) has studied in detail the pulsation in RR Lyrae models. Following Schwarzschild's early suggestion that the RR Lyrae type *c* variables are pulsating in the first overtone, Christy has been able to describe how the transition from the fundamental to the first overtone pulsation occurs. He has also determined luminosities and masses for cluster type variables, discussing the possibility that in a given cluster the RR Lyrae stars may show a range of masses from 0·45$\mathfrak{M}_\odot$ to 0·60$\mathfrak{M}_\odot$.

Kheylo (**54**) investigated the variables in M 92 and M 3.

Thänert (**55**) has compared the mean period of the RR Lyrae stars in a globular cluster with the age of the cluster. Some of the more massive RR Lyrae's in the younger globular clusters have shorter mean periods than the less massive ones of older clusters.

Balazs-Detre and Detre (**56**) in their paper on period changes of variables and evolutionary paths in the HR diagram make special reference to M 3. From Szeidl's work they conclude that the standard deviation of random period fluctuations is strongly dependent on the period of RR*ab* stars, and that a continuous evolution through the RR Lyra gap appears improbable.

RR Lyrae stars in clusters are also considered in the large review papers by Arp (**57**) on globular clusters, and by Plaut (**58**) on variable stars.

Fernie (**59**) in his discussion of the period-radius relation for pulsating stars points out Var. 42 in M 5, with period 25ᵈ74 as the only W Virginis star which has both a reliably determined colour and absolute magnitude. He also gives data (**60**) on individual W Vir stars in various clusters.

Stothers (**61**) has given a comprehensive discussion of the RV Tauri stars and their absolute magnitudes in a number of globular clusters. Later, with collaborators, he has continued with an investigation of ultraviolet dwarfs (**62**), concluding that the nova in M 80 was a cluster member, that the U Gem star near M 5 is likely a member of that cluster, and that no W UMa stars exist in globular clusters.

(*h*) *Catalogues of Variable Stars in Globular Clusters.*

The Cordoba Observatory is preparing an atlas of photographs of all the globular clusters south of −29°. Fourcade and Laborde are identifying all the variable stars in and around each cluster. The plates are taken with the 154-cm telescope of Bosque Alegre.

The third catalogue of H. Sawyer Hogg, mentioned in the IAU 1964 report, has been delayed in preparation, but should be published within a year or so.

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(*j*) *Reports of Miscellaneous Current Investigations*. (Details still to be published).

NGC 5024 R. Margoni is continuing his investigations of M 53 at Asiago. On a new series of blue and visual (103*a*–D + GG11) plates, period and light curves in two colours have been obtained for most of the variables, and their position on a *C–M* diagram has been derived. A preliminary report was given at the Bamberg Conference (**7**), and another paper is in press.

NGC 5139 H. Wilkens of La Plata is continuing the investigations of 130 variables in this cluster.

NGC 5904 Margoni and Stagni are taking plates at Asiago for the study of the variables in *UBV*.

A long series of plates is being accumulated at Konkoly Observatory for period studies.

Miss C. Coutts is studying a 30-year series of plates taken by H. Sawyer Hogg at the David Dunlap Observatory for determination of period changes.

NGC 6171 A paper by Coutts and Sawyer Hogg on David Dunlap observations of these variables will appear shortly.

NGC 6402 The variables are under investigation on more than 120 blue plates taken with the 122-cm reflector of Asiago from 1962–65, and preliminary periods have been derived for many. Margoni and Stagni are now collecting yellow material for the *V* magnitudes.

Sawyer Hogg and Wehlau, with 40 periods completed in this cluster, (**23, 24**) are continuing their work on the other variables on the more than 250 plates taken over 30 years with the two large Canadian reflectors.

No further observations of the nova found by Sawyer Hogg and Wehlau (**63**) have come to light.

NGC 6760 Taffara has determined periods of the variables in the cluster, and of some field variables.

NGC 6934 Sawyer Hogg plans to have the periods of more than 40 variables in this cluster published within a year.

NGC 6981 Margoni is now examining the accumulated Asiago plates to improve the periods and light curves given by Rosino in 1953.

NGC 7006 With material taken at Mt Wilson by Hubble and Baade in 1931–33, plates obtained at Palomar by Sandage, and at Asiago from 1953–58, Rosino has determined improved periods for 27 RR Lyrae variables, and derived blue and visual light-curves. The paper is in print.

NGC 7078 A long series of plates is being accumulated at Konkoly Observatory for period studies.

NGC 7089 Margoni and Stagni have obtained more than 150 blue and yellow plates to determine light-curves in *B* and *V* and the position of the variables in the colour-magnitude diagram.

