DIVISION V - VARIABLE STARS

COMMISSION 27. VARIABLE STARS (ETOILES VARIABLES)

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1. Introduction (M. Jerzykiewicz)

The three special projects sponsored by Commission 27: the Information Bulletin on Variable Stars (IVBS), the Archives of Unpublished Observations of Variable Stars, and the General Catalogue of Variable Stars (GCVS) continue to serve the astronomical community. Katalin Oláh, Laszlo Szabados, András Holl, Zsolt Kővári and their colleagues have made the Bulletin available in electronic form, including back issues. In addition, András Holl succeeded in setting up a WWW home page for our commission. Chris Sterken and the Editorial Board strived to maintain high scientific standard of the IVBS. The Archives, under Ed Schmidt, increased to over three hundred files. Nikolai N. Samus and his co-workers published the final volume of the 4th edition of the GCVS. The Catalogue is also available electronically. All these people should be highly prized for their hard work for the IAU and astronomers at large.

The report covers the interval from mid-1993 to mid-1996. The table of contents is the same as in the previous report. An unsuccessful attempt was made to add a new section on "Variable Stars from Major CCD Surveys." Apparently, the letter with the text of that section was lost in the mails. All the other ones, however, were on time. We have been lucky that so many distinguished experts agreed to contribute. I am grateful to them all for their excellent reviews.

In addition to the journal abbreviations, which are easy to decipher, the most frequently quoted IAU Symposia and Colloquia (and the corresponding proceedings) are abbreviated as follows: Symp. 162 = PRML, Symp. 177 = CSP, Coll. 134 = NPSV, Coll. 137 = IS, Coll. 139 = NPSP, Coll. 151 = FF and Coll. 155 = AASP. Details of these meetings, and of other IAU Symposia and Colloquia referred to in this chapter, can be found in recent IAU Information Bulletins. Most of the meetings were sponsored or supported by Commission 27.

2. Commission Activities

a) IBVS (L. Szabados and K. Oláh)

In the interval covered by this report, the number of published issues of the Information Bulletin on Variable Stars progressed from #3903 to #4351.

From 1995 on, there are two versions of the Bulletin: the conventional printed one (preferably for libraries) and the electronic version which is accessible via the World Wide Web for any user (but a registration is requested). The two versions are absolutely identical, the electronic version is free of charge, while the subscribers of the hardcopy version are charged with a nominal fee of 50 US$.

Owing to the effort of the technical editor, András Holl, the back issues of the IBVS are prepared for electronic retrieval in PostScript and in ASCII text formats. It is hoped for that, by the time of the Kyoto GA, IBVS will be the first astronomy journal accessible completely electronically, since the first 4000 issues will be published on a CD. Each recent volume (consisting of 100 issues) is also published in the CD journal JAD (Journal of Astrophysical Data, ed. by Sterken), and after the publication those

I. Appenzeller (ed.), Reports on Astronomy, Vol. XXIIIA, 325–361.

issues are removed from the WWW pages. However, upon request, all back issues available will be sent to the interested readers.

The electronic production of the IBVS imposes stricter requirements on the submission of the manuscripts. The most important change is that apart from very few cases (less than 1%), we accept only electronic submissions (for details see the Editorial Note published in January 1996). In addition, a thorough yet fast (possible because of the electronic submission) refereeing suggested by the Editorial Board was introduced.

The Editorial Board had "partial" meetings during the major variable star conferences. Its activity is mainly carried out via e-mail and thanks to enthusiasm of the Chairman, Chris Sterken.

For more detailed and up-to-date information see the WWW Home Page at URL:
http://www.konkoly.hu/IBVS/IBVS.html

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At present, four persons are responsible for IBVS at Konkoly Observatory: the two scientific editors compiling this report, as well as András Holl (technical editor) and Zsolt Kővári (administrative editor).

b) Archives of Unpublished Observations (Edward Schmidt)

The Archives of Unpublished Observations of Variable Stars is a depository for photometric observations which will not be published elsewhere. Such details as the addresses of the archive sites, how to submit and obtain data from the archives and files which are currently in the archives can be found in the previous report of Commission 27 and in references given there.

The following table lists the 42 files which have been submitted to the archives since the previous report of Commission 27. This brings the total number of files currently in the archives to 289.

File	Contributor	Star(s)
244	Krisciunas	9 Aur
256E	Breger	BU Cnc
257E	Coates	CY Aqr
261E	Poretti	HD 18878, HD 19279
263E	Poretti	BI CMi, HD 67028
271E	Hall & Burke	HR 6469
273E	Hall	HR 7275
274E	Poretti	FG Vir
277E	Poretti	HD 224638, HD 224995
278	Park	44 Tau
280	Park	VZ Cnc
281E	Oja	BD+31°0849
282E	Rodriguez	CC And
283E	Breger	63 Her
284E	Barenbaum	PV Cas
285E	Krisciunas	9 Aur
286E	Schmidt	21 stars in And, Ari and Aur
287E	Schmidt	16 stars in Boo, Cam and Cnc
288E	Schmidt	16 stars in CVn, CMi and Cas
289E	Schmidt	17 stars in Cep, Com, CrB, Cyg, Del and Dra
290E	Schmidt	20 stars in Gem, Her, Hya and Leo

291E	Schmidt	19 stars in LMi, Lyn, Lyr, Mon, Oph and Ori
292E	Schmidt	20 stars in Peg, Per, Ser and Tau
293E	Schmidt	17 stars in UMa, UMi and Vir
295E	Rodriguez, Rolland & Costa	RS Gru, RY Lep
296E	Poretti	BH Psc
297E	Kjurkchieva & Marchev	UX UMa
298E	Cerruti	LT Pav
299E	Snyder	UV Leo
300E	Burke	HD 191706
301E	Breger	FG Vir
302E	Krisciunas	8 Hyades F stars
304E	Frederik	UV Leo
305E	Kurtz	HD 6532
307E	Krisciunas & Crowe	V777 Tau, HD 23375
309E	Oja	HY Com
310E	Jerzykiewicz, Pigulski & Kopacki	Variables in NGC 7235
311E	Matthews	FM Com
312E	Szuszkiewicz, Musielok, Ratajczyk, Tomczak & Włodarczyk	DD Lac and EN Lac
314E	Wehlau, Wehlau & Matthews	V1208 Aql

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

In January 1995, Vol. V of the 4th edition of the GCVS appeared in print. It contains 10979 variable or suspected variable stars in 35 external galaxies and 984 reliable or suspected extragalactic supernovae. This volume closes the 4th edition. A number of copies have already been distributed among the international astronomical community, but the process of distribution is slowed down by shortage of funds for postal expenses.

The 72nd Name-list of variable stars was published (IBVS 4140); the 73rd Name-list is expected to appear before mid-1997.

The Strasbourg data center has received from the GCVS team the electronic versions of Vol. IV (including a new, corrected version), of Vol. V, and of combined Name-lists Nos. 67 – 72. The electronic version of the GCVS is now also available from Moscow by ftp (neptun.sai.msu.su, archived files in the directory /pub/groups/cluster/gcvs/...).

The electronic version of a supplement to the NSV catalog, containing about 10000 stars, has been compiled. After final editing, it will be made available through computer nets.

Much effort is being undertaken to improve positional information on variable stars. An electronic GCVS version for Andromeda variables with improved positions for practically all stars has been prepared. Accurate equatorial coordinates have been published for variable stars in the variable-richest globular clusters M 3, M 5, ω Cen and in several other globulars. This makes it principally possible to include variables in globular clusters in the system of the GCVS.

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

Pulsation in Early-Type Stars. Now that the driving mechanism for pulsation among B-type stars is understood, there has been considerable progress in matching the predicted properties of models with observations. The effect of opacity and metal abundance on the instability strip is reviewed by Dziembowski (PRML, 55) and Moskalik (AASP, 44).

The effect of rotation on stellar pulsation, which is of particular importance for the B-type stars, is still poorly understood. Lee & Baraffe (A&A 301, 419) have examined the pulsational stability of rotating OB stars. They find that it is necessary to work to fourth-order as second-order effects only weakly influence stability. Fourth-order effects may be important in stabilizing pulsations, especially for high-frequency p-modes. Buchler, Goupil & Serre (A&A 296, 405) study the nonlinear behaviour of rotationally split triplets. They find that nonlinear effects can lead to substantial asymmetries in the amplitudes of the $l = 1$ triplets and that nonlinear phase lock may cause symmetric frequency spacing.

Balona (ApSS 230, 17) reviews the observational status of several types of OB variables and proposes a classification scheme for these stars. A review by Jerzykiewicz (PRML, 3) describes how astrophysical parameters may be derived from pulsating OB stars and how modes may be identified using multi-colour photometry. The identification of pulsation modes is crucial for asteroseismology. Perhaps the best method is to use the information in the line profiles. Aerts (PRML, 75) reviews this and other methods. Heynderickx, Waelkens & Smeyers (A&AS 105, 447) describe how the amplitudes at different wavebands may be used for mode identification and apply the method to many β Cep stars. Using results of linear, nonadiabatic calculations of β Cep models, Cugier, Dziembowski & Pamyatnykh (A&A 291, 143) calculate amplitudes and phases of unstable modes of low degree. Diagnostic diagrams involving the ratios of amplitudes of different colours and phase differences allow mode identification.

In all these studies, the effect of rotation has been ignored. Owing to the difficulty of the problem, this state of affairs is likely to persist for some time. Nevertheless, until it is addressed, results of mode identification must remain suspect.

β Cep Stars. New CCD searches for β Cep stars and other short-period variables were conducted in the open clusters NGC 3293 (Balona, MN 267, 1060), NGC 4755 (Balona & Koen, MN 267, 1071), NGC 6231 (Balona & Laney, MN 276, 627) and NGC 2362 (Balona & Laney, MN 281, 1341). Jerzykiewicz et al. (Acta Astr. 46, 253) use the same technique on the northern cluster NGC 7128. Krzesiński (PhD, Cracow 1996) finds three β Cep stars in h & χ Per. Hambly et al. (MN 267, 1103) describe a search for high galactic latitude β Cep stars. Of the nine candidate stars, one shows light variability with a period characteristic of β Cep variables.

The Be star 27 CMa has been confirmed to be a β Cep variable (Balona & Krisciunas, IBVS 4022). Heynderickx & Haug (A&AS 106, 79) find four periodicities in photometry of IL Vel including a closely-spaced triplet. Mathias et al. (A&A 289, 875) present high spectral and time resolution observations of 12 (DD) Lac. This star has six frequencies of which three are equidistant. Porri et al. (ApJ 424, 401) present an analysis of Voyager spectra of ν Eri.

Mode identification in β Cep stars using line profile variations has been performed by Mathias et al. (A&A 283, 813) for α Lup; Aerts et al. (A&A 286, 109) for β Cep; Aerts, Waelkens & De Pauw (A&A 286, 136) for KK Vel, ν Eri, β CMa, V348 Nor and Aerts et al. (A&A 301, 781) for BW Vul. Dziembowski & Jerzykiewicz (A&A 306, 436) use photometry and radial velocities and also computed frequencies to identify the modes in the eclipsing binary 16 (EN) Lac. They conclude that the interior of the star rotates significantly faster than the outer layers. Chapellier et al. (A&A 304, 406) find no period variations in 16 Lac. They identify the modes using photometric and radial velocity amplitudes and agree with Dziembowski & Jerzykiewicz that the main oscillation is radial and the other two oscillations are nonradial with $l = 1$ or 2. Chappelier et al. confirm an orbital resonance between the radial and nonradial modes. However, this is disputed by Jerzykiewicz & Pigulski (MN, in press) who discuss the long-term behaviour of the pulsation amplitudes and conclude that nonlinear interaction between coupled modes may be responsible. They resolve one of the three frequencies into a close pair.

Pigulski (A&A 274, 269; 292, 183) studies period changes in BW Vul and 12 (DD) Lac. In the former, these can be fully understood in terms of an evolutionary effect and a light-time effect in a binary system, but in 12 Lac all six periods appear to be variable and cannot be explained in this way.

53 Per (SPB) Stars. A search for 53 Per (or SPB) stars in the open clusters NGC 3293, NGC 4755, NGC 6231 and NGC 2362 by Balona et al. (see references above) has failed to produce any convincing evidence that they are present in these young systems. It is known that 53 Per stars are slow rotators, whereas the mean rotational velocities of stars in the clusters is large. Balona et al. suggest that long-period g-mode pulsation in B-type stars may be damped by rotation.

One of the problems in studying the 53 Per stars is that they require intensive observations over a prolonged period if the correct periods are to be identified. This is illustrated by Balona (MN 270, 914) who presents photometric observations of HR 3562 and HR 3600 over six seasons. HR 3562 seems to contain three periods, but the behaviour of the periodograms from season to season is complex. HR 3600 may be singly-periodic.

North & Paltani (A&A 288, 155) report five periodicities in photometry of the B8 V star HD 37151 and also obtain line profile observations which confirm two of the periods. The star has narrow lines and is one of the coolest of its type. A strong correlation between the colour/light amplitude ratio and effective temperature is found for the SPB stars. Another cool SPB star, HR 1328, was discovered by Chapellier et al. (A&A 307, 91).

Huang et al. (ApJ 431, 850) presents results of a period analysis of photometry of 53 Per in which the two main periods are confirmed. Smith & Huang (PRML, 37) use results from Voyager photometry in conjunction with optical photometry to show that thermal effects dominate over geometrical effects in producing the light variations. In addition, the dominant variation is found to be $l = 2$ (or perhaps 1).

Clausen (A&A 308, 151) has obtained photometry for V539 Ara, an SPB star in a detached, double-lined eclipsing system. These observations allow accurate dimensions of the system to be made and the placement of the SPB component on the theoretical HR diagram.

ζ Oph Stars. The ζ Oph stars are characterized by high-order line profile variations (moving bumps). Whether this is due to the same mechanism as the low-order profile variations is not yet clear. Until this is understood, it is useful to distinguish between these types of variation. These stars have been poorly studied – in most cases even the most fundamental parameter, the periods, are unknown or uncertain.

Fullerton, Gies & Bolton (ApJS 103, 475) conducted a spectroscopic survey of a magnitude-limited sample of O stars to search for intrinsic line profile variations characteristic of pulsation. Profile variations were found in 23 out of 30 stars observed, the amplitude increasing with radius and luminosity. They conclude that pulsation is a likely cause of the variability, though it is not clear how much of the variability is contributed by the stellar wind. Fundamental data, such as the period(s) and velocity amplitudes are required before one can conclude that pulsation is the cause.

Preliminary results for individual stars were presented by Reid et al. (AASP, 309) for the O9.5 V star HD 93521 in which two periods were determined. Koubsky et al. (AASP, 307) presented preliminary results for the Be star 60 Cyg.

One of the most detailed studies of ζ Oph itself has been performed recently by Kambe et al. (ApJ, in press). Using multisite photometric and line-profile observations, the authors are able to determine two periods which have a common superperiod of about 10.05 h. Detailed modelling is required to test whether this is a pulsational or rotational effect.

Be Stars. The question of whether pulsation or rotation is the mechanism responsible for the periodic light and line profile variations in some Be stars (the λ Eri variables) is still not resolved. Arguments for both cases are presented by Baade & Balona (PRML, 311). Balona (MN 277, 1547) uses all available photometric periods to refine the correlation with projected rotational velocities. The correlation places limits on the allowed periods in the co-rotating frame. These turn out to be very long and restrict any pulsational velocity to just a few km/s. This means that the dominant effect is a temperature variation, making the pulsational and starspot hypotheses practically indistinguishable. However, some stars have radial velocity amplitudes much too large to be explained by either pulsation or starspots. Two cases in point are η Cen (Štefl et al. A&A 294, 135) and DX Eri (Štefl & Balona A&A 309, 787) where simultaneous line-profile and photometric data are analysed. The conclusion in both cases is that neither model can explain the observations.

The atmospheres of Be stars are too complex to be understood just in terms of pulsation or starspots: transient features are seen in the line profiles. Smith et al. (ApJ, in press) continue their study of this phenomenon in λ Eri and suggest the presence of surface activity and, by implication, a magnetic field. So far, no clear correlation between the amplitudes of the line profile variations and emission episodes has been found. However, Kambe (ApSS 221, 459) finds that the range in wavelength of the line-profile variation in λ Eri increases by about 20% during the emission phases.

In addition to the low-order line profile variations, some Be stars also show low-intensity features moving from blue to red (the ζ Oph phenomenon described above). Floquet, Hubert & Briot (A&A 287, 789) obtained high-resolution spectra of η Cen and conclude that the moving bumps are consistent with modes of $l = |m| \approx 14$ or with $l \approx 7, m \approx 6$. Štefl et al. (A&A 294, 135) find that the super-period of the moving bumps in the same star is close to the photometric period. Floquet et al. (A&A 310, 849) obtained high resolution spectra of 48 Lib and obtained $l = 8 \pm 2$ for the moving subfeatures. They also conclude that the star is multiperiodic. This would be an important finding if it can be confirmed.

McDavid (PASP 106, 949) presents optical polarization data for eight bright northern Be stars. There are no strong cases of night-to-night variability in polarization. Aerts & Molenberghs (A&A 293, 828) use photometric, polarimetric and spectroscopic data to put constraints on the geometry of Be disks. They conclude that polarization is a function of projected rotational velocity and a possible link between pulsation and mass loss. Juza et al. (A&AS 107, 403) collect data for κ Dra and find that the intensity of the Balmer emission varies with a period of 23.01 yr. The optical brightness and polarization seem to vary with the same period. Mennickent, Vogt & Sterken (A&AS 108, 237) present photometry of seven Be stars.

Hirata (PASJ 47, 195) shows that the long-term photometric variation of Pleione can be understood in terms of variations in the envelope and another very opaque region. These two regions behave differently, implying different origins.

4. δ Sct, γ Dor and roAp Stars (D.W. Kurtz)

a) δ Sct and γ Dor Stars

The "Delta Scuti Newsletter" = DSN is edited by Michel Breger (breger@procyon.ast.univie.ac.at). There is no subscription charge, and papers are indexed in AAA. The newsletter (past and present) can be accessed on the WWW at http://dsn.ast.univie.ac.at, along with much more information about δ Sct stars, observing networks, multi-site campaigns, and data acquisition, analysis and reduction. For those new to δ Sct stars the DSN and this WWW site are good starting points.

Catalogues. García et al. (A&AS 109, 201) present a catalogue with data on, and references to the literature for, 302 δ Sct and SX Phe stars. Rodrígues et al. also present a catalogue of 298 δ Sct stars available electronically. Both catalogues are up-to-date to November 1993.

Reviews and Asteroseismology. Helioseismology is now a well-developed discipline with hundreds of astronomers working on the subject, both observationally and theoretically. The potential to apply seismic techniques to others stars is exciting, but, as of this writing (July 1996), no solar-type star has been found which unequivocally shows a frequency spectrum of p modes like that of the sun. Asteroseismology has thus, so far, turned its attention to white dwarfs pulsating in g modes (with good success), β Cep and SPB stars, roAp stars and δ Sct stars (with lesser degrees of success), and (technically) to beat Cepheids and RR Lyrae stars. This has a unifying effect on the study of stellar pulsation, bringing together astronomers who work in all parts of the HR diagram.

In the triennium covered by this report the whole field of asteroseismology has been reviewed by Brown & Gilliland (ARA&A 32, 37). Two reviews of δ Sct stars are given by Breger (GONG94, 596 and AASP, 70). Matthews (GONG92, 303) reviews both δ Sct and roAp stars. Reviews of asteroseismology of roAp stars are given by Martinez & Kurtz (AASP, 58) and Kurtz (GONG94, 606). Many further reviews and papers on δ Sct and roAp stars by Dziembowski, Däppen, Shibahashi, Guzik & Bradley, Kennelly, Gilliland, and others, can be found in: GONG92 = ASPCS vol. 42, NPSV, IS, GONG94 = ASPCS vol. 76, and AASP. By the time this report is published, the proceedings of IAU Symp. 181 and 185 will be in print, and will contain many more papers on δ Sct, roAp and γ Dor seismology, or prospects for seismology. Goupil et al. (A&A 305, 487) theoretically discuss asteroseismic probes of interior rotation rates of δ Sct stars, in anticipation of space-based data.

γ Dor Stars. The emergence of the γ Dor stars as a new class of variables, and the recognition of them as probable g-mode pulsators, is an exciting development. Variability in the F0V star γ Dor was first discovered by Cousins & Warren (MNASSA 22, 65). After years of puzzling over this star, Cousins (Obs. 112, 53) and Balona et al. (MN 267, 103) finally showed that its variations are multiperiodic with periods of 0.7570 and 0.7334 d. Other early F dwarfs had also been noted in recent decades to show similar time-scale variability (e.g. Mantegazza et al. MN 270, 439). Antonello & Mantegazza (A&A 164, 40) found four "long-period" variables with time-scales between 0.2 and 0.4 d in NGC 2516. This is too long for radial pulsation, so they suggested the possibility of g modes, ellipsoidal variability, or spotted rotators. Balona et al. (MN 270, 905) and Krisciunas et al. (MN 273, 662) have now made a good case for the γ Dor stars to be a class of stars pulsating in non-radial g modes. Especially, the discovery of a third periodicity in γ Dor itself by Balona & Krisciunas (AASP, 341) argues in favour of the g-mode interpretation. This is an exciting development since g modes probe the cores of these stars providing substantially different information from the p modes of the δ Sct stars. The search for g modes in the sun is an intensely pursued goal; that they have been found relatively close by in the HR diagram first is a coup for stellar astronomy.

