27. VARIABLE STARS (ETOILES VARIABLES)

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1. Introduction

The field of variable-star research is so broad that no report of this nature could possibly mention all the papers that have appeared in the last three years. It is hoped, however, that the reviews below include the most important work and identify the most significant trends. This report comprises ten sections on as many different research topics, each written by a different member of Commission 27. In addition there are (in Section 12) three short reports about ongoing activities of the commission. The commission president is very grateful to the authors of the individual contributions who have worked so conscientously.

A number of international conferences on one aspect or another of variable stars have been held during the period covered by this report. These are mentioned in the appropriate sections below.

There are two very active and important fields on which one might expect to find reports here, but which are mentioned only incidentally. The first is the subject of *Catacylsmic Variables*. An impressive amount of work, both observational and theoretical, has been done on these fascinating objects in the last few years, and there have been a number of major conferences and review articles. The topic is reviewed in the report of Commission 42 (Close Binary Stars), and in order to avoid duplication is not covered here.

The second important omission is *Solar Oscillations*. It is by now clear that the Sun belongs to the ranks of variable stars, and the study of solar oscillations has become a very active field. From the theoretical side stellar and solar oscillations now constitute a single field of research. Since the discovery of stellar variations similar to the solar five-minute oscillations, the essential unity of stellar and solar oscillation phenomena is becoming obvious from the observational viewpoint as well. Variable-star astronomers should be aware of the opportunities now arising in this type of research. Observational work on solar oscillations is discussed in the contribution of T. Duvall to the Report of Commission 12 (Radiation and Structure of the Solar Atmosphere). The theoretical side of the subject is covered by J. Christensen-Dalsgaard in the Report of Commission 35 (Stellar Constitution).

In the following a uniform and very terse style has been adopted for citations to the literature. Volume numbers appear in bold face, other numbers are page numbers unless otherwise identified. In general the abbreviations used in *Astronomy and Astrophysics Abstracts (AAA)* have been used. Frequently-cited journals, however, have been given very succinct designations: these are identified by their *AAA* abbreviations in the following key.

AA	*Astron. Astrophys.*
AA Supp	*Astron. Astrophys., Suppl. Ser.*
AJ	*Astron. J.*
AN	*Astron. Nachr.*
Ann Rev AA	*Annu. Rev. Astron. Astrophys.*
ApJ	*Astrophys. J.*
ApJ Lett	*Astrophys. J., Lett. Ed.*
ApJ Supp	*Astrophys. J., Suppl. Ser.*
Ap Sp Sc	*Astrophys. Space Sci.*

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BAAS	*Bull. Am. Astron. Soc.*
Bull Ast Soc India	*Bull. Astron. Soc. India*
Bull Crimean Ap Obs	*Bull. Crimean Astrophys. Obs.*
DAO Publ	*Publ. Dom. Astrophys. Obs.*
IAU Coll 00	*Proc. IAU Colloquium No. 00*
IAU Symp 00	*Proc. IAU Symposium No. 00*
IBVS	*Inf. Bull. Variable Stars*
JAAVSO	*J. Am. Assoc. Variable Star Obs.*
J Ap Ast India	*J. Astrophys. Astron.*
JRAS Can	*J. R. Astron. Soc. Canada*
MN	*Mon. Not. R. Astron. Soc.*
MVS	*Mitt. Veränderliche Sterne*
Obs	*Observatory*
PASP	*Publ. Astron. Soc. Pac.*
Per Zv	*Perem. Zvezdy*
Per Zv Supp	*Perem. Zvezdy, Prilozh.*
Rev Mex AA	*Rev. Mex. Astron. Astrofis.*
SAAO Circ	*S. Afr. Astron. Obs., Circ.*
SAO Spec Rep	*Smithson. Astrophys. Obs., Spec. Rep.*
Sov Ast	*Sov. Astron.*
Sov Ast Lett	*Sov. Astron. Lett.*

2. T Tauri Stars
(Martin Cohen)

An unusual amount of attention has been directed toward the T Tauri stars (TTS) since the previous Commission 27 report. This is demonstrated by the number of major reviews of TTS, or of Herbig-Haro (HH) objects, that have appeared recently, by Bertout (*Rep Prog Phys* **47**, No2), Schwartz (*Ann Rev AA* **21**,209), Cohen (*Phys Rep*, in press).