NGC 7492 Mrs S. A. Barnes is completing a study of the variables in this cluster at the Goethe Link Observatory.

2. *Variables in Galactic Clusters and Associations*

Part A of this section deals with cepheids, eclipsing stars and miscellaneous types of variables, while Part B by Dr George Herbig is concerned with the irregular variables in young clusters and associations.

Part A

(a) RR Lyrae Stars in Galactic Clusters.

Probably the most important development in this area of Part A since the Hamburg meeting is that RR Lyrae stars continue to be non-existent in galactic clusters. At the time of the Hamburg meetings great interest was aroused by the announcement by Hoffmeister (**64**) from plates of the Karl Schwarzschild Observatory of four short period variables in the old galactic cluster NGC 188. Two short period variables, the stars SVS 1277 and SVS 1284 were also known in M 67. Now Efremov, Kholopov, Kukarkin and Sharov (**65**) and Kukarkin and Kurochkin (**66**) have showed that these rapid variables in M 67 and NGC 188 are not RR Lyrae stars, but are W UMa stars. This was proved by Kurochkin (**67**) for AH Cnc (SVS 1284) in M 67, and by Kholopov and Sharov (**68**) for four stars in NGC 188. They measured 69 plates of NGC 188 (JD 38389–39270) and obtained the *B*, *V* light curves for these stars, which are typical for W UMa stars.

Some of these stars were discussed at the Variable Star Symposium in Bamberg where Eggen (**69**) reported also that the light curve and colour showed SVS 1284 to be a contact binary, and Mammano reported that a slit spectrum at Asiago revealed it to be type F5–F7.

In NGC 6871 a new RR Lyrae star found by Bakos (**70**) with a period of 0·275 days cannot be a cluster member as its distance is twice that of the cluster.

(b) New Variables in Galactic Clusters.

Bakos and Rymer (**71**) hunted 19 galactic clusters for variables. Only three new variables (of 11 found) are specifically mentioned. These are a short period eclipsing star in NGC 1893, a flare star in M 67 which subsequently proved (**70**) to be not a cluster member, and the variable mentioned in NGC 6871.

In NGC 7789 a new variable is reported by Starrfield (**72**), a red giant with low amplitude variability. However, Starrfield confirms the earlier findings by Burbidge and Sandage (**73**) that the variable found independently by Weber and Romano (**74**) does not vary.

Smak has commented (**75**) that the number of binaries which should exist in clusters like M 67 and NGC 188 in order to explain the observed number of blue extension stars is much larger than that actually known.

(c) Cepheids in Galactic Clusters.

In NGC 7790 the Cepheids CE Cas *a* and CE Cas *b* continue to get attention. Following the long series of early observations by Payne-Gaposchkin and Gaposchkin (**76**) in which the cepheids were not separated on Harvard plates, attempts are made to get individual magnitudes. Kukarkin reports that Efremov and Kholopov measured separately the light of each of the components of CE Cas on plates obtained at the Cassegrain focus of the 70–cm reflector in Moscow, with the following results

	CE Cas a	CE Cas b
V mag	10·82	10·90
$B-V$	1·34	1·20

Smak (**77**) notes that a comparison with CF Cas, the third cepheid in this cluster, leads to a conclusion that the existing data on magnitudes and colours of these three cepheids do not show any large discrepancies, both internally, as compared with each other, and in comparison with the mean period-colour-luminosity relations.

Fernie and Marlborough (**78**) have derived absolute magnitudes (M_v) by two independent methods for five classical cepheids whose membership in a galactic cluster is well established.

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(*d*) *Variables in the Halos of Galactic Clusters.*

Along the lines of previous investigations for globular clusters, the Soviet astronomers have looked for variables in the surroundings of galactic clusters. Efremov (**79, 80**) found that the following cepheids could belong to the halos of open clusters: SZ Tau (NGC 1647), GU Nor (NGC 6067), CG Cas (NGC 7790) Y Sgr (M 25), TY Sct (Tr 35). He found also that modern data confirm Bidelman's suggestion that a number of cepheids from the large surroundings of *h* and *χ* Per could belong to the cluster, especially SZ Cas. Tsarevsky, Ureche and Efremov (**81**) drew up a list of about 40 cepheids whose relationship to the halos of open clusters needs classification.

The researches of Terzan (**21, 22**) have shown many variables in the region of the galactic centre around the cluster Tr 26.

