27. VARIABLE STARS (ETOILES VARIABLES)

PRESIDENT: B. Szeidl
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ORGANIZING COMMITTEE: A.N. Cox, R.E. Gershberg, M. Jerzykiewicz, L.N. Mavridis, L.N. Mirzoyan, J.R. Percy, M.A. Smith, A.M. van Genderen, B. Warner

1. Introduction

The field of variable star research has become so broad and the amount of research to be reported on has grown so rapidly that it is a vain hope that a report of this kind, in a very limited space, could cover the whole field of research and could mention all the papers that have been published in the last three years. It is only hoped that this report presents the significant results achieved in the field of the most important aspects of variable star research. Some important subjects (e.g. cataclysmic variables) relevant to the variable star research are reviewed in the reports of other commissions. This is a consequence of the fact that the research has become very complex and the phenomena producing light variability belong to the field of interest of other commissions, too.

Before reporting the scientific works, three short reports about ongoing activities of the Commission are given. In general the abbreviations for identifying the cited publications are the same as used in the previous triennial report.

The commission president is very grateful to the authors for their individual contributions.

2. Commission Activities

A. ARCHIVES OF UNPUBLISHED OBSERVATIONS: 1984-1987 (M. Breger)

The Archives of Unpublished Photoelectric Observations of Variable Stars was created to provide permanent archives in different parts of the world.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

The number of completed files with data sets has grown to 174, and considerably more files have been assigned to data not yet received. The time period has been one of rapid growth. Rapid retrieval of past files, often at no cost, has been reported from the depositories.

The Publications of the Astronomical Society of the Pacific has kindly agreed to publish, on a regular basis, the summaries of recent files. Detailed reports can be found in PASP 91.408; 93.528 and 97.85. Other summaries and announcements can be found in the Information Bulletin on Variable Stars. At present, astronomers who wish to obtain unpublished photoelectric measurements on variable stars may do so by requesting whole files (not partial files) from one of the three archives:

P.D. Hingley, Librarian,	Dr. C. Jaschek,	Dr. Yu.S. Romanov,
Royal Astronomical Society,	Centre de Données Stellaires,	Odessa Astronomical
Burlington House,	Observatoire de Strasbourg,	Observatory,
London, W1V ONL,	11, Rue de l'Université,	Shevchenko Park,
Great Britain	F-67000 Strasbourg,	Odessa 270014,
	France	U.S.S.R.

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The requested file number should be specified. There is no charge for short files.

Astronomers who wish to submit new files, should submit three copies of the data and five copies of the cover sheet to the Coordinator, who will forward the data with the cover sheet to the three archives. Please consult IBVS, 2853, 1986 for helpful details and formats. If a new file number is required for scientific publications (in place of extensive tables of measurements), the file number can be assigned by the Coordinator before receipt of the actual measurements. The address is:

Prof. Dr. Michel Breger,
Institut für Astronomie,
Türkenschanzstr. 17,
A-1180 Wien,
Austria

The main purpose of the Archives has in the past been to preserve and make available data in paper form. Through the Centre de Données Stellaires in Strasbourg it is possible to submit new data by computer tape (ASCII), diskettes, or computer networks.

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

53.	HD 219989	- D.S. Hall
54.	HR 454	- D.S. Hall
90.	SV Cam	- A. Cellino
139.	V396 Per	- D.S. Hall
142.	λ And	- A. Cellino
143.	AR Dra	- P. Broglia
144.	RS Cep	- E.C. Olson
145.	Φ Cas	- A. Arellano-Ferro
146.	AC And	- R. Robb
147.	22 late-type stars	- J.A. Eaton
148.	RS CVn	- J.A. Eaton
149.	V444 Cyg	- J.A. Eaton
150.	HR 6469	- D.S. Hall
151.	HD 8358	- D.S. Hall
152.	CZ Aqr	- J.R. Burton
153.	σ Gem	- K. Strassmeier + D.S. Hall
179.	Bright Southern Be Stars	- C. Stagg
181.	UV Psc, UX Ari	- F. Scaltriti
182.	FO Vir	- J.D. Fernie
183.	λ And	- E.S. Guinan + S.W. Walker
184.	EG Cep	- J. Kaluzny + I. Semeniuk
185.	VY Lac	- J. Kaluzny + I. Semeniuk
186.	λ Eri	- J.R. Percy
187.	27 Cyg	- J.R. Percy
188.	YY Gem	- E.H. Geyer + B.D. Kämper
189.	TZ CrB	- A. Giménez
190.	U Sag	- E.C. Olson
191.	CW Cep, Y Cyg, AG Per	- A. Giménez
192.	BP Mus	- Z. Kviz
193.	Cluster Stars	- J.R. Sowell
194.	YZ Cas	- R. Diethelm
195.	RU Cnc, VV Mon, TY Pyx	- F. Scaltriti
196.	SAO 77615, AZ Vir	- R.M. Campbell
197.	RS Ind	- M.A. Cerruti
198.	V677 Cen	- R.H. Koch
199.	BW Vul	- A.P. Odell
203.	RZ Oph	- E.C. Olson
204.	CG Cyg	- J.R. Sowell

B. GENERAL CATALOGUE OF VARIABLE STARS (N.N.Samus)

During the last three-year cycle the compilation and publication of the 4th edition of the General Catalogue of Variable Stars (GCVS) has been continued. Volume I (Andromeda - Crux), and Volume II (Cygnus-Orion) of the GCVS appeared in 1985, Volume III (Pavo-Vulpecula) was published by "Nauka" Publishers in 1987 (Editor-in-chief: Prof. P.N. Kholopov). Thus, the publication of the main body of the Catalogue, comprising data for 28435 variable stars of our Galaxy, has been completed. The magnetic tape version of the main table of the GCVS for astronomical data centres has been prepared. The 67th Name-List of Variable Stars was published in 1985; the 68th Name-List was compiled in 1987. These two Name-Lists contain final GCVS designations for 1310 new variable stars not yet entered in the GCVS IV. The Name-Lists have been prepared in a new form providing users not only with identification data, but also with basic information on the character of variability of the stars.

The preparation of Volume IV of the GCVS is now under way. It will contain

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information on approximately 10000 variable stars in external galaxies (information of this kind is being included in the GCVS for the first time), as well as on optically variable quasars, galactic nuclei, and BL Lacertae objects. In the course of this work numerous inconsistencies in the coordinates of Magellanic Cloud variable stars, as well as unknown cross-identifications among these variables and of these variables with stars of the main body of the GCVS or with stars of the NSV catalogue have been found. The work on Volume V has been commenced; this volume along with the lists of variables in the order of their right ascensions and of variable stars arranged according to their types of variability, will contain detailed cross-identification tables with principal astronomical catalogues. Such cross-identification tables have not been published since 1958. The compilation of the Astrometric Supplement to GCVS has also been initiated; it will present accurate coordinates for variable stars with available astrometric data.

The members of Commission 27 will have their complimentary copies of the GCVS Volume III forwarded to them in due course. The 68th Name-List has been published in IBVS 3058.

C. INFORMATION BULLETIN ON VARIABLE STARS (L. Szabados)

During the period covered by this report, the number of issues of the IBVS progressed from No.2544 (July 1984) to No.3041 (June 1987). The yearly average of published issues is somewhat lower than during the previous three years. This decrease is mainly due to the fact that the editors now impose stricter requirements when receiving the submitted manuscripts. This procedure cannot be avoided because Konkoly Observatory is unable to publish more than 200 issues per year, nor have the editors the intention of allowing the scientific level of the IBVS to decrease. If a system of independent referees were to be introduced, this would jeopardize the promptness of publication. All correspondence concerning the IBVS should be addressed to:

The Editors, IBVS
Konkoly Observatory,
H-1525 Budapest, P.O. Box 67,
Hungary

3. Early-Type Variable Stars
(John R. Percy)

INTRODUCTION

Review papers on early-type variables appear in Highlights of Astronomy vol. 7 p221; 229; 247; 255; 265 and 273; and in proceedings of other conferences on stellar pulsation and on UV astronomy. For a complete bibliography, see Astronomy and Astrophysics Abstracts.

Information about early-type variables has been obtained not only by conventional techniques but also by strategies such as: UV spectroscopy and photometry from space (IUE, Voyager and Pioneer), sometimes during multi-technique and multi-longitude "campaigns", collaborative monitoring of slow variables (such as by the ESO observers led by Sterken /IAPPP Comm 22.42/), and high S/N spectroscopy of line-profile variations. To monitor southern variables continuously in winter, LeContel and Valtier proposed a photometric telescope at the south pole, and other astronomers have proposed a network of automated (or non-automated) telescopes at different longitudes. Automated photometric telescopes are now in routine operation.

NORMAL B STARS

Searches for β Cep stars have been carried out in NGC 6231 by Balona & Engelbrecht (MN 212.889), in the Scorpius complex by Waelkens & Cuypers (AA 152. 15), in NGC 3766 by Balona & Engelbrecht (MN 219.131), and in IC 4996 by Delgado et al. (AA Supp 61.89). Chapellier et al. (AA 143.466) observed αVir in 1983 and found marginal evidence for pulsation; Sterken et al. (AA 169.166) found no pulsation on 13 nights in 1985. Smith (ApJ 297.206 and 224) found commensurable l=m=-8 and -16 modes and a quasitoroidal mode in α Vir. Goossens et al. (AA 140.223) reanalyzed van Hoof's photometry of σ Sco. Sterken (AA Supp 58.657) and Jerzykiewicz & Sterken (MN 211.297) obtained new observations of this star, and derived four periods. Costa & Ringuelet (Rev Mex AA 10.293) discussed the van Hoof effect in this star, and Dunham (Occultation Newsletter 3.16.346) discussed its close binary nature. Kubiak and Seggewiss (Acta Ast 34.41) obtained spectroscopy and photometry of HR 6684. Cuypers (AA Supp 69.445) analyzed new and existing photometry of τ' Lup, finding a single period with dP/dt < 0.5 s/century. Sterken et al. (AA Supp 66.11; AA 177.150) obtained photometry of BW Vul from 13 sites, and found a stable light curve. BW Vul was observed by Herrera et al. (IBVS 2597) and Jung & Lee (J Korean Ast Soc 18.1). Barry et al. (ApJ 281.766) observed BW Vul with Voyager 2, and measured the temperature and UV and radius amplitude. Peters et al. (ApJ 314.261) observed γ Peg and δ Cet with Pioneer 10. Van der Linden & Sterken (AA 150.76) identified HR 5488 as a β Cep star, and found a triplet of frequencies. Valtier et al. (IBVS 2843) observed three β Cep stars. Chapellier et al. (AA 176.255) observed small variations in ι Her, Wolf (IBVS 3003) found an increased amplitude in 53 Psc. Sterken (AA, in press) found no variability in 53 Ari. Clarke (AA 161.412) found no pulsation-related polarization variations in three β Cep stars.

Shobbrook (MN 214.33) used an improved luminosity calibration to derive Q-values for β Cep stars, which suggest that most of the stars are pulsating in the first overtone. Balona (preprint) noted the occurrence of β Cep stars near the ZAMS in clusters. Engelbrecht & Balona (MN 219.449) discovered that HD 92024 in NGC 3293 is an 8-day eclipsing binary β Cep star. Engelbrecht (MN 223.189) used the β Cep stars in NGC 3293 to derive Q-values and period ratios for mode identification. Other studies involving β Cep stars in clusters are noted above.

Chapellier (AA 147.135) proposed that all long-term period changes in β Cep stars are abrupt. He also noted slow cyclic changes in amplitude (AA Supp 64.275), and in phase lag between light and velocity (AA 163.329) in several β Cep stars. However Jerzykiewicz (AA, in press) cautioned against inferring amplitude changes in such stars from inadequate data. Balona (MN 217.17p) suggested that the amplitude changes in α Vir and 16 Lac might be due to precession in a binary system. Jerzykiewicz (Acta Ast 34.409) has commented on the absence of β Cep stars in close binaries. Sato & Hayasaka (PAS Japan 38.47) confirmed the slow amplitude change of one period in 16 Lac. Sareyan et al. (AA Supp 65.419) detected slow amplitude changes in δ Cet from multi-longitude photometry. Cuypers (AA 167.282) used a new period analysis method to derive a dP/dt of +0.14 s/century in δ Cet. Bloome & Hensberge (AA 148.97) determined mass-loss rates for BW Vul and σ Sco from UV spectra.

53 Per stars are normal OB stars which undergo pure non-radial pulsation (NRP). Until recently, NRP has been studied by comparing theoretical and observed line profiles. Balona used the moments of the line profile to derive NRP periods and modes (MN 219.111) and developed a quantitative algorithm for applying it (MN 220.647). He also investigated the effects of temperature variations on the line profiles (MN 224.41). Baade (IAU Symp 132) and Gies & Kullavanijaya (preprint) carried out period analyses of time series of line profiles of B stars, deconvolved with the window function by means of the CLEAN algorithm. This enabled them to derive NRP periods and modes in these stars. The bright B0.7III star ε Per was studied by Smith (ApJ 288.266: identification of three low-order prograde modes from line-profile variability; ApJ 307.213: investigation of NRP and vertical shocks as a means of driving mass loss), by Smith et al. (ApJ, in press: results of a coordinated spectroscopic-photometric study of the star in 1984) and by Gies & Kullavanijaya (preprint: detection of four low-order modes by the method mentioned above). Smith (ApJ 304.728) identified six commensurable NRP modes in the B0.3IV star δ Sco. Photometric studies of 53 Per stars were carried out by Balona & Engelbrecht (MN 214.559); Waelkens & Rufener (AA 152.6) discovered several probable 53 Per stars. Balona (preprint) reinterpreted existing photometry

of 53 Per in terms of a double-wave light curve with a period of 3.45 days. Balona & Laing (MN 223.621) suggested that two suspected 53 Per stars may actually be ellipsoidal variables. Gry et al. (AA 137.29) and Prinja & Howarth (ApJ Supp 61. 357) discussed the narrow absorption components which occur in the UV spectra of ε Per and many luminous OB stars.

The "hypothetical" Maia variables are a group of mid- to late-B stars, suspected by Otto Struve and others of light and velocity variations. Photometric surveys of Pleiades stars by McNamara (ApJ 289.213) and of mid-B field stars by Waelkens & Rufener (AA 152.6) yielded several new low-amplitude variables with periods about a day. This suggests that the Maia variables are the same as 53 Per stars - probably non-radial pulsators. The Maia star 23 Tau is an X-ray source (Micela et al. ApJ 292.172).

Be STARS

Most aspects of Be stars were reviewed in "The Physics of Be Stars" (ed. Slettebak, Cambridge, 1987); see also the report of Commission 29 in this volume. That Commission's Be Star Newsletter (ed. Peters) contains a complete bibliography on Be stars. Baade (AA 148.59) reviewed concepts of modelling Be stars.

Long-term photometric variations of Be stars continue to be monitored by Harmanec and colleagues (Ondrejov), Percy (Toronto), Halbedel (Las Cruces) and others. Spectroscopic variations are monitored by Barker (London, Canada). Doazan and colleagues studied long-term visual/UV variability of several stars: 59 Cyg (AA 152.182), Θ CrB (AA 158.1; 170.77; 173.L8), 88 Her (AA 159.65 and 75) and γ Cas (AA, in press). The polarimetric monitoring program of Hayes at Columbia U. has unfortunately been terminated. Short-term variability of southern Be stars was surveyed by Stagg (MN 227.213). Balona studied Be stars in NGC 3766 (MN 219. 131), and in the field (IAU Coll 92), and found that the majority have double-wave light curves. Balona et al. (MN 227.123) found 1.26 day photometric variability in α Eri - the brightest Be star.

There are two main models for the short-term variability of Be stars: rotation (spots or circumstellar matter) and NRP. Evidence for the former includes the time scales, the double wave light curves, and the analogy to magnetic oblique rotators such as σ Ori E (Harmanec, BAI Czech 35.193). Harmanec et al. (IAU Coll 92) fitted a spot model to light curves of o And. Clarke & McGale (AA 169.251;178.294) modelled the polarization curves of Be stars in terms of inhomogeneities in an extended atmosphere. The non-radial pulsation model is supported most strongly by the extensive spectroscopic studies of Baade and of Penrod (IAU Coll 92), who find low-order (l=2) NRP modes in all Be stars observed. Photometric variations with the same period, and (variable) amplitudes up to 0.1 occur in the same stars.

Changes in the NRP amplitude may produce mass-loss episodes; see the proceedings of "The Connection between Non-Radial Pulsation and Stellar Winds in Massive Stars" (PASP 98,29) for a discussion. It is difficult to test this theory observationally, but Guinan & Hayes (ApJ 287.L39) and Peters (ApJ 301.L61) observed the rapid onset of emission episodes in ω Ori and μ Cen. A major campaign on o And, KY And, ω Ori and λ Eri was carried out in 1987 to obtain a "multi-wavelength understanding" of the short-term variability. As in the case of other pulsating B stars, the cause of the variability is unclear. Osaki's (ApJ 189.469) mechanism is still promising, and Ando (AA 108.7; 163.97) explored the wave-rotation interaction as a way of feeding pulsation energy into the wind.

O STARS AND WOLF-RAYET STARS

The variability of O and WR stars in the visible and UV has been reviewed by Baade and by Henrichs in "O, Of and WR Stars" (ed. Conti & Underhill, NASA 1987). Many O stars are photometric variables, though no thorough survey has been done. Fullerton et al. (J.P. Cox Symp) have surveyed line-profile variability in 46 O stars, and found it in about a third. O stars previously known to be line-profile variable include 10 Lac, υ Ori, ζ Oph and ζ Pup. The variability is thought to be due to non-radial pulsation, but the driving mechanism is unknown.