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The existence of the p-mode β Cep stars among the early B stars, the g-mode SPB stars among the late B stars, the p-mode δ Sct stars among the A stars, and the g-mode γ Dor stars among the early F stars presents a fascinating pattern. It is important to find stars pulsating in both p and g modes, a possibility among the δ Sct stars where claims of long-period variations have been made for some stars. This has often been attributed to instrumental effects, but some investigators believe it to be intrinsic and evidence of g modes in δ Sct stars. Breger & Beichbuchner (A&A, in press) have re-examined all the δ Sct star literature and discuss this problem is detail. They conclude that the case for some stars pulsating in both p and g modes is good, and they call for intensive studies of a few individual stars – the best case being BI CMi (see Mantegazza & Poretti A&A 281, 66).

High Overtone and Low Overtone Pulsation. While there seem to be some δ Sct stars which show both p and g modes, there is a clear separation in the frequencies of the δ Sct stars and the roAp stars. The δ Sct stars pulsate in low overtone ($n \leq 6$) modes with periods in the range of 30 min to many hours; the roAp stars pulsate in high overtone modes ($10 \leq n \leq 80$) with periods between 5 and 15 min. The reasons for this are not known, although the presence, or absence of a strong global magnetic field is suspected, since the roAp stars are magnetic and the δ Sct stars are not. The high-speed photometric techniques used to observe the roAp stars cannot easily detect low amplitude, low frequency variations; the differential 3-star techniques to observe δ Sct stars do not have the time resolution to detect high frequency variations. Breger et al. (A&A 309, 197) used the Delta Sct Network and the WET (Whole Earth Telescope) simultaneously to study the δ Sct star FG Vir at all pulsation frequencies up to 10 mHz. They found that FG Vir only pulsates in low frequency modes; no high frequency modes like those in the roAp stars are present. This important result should be tested further on other δ Sct stars. A similar observing campaign on an roAp star is needed, as it has not been demonstrated that the roAp stars have no low frequency, low amplitude modes. The work by Breger et al. also shows great care in handling False Alarm Probability. Their discussion should be read by, and their techniques emulated by, all who are trying to extract significant information from frequency spectra at low s/n.

Multi-site Campaigns. The Delta Sct Network continues to undertake lengthy photometric multi-site campaigns of selected δ Sct stars to determine and identify the large number of pulsation modes present in these stars, and to model them. The most successful campaign published so far was on FG Vir (Breger et al. A&A 297, 473). It identified 19 frequencies; a detailed theoretical discussion of them is given by Guzik & Bradley (DSN 9, 7). No models yet explain all the identified frequencies, but substantial progress has been made. ¿From preliminary reductions of a new 1995 campaign with over 550 hours of data obtained at 8 observatories Breger (priv. comm.) estimates that over 30 frequencies will be identified, including many g modes. Mantegazza et al. (A&A 287, 95) observed FG Vir with simultaneous spectroscopy and photometry identifying the dominant mode as probably radial first overtone; Breger et al. rule this out based on the phase of the light and colour curves. This disagreement shows the difficulty of mode identification, even in this intensively observed star. Frequencies reported by Breger et al. include the observations of Mantegazza et al.

Breger et al. (A&A 289, 162) found three frequencies for 63 Her, but failed to confirm two low frequency, possible g modes previously reported. Poretti et al. (MemSAI 65, 787) give a synopsis of the extensive work on δ Sct stars by the Merate group.

STACC is a network of small telescopes using CCDs to study δ Sct stars. The first campaign (Frandsen et al. A&A 308, 132) had only two participating sites for 10 d, so its success was modest. It identified, or confirmed, six δ Sct stars in the open cluster NGC 6134, and suggested some mode identifications. Importantly, it showed that small telescopes with CCDs are an excellent way to study cluster δ Sct stars. I hope that future STACC campaigns will attract more participants from around the globe, for longer observing runs. A campaign lasting months from many sites is the next big observational step for δ Sct star research. Frandsen et al. (A&A 301, 123) demonstrate (surprisingly and convincingly) that CCD detectors allow poor photometric sites to produce usable data on δ Sct stars.

The fourth STEPHI campaign (Belmonte et al. A&A 283, 121) identified several frequencies in each of the Praesape δ Sct stars, BN Cnc and BU Cnc. With a 46% duty cycle and coverage well-spread in longitude, this work shows an impressive window function. Suggestions for mode identification and possible rotational splitting are given by Pérez Hermández et al. (A&A 295, 113).

Coates et al. (MN 266, 1) show that CY Aqr, which was thought to be a double-mode δ Sct star with an unusual period ratio, is singly periodic to a precision of 1.5 mmag. They suggest that abrupt changes provide the best description of the interesting period variability of CY Aqr. Arellano Ferro et al. (PASP

106, 696) discuss the problem of period variability in VZ Can. The problem of period changes is discussed for δ Sct stars in general by Rodríguez et al. (A&A 299, 108).

WET serendipitously discovered δ Sct variability in CD$-24^\circ 7599$ (Handler et al. A&A 307, 529). An analysis of 177 hr of observations found 7 low overtone p-mode frequencies, and no overtone frequencies in the range of the roAp. Rotational splitting is likely. One harmonic and non-linear coupling frequencies were found for the highest amplitude (0.01 mag) frequencies. This is the lowest amplitude δ Sct star for which such non-linear effects have been seen; many roAp stars show non-linearities for frequencies with amplitudes of only a few mmag.

High Order Modes. Most observational studies of δ Sct stars have been, and will continue to be, photometric. The massive efforts that go into multi-site observing campaigns require a lot of telescope time – time that is available on small photometric telescopes, but not on larger telescopes. Photometric studies measure variability in integrated light, usually through broad-band or intermediate filters; they are sensitive to modes of low degree, $l < 4$. Line profile variability provides different information, and, in the case of rapid rotation, is sensitive to much higher degree. Line profile variations can also be used to identify the degree and order of a mode. But spectroscopic studies require larger telescopes because of the high resolution needed. Hence, usually spectroscopic runs on larger telescopes are of short duration. The MUSICOS collaboration is an exception to this, although their δ Sct campaigns are yet to be published. Some results on θ^2 Tau can be found in the review by Kennelly (GONG94, 568), along with a good general discussion of spectroscopic techniques for asteroseismology. Kennelly & Walker (PASP 108, 327) suggest they have found a prograde $m = 8$ or 9 mode in θ^2 Tau. Korzennik et al. (ApJ 443, L25) suggest prograde modes of order $m \approx 7$ and 11 in the δ Sct star υ UMa. For both υ UMa and θ^2 Tau the frequencies of the high-degree modes are similar to those for low degree modes, suggesting that the overtones are similar, and low: $n \leq 2$ or 3. It is desirable to identify a bright δ Sct star pulsating in both p and g modes and in both low and high degrees which could be the subject of an intensive spectroscopic and photometric multi-site campaign. With p modes and g modes, several overtones and several degrees, detailed seismology would be possible.

λ Boo Stars. The λ Boo stars are a small group of metal deficient, rapidly rotating, early A stars which are not theoretically understood. The recent discovery that many of them are δ Sct stars (Weiss et al. A&A 281, 797, Paunzen et al. AASP, 315) is an exciting development, since it offers the opportunity to use seismic methods to determine their masses and evolutionary states. Bohlender et al. (A&A 307, L9) have found line profile variations in the λ Boo star HD 111604 typical of a high order ($m \approx 20$) p mode.

HST. Gilliland et al. (ApJ 447, 191) used the WF/PC on HST to observe the core of 47 Tuc almost continuously for 38.5 hour with 900 to 1000-s integration times. Their preliminary results show good s/n for a double-mode δ Sct blue straggler. Weiss, Kuschnig & Martinez (priv. comm.) have found a δ Sct star using FGS data. They have demonstrated very good s/n, hence the usefulness of the FGS for the study of variable stars.

Metallicism and Pulsation. Kurtz et al. (MN 276, 199) found δ Sct pulsation with a peak-to-peak B amplitude of 0.21 mag in HD 40765, which they classify as a ρ Pup, or evolved Am (kA7hF5mF5) star. This shows that large amplitude δ Sct pulsation and strong metallicity can co-exist in a single star. If diffusion is the sole explanation of the peculiarities in this star, then the pulsation, which has an inferred surface radial velocity amplitude of 14 km/s, must be laminar and non-turbulent on order of cm/s. Lloyd & Wannacott (MN 266, L13) conclude that the primary Am star of the eclipsing binary δ Cap is not a δ Sct star.

δ Sct Herbig Ae Star. Kurtz & Marang (MN 276, 191) found δ Sct pulsation with a period of 5 hr in the pre-main-sequence Herbig Ae star, HR 5999. They showed that 0.01 mag pulsational light variability can be detected in the presence of longer term, stochastic light variations of over a mag. These pulsation variations should be studied in more detail and other Herbig Ae stars in the instability strip should be tested for pulsation. Because of their different internal structure the pre-main-sequence and post main sequence δ Sct stars of the same $T_{\rm eff}$ and L should differ in pulsation frequency.

AC And. Kovács & Buchler (A&A 281, 749) have fitted models using the new opacities to the unusual triple mode pulsator AC And. They conclude that it cannot be an RR Lyrae star, and is likely to be an evolved δ Sct star. Fernie (MN 271, L19) makes the standard assumption for this star that the three modes are radial fundamental, first and second overtones. He shows that for an evolving 3 $M_\odot$ star, the fundamental mode obeys the P-L relation for δ Sct stars and Cepheids, suggesting that AC And is intermediate between those classes on its first, and only, crossing of the instability strip. Eggen (AJ 107,

2131) suggests that two RR Lyr stars, FW Lup and ST Pic, may be first overtone δ Sct stars which, if correct, puts them in a similar evolutionary state to AC And. Petersen et al. (ApJ 465, L47) have found that RR Lyr stars have no detectable rotation, whereas δ Sct stars do; thus, it may be possible to use rotation to test the evolutionary state of the above three stars.

Blue Edges. Li & Stix (A&A 286, 815) find that the new opacities have little effect on the problem of the δ Sct theoretical blue edges being too red. They do find, intriguingly, that placing the outer boundary of the acoustic cavity at $\tau = 0.01$ fixes the blue edge problem. It does so by increasing the driving contribution of the H I ionisation zone. Density gradients there may have bearing on driving and mode selection. Interestingly, a high, sharp surface boundary layer is also needed in the roAp stars to solve the critical frequency problem.

UV and $T-\tau$. Monier & Kreidl (A&A 284, 210) observing with IUE found that continuum flux variations in 44 Tau increased from 13% at 3000 to 40% at 1800 Å; δ Sct itself behaves similarly. They estimate that $T_{\rm eff}$ varies by < 250 K over the pulsation cycle. The analytical results of Kurtz & Medupe (BASIndia 24, 291) suggest that the increase in amplitude towards shorter wavelength is mostly a level effect: at shorter wavelengths the higher opacity means the observations refer to a higher level in the atmosphere where the T is lower, resulting in higher observed amplitude. Thus, these UV observations offer the possibility of an empirical study of $T - \tau$ in the upper atmosphere.

Baade-Wesselink Radii. Wilson et al. (PASP 105, 809) and Milone et al. (PASP 106, 1120) re-examined EH Lib to find $R = 2.62 \pm 0.19\ R_\odot$ and DY Her to find $R = 2.77 \pm 0.20\ R_\odot$.

Abundances. Russell (ApJ 451, 747) finds that there is significant Li depletion in 23 δ Sct stars. He concludes that the δ Sct stars cannot be the precursors of the cluster Li-dip stars, and that mass loss is unlikely to be the mechanism of the Li depletion. He also finds significant C depletion in all stars where he could measure it. This is consistent with long-term work of Rachkovskaya who finds normal to slightly deficient abundances of CNO in the δ Sct stars 28 And (BCrAO 87, 62), 44 Tau (BCrAO 88, 1), V644 Her (BCrAO 90, 96) and 20 CVn (Astr. Rep. 38, 566). She finds overabundances of the heavier elements in 20 CVn, as have many previous studies.

b) roAp Stars

Reviews. Matthews (GONG92, 303) and Martinez (PhD Thesis, U. Cape Town) review the roAp stars. The number of these stars is now (August 1996) 28 (Martinez & Kurtz ApSS 230, 29; AASP, 58; IBVS 4209). See those references for papers on individual stars.

Frequency Variability. HR 3831 continues to be the best-observed of the roAp stars. Long-term monitoring shows it to have cyclic frequency variability (Kurtz et al. MN 268, 641; GONG94, 606; AASP, 158). HD 134214 (Kreidl et al. MN 270, 115) and other roAp stars also show frequency variability which is, as yet, unexplained. It is not yet known whether the frequency variability of the roAp stars and of the δ Sct stars are related.

Dipole Modes. HD 6532 is now known to have a frequency quintuplet generated by a distorted dipole mode (Kurtz et al. MN 281, 883). Kurtz et al. (MN 270, 674) have shown that the principal mode in α Cir is a pure dipole mode. To understand the distorted dipole frequency septuplet of HR 3831, Takata & Shibahashi (PASJ 47, 219) examine the effects of a quadrupole component to the magnetic field on the pulsation. Although this generates the observed amplitudes, the phases of all components of the septuplet cannot yet be matched. Dziembowski & Goode (ApJ 458, 338) calculate that the effect of the magnetic field on the mode frequencies is very significant. They estimate that the frequencies are shifted 10 to 20 μHz from their non-magnetic values. Thus they expect that the observed modes should depart substantially from pure spherical harmonics. They question the validity of the perturbation approach to the problem used by Shibahashi & Takata.

Excitation. Dziembowski & Goode also find that a peak in the work integral in the H ionisation zone comes close to providing driving in their model, and they feel that a more realistic Ap star atmosphere will show that the κ-mechanism in the H I ionisation zone drives the pulsations in these stars. If this can be confirmed, it will be an important advance. The paper of Li & Stix discussed under "blue edges" above finds similar driving for the δ Sct stars. This may be relevant to the unsolved problem of the mode overtone selection mechanism.

Kinematics. Mathys et al. (A&A 311, 901) compare the kinematics of the roAp stars and similar, non-pulsating Ap stars. Intriguingly, they find from the velocity ellipsoids and galactic orbital elements that the roAp stars are significantly older than their non-pulsating counterparts. This is the first indication of a measurable difference between the two groups, but it needs clarification and further study. The publication of HIPPARCOS parallaxes will help.

Magnetic Fields. Mathys has an ongoing program to observe magnetic fields in Ap stars which includes observations of all the roAp stars. Some of those observations are reported in a series of important papers (Mathys A&AS 108, 547; 293, 733; 293, 746) which discuss the details of magnetic measurements of Ap stars, and the information that can be extracted from them.

Pulsation Amplitude versus Wavelength. The pulsation amplitude of the roAp stars drops precipitously as a function of wavelength from the blue to the near IR. Matthews et al. (ApJ 459, 278) interpret this as an effect of limb-darkening. They use derived limb-darkening coefficients to determine the atmospheric $T-\tau$ of HR 3831 empirically. Kurtz & Medupe (BASIndia 24, 291) present an analytical derivation of the expected amplitude versus wavelength relation for the roAp stars. They conclude that limb-darkening contributes little to the observed amplitudes, and that the technique of Matthews et al. is not correct. Instead, Kurtz & Medupe suggest that the drop in amplitude at longer wavelengths is a atmospheric level effect.

Attempts to extend observations of the pulsation amplitudes of roAp stars to K in the IR yield an upper limit for HD 217522 (Martinez et al. MN 268, 169) and a marginal detection in HR 1217 (Martinez & Seckiguchi IBVS 3809).

5. Cepheids (J.W. Pel)

Introduction. Three important recent developments made a clear impact on the Cepheid studies of the past three years: the HST observations of Cepheids all the way out to Virgo, the rich new data on large numbers of Magellanic Cloud Cepheids from the gravitational microlensing surveys, and the new OPAL/OP opacities. The new opacities solved or improved some long-standing problems in the theory of Cepheids, whereas the new data on extragalactic Cepheids are so abundant that the database for extragalactic Cepheids may soon be more extensive than its Galactic counterpart. These new theoretical and observational results clearly stimulated new activity in the Cepheid field, as is evident from the many Cepheids-related papers that appeared recently. This report, covering the period from July 1993 till July 1996, concentrates on the main results. It should be noted that the papers on Cepheids in NPSP, although published in the current report period, are not included because they were reviewed already in the previous Comm. 27 report.

Cepheids and the Hubble Constant. One of the many spectacular HST results is the detection of many Cepheids in galaxies out to distances of about 20 Mpc. While the HST distance scale project is still going on, the data on distant extragalactic Cepheids obtained in the past three years are already very impressive. HST found Cepheids in 11 galaxies: IC 4182 and NGC 5253 (Sandage et al. ApJ 401, L7; 423, L13, Saha et al. ApJ 425, 14; 438, 8), M 81 (Freedman et al. ApJ 427, 628), M 101 (Kelson et al. ApJ 463, 26), M 100 (Freedman et al. Nature 371, 757, Mould et al. ApJ 449, 413, Ferarese et al. ApJ 464, 568), NGC 4639 (Sandage et al. ApJ 460, L15), M 96 (Tanvir et al. Nature 377, 27), NGC 925 (Silberman et al. BAAS 26, 1353), M 95 (Phelps et al. BAAS 27, 820), NGC 4414 (Turner et al. BAAS 27, 1294), NGC 4536 (Saha et al. ApJ 466, 55).

To this list we should add the galaxies with Cepheids that were studied with ground-based telescopes during the last three years: Sextans A+B (Piotto et al. A&A 287, 371), DDO69 (Hoessel et al. AJ 108, 645), NGC 4571 (Pierce et al. Nature 371, 385), DDO155 and NGC 2366 (Tolstoy et al. AJ 109, 579; 110, 1640), M 101 (Alves & Cook AJ 110, 192), Sextans dwarf-spheroidal (anomalous Cepheids, Mateo et al. AJ 110, 2166), NGC 7793 (Catanzarite et al. BAAS 27, 1294), IC 10 (Saha et al. AJ 111, 197). Most of the latter galaxies are much more nearby than the HST sample, but M 101, at about 7 Mpc, and NGC 4571 in the Virgo cluster are two striking exceptions. To observe Cepheids at such large distances with ground-based instruments is a great achievement.

It is well known that the H_0 calibrations based upon these new Cepheid data have not yet solved the long-standing discrepancy between the "long" and the "short" cosmic distance scales. A summary of the many recent papers that addressed this problem is outside the scope of this report, but discussions of the error sources in H_0 can be found in several of the above papers (e.g. Freedman et al. Nature 371, 757; ApJ 427, 628, Mould et al. ApJ 449, 413). From the point of view of the Cepheid distance scale this error budget can be devided into three parts: a) the Cepheid zeropoint itself, b) errors related to the use of Cepheids in distant galaxies (such as selection bias, photometric errors, incomplete sampling, reddening,

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metallicity effects), c) all other, not Cepheid-related uncertainties (secondary calibrators, deviations from the Hubble flow). It is probably fair to summarize the present state as follows. Although there is still discussion about the Cepheid zeropoint, it can probably be trusted to 0.1 mag (Feast AASP). The class b) errors are certainly bigger and one could try to explain the H_0 discrepancy primarily by systematic effects of this kind, but the largest uncertainties are those of group c). An important extra handle on the problem of metallicity effects – possibly one of the main type b) error sources (cf. Simon & Clement ApJ 419, L21, Gould ApJ 426, 542) – will be provided by comparison of HST Cepheid data in different fields of M 101 (Stetson et al. BAAS 27, 821, Hughes AASP).

Magellanic Cloud Cepheids and Early Results from the Gravitational Microlensic Surveys. While within a few years HST multiplied the data on distant extragalactic Cepheids, something similar happened in the Magellanic Clouds, where hundreds of new Cepheids were discovered by the gravitational microlensing surveys MACHO and EROS. The huge variable star databases produced by these projects in the Clouds and the Galactic bulge have only partly been analyzed, but early results have already provided a wealth of new data on LMC Cepheids, particularly in the short-period part of the instability strip. Summaries of the variable star databases and first Cepheid results were given for MACHO by Cook et al., Welch et al. and for EROS by Beaulieu (all AASP).

¿From the first year of MACHO data 1500 LMC Cepheids were found, according to a preliminary classification 950 fundamental (F) and 550 overtone (1H) pulsators. Two thirds of these (57% of the F and 94% of the 1H) are new discoveries, indicating that earlier surveys were very incomplete for low-amplitude variables. Of particular interest are the 45 new double-mode Cepheids found by MACHO (Alcock et al. AJ 109, 1653). Of these 45, 30 are F/1H pulsators and 15 are 1H/2H pulsators. The number of beat Cepheids is unexpectedly high: about 20% of the stars with F periods below 2.5 d. The period ratios, which are systematically higher than for Galactic beat Cepheids due to the lower LMC metallicity, were compared with new pulsation models based on OPAL opacities by Christensen-Dalsgaard & Petersen (A&A 299, L17; AASP) and were found in good agreement with an LMC metal content of Z=0.005 – 0.01 and "evolutionary" masses.

