27. VARIABLE STARS (ETOILES VARIABLES)

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1. Introduction (J.R. Percy)

Commission 27 sponsors three special projects which are of great importance to the astronomical community: the Information Bulletin on Variable Stars (IBVS), the Archives of Unpublished Observations of Variable Stars, and the General Catalogue of Variable Stars (GCVS). The reports from the centers which organize these projects are found in section 2.

Several individuals and groups deserve the warm thanks of the IAU, of Commission 27, and of variable star astronomers everywhere: Katalin Oláh and Laszlo Szabados for editing the IBVS so effectively, and Christiaan Sterken and the Editorial Board of the IBVS for giving their time, effort and thought to support this project in difficult times; Nikolai N. Samus and his colleagues for continuing the progress with the GCVS in even more difficult times; Michel Breger for maintaining the Archives since their inception, and Ed Schmidt for willingly taking over this project. We thank all those named who have written the sections of this report with such promptness, diligence and good judgement. Don Fernie provided me with helpful comments. I am especially grateful to Elizabeth Kobluk who typed this lengthy report quickly and effectively, from very inhomogeneous input, at a busy time of year.

The sections of the report cover the time period mid-1990 to mid-1993. They are not intended to be comprehensive; space and time limitations make that impossible. Readers are referred to Astronomy and Astrophysics Abstracts for a complete bibliography. The journal abbreviations include: AJ = Astronomical Journal; Ap = Astrophysics; ApJ(S) = Astrophysical Journal (Supplement); AA(S) = Astronomy and Astrophysics (Supplement); ApSS = Astrophysics and Space Science; MN = Monthly Notices of the Royal Astronomical Society; PASJ = Publications of the Astronomical Society of Japan etc. Major conferences sponsored or supported by Commission 27 included: "Confrontation between Stellar Pulsation and Evolution, Bologna, Italy, May 28-31, 1990; proceedings: ASP Conference Series 11, 1991, ed. C. Cacciari and G. Clementini (hereinafter Bologna), IAU Colloquium #134, "Nonlinear Phenomena in Stellar Variability", Mito, Japan, Jan. 7-10, 1992, proceedings in press (hereinafter Mito); IAU Colloquium #139, "New Perspectives on Stellar Pulsations and Pulsating Variable Stars", Victoria, Canada, July 15-18, 1992, proceedings in press (hereinafter Victoria). The first European meeting of the AAVSO was held in Brussels, Belgium, July 24-28, 1990; the proceedings, "Variable Star Research: An International Perspective", were published by Cambridge Universities Press, ed. J.R. Percy et al., 1992. A symposium on "Variable Stars and Galaxies" was held in Cape Town, South Africa in honour of Michael W. Feast; proceedings: ASP Conference Series 30, 1992, ed. B. Warner. Other relevant conference proceedings are mentioned in the sections below.

2. Commission Activities

a) Information Bulletin on Variable Stars (L. Szabados and K. Oláh)

During the period covered by this report, the number of issues of the IBVS progressed from #3488 (July 1990) to #3902 (June 1993).

According to the decision of the Commission 27 meeting held during the GA in Buenos Aires, an Editorial Board (EB) of the IBVS has been established. The role of the board is to help maintain the scientific level of the Bulletin and assist in solving the financial problems of the distribution. The members of the EB are: L.A. Balona, M. Breger, M. de Groot, D.S. Hall, R. Koch, J.-M. LeContel, J.R. Percy, M. Rodono, J. Smak, N.N. Samus, C. Sterken (Chair) and the editors. This constitution also reflects the fact that IBVS is now co-sponsored by the IAU Commission 42 (Close binary stars).

In view of the budgetary situation at Konkoly Observatory, circulation of the IBVS had to be reduced in 1991. Following the first meeting of the EB (Vienna, November 1991) a new circulation policy was introduced in 1992. Instead of free circulation, IBVS can be obtained on a subscription basis for a nominal fee which covers only the mailing cost. This unavoidable measure did not cause

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any interruption in the publication of the Bulletin: the number of subscribers was 328 in 1992, and for the time being there are 366 subscribers for 1993. The IAU kindly provided a grant of 1000 US$, a sum that allows to keep 25 East-European and Asian astronomy libraries on the mailing list for two years. The financial matters of the IBVS are handled by the international institute "Astronomy Research and Education Support" at the University of Brussels. The editors are grateful to Dr. Christiaan Sterken for his enormous help in the financial and administrative matters related to the IBVS. Thanks are also due to the other members of the EB for their help and co-operation.

In order to minimize the duration of the publication process, the majority of the manuscripts submitted for publication in the IBVS are refereed by the editors. In a number of cases, however, members of the EB, complemented by external referees, assist the editors with the refereeing process. It turns out that one out of two manuscripts can be accepted without revision, while publication of the other manuscripts is delayed for reasons of content, method or style. The editors strive for prompt editorial decisions concerning the acceptance of a paper, and — in order to avoid any delay — manuscripts can be sent via fax to referees. The percentage of the rejected manuscripts is not too high (about 4 per cent in 1992).

Our aim is to give the individual issues homogeneous appearance using LaTeX typesetting. Electronic submission of the text-file (even if it is in a plain ASCII or TeX is much appreciated. We are also planning for the electronic distribution of the Bulletin.

The address for editorial correspondence is: IBVS, Konkoly Observatory, P.O. Box 67, H-1525 Budapest XII, Hungary. e-mail addresses: H1036IBV@ella.hu *or* IBVS@ogyalla.konkoly.hu *or* IBVS@RMKI.KFKI.HU.

b) Archives of Unpublished Observations (Edward Schmidt)

The Archives of Unpublished Observations of Variable Stars is a depository for photometric observations which will not be published elsewhere. By placing data in the archives, they are available to other investigators without the need for lengthy and expensive tables in published journals. The archives also provide a means to preserve and make available observations which are never used in publication but may, nonetheless, be of use to other investigators.

There are now 247 completed files in the archives. Descriptions of older files have been published from time to time (see IBVS #3733 for references) and a description of more recent files, including those listed below, is in preparation for publication.

Astronomers wishing to obtain hard copies of files may request them from one of the addresses listed below. Some files are also available in electronic form. These can be obtained by electronic mail from the Centre de Données Stellaires. The addresses of the archives are:

Dr. P. Dubois
Centre de Données Stellaires
11, Rue de L'Université
F-67000 Strasbourg
France
e-mail:dubois@simbad.u-strasbg.fr

P.D. Hingley, Librarian
Royal Astronomical Society
Burlington House
London, W1V 0NL
United Kingdom

Dr. Yu. S. Romanov
Astronomical Observatory
Shevchenko Park
Odessa 270014
Ukraine

Astronomers who wish to submit new files should obtain a file number by contacting the coordinator at the following address:

Dr. Edward G. Schmidt
Department of Physics and Astronomy
University of Nebraska
Lincoln, NE 68588
USA
e-mail: eschmidt@unlinfo.unl.edu

Electronic transmission of data should be followed by a paper copy of both a descriptive cover sheet and the data. If electronic submission is not used, three paper copies of the data and the cover sheet should be submitted.

Since the previous report to IAU Commission 27, the following files have been assigned and completed:

File No.	Star	Contributor
155.	HD 155638	Hall
158.	GO Cyg	Hall
159.	BV Dra, BW Dra	Hall
160E.	SAO 4710	Poretti
201.	P Cyg	Percy
213.	Seven Algols	Caton
219.	50 suspected variables	Hooten and Hall
224E.	8 peculiar stars	Adelman
226E.	HD 101158	Poretti
227E.	V833 Tau	Oláh and Peterson
229.	UZ Psc	Hall
231.	τ Per	Hall
232E.	X Cae	Poretti
233E.	τ Per	Breger
234E.	VY Ari	Strassmeier and Bopp
235.	AB Dor	Anders
236E.	44 Tau	Poretti
238E.	9 Aur	Krisciunas et al.
239.	V365 Lac	Morris
242E.	LQ Hya	Strassmeier
243.	UL Leonis	Hegedüs
245E.	25 variables	Jerzykiewicz
246E.	UY Cam	Broglia
247E.	eclipsing binary	Broglia
248.	35 binaries	Caton and Burns
250E.	44 Boo	Jones
251E.	17 stars	Schmidt
252E.	18 stars	Schmidt
253E.	22 stars	Schmidt
254E.	23 stars	Schmidt
255E.	13 stars	Schmidt
258E.	28 And	Rodriguez
259E.	BF Phe, RX Sex, HY Vir	Rodriguez
260.	DH Leo	Hall
262E.	EN Lac, V360 Lac	Jerzykiewicz
264E.	44 Tau	Akan
265.	BF Dra	Diethelm
272E.	EP Cnc	Breger

c) General Catalogue of Variable Stars (N.N. Samus)

Our hopes expressed in the previous 3-year report to finish Volume V of the GCVS in 1991 were too optimistic. We have met serious problems, mainly connected again with co-ordinates of variables and cases of identical stars considered different by their discoverers. By now (May 1993) we have overcome these problems and expect to be able to send the manuscript to the printers later this year. It will contain a unified catalogue of variable stars in extragalactic systems. Simultaneously a magnetic tape for the Strasbourg centre will be prepared.

During the 3-year cycle we have published two name lists of variable stars, #70 and #71. We compiled and sent to Strasbourg a computer version of the name lists #67-70. Recently we have added the name list #71 to this computer version.

The magnetic tape versions of the GCVS Volumes I-III contain only the main table, without remarks and lists of references. We have prepared the earlier missing computer files. They still need some editing, and after it they will be sent to the Strasbourg centre.

We continue work on the GCVS data base in computer readable form. Unfortunately this work has been slow due to insufficient funding. There already operates the special GCVS data management and retrieval system developed by Dr. Yu. Fadeyev, but the fraction of our card catalogue available in computer readable form is not sufficient yet.

Our plans for the nearest future include an astrometric supplement to the GCVS, giving for the majority of GCVS stars co-ordinates good enough for automatic pointing of ground-based and space-borne telescopes. To prepare this supplement, we have to undertake effort-consuming checks of identifications of GCVS stars with positional catalogues (including the HST Guide Star Catalog) using published finding charts.

3. Early-Type Variable Stars (Luis A. Balona)

The workshop proceedings "Rapid Variability of OB Stars: Nature and Diagnostic Value", ed.

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D. Baade, ESO, 1991, [hereinafter Munich] contains many relevant reviews and contributions.

Excitation of Pulsations. The most outstanding advance in the study of early-type stars in the last three years has been the realization that the same mechanism which causes classical Cepheids to pulsate also operates in certain B-type stars. The difference is that whereas the ionization zones of hydrogen and helium are responsible for driving the Cepheids, it is the sudden appearance of a tremendous number of iron lines at a temperature of about 150 000 K which is responsible for driving pulsations in β Cep stars and probably other pulsating B stars. This change in our understanding is due to the revision of metal opacities which was first suggested by Simon (ApJ 260, L87) on purely observational grounds and confirmed by Iglesias and Rogers (ApJ 371, L73) by opacity calculations. Calculations of pulsational driving in B-type stars by Cox et al. (ApJ 393, 272), Kiriakidis et al. (MN 255, 1p), Moskalik and Dziembowski (AA 256, L5), Dziembowski and Pamyatnykh (MN 262, 204) and Gautschy and Saio (MN 262, 213) all show that the mechanism which drives β Cep stars is now understood, but many problems remain unresolved. In particular, there is some discrepancy between the observed and calculated instability strip. More seriously, the mechanism does not explain long-period low spherical harmonic order pulsations found in hot B stars, though it predicts such pulsations for the cooler stars on the main sequence (see for example Degryse et al. AA 263, 137). Much of the predicting power of the models is lost because in all cases there is a fine balance between driving and damping and small changes to the opacities (or in the way they are treated in the models) can lead to large changes in the observed properties.

β Cep Stars. The dependence of β Cep pulsational driving on metal abundance predicted by the opacity mechanism has promoted observational studies to confirm this effect. Waelkens et al. (AA 251, 69) found a trend in the mean colour of these stars with galactocentric distance which may be explained in this way. Delgado and Alfaro (ApSS 169, 117) found a similar result. Perhaps the most convincing result of the metallicity effect is the total absence of β Cep stars in three Magellanic Cloud clusters: NGC 330 (Balona MN 256, 425) and NGC 2004, NGC 2100 (Balona & Jerzykiewicz MN 260, 782 and Balona MN 260, 795).

A connection between β Cep stars and Be stars was established when β Cep itself was found to have developed strong Hα emission (Mathias et al. Munich 193). While observing the well-known Be star 27 CMa, Balona and Rozowsky (MN 251, 66P) discovered that it had developed β Cep pulsations sometime during 1988 or 1989.

A major photometric study of β Cep stars which includes new period determinations for 57 stars has been completed by Heynderickx (AAS 96, 207). Other recent observational work on these stars can be found in Jerzykiewicz and Sterken (MN 257, 303), Jerzykiewicz (AAS 97, 421) and Sterken et al. (AAS 98, 383). Delgado et al. (AJ 103, 891) list suspected variables in two open clusters.

Mode identification in β Cep variables is necessary to test models of these stars and for asteroseismological studies. Waelkens and Aerts ('Workshop on the atmospheres of early-type stars', ed. Heber & Jeffery, Springer-Verlag, 159) and Aerts (same volume, 163) use the information contained in the moments of the line profile variations to determine the modes of selected β Cep stars. Aerts et al. (AA 266,294) use the same method to show that δ Cet is a radial pulsator. A different method based on visual and UV light amplitudes, radial velocities and phase shifts was used by Cugier and Boratyn (Acta Ast 42, 191).

53 Per And ς Oph Stars. This classification of intrinsic B-type variables has not been formalized and to some extent is a matter of personal taste. In this report we follow the classification scheme of Balona (Munich 249). The 53 Per group of stars may be identified with the 'mid B-type variables' or the 'slowly pulsating B stars' of Waelkens (AA 246, 453). This later work has considerably advanced the photometric study of 53 Per stars by showing the multiperiodic nature of seven long-period B-type stars. Other stars which may belong to this group are HD 80859 (van Genderen et al. AA 259, 574) and λ Col (Jerzykiewicz & Sterken MN 260, 826). An intensive photometric study of a member of this group, HR 2680, was made by Balona and Cuypers (MN 261, 1). The primary component of this eclipsing binary has two closely-spaced periods which do not appear to be stable. The lack of line profile observations of these photometrically detected stars is a serious obstacle to further progress. It is also abundantly clear that intensive photometry is required to resolve the periodicities, but it now appears that in some stars the stability of these periods must be questioned. This makes a definitive determination of their periods a very difficult process.

Many rapidly rotating B-type stars show 'moving bumps' in their line profiles, which defines them as belonging to the ζ Oph group. ζ Oph itself has been studied recently by Kambe et al. (PASJ 42, 687) who employ a novel method of detecting periodicity in the line profiles. Two NRP modes were found to be excited at the time of their observations. Yang et al. (ApJS 74, 595) performed a similar study of ζ Tau, while moving bumps in κ Dra were seen by Hill et al. (AA 246, 146). In all these stars the modes have very long periods in the co-rotating frame. One of the problems with line profile observations is that it is often not possible to obtain definitive periods for the oscillations owing to limited or ambiguous data particularly if more than one pulsation mode is involved. Furthermore, a theory which enables physical parameters to be derived (including the effect of temperature variations) is not available for rapidly rotating stars at present.

λ Eri Stars. The periodic light variations in Be stars are a characteristic feature of these objects and are in some unknown way connected with the enhanced mass loss in these stars. A statistical study by Balona (MN 245, 92) shows a strong correlation between the projected rotational velocity and the photometric period. He interprets these variations as due to some kind of rotational modulation, though the consensus of opinion is that non-radial pulsation (NRP) is involved. The idea of rotational modulation is strengthened by the discovery of many periodic Be stars in the SMC cluster NGC 330 (Balona MN 256, 425). No pulsational driving is expected in stars with low metal abundances.

Intensive photometric observations of these stars is presented in Balona et al. (AAS 92, 533). Balona et al. (MN 252,93) present detailed photometry of four λ Eri stars in NGC 3766 showing that the periods are strictly constant over five years.

Results of a multiwavelength campaign on Be stars aimed at determining the cause of short-term optical variability, are reported by Peters et al. ('Evolution in astrophysics: IUE astronomy in the era of new space missions', ed. E.J. Rolfe, ESA, p.257, 1990). The observations confirm that it is the modulation in the star's photospheric temperature that causes the flux variability. The authors find that NRP in an $\ell = 2$ sectorial mode can explain the results.

High resolution line profile studies of λ Eri itself in combination with near-simultaneous UV continuum observations have been analyzed by Smith and Polidan (ApJ 408, 323). They find several examples of a weakening in the C IV, N V resonance lines that coincides with the appearance of dimples in the λ6678 line profile. They interpret these results in terms of a condensation of high density structures above the photosphere. They speculate that small scale magnetic fields of several hundred gauss may exist in the atmospheres of mild Be stars. Evidence for violent magnetic activity in λ Eri comes from the detection of a giant X-ray flare on λ Eri (Smith et al. ApJ 409, L49). The results cannot be explained in terms of a cool secondary or degenerate companion.

O Stars, Supergiant Variables and Wolf-Rayet Stars. Balona (MN 254,404) conducted a photometric survey of several O-type stars to search for periodic variations which could be interpreted in terms of NRP. Although microvariability with a time scale of days was found in all supergiants and some dwarfs, evidence for NRP was not found. However, Baade ('Workshop on the atmospheres of early-type stars', ed. Heber & Jeffery, Springer-Verlag, 145) comes to the opposite conclusion from a spectroscopic point of view. Both viewpoints can be reconciled when it is realized that photometric observations are not sensitive to the high-order spherical harmonic modes seen in the line profiles of the stars. There is no doubt, however, that irregular or semi-regular variations due to variability of the winds of these stars play a role in both the photometry and line profiles.

Photometric observations of four supergiant variables (α Cyg stars) are presented by van Genderen et al. (AA 264, 88). Quasi-periods between 24 and 58 days are found. These variations are thought to be due to NRP, but the excitation of these modes is still a puzzle. Gautschy (MN 259, 82) has studied NRP in models of these stars and finds a number of excited low-order modes.

One of the most exciting developments in the study of Wolf-Rayet stars was the detection of a 627-second optical pulsation in the WN8 star HD 96548 (Blecha et al. Nature 360, 320). Whereas the reality of pulsations in this star seems to be well established, it is of great importance that this detection be independently confirmed. Unfortunately, this may not be a simple matter as the pulsations might be obscured most of the time by the optically thick expanding atmosphere. The importance of this work lies in the prediction that WR stars with masses exceeding 12-16 $M_\odot$ should be pulsationally unstable (Maeder QJRAS 32, 217). Good agreement is found between the period in HD 96548 and a model with a mass of 14-15 $M_\odot$.