Vreux et al. proposed that the velocity variations in HD 192163 (AA 149.337)

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and other WR stars (PASP 97.274) may have periods < one day (rather than several days as previously believed) and may therefore be due to pulsation. Both the time scale and the complex spectra of WR stars make it difficult to confirm this suggestion. Maeder (AA 147.300) and Cox & Cahn (preprint) have found a radial pulsation instability in some model WR stars, driven by nuclear processes; the period is < one hour. Lamontagne & Moffat (preprint) found no brightness variations in one WR star on this scale. Scuflaire & Noels (AA 169.185) found that NRP modes may be trapped and amplified in H-burning shells in WR stars.

OB SUPERGIANT VARIABLES

S Dor or Hubble-Sandage variables were reviewed in three papers in "Luminous Stars and Associations in Galaxies" (ed. de Loore et al., D. Reidel Co.) p139,p151 and 157, and at an April 1986 conference on "Instabilities in Luminous Early Type Stars" (ed. Lamers & de Loore, to be published by D. Reidel Co.). Van Genderen and his colleagues continued to search for and observe OB supergiant variables (AA 151.349; 153.163; 157.163; AA Supp 61.213; 62.291). They have irregular light curves with amplitudes of up to 0.1 and time scales of days to weeks, depending on their Mbol and Te. Stahl & Wolf (AA 154.243) studied R127, an erupting S Dor star. Percy et al. (AA, in press) investigated the light curve of P Cyg over two years, and Markova (AA 162.L3; Ap Sp Sc 123.5) investigated the spectrum, and concluded that there are both pulsations and expanding shells in the atmosphere of this star. Both van Gent & Lamers (AA 158.335) and Percy et al. have concluded that P Cyg is not periodic, but has a quasi-period of about 40 days. Baade & Ferlet (AA 140.72) observed line-profile variability in γ Ara (B1Ib). This and other studies suggests that the variability of OB supergiants is due to nonradial pulsation, but Harmanec (BAI Czech 38.52) proposed that it may be due to duplicity or rotation.

HOT DEGENERATE VARIABLES

The PV Tel variables (as they are now called in the GCVS) are hot hydrogen-deficient stars with temperatures and luminosities similar to those of the β Cep stars. They are part of a sequence which includes the R CrB stars. Various papers on these stars appear in "Hydrogen-Deficient Stars and Related Objects"(ed. Hunger et al., D. Reidel Co., 1986), including a comprehensive review by Landolt. Hill and colleagues at St. Andrews (Scotland) published several papers on individual stars: BD+10^{o}2179 (MN 207.823), BD+13^{o}3224 (MN 209.387; 210.731; 221.975), BD+1^{o}4381 (MN 213.61P; 224.1083), HD 168476 (AA Supp 61.303), BD-9^{o}4395 (MN 217.701), CPD-58^{o}2721 (IAU Circ 4086; 4097; MN 225.1005), υ Sgr (MN 222.543), LSIV-1^{o}2 (MN 224.1083), V348 Sgr (IAU Circ 4399), KS Per and LSII+33^{o}5 (MN, in press) and HD 160641 (MN, in press). Virtually all the hot hydrogen-deficient stars show small, complex (except in the case of BD+13^{o}3224) and often sporadic variability, in some cases radial, and in other cases, non-radial. BD+13^{o}3224 appears to be contracting to the helium main sequence (Jeffery, MN 210.731). Ando (MN 221.1P) constructed models of BD+13^{o}3224; the radial periods agreed with the observed period, but the radial modes were all stable.

The DB variables are hot helium white dwarfs, pulsating non-radially with periods of minutes. According to Liebert et al. (ApJ 309.241), 23,000 < Te < 28,000 K approximately; the prototype GD358 has Te = 24,000 K and log g = 8.0 (Koester et al., AA 149.423). Winget et al. (ApJ 316.305) observed PG1115+158, which has a complex mixture of periods, and PG1351+489, which has only a single period (489.5 s), unlike the other three members of this class. Hansen et al. (ApJ 297.544) and Cox et al. (ApJ 317.303) studied the pulsational stability of models of these stars.

The PG1159-035 (GW Vir) stars are hot (80,000 < Te < 160,000) degenerate (6 < log g < 8) stars which show complex, non-radial pulsation. Five such variables are known: PG0122+200, PG1159-035, PG1707+427, PG2131+066 and the nucleus of PN K1-16. Grauer et al. (preprint) surveyed 15 candidate stars and found only one new variable. This seems to indicate that not every star in the PG1159-035 instability strip is variable. The pulsations are thought to be due to the effect of the C and O ionization zones, or possibly to helium shell burning instabilities (Kawaler et al., ApJ 306.L41). Barstow et al. (ApJ 306.L25) reported X-ray pulsations in PG1159-035 itself. These stars were reviewed by Winget and by Cox (Highlights of Astronomy vol. 7, p221 and 229). (A more detailed review on these objects is given by D.E. Winget in this report.)

4. Cepheids
(E.G. Schmidt)

INTRODUCTION

During the interval surveyed, the proceedings of two conferences on pulsating stars have appeared, "Cepheids: Theory and Observations", IAU Colloquium No. 82, and "Stellar Pulsation", a conference held as a memorial to John P. Cox (Lecture Notes in Physics No. 274, eds. Cox, Sparks & Starrfield, Springer-Verlag, referred to below as St Puls). Both contain reviews and contributed papers which summarize recent work on Cepheids. Böhm-Vitense and Querci (in Exploring the Universe With the IUE Satellite, ed. Kondo, Reidel, p. 233) reviewed ultraviolet observations of Cepheids and other pulsating stars.

LIGHT AND VELOCITY DATA

A considerable amount of new, high quality, well-sampled light and velocity data has been published during the past few years. Notable studies include those of Moffett & Barnes (photometry of 112 Cepheids: ApJ Supp 55.389; summary of mean parameters: ApJ Supp 58.843), Barnes & Moffett (velocity curves for 88 stars from the same sample: IAU Coll 82.32), Berdnikov (photometry of 77 stars: Per Zv 22. 69), Caldwell & Coulson (photometry of SMC Cepheids: SAAO Circ 8.1), Coulson et al. (photometry and velocities for six stars: ApJ Supp 57.595), Coulson & Caldwell (photometry and velocities for 27 stars: SAAO Circ 9.5), Eggen (intermediate band photometry of 50 Cepheids: AJ 90.1297), Evans & Lyons (velocities for three stars: AJ 92.436) and Imbert et al. (velocities for six LMC Cepheids: AA Supp 61.259).

PULSATIONAL PROPERTIES

Fourier decomposition has been employed extensively to study the pulsational properties of Cepheids. Topics explored in this way include trends of light curve properties with period (Simon & Moffett, PASP 97.1078), the properties of type II Cepheids (Simon, ApJ 311.305), the phase lag between velocity and light (Simon, ApJ 284.278) and the comparison of LMC Cepheids with those in the Galaxy (Andreasen & Petersen, St Puls, p195). Petersen (AA 170.59) has developed methods of estimating the errors in this technique.

Fernie & Chan (ApJ 303.766) showed that stars with periods between 7.2 and 11 days exhibit a remarkably small range of amplitude while Tsvetkov (Ap Sp Sc 116. 43) derived relations among various amplitudes. Moffett (IAU Symp 118.305) pointed out that light curve dips are potentially important to pulsation.

Arellano Ferro (MN 209.481) and Antonello & Poretti (AA 169.149) have studied the properties of the low amplitude short period type S (also called type C) Cepheids and conclude that they are almost all fundamental pulsators. Why they appear distinct from the larger amplitude Cepheids (as shown by Eggen, AJ 90.1278) is not yet clear. Eggen's (AJ 90.1260) suggestion that the S Cepheids are on the first crossing of the instability strip deserves further consideration.

Double mode Cepheids seem to have attracted less interest from observers than in the past but Gieren (IAU Coll 82.98) presented evidence for double mode behavior for EU Tau and new periods were derived for EW Sct (Cuypers, AA 145.283) and CO Aur (Antonello et al., AA 159.269). The latter star has the unusual period ratio of 0.8007 which the authors attribute to the presence of the first and second overtones. Balona & Engelbrecht (IBVS 2758) showed that BQ Ser is near the cool edge of the instability strip unlike other known double mode Cepheids.

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RADII

There is continued interest in the radii of Cepheids. Fernie (ApJ 282.641) compared the period-radius relations derived by various methods and found serious disagreements. A number of investigators have used versions of the Baade-Wesselink method to try to improve this situation. Noteworthy are studies by Burki (IAU Coll 82.34), Caccin et al. (IAU Coll 82.43), Welch et al. (IAU Coll 82.51), Barnes & Moffett (IAU Coll 82.53), Gieren (ApJ 282.650) and Coulson et al. (ApJ 303.273). A recent discussion of the period-radius relation by Moffett & Barnes (St Puls p169) shows that progress has been made.

THE TEMPERATURE SCALE

Teays & Schmidt (St Puls p173) derived a new effective temperature scale from Cepheid energy distributions. It agrees with the cooler among previous scales.

CEPHEIDS IN CLUSTERS AND ASSOCIATIONS

The search for additional calibrating stars for the PLC relation has been an active area. Cluster or association membership has been discussed for SU Cas (Turner & Evans, ApJ 283.254), BB Sgr (Turner & Pedreros, AJ 90.1231), three Cepheids in NGC 6067 (Walker, MN 214.45; Coulson & Caldwell, MN 216.671; Moffett & Barnes, MN 219.45P), V 378 Cen (Turner, ApJ 292.148), TW Nor (Anderson et al., IAU Coll 82.203), SZ Tau (Gieren, AA 148.138) and S Vul (Turner, JRAS Can 79.175). Attempts to locate associations near southern Cepheids have been mostly unsuccessful (van den Bergh et al., ApJ Supp 57.743). Walker (SAAO Circ 11.131) summarized work on known and suspected cluster Cepheids.

BINARY CEPHEIDS

A number of investigators have searched for companions to Cepheids using radial velocities and photometry (Gieren, ApJ 295.507; Coulson et al., ApJ 303.273), CaII H and K line profiles (Evans, IAU Coll 82.79), ultraviolet energy distributions (Böhm-Vitense & Profitt, ApJ 296.175; Arellano Ferro & Madore, Obs 105.207) or collections of available data (Szabados, IAU Coll 82.75; Gieren, AA 148.138). While the various methods sometimes yield contradictory results, the binarity of individual stars and the nature of the companions (e.g. Leonard & Turner, JRAS Can 80.240) are becoming more and more certain.

Orbits for binary Cepheids are important to resolving the long-standing mass question. Imbert (AA Supp 58.529) and Evans & Bolton (St Puls p163) derived spectroscopic orbits for SU Cyg. The latter authors then used IUE spectra to measure the velocity curve of the companion and obtained a mass for the Cepheid in agreement with evolution theory. Unfortunately, the companion is also a spectroscopic binary; its total mass and thus the Cepheid mass depends on the inferred types of the two components. Jacobsen et al. (PASP 96.630) were unable to determine an orbit for W Sge even with additional new data.

LUMINOSITIES AND THE PERIOD-LUMINOSITY-COLOR RELATION

There have been many studies aimed at addressing the question of Cepheid luminosities. The much-cited Sandage & Tammann (ApJ 157.683) PLC relation corrected to a Hyades distance modulus of 3.3 (referred to as S&T) will be used as a basis to compare the results. It should be realized that the comparison is complicated by various assumptions regarding such things as reddening, metallicity corrections, etc. so the values given below are only approximate.

Some investigators have redetermined distances of clusters with Cepheid members. H-Beta photometry of cluster B stars (Schmidt, ApJ 285.501; revised by Balona & Shobbrook, MN 211.375) implied Cepheid luminosities 0.4 mag fainter than S&T. Pel's (IAU Coll 82.1) Walraven observations of main sequence stars in two clusters, M 25 and NGC 6087, implied luminosities about 0.2 mag fainter than S&T. Additional UBV observations of individual clusters were made by Pedreros et al. (NGC 7790, implies luminosities 0.1 mag brighter than S&T, ApJ 286.563), Walker (Ly 6, 0.3 mag fainter than S&T, MN 213.889), Walker & Laney (NGC 6649, 0.2 mag fainter than S&T, MN 224.61), Turner (NGC 6087, 0.15 mag fainter than S&T, AJ

92.111) and Walker (NGC 6067, 0.4 mag fainter than S&T, MN 214.45). A study of blue companions of five Cepheids by Böhm-Vitense (ApJ 296.169) produced magnitudes which were about 0.8 mag fainter than S&T while Evans & Arellano Ferro (St Puls p183) obtained luminosities by the same method which were about 0.3 mag fainter than S&T. Gieren (ApJ 306.25) applied the surface brightness technique and obtained luminosities about 0.3 mag fainter than S&T. Although there is still a range, it appears that the various determinations are converging on values a few tenths of a magnitude fainter than was accepted several years ago.

Welch et al. (ApJ Supp 54.547; ApJ 292.217) derived an improved PL relation for the J, H and K bands. Pritchet & van den Bergh (ApJ 316.517) found that the resulting distance of M 31 was in good agreement with what they obtained from the RR Lyrae stars. Cester & Marsi (Ap Sp Sc 107.167) rediscussed the color term in the PLC relation while Tsvetkov (Ap Sp Sc 117.227) derived separate PL relations for the long and short period Cepheids and for the S Cepheids.

Eggen (AJ 90.1278) used narrow band indices to argue that at a particular metallicity no color term is needed to account for the scatter in the Period-Luminosity relation. He then derived a Period-Luminosity-Abundance relation.

MASSES AND EVOLUTION

The fainter luminosity scale implied by many new observations again causes the pulsational masses to disagree with the evolutionary and theoretical masses of Cepheids (see Schmidt, ApJ 285.501, for example). When masses implied by Wesselink radii are compared with theoretical masses, various investigators have found conflicting results (Gieren, MN 222.251; Burki, IAU Coll 82.71).

Böhm-Vitense (ApJ 303.262 and St Puls p159) used binarity to infer the masses of Cepheids. However her conclusion that the Cepheids are under-massive compared with evolutionary theory, conflicts with the mass of SU Cyg found by Evans & Bolton (discussed above). While the important question of Cepheid masses is still unresolved, these new studies of binaries promise to finally put it to rest.

Deasy & Wayman (MN 212.395) discussed period changes of Magellanic Cloud Cepheids and concluded that evolution caused some but not all of the effect.

McAlary & Welch (AJ 91.1209) and Deasy & Butler (Nature 320.726) searched the IRAS catalogue for Cepheids. The majority of detected classical Cepheids exhibited only a photospheric continuum in the infrared while most of the type II Cepheids had an infrared excess. Szabados (IBVS 2910) suggested that the presence of a companion might affect the infrared behavior. Deasy & Wayman (Irish Ast J 17.286) derived a very low mass loss rate for Zeta Gem from MgII h and k line profiles. The suggestion that pulsational mass loss plays an important role in classical Cepheid evolution (Willson & Bowen, Nature 312.429) seems unlikely in view of these results.

ATMOSPHERES AND ELEMENTAL ABUNDANCES

Harris & Pilachowski (ApJ 282.655), Luck & Lambert (ApJ 298.782), Luck & Bond (PASP 98.442), Wallerstein et al. (PASP 96.613), Giridhar (IAU Coll 82.100) and Sanwal et al. (Ap Sp Sc 123.183) carried out high dispersion spectral studies of Cepheids. The abundance gradient in the galactic disk found previously from photometry was confirmed. On the other hand, within the limits of present day model atmospheres and spectroscopy, there is no compelling reason to postulate a dredge up of processed material in these stars.

TYPE II CEPHEIDS

Harris (IAU Coll 82.232 and St Puls p274) and Wallerstein & Cox (PASP 96.677) have reviewed the properties of type II Cepheids and Harris (AJ 90.756) has compiled a catalogue. Petersen & Diethelm (AA 156.337), Simon (ApJ 311.305), Petersen & Andreasen (AA 176.183) and Carson & Lawrence (St Puls p293) applied Fourier decomposition to light curves of these stars. While some evidence for resonant behavior was claimed, type II Cepheids are a very heterogeneous group and more photometric and abundance studies like that of Diethelm (AA Supp 64.261) are needed.

EXTRAGALACTIC CEPHEIDS

Studies of extragalactic Cepheids have continued to be primarily concerned with distance determination (as reviewed by Aaronson & Mould, ApJ 303.1 and Walker, SAAO Circ 11.125). Older photometry of Cepheids in M 33 has been recalibrated using modern techniques (Christian & Schommer, AJ 93.557) while Walker (MN 225.627) redetermined the LMC distance with new CCD photometry of Cepheids. Following a suggestion by Madore and collaborators near infrared photometry of Cepheids has been used to determine the distances of the Magellanic Clouds (Visvanathan, ApJ 288.182), M 31 (Welch et al., ApJ 305.583), M 33 (Madore et al., ApJ 294.560) and NGC 2403 (McAlary & Madore, ApJ 282.101). On the other hand, Welch (ApJ 317.672) was unable to use JHK photometry of type II Cepheids to obtain the distance of the Magellanic Clouds due to infrared excesses. Freedman et al. (ApJ Supp 59.311) pointed out advantages offered by R band photometry with CCD's. Madore (ApJ 298.340) and Madore & Freedman (AJ 90.1104) discussed ways to optimize observations of extragalactic Cepheids for distance determination. However, one suggestion, the "Feinheit" function, was shown by Moffett & Barnes (ApJ 304.607) to be inappropriate to extragalactic studies.