The primary foci of recent studies of the TTS have been attempts to define the geometry of circumstellar shells; major observational efforts with the VLA at centimeter wavelengths; progress in theoretical modelling of their chromospheres and outer atmospheres; the recognition of highly variable phenomena in all spectral regions; the likelihood that episodic and anisotropic mass loss characterizes at least the most active (youngest?) TTS; and the potential relationship between TTS and the exciting stars of HH nebulae.

Several of these recently developed areas bear upon the geometry of the circumstellar envelopes of TTS, particularly the prospects for disks, and the likely nature of the dusty component. Bastien's (*AA Supp* **48**,153,513) major optical polarimetric survey of the TTS showed the rarity of high degrees of visible polarization, and highlighted the importance of the outstandingly polarized stars (e.g., HL Tau and DG Tau, with 13% and 6%, respectively). Both Bastien and Hough *et al* (*MN*, in press) noted a correlation between near-infrared color indices and visual polarization, which they interpreted as a consequence of flattened dust shells. Hough *et al* (*MN* **195**,429) saw evidence specifically for the presence of silicate particles in asymmetric shells, on the basis of the p(λ) curves which they extended as far as 2.2 and sometimes 3.5 μm. From 8-13 μm spectrophotometric surveys of almost 50 young stars, Cohen (*MN* **191**,499) and Cohen and Witteborn (*ApJ*, in press) concluded that silicate materials are definitely found around TTS. They felt that the circumstellar envelopes are likely to be disklike rather than spherical in order to explain the correlations between silicate optical depth and visual extinction, near-infrared color indices, and optical polarization, as well as the infrequency of absorption, as opposed to emission, features. Cohen (*ApJ Lett* **269**,L70) has interpreted the unique properties of HL Tau in terms of our viewing this star through an edge-on circumstellar dust disk. Likewise, DG Tau has shown a resolved biconical radio continuum emitting zone (Bieging, Cohen, & Schwartz *ApJ* **282**,699) with "waist" oriented in the plane of

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the electric vector of polarization. Rydgren & Cohen (*Protostars and Planets II*, Univ Ariz Press, in press) too have discussed all the diverse observations that are relevant to the dust geometry in TTS and have decided in favor of disklike dust distributions.

It is possible that some of the circumstellar dust grains around TTS either were created in the stellar winds or at least represent thermally-modified prestellar grains. Certainly there are grains present with temperatures rather close to the condensation temperature for silicates (Rydgren, Schmelz, & Vrba *ApJ* **256**,168). These silicates seem to be more crystalline than typical interstellar silicates and their optical depths may correlate with wind activity in the TTS (Cohen & Witteborn, *ApJ*, in press). Variable CaII absorption features toward some TTS could also represent the condensation of gas into grains, locking up Ca atoms; these same data strengthen the case for episodic rather than continuous mass loss from TTS (Bertout *et al*, *AA Supp* **47**,419; Mundt *ApJ* **280**,749).