An attempt to understand the periodic light variation in the peculiar WR star EZ CMa was made using photometry, polarimetry, spectroscopy and spectropolarimetry by Robert et al. (ApJ 397, 277). The linear polarization data are well fitted by an eccentric binary model, but the spectroscopic results are ambiguous and the question of the presence of a compact companion remains unresolved. Intensive photometry of HD 191765 (Antokhin et al. ApJS 82, 395) show irregular variations on different time scales, but there is some evidence for a 2-day quasi-periodicity. The cause of the periodic variations in this star is probably of the same nature as in EZ CMa.

4. Delta Scuti and roAp Stars (D.W. Kurtz)

In this report, I will recount some developments that have caught my attention and give a few opinions about needs in this research subfield; for a comprehensive review, consult Astronomy and Astrophysics Abstracts (AAA).

δ Scuti Star Newsletter = DSN. The "δ Scuti Star Newsletter" continues to be published by the Austrian Academy of Sciences with Michel Breger as editor. This newsletter is most interesting and useful; I encourage all who are interested in the field to read it and to submit notes, discoveries, abstracts, papers and opinions to it. The Editor's address is Institut für Astronomie, Türkenschanzstraße 17, A-1180, Wien, Austria and his email address is breger@avia.una.ac.at. There is no subscription charge and papers are indexed in AAA.

Catalogues. We all need access to up-to-date complete lists of δ Scuti stars. Various individuals and groups of astronomers have taken on the task of providing such lists. López de Coca et al. (AAS 83, 51) provided a list of 192 δ Scuti stars which has been used by others — probably because of its accessibility in the library. A more complete list of 254 stars is provided by Garcia et al. (CDS Bull. 34), but the latest, most up-to-date is a PC DOS data base compiled by Garcia et al. (see DSN 6, 14) which is available from the authors for a nominal charge. Contact them by email at jgarcia@icoper.edu.ar. This data base collates name, spectral type, pulsational data, photometric indices, v sin i, references to the literature and more. We all must thank the authors for their immense effort and I am sure we will all have many uses for their data base. On this point: It would be useful if workers could inform Garcia directly of publications of the discovery of new δ Scuti stars and other information relevant to keeping the data base up-to-date.

Reviews and other work. No comprehensive review of δ Scuti stars has appeared since Breger's 1979 (PASP 91, 5) or Wolff's 1983 monograph on the A stars. There is a need for this from both the theory and observational sides. Are there two collaborating volunteers (or one person who knows everything)?

At the Oji Seminar on Seismology of the Sun and Stars, Dziembowski (Lec. Not. Phys. 367, 359) gave a theoretical discussion of δ Scuti stars with synopses of much of his previous work with Królikowska and their co-workers (*e.g.* Dziembowski & Królikowska Acta Ast 40, 19). They repeatedly call for more mode identifications and frequency determinations from observers. They find mode trapping for non-radial modes primarily for $\ell = 1$, but generally not for $\ell = 2$ and 3; higher degree modes exhibit more and more trapping — an interesting result given line profile variability for $-m = \ell = 10$ to 20 found for 4 δ Scuti stars by Kennelly et al. (Bologna 320; see also Kennelly et al. PASP 103, 1250). Dziembowski and Królikowska suggest that detection of modes with $\ell \geq 2$ would imply that something more than mode trapping is acting in δ Scuti stars, but they are referring to the *photometric* detection of such modes which would imply large amplitudes; the detection of large ℓ modes spectroscopically does not imply these problematic large amplitudes. The $\ell = 1$ trapping is also interesting since that is what is unequivocally found in several roAp stars: HD 6532, HR 3831, and α Cir. Dziembowski also discussed the thorny problems of mode selection and amplitude modulation. Dziembowski and Pamjatnikh (AA 248, L11) calculate that one g-mode may be trapped by the boundary of the convective layer in the core for slightly evolved δ Scuti stars, and that observations of the frequency of this mode could constrain theories of convective overshoot. There have been suggestions from observers that g-modes may explain some observed frequencies. This is an unresolved issue which is strongly coupled to the issue of the degree to which frequencies claimed by observers can be believed — an issue which is discussed more below. Observers should keep this g-mode suggestion in mind; theoreticians should examine observers' claims of g-mode detections carefully.

Breger (Bologna 263) gives a review of observational results, concentrating on amplitude and frequency stability and their implications for stellar evolution. He lists a number of determinations of dP/dt in δ Scuti stars. These are often orders of magnitude larger than expected from theoretical predictions and both positive and negative values are found. The latter, if evolutionary, imply stars evolving bluewards. However, see Fernie's (AJ 103, 1647) suggestion that all of the δ Scuti stars are core burning and lie *below* the evolutionary blue loop (more about that paper below). Many of the period changes in δ Scuti stars are better interpreted as episodic, discrete changes, rather than continuous changes (*e.g.* CY Aqr — Coates et al. DSN 4,10; MN, in press). This is not necessarily in contradiction with stellar evolution. Discovery of significant dP/dt for main sequence stars where evolution is slow could refute the evolutionary origin of all dP/dt, as could the discovery of multiperiodic stars with very different dP/dt for different periods, although this must be modelled. Thompson and Coates (Proc. Ast. Soc. Aus. 9, 281) find a factor of 6 ratio in the rate of period change for P_0 and P_1 in SX Phe and both are an order of magnitude larger than expected from main sequence models. Both are also negative as are the dP/dt in three other Pop II δ Scuti stars. Breger points out that in the Blue Straggler Hypothesis for the SX Phe stars the decreasing periods need to be explained; in the post-HB hypothesis it is expected from the direction of evolution. Walraven et al. (MN 254, 59) find $dP_0/dt = 0$ and $dP_1/dt = 4.74 \times 10^{-9}$ from 38 years of observations of AI Vel.

Those working on frequency variability should look at interpretations other than stellar evolution for the apparent dP/dt that are being measured. Note that some of the roAp stars (see the last section of this report) show cyclic frequency variability which is intrinsic to the star and cannot be evolutionary. The sun is known to show pulsation frequency variability over the solar magnetic cycle. And the ZZ Ceti white dwarf G29-38 shows cyclic frequency variability in one pulsation frequency and not variability in another frequency (Winget et al. ApJ 357, 630).

Some years ago I claimed that it had not been shown that any periods or amplitudes were not constant in δ Scuti stars (how is that for a negative statement?). Breger in his review argues persuasively that both periods and amplitudes are not constant on a long time scale. These results come from many years of work and many multi-site campaigns (see Breger AA 240, 308).

The SX Phe stars are thoroughly reviewed by Nemec and Mateo (Bologna 64). They discuss this problem of the changing periods in SX Phe stars with a suggestion that the period of XX Cyg is probably increasing. They point out that the changing ratio of P_0/P_1 in SX Phe itself implies mass loss, if the change is evolutionary in origin. Most interestingly, they discuss their discovery of many SX Phe (or δ Scuti) stars in globular clusters and dozens of them in the Carina dwarf galaxy. (See their paper in ASP Conf. Ser. 10, 134 for a look at convincing δ Scuti light curves of 23rd magnitude stars.) The Carina galaxy contains stars of intermediate and old populations; it is not clear yet to which group the δ Scuti stars belong. Nemec and Mateo support the hypothesis that the SX Phe stars are blue stragglers which can be accounted for by binary coalescence. McNamara and Powell (Bologna 316) find a correlation of log P with [Fe/H] for SX Phe and δ Scuti stars which they suggest implies that SX Phe stars evolve from low mass, low metal stars; this explains why they are found only in the lower part of the instability strip. Gilliland and Brown (AJ 103, 1945) serendipitously discovered two blue straggler δ Scuti or SX Phe stars in M67 while searching for solar-type oscillations in cooler stars. A third blue straggler did not vary. Both the variables are multi-mode, but it was not possible to distinguish from the pulsation frequencies whether the stars had the high He content expected in the coalescence model for blue stragglers.

Frequency Analysis. This is an issue on which I have strong opinions with which some of you will disagree. I suggest that we argue this out in the pages of the DSN. The community of theoreticians for years has been calling for more frequency determinations and for mode identifications for δ Scuti stars. The great success of helioseismology has caused the large community of solar astronomers and helioseismologists to cast their eyes on the δ Scuti stars for more observations on which to apply their well-developed theory. The observational community continues to produce a large amount of material on the δ Scuti stars, and much of this is of a higher-than-previous quality, with much more effort going into multi-site campaigns (discussed further below). But we are not there yet, and many of our published frequencies are erroneous. This is worse than no frequencies at all, since it leads unsuspecting theoreticians astray. I urge conservatism in frequency analysis.

There are many methods of frequency analysis and a huge literature on the subject which I have no space here to review. Most techiques used for δ Scuti stars are equivalent to Discrete Fourier Transforms (DFTs) for unequally spaced data, and those are equivalent to least-squares fitting of sinusoids for well-sampled data sets. Some use the Maximum Entropy Method. I do not know, and do not claim, that these are optimum methods of frequency analysis. There may be better ways to extract information from time series yet to be discovered, so we must examine each new technique as it is developed.

The variations of the DFT that worry me are the many methods that treat the alias problems arising from the gaps in the time series in an automatic way; some of these fill in the gaps in the data with predictive methods, then revert to Fourier analysis. The most widely used and misused method is CLEAN, an algorithm to remove, or reduce, the alias patterns to leave a frequency spectrum with only the "true" frequencies.

Michel et al. (Bologna 332; AA 255, 139) observing GX Peg and Belmonte et al. (AA 246, 71) and Mangeney et al. (AA 244, 351) observing 63 Her report the results of multi-site campaigns of the STEPHI network and give theoretical interpretations. They have used CLEAN for the frequency analysis; while some of their identified frequencies are convincing, not all are believable. The amplitudes of some peaks differ by orders of magnitude more than the noise between the DFT and CLEANed spectra, and all of the amplitudes are reduced in the CLEANed spectra. Michel (DSN 6, 19) discusses this latter problem and its solution. Ostermann (DSN 4, 5) finds only 3 frequencies for 63 Her, instead of the 7 found and interpreted by the STEPHI networkers.

Another example of this can be found in the CLEAN analysis of κ Boo (Jones et al. DSN 5, 15) which found 11 frequencies, rotational splitting and changing frequencies between two high duty cycle data sets. Two independent frequency analyses by Balona and by me (both unpublished) using DFTs found two certain frequencies which were the same in both data sets, good evidence of a third frequency with an alias problem, and no evidence of any further frequencies. These are radically different results which need to be resolved amongst the observers before the theoreticians can realistically use the results to constrain their models.

My opinion is that CLEAN is being applied as a "black box" frequency analysis technique in some cases. It does help remove the confusing aliases from the frequency spectrum, but it must be remembered that those aliases tell us something about what we do not know, and where we might be confused; they must be examined, even where CLEAN is used. The helioseismology community had an extensive "hare and hound" exercise which was reported in the GONG newsletter, where "hares" made up realistic artificial solar time series with noise and time gaps. With no knowledge of the input the "hounds" then attempted to reconstruct the frequency spectra. They had major problems with data sets with duty cycles under 80%. We almost always have data sets with lower duty cycles, even for our multi-site campaigns. I suggest that regular workers in the field may wish to participate in similar "hare and hound" exercises to obtain experience with our frequency analysis techniques and confidence in the reliability and reproducibility of our results. Let the theoreticians be "hares" and the observers and frequency analysers be "hounds".

We need identified frequencies in δ Scuti stars which can be trusted with confidence by those who cannot easily judge frequency analyses independently. Suggestions are solicited for how we might provide that confidence to the astronomical community. As a start, I would urge more widespread availability of the data. Much data is available through Strasbourg, but much is not. As a start, I would urge Garcia et al. to add to their δ Scuti data base information about availability of observations. I would prefer that the observations actually be part of the data base, but this may not be acceptable for reasons of administration and expense. Other ideas are solicited. The widespread availability of all published observations would allow any interested researcher to reanalyse data to check published results, with old or new techniques. As an example of this: Walraven et al. (MN 254, 59) have reanalysed old data using the newer DFT technique and discovered two new frequencies in AI Vel, one of which they identify as 5th radial overtone (interesting because Stellingwerf's 1979 models showed highest growth rates for 5th overtone). Ostermann et al. (AA 245, 543) say that "a complete frequency solution should leave only white noise in the power spectrum of the residuals". I add to that *"and the solution must fit the data"*.

Multi-site Networks. There has been admirable success in instituting and running multi-site networks. The results of the observing campaigns of these networks have dramatically increased our knowledge of the frequencies in δ Scuti stars. Some of them are: The STEPHI (Stellar Photometry International) network (Michel et al. Bologna 332; AA 255, 139; Belmonte et al. AA 246, 71; Mangeney et al. AA 244, 351; Belmonte & Michel DSN 3, 16). The Delta Scuti Network (Breger AA 240, 308; Breger et al. AA 231, 56; Breger et al. AA 243, 160; DSN 5, 3). The newly constituted GLOBUS Network (DSN 6, 5) comprising the Delta Scuti Network and the Whole Earth Telescope (WET — see *e.g.* Clemens et al. ApJ 391, 773) has observed FG Vir with both standard differential photometry and high-speed photometry. Also newly constituted is A Small Telescope Array with CCD Cameras = STACC (Frandsen DSN 5, 12) which had its first campaign on δ Scuti stars in the cluster NGC 6134 in May 1993. I also must mention the prolific work of Poretti, Mantagazza and their coworkers at the Merate observatory, both in single-site work and as part of multi-site campaigns (AA 228, 350; 230, 91; 245, 136; 255, 153; 256, 113).

Eclipsing binary. Kollath and Nuspl (IAU Symp. 151, 289) discuss tidal excitation and damping of p-modes — an old topic much discussed for 1 Mon and 14 Aur, amongst other stars. Volkov (IBVS #3493) has announced δ Scuti variability in the primary of the eclipsing binary V 577 Oph. This is an equatorial star observable from both hemispheres. I here suggest a multi-site campaign on this star for June 1994 with both photometric and radial velocity observations. This would solve the binary orbit, solve for masses and radii, and study the pulsation frequency/ies. It might also be possible to watch the phase of the pulsation mode/s during ingress and egress from eclipse, leading to constraints on, and possible identification of, the degree of the mode. The orbital period is 6.07 days, so a two-week multi-site campaign would be ideal. At V = 11, small telescopes will be adequate.

X-ray Emission. Ayres et al. (ApJ 376, L45) announced the serendipitous discovery of soft X-ray emission from CN Boo — additional evidence of some chromospheric activity in A stars (*e.g.* see Simon & Drake ApJ 346, 303) and in a δ Scuti stars in particular.

PLC Relation. In an intriguing paper Fernie (AJ 103, 1647) suggested that the δ Scuti stars and Cepheids form a single class of pulsating stars with a single PLC relation. He says "If this [κ] mechanism is sufficient to connect the 2 and 100 day pulsators to the same Cepheid family, why should it not connect the <0.2 day pulsators as well?". My first thought is: because δ Scuti stars and Cepheids are not homologous. But Fernie's PL diagram is impressive. The problem is that it compares δ Scuti stars in the galaxy with Cepheids in the LMC. If there is no zero point shift between these two groups, then the linear relation he shows is correct and the zero point can be refined by this technique; but if there is an undetected zero point shift between the two groups, then the relation may not be linear. The test of this is to observe some δ Scuti stars in the LMC. With a distance modulus of 18.5, the δ Scuti stars should have V about 20 to 21 — well within the capabilities of the kinds of observations reported by Nemec and Mateo (ASP Conf. Ser. 10, 134) for 23rd magnitude δ Scuti stars in the Carina dwarf galaxy.

Rapidly Oscillating Ap (roAp) Stars. The roAp stars were last reviewed by Matthews (PASP 103, 5). HR 3831 has been discovered to pulsate in a distorted oblique dipole mode which gives rise to a frequency septuplet in the amplitude spectrum (Kurtz et al. MN 260, 343). Shibahashi and Takata (PASJ, in press) have shown that such a septuplet is expected for a dipole pulsation mode from the effects of magnetic and rotational second-order perturbations. It is not yet clear whether the observations and theory are in complete agreement.

HR 3831 also has an unstable pulsation frequency which I have recently shown (in preparation) varies cyclically with a period of 2 years. This is not a Doppler shift in a binary system, and its explanation is problematic. The amplitude of the frequency change is similar to that seen on the sun over the 11-year solar cycle, but A stars are not expected to have magnetic cycles because of their rigid rotation and lack of any significant surface convection zone. So far, all roAp stars that have been studied long enough show frequency variability (see Kriedl et al. MN 250, 477; Kurtz et al. MN 260, 343; Kurtz et al. MN 251, 152).

An important development is a multi-colour study of the pulsation of HR 3831 by Matthews et al. (ASP Conf. Ser. 44, 617) which requires a T-τ structure with a substantially steeper gradient than in a normal A-star atmosphere. This supports the same requirement independently suggested by Shibahashi and Saio (PASJ 37, 245) based on arguments concerning the critical frequency. If these steep temperature gradients are borne out, and if they apply to other Ap stars, then previous analyses will have overestimated the abundance peculiarities in these stars. That, in turn, has strong implications for diffusion theory.

Martinez finished a Ph.D. thesis with me in mid-1993 in which he discovered 10 new roAp stars (compare this to the 15 found during the 12 years prior to his thesis). A list of 23 of the 25 known roAp stars can be found in Kurtz and Martinez (ASP Conf. Ser. 44, 561). First results from, and a description of Martinez's survey are in Martinez et al. (MN 250, 666).

5. Cepheids (Nancy Remage Evans)

Fundamental Data. The first step in studying Cepheids is to identify them, particularly in directions useful for studying galactic structure. Such a search was performed by Caldwell et al. (AJ 101, 1763), followed up by photometry and velocity studies (listed below). Many papers containing photometry of Cepheids have appeared: Berdnikov (Pis'ma Astr Zhurnal 18, 325: UBVR), Laney

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and Stobie (AAS 93, 93: JHKL), Shobbrook (MN 255, 486: UBVRI), and Schechter et al. (AJ 104, 1930). Progress reports on photometric programs were given by Schmidt (AJ 102, 1766), DuPuy et al. (Victoria), Henden (Victoria) and Heiser (Victoria). Velocity data and discussions were published by Gorynya et al. (Pis'ma Astr Zhurnal 18, 777), Metzger et al. (ApJS 76, 803), Metzger et al. (AJ 103, 529).

Among the discussions of photometry, Fernie (Victoria) found no evidence of changes in light curves. He also found that the period change of Y Oph is well represented by a cubic polynomial (PASP 102, 905).

Other discussions of period changes and the techniques involved in determining them are provided by Berdnikov (Pis'ma Astr Zhurnal 18, 519), Szabados (Mitt. Sternw. Ugaris. Akad. Wissen. 96, 125), and Vinko (ApSS 183, 17). A particularly exciting development has been the application of high accuracy velocity techniques to Cepheids (Marcy & Butler PASP 104, 270). They reported a variable with an amplitude of 200 m/sec (Butler ApJ 394 L25), providing a new technique to investigate low-amplitude variability in the instability strip. Another techique to search for Cepheid candidates was presented by Sowell (AJ 100, 834) in his discussion of Hα profiles of supergiants. Polyakova (Pis'ma Astr Zhurnal 16, 916) reported polarimetry of 3 Cepheids.