First EROS results for 97 Cepheids in the LMC bar were discussed by Beaulieu et al. (A&A 303, 137). Their conclusions confirm the MACHO results in several respects: 2/3 of the Cepheids are new discoveries and 30% of the Cepheids with periods below 10 d are overtone pulsators. When the 1H-periods are converted to F-periods both types of Cepheids obey a common P-L-C relation. This also confirms the reality of the P-L-C colour term. Fourier decomposition of the EROS light curves shows that the resonance features in F-pulsators occur at the same period for LMC and Galactic Cepheids, but that they are clearly shifted for the 1H-pulsators, probably due to the lower LMC metallicity.

While the exciting MACHO/EROS data attract most attention, several other recent studies of Magellanic Cepheids should be mentioned. Antonello (A&A 279, 125) compared light curve asymmetries of Galactic and LMC/SMC Cepheids and underlined again the value of Fourier decomposition as a tool to recognize resonance features that allow checks on stellar models. As a follow-up of this work Poretti et al. observed 21 short-period LMC Cepheids and reported interim results (AASP). Buchler & Moskalik (A&A 292, 450) compared Fourier components of SMC and Galactic Cepheids and confirmed that the short-period s-Cepheids are indeed overtone pulsators. Sebo & Wood (AJ 108, 932; ApJ 449, 164; AASP) made extensive VI photometry of the young Magellanic Cloud clusters NGC 330 (SMC) and NGC 1850, 2058 and 2065 (LMC) and found numerous variable stars in/near these clusters. For the long-period Cepheids around NGC 1850 the pulsation masses are still 20% smaller than evolution masses. Only a large amount of convective core overshoot would bring the two masses in agreement. Most Cepheids around NGC 330 are less massive and indicate small to moderate overshoot. For Imbert's discovery of binary Cepheids in the Clouds see below.

Pulsation and Evolution Theory. As was concluded already at the time of the previous Comm. 27 report, the OPAL/OP opacities solved the beat Cepheids mass problem, eased the "bump-mass" problem, but did not remove the pulsation/evolution mass discrepancy. The latter problem probably requires convective core overshoot on the main sequence, but the observational constraints are still insufficient to decide about the correct overshoot parameters. New evolutionary tracks relevant for Cepheids can be found in extensive grids that were calculated recently using new opacities and including core overshoot and mass loss: Schaller et al. (A&AS 96, 269), Claret & Gimenez (A&AS 96, 255), Schaerer et al. (A&AS 98, 523; 102, 339), Charbonnel et al. (A&AS 101, 415), Bressan et al. (A&AS 100, 647), Meynet et al. (A&AS 103, 97), Fagotto et al. (A&AS 104, 365; 105, 29), Bertelli et al. (A&AS 106, 275). More specific

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discussions of opacity and overshoot effects on the core He-burning "blue loops" were given by Cassisi et al. (A&A 282, 760) and El Eid (MN 275, 983).

Of the many papers on pulsation theory we mention only those most directly related to Cepheids. A review of recent developments in stellar pulsation theory was given by Gautschy (AASP). In NPSV, mode interactions and double-mode behaviour are discussed in the contributions of Aikawa, Antonello, Buchler, Fadeyev, Kovács, Petersen and Zalewski. Bono & Stellingwerf computed convective Cepheid models with a new hydrodynamic code (MemSAI 64, 559). Antonello & Aikawa (A&A 279, 119; 302, 105) computed light curve Fourier parameters for overtone Cepheid models and showed that these partly fit the observations and support the presence of the F-4H resonance. Resonances in F-, 1H-, and beat-Cepheids were discussed by Antonello (A&A 282, 835; 291, 820). Antonello et al. (A&A 309, 144) showed that the beat Cepheid CO Aur is still a puzzle, even with new opacities. The theoretical interpretation of the new MACHO data on LMC beat Cepheids by Christensen-Dalsgaard & Petersen was mentioned above already.

Simon et al. (ApJ 414, 310) used hydrodynamic pulsation models to explain the constancy of Cepheid spectral types at maximum light. Simon & Kanbur (ApJ 429, 772) calculated pulsation models with new opacities to study metallicity effects in the period-ratios of bump and beat Cepheids. The results indicate a Z-range in observed Galactic Cepheids of perhaps $0.01 < Z < 0.02$. The same authors (ApJ 451, 703) compared light curve Fourier components of 50 long-period Cepheids with hydrodynamic models. The theoretical values fit the observed trends only roughly, with systematic differences particularly at the shorter periods. Simon & Young (BAAS 27, 828) reported computation of a large number of pulsation models for different Cepheid evolution tracks. The different sets of tracks generate a range of theoretical P-L relations that will be used to put constraints on the evolution models by comparison with the observed P-L relation. Buchler et al. (ApJ 462, L83) pointed out that the Magellanic Cepheids may pose a new problem for Cepheid theory: while the observed F-2H resonance around P = 10 d is already difficult to reconcile with low-Z Cepheid models and requires a large shift in the evolutionary M-L relation, the problem worsens if the proposed F-4H resonance near P = 3 d in overtone Cepheids is real.

Cepheid Atmospheres and Abundances. For many years relatively little progress was made in the detailed analysis of Cepheid atmospheres. This situation is now changing rapidly.

Breitfellner & Gillet (A&A 277, 524; 541; 553) made a study of line-broadening and turbulence in δ Cep, η Aql, S Sge and X Cyg from high-dispersion spectra around Hα and Na D. They found in all cases that turbulence varies strongly with phase and increases with larger pulsation amplitude. In η Aql and S Sge the turbulence variation is clearly influenced by the F-2H resonance. In X Cyg (P = 16 d) the pulsation has already the form of a running wave at the level where the Fe I and Na D lines are formed. In a subsequent paper Fokin et al. (A&A 307, 503) compared these observations with calculated Fe I line widths based on a pulsation model for δ Cep. They concluded that a significant fraction of the observed widths is due to velocity gradients. Bersier & Burki (A&A 306, 417; AASP) determined line-broadening as a function of phase from CORAVEL data for 41 fainter Cepheids. They found that turbulence is the major source of variable line widths in Cepheids and that the behaviour of classical and s-type Cepheids in this respect is different. On the basis of this difference a few new s-Cepheids were discovered.

Butler (ApJ 415, 323) obtained high-precision velocity curves from many lines for FF Aql, δ Cep, η Aql and X Cyg. He found systematic velocity shifts as large as 5 km/s and asymmetry differences between low- and high-excitation lines. These differential velocity effects were then modelled by Butler et al. (ApJ 461, 362) with synthetic spectra including velocity gradients. It was found that a large gradient near the phase of fastest infall is needed to fit the spectrum of η Aql. The effect of this gradient is to reduce the amplitude of the velocity curve at $\tau = 2/3$ by 20% and to decrease the γ-velocity. Taking these effects into account in the Barnes-Evans method reduced the radius and distance of η Aql by 17%.

Böhm-Vitense & Love (ApJ 420, 401) studied emission-line fluxes as a function of phase for the long-period Cepheid l Car. All emission fluxes show a steep increase just before maximum light, suggestive of a shock moving through the surface layers. C II/IV line ratios indicate that the shock velocity can exceed 100 km/s. With such velocities mass outflow appears possible, a conclusion that is supported by evidence for a circumstellar shell in the Mg II lines. Sasselov & Lester (ApJ 423, 777; 785; 795) used the FT-spectrometer at CFHT to observe 7 bright Cepheids at 1.08 μm. They reported the first detection of the He I 1.083 μm absorption line in Cepheids. This line is present throughout the cycle, indicating persistent chromospheric heating plus transient heating by pulsation-induced shocks. It is systematically blueshifted in at least 4 Cepheids, indicating steady outflow in the upper atmosphere. The authors studied the He I line formation by means of time-dependent non-LTE models and used this to model Cepheid chromospheres.

Albrow & Cottrell (MN 267, 548) calculated a grid of synthetic line profiles for Cepheids, including a new treatment of macroturbulence. The velocity projection "p-factors" from these models are up to 10% higher than previous values. Comparison with high-resolution Cepheid spectra shows differences in line asymmetries that cannot be due to geometric projection of a single pulsational velocity. In a following paper the same authors (MN 278, 337; AASP) calculated contribution functions and formation depths for Cepheid spectral lines in order to model the effect of pulsational velocity fields on line profiles.

The problem of the p-factor and phase dependent disk brightness distribution was addressed also by Sasselov & Karovska (ApJ 432, 367) in the context of interferometric measurements of Cepheid diameters (see also Booth et al. AASP). They computed time- and wavelength-dependent Cepheid disk distributions from dynamical non-LTE model atmospheres. Using high-resolution spectra and synthetic line profiles, Sabbey et al. (ApJ 446, 250, see also Sasselov AASP) examined techniques to measure line centers and asymmetries of Cepheid absorption lines and concluded that a) the p-factor varies with phase, b) there is a systematic offset of about 1 km/s in γ-velocity and c) these effects should be taken into account in Baade-Wesselink solutions to reach better than 7% accuracy in Cepheid distances. It should be stressed that the latter conclusion is a result that many of the above studies have in common, and which is a strong caveat for Baade-Wesselink-type determinations of Cepheid radii and distances.

In a series of spectroscopic studies Andrievsky et al. (MN 265, 257; A&A 281, 465; A&AS 108, 433, see also Usenko et al. AASP) determined atmospheric parameters and abundances for many elements in double-mode and s-Cepheids. The abundance patterns in most s-Cepheids make it unlikely that these are first crossing Cepheids, except in two cases where the CNO abundances are indicative of a first crossing. Adding redetermined [Fe/H] values for southern beat Cepheids the authors found a relation between period ratio and metallicity for Galactic beat Cepheids. As was pointed out by Feast (AASP), however, this result seems in conflict with the new MACHO results which show narrow P_1/P_0 vs. P_0 relations for the beat Cepheids. Kovtyukh et al. (Astr. Lett. 20, 177) made abundance analyses for three bright classical Cepheids and found Na,Mg slightly overabundant and C,O somewhat deficient with respect to solar, while other elements are normal. They estimated a lower limit on the He abundance of δ Cep from the spectrum of its B7 IV companion. Studying yellow supergiants in general, Barbuy et al. (A&A 305, 911) and El Eid & Champagne (ApJ 451, 298) discussed CNO and Na abundances.

P-L and P-L-C Relations, Basic Parameters. The HST cosmic distance scale project has strongly underlined the importance of the Cepheid distance scale and stimulated renewed efforts to improve the P-L and P-L-C relations.

The Barnes-Evans visual surface brightness method was applied to 100 Galactic Cepheids by Gieren et al. (ApJ 418, 135). The resulting P-L zeropoint was found to be 0.15 mag brighter than the P-L zeropoint calibrated by Cepheids in open clusters (Gieren & Fouque AJ 106, 734). Subsequent work on cluster Cepheids confirmed this systematic difference (Matthews et al. AJ 110, 2280, Gieren et al. AJ 107, 2093; 111, 2059 and AASP, Barnes & Moffett AASP). By using a near-IR (V, V−K) variant of the Barnes-Evans method, Welch (AJ 108, 1421) found a modulus for the cluster Cepheid U Sgr which is 0.27 mag smaller than the value from the visual surface brightness method, suggesting that consistency between the two P-L relations could be obtained by using an IR surface brightness method. That considerable improvement in Baade-Wesselink radii can indeed be achieved by using near-IR indices was demonstrated by Laney & Stobie (MN 266, 441; 274, 337, see also AASP) who derived P-L relations and Baade-Wesselink radii from VJHK photometry and radial velocities for a large sample of Galactic and MC Cepheids. As expected, the improvement came primarily from the use of near-IR indices, which are more sensitive to the radius variations and less affected by reddening, metallicity, gravity or microturbulence. The LMC and SMC distance moduli of 18.58 and 19.00 (±0.04) are in excellent agreement with the values 18.53 and 18.94 (±0.04) derived from cluster Cepheids together with a Pleiades modulus of 5.57.

While the above results are encouraging, the Cepheid zeropoint is not yet settled and a number of papers addressed other aspects of P-L and P-L-C relations. Fouque & Gieren (A&A 275, 213) confirmed that solutions of the P-L-C colour term from Baade-Wesselink methods still lead to deviant values. On this basis they recommended to use the P-L relation for Cepheid distances. This does not solve all problems, however. The sensitivity of the P-L relation to metallicity effects was discussed by Gould (ApJ 426, 542), Di Benedetto (ApJ 452, 195) and Stift (A&A 301, 776), while Feast (AASP) reiterated the fact that the finite width of the Cepheid strip (and thus of the P-L relation) is well documented. Fry &

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Carney (BAAS 26, 864; 27, 821) reported metallicity determinations from echelle spectra of 15 cluster Cepheids indicating a spread of 0.5 dex in [M/H]. Turner (AJ 107, 1796) discussed new observations of the cluster Anon. Platais and its Cepheid member V1726 Cyg and reviewed some problems related to the cluster calibration (AASP). From a new moving cluster solution, Zhao & Chen (A&A 287, 68) gave a Hyades modulus of 3.29 ±0.03, but the "final" answer will have to come from Hipparcos. Unfortunately a direct check on Cepheid parallaxes with HIPPARCOS will be very difficult, as there will only be very few Cepheids with marginal HIPPARCOS distances (Turon et al. AASP).

Van den Bergh (ApJ 446, 39), Walker (AASP) and Feast (AASP) discussed the fact that Magellanic Cloud distance moduli from Cepheids and RR Lyrae stars can differ by 0.2 - 0.3 mag. Although the most deviant RR Lyrae calibrations are the most uncertain ones, while part of the problem may be removed by improved statistical treatment of the data, the discrepancy is potentially serious; also in this case HIPPARCOS will hopefully bring the answer.

In their long-term photometry and radial velocity programs, the Geneva group collected a large set of accurate Cepheid data. Three papers presenting data and results for Cepheids were published by Bersier et al. (A&AS 108, 9; 25; A&A 306, 417). The analysis of turbulence in Cepheid atmospheres in the latter paper was reported above already. Bersier (A&A 308, 514) derived reddenings from the Geneva photometry of F-supergiants and Cepheids. Radial velocities of more than 100 Cepheids were used by Pont et al. (A&AS 105, 165; A&A 285, 415 and AASP) to study Galactic rotation. A Galactic center distance of 8.1 ± 0.3 kpc was found, in good agreement with other determinations and indicating that the Cepheid zeropoint may indeed be accurate to 0.1 mag.

Since the early eighties the Moscow group carried out a large project of UBVRI photometry and spectroscopy of Galactic Cepheids. These data, together with extensive photometry and radial velocities from the literature, have now been merged into a large Cepheid database (Berdnikov AASP and references therein). Another Cepheid database was recently compiled by Fernie et al. (IBVS 4148). Using this catalogue, Fernie (AASP) analyzed the Galactic distribution of Cepheids.

Of the many other papers on new basic Cepheid data we mention the work by Evans et al. (energy distrib. of Cepheids and yellow supergiants, AJ 106, 726), Henden (UBVRI data on 36 faint Galactic Cepheids, AJ 111, 902), Eggen (*uvby*-Hβ photometry for 65 short-period Cepheids, AJ 111, 1313), Gatewood et al. (trig. parallaxes of δ Cep and EV Lac, PASP 105, 1101), and four papers on the declining pulsation of Polaris (Brown & Bochonko PASP 106, 964, Garnavich et al. JRASC 87, 187, Fernie et al. ApJ 416, 820, Andrievsky et al. A&A 281, 465).

Cepheids with Companions. A remarkably large number of papers on Cepheids with companions appeared. Evans and collaborators continued their long-term program on binary Cepheids based on an IUE survey of all Cepheids brighter than 8 mag. New results were presented for Z Lac, YZ Car, S Sge, T Mon, S Mus (Evans et al. PASP 105, 836; 915; AJ 106, 1599; 107, 2164; 108, 2251) and for a sample of 8 Cepheids with terminal age main sequence companions (Evans ApJ 436, 273). An on-going radial velocity study of 14 known/suspected Cepheid binaries was reported by Sugars & Evans (JRASC 88, 270). BVR photometry of the companion of FF Aql by Udalski & Evans (AJ 106, 348) indicates that this star is probably unrelated to the Cepheid. Evans & Udalski (AJ 108, 653) measured V and B magnitudes for 13 Cepheid companions; 9 of these are very blue, confirming that they are young stars associated with the Cepheids. In continuation of his earlier extensive photometric searches for Cepheid companions Szabados (A&A 311, 189) discussed the results of a study of more than 250 Cepheids using radial velocity data from the literature. Evidence for companions was found in 22 cases.

Imbert (A&AS 105, 1), using CORAVEL, detected for the first time spectroscopic binary Cepheids in the Magellanic Clouds. Orbits were derived for HV 883, 837 and 11157; HV 883 is perhaps even a triple. The same author (A&AS 116, 497) discussed the discovery of 4 binaries from CORAVEL data for 25 Galactic Cepheids; orbits were determined for the new binary Cepheids RX Cam, MW Cyg, Z Lac and U Vul. The Geneva group (Bersier et al. A&AS 108, 25, Pont et al. A&A 285, 415; A&AS 105, 165) presented CORAVEL data for more than 100 galactic Cepheids, including many known binaries but also several new binary candidates. New orbits were determined for DL Cas and W Sgr. Albrow & Cottrell (MN 280, 917) obtained high-resolution spectra over a 7-year period for W Sgr. Radial velocities from these spectra were combined with CORAVEL data for a new orbit solution; the residuals of this show some evidence for a long-period third component.

The duplicity of VZ Cyg, MW Cyg and BY Cas was announced by Samus et al. and Gorynya et al. (IBVS 3934; 4130; 4199), together with improved orbits for several previously known binary Cepheids.

DL Cas, both a binary and member of the open cluster NGC 129, was revisited in a detailed study by Gieren et al. (AJ 107, 2093). Improved orbital and pulsational velocity curves were obtained from a large set of accurate radial velocities. The 684-d orbital period is one of the shortest known for binary Cepheids. Improved orbital elements and physical parameters were derived which indicate that DL Cas is a 5.6-$M_{\odot}$ Cepheid that is probably on its third crossing. A surface brightness solution for the radius and distance of DL Cas gives 66 $R_{\odot}$ and 2034 pc.

Gonzalez & Wallerstein (MN 280, 515) added ST Pup to the short list (now containing four objects) of known Pop. II binary Cepheids. The orbital period of ST Pup (410 d) is considerably longer than that of the other three type II binary Cepheids, which average about 100 d.

Recent reviews of statistics, masses, orbits and evolutionary state of binary Cepheids were given by Evans (Conf. in Honour of K.H. Böhm and E. Böhm-Vitense, ASPCS 57, 137; ApJ 445, 393; AASP) and Szabados (AASP; A&A 311, 189). The main conclusions are as follows. As a result of more effective searches the estimated frequency of binary Cepheids is still increasing. The true incidence of binary Cepheids may exceed 50%. The mass-ratio distribution is strongly peaked to low-mass companions. Most periods exceed one yr and in general it is unlikely that mass transfer between components has occurred. Whereas in priciple binary Cepheids can put important constraints on the physical parameters and evolutionary state of these stars, the present results are not unambiguous. Comparison with evolutionary tracks shows that many systems are consistent with little or no convective overshoot, but several cases do not fit any current isochrones.

Population II Cepheids. In comparison with the classical Cepheids, type II Cepheids are still a somewhat neglected group. This may be due to the larger intrinsic scatter in type II Cepheid properties and the difficulty to define the group, but also to the fact that these stars are more difficult to model.

In the important study of Pop. II variables by Nemec et al. (AJ 108, 222), which covered not only type II Cepheids but also anomalous Cepheids, RR Lyrae and SX Phe variables, P-L-[Fe/H] relations for the different classes of variables were derived from BVK data of over 1200 stars in some 40 different stellar systems. The authors concluded from the available BV photometry of 40 of the known globular cluster Cepheids that among these stars both fundamental and overtone pulsators occur. The majority of the BL Her Cepheids are probably 1H pulsators, while most W Vir Cepheids appear to pulsate in the F mode. The P-amplitude diagram indicates that at a given period the 1H pulsators have the largest amplitudes. It should be noted, however, that the pulsation mode issue is not yet unanimously resolved. In a later study McNamara (AJ 109, 2134) concluded that all Pop. II Cepheids are probably fundamental-mode pulsators.