Part B

Second Supplement to Report on Irregular Variable Stars in Young Clusters and Associations (*Trans. IAU*, **11A**, 275-278, 1962 *and* **12A**, 395-398, 1965)

(Prepared by G. H. Herbig)

This second supplement has the same format as the earlier lists, and the numbering of the bibliography continues on from the last one. It is the result of an examination of the literature up to about November 1966, and thus is an index of the activity in this subject over the past three years. The degree of activity appears to be declining, partly because there has been a

Region	α, δ (1900)	Spectroscopic survey (usually Hα) by:	Slit spectroscopic observations by:	Variable star search or observations by:
IV Cep (C214)	$0^h\ 00^m$, + 65°	**134**	**130**	**134**
NGC 225	0 40, + 61	**128**	—	**128**
IC 348, B4	3 38, + 32	—	—	**131**
Tau-Aur dark clouds	$4^h - 5^h$, + 16° − + 30°	**139, 140**	—	**123, 124, 125 133, 151, 152**
NGC 1579	4 24, + 35	—	—	**136**
IC 405	5 10, + 34	—	—	**136**
(IC 2118)	5 15, − 6	—	**130**	**151**
Orion Nebula	5 30, − 5	—	**142**	**141**
λ Ori, B 35	5 40, + 9	—	**129**	—
IC 2169	6 26, + 10	—	—	**137**
NGC 2245, 2247, IC 446	6 27, + 10	—	—	**137**
NGC 2261	6 33, + 8	—	—	**138, 143**
NGC 2264	6 36, + 10	**126**	**126**	—
IC 2944	11 32, − 62	—	**146**	**145**
ν Sco	16 06, − 19	**147**	—	—
Dark nebula B 44	16 35, − 24	**149**	—	—
Dark nebulae Kh 618, 635, 655*	16 43, − 15	**127**	—	—
Dark nebula B59	17 04, − 27	**148**	—	—
NGC 6383	17 28, − 32	**150**	—	**150**
M 20	17 56, − 23	—	—	**135**
M 16	18 13, − 14	—	—	**132**
M 17	18 15, − 16	—	—	**135**
IC 1396	21 38, + 57	—	—	**144**

* Dark nebulae as numbered in the *Atlas* of J. Khavtassi (Ak. N. Georg. SSR, Tbilisi, 1960).

shift of observational effort away from survey-type work toward more detailed studies of individual stars. The most active survey work for new emission-Hα stars is being carried out by Miss Dolidze (Abastumani) and by The (Lembang), while the photometric work of the Sonneberg group and of Badalian (Burakan) continues to be noteworthy. The searches for faint variables in nebulae by Rosino and his associates (Asiago) continue; an extensive search for flash variables in Orion, the Pleiades, and Praesepe is underway. Similar work is now being pressed vigoriously by Maffei (Roma).

Several reviews of this subject have appeared recently. Special attention should be drawn to a very thorough study by W. Götz: 'Einige Beziehungen der RW-Aurigae-Sterne zur Interstellaren Materie', *Veröff. Sternw. Sonneberg*, **7**, 7, 1965. L. Rosino has reviewed the subject of nebular variables in *Star Evolution* (ed. L. Gratton, Academic Press, 1963), p. 264, and in *Trans. IAU*, **12B**, 450, 1964. A critical examination of the photometric behavior of stars assigned to the RW Aur class, by L. Meinunger in *Mitt. veränd. Sterne*, **3**, 137, 1966, has important implications. Some of these matters are discussed in the preceding Report of Commission 27.

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3. *Variables in Clusters of External Galaxies*

Once again this discussion is limited by observation to the clusters of the Magellanic Clouds. Gascoigne (**82**) has recently shown that nine globular-like clusters in the Clouds can be divided into three groups. One group of four is comparable with the globular clusters in our Galaxy, and the members contain RR Lyrae stars. A second group of five is in the Small Cloud, as noted by Arp 1962, of intermediate age. There seems so far to be no evidence of variables in these. The third group, numbering three, is all in the Large Cloud and has no recognizable galactic counterparts.

Arp (**83**) has discussed eight cepheids within 5'.2 of the center of NGC 1866 which are apparently members. Photographic and photovisual light curves have been obtained for seven, with detailed observational material of Arp and Thackeray to be published later. The periods range from 2·6 days to 3·5, and the apparent magnitude at mean light, $\bar{B}$ = 16·77 to 16·41. From the color-magnitude relation the stars are less than 10^8 years old. According to Arp, these cepheids are a better fit to the period luminosity relation of the Small Cloud than of the Large Cloud. All the cepheids are at essentially the same color index.

Thackeray (**84**) has commented that the discovery of the RR Lyrae stars in NGC 121, 1466 and 2257 has proved that 'old' representatives of Population II similar to those in our galaxy are indeed present in both Clouds.

Wesselink and Shuttleworth (**85**) have discussed the RR Lyrae stars around NGC 121.

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