Gray (AA 252, 237) derived colour excesses from Stromgren photometry. Antonello et al. (Victoria) measured temperatures from spectrophotometry for 6 short-period Cepheids.

Individual Stars. New data for the following individual stars has been published: EW Sct (Figer et al. MN 249, 563 and Berdnikov et al. IBVS #3710), NSV 07453 (Shugarov IBVS #3778), V1334 Cyg (Usenko IBVS #3784), NO Cas and CN Tau (Schmidt & Gross PASP 102, 978), CE Cas (Berdnikov Soviet AJ 34, 400), EE Aql (Usenko IBVS #3519), V367 Sct (Berdnikov IBVS #3712), and AS Cas (Berdnikov et al. IBVS #3711).

Atmospheres. A number of studies have appeared discussing results pertaining to the details of Cepheid atmospheres. Sasselov and Lester (ApJ 360, 227) have investigated line ratios in the 1.1 micron region which provide very accurate relative temperatures, and reddenings. They (ApJ 362, 333) also provide continued studies of line profiles in the same wavelength region, showing asymmetries and occasional extra absorption components. Wallerstein et al. (MN 259, 474) presented velocity differences between Hα and metallic lines, and also Hα asymmetry for 7 Cepheids throughout their pulsation cycles, including the surprising result that the Hα asymmetry is in the same sense at all phases. Interpreting these results in atmospheric computations provides a significant challenge. Rodrigues and Böhm-Vitense (ApJ 401, 695) searched for mass loss signatures in ultraviolet lines in S Mus, but only determined an upper limit. Abundance analyses of Cepheids were performed by Klochova (Pis'ma Astr. Zhurnal 17, 732), Fenian et al. (IBVS #3595), Giridhar et al. (JApA, 12, 27) and Klochkova and Panchuk (Pis'ma Astr Zhurnal 17, 536).

Clusters and Associations. Four open clusters suggested to contain Cepheids were studied. Vazquez and Feinstein (AAS 86, 209) conclude that GH Car is a member of Tr 18. Turner et al. (AJ 104, 1132) reanalyzed NGC 129 containing the Cepheid DL Cas using additional photometry. Turner (AJ 104, 1865) concluded that SZ Tau is a member of the cluster on the basis of similar radial velocity and age, even though it is 2° from the cluster. This requires that it is pulsating in the first overtone mode. Claria et al. (MN 249, 193) presented new photometry of NGC 5662, from which they concluded that the Cepheid V Cen is a likely member. Turner et al. (ApJS 85, 119) discussed a search for clusters around southern Cepheids. Turner (AAS 97, 755) discussed unusual reddening in late B stars in the cluster Ros 3, which may also be found in clusters containing Cepheids.

Binaries. Evans (ApJ 384, 220) has used a survey of Cepheids brighter than 8th magnitude with the IUE satellite to determine that 21 per cent have blue companions. If corrected to the detection rate for radial velocity surveys, this is larger than the fraction of B stars of comparable mass which are binaries and have long period orbits. Szabados (Victoria) discussed other ways in which blue companions can be detected.

Orbital motion has been found or suspected for the following stars: VY Per (Szabados Observatory 112, 57); RX Cam (Szabados IBVS #3812); and MW Cyg (Gorynya et al. IBVS #3776). Gieren and Brieva (AA 253, 126), however, find that the suspected binary SV Per probably shows no orbital motion. Vinko (MN 260, 273) provides a now orbital solution for AW Per. Evans et al. (PASP 102, 981) observed suspected binaries FM Aql, FN Aql, RX Aur, Y Lac, and RS Ori with IUE and found that only Y Lac and possibly RS Ori may have blue companions.

The Period-Luminosity-Colour Relation and the Instability Strip. Wilson et al. (ApJ 378, 708) have calibrated the Cepheid period-luminosity (PL) relation using statistical parallax analysis. Fernie (AJ 103, 1647) derived a PL relation by treating Cepheids and δ Sct stars as one class. Hindsley and Bell (Victoria) reported a correction to Cepheid distances derived using a colour-surface brightness relation from model atmospheres. In a second paper, they discussed the absolute magnitudes derived from the very accurate Butler velocities. In a series of papers, Evans (ApJ 372, 597; ApJ 389, 657; AJ 104, 216) has developed the use of IUE observations of blue companions of Cepheids to determine Cepheid luminosities. These luminosities were combined with cluster luminosities to confirm the "wedge shape" of the instability strip. Evans (AJ 105, 1956) found minimal overlap in the HR diagram between Cepheids and nonvariables, but cautions about the interpretation of the blue edge. Schmidt (Observatory 111, 1103) reviewed recent determinations of the period-luminosity relation, and found a range in Mv of ±0.1 magnitude at $\log P = 0.8$. Gieren and Fouque (Victoria) also found a dispersion in PL zero-points similar to that of Schmidt. Simon (Bologna), however, cautioned that intercomparing the results from Baade-Wesselink studies from different groups shows a very large scatter for individual stars.

The calibration of the period-luminosity-colour relation (PLC) is, of course, closely connected with extragalactic distance determination. A comprehensive review of the Cepheid distance scale is provided by Madore and Freedman (PASP 103, 933), which has extensive discussion of the PLC in many wavelength bands.

Fourier Analysis: Overtone Pulsation. Any use of Cepheids in distance determination requires the determination/assumption of their pulsation mode. Fourier analysis of light curves is a promising method to identify pulsation mode, and a number of studies have produced Fourier coefficients. Laney and Stobie (MN 260, 408) have analyzed infrared light curves. The use of Fourier coefficients to determine pulsation modes (especially for 's' Cepheids, suggested to be first overtone pulsators) has been discussed by Antonello et al. (AA 236, 138), Mantegazza and Poretti (AA 261, 137), and Antonello (Victoria). Berdnikov (Pis'ma Astr Zhurnal 18, 654) provides light curves for double mode Cepheids at many phases of the modulation cycle. Studies of a number of individual double mode or 's' Cepheids have been made: V950 Sco (Poretti & Mantegazza IBVS #3774), TU Cas (Matthews et al. AJ 104, 748, Andrievsky et al. Victoria) and also Szabados (Victoria), and V 473 Lyr (Fabregat et al. MN 245, 542). The colour-colour diagram of 's' Cepheids was discussed by Usenko (Kinematics and Physics of Celestial Bodies 6, 95).

So far, however, independent confirmation of the pulsation modes inferred from Fourier coefficients has been scarce. IUE studies (Evans ApJ 385, 680) of binary companions have shown that an 's' Cepheid (SU Cas) and a double-mode Cepheid (Y Car), and also V367 Sct lie on the blue edge of the instability strip as predicted by pulsation calculations. Furthermore, this study showed that Y Car is a second double-mode Cepheid to have a luminosity appropriate to its fundamental period, confirming that double-mode Cepheids are normal Population I Cepheids.

Pulsation Theory. See also section 11. New opacity calculations (Iglesias et al. ApJ 360, 221; Iglesias & Rogers ApJ 371, L73; Seaton, Victoria; Rogers, Victoria; Mihalas, Bologna) have significantly enhanced opacity near 250 000 K. These opacities provide a crucial alteration in pulsation calculations which removes or decreases the Cepheid mass discrepancy between beat and evolutionary masses.

An important aspect of research during this period has been the assessment of the effects of the revised opacities. Calculations by Moskalik et al. (ApJ 385, 685) found agreement between beat and evolutionary masses, and improved agreement between bump and evolutionary masses. Ultimately, however, some additional convection is required for complete agreement between bump and evolutionary masses according to Cox (Victoria) and Moskalik and Buchler (Victoria). Petersen (AA 265, 555; Victoria) discussed the sensitivity of period ratios to opacity, and the sensitivity of period-ratio to mass. Further work using the amplitude formalism has shown that 'resonances' produce additional detail in pulsating models (Buchler et al. ApJ 380, 195) including RV Tau characteristics in a Populaton I Cepheid (Moskalik & Buchler ApJ 366, 300). Rotation was found by Kovacs and Buchler (Bologna) to have no significant effect on Cepheid pulsation. Extensive calculations by the Japanese group have included investigation of the effects of the calculation grid mesh (Ishida & Takeuti PASJ 43, 795), a gray atmosphere (Zalewski PASJ 43, 345), modal interaction (Ishida ApSS 168, 243; Ishida & Saitou ApSS 182, 69; Takeuti et al. PASJ 44, 101; Ishida & Takeuti ApSS 178, 311; Tanaka et al. PASJ 44, 331) and period changes (Saitou & Takeuti PASJ 42, 341). Calculations from another group were discussed by Fadeyev and Muthsam (AA 260, 195), stressing different causes for light curve bumps in different period ranges. Li (Victoria) discussed the red edge of the instability strip; Morgan (PASP 105, 123) also discussed extensive calculations.

A number of computational improvements have been investigated. Gautschy and Glatzel (MN 245, 154) and also Dorfi and Feuchtinger (AA 249, 417) presented new methods of solving pulsation equations. The sensitivity of the models to the equation of state is discussed by Kanbur (AA 250, 395; 259, 175). Costa et al. (ApJ 373, 237) investigated the effect of radiation pressure on a one-zone pulsation model. Finally, future improvements in pulsation calculations were discussed by Kovacs (Victoria), Petersen (Bologna) and Davis (Bologna).

Evolution. Chiosi et al. (ARAA 30, 235) reviewed stellar evolution in detail, including considerable discussion of intermediate mass stars in the instability strip. The Padua group also discussed in detail the Cepheid instability strip (Chiosi et al. ApJ 387, 320) and the evolutionary/pulsation mass discrepancy (Chiosi et al. ApJ 385, 205). They found that they could duplicate the wedge shape of the instability strip and the morphology of LMC cluster NGC 2157 with models including core convective overshoot near the main sequence. A major summary of the Padua computations is presented by Chiosi et al. (ApJS 86, 541), who discussed in detail the instability strip and PL relations from this extensive grid of computations. However, these models were computed using old opacities; although evolutionary tracks are little affected by the change in opacity, it is not clear, for instance, how the edges of the instability strip are changed. The Padua group plan to look further into this in the future. Also relevant to the evolutionary state of Cepheids are the new evolutionary tracks by Schaller et al. (AAS 96, 269), using the new opacities, although they do not discuss Cepheids explicitly.

Observational results include the study of the Cepheid BP Cir (Evans et al. AJ 103, 1638) and Cepheids with evolved companions (Evans, Victoria). Cepheids with evolved main sequence companions are best matched with isochrones with at most a small amount of overshoot, at least for short period stars. Furthermore, some evolved companions are cooler than the ZAMS, possibly because of rapid rotation. Tsvetkov (ApSS 173, 31) discussed the relation between light curve morphology and instability strip crossing.

Extragalactic Cepheids. Studies of variable stars in the clusters in the Large and Small Magellanic Clouds (LMC and SMC) have progressed enormously through the use of CCD images and multi-aperture spectrographs. Detection of the variables is labourious, but automated techniques are being developed (Welch & Stetson AJ 105, 1813). The high relative accuracy of photometry of stars in the same cluster make cluster observations an excellent way to investigate long-standing questions such as the width of the PLC (very small: NGC 1866, Welch et al. AJ 101, 490), the identification of overtone pulsators (Welch et al. AJ 105, 146), the relation between variable and nonvariable stars (Mateo et al., Bologna; Balona MN 256, 425). Wesselink radii have also been determined for several Cepheids (Cote et al. AJ 101, 1681; Barnes et al. ApJ 405, L51). Photographic photometry of field Cepheids (short period) in the SMC (Smith et al. AJ 104, 1430) showed well-defined sequences of fundamental mode and overtone pulsators.

Investigations into non-uniform spatial distribution of Cepheids in the LMC have been made by Karimova (Pis'ma Astr Zhurnal 16, 48 and 16, 261). Vardanyan and Pogosyan (Astrofizika 34, 95) have determined a PLC relation.

Luck and Lambert (ApJS 79, 303) have extended abundance analyses to include Cepheids and nonvariable supergiants in both Magellanic Clouds, and conclude that there may be abundance differences between LMC stars, but differences between SMC stars are not measureable.

A number of studies have been done on extragalactic Cepheids more distant than the Magellanic Clouds using CCD photometry, particularly in the near IR, as summarized by Freedman and Madore (Victoria). These include M33 (Freedman et al. ApJ 372, 455), NGC 300 (Freedman et al. ApJ 396, 80), DDO 216 (Hoessel et al. AJ 100, 1151), NGC 3109 (Capaccioli et al. AJ 103, 1151) and NGC 6822 and WLM (Lee et al. Victoria).

In addition, Metcalfe and Shanks (MN 250, 438) have used CCD photometric sequences to reinvestigate variables in several galaxies. The distances from these studies have been used by Freedman (ApJ 355, L35) to calibrate an infrared Tully-Fisher relation. Freedman and Madore (ApJ 365, 186) studied Cepheids in three fields in M31 at 3, 10, and 20 kpc from the center to see whether differences in the PLC due to differences in metallicity could be detected. They concluded that differences in the distance moduli could be explained by differences in extinction, and were consistent with a small PL relation dependence on metallicity.

Special techniques have been used to observe Cepheids at larger distances. High resolution images from the ground of NGC 4571 in the Virgo cluster make it possible to search for Cepheids (Pierce et al. ApJ 393, 523), and several candidates have been identified (Pierce et al., Victoria). Using the Hubble Space Telescope, Cepheids have been detected in IC 4182 (Sandage et al. ApJ 401, L7), which in turn have been used to calibrate the distance to SN Ia 1937c. Freedman and collaborators (1993, AAS Abstract) have used the Hubble Space Telescope to increase the number of Cepheids measured in M81 from 2 to 31 and decrease the uncertainty in the distance (3.4 Mpc) to 10 per cent.

Finally, an excellent review of the use of Cepheids and other extragalactic distance indicators was provided by Jacoby et al. (PASP 104, 599). For example, they concluded that the uncertainty in the distance to the LMC as determined from Cepheids is dominated by the uncertainty in the calibration of the PLC, which they estimate to be ± 0.3 magnitude. They also discussed the distance to the LMC from the circumstellar-ring light echo of SN 1987A which has an uncertainty of 6 per cent and can be used to calibrate Cepheid luminosities. Pierce and Tully (ApJ 387, 47) also found that "the primary source of uncertainity in the extragalactic distance scale now lies with the Galactic calibration of the Cepheid and RR Lyrae variables". The application of the Cepheid PLC to other galaxies requires an understanding of its sensitivity to properties such as metallicity. Saha (1993, private communication), however, suggests that the accuracy of secondary calibrators must also be carefully scrutinized in assessing extragalactic distance accuracy.

Population II Cepheids. A good recent review of Population II variable stars was provided by Wallerstein (Bologna), starting with the difficulty of defining the group. This was also discussed by Nemec (Victoria) and Lutz and Nemec (Victoria). Observational and theoretical aspects of classifying short period variables are discussed by Diethelm (AA 239, 186) and Petersen (AA 272, 217) respectively.

Observational work on the group has included Stromgren photometry (Meakes et al. AJ 101, 1795), and identification of a possible new BL Her star (Sanwal & Sarma JApA 12, 119). High resolution spectral studies showing the complexity of the line profile changes during the cycle (Lebre & Gillet AA 255, 221; Lebre, Bologna) were particularly exciting. An introduction to the complexity of the phenomena needed to explain them was given by Wallerstein and Elgar (Science 256, 1531). The Cepheid in the AU Peg binary system had rapid changes in the pulsation period (Vinko, Victoria).

Theoretical models of the pulsation behaviour (Buchler & Moskalik ApJ 391, 736; Fadeyev & Muthsam AA 234, 188; and Moskalik & Buchler ApJ 406, 190) and the hydrogen lines (Fokin MN 250, 258; Huguet et al. AA 255, 233) have been produced.

Extragalactic Population II Cepheids (anomalous Cepheids) have been found in CCD observations of the Sextans dwarf spheroidal galaxy (Mateo et al. AJ 101, 892).

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6. RR Lyrae Stars in the Field (T.G. Barnes III)

This survey of field RR Lyrae variables covers the period from the last report through July 1993. Because of page limitations not all research can be cited. Additional reports on RR Lyrae research are contained in the sections on pulsation theory and variable stars in globular clusters and related systems.

Conferences and Reviews. The following conferences, which included significant discussion of RR Lyrae research, took place or appeared in print during the report interval: "Observation and interpretation of pulsating stars," a meeting of Subproject 3 of the Multinational Cooperation of the Academies of Sciences of Socialist Countries, Sep 4 - 8, 1989, Veroeff. Sternw. Sonneborg, Vol 13, 1990, ed. W. Wentzel; "New Results on Standard Candles," Proceedings of a workshop, Trani, Italy, Aug 26 - 30, 1991, Mem. Soc. Astron. Italy 63, 223, 1992, ed. F. Caputo (hereinafter Trani); "New Aspects of Magellanic Cloud Research, " Heidelberg, Germany, Jun 15 - 17, 1992; and "Stellar Photometry," IAU Coll. 136, Dublin, Ireland, Aug 4 - 7, 1992, as well as the Bologna, Mito and

Victoria conferences (see section 1).

Absolute Magnitudes. The Baade-Wesselink technique, modified in various ways, has continued to be used to determine RR Lyrae absolute magnitudes and their correlation with [Fe/H]. These analyses appear to have converged on a common solution for the absolute magnitudes and metallicity dependence. Within a few hundredths in each parameter, the B-W results published in the last three years agree with that given by Jones et al. (ApJ 386, 646): Mv = 1.02 + 0.16[Fe/H]. As noted below, this distance scale is about 0.3 mag fainter than the distance scale which is required to make the RR Lyrae and Cepheid variables in the LMC agree in distance.

Absolute magnitudes have been determined for UU Cet, W Tuc, and RV Phe using both the IR Flux and Surface Brightness versions of the B-W method by Clementini et al. (ApJ 396, 219; Trani 397). The two methods gave concordant results. When B-W results for 24 field stars were combined, they determined Mv = 1.01 + 0.19[Fe/H]. BVRI and CORAVEL data for these analyses were published in Cacciari et al. (AAS 85 865).

Fernley and collaborators continued to investigate RR Lyrae absolute magnitudes using their IR version of the B-W method. Supplementing previous work, they have applied it to the RR Lyrae variables V445 Oph, SS Leo, and VY Ser (Fernley et al. MN 247, 287).

Liu and Janes reviewed recent B-W methods for determining RR Lyrae absolutes (Trani 445; "Relativity and Gravitation: classical and quantum," Proc. 7th Latin Amer. Symp. on Rel. and Grav., Cocoyoc, Mexico, Dec 2 - 8, 1990, eds. J. D'Olivo et al. 278). They argued that the results from various groups are consistent with Mv = 1.06 + 0.20[Fe/H].