Discoveries of new extragalactic Cepheids were reported for the LMC (van Genderen et al., IBVS 3026), M 31 (Ivanov, Ap Sp Sc 115.409), M 33 (Kinman et al., AJ 93.833), M 101 (Cook et al., ApJ 301.L45), NGC 205 (Richer et al., ApJ 287.138), NGC 300 (Graham, AJ 89.1332), Sextans B (Sandage & Carlson, AJ 90.1019) and WLM (Sandage & Carlson, AJ 90.1464).

Studies of the properties of individual extragalactic Cepheids have also been reported. Wallerstein (AJ 89.1705) inferred the metallicity of the SMC from the spectra of seven Cepheids while Caldwell et al. (MN 220.671) and Imbert (AA 175.30) obtained radii of Magellanic Cloud Cepheids from Baade-Wesselink analyses. Caldwell & Coulson (MN 212.879) obtained reddening measurements of individual Magellanic Cloud Cepheids. Schmidt & Simon (St Puls p180) obtained light curves for stars in NGC 6822 which were of sufficient accuracy to study their pulsational properties. Ivanov & Sharov (Ap Sp Sc 124.329; 125.201) compared the period-amplitude relation in various galaxies.

STARS RELATED TO THE CEPHEIDS

There is considerable interest in luminous variable stars located in an extension of the Cepheid strip. Photometric observations were published for such stars in the Magellanic Clouds (Grieve et al., ApJ 294.513; Grieve & Madore, ApJ Supp 62.451), M31 (Ivanov, IBVS 2729) and the galaxy (Arellano Ferro, MN 216.571; Eggen, AJ 91.890) and Arellano Ferro (Rev Mex AA 11.113; PASP 96.641) made spectroscopic observations. The pulsation of Rho Cas was investigated by Sheffer & Lambert (PASP 98.914) and Percy & Kieth (IAU Coll 82.89). Sasselov (IAU Coll 82.85) discussed the status of such stars in the galactic halo.

Arellano Ferro & Madore (ApJ 302.767) surveyed F and G supergiants near the instability strip for companions using IUE. Similarly to the Cepheids, about 26% of such stars are binaries and this seems to suggest that binarity cannot inhibit pulsation and account for non-variables inside the instability strip. However, in a study of yellow giants in clusters, Schmidt (ApJ Supp 55.455; ApJ 287.261) was able to find few within the instability strip and concluded that they might be rare or non-existent contrary to previous findings (for example, Bidelman, IAU Coll 82.83).

PECULIAR CEPHEIDS

The peculiar Cepheid V473 Lyr (HR 7308; see Burki, IAU Symp 105.453, for a summary of its properties) continued to attract interest although no convincing explanation for the long term amplitude modulation was found. Burki et al. (AA 168.139) carried out an extensive observing campaign and were able to estimate the radius. Second or higher overtone pulsation was suggested. The metallicity appeared from intermediate band photometry to be solar.

Teays & Simon (ApJ 290.683) studied the peculiar variable XZ Cet. They concluded that this star is possibly an anomalous Cepheid. If so, it is only the second found in the galaxy.

MISCELLANEOUS

Jacobsen & Wallerstein (PASP 99.138) studied atmospheric level effects and the period of Eta Aql. Caldwell & Coulson (AJ 93.1090) applied Cepheids to the determination of galactic rotation and the distance to the galactic center. They obtained a galactocentric distance of 7.8 kpc in accord with other recent determinations. Giridhar (J Ap Ast India 7.83) used Cepheids to study local chemical inhomogeneities in the galactic disk.

Cepheids were used to probe the structure of the Magellanic Clouds by Mathewson et al. (ApJ 301.664), Caldwell & Coulson (MN 218.223) and Laney & Stobie (SAAO Circ 10.51; MN 222.449).

5. Delta Scuti Stars
(Michel Breger)

LARGE-AMPLITUDE DELTA SCUTI STARS

This group of pulsators with Av$\geq$0.30 mag contains both Population I and II stars. Burki & Meylan (AA 159.261) determined Wesselink radii using CORAVEL radial velocities and Geneva photometry for two stars. They found 3.2 $R_\odot$ for BS Aqr and a smaller value of 1.4 $R_\odot$ for DY Peg, which has an evolutionary status similar to the other SX Phe-like variables. The connection between slow rotation and large amplitude was examined by McNamara (PASP 97.715), who found v sin i values less than 20 km/s for a group of large-amplitude variables. He also found these stars to occupy a smaller region in the HRD than the δ Scuti stars with smaller amplitudes. Cox et al. (ApJ 284.250) considered the observed period ratio of 0.80 for VZ Cnc in terms of atmospheric depletion of helium as well as the position in the HRD. Period decreases were reported for DY Peg (Pena & Peniche, AA 166.211), CY Aqr (Rolland et al., AA 168.125; Kämper, IBVS 2802) and BS Aqr (Kozerska & Stepien, Acta Ast 34.377).

Other studies include: HD 200295 = V1719 Cyg (Johnson & Joner, PASP 98.581; Mantegazza & Poretti, AA 158.389), HD 38882 = RY Lep (Diethelm, AA 149.465), EH Lib (Joner, PASP 98.651; Hamdy, IBVS 2810), YZ Boo (Peniche et al., PASP 97.1172), SZ Lyn (Bardin & Imbert, AA Supp 57.249), AI Vel (Bates & Halliwell, AA 151,403), HD 94033 (McNamara & Budge, PASP 97.322; Hobart et al., Rev Mex AA 11.19).

FREQUENCY AND MODE DETERMINATIONS

The difficulty of extracting the multiple frequencies present from a limited amount of photometry is demonstrated by the large number of studies with inconclusive results of frequency analysis. We can only repeat the comments of Kurtz made in these pages three years ago: "Observationally, extensive observation sets of selected multiperiodic δ Scuti stars are needed now, rather than short studies...". The progress of the last years shows that the most promising approach for the future consists of extensive high-quality measurements of one observatory or, better, at several observatories. A multisite campaign at the Beijing (China), McDonald (USA), and Merate (Italy) observatories led to the discovery of four close (nonradial) frequencies in Θ^2 Tau (Breger et al., AA 175.117) which were confirmed in a subsequent campaign. Despite the complexity of some variables, BD +43°1894 was found to have only one pulsation frequency (Costa et al., AA Supp 57. 233). 28 And = HR 114 is also monoperiodic, but has a variable amplitude from season to season (Garrido et al. AA 144.211).

Other studies include: HR 151 and HR 239 = AZ Phe (Kreidl, MN 216.1017), HD 37819 (Padalia & Gupta, Acta Ast 34.303), HD 96008 (Lampens, AA 172.173), HD 101158 (Lampens, Ap Sp Sc 127.27), HR 4684 = FM Com (Antonello et al., AA 146.11; Paparó & Kovács, Ap Sp Sc 105.357), 73 Vir (Sterken & Jerzykiewicz, AA 169.164), HD 126859 (Vander Linden & Sterken, AA 168.155), HR 7222 = LT Vul (Lopez de Coca et al., AA Supp 58.441), V 1719 Cyg (Poretti, AA Supp 57.435), BD-7°1108 (Lampens, IBVS 2794), BD+28°1494 (Broglia & Conconi, AA 149.15), Y Cam (Broglia & Conconi, AA 138.443).

LINE PROFILE VARIATIONS AND RADIAL VELOCITIES

The examination of line-profile variations is a powerful tool to examine nonradial oscillations. In a series of papers (see MN 224.41), Balona discusses the problem of mode identification from line-profile variations by introducing moments. He also points out that the temperature variations during a pulsation cycle can significantly affect the line profiles, if the projected rotational velocity is large. Yang & Walker (PASP 98.1156) detected absorption features moving across spectral line profiles in the star HR 1298 = 38 Eri. They offer an explanation for the different radial velocities found for different spectral lines and point out that the velocity/light amplitude ratio may not be an appropriate criterion for mode identifications. For HR 5017 = AO CVn a radial velocity amplitude of just over 1 km/s has been reported (Yang & Walker, PASP 98.862) while HR 21 = β Cas shows a variable radial-velocity amplitude associated with its (presumably) single frequency of oscillation (Weiss et al., PASP 99.303).

MISCELLANEOUS

The search for δ Scuti variables in clusters has received some attention: NGC 2516 (Antonello & Mantegazza, AA 164.40), NGC 6871 (Delgado et al., AA Supp 58.447), and NGC 6405 (Schneider, IBVS 2626).

Nonlinear mode coupling is a promising explanation for the complex frequency combinations found for many (but not all!) low-amplitude pulsators. Dziembowski & Krolikowska (Acta Ast 35.5) theoretically examined acoustic and gravity mode instabilities. Moskalik (Acta Ast 35.229) reported that resonant mode coupling can lead the periodic amplitude modulation with a time scale of years.

Tsvetkov (see Ap Sp Sc 128.319) compared the observed period lengths of δ Scuti stars with theoretical evolutionary tracks. Antonello et al. (see AA 171.131) examined the Fourier decomposition of light curves for various subgroups of δ Scuti stars. Hauck et al. (AA 149.167) published a detailed abundance analysis of HR 5017 = 20 CVn and determined a [Fe/H] ratio relative to the Sun of +0.49. Eggen (AJ 90.1046) discussed the known δ Scuti variables in the context of the Hyades Supercluster.

The "mythical" Maia variables comprise a group of stars outside the hot border of the δ Scuti instability strip in the HRD, which may or may not be really variable with δ Scuti-like periods. In the latest installment of the continuing saga, Philip & Hayes (PASP 96.546) report that for the star 109 Vir, no evidence for photometric or spectroscopic variations larger than the rms errors of observations seems to exist.

PULSATION OF Ap STARS

Cool magnetic Ap stars have rapid oscillations with periods in the range of 4 to 15 minutes (e.g., HD 60435, Matthews et al., ApJ 300.348). The light amplitudes are on the order of millimags with the largest known value being 15.7 millimag (HD 60435, Kurtz, MN 209.841). The frequency splitting can be understood in terms of Kurtz's oblique pulsator model (Dziembowski & Goode, ApJ 296.L27; Kurtz & Shibahashi, MN 223.557; Gabriel et al., AA 143.206). The mode identification of the pulsation frequencies requires extensive observational data of the highest accuracy. One of many excellent recent examples is the study of α Cir = HD 128898 (Kurtz & Balona, MN 210.779), in which observations covering 38 nights showed two close high-overtone frequencies near 6.8 minutes. Kurtz (Ap Sp Sc 125.311) searched for rapid oscillations in FG Sge, since the spectrum of FG Sge is starting to resemble that of Przybylski's star. However, over 25 hours, no variations were found.

Further observational studies to determine which Ap stars have normal, longer-period δ Scuti-like variations were also reported. Generally, no further variability was found (see Kreidl, MN 212.337; 216.1013). However, for 49 Cam (Matthews & Wehlau, PASP 97.841) and HD 92664 (Megessier, AA Supp 59.485) longer

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periods were suspected, which need to be reconfirmed in further studies.

6. RR Lyrae Stars
(B. Szeidl)

This section is devoted to field RR Lyrae stars. The studies carried out on RR Lyrae stars in clusters and related systems are described in the following section.

Great efforts have been made to obtain new accurate photometric and spectral photometric data on RR Lyr stars. Poretti (AA Supp 57.435) performed UBV observations of V1719 Cyg. From its photometric characteristics the star is classified as an RRc variable. The star may be a double mode pulsator in the first and second radial overtones (Mantegazza & Poretti, AA 158.389). The unusual pulsating variable XZ Cet was observed by Teays & Simon (ApJ 290.683). Their new photometry has confirmed the star's long period of 0.823 day. Energy distributions obtained from spectrum scans were used to derive the temperature and surface gravity of this star. Pulsation models suggest the possibility that XZ Cet is an anomalous Cepheid or an overtone BL Her star. Tan (Acta Ast Sin 26.301; IBVS 2533) obtained UBV photometry for a new RR Lyr star in Leo discovered by Huruhata (IBVS 2402) and determined its correct period. From photometric and spectroscopic observations of UY Phe - previously classified as a dwarf nova - Warner & Barrett (Ap Sp Sc 124. 199) found that it is a type RR Lyr halo variable with a period of 0.512 day. Grauer (PASP 96.84) investigated a new variable (15h 20.9m, $+52^{o}$ 39'; 1950) in the UBV system and recognized that the new variable is a halo RRc star. Saha (ApJ 283.580) reported on searches for distant halo RR Lyr stars. Photoelectric photometry and spectroscopy of the faint RR Lyr stars found in this survey were used to derive the chemical abundances and radial velocities of these objects (Saha & Oke, ApJ 285.688).

Nikolov et al. (Publ Astron Dept Univ Sofia) compiled a catalog of mean light and colour curves of 210 RR Lyr type stars.

Observations of RR Lyr and X Ari were obtained in the ultraviolet spectral range with the IUE satellite (Bonnell & Bell, NASA CP-2349 p334; PASP 97.236). Excellent agreement between observed and calculated fluxes was found for X Ari, but the analysis of the IUE observations of RR Lyr encountered some difficulties which are believed to be due to the star's secondary cycle.

Butler et al. (AJ 91.570) investigated the oxygen abundances for a large number of RR Lyr stars and found some connection between the metal abundance and the [O/Fe] values. Alania (Ap Sp Sc 132.313) used uvbyβ photometry to accurately determine the metallicity index m1 and Δs for eight RR Lyr stars. Grenon & Waelkens (AA 155.24) paid special attention to the long period, small amplitude RR Lyr star HD 47147 which is extremely metal poor. The evolutionary stage of this star appears to be rather exceptional. New photometric observations and ephemerides were obtained for the variables in the field RRI(MWF 361A) (Kinman et al., AJ 89.1200) and the metal abundances of RR Lyr variables in this field were determined and discussed (Kinman et al., AJ 90.95).

A new search for RR Lyr stars in Baade's Window was carried out and the relationship among the different parameters of light curves were considered (Blanco, AJ 89.1836); the distance to the galactic centre, R_o , has been determined using the newly obtained data (Blanco & Blanco, Mem S A It 56.15). Using CCD measurements of eleven RR Lyr variables in Baade's Window Walker & Mack (MN 220.69) have given a new estimate of R_o. Their data tend to deny the existence of an absolute magnitude-metallicity relation for RR Lyr stars. Gratton (MN 224.175) obtained radial velocities for seventeen RR Lyr stars in Baade's Window. New mean radial velocities were determined for a further 46 RR Lyr stars (Hawley & Barnes, PASP 97.551). Later, the same authors (Barnes & Hawley, ApJ Lett 307.L9) rediscussed these data.

The Baade-Wesselink method (or a modification of this) was utilized to obtain

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the physical parameters and the distances of a number of RR Lyr stars (SW And, X Ari, YZ Cap, RR Cet, DX Del, SU Dra, SW Dra, SS For, RR Lyr, RV Phe, V440 Sgr, VY Ser) and the results have been discussed in detail (Burki & Meylan, AA 156. 131, 159.255; Meylan et al., AA Supp 64.25; Jones et al., ApJ 312.254, 314.605; Longmore et al., MN 216.873; Buonaura et al., Mem S A It 56.153; Cacciari et al. ibid 57.345; Jameson, Vistas Astron 29.17).

The kinematic properties and absolute magnitudes of RR Lyr stars have been investigated by Wan et al. (Publ Beijing Astr Obs No.6.191), Saha (ApJ 289.310), Hawley et al. (ApJ 302.626) and Strugnell et al. (MN 220.413). A thorough investigation using earlier data and new infrared observations, was carried out on the dependence of absolute magnitude on metallicity and the distance to the Galactic Center (Fernley et al., MN 226.927).

Fourier decomposition parameters were determined for RR Lyr variables (Hansen & Petersen, IAU Coll 82.272) and employed to compare the light curves with those emerging from hydrodynamic models (Simon, BAAS 17.559; ApJ 299.723).

Elements have been derived, revised or refined for a great number of known RR Lyr stars and for some accidentally discovered ones. The results have mostly been published in MVS, IBVS, Per Zv, Per Zv Supp, JAAVSO, J Br Astron Assoc, Astr Tsirk, BAV Rundbrief and GEOS Circ. Ephemerides of RR Lyr variables have been compiled by Tsessevich, Firmanyuk and Kreiner for the years 1985, 1986 and 1987 (Rocznik Astron Obs Krakow).

The Blazhko-effect was investigated by Tsessevich & Mandel (Per Zv 22.237) in V421 Her and by Firmanyuk et al. (Astr Tsirk 1395.6) in TT Cnc.

7. Variable Stars in Globular Clusters and Related Systems

(Amelia Wehlau)

STUDIES OF PULSATING VARIABLES IN GALACTIC GLOBULAR CLUSTERS

A brief review of the properties of RR Lyrae stars and of current problems in RR Lyrae research in globular clusters is given by Hazen (JAAVSO 15.201).

C0911-646 (NGC 2808) Clement et al. (JRAS Can 79.235) report the discovery of 3 more variables.

C1323-472 (NGC 5139) Spectra of 18 RR Lyrae variables in ω Cen have been used by Gratton et al. (AA 169.111) to derive values of ΔS which do not correlate with period shift within the cluster in contrast to 17 variables within Baade's window which do show such a correlation. The authors suggest RR Lyrae stars in the cluster are not ZAHB stars but show the effects of post-HB evolution. In a paper on blue stragglers in the cluster, Da Costa et al. (ApJ 308.743) point out that further observations of the dwarf Cepheids in ω Cen would yield masses which would constrain competing theories for the blue stragglers. An analysis by Nemec et al. (AJ 92.358) of Martin's photometry for 55 RR Lyrae stars in the cluster has found no double-mode variables. Walker & Mack (SAAO Circ 11) present CCD light curves for V84 and V85.