Harris (BAAS 25, 1408) observed improved CCD light curves and colours for the type II Cepheids in three (NGC 6284, 6293, 6333) of the 22 globular clusters that are known to contain Cepheids. On the basis of these data he discussed the P-L relation for type II Cepheids and the occurrence of these stars in metal-poor clusters. Berdnikov and Goranskii (Perem. Zv. 23, 64; 71; 74) published photometry of 16 type II Cepheids. Four of these were re-classified as RV Tau or semiregular variables. Vinko et al. (A&A 279, 410) discussed new BV photometry of AU Peg. This Cepheid is a member of a relatively narrow binary, where tidal forces may perturb the pulsation. The non-linear period changes of AU Peg can hardly be explained by tidal effects alone, however. Baade-Wesselink solutions for some Cepheids of uncertain type were used by Vinko & Balog and by Laney (both AASP) to decide about the classification, but not always with the same result (cf. TX Del).

ST Pup, mentioned already as one of the 4 known type II binary Cepheids, was studied with UBVRI photometry by Kilkenny et al. (SAAO Circ. 15, 85). No systematic period changes were found in the new data, but cycle to cycle light curve changes were clearly present. Photometry and spectroscopy of ST Pup and five Cepheids in ω Cen were used in the thesis study of Gonzalez (PASP 106, 201) to derive photospheric parameters and masses. The resulting masses range from 0.51 to 0.67 $M_{\odot}$ and are consistent with theoretical predictions. Period changes were found in all variables, but while the fainter stars show constant period derivatives, the most luminous Cepheids experience large abrupt changes. While all variables display clear CNO enhancements, ST Pup does not share the strong enhancement of s-process elements seen in the ω Cen Cepheids.

The peculiar type II Cepheid RU Cam was observed photoelectrically for many years at Konkoly (Szeidl et al. Konkoly Bul. 97, 245) in order to study systematic period and light curve changes. A continuous period decrease of less than 1% between 1907 and 1965 was found, but after 1965 the light curve became very unstable. Fourier analysis of the data showed no signs of modulation effects. New UBVR photometry of RU Cam was published by Berdnikov & Voziakova (IBVS 4154).

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

This survey of field RR Lyrae variables covers the period from the last report through August 1996. Because of page limitations not all research can be cited. Additional reports on RR Lyrae research are contained in Section 7 (Variable Stars in Globular Clusters and Related Systems) and in Section 11 (Theory of Stellar Pulsation).

Conferences and Reviews. The following conferences, which included significant discussion of RR Lyrae research, took place or appeared in print during the report interval: NPSP, "Stellar Populations," 2nd Teramo Workshop on Stellar Populations, held in Teramo, Italy, Sept. 27-29, 1993 (eds. Brocato et al. MemSAI 65, 635-963), ILTM = "The Impact of Long-term Monitoring on Variable Star Archiving," NATO Advanced Research Workshop, held Nov. 15-18, 1993, in Ghent, Belgium (eds. C. Sterken and M. de Groot, Kluwer, 1994), AASP, FGH = "Formation of the Galactic Halo ...Inside and Out," a meeting in honor of the 65th birthday of George Preston, held in Tucson, Arizona, Oct. 9-11, 1995 (eds. Morrison and Sarajedini, ASPCS vol. 92).

The new book "RR Lyrae Stars" by Horace Smith (Vol. 27, Cambridge Astrophys. Ser. 1995) is also a rich source of information on RR Lyrae stars.

Absolute Magnitudes. Various Baade-Wesselink techniques and the Infrared Flux Method continued to be used to determine RR Lyrae absolute magnitudes, although fewer such studies appeared in the 1993-1996 period than in the period 1990-1993 of the previous summary.

An important modification to the zero point of the absolute magnitude scale has been suggested by Fernley (A&A 284, L16). He argued that most previous studies have adopted an inappropriate value for the correction factor from radial velocity to pulsational velocity. Adopting a factor $p = 1.38$ for RR Lyrae stars, instead of $p = 1.32$ as used in most previous work, shifts the zero point of the absolute magnitude scale 0.07 mag brighter. This is in the correct sense to improve the comparison between B-W and IR methods, on the one hand, and theory and the Cepheid distance to the Magellanic Clouds, on the other hand.

Recent analyses agreed with previous work regarding the dependence of absolute magnitude on metallicity. (The following results have all had their zero points adjusted to the above Fernley scale, where necessary, in order for them to be intercompared.) Skillen et al. (MN 265, 301) determined absolute magnitudes for WY Ant, W Crt, RV Oct, and BB Pup by the infrared flux method and by the Baade-Wesselink method using new photometry and radial velocities. The authors combined these results with other absolute magnitudes for RR Lyrae stars to create a sample of 29 variables; the sample yielded a relation $M_V = 0.97 + 0.21[Fe/H]$. Clementini et al. (AJ 110, 2319) combined new [Fe/H] data with new B-W absolute magnitudes to obtain $M_V = 0.96 + 0.19[Fe/H]$. Based on new [Fe/H] values determined through high-resolution spectra, Lambert et al. (ApJS 103, 183) determined $M_V = 0.93 + 0.17[Fe/H]$. The previous IAU summary of field RR Lyrae work (1993) quoted $M_V = 0.94 + 0.16[Fe/H]$ as representative.

These relations should also be compared with statistical parallax results by Hawley et al. (FGH, 188). Using her maximum likelihood model with new proper motions, abundances, radial velocities and photometry, they find $M_V = 0.74 \pm 0.12$ mag at $[Fe/H] = -1.6$, which may be compared with $M_V = 0.66 \pm 0.06$ mag from Lambert's representative work above.

However, Bono et al. (ApJ 432, L51) criticized the B-W method for determining absolute magnitudes of RR Lyrae stars. ¿From a nonlinear, non-local, and time-dependent convective model, they found strong dependence of the colors upon surface gravity throughout the cycle as well as strong velocity gradients throughout the cycle. Bono et al. also criticize the generally accepted method for determining the center of mass velocity from the radial velocity curve.

Skillen et al. (MN 265, 301) have also determined $M_K = -1.07 - 2.95 \log P$ from a sample of 29 field variables. Longmore (NPSP, 21) reviewed theory and observation regarding the $M_K - \log P$ relation. He found that theory and globular cluster variables have similar slopes in this relation, averaging -2.38 for the clusters. If this is taken as the correct period dependence, the steeper slope found for field variables may imply a small [Fe/H] dependence in the $M_K - \log P$ relation.

Storm et al. (in "Hot Stars in the Galactic Halo", eds. Adelman, Upgren, and Adelman, Cambridge Univ. Press, 298, 1994) compared the $M_V-[Fe/H]$ and $M_K - \log P$ relations for field and cluster variables.

They concluded that the cluster variables may be marginally brighter.

Castellani et al. (ApJ 430, 624) investigated use of "pulsational magnitudes" for inferring absolute magnitudes and compared those values with B-W magnitudes.

Reviews of absolute magnitude determination for RR Lyrae have been given by Yaqing and Lai (Prog. Astr. 11, 323) and by Nemec et al. (AJ 108, 222; NPSP, 31).

Abundances. Researchers have been quite active in determining metal abundances of field RR Lyrae stars in the past three years. Many of these works have used model atmospheres based on moderate-to-high resolution spectroscopy instead of ΔS.

Clementini and collaborators (AJ 110, 2319; FGH, 367) reported ten new metal abundances using R = 18000 spectra from which they determined $[Fe/H] = -0.194\Delta S - 0.08$. Lambert et al. (ApJS 103, 183) reported 18 new iron and calcium measures from R = 23000 spectra. They determined a relationship $[Fe/H] = -0.195\Delta S - 0.128$. Low-to-moderate resolution spectra of 302 RR Lyrae stars have been used by Layden (AJ 108, 1016; 110, 2288; 110, 2312; FGH, 141) to infer metallicities and determine radial velocities for "ab" stars. These were used to investigate the kinematics of the nearby halo and its relation to metallicity. Suntzeff et al. (ApJS 93, 271) give about 500 ΔS values for field RR Lyrae variables.

A comparison of the [Fe/H] scales for globular cluster and field RR Lyraes has been made by Jurcsik (Acta Astr. 45, 653). She proposed a recalibration of the [Fe/H] scale of Zinn and West in clusters to resolve the discrepancy between the clusters and the field abundances.

Kovács (A&A 293, L57) has suggested that RR Lyrae light curves depend only on a few parameters including metallicity. He then modeled the metallicity dependence of the light curve as a way to infer metal abundance. The results suggested a precision of order 0.2 dex in [Fe/H].

Radial Velocities, Proper Motions, Rotation. Skillen et al. (MN 265, 301) gave new radial velocity curves for WY Ant, W Crt, RV Oct, and BB Pup. Carrillo et al. (A&AS 113, 483) reported radial velocities for five RR Lyrae field stars.

In RR Lyrae itself Chadid and Gillet (A&A 308, 481) reported line doubling for Fe lines at phase 0.93. They discussed this in the context of a shock propagating through the atmosphere. Peterson et al. (ApJ 465, L47) investigated spectral line widths in eight RR Lyraes. They interpreted the results as indicating that lines are broadened in RRab stars by shock-induced plumes or turbulence during the rise to maximum light. Also for RR Lyrae, Mathias et al. (A&A 298, 843) reported a phase lag in the radial velocity between hydrogen lines and metal lines. Peterson et al. also estimated an upper limit of $v \sin i < 10$ km/s for the rotational velocity.

Yaqing (Ann. Shanghai Obs. 15, 189) determined new proper motions for 30 RR Lyrae field stars using an 18 yr time interval. New mean magnitudes and metallicities are also given for these stars.

Magnetic Fields, Blazhko Effect. Teays (NPSP, 410) described preliminary results from UV spectra of RR Lyrae itself over full pulsation cycles at various phases in the Blazhko cycle. He found that as RR Lyrae goes through its Blazhko cycle, the key Fourier decomposition parameters of its IUE's FES V light curve span the values shown by all other RR Lyraes of similar pulsation period.

Cox (NPSP, 409) suggests that non-radial g modes be investigated as a possible source of the Blazhko effect in RR Lyraes.

Udonichenko et al. (Odessa Astr. Publ. 6, 33; Bull. Spec. Ap. Obs. 38, 169) have studied the variation of magnetic field strength in RR Lyrae with respect to pulsation phase and Blazhko phase.

The star AH Cam has been found to have the shortest known Blazhko period at 11 d by Smith et al. (AJ 107, 679). The star has a relatively high metallicity which may account for its very short Blazhko cycle.

Multi-mode Behavior. Berdnikov (Pis'ma Astr. Zh. 19, 609) has constructed a light curve of each oscillation of the triple-mode star AC And. He found the maximum and minimum amplitudes of the oscillations to be linked in phase, similarly to double-mode Cepheids. Kovács and Buchler (A&A 281, 749; NPSP, 278) were unable to find any linear, radial pulsation model which would fit the observations of AC And unless the mass is $> 1.1\ M_\odot$. They suggested that AC And is actually an unusual δ Sct star.

RR Lyrae Variables in Special Fields. Candidate RR Lyrae stars found from objective prism plates in SA 57 and RR 7 have been studied by Kinman (NPSP, 340; AJ 108, 1722). He used spectrophotometry to determine their metallicities and used photometry to separate variables from non-variable BHB stars. In a later paper, Kinman et al. (AJ 111, 1164) reported on the kinematics of RR Lyr variables near the north Galactic pole. In a recent PhD thesis Wetterer ("RR Lyrae variable stars in the CCD/Transit instrument survey," US Air Force Inst. of Techn., Wright-Patterson AFB, Ohio, 1995) discussed the Galactic distribution (0.6 to 40 kpc) of RR Lyrae variables discovered in a CCD survey. An examination by Clementini et al. (MN 275, 929) of eight stars thought to be RRab, short period variables at high z distance showed only DL Com to be confirmed as an RRab star with short period and high z.

Layden (11th Santa Cruz Summer Workshop in Astr. and Ap.: The globular cluster - galaxy connection, 326) has compared the properties of RR Lyrae stars in galactic globular clusters with those in the field. He found no substantive differences in the populations in kinematics, spatial distribution, and abundances.

Walker (NPSP, 15) reviewed recent work on RR Lyrae stars in the Magellanic Clouds. Reid and Freedman (MN 267, 821) reported on the properties of 27 RR Lyraes in the neighborhood of the LMC cluster NGC 2210. Using RR Lyrae pulsational properties, Van den Bergh (ApJ 446, 39; 451, L65) proposed that the discrepancy between RR Lyrae and Cepheid distances to other galaxies may be related to the metal abundance of the host galaxy. Using pulsational properties, Catelan (A&A 307, 13) argued against this proposal.

Alcock et al. (AJ 111, 1146) reported on the RR Lyrae variables discovered in the Large Magellanic Cloud by the MACHO program.

Large numbers of RR Lyrae variables are being discovered in other galaxies as CCD surveys probe such systems. Goldsmith (NPSP, 358) reported discovery of large numbers of RR Lyrae variables in the Sculptor dwarf galaxy. Kałużny et al. (A&AS 112, 407) listed 226 RR Lyrae variables in the Sculptor galaxy discovered by the OGLE project. Silbermann et al. (FGH, 536) reported new RR Lyrae variables in the Draco dwarf galaxy. Alard (ApJ 458, L17) reported 314 probable RR Lyrae members of the new Sagittarius dwarf galaxy. Mateo et al. (AJ 109, 588; ApJ 458, L13) also listed RR Lyraes in the Sagittarius galaxy. Smecker-Hane et al. (AJ 108, 507) discuss the properties of RR Lyrae stars in the Carina dwarf galaxy.

Photometric Data, Light Curves. Fernley (Obs. 113, 197) reviewed the claim that BB Vir is a binary with a BHB companion in light of new ultraviolet spectra. He favored the binary interpretation and determined a new effective temperature for the companion of 7900 ± 200 K. A revision to the orbit for the proposed binary star TU UMa was given by Kiss et al. (IBVS 4205) based on new time-of-maximum measures.

Piersimoni et al. (A&AS 101, 195) reported BV photometry for four RR Lyrae stars. Skillen et al. (MN 265, 301) gave new JKH light curves for WY Ant, W Crt, RV Oct, BB Pup, and AU Vir. UBVRI results for the same stars were published by Skillen et al. (SAAO Circ. 15, 90). Eggen (AJ 107, 1834) listed light and color curves for 43 very short period RR Lyrae variables. Carrillo et al. (A&AS 113, 483) reported contemporaneous measurements in the Geneva seven-color photometric system and in radial velocity for five RR Lyrae field stars.

Bono and collaborators (MemSAI 65, 781; ApJ 432, L51; ApJS 99, 263) reported and discussed a disagreement between the equivalent static mean temperature (color) of RR Lyrae stars near the blue edge of the instability strip and the true mean colors.

Antonello and Cernuti (NPSP, 339) used a one zone model to study the amplitudes for light curves of RR Lyrae stars. A review of the origins of light curve variation has been given by Szabados (ILTM, 213). Kovács (Stochastic Proc. in Astrophys., Ann. NY Acad. Sci. 706, 70) discussed long term modulation of RR Lyrae light curves.

Schmidt et al. (AJ 109, 1239) continued their study of poorly known variables in the GCVS with paper 3, which includes discussion of several RR Lyrae stars.

Frolov (Astr. Tsirk. 1555, 5) discussed determination of interstellar extinction for RR Lyrae variables with reliable V and K magnitudes.

Large numbers of RR Lyrae variables have had elements determined or revised in the past three years. The results have been published in BAV Rundbrief, IBVS, MVS, GEOS Circ., Astr. Tsirk., JAAVSO, Per. Zv., and JBAA. These sources also include references to period variations, to newly discovered RR Lyrae variables and to stars with newly discovered Blazhko effect. Ephemerides for RR Lyrae variables were published by Zakrzewski for 1993 (Rocznik Astr. Obs. Krakowskiego, Intern. Suppl. No. 64, 121), for 1994 (ibidem No. 65, 121), for 1995 (ibidem No. 66, 119), and also in special publications by the AAVSO for the same years.

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

As far as possible this review covers material published in the three years ending in mid-summer 1996 although space limitations make it impossible to cite every paper on the subject. The reader is referred to the Comm. 38 report on globular cluster research, and to the following conference proceedings: NPSP, BS = Blue Stragglers (ed. Saffer, ASPCS vol. 53), and AASP. The reader is also referred to the book, RR Lyrae Stars, by Horace Smith, mentioned in the preceding section, which discusses many of the topics reviewed below.

Pulsating Variables and Contact Binaries in Galactic Globular Clusters. References are given below in order of IAU cluster designation. In addition to these see Feast (MN 278, 11) for a summary of J−K colors and metallicities of Miras and SR variables in Galactic globular clusters, Simon & Clement (NPSP, 315) and Cacciari & Bruzzi (A&A 276, 87) for parameters derived from Fourier decomposition for RRc stars in several clusters, and Jurcsik & Kovács (A&A 312, 111) for metallicities of galactic and LMC cluster variables.

The Third Catalogue of Variable Stars in Globular Clusters published by Helen Sawyer Hogg in 1973 has now been updated to 1988 and put in machine readable form. It can be obtained by contacting Christine Clement at clement@doncarlo.astro.utoronto.ca.

C0021−723 (NGC 104, 47 Tuc): Examples of light curves for newly detected variables are given by Gilliland et al. (ApJ 447, 191) in the first paper of a series on HST monitoring of the cluster core. Among the variables detected were several binary systems and four SX Phe stars (ASPCS 83, 335). Edmonds et al. (ApJ 464, L157) report the discovery of a new class of pulsating K-giants as a result of the same survey. Storm et al. (A&A 291, 121) present a Baade-Wesselink analysis of V9 and show it to be a highly evolved RR Lyrae star with a rather low mass. Layden (AJ 110, 2312) suggests this is due to mass loss induced by stellar interactions in the relatively dense environment of V9. Observations of nine giant branch variables are included in a paper on JK photometry of the cluster by Montegriffo et al. (MN 276, 739).

C0310−554 (NGC 1261):Ferraro et al. (MN 264, 273) present BV CCD photometry for more than 3300 stars including 18 variables, and discuss the overall properties of the color-magnitude diagram (CMD).

C0647−359 (NGC 2298): Clement et al. (AJ 110, 2200) present light curves for the three RR Lyraes and announce the discovery of one more. The light curves of two RRc stars are used to derive luminosities, masses and temperatures which are compared to the values for M 3 variables.

C1015−461 (NGC 3201): Accurate equatorial coordinates of the cluster variables are given by Samus et al. (Astr. Lett. 22, 239).

C1223−724 (NGC 4372): Kałużny & Krzemiński (MN 264, 785) report the discovery of 19 variable stars, eight of which are SX Phe stars, and eight contact binaries.

C1236−264 (NGC 4590, M 68): Brocato et al. (AJ 107, 622) present light curves for 21 variables based on B and V CCD photometry. They do not find any period shift compared to M 3 variables. However a period shift of −0.11 is derived by Walker (AJ 108, 555) in a paper on BVI CCD photometry of the cluster which presents light curves for 40 RR Lyraes five of which are newly discovered, and two probable SX Phe stars. Walker also derives RR Lyrae masses and discusses the cluster CMD.

C1236−508 (Ruprecht 106): Kałużny et al. (AJ 110, 2206) present BV photometry and light curves for 18 newly discovered variables, including 12 RR Lyraes, three SX Phe stars and two contact binaries.

C1313+179 (NGC 5053): BV photometry of the RR Lyrae stars in this metal-poor cluster is presented by Nemec et al. (AJ 109, 618) and used to estimate fundamental parameters for the stars. Five SX Phe stars in the cluster are identified and discussed by Nemec et al. (AJ 110, 1186).

C1323−472 (NGC 5139, ω Cen): In a photometric study of the UV-bright stars in the cluster Gonzalez (AJ 108, 1312) presents B and V CCD observations of five type II Cepheids and uses the data to derive masses, temperatures and surface gravities, and to investigate period change rates. Spectroscopic observations of the same stars by Gonzalez & Wallerstein (AJ 108, 1325) are used to derive abundances. Equatorial coordinates are given by Shokin & Samus (Astr. Lett.). The concentration to the center of the cluster of the RR Lyrae variables is discussed by Petersen & Andersen (ASPCS 83, 389). Two papers by Petersen (A&AS 105, 145; A&A 301, 463) catalogue and discuss Fourier decomposition parameters based on Martin's photographic data.

C1339+286 (NGC 5272, M 3): Yao et al. (IBVS 3955; 3962; 4003) announce and discuss three new short period red variables in the cluster. Using HST observations of stars in the cluster core Guhathakurta et al. (AJ 108, 1786) have identified 40 variables, mostly RR Lyrae stars, for which they obtain colors and light curves. The relative positions of these variables are reduced by Goranskij (IBVS 4129) to equatorial coordinates in the system of Evstigneeva et al. (Astr. Lett. 20, 596) and 29 of them are identified with previously known variables. In a paper presenting photographic photometry of 10,000 stars in the cluster Buonanno et al. (A&A 290, 69) summarize properties of more than 90 of the variables using data from the literature. New BVI observations of 38 RR Lyraes are used by Cacciari et al. (NPSP, 325) to derive relations between various parameters. Kraft et al. (AJ 109, 2586) include data on V95 in a paper on oxygen abundances in halo giants. Meinunger (MittVerSt 12, 160) presents photometry of eight variables.

C1403+287 (NGC 5466): Corwin et al. (BAAS 25, 1423) have BV photometry for fourteen RR Lyrae variables in the cluster.