Jones et al. (ApJ 386, 646) used their IR version of the B-W method to determine the distances to SW And and DX Del. Combining these results with previous work using B-W methods, they find a best absolute magnitude calibration of Mv = 1.02 + 0.16[Fe/H]. Using a similar technique, Storm (Trani 387) determined the absolute magnitudes for three RR Lyraes in M5 and M92. His results for these stars agree with the field RR Lyrae Mv - [Fe/H] relation.

In work comparing B-W and other methods of Mv determination, evidence has appeared that the B-W method may be giving too faint a result. Carney reviewed the B-W method, main sequence fitting, and period-shift methods for calibrating the Mv - [Fe/H] relation (Trani 409; and "The Stellar Populations of Galaxies," IAU Symp. 149, Angra dos Ries, Brazil, Aug 5 - 9, 1991, eds. B. Barbuy & A. Renzini, 15). He suggested a best relation Mv = 1.01 + 0.15[Fe/H]. Fernley has also reviewed the determination of RR Lyrae absolute magnitudes by the usual methods (AA 268, 591; Trani 453). He calls attention to fainter absolute magnitudes found through B-W solutions than through the period-shift method and models of horizontal branch stars. Sandage (AJ 106, 703) makes the latter point as well. Clement et al. (ApJ 395, 192) and Simon and Clement (ApJ 410, 526) have use ϕ_{31} to establish a luminosity scale for RRc variables which is also brighter than the usual B-W scale. If indeed the B-W scale is too faint by 0.2 - 0.3 mag, as these latter works claim, and the true absolute magnitudes of RR Lyrae stars are that much brighter, the discrepancy between Cepheid and RR Lyrae distances to the LMC would be eliminated.

Use of the main sequence fitting method to determine absolute magnitudes of RR Lyraes has been explored by Fusi Pecci et al. using theoretical HB models (Bologna 31).

Carney (1991, in "Astrophysics with Infrared Arrays," Proceedings of a conference held in Tucson, Arizona, Feb 19 - 21, 1990, ASP Conf. Ser. 14, 115, ed. R. Elston) has reviewed the use of K-band photometry for distance determination of RR Lyrae stars. He discussed distance estimates to the Galactic Center, the LMC, the SMC and M31. Longmore et al. also discussed the role of IR photometry in RR Lyrae pulsation and distance studies, including the Mv - logP relation (Bologna 36). The period-luminosity relation in the K magnitude for globular cluster variables has been discussed by Buckley et al. (Trani 433) and by Janes and Liu (Trani 445).

Period-Shift Effect. The Sandage Period Shift measures the change in the mean period of pulsation with metallicity among RR Lyrae stars; it is closely related to the Oosterhoff dichotomy for globular clusters. An understanding of this phenomenon has eluded researchers for decades, but in the last three years progress has been made. Reviews on the topic have been given by Rood (Bologna 11), Lee (ApJ 363, 159); Bencivenni et al. (ApJ 380, 484); Carney et al. (ApJ 386, 663); Catelan and de Frietas Pacheco (AA 261, 457; AJ 106, 175); Fernley (AA 268, 591); and Sandage (AJ 106, 687).

The key to recent progress derived from realization that the period-shift effect arises, at least in part, from evolutionary effects along the horizontal branch, as discussed by Lee et al. (ApJ 350, 155), Lee (ApJ 363, 159), Bencivenni et al. (ApJ 380, 484) and Sandage (AJ 106, 687). The latter paper by Sandage gives a particularly good review of the history. Additional research on this topic includes that by Caputo (Bologna 22) who discussed the Sandage period-shift effect as a test of stellar evolution and pulsation theories. Lee (ApJ 373, L43) examined the absence of correlation between Mv and [Fe/H] for RR Lyrae stars in ω Cen in the context of his horizontal branch models. He argued that this is a consequence of the mean luminosity of the RR Lyrae stars depending sensitively on HB morphology as well as metallicity. Caputo and De Santis used reddening free parameters to determine the period-shift effect for field (AJ 104, 253) and globular cluster (ApJ 401, 260) variables. Sandage (AJ 106, 687 and 106, 703) proposed an interpretation of the period-shift effect and the Oosterhoff dichotomy which rests upon an increase in pulsation period (due to increased luminosity) and a change in the morphology of the horizontal branch which both come about as the metallicity decreases.

Catelan and de Freitas Pacheco (AA 261, 457; AJ 106, 175) have used new synthetic models of horizontal branch stars to study phenomena in RR Lyrae stars. In particular they have examined the effect of choosing Sweigart or Lee and Demarque opacities upon the Sandage period-shift. They concluded that these opacities lead to different predictions for the period-shift.

Multimode Behaviour, Period Ratios. Double-mode pulsators have been used for a long time to infer masses for RR Lyrae variables, but those masses have been somewhat less than masses inferred by other techniques as discussed by Simon and Cox (ApJ 376, 717). Recently this discrepancy has been investigated using new opacities for the models. Discussions of the effects of revised opacities on double-mode masses have been given by Cox (ApJ 381, L71), Kovacs et al. (AA 252, L27). Petersen (AA 243, 426; AA 265, 555), and Simon (ApJ 387, 162). Petersen has reviewed this issue and concluded that the pulsational models and the observations are now in reasonable agreement (Trani 345). The masses inferred from double-mode pulsation are increased to about 0.7 $M_\odot$ from the previous value near 0.6 $M_\odot$.

In addition, Kovacs et al. have explored the effect of changing the relative abundances of oxygen and other heavy elements in models of RR Lyrae star pulsation (AA 259, L46). They concluded that the masses of double-mode pulsators will be uncertain by about 0.1 $M_\odot$ until accurate abundances for the individual dominant elements are available.

Masses for RRc variables in five Oo I and five Oo II clusters have been determined by Bruzzi and Cacciari using Simon's ϕ_{31} method ("Star Clusters and Stellar Evolution," Mem. Soc. Astron. Italy, 63, 79). Their results suggested a mass difference of 0.1 $M_\odot$ between the Oosterhoff types and somewhat larger mean masses than determined by the double-mode analysis. Clement et al. also used this method to determine masses for six stars in M68 and concluded that the masses must lie in the range 0.75 - 0.90 $M_\odot$, depending on the metallicity and luminosity assumptions (ApJ 412, 183).

The number of known double-mode, field RR Lyrae stars has been increased from one to three by Clement et al. (ApJ 372, 273). They published periods, mean magnitudes, colours, metallicities and inferred masses for two stars.

Abundances. New ΔS values for 35 field RR Lyrae stars have been reported by Kinman and Carretta (PASP 104, 111). They also proposed that the anomalous colours and spectra of BB Her, and possibly of AR Her as well, may be a result of the star being binary with a non-variable, blue horizontal branch star. Suntzeff (ApJ 367, 528) has investigated the metallicities of RR Lyrae variables in the galactocentric distance range 4 - 30 kpc using ΔS. He found the metallicity to be a constant [Fe/H] = −1.65 outside the solar circle and to have a gradient −0.06 dex/kpc inside the solar circle. A calibration of equivalent width of the CaII K line with [Fe/H] has been made by Clementini et al. (AJ 101, 2168). They claim a tighter and more reliable relation than that based on ΔS.

Caputo (AJ 106, 301) has used light-to-mass ratios for RR Lyrae stars in the field over the galactocentric range 0.5 - 19 kpc to infer the field horizontal-branch morphology. He concluded from comparison of this morphology to models that the intial helium abundance had to be a constant Y = 0.23 for all field RR Lyraes with [Fe/H] < -0.7.

Radial Velocities. According to pulsation models constructed by Simon (MN 246, 70), the phase lag between light and velocity curves may be interpreted to give the distances of RRc stars from their respective blue edges. Liu (PASP 103, 205) has established a correlation between velocity curve and light curve amplitudes from a large number of RR Lyraes having high-precison data. From this correlation a synthetic radial velocity curve for RRab stars is constructed for use in determining systemic velocities. CORAVEL data for several stars were published by Cacciari et al. (AAS 85, 865). Fernley et al. (AAS 97, 815) published new CORAVEL radial velocities for 13 RR Lyrae stars.

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Radii. Using a new CORS method, Cucurachi et al. (Bologna 116) determined radii for SW Dra (5.6 $R_\odot$) and X Ari (7.3 $R_\odot$). They argue from this result that X Ari is actually an anomalous Cepheid.

RR Lyrae Variables in Special Fields. The RR Lyrae variables in Baade's window have been studied using ΔS by Walker and Terndrup (ApJ 378, 119). They found the metallicity to be strongly peaked at [Fe/H] = −1.00 with very small dispersion. In a different window into the Galactic bulge, Blanco (AJ 103, 1872) found 112 new RR Lyrae stars, for which she gives light curves and finding charts.

Walker summarized work on photometry of RR Lyrae stars in the Magellanic Clouds ("The Magellanic Clouds," Proc. IAU Symp. 148, Sydney, Australia, Jul 9 - 13, 1990, eds. R. Haynes and D. Milne, 307). A review of RR Lyrae variables as standard candles for extragalactic work was given by Lee (Trani 331). From preliminary results of a new survey for RR Lyrae variables in the LMC, Reid and Freedman reported 550 likely candidates (Bologna 120). Kinman et al. discussed five new LMC field RR Lyrae variables (PASP 103, 1279). Walker used RR Lyrae variables in many LMC clusters to determine properties of the clusters and a mean absolute magnitude of the variables (Trani 479; ApJ 390, L81; AJ 105, 527). He found Mv = +0.44 mag at [Fe/H] = -1.9, which is nearly 0.3 mag brighter than suggested by statistical parallax and B-W studies of Galactic field RR Lyrae stars.

Saha and collaborators have found and measured photometrically numerous RR Lyrae variables in nearby galaxies: 32 in NGC 147 (AJ 100, 108), 30 in NGC 205 (AJ 103, 84) and 15 in IC 1613 (AJ 104, 1072). Finzi (AA 255, 115) has proposed, and discussed, the possibility that RR Lyrae stars in dwarf spheroidal galaxies, including NGC 147, have high luminosities.

Photometric Data, Light Curves. BVRI data for several stars were published by Cacciari et al. (AAS 85, 865). Observations of T Sex in the uvbyβ system are reported by Alaniya (Abastumani Ap. Obs. Bull 68, 4). Pena et al. (Rev. Mex. Astr. Ap 20, 139) reported uvbyβ photometry of several RR Lyrae variables in Serpens. Hobart et al. (Rev. Mex. Astr. Ap 22, 275) suggested that the light variation of T Sex is best represented by three periodicities. Barnes et al. (PASP 104, 514) published contemporaneous BVRIJHK data on four RR Lyrae stars. They also use these data to examine Saha's proposal that TU UMa may be binary. BV photometric data for six field stars has been published by Burki et al. (AAS 97, 827). Fernley et al. (AAS 97, 815) published JHK data on 110 variables in the first installment of a large program to obtain IR data on field RR Lyrae variables.

Simon (MN 246, 70) has used hydrodynamic models of RRc variables to study the Fourier decompostion parameters for these stars. He found the models to mimic the observations very well for ϕ_{31} but to fail for the parameter ϕ_{21}. Grieco and Antonello have used one and two-zone models to study the light curves of RR Lyrae stars (Bologna 101). They discuss the dependence of Te and radius estimates on the colour indices in the two-zone model.

In the first results from his continuing survey of poorly studied variable stars, Schmidt found six out of seventy-nine stars classified as RR Lyrae actually to be eclipsing or ellipsoidal variables (AJ 102, 1766). From this he concluded that there may be as many as 400 - 500 stars listed as RR Lyrae variables in the GCVS which may be short-period binaries instead.

Large numbers of RR Lyrae variables have had elements determined or revised in the last three years. The results have been published in BAV Rundbrief, IBVS, MVS, GEOS Circ, Astr. Tsirk., JAAVSO, Per. Zv., and JBAA. These sources also include references to period variations, to newly discovered RR Lyrae variables and to stars with newly discovered Blazhko effect. Ephemerides for RR Lyrae variables were published by Firmaniuk and Zakrzweski for 1990, 1991 and 1992 (Rocznik Astr. Obs. Krakow, Intern. Suppl. #61, 115, #62, 119, and #63, 121, respectively), and also by the AAVSO.

7. Variable Stars in Globular Clusters and Related Systems (Amelia Wehlau)

As far as possible this review covers material on this subject published in the three years ending in mid-summer 1993. As usual space limitations make it impossible to cite every paper published during this time. The reader is referred to the Comm. 38 report on globular cluster research and to the following conference proceedings: ASPCS (ASP Conference Series) 13, The Formation and Evolution of Star Clusters, ed. Janes, 1991; IAU Symp 149, The Stellar Populations of Galaxies, eds. Barbuy and Renzini, 1992; Star Clusters and Stellar Evolution, eds. Brocato, Ferraro and Piotto, MemSAIt 63, No. 1, 1992; ASPCS 48, The Globular Cluster-Galaxy Connection, eds. Brodie and

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Smith, 1993 as well as the Bologna, Trani, and Victoria meetings mentioned in section 6.

Studies of Pulsating Variables In Galactic Globular Clusters. Listed in order of IAU cluster designation. CJS referes to Clement, Jankulak and Simon (ApJ 395, 192).

C0021-723 (NGC 104, 47 Tuc): Corwin and Carney (IAU Coll #139, 410) report on BV photometry of V9.

C0512-400 (NGC 1851): CCD observations for 22 of the 26 previously known variables are included in the data for a new CMD presented by Walker (PASP 104, 1063). Thirteen candidate RR Lyrae stars were also found.

C0522-245 (NGC 1904, M79): CCD photometry for a CMD by Ferraro et al. (MN 256, 391) includes observations of 10 known or possible variables. Among these, V5 apears to be a blend of two variables, both possible RR Lyrae stars.

C0734+390 (NGC 2419): Clement and Nemec (JRASC 84, 434) report V39 is a double-mode RR Lyrae star.

C1236-264 (NGC 4590, M68): Nine double-mode variables identified by Clement et al. (ApJ 412, 183) have been found to have masses and Fourier parameters similar to those found for the variables in M15.

C1310+184 (NGC 5024, M53): Kravtsov (Astr Tsirk 1544, 21) presents a finding chart and coordinates for 11 new variable stars in the central region. CJS give Fourier parameters for 15 RRc stars.

C1323-472 (NGC 5139, ω Cen): Simon (ApJ 360, 119) uses pulsation models to derive masses, temperatures and absolute luminosities for a large sample of RRc stars in the cluster and finds results which are not consistent with HB models. The lack of correlation between mass and metallicity of the RR Lyraes in this cluster (also found by Simon) is attributed by Lee (ApJ 373, L43) to effects of HB morphology. Frolov (IBVS #3566) determines masses for three pulsating blue stragglers to be comparable to RR Lyrae masses. Mukherjee et al. (PASP 104, 561) identify two new possible variables. Observations of the eclipsing blue straggler NJL5 are used by Helt et al. (AA 270, 297) to obtain tight constraints on the component masses and to determine $M_{V,HB} = 0.7$.

C1339+286 (NGC 5272, M3): CJS give Fourier parameters for six RRc stars. Frolov (IBVS #3566) finds a mass of 0.8 $M_{\odot}$ for the pulsating blue straggler and (Astr Tsirk #1553) shows that the most evolved RR Lyraes are well separated in the IR period-colour and HR diagrams. Photometry of variables 61 through 87 and V133 is presented by Meinunger (MittVerSt 12, 64, 67 & 70 (1990); 78, 95, 96 & 115 (1991)).

C1403+287 (NGC 5466): Photometry of three eclipsing blue stragglers is presented by Mateo et al. (AJ 100, 469). For 4 out of 5 blue stragglers Frolov (IBVS #3566) finds masses in accordance with those expected from coalesced binaries.

C1452-820 (IC 4499): A CCD CMD study by Sarajedini (AJ 105, 2172) includes photometry of 71 RR Lyrae stars, three newly identified. Reasons for the high frequency of these stars which comprise 68% of the HB stars are discussed. The study also turned up three probable variable blue stragglers.

C1516+022 (NGC 5904, M5): Cohen and Matthews (PASP 104, 1205) present visual CCD photometry for 8 RR Lyrae variables and IR photometry for four of these. The Baade-Wesselink analyses based on this photometry are given by Cohen (ApJ 400, 528). Fourier parameters for 13 RRc variables are given by CJS. Storm, Carney and colleagues (PASP 103, 1264) present BV CCD photometry for eleven RR Lyrae variables and for two of these, V8 and V28, radial velocity curves and K-band light curves are also given (PASP 104, 159 & 168). Photometry of two new RRc stars near the cluster center is given by Kravtsov (Soviet AJ Lett 17, 465).

C1620-264 (NGC 6121, M4): Liu and Janes (ApJ 360, 561) report on Baade-Wesselink analyses of four RR Lyrae stars. Yao presents CCD photometry of two low amplitude variables lying outside the instability strip (IBVS #3622 and IBVS #3846).

C1624-387 (NGC 6139): Photometry for 16 new variables, 10 within the tidal radius, is presented by Hazen (AJ 101, 170). Periods are given for 5 RR Lyraes.

C1629-129 (NGC 6171 M107): CCD photometry presented by Ferraro et al. (MN 252, 357) includes observations of 14 RR Lyrae stars. A study by Cudworth et al. (AJ 103, 1252) includes an investigation of cluster membership for 17 of the known RR Lyrae variables. CJS present Fourier parameters for six RRc stars.

C1645+476 (NGC 6229): Three possible new variables are identified by Carney et al. (AJ 101,

1699) as a result of their photometric study of the cluster.

C1715+432 (NGC 6341, M92): Cohen and Matthews (PASP 104, 1205) present visual CCD photometry for 5 RR Lyrae variables and IR photometry for two of these. Radial velocities and Baade-Wesselink analyses for V1 and V6 are given by Cohen (ApJ 400, 528). New proper motions given by Rees (AJ 103, 1573) confirm that almost all previously known or suspected variables are highly probable members of the cluster. His search for new variables revealed some possible candidates. Carney et al. (PASP 104, 44) discuss BV CCD photometry for seven RR Lyrae variables. For two of these, V1 and V3, Storm et al. (PASP 104, 159 & 168) present radial velocity curves and K-band light curves.

C1735-032 (NGC 6402, M14): Margon et al. (ApJ 369, L71) report HST U and B images of the field of the 1938 nova reveal no object with a marked UV excess.

C1742+031 (NGC 6426): Clement and Nemec (JRASC 84, 434) report V3 is a double-mode RR Lyrae star.

C1800-300 (NGC 6522): Abundances and radial velocities are given by Walker and Terndrup (ApJ 378, 119) for five RRc stars in this cluster, situated in Baade's window. Metallicities of the four variables which appear to be cluster members are close to that of the surrounding RR Lyraes in the nuclear bulge.

C1804-250 (NGC 6544): Hazen (AJ 106, Sept.1993) identifies a possible RR Lyrae star.

C1821-249 (NGC 6626, M28): Wehlau and Butterworth (AJ 100, 686) present photometry of the variables. A proper motion study by Rees and Cudworth (AJ 102, 152) includes four previously known variables and identifies four possible variables.