Centimetric radio emission, detected with interferometers which yield very high spatial resolution, characterizes some TTS (Felli *et al*, *AA* **107**,354; Bertout & Thum *AA* **107**,368; Cohen, Bieging, & Schwartz *ApJ* **253**,707), although an unbiased, luminosity-limited survey at 6 cm of the nearby Taurus-Auriga complex suggests that it is extremely rare to detect typical, older TTS, as opposed to those vigorous, young stars that excite HH objects (Bieging, Cohen, & Schwartz, *ApJ* **282**,699). The nature and origin of the radio emission is rather unclear. A variety of spectral indices is seen, from definitely non-thermal ($\propto \nu^{-0.4}$) through very flat spectra, to steeply rising ones ($\propto \nu^{1}$). The surprising radio strength of V410 Tau, a fast rotator, its recently-discovered strong radio variability and the flat spectrum in the off-state but steep spectrum in the on-state (Bieging & Cohen, *Proc. Boulder Worshop on "Radio Stars"*, D. Reidel, in press) suggest a possible kinship with the flarelike activity seen in RS CVn stars. T Tau itself was found to be a double source at 6 cm, with some 100 AU projected separation (Cohen, Bieging, & Schwartz *ApJ* **253**,707), which prompted a very accurate redetermination of its optical position (De Vegt *AA* **109**,45; Hanson, Jones, & Lin *ApJ Lett* **270**,L27). This probable binarity was also seen in the near-infrared, using the speckle technique in declination (Dyck, Simon, & Zuckerman *ApJ Lett* **255**, L103). It is the optically unknown companion that contributes the dominant radio emission, which has been attributed variously, either to an outflow from a very young, low-mass object, or to accretion onto a protostar (Bertout *AA* **126**,L1) or perhaps even onto a giant protoplanet (Hanson *et al*, *ApJ Lett* **270**,L27). These observations are a disturbing reminder of how little we understand even the prototype, and it raises again the rather puzzling issue of the paucity of known binaries among these young stars.

Theoretical progress in understanding the chromospheres of TTS has been discussed in detail by Bertout (*Rep Prog Phys* **47**, No2), summarized by Calvet (*Rev Mex AA* **7**,169). Recently Calvet, Basri, & Kuhi (*ApJ* **277**,725) have studied, semi-empirically, the effects of chromospheric temperature structure on diagnostic spectral features. A very detailed model of the physical and excitational conditions in the outer atmosphere of T Tau itself has been presented by Brown *et al* (*Nature* **290**,34) and by Brown, Ferraz, & Jordan (*MN* **207**,831), who propose a two-component atmosphere: one to yield the X-ray emission, the other the mass loss. Bertout (*Proc 3rd Eur IUE Conf*, 89) favors a second transition zone too, between the wind and the circumstellar medium. Ulrich *et al* (*ApJ* **267**,199) have advanced a model for DR Tau in which the 3200-11000 Å energy distribution is modelled by emission from an optically thin, very hot (65,000 K) gas. This they term a "turbosphere". It is powered by turbulence dissipated by shocks generated by the accretion of cometary-sized clumps onto the star.

Variability of the TTS is legion. Of late, rapid behavior has been detected in the ultraviolet, where an ensemble of solar-type flare events may be responsible (Worden *et al*, *ApJ* **244**,520), and in the optical, for example in RW Aur (Mundt & Giampapa *ApJ* **256**,156). In the X-ray region, a dramatic individual flare event was seen in its entirety in AS 205 (Walter & Kuhi *ApJ*, in press). Repeated flaring of several pre-main-sequence stars in ρ Oph, with a power-law dependence

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of frequency of occurrence on amplitude strongly reminiscent of solar flares, has been described by Montmerle *et al* (*ApJ* **269**,182). Longer-term optical monitoring (Herbst, Holtzman & Klasky *AJ* **88**,1648) has also been fruitful, especially for CO Ori (and UX Ori) which showed occasional "aperiodic minima", incompatible with mere variable circumstellar obscuration. Most bizarre has been the singular behavior of SY Cha (Schaefer *ApJ Lett* **266**,L45) which underwent periodic (∿6 days), large-amplitude optical variations for 3 years, after which it reverted to its former, low amplitude, irregular variability. If this were caused by a giant, bright starspot, modulated by stellar rotation, then the stability and longevity of this putative spot would be truly remarkable. Given this general framework, it is not surprising to find radio variability (see Cohen *Phys Rep*, in press) and X-ray variability of TTS.

The phenomenon of anisotropic mass loss from TTS (Cohen *PASP* **94**,266) has also been addressed by Jankovics, Appenzeller, & Krauter (*PASP* **95**,883), who found a strong tendency for forbidden emission lines in some TTS to be blue-shifted relative to the stars. If these lines represented an interaction between a bipolar stellar outflow and the ambient medium, then the red-shifted lines might be hidden by an extended circumstellar dust disk (Appenzeller *Rev Mex AA* **7**,151). Microwave CO emission provides a ready probe of the existence of systematic, high-velocity outflows from TTS, for example, that near T Tau itself (Kutner *et al*, *ApJ Lett* **259**,L35). These high-velocity wings to the cloud CO line profiles also occur toward other TTS (Edwards & Snell *ApJ* **261**,151; Calvet, Canto, & Rodriguez *ApJ* **268**,739). However, it is important to recognize that these bipolar molecular flows characterize primarily those TTS associated with HH nebulae (e.g., Edwards & Snell *ApJ* **281**,237), rather than isolated stars, a point little-noted in the literature.