C1436−263 (NGC 5694): A search for variable stars by Hazen (AJ 111, 1184) turned up no candidates.

C1452−820 (IC 4499): Ferraro et al. (MN 275, 1057) present a new CMD and 88 candidate HB variables, four of which were not identified earlier.

C1514−208 (NGC 5897): A search for variables by Shi et al. (JRASC 88, 269) has identified one SX Phe star and one RR Lyrae star.

C1516+022 (NGC 5904, M 5): Proper motions based on an epoch range of 88 years show all but two of the 55 known or suspected variables included in the study by Rees (AJ 106, 1524) are highly probable cluster members. Liu & James (NPSP, 30) present an infrared period-luminosity relation based on K band observations of 44 RR Lyraes. Reid (MN 278, 367) presents V and I light curves for 54 variables, including 49 RR Lyrae stars, some newly discovered. Period change rates are determined for 30 of these stars and compared to those of the RR Lyrae stars of M 68. B and V light curves for 26 RR Lyraes are used by Brocato et al. (AJ 111, 809) to investigate the pulsational properties of the stars and to compare them with the variables of M 68, M 3 and M 15. Evstigneeva et al. (Astr. Lett. 21, 451) present accurate equatorial coordinates of 143 known and suspected variables. Baade-Wesselink analyses of V8 and V28 are used by Storm et al. (A&A 290, 443) to derive absolute magnitudes and distances.

C1620−264 (NGC 6121, M 4): Clementini et al. (MN 267, 83) present four color photoelectric photometry and radial velocity data for four RR Lyrae stars and confirm the occurrence of shock waves during the ascending branch of the light curve. They also draw attention to the unusual light-curve of V15. In another paper (MN 267, 43) abundances based on high-resolution spectroscopy are presented for three of the stars. A summary of previous determinations of distance moduli using the cluster RR Lyraes is given by Dixon & Longmore (MN 265, 395).

C1624−387 (NGC 6139): Samus et al. present equatorial coordinates for ten variables (Astr. Lett.).

C1629−129 (NGC 6171, M 107): Feast & Whitelock (A&A 287, L29) report that infrared photometry of the Mira star and OH maser V720 Oph seems to indicate that it is a foreground star and not a cluster member.

C1645+476 (NGC 6229): A list of 12 new possible variables in the cluster core is given by Spassova & Borissova (IBVS 4296).

C1715+432 (NGC 6341, M 92): Baade-Wesselink analyses of V1 and V3 are used by Storm et al. (A&A 290, 443) to derive absolute magnitudes and distances and to discuss the age of the cluster.

C1716−184 (NGC 6333, M 9): Clement & Shelton (AJ 112, 618) report nine new RR Lyrae stars and present precise light curves for six previously known ones.

C1726−670 (NGC 6362): Clement et al. (AJ 110, 2195) present B magnitudes and period determinations for 30 RR Lyrae stars.

C1725−050 (NGC 6366): Harris (AJ 106, 604) reports a search for variables in this metal-rich cluster found no SX Phe stars among the numerous blue stragglers. V magnitudes and the light curve for V1, the one known RR Lyrae star, are presented.

C1732−447 (NGC 6388): In a paper presenting CMDs for this bulge metal-rich cluster, Silbermann et al. (AJ 107, 1764) report three new RR Lyrae stars and discuss membership of these and previously discovered RR Lyrae stars near the cluster.

C1736−536 (NGC 6397): Rubenstein & Bailyn (AJ 111, 260) announce the discovery of a contact binary in this metal-poor core-collapse cluster. No other variables were found in their search for variability among 3000 main sequence stars and 14 blue stragglers.

C1804−437 (NGC 6541): Hazen (AJ 107, 1793) announces seven new RR Lyrae stars within the tidal radius of the cluster.

C1807−317 (NGC 6558): Hazen (AJ 111, 1184) reports six new variables within the tidal radius. A horizontal branch (HB) blue magnitude and approximate distance to the cluster are derived.

C1814−522 (NGC 6584): Sarajedini & Forrester (AJ 109, 1112) present the first CMD of the cluster and report 56 newly identified possible RR Lyrae stars. Samus et al. (Astr. Lett. 21, 528) present accurate coordinates of 52 variables in and around the cluster.

C1833−239 (NGC 6656, M 22): Kratsov et al. (Astr. Lett. 20, 339) announce eight new and suspected variables and present improved equatorial coordinates for all known variables.

C1851−305 (NGC 6715, M 54): Sarajedini & Layden (AJ 109, 1086) present a VI CMD for the cluster, including photometry for 16 of the RR Lyrae stars, and suggest the cluster is physically associated with the recently discovered Sagittarius dwarf galaxy.

C1951+186 (NGC 6838, M 71): Yan & Mateo (AJ 108, 1810, AJ 111, 567) discuss five short-period eclipsing binaries near the cluster center, confirming two previously identified and announcing three others.

C2050−127 (NGC 6981, M 72): Kadla et al. (A&A 302, 723) present positions and photometric data for nine previously unknown variables.

C2059+160 (NGC 7006): Newly determined periods and light curves for four variables are presented by Wehlau et al. (ASPCS 83, 391).

C2127+119 (NGC 7078, M 15): Silberman & Smith (AJ 110, 704) present B,V,R and I light curves for 44 RR Lyraes, one newly discovered, and for one Cepheid in the cluster. Physical properties of the RR Lyrae stars are derived and discussed. In an earlier paper (AJ 109, 1119) they report on an investigation of period changes for 49 RR Lyraes. A further paper in the series by Purdue et al. (AJ 110, 1712) discusses the pulsational behavior of the seven known or suspected double-mode stars in the cluster. Barlai & Szeidl (ASPCS 83, 387) summarize period changes of 62 RR Lyraes based on 100 years of observation. The same authors (IBVS 4171) discuss the long term behavior of V99 and suggest it might be due to the onset of pulsation. Liu & Janes (NPSP, 30) present an infrared period-luminosity relation based on K band observations of 47 RR Lyrae stars. Yao & Qin (IBVS 3920) announce a new short period red variable.

Population II Variables in Magellanic Cloud Clusters and Local Group Dwarf Spheroidal Galaxies. Reid & Freedman (MN 267, 821) report on the results of their search for RR Lyraes in the vicinity of NGC 2210 in which they identified 44 variables, of which 31 were known previously. The majority of the RR Lyraes are associated with the cluster. It is suggested by van den Bergh (AJ 451, L65) that the discrepancy between the Cepheid and RR Lyrae distance scales in the LMC may be due to second parameter effects on the LMC RR Lyraes. In an effort to discover whether LMC RR Lyraes are intrinsically brighter by 0.3 mag than those in Galactic clusters, Catelan (A&A 307, L13) compares the pulsational properties of RR Lyrae stars in four old LMC clusters with those in M 3 and M 15. He finds no reasonable differences in physical parameters which would result in a difference in brightness sufficient to reconcile the distance scales.

There are a number of papers on variables in dwarf spheroidal galaxies and clusters associated with them. Kałużny et al. (A&AS 112, 407) report identification of 231 variables in Sculptor. The coordinates of these stars and their cross identification with variables discovered earlier by van Agt is discussed by Antipin & Samus (IBVS 4252). Results of a survey of Sextans are presented by Mateo et al. (AJ 110, 2166) who present B and V light curves for 40 of the 36 RR Lyraes, six anomalous Cepheids and one long-period variable discovered. In papers on photometry of Leo I, Demers et al. (MN 266, 7) include some observations of 15 variables, mostly anomalous Cepheids, and Lee et al. (AJ 106, 1420) report they have located 45 candidate anomalous Cepheids. A search for variables in Leo II is underway by Canzian et al. (BAAS 27, 867) and Harris et al. (BAAS 26, 1396) are obtaining new observations for all known variables in Draco. Smith et al. (AJ 111, 1596) report on their study of the globular clusters 1 and 5 associated with the Fornax dwarf spheroidal galaxy. They find 21 candidate variables in cluster 1 but only two possible variables in cluster 5. In a discussion of the variable star population of the recently discovered Sagittarius dwarf spheroidal (Sgr) Mateo et al. (AJ 110, 1141) report ten variables near the galaxy, seven of which appear to be member RR Lyrae stars. Both Mateo et al. (ApJ 458, L13) and Alard (ApJ 458, L17) report populations of remote RRab stars in fields each several degrees from Sgr, indicating that it may extend for 20 degrees. Four red variables in the same galaxy with periods of order 150 to 300 d are reported by Whitelock et al. (NewA 1, 57).

The Oosterhoff Dichotomy, Period-Shift Effect and Pulsational Properties of Cluster RR Lyrae Stars. Despite a great deal of effort there is still considerable controversy over the underlying causes of the Oosterhoff dichotomy and the related RR Lyrae period-shifts from cluster to cluster. Two reviews of the topic are given by Sandage (AJ 106, 687; NPSP, 3) who finds increasing luminosity and decreasing temperature with decreasing metallicity and a high slope of −0.12 for the RRab period-luminosity relation. On the other hand, using synthetic HB (SHB) models and their convective RR Lyrae models, Bono, Caputo and their coworkers (ApJ 423, 294; ApJ 448, L115; AJ 110, 2365) find they can reproduce the observed dichotomy, taking into account the change of HB type with metallicity and assuming the transition between c- and ab- type variables is affected by the hysteresis effect first suggested by van Albada & Baker. SHB calculations by Catelan (A&A 285, 469) also seem to indicate hysteresis. In addition to the work discussed above Bono et al. (ApJ 442, 159) use their models to investigate dependence of the pulsational red edge on mass and helium abundance and find their results agree well with observations of variables in M 15 and M 68.

There have been several investigations as to what besides metallicity determines HB morphology. SHB calculations by Lee et al. (ApJ 423, 248) and Caputo et al. (A&A 276, 41) suggest that age is the "second parameter". However Catelan finds evidence in the case of Oosterhoff type II (OoII) clusters that other parameters besides age and mass loss are affecting HB type (AJ 107, 2077). See also Catelan & de Freitas Pacheco (A&A 289, 394) and Stetson et al. (PASP 108, 560).

The Relation between Luminosity and Metallicity for RR Lyrae Stars. Closely related to the problems discussed above is the question of the absolute luminosities of RR Lyrae variables. This has implications for the distances and ages of the systems in which these stars are found (see Sandage, AJ 106, 719). It is known that RR Lyrae absolute visual magnitudes increase with metallicity but there has been controversy over the slope of this dependence, Sandage (AJ 106, 703) finding a steep slope of 0.30, and others a much milder slope of 0.15. Several new methods have been used to investigate this. Simon's method of determining luminosity and mass of RRc stars from Fourier analysis of their light curves is applied by Cacciari & Bruzzi (A&A 276, 87) to variables in six OoI and four OoII clusters, yielding a slope of 0.22 for the V mag-[Fe/H] relation for RRc stars. In addition, their analysis of 48 RRc variables in ω Cen does not show much dependence on metallicity for the mass or luminosity of the variables within the cluster. An upper limit of 0.19 for the slope is found by Kovács & Jurcsik (ApJ 466, L17) using a relation between Fourier decomposition parameters and luminosity derived from a large sample of RRab stars in Galactic globular clusters and in the Sculptor dwarf spheroidal galaxy. Castellani & De Santis (ApJ 430, 624) test the use of blue amplitude and period of pulsation to determine the intrinsic luminosity of the variables in several clusters. These pulsational luminosities are about 0.2 mag brighter than those obtained from Baade-Wesselink analyses and give distance moduli for the clusters in agreement with those obtained from main sequence fitting. Using this method De Santis (A&A 306, 755) determines mean V absolute magnitudes for RR Lyrae stars in 17 globular clusters and derives distance moduli for a number of galactic and LMC clusters from which he determines a slope of 0.15 in the V mag-[Fe/H] relation. A preliminary study of HB stars in three M 31 clusters by Ajhar et al. (AJ 111, 1110) may point to an even milder metallicty dependence for RR Lyraes in M 31 clusters.

All these discussions depend on an accurate metallicity scale. Jurcsik (Acta Astr. 45, 653) presents a new ΔS to [Fe/H] transformation formula which is valid for both field and cluster variables. Metallicities of RR Lyrae variables in several clusters are determined by Jurcsik & Kovács (A&A 312, 111) using a method of deriving [Fe/H] from Fourier decomposition parameters of light curves of RRab stars.

8. *Long Period Variables (Patricia Whitelock)*

Relevant monographs and conference proceedings include Habing (A&AR 7, 97), Schwarz (ESO Conf. Proc. 46), Clegg et al. (1994 Herstmonceux Conf. CUP), AASP and CSP.

The period of Mira T UMi is decreasing (Gál & Szatmáry A&A 297, 461), while that of BH Cru is increasing (Walker et al. Southern Stars 36, 123); possibly due to He-shell flashes. Cohen & Hitchon (AJ 111, 962) find C-stars with periods up to 2 yr. Barthès et al. (AJ 111, 2391) discuss the variability of R For. Koen & Lombard (MN 274, 821) describe statistical tests for intrinsic scatter in light curves. The following Miras may have companions: U Cnc (Castelaz & McCollum AJ 109, 341); IW Hya (IRC−20197) (Le Sidaner & Le Bertre A&A 278, 167). A Mira in 47 Tuc, V42 (IRAS13237–44713), was detected at 10 μm (Origlia et al. MN 277 1125).

Optical photometry was published by Groenewegen & de Jong (A&AS 101, 267) for C-stars and by Celis S. (ApJS 98, 701) for red variables. Visual light-curves of SRs are discussed by Cristian et al. (PASP 107, 411) and Szatmáry et al. (A&A 308, 791). Optical spectra are described in Keenan (PASP 105, 905), Cohen at al. (AJ 111, 1333), Barnbaum (ApJS 90, 317) and Woodsworth (ApJ 444, 396). Jiang et al. (AJ 111, 231) optically identify IRAS sources. IR photometry is given by Le Bertre (A&AS 97, 729), Guglielmo et al. (A&AS 99, 31), Groenewegen et al. (A&AS 101, 513), Kerschbaum & Hron (A&AS 106, 397; 113, 441; A&A 308, 489), Lepine et al. (A&A 299, 453), Xiong (A&AS 108, 661) and Whitelock et al. (MN 267, 711; 267, 881; 276, 219). IR spectra are described by Kelly & Latter (AJ 109, 1320), Lázaro et al. (MN 269, 365), Goebel et al. (ApJ 449, 246), Sloan et al. (ApJ 463, 310), Groenewegen et al. (A&A 287, 163) and Chan (MN 268, 113). Kahne & Jura (A&A 290, 183) detected CO emission from SRs.

Allen et al. (ApJ 411, 188) suggest that bright IRAS variables are better tracers of galactic structure than colour-selected IRAS sources. Jura et al. (ApJ 413, 298; 422, 102) examine the spatial distribution of various Miras near the Sun. Galactic structure with respect to LPVs was reviewed by Whitelock (AASP, 165).

Abia & Isern (ApJ 460, 443) find that stars with high Li abundance are also J stars (^{13}C rich). Ohnaka & Tsuji (A&A 310, 933) studied ^{12}C/^{13}C at high resolution, finding significantly different values from some previous works. C stars with IRAS Si features are discussed by Chan (AJ 106, 2126) and Kwok & Chan (AJ 106, 2140), many are J stars. Theory relevant to J stars is discussed by Boothroyd et al. (ApJ 442, L21) and Wasserburg et al. (ApJ 447, L37). Cool bottom-processing may be important. Kastner et al. (A&A 275, 163) and Groenewegen et al. (A&A 293, 381) discuss the initial masses of C stars.

Johnson et al. (ApJ 443, 281) describe HST UV spectra of the C star UU Aur. Feast (MN 278, 11) provides a new calibration of $T_{\rm eff}$ as a function of J−K and discusses metallicity. Detailed radial velocity studies are given by Barnbaum & Hinkle (AJ 110, 805) for C variables and by Hinkle & Barnbaum (AJ 111, 913) for S Cep.

Although some detached dust shells are clearly real, and due to a previous high mass-loss phase, they may not be as prevalent as was thought. It seems likely that cirrus is responsible for the IRAS 60 and/or 100 μm flux from many AGB variables (Ivezić & Elitzur ApJ 445, 415, Zuckerman A&A 276, 367; but see also Chan PASP 105, 1107, Egan et al. A&A 308, 738). Specific observations of and/or models for detached shells are discussed by Waters et al. (A&A 281, L1), Groenewegen & de Jong (A&A 282, 115), Bujarrabal & Cernicharo (A&A 288, 551), Olofsson et al. (ApJS 87, 267) and Bauer & Stencel (AJ 107, 2233). The S star RZ Sgr is surrounded by an optical nebulosity (Whitelock MN 270, L15). Hashimoto (A&AS 107, 445; ApJ 442, 286) suggests AGB stars undergo many phases of moderate mass loss, before a brief phase of high mass loss. Justtanont et al. (ApJ 435, 852; 456, 337) found evidence for lower mass-loss rates at earlier times.

The relative importance of amorphous carbon and SiC in dust shells is discussed by various authors. Groenewegen (A&A 290, 207) finds no SiC in the IRAS spectra of M or MS stars previously suggested to show it. For C stars Groenewegen (A&A 293, 463) and Lorenz-Martins & Lefèvre (A&A 280, 567; 291, 831) find SiC grains make only a small contribution, but it is more significant for thin envelopes or low C/O. Blanco et al. (A&A 283, 561) find a larger fraction of SiC is needed to fit their sample. Nucleation of SiC precedes that of C grains (Kozasa et al. A&A 307, 551, Goebel et al. ApJ 449, 246). Grain formation is modelled by Egan & Leung (ApJ 444, 251). Dust around O-rich variables is discussed by Sloan & Price (ApJ 451, 758), Goebel (ApJ 430, 317) and Le Sidaner & Le Bertre (A&A 278, 167).

Strong far-IR and mm emission is detected from various red variables (van der Veen et al. A&A 295, 445, Le Bertre et al. A&A 299, 791, Knapp et al. ApJ 429, L33; ApJS 88, 173, Young et al. ApJ 455, 293). This has been explained in various ways. There may be multiple contributors but the detection of numerous molecular sub-mm lines in CW Leo by Groesbeck et al. (ApJS 94, 147) suggests line emission is important. Chen & Neufeld (ApJ 453, L99) model expected far-IR H_2O emission. Yates et al. (MN 273, 529) detected sub-mm H_2O masers. Various microwave transitions were observed by Bujarrabal et al. (A&A 285, 247).

The driving mechanisms of mass loss in AGB stars remain unclear. Charbonneau & MacGregor (ApJ 454, 901) consider Alfvén waves. Pijpers' (A&A 295, 435) calculations suggest sound waves may be important. Short time-scale variations are found in SiO maser emission by Pijpers et al. (A&A 286, 501) which may be caused by sound waves and in B & I magnitudes by Maffei & Tosti (AJ 109, 2652) which may be caused by shock waves. Fix & Mulhern (ApJ 430, 824) find a relationship between the velocity and excitation potential of CO lines. Danchi et al. (AJ 107, 1469) find changes in the spatial distribution of the dust in phase with the Mira pulsation. Mass-loss rates were measured by Groenewegen (A&A 290, 544) and Olofsson et al. (ApJS 87, 267). Blöcker (A&A 297, 727) discusses mass loss at the AGB tip and stellar evolution. Mass-loss models are described by Winters et al. (A&A 288, 255; 290, 623; 302, 483), Ivezić & Elitzur (MN 279, 1011) Krüger et al. (A&A 290, 573), Fleischer et al. (A&A 297, 543) and Höfner et al. (A&A 297, 815). Some models indicate that an external κ mechanism may drive mass loss in thick shells. Other papers dealing with cs-shells were by Charnley et al. (MN 274, L53), Wirsich (ApJ 424, 370), Fukasaku et al. (ApJ 437, 410), Olofsson et al. (ApJS 87, 305) and Groenewegen (A&A 290, 531).

Habing (A&AR 7, 97) discusses LPV masers in detail; only more recent work is quoted below. Surveys for OH masers were published by Blommaert et al. (A&A 287, 479), Chengalur et al. (ApJS 89, 189) and Lewis (ApJS 93, 549). Collison & Nedoluha (ApJ 422, 193) calculate models for pumping the main-line OH masers. Szymczak & Le Squeren (MN 276, 635) find that OH Miras are illuminated by a stronger interstellar UV field than are non-OH Miras. Surveys for H_2O masers were published by Lewis & Engels (MN 274, 439), Engels & Lewis (A&A 116, 117) and Seaquist et al. (MN 276, 867). SiO masers were measured by Baudry et al. (A&A 293, 594) and Cho et al. (A&AS 115, 117; AJ 111, 1987) who find a correlation between SiO maser flux and optical phase. Doel et al. (A&A 302, 797) model SiO maser production. HCN masers are investigated by Izumiura et al. (ApJ 440, 728). Lewis (ApJ 462, 786) discuss the correlations between maser emission and IRAS spectral type. Nedoluha & Watson (ApJ 423, 394) and Elitzur (ApJ 457, 415) discuss the theory of polarisation in masers.