C1828-235 (NGC 6642): Hazen (AJ 105, 557) presents photometry for 18 variables within the tidal radius and 11 variables beyond it. Light curves are shown for 13 RR Lyrae stars, 10 of which fall within the tidal radius.

C1951+186 (NGC 6838, M71): Light curves based on deep CCD photometry by Hodder et al. (AJ 103, 460) are presented for four new variables, including one variable blue straggler and two candidate eclipsing binary systems.

C2059+160 (NGC 7006): Period change rates for 46 RR Lyrae variables given by Wehlau et al. (AJ 103, 1583) indicate a radial gradient in the rates.

C2127+119 (NGC 7078, M15): CJS give Fourier parameters for 24 RRc stars. Comparing theoretical models with observed data for 62 RR Lyrae stars, Simon (ApJ 387, 162) finds no single set of models can reproduce all the periods and luminosities and the ratio of blue to variable stars. Improved values for periods and masses of eight RRd stars are given by Clement and Walker (AJ 101, 1352). A CM study by Durrell and Harris (AJ 105, 1420) includes a comparison of the slope and zero point of the $M_{V,RR}$-metallicity relation derived by several methods. Meinunger (MittVerSt 12, 34, 58, 67 & 69) reports on observations of variables. HST observations of the inner region have discovered 19 new variables, including 15 probable RR Lyrae stars (Ferraro & Paresce AJ 106, 154).

C2137-234 (NGC 7099, M30): Observations presented by Machin et al. (MN 250, 602) indicate that the cataclysmic variable V4 is a not a cluster member.

Population II Variables in Magellanic Cloud Clusters and Local Group Dwarf Galaxies. Hazen and Nemec (AJ 104, 111; 105, 359) present photometry and light curves for 11 RR Lyrae stars within the tidal radius of the LMC cluster NGC 2210 and 52 field RR Lyraes. Walker, continuing his studies of variables in LMC clusters, presents light curves for RR Lyrae stars in NGC 1841 (AJ 100, 1532), Reticulum (AJ 103, 1166), NGC 1466 (AJ 104, 1395), and NGC 1835 (AJ 105, 527). Using his CCD photometry of 182 RR Lyraes in seven old LMC clusters he compares the magnitude-metallicity relation for these stars to that of galactic field RR Lyraes and finds the zero point for the LMC variables to be almost $0^m.3$ brighter (ApJ 390, L81). From the LMC relation he determines ages for galactic clusters and suggests an increase in the distance to the galactic center. Suntzeff et al. (AJ 104, 1743) review the properties of variables in old LMC clusters and find them to be very similar to those in outer galactic clusters, consistent with theories of the formation of the Galaxy from LMC-like clouds.

Observation of RR Lyrae stars in increasingly distant Local Group galaxies has become possible through the use of CCDs. Reid and Mould (AJ 101, 1299) report on R and I-band CCD photometry of stars in Leo I including observations of two variables, one of which seems to be a red variable instead of an anomalous Cepheid on the basis of its colour. Observations of variables in Leo I are also reported by Demers and Irwin (MN, in press) and M.G. Lee et al. (ASP CS 48, 1993; AJ, in press). For Leo II, 79 candidate HB variables and one possible anomalous Cepheid have been identified by

Demers and Irwin (MN 261, 657). Reports on studies in progress on the variables in Sculptor are given by Goldsmith (Victoria, 347) and in Sextans by Weller et al. (BAAS 877 (1991)) who report the discovery of approximately 40 RR Lyrae variables as well as possible anomalous Cepheids. Saha, Hoessel and colleagues present photometry and light curves for 42 variables in NGC 205 (AJ 103, 84) and 15 RR Lyraes in IC 1613 (AJ 104, 1072).

Red Variables, RRd and RRc Variables in Clusters. Perl and Tuchman (ApJ 360, 554) compare their theoretical mapping of the luminosity-period relation with the observed period-luminosity relation for red variables in 47 Tuc and suggest the dominant mode of pulsation is the second overtone for red semiregulars and the first overtone for Miras.

Clement and Walker (AJ 101, 1352) report that analyses of observations in three clusters found no RRd stars. Combining this result with an earlier search of 22 other clusters by Clement and Nemec (JRASC 84, 434) they suggest the occurrence of RRd stars is related to metallicity. Simon and Clement (ApJ 410, 526) match pulsation models with observations of cluster RRc stars to derive masses, luminosities and temperatures as functions of period and Fourier phase parameter and obtain a provisional RR Lyrae distance scale.

The Sandage Period-Shift Effect and Horizontal Branch Models. See also section 6. There is continuing controversy over the cause of the Oosterhoff dichotomy and the related Sandage period-shift effect, which appears to require an anticorrelation between helium abundance and metallicity. Still another aspect of this debate deals with the RR Lyrae luminosity-metallicity relation which directly impacts on use of these stars to yield information on distances, globular cluster ages and formation of the Galaxy. There are several papers dealing with these and related problems in the conference proceedings listed at the beginning of this report. A good review of the status of this controversy three years ago is given by Rood in ASP CS 11,11. Additional observational data has been published since then. A study of field RR Lyraes by Suntzeff et al. (ApJ 367, 528) finds an "Oosterhoff" gap and period-shift dependence on metallicity similar to that in the globular clusters. IR photometry of RR Lyrae stars in eight clusters is used by Longmore et al. (MN 247, 684) to establish a period-IR luminosity relationship and investigate the dependence of M_V upon metallicity. Recently published IR photometry of stars in M3, M5 and M15 is used by Fernley (AA 268, 591) to derive $M_{V,RR}$-metallicity and log P-metallicity relations. He compares methods of determining $M_{V,RR}$ and also finds the slope of the mass-metallicity relation from pulsation theory is in serious disagreement with that from HB theory. Nemec and Lutz (Victoria, 29) present new P-L-metallicity relations for four types of Pop II variables from observations of over 1200 stars in $\sim$40 stellar systems. Van den Bergh (MN 262, 588, AJ 105, 971) finds Oosterhoff type I clusters are significantly more likely to lie on retrograde orbits than type II clusters and suggests some second parameter effects are due to the way in which the protoGalaxy collapsed. Clement et al. (ApJ 395, 192) find, for RRc stars in 5 clusters, that the Fourier phase parameter ϕ_{31} is related to metallicity and period.

In an effort to understand the cause of these relationships, synthetic horizontal branches based on HB evolutionary tracks have been constructed by several groups and compared with observed correlations. Y.-W. Lee uses the synthetic HBs of Lee, Demarque and Zinn (LDZ) and his new HB morphology type in several investigations. The HB type, (B-R)/(B+V+R), (based on the numbers of blue HB, RR Lyrae and red HB stars) are listed for a number of clusters by Lee (ApJ 363, 159) who argues that the period shift arises from the fact that most of the RR Lyraes in Oosterhoff type II clusters are highly evolved stars from the blue side of the instability strip. Lee (ApJ 367, 524) finds agreement within the errors between observed secular period change rates of RR Lyrae stars with those predicted by the LDZ models. He suggests the mean luminosity of RR Lyraes in a cluster is a function of HB morphology and uses this to explain the lack of correlation between luminosity and metallicity of ω Cen RR Lyrae stars (ApJ 373, L43). See Simon (ApJ 360, 119) for a further comparison between observed parameters and predictions from HB models for RR Lyrae variables in this cluster. In several review papers presented at conferences Lee extends his discussion of cluster HB stars to derive information about cluster ages, galactic evolution and distances to other galaxies (ASPCS 13; Victoria). However a detailed study of the RR Lyrae stars in M15 by Simon (ApJ 387, 162) finds that the Lee and Demarque tracks cannot account for the observed properties of the variables in this cluster. The RRab/RRc transition in M15 is compared to that in ω Cen by Caputo (AA 239, 137).

Bencivenni et al. have also constructed synthethic HBs using enhanced abundances of O, Ne, Mg and Ca and have used them, along with the Lee HB type, to investigate the relations between metallicity and RR Lyrae mean luminosity and light-to-mass ratio as well as the age spread among clusters (ApJ 380, 484). Their results generally agree with those of LDZ. Caputo and De Santis (AJ 104, 253; ApJ 401, 260) investigate the correlations of light-to-mass ratio with metallicity and HB morphology for both RR Lyrae stars in the field and in clusters. They find agreement with the synthetic HB predictions, using a value of Y = 0.23 for all clusters. Carney et al. (ApJ 386, 663) compare the slope they obtain from Baade-Wesselink analyses and find it agrees within the errors with that obtained from other methods without requiring an anticorrelation between helium and heavy-element abundances. They extend their results to find there is a range in ages among intermediate-metallicity clusters and suggest the Oosterhoff dichotomy results from a sudden change in HB morphology at [Fe/H] = −1.7. Catelan (AA 261, 443 & 457; AJ 106, 175) discusses the use of several synthetic HB models in an attempt to reconcile the various values found for the slope of the HB luminosity-metallicity relation and to explain the cause of the period-shift effect.

8. Mira Variables, RCB Stars and Related Objects (M.W. Feast)

The application of interferometric techniques to obtain high resolution two-dimensional images of Miras opens a new and important phase in the study of these objects. *o* Ceti shows departures from spherical symmetry which may indicate non-radial pulsation modes co-existing with the radial modes which produce the photometric variability (cf. Karovska et al. ApJ 347, L54; Wilson et al. MN 257, 369; Haniff et al. AJ 103, 1662; Quirrenbach et al. AA 259, L19). Infrared (2 micron) diameters of *o* Ceti and R Leo have been published (from interferometry, Ridgway et al. AJ 104, 2224: and an occultaton, Di Giacomo et al. AAS 249, 397). A high-quality astrometric distance for R Leo (Gatewood PASP 104, 23) together with an interferometric diameter show that the star is pulsating in the first or higher overtone (Tuthill et al. preprint). Since R Leo fits the Mira PL relation closely (Whitelock, in IAU Symposium 153 in press) this would seem to establish that the Miras are not fundamental mode pulsators — a matter that has been under discussion for some time.

The galactic distribution and kinematics of Miras has much to tell us about galactic structure as well as about late stages of stellar evolution. A general overview of Miras in relation to stellar evolution can be gained from Highlights in Astronomy 9, 603-645. Whitelock (IAU Symposium 153 in press) reviews Miras in the Galactic Bulge and Whitelock and Catchpole (in The Center, Bulge and Disk of the Milky Way ed. Blitz 1992 (Kluwer)) show from Miras that the Bulge is bar-shaped. Jura et al. (ApJS 79, 105) discuss the space densities, lifetimes and mass loss rates of nearby Miras. Whitelock et al. (preprint) discuss the distribution and kinematics of high mass loss AGB stars (mainly Miras) in the South Galactic Cap. They conclude (contrary to one of the results of Jura et al.) that the period of a Mira is unlikely to undergo a large change during most of its life. The distribution and kinematics of OH/IR stars close to the Galactic Centre are correlated with envelope expansion velocity (Lundquist et al. AA 259, 118). Two high-velocity (about -350km/s) OH/IR stars have been found near the Centre (van Langevelde et al. AA 261, L17). The few OH/IR stars in the outer Galaxy are likely to be high mass objects (Blommaert et al. AA 267, 39). OH/IR stars in the Galactic Centre have been used to study the scattering properties of the interstellar medium (van Langevelde et al. ApJ 396, 686).

Interferometry at 11 microns shows that the dust in *o* Ceti reaches to within 3 stellar radii of the star (Bester et al. ApJ 367, L27). The acceleration of the circumstellar gas may begin at these small radii (Bowers ApJ 390, L27). Dust formation in Mira winds is discussed by Dorfi and Hofner (AA 248, 105; AA 265, 207) and Fleischer et al. (AA 266, 321). New candidates were found for C stars with silicate shells (Chan & Kwok ApJ 383, 837). Infrared emission and mass loss from circumstellar shells was modelled by Justtanont and Tielens (ApJ 389, 400).

The discovery of OH/IR variables in the Magellanic Clouds (Wood et al. ApJ 397, 552) is of great importance for the study of these objects. A number of large surveys of IRAS sources for OH and water masing have been published (Le Squeren et al. AA 254, 133; te Lintel Hekkert AA 248, 209; AAS 90, 327; Dickinson & Turner ApJS 75, 1323; Lewis & Engels MN 251, 391). The efficiency of OH masing increases with redness of the stellar envelope and probably also with decreasing distance from the Galactic Centre (Dickinson ApJ 379, L29). Le Bertre (AA 250, 351) suggests that all OH/IR stars with periods greater than 800 days are supergiants. A detailed study of the OH envelope of U Ori was made by Chapman et al. (MN 249, 227) and an ellipsoidal shell model proposed (Bowers ApJS 76, 1099); see also Collison and Fix (ApJ 390, 191). However Spaans and van Langeveldte (MN 258, 159) conclude that the average shape of OH lines in OH/IR stars can be explained by a spherically symmetric, homogeneous, constantly expanding shell and that the 'platelet' model of Alcock and Ross is not required. Studies of the circular polarizaton of OH emission suggest complex magnetic field structures with intensities of 1-100 microgauss (Zell & Fix ApJ 369, 506).

New, detailed maps of water masers around Miras and variable supergiants have been made by Bowers et al. (AJ 105, 284). In some cases there has been marked changes in structure over several years. The importance of the study of mm and submm water masers as probes of the physical state of the emitting gas was emphasised by Neufeld and Melnick (ApJ 368, 215); see also Menten and Melnick (ApJ 377, 647). Rapid time variations in astrophysical masers are considered by Scappaticci and Watson (ApJ 400, 351). A great deal of work has been done recently on maser and non-maser SiO emission in Miras. Sahai and Bieging (AJ 105, 595) made medium resolution images of non-maser SiO in Miras and found them to be largely spherically symmetric on angular scales of 3-9 arcsecs. Alcolea and Bujurrabal (AA 253, 475) made a systematic study of isotopic maser lines (see also Cernicharo et al. AA 249, L27; ApJ 401, L109) and new high excitation SiO maser lines have been detected in VY CMa (Cernicharo et al. ApJ 407, L33). McIntosh and Predmore (ApJ 404,L71) show that in *o* Ceti three different maser rotational transitions of SiO originate in the same volume. Detailed modelling by Lockett and Elitzur (ApJ 399, 704) shows that the primary pumping mechanism for SiO masers is collisional.

The carbon Mira IRS+10216 (CW Leo) continues to be intensively studied both for an understanding of the complex circumstellar chemistry it exhibits and for the detailed asymmetric shape of the molecular shell (cf. ApJ 388, L31; 388, L35; 396, 643; 407, L37; 382, 321; AA 259, L23; 266, 365; 249, 435; MN 254, 7). The extent of the molecular envelope in CO and SiO around several Miras is discussed by Bujarrabal and Alcoleo (AA 251, 536) and a fast bipolar outflow in CO found from the S-type variable π Gruis (Sahai AA 253, L33). The envelope of the interesting Mira OH231.8+4.2 contains both O-rich and C-rich molecules (including formaldehyde (Lindquist et al. AA 263, 183)). The time variations in the bipolar nebula (at 2 microns) around this star were studied by Kastner et al. (ApJ 398, 552). Brightness variations are out of phase in different parts of the nebula due to light travel time effects thus reducing the amplitude of the integrated light by about 2 magnitudes.

Pijpers (AA 267, 471) suggests that mass loss can significantly affect the pulsation periods of Miras and related stars whilst Icke et al. (AA 258, 341) find that some of the characteristics of these stars can be interpreted in terms of weak chaos. Two time scales in the variations of small amplitude red variables were found by Percy et al. (PASP 105, 287) and a number of periods (including 1190 days) identified in the SRc variable Y Lyn (Szatmary & Vinko MN 256, 321). Kerschbaum and Hron (AA 263, 97) discuss the relationship between Miras and SR variables. A detailed study (Goebel et al. ApJ 402, 680) shows that the results of the CNO tricycle dominate the photospheric abundances in the carbon star RX Psc. Wallerstein (PASP 104, 511) obtained the Rb/Zr ratio in the S-type Mira R And and deduced the neutron density at the time of s-processing. The effects of velocity stratification of a Mira photosphere on line strengths and curves of growth were evaluated by Scholz (AA 253, 203). Jonsson et al. (MN 258, 49p) identified the molecule TiS in S-type Miras whilst Hron (AA 252, 583) deduced a possible metallicity spread amongst short period Miras.

The relation between Miras and PNe was discussed by Whitelock and Feast (IAU Symposium 155 in press). Most old disc stars seem to go through both the Mira and PNe phases. However the most metal rich stars in the Galactic Bulge may go through neither phase. Schaefer (ApJ 366, L39) assembled evidence of 14 cases of flares (typically 0.5 magnitude, each lasting a few minutes) in Miras. In a sample of carbon Miras the optical radial velocities are consistently redshifted with respect to CO, possibly due to shock structure (Barnbaum ApJ 385, 694). VLA continuum observations show the existence of a hot plasma around carbon SR variables (Luttermoser & Brown ApJ 384, 634).

A large amount of work has been published on symbiotic stars, some of which contain Miras and it is impossible to review it all. Subarcsec structure in the R Aqr nebula has been studied from the ground and from space (Hege et al. ApJ 381, 543; Burgarella & Paresce ApJ 389, L29; Hollis et al. ApJ 386, 293) and a detailed binary model proposed (Burgarella et al. AA 262, 83). V1016 Cyg (already known to show bipolar structure) is surrounded by a 24 arcsec nebulosity (Bang et al. (MN 256, 59p). BI Cru is also found to have a bipolar nebula (Schwarz & Corradi AA 265, L37). A set of new near simultaneous UBVRI and JHKL observations of a large sample of symbiotics is given by Munari et al. (AAS 93, 383). Mm observations of some symbiotics suggest that free-free emission becomes optically thin at these wavelengths (Ivison et al. MN 257, 47) though this is apparently not the case for RX Pup (Seaquist & Taylor ApJ 387, 624). Analysis of emission line intensities in five symbiotics shows that helium abundances are similar to those in PN and correlated with N/O as expected from dredge-up theory. A discussion of the outburst of the symbiotic nova AS296 (Munari et al. AJ 104, 262; see also AA 257, 163; Gutierrez-Moreno et al. ApJ 395, 295) leads to the idea that such objects may be the progenitors of SNIa (see Munari & Renzini

ApJ 397, L87; but cf. Kenyon et al. ApJ 407, L81). The mechanism of jet formation discussed by Soker (ApJ 389, 628) may have relevance for symbiotics. Karovska et al. (ApJ 402, 311) provide an accurate stellar separation in the *o* Ceti system using speckle interferometry. The M giant components of symbiotics have similar IR colours to giants in the Galactic Bulge (Whitelock & Munari AA 255, 171). CH Cyg is in a triple system (Hinkle et al. AJ 105, 1074) and its pulsation period is increasing (Mikolajewski et al. AA 254, 127); see also Taranova and Yudin (AA 257, 615) for a possible obscuration phase of this star. H92α has been detected in the Mira symbiotic H1-36 (Bastian ApJ 387, L77). Murset et al. (AA 248, 458) find the hot component in symbiotic stars to be post-AGB whilst Schmid (AA 254, 224) presents models of Raman scattering in symbiotics.