It is important to understand the generic relationship, if any, between stars that excite HH objects and typical TTS. From near- and airborne far-infrared studies, Cohen and his colleagues (*ApJ* **265**,877;**278**,671;**281**,250) have discovered a number of optically invisible HH-exciting stars with rather low (<100 $L_{\odot}$) bolometric luminosities (except for the much more luminous R Mon, at around 800 $L_{\odot}$). These stars have been identified as extremely early (<10^5 yr) precursors of visible TTS (Cohen *Rev Mex AA* **7**,241), whose mass loss is highly non-spherical and which sometimes possess substantial dust disks (e.g., Cohen *Phys Rep*, in press). These same objects are sometimes associated with well-collimated radio and optical emission "jets" (Cohen, Bieging, & Schwartz *ApJ* **253**,707; Bieging & Cohen, *ApJ Lett*, in press; Mundt & Fried, *ApJ Lett* **274**,L83), and at least one (L1551IRS5) may be a binary (Bieging & Cohen, *ApJ Lett*, in press).

Along more global, evolutionary lines, Appenzeller, Jankovics, & Krautter (*AA Supp* **53**,291) have presented low-resolution optical spectroscopy for 60 southern TTS, in Cha and in Lup, sufficient to permit spectral classification. These were supplemented with a number of medium-resolution spectra and with near-infrared photometry for 28 stars. Their spectra are displayed, and classified, in the identical format and by the same criteria as in the massive Cohen-Kuhi sample (*ApJ Supp* **41**,743), although HR diagrams were not constructed. Stahler (*ApJ* **274**,822) has investigated when TTS first become visible objects [extending the earlier spherical protostellar collapse calculations by Stahler, Shu, & Taam (*ApJ* **241**,637;**242**,226) to other masses]. He found a remarkable coincidence between the "birthline" - the locus in the HR diagram along which stars of different mass first become visible - and the upper envelope of all the TTS observed by Cohen and Kuhi. Previously determined ages for the youngest stars (∿10^5 yr), based on isochrones, were underestimated and should be augmented by the duration of the accretion phase (about 10^5 yr for a 1 $M_{\odot}$ star). One would expect to find a large population in dark clouds of objects with similar, but less extreme, properties to the TTS, representing the "post-T Tauri" phase of evolution. The bulk of this group is yet unknown, although the optical characteristics of a few serendipitous X-ray sources suggest their post-TTS nature (Mundt *et al*, *ApJ* **269**,229). These may differ from the TTS principally because they lack extensive circumstellar envelopes (Walter & Mundt *Rev Mex AA* **7**,195), which may have been dissipated at the end of the true TTS phase (Walter *Rev Mex AA* **7**,196). However, there remains confusion as to the distinction between weak-lines TTS and post-TTS; perhaps some low-mass stars can entirely bypass the T Tauri phase?

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

INTRODUCTION

This report contains selected highlights in the study of early-type (primarily pulsating) variable stars, mid-1981 to mid-1984. The reader should consult *Astronomy and Astrophysics Abstracts* for a more complete bibliography.

The following reviews and conference proceedings have recently been published: *Workshop on Pulsating B Stars*, ed. Auvergne *et al* (Obs de Nice, 1981), *IAU Symposium 98* on "Be Stars", Jaschek & Groth, eds (D Reidel 1982), "Rapid Variability of Early-Type Stars", Harmanec & Pavlovski, eds (*Hvar Obs Bull* **7**,1) and *B Stars with and without emission lines*, Underhill & Doazan, eds (NASA SP-456 & 457, 1982). A conference on "The Origin of Non-radiative Heating and Momentum in Hot Stars", with several papers relevant to variability, was held at NASA Goddard Space