CW Leo (IRC+10216): Spatially resolved images in HC_3N were obtained by Wootten et al. (A&A 290, 198) and Audinos (A&A 287, L5), in SiC_2 by Gensheimer et al. (ApJ 439, 445), in HCN, $H^{13}CN$ and CN by Dayal & Bieging (ApJ 439, 996) and in MgNC by Guélin et al. (A&A 280, L19) who suggest it may be a binary system. Many images show evidence for asymmetric hollow shell structure. The following species were identified or tentatively identified in the cs shell: MgCN (Ziurys et al. ApJ 445, L47); MgNC (Guélin et al. A&A 297, 183); C_8H (Cernicharo & Guélin A&A 309, L27); hot HCN (Avery et al. ApJ 426, 737); NaCN (Turner et al. ApJ 426, L97); ^{14}CO (Wright ApJ 436, L157); CI (Keene et al. ApJ 415, L131); C_3S & C_5S (Bell et al. ApJ 417, L37); SiS (Boyle et al. ApJ 420, 863); HC_9N (Truong-Bach A&A 277, 133); AlF (Ziurys et al. ApJ 433, 729); CH_3OH (Latter & Charnley ApJ 463, L37). Millar & Herbst (A&A 288, 561) discuss chemical models of the cs environment. Wright & Baganoff (ApJ 440, 322) point out that light-travel-time effects are important for measurements made of extended sources with large beams. Cherchneff & Glassgold (ApJ 419, L41) discuss the formation of carbon chain molecules; C_{60} was not detected (Clayton et al. AJ 109, 2096). The dust shell morphology was investigated by Jura (ApJ 434, 713), Ivezić & Elitzur (MN 279, 1019), Bagnulo et al. (A&A 301, 501), Sloan & Egan (ApJ 444, 452) and Danchi et al. (AJ 107, 1469). The IR spectrum of the weakly bipolar nebula can be fitted with amorphous carbon without SiC. Particles larger the 1 μm diameter may contribute to the dust mass. New dust forms at smaller radii during minimum luminosity.

Stellar diameters, measured interferometrically, were reported by Haniff et al. (MN 276, 640), Dyck et al. (AJ 109, 378; 111, 1705), Quirrenbach et al. (A&A 285, 541). Lunar occultation diameters were reported by Richichi et al. (A&A 301, 439). Tuthill et al. (MN 277, 1541) interferometrically monitored the angular diameter of o Ceti over about 3 yr finding significant changes at some wavelengths which were uncorrelated with the pulsation. Dust shell diameters (11 μm) were reported by Danchi et al. (AJ 107, 1469, see also A&A 300, 214; MN 279, 1011). The following papers also contributed to the debate over which pulsation mode dominates in Miras: NPSV, 311; A&A 288, 782; 289, 429; 290, 183; 307, 481; ApJ 449, 164; MN 278, 11. Ya'ari & Tuchman (ApJ 456, 350) performed dynamical simulations for LPVs over $>$ 500 yr, finding a change in the envelope structure of a typical star such that it pulsates in the fundamental mode with a shorter period than had previously been predicted. This might resolve the apparent inconsistencies between observed radii and theoretical predictions.

Measurements of stellar diameters (see above) often reveal non-uniform disks. Asida & Tuchman (ApJ 455, 286) consider anisotropic mass ejection from AGB variables caused by rotation acting on the pulsating atmosphere. Barnbaum et al. (ApJ 450, 862) suggest that rapid rotation of V Hya is due to spin up by the companion. Plez & Lambert (ApJ 425, L101) examine resonance fluorescence of KI up to several arcsec from the star: V Hya & g Her bipolar, R Leo highly asymmetric. They suggest that non-radial pulsation may be important as well as duplicity. Asymmetry may explain problems in modelling chromospheric emission from g Her (ApJ 422, 351). SiO measures of R Leo during lunar occultation imply non-spherically symmetric shell (Cernicharo et al. ApJ 423, L143). Frank (AJ 110, 2457) suggests cool star-spots may be responsible for AGB wind asphericities. Asymmetries were found in CO maps of some AGB variables (Stanek et al. ApJS 100, 169, Yamamura et al. ApJ 427, 406) and in the SiO maser of VX Sgr (Greenhill et al. ApJ 449, 365). Many other high spatial resolution studies of cs-masers reveal non-spherical shells (see A&AR 7, 97).

Sjouwerman & van Langevelde (ApJ 461, L41) detected double-peak OH masers associated with H_2O masers (ApJ 452, L37; 461, L41) near the Galactic centre, proving they are AGB stars rather than star forming regions. Frail et al. (ApJ 427, L43) measure the angular broadening, due to anisotropic scattering, of OH masers from AGB stars near Sgr A*. Van Langevelde et al. (A&AS 101, 109) and Jones et al. (AJ 107, 1111) have measured periods and luminosities for OH/IR stars around the Galactic Centre. Glass et al. (MN 273, 383) studied the Miras in the Sgr I window of the Bulge. Izumiura et al. (ApJ 437, 419; 453, 837; ApJS 98, 271) detected SiO masers and discuss their kinematics.

Reid et al. (MN 275, 331) present data on 302 LPVs in the LMC. Zijlstra et al. (MN 279, 32) and Groenewegen et al. (ApJ 449, L119) describe IR observations of obscured AGB stars and supergiants in the MC; mass-loss rates in the MC seem to be somewhat lower than in the Galaxy. Sebo & Wood (AJ 108, 932; 449, 164) report the discovery of LPVs near MC clusters. Li & Gong (A&A 289, 449) discuss pulsation of red supergiants in the LMC. Van Loon et al. (A&A 306, L29) report the first extragalactic SiO maser in an LMC supergiant. Groenewegen & de Jong (A&A 288, 782) discuss models which explain the apparent discrepancy between numbers of LPVs in the Galaxy and in the LMC. However, it remains possible that the problem is incompleteness, combined with a larger fraction of C stars in LMC. Models involving hot-bottom convective envelope burning in intermediate mass stars (Boothroyd et al. ApJ 416, 762) can explain the high Li abundances found for luminous AGB variables in the MC (Plez et al. ApJ 418, 812, Smith et al. ApJ 441, 735).

Rich et al. (AJ 106, 2252; ApJ 439, 145) report the detection of luminous red stars in the bulge of M 31, that are probably Miras. Whitelock et al. (NewA 1, 57) report the discovery of C variables in the Sgr dwarf galaxy.

9. R Coronae Borealis, RV Tauri and Related Variables (J.R. Percy)

In addition to papers in NPSV, NPSP and AASP, the dissertation by Pollard (1994 PhD thesis, University of Canterbury, NZ) contains much important data on both R CrB (MN 268, 544) and RV Tau (MN 279, 949) stars. Another recent highlight has been the discovery, as a by-product of gravitational microlensing surveys, of more R CrB and RV Tau variables in the Magellanic Clouds.

R Coronae Borealis Variables. Several significant reviews have appeared, including those by Lambert & Kamesware Rao (JApA 15, 47), Clayton (PASP 108, 225), Jeffery and Heber (ASPCS vol. 96, hereafter HDS) and CSP.

Southern R CrB stars continue to be monitored photometrically and spectroscopically by Cottrell, Lawson and their collaborators (e.g. MN 271, 919). Fernie & Seager (PASP 106, 1038) continue to monitor R CrB photometrically; Rosenbush (AN 316, 213) has monitored this and other R CrB stars. AAVSO, using its international database, has continued to publish long-term visual light curves of R CrB and RY Sgr in their monograph series, and Fernie (CSP) has reminded us that the low-amplitude pulsations of R CrB were discovered visually by Jacchia many decades ago. Clayton et al. (PASP 107, 416) have published a detailed, long-term, multi-technique study of R CrB.

Pugach (Soviet AJ 36, 612; Astr. Rep. 37, 169) and others have modelled the light curves of the fadings in terms of the geometry of the star-cloud system.

There remain several outstanding problems with these stars. First, there are two competing theories of their origin: a final helium shell flash, and the coalescence of a binary white-dwarf system. Both of these mechanisms may be capable of producing R CrB or related stars. The location and mechanism of the dust formation is also not clear: is it close to the photosphere ($2R_*$), or far away ($20R_*$)? Is there a preferred plane for the formation of the dust? What is the nature of the low-amplitude pulsations which are found in almost all of these stars – non-radial or radial? And what is their relation, if any, to the dust formation? There is a promising model (described in Clayton's review) in which the dust is formed near the star under non-equilibrium conditions created by shocks caused by the pulsations but, as Schonberner has summarized, "none of the existing theories is able to explain properly the multitude of observations"

RV Tauri Variables. RV Tau variables are pulsating yellow supergiants whose light curves show alternating deep and shallow minima. They are believed to be post-AGB stars. Zsoldos has continued his systematic UBV photometry of these stars, together with studies of their periods and $(O - C)$ diagrams (EP Lyr: A&A 296, 122; RV Tau: A&AS, in press). The $(O - C)$ diagrams are dominated by cycles of irregular length. Percy et al. have explained these as being due to the accumulation of random cycle-to-cycle fluctuations in period, through simulations (JAAVSO 21, 86) and through analysis of the $(O - C)$ data using the formalism of Eddington and Plakidis (PASP, in press).

Giridhar, Kameswara Rao, Lambert et al. have studied the photospheric composition of the RV Tauri stars (ApJ 437, 476; Gonzalez et al., preprint). They find several of them to be metal-depleted – perhaps due to dust formation in their atmospheres. They also find evidence that CN cycle material has been mixed with their surface layers, consistent with the presumed post-AGB status of these stars. Arellano Ferro and his collaborators (AJ 106, 2516) have continued to work on calibration of the photometric properties of yellow supergiants in general.

Over the past decade, there have been several interesting theoretical studies relating to the alternating deep and shallow minima in these stars, and the irregularity which is also a characteristic of these stars e.g. by Aikawa, Takeuti & Tanaka (e.g. MN 262, 893; PASJ 47, 487). Fokin (A&A 292, 133) has published non-linear pulsation models of RV Tauri stars. A 2:1 resonance between the fundamental and first overtone periods satisfactorily explains the alternating deep and shallow minima. He finds that the models exhibit low-order chaotic behaviour. Tuchman et al.'s (A&A 271, 501) linear study also supports the resonance hypothesis. Buchler et al. (ApJ 462, 489) find that R Sct exhibits deterministic chaos; the light curve can be represented by a simple, four-dimensional polynomial map or flow i.e. in terms of four first-order ordinary differential equations. This result is consistent with Buchler & Kovács' models (ApJ 320, L57; 334, 971) and those of Fokin. The nature and cause of the pulsational variations thus seem reasonably well understood.

Percy (ASPCS 45, 295), Fokin (A&A 292, 133) and others have discussed a binary model for the RVb phenomenon – the long-term changes in mean magnitude of some RV Tauri stars. The data of Pollard (1994) should be very helpful in shedding light on this topic. There may be some relation between the RVb stars and the peculiar, metal-depleted post-AGB binaries studied by Waelkens, Van Winckel et al. (A&A 293, L25) and others.

Related Stars. These include massive yellow supergiants such as ρ Cas, which continue to be monitored by photometric (Percy & Zsoldos A&A 263, 123) and spectroscopic (Sheffer & Lambert PASP 104, 1054) observers, and irregular yellow giant variables. Very few of the latter have been studied in detail, but they may be similar to RV Tauri stars, but not in a stage in which, because of a period resonance, the alternating deep and shallow minima are conspicuous (Percy NPSV, 123).

FG Sge, in the course of several decades, has evolved from a hot (10000 K) to a cool (4500 K) star, increasing its period from a few days to over 100 d. In 1992-93, this star underwent a dramatic fading of four magnitudes – perhaps due to dust formation as in an R CrB star. The overall behaviour of this star can be explained by the final He-shell flash of a 0.6 $M_{\odot}$ star during its post-AGB evolution, roughly 100 yr ago (Blocker & Schonberner HDS).

10. The Compact Pulsators (D.E. Winget)

We define the compact pulsators as the pulsating variable stars found below the main sequence. They all are, or soon will be, white dwarf stars. This said, we should keep an eye on the area of neutron star pulsations (see, for example, recent papers by Bildsten & Cutler ApJ 449, 800 and Bildsten ApJ 460, 827 and references therein). The promise is to do "oceanography" (rather than asteroseismology) of neutron star outer layers if the quasi-periodic oscillations in the brightest X-ray sources are associated with nonradial oscillations in the fluid ocean. We excuse the omission of this interesting area on the grounds that interacting binaries are beyond the scope of this review.

Space limitations dictate that we cover only a few of the highlights from the period of this report, and refer the reader to the many excellent reviews noted below for a more complete picture. There were several meetings of interest during the period covered by the report. Much of the work was directly or indirectly the result of the Whole Earth Telescope collaboration and so perhaps the most directly relevant of these was the "Third WET Workshop", Ames, Iowa, USA July 1995 (eds. Meištas & Solheim, Baltic Astr. 4, Nos. 2/4, 1995; hereafter WET3), essentially all the papers from this meeting are relevant to our section. Other meetings of interest include AASP, the "Ninth European Workshop on White Dwarfs", Kiel, Germany, August 1994 (eds. Koester & Werner, Springer: New York 1994; hereafter NEWWD), and ASPCS vol. 96, hereafter HDS.

Recent progress has been reviewed by Kawaler (AASP, 81), Nather (WET3, 117), Winget (WET3, 129), Kawaler (WET3, 137; 329), Clemens (WET3, 142), Kleinman (WET3, 270), Bradley (WET3, 311), Werner (WET3, 340), O'Brien (WET3, 349), Vauclair (HDS, 397), Werner et al. (HDS, 267), Clemens (Ph.D. Thesis, University of Texas 1994; hereafter C94), Kleinman (Ph.D. Thesis, University of Texas 1995; hereafter K95), Giovannini (Ph.D. Thesis, Universidade Federal do Rio Grande do Sul, 1996; hereafter G96) and Kanaan (Ph.D. Thesis, University of Texas 1996; hereafter K96). Kepler & Bradley (WET3, 166; hereafter KB) give a reasonably complete and excellent review of white dwarf stars, with special attention to the compact pulsators.

The instability strips currently known are all associated with non-radial gravity modes, with the exception of the recently discovered pulsating subdwarf B stars (Kilkenny et al. MN, in press; although this paper mentions that these stars are found only in binaries, they are presumably non-interacting), they refer to these stars as EC14026 stars, and they are hereafter referred to as the sdBV stars. The authors of the discovery paper point out that the sdBV stars are most likely pulsating in nonradial p-modes. We had anticipated, theoretically, the possibility of pulsations in sdB and sdO stars based on thermal time-scale analysis of the ad hoc models (the evolutionary status of these models is dubious, but the envelope structure is probably quite reasonable) of Winget & Cabot (ApJ 242, 1166) and Wesemael et al. (ApJ 254, 221). On this basis, an unsuccessful search for hot subdwarf variables was launched at McDonald Observatory in the mid 1980's by B.P. Hine, M.A. Wood, J.A. Hill, and the author; the unpublished null results are available on request. If these models are relevant they suggest that the driving mechanism is a deep H/He-partial ionization, consistent with their location in the HR diagram. In any event we eagerly await more on these stars as application of asteroseismology may help us solve their evolutionary status, and particularly their pathway into the white dwarfs. We will defer further discussion of these stars to a future report.

The compact pulsators, through application of asteroseismology, play a special role in our understanding of the structure and evolution of white dwarf and pre-white dwarf stars; interest in the white dwarf luminosity function has spread into wider areas of astronomy from considerations of the age and history of the galactic disk into halo white dwarfs and the missing halo mass (see Adams & Laughlin ApJ 468, 586 and Chabrier et al. ApJ 468, L21 for discussion). The compact pulsators consist of the pulsating planetary nebula nuclei (hereafter PNNV) stars, the related pulsating PG 1159−035 stars (hereafter the DOV stars), the helium pulsators (hereafter the DBV stars), and the hydrogen, or ZZ Ceti stars (hereafter referred to as DAV stars). Note that we are attempting to follow the classification convention of Sion et al. (ApJ 269, 253). Bradley (WET3, 536) has published an extremely useful up-to-date census of the compact pulsators (excluding, of course, the newly discovered sdBV stars) and summarized their physical and pulsational properties.

The Instability Strip Boundaries in the HR Diagram. In order to interpret the asteroseismological information in the contexts described above, we must have an accurate idea of the locations of the various instability strips. We also seek to determine the purity of the instability strip: if there are no non-pulsating stars of the same spectroscopic type as the pulsators to be found within a given strip, we define it to be pure. Although much remains to be done, there has been significant progress in this area. In this spirit we first consider the hottest compact pulsators the pulsating planetary nebula nuclei (PNNV) stars, and the pulsating PG 1159 stars (GW Vir stars, hereafter the DOV stars). This is discussed in detail by Werner et al. (AASP, 96) and Werner et al. (HDS, 267); they come up with boundaries for the instability strip at $\log g = 7$ of $140 < T_{\rm eff} < 100$ kK using pulsator/nonpulsator pairs. The luminosity boundaries are given by NGC 246 on the high end, $\log L/L_{\odot} = 4.2$, and PG 0122+200 on the low end, $\log L/L_{\odot} = 1.1$. They point out that these limits must be treated with caution because the boundaries are sensitive to gravities, and hence luminosities, as well as composition. Also, they note that several non-pulsators are located within the boundaries of the instability strip. This last is important not only in the determination of the boundaries, but also cautions us against applying the asteroseismologically determined parameters of the pulsators to the non-pulsators. There still is a high-luminosity region where the PNNV stars are found, and a low-luminosity region where the DOV stars are found, thus it is premature to consider these objects as a single class of objects. We await further work to see if the apparent separation is significant.

Wesemael et al. (HDS, 322) have investigated the location of the observed DBV instability strip. They find evidence for an extremely broad instability strip for the DBV stars with the blue edge defined by

PG 1654+160 near $T_{\rm eff} \sim 30$ kK, and the red edge defined by the star PG 1456+103 near $T_{\rm eff} \sim 22$ kK. They also note that there are three confirmed constant stars between PG 1456+103 and the next coolest variable which is 3 kK hotter. They point out that PG 1456+103 is a DBA star. This suggests that if the H abundance is sufficiently high, it may keep the base of the partial ionization zone closer to the surface – too close to drive the pulsations – until lower temperatures are reached. Thus the true DB strip red-edge (for stars without significant H) may be 3 kK hotter.

The location of the DAV strip has also been re-investigated recently by a number of authors (see G96, K96 and references therein). Perhaps the largest-scale effort is the landmark work of Bergeron et al. (ApJ 449, 258; hereafter BEA). They establish that the best values for the boundaries of the strip are $11.16 < T_{\rm eff} < 12.46$ kK, but are sensitive to the treatment of convection used in the atmospheric models. This work also confirmed the theoretical prediction of Bradley & Winget (ApJ 421, 236; hereafter BW) that the blue-edge temperature depends on the total stellar mass. As pointed out by BEA, with the mass-dependence taken into account the mean mass of the DAV stars is consistent with the mean mass of the hotter DA stars, and it is possible to tightly constrain the convective efficiency in the atmospheres of the DA white dwarfs. Kepler et al. (WET3), and G96, identify 15 non-variables within the ZZ Ceti strip temperatures. They show that all but one of these can be accounted for in terms of the total stellar mass effects. Thus the relative purity of the strip, originally suggested by the work of Fontaine et al. (ApJ 258, 651) and Greenstein (ApJ 258, 661) seems intact – and the only non-pulsator becomes even more interesting.

Driving Mechanisms. The driving mechanism for DOV and PNNV stars is thought to be due to the partial ionization of C and O (Starrfield et al. ApJ 281, 800, Stanghellini et al. ApJ 383, 766). These models, however, had problems accommodating the observed He abundances and still having sufficient C/O partial ionization. Bradley & Dziembowski (ApJ 462, 376) re-investigated C/O driving using models including the latest OPAL opacities. This dramatically alters the spectrum of unstable modes in the models. However, there are still difficulties understanding the longer period pulsations observed in some of the stars. Also, they conclude that the non-adiabatic calculations suggest that no DOV has photospheric abundances in the driving region.

The theoretical instability strip in DB white dwarf stars has been re-investigated by BW and Althaus & Benvenuto (MN, in press). The latter is of particular interest in that they employ the Canuto and Mazzitelli theory of convection, and obtain theoretical blue-edge temperatures very similar to BW for their ML2 models: $T_{\rm eff} \sim 25$ kK. We note that no published calculations are hot enough to match the observed blue-edge temperature of 30 kK.

For the DAV stars, in addition to BW mentioned above, non-adiabatic investigations of model DAV stars were described by Fontaine et al. (ApJ 428, L61). The latter employs a finite element technique described in the last report in these pages. This method is the most accurate and self-consistent method for solving the nonadiabatic equations of nonradial stellar pulsation. It was used by BEA in the investigation of the atmospheric parameters of the DAV stars and is also discussed there. Both investigations are in substantial agreement regarding the insensitivity to hydrogen surface layer mass, and total stellar mass, and change in the periods of the most unstable modes with effective temperature. None of these calculations, however, address the nature of the observed red edge, and this problem remains vexing (see K96 for a detailed examination of this problem).