Rao and Lambert (AJ 105, 1915) carried out detailed high resolution spectroscopy of the RCB star V854 Cen in deep minimum. Their results suggest a model in which the object is a bipolar nebula with a thick dust torus. It remains to be seen whether other RCB observations can be fitted into this picture. In minimum this variable shows polarization of the continuum but not the emission lines (Whitney et al. AJ 103, 1652) hence the latter are unobscured by (thin) dust . The UV spectrum seems unique (Clayton et al. ApJ 384, L19). Lawson (MN 258, 33p) suggests that the emission spectrum becomes obscured by optically-thick dust during decline. Evidence that the decline is linked to pulsation phase leads him (MN 256, 339) to the view that dust is formed close to the stellar surface (a view supported by Clayton et al. ApJ 397, 6527; see also Lawson in ASP Conf Series 30, 357). RCB light curve modelling has been carried out by Pugach (Sov AJ 67, 1280; 68, 122; 69, 1195) and a rather detailed physical model of dust formation and decline given by Goeres and Sedlmayer (AA 265, 216). Dick and Walker (AA 252, 701) claim that the declines of R CrB, RY Sgr and S Aps are random whereas that of SU Tau is not. Fernie (PASP 103, 1091) found R CrB at maximum with a period of 44 days in 1990. Lawson (MN 253, 625) discusses the best period at earlier times and concludes that declines are not related to periodicity in this star. The unusual hot RCB star DY Cen has H/He=0.1 (by numbers) and C/He=0.01 (Jeffery & Heber AA 270, 167).

9. RV Tauri Variables and Related Objects (J.R. Percy)

Whereas the pulsation of Cepheids can normally be defined by one or two periods, many yellow supergiant variables are less regular. These include RV Tau variables, and an assortment of stars which are usually classified as SRd variables. One subset of these are the UU Her stars - high-latitude yellow supergiants which continue to be puzzling and controversial as to their nature. While often superficially resembling normal population I stars, their high latitudes, unstable variability and spectral peculiarities at high resolution suggest that most are post-AGB stars. An extensive workshop encompassing the subject was held at the Center for Astrophysics, Cambridge USA in May 1992; the proceedings (Luminous High-Latitude Stars, ed. D.D. Sasselov, ASP Conference Series 45, 1993), hereinafter LHLS, contains useful reviews of UU Her and RV Tau variables, and related objects. There are also many interesting papers in "From Miras to Planetary Nebulae: Which Path for Stellar Evolution?" (ed. M. Mennessier and A. Omont; Editions Frontieres, 1990).

Light Curves. Long-term visual observations of R Sct have been published by Mattei et al. (AAVSO Monograph #3, Suppl. #1). Computerization of AAVSO visual observations (including RV Tauri stars) is now virtually complete. The French Association of Observers of Variable Stars (AFOEV) has also created a data bank of observations (Gunther Bull. AFOEV #60, 17). The long-term light curves of RVb stars (RV Tauri stars with long-term light variations) have been studied by Percy (LHLS 205). Long-term photoelectric photometry of bright RV Tauri stars has been obtained by Zsoldos (see references below).

Period Changes. Period changes in RV Tauri stars have been studied by Zsoldos (SS Gem: ApSS 181, 203; AC Her, R Sge, V Vul: AA 268, 149), Zsoldos and Kollath (TW Cam: ApSS 181, 251), Percy et al. (U Mon, R Sct: ApJ 375, 391; SS Gem, V Vul: JAAVSO, in press). There is a wide spectrum of behaviour, ranging from cyclic (AC Her) to abrupt (U Mon); it may be that the period changes are due to random cycle-to-cycle fluctuations as in the Mira stars (Percy et al. JAAVSO, in press). If these stars are truly post-AGB stars, some evolutionary period change should be detectable.

Spectroscopy. Gillet, Lebre and their collaborators (AA 251, 549; AA 246, 490; AA 237, 159) have used high-resolution spectroscopy to study the pulsational motions in the atmospheres of R Sct and AC Her. They were able to explain their results in terms of the propagation of a running wave, with two shock waves per (double) period. The main shock appears just after primary luminosity minimum, and produces strong Hα emission. A second weaker shock emerges from the photosphere at secondary luminosity minimum, when the main shock is disappearing in the high atmosphere. There is also some evidence in R Sct for a blue-shifted component in the sodium line, perhaps connected with the very high atmosphere, or with a circumstellar shell.

Abundances. Studies of the chemical abundances in RV Tauri stars (Wahlgren AJ 104, 1174; Baird BAAS 23, 944; Luck, in LHLS 87; Wahlgren, in LHLS 270; Bond, in Proc. IAU Symp. #145, 341) indicate that they are a rather heterogeneous group, with [Fe/H] ranging from near-solar to −1.7 or less, some with TiO absorption and/or Hα emission, at least at some phases.

Infrared Photometry. Infrared observations (Taranova & Torgovkina Astr Tsirk #1547, 11; Shenton et al. AA 262, 138) have revealed infrared excesses which can be explained in terms of post-AGB evolution. Shenton et al. postulate two dust shells — one, the AGB "fossil", the other, more recently formed. Both silicon carbide and silicates appear to be present, and the C12/C13 ratio appears to be consistent with post-AGB evolution.

Polarimetry. Several groups have obtained polarimetry of RV Tauri stars, including Polyakova (Sov AJ 36, 52) and especially Nook et al. (AJ 100, 2004), who conclude that, despite their extensive data, "we cannot determine the polarigenic mechanism responsible for the observed polarizations of these objects. The data do appear to rule out pure dust scattering and pure photospheric scattering as the polarigenic mechanisms. We suggest that the scattering of a time-variable anisotropic radiation field off an extended circumstellar dust layer could produce the magnitude of the variations that are observed".

Theory. Tuchman et al. (AA 271, 501) carried out a linear pulsation analysis of models of 0.5 to 0.8 $M_\odot$. The results were consistent with most observed features of RV Tauri stars. They suggested that the alternating deep and shallow minima in these stars are due to a resonance ($P_0 \sim 2\ P_1$) between the fundamental (P_0) and first overtone (P_1) periods. Gillet (AA 259, 215), on the other hand, explained the alternating minima in AC Her and R Sct as being due to a radiative shock associated with the development of an extended running wave in the envelopes of these stars. Buchler, Kovacs, Moskalik and their collaborators (e.g. ApJ 366, 300; ApJ 385, 685; see also sections 5 and 11) have found evidence for period doubling and incipient chaos in models appropriate for RV Tauri stars. Attempts to find evidence for chaotic behaviour in these stars (Kollath MN 247, 377; Veldhuizen and Percy JAAVSO 18, 97; Saitou & Takeuti PASJ 41, 297) have concluded that the (photometric) data are not yet accurate or extensive enough for this purpose.

The above-mentioned mechanisms are not independent, and it is possible that all of them contribute to the alternating minima phenomenon — especially since the phenomenon is not always regular in any case.

10. Asteroseismology of Compact Pulsators (D.E. Winget)

We will consider pulsating white dwarf and hot pre-white dwarf stars collectively as the compact pulsators. This covers essentially the entire region below the main sequence from the pulsating planetary nebula nuclei (PNNV stars) down to the comparatively cool pulsating hydrogen surface layer white dwarf (DAV) stars; these stars span an incredible six orders of magnitude in luminosity, and more than a factor of ten in effective temperature.

Many articles of interest can be found in the proceedings of relevant meetings held during the period covered by this report. These include the NATO Advanced Research Workshop, "Seventh European Workshop on White Dwarfs", Toulouse, France, September 1990 (eds.: G. Vauclair, E. Sion, Kluwer, 1991; hereinafter referred to as WD); the IAU Coll #139, "New Perspectives on Stellar Pulsation & Pulsating Variable Stars", Victoria, Canada July 1992 (Ed. J. Nemec & J.M. Matthews, Cambridge University Press, in press, hereinafter Victoria; the NATO Advanced Research Workshop, "Eighth European Workshop on White Dwarfs", Leicester, England, July 1992 (ed.: M. Barstow, Kluwer, 1993; hereinafter WDAOT); Gong 1992: "Seismic Investigations of the Sun and Stars", Boulder, Colorado, August 1992 (ed.: T. Brown, ASP Conf. Ser., 42, 1993, hereinafter Gong) and the Second Whole Earth Telescope Conference, Vilnius, Lithuania, August 1993 (ed.: E. Meistas, Baltic Journal of Astronomy, in press; hereinafter WETCon); Recent progress has been reviewed by Bond and Ciardullo (WDAOT 491, hereinafter BC), Cox (Victoria), Wesemael et al.

(WD 159), Winget (WD 129; WDAOT 449; Gong 331); Brickhill (WDAOT 467); Bradley (Ph.D. Thesis, Univ. of Texas, 1993; hereinafter B93); Nather (WDAOT 499; WETCon), and Clemens (WETCon).

The primary goal of white dwarf asteroseismology is to determine basic structural and evolutionary parameters of the white dwarf stars. This will allow us to develop a chronology of star formation in our galaxy, and study the poorly understood phases of pre-white dwarf evolution. Considerable progress in this direction has been made since the last review in these pages (Winget, Trans. IAU, vol. XXIA, 267). Most significantly a number of controversial issues have been sorted out, some surprising discoveries made, and new puzzles uncovered. Given the space limitations at hand, we will focus our attentions on a sampling of these.

The count of PNNV stars has grown to 7. The PNNV stars have effective temperatures in excess of 100,000 K and surface gravities near log g = 6 (BC). All of these stars have complex, unresolved, and perhaps inherently unstable, dominant pulsation periods between 1,000 - 2,000 s. These stars are likely the progenitors of a significant fraction of the white dwarf stars and asteroseismological analysis of their interiors will be crucial to understanding both the post-main-sequence-planetary nebula connection and the planetary nebula-white dwarf connection (see discussion in BC). Of particular interest is their relationship to the DOV stars. In this regard the discovery of pulsations in the ROSAT soft x-ray source RX J2117.1+3412 (Motch et al. AA 268,561) reported by Watson (IAUC #5603) and Vauclair et al. (AA 267, L35) is extremely exciting. This object has pulsation periods intermediate between the PNNV and DOV stars and is embedded in a faint, extended planetary nebula. Asteroseismological analysis of its pulsation properties are currently underway (Vauclair, WETCon).

The DOV stars have effective temperatures between 100,000 K and 150,000 K and have luminosities between 100 and 1,000 times solar. The prototype of this class of stars, McGraw's star (PG1159-035, GW Vir), was the target of a Whole Earth Telescope (WET) run; the data and a preliminary asteroseismological analysis were presented by Winget et al. (ApJ 378, 326). The recent asteroseismological analysis of Bradley (B93) and Kawaler and Bradley (WDAOT, 459; preprint) give T_e = 141,000 K, surface gravity of log g = 7.4, mass = 0.59 $M_\odot$ and log L = 2.39 in solar units, in excellent agreement with the spectroscopically determined values reported by Warner and Heber (WDAOT, 303, and references therein). Matching the asteroseismologically and spectroscopically determined surface abundance ratios remains problematic. In a related way we note that the question of why some spectroscopically identical DO stars pulsate and others do not is still with us. Additionally, asteroseismologically determined parameters include the mass of the surface helium-rich layer which is between 0.003 and 0.006 $M_\odot$. The luminosity gives a distance of 500 ± 40 pc. This value is consistent with that reported by Werner et al. (AA 244, 437) but with errors ten times smaller, pointing out the value of asteroseismologically determined distances.

Preliminary asteroseismological analyses of other DOV stars have also been reported. Fontaine et al. (ApJ 378, L49) report a mass of approximately 0.7 $M_\odot$ for PG1707+427 (Fontaine et al. ApJ 378, L49), although B93 reports a mass between 0.47 and 0.58 $M_\odot$ using a preliminary analysis of WET data. B93 also gives mass estimates for PG0122+200 near 0.8 $M_\odot$, and for PG2131+066 near 0.6 $M_\odot$. These values must all be regarded with some caution until more data is available; only the mass of McGraw's star is firm at this time.

The question of the location of the DBV instability region seems to be resolved in favour of the lower temperatures. The seven known DBV stars are found with luminosities of less than 0.1 solar and in the temperature range from 21,500 K to 24,000 K (Thejl et al. ApJ 370, 355).

We have achieved a real breakthrough in our understanding of these stars through the analysis of WET observations of the prototype GD358 (Nather, WETCon; Winget et al. IAU Coll. #137, 789: Winget et al. preprint). This work shows the dominant power is made up of $\ell = 1$ multiplets of consecutive radial overtone number between 8 and 18. Based on comparison with the theoretical work of Bradley et al. (ApJ 406, 661) we derive a mean mass for GD358 of 0.61 ± 0.03 $M_\odot$, and show that the mass of the surface He layer is log M < –5 in $M_\odot$ units. This value is much thinner than might naively be expected from stellar evolution calculations, and is even one to two orders of magnitude thinner than the values from the solution of the C pollution problem (Pelletier et al. ApJ 307, 242).

The surprises from this star don't end here. First, it is differentially rotating with a surface rotation period of 0.89 d for the helium envelope, and a core which rotates at least 1.8 times faster! Second, the fine structure frequency splitting is consistent with a magnetic field which is about B = 1300 ± 300 G; this magnetic field is about two orders of magnitude smaller than the smallest magnetic field detectable from polarization work. A field of this magnitude may well be generated in the surface convection zone as suggested by Winget (WDAOT). The models of Van Horn et al.

(preprint) indeed indicate that a convection zone dynamo can generate magnetic fields of the observed magnitude, and even produce a dynamo cycle time on time scales of order months to years — in agreement with the observed time scale for amplitude changes in GD358. The results of Van Horn et al. suggest that magnetic fields may play a much larger role in the pulsation properties of the white dwarf stars than we had realized. Finally, the distance to GD358 derived from the asteroseismologically determined luminosity (0.05 ± 0.01 $L_\odot$) gives a distance of 42 ± 3 pc, in agreement with the observed parallax distance. This value confirms that the observed modes are $\ell = 1$ ($\ell = 2$ moves the distance almost twice as far and is completely inconsistent with the measured parallax), providing a fundamental calibration of asteroseismology of white dwarf stars.

This brings us to the coolest of the pulsating white dwarfs, the hydrogen atmosphere DAV stars. The twenty-two known DAV stars have temperatures between 11,000 K and 13,000 K (Wesemael et al. WD 159; Bergeron et al. ApJ 387, 288). In contrast to previous notions, the results of Dolez et al. (WD 361) and Kepler and Nelan (AJ 105, 608) suggest that there may be a small but significant number of nonvariable DA white dwarfs with temperatures inside the observed instability strip.

Kepler (WETCon) has measured the rate of period change in the dominant pulsation mode of the DAV G117-B15A. He finds $dP/dt = (3.2 \pm 2.8)e^{-15}$, some 4 times smaller than the previously reported value of Kepler et al. (ApJ 378, L45). This new value is completely consistent with the value expected for secular evolution in models with C/O cores (Bradley et al. ApJ 391, L33).

Asteroseismological determination of the surface hydrogen layer masses based on the distribution of pulsation frequencies has been carried out for several individual stars (Bergeron et al. AJ in press; Fontaine et al. WDAOT 479; Fontaine et al. ApJ 399, L91; B93). These authors find evidence that five DAV stars have hydrogen layer masses with $-4 < \log M > -7$. Vauclair et al. AA 264, 547) and B93 find three DAV stars with hydrogen layer masses $\log M << -7$.

These results, based on adiabataic theoretical calculations of eigenfrequencies, suggest that the pulsations occur in DA white dwarf stars over a range of hydrogen layer masses including relatively thick hydrogen layers, consistent with expectations based on the non-adiabatic calculations of Cox and collaborators (cf. Cox Victoria and references therein). This is in contrast to the results of Winget and collaborators (cf. Winget, IAU Symp. #123, 305 and references therein) who found that only thin hydrogen layers were pulsationally unstable. Recently, B93 and Bradley and Winget (preprint), have repeated the investigation of the dependence of the temperature of the blue edge on the surface hydrogen layer mass. They incorporated improved equilibrium models (see Wood ApJ 386, 539; and Wood PhD thesis Univ. Texas 1990) and better numerical techniques (Lee and Bradley preprint, and Brassard et al. in preparation) for solving the pulsation equations. They find that the hydrogen layer mass dramatically affects the growth rates of the modes, consistent with the previous results of Winget and collaborators, but not the overall stability of the mode, consistent with the results of Cox and collaborators. This latter result is also consistent with the conclusions of Brickhill (WDAOT 467 and references therein) and Brassard et al. (in preparation), as described in Fontaine et al. (WDAOT 479).

Thus the issue of the surface hydrogen layer masses and "thick" versus "thin" seems finally to be settled. In settling this mystery, however, we reopen the problem of how to understand significant numbers of nonvariables within the instability strip.

Some interesting progress has been made on the theory of the origin of the linear combination frequencies observed in many of the DAV stars. Brickhill (WDAOT 467) and Brassard et al. (WDAOT 485) have shown how the amplitude of the linear combination frequencies can be used to test models of how the pulsations originate (Brickhill), and independently determine the effective temperature (Brassard et al.).

Clemens (WETCon) has re-examined essentially all of the information we currently have on the DAV stars near the blue edge. He shows that all of these stars have surface hydrogen layer masses in the range from $-5 > \log M > -6$, a remarkably narrow range. His work also suggests that the longest period mode excited to large amplitude in each of these stars is a measure of the thermal time scale at the base of the partial ionization zone. This taken with the steady increase in observed amplitudes with decreasing effective temperature indicates that the amplitude limiting mechanism is saturation of the driving regions (the H partial ionization zone). If correct this solves one of the outstanding puzzles of the pulsating white dwarf stars.

11. Theory of Stellar Pulsation (Siobahn M. Morgan)

There were several publications of conference proceedings where papers on stellar pulsation theory were presented. Among the more prominent are the following: "Nonlinear Astrophysical Fluid

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Dynamics," Gainesville, Florida, Oct. 1989, (eds. Buchler & Gottesmann, New York Academy of Sciences, 1990, [hereinafter referred to as Gainesville]), "The Numerical Modelling of Nonlinear Stellar Pulsations: Problems and Prospects," Les Arcs, France, Mar. 1989, (ed. Buchler, Kluwer Acad. Publ., 1990), "Physics of Luminous Blue Variables," Val Morin, Canada, Aug. 1988, (eds. Davidson, Moffat, & Lamers, Kluwer Acad. Publ., 1989), "Progress of Seismology of the Sun and Stars," Hakone, Japan, Dec. 1989, (eds. Osaki & Shibahashi, Springer-Verlag, 1990), in addition to the Bologna and Victoria meetings mentioned in section 1.