C1339+286 (NGC 5272) Meinunger presents observations of 12 variables in M3 (MVS 10.89; 10.134).

C1514-208 (NGC 5897) Spectra taken by Smith (AJ 90.1242) of a possible non-variable in the RR Lyrae gap of the cluster show that the star has a metallicity and radial velocity consistent with cluster membership.

C1516+022 (NGC 5904) Cohen & Gordon (ApJ 318.215) report on a determination of the distance to M5 obtained by applying a modification of the Baade-Wesselink method to four RR Lyrae variables in the cluster.

C1620-264 (NGC 6121) Yao (Ap Sp Sc 119.41) reports on four possible red variables in M4.

C1639+365 (NGC 6205) Ruseva & Rusev (Per Zv 22.49) present observations for seven variables in M13 and discuss period changes as well as cluster period-luminosity, period-amplitude and period-color relations. Most of the red variables in the cluster are included in a radial velocity study by Lupton et al. (AJ 93.111).

C1654-040 (NGC 6254) Fifty-two years of observations of three slow variables in M10 are discussed by Clement et al. (AJ 90.1238).

C1715+432 (NGC 6341) Several new variables have been found by Kadla et al. (Per Zv 21.827) in the central region of M92. Data are given for 11 stars.

C1732-447 (NGC 6388) Hazen & Hesser (AJ 92.1094) present photometry for four newly found field variables and for 14 new and three previously known variables within the tidal radius of this cluster, the cluster with the highest metallicity thought to contain RR Lyrae variables.

C1800-300 (NGC 6522) Walker & Mack (MN 220.69) report that four of the RR Lyrae variables in Baade's window appear to be cluster members on the basis of CCD photometry of the cluster and of nearby variables. Blanco (AJ 89.1836) also discusses the possible cluster membership of other variables in Baade's window. Also see Gratton et al. (AA 169.111).

C1810-318 (NGC 6569) Hazen-Liller (AJ 90.1807) presents photometry of 17 new and 6 previously known variables within the tidal radius of this cluster, which has an unusually blue horizontal branch for its metallicity.

C1821-249 (NGC 6626) Wehlau et al. (AJ 91.1340) present period changes for variables in M28 derived from observations from 1939 through 1985. Margon & Anderson (PASP 97.962) report that a spectrum of V7 shows it to be a normal Mira variable. Low resolution spectra of V7, one red variable and 4 RR Lyrae stars in the cluster are discussed by Smith & Wehlau (AJ 298.572).

C1827-255 (NGC 6638) Spectroscopy of six RR Lyrae stars, confirming their designation as c-type, is reported on by Smith & Stryker (AJ 98.453) who attribute the large ratio of c-type stars to ab-type stars in the cluster to a gap in the color distribution of HB stars.

C1828-323 (NGC 6637) A possible cataclysmic variable in M69 (IAUC 4247) has been shown to be a late type Mira-type variable by Charles et al. (IAUC 4285).

C1832-330 (NGC 6652) A search by Hazen has failed to find any variables (IAU Symp 118.287).

C1833-239 (NGC 6656) Marinchev (Per Zv 22.65) presents period changes for 12 RR Lyrae stars and observations of 8 long period variables in M22. Of the 13 variables included in a proper motion study of the cluster by Cudworth (AJ 92.348), 11 are confirmed as cluster members. V17 is shown to be a non-member, and V16 only a possible member.

C1850-087 (NGC 6712) Infrared photometry of 15 red giants including 5 variables is presented by Frogel (ApJ 291.581).

C1914+300 (NGC 6779) Wehlau et al. discuss 50 years of observations of V1 and V6 in M56 (ed. Madore, Cepheids:Theory and Observations, 284). Photometry of all 12 known variables (including 5 probable non-members of the cluster) are presented by Wehlau & Sawyer-Hogg (AJ 90.2514).

C1915+186 (NGC 6838) Pogossiantz (Per Zv 22.85) presents observations of the semi-regular variable Z Sagittae, V1 in M71. Welty (AJ 90.2555) confirms the variability of 1-29 and S142. All the known variables are included in the proper motion study of the cluster by Cudworth (AJ 90.65).

C2127+119 (NGC 7078) Kadla et al. (Astron Tsirk 1314.1; 1342.8) report the discovery of 8 new variables in M15 while Gordenko et al. (Prob Kosm Fiz Vyp 19.93) have studied period changes in 35 of the variables.

C2130-010 (NGC 7098) Several of the known variables in M2 are included in the dynamical studies by Pryor et al. (AJ 91.546) and Cudworth & Rouscher (AJ 93. 856).

VARIABLES IN DISTANT GALACTIC CLUSTERS, LMC CLUSTERS AND DWARF SPHEROIDAL GALAXIES

A review of variables in 23 Palomar-like clusters is given by Rosino & Ortolani (Mem S A It 56.113). CCD photometry by Ortolani (AA 137.269) of AM-1 (C0353-497), one of the most distant galactic globular clusters known, includes 5 stars in the variable star gap, three of which show suspected variability, although a search during a similar CCD study of the cluster by Aaronson et al. (ApJ 276.221) turned up no variables.

Using CCD photometry of 9 RR Lyrae stars in the LMC cluster NGC 2210, Walker

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(MN 212.395; SAAO Circ 9.111) has obtained a distance modulus of 18.42 ± 0.10 using a value of MvRR = 0.6. In this cluster a few additional variables have been found by Hazen. In another LMC cluster, NGC 1786, Graham (PASP 97.676) has identified 12 variables. Periods obtained for 10 of them show an Oosterhoff type II distribution. One star may be an anomalous Cepheid. Nemec et al. (ApJ Supp 57.287) studied 41 RR Lyrae stars in the LMC cluster NGC 2257 and 47 field variables in the region while Nemec et al. (ApJ Supp 57.329) have derived period changes for 38 of the cluster variables.

A review of the properties of dwarf spheroidal galaxies by Zinn (Mem S A It 56.223) includes a summary of the properties of the variables found in these galaxies and their associated globular clusters. Light et al. (BAAS 17.883) report on CCD photometry of the two brighter variables discovered along with several probable RR Lyrae stars by Buonanno et al. (AA 152.65) in the fields of clusters of the Fornax dwarf galaxy. One star appears to be an anomalous Cepheid and the other a Pop II Cepheid, the first to be found in a dwarf spheroidal galaxy. Demers & Irwin (MN 226.943) have identified 30 long-period variables in Fornax and determined periods for 26 of them. Smith & Stryker (AJ 92.328) present metal abundances obtained from low resolution spectra for three anomalous Cepheids in the Sculptor dwarf galaxy. Saha et al. (AJ 92.302) report on a search for variables in the Carina dwarf galaxy. Light curves and periods were obtained for 73 variables, most of which seem to be RR Lyrae stars. Of these, 58 appear to be members of the galaxy with a mean period for the ab-type stars of 0.62, intermediate between Oosterhoff types I and II. Using new data, Nemec & Wehlau have determined periods for 49 more RR Lyrae stars in Ursa Minor. Wehlau & Demers (IBVS 2914) present recent observations of bright variables in Draco.

COLOUR STUDIES OF RR LYRAE STARS AND THE OOSTERHOFF DICHOTOMY

Longmore et al. (MN 220.279) present near-infrared photometry of RR Lyrae stars in three clusters, yielding a period-absolute K magnitude relation with remarkably small scatter which could be a useful tool in determining distances. Scaria (Ap Sp Sc 103.207) derives a possible P-L relation for cluster RR Lyraes, luminosity decreasing with period. Magnitudes and colors of RR Lyrae stars belonging to 10 globular clusters are discussed by Cacciari et al. (Mem S A It 56.97) and relations among periods, amplitudes and metallicity are shown. Caputo and her collaborators (AA Supp 55.463) present synthetic horizontal branch computations leading to constraints on the expected properties of RR Lyrae variables in Pop II systems and in a further series of papers (AA 138.457; 143.8; 172.67; Mem S A It 57.437) use the properties of the RR Lyrae stars in M4, M15 and M3 to derive reddenings, distance moduli and ages of 16 billion years for each cluster. VBLUW photometry of RR Lyrae stars in M4 and ω Cen by de Bruijn & Lub (eds. Cox et al., Stellar Pulsation, 233) has been used to derive reddening, blanketing, Teff and g for these stars.

Stellar evolution calculations which suggest possible explanations of the Oosterhoff dichotomy, the Sandage effect, and the second parameter problem are discussed by Caputo (Mem S A It 56.73), Torambe (Mem S A It 56.85) and Torambe & Gratton (Mem S A It 57.361). Using a new grid of ZAHB models, Sweigart et al. (ApJ 312.762) fail to find any satisfactory explanation for the Sandage effect while Jones et al. (ApJ 314.605), using the Baade-Wesselink method, find no evidence of a difference in luminosity between two field RR Lyraes which differ greatly in metallicity. Using their derived absolute magnitudes they find the metal-poor cluster M92 to be considerably older than the metal-rich cluster 47 Tuc. Cacciari & Clementini give a preliminary report on a similar study (Mem S A It 57.345). In order to investigate the Oosterhoff dichotomy, Castellani & Quarta (AA Supp 71.1) present an updated catalogue of RR Lyrae period distributions in graphical form with the clusters ranked according to metallicity. Caloi et al. (AA Supp 67.181) point out the importance of the RR Lyrae rich cluster, M62 (NGC 6211, C1658-300), in the context of globular cluster evolutionary status. Kadla & Gerashchenko (Izv Glav Ast Obs Pul No. 202) discuss the numbers and period distribution of RR Lyrae variables for 48 clusters.

POPULATION II CEPHEIDS AND RED VARIABLES

Two reviews by Harris (ed. Madore, Cepheids:Theory and Observations, 232; eds. Cox et al., Stellar Pulsation, 274) present statistics for Pop II pulsating variables (excluding RR Lyrae stars) in globular clusters and in field. Included are the 8 Pop II Cepheids recently identified in globular clusters as discussed by Clement et al. (ed. Madore, Cepheids:Theory and Observations, 262). The evolutionary status of Type II Cepheids in clusters and in the field is reviewed by Gingold (Mem S A It 56.169) and the population distribution of these stars discussed. Three of the cluster Cepheids are included in the low mass variables whose light and color curves are discussed by Eggen (AJ 91.890).

Results from infrared photometry of red variables in globular clusters are summarized by Frogel (Mem S A It 56.193) and Frogel & Elias (ApJ, 1988). Mass loss rates are discussed and evidence is presented for circumstellar dust shells about these stars. Menzies & Whitelock (MN 212.783) present JHKL photometry for 31 Mira variables in 15 galactic globular clusters and use it to obtain a period-luminosity relation which differs from that found for LMC Miras. Whitelock (MN 219.525) derives a P-L relationship which includes cluster variables with periods ranging from 1 to 300 days. Observations of 7 red variables are included in a paper on spectroscopic data for giants in ω Cen by Lloyd Evans (SAAO Circ 10.1). A search for giant and asymptotic branch variables in 6 clusters by Welty (AJ 90.2555) has found no variables below the tip of the giant branch although Yao (Ap Sp Sc 119. 41) presents evidence for the variability of 4 such stars in M4.

PULSATION MODES AND FOURIER ANALYSIS OF LIGHT CURVES

A review of double-mode RR Lyrae stars by Cox (IAU Coll 95 on Faint Blue Stars) includes work by Ostlie showing that double-mode behaviour may require time-dependent convection with a high helium content. Nemec (AJ 90.240) has reanalyzed the double-mode variables in M15 using simulated photometry to determine the effects of random scatter on the derived periods and showing that the secondary oscillations are probably real. Nemec (AJ 90.204) has also studied 10 double-mode stars in the Draco dwarf galaxy and compared their derived physical characteristics to those of double-mode stars in galactic globular clusters. In the Oosterhoff type I cluster IC 4499 (C1452-820), Clement et al. (AJ 92.825) have identified 13 double-mode RR Lyrae stars and obtained a mean mass of 0.54, about 0.11 smaller than that found for Oosterhoff type II systems. However, thorough searches by Nemec and his collaborators have failed to find any double-mode RR Lyraes in ω Cen or M5.

Cox & Proffit (ApJ, 1988) present detailed pulsation studies of the anomalous Cepheids in the Draco galaxy and galactic globular clusters, but find they are not able to distinguish between fundamental and first overtone pulsation for any of the stars. The question of second-overtone pulsation in RR Lyrae stars has recently been discussed by Stothers (ApJ 319.260) who concludes that such pulsators probably do not exist among RR Lyrae stars although Stellingwerf et al. (ApJ 313.L75) feel such stars might exist.

Peterson reports on Fourier analysis of the RR Lyrae light curves in ω Cen (AA 139.496) and M15 (AA 170.59). Although the ω Cen light curves exhibit a Cepheid-like progression for both the overtone variables and the fundamental mode variables with periods from 0.5 to 1.5 day, confirmation or disproof of such a sequence in M15 requires better observations than currently available. Kovács et al. (ApJ 307.593) compare their Fourier decomposition parameters for variables in the two Oosterhoff I clusters, NGC 6171 (M107, C1629-129) and NGC 6723 (C1856-367), to those in the Oosterhoff II cluster M15 and find there may be small systematic differences between the two Oosterhoff classes. In a study of Fourier coefficients of RR Lyrae stars in NGC 6171 Stellingwerf & Dickens (ApJ, 1988) point out that the stellar light curves are not sensitive to composition or interior structure of the star. Several globular cluster stars are included in a study of Fourier phases of Type II Cepheids by Petersen & Andreasen (AA 176.183).

CATACLYSMIC BINARIES AND X-RAY VARIABLES

Shara and his collaborators present observations of an outburst of the dwarf nova V101 in M5 (AJ 94.357) and report that a search for cataclysmic binaries in M3 found no bright emission-line sources between 4 and 30 core radii from the center (IAU Symp 113.103). Margon & Bolte (ApJ Lett 321) found no optical evidence of cataclysmic binaries in ω Cen despite a thorough search. Another such search by Shara et al. (AJ, 1988) in two fields in ω Cen and one in 47 Tuc (NGC 104, C0021-723) was equally unsuccessful, indicating a density of contact binaries at least 8 times lower than in the solar neighborhood. On the basis of CCD photometry Shara et al. (ApJ 311.796) suggest an optical candidate for nova 1938 in M14 (NGC 6402, C1735-032). A search for millisecond pulsars by Hamilton et al. (AJ 90.606) turned up one source in M28 within one core radius of the center of the cluster, later confirmed by Erickson et al. (ApJ 314.L45). Lyne et al. (Nature 328.399) find a period of 3054 μs and no evidence for a binary period. CCD U-band photometry by Ilovaisky et al. (AA 179.L1) indicates an orbital period of 8.537 hours for the X-ray binary in M15 in agreement with the spectroscopic period found by Naylor et al. (IAUC 4263) and the X-ray period of Hertz (IAUC 4272). Verbunt (ApJ 312. L23) presents mechanisms for cluster binaries containing a white dwarf and a neutron star as is indicated by the discovery by Stella et al. (ApJ 312.L17) of a 685 sec orbital period for the X-ray source in NGC 6624 (C1820-303). Data on this source are also used by van Paradijs & Lewin (AA 172.L20) to derive constraints on the mass-radius relation for the neutron star.

8. Mira Variables and Related Objects

(M. W. Feast)

A knowledge of the distances of Mira variables is basic to practically all studies of these objects. The infrared period-luminosity relation, first found in the LMC has been further refined (Glass et al., Late Stages of Stellar Evolution, ed. Kwok & Pottasch, Reidel 1987 (= LSSE) p51) and now shows a scatter of only σ = 0.13 mag. Further LMC Miras have been discovered and studied by Reid, Glass and Catchpole (in preparation). The P-L zero point was rediscussed by Feast (eds. Gilmore & Carswell, The Galaxy, Reidel 1987 p1). An important new result is that SMC Miras follow an infrared P-L relation of closely the same slope and zero point to that in the LMC (Lloyd Evans et al., MN in press). This, together with the close similarity of P-L slope and zero point for Miras in globular clusters, the galactic bulge and the LMC (Feast & Whitelock, LSSE p33) strengthens considerably the value of Miras as distance indicators in stellar systems which may differ in age-metallicity relations. Herman & Habing (Phys Rep 124.255) give a general review of distance determinations for OH/IR Miras by the phase lag method. Herman et al. (AA 143.122) use distances for six objects derived in this way, together with kinematic distances, to infer a distance to the galactic centre (9.2 ± 1.2 kpc). The empirical relation established between the OH luminosity and the shell radius, has been used by Herman et al. (AA 167.247) to deduce distances of a number of OH/IR sources. Luminosities based on kinematics and membership of the galactic bulge are discussed for some OH/IR sources by Baud et al. (ApJ 292.628 see also Herman et al. AA 139.171). Empirical relations involving VRI colours were used by Celis (AJ 89.1343) to estimate Mira distances.

Whitelock (MN 219.525) studied the period-luminosity-temperature relationship for red and yellow variables (including Miras) in globular clusters and found that the higher temperature, more metal-deficient cluster variables pulsate in the fundamental mode whilst the lower temperature more metal-rich variables pulsate in the first overtone. On the theoretical side, a new linear survey of the Mira instability region was carried out (Ostlie & Cox, ApJ 311.864). A detailed review of the properties of Miras in symbiotic systems and their relation to single Miras was prepared by Whitelock (PASP in press).

