27. VARIABLE STARS (ETOILES VARIABLES)

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1. INTRODUCTION

With the enormous rise in publication costs, the space available for these triennial reports is becoming ever more precious, while the amount of research to be reported on becomes ever larger. Thus while my predecessors have used this introductory section to detail the symposia and colloquia held over the past three years, as well as other administrative matters, I have decided to omit this material (which is available elsewhere) in favour of maximizing the space available for science reporting.

2. PULSATING B STARS

(John R. Percy)

Introduction. The following are the highlights of research on pulsating B stars from mid-1978 to mid-1981. For a more complete survey, see *Astronomy and Astrophysics Abstracts*.
Review. An important Workshop on Pulsating B stars was held in Nice, France in June, 1981. The proceedings, to be published by L'Observatoire de Nice, will provide a valuable review of all aspects of the subject. Significant papers on pulsating B stars also appear in the following conference proceedings: "Changing Trends in Variable Star Research" (Bateson *et al*, 1979), "Current Problems in Stellar Pulsation Instabilities" (Fischel *et al*, 1980), "Nonradial and Nonlinear Stellar Pulsation" (Hill and Dziembowski, 1980) and "Stellar Hydrodynamics" (Cox and King, 1980). Papers from these five proceedings will be referenced as Nice, CTVSR, CPSPI, NRNLSP and SH, respectively. General reviews of β Cep and related stars have been published by Shobbrook (1979a), Jerzykiewicz and Sterken (1980), Percy (SH) and Smith (1980a).
Subclasses (?) of Pulsating B Stars. Many subclasses of variables have been found among the B stars, and the question of the relationship of these to β Cep stars and to each other, and the question of the definition of β Cep stars, are being hotly debated (LeContel, Nice; Sareyan, SH). The subclasses, excluding the β Cep stars themselves, are: (i) Line-profile-variable or 53 Per stars, which have been studied extensively by M. Smith and his collaborators. These are O8-B5 stars, undergoing g-mode non-radial pulsations; see Smith (CPSPI and NRNLSP) for good reviews. (ii) Ultra-short-period B stars, with spectral types B2-B3V, periods $\lesssim 1^h$, and small amplitudes (Jakate, 1979a; Percy, IBVS 1734). (iii) Be stars with "periods" of $0\overset{d}{.}1$ to $1\overset{d}{.}0$ and small amplitudes (Percy *et al*, 1981; Percy, Nice). The variability is complex and may not be strictly periodic. In at least one star (λ Eri), the amplitude of variability varies, and may correlate with the strength of the hydrogen emission. The variability *may* be due to pulsation and - if so - is probably non-radial, since the periods are rather long and since Be stars are non-radial in structure. Be stars lie near the β Cep instability strip, and the variability may play some role in producing or modulating the Be phenomenon. (iv) Bn stars: rapidly-rotating B stars without emission, have been found to be variable with periods of up to $\sim 0\overset{d}{.}5$ and small amplitudes (Jerzykiewicz and Sterken, Nice); these may like the Be stars, be non-radial pulsators. (v) B supergiants are known to be variable in brightness, both through statistical studies (Maeder,

1980) and studies of individual objects (Percy, Nice). The time scales (days to weeks) indicate non-radial modes (Maeder, 1980). Despite the report by Elst (IBVS 1697), there appears to be no short-period variability in B supergiants (Percy, IBVS 1946 and Nice). (vi) Numerous "slow variables", with periods $\gtrsim 8^h$, have been found in searches for β Cep stars, but are not always followed up. These may be ellipsoidal variables, variables of classes iii, iv and v above, or variables of other classes not yet identified. (vii) The helium star BD +13°3224 has a T_e and log g similar to those of β Cep stars, and varies with a period of $0^d.1$ (Landolt, 1975; Hill et al, preprint). (iii) The hypothetical "Maia variables", with late B spectral types and short periods, exist according to Beardsley et al (CPSPI) but not according to Percy (1978) and Breger et al (IBVS 1966).

Searches. Searches for pulsating B stars have been or are being carried out by Balona (Balona and Engelbrecht, Nice), Elst (IBVS 1562), Jakate (1978, 1979b), Jerzykiewicz and Sterken (e.g., Nice), Percy (e.g. Percy et al, 1981) and Shobbrook, as well as observers in Granada, Mexico and Nice. High priority should be given not only to finding new variables, but to confirming variables found in previous searches.

Observational Correlations. The β Cep instability strip is narrow ($0^d.15$ to $0^d.50$, depending on the observational errors in the photometric indices: Shobbrook, 1979), parallel to and about 1^m above the main sequence. According to Shobbrook (1980), it is fixed in the luminosity-temperature plane, despite significant differences in the locations of the main sequences of the clusters containing β Cep stars. This result has interesting implications for the evolutionary state and pulsation mechanism of these stars. Within the instability strip, 60-100% of stars are variable (Shobbrook, 1978; Balona and Engelbrecht, Nice). The amplitude of varibility is largest in the centre of the instability strip ($T_e \sim 20{,}000$ K); rapidly-rotating β Cep stars have smaller amplitudes, and are found only near the centre of the strip (Jakate, 1979a).

A period-luminosity relation exists, at least for the well-established β Cep stars (Shobbrook, CTVSR and 1979; Jakate, 1980; Waelkins, 1981), though a few stars such as HR 3088, α Lup and τ^1 Lup deviate. The situation with regard to the newly-discovered β Cep stars is not clear (Shobbrook, 1979a) and must await confirmation of the properties of these stars.

Evolutionary State. Methods for determining the evolutionary state of β Cep stars include (i) location of instability strip, (ii) frequency of occurrence, (iii) period changes and (iv) occurrence in clusters and associations. New or improved methods or results include the following: (v) The majority (60-100%) of stars in the instability strip are variable (Shobbrook, 1978; Balona and Engelbrecht, Nice), (vi) NGC 4755 contains at least 3 β Cep stars (Jakate, 1978) and NGC 3293 contains at least 9 (Balona and Engelbrecht, Nice) (vii) β Cep stars in clusters and associations fall below a gap in the H-R diagram associated with the overall gravitational contraction phase of evolution (Jakate, 1978). The conclusion is that β Cep stars occur during a limited phase of core hydrogen burning, near though not necessarily exactly at the end of this stage of evolution.

Pulsation modes. The pulsation modes in β Cep stars have been reviewed by Aizenman and Lesh (CPSPI), Jerzykiewicz and Sterken (SH), Percy (SH) and most recently and comprehensively by Smith (Nice). Mode identification can be done using (i) Q-value, (ii) Existence of one or more period-luminosity relations (Shobbrook, 1979a), (iii) Amplitudes and phases of light, colour and velocity variations (Balona and Stobie, 1979), (iv) Amplitude as a function of wavelength (Stamford and Watson, CTVSR), (v) Period ratios (e.g. Jerzykiewicz, 1978; Kubiak, 1980), (vi) Line profiles (Campos and Smith, 1980; Smith, 1980b; Smith, 1981) and (vii) Polarization (Odell, 1979; Odell, Nice). The conclusion is that most and perhaps all β Cep stars pulsate in a radial mode, though it may not always be the dominant mode. Many β Cep stars pulsate in one or more non-radial modes as well. These modes may be close to the radial mode in frequency, producing the well-known "beat effect". Multimode pulsation may be excited by resonance between close radial and non-radial modes (Fitch, NRNLSP). Two interesting cases are 12 Lac (Jerzykiewicz, 1978; Smith, 1980b) and ν Eri (Kubiak, 1980; Smith, 1981) both of which have three equally-spaced modes separated slightly in frequency from a fourth small-amplitude mode. According to the line-profile studies by Smith, the first three modes are non-radial (l=2, m=-2, -1, 0) and the fourth is radial.

Theory and Pulsation Mechanisms. Reviews have been published by Osaki (CTVSR), Aizenman (NRNLSP) and Percy (Nice). In an important paper, Odell (1980) has attempted to reconcile the physical parameters, pulsation parameters and internal structure of α Vir, with limited success. Stability analyses of standard β Cep models have been carried out by Saio and Cox (NRNLSP).

Among the pulsation mechanisms proposed for β Cep stars are the following: (i) Excitation in a semi-convective zone; as discussed by Aizenman (NRNLSP), this is no longer a likely mechanism. (ii) Sudden limited mixing of hydrogen in a semi-convective zone (Cox and Hodson, SH); this would produce rapidly-growing and slowly-decaying oscillations, which are observed in some stars (e.g. α Vir) but not others. (iii) Coupling of motions in a rotating convective core to oscillations in the envelope. This mechanism, first proposed by Osaki, is probably theoretically valid, but is rather "contrived" and "*ad hoc*" (Aizenman, NRNLSP) in the sense that it does not explain the limits of the instability strip, it requires a specific internal rotation period, and it would have trouble exciting all 9 stars in the instability strip in NGC 3293 with comparable periods (Balona and Engelbrecht, Nice). (iv) The opacity "bump" at 150,000 K (Stellingwerf, 1978) is a promising mechanism, but has not been shown to produce instability; however, Cox and Stellingwerf, 1979) have shown that such a mechanism, in the presence of radiation pressure, could explain the location of the observed instability strip. (v) Young and Furenlid (SH, Nice) on the basis of high-quality spectroscopic observations of BW Vul, have suggested that helium ionization may act as a driving mechanism for atmospheric pulsations.

It is not clear whether these mechanisms, individually or together, can produce the β Cep pulsation or explain the position of the instability strip. Possibly they can excite non-radial pulsations in the more widely-distributed 53 Per stars, which may then be coupled to radial pulsations by resonance processes (Fitch, NRNLSP). The Young and Furenlid mechanism may explain the large amplitudes of the β Cep stars with $T_e \sim 20{,}000$ K.

A number of theoreticians are studying instabilities in rapidly-rotating B stars; this seems to be a promising area of research, in view of the observed variability of Bn and Be stars discussed above.

Polarization. Odell (1979) and Stamford and Watson (1980) have shown that variable polarization should be observed in a β Cep star pulsating non-radially with a large amplitude. No variable polarization was detected in β Cep (which has a small amplitude) by Schlafgans and Tinbergen (1979), but variable polarization *was* detected in BW Vul (which has the largest amplitude of any β Cep star) by Odell (Nice) and by Kemp (private communication). This suggests that a non-radial mode is present in BW Vul.

Ultraviolet Observations. Satellite UV observations of β Cep stars have been published by Burger *et al* (1980a; 1980b), Hutchings and Hill (1980) Lesh and Wesselius (1979) and Lesh (Nice).

Miscellaneous. (i) Significant amplitude changes have been observed in α Vir (Lomb, 1978) and 16 Lac (Jarzebowski *et al*, 1979), and are suspected in δ Cet (Ciurla, 1979), but probably do not occur in BW Vul. (ii) The changing period of δ Cet has been followed by several observers (Lane, 1978; Ciurla, 1979; Mohan, 1979). (iii) 16 Lac is a shallow eclipsing binary; its physical parameters have been derived by Jerzykiewicz *et al* (IBVS 1508; NRNLSP). (iv) HD 80383 is a large-amplitude β Cep star (Haug, 1979). (v) HR 3593 is a β Cep star with the long period of 7^h (Burki *et al*, IBVS 1820).

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3. δ-SCUTI STARS

(John R. Percy)

Introduction. This is a brief review of the highlights of research on δ Sct stars from mid-1978 until mid-1981, i.e. since the previous review by Breger in these Reports. For a more complete bibliography of research papers, especially ones dealing with the discovery and study of individual δ Sct stars, see Astronomy and Astrophysics Abstracts.

It is now apparent (Breger, 1980a; McNamara and Feltz, 1978) that there is no astrophysical distinction between δ Sct stars and dwarf Cepheids (or RRs or AI Vel stars). In fact, Balona and Stobie (1980) have used BVRI photometry and radial velocities to show that the prototype AI Vel is a δ Sct-type star. Therefore, δ Sct and dwarf Cepheid variables will be considered together in this review.

Reviews. The following reviews of δ Sct stars have recently been published: Auvergne et al. (1980), Baglin et al. (1980), Berger (1979, 1980b, 1980c), Eggen (1979) and Percy (1980). The review by Breger (1979) and Eggen (1979) are the most extensive.

New Observational Techniques. Imbert (1980) and Burki and Mayor (1981) have used the radial velocity spectrometer CORAVEL to discover and study δ Sct stars. CORAVEL provides not only radial velocities but also line profiles, which can be used for inferring the pulsation mode. Heacox (1980) has proposed the use of the University of Arizona radial velocity spectrometer to search for very low amplitude δ Sct stars. Hildebrandt and Lange (1980) have used a twin telescope system to study the δ Sct star HD 181333.

Several authors have described new or improved methods of period determination, applicable to δ Sct stars: Breger (1980d), Marraco and Muzzio (1980), Murdin (1979), Renson (1978), Stellingwerf (1978), Weiss and Kreidl (1980) and Wizinowich and Percy (1979).

Surveys and Individual Studies. Horan (1979) has surveyed 14 Hyades stars, and found 36% to be variable. Kurtz has published a long series of detailed studies of individual δ Sct stars; see Kurtz (1980a) for a partial summary of these. Morris and DuPuy (1980) have reported on detailed photometry of three southern δ Sct stars. In addition to Breger (Austin, U.S.A.) and Kurtz (Cape Town, South Africa), there are active groups of δ Sct observers in Bologna and Milano-Merate, Italy; Budapest, Hungary; Ege, Turkey; Granada, Spain; Nice, France; Uttar Pradesh, India, among other places.

Periods of δ Sct Stars. Because many δ Sct stars have small amplitudes it is obvious that careful observations are necessary for the reliable identification of δ Sct stars. Breger (e.g. 1980b) has emphasized the requirements for reliable period determination in δ Sct stars: careful observations, sufficient nights of observations per component period, and a foolproof method of power spectrum analysis. By way of illustration, Guerrero et al. (1979) have found three non-radial periods in 38 Cnc; Breger (1980d) has found three radial periods, using the same observations! Gupta (1979) also finds radial periods in 38 Cnc.

Kurtz (1980b) has discussed the question of whether pulsation modes in δ Sct stars grow or decay on a time scale of days. He concludes that there is no strong evidence for such rapid growth or decay, and he cautions that "claims of changing frequencies for δ Sct stars should only be made with caution and a large amount of data".

Period changes in "dwarf Cepheids" have been studied by Mahdy and Szeidl (1980) and by Percy, Matthews and Wade (1980); the latter authors have calculated the period changes to be expected, depending on the evolutionary state of these stars. Several groups (e.g. Bohusz and Udalski (1980) have monitored the changing period of CY Aqr.

Pulsation Modes in δ Sct Stars. Various methods have been used to infer the pulsation modes present in δ Sct stars. Pulsation constants (Q) provide limited information, especially if carefully determined and if the pulsation is assumed to be radial. Period ratios have been used by Breger (1980b,c,d), Kurtz (1980a) and others: ratios near 0.76 and 0.81 usually indicate radial modes; ratios near 1.00 indicate that non-radial modes are present. Balona and Stobie (1979) and Stamford and Watson (preprint) have shown how relative amplitudes and phases of light, colour and radial velocity can be used to infer the pulsation modes in δ Sct stars. Campos and Smith (1980) have used line profile variations to infer a radial mode in ρ Pup and radial and non-radial modes in δ Sct.

Fitch and Wisniewski (1979) have obtained extensive photometric observations of the spectroscopic binary/ellipsoidal variable/δ Sct star 14 Aur. From these, they have deduced the pulsation modes (ℓ=1, P_5), and they have combined this information with the orbital parameters to construct a rather complete picture of the physical properties of the two components in the system.

Theoretical Studies. Almost all δ Sct stars appear to be population I objects on or near the main sequence. The exceptions are GD 428, SX Phe, CY Aqr and DY Peg. McNamara and Feltz (1978) have suggested that these may be recently ($\sim 3\times10^9$ yrs) formed metal-poor main sequence stars; Saio and Takeuti (1980) have modelled SX Phe as a star which has evolved and subsequently mixed.

Stellingwerf (1979) has carried out a linear stability analysis of model δ Sct stars. Andreasen et al. (1980) have constructed evolutionary models of δ Sct stars and detemined their periods. Cox et al. (1979a) have investigated the use of theoretical period ratios to determine the physical properties of double mode δ Sct stars. Dziembowski (1980) has given an excellent general discussion of the stability of δ Sct stars against radial and non-radial pulsation.

The pulsational stability of Am stars has been explained theoretically, by several authors, as being due to the downward diffusion of helium from the outer envelope of the star; see Cox et al. (1979b) for a review of these studies. The more difficult problem of the coexistence of pulsational instability and abundance anomalies in δ Del stars has been investigated by Valtier et al. (1979) and Cox et al. (1979b). They find that hydrogen ionization is probably capable of destabilizing a giant star in the lower Hertzsprung gap; any residual helium also contributes to the destabilization.

There is no clear explanation of what determines the amplitude of a δ Sct star. Stellingwerf (1980) has investigated this question through a non-linear stability analysis of model δ Sct stars, but he found that the amplitudes were critically dependent on the artificial viscosity parameter. Furthermore, the non-linear stability properties of the models depend primarily upon the amplitude! Rotation is a factor which seems to favour small amplitudes, and non-radial pulsation (Breger, 1980b). Breger (private communication) has speculated that the large amplitudes found in "dward Cepheids" are the normal state associated with slow rotation; one or two radial modes are excited in such stars, as in RR Lyr and Cepheid variables. The small amplitudes found in other δ Sct stars are due to rapid rotation and mode-sharing. Fitch (1980) has suggested that multimode behaviour may be excited preferentially in stars in which a resonance occurs between radial and non-radial modes; he states that the necessary and sufficient condition for the existence of multimode excitation may be that the excited periods be close to a direct resonance with each other, and that their excitation growth rates be relatively small. Radial modes occur when nonspherical perturbations are small or variable; non-radial modes only appear when figure perturbations are significant.

Related Types of Variables. The existence of the "Maia variables", located between the β Cep and δ Sct instability strips, continues to be debated. Observations by Percy (1978) and Breger *et al*, (1981) argue against their existence, but Fernie (1981) has presented convincing evidence for the variability of Vega.

Kurtz has discovered rapid photometric variability in several cool Ap stars, the prototype being HD 101065 (Kurtz and Wegner, 1979; Kurtz, 1980c). Although the periods are only a few minutes, implying very high overtones, the pulsation is probably related to that in the δ Sct stars. The 30-minute variable 21 Com (Weiss *et al*. 1980) may well be an intermediate case.

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4. RR LYRAE STARS
(B. Szeidl)

Several review papers on RR Lyrae stars were published which summarized their observational properties and theoretical aspects (Alania: Proceedings of the first school of young astronomers, Abastumani, 1976; Cox: Sp. Sci. Rev. 27.475; Stobie: IAU 5th ERMA; Romanov et al.: Highlights of Astronomy 5.489). Pel and Lub (IAU Symp. 80.229) used a great number of VBLUW measurements on 100 RR Lyrae stars to derive physical properties of these variables. Balona (IAU Symp. 80.241) discussed the problem of the radii of RR Lyrae variables. Davies (MN 185.573) derived the radius of UV Oct using his VBRI observations and Woolley and Savage's velocity curve. Manduca and Bell (Sp. Sci. Rev. 27.509) derived the absolute magnitudes of RR Lyr and X Ari. Heck and Lakaye (MN 184.17) discussed the problem of metallicity and luminosity and gave a refined relation between M_V and ΔS. They failed to find any relation between luminosity and period. Mahra and Sinvhal (BAS India 6.43 and Ap. Sp. Sci. 68.121) also investigated the dependence of the period-luminosity-colour relation for RR Lyrae stars on the metallicity parameter ΔS. They derived modified P-L-C relations. In another paper (Ap. Sp. Sci. 68.111) they studied the effect of metallicity on effective temperature and colour of RR Lyrae stars and derived relations between T_e, intrinsic colour $(B-V)_o$, and ΔS parameter. Lub (AJ 84.383) investigated the reddening and blanketing of 86 RR Lyrae stars measured in the VBLUW photometric system. It was shown that the different metallicity parameters (reddening-free colour index [B-L], $\delta(U-B)_S$, m_1, ΔS) led to the same blanketing corrections. Butler et al. (AJ 84.993) gave revised periods, light curves and metal abundances (ΔS and corresponding [Fe/H] values) for nearly 40 RR Lyrae stars of the Lick North Galactic Pole survey. Because of its importance in determining iron abundances in RR Lyrae stars, Manduca (ApJ 245.258) derived a new theoretical calibration of the ΔS system, and compared that with empirical and semiempirical calibrations. Several short notes on the influence of metal abundance have also been published in Astr. Tsirk. (Nos. 963,1002,1035) by Soviet astronomers.

The RR Lyrae stars in globular clusters provide a good opportunity to determine their physical properties. A number of papers have been dealing with the metal abundance and helium content of these variables (Butler et al.: ApJ 225.148, IAU Symp. 80.183; Cacciari: AJ 84.1542; Cacciari and Freeman: IAU Symp. 85.427; Caputo: Mem. Soc. ast. It. 50.113, Ap. Sp. Sci. 76.329; Caputo et al.: AA 82.79; Coutts Clement and Dickens: AJ 84.217; Keith and Butler: AJ 85.36; Manduca and Bell: ApJ 225.908; Smith and Butler: PASP 90.671; Sturch: PASP 90.264). These investigations confirmed that in some clusters the observed range in Fe/H and Ca/H was real.

A detailed study of the physical properties of RR Lyrae stars in M15 has been carried out by Sandage et al. (ApJ Suppl 46.41). The distribution of colours, amplitudes, light curve shapes and periods within the instability strip was investigated and compared with similar data for M3. Sandage (ApJ 244.L23, ApJ 248.161) found evidence for a period-luminosity-amplitude relation for equal metallicity RRab Lyrae variables. This function permits absolute magnitudes to be determined once the periods and amplitudes of variables are known. Caloi (AA 75.247) also investigated the period-amplitude relation for RR Lyrae stars and its connection to the luminosity of the horizontal branch.

It was shown by Cester et al. (Ap. Sp. Sci. 58.441) that a relation exists between the period and the area of the closed counter-clockwise path described in a two-colour diagram by an RR Lyrae star. They called the attention to the anomalous behaviour of RU Psc. Theoretical mean colours for RR Lyrae variables were derived by Davis and Cox (Current Problems in Stellar Pulsation p.293, Greenbelt, 1978) and and the full-amplitude behaviour of these variables was explored.

The RR Lyrae stars were extensively used to study galactic structure. (Blanco and Blanco: IAU Symp. 84.201; Castellani: Mem. Soc. astr. It. 50.37; Clube and Dawe: IAU Symp. 80.53; van Genderen and Block: AA Suppl 39.199; Hesser et al.:IAU Symp. 85.347; Rosino: European Satellite ast. Coll. Padova, 1978; Saio and Yoshii:

PASP 91.553). The occurrence of RR Lyrae stars in binary systems was discussed by Sidorov (Per. Zv. 20.557), with suggested interpretations of the observed deficit.

The investigation of period changes of RR Lyrae stars is still an attractive program. The period changes of a number of RR Lyrae type stars have been investigated (RZ Cep by Firmanyuk and Sakharova: Astr. Tsirk. 1015.8; RR Cet and SV Eri by Smykov: Astr. Tsirk. 1025.2,5; AT And, SU Dra, RR Leo, TT Lyn and AR Per by Olah and Szeidl: Budapest Mitt. 71). The period behaviour of field RR Lyrae stars was also intensively investigated at AAVSO (JAAVSO 7.76; 8.1,44,67,69). Photoelectric photometry has been reported on W CVn by Tremko (Contrib. Skalnate Pleso 8.141), ST Com by Alania and Abuladze (IBVS 1660) and Lemeshchenko and Sakharova (Astr. Tsirk. 1031.5).

The origin of period changes in RR Lyrae stars was discussed by Renzini and Sweigart (AA 71.66). They showed that small mixing events within the core of an RR Lyrae star can produce changes of both signs in the pulsation period comparable with those typically observed. Stothers (PASP 92.475) strengthened the idea that an analog of the solar magnetic cycle is operating in RR Lyrae stars. He suggested that changes of photospheric radius and of magnetic energy content during a magnetic cycle should give rise to changes in the pulsation periods. The predicted changes are also compatible with those observed.

The Blazhko-effect has been detected in a few RR Lyrae stars. RZ Cep has a secondary period of $29\overset{d}{.}9$ (Ficarrotta, Romoli: IBVS 1642) and the Blazhko-period of BH Peg is $39\overset{d}{.}8$ (Kudryashova: Astr. Tsirk 1012.7). DV Vir also seems to show the Blazhko-effect (Tsesevich, Mandel: Astrometriya i Astrofizika No. 37 p.45). Goranskij has systematically investigated the cluster RR Lyrae stars exhibiting light curve variations. He was able to derive secondary periods of two stars. V14 and V63 in M5 have Blazhko-periods of 74.97 and 146.8 days, respectively (Astr. Tsirk. 1096.3 and 1111.4). He also studied the slow irregular amplitude variations of V79 in M3 (Astr. Tsirk. 1111.6). Observations and short discussions were published on RR Lyr (Schoneich, Lange: IBVS 1577; Murnikova: Per. Zv. Suppl. 3.221), RW Dra (Firmanyuk: Astr. Tsirk. 1019.3) and XZ Cyg (Taylor: JAAVSO 7.82). Kanyo (IBVS 1832) found a third period of about 60 days in the light variations of RS Boo. The double-mode pulsation was proposed by Borkowski (Acta Astr. 30.393; Sp. Sci. Rev. 27.511) as an explanation of the Blazhko-effect in AR Her. A comparison of the theoretical and observed period ratio, however, yielded a "beat" mass which was different from the currently accepted masses of RR Lyrae stars. Cox et al. (BAAS 11.729; ApJ 236.219) calculated both homogeneous envelope and helium enriched surface-layer models in order to predict the observed period ratio for the double-mode RR Lyrae variable AQ Leonis. Jakate (ApJ 224.603) obtained UBV photometry of the triple-mode variable AC And. His results support the idea that AC And is an RR Lyrae star.

5. CEPHEIDS

(Bruce C. Cogan)

Studies of Cepheids in the past three years have been conducted in a wide variety of specific areas. The following subsections summarize the work of many of these areas. The review covers both classical Cepheids and type II Cepheids (W Vir and BL Her variables). Only some theoretical studies are included. Others are reviewed by A. Cox elsewhere in this Commission's report and by J. Cox in the report of Commission 35.

Newly-Discovered Cepheids. Several stars which may be Cepheids with exceptionally long periods have received considerable attention. Most notable is V810 Cen (=HR 4511 = HD 101947). Eichendorf and Reipurth (AA 77.227) observed the star photoelectrically for six months, and concluded its behaviour was consistent with it being a Cepheid with a period of about 125 days, and an amplitude in the V-band of 0.2 mag. Furthermore they noted that it is a member of the open cluster Stock 14, which gives an independent determination of the distance modulus. Stift (AA 80.134) also detected its variability, and Bohm-Vitense and Dettmann (ApJ 236.560) observed emission in their ultraviolet observations. From their IUE data Eichendorf and Reipurth (IBVS 1680) concluded that V810 Cen has a blue companion. This was confirmed by Parsons (ApJ 245.201), whose IUE data showed P Cygni profiles of lines arising from the B star. van Genderen (AA 100.175) attempted to separate the effects of the companion from the observations of the Cepheid, and concluded that V810 Cen lies near the blue edge of the instability strip with M_V=-7.94 and $(B-V)_0$ =0.53. Further work on this star will be necessary to confirm its Cepheid nature, especially since observations made by Dean (IBVS 1892) failed to show the 125 day period.

Ferro (PASP 93.351) observed 43 yellow supergiants in a search for variability. New variables which may be Cepheids include HR 4912, with a period between 44 and 68 days, and HR 4110 with a period of 59 days and a B-amplitude of only 0.07 mag. This latter star is in the open cluster IC 2581, and Ferro concludes that its colour places it outside the instability strip. Several other variable yellow supergiants, such as 89 Her, HD 159378 and HD 161796 have been observed (Percy and Welch, PASP 93.367; Fernie ApJ 243.576; Bakker and van Genderen, IBVS 1964). They probably are not Cepheids, but the distinction between the two classes of variables seems somewhat uncertain at present.

In their survey of variability Percy et al. (PASP 91.368) discovered that HR 7308 (=HD 180583) was a short period Cepheid. Burki and Mayor (AA 91.115) on the basis of 132 spectroscopic measurements determined a period of 1.49 days - the shortest known for a type I Cepheid. They also found that the amplitude decreased from 20 km/sec to 4 km/sec over a span of 250 days, and then increased to 6 km/sec over the next 140 days. Percy and Evans (AJ 85.1509) found a similar behaviour of the photometric amplitude. Burki and Mayor (Sp. Sci. Rev. 27.429) reported a continuation of their earlier velocity data in which the amplitude has grown larger, to about 10 km/sec, and Breger (Sp. Sci. Rev. 27.431) described unpublished observations made in 1966-1969 which show a variation in the amplitude over a period of 970 days. van Genderen observed this star in the Walraven system to determine its intrinsic colour and composition. He found that it had a normal solar abundance and a reddening of 0.03 in (B-V). This corresponds to a temperature of about 6060 K, and puts HR 7308 several hundred degrees cooler than the red edge of the instability strip.

Several other new discoveries are of interest for a variety of reasons. HR 9250 and HR 690 are both bright, but low-amplitude Cepheids observed by Burki et al. (AA 91.276). Kurtz (MNRASSA 38.36) has found that HD 129708 is a short-period cepheid with absorption-line ratios like those of Am or δ Del stars. Kovacs and Szabados (IBVS 1719) found that HD 179315 was a low-amplitude Cepheid, and they suspected the presence of a companion, although Fernie and Garrison (PASP 93.330) found no evidence for it being binary. V1726 Cyg, discovered by Platais (Astr. Tsirk. 1049.4) may be a member of an anomalous open cluster (see also Platais and Shugarov, IBVS 1982). Eggen (IBVS 1853) has found that HD 144972 is a Cepheid which may be a member of NGC 6067.

Chemical Composition. There has been renewed interest in the chemical abundances in Cepheids, in part due to Cox's proposal (see e.g., IAU Coll. 46.318) that the abundance of helium in the outer layers may be as high as Y=0.75. Model atmospheres were constructed by Kemp and Deupree (PASP 91.681) to look for spectral features which might indicate very high helium. They found that there were significant effects in the equivalent widths of metal lines and broad-band colours, but that calibrating them in terms of helium abundance required a very accurate determination of the effective temperature. Sonneborn et al. (ApJ 232.807) carried out a similar analysis and noted that effects of helium abundance could not be separated from microturbulence. They concluded that there was no spectral feature between 2000 and 10000 A that could be attributed solely to a variation in helium abundance.

Deupree (ApJ 236.225) used the observed width of the instability strip as an abundance indicator. He computed pulsation models which include the effects of convection in the envelope, and on the basis of these models predicted the position of the red edge of the instability strip. He found that the predicted width depended on the helium abundance and that comparison with observations gave Y=0.26

with some uncertainty due to choice of reddening and temperature scales. His results also predicted that the instability strip will be narrower at lower luminosities.

The variable V553 Cen is of interest because of the strong CN, CH, and C_2 features in its spectrum. Cottrell (MN 189.13) carried out a spectroscopic and photometric study of this star. He found a near-solar value for [Fe/H], but carbon and nitrogen overabundant by factors of about 5 and 3 respectively. He interpreted these results as the result of both CN and triple-alpha processed material being mixed to the surface. Wallerstein et al. (PASP 91.47) carried out a similar study of this star. They did not find such strong enhancement of carbon, and found heavy elements deficient by a factor of about 5. Both papers concluded that V553 Cen was a low-mass star with compositon affected by nuclear processing and mixing.

A model-atmosphere analysis of 14 Cepheids has been carried out by Luck and Lambert (ApJ 245.1018). Their results show that CNO processed material is in the atmospheres of all stars observed. However, their results show C and N more abundant and O less abundant than would be expected by simple dredge-up of processed material. They suggest that core convection and mixing into a hydrogen-burning shell on the main sequence could result in oxygen depletion. This mixing process would also affect the helium abundance at the surface. In the case of the double-mode Cepheid TU Cas, they assign a value of Y=0.8.

An extensive survey was carried out by Harris (AJ 86.707,719, and 1192) using The Washington photometric system to determine metal abundances for type I and type II Cepheids and for SMC Cepheids. For type I Cepheids, he found an abundance gradient in the galaxy given by $d[A/H]/dr=-0.07\ kpc^{-1}$ over a range of 10 kpc. Among the type II Cepheids he found a wide range of [A/H]: one-fifth were more metal rich than the Sun, one-fourth had [A/H]<-1.0. Most appeared to be old-disk population stars. Harris observed 45 stars in the Small Magellanic Cloud, and found a mean composition of [A/H]=-0.54. A study of 8 stars in the SMC by Pel et al. (AA 99.L1) using the Walraven system found a value of [Fe/H]=-0.70±0.25. Both these papers disagree with the proposal by DeYoreo and Karp (ApJ 232.205) that the blueness of SMC cepheids was due to unresolved companions.

Cepheids in Open Clusters and Associations. The membership of some Cepheids in clusters and associations has been used by many authors for determining the absolute magnitudes and thus, the distances and masses of Cepheids. Turner has published a series of papers which clarifies and extends the list of cluster members. In AA 76.350, he showed that RZ Vel was a member of Vel OB1 and that SW Vel and KQ Sco were members of anomalous associations. In ApJ 235.146, he reported on spectroscopic observations of stars in Vul OB2 which helped establish that S Vul was a likely member. The membership of RU Sct in a cluster was proposed in ApJ 240.137. Turner (AJ 86.321) re-examined the existing data for NGC 6649 and his results strengthened the membership claim of the double-mode Cepheid V367 Sct. Turner and Evans (BAAS 12.863) studied the field near SU Cas and determined a new distance modulus for its R association. The new distance is consistent with SU Cas pulsating in the fundamental mode.

Schmidt published several papers (AJ 85.158 and 695, 86.242) in which he determined the distance of several clusters - NGC 6089, NGC 129, and NGC 7790 - from uvbyβ photometry. This method is intended to circumvent some of the major difficulties that arise in the use of main-sequence fitting with UBV photometry. His results, summarized in Sp. Sci. Rev. 27.449, were that his moduli were 0.4 to 0.8 mag smaller than what have been generally accepted. This result disagrees with what has become a fairly generally accepted opinion that Cepheids have normal evolutionary masses.

Colours and Reddenings. Several methods of determining the reddening of Cepheids use the existence of a narrow Cepheid locus in a two-colour diagram of a suitable photometric system. Feltz and McNamara (PASP 92.609) devised such a scheme using ubvyβ and photometric measurements of Hδ, and K line and the G band. They applied their method to 41 Cepheids, and found significant differences between their results and others. The disagreement is in the sense that reddening determined by others when E is small are too large, and when E is large they are too small.

Fernie (preprint) proposed a method for getting reddenings from UBVRI photometry. Applied to 24 Cepheids the method agrees well with the reddenings determined by Parsons and Bell. Cogan (MN 188.297) examined the use of mean UBV colours for obtaining reddenings and concluded that such a system could not separate reddening from true colour variation across the instability strip.

Surveys. The results of several general surveys have been published. Martin and Warren (S. African Astr. Obs. Circ. 1.98) published UBV photometry of 59 stars in the LMC and 24 in the SMC, and Martin (S. African Astr. Obs. Circ. 1.172) gave BVI data for 10 LMC Cepheids. Henden (MN 192.621) as part of a search for new double-mode Cepheids observed 32 Cepheids with periods less than 5 days. Moffett and Barnes (ApJ Suppl 44.427) published BVRI observations of 24 stars. Evans (S. African Astr. Obs. Circ. 1.257) gave radial-velocity measurements for 50 variables which were made as part of a search for members of binary systems.

Cepheids in Binary Systems. Fernie (AA 87.227) proposed a new method of detecting binary members. He noted that the phase of the minimum in U-V will be shifted by a hot binary companion. Applying the phase-shift technique to 202 Cepheids Madore and Fernie (PASP 92.315) found about 35% were binaries. However, only 15% were common to the list obtained by Madore previously by looking for open loops in the two-colour diagram.

Reports of the binary nature of several individual stars have appeared. Mariska et al. (ApJ 238.L87 and 242.1083) have found from IUE data that both η Aql and T Mon have hot companions. Parsons' UV data (ApJ 247.560) confirmed the binary nature of V1334 Cyg, and his survey of yellow supergiants found 34% to be double stars and 20% to have hot companions. Harris et al. (AJ 84.1598) have studied the type II Cepheid AU Peg and found that it is in a binary system with a period of less than 50 years.

Period Changes. Szabados (Mitt. Sternw. Budapest-Szabadsaghegy 76 and 77) completed an extensive survey of photometric data relating to period changes. In addition to stars with no apparent change and those with a constant rate of change, he found a group whose period jumped discontinuously and later jumped back to the original value. These appeared to be mostly stars in binary systems. Individual stars that have been analyzed include 1 Car (Cogan et al. AA 86.283), SV Vul (Fernie, ApJ 231.841) and η Aql (Jacobsen and Wallerstein PASP 93.481). Cogan (Sci. 204.1078) pointed out that since a period change reflects a change in radius, observed changes in periods might be used to learn something about changes in the efficiency of convection near the surface of these stars.

Masses and Radii. Caccin et al. (AA 97.104) developed a generalization of the Baade-Wesselink method of determining radii that uses the whole light curve, and not just pairs of points. It requires the colour index to be a function of temperature, but not that surface brightness be a function of colour index. Comparison with older methods suggests that the new one gives significantly improved results in some cases. Sollazzo et al. (AA 99.66) applied the method to a number of Cepheids and obtained a period-radius relationship that agrees well with theoretical predictions.

Evans (BAAS 12.862) has studied the orbit of the Cepheid binary SU Cyg over a period of 5 years. She finds that the orbit is quite consistent with the Cepheid having an evolutionary mass. This is the only Cepheid for which a mass has been determined from binary motion.

Barnes (IAU Coll. 46.409) has used a relationship between surface brightness and (V-R) to obtain distances of several Cepheids with an overall uncertainty of about 10%. These distances are consistent with the new Hyades distance modulus.

Stobie and Balona (MN 189.641) obtained Wesselink radii of 8 short-period Cepheids using simultaneous velocity and photometry. They found that these stars fit the period-radius relation previously established by Balona from longer period variables. Wallerstein and Brugel (AJ 84.1840) showed that the field type II Cepheid XX Vir had a radius which indicated that its absolute magnitude agreed with that of Cepheids of similar periods in globular clusters.

Spectroscopic Studies. Parsons (ApJ 239.555) examined IUE spectra of δ Cep and β

Dor, and found MG II and OI emission at all phases of the latter but not phases of the former. He speculated that the existence of a chromosphere depends upon the mean properties of a Cepheid, not the temperature at a given phase. Schmidt and Weiler (AJ 84,231) looked at Mg II emission in β Dor and found the emission strength greater than non-variables of the same magnitude, and the correlation with phase different from that of Ca II.

Patterson and Neff (ApJ Suppl 41.215) carried out medium resolution narrow-band spectrophotometry of 9 Cepheids and 14 supergiants. They found no significant differences in the strengths of the strongest absorption features, but did find differences in the continuum fluxes in that the non-variables did not fit the models well in the wavelength range 3400-4600 A. The UV photometry of β Dor by Lub _et al_. (AA 72.82) gave fluxes that agreed well with model atmospheres at maximum light, but showed discrepancies at minimum light.

The Period-Luminosity-Colour Relationship. Martin _et al_. (MN 188.139) used the extensive new photometry of LMC Cepheids by Martin and Warren to re-derive the PLC relationship. An important part of their work was to use a maximum-likelihood method in place of a conventional least-squares regression for deriving their results. In addition they derived individual reddenings for many of the stars. They were thus able to get a much more reliable PLC relationship and show that the colour term is intrinsic and not due to differential reddening. They also concluded that the LMC Cepheids were bluer, at a given period, than those in the Galaxy, presumably because of a relative metal deficiency.

Cogan (ApJ 239.941) derived PLC relationships for the LMC and SMC and showed that the empirically-derived coefficients agreed well with theoretical predictions and that differences between the two systems could be explained by differences in chemical composition. He also showed that at periods greater than about 12 days the observed blue edges of the instability strip in the Galaxy, LMC, and SMC all departed significantly from theoretical predictions. An analysis of amplitudes of Galactic cepheids showed a general decrease to the red except for low-amplitude and double-mode Cepheids.

Clube and Dawe (MN 190.591) argued that the colour term in the PLC relationship cannot be derived empirically, due to the observational scatter in the intrinsic colours and the narrow width of the strip. This was further discussed by Brodie and Madore (MN 191.841) who carried out a series of numerical experiments to demonstrate the problem. However, Feast and Balona (MN 192.439) showed that these difficulties were related to using conventional least-squares regressions, and that the maximum-likelihood solutions did give a significant value for the colour term.

Double-mode Cepheids. There has been considerable effort to try to understand the nature of double-mode Cepheids - why they exist at all and why the ratio of the two periods does not agree with conventional models. Cox _et al_. (ApJ 230.L109) refined their model of helium enrichment to better fit the observed period ratios. They found the best models have Y=0.65 for the outer 0.1% of the star (by mass) an Y=0.46 for the next 0.1%. A similar structure was used to obtain longer-period models with velocity curve bumps at the proper phases.

Simon (AA 75.140) proposed that double-mode pulsation is due to a resonance between the second overtone and the first harmonic of the fundamental mode. Adopting this hypothesis allows one to identify double-mode Cepheid models simply by examining the periods derived from a linear analysis. Petersen (AA 80.53) calculated a series of linear models and showed that chemically homogeneous models do not produce the proper ratios but two-zone inhomogeneous ones do. Petersen (AA 84.356) also showed that to obtain both the correct ratio and a close resonance required an extremely deep surface zone and very small hydrogen content.

Several searches (Henden, MN 189.149; Barrell, Thesis, Australian Nat. Univ.) have been made for new double-mode Cepheids, but none have been found. Most known ones have been the subject of one or more intensive observing programs. Stobie and Balona (MN 188.695 and 189.627) obtained simultaneous photometric and velocity data for 8 stars. The Fourier analysis of their data showed a strong energy cross-coupling between the two modes. Balona and Stobie (MN 189.659) derived Wesselink radii from the data and found that the radii were indistinguishable from those of single mode type I Cepheids with similar periods. Faulkner and Shobbrook (ApJ 232. 197) obtained 481 UBVRI observations of U TrA and compared the Fourier-analyzed results with data collected 20 years ago. They found that the periods and total energy of pulsation had not changed but that there was relatively more energy in the overtone mode than previously. Niva and Schmidt (ApJ 234.245) compared the radius of TU Cas and SU Cas from new data and concluded that the double-mode star has a normal radius and mass. Niva (ApJ 232.L43) examined 60 years of radial-velocity data and found that the relative importance of the overtone was decreasing. Barrell et al. (Highlights Astr. 5.483) reported a re-analysis of all published photoelectric data for TU Cas and found an increase in the fundamental period and a decrease in the overtone energy. Barrell's (Thesis, Australian Nat. Univ.) analysis of AX Vel based on new photometric data led to the conclusion that its periods were subject to erratic wandering.

The position of double-mode Cepheids in the instability strip has been clarified somewhat. Balona and Stobie (MN, 189.659) obtained reddening for the stars they observed and showed that the colours scattered around the mean period-colour relationship. Barrell (MN 196.357) obtained temperatures from Hα profiles, and her results showed a tendency for the brighter stars to lie above the mean period-colour line and the fainter ones to lie below it. This means that they lie in a very narrow temperature range and do not lie along the edge of the instability strip.

6. MIRA VARIABLES

(R.F. Wing)

During the past three years there has been a significant improvement in our understanding of these large-amplitude variables, largely as a result of high-resolution spectroscopy in the low-opacity regions of the infrared, major photometric programs, and theoretical work on their atmospheric structures and pulsational characteristics. Several new kinds of observation - UV spectroscopy, radio continuum measures, VLBI investigations of circumstellar structure, and studies of the wavelength dependence of polarization and angular diameter - have provided additional insight but have not yet been pursued comprehensively.

Many hundreds of Mira variables continue to be monitored visually by amateur organizations, notably the AAVSO in the United States and the AFOEV in France. The Bulletins of these organizations give observations, predictions, and observed times of maximum and minimum; the activity of Miras from 1969 to 1977 has been summarized by Aubaud (Bull. AFOEV 12.62). A list of 20 variable-star organizations and their addresses is given by Mattei et al. (S&T 60.180). The AAVSO Variable Star Atlas (Sky Publ. Corp.), which shows essentially all SAO stars and more than 3000 variables, has appeared and has been described by its compiler (Scovil, S&T 60.99). Bateson et al. (New Zealand) continue to issue charts for southern variables (mainly Miras and flare stars), with series 10-12 appearing during the report period.

Photoelectric multicolour observations of Miras have been published by Hill et al. (Pub. DAO 15.339), Nakagiri & Yamashita (Ann. Tokyo Astr. Obs. 2nd ser. 17. 221), and Celis S. (AA 74.146); Celis discusses the visual and red amplitudes of Miras and SR variables. Goossens et al. (IBVS 1760) give photographic light curves for 22 new southern long-period variables. Maehara and Yamashita (Ann. Tokyo Astr. Obs. 2nd ser. 17.93) have studied the energy distributions of 18 Miras from 3700 to 5500 A with a photoelectric spectrum scanner. At longer wavelengths, a major body of JHKL data has been provided by Catchpole et al. (SAAO Circ. 1.61). These observations have been used together with statistical parallaxes in a new determination of the mean absolute visual, infrared, and bolometric magnitudes of Miras (Robertson & Feast, MN 196.111). Additional IR photometry has been obtained from the ground by Smak & Wing (Acta Astr. 29.199) and by satellite by Maran et al. (Current Problems in Stellar Pulsation Instabilities, NASA TM 80625, p.629). DeGioia-Eastwood et al. (ApJ 245.L75) have confirmed the correlation between 10 μm excess and period for Miras. Individual objects studied photometrically during the report period include V879 Sco (Yao et al. Acta Astr. Sinica 20.327) and CSV 6110 in Taurus (Howarth et al. JBAA 90.69), both of which were found to be Miras.

Hinkle & Barnes have continued their important series of papers on the temperature and velocity structures of the extensive atmospheres of Miras as deduced from high-resolution infrared spectroscopy, and they have discussed the H_2O lines (ApJ 227.923) and atomic lines (ApJ 234.548) in R Leo; they also call attention to the detectability of CN lines in this late M star. In the 2 μm region the atmospheric opacity is so low that lines (or components of doubled lines) can be seen that are formed deep in the photosphere, well below the region of formation of lines seen in the visible region. The spectrum of the cool Mira R Cas has been observed at high resolution in the 2 μm region by Flaud et al. (Les Spectres des Molecules Simples, Liege Coll. 21.246). Smith (BAAS 11.449; 12.521) has derived H_2O abundances and effective temperatures for Miras by comparing weak photospheric steam lines in the 2 μm region to calculations with model atmospheres.

In a review of the evidence that Miras are pulsating, Wind (Current Problems in Stellar Pulsation Instabilities, NASA TM 80625, p.533; also Perkins Obs. Contr. ser. II, No.80) has shown that the velocities of the photospheric lines observed by Hinkle remove a long-standing discrepancy between the spectroscopic and photometric indicators of radius variation. The velocity structure of Mira atmospheres has been considered theoretically by Hill and Willson (ApJ 229.1029) and observationally by Pilachowski, Wallerstein & Willson (NASA TM 80625, p.577), and a program of radial-velocity measurement of absorption and emission lines with a Griffin-type device has been undertaken by Pierce, Willson & Beavers (PASP 91.372).

The hydrodynamics of Mira atmospheres has been the subject of several studies. Phillips (AA 71.115) has considered supersonic mass flow, and Littleton (Physical Processes in Red Giants, p.241) has called attention to the possible importance of radiation pressure on molecules. The onset of shock-driven mass loss has been discussed by Willson & Hill (ApJ 228.854), and Wood (ApJ 227.220; NASA TM 80625, p.611) has discussed the pulsation of Mira atmospheres as it relates to mass loss.

The question of whether Miras are fundamental or first-overtone pulsators has been discussed by Wood (Physical Processes in Red Giants, p.205), Willson (ibid. p.225), Cahn (Sp. Sci. Rev. 27.457), and Feast (Highlights of Astronomy 5.493). Various questions concerning the absolute magnitudes, effective temperatures, and pulsational characteristics of Miras have been addressed by Feast (Variability in Stars and Galaxies, p. B.1.1; Physical Processes in Red Giants, p.193).

It is generally supposed that planetary nebulae are produced by red giants in some form. Two papers that deal specifically with Mira variables as the progenitors of planetaries have been published by Tuchman et al. (ApJ 234.217) and Willson (IAU Coll. 59, Trieste).

Among the recent spectroscopic observations of Miras is the detection of the Mg II doublet at 2800 A in emission in R Aql, but not in W Hya (Kafatos et al. AA 92.320). At the opposite end of the spectrum, R Aql and R Aqr have been detected as radio continuum sources (Bowers & Kundu, AJ 84.791). R. Leo was not detected in the radio continuum with the VLA (Ghigo & Cohen, ApJ 245.988), and a stringent upper limit of 0.7 mJy was placed on its flux at 6 cm.

In the near infrared, 21 members of the Paschen series were observed in emission in R Cas at maximum light (Duch, Acta Astr. 30.191; 9 missing members were accounted for in terms of overlying absorption. Similarly, the strengths of the emission lines of the Ca II infrared triplet were found to be anticorrelated with the TiO band strength (Contadakis, dissertation, Heidelberg; Solf & Contadakis, Mitt. Astr. Ges. No.45, p.142), and consequently these lines tend to be particularly strong in S-type spectra.

Wavelengths measured by Merrill and Greenstein in the spectrum of R And, an S-type Mira, have been analyzed by the method of wavelength coincidence statistics (Cowley & Hensberge, ApJ 244.252), and the atomic species identified agree well with the results of classical methods. In the cool C-type Mira V CrB, Goebel et al. (ApJ 246.455) have identified several bands of HCN and C_2H_2 that appear in the 1-13 μm spectrum observed at low resolution from the Kuiper Airborne Obsevatory.

The nebulous Mira variable R Aqr has been the subject of numerous studies.

Its unique light curve has been discussed by Mattei & Allen (JRASC 73.173), and new UBV photometry is given in Hill *et al*. (Pub. DAO 15.339). The spectrum of the nebula during the deep minimum of 1977 is discussed by Wallerstein & Greenstein (PASP 92.275), and recent changes in the appearance and spectrum of the nebula have been reported by Herbig (IAU Circ. 3535). Photoelectric measurements of several nebular emission lines on 16 nights are presented by Kaler (ApJ 245.568). R Aqr has been found to be an SiO maser (Zuckerman, ApJ 230.442), and its very large optical polarization has been discussed by Nikitin & Khudyakova (Pisma AZh 5.611). The rich UV spectrum of R Aqr, consisting of strong permitted and forbidden emission lines superimposed on a bright continuum probably emitted by a hot subliminous companion, has been studied with the IUE satellite by Michalitsianos *et al*. (Nature 284.148; ApJ 237.506). Johnson (BAAS 11.730; ApJ 237.840; ApJ 244.552) has obtained IUE spectra, $H\alpha$ observations, and radio continuum measurements of R Aqr and has discussed its evolutionary status.

Another variable receiving individual attention was the prototype o Cet. A campaign to coordinate observations of the 1979 maximum was organized by McLean (IAU Circ. 3407), and spectrophotometry at 50 A resolution from 4000 to 7500 A was obtained on an absolute scale by Joshi *et al*. (IBVS 1754). Grudzinska (BAS Torun, No.57) has discussed the excitation of some of the emission lines. In the UV, the spectrum of o Cet observed with IUE is dominated not by the hot companion but rather by an emission nebula excited by the companion (Wing & Carpenter, The Universe at Ultraviolet Wavelengths, NASA CP 2171, p.341; Cassatella *et al*. IAU Circ. 3425).

Angular diameters have been measured by speckle interferometry for χ Cyg (Christou & Worden, AJ 85.302) and o Cet (Welter & Worden, ApJ 242.673) and by lunar occultation observations for 3 fainter Miras (Ridgway *et al*. AJ 84.247). The speckle results tend to confirm earlier indications that the effective temperatures of Miras are higher than generally supposed and that their diameters are smaller at longer wavelengths. In the infrared (2-5 μm), o Cet and R Cas were resolved (diameter less than 0".1) in the speckle observations of Foy *et al*. (AA 79.L5).

The variation of intrinsic polarization with wavelength, particularly across strong bands of TiO, has been studied by narrow-band photometry in R Tri (McLean, MN 186.21), o Cet (Tomaszewski *et al*. ApJ 238.935), and four southern Miras (Codina-Landaberry & Magalhaes, AJ 85.875).

Considerable attention has been given to the radio and microwave maser emission lines of OH, SiO, and H_2O that are produced in the circumstellar shells of many late M stars, and here we mention only the studies that specifically pertain to Mira variability. Hagen (PASP 91.165) and Cox & Parker (MN 186.197) have obtained concurrent IR and H_2O observations for several Miras, and Wallerstein & Fawley (PASP 92.183) have presented new radial-velocity data for maser stars. Scharlach & Woolf (PASP 91.380) found that the strength of hydrogen emission is not correlated with maser activity, although the observations were not simultaneous. Variations in SiO maser intensity have been reported by Ukita & Kaifu (Interstellar Molecules, IAU Symp. 87 p.539) and Hjalmarson & Olofsson (ibid. p.541), and linear polarization in the SiO lines has been detected by Clark *et al*. (ibid. p.543). Hjalmarson & Olofsson (ApJ 234.L199) noted that the strength of the SiO maser lines in R Leo and o Cet is correlated with the infrared flux. Elitzur (BAAS 11.624) has presented a model for SiO masers that supposes the origin to be in the upper photosphere rather than the circumstellar envelope. Nguyen-Q-Rieu *et al*. (AA 75.351) and Epchtein *et al*. (AA 85.L1) have discussed the production of OH emission by radiative pumping by IR emission from circumstellar dust. Gomez B. and Lepine (IAU Circ. 3532) announced the unexpected disappearance of H_2O emission in W Hya near maximum light, while the SiO maser remained strong. This may indicate that the H_2O maser operates close to the photosphere, where dissociation of H_2O occurs at maximum light.

VLBI observations of molecular maser lines have been used to map out the spacial structure of the emitting regions in a few cases. The SiO lines near 7 mm have been used to study R Cas (Moran *et al*. ApJ 231.L67) and W Hya (Lane *et al*. IAU Symp. 87.535), while the main-line OH emission at 1665 MHz has been used for U Ori (Fix *et al*. ApJ 241.L95) and 9 other Miras, 4 of which were resolved (Fix *et al*. BAAS 11.731). U Ori has also been mapped in H_2O radiation (Lada *et al*. ApJ

243.769), which comes from a much smaller volume than does the OH emission.

Cahn and Elitzur (ApJ 231.124) have advocated the use of SiO maser intensities as distance indicators for Miras. On this basis, Wyatt and Cahn (BAAS 11.415) have studied the galactic kinematics of Miras. The kinematics of Miras in the galactic center region has been studied by Feast et al. (MN 190.227) and Feast (IAU Symp. 84.376) on the basis of new radial velocity measurements.