Other conferences which had several papers presented that dealt with stellar pulsation theory include the following: "White Dwarfs," Toulouse, France, Sept. 1990, (eds. Vauclair & Sion, Kluwer Acad. Publ., 1991, [hereinafter Toulouse]), "Challenges to Theories of the Structure of Moderate-Mass Stars," Santa Barbara, California, June 1990, eds. Gough & Toomre, Springer-Verlag, 1991, [hereinafter Santa Barbara]), "ESO Workshop on Rapid Variability of OB-Stars: Nature and Diagnostic Value," Garching bei München, Germany Oct. 1990, (ed. Baade, European Southern Observatory, 1991).

Chaos and Multimode Pulsations. Goupil et al. ("Applying Fractals in Astronomy," ed. Heck & Perdang, 1991) provide a thorough review of the theoretical and observational aspects of chaos in pulsating stars. Buchler (Gainesville 17) also reviews various aspects of chaos, including the causes of chaotic behaviour in stars and the occurrence of chaos in models that even include time-dependent convection.

Seya et al. (PASJ 42, 405) studied two-mode coupling using coupled van der Pol oscillators. They suggest that features such as double mode pulsation might be due to subharmonic phase-locking, rather than the superposition of two non-synchronized oscillations. In a similar study, Ishida and Takeuti (ApSS 178, 311) examine the criterion for double mode pulsations in oscillator model equations with two mode nonresonant coupling. Double mode pulsations in RR Lyrae models were examined by Kovács and Buchler (ApJ 404, 765). They find that double mode pulsations can be sustained in purely radiative models, mainly by reducing the artificial viscosity influence. Ishida (ApSS 168, 243) investigates the connection between three mode coupling and chaos. He finds that chaotic behaviour may result by modal coupling, even in classical Cepheids. In a followup paper, Ishida and Saitou (ApSS 182, 69) find other results of nonresonant three mode coupling, including second overtone pulsations and three mode behaviour.

Input Physics. The new opacity results from the OPAL calculations have been published in several papers including Iglesias et al. (ApJ 360, 221), Iglesias and Rogers (ApJ 371, L73), and Rogers and Iglesias (ApJS 79, 507). A significant number of pulsation studies have already made use of these updated opacity tables. The influence of diffusion on pulsation and vice-versa is reviewed by Guzik (Victoria 234).

The energies of adiabatic nonradial oscillations of nonrotating and uniformly rotating stars are investigated by Lee and Saio (ApJ 360, 590). They find that the oscillation energies of p- and g-modes of nonrotating stars are positive, as well as the g-modes of rotating stars. The effects of rotation on the pulsational characteristics of Cepheids were studied in hydrodynamic models by Kovács and Buchler (Bologna 226). They find that rotation causes the fundamental mode growth rate to increase. The effect of radiative transfer in a spherical, pulsating atmosphere is examined by Zalewski (PASJ 43, 345). Various models are produced, and the only major difference between the radiative transfer models and those with the diffusion approximation is in the amplitude of the flux variations. Further work by Zalewski (PASJ 44, 27) tested how the properties of the so-called strange modes are affected by the boundary conditions and radiative transfer. The effects of mass loss on the radial pulsations of stars is examined by Pijpers (AA 267, 471) who finds that the leakage of pulsation energy out from the star may help to stabilize the pulsation modes.

Numerical Methods. The various papers in the book "The Numerical Modelling of Nonlinear Stellar Pulsations" cover virtually every aspect of numerical modelling of stellar pulsations and is highly recommended. Dorfi and Feuchtinger (AA 249, 417) introduce a new adaptive grid method to compute nonlinear stellar pulsations. The main advantage of this method is the greater resolution obtained for regions with steep gradients. A similar method for the calculation of nonlinear radial oscillations in convective variable stars is presented by Gehmeyr (ApJ 399, 265 & 272). The method is applied to RR Lyrae models and the energy flow, light and velocity curve amplitudes, as well as the appearance of bumps in the light curves is examined. Li (AA 257, 133 & 145) introduces a linear oscillation theory for stars which includes the nonequilibrium effects of gas and radiation. Li uses this method to study the red edge of the Cepheid instability strip (Victoria 295). A modelling technique for calculating linear, nonadiabatic pulsations was introduced by Gautschy and Glatzel (MN 245, 154). They use the Riccati method to transform a linear first-order ordinary differential system describing a boundary eigenvalue problem into a numerically stable, nonlinear initial value problem. This technique is used to examine the origin of pulsations and strange modes in hydrogen deficient stars, and they find that the pulsations, as well as the strange modes, are due not to the κ mechanism, but rather to mode coupling. The Riccati method is also applied to RCrB stars (Glatzel, Santa Barbara 387), and is used in the calculation of nonradial, nonadiabatic oscillations in a helium star (Glatzel & Gautschy, MN 256, 209).

Massive Pulsating Stars. The new OPAL opacities have produced some rather significant results in the area of high mass pulsating stars. Several groups have modeled the pulsations of B stars using the new opacity results, including Cox et al. (ApJ 393, 272), Kiriakidis et al. (MN 255, 1P) and Moskalik and Dziembowski (AA 256, L5). They all find that the κ mechanism produces both radial and nonradial pulsations. One of the more thorough surveys of B star pulsations was done by Dziembowski and Pamyatnykh (MN 262, 204), who find the fundamental radial mode unstable in nearly all models, as well as a large number of nonradial modes. The pulsational characteristics of supergiant stars are studied by Schaller (Bologna 300 & 304). The effects of mass loss on the pulsations of Wolf-Rayet stars is noted. The radial pulsations of massive stars are examined by Glatzel et al. (MN 262, L7) and Glatzel and Kiriakidis (MN 262, 85). In both studies, they find that strange modes are the dominant instabilities, while the κ and ε mechanism instabilities are weaker and less prevalent. Stothers (ApJ 392, 706) uses the OPAL opacities to determine the maximum main sequence mass of a pulsationally stable star. For various compositions, the maximum mass is found to be significantly higher with the new opacities, up to nearly 150 $M_{\odot}$ for some compositions.

Long Period Variables (Miras, R CrB, AGB Stars). The pulsational characteristics of Mira stars is reviewed by Wood (Bologna 355), who discusses the problems of mode determination and the modelling of the atmosphere. Bowen (Gainesville 104) discusses models of Mira variables, which include the formation of shocks in the photosphere and dust grain formation in the cool outer layers of the atmosphere. Perl and Tuchman (ApJ 360, 554) constructed linear nonadiabatic models of red variables as observed in globular clusters. Initially the models are pulsationally unstable with the second overtone dominating, and would be observed as a semiregular red variable. As the luminosity is increased, the first overtone mode starts to dominate, and the models resemble Mira variables. The pulsations of hydrogen deficient stars were discussed by Saio (Bologna 557) who reviews the possible instability mechanisms.

Classical Pulsators (Cepheids, RR Lyrae Stars). Moskalik et al. (Gainesville 37) surveyed classical Cepheid models to investigate the relation between the fundamental and second overtone periods, as well as the shape of the velocity and light curves. The various Cepheid mass problems were discussed by Moskalik et al. (ApJ 385, 685) who used the new OPAL opacity tables. They find that the beat Cepheid mass discrepancy is no longer a problem, but the bump Cepheid mass differences are still present. The pulsational characteristics of BL Her stars are modeled by Buchler and Moskalik (ApJ 391, 736) and Moskalik and Buchler (ApJ 406, 190). They find the radial velocity Fourier parameters to be similar to the classical Cepheid models. The light Fourier coefficients do not follow the trends seen in the velocity coefficients, nor do they follow the coefficients found in classical Cepheid models.

The application of the new OPAL opacities to RR Lyrae stars was a very popular topic, particularly in trying to remove the mass discrepancy between the evolutionary and pulsational masses of RRd stars. Cox (ApJ 381, L71) finds better agreement between the pulsation and evolutionary masses for both Oosterhoff groups using a modified Stellingwerf opacity fit. Kovács et al. (AA 252, L27) used cubic spline interpolated values from the opacity tables, and their masses are slightly higher than those found by Cox for both Oosterhoff groups. In a followup, Kovács et al. (AA 259, L46) found that the double mode masses are influenced by variations in the heavy metal abundance as well as variations in the metal mixture.

White Dwarfs and Central Stars of Planetary Nebulae. A review of the theoretical work concerning the location of the ZZ Ceti instability strip was presented by Wesemael et al. (Toulouse 159). In a series of papers by Brassard et al. (ApJ 367, 601; ApJS 80, 369 & 725; ApJS 81, 747), the properties of DA white dwarfs are examined. They introduce a new method for solving the nonradial pulsation equations and perform a very thorough survey of the pulsational characteristics of the stars, including the effects of hydrogen and helium layer mass, convection, composition variations, mass and effective temperature on the pulsations. Stanghellini et al. (ApJ 383, 766) use post-asymptotic giant branch stellar models, with four different surface compositions to determine the location of the instability strips. The instability strips obtained correspond to the observed locations of such objects. Cox (Victoria 103) discusses possible pulsation mechanisms in DAV and DBV pulsators. It appears that with the effects of time-dependent convection included, only a thin CO convective layer can produce pulsations and stars with thick surface layers of hydrogen and helium will not pulsate. Bradley et al. (ApJ 391, L33) model the maximum rates of period change expected for ZZ Ceti stars with carbon and oxygen core compositions. The largest values for the rates of period change are found near the blue edge of the DAV instability strip.

Neutron Stars and Strange Stars. Models of neutron stars with a solid crust or core are examined by Finn (MN 245, 82). The crust or core leads to the appearance of nonradial elastic modes that are coupled to the star's g-modes. The pulsational characteristics of strange stars, which may be very similar to neutron stars, are examined by Benvenuto and Horvath (MN 250, 679). The damping mechanisms that can exist in these stars makes the detection of any pulsations very doubtful, though they could develop due to transient events. The radial oscillations of both neutron stars and strange stars are studied by Väth and Chanmugam (AA 260, 250). They find that the periods of all modes of strange stars go to zero as the central density approaches its smallest possible value.

12. Flare Stars (C.J. Butler)

Meetings. The field of active star research has continued to prosper in recent years with an increasing number of colloquia on the topic. The following list gives details of venues, dates and publications: Sixth Cambridge Workshop on Cool Stars, Stellar Systems and the Sun, Seattle, USA, September 1989 - hearafter 6CW; 'The Dynamic Sun' Debrecen, Hungary, May 1990, (ed. Dezsó, Pub. Debrecen Heliophysical Observatory Vol 7); 'The Sun and Cool Stars: Activity, Magnetism and Dynamos', IAU Coll. 130, Helsinki, Finland, July 1990, (ed. Tuominen et al., Springer-Verlag) - hereinafter AMD; 'Surface Inhomogeneities on Late-type Stars' Armagh, N. Ireland, July 1990, (ed. Byrne and Mullan, Springer-Verlag) - hereinafter SILTS; Flare 22 Workshop - 'Dynamics of Solar Flares' Chantilly, France October 1990. 'Eruptive Solar Flares', IAU Coll. 133, Buenos Aires, Argentina, August 1991, (ed. Jackson et al. Springer-Verlag) - hereafter ESF; Seventh Cambridge Workshop on Cool Stars, Stellar Systems and the Sun, Tucson, USA, October 1991, (Ed. Giampapa and Bookbinder, ASP Conf. Ser.); 'Physics of Solar and Stellar Coronae', Palermo, Italy, June 1992, (ed. Linsky and Serio, Kluwer); IAU Colloquium No 157, 'The Cosmic Dynamo', Potsdam, Germany, September 1992, (ed. Krause et al., Kluwer); Flare 22 Workshop - 'Recent Observations and Theories of Solar Flares', Ottawa, Canada, May 1993.

Reviews. Several excellent reviews have appeared including: a compendium edited by Petersen (Mem. del. Soc. Astron. Ital. 62, 211 - hereinafter MSAI) which contains articles on both observational and theoretical studies of stellar flares; a review by Haisch et al. (ARAA 29, 275); two by Pallavicini (NATO Adv. Study Inst. 'Sun - a Laboratory for Astrophysics', 509 and IAU Symp. 142, 'Basic Plasma Processes in the Sun', 77); and lastly one by Chugainov (Ap 34, 138) which reviews magnetic fields on stars and their effects.

Flare Stars in Stellar Aggregates. Our knowledge of the evolutionary status of FS rests largely on the study of those stellar aggregates that contain them. Mirzoyan (Ap Invest. 6, 71 and 'Phys. and Evol. of Stars - Star Clust. and Assoc.' hereinafter PESCA, 51) and Mirzoyan et al. (Ap 31, 567), from a comparison of flare frequency in late type dwarfs in the Orion Association, the Pleiades and the solar neighbourhood, have shown that the proportions of FS amongst main sequence dwarfs increases with decreasing luminosity and that the magnitude of the brightest FS in a group is indicative of age. Solar neighbourhood FS are found to be relatively old and are believed to have formed in stellar systems that have long since disintegrated.

Several studies of cluster FS have appeared including: a catalogue of Orion FS by Natsvlishvili (Astrofizika 34, 243), a reexamination of old Schmidt plate material of Orion by Chavira and Parsamyan (Rev. Mex. A. Ap. 22, 15) in which 38 new FS were discovered, and spectroscopic studies which examine the TiO bands and Hα respectively of Pleiades FS by Mirzoyan et al. (Ap 33, 291), Hamilton and Stauffer (AJ 105, 1855) and Szécsényi-Nagy (PESCA 55).

The relative energy involved in slow and fast flares (greater or less than 30m duration) has been investigated from U-band observations of Pleiades FS by Kelemen (Ap Invest. 6, 103) and shown to be approximately equal. Parsamyan and Oganyan (Ap 33, 438) find that flare amplitudes depend on the reciprocal of the rate of flare build-up and suggest that the more powerful flares lie deeper in the atmosphere.

Evolutionary studies of FS require surveys of a broader selection of young and not-so-young clusters which contain FS than are currently available. Searches for new FS in the southern open clusters: IC 2062, IC 2391, NGC 2516 and M7 have been undertaken by Jones and Page (Proc. A. Soc. Austr. 9, 277 and Southern Stars 34, 39) and a survey of the η Tau region was made by Szécsényi-Nagy (ApSS 170, 63).

Flare Stars in the Solar Neighbourhood. A comprehensive review of the properties of solar neighbourhood FS, by Pettersen (MSAI 62, 217), discusses the importance of duplicity, rotation and age to their activity levels. This review also incorporates an updated list of nearby FS. A substantial catalogue, by Panagi and Mathioudakis (AAS 100, 343), lists basic data for approximately 600 K and M dwarfs, including FS. In addition to V, (B-V), (R-I), radius etc., Hα, CaII, MgII and quiescent X-ray fluxes are given. A subset of these data has been analysed by Mathioudakis and Doyle (AA 262, 523) in a discussion of the relative importance of acoustic and magnetic heating in the quiescent atmospheres of dK-M stars. Weis (AJ 105, 1962) has compiled UBVRI photometry for 688 K-M dwarfs.

Observations by Rumsey (Southern Stars 34, 9) and Allen (Southern Stars 34, 15) suggest that all late M type stars are variable. Though the observational evidence at present is sparse, the appearance of flares on stars later than M5 which are believed to be fully convective, has significant repercussions for our understanding of how magnetic fields are generated in these stars.

X-Ray Observations. A review by Linsky (MSAI 62, 307) lists soft X-ray observations of stellar flares by Einstein, EXOSAT and some earlier satellites. It also provides references to earlier reviews.

EXOSAT and Einstein data on the double flare star Gliese 867 have been analysed by Pollock et al. (SILTS 331 and AA 241, 451) who propose that a previously suspected rotational modulation of the X-ray flux was due to flares.

Einstein observations of late type stars have been re-analysed by Schmitt et al. (ApJ 365, 704) who find that M dwarfs show evidence for the presence of material at both $T > 10^7$ K and $T \sim 3.10^6$ K. Schmitt and Snowden (ApJ 361, 207) estimate that late type stars contribute approximately 40% of the X-ray background at low galactic latitudes.

A correlation established earlier, between the integrated soft X-ray and Balmer emission from flares, has been extended by Butler (AA 272, 507) to include solar data (see also Haisch, AA 219, 317) and a flare on II Peg. A common relationship is found for flares on the Sun, dMe and RS CVn stars. A similar correlation between X-ray and Hγ flux for *quiescent* dM stars has been found by Mathioudakis and Doyle (AA 240, 357) which tends to confirm the suggestion that the quiescent X-ray emission of dMe stars arises from low level flaring.

Ultraviolet Observations. In spite of the fact that IUE observations have continued almost uninterrupted, over the past decade and a half, relatively few flares have been well observed in the optical and ultraviolet simultaneously. An exception is the giant flare seen on AD Leo in April 1985 by Hawley and Pettersen (ApJ 378, 725). Much of the difficulty arises from the poor time resolution possible with IUE and the problems associated with capturing a spasmodic event with satellite and ground-based telescopes. Though HST will help to overcome the first restriction, its relatively poor duty cycle and the difficutly of coordination with ground-based facilities means that we are unlikely to see a sudden improvement in the situation. The provision of optical detectors on board UV/X-ray satellites seems to be the best long-term solution.

From IUE observations, Phillips et al. (ApJ 385, 731) have concluded that the UV continuum of stellar flares arises from recombination of SiII which has been produced by ionization by strong UV lines. The same mechanism is believed to occur on the Sun and RS CVn stars. Elgaroy et al. (AA 234, 308) find the widths of the MgII h and k lines in M dwarfs to be narrower than expected from the Wilson-Bappu relationship for more luminous stars. They suggest that the optical thickness of the lines may depend on activity.

Mathioudakis et al. (AA 244, 155) reported a large UV flare on Gliese 182 which was simultaneously observed by the VLA. They estimate total radiative losses from $4 \leq \log T_e \leq 8$ of 6.10^{34} ergs. Byrne and Doyle (AA 238, 221), from IUE spectra of two dM and one dM(e) star, conclude that the transition region fluxes in these stars are more than an order of magnitude weaker than dMe stars and are more typical of solar values. Quin et al. (AA 272, 477) have confirmed the lack of any distinctive rotational modulation in ultraviolet (IUE) lines for the single dMe star AU Mic. It is becoming increasingly evident that large filling factors and frequent flaring obscure any inherent rotational modulation in chromospheric/transition region lines on the very active M type dwarfs.

Barstow et al. (Nature 353, 635) have detected a flare on BY Dra, with ROSAT, which has a substantial fraction of its total radiative energy in the EUV range. Doyle (AA 214, 258) and Butler (AA 272, 507) have estimated the EUV flux in quiescent dM stars and solar flares, as respectively 3.5 and 5 times the soft X-ray flux and have pointed to its possible role in exciting Balmer emission. For stellar studies, much of the EUV emission remains beyond the limits of current detectors.

From ROSAT observations reported by Jeffries and Bromage (MN 260, 132), Gliese 841A has been identified as a new short period, active, binary with a visual binary white dwarf companion.