The recognition (Habing; ed. Israel, Light on Dark Matter, Reidel 1986 (=LDM) p329; Feast, LDM p339; Whitelock et al., MN 222.1; Glass, MN 221.879) that at least a substantial fraction, if not all, IRAS sources in the galactic bulge are Miras or Mira-like objects, has stimulated considerable work on these stars. Ground-based studies suggest an upper limit to the luminosity of these stars of M(Bol)$\sim$-4.7 corresponding to an upper limit to their periods of $\sim$400 days and a lower limit to the age of the bulge population of $\sim$5 Gyr (Feast & Whitelock, LSSE p33). This is consistent with recent work on masses of planetary nebulae in the bulge (Kinman, Feast, Lasker, in preparation). There is considerable other work on the identification of IRAS sources as OH/IR (Mira) stars (Whitelock et al., MN 210.25p; 213.51p; Lewis et al., Nature 313.200; Engels et al., AA 140.L9; Hrivnak et al., ApJ 294.L113; Zuckerman & Lo, AA 173.263; Le Bertre & Epchtein, AA 171.116; Sivagnanam & Le Squeren, AA 168.374). Problems in identifying IRAS sources were noted by Craine et al. (PASP 97.303). Persi & Ferrari-Toniolo (AA Supp 55.165) have made ground-based infrared searches for AFGL sources. The periods of some Miras in the galactic bulge (Plaut fields) have been revised (T. Wesselink, Thesis, Nijmegen, 1987) and the completeness of discovery discussed.

Detailed high dispersion spectroscopy of emission and absorption lines in Miras including variation with phase is now yielding results which may be meaningfully compared with shock-wave models, enabling a beginning to be made in the quantitative understanding of the complex structure and kinematics of these atmospheres (Gillett et al., AA 148.155; 150.89; Fox et al., ApJ 286.337; 297.455; Bertschinger & Chevalier, ApJ 299.167). Hinkle et al. (ApJ Supp 56.1) continued their work on time series infrared spectroscopy of Miras.Data on CO gives evidence for an outward propagating shock-wave driven by stellar pulsation. The appearance of the silicate and other infrared spectral features in Miras is related to the degree of asymmetry of the visual light curves and this indicates that the nature of the dust condensates depends on the strengths of the atmospheric shock-waves (Vardya et al., ApJ 304.L29). The results of spectropolarimetry of Miras is complex and no general pattern has yet been established. Both photospheric and circumstellar polarization are, in general, important (Boyle et al., AA 164.310). In the case of L2 Pup there are secular changes in polarization, indicating the evolution of a circumstellar cloud on a time scale of several years (Magalhaes et al., AA 154.1). The time dependent spectropolarimetry of the SRa variable, V CVn (Magalhaes et al. AJ 91.919) can be interpreted in terms of a scattering layer at an intermediate level in the stellar atmosphere. Dominy & Wallerstein (ApJ 310. 371) derive s-process element abundances in some Miras and interpret the diverse results in terms of differing neutron exposure events (e.g. an s-process event $\leq$1.5x10.0E5 yr ago in χ Cyg). Wallerstein et al. (MN 215.67) interpret the spectrum of R Cyg at an unusually low maximum as indicating enhanced limb brightening.

Mennessier (AA 144.463) has attempted to classify the various types of visual and infrared light curves of Miras and Hoeppe (AA Supp 68.419) has listed maxima and minima of R Leo since 1757. The IRC catalogue, late type, long period (~500 day) Miras are an important intermediate group between the "optical" Miras and the very long period OH/IR stars. Lockwood (ApJ Supp 58.167) has given near infrared photometry for stars in this class. Amongst other basic data published is the spectral classification of 72 southern Miras round their cycles (Crowe, JRAS Can 78.103), UBVRI of Miras and discussions of their light and colour variations (Celis, ApJ Supp 60.879; AJ 91.405).

Mass loss at the Mira stage (that is, at the top of the AGB) is a crucial factor in the evolution of low mass stars. Consequently a large amount of effort continues to be devoted to the study of the circumstellar molecules and dust of Miras. This work is carried out principally at infrared, mm and cm wavelengths and includes studies of circumstellar masing. Mass loss rates from Miras and other stars can be calculated from infrared data and models (for the dust component) and from mm CO observations from the gaseous component (Knapp et al., ApJ 292.640; 293.273; 293.281). The results suggest a ratio of gas to dust mass in the envelopes of $\sim$160 for O-rich stars and $\sim$400 for C-rich stars. Knapp suggests that the carbon stars in her sample all have masses $\sim 2M_{\odot}$. The CO observations also suggest that $^{12}C/^{13}C$ is in the range 5-20 for M type Miras and 30-100 for C stars.

Further data on mass loss from CO observations are given by Wannier & Sahai (ApJ 311.335) and Zuckerman et al. (ApJ 304.394; 304.401). The latter workers find a class of (probably massive) carbon stars with large (~34 km/s) outflow velocities. In addition they suggest that the well known object IRC +10216 (a C-type Mira with a thick dust and molecular shell) is only 100-150 pc away. Extensive studies continue of the circumstellar chemistry and shell structure of this object (Thaddeus et al., ApJ 294.L49; Guelin et al., AA 157.L17; Lucas et al., AA 154.L12; Glassgold et al., AA 157.35; Rengarajan et al., ApJ 289.630; Lester et al., ApJ 304.623; Huggins & Healy, ApJ 304.418; Sahai et al., ApJ 284.144). The four known carbon Miras with thick dust shells all have very long periods (495-650 days), (as do the thick-shelled O-rich Miras, OH/IR stars), showing that these objects are not simply normal C-type Miras undergoing episodic mass ejection (Feast et al., MN 215.63p). Zuckerman & Dyck (ApJ 311.345) use IRAS data to estimate dust grain emissivities for C- and O-rich late type stars. They also find V Hya (a C star) to be the first known CO maser. Willems (Thesis, Amsterdam 1987) has given an extended discussion of data on carbon stars and their circumstellar shells from IRAS data. Quasi-simultaneous JHKL and IRAS observations of 18 Miras were analysed by Whitelock et al. (LSSE p269). There is a relationship, with very little scatter, between the period (or luminosity), the pulsation amplitude and the mass of the dust shell. This shows rather clearly that pulsation is important in facilitating mass loss and that Miras behave in a rather predictable manner. Infrared data on OH/IR sources were discussed by Le Bertre et al. (AA 132.75) and Keping et al. (Ap Sp Sc 107.373). Infrared speckle techniques are being increasingly used to study the circumstellar emission from cool stars, including Miras and related objects. A number of objects seem to have bipolar rather than spherical symmetry (Dyck et al., ApJ 287.801; Cobb & Fix, ApJ 315.325; Ridgway et al., ApJ 302.662). Cobb & Fix interpret their data on several OH/IR sources at 5 and 10 μm, as indicating partially resolved circumstellar shells together with dominant unresolved cores. Several discussions of circumstellar dust models in late type stars are of particular relevance for Miras (Rose, ApJ 312.284; Papoular & Pegourie, AA 156.199; Rowan-Robinson et al., MN 222.273; Gail & Sedlmayr, AA 161.201). Contrary to earlier work, Volk & Kwok (ApJ 315.654) find that the interstellar component of the 10 μm dust feature in OH/IR stars is small. Studies of circumstellar dust at submillimeter wavelengths has the advantage that the shells may be assumed to be optically thin and the emissivity is less sensitive to temperature than at shorter wavelengths. Observations at 400 μm of a range of evolved objects yield gas/dust ratios of ~100 in most cases (Sopka et al. ApJ 294. 242).

Maser and thermal emission from SiO in Miras and other objects has been intensively studied in recent years. One reason for this is that the SiO masers are believed to reside close to the central star and hence are important in studying mass loss mechanisms. Several studies have been devoted to detecting new SiO masers (Jewell et al., ApJ 298.L55; Nyman et al., AA 160.352; Bujarrabal et al., AA 162.157; Barcia et al., AA 142.L9). The possibility of determining the SiO maser luminosity function of OH/IR stars is opened up by the detection of SiO in some of these objects in the galactic centre region (Lindquist et al., AA 172.L3). SiO-infrared phase lag observations (Clark et al., ApJ 283.174) suggest that the SiO is excited by shocks rather than by radiation. Polarization studies yield much detailed information on the circumstellar shells (Barvainis & Predmore, ApJ 288. 694; Miller et al., ApJ 287.892; Clark et al., ApJ 289.756; Olofsson et al., AA 150.169). These and other studies (Nyman & Olofsson, AA 147.309; Gomez et al., AA 159.166; Snyder et al., AJ 92.416) suggest that the variations are in general related to the periodicity of the stellar pulsation. The line structure is complex, but the time-averaged centre of the weak emission pedestal gives the stellar radial velocity. To explain thermal SiO emission in Miras, the existence is suggested of an extended inner envelope (~10.0E15 cm) in which grains have not completely formed (Bujarrabal et al., AA 162.157). In the supergiant variable VX Sgr, the SiO masers exist in dense cloudlets rather than in a spherically expanding wind (Alcock & Ross, ApJ 310.838) and Langer & Watson (ApJ 284.751) have indeed shown that simple wind models fail to produce sufficient maser power. The importance of SiO formation, not only as a first step in dust production, but as an efficient radiative cooling agent has been emphasized by Muchmore et al. (ApJ 315.L141).

Search for H_2O masers in OH/IR stars has continued. Both the H_2O luminosity and the ratio of H_2O/OH maser luminosities appears to depend on mass loss rate (Bowers & Hagen, ApJ 285.637). The increase of H_2O intensity with mass loss rate is expected theoretically (Cooke & Elitzur, ApJ 295.175). The H_2O masers are within the OH maser shell and vary with larger amplitude and less regularity than the OH emission (Engels et al., AA 167.129). Periodicities in H_2O variations equal to multiples of the optical period as well as aperiodic behaviour have been reported (Gomez et al., AA 159.166). Aperiodic outbursts can occur in OH maser emission (e.g. R Leo, Le Squeren & Sivagnanam, AA 152.85). VLA observations show that the structure of H_2O masers round Miras consists of small (unresolved) knots distributed over a region of size ~8x10.0E14 cm (larger by a factor ~10 than some earlier estimates). Observations at two epochs indicate considerable changes in structure and velocity with time (Johnston et al., ApJ 290.660). An unsuccessful search for 183 GHz H_2O emission from Miras and other objects was carried out (Kuiper et al., ApJ 286.310). Diamond et al. (AA 174.95) have carried out detailed mapping of the H_2O and OH masers surrounding the supergiant red variable S Per. The masers around the supergiant red variable VX Sgr were mapped by Chapman & Cohen (MN 220.513) and the structures, magnetic field and driving force on the shell, discussed. Lopez (IBVS 2905) suggests an appreciable proper motion in declination for VX Sgr which is surprising for a supergiant.

The problem of the symmetry of the OH masing shell in Miras and OH/IR stars is important both for physical questions of shell formation, structure and excitation, and for the use of the phase-lag method of distance determination. Continuing work suggests at least rough spherical symmetry but with a good deal of complexity, including incomplete shells (Diamond et al., MN 121.1; 216.1p) and fluctuating velocity fields (Ukita & Le Squeren, AA 138.343). High resolution 18 cm spectra of Miras (Fix, AJ 93.433) as well as other data, are consistent with a model in which mass loss is by the ejection of blobs of material which evolve into plate-like structures in the OH masing region (Alcock & Ross, ApJ 305.837). Alcock & Ross (ApJ 290.433; 299.763; 306.649) have also made a detailed theoretical study of saturation and beaming in astrophysical masers. Dickinson (ApJ 313.408) finds that the far infrared flux is sufficient to pump all types of OH masing stars. For OH/IR stars the pump efficiency is ~8% and for optical Miras ~4%. The possibility of H_2O photodissociation as a pump mechanism for OH masers was discussed by Andresen (AA 154.42) in the light of a revision of the assignments in the Λ-doublet states of OH (see also Field, MN 217.1). Herman et al. (AA 144.514) failed to detect 6 cm continuum emission from OH/IR sources. Such emission might be expected if any of the objects were in the transition phase to planetary nebulae (with an inner ionized region developing). This suggests that the transition time must be very short. Infrared and OH data on a radio complete sample of OH/IR stars is given by Willems & de Jong (AA Supp, in press). Studies of circumstellar masing have now been extended to the shorter period, hotter Miras and SRd variables and semiregular variables. R Cet (P = 166 days) has OH main line emission (Dickinson, AJ 92.627) and three short period Miras are found with SiO emission. Fix & Claussen (ApJ 287.L35) find OH masers in two SRd variables (other work on SRd variables includes an analysis of DDO colours (Mantegazza, AA 135.300) and the removal of IS Gem from this class (Crimi & Mantegazza, Ap Sp Sc 100.255).

Studies of the remarkable object OH 231 + 4.2 (= OH 0739 -14), which contains a red long period variable component (possibly a Mira), continue. Jura & Morris (ApJ 292.487) note that it is in the cluster M46 and deduce an initial mass of 3$M_\odot$. They and Knapp (ApJ 311.731) discuss the high mass loss rate. Beautiful CCD images of the object have been obtained by Reipurth (Nature 325.787). He and Cohen et al. (ApJ 297.702) discuss this object which has shocked bipolar bubbles expanding supersonically (200 km/s) at right angles to the dust disc. The dynamic age is 1500 yr and there are Herbig-Haro objects at the front of the bubbles. The object shows HCN emission (Deguchi & Goldsmith, Nature 317.336) as does IRC +10420 (Jewell et al., Nature 323.311) a probable post AGB object. OH 231.8 + 4.2 was originally unique in showing a 12 μm feature attributed to relatively pure water ice but another OH/IR source has been found to show a similar feature (OH 32.8 -0.3, Roche & Aitken, MN 209.33p).

9. Observations of Pulsating Compact Stars
(Don E. Winget)

The pulsating compact objects were last reviewed in these pages by Robinson (Trans IAU vol.19A p303). Here, we will discuss only the important developments since that review; other recent reviews have been published by Kawaler (IAU Coll 95, in press), Starrfield (IAU Coll 95, in press), Cox (ed. J.-P. Swings, Highlights of Astron vol.7 p229), and Winget (ed. J.-P. Swings, Highlights of Astron vol.7 p221; IAU Symp 123 in press). The compact pulsators divide into at least three distinct classes of pulsating variable stars, which we will refer to according to the classification scheme of Sion et al. (ApJ 269.253): the DOV stars, the DBV stars and the DAV stars. The three classes are almost uniformly distributed in log Te, and lay along white dwarf evolutionary tracks in the H-R diagram.

In spite of the wide separation of the three classes in the H-R diagram, they do seem to have remarkably similar pulsation properties. All are multiperiodic, with periods in the range from about 100 s to 2000 s (although this upper limit may be an observational selection effect imposed by limits of the observing technique). All are low-amplitude pulsators in the optical, with typical semi-amplitudes of individual modes of one percent or less. All seem to be pulsating in non-radial gravity-modes with very low spherical harmonic index. It is interesting to note that the radial overtone number required to match the observed periods decreases dramatically with the decreasing effective temperatures of the respective classes.

The hottest group, the DOV stars, have effective temperatures in excess of 100,000 K. This group includes the pulsating PG 1159-035 (GW Vir) stars, and possibly the pulsating planetary nebula nucleus K1-16 - although this may be a different sort of beast representing a possible fourth class. The total number of known pulsators in this group has risen to five with the discovery of pulsations in PG 0122+200 by Grauer et al. (preprint).

The survey for additional pulsating DOVs has also turned up 15 null results (Grauer et al., preprint). These candidates were selected because of their similarity to the other DOV stars. Three were spectroscopically identical with PG 1159-035 and four were similar to K1-16. The absence of pulsations in these objects presents a serious challenge to our understanding of the driving mechanism in these stars.

Although the amplitude of the DOV pulsation modes is relatively small in the optical, the high effective temperatures of the DOVs suggest that it is very interesting to look at shorter wavelength. Indeed, Barstow et al. (ApJ 306.L25) have reported the first observation of pulsations in the X-ray band. Their observations in the soft X-ray (44-150 A) demonstrated large amplitude pulsations (up to 17% for individual mode semi-amplitudes) at the same frequencies detected in the optical.

The power spectra of the light curves of the DOV stars separate into distinct bands of power, with most bands exhibiting some fine structure. In a series of recent papers Kawaler (cf. Kawaler, IAU Coll 95, in press and references therein) has shown, using the observations of PG 1159-035, that the period spacing between these bands can be used to determine the mass of the DOV to two significant figures, as well as to determine the l values of the observed modes. Observations of the new DOV, PG 0112+200, by Hill et al. (IAU Coll 95, in press) have resolved the period bands present in it. They find the same sort of regular period spacing ex-

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pected by Kawaler - thereby demonstrating the usefulness of this new technique to extract seismological information from the DOV stars. For this reason the resolution of the band structure in the other DOV stars should be of highest priority.

Recent observations of the PG1159-035 by Koupelis & Winget (IAU Coll 95, in press), have revealed that at least four new bands of power were found in the 1987 data which could not be detected in the considerable body of archival data from 1979-1984. Most puzzling is that the eight bands of power previously reported in the star (Winget et al., ApJ 292.606) are still present at amplitudes consistent with the previous data - indicating that the new period bands grew in leaving the old unchanged. This view is lent further support by the analysis of the 1987 data for the phase of the 516 s peak (a single isolated peak) by Winget & Kepler (Workshop on Multiperiodic Variable Stars, Comm Konkoly Obs, in press). The new data are consistent with the ephemeris of Winget et al. (ApJ 292.606), and suggest that the 516 s peak has not only maintained its amplitude and frequency but its phase as well (including the slow secular evolutionary change), even as the new bands appeared. These observations will severely challenge models for the mode-selection mechanism in these stars, and also possibly provide unprecedented information about their nonlinear behavior.