Asteroseismology. Asteroseismological determinations of the basic parameters of white dwarf stars including stellar masses, surface layer structure, temperature, luminosity and even distance are all being routinely attempted now. Considerable progress has been made in this area, and is described in the reviews mentioned above, including detailed references to specific objects; I therefore will focus on more general results. Of particular interest is "ensemble asteroseismology" as described by Kleinman (WET3, 270). This is an important generalization of the technique applied by Clemens (Baltic Astr. 2, 407; C94) to an ensemble of hot DAV stars, which taken collectively allow mode identification and tightly constrain surface H layer masses, which would not be possible for any star taken individually because of a lack of observed modes. For the cool DAs the problem is not the paucity of peaks in the power spectrum, but rather their short coherence times. Kleinman takes an ensemble of runs, for many different seasons, to establish the set of normal modes present in a star. Using this technique he showed that in spite of dramatic seasonal changes in the complex power spectra of the cool DAV stars, the observed periods taken collectively over all seasons demonstrate that the apparently complex cool DAVs are normal mode pulsators. He demonstrated that these stars can now be productively studied with the techniques of

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asteroseismology. Similarly Winget (WET3, 129) applies this technique to the complex PNNV pulsators to show that the PNNV stars are also normal mode pulsators. This approach may well solve some of the problems described by Kawaler (WET3, 137).

Two new techniques have been developed and applied to determine the degree, l, of pulsation modes in pulsators with relatively few excited modes – where period distributions alone cannot help. Robinson et al. (ApJ 438, 908) and Kepler et al. (WET3) developed a technique which uses the ratio of amplitudes at different wavelengths in the UV and optical where the dramatically different limb darkening alters the geometric cancellation effects. Brassard et al. (ApJS 96, 545; and see references therein) have developed a second, and potentially very powerful technique which allows the exploitation of amplitude information to obtain the degree, l. This technique seems to be particularly valuable in the presence of linear combination frequencies and harmonics. Preliminary applications of both techniques seem promising for the future.

11. Theory of Stellar Pulsation (Joyce A. Guzik)

The conference proceedings published between July 1, 1993 and June 30, 1996 with a high density of papers related to stellar pulsation theory include NPSV, AASP and PRML.

Gautschy & Saio's Annual Reviews article (ARA&A 33, 75) summarizes stellar pulsation across the HR diagram, featuring a primer on the minimum amount of pulsation theory background required to follow developments in the field, and highlighting recent applications to neutron stars and hydrogen-deficient stars. Saio (NPSV, 61) reviews the basics of stellar pulsation theory. Gautschy's (AASP, 31) review of recent developments in pulsation theory, emphasizing high-luminosity stars, is highly recommended. Hansen & Kawaler's new textbook Stellar Interiors (Springer-Verlag, 1994) includes a chapter on stellar pulsation theory, with emphasis on helioseismology and white-dwarf asteroseismology.

Below are summarized the major themes in stellar pulsation theory during the past three years, with a focus on techniques that are applicable to several classes of variable stars. Discussions of theoretical developments and modeling for specific variable star classes are found in other sections of Chapter 27.

Nonlinear Radial Pulsation Theory. NPSV contains many papers discussing double-mode behavior, bifurcation, and chaos in nonlinear hydrodynamic pulsation models. Buchler (NPSV, 9) reviews the complementary techniques of dynamical systems theory, applicable to nonlinear phenomena in weakly nonadiabatic systems. Recently Serre et al. (A&A 311, 833) developed a global flow (also known as global polynomial phase space) reconstruction method to extract properties of the pulsation physics from a single observable quantity such as luminosity or radial velocity variations. Serre et al. (A&A 311, 845) use the technique to analyze a W Vir model light curve previously shown to have a chaotic nature. Their analysis shows that this light curve can be obtained as the solution of only three first order ordinary differential equations. Physically, this implies that dynamics of this chaotic model light curve is governed by interaction of just two modes. Buchler et al. (ApJ 462, 489; Phys. Rev. Lett. 74, 842) apply global flow reconstruction to the light curve of the RV Tauri star R Sct. They conclude that the irregular pulsations of R Sct are a manifestation of deterministic chaos of dimension 4, and arise from nonlinear interactions of only two modes. Buchler et al. are optimistic about the prospects for this type of analysis to open the field of nonlinear asteroseismology.

Nonlinear Adaptive Grid Hydro Codes. Several groups developed nonlinear hydrodynamics codes featuring adaptive grid techniques for radial pulsation analyses. These techniques are a hybrid of Lagrangean and Eulerian schemes; mass is advected between Lagrangean zones to resolve ionization regions or shock fronts during the pulsation cycle. Gehmeyr (ApJ 412, 341) uses his adaptive grid code including time-dependent convection (ApJ 399, 265; 399, 272) to investigate the red edge of the RR Lyrae instability strip. He finds that, as the effective temperature of the models decreases, the increased amount of energy transported by convection in the hydrogen and first helium ionization zones quenches the radial oscillations. He also discusses a distinctive "convective bump" in the model light curves that should be resolvable in light curves of RR Lyraes near the red edge. Feuchtinger & Dorfi (A&A 291, 209) improved and applied their adaptive grid technique (1991, A&A 249, 417) to radiative RR Lyrae models, and obtain very smooth light and velocity curves. Very recently Buchler, Kollath & Marom (preprint) introduced their radiative adaptive grid code. They demonstrate that second order advection schemes (e.g. van Leer) are preferable to first order (or donor cell) advection schemes. Also, conserving total energy rather than using an internal energy equation reduces the cumulative numerical deterioration due to advection errors. They apply their code to a classical Cepheid model and obtain smoother velocity and light curves than obtained with their Lagrangian code. They point out that adaptive grid calculations do require pseudo-viscosity, but require less than is needed for Lagrangian calculations. Finally, Gehmeyr and Mihalas (BAAS 185, 4006; 183, 4806) introduce an adaptive grid radiation hydrodynamics code called TITAN, which solves the coupled set of radiation transfer and hydrodynamics equations. They intend to make this code available to the astrophysics community for application to a broad variety of problems.

Nonlinear Nonradial Pulsation Theory. While nonlinear radial and nonradial linear theory/modeling are well-established, very little work has been done to tackle the problem of nonlinear nonradial oscillations. This step is a prerequisite to understanding amplitude variability and mode selection in multi-mode nonradial pulsators such as white dwarfs, β Cephei and δ Scuti variables. Recent work has been done to derive nonlinear mode coupling equations for the temporal evolution of the amplitudes of a pre-selected set of modes. Goupil & Buchler (A&A 291, 481) extend the amplitude equation formalism for radial modes to nonradial pulsations, and derive nonlinear coupling coefficients up to third order. Buchler et al. (A&A 296, 405) apply these results to the nonlinear behavior of an $l = 1$ mode split by slow rotation. This method shows promise for explaining amplitude variations and frequency spacing asymmetries within $l = 1$ triplets. Van Hoolst and Smeyers (A&A 279, 417) derive third-order coupled mode equations that describe the isentropic radial and nonradial oscillations of a static, spherically symmetric star. Van Hoolst (A&A 295, 371) applies these equations to study the nonlinear interactions between a radial mode and a nonradial higher-degree mode with nearly the same frequency. Van Hoolst (A&A 286, 879) derives coupled-mode equations to third order using a Hamiltonian formalism, with the advantage that the symmetry of the coupling coefficients follows naturally. In his study of low-order modes of an index=3 polytrope, he finds that modes with equal radial displacements at the surface couple most strongly to modes of nearly the same radial order. He also finds that higher-order modes are more influenced by nonlinearities than low-order modes, and that the coupling coefficients are most sensitive to the structure of the outer regions of the model.

Asymptotic Theory of Nonradial Oscillations. Efforts continue to extend the asymptotic theory description of nonradial p and g modes including the Eulerian perturbation of the gravitational potential (i.e. omitting the Cowling approximation). Roxburgh & Vorontsov (MN 268, 143) extend the asymptotic description for low-degree p modes to fourth order. They also develop a second-order asymptotic description that works well for high-frequency p modes of intermediate degree for use in helioseismology (MN 278, 940). Smeyers et al. (A&A 301, 105) derive an asymptotic representation for low-frequency isentropic g modes, beginning with a fourth order system of differential equations that includes the divergence of the Lagrangian displacement. By working with the divergence of the displacement instead of the displacement itself, they avoid a singularity that arises for g modes between the center and surface of the star. Smeyers et al. (A&A 307, 105) also derive an alternative second-order asymptotic representation of high-frequency, low-degree p modes, again using the divergence of the Lagrangian displacement.

Excitation and Amplitudes of Solar-type p Modes. One of the challenges of nonradial pulsation theory is a quantitative understanding of the excitation and damping of solar oscillations. The prevailing theory is that solar p modes are excited by convective motions near the solar surface. Goldreich et al. (ApJ 424, 466) solve the inhomogeneous wave equation that determines the stochastic excitation of p modes by turbulent convection. They are able to match observationally determined excitation rates (product of mode energy and line width) using energy input rates derived from the standard mixing length theory of convection. However, their approach requires two input parameters associated with the eddy correlation time that are poorly constrained by theory, so their method is not yet predictive. Kjeldsen & Bedding (A&A 293, 87) use the only available predictive model for solar oscillation amplitudes (1983, Christensen-Dalsgaard and Frandsen, Sol. Phys. 82, 469) to derive scaling relations that predict the velocity and luminosity amplitudes of solar-like oscillations for other stars. They conclude that current observational sensitivities are inadequate to detect oscillations in solar-type stars at the amplitudes they predict. Their predicted amplitudes are above the detectability threshold for F-type stars, but observational searches (Procyon & members of M 67) give negative results. Because of this, Kjeldsen & Bedding surmise that the Christensen-Dalsgaard/Frandsen model using the mixing-length theory probably overestimates the convective flux in hot stars, and thus overestimates the amplitudes of convectively-driven oscillations.

OPAL/OP Opacities. The opacity increases in the 1992 OPAL (Rogers and Iglesias ApJS 79, 507, Iglesias et al. ApJ 397, 717) and 1994 OP (Seaton et al. MN 266, 805) opacity tables compared to the older Los Alamos tables continue to resolve outstanding puzzles in variable star modeling. Many recent papers deal with the effects of the OPAL/OP opacities on O and B star stability, in particular the success of a new opacity bump in producing the observed β Cep instability strip (e.g. Dziembowski PRML, 55, Moskalik AASP, 44, Dziembowski & Pamyatnykh MN 262, 204, Dziembowski et al. MN 265, 588, Gautschy & Saio MN 262, 213). This bump (hereafter called the Z-bump) at about 200,000 K is due to better treatment of interatomic transitions of iron peak elements. Iglesias and Rogers updated the OPAL opacities (ApJ 464, 943) to explicitly include 19 metals instead of 12, and include the effects of an improved equation of state (Rogers et al. ApJ 456, 902). The updated OPAL opacities are 20% higher than before in the region of the Z-bump for Pop. I compositions. However, equation of state improvements slightly decrease the opacities for solar interior conditions, which will probably make the convection zone depth of standard solar models shallower than the helioseismically-determined depth.

The inclusion of the Ni, Mg, and Cr in the updated OPAL opacities has improved agreement between the OPAL and OP opacities in the Z-bump region. Pamyatnykh et al. (PRML, 70 and AASP, 291) discuss the effects of differences between the OP and original/updated OPAL opacities for B star pulsation. The blue edge of the β Cep instability strip is sensitive to metallicity, so the metallicity of a cluster can be inferred by observing the cluster blue edge. With the OP opacities, almost all cluster β Cep variables can be explained with Z=0.015, similar to the Z=0.018 required for the updated OPAL opacities. In contrast, $Z \approx 0.03$ is required for models based on the original OPAL tables.

Fadeyev & Lynas Gray (MN 280, 427) compare the OPAL and OP opacities in their nonlinear models of extreme helium stars, and find two distinct instability regions due to helium ionization and the Z-bump. The OP opacities give the best agreement between observed and model light curves of V652 Her.

Strange Mode Instabilities. During the past three years, the status of strange modes has changed from a curiosity to a commonly-predicted theoretical phenomena for stars in the upper HR diagram. Strange modes arise only in nonadiabatic calculations, and appear to be associated with high luminosity/mass ratios and a low heat-capacity envelope dominated by radiation pressure.

Saio (MN 277, 1393) finds unstable strange modes in his linear analysis of higher luminosity hydrogen-deficient stellar models, and attributes strange mode instability to the Z-bump in the new OPAL opacities, as well as trapping of pulsation energy around an envelope density inversion. Similarly, Aikawa & Sreenivasan (PASJ 48, 29) suggest that density inversions in the H and He I ionization regions are responsible for strange mode pulsations in their nonlinear pulsation models. Glatzel (G), Kiriakidis (K), and Fricke (F) published six papers in MN on linear radial stability analyses of massive main-sequence stars, helium main sequence/Wolf-Rayet stars, and luminous blue variables (LBVs) (GKF 262, L7; GK 262, 85; 263, 375; KFG 264, 50; G 271, 66; KGF 281, 406). They conclude that two classes of strange modes should be distinguished. The first class occurs in massive stars, in which the He and Fe ionization opacity maxima act as acoustic barriers, setting up acoustic cavities that each produce their own spectrum. This is similar to the findings of Saio, and Aikawa & Sreenivasan. These modes were classified in an arbitrary way as "ordinary" or "strange", depending on which cavity they belong to. While the run of opacity is important in setting up the acoustic cavity, the origin of instability is actually a phase shift between density and pressure perturbations induced by the high radiation pressure. WR stars show a second class of strange modes, which occur in complex conjugate pairs, and exists even when the opacity derivative with respect to temperature is artificially set to zero. However, this second class of strange modes is stable unless the opacity derivative with respect to density is nonzero.

GKF suggest that strange modes that grow on dynamical timescales are responsible for high mass loss rates and LBV outbursts, and that the onset of strange mode instabilities is responsible for the Humphreys-Davidson (HD) limit. Stothers & Chin (ApJ 408, L85; 426, L43) offer an alternative explanation for LBV outbursts that does not directly implicate strange modes. In their scenario, the adiabatic exponent Γ_1 drops below 4/3 in the outer envelope of massive stars at the beginning and end of core helium burning. This causes a dynamical instability and an LBV-type outburst, which results in ejection of the outer envelope. However, they predict onset of instabilities much redder than the HD line. Stothers & Chin suggest that the HD line instead marks the end of core hydrogen burning, and further evolution to the red is too rapid to be observable.

Pulsation and Rotation. Clement (PRML, 117) reviews the theoretical effect of rapid rotation on the eigenfunctions of normal mode stellar pulsations. Low-order axisymmetric modes couple strongly to rotation, significantly affecting velocity distributions, while high-order non-axisymmetric modes couple weakly to rotation and retain much of their spherical harmonic character. Lee & Baraffe (A&A 301, 419) examine the effects of both the centrifugal and Coriolis forces on the nonadiabatic pulsations of rotating

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main-sequence OB stars. They find that second-order rotational effects do not influence the pulsational stability of p and g modes. However, they suggest that fourth-order effects (not all of which are included in their analysis) may stabilize some p modes. Clement (BAAS 186, 2112) discusses progress on his effort to develop a robust numerical method to compute nonradial eigenmodes of arbitrary order with arbitrary rotation rate.

Pulsation and Magnetic Fields. Takata & Shibahashi (PASJ 46, 301; 47, 219) further refined their theoretical treatment of nonradial pulsations in the case where magnetic field effects dominate rotation, and apply it to the rapidly oscillating Ap stars (see section by Kurtz). Das et al. (ApJ 433, 786) investigate nonlinear radial adiabatic oscillations for polytropic stellar models with a toroidal magnetic field. They find that interior toroidal magnetic fields of plausible strength increase the fundamental mode frequency, and could significantly affect amplitudes and velocity profiles. Lydon & Sofia (ApJS 101, 357) present a method of modifying the equations of stellar structure and evolution to include a large-scale magnetic field confined within a star. They implement this method in a standard stellar evolution code, and test it on a solar model containing a magnetic perturbation designed to mimic the effects of the solar dynamo. Lydon et al. (ApJ 456, L127) show that the changes in p-mode frequencies during the solar cycle can be explained by a variation in horizontal magnetic field strength of 400 G at a depth of 320 km below the solar surface. Their results differ in several respects from earlier results (e.g. Goldreich et al. ApJ 370, 752, Jain & Roberts A&A 286, 254), most notably in requiring a decrease (instead of increase) in B field strength to explain the increasing solar p-mode frequencies during 1986-1989.

White Dwarfs. The field of white dwarf asteroseismology has become more firmly established with the publication of theoretical g-mode pulsation periods for DB (Bradley et al. ApJ 406, 661), DA (Bradley ApJ 468, in press), and PG 1159 (Kawaler & Bradley ApJ 427, 415) models. The periods, period spacing, and deviations from the mean period spacing due to mode trapping can be used to determine the total mass, surface layer masses, and the location and extent of H/He, He/C or C/O transition zones (see section by Winget). Various authors compare nonadiabatic theoretical predictions with the position of the observed instability regions, and agree that the hot boundary of the hydrogen atmosphere white dwarf instability strip is not sensitive to the hydrogen layer mass, in contrast to results from the late 1980's. However, these authors use several different numerical methods to solve the nonadiabatic nonradial pulsation equations. Lee & Bradley (ApJ 418, 855) present an improved numerical method to calculate nonadiabatic nonradial oscillations designed to cope with the large difference between thermal and dynamical timescales in the degenerate cores of white dwarfs. They employ a weakly nonadiabatic analysis in the core, and switch to fully nonadiabatic calculation in the outer layers where pulsation driving occurs, thereby avoiding numerical instability in the thermal eigenfunctions present in previous methods. Fontaine et al. (ApJ 428, L61) study the dependence of pulsational instabilities on the hydrogen layer mass for DA variables using a nonadiabatic version of the Galerkin finite element method code of Brassard et al. (1992, ApJS 80, 725). Gautschy et al. (A&A 311, 493) combine hydrodynamic convection modeling with their Riccati method nonradial nonadiabatic program to analyze DA white dwarf models. They find pulsationally unstable modes only for instantaneous adaption of convection to the pulsations and vanishing shear in the convective layers. Their derived blue edge is 200 – 600 K cooler than the observationally-determined blue edge, but this may not be significant, given the uncertainties in modeling convection. Finally, Bradley & Dziembowski (ApJ 462, 376) conduct a parametric survey of pulsation driving in PG 1159 stars and conclude that the driving regions at 10^{-9} M_* are probably oxygen-rich relative to the photospheric abundances.

12. Flare Stars (C.J. Butler)

This review summarises the progress in research on flare stars (FS) other than the Sun. For information on the copious material covering observations and theories of the active Sun the reader is referred to the report for Commission 10.

A valuable source of information on current cool star research, including details of forthcoming meetings, coordinated multiwavelength campaigns, abstracts of papers etc, and which is available by email, is "Coolnews", a monthly circular edited by Steve Skinner. For further information, contact coolnews@jila.colorado.edu.

Meetings. Whilst there were no meetings during the last three years devoted entirely to FS there were a number in which FS research was included along with related topics. These were: IAU Coll. 142; IAU Coll.

143; "Solar Magnetic Fields", Jun-Jul 1993, Freiburg (eds. Schüssler and Schmidt, Cambridge); IAU Coll. 144; "The 8^{th} Cambridge Workshop on Cool Stars, Stellar Systems and the Sun", (hereafter 8CW), Oct 1993, Athens, Georgia (ed. Caillault, ASPCS vol. 64); "Fragmented Energy Release in the Sun and Stars", Oct 1993, Utrecht (ed. van den Oord, Kluwer); FF; IAU Coll. 153 (hereafter MPSA); "Astrophysical MHD Flows", NATO ASI, Jun 1995, Heraklion (ed. Tsingaros, Kluwer); "The 9^{th} Cambridge Workshop on Cool Stars, Stellar Systems and the Sun", (hereafter 9CW), Oct 1995, Florence (eds. Pallavicini et al. ASPCS); IAU Symp. 176 (hereafter SSS).

In addition to the above, the following reports of earlier meetings were published during the past three years: IAU Symp. 157; "The Physics of Solar and Stellar Coronae" (hereafter PSSC), Jun 1992, Palermo (eds. Linsky & Serio, Kluwer). Two monographs appeared on related topics: "Solar and Stellar Activity Cycles", (Wilson, P.R., Cambridge, 1994), and "Plasma astrophysics – kinetic processes in solar and stellar coronae", (Benz, A.O., Kluwer, 1993).

Reviews. In general, review articles are listed under the topic to which they refer. The following, however, are not included in any other section. Mirzoyan (Ap 36, 170) has reviewed the historical development of how FS fit into our picture of stellar evolution and discusses the evidence that solar and stellar flares are basically similar. He concludes that there are significant differences. The relationship of stellar activity to basic stellar parameters has been reviewed by Giampapa (8CW, 509) and Hawley (PASP 105, 955) and to magnetic braking and rotation by Hubbal (8CW, 309), Saar (8CW, 319) and Schrijver (8CW, 328). In SSS a number of review articles appear which are concerned with surface inhomogeneities, such as dark spots and plages, on dwarf M stars. Just how spots, plages and active regions on dMe and other late-type stars relate to each other in space and time is not yet clear. Whilst evidence for solar type behaviour has been found (Kürster & Dennerl PSSC, 443, Butler SSS, 423) the picture becomes confused by saturation effects in very active stars.