The discovery of Mira variables in clusters is an important clue to their mass, age, and evolutionary status. Alcaino (AA Suppl 35.233) has found that the variable V1 in NGC 6541, an apparently metal-poor globular cluster, is a Mira with a high probability of membership. Two of the 15 known variables in the globular cluster NGC 6284 are Miras (Clement et al. AJ 85.1604), but their membership is uncertain. Hoffleit (AJ 84.1701) has studied the frequency distributions of Miras in the fields of globular clusters and emphasizes the risk involved in assuming membership, particularly in low-latitude fields.

7. THEORY OF STELLAR PULSATION

(Arthur N. Cox)

This review covers the theoretical research on three classes of variable stars during the last several years from near the end of 1978 to about the end of 1981. In another section of this Commission 27 report, Cogan covers all aspects of Cepheid variable research both observational and theoretical. For Commission 35 J. Cox covers pulsation theory for the sun, Mira variables, R Cr B stars, hot and cool white dwarfs, and the effects of magnetic fields on Cepheid pulsations. He also discusses time dependent convection theory, the extended (non-linear) work integral of N. Simon, and recent books on stellar pulsation. In this review we complete the survey of the theoretical aspects of stellar pulsation and review β Cephei and 53 Per star theory, δ Scuti variable theory, and the RR Lyrae, BL Herculis, and longer period population II Cepheids (W Virginis stars) theory including the Blashko effect and the resonances and light curve bumps of these population II stars.

β Cephei and 53 Persei Variables. Since the Los Alamos/Goddard conference on stellar pulsation in June of 1978 (NASA TM 80625), which was discussed in the previous report, there have been four conferences where β Cephei and related variables have been discussed. In March of 1979 there was the Workshop on Nonradial and Nonlinear Stellar Pulsation (Lecture Notes in Physics, Vol.125, Springer-Verlag). At the IAU General Assembly in August 1979, the Joint Discussion VI on Stellar Instabilities has a short review on mode typing by Smith (Highlights of Astronomy 5.457). The IAU Colloquium 58 was held at Los Alamos in August 1980 (Sp. Sci. Rev. 27). Finally, a Workshop on Pulsating B stars was held in Nice in June 1981. These proceedings are not yet available as of November 1981.

As a background to purely theoretical research on β Cephei variables, I here review some basically observational papers which have implications more than usual for the theoretical interpretation. These papers go beyond the many papers reporting new variables and their luminosities or new behaviour of the light curves and spectra, etc. and try to identify the actual observed pulsation modes and pulsation mechanisms. Only for the β Cephei and 53 Persei variables has mode typing had some success.

The theoretical papers discuss details of radial and nonradial pulsations as a function of evolution, semiconvection, or rotation, but their main goal usually is to identify conclusively the actual cause of pulsations. As has long been known, this mechanism or these mechanisms are the key to understanding all aspects of this branch of variable star research.

Smith (1980, Lecture Notes in Physics, 125.60) points out that the 53 Per variables (3.6 hrs to 2.0 days) are related to the β Cephei variables (3.5-6.0 hrs). It seems that all the 53 Per star pulsations are nonradial g-modes with ℓ=2 or 3, whereas the β Cephei stars always show at least one radial mode. Smith further, at Montreal (1980, Highlights in Astronomy 5.457), suggests that a working hypothesis be that a β Cephei variable "resides in the upper left portion of the H-R diagram and exhibits continuous changes in light and radial velocity (line centroid!) which are too rapid to ascribe the stellar rotation or binary motion, and which are stably periodic over several years (Except for multiperiodic modulations). Its optical spectral lines may exhibit opposite profile asymmetries every half period and possible discontinuous changes in width".

In the Percy review (1980, Sp. Sci. Rev. 27.313) at Los Alamos, he discusses among other observational aspects, the position of the β Cephei instability strip in the H-R diagram. There are blue and red edges parallel to the main sequence, and the largest amplitude pulsators are at the strip center. The 53 Per stars surround this instability strip. Perhaps evolution off the main sequence gives first 53 Per stars and then near but not at the core hydrogen exhaustion β Cephei stars. Later in hydrogen shell burning stages the 53 Per stars appear again. This evolutionary state is further elaborated at Nice by Percy.

Amplitude changes are rare except for the well documented cases for α Vir and 16 Lac where striking decreases have been observed. Circula (1979, Acta Ast. 29. 537), however, claims that δ Cet has increased its amplitude. If the pulsation mechanism is due to a single jolt or maybe an episode of them somewhere in the star, a decay over some years would be predicted.

Percy gives tentative mode identifications which for many β Cephei stars are dominated by a radial mode. Smith at Los Alamos and Nice proposed that a β Cephei variable is one with at least one radial mode and frequently several other nonradial ones. Other mode-typing results were given by Lesh at Nice using photometric data and by Smith at Nice using line profiles.

Percy at Los Alamos and Nice further lists five destabilizing mechanisms. An interior mechanism is a jolt due to mixing of H and He is the semiconvection (μ gradient) zone or overshooting region of these 10-20 $M_\odot$ stars in their late hydrogen burning in a convective core (Cox and Hodson, 1980. Sp. Sci. Rev. 27.323). Interior-exterior mechanisms include oscillatory motions in a rotating convective core which couple to nonradial envelope modes (Osaki 1974, ApJ 189.469) and the newly discussed Helmholtz-Kelvin instability due to a rapidly rotating convective core rubbing against a slower rotating envelope (Ando 1981, in press). This was also discussed by Papaloizau and Pringle (1978, MNRAS 182.423). Exterior (envelope) mechanisms include (1) an opacity effect due to an opacity bump at 150,000 K (Stellingwerf 1978, AJ 83.1184; Cox and Stellingwerf 1979, PASP 91.319), (2) helium ionization at 20,000 K (Young, Furenlid, and Snowden 1981, ApJ 245.998) (3) and use of different opacities such as the unpublished ones of Carson which give larger opacities in the regions of 40,000 K and 500,000 K (Stothers 1976, ApJ 210.434).

Mode typing has been discussed by Jerzykiewicz (1978, Acta Ast. 28.465) for 12 Lac where he finds 6 periods. The four strongest are proposed to be (in decreasing period) a radial mode and then three nonradial modes with ℓ=2 and m=0, -1, and -2. Smith (1980, ApJ 240.149) confirms this identification. However, Saio (1981, ApJ 244.299) suggests second order rotation terms would fit the mode spacing if the m=0 and the radial mode identifications are interchanged and the longest period is m=0. Saio also proposes identifications for 3 periods in 16 Lac and 3 periods in β CMa based on his theory for rotation and tidal perturbations of nonradial modes. The negative m modes are more unstable than the positive m ones.

Odell (1980, Sp. Sci. Rev. 27.345) gets for α Vir a Hα line fit with ℓ=2, m=-2, V_{Rot}=120 km/s and a pulsation amplitude of 27 km/s.

Smith and Buta (1979, ApJ Lett 232.L193) have proposed for 53 Per only nonradial modes with ℓ=3 and m=-2 and -3. In this case the identification is based on line profile observations as well as simultaneous light and colour data. On the other hand, for γ Peg, β Cep, δ Cet, and σ Sco, Campos and Smith (1980, ApJ 238.250) can find only a single radial mode present. In σ Sco there is a second period (nonradial) at 0.97 the radial mode period.

A basic review of the theoretical aspects of B stars and their β Cephei type pulsations is given by Aizenman in his Tucson talk (1980, Lecture Notes in Physics, 125, Springer-Verlag, p.76). At this same conference Saio and Cox (p.169) suggest that the instability of the β Cephei stars may be due to a combination of envelope driving by He ionization at 40,000 K and 150,000 K and a rearrangement or jolt in the deep semiconvection structure. A third paper (p.135) in Tucson by Saio, Cox, Hansen, and Carroll describes their nonradial nonadiabatic computer program and some results for a 7 $M_\odot$ model. These early results are further elucidated by Saio and Cox (1980, ApJ 236.549) giving the nonadiabatic theory, and by Saio (1980, Sp. Sci. Rev. 27.649 and 1981, ApJ 244.299) giving the rotation and tidal perturbations for a polytropic stellar model.

An aspect of the Stellingwerf (1978, AJ 83.1184) opacity bump mechanism, which is important and actually always included is discussed by Cox and Stellingwerf (1980, PASP 91.319). Radiation pressure serves to reduce the gamma in these massive stars which enhances the Stellingwerf κ mechanism with the original Cox γ mechanism.

An important paper on α Virginis has been written by Odell (1980, ApJ 236.536). Stellar structure models were generated to match photometric and binary properties of Spica, and radial and nonradial (ℓ=2) pulsation modes were calculated. In these models no clear interpretation could be made, but the best fit to the single strong mode (disregarding the seven other weak or unreal modes reported at one time or another) is g_1 with ℓ=2.

Cox and Hodson (1980, Sp. Sci. Rev. 27.323) and Cox, Hodson, and Clancy at Nice have continued this discussion of α Vir. They prefer the mode to be interpreted as a radial fundamental pulsation with the excitation due to a jolt by a readjustment in the μ gradient zone or by core convection overshoot.

Chiosi (1980, Ap and Sp. Sci. 70.441) points out that mass loss affects somewhat the μ gradient region and its semiconvection. He suggests possible effects of an intermediate convective shell after hydrogen ignition can give pulsation by the Kato (1966, PASJ 18.374) mechanism.

The largest amplitude β Cephei variable BW Vul has been discussed in several recent papers. Odell (1981, Nice and 1981, ApJ Lett 246.L77) has measured the polarization variations and has concluded that there is some nonradial pulstion present even though only one period is seen. His basic analysis is given by Odell (1979, PASP 91.326) and Schafgans and Tinbergen (1979, Ast and Ap Suppl 35.279). Pesnell and Cox (1980, Sp. Sci. Rev. 27, 337) assume that the pulsation is radial and do a nonlinear calculation to see if observed light and velocity curve characteristics can be predicted. Stanford and Watson (1980, preprint for the Proceedings of the Australian Astronomical Society) do a similar nonlinear calculation. Using fast time spectroscopy, Young and Furenlid (1980, Sp. Sci. Rev. 27.329, at Nice, and see 1981, ApJ 245.998) studied the detailed atmosphere effects which are proposed to give some pulsation driving due to the ionization of helium just at the surface. Cox, Hodson, and Clancy at Nice discussed the jolt mechanism for BW Vul and concluded that there must be episodes of core overshooting every few years to keep the observed amplitude so long. They cannot get any envelope ionization driving to cause pulsations.

Nevertheless, Dziembowski at Nice and Lee and Osaki (preprint) have made further calculations. They find that the Stellingwerf bump mechanism is not large enough to destabilize the star as a whole, especially in the region of the H-R diagram where the β Cephei variables are found.

δ Scuti Variables. There were four conferences where δ Scuti variables were reviewed or discussed during our reporting period. These are the NASA Goddard Conference on Current Problems in Stellar Pulsation Instabilities (NASA TM 80625) in June 1978, the Workshop on Nonradial and Nonlinear Stellar Pulsation (Lecture Notes in Physics 125, Springer-Verlag) in Tucson in March 1979, the Liege Fifth European Regional Astronomy Meeting on Variability in Stars and Galaxies in July 1980, and the IAU Colloquium 58 on Stellar Hydrodynamics (1980, Sp. Sci. Rev. 27) at Los Alamos in August 1980. Reviews by Breger and Percy at the IAU Joint Discussion VI at Montreal are useful to read also.

Breger (1979, PASP 91.5) has given a review and summary of the properties of δ Sct stars. He finds that there is a well defined instability strip which includes all well determined δ Sct stars. The many periods seen in these stars have pointed to both radial and nonradial modes being present. They are identified by period ratios, photometric values of the pulsation constant (using g, L from the β index, and T_e), the spectral line profile shape changes, the light, colour and radial velocity phase lags, and amplitude ratios of these latter three variations. Actual pulsation modes are believed identified in many multimode cases. Radial modes are the fundamental in the cool region and higher overtones 1H and 2H at the blue boundary. Nonradial modes occur across the whole strip but not in every star.

The Nice team emphasizes further observational and theoretical problems. These are metal abundances of the atmospheres which are related to ages, rotation, and convection where gravitational settling of helium with age is counteracted by rotation and convection. Auvergne, Baglin, LeContel, and Valtier (1980, NASA TM 80625) and Baglin, Auvergne, Valtier, and Saez (Liege) discuss these points as well as the problems on non-variability in the strip and the nature of the dwarf Cepheids on AI Vel stars. Four of these latter variables (GD 428, SX Phe, CY Agr, and DY Peg and maybe HD 94033 according to Przybylski and Bessell (1979, MNRAS 189. 377) seem to be of population II and likely blue stragglers. They need a new name since the terms RRs, dwarf Cepheid, and AI Vel stars should indeed be dropped in favour of the correct term for the entire class, δ Scuti.

The conclusions of a series of reviews by Breger is given by him (1980, ApJ 235.153). He draws on his work, that of the Nice group and that of McNamara reviewed by McNamara and Feltz (1976, PASP 88.510 and 1978, PASP 90.215). The remaining problems are mostly theoretical, such as the pulsation theory problems of modal selection, convection, and composition and the evolution problems of rotation, age, and the cause of the possible blue stragglers. On this last point, Jorgensen (1982, Proceedings of the IAU Coll. 68, Dudley Observatory) has reported on two blue stragglers in ω Cen which are seen as dwarf Cepheids, clearly of population II.

Percy, Mathews, and Wade (1980, AA 82.172) have looked at period changes in 8 dwarf Cepheids to see if they can be predicted from stellar evolution theory. They all seem too large, if they are real, and are probably not due to the slow evolution.

Balona and Stobie have studied AI Vel (1980, MNRAS 192.625) and Balona, Dean, and Stobie have studied δ Sct (1981, MNRAS 194.125). For AI Vel they derive from BVRI photometry and photoelectric radial velocities a radius of 3.1 $R_\odot$ and, therefore, mass of about 2 $M_\odot$. This agrees with the "theoretical" AI Vel mass of Cox, King, and Hodson (1979, ApJ 228.870) but not with Simon's beat mass (1979, AA 74. 30) based on Fourier fits for amplitudes and phases of the two pulsations.

For δ Sct the result is that the longest amplitude period is a radial mode and the second period at 0.964 P is an ℓ=2 nonradial mode. Thus some of the double-mode δ Sct stars are not in purely radial modes.

At the Tucson conference, Fitch (p.7) discusses these period ratios, which he finds in 29 or 30 cases are ratios of integers. Dziembowski (p.22) suggests that the many modes, some nonradial, in δ Sct variables are due to nonlinear coupling of them which limits the pulsation driving whereas for Cepheids the driving mechanisms are limited by saturation. This also gives many small amplitude modes.

Valtier, Baglin, and Auvergne (1979, AA 73.329) investigate whether the settling of helium due to the strong gravity and long lifetime of these δ Sct stars can deplete the pulsation driving layers and result in possibly not enough pulsation driving. They conclude that hydrogen alone can give enough driving. This result is disputed by Cox, King, and Hodson (1981 ApJ 231.798) who have calculated the width of the instability strip for various helium depletions. At zero helium abundance, due to complete settling and no remixing, the width of the strip is zero and hydrogen alone cannot give enough driving to cause any pulsations.

Saez, Auvergne, Valtier, Baglin, and Morel (1981, AA 101.259) discuss this problem further and conclude that indeed some helium is necessary for these metallic line (δ Del) stars.

Saio and Takeuti, at the Goddard Conference and in the 1979, Science Report of Tohoku University 62.13, discuss the evolutionary state of SX Phe. They assume the star was a least partially mixed after it evolved off the main sequence and is now in the second hydrogen burning stage. Low masses like 0.70-0.75 $M_\odot$ seem to fit the population II composition and age as well as the pulsation properties.

Stellingwerf at the Tucson workshop (p.50, also 1979, ApJ 227.935) discusses nonlinear calculations for 0.4 $M_\odot$, M_{bol}=2.55, and a 2.0 $M_\odot$, M_{bol}=0.89 models. For this first model the limiting amplitude is too large, but it can be reduced by increasing the artificial viscosity. The second model did not truly converge to a limiting amplitude, but it clearly was also going to be too large. Some unknown dissipation of the pulsations seems required.

Cox and Hodson at Tucson (p.41) also reported on nonlinear δ Sct calculations for a 1.8 $M_\odot$, 23 $L_\odot$, 7500 K model of AI Vel. While true convergence was again not achieved, it appeared that the fundamental mode light amplitude was 0.2 magnitude and the velocity peak to peak range was 14 km/s. The overtone mode was also stable. Since no permanent double-mode behaviour was found, it is argued that double-mode behaviour for δ Sct stars as well as for the classical Cepheids is caused by mode switching only.

For AI Vel, Simon (1979, AA 74.30) gets a mass of only 0.25-0.45 $M_\odot$ using the structure of the light and radial velocity curves obtained from least squares Fourier fits to the data. He states, however, that the reuslt is very uncertain.

Period ratios and possible resonances based on actual evolution tracks for δ Sct stars have been given by Andreasen, Hejlesen, and Petersen (1980, Sp. Sci. Rev. 27.381). They find that the settling of helium can change the structure and increase period ratios, and this reduction of helium can mimic a decrease in the heavier element mass fraction Z. It appears that the resonance of the fundamental the first and fourth overtones $\omega_0+\omega_1=\omega_4$ is not likely to occur for δ Sct stars because this resonance occurs beyond the red edge of the instability strip.

Two zone models with a surface layer either richer or poorer in helium have been calculated by Petersen 1979, (AA 80.53). Resonances predicted by Simon are investigated for models with masses from 0.2 to 8 $M_\odot$.

RR Lyrae, BL Herculis and W Virginis Variables. A tremendous amount of information has been recently published on RR Lyrae variables and the population II Cepheids. Theoretically oriented papers were presented at the NASA Goddard conference (NASA TM 80625) at the Los Alamos IAU Coll. 58 (1980, Sp. Sci. Rev. 27), and at the end of this reporting period, at the Union College IAU Coll. 68 (1982, Pub. Dudley Obs.). The one review is by Cox (1980, Sp. Sci. Rev. 27.475) who points out that there seems no possibility of redward evolution at RR Lyrae variable luminosities because the Christy and Von Sengbusch transition line between the either fundamental or first overtone region and the fundamental only region no longer seems to exist (Cox, Hodson, and King 1979, BAAS 729). The two Oosterhoff groups are discussed, and they are probably due to a lower Y or lower mass in Group I. Given a mass and a composition the absolute luminosity of the RR Lyrae variable with an observed mean period can be found.

Observational papers which bear on this Oosterhoff group problem are by Sandage, Katem, and Sandage (1981, ApJ Suppl 46.41) and Sandage (1981, ApJ 248.161). M15 and M3 variable star observations have been used to propose that the difference between the two groups of globular clusters is a lower helium abundance in the higher metal content group I clusters like M3. The ages of these two clusters, however, are, both about 16 billion years. In the second paper 6 globular clusters are studied to verify results of the first paper and that of a tight amplitude, T_e correlation (1981, ApJ Lett). He believes that stellar evolution in the H-R diagram is one way only (probably redward) in group I clusters and both redward and blueward in group II clusters like M15 and ω Cen. A period luminosity amplitude relation is derived, where the amplitude is shown to be a good indicator of log T_e. In two more papers in preprint form at this writing, the age of the globular cluster system ($17\pm2\times10^9$ years) is derived using the RR Lyrae variable periods as luminosity indicators and evolution data from many others. The age of the galactic disc is discussed using the high metallicity RR Lyrae variables and an enrichment of metals history is proposed.

More data on the key globular cluster M15 RR Lyrae variables, however without any theoretical interpretation, is given by Filippenko and Simon (1981, AJ 86.671).

Effective temperatures allowing for both interstellar reddening and blanketing has been discussed by Mahra and Sinvhal (1980, Ap and Sp Sci 68.111). This is extended by them to discuss the period luminosity-colour relation for RR Lyrae stars (1981, Ap and Sp Sci 68.121).

Period changes in RR Lyrae variables, which are larger than expected from evolution theory and are of both signs, have been discussed by Stothers (1980, PASP 92.475) in terms of magnetic cycles like that in the sun. A magnetic field could be generated and annihilated which could change the pulsation period through its energy content and through its changes in the stellar radius. Period changes should occur on time scales like 1-100 years.

Sweigart and Renzini (1979, AA 71.66) have proposed that the RR Lyrae period changes are due to radius changes caused by changes in the structure of the semi-convection zone. Both period increases and decreases can be predicted. Another version of this work at the Goddard Conference is by Renzini and Sweigart (1980. NASA TM 80625, p.271).

At this NASA Goddard meeting, Davis and Cox (1980, NASA TM 80625, p.295) discuss the proper way of getting the mean colour and, therefore the mean log T_e. They conclude that separate intensity means of B and V converted back to magnitudes is the proper way to get (B-V) just as they previously found for the Cepheid case.

Period-amplitude variations in globular clusters have been studied by Caloi (1979, AA 75.247). Agreement with theoretical results of Stellingwerf (1975, ApJ 195.441) is not good since log L/L_o is found to be about 1.7 for c-type variables and is about 1.5 for ab-types. Plotting the data of ΔM_{bol} vs. period, most globular clusters have about the Stellingwerf predicted slope, but the shallow slope in ω Cen leads one to believe that this cluster has a higher luminosity of its horizontal branch stars.

In ω Cen, Caputo (1981, Ap and Sp Sci 76.329) has studied the RR Lyrae variables and their pulsation modes. The interpretation involves the dichotomy of pulsation modes, depending on whether the evolution is mostly redward or blueward. It is declared that ω Cen is in the group I because it has many short period fundamental mode pulsators like M3, M14, and IC 4499 also in group I. It is known that both metal poor and metal rich RR Lyrae variables exist in the cluster which is then actually of both types. Since the position or even the existence of transition lines in the center of the instability strip is not certain, the identification of which Oosterhoff group obtains is also not certain. The ω Cen helium content is derived to be 0.05 in Y larger than for M3.

For M4 RR Lyrae variables, Cacciari (1979, AJ 84.1542) derives a helium content of 0.28±0.05 with the latest opacity data for the pulsation results and the most modern conversion from colour to log T_e. On the assumption that all the horizontal branch stars have a luminosity of log L/L_o=1.68±0.4, the mass of the RR Lyrae variables have a mass of 0.6±0.1 $M_\odot$.

A review of the influence of rotation on the expected properties of RR Lyrae pulsators has been given by Castellani, Ponte, and Tornambe (1980, Ap and Sp Sci 73.11). Rotation increases the helium core on the zero age horizontal branch, and together with mass loss in an earlier stage, the hydrogen-rich envelope mass is decreased. This results in higher T_e and L. Synthetic rotational horizontal branches have been constructed for Y between 0.2 and 0.3, and Z between 10^{-4} and 10^{-3}, and for reasonable values of mass loss and rotation. The close correlation between Y and the luminosity is no longer valid, and luminosities with rotation and mass loss decrease. Observations such as the same luminosity for RR Lyrae variables in ω Cen with different Z values point to rotation existing in these stars.

With standard evolution on the horizontal branch, Caputo, Castellani, and Tornambe (1980, AA 82.79) have constructed synthetic horizontal branches. Pulsation periods are strongly correlated with the original helium content, independent of mass loss or mass variations on the horizontal branch. A Y=0.28 was obtained for group I clusters. The use of the Stellingwerf transition line between the overtone and fundamental pulsation modes for redward evolution leads to the result that the last phases of horizontal branch evolution are likely to be overestimated. It is suggested that Y may be higher in the lower Z Oosterhoff group II clusters. In general, however, they feel that standard evolution and pulsation theory is adequate to account for the characteristics of RR Lyrae variables.

In spite of this reassuring paper, Castellani and Tornambe (1981, AA 96.207) report that they need $Y\sim0.22$ for the metal poor ($Z=10^{-4}$) Oosterhoff group II globular clusters. Since this produces a lower luminosity than for a larger Y, the core mass is here assumed to be 6 percent larger than given by standard stellar evolution theory. This larger core seems possible if mass loss and rotation are considered in the evolution tracks. For Oosterhoff group I clusters then, the larger core mass is also possible, but a larger mass loss rate is needed. Justification of the low Y pulsation theory results is sought by asserting that the overtone region is wide only at low L and, therefore, low Y. This seems a faulty analysis since at any L the overtone region increases with Y and to get a $\Delta \log T_e$ width of 0.03-0.05 for Oosterhoff group I-II, Y needs to be large. Another justification cited is that the overlap range in periods between the overtone and fundamental modes is very small at low Y, and this small overlap is observed in many clusters.

There is a problem with the Italian analyses, this reviewer feels. The evolution of the horizontal branch stars cannot be made definitive until the earlier helium core flash stages are better understood. The position, or even existence of transition lines is still disputed. Finally, the conversion from colour to T_e is still being debated. While the RR Lyrae variables are extremely useful for understanding the early epochs of our galaxy, all the answers are not yet available.

The field RR Lyrae variable AQ Leo is pulsating in two modes, the fundamental and the first overtone. Hodson, Cox, and King (1979, BAAS 11.729) and Cox, King and Hodson (1980, ApJ 236.219) have investigated this variable and found that it can be explained with a normal population II composition in the pulsating envelope layers.

Cox, Hodson, and Clancy (IAU Coll. 68) have found that 10 RR Lyrae variables in M15 also show two pulation modes, and these have been used to derive a mass of $0.65\pm0.05\ M_\odot$ for these horizontal branch stars. With the mass known, the observed RR Lyrae periods give the luminosity of these stars and, therefore, the distance of the cluster. M3 in Oosterhoff group I and ω Cen in group II are also discussed and distances given. It is proposed that $M_{bol}=0.30$ for group I RR Lyrae variables and $M_{bol}=0.60$ for group II.

The later evolution stage BL Herculis variables were studied with a hydrocode by Carson, Stothers, and Vemury (1981, ApJ 244.230). From the bumps on the light and velocity curves they get using the unpublished Carson opacities, $0.59\pm0.03\ M_\odot$ for globular cluster BL Her variables and 0.54 ± 0.01 for BL Her itself. Normal helium like $Y=0.31\pm0.08$ is found to explain these observed population II variables.

Linear and nonlinear studies of BL Herculis variables have also been studied by King, Cox, and Hodson (1979, BAAS 11.229, and 1981, ApJ 244.242) and by Hodson Cox, and King (1980, Sp. Sci. Rev. 27.503). The resonance of the second overtone with the fundamental mode pulsation is discussed, and it seems that these stars behave with a Hertzsprung progression just like the classical Cepheids. In a preprint Hodson, Cox, and King have done even more nonlinear calculations to show that the ratio $\Pi2/\Pi0$ is different when using nonlinear theory from what it is in linear theory. Low masses like $0.55\ M_\odot$ are needed just as Carson, Stothers, and Vemury found.

Petersen (1980, Sp. Sci. Rev. 27.495) has also derived bump masses for 18 BL Her variables from the observed bump phases and the periods. A mass of $0.60\pm0.09\ M_\odot$ is obtained for these stars. More data are given by Petersen (1981, AA 96.146). The radius of V553 Cen agrees with recent Wesslink radius determinations. The existence of bumps as either echos or a $\Pi2/\Pi0$ resonance is discussed.

Resonances of $\pi2/\pi0\sim0.5$ has been greatly discussed by Simon (1979, AA 75.140; 1980, ApJ 237.175; 1980, ApJ 237.550; and 1981 ApJ 247.594). In the first paper it is proposed that the sum of the angular frequencies $\omega_0+\omega_3=\omega_3$ is the Cepheid resonance giving two modes and $\omega_0+\omega_1=\omega_4$ is the δ Sct resonance for those double-mode pulsators. An iterative treatment of the nonlinear effects for double-mode pulsators is given in the second paper. The last paper together with the Simon, Cox, and Hodson (1980, ApJ 237.550) work is reviewed by J. Cox in the Commission 35 report.

Multimode behaviour is also discussed as the Blashko effect seen in many RR Lyrae variables. The one theoretical paper is by Borkowski (1980, Sp. Sci. Rev. 27.511). AR Her is interpreted as a nonlinear superposition of the fundamental mode and another with $P \sim P_{0}/2$, which is the second or third radial overtone. Many other Blashko effect variables have been used to plot the period ratio vs. log P diagram. If the unknown mode with period P is the second overtone, the RR Lyrae variable star mass is less than 0.2 $M_{\odot}$. If it is the third overtone, the masses are about 0.7-1.1 $M_{\odot}$.

Time-dependent convection, to be discussed more by J. Cox, has been applied to RR Lyrae variables by Baker and Gough (1979, ApJ 234.232). Radial pulsations are studied in the linear nonadiabatic theory with generalized mixing length theory. A red edge to the instability strip has been found, but it seems much too cool to accord with observations.

8. FLARE STARS

(R.E. Gershberg)

The significant progress in investigations of Flare Stars (FSs) during the last 3 years is due both to traditional studies and to new directions initiated in this period by the IUE and HEAO satellites. Some problems of FSs have been discussed at the Symposium held in 1979 in Byurakan (L. Mirzoyan (ed.) "Flare stars, fuors and Herbig-Haro objects", Yerevan, 1980 - cited below as Byurakan Symp. 1979) and in the review by M. Rodono (Mem SA It. 51.623). The English version of the book "Flare stars" by G. Gurzadyan was published by Pergamon Press, the book "Non-Stationarity and evolution of stars" by L. Mirzoyan was published by Adacemy Press in Yerevan (1981).

Several new FSs in the solar neighbourhood have been discovered: Gliese 867 and Gliese 825 - by Byrne (MNRAS 187.153 and 195.143), Gliese 490 AB, G51-15 and G141-29 by Pettersen (PASP 92.188 and AA, in press); flare activity is suggested for the F8 star BD +32°2477 by Olson (IBVS 1825), and for CW UMa by Bidelman (IBVS 1873). The BY Dra syndrome is found for HD 1835 and HD 29697 by Chugainov (Byurakan Symp. 1979, p.15), for SV Cam by Hilditch *et al.* (MNRAS 187.797), for EV Lac by Pettersen (AJ in press), for Gliese 490 AB (=BD +36°2322) by Pettersen (IBVS 1604) and by Anderson (PASP 91.202), for Vyss 124 by Busco *et al.* (IBVS 1898), confirmed for EQ Vir and UZ Lib by Hoffmann (IBVS 1878) and suspected for HD 172268 and HD 172468 by Melkonyan *et al* (Astrofizika 17.215). Photoelectric observations of known FSs have been reported by Melikyan *et al.* (IBVS 1546,1827) Sanwal (IBVS 1572), Jarrett and van Rooyen (IBVS 1585,1587,1588,1612,1641,1664), Mavridis *et al.* (IBVS 1620,1653,1654,1784,1792,1793,1799,1803,1804,1806,1891,1906,1907), Busco *et al.* (IBVS 1897), Mahmoud and Olah (IBVS 1943), Panov and Tsvetkov (IBVS 1971), Hoffmann (IBVS 1977), Kilyachkov *et al.* (Astrofizika 15.423 and 605), Melkonyan *et al.* (Astrofizika 16.107), Byrne and McFarland (MNRAS 193.525), Walker (MNRAS 195. 1029), Ichimura and Shimizu (Tokyo Ast. Bull. 264), Tsikoudi (in press), Mavridis *et al.* (in E.G. Mariolopoulos, P. Theocaris and L. Mavridis (eds.) "Compendium of Astronomy" Reidel, Dordrecht, 1981, p.253) discovered long-term fluctuations with an amplitude of $0\overset{m}{.}3$ and a period of about 5 years in the quiet state luminosity of the FS EV Lac and fluctuations with an amplitude of more than $0\overset{m}{.}3$ and a period of at least 14 years for the FS BY Dra; similar periodicities in flare activity levels are suggested for these FSs as well.

Results on the search for FSs in regions of stellar clusters have been published by Erastova (IBVS 1616), Chavushyan *et al.* (Soobshch. Byurakan Obs. 52. 78; IBVS 1626,1628,1629), Jankovics *et al.* (IBVS 1627,1746,1750,1779,1780), Kiladze, Natsvlishvili and Melikyan (IBVS 1725,1726,1926), Gotz (IBVS 1731), Tsvetkov *et al.* (IBVS 1749,1888,1889; Byurakan Symp. 1979 p.19; Ap. Investigations (Bulgarian) 3. 76), Tsvetkova (IBVS 1887), Mirzoyan *et al.* (Astrofizika 17.71 and 197). Some data on photographic colorimetry of flares are given in several of these papers.

Parsamyan (Astrofizika 16.87 and 231) has reported brightness curves of slow flares in the Pleiades, Praesepe, Hyades and Orion association. Statistical studies on flare activity of FSs in stellar clusters have been carried out by Ambartsumyan (Byurakan Symp. 1979 p.85), Szecsenyi-Nagy (Byurakan Symp. 1979 p.129), Mirzoyan and Brutyan (Astrofizika 16.97), Parsamyan (IAU Symp. 85.249; Astrofizika 16.677). Mirzoyan *et al*. (Byurakan Symp. 1979, p.113) and Kosarev (Sov. Ast. Lett. 6.408) have discussed the spatial distribution of FSs in Pleiades. Jones (AJ 86. 290) has determined proper motions for FSs in the Pleiades region and found that a significant fraction of these FSs are nonmenbers of the cluster.

Bruevich *et al*. (Izv. Krymsk. Astrofiz. Obs. 61.90) have observed FSs photoelectrically in B and the IR region simultaneously; they registered more than a hundred optical flares, found that practically all strong optical flares are accompanied with synchronous IR flares, and in about 70% of the cases the IR preflare dips were observed. Preflare phenomena in the IR have been reported also by Kilyachkov and Shevchenko (Byurakan Symp. 1979 p.31). Cristaldi *et al*. (AA 89. 123) have studied the photometric features near initial phases of flares and found some correlations between the preflare dip appearance and the flare amplitude, equivalent duration of the flare and rise time to brightness maximum; they found also that the FS EQ Peg becomes bluer at a preflare increase and redder at a dip minimum. B band dips were registered by Mahmoud and Soliman (IBVS 1866). A clear preflare dip in the U band has been registered for the FS EQ Peg by Giampapa *et al*. (ApJ in press). A theoretical model for preflare dips as a result of a disturbance of a stellar photosphere due to an impulsive irradiation by a hard emission at the initial phase of the flare was discussed by Grinin (Byurakan Symp. 1979 p.23). Giampapa *et al* proposed alternative schemes: disappearance of filaments or broadening of absorption lines due to MHD perturbations. Cristaldi and Longhitano (AA Suppl 38.175) have found that within the range of errors the flare U-B and B-V colours remained constant during the 9 observed flares of 4 FSs.

Pettersen and Hsu (ApJ in press) have carried out multifilter polarimetric measurements of 19 FSs and spotted stars outside of flares and non linear polarization was detected. During a complex flare on AD Leo they could not detect any linear polarization even in the U band where the flare light contributed a significant part of the received flux.

Shakhovskaya (Izv. Krymsk. Astrofiz. Obs. 60.14) has analyzed statistically more than 1500 flares registered photoelectrically on 21 FSs; she has found that energetic spectra of flare activity can be represented by power functions with spectral indices within the range from 0.4 to 1.4 and absolutely brighter stars have systematically steeper spectra; rise times and absolute rates of flare luminosity increase are statistically independent on the flare luminosity at maximum, and on the total flare optical energy. A mean specific luminosity of flares of FSs in the solar vicinity is not less than $3x10^{27}$ erg $s^{-1}pc^{-3}$ in U and B. Mirzoyan (Byurakan Symp. 1979 p.45) has attempted to represent the observed light curves of flares as superpositions of several elementary light curves. Romeo (Mem SA It. 51. 659) has compared theoretical light curves deduced from the Gershberg's (thermal), Gurzadyan's (non-thermal) and Mullan's (radiative + conductive) models of flares and observed light curves. The result is that the thermal model reproduces better the slow flares while the non-thermal model better represents the faster flares, and including the conductive component does not reproduce either secondary maxima nor preflare features. Pazzani and Rodono (Ap Sp Sci 77.347) have carried out a detailed statistical analysis of the Catanian observations for FSs UV Cet, EQ Peg and YZ CMi and found that flares of these FSs are not randomly distributed in time.

Pettersen (AA 82.53) has determined effective temperatures, bolometric luminosities and radii for 36 solar neighbourhood FSs from multicolour photometry and found that these stars are situated on or close to the main sequence. Starikova (Sov. Astr. Lett. 5.353) has determined dynamical parallaxes, absolute magnitudes and masses for 19 FSs which are members of visual binary systems with known orbits and found that M4 FSs are fainter than non-variable M4 stars by $1\overset{m}{.}7$, and FS masses are lower by a factor of 0.65. Vogt and Fekel (ApJ 234.958) have redetermined the orbit, mass ratio and luminosity ratio in the BY Dra system; for the primary dMOe they found an unexpectedly large radius, more than 0.9 $R_\odot$, which supports the hypothesis that the BY Dra syndrome is a fading remnant of a previous T Tau activity.

Carrasco *et al.* (AA 86.217) have considered the angular momentum per unit mass for a number of the BY Dra-type stars and found that for spectral types later than KO this ratio exceeds by several orders of magnitude any possible extrapolation from intermediate masses.

Nelson *et al.* (MNRAS 187.405) have conducted a cooperative optical and radio survey of 15 FSs. Radio observations were made at 80 and 160 MHz. Optical observers detected 37 flares in 183^h of monitoring, while radio emission was detected on 162 occasions during 567^h of observation. During 110^h of common optical and radio monitoring, 21 optical and 19 radio events were independently detected; of these only 4 pairs appear to have been correlated. For the radio events circular polarization was detected on 8 occasions. Successful coordinated optical and microwave observations of FSs have been reported by Slee and Page (IAU Coll. 46.150) and then by Slee *et al.* (Nature 292.220; Proc. IAU Second Asian-Pacific Regional Meeting, Bandung, 1981, *in press*). For $97\overset{h}{.}2$ of the microwave monitoring of Proxima Cen, overlapping with $62\overset{h}{.}8$ of the optical patrol, 23 5 GHz events and 19 optical events were registered, 6 of them correlated. In the latter cases the brightness peaks occur simultaneously at 5 GHz and the U band, and observed durations of microwave and optical flares are similar. Lower limits of peak brightness temperatures are found to be about $5x10^7$ K for Proxima Cen and $(1-5)x10^9$K for AU Mic and AT Mic, which suggests a non-thermal, gyro-synchrotron nature or a coherent mechanism for this microwave emission. Gary and Lynsky (ApJ in press) have observed near-by late-type dwarfs with the VLA and detected the non-flare microwave emission at 6 cm from UV Cet; they believe that the most likely emission mechanism is gyroresonance emission: fluxes observed are consistent with emission in the 6th or lower harmonics with coronal magnetic fields of about 300 Gs or more covering a large fraction of the star. Whitehouse (in press) concluded that radio flare activity on FS YZ CMi has decreased since 1978, perhaps due to the star undergoing an activity cycle.

After some tentative results obtained with the HEAO-1 (Cash *et al.* ApJ 231. L137; Ayres *et al.* ApJ 232.L117), Haisch and Linsky (ApJ 236.L33) have registered X-ray fluxes of Proxima Cen with the Einstein Observatory. The quiescent soft X-ray emission outside flares is characterized by $L_x=1.5x10^{27}$ erg s^{-1}, $L_x/L_{bol}\sim 2x10^{-4}$ and a coronal temperature of about $3.5x10^6$ K. These observations are the first concrete evidence for a quiescent corona in an M dwarf outside of flares, and the authors showed that the measured coronal properties are consistent with the coronal loop model of Rosner-Tucker-Vaiana. Pettersen *et al.* (SAO Special Report 389.113) have reported similar X-ray flux from YZ CMi and found the X-ray luminosity of its corona to be about $3x10^{28}$ erg s^{-1}. Cash *et al.* (ApJ 239.L23) have found a stellar corona of the X-ray flux about $2x10^{28}$ erg s^{-1} for the flaring dM4e component in the 40 Eri system. Vaiana *et al.* (ApJ 244.163) have surveyed the detection of quiet coronae for 13 FSs with the Einstein Observatory.

Kahn *et al.* (ApJ 234.L107) have reported the detection of X-ray flares from FSs AT Mic and AD Leo with HEAO-1 in the range 0.15-18 keV. The spectrum obtained during the brighter AT Mic flare, the first X-ray spectrum of a stellar flare, is well matched by a thermal model with a T_e of about $3x10^7$ K and the iron K-alpha emission line. The X-ray luminosities derived are in the range $(1.3-16)x10^{30}$ erg s^{-1} while emission measures are $(1.1-14)x10^{53}$ cm^{-3}. The estimated L_x/L_{opt} ratios exceed unity.

Haisch *et al.* (ApJ 242.L99; 245.1009) have reported results of a coordinated program involving X-ray, UV, optical and radio observations of Proxima Cen on March 1979. They detected one major X-ray flare with $L_x(0.2-4\ keV)\sim 6x10^{27}$ erg s^{-1}, $T\sim 1.7x10^7$ K and $EM\sim 8x10^{50}$ cm^{-3} during the rise-time and $L_x\sim 7x10^{27}$ erg s^{-1}, $T\sim 1.2x10^7$ K and $EM\sim 12x10^{50}$ cm^{-3} during the decay phase, but no UV, optical, or radio emission corresponding to this X-ray event. This fact is interpreted in terms of an arch flare model in which the flare cools predominantly by X-ray radiation. The observed 20 min. exponential cooling time is consistent with $n_e\sim 10^{11}$ cm^{-3} during the decay phase and a flare of the total arch length of $3x10^{10}$ cm, comparable to the size of the star itself. The second Einstein-IUE cooperative program for this FS was carried out in August 1980, and during a strong X-ray flare enhancements of several UV lines were observed. During the coordinated X-ray, optical and radio observations of YZ CMi in October 1979 the detection of the first flare of a FS was made simultaneously in all three wavebands and this flare occured when a large starspot on the star was facing the Earth (Kahler et al ApJ in press). Johnson (ApJ 243.234) has found an X-ray flare on the FS V 1054 Oph and suggested such an event on the FS WX UMa.

Natanzon (AJ USSR 58.576) has shown that the first X-ray data on flares of FSs obey the Rosner-Tucker-Vaiana relation between flare temperature, pressure and size which is valid for solar flares; this supports the loop model for flares of FSs. Oks (Sov. Astr. Lett. 4.415 and in press) had developed the theory of Stark broadening of hydrogen lines in the plasma turbulence condition up to the level of a diagnostic method, applied it to flares on AD Leo, for which widths of several Balmer Lines had been measured simultaneously, and concluded that for these flares 5×10^{15} $cm^{-3} > n_e > 4\times10^{13}$ cm^{-3} and optical thicknesses in H-beta were in the range from 1 up to 30. Grinin (Izv. Krymsk. Astrofiz. Obs. 62.54) has shown that the appearance of the anomalous high inverse ratio ($I_{H\text{-}gamma}/I_{H\text{-}beta}$ in flare spectra may be considered as evidence of the large gradient of the physical conditions in combination with the radiative coupling in spectral lines between regions of high and low density. Katsova et al. (Sov Astr Lett 6.498; Astrofiz. 17.285) have applied to red dwarf flares the concept of the solar optical flare being the result of a dynamical response of the chromosphere to an accelerated electron beam heating. They have shown that the greater density of FS atmospheres as compared to the solar one, smaller scale height and greater power of stellar flares, mean that in practically all stellar flares one can expect an appearance of a short-lived continuum optical emission. Physical conditions within a region compressed by a downward propagating shock wave that is responsible for the continuum emission turn out to be $n_e \sim 10^{15}$ cm^{-3}, $T \sim 9000$ K and height from 1 to 12 km. Katsova (AJ USSR 58.350) has concluded that within the flare model considered, a ratio L_x/L_{opt} is determined not only by a mechanism of emission but by a magnetic field structure in the flare region as well. The Gurzadyan fast electron concept was debated in Astrofiz. (15.431; 16.375 and 383) as well as at the Byurakan Symp. 1979.

Grinin (Izv.Krymak. Astrofiz.Obs. 59.154) has analyzed physical conditions in active regions of FSs using observed relative intensities and equivalent widths of Balmer lines and colour excesses δ(U-B); he found for AD Leo $T_e \sim 10000-15000$ K, $n_e \sim 3\times10^{12}$ cm^{-3}, the total area of the emission regions $q \simeq 6-7\%$ of the stellar hemisphere, and for EQ Peg A $T_e \sim 10000$ K, $n_e \sim 3\times10^{12}$ cm^{-3} and $q \simeq 14\%$. To use the Balmer lines as chromospheric diagnostics, Cram and Mullan (ApJ 234.579) have computed a grid of chromospheric models by superposing prescribed temperature rises on published model for the M dwarf photosphere. According to their computation, as the amount of chromospheric material increases, these absorption lines first become deeper, then develop emission peaks on the outer edges of their wings, and finally, when the chromosphere is sufficiently massive, the Balmer lines become strong emission lines.

Vogt (ApJ in press) has proposed an elegant method for the unambiguous determination of starspot temperatures and areas. Using this method, a synoptic modelling of the last 27 years of the FS BY Dra photometry has been carried out and leads to the conclusion that a large spot initially formed in 1965 near 40° latitude and then drifted poleward, leaving a bright remnant in 1970 through 1976 as it dissolved; in 1977 a new spot formed down near the original 40° latitude. These results indicate a differential rotation or latitudinal shear on BY Dra of -9.7×10^{-9} rad s^{-1} $degree^{-1}$, in surprising agreement with the solar value of -1.4×10^{-8}.

Hartmann and Rosner (ApJ 230.802) have examined the implications for convection in the late type stars arising from the observations by BY Dra type variability. The possibility that the total luminosity of such a star is not constant is emphasized, and an alternative to standard spot models is explored in which the missing flux from the dark spot is temporally redistributed. The time scales of the long period variability of these stars appear to require secular changes in convective energy transport.

Vogt (ApJ 240.567) has carried out magnetometric observations with a multichannel photoelectric Zeeman analyzer for 7 normal, 5 spotted, and 7 FSs, but neither absorption lines, nor the H-alpha emission line gave evidence for the existence of a magnetic field $\gtrsim$100 Gs. This estimate of a general magnetic field means that local and transverse magnetic fields that are stronger than 1.2 kGs and cover the whole star are unlikely to exist, but permits magnetic fields within dark spots up to 10-15 kGs. Brown and Landstreet (ApJ 246.899) have accurately measured the mean longitudinal component of the photospheric magnetic field by a new multi-line Zeeman polarimetric technique and found for the FS EQ Vir B_e +=-10±110 Gs and FS Gliese 803 B_e=-4±160 Gs. The detailed theoretical consideration of the detectability of starspot magnetic fields has been carried out by Mullan (ApJ 231.152).

Mullan (ApJ 234.588) and Dolginov (Sov. Astr. Lett. 6.241) have considered FSs as a sourse of the galactic cosmic rays. Karpen and Worden (AA 71.92) have concluded that less than 10% of the Li^7 observed in the interstellar medium may be due to flares of the UV Cet-type stars. Shlosman et al. (AA 73.358) have demonstrated that FSs can be an important source of enriching the interstellar medium with He^3.

Results of spectral studies of FSs are given in the Commission 29 report.

9. CATACLYSMIC VARIABLES

(F.A. Cordova and K.O. Mason)

Introduction. The term cataclysmic variable (CV) was first used (1) to encompass the classical novae which had single, dramatic eruptions, and the dwarf novae ("U Gem" or "Z Cam" Stars) which had frequent, but far less spectacular outbursts. More recently, the term has been applied to any close binary system (with an orbital period, usually, of less than a day) in which a low-mass red star transfers matter via an accretion disk onto a white dwarf. Cataclysmic variables exhibit some or all of the following characteristics: a flat or blue optical spectral distribution, broad emission or absorption lines of hydrogen and helium, rapid temporal variability ("flickering"), large aperiodic changes in optical brightness ("outbursts"/"high states"), and low luminosity X-ray emission.

Study of the CVs yields information on the evolution of low-mass binaries, the viscosity and radiative processes associated with disk accretion, and the properties of matter in high gravitational fields. About 200 CVs are bright enough that amateur observers with small telescopes can monitor their changes in visual magnitude. Thus for many stars there exists a long historical record of their optical light; this has proven extremely valuable in guiding current observations and in assisting in the interpretation of the optical "cataclysms" of the various types of CV. For example, the visual light curves of the classical nova eruptions have been instrumental in the interpretation of the nova outburst as a nuclear burning event on the surface of the compact star (see Gallagher and Starrfield (2) for a comparison of the theory with the observations). In contrast, the light curves of the dwarf nova eruptions support the idea that these outbursts are caused by a brightening of the disk (3). It has further been determined (4,5) that there is a relationship between the orbital period of a dwarf nova and the characteristc decay time of its outburst; such a relationship is expected in a model where the decay reflects the time it takes to empty a disk whose size is limited by the Roche lobe of the accreting star.

In the past two years there has been a surge of interest in CVs, mainly because (a) high-energy observations from satellites have allowed the bulk of the radiation from these objects to be observed for the first time, (b) new detector developments in the optical and infrared, coupled with the use of larger telescopes, have led to detection of faint companion stars, refinement of the orbital parameters, and better distance estimates, and (c) the discovery of several CVs in which the compact star has a magnetic field high enough to modify the standard disk accretion picture has yielded the opportunity to study the physics of accretion in the presence of relatively strong magnetic fields. Reviews on the theory and observations of CVs up to a few years ago can be found in Bath (3), Warner (6), Robinson (7), and Bath (8). A guide to more recent literature is given by Cordova and Mason (9).

In the limited space available for this review, and to reflect the most recent trend of investigation, we will concentrate on the continuum distribution of CVs from X-ray to infrared wavelengths. In the second section we briefly review theoretical models for accretion in the presence of strong gravitational and magnetic fields, and examine how variations in the mass accretion rate, or magnetic or gravitational field strength, affect the overall spectral distribution. In the third section we compare the observed energy distributions with these models.

For recent results on subjects related to other aspects of CVs, we cite additional references: (a) measurements of orbital parameters (see Table 1 of (9) for a list of 55 CVs for which orbital periods have been measured, and references to recent studies of individual systems); (b) the rapid oscillations seen in many CVs (see (10) for a review of the optical oscillations; (11) for a review of the X-ray oscillations; and Table 4 in (9) for a list of all the pulsations periods detected in CVs up to mid-1981); (c) details of the X-ray observations (see (12), and Table 4 in (9) for a list of more than 70 CVs and their X-ray fluxes); (d) the extensive literature on the magnetic variables or AM Her stars, now numbering at least six (9,13,14); (e) the evolution of cataclysmic binaries (15,16,17); and analyses of the optical and UV emission line spectrum of CVs (18,19,10,21).

The Standard Picture. A. The Steady-State Disk Model. The high angular momentum of the matter streaming off the low-mass companion may cause the formation of a differentially rotating disk around the accreting star. If the accretion rate is constant and the disk optically thick, each elemental annulus of the disk will emit a spectrum that can be approximated by a blackbody whose temperature is a function of radius. The temperature in the disk is then given by (22,23)

$$T(R)=T_*(R/R_1)^{-3/4}\ (1-(R_1/R)^{1/2})^{1/4}$$

where

$$T_*=7.3x10^4(m/10^{17}g\ s^{-1})^{1/4}\ (M_1/M_\odot)^{1/4}(R_1/10^9\ cm)^{-3/4}K. \qquad (1)$$

R_1 is the inner radius of the disk, m is the mass accretion rate and M_1 is the mass of the accreting star. Here the units chosen are appropriate to a white dwarf. For a neutron star $R_1 \sim 10^6$ cm; thus $T_*=1.3x10^7$K, if all other parameters are the same. The maximum temperature in the disk, $T_{max}=0.488\ T_*$, occurs at a radius 49/36 R_1. The minimum temperature, T_{out}, occurs at the outer edge of the disk, R_{out}. The total luminosity of the disk is

$$L_d=6.7x10^{33}\ (m/10^{17}g\ s^{-1})(M_1/M_\odot)(R_1/19^9\ cm)^{-1}\ erg\ s^{-1}. \qquad (2)$$

In a white dwarf binary, the bulk of the luminosity will be radiated at UV wavelengths, but in a neutron star binary most of the disk radiation will be emitted in the X-ray band because of the much higher effective temperature of the disk. Note that L_d is of order 10^{37} erg s^{-1} in the latter case.

For frequencies, ν, such that $kT_{out} << h\nu << kT_{max}$, Lynden-Bell (24) has shown that the spectrum of a steady-state disk will have the form $F\nu \propto \nu^{1/3}$ (where $F\nu \propto \nu^\alpha$ implies $F_\lambda \propto \lambda^{-(2+\alpha)}$. When $H\nu < kT_{out}$, the disk spectrum will approach a Rayleigh-Jeans form with $F\nu \propto \nu^2$, while at frequencies such that $h\nu \sim kT_{max}$, the spectrum decays exponentially. By fitting such a disk model to the data, the mass accretion rate, the size of the disk, and conditions at the outer disk edge (temperature and opacity) can be estimated (23,25).

The steady disk model predicts that up to one-half of the accretion luminosity will be emitted at the boundary layer where the material orbiting at Keplerian velocity must lose energy in order to settle onto the (more slowly rotating) accreting star. If the emitting region is optically thick, this radiation will be thermalized, resulting in a large blackbody flux (26). For a white dwarf this component will peak in the extreme ultraviolet (EUV), with possibly some contribution to the very soft X-ray band (0.1-0.5keV). If the emitting region is optically thin (i.e. for lower accretion rates), hard X-ray emission (with a temperature as high as $2x10^8$ K for an accreting degenerate dwarf) may be produced by shock or turbulent heating (27,28). Thus, for a disk-accreting white dwarf, $L_x/(L_{uv}+L_{opt}) \lesssim 1$, where L_x, L_{uv}, and L_{opt} are the X-ray, ultraviolet and visual luminosities, respectively. In contrast, for a disk-accreting neutron star, $L_x/(L_{UV}+L_{opt}) >> 1$ because of the much deeper potential well of this compact star.

B. The Magnetic Accretion Model. If the white dwarf has a magnetic field strong enough to channel the accreting matter, the spectral distribution will be substantially altered from the steady disk picture (29,30,21). In this case the accretion flow is pseudo-radial and a strong shock is formed in the accretion column at a distance above the stellar surface that depends on the velocity of the flow and the cooling rate of the falling gas. In the hot, post-shock emission region the electrons will be cooled through both bremsstrahlung and cyclotron interactions. About one-half of the flux in this region is emitted outwards, either as bremsstrahlung emitted at hard X-ray wavelengths, or blackbody-limited cyclotron radiation at longer wavelengths (i.e., in the UV, optical or infrared, depending on the value of the magnetic field strength, B, the mass accretion rate, m, and the mass of the accreting star, M). The competition between bremsstrahlung and cyclotron radiation is determined by m and B. At high accretion rates or low magnetic field strength, bremsstrahlung dominates, but at low accretion rates or high field strength, the balance shifts toward cyclotron cooling. The other half of the radiation emitted in the post-shock region is absorbed by the surface of the degenerate star, producing a blackbody component which has an effective temperature around a few $x10^5$K. Conduction of energy by electrons may also heat the stellar surface (32). For large enough m and/or B the blackbody component may be observable at soft X-ray wavelengths. Additional contributions to the UV and visible may result from emission from falling material (above the shock) that is heated by Compton scattering or cyclotron absorption (33,34).

The Observations. A. Dwarf Novae in Quiescence. Recent observations at high energies suggest that the dwarf novae are accreting at very low rates between outbursts. Therefore, sources of luminosity other than the disk, such as the component stars or the mass transfer region on the outer disk, may dominate the UV + optical +IR continuum. In two dwarf novae, SS Cyg and U Gem, a λ^{-4} component is detected in the far UV (35); this radiation may be from a very hot white dwarf whose EUV emission greatly exceeds the combined UV and optical emission, or from a very small, hot disk. In any case, it is difficult to estimate the luminosity of this component from the low-energy tail of the spectrum alone. In three other dwarf novae (AH Her, YZ Cnc, and SU UMa) the far UV distribution does not differ appreciably from the $\lambda^{-2.33}$ slope of a steady disk, but the distribution longward of 2200 A is flatter (i.e. falls less steeply with wavelength) than a steady disk spectrum (36). This may be due to the contribution of the "bright spot" where the mass stream impact the outer disk (e.g. in (9) a 10,000 K blackbody is fit to a phase-dependent component associated with the bright spot of U Gem). EX Hya is, to date, the only dwarf nova inquiescence which seems to fit the steady disk model from 1200 A to 2.2μ (23,37) (and this star may be a rather exotic "dwarf nova"; see later discussion). Most dwarf novae in quiescence do not lie in the steady disk region of the U-B, B-V (colour/colour) diagram (38).

"Hard" X-ray emission ($kT_{eff}>2$ keV) has been detected from 70% of the more than 70 CVs observed at high energies (9). It is thought that this emission comes from the inner region of the disk because of its high temperature ($\sim$10 keV (49)) and because of the observation of a hard X-ray eclipse coincident with the optical eclipse of HT Cas (12). The ratio of hard X-ray flux, f_{hx}, to the visual flux, f_v (5000-6000 A), is of order unity for the dwarf novae in quiescence (39,12). This is the highest ratio exhibited by any class of nonmagnetic CV. The hard X-ray luminosity in some of these systems (e.g. EX Hya, SS Cyg, HT Cas) is comparable to the combined UV+ optical disk luminosity (23,39,12,36). This implies, according to the disk model discussed in Section IIa, that the boundary layer emission is optically thin, and hence the accretion rate is low ($M<10^{16}$ g s^{-1}). (It is clearly important, however, to measure the EUV luminosity: if a flux is detected in excess of the accretion energy liberated in the disk (e.g. 35) an additional source of energy must be sought.)

In the only cases where the X-ray statistics have been good enough to produce high quality spectra (SS Cyg and EX Hya), two hard X-ray components are detected: an optically thin thermal bremsstrahlung component with $kT\sim10$ keV, and a lower-luminosity component with $kT\sim0.6$ keV (40). In SS Cyg the higher temperature emission is variable in both luminosity and spectral shape as a function of outburst state, but the lower temperature component does not appear to change. For EX Hya, extensive X-ray observations reveal that the lower temperature component is strongly modulated with a period of 67 min. (41); this is the same period discovered earlier in the optical light of EX Hya, and corresponds to ∿2/3 the orbital period of 98 minutes (42). The agreement in period between the X-ray and optical modulations suggests that they both have the same origin. Mechanisms proposed for the variation include a mass-transfer instability, or the effects of the rotation of a weakly magnetic central star (42,43,44,45).

B. Dwarf Novae in Eruption. During the outburst rise and decline the spectrum of a dwarf nova undergoes dramatic changes. At the beginning of the outburst the optical continuum reddens, suggesting that there is an influx of material through the outer parts of the disk (38); changes in the shapes of the eclipse profiles of highly inclined systems (46,47) indicate that the disk expands. The hard X-ray bremsstrahlung component of SS Cyg becomes more intense by a factor of three, but then drops after the initial stages of the outburst to a level of ∿1/4 the quiescent X-ray emission, whereupon it increases again above the quiescent level during the outburst decline. The relationship between this component and the enhanced soft X-ray component which appears during the maximum of the eruption has not been established (9). During the eruption the UV+optical distribution closely emulates that of the steady disk model for many systems (23,9,36).

The average f_{hx}/f_V for erupting dwarf novae is $\lesssim 0.06$, indicating that the hard X-ray component suffers relatively small changes compared to the optical and UV light (12). However, in both SS Cyg and U Gem a very bright soft X-ray component is observed during outbursts (50,51) (for U Gem, this emission is at least 100 times the level of the quiescent state emission in the 0.1-0.5 keV band). This component has an effective blackbody temperature $kT \lesssim 50$ eV; thus much of the emission is presumably radiated in the EUV band.

C. The Novae. The classical novae, recurrent novae and nova-like objects have f_{hx}/f_V ratios that are on average less than those of dwarf novae in quiescence (12). The "fast" novae (i.e. those whose visual brightness decays rapidly after an eruption) appear to be more luminous hard X-ray sources than the slow novae (52). The much fainter absolute visual magnitudes of the fast novae after their return to quiescence shows that these stars probably have lower mass accretion rates during quiescence than the slow novae. Thus, as in the case of the dwarf novae, more copious hard X-ray emission seems to be associated with a lower accretion rate.

The structure of the disk may differ for the classical novae, nova-like objects and dwarf novae. In the latter, hard X-rays are observed even when the inclination angle of the plane of the disk to the observer is high (e.g. Z Cha, HT Cas, U Gem, EX Hya, WZ Sge, EM Cyg), but this is not true for the other systems (e.g. the slow novae DQ Her and T Aur and the novalike disk star UX UMa) (12). A thicker disk with perhaps more curvature could shield the X-ray emitting inner portion of the disk of a classical nova or novalike object.

The hard X-ray luminosity for any CV thus far examined does not exceed a few $\times 10^{32}$ erg s^{-1}; for the novae this is 10^2-10^3 times lower than the observed ultraviolet luminosity (39,12,52,53,54). Therefore, we might expect the balance of the boundary layer emission to be emitted as optically thick radiation in the EUV, which would imply a higher mass accretion rate (Section IIa). The slope of the UV continuum for ex-novae is flatter than that for a steady disk in the cases studied (V603 Aql (54), HR Del (55,54), RR Pic (54), DQ Her (21), GK Per (56)). In agreement, the optical colours of the novae are not situated in the steady-state, optically thick disk region of the colour-colour diagram (38).

For the recurrent novae there exists published UV data only on T CrB and U Sco. For the former, the continuum was too weak to be measured successfully (54). Data on the latter were taken during the decay from an outburst when large changes in the continuum and line emission were taking place (57). The novalike "disk" stars (TT Ari (58,54), V3885 Sgr (59), RW Sex (59), 2A0526-328 (60)) are presently being studied in some detail. Their optical and UV spectra are consistent with large steady disks (38,60). Their UV+optical continuua have also been roughly fit (58, 59; see also 55) to model atmospheres (61) of 15,000-18,000 K; as illustrated by the present authors, however, this model distribution may be fortuitous because it is also similar to the spectrum of a large accretion disk with a high effective temperature plus an optical excess (such as might be expected from a bright spot on the outer disk) (62). In table 3 of (9) the accretion disk parameters (T_*, T_{out}, R_{out}/R_1, m) derived for some of these sources are culled from the recent literature.

D. *Magnetic Variables.* *The continuous energy distribution* of AM Her in its bright state can be approximately fit with a λ^{-1} power law over the UV and optical region (34). From UV spectrophotometry around the 3.1 hour binary orbit Raymond et al. (63) deduce the presence of an additional component with a slope of λ^{-4} that dominates in the far UV and is modulated with the binary period. The far UV continuum of 2A0311-227, another magnetic variable, is also consistent with a λ^{-4} distribution (60). The low-energy spectrum of AM Her reveals an excess in the near infrared (1-2 μ) which is associated with the red companion (64,65), and a variable excess at 10 μ (66). Fro 2A0311-227 an excess in the IR is also observed, but the spectrum of the companion is not detected (65).

Some of the best data on the X-ray spectrum of a cataclysmic variable has been obtained on AM Her which has been measured from 0.1 to 150 keV (67). A single component bremsstrahlung distribution does not adequately fit the hard X-ray (>2 keV) data, but a model in which part of the X-ray flux is refelected back from the surface of the white dwarf with a higher effective absorption than the radiation seen directly yields an acceptable spectral fit with a temperature of ∿30 keV. Similar departures from a simple optically thin spectrum could be produced by Compton scattering (68) in the accretion column above the X-ray source. The flux in soft X-rays (f_{sx}:0.1-0.5 keV) is comparable in strength to the total hard X-ray flux (f_{hx}:>2 keV), i.e. $f_{sx} \sim f_{hx} \sim 10^{33}$ erg s^{-1} for d=100 pc (69,70,67). The soft X-ray spectrum, however, is but the high-energy tail of a blackbody peaking in the EUV (69). Since the temperature of this component is not well defined (16<kT<50 eV0), the total flux is uncertain by two orders of magnitude ($L_{EUV} \simeq 10^{33}-10^{35}$ erg s^{-1}). If the ultraviolet blackbody and the soft X-ray blackbody are part of the same spectrum, $kT_{BB} \sim 25-30$ eV and the luminosity implied is $\sim 10^{35}$ erg s^{-1} (63). This is 100 times greater than the observed luminosity in the UV + optical + IR band ($\sim 10^{33}$ erg s^{-1}) (71) and the hard X-ray band.

Zeeman split Balmer absorption lines observed in the spectrum of AM Her during a faint state yields a value of 2×10^7 G for the strength of the magnetic field at the poles of the compact star (72,73). For this field strength and a mass for the white dwarf of 0.6-0.9 $M_\odot$ (64), the magnetic accretion model (31) (section IIB) is in good agreement with the observed spectral distribution if $L_{EUV}<10^{34}$ erg s^{-1} (69, 72). If the EUV luminosity is larger than this, an additional radiation source, possibly nuclear burning beneath the accretion shock, would have to be invoked (35,67,71).

E. Low-Mass Neutron Star Binaries: A Comparison. About half the approximately 40 galactic X-ray sources listed as optically identified in the catalog of Bradt et al. (74) are associated with faint (M_b=16-20) blue stars. Some of these objects are X-ray bursters or transient (75). Recent optical observations have revealed modulation periods for some of these systems on a timescale of a few hours. These periods, if interpreted as orbital motion, are similar to the orbital periods of CVs and suggest the existence of a low-mass system containing a compact star. The large ratio of X-ray to optical flux (i.e. 10^2-10^4) suggests that the accreting object has a deeper potential well than that of a white dwarf (Section IIA). The systems which are confirmed or suspected low-mass binaries of this kind are: 2S1822-371 (76,77), 4U2129+47 (78,79), 4U1626-67 (80), Aql X-1 (81), Cen X-4 (82, 83), and Her X-1 (84). Of these, only Her X-1 and 2S1822-371 are brighter than m_v=16 and thus they are the best studied at all wavelengths. For the former, the relatively flat UV + optical spectral distribution (λ^{-1}) is attributed to X-ray heating of the secondary, and possibly the disk (85,86). The optical and UV light curves of 2S1822-371 (87), which has a much fainter companion than Her X-1 (76), and the broad, shallow absorption lines in the optical spectrum (88), are consistent with the presence of a disk (87). The continuum distribution from the UV to the near IR can be fit with a single blackbody of temperature 2.7×10^4 K, or an optically thick disk model with parameters $T_*=1.2x10^5$ K and $R_{out}/R_{in}\sim 30$ (87). However, the ratio of the observed X-ray flux (0.5-50 keV) to the observed UV + optical flux is $\sim$70 (77,87), although a correction for interstellar reddening reduces this ratio by about one half (87). The emission of the disk in this system is thus likely to be severely modified by the effects of X-ray heating (89).

F. Conclusions. Detailed modelling of the continuous spectra of CVs is hampered at present by the lack of, among other things, (1) simultaneous spectroscopy and high time resolution photometry in all spectral bands, (2) EUV observations, (3) hard X-ray observations with the sensitivity limit of the soft (<4 keV) X-ray observations, and (4) theoretical understanding of the nature and origin of the line emission region(s). In spite of this, the measurements to data are sufficient to show that, in general, the standard disk and magnetic accretion models adequately represent much of the data, particularly in the regimes of high mass accretion rates and/or high magnetic field strengths ($B\gtrsim 10^7$ G). The cases where the standard picture fails emphasize our present ignorance concerning the way in which the energy distribution will be affected by accretion at a very low rate, a small but nonnegligible magnetic field which disrupts the disk at a few white dwarf radii, and localized nuclear burning on the surface of the compact star.

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10. VARIABLE STARS IN GALACTIC GLOBULAR CLUSTERS

(H.B. Sawyer Hogg)

Introduction. The discovery of new variables in globular clusters, determination or refinement of periods, and period changes proceed steadily. The problem of cluster membership is being solved slowly for individual variables, with special interest on the presence of binaries in globular clusters. Many aspects of variable stars in globular clusters were discussed at IAU Symposium 85 (Star Clusters, J. Hesser, Ed. 1980, Dordrecht Reidel) and also at IAU Colloquium 68, Schenectady, N.Y., October 1981, A.G. Davis Philip Chairman. An invaluable compendium "A Catalogue of Radial Velocities in Galactic Globular Clusters" by R. Webbink (1981 *ApJ Suppl 45.259) gives velocities for 79 variables in 25 clusters.*

Because of space limitation, this report cannot cite all references, but will show trends. References are indicated by author's name and year and may be identified in Astronomy and Astrophysics Abstracts. We also note that papers on colour magnitude diagrams of individual clusters sometimes contain useful comments on variables.

New Variables and New Periods. The cluster with the largest number of newly discovered variables is NGC 6584 with 47 reported by Millis and M.H. Liller (1980) and periods determined for 45 RR Lyrae type from 21 plates, 1976-7.

Messier 3 continues as the cluster with the largest number of variables known.

Kadla and Gerashchenko (1980) consider 213 RR Lyrae's known in the cluster and forecast 251-260 as the total. About 10 other variables are known. Meinunger (1980, 1981) reports 6 new variables, with studies of V95, V154, vZ1397 and V13. In his search for small amplitude red variables White reported at IAU Coll. 68 the discovery of 8 such stars in M3, with periods ranging from 58 to 244 days for 6 of them.

In M13 White has 3 similar stars, and Russeva and Russev (1980) report 3 new red variables with light curves for five such stars, while Kadla, Gerashchenko and Yablokova (1980) have 4 new variables with RR Lyrae characteristics. In M4 a group from the Purple Mountain and Beijung Observatories (1979) note some unusual small amplitude variables beneath the red giant branch. In M5 Buonanno, Corsi and Fusi Pecci (1981) have 2 possible variables. In M15 Filippenko and Simon (1981) for 52 variables derive current periods, accurate epochs of maxima and light curves from a homogeneous group of 208 plates with the 30-cm Lick refractor, 1976-8.

Other discoveries are: near NGC 6101, M. Liller, 15 new variables, 11 possible RR Lyrae cluster members; NGC 6284, C. Clement, Sawyer Hogg and Wells (1980), 5 new variables and periods for 13 of 15 in and around the cluster, 9 RR Lyrae type, 2 Pop II Cepheids, 2 Mira stars. This cluster has the highest metallicity of any containing Pop II Cepheids. Around NGC 6304, Hartwick, Barlow and Hesser (1981) 42 new field variables; NGC 6352, Hesser (1980) a new red variable; NGC 6934, Sawyer Hogg and A. Wehlau (1980) periods and light curves for 50 RR Lyrae stars, 1911-64. The period frequency in this cluster is remarkably like that in M3. The 51st variable is a red irregular. Palomar 12, Harris and Canterna (1980) suggest that the 3 very faint announced variables may actually be non-stellar objects.

Observed Period Changes. In RR Lyrae stars. In M15 Smith and Sandage (1981) in a study of 38 variables find five times as many period increases as decreases for recognized change. The mean rate of period changes is larger than can be explained by stellar evolution and the cause remains unknown. In NGC 6934 Stagg and A. Wehlau, with observations 1911-78, find 31 constant periods, 6 increasing and 11 decreasing, 2 irregular, with median rate of increasing period +0.03 of decreasing -0.08, days per million years, and give a summary of observed period changes in 11 globular clusters.

In Pop II Cepheids. The 20 BL Her type stars in globular clusters, periods 1.13-7.80 days have been studied by A. Wehlau and Bohlender, (IAU Coll. 68, 1981). No decreasing periods were found, with 8 increasing. This agrees with the theory that these stars are evolving away from the horizontal branch toward the asymptotic giant branch. In M3 Hopp (1980) finds the period of the Cepheid V154 has shortened by 0.0012 day to 15.2842 since elements were determined by H. Arp in 1955.

Double mode and amplitude modulation RR Lyrae stars have been recognized by Goranskij (1980) M3, V79 and M5, V14, (1981) M3, V68 and Andrews, (1980) a variable in NGC 4590.

Binaries. The problems of close binaries in globular clusters have been carefully summarized by Trimble (1980). Following the suggestion of Alexander and Budding (1979) and Webbink (1980) V101 in M5 has been proved to be a dwarf nova by Margon, Downes and Gunn (1981 ApJ 247.L89). This star becomes the strongest candidate for a close binary in a globular cluster. Long regarded as a U Gem star, at a typical quiescent magnitude of V20, the variable shows strong Balmer and He I emission with the Hale 5m reflector. Because of its faint magnitude, (Oosterhoff, its discoverer, reported it at 17.5 at maximum) the star has been little studied since it is below the magnitude limit of most M5 plates, including those of the writer.

A search in 6 globular clusters by M. Liller (1980) for main sequence eclipsing binaries yielded none, but in 47 Tuc Belserene and W. Liller (1980. priv. comm.) find a possible one, out of 40,000 main sequence stars examined. In NGC 6838 results showing V3 to be a non-member are given by M.H. Liller and Tokarz (1981).

The hunt by Niss, Jorgensen and Laustsen (1977) for eclipsing binaries in Omega Centauri has not yet led to the discovery of any which are cluster members. Variable NJL 5 had earlier been shown by M. Liller (1977) to be an eclipsing star with P=1.3761662 days (confirmed by E. Geyer, priv. comm. 1979) but is not considered a cluster member. The search has produced interesting results as shown in the next section.

Unusual Variables. In Omega Centauri two dwarf Cepheids have been announced as an outcome of this hunt. For NJL 220, 12' from the cluster center, V=16.7, Niss (1981) has determined a very short period, 0.0463 days, for an amplitude of 0.5 mag. Only GD 428 has a shorter period for this class, $0\overset{d}{.}038$. A second dwarf Cepheid, NJL 79 was reported by H. Jorgensen at IAU Coll. 68. Virtually the same magnitude, V=16.79, only 6' from the center, the star has a period of $0\overset{d}{.}063$. Radial velocity measurements are needed to confirm cluster membership.

In M15 the UV bright star K 1082 announced as variable by Chu Y.-H. (1977) has been studied by M. Liller and Schommer (1980) who find no evidence for the 2-hour variation, but variations over a longer period are possible. Spectra by Hesser and Nemec (1979) confirm cluster membership of the star. The star K 754 in this cluster is announced as a second possible hot Cepheid by Chu Y.-H. et al. (1981).

Field Variables. A new criterion has been added to distinguish field stars from cluster members, - metal abundance. On this basis Keith and Butler (1980) in 47 Tuc conclude that V9 is a probable member while V12 and HV809 are non-members. In identification of cluster members by proper motion, Cudworth (1980) has continued his series which now includes M3, M5, M13, M15, and M92. On the basis of C-M diagrams M. Liller (1980) rules out cluster membership of 2 RR Lyrae stars in NGC 6535, but accepts it for 3 such stars in NGC 6235. From radial velocities, in Omega Cen M. Liller and Tokarz (1981) show that V56 and V168 are non-members. From a statistical analysis Hoffleit (1979) concludes that many of the Mira stars around globular clusters are probably non-members except in the case of a high latitude cluster like 47 Tuc.

X-Ray Burst Sources. These have been conveniently discussed by Lewin and Joss (1981 Sp. Sci. Rev. 28.30). Of 10 globular clusters which are in the error boxes of X-ray sources, 6 are burst sources (including the Rapid Burster in Liller 1) and 2 may be. In the Rapid Burster, Basinska et al. (1980) have studied long-type X-ray bursts, and Apparao and Chitre (1980) infrared bursts. Burst sources in the cluster Terzan 1 and Terzan 5 have been observed by Makishama et al. (1980), and in Terzan 2 by Grindlay et al. (1980). In M15 (not a burst source) the 17-day Cepheid V86 has been investigated by Goranskij (1979) and Fusi Pecci, Rosino and Voli (1980) as perhaps the X-ray source, but is considered unlikely to be such.

Theories and Correlations. For Type II Cepheids in the period range 1-10 days models have been constructed by Carson, Stothers and Vermury (1981). The features of the light and velocity curves agree in detail with those observed in 17 such variables in globular clusters. Masses average 0.59 $M_\odot$ and the He abundance, Y=0.31, agrees with spectroscopic and evolutionary data for these stars. From the RR Lyrae stars in M3 and M15 Sandage, Katem and Sandage conclude that at every temperature period shifts exist between variables in one cluster relative to another in a different Oosterhoff group. A. Sandage (1981) gives evidence for a period-luminosity-amplitude relation for RR Lyrae stars, then using data for six clusters shows the same shift in the period temperature as in the period-amplitude relations. A P-L-A relation is derived for equal metallicity abRR Lyr variables. E. Kemper (1980) confirms for field variables Sandage's findings on period differences at a given temperature.

In Omega Cen Caputo (1981) finds that the observational properties of the RR Lyrae variables belong to those of an Oosterhoff Group I while the value of the periods of the ab-type RR Lyrae's suggest Group II. The helium content derived from variables is Y=0.30. A. Cox and S. Hodson concluded at IAU Coll. 68 that the two Oosterhoff groups are not as discrete as originally believed, and probably reflect the two different horizontal branch and blueward evolution luminosities. Hodson and Cox also studied masses and pulsations of BL Her variables, showing a Hertzsprung progression of bumps on their light curves, and deriving a mass of 0.55 $M_\odot$. From infrared photometry in 47 Tuc, Frogel, Persson and Cohen (1981) consider that the four long period variables must be AGB stars, with luminosities, temperatures and periods in qualitative agreement with model prediction.

Numerous papers on theoretical considerations for Pop II variables by Breger, Castellani, Stothers and other investigators are pertinent to variables in globular clusters.

11. ARCHIVES OF UNPUBLISHED OBSERVATIONS

(Michel Breger)

The Archives of Unpublished Photoelectric Observations of Variable Stars was created to provide permanent archives in different parts of the world. The Archives can replace lengthy and expensive tables in scientific publications by a single reference to the archival file number. Furthermore, many observations are never used for scientific publications, and the Archives could make such observations available to other astronomers at a time when they might become very important.

Since the previous report to the IAU, the number of assigned file numbers has grown from 59 to 91. This represents a welcome acceleration of growth. A temporary delay in the retrieval of previous files from the Royal Astronomical Society in Great Britain has been rectified.

The Strasbourg Data Center (Centre de Données Stellaires) had kindly agreed to join the Variable Star Archives. In addition to providing an additional depository the center will provide computerization and free retrieval. Discussions are presently taking place concerning the handling of extremely lengthy files, and optional submission of data files by computer tape. A full report and proposal concerning this new aspect of the Variable Star Archives will be presented at the 1982 IAU General Assembly.

The _Publications of the Astronomical Society of the Pacific_ has kindly agreed to publish, on a regular basis, the summaries of recent files. Two detailed reports can be found in the _PASP_ 91.408 (1979), and _PASP_ 93.528 (1981). Other summaries and announcements can be found in the _Information Bulletin on Variable Stars_.

At present, astromoners who wish to _obtain_ unpublished photoelectric measurements on variable stars may do so by requesting whole files (_not_ partial files) from _either_

Mrs. E. Lake, Librarian
Royal Astronomical Society
Burlington House
London, W1V ONL, Great Britain

_or_

Dr. E. Makarenko
Odessa Astronomical Observatory
Shevchenko Park
Odessa 270014 U.S.S.R.

There is no charge for short files. Astronomers who wish to _submit_ unpublished photoelectric observations of variable stars to the Archives, should submit _three_ copies (note change) as well as a brief descriptive cover sheet to the Coordinator (address listed below). Alternatively, one of the three copies should be sent directly to Dr. Makarenko (USSR). The Coordinator will assign file numbers and forward the observations to London and Strasbourg (and Odessa, if necessary). New files must be printed or handwritten in _black ink_. The printed part should be no larger than 8.5 by 11 inches (21.6 by 28 cm). If a new file number is required for scientific publications (in place of extensive tables of measurements), the file number can be assigned by the Coordinator before receipt of the actual measurements. The address is:

Dr. M. Breger
Department of Astronomy
University of Texas
Austin, TX 78712 U.S.A.

The new acquisitions are files:

60. Nova Cyg 1978 by W. Blitzstein, D.H. Bradstreet, B.J. Hrivnak, R.H. Koch, and A.P. Galatola.
61. Multicolor Observations of AW UMa by E.J. Woodward, R.H. Koch, and R.P. Eisenhardt.

62. UBV photometry of U Cephei by N.R. Markworth.
63. Observations of Three Southern δ Scuti Stars: AI Scl, WZ Scl, and XX Scl by D.L. Dupuy. 64.
64. UBV Photometry of the eclipsing binaries Z Her, RS Vul, AR Lac, and AW Peg by Th. Wesselink.
65. Unfiltered Photometry of V523 Cas by D.H. Bradstreet.
66. BV Photometry of RW COM by M. Hoffman.
67. Intermediate-band Photoelectric Observations of U Cephei by E.C. Olson.
68. Intermediate-band Photoelectric Measurements of S Cancri by E.C. Olson.
69. UBV Magnitudes of AL Vel by F.B. Wood.
70. V757 Centauri by M.A. Cerruti.
71. HR 7308 by A. Greenberg.
72. Differential B and V Photometry of HD 132209 by D.W. Kurtz.
73. Differential B and V Photometry of HD 101065 by D.W. Kurtz.
74. Differential Photometry of 28 Cygni, and HR 7807 by G.G. Spear, J. Mills, and S.A. Snedden.
75. UVBY Observations of Peculiar A Stars by P. Renson and J. Manfroid.
76. B and V Observations of the Delta-Scuti Variable BD+28°1494 by P. Broglia.
77. Red Spectrophotometry of VW Cep in 1976 by J.A. Eaton.
78. VRI Observations of Five W UMA-type Binaries for 1976 by J.A. Eaton.
79. AW Uma: Photoelectric Observations by B.J. Hrivnak.
80. XY Leo: Photoelectric Observations by B.J. Hrivnak.
81. Ultraviolet Spectrophotometry of Close Binary Systems: CV Velorum, RS Vulpeculae and DH Cephei by C. Wu and J.A. Eaton.
82. Individual Observations of AG Phe by M.A. Cerruti.
83. Differential V,B Photometry of 54 CAM by D.S. Hall.
84. UBV Photometry of UV Lyncis by N.L. Markworth.
85. BV Photometry of DM UMa by R. Kimble.
86. UBV Photometry of RY Gem by D.S. Hall, Tilman Stuhlinger, and John W. Wilson.
87. Photoelectric Photometry of HR 7275 by D.S. Hall.
88. Photometry of θ ORI A by D.S. Hall and J.R. Sowell.
89. Photoelectric Observations of 44 i Boo, by Russell M. Genet.
90. B Magnitudes of BW Vul, by A.P. Odell.
91. B Magnitudes of HR 151, HR 239, and HR 7461, by Donald W. Kurtz.

12. T TAURI STARS

(L.V. Kuhi)

Rather than conduct a complete review of all the work done on T Tauri stars since December, 1978, I will instead concentrate on several areas in which important new results have appeared.

Proper motions of 75 T Tauri and related stars in the Taurus-Auriga dark clouds have been measured by Herbig and Jones (AJ 84.1972). They found that the dispersion of proper motion vectors of known cloud members is very small and that of stars in different subgroups is ∿1-2 km/sec. Most stars do not have sufficient velocity to escape from its subgroup. Three-quarters of the non-Hα-emission stars do not share the motion of the Hα emission stars and hence Herbig and Jones conclude that there are very few post T Tauri stars in these dark clouds. They also suggest that there is no significant population of embedded stars or stars concentrated toward the centers of the clouds.

Cohen and Kuhi (ApJ Suppl 41.743) published their massive survey of almost 500 pre-Main Sequence stars which resulted in the placement of young stars reasonably accurately on the HR diagram. Spectral types and reddening corrections were obtained from optical scans of the λ4270 to λ6710 region and were combined with infrared broad-band measurements to obtain T_{eff} and L_{bol}. Most Hα emission stars lie in the convective part of the HR diagram and are typically of spectral type late K and luminosity class III-IV. The coolest stars found are of type M5 and

M5.5 and the youngest stars are ~10^4 to 10^5 years old if convective tracks are used. Published dynamical tracks do not pass through the region where most stars are actually located. Star formation is not coeval on timescales of ~10^5 to 10^6 years and an overall efficiency was estimated to be ~10%. They concluded that the Taurus-Auriga complex is probably the youngest and most vigorous (in terms of emission-line stars) collection of pre-Main Sequence stars. They also established correlations between selected emission lines which suggested a chromospheric or at least a common origin for much of the observed emission. In addition, there was some indication that emission activity decreased with increasing age and that the nebulous stars were likely to be the youngest stars in an aggregate.

High resolution line profiles have been obtained by many observers: Hα and NaID by Schneeberger, Worden and Wilkerson, ApJ Suppl 41.369; Hα,β and NaID by Ulrich and Knapp, ApJ Lett 230.L99; CaII IR triplet by Shanin, Astrometr. Astrofiz. 40.28; Hα,δ by Edwards, PASP 91.329; HeI 5876 and 10830 and NaID by Ulrich and Wood, ApJ 244.147.) The profiles show a bewildering complexity of behaviour which is often variable with time, atomic species and principal quantum number and points to several possible places of origin for the emission lines: a deep lying chromosphere, an extended envelope, a very low density nebulous region, stellar winds or infall of matter. An extreme example is DR Tau (Krautter and Bastian, AA 88.L6) which shows both P Cygni and inverse P Cygni profiles at different Balmer lines in the same spectrum. Short term line variations (on timescales as short as 2 hours have been detected by Bastian and Mundt (AA 78.181) for DI Cep. Even shorter time-scales for broad-band light variations (~5% in 10 minutes) have been reported by Schneeberger, Worden and Africano (BAAS 11.439) and indicate a strong similarity to the variations observed for flare stars.

Interpretation of T Tauri spectra has consistently lagged far behind the observational data. However, significant advances were made in the deep-lying chromospheric model by Cram (ApJ 234.949), Calvet (Ph.D. dissertation, Berkeley), and Heidmann and Thomas (AA 87.36) who showed that the fluxes of most of the chromospheric lines (CaII, FeII, etc.) could be reproduced by such a model. This is not true for the hydrogen emission, especially Hα which requires an extended emitting region to produce the observed flux. Velocity fields have not been adequately considered in most of this work (except for Heidmann and Thomas) but clearly play an important role given the large widths of the emission lines. The representative model calculated by Cram fit the range of observed CaII line fluxes (Herbig and Soderblom, ApJ 242.628) quite well. The same paper showed that the CaII IR triplet was optically thick and must arise in regions of increased activity (i.e. spots) covering different fractional areas from star to star. This conclusion came from the fact that the relative line ratios changed little from star to star but the line-to-continuum ratio did.

The advent of IUE has lent further support to the solar-stellar connection. The far ultraviolet has yielded a host of emission lines ranging from the chromospheric MgII doublet to the transition region lines of CIV and NV. (Gahm et al. AA 73.L4; Appenzeller and Wolf, AA 75.164; Appenzeller et al. AA 90.184; Imhoff and Giampapa, ApJ 239.L119). Emission measures have been estimated by Cram, Giampapa and Imhoff (ApJ 238.905) who conclude that the large energy requirement implies local non thermal heating of the transition region, not by conduction from the corona. The degree of non radiative heating of the chromosphere was estimated by Giampapa et al. (ApJ in press) who concluded that the strong-line T Tauri stars are extreme examples of chromospheric and transition region activity. Curiously no correlation of ultraviolet line behaviour with the presence of winds or infall or even general visual spectral appearance was found. The extreme variability in the optical indicates the need for simultaneous observations before any serious interpretation can be made. The workshop held in Porto in 1981 came to the same conclusion and led to the naming of Giampapa as a coordinator of such future observations.

The most exciting discoveries were made by the Einstein X-ray observatory. Pre-Main Sequence stars were detected in Orion by Ku and Chanan (ApJ 234.L59) and by Chanan et al. (BAAS 11.49). At least 50% were T Tauri stars. Gahm (ApJ 242.L163), Feigelson and DeCampli (ApJ 243.L89) and Walter and Kuhi (ApJ in press) surveyed ∿60 T Tauri stars and detected many sources. Typical X-ray luminosities were $\sim 10^{31}$ ergs/sec. Surprisingly, two very extreme emission-line objects were not detected. Also no obvious correlations were found by Feigelson and DeCampli. However, the doubling of the sample by Walter and Kuhi led to a clear cut inverse correlation: the stronger the Hα emission, the less likely that the star will be detected in X-rays; stars with Hα equivalent widths above 100A were not detected. This was interpreted in terms of a low-lying quiescent corona surrounded by an extended envelope of cool gas which absorbed the X-rays. An alternative picture in which the energy required to maintain a hot corona goes instead into a cool wind cannot be ruled out because of the lack of simultaneous observations in the X-ray, ultraviolet and optical spectral regions.

Feigelson and DeCampli also observed a flare in DG Tau which increased its X-ray flux by a factor of ten in 35 minutes with a significant rise occurring in four minutes. The flare released 10^{34} ergs in ∿200 sec. Gahm suggested that T Tauri stars were only detected when they flared but the fact that no other flares were observed in the much larger combined sample suggests a quiescent corona with occasional flares as a more likely interpretation.

A serendipitous result of these surveys was the detection of other X-ray sources in the field (Walter and Kuhi; Feigelson and Kriss, ApJ Lett 248.L35) which typically turned out to be late type stars with weak Hα emission (and strong CaII K emission for those observed in that region). They would have escaped detection in the usual surveys for emission line stars but seem like ideal candidates for Herbig's missing post-T Tauri stars. Their X-ray luminosities are high ($\sim 10^{30}$ ergs/sec) perhaps because of their youth but optically they differ little from normal main sequence stars.

The question of the rotation of pre-Main Sequence stars was studied by Vogel and Kuhi (ApJ 245.960) who measured rotational velocities in NGC 2264 and Taurus-Aurgia. The results were somewhat surprising: most of the low mass ($M \lesssim 1.5 M_\odot$) stars do not have measurable velocities. Neither do the Hα emission line stars. They concluded that T Tauri stars are not rapid rotators ($\lesssim 25$ km/sec) except for a few stars of mass $>1.5 M_\odot$. Nor are non-Hα emission stars rapid rotators unless their mass $>1.5 M_\odot$. The break in rotational velocity found for main sequence stars is therefore already present as soon as the stars appear with a photospheric spectrum. The angular momentum problem must also have been solved before we see the stars. Vogel and Kuhi also showed that the Skumanich relation could be made to hold for pre-Main Sequence stars if the angular momentum were used in place of the surface rotational velocity. This would allow changes in the internal density distribution to be taken into account. They further speculate that the rapid rotators may be found among the strong-line stars for which no photospheric lines are visible. The upper limits still allow considerable braking to take place via stellar winds during subsequent evolution but at mass loss rates well below detectable levels.

The continuous emission from the surroundings of T Tauri stars has been studied at radio frequencies by Bertout (in press) and Cohen and Bieging (ApJ in press). The radio emission is ascribed to free-free emission from a hot gas which is very likely aspherical in distribution according to the latter authors. This free-free emission is also detected at infrared wavelengths for many T Tauri stars but Cohen and Kuhi (ApJ Suppl 41.743) used infrared colour indices to show that for most stars the infrared energy distribution was likely due to thermal re-emission from circumstellar dust. Rydgren and Vrba (AJ 86.1069) have confirmed this conclusion. A survey for circumstellar OH emission was carried out by Gahm et al. (AA 83.263) who found no such emission clearly associated with T Tauri stars hence confirming earlier negative results.

Extensive polarization measurements have been carried out by Bastien and Landstreet (ApJ Lett 229.L137) and Bastien (AA 94.294) who conclude that most of the polarization must be produced by circumstellar dust envelopes lying outside the emission-line producing region. Bastien interprets the variations in the wavelength dependence of polarization as due to variations in dust grain size, i.e. consistent with the idea of grain formation amound T Tauri stars. We also note Walker's (PASP 92.66) observations of the spectral and light variations of BM And. No spectral change correlated with light variation occurs and Walker concludes that the light variations must be due to variable extinction produced by material close to the star, perhaps of protoplanetary origin. Thus BM And joins a growing list of such objects with possible protoplanets.

Finally, we note that discussion of various aspects of T Tauri emission and their interpretation are to be found in the proceedings of the symposium "Stellar Physics and Evolution" held in 1979 in Byurakan (edited by Mirzoyan).

J.D. Fernie