The pulsating compact stars of intermediate temperature are the DBV stars. Since the review of Robinson, three new DBV stars have been found: PG 1351+489, PG 1115+158 (Winget et al., ApJ 316.305), and PG 1456+103 (Grauer et al., preprint), bringing the total known to five. Studies of the temperature range of these stars indicate that all the variables fall into a very narrow range near the highest temperatures of the DB stars. The exact values of this temperature range remain somewhat uncertain due to difficulties in reconciling optical and IUE temperature estimates (cf. Liebert et al., ApJ 309.291 and Koester et al. AA 149.423). The IUE results (Liebert et al., ApJ 309.291) imply a blue edge of 28,000 +/- 2,000 K, and a red edge of 24,000 +/- 2,000 K. However, if the optical temperature scale is adopted the blue edge may be up to 3,500 degrees cooler, and the red edge about 2,000 K cooler. The work of Liebert et al. serves to define an empirical instability strip, and suggests that most or all of the stars in the temperature strip pulsate and those outside do not. This suggests that similar to the DAV stars the pulsations are strictly an evolutionary effect, and that the DBV stars are otherwise normal DB stars. These conclusions must be regarded as tentative however, because the sample of stars, variable and nonvariable, upon which they are based is perilously small.

Only the light curve of PG 1351+489 can be considered resolved, and its simplicity and similarity to some DAV light curves suggest that it may be a special case (cf. Winget, IAU Symp, 123 in press). Attempts to resolve the light curve of GD 358 by Hill (IAU Coll 95, in press), succeeded in demonstrating, surprisingly, that the pattern of sets of five regularly spaced (in frequency) modes are not stable, and that this spacing appears to change, and on occasion the star appears to be nearly a mono-periodic pulsator. Hill points out that this sort of behavior casts serious doubt on the rotational splitting explanation for the equally spaced modes, and also indicates that the pulsations are not stable, since beating is not a plausible explanation for the dramatic changes in the character of the light curve.

Rotational splitting still seems to be the explanation of choice for at least one of the coolest class of compact pulsators, the DAV stars. The work of O'Donoghue & Warner (MN, in press) on L19-2, has demonstrated that rotational splitting is very succesful in explaining not only the generally equally-spaced structure of the power spectrum, but also that the slight deviations from equal spacing can be accounted for by the next highest order terms due to rotational splitting.

O'Donoghue and Warner are also monitoring the phase of the pulsation in this star attempting to measure a rates of period change. The same is being done for R 548 (Tomaney, preprint), and for G117-B15A (Kepler & Winget, IAU Symp 123, in press). Currently, the limits on all three stars are rapidly approaching the values expected from theoretical evolutionary calculations, and the best limit comes from G117-B15A: $dP/dt < |9.9 \times 10^{-15}|$, at the 68% confidence level.

Observations of a DA star (PG 2303+243) from the Palomar Green survey by Vauclair et al. (AA 175.L13), indicate that it is the 20th DAV, and the only new one discovered since the review of Robinson (Trans IAU vol. 19A p303). New variables may be found at a somewhat higher rate in the future, however, after the work of Fontaine et al. (AJ 90.1094). They showed that the well defined temperature instability strip for the DAV stars based on G-R colors (cf. Robinson's Review), can be almost as sharply defined using the much more readily available Stromgren colors. This result should increase the ease of identification of candidate stars.

10. Theory of Stellar Pulsation

(J. Christensen-Dalsgaard)

INTRODUCTION

There has been considerable activity within the area of stellar pulsation theory. Thus, rather than a comprehensive summary, the following is largely the reviewer's biased selection from a considerable larger number of relevant publications.

The understanding of non-linear stellar oscillation is advancing rapidly. Simple models have been analysed which reproduce important features of observed light curves. Resonant mode interaction may be able to explain the low amplitudes of main sequence pulsators, and amplitude variations in certain classes of pulsators. A very interesting development is the emerging connection between chaotic dynamics and irregular stellar variability.

An important trend has been the growing interest in using observed frequencies, for stars where many modes of oscillation are excited simultaneously, to carry out asteroseismic investigations of stellar interiors. This has so far concentrated on solar-like stars, rapidly oscillating Ap stars and white dwarfs; however an analysis of δ Scuti variables with rich spectra of oscillations would also be rewarding. The related subject of helioseismology is not touched upon here.

In the period considered a number of relevant conferences have been held. These include NATO Advanced Research Workshop on "Chaos in Astrophysics", Palm Coast, Florida, April 1984 (eds.: J.R. Buchler et al., Reidel, 1985; in the following referred to as FLORIDA); IAU Colloquium No 82 "Cepheids: Theory and Observations", Toronto, May 1984 (ed.: B.F. Madore, Cambridge University Press, 1985); NATO Advanced Research Workshop on "Seismology of the Sun and the Distant Stars", Cambridge, June 1985 (ed.: D.O.Gough, Reidel, 1986, in the following referred to as CAMBRIDGE); IAU Symposium No 123 "Advances in Helio- and Asteroseismology", Aarhus, July 1986 (eds.:J. Christensen-Dalsgaard & S. Frandsen, Reidel, in press); and "Stellar Pulsation-a Memorial to J.P. Cox", Los Alamos, August 1986. The proceedings of the latter two conferences were not available at the time of writing. In addition the proceedings of the conference on "Theoretical Problems in Stellar Stability and Oscillations", Liege, July 1984 (Institut d'Astrophysique, Liege; eds.: A. Noels & M. Gabriel, in the following referred to as LIEGE) have been published.

PHYSICS OF STELLAR PULSATION

Stellar stability is largely determined by the interactions between the radiation field and the motion. The fundamental aspects of these interactions were described by Mihalas & Mihalas in "Foundations of Radiation Hydrodynamics" (Oxford University Press, 1984), which will undoubtedly provide the basis for a more consistent treatment of effects of radiative transfer in stellar stability. The specific application to stellar oscillations was considered by Mihalas (ApJ 284.299).

The difficulty in treating convection remains a major impediment to the theory of most pulsating stars. Gonczi (AA 157.133) calculated stellar stability with a linearly perturbed non-local mixing length theory. The effects of Reynolds stress perturbations on solar oscillations were considered by Gabriel (AA 175. 125). Stellingwerf applied his, essentially phenomenological, model of convection to RR Lyr stars (ApJ 284.712); he also presented a simple one-zone model (ApJ 303. 119) which may be useful for understanding the effects of convection. A diagnostic of the behaviour of convection, as a function of oscillation phase, may eventually be obtained from measurements of turbulent velocities in the stellar atmosphere (Benz & Stellingwerf, ApJ 297.686).

Asymptotic techniques have proved very useful for the understanding of the properties of stellar oscillations, particularly for the high-order acoustic modes observed in, e.g., the Sun. Gough (Hydrodynamic and Magnetohydrodynamic Problems in the Sun and Stars, p117, ed.: Y. Osaki, University of Tokyo; 1986) presented an illuminating derivation of the asymptotic relations on the basis of a ray analysis.

NONLINEAR DYNAMICS OF STELLAR PULSATION

Analysis of observed light curves

Detailed hydrodynamical nonlinear calculations have generally been used to interpret the observed light curves. However it is becoming clear that a more fundamental understanding can be obtained from expansions of the non-linear equations in terms of amplitude equations. They were reviewed by Buchler (FLORIDA, p137). Klapp et al. (ApJ 296.514) compared the results of using the amplitude equations with detailed hydrodynamical calculations. They also applied the results to the interpretation of Fourier transform analysis of observed light curves (e.g. Simon, ApJ 284.278). This was investigated in more detail by Buchler & Kovács (ApJ 303.749; 318.232).

Stellingwerf & Donohue (ApJ 306.183; 314.252) computed Fourier transform coefficients from one-zone models, with results that were remarkable similar to the observations.

Resonant mode coupling

Dziembowski & Krolikowska (Acta Ast 35.5) showed that in a model of a ZAMS δ Scuti star parametric resonance between an unstable acoustic mode and a pair of stable gravity modes limits the acoustic mode amplitude to less than about 0.02 mag. This accounts naturally for the low observed amplitude of these stars, and explains why it is not reproduced by non-linear radial calculations. Dziembowski (LIEGE, p346) suggested that the observed decrease in amplitude with increasing rotation rate may be explained by the increasing probability of resonance due to non-uniform rotational splitting. Amplitude modulation caused by resonant nonlinear interactions was investigated by Moskalik (Acta Ast 35.229; 36.333): he suggested that with a reasonable choice of parameters this can reproduce the observed Blazhko-effect for RR Lyr stars.

Irregular stellar variability

Irregular variability is an extreme manifestation of nonlinearities. An extensive review of both observational and theoretical aspects was given by Perdang (FLORIDA, p11). Nonlinearly coupled sets of adiabatic modes exhibit chaotic phenomena similar to those found in simpler dynamical systems (Perdang & Blacher, AA 136.263; Däppen & Perdang, AA 151.174; Däppen, FLORIDA, p273). It remains to be seen whether these phenomena set in at sufficiently low amplitudes to be relevant to, e.g., solar oscillations. Auvergne & Baglin (AA 142.388) and Regev & Buchler (FLORIDA, p285) obtained chaotic behaviour in simple one-zone models. Very recently Buchler & Kovács (ApJ Lett 320.L57) found that hydrodynamical models of W Vir variables display period-doubling bifurcations and transition to chaos.

Chaos of a different nature, caused by departures from sphericity, was investigated by Perdang (CAMBRIDGE, p141); it manifests itself as irregularities in the frequency spectrum of the pulsating star.

Auvergne & Baglin (AA 168.118) investigated methods for determining parameters characterizing irregular variability from observed time series.

ASTEROSEISMOLOGY

Solar-like stars

The potential, and in a few cases actual tentative, observations of stellar analogies to the solar five min oscillations have prompted investigations of the properties of such oscillations in stellar models. Christensen-Dalsgaard (Space Research Prospects in Stellar Activity and Variability, p11, ed.: F. Praderie, Paris Observatory; 1984) showed that a two-dimensional classification, separating stellar mass and evolutionary state, can be established on the basis of frequency separations among low-degree high-order acoustic modes. This was discussed further by Ulrich (ApJ Lett 306.L37). As emphasized by Gough (Nature 326.257) the utility of such a classification depends on its sensitivity to the other parameters characterizing the star.

Observations of apparent 5 min oscillations in α Cen A are very difficult to reconcile with normal models (Demarque et al., ApJ 300.773). The interpretation of observations of such oscillations in ε Eri was discussed by Guenther & Demarque (ApJ 301.207) and Guenther (ApJ 312.211).

Rapidly oscillating Ap stars

The modes observed in these stars are similar to the solar five min oscillations. However, in contrast to the solar case, the oscillations maintain phase over very extended periods of time; furthermore the modes are closely linked to the large-scale magnetic field of the stars.

Oscillation frequencies for models of Ap stars were computed by Shibahashi & Saio (PAS Japan 37.245) and Gabriel et al. (AA 143.206). The results were largely consistent with the observed frequencies, although problems remained with the details of the frequency separations. Furthermore Shibahashi & Saio found that some observed frequencies exceeded the critical frequencies for the assumed, simple atmospheric models.

Dziembowski & Goode (ApJ Lett 296.L27) showed that the association between the oscillations and the magnetic field can be understood in terms of the rotational and magnetic splitting of the oscillation frequencies. An alternative explanation, based on the surface inhomogeneities of the stars, was proposed by Mathys (AA 151.315), but not developed in detail.

Compact pulsators

The study of the pulsating compact stars has undergone a rapid observational (see the section by Winget) and theoretical development. Pulsations are observed in central stars of planetary nebulae (PNN), and oxygen (DO), helium (DB) and hydrogen (DA) white dwarfs.

Cox et al. (ApJ 317.303) made a detailed analysis of the stability of DA and DB white dwarfs. To match the observed blue edge of the instability strip, convection had to be very efficient, as first suggested by Fontaine et al. (LIEGE, p328). Instability in PNN stars was studied by Starrfield et al. (ApJ Lett 293. L23); stellar models consisting solely of carbon and oxygen were found to be unstable due to partial ionization of these elements. Kawaler et al. (ApJ Lett 306. L41) found efficient driving from the perturbation in the nuclear energy generation rate, in PNN stars with a helium-burning shell, but at periods considerably shorter than those observed. The absence of oscillations at the periods found to be unstable might indicate that He burning is not active in these stars.

Period changes have been measured for the pulsating DO star PG 1159-35, and the observed upper limits on period changes for DB and DA variables are approaching the theoretically expected values. Kawaler et al. (ApJ 295.547; 302. 530) calculated period changes; for PG 1159-35 a period increase was found, of the same order of magnitude, but opposite sign, as the observed period decrease. This discrepancy can be explained by variations in the rotational splitting (Kawaler et al., ApJ 298.752), if the observed mode is prograde; however it is not obvious why such a mode should preferentially be excited.

11. Flare Stars
(R.E. Gershberg and N.I. Shakhovskaya)

The symposium "Flare Stars and Related Objects" was held in Byurakan, 1984, the Proceedings volume was edited by Mirzoyan and published by the Publishing House of the Armenian Academy of Sciences, Erevan, 1986; hereafter it is referred to as 'M'. Activity in red dwarf stars has been considered in conjuction with solar activity at many meetings: the 4th Cambridge Workshop "Cool Stars, Stellar Systems and the Sun", Santa Fe, 1985, the Proceedings being edited by Zeilik and Gibson and published in Lecture Notes in Physics Vol. 254, Springer Verlag and referred to as 'ZG'; the meeting "Solar and Stellar Flares", Rutherford-Appleton Laboratory, Chilton, 1986, Gondhalekar edited the Proceedings, it is referred to as 'G'; the 12th symposium "Solar and Stellar Activity" at the 26th COSPAR General Assembly, Toulouse, 1986 (Adv Sp Res, in press); the meeting "Solar and Stellar Physics", Titisee, 1987 (Lecture Notes in Physics, in press). Many reviews on different aspects of flare stars (FSs) have been published: by Mirzoyan & Chavushian on photographic observations of FSs (Comm Byurakan Obs 40.27); by Mirzoyan on FSs in clusters and on the Byurakan conception of stellar flares (Vistas in Astron 27.77; Comm Konkoly Obs 86.409); by Mullan on energy dissipation mechanisms in FSs (Unstable Current Systems and Plasma Instabilities in Astrophysics, eds.: Kundu & Holman, Reidel, 1985, p245) and on non-thermal radio emission from FSs ("Radio Stars", eds.: Hjellming & Gibson, Reidel, 1985, p173); by Gary on quiescent microwave emission (ibid, p185); by Rodono on coordinated ground-based and space observations of FSs (M, p19) and on starspots and plages (Highlights in Astronomy, ed.; Swings, Reidel, 1986, p429); by Oláh on starspots (Comm Konkoly Obs 86.393); by Baliunas & Vaughan on stellar activity cycles (Ann Rev AA 23.379); by Butler on solar activity phenomena among dKe-dMe stars (G, in press); by Haisch on stellar coronae (Irish AJ 17.200); by Pallavicini on solar-stellar relationships (G, in press) and on solar and stellar coronae (Lecture Notes in Physics, in press); by Pettersen on atmospheric activity of red dwarf stars (Vistas in Astron, in press).

For the last three years new, important results have been obtained due to the realization of methods for photospheric magnetic field measurements on FSs, to the X-ray observations with the EXOSAT, to microwave observations with the VLA, and to fast photometry of 3x10.0E-7 s resolution with the 6 m telescope.

In the solar vicinity a number of new FSs were found and several objects are suspected to be of the same kind: Doyle & Byrne (AA 154.370 registered 3 faint flares during 11.7 h in Gliese 812; Kovalchuk & Pugach (IBVS 2557) registered a flare with an amplitude of 0.25 mag and duration of about 1 min in the G5 star HD 282773; Good (IBVS 2581) found a flare on an anonymous star of 16.5 mag; Yang & Liu (IBVS 2705) registered a flare of 0.11 mag amplitude in the contact binary CN And; Pettersen & Hawley (AA, in press) discovered a flare activity in the dMe star BD +3°4138B; Wenzel (IBVS 2740) confirmed that SVS 2559 is a FS; Donahue et al. (ZG) registered a flare in the dM star HD 95735 during photoelectric observations in Ca II H and K lines and the continuum between them; Pesch & Sanduleak (IBVS 2989) found a FS and two probable late type emission line variables on an objective prism plate; Bopp et al. (IBVS 2604) found spottedness on the dK0 star HD 91816; Udalski & Geyer (IBVS 2691 and 2525) and Bopp et al. (in press) found a variability probably due to starspots on HD 102077, 119285, 127535, 139084,155555, 174429 and 202134; Bopp (in press) found a faint H-alpha emission in spectra of dwarf stars Gliese 256, 425A, 900 and 907.1. Barden & Nations (BAAS 17.879) discovered variable H-alpha emission and strong Ca II IR triplet reversals for the binary HD 80715 consisting of two K dwarfs, and they estimated a period of 3.8025 days. Oskanian (M, p11) has given 8 cases of photometric observations of the UV Cet type flares in stars of different spectral classes and luminosities. Kovalchuk (Comm Konkoly Obs 86.443) gave light curves of fast flares in 4 antiflare stars. Pettersen et al. (AA, in press) studied the fast rotating dwarf Gliese 890, estimated its period of 0.4312 day and rotational velocity of 60 km/s

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and found its flare activity. Van Leeuwen (M, p289) found spottedness and fast rotation for the brightest FSs in Pleiades.