Flare Stars in Stellar Aggregates. The presence of FS in young stellar aggregates continues to provide a valuable source of information on basic stellar parameters generally associated with activity, such as age and rotational velocity (see review by Stauffer 8CW, 163). With the availability of X-ray area detectors, initially on EINSTEIN and more recently on ROSAT, it has become possible to link X-ray brightness, an activity diagnostic, to other parameters such as spectral type and rotation, and to assess the influence of age. The Orion Association and the Pleiades Cluster are the most popular aggregates for such studies (see Gagne et al. ApJ 437, 361; 445, 280; 450, 217, Pravdo & Angelini ApJ 447, 342). These authors have detected X-ray emission in all types of cluster members, from O to M, with the hottest coronal temperatures evident in the later spectral types. Up to 40% of the late-type Pleiades objects are variable in X-rays. X-ray flares with energies in excess of 3×10^{35} ergs have been seen in sources in Orion, comparable to the largest energies seen from RS CVn stars in the solar neighbourhood.

Disconcertingly, Gagne et al. (ApJ 445, 280) find no clear dependence of activity on rotation in Orion Nebulae FS. Also, we note that ROSAT data of Pleiades, Hyades and solar neighbourhood FS by Hempelmann et al. (A&A 294, 515) show no intrinsic dependence of coronal flux with age. Recent reviews of ROSAT observations of young clusters were given by Caillault (9CW) and Krautler (9CW).

The transition to fully convective envelopes has long been suggested to cause a drop in the activity level of very late dM stars. Hodgekin et al. (ESO Workshop: "The bottom end of the main sequence and beyond", Aug 1994, Garching, ed. Tinney, Springer, 228) found strong differences in behaviour of the chromospheric and coronal emission in these stars. Whereas chromospheric activity turned over at 0.3 - 0.4 $M_{\odot}$ they found the coronal X-ray flux level to be maintained down to 0.1 $M_{\odot}$. Observations of the dM8 star VB10 with the GHS on HST by Linsky et al. (ApJ 455, 670) also suggest continuing magnetic heating below the fully convective envelope threshold.

Flare Stars in the Solar Neighbourhood. A database of basic observational parameters of solar neighbourhood FS is in preparation by Gershberg et al. (8CW, 411). It contains data on 230 FS with 2100 references and updates an earlier list by Pettersen (Oslo, 1976).

The presence of lithium in late-type stars has long been considered as evidence of youth. The question of how the lithium abundance is affected by rotation and frequent surface activity remains. These topics were the subject of a series of reviews in 8CW by Strom (p. 211), Balachandran (p. 234), Pallavicini (p. 244) and Pinsonnealt (p. 254). A later review by Soderblom (9CW) considers the evidence provided by FS in aggregates.

In addition to the well-known 11-year cycle, historical evidence points to longer term changes in solar activity levels. Similar variations in stellar activity levels are more difficult to ascertain due to the scarcity of data. However, the topic has received increasing attention for the brighter and most frequently observed FS. Recent papers by Mavridis (A&A 280, 65; 296, 705), Mahmoud (ApSS 208, 217), Bondar (A&AS 111, 259) and Berdyugin et al. (BCrAO 89, 78) conclude that such long-term variations in stellar activity do indeed occur and that certain longitudes are preferentially active.

The extremely rapidly rotating (P < 0.5 d) K-type FS, AB Dor and HK Aqr, have received increasing attention. In addition to flares and spots, these stars show evidence of prominences which are visible in absorption in Hα as they transit in front of the stellar disk. Papers by Kubiak et al. (Acta. Astr. 45, 279) and Cameron (MN 275, 534) confirm the long-term stability of the low latitude active regions on these stars. However, it appears that high latitude spots are more variable. Another rapidly rotating K dwarf, HD 197890 (Speedy Mic) has been identified from ROSAT observations.

γ-ray, X-ray and EUV Observations. The possibility that the γ-ray bursts detected by satellites may originate from flares on magnetically active stellar systems has been considered by Rao et al. (PSSC, 497) on the basis of an extrapolation of the X-ray fluxes from stellar flares. Hurley et al. (ApJ 446, 267) have examined 3000 known stellar flares, but find no coincidences with γ-ray bursts. They speculate that a value for L_X/L_{opt} at least four orders of magnitude greater than is found in solar flares would be required to explain some weak γ-ray events by stellar flares.

Over the past few years, as ROSAT and EUVE results have come on stream, the number of observational studies of soft X-ray and EUV emission from FS has increased significantly. A recent review of stellar X-ray flares has been given by Haisch (MPSA, 235). Other relevant reviews have appeared in the proceedings PSSC, MPSA and 8CW. Both satellites include high-resolution imagers and a wide-field camera. These instruments have facilitated the discovery and subsequent identification of many new sources (see Mathews et al. MN 266, 757, Mullass & Bopp PASP 106, 822, Gudel et al. 8CW, 86, Micela et al. A&A 298, 505, Mathioudakis et al. A&A 300, 775). In addition, spectral information from EUVE has given access to a range of new diagnostics in the 70 – 380 Å region (see Brown 8CW, 23 and Giampapa et al. ApJ 463, 707). Giampapa et al. find that the coronae of low-mass dwarfs consist of two distinct thermal components with temperatures $T \sim 2-4 \times 10^6$ K and $T \sim 10^7$ K. They find that only the hard, 10^7 K, component is variable as might be expected if this were to originate from magnetically heated plasma. Mullan & Fleming (ApJ 464, 890) note that there is a dichotomy in the surface X-ray brightness of late-type stars and suggest that the coronae of stars in the low flux group may be heated acoustically, in contrast to the coronae of stars in the high flux group which are heated in part by magnetic processes. Their results reconfirm the proposition that the coronae of the active dMe stars cannot be predominantly acoustically heated.

EUVE spectra of FS in their quiet state have been obtained of ϵ Eri by Schmitt et al. (ApJ 457, 882), of EQ Peg by Monsignori Fossi et al. (ApJ 449, 376) and AU Mic by Monsignori Fossi & Landini (A&A 284, 900). Drake et al. (8CW, 35) find a larger enhancement factor and faster decay times for the higher temperature iron lines ($T \sim 10^7$ K) compared to lower temperature lines ($T \sim 10^6$ K) during EUVE observations of flares on AU Mic. The fact that these lines persist throughout the decay phase, suggests additional post-impulsive heating and/or expansion. Culley et al. (ApJ 414, L49) conclude, from the emission measure of the AU Mic flare, that the flare plasma has a length scale of the order of the stellar radius. This type of result occurs frequently in such analysis and leads to a suspicion felt by some that stellar flares are stretching the solar paradigm beyond normal limits.

Evidence for high velocity mass motions, both during quiescence and during flaring on AU Mic has been observed in the ultraviolet transition region lines of C IV and Si IV by Linsky & Wood (ApJ 430, 342). Observations of similar phenomena with EUVE by Cully et al. (ApJ 435, 449) gave estimates for the total energy of this event as 10^{36} ergs – equivalent to the radiative energy budget of a large flare on an RS CVn star.

Optical and Infra-red Observations. A review describing optical observations of continuum emission from stellar flares and the mechanisms that have been proposed to account for it has been presented by Butler (MPSA, 217). The emission, though similar in appearance to black-body in the early stages of a flare, becomes increasingly dominated by optically thick hydrogen as a flare progresses. Models with NLTE codes suggest that the *compact condensation* or *hot kernel* model, proposed by Katsova et al. (Ap 17, 285) and Houdebine (Irish AJ 20, 248) can account for many of the properties of the continuum emission.

The importance of mass motions in the energy budget of stellar flares has been frequently noted in the past (Byrne PSSC, 489). A number of new spectroscopic observations, mostly in the optical, have enabled estimates for such mass motions to be computed (e.g. Gunn et al. A&A 285, 157; 285, 489, Houdebine et al. A&A 278, 109; 274, 245). Estimates for the KE of high velocity material originating in flares varies from, two orders of magnitude less than, to approximate parity with, the radiative energy.

Progress in the detection and measurement of magnetic fields on FS using the Zeeman effect has been reviewed by Saar (IAU Symp. 154, 437 & 493). He finds field strengths in K/M dwarfs to be higher than in RS CVn binaries, consistent with the expected balance between magnetic and gas pressure in stellar atmospheres. He also finds evidence of spatial variation in the field strength. Johns-Krull & Valenti (ApJ 459, L95) report the detection of Zeeman splitting in the Fe I 8468.4 Å line in two dM4.5e stars: Gliese 729 and Gliese 873 (EV Lac). They find approximately 50% coverage by fields in the 2.5 – 4.0 kG range on these two stars.

Mathiodakis & Doyle (A&A 280, 181) and Katsova & Tsikoudi (8CW, 426) have examined the 12 μm IRAS flux for G/K dwarfs and compared it with various stellar parameters. They find dKe/dMe stars to be systematically brighter at 12 μm compared to less active stars.

Radio Observations. Several reviews concerning observations of radio emission from FS and their interpretation are given in the MPSA proceedings (Lang p. 267, Bastian p. 259, Stepanov p. 281). The radio emission from FS is characterised by its high brightness temperature, its frequent high degree of polarization and its variability. Melrose (PAS Aust. 10, 254), following others, proposes that this emission is basically coherent in nature. A similar conclusion was reached by Abada-Simon et al. (A&A 288, 219) from Aricibo observations of AD Leo.

Lang (ApJS 90, 753) has looked at the VLBI observations of radio emission from flares on several types of star; the RS CVn binaries, T Tauri stars and FS. He finds that flares on the RS CVn and T Tauri stars often require magnetospheres with length scales several times larger than the stellar radius, whereas flares on dMe stars require sources much smaller than the stellar disk.

Lim & White (ApJ 453, 207) report the first detection of radio flares on FS in the Pleiades. Both their quiescent and flaring emission are broadly similar to nearby, rapidly rotating, late type dwarfs.

Lim et al. (ApJ 460, 976) report observations of Prox Cen at centimetre wavelengths. The results place constraints on the filling factors of magnetic structures and suggest a coverage of not more than 13% for hot (2×10^7 K) loops and not more than 90% for cooler (3×10^6 K) loops.

Multi-wavelength Observations. When efforts are made to fit physical theories to observations of stellar flares there is a clear and undisputed advantage to be gained from coordinated multi-wavelength observations. Though difficult to obtain, particularly with low Earth-orbit satellites, they provide constraints on physical theories that cannot be obtained from single-wavelength observations. A number of multi-wavelength studies have appeared during the past three years; notably of AB Dor (Vilhu et al. A&A 278, 467, Robinson et al. MN 267, 918), EV Lac (Gershberg et al. Astr. Rep. 37, 497, Berdyugin et al. BCrAO 89, 81, Alekseev et al. A&A 288, 502), YZ CMi (van den Oord A&A 310, 908), UV Ceti (Schmitt et al. ApJ 419, L81), AU Mic (Robinson et al. ApJ 414, 872) and AD Leo (Hawley et al. ApJ 453, 464). Several of these studies fit detailed physical models including, in some cases, models of the particle beams believed to be responsible for the initial impulsive energy release.

Catala (IS, 634) has discussed the observations required to test models of stellar activity and concludes that the most pertinent of them can only be obtained from space. A mission intended to provide such simultaneous multi-wavelength observations, the now-disbanded ESA PRISMA project, was described by Lemaire (IAU Coll. 147, 540).

A search for the signatures of proton beams during flares on AU Mic from coordinated HST, IUE and optical monitoring by Robinson et al. (ApJ 414, 872) resulted in the conclusion that proton beams were unlikely in the small flare observed. A theoretical treatment of the interaction of proton beams with stellar atmospheres has been given by Brosius et al. (8CW, 360).

Microflares and Oscillations. The existence of small (Δm $\sim$ 0.01 mag), approximately sinusoidal, photometric variations on FS, as originally detected by Andrews, has been confirmed by observations with a two-star photometer by Peres et al. (A&A 278, 179). Following Mullan (ApJ 391, 265), such oscillations have been attributed by Andrews & Doyle (Irish AJ 21, 83) to resonances in magnetic coronal loops. A similar explanation has also been proposed by Mullan & Johnson (ApJ 444, 350) for the rather longer period oscillations seen in X-rays on EQ Peg, Prox Cen and AD Leo.

The controversy over whether or not stellar micro-flares exist, and what their role might be in coronal heating, has continued. Robinson et al. (ApJ 451, 795) have detected frequent microflares with integrated energies 10^{27} – 10^{28} ergs on the dM8e star CN Leo at 240 nm with HST. However, for this star, it appears that the accumulated energy from such events represents less than 30% of the total flare energy in that wavelength region. The occurrence rate for micro-flares on CN Leo appears to follow the same slope as that for normal flares.

Model Atmospheres of Flare Stars. Liebert (8CW, 520) has reviewed the state of our knowledge of the basic parameters: mass, luminosity, effective temperature and radius of M dwarfs. He concludes that much remains to be done to bring observational results and theoretical predictions into convergence. Inaccurate and inadequate opacity tables are one source of uncertainty in the computation of model atmospheres for FS; the lack of a full understanding of the chromospheric and coronal heating processes are another.

The publication by Allard & Hauschildt (ApJ 445, 433) of a grid of model atmospheres for a wide range of parameters encompassing M-dwarfs, as well as sub-dwarfs and brown dwarfs, represents a significant step forward. With the exception of the water bands, the models agree closely with the optical fluxes of M-dwarfs from the blue to the near infra-red.

Houdebine, following an earlier account (Irish AJ 20, 248) of his semi-empirical models of quiet and flaring atmospheres, has presented a series of papers which model the chromospheres of M-dwarfs (see Houdebine et al. A&A 289, 169; 289, 185; 294, 773; 302, 861; 305, 209). In these studies a modified version of the model atmosphere code MULTI has been used to fit the hydrogen fluxes and line profiles for AU Mic and other ms-dwarfs. A grid of model chromospheres has been presented based on constraints from quiet and active stars. These have been used to predict continuum ultraviolet fluxes which are then compared with observations. A review of this work has appeared (SSS, 547).

A semi-empirical model for the quiet atmosphere of AD Leo, which successfully fits the continuum and a number of photospheric and chromospheric lines, has been constructed by Mauas & Falchi (A&A 281, 129). This has been followed by an attempt to fit similar diagnostics during a flare on AD Leo. Differences between the models and observations are found for the Ca II K line in the quiet atmosphere and in the long wavelength continuum ($\lambda > 4500$ Å) during the flare. Lanzafame (A&A 302, 839) has computed models for the quiet chromosphere and lower transition region of FS based on the Si II, Mg II, Hα and Lyα lines.

13. Variability of T Tauri Stars (L. Hartmann & E. Gullbring)

T Tauri stars exhibit both periodic and highly irregular variations in brightness. The time scales of variability range from less than one hour to years, with amplitudes of a few percent to several magnitudes. These brightness fluctuations are thought to be caused by magnetic star spots modulating both the stellar photospheric emission and the mass accretion from the circumstellar disk, and by intrinsic variations in the disk accretion rate. Sorting between these two qualitatively different physical processes is not easy at present.

Most of the periodic brightness variations of T Tauri stars are believed to be produced by cool and/or hot spots on the rotating stellar surface (see for instance Simon et al. AJ 100, 1957, Bouvier et al. A&A 272, 176; 299, 891, Herbst et al. AJ 108, 190, Choi & Herbst AJ 111, 283). Typical amplitudes are V < 0.6 mag over time scales of 1 to 30 d. Starspot models matching the light curves indicate large cool spots, covering up to 50% of the stellar surface, with temperatures 500 to 2000 K below that of the stellar photosphere. The presence of cool spots is consistent with the expectation that the moderately rapidly-rotating T Tauri stars should exhibit strong magnetic activity. Models suggest that the hot spots have temperatures of up to 10000 K or more and cover less than a few percent of the stellar surface. The hot spots have so far only been observed on the classical T Tauri stars (CTTS) (e.g. Herbst et al. AJ 108, 1906) and are believed to originate from thermalized shock emission where magnetically channeled accretion flows hit the stellar surface (Bertout et al. ApJ 330, 350). The rotational periods of T Tauri stars inferred from periodic brightness variations show a bimodal distribution, with the so-called weak-emission T Tauri stars (WTTS) rotating faster than the CTTS (Bouvier et al. A&A 272, 176; 299, 89, Attridge et al. ApJ 398, L61, Choi & Herbst AJ 111, 283). The two distributions are centered at 3 and 8 d, respectively. A likely explanation for this is that the stellar rotation of the CTTS have slowed down due to magnetic breaking by magnetic field lines anchored in the disk, while this effect has been less severe for the WTTS (Camenzind Rev. Modern Astr. 3, 234, Königl ApJ 370, L39, Shu et al. ApJ 429, 781, Armitage & Clarke MN 280, 458, Ghosh MN 272, 763, Li ApJ 456, 696). It has also been speculated that differential rotation could explain the bimodal distribution (e.g. Smith A&A 287, 523) but the constant phase of the periodic brightness modulations (Choi & Herbst AJ 111, 283) and the shape of the photospheric line profiles (Johns-Krull A&A 306, 803) seem to violate that explanation. A few T Tauri stars show periodic or quasi-periodic brightness variations on time scales (months, but sometimes as short as days) and amplitudes (up to 3 mag in V) much larger than what is expected from stellar rotation. These variations are likely to be caused by obscuration of the central star by orbiting gas/dust clouds. The change in color during such brightness dips agrees well with that of an extinction law (Gahm et al. A&A 279, 477, Herbst et al. AJ 108, 1906 and references therein).

The origin of the irregular light fluctuations is not well known. Both magnetic activity at the stellar surface (e.g. Appenzeller & Dearborn ApJ 278, 689) and processes related to the accretion of material onto the central star have been discussed (see Gahm FF, 203 and references therein, Safier ApJ 444, 818). The time scales of these events range from less than one hour to years with amplitudes of $V < 0.05$, for the fast events, to several magnitudes in V, for the long term variations. Kuan (ApJ 210, 129) and Worden et al. (ApJ 244, 520) proposed that intensity variations over hours could be due to the superposition of a number of stellar flares of short time duration. However, analysis of time series of the classical T Tauri star BP Tau showed that irregular brightness variations on time scales as short as less than one hour probably are produced by inhomogeneous accretion (Gullbring A&A 287, 131, Gullbring et al. A&A 307, 791). There are, however, differences in the properties of the optical flares between WTTS and CTTS in that the events on the WTTS have shorter rise times and are hotter than those on the CTTS (Vrba et al. AJ 106, 1608, Gahm et al. A&A 301, 89). Thus, it seems that the irregular brightness variations of the WTTS are related to magnetic activity on the stellar surface, as for dMe flare stars, while variable accretion dominates the observed brightness variations in CTTS.

T Tauri stars have been known to exhibit X-ray emission of considerable and variable intensity since the pioneering observations with the Einstein Observatory X-ray mission (Montmerle et al. ApJ 269, 182, Walter et al. AJ 96, 297, Feigelson & Kriss ApJ 338, 262). A spectacular example of X-ray variability is the huge X-ray flare observed on LkHα 92 by Preibisch et al. (A&A 279, L33) with ROSAT. If the flare events are produced in magnetic loops, as is believed to be the case for UV Ceti flare stars, a correlation between the optical and X-ray brightness variations should be expected. Only a very limited number of X-ray observations of TTS have been carried out simultaneously with other wavelength regions. Feigelson et al. (ApJ 432, 373) observed V773 Tauri (a WTTS) in X-ray with ROSAT, ultraviolet, optical and radio simultaneously during $\sim$8 hours. During what could be the decline of a radio-flare the star was constant in all other observed spectral regions. Similarly, Gullbring, Barwig & Schmitt (A&A, in press) found no correlation between optical and X-ray variability in BP Tau over a period of five nights.

The emission lines of T Tauri stars are variable over a wide range of time scales (Basri MemSAI 61, 707, Giampapa et al. ApJS 89, 321, Guenther & Hessman A&A 268, 192; 276, L25, Gahm et al. A&A 301, 89, Johns & Basri ApJ 449, 341, AJ 109, 2800, Gullbring, Petrov et al. A&A, in press, Petrov et al. A&A, in press). The connection between the line and continuum variability of TTS is not well understood. Gahm et al. (A&A 301, 89) showed that the relation between the strength of the emission lines and the brightness level is different for different T Tauri stars, indicating that for some stars the line emission region is responsible for the brightness variations, while for other stars it is not. Johns & Basri (AJ 109, 2800) have performed extensive monitoring of the Balmer line profile variations for a number of T Tauri stars to search for periodic modulations of the profiles. They found that certain parts of the Balmer line profiles show periodic brightness variations and interpret that they arise both in a magnetosphere, inclined relative to the stellar rotational axes, and in a wind. Periodic modulations of the photospheric line profiles recently have been used to make surface (Doppler) imaging maps of T Tauri stars (Joncour et al. A&A 291, L19, Petrov et al. A&A, in press).

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