Optical Observations. Optical photometry and spectroscopy of flares have been reviewed by Pettersen (MSAI 62, 217) and Butler (MSAI 62, 243).

Photometric monitoring, previously a tedious occupation, has received a new lease on life with the advent of automatic photoelectric telescopes (APTs). Several monitoring datasets have appeared, notably by Boyd et al. (IAPPP Comm. 42, 44), Ichimura (Pub Nat Obs Japan 1, 317), Cutispoto (AAS 84, 397), Mahmoud (ApSS 186, 109 & 113), Byrne et al. (AA 236, 455), Houdebine (IBVS #3631), Honeycutt et al. (PASP 104, 1039) and Liu Yanying et al. (Acta A Sinica 12, 42).

Two rather unusual papers describe how the complex structure of flare light curves may give constraints on the topology of magnetic fields (Houdebine IBVS #3643) and on the presence of nearby stellar or planetary bodies (Bromley PASP 104, 1049).

Several authors have pointed to the importance of time-resolved optical spectroscopy for our understanding of the detailed behaviour of stellar flares. Two recent studies have advanced our knowledge in this field. Firstly, Hawley (MSAI 62, 271) and Hawley and Pettersen (ApJ 378, 725) have described simultaneous IUE and optical spectroscopy of an exceptionally large flare ($\sim 10^{34}$ ergs) on AD Leo for which they have modelled the chromospheric and photospheric emission with considerable success. Secondly, Houdebine (Irish AJ 20, 213) has given a comprehensive description of spectroscopic signatures of stellar flares in the optical in which he has modelled a number of flares with a 'dense kernel' model atmosphere. He reports that the model can reproduce all the observed spectral features including broad band optical colours, Balmer and CaII line profiles etc. Cooling curves for several stellar flares were derived by Houdebine et al. (AAS 87, 33) which provided evidence that Balmer and CaII line fluxes were largely influenced by electron temperature. A gas-dynamic model was applied by Katsova et al. (MN 250, 402) to optical spectroscopic and soft X-ray observations of a flare on YZ CMi. Katsova (Sov AJ 34, 614) has discussed the use of Balmer decrements in the study of the physical conditions in the lower chromosphere and photosphere of active stars. Evidence for electron densities in the optically emitting regions $\geq 10^{14}$ cm^{-3} have been found in several of the above studies.

A 5^m (U) flare on UV Ceti was observed spectroscopically by Eason et al. (AJ 104, 1161) for which the total optical flare energy was $\sim 3\%$ of the quiescent bolometric luminosity. Line profiles showed evidence of moving chromospheric material with a turbulent velocity ~ 150 km/s and a systematic velocity of 70 km/s. The authors propose that Hα flare emission may arise from a relatively large volume rather than a compact high pressure region. Much higher bulk velocities (~ 5800 km/s) were observed by Houdebine et al. (AA 238, 249) in the Balmer lines from a 2.1^m flare on AD Leo. They point to the significance of such large mass ejections for stellar evolution. In a further paper, Houdebine et al. (AA 274, 245) report weak P Cygni profiles in the CaII lines, prior to the flare onset, which they explain in terms of a dark solar-like filament. During the decline of the flare a 2.68-minute oscillation developed in the position of the line centroids.

High resolution ($\Delta\lambda/\lambda \sim 8.10^4$) spectra of the CaII H line in late type dwarfs, by García López et al. (AA 262, 195), have shown evidence for chromospheric vertical velocity fields which persist for several years. Other time-resolved optical spectroscopic studies of FS were made by Falchi et al. (Ap Let Com 28, 15), McMillan and Herbst (AJ 101, 1788), Doyle et al. (AAS 86, 403) and Newmark et al. (AJ 100, 560). The latter detected some correlation between photometric and spectroscopic modulation which they interpreted as rotational modulation of plages associated with cool starspots.

Radio Observations. Three reviews of radio emission from FS have appeared: Stewart (ESF 301), Bookbinder (MSAI 62, 321) and Bastian (Sol Phys 130, 265). Bookbinder has stressed the relative

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paucity of radio observations of stellar flares and the importance of radio coverage in multiwavelength campaigns.

VLBI observations of YZ CMi by Benz and Alef (AA 252, L19) gave a radio diameter 1 ± 0.5 mas which strongly suggests emission by non-thermal particles. Lim (ApJ 405, L33) observed a steady, intense, radio emission from the rapidly rotating dM4e star Rositter 137B. Two flares were also observed.

Doyle and Mathioudakis (AA 241, L41) found weak quiescent emission, at the 3σ level, in millimetre radiation from two dM stars, in agreement with their finding of excess infrared emission believed to be associated with circumstellar matter (Mathioudakis & Doyle, AA 244, 433).

A combined photometric, spectroscopic and radio campaign on EV Lac was reported by Gershberg et al. (Sov AJ 35, 269). No microwave emission at 8 mm was detected from the 50 flares seen optically.

Peridicities, Oscillations and Microflares. Since the discovery of the 150^d periodicity in the occurrence of solar flares several authors have analysed stellar flare data gathered over recent decades for periodicities. No significant periodicities, in the range 1-14 days, were found in 228 flares on YZ CMi, AD Leo and EV Lac by Ishida et al. (ApSS 182, 227). On the other hand Cardona et al. (Rev Mex A Ap 22, 213) found two periods of 3060 days and 23.8 days in data for HII 2411. Kiang (Irish AJ 19, 161) discussed the probability that four flares observed on YY Gem occurred regularly spaced in time. For 22 years of data on UV Ceti, Pettersen et al. (6CW, 177) found 'definite' variations in flare frequency with time. Reviews of stellar activity cycles were published by Dravins (IUE Astron. in the Era of New Space Missions, 61) and Hall (NATO Adv. Stud. Inst. - Active Close Binaries, 95). Progress in this field is important for our knowledge of whether solar-type activity cycles are common in other active stars.

Andrews (AA 245, 219; AA 239, 235 and AA 235, 264) and Mullan et al. (ApJ 391, 265) have applied Fourier and autocorrelation techniques to search for low amplitude oscillations in dM-dMe stars. In some cases they report statistically significant variability with periods of tens of seconds to a few minutes. It is suggested that the oscillations originate in resonating coronal loops.

The existence of stellar microflares in optical and X-ray data is still a subject of discussion. Reviews by Haisch et al. Butler and by Bookbinder, previously referenced, discuss the evidence for optical, X-ray and radio microflares and their possible importance for coronal heating. Pustil'nik et al. (Int. Workshop on Reconnection in Space Plasma 179), Zhilyaev (Kinematic Phys. Celestial Bodies 7, 61) and Pustil'nik (AMD 504) have subjected rapid photometric observations to exhaustive statistical tests and conclude that, in general, stellar flares are not detected on time scales of less than a few tenths of a second. This is consistent with a thermal origin for the optical continuum emission.

Models of Stellar Flares. The successful development of computer codes for the interpretation of spectroscopic, photometric and X-ray data on flares has been one of the most productive areas of research over the past few years. A model by Hawley and Fisher (ApJS 78, 565; ApJS 81, 885; ApJ 357, 243) which included the effects of chromospheric evaporation and heating by coronal X-rays gave a good fit to observed transition region fluxes. However it predicted a continuum flux redder than that observed. Hawley and Fisher propose that the observed continuum is formed by photospheric reprocessing of the EUV and UV emission originating in the chromosphere.

The gas-dynamic model for a flare kernel, developed by Katsova and Livshits (Sov AJ 35, 65), has been used to describe the high time resolution observations of the CIV (1550Å) line by the ASTRON satellite and the rapid 1^s microflares seen by the 6m telescope. Houdebine (Irish AJ 20, 213) finds that a 'flare kernel' model is more successful in predicting the observed time profiles in optical emission lines etc. than soft X-ray backwarming or radiative pumping.

The X-ray emission from stellar flares is, on the solar model, believed to originate in giant magnetically confined loops. Cheng and Pallavicini (ApJ 381, 234) have modelled the process for dMe stars with good agreement of X-ray intensities, time profiles and coronal temperature with observations. The application of scaling laws to such models has been discussed by Reale et al. (AA 272, 486).

The primary source of the energy for solar and stellar flares is widely believed to lie in the disruption and reconnection of magnetic fields. However, this view is not universally held. Two papers on alternative schemes appeared: firstly a convective model by Grandpierre (MSAI 62, 401) and secondly a linear Z-pinch mechanism by Airapetyan and Nikogosyan (Ap 30, 329) and Airapetyan et al. (Ap 32, 230) in which rapid heating of the plasma follows a sudden compression by the magnetic field similar to that which occurs in 'Tokamak' machines.

The transport of the released energy down to the chromosphere and upper photosphere, where it is believed to be responsible for the optical emission, is also a controversial topic. Fast electrons are commonly considered to be responsible, however Mullan (Irish AJ 361, 215) and Grinin (MSAI 62, 389) have pointed to problems with this interpretation. Grinin and Sobolev (Ap 31, 729) have shown how the dependence of flare continuum colours on flare amplitude can be predicted by a proton heating theory. Direct evidence for proton beams during the impulsive phase of a flare on AT Mic, observed by the HRS on the HST, has been given by Woodgate et al. (ApJ 397, L95).

Flares on Non-Red-Dwarf Stars. Flare activity has, until recently, been largely the preserve of late type dwarfs and their close associates in the HR diagram. Evidence is now accumulating that magnetic activity is much more widespread than once thought; it has been observed (in one spectral range or another) in main sequence stars from B to M type and over a luminosity range from supergiants to dwarfs. Thus neither low temperature nor low luminosity are pre-requisites for flare activity. Flares have been recently reported on the following non-red-dwarf types: Miras (Shaefer, ApJ 366, L39), Low Mass X-ray Binaries (Kuijpers, NATO Adv. St. Inst. Active Close Binaries, 761), Algol systems (Stern et al. 6CW, 224) an FK Comae star (Cutispoto et al. AA 263, L3), an A type star (Wang IBVS #3863), a Be star λ Eri (Smith et al. ApJ 409, L49) and RS CVn stars (Stern et al. 6CW 227; Doyle et al. AA 262, 533; AAS 96, 351; MN 248, 503; Mathioudakis et al. MN 255, 48; Tagliaferri AA 251, 161; Henry and Hall, ApJ 373, L9; Huenemoerder et al. 6CW, 236). Though binarity is common in this list, it too is not a pre-requisite condition (witness FK Comae types and λ Eri). Other than dMe stars, the largest group of stars with well established flare activity are the RS CVn binaries on which reviews have recently been written by Neff (MSAI 62, 291), Kuijpers (ref above) and Ramsey (6CW, 195).

The enormous energies in some non-red-dwarf stellar flares ($\sim 10^{39}$ ergs on HD 32918, by Cutispoto) continues to stretch the solar analogy to its limits. The volume of plasma required to radiate the total energy observed in some RS CVn flares is comparable with the volumes of the systems themselves, suggestive of enormous magnetic loops linking the binary components. In this context the VLBI observations of a flare on HR 1099 by Triglio et al. (MN 260, 903) are important in that they confirm the involvement of a region with a linear size equal to the separation of the binary components.

Coordination of Multiwavelength Observations. The value of stellar flare observations is considerably increased if they are made over a broad spectral range and in particular if they include X-ray, UV, optical spectroscopy and radio coverage. Whilst the coordination of the various space and ground-based facilities poses many problems, it can and has been done, with dramatically successful results. A network of interested ground-based observers can be contacted via an email newsletter operated by the author. Those who would like further information are invited to contact CJB@STAR.ARM.AC.UK by Internet or the author at Armagh Observatory, BT61 9DG, N. Ireland by ordinary mail.

13. Variability of T Tauri Stars (L. Hartmann)

In the last year, great strides have been made in understanding the variability of T Tauri stars. Many pre-main sequence stars have large starspots on their surfaces, and these spots cause the apparent flux of the star to vary as the spot rotates into and out of view (Rydgren & Vrba ApJ 267, 191; Rydgren et al. AJ 89, 1015; Vrba et al. AJ 97, 483). Progress in understanding the light curves has been slowed by the difficulty of obtaining photometry extending over the typical one-week rotation periods. However, extensive campaigns of photometric monitoring have been mounted (Attridge & Herbst ApJ 398, L61; Edwards et al. AJ, in press), using telescopes at different sites (Bouvier et al. AA 272, 176). This work has led to a much better understanding of T Tauri variability. Most importantly, the determination of accurate rotational perods for T Tauri stars has led to a surprising result, with important implications for understanding the early angular momentum evolution of solar-type stars.

The extensive study of pre-main sequence stars in the Taurus-Auriga molecular cloud by Bouvier et al. (AA 272, 176), building on earlier work (Rydgren & Vrba; Rydgren et al.; Vrba et al.; ref. cit.), has led to the following picture of spot properties. First, many T Tauri stars exhibit spots. The clearest, most stable light curves are exhibited by the so-called "weak-emission" T Tauri stars or WTTS. Simple models suggest that the spots on WTTS are generally cooler than that of the surrounding photosphere. The "classical" or strong-emission T Tauri stars (CTTS), on the other hand, show much less clear photometric periods in general, and the optical colours suggest either hot or cool spots. In either case, the spot areas must be quite extensive, covering tens of percent of the photospheres of these stars.

These properties can be explained nicely with the standard model of T Tauri stars, in which the strong emission of the CTTS is powered by accretion from a circumstellar disk (Liseau et al. AA 183, 274; Bertout et al. AA 330, 350) while the WTTS show only chromospheric emission from solar-type activity, since they have no accretion disk (at least close to the star) (Walter et al. AJ 96, 297; Cabrit et al. ApJ 354, 687; Edwards et al. AJ, in press). In this model the WTTS show large spots due to enhanced solar-type magnetic activity. The CTTS also have spots, but the magnetic fields channel the accretion to the stellar surface, where it can create a hot spot for sufficiently rapid mass flow. Hence, depending upon the accretion rate, the spot may appear hot or cool. Moreover, it is likely that accretion is non-steady (Bouvier et al. AA 272, 176), which provides a natural explanation of the aperiodicity seen in some CTTS light curves.

The most interesting results concern the rotational periods. Attridge and Herbst (ApJ 398, L61) showed that the stars in the Orion Nebula Cluster (Trapezium cluster) exhibited a bimodal distribution in their photometric periods. Attridge and Herbst speculated that some sort of magnetic braking might produce this bimodal distribution. Edwards et al. (AJ, in press) followed up this work, identifying the spectral types of the stars observed by Attridge and Herbst. Combining these with previous results for stars in Taurus, the results showed that low-mass T Tauri stars ($\sim$0.8-0.5$M_\odot$) rotate more slowly if they have infrared excesses thought to signify the presence of an inner accretion disk, while diskless stars were faster rotators. This was true even though the stars with and without disks had similar ages and masses. Simultaneously, Bouvier et al. (AA 272, 176) found similar results from their extensive monitoring of Taurus pre-main sequence stars, using a distinct but not completely independent sample. Bouvier et al. found that K7-M1 CTTS (stars with accretion disks) have rotational periods of 7.6 ± 2.1 days while the WTTS (weak-emission, stars without inner disks) have rotational periods of 4.1 ± 1.7 days. Thus, it appears that the presence of a circumstellar disk is strongly correlated with slower rotation in T Tauri stars.

This is an exciting result because it addresses a long-standing problem in the early evolution of solar-type stars. Current thinking suggests that T Tauri stars accrete substantial amounts of mass from circumstellar disks (Lynden-Bell & Pringle MN 168, 603; Bertout et al. AA 330, 350). This material contains substantial angular momentum, and would very likely spin up the central star to velocities close to breakup in the absence of any other angular momentum transfer (Hartmann et al. ApJ 309, 275). Yet most T Tauri stars rotate at $\sim$10% of breakup or less (Bouvier et al. AA 165, 110; Hartmann et al. ApJ 309, 275; Bouvier AJ 99, 946). One standard explanation of this result is that a solar-type, magnetically-coupled stellar wind could carry away the needed angular momentum. However, this is difficult to explain in terms of the observed rotational velocities of young cluster stars, which suggest that they spun up as they contracted to the main sequence with very little, if any, angular momentum loss. In other words, the wind mechanism has to be very efficient, spinning down the T Tauri star as it rapidly acquires angular momentum on a typical time scale of 10^6 yr or less; but the subsequent stellar wind must be very inefficient in carrying away angular momentum during the $\sim 5 \times 10^7$ yr contraction to the main sequence.

Königl (ApJ 370, L39) (see also Camenzind (Rev. Mod. Ast. 3, 234) and Cameron & Campbell (AA, in press) proposed that T Tauri stars have extensive magnetic fields which couple to their circumstellar disks. In this situation it is possible for the star to transfer angular momentum to the disk, in a manner similar to that originally suggested for pulsars. This suggestion can explain the early spin evolution of solar-type stars. In the earliest phases, the disk-magnetosphere coupling prevents the star from spinning up to breakup as it accretes. Later on, when the disk dissipates or is all accreted, there is nothing to prevent the star from spinning up as it contracts to the main sequence, except for the stellar wind, which slows down the star on much longer time scales. The new rotational period determinations seem to provide some important support for a model in which the existence of a circumstellar disk provides a sink for stellar angular momentum via magnetospheric coupling.

Photometry and spectroscopy of the T Tauri star RY Lup by Gahm, Liseau, and collaborators (AA 183, 274; AA 211, 115; AA, in press) has suggested light variability due to variable extinction with a period of 3.75 days, comparable to the expected rotation period for this G8 star given the measured v sin i. It is conceivable that an asymmetric stellar magnetic field, rotating with the star, could disrupt the disk asymmetrically and produce variable disk extinction; more work should be done to test this possibility. Alternatively, if magnetic fields channel accretion as suggested by Bertout et al. (AA 330, 350) for DR Tau, then the light curves could be quite complicated, with a mixture of underlying dark, cool stellar photospheric spots along with bright, hot spots at the base of the accretion column. The resulting effects could be quite complex, and have not been thoroughly explored.

If spindown is accomplished by coupling the disk to the star by the stellar magnetic field, then the disk must be disrupted at several stellar radii. In turn, this implies that the accretion onto the star is through a magnetosphere, and not through the disk. The observations of ultraviolet excess emission must then be interpreted in terms of accretion columns rather than hot spots. Moreover, if the accreting gas is sufficiently hot, it might produce observable emission lines. In fact, Calvet and Hartmann (ApJ 386, 239) have proposed that the permitted emission lines of many T Tauri stars arise in infalling matter channeled by the stellar magnetic field, because infall models are able to explain many observed line profiles much better than wind models. In this picture most of the emission arises in infalling material in the magnetosphere, while the wind components arise in a much more tenuous flow further out. Further tests of this picture, with improved observational surveys and radiative transfer solutions, are forthcoming. For example, periodic behaviour in the wind of SU Aur has been found by Giampapa et al. (ApJ, in press). Observations of T Tauri line profiles, especially in conjuction with simultaneous photometry, may provide strong evidence for magnetospheric infall, and hence support the magnetosphere-disk interaction model for the spindown of young solar-type stars.