Results of patrol observations of known FSs were published by Tsvetkov et al. (IBVS 2618, 2954 and 2972), by Melikian (IBVS 2630), by Malcolm (IBVS 2647), by Reglero et al. (IBVS 2752), by Orchiston et al. (IBVS 2785), by Geyer & Kämper (IBVS 2819), by Panov et al. (IBVS 2826), by Ilyin (IBVS 2985), by Oláh et al. (IBVS 2889), by Avgoloupis et al. (IBVS 2997, 2998 and 3016), and by Chugainov (Bull Crimean Ap Obs 68.114).

New FSs in stellar clusters were discovered by Rosino et al. (IBVS 2620 and 2981), by Melikian (IBVS 2621), by MacConnell & Mermilliod (IBVS 2633), by Hojaev (IBVS 2635 and 2636), by Santangelo (IBVS 2665), by Tsvetkova et al. (IBVS 2730), by Yao et al. (Publ Beijing Ast Obs 6.226), by Chavushian & Jankovics (IBVS 2814), by Melikian & Della Valle (IBVS 2929), by Parsamian & Pogosian (M, p130; Astrofizika 24.239), by Gasparian & Parsamian (Astrofizika, in press), by Hambarian (M, p120), by Parsamian et al. (Astrofizika 22.87, 22.315; M, p79), by Tsvetkova (M, p84), by Tsvetkov et al. (Comm Konkoly Obs 86.429) and by Tsvetkova & Tsvetkov (ibid. p431).

Hojaev (M, p91; Astrofizika 24.65) compared the statistical properties of FSs in dark clouds in Taurus and in other clusters. Chavushian (M, p125) tested the track method as a means of registering flares in stellar clusters. Parsamian (Comm Byurakan Obs 57.79) and Kelemen (Comm Konkoly Obs 86.433) analysed distortions of light curves of flares due to low time resolution. Szécsényi-Nagy concluded that in the Pleiades the most FSs with a high frequency of flares are known, but there exist many unknown FSs with lower flare frequency (M, p101); he suggested an activity variation in FS HII 2411 with a characteristic period of 10-15 years (Comm Konkoly Obs 86.425). Mirzoyan & Ohanian (M, p68) suggested that the flare activity of FSs in clusters have a cyclic character. Mnatsakanian (Astrofizika 24.621) represented the time distribution of flares in the Pleiades by two Poisson groups with different flare frequencies and estimated the total FS number of 750 for this cluster, 1250 for the Orion cluster and 350 for the Taurus clouds; Natsvlishvili (Comm Konkoly Obs 86.427) found the total number of FSs of 1850 for Orion. Parsamian (Astrofizika 22.633) concluded that the fraction of visual binaries among FSs in the Pleiades is 3 times higher than the field stars. Gasparian (Comm Konkoly Obs 86.439) showed that in the Orion cluster the FS and H-alpha star densities decrease whereas the distance from the cluster centre increases and for FSs this decrease is smaller. Mirzoyan (in press) found a clear dependence of a fraction of FSs among stars of a luminosity fixed on the age of stars under consideration.

Kaluzny (IBVS 2627) published BV observations of a spotted star HD 175742. Zsoldos (IBVS 2860) improved the orbital period of YY Gem. Dahn et al. (IBVS 2796) specified the spectral type as M6.5e and M(V)= 16.6 mag for the FS AZ Cnc. Melikian (IBVS 2622) described a long - about 4 h - flare in AZ Ori with unusual colours: $\Delta U < \Delta B < \Delta V$.

Byrne et al. (Armagh Obs Preprint 43; AA, in press) and Byrne & Doyle (AA, in press) improved the rotational period of a FS Gliese 867A (4.39 days), found non-synchronous rotation of the binary components, did not find any significant seasonal variations in total flare energy output and noted the advantages of the Walraven photometric system for investigating stellar flares. Doyle et al. (AA 156.283) registered about a dozen flares in Gliese 867B during 6.4 h patrol observations, did not find noticeable variations of flare activity level in 1977-81 and discovered brightness variations with an amplitude ΔV = 0.15 mag and a period of 1.95 days. Rojzman (Ast Tsirk 1484) confirmed periodic brightness variations for EV Lac (P = 4.38 days, ΔV = 0.44 mag), discovered such variations for V1396 Cyg (P = 3.34 days, ΔV = 0.044 mag) and V1285 Aql (P $\sim$12-13 days, ΔV = 0.03 mag) and found - for Gliese 48, 687, 699, 752A, 908, GX And and GQ And - that periodic variations, if they exist, have amplitudes less than 0.025 mag.

Pettersen et al. (AA Supp 66.235; ZG, p91) carried out a statistical analysis of more than a hundred of the AD Leo flares and found that their mean frequency showed a weak periodicity with P $\sim$8 years, confirmed the random time distribution of flares, and did not find noticeable variations of energy flare spectra from season to season. They found that flare fading times are distributed at random and there is a maximum near 30-50 s in a flaring up time distribution.

Doyle (AA 177.201) analysed observations of EV Lac in 1973-82 and found that in 1973-76 there was a modulation of flare frequency by stellar rotation but later the modulation disappeared. Rojzman & Kabichev (Sov Ast 62.1095) did not find the modulation of flare frequency in EV Lac by stellar rotation in 1980-81, they registered 3 very long flares and found that fast preflare dips occur; the minima of preflare dips are not lower than the normal stellar brightness. Panov & Korhonen (in press) registered intricate drifts of the EV Lac flare radiation in the U-B,B-V diagram. Gershberg & Petrov (M, p38) registered a flare in EV Lac with a total duration of 2.4 s. Tsvetkov et al. (Comm Konkoly Obs 86.423) registered fast flares in this star with total duration of 1-2 s and amplitudes till ΔU = 1.8 mag. Zalinian & Tovmassian (ibid, p435 and IBVS 2992) tested a new method for flare detection with a photoelectric photometer programmed to wait for a brightness increase exceeding the fixed level and registered flares in EV Lac with a duration of 0.1 - 0.2 s. Mavridis & Avgoloupis (AA 154.171 and in press) found small (0.3 mag) and slow (P ~5 years) fluctuations of the mean brightness level of EV Lac and a clear correlation of this level with the stellar flare activity level. At different phases of fluctuations the relative number of fast and slow flares is different, the energy spectra of flares vary and the time-averaged energy of flares changes by at least double. Avgoloupis (AA 162.151) considered 183 light curves of the EV Lac flares and concluded that statistical correlations become stronger if one considers flares of different Oskanian's type separately.

Melikian & Grandpierre (IBVS 2638) analysed the time distribution of about a hundred flares in UV Cet and found essential deviations from random distributions.

Mirzoyan & Melikian (M, p153) concluded that flares of larger energy have longer flaring up stages, the majority of such flares have complicated light curves, and flares with slow flaring up have "redder" colour indices. Melikian (IBVS 2661) found a similarity of the mean amplitudes of flares for 8 FSs with different luminosities. Gershberg (Astrofizika 22.531) showed that the mean amplitude of flares in a FS is mainly determined by the amplitude of the faintest detectable flare in the star and therefore the mean amplitude is not a measure of the flare activity level. The intrinsic frequency of flares is higher in absolutely brighter FSs although due to the observational selection in absolutely fainter FSs the flares are registered more often. The constructed luminosity function for FSs in the Pleiades permitted one to conclude that the total number of FSs in the cluster exceeds 1100 and they have mean frequencies of flares photographically registered from 10.0E-4 to 10.0E-2 /hour.

Shevchenko (M, p135) found that relative portions of fast and slow flares are the same for FSs in the solar vicinity and in stellar clusters.

Beskin et al. (M, p60; Bull Crimean Ap Obs 79, in press) registered more than a hundred flares during patrol observations for 8 FSs with a time resolution of 3 x 10.0E-7 s at the 6 m telescope. Data analysis permitted the conclusion that in all flares there is no fine structure within the range 10.0E-6 - 10.0E-1 s, the lowest lifetime of significant variations are 0.3-0.8 s at phases of fast flaring up and these data fit the prediction of the gasodynamical model of flares. Flares with total durations of several seconds are registered in detail, their fading phases are found to be determined by the relaxation time of gas heated in the flare. The energetics of faintest registered flares is compatible with the solar subflare energetics. The upper limit for the total power of stellar microflares does not exceed the time-averaged power of individually registered flares, i.e. there is no reason to believe that microflares dominate in stellar coronae heating.

Chugainov & Lovkaya (M, p52) suggested global oscillations in BY Dra with the periods 160 and 82 min.

Rodono et al. (AA 165.135) mapped the spotted surfaces of FSs BY Dra and AU Mic using multicolour observations and two-spot approximation. Poe & Eaton (ApJ

289.644) proposed a computer program for generating light curves for rotating spotted stars and used it to solve multicolour observations of BY Dra; they found that the BY Dra photometry can be represented by the single cold spot model, and the wavelength dependence of limb darkening contributes a surprisingly large amount of the variation in the visible colours. Melkonian (Astrofizika, in press) found variations of the mean annual brightness of Gliese 5, 836.7, 841.1, 908, BD +14°4637 and BD +22°3208 probably due to activity cycles.

Pettersen & Hawley (Publ Inst Theor Astrophys Oslo 2) published the spectral atlas of 26 dwarf G9-M6 FSs in the solar vicinity in the quiet state. Pettersen & Tsvetkov (IBVS 2660) did not find emission in either the Balmer lines or the Ca II lines in the spectra of 4 FSs, one of them -V654 Her- shows spectral features inherent in giants. Pettersen et al. (AJ 90.2296) found two faint M-stars without emission lines and concluded that the effect of emission lines on the B-V index is large enough to separate dMe from dM stars.

Byrne (Irish Ast J 17.N3) found unusually strong emission lines in the spectrum of FS HDE 319139. Tomkin & Pettersen (AJ 92.1424) found that Gliese 268 is a spectroscopic binary with the period of 10.4 days, the eccentricity of the orbit is 0.34 and it consists of two dKe components with masses of 0.16 and 0.19 solar mass.

Bopp (ApJ Supp 54.387) determined fluxes in CaII H and K lines for 14 spotted stars. Kodaira (M, p43) analysed H-beta emission in the system YY Gem in 1978-84 and interpreted the variations found in terms of the rotation of components and changes in a sector structure of the main component. Using coordinated observations Baliunas et al. (ESA SP-263 p181) found noticeable surface inhomogeneity of the YY Gem components and they registered flares in H-beta and brightening in ultraviolet.

The main success in FS studies over the last 3 years is the direct registration of photospheric magnetic fields on late dwarfs. Analysing the IR region of the AD Leo spectrum with a Fourier spectrometer, Saar & Linsky (ApJ 299.L47) found strong magnetic fields (B = 3.8 kGs) overlapping about 73% of the stellar surface. Then Saar et al. (ApJ 302.777) studied line profiles in the optical range of the EQ Vir spectrum and found a magnetic field of 2.5 kGs over 80% of the stellar surface. At the Santa Fe meeting Saar & Linsky (ZG) reported magnetometric results for 5 additional chromospheric active stars: HD 17433 (1.9 kGs, 50%), HD 28099 (1.7 kGs, 30%), PZ Mon (2.2 kGs, 80%), HD 45088 AB (2.4 kGs, 50% and 3.0 kGs, 65%) and noted a correlation between stellar rotational velocity and the portion of the stellar surface occupied by magnetic fields.

Important results have been obtained in the course of simultaneous observations of FSs at different wavelengths.

Butler et al. (AA 174.139; ESA SP-263) found a weak anticorrelation between UV line intensities and optical brightness for BY Dra that can be interpreted as the effect of bright plage above photospheric spots; but such a correlation is absent for AU Mic; for both FSs there exist dependences of differential emission measures on temperature similar to the solar ones.

Andersen et al. (ESA SP-263 p87) found anticorrelation between UV chromospheric line intensities and the visual brightness for EV Lac, but no correlation for transition zone UV lines that can be due to the large size of the transition zone. Ambruster et al. (ESA SP-263) registered a two-fold drop of the whole UV spectrum of EV Lac for 1.5 h that may be due to an episode of mass expulsion during a noticeable flare that occurred just before the UV observations; no modulation of Mg II and C IV line intensities by stellar rotation was found.

Doyle (MN 224.1p) studied the relation between the intensity of Mg II lines and the rotational period for dMe stars and the correlation found follows the known correlation for hotter stars. Doyle et al. (MN 220.223) when carrying out photometric investigations of Gliese 1, 461, 825, 899 and 908, found neither flares nor starspots; this fits the known correlation between X-ray luminosity and optical flare activity level.

De Jager et al. (AA 156.95) registered - in the course of coordinated observations of BY Dra in optical, radio and X-ray ranges - one strong and two weak flares; in the strong one the brightness temperature reached 25000 K at a surface of about 2 x 10.0E7 km^2 for 5 min, and the heated gas (with a density of 2 x 10.0E11 cm^{-3} and area of 10.0E10 km^2) was responsible for one hour X-ray emission. Using the Einstein and EXOSAT data, Smale et al. (MN 221.77) discovered a flaring X-ray source that was identified with a 13 mag dMe star at a distance of 13 pc from the Sun; they showed that the quiet stellar corona can be represented by a symmetrical homogeneous model but not by a loop structure.

Harris & Johnson (ApJ 294.649) observed 4 nearby binaries containing M dwarfs and found X-ray flares with durations of dozens of minutes in Gliese 34A, 338B and 669B. Johnson (ApJ 316.458) observed the multiple system Wolf 630 in soft X-ray and found one of the components - VB 8 - an anomalous cold (0.6 x 10.0E6 K) corona and hotter radiation during a flare.

Connors et al. (ApJ 303.769) systematically revised X-ray data from the A-2 HEAO-1 experiment, discovered 5 flaring sources with flare durations from 1 to 30 minutes, and concluded that most of such sources are dKe-dMe stars; one may expect about 2 x 10.0E4 such X-ray flares per year over the whole sky.

Doyle et al. (MN 223.1p; AA in press) carried out photometric, spectral, radio and X-ray observations for YZ CMi and, during optical flaring with the amplitude ΔU = 1.2 mag, did not register any X-ray flux variations. During faint flares no correlation was found between the X-ray flux and U band brightness, and a weak correlation between X-ray flux and the Balmer line emissions was suggested. In the maximum of the strong flare the essential broadening of Balmer lines was registered, the H-gamma and H-delta lines were symmetric, and the higher members of the series had an enhanced red wing. During one of the long flares the whole X-ray energy was 5 times greater than the optical radiation, and Balmer lines' emission was about 10% of the U band radiation.

Elgaroy et al. (ESA SP-263; AA, in press) carried out optical and UV observations for the binary AT Mic and found that the mean frequency of flares in the U band is about 1.3 per hour, UV line flux densities are similar to the solar active region ones, variations of Mg II lines are not well correlated with the U band brightness, "hot" UV lines - C IV and Si IV - are more broadened and blue shifted compared with "cold" UV lines - Fe II and Mg II; the high flare activity of the star casts doubt on a simple model of magnetic energy dissipation within the stellar atmosphere as the flare energy source.

Pettersen (ESA SP-263 p157) carried out optical and UV observations of a strong flare in AD Leo and found that near flare maximum coronal plasma radiation (10.0E7 K) can well represent optical radiation but it gives too high values for the UV region; the upper limit of gas density in the flare is estimated as 6 x 10.0E13 cm^{-3} using the Inglis-Teller formula.

Haisch et al. (Armagh Obs Preprint 42; AA, in press) performed UV and X-ray observations for EQ Peg AB and found the Mg II lines' enhancement during a flare; X-ray data gave a coronal temperature of 26 x 10.0E6 K at the flare maximum and 14 x 10.0E6 K at the fading stage thereby permitting one to note a similarity between this stellar flare and two-ribbon solar flares. An unusual feature of the stellar flare is that the soft X-ray flaring up time exceeds the duration of the fading stage although in moderate X-ray the light curve is of usual shape.

Doyle et al. (Armagh Obs Preprint 50; AA in press) registered in Gliese 644AB a strong flare in H-alpha and X-ray; flaring ups in soft and moderate X-ray and in H-alpha occurred simultaneously but in soft X-ray the maximum took place slightly later and the fading stage was longer than for moderate X-ray. The X-ray flare can be represented by 2-3 loops with a height of about 10.0E9 cm and an electron density of about 10.0E12 cm^{-3} . De Jager et al. (in preparation) registered a strong flare in UV Cet whose parameters differ essentially from a mean solar flare: a factor of 30 in vertical scale, a factor of 40 in optical thickness, a factor of 4 in area. The temperature of the coronal plasma was (1-4) x 10.0E6 K, EM = 10.0E51 cm^{-3} and n_e = 10.0E12 cm^{-3}.

Pallavicini et al. (ZG, p225) registered with EXOSAT and VLA a strong flare in EQ Peg with a duration of about 2 hours, peak luminosity L(X) $\sim$ 2 x 10.0E30 erg/s, and a total X-ray energy E(X) $\sim$ 10.0E34 erg. Pallavicini (BAAS 18.962) reported that in the course of patrol observations with EXOSAT for 9 hours for each of 4 FSs - UV Cet, EQ Peg, YZ CMi, and AD Leo - very different X-ray activity and different levels of quiet states were found.

Agrawal et al. (MN 219.225) estimated a mean level of X-ray emission from 7 FSs in quiet states as 2 x 10.0E28 erg/s, found a coronal temperature of about 3 x 10.0E6 K. They registered gradual variations of radiation from Gliese 735 and a flare in Gliese 729. For all FSs they found a close correlation between bolometric and X-ray luminosities but neither L(X) nor L(X)/L(bol) correlate with rotational periods or stellar equatorial velocities.

Bookbinder et al. (ZG) found that X-ray emission from K-M dwarfs is strongly dependent on the stellar age and effective temperature, and distributions of L(X) (or L(X)/L(bol)) along T(eff) for each kinematic population change markedly at the point where theory predicts the onset of full convection in the stellar interior.

Ambruster et al. (ApJ 284.270) carried out one week patrol observations for EV Lac with the Einstein Observatory and registered two strong flares with the amplitudes 7 and 50, and durations of 1-4 hours. Variations of the X-ray emission in the quiet state were discovered. Time-averaged X-ray flare luminosity is found to be larger than X-ray luminosity of the star in the quiet state and than time-averaged optical flare luminosity. Using the Einstein Observatory data, Ambruster et al. (ApJ Supp, in press) studied the stability of the X-ray flux levels in the quiet state for FSs: in the 16 of 19 cases they found variability in the scale from 10.0E2 to 10.0E3 s with the amplitude of about 30% independently of the spectral classes. They concluded that microflares cannot be responsible for stellar corona heating.

Doyle & Butler (Nature 313.378) and Byrne (Irish Ast J 17.216) noted a similarity between total X-ray luminosities of stellar coronae of FSs and time-averaged powers of stellar flares and suggested that coronal heating is due to flares. Butler & Rodono (Irish Ast J 17.131) and Butler et al. (Nature 321.679) carried out ground-based and space patrol for FSs UV Cet, EQ Peg and Prox Cen and discovered fast - less than a minute - soft X-ray variability and close correlation between X-ray radiation and the H-gamma intensity for UV Cet that gave grounds for the hypothesis that quiet X-ray stellar radiation is due to superposition of many microflares but not to stellar corona. Skumanich (Austr J Phys 38.971 and ApJ 309.858) found that the Sun fits the relation which exists between time-averaged flare luminosity and X-ray coronal luminosity for FSs and proposed an evolutionary scenario for flare activity where the total flare rate remains more or less constant but the mean flare yield decreases linearly with coronal X-ray flux.

Pallavicini et al. (AA 149.95) confirmed the existence of quiet emission at 6 cm for UV Cet, EQ Peg and YZ CMi and estimated the upper limits of such emission from YY Gem and EQ Vir. They registered impulse (10 s) and gradual (10-20 min) radio flares for YZ CMi with the increase in the degree of circular polarization.

Lang (Solar Phys 104.227) patrolled YZ CMi at 3 frequencies and found flux variability at 1415 and 1515 MHz with a characteristic time of about an hour and non-coincident maxima and flux constancy at 4885 MHz. Within a framework of cyclotron maser mechanism these data lead to a magnetic field strength of several hundred Gs within the stellar corona. Gary (in "Radio Stars", p385) registered the AD Leo radio flare at 6 cm with nearly 100% circular polarization. Lang et al. (ibid, 267) studied 31 stars with active chromospheres and coronae at 6 cm with VLA, detected radio emission from 6 stars but not from stars of G-K spectral classes. Twenty hours of observations of AD Leo enabled Lang & Willson (ApJ 305. 363) to register two flares at 1415 MHz of 50 and 25 s durations. For the longer flare quasi-periodic oscillations with a period of 3.2 s were observed during 25 s and peaks of such pulsations had a fine structure of 5 ms with nearly 100% circular polarization. Data analysis led to the conclusion that the size of the radiating region was about 10.0E8 cm; the high brightness temperature and high circular polarization were due to coherent maser emission, and quasi-periodic pulsations that modulate the maser action were due to magnetoacoustic oscillations in a coronal loop.

Kundu & Shevgaokar (ApJ 297.644) observed YZ CMi, L 726-8A and UV Cet at 6 and 20 cm simultaneously and concluded that quiet radio emission of FSs is due to gyrosynchrotron radiation of electrons having a power-law energy distribution and this emission originates from sources whose sizes are of several stellar radii. From the lifetime of 1 hour for non-thermal particles they estimated stellar photospheric magnetic fields to be a few kGs. Jackson et al. (ApJ 316.L85) registered the UV Cet flare of about 10 min duration at 4 frequencies from 1385 to 1652 MHz and found a rather complex dynamic spectrum involving both positive and negative frequency drifts.

Nelson et al. (MN 220.91) made simultaneous observations for AT Mic in optical, infrared and microwave ranges and found essential disagreement between the observable features of flares and the expected ones within the framework of Gurzadian's model. The data obtained can best be accounted for in terms of a hot (10.0E5 K) plasma model; the ratio of optical to microwave flare luminosities shows a variation of at least several orders of magnitude which means that various mechanisms are responsible for these radiations.

Stewart et al. (Proc Astr Soc Australia, in press) found a correlation between peak flare luminosity at 8.4 GHz and stellar surface velocity. Vaughan & Large (MN 223.399) found variable emission at 8.4 GHz for 2 of 8 studied FSs; the emission mechanism is not known (Proc Astr Soc Australia 6.319 and in press).

A set of theoretical studies on FSs have been carried out.

Zarro & Zirin (AA 148.240) demonstrated that the series merging of Stark broadened line profiles can produce a significant continuum enhancement that may be responsible for the "blue" continuum in solar and stellar flares, Gurzadian (Ap Sp Sc 106.1) calculated postflare relaxation of different chromospheric lines. Cram & Giampapa (ApJ, in press) developed a theory of the formation of H-alpha and Ca II lines in dM stars. Poletto et al. (BAAS 18.962; Adv Sp Res, in press) showed that the solar two-ribbon flare model can be used to interpret long-lived stellar flares. Gurzadian (Ap Sp Sc 125.127) concluded that a usual fast flare that occurred on the opposite side of a star can be seen as a very slow event due to the diffusion of flare radiation.

Grandpierre (M, p176) proposed a convective theory of flares. On concluding that the theory of current sheets cannot energize the most powerful solar and stellar flares Gershberg et al. (IZMIRAN Preprint No 41a(655); Kinematics and Physics of Celestial Bodies 3.N5) proposed that a soliton gas is formed within subphotospheric convective layers as a flare energy source.

Badalyan (Sov Ast 63.762) found a general analytical formula for EM of isothermal hydrostatic stellar coronae; using this formula and X-ray observations, Katsova et al. (Sov Ast 64.N5) estimated the EM of FS coronae and n_e in their lower layers, found a systematic increase of the coronal densities for FSs from G to M3 spectral classes and a decrease for later stars. Katsova & Livshits (M, p183; Comm Konkoly Obs 86.437) estimated the least flaring up times within the framework of their gasodynamical model of flares and found these times for optical flares to be several tenths of a second.

Gurzadian (Ap Sp Sc 113.213) proposed stellar aggregates containing many FSs as sources of galactic cosmic rays. Caillault et al. (ZG) concluded that the integrated contribution to the diffuse soft X-ray background from M dwarfs is less than 10 %.

12. T Tauri Stars
(Claude Bertout)

Major progress has been achieved in our understanding of the T Tauri phenomenon since the previous Commission 27 report and this overview concentrates on these advances. In the picture which is now emerging, a typical T Tauri "system" is made up of a late-type, active star, surrounded by and interacting with the dusty equatorial disk which has been formed together with the star during the protostellar collapse of a dense molecular core.

Recent reviews of several theoretical and observational aspects of the formation of low-mass stellar objects are found in "Protostars and Planets II", (eds. M.S. Matthews & D.C. Black, Tucson, University of Arizona Press), in "Nearby Molecular Clouds", (ed. G. Serra, Lecture Notes in Physics No. 237, Heidelberg, Springer), in "Circumstellar Matter", (IAU Symp 122, eds. I. Appenzeller & C. Jordan, D. Reidel) and in "Protostars and Molecular Clouds", (eds. T. Montmerle & C. Bertout, Saclay, Commissariat a l'Energie Atomique). Current theoretical ideas about low-mass star formation are summarized by Shu et al. in Ann Rev AA 25.23.

A great deal of work has been devoted to the study of the spectral appearance of protostar models by Adams & Shu (ApJ 296.655; 308.836), who show that observed spectra of several low-luminosity infrared sources can be reproduced by models involving a central protostar surrounded by the nebular disk expected to be formed at the same time as the star during the protostellar collapse of a slowly-rotating molecular cloud core (e.g. Terebey et al., ApJ 286.529). Wilking & Lada (ApJ 287.610) classified the ρ Ophiuchi infrared sources in different categories according to the shape of their infrared spectra, and Adams et al. (ApJ 312.788) proposed an interpretation of these classes according to their evolutionary status. In this theory, stars with mid-infrared spectra rising toward long wavelenghts (Class I) are still surrounded by a disk and an infalling envelope. Stars with power-law infrared spectra whose flux decreases toward longer wavelenghts (Class II) have accreted their envelope but are still surrounded by optically thick disks, and stars with approximate blackbody spectra (Class III) have lost both their envelope and disk. Many T Tauri stars have Class II energy distributions.

The observational search for protostellar disks has been quite active, and many of these efforts were aimed at HL Tauri, a star long suspected to have an equatorial disk (Cohen, ApJ 270.L69). The presence of a scattering disk around this object was inferred by Grasdalen et al. (ApJ 283.L57) from direct infrared imaging followed by maximum-entropy image reconstruction and by Beckwith et al. (ApJ 287.793), who used speckle interferometric techniques. Beckwith et al. (ApJ 309.755) observed an elongated structure in ^{12}CO with extension about 4000 AU, and Sargent & Beckwith (ApJ, in press) found that this molecular structure may be rotating around the star. At this point, this is the only direct evidence for a disk around a low-mass young stellar object.

There are, however, several lines of indirect evidence for disks surrounding T Tauri stars (TTS). Rucinski (AJ 90.2321) searched the IRAS Point Source Catalog for TTS and found that a number of them display far-infrared power-law spectra reminiscent of those expected from optically thick accretion disks ($\lambda F_\lambda \propto \lambda^{-3/4}$). Appenzeller et al. (AA 141.108) were first to suggest that the lack of red emission often noted in the forbidden lines of TTS optical spectra is best understood if a large (typically 100 AU), optically thick disk hides from our view the receding parts of the stellar wind. Detailed profile computations by Edwards et al. (ApJ, in press) confirm this and demonstrate that latitude-dependent wind best accounts for the observed profiles. Rydgren & Cohen (in Protostars and Planets II) discuss additional evidence suggesting that dust is anisotropically distributed around TTS. Bertout (IAU Symp 122) suggested that the interaction between a fast-rotating, Keplerian accretion disk and the slow-rotating TTS photosphere should give rise to a boundary layer emitting mostly in the ultra-violet, so that infrared excess and the strong ultraviolet excess characteristic of TTS (Herbig & Goodrich, ApJ 309.294) may be correlated as is often the case.

There is some controversy about the exact nature of the disks surrounding TTS. Adams et al. (ApJ 312.788) favor geometrically thin but optically thick "passive" disks, which merely intercept stellar photons and re-distribute them at longer wavelenghts. They show that the system luminosity can then be up to 1.25 times the stellar luminosity and that the expected spectral slope in the IR is the same as that of an accretion disk. Kenyon & Hartmann (ApJ, in press) also favor

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passive disks, but argue that they need not be geometrically thin ("flaring" disk). In that case, the outer parts of the disk can intercept more stellar photons, with the results that the system luminosity can be up to 1.5 times the stellar luminosity and that more energy can be emitted at long IR wavelenghts. There are several TTS whose "flat" infrared spectra cannot be reproduced when assuming a passive, flat disk, and a "flaring" disk represents one possibility to account for them in the framework of the passive disk model. Other possibilities are discussed by Adams et al. (ApJ, in press), who propose instead that TTS with far-IR spectra are surrounded by "active" disks (i.e., intrinsically luminous disks) with temperature distributions different from those of passive disks or classical accretion disks. A recent detailed study of the continuous energy distribution from the IUE range to the far-IR range of several TTS by Bertout et al. (ApJ, in press) confirms that active accretion disks with boundary layers between the disk and the star are probably present around a number of TTS. In this case, the system luminosity can range from 1 to 3 times the stellar luminosity depending on the mass-accretion rate, which typically ranges from 5x10.0E-8 to 5x10E-7 $M_\odot$ /yr. It is clear, however, that the TTS with flat IR spectra discussed above cannot be understood in such a simple framework.

Progress has also been made in recent years by studying TTS with low emission characteristics, which differ little from other active late-type stars. In the framework outlined above, TTS with small UV and IR excesses and low-level activity are probably more evolved than more active TTS. Their energy distribution is not dominated by the disk, which either optically thin or has been accreted or dissipated. Thus, we expect their activity to be stellar rather than circumstellar.

Rotational velocities of a large sample of TTS with low to moderate emission characteristics were measured by Hartmann et al. (ApJ 309.275) using Fourier techniques and by Bouvier et al. (AA 165.110) using mainly CORAVEL. Both groups find that v sini ranges typically from 5 to 25 km/s. The detection limit of CORAVEL is about 2 km/s, but Bouvier et al. did not find TTS rotating slower than about 5 km/s in their sample of 30 stars. If confirmed by further work, this result would have far-reaching consequences. Studies of correlations between various activity diagnostics and rotation rates demonstrate that TTS, together with RS CVn systems, continue upwards the relationship found for main-sequence late-type stars between v sini and X-ray flux. This suggests that X-ray activity is dynamo-driven in TTS just as it is in RS CVn stars. Furthermore, the anticorrelation between X-ray flux and rotation period observed in RS CVn systems also seems present in TTS, although the small number of TTS for which both X-ray flux and rotation period are known makes this conclusion somewhat controversial at this point (Bouvier in Protostars and Molecular Clouds).

Intensive photometric and spectroscopic monitoring of various TTS was performed at several observatories around the world. The large number of publications that resulted over the last few years cannot be detailed here because of limited space, but the interested reader can consult the Astronomy and Astrophysics Abstracts for works about specific objects.

One highlight of this intensive monitoring was the discovery of periodic components in the light-curves of more than a dozen TTS with usually low or moderate emission characteristics, including T Tauri itself (cf. Vrba et al., ApJ 306.199; Bouvier et al., AA 158.149; Bouvier in Protostars and Molecular Clouds and Herbst et al., ApJ 310.L71). Bouvier reproduces the periodic light-curves by assuming that the modulation is rotational and is caused by an inhomogeneous surface temperature distribution. He shows that the derived properties of the spots on the stellar surface are similar to those of RS CVn spots. Thus the intrinsic properties of TTS - as opposed to properties caused by their circumstellar environment - appear similar to those of other late-type active stars.

Optical line emission, a characteristic property of TTS, has also been the subject of many investigations, but only a few results can be mentioned here. No correlations were found between the Hα or CaII K line fluxes and the rotation rate (e.g. Hartmann et al., ApJ 309.275), ruling out dynamo mechanisms for the production of these lines. Detailed models of the formation of emission lines in deep-lying chromospheres by Calvet et al. (ApJ 277.725) confirmed that Hα cannot be purely chromospheric. However, Calvet et al. (ApJ 293.575) report a strong correlation between MgII k and CaII K line fluxes, and Bouvier (op. cit.) finds that Hα and CaII K line fluxes are also strongly correlated at all emission levels. This suggests that these three lines are all formed in the same atmospheric region and the same physical mechanism is responsible for their formation even in stars with different activity levels. Bertout et al. (ApJ, in press) suggest that these strong emission lines originate partly from the atmosphere of the boundary layer between disk and stellar photosphere.

The long-standing problem of the apparent lack of post-T Tauri stars (i.e., stars more evolved than TTS but still in their pre-main-sequence evolutionary phase) may also be on the way to a solution. Walter (ApJ 306.573) and Feigelson et al. (ApJ, in press) identified a number of pre-main-sequence objects with low-emission characteristics through follow-up observations of X-ray surveys in star-forming regions (see also the review by Feigelson in Protostars and Molecular Clouds). While some of these objects appear older than classical TTS, many of them fall in the same region of the H-R diagram as TTS and are denoted "naked" TTS by Walter because their circumstellar environment appears empty. The calcium-emission stars found in a survey of the Taurus-Auriga region by Herbig et al. (AJ 91.575) fall in the same category; they are not genuine post-T Tauri stars, but their study brings useful insight into the structure of their atmospheric layers. Finkenzeller & Basri (ApJ 318.823) performed high-resolution spectroscopy of a number of stars with low emission characteristics. They are able to show that their metallic emission spectra are very similar to the solar chromospheric spectrum.

Walter (ApJ 306.573) also finds that a significant fraction of pre-main-sequence objects found from X-ray surveys appear older than TTS, and that there is little besides their X-ray properties to distinguish them from field stars.
Another way to detect objects in the post-T Tauri phase might be through surveys at radio wavelenghts. Andre et al. (AJ 93.1182) used VLA to survey the ρ Ophiuchus cloud and discovered there a number of sources apparently associated with Class III stars that are as close to the molecular cloud core as are typical TTS. The evolutionary status of these objects is however unclear at this point, as is the nature of their radio emission (see Andre in Protostars and Molecular Clouds).

Finally, yet another long-standing question - the apparent deficit of binary systems among TTS - may be finding an answer with the discovery via Moon occultation techniques of close companions to several TTS (Simon et al., ApJ 320.344).

B. Szeidl
President of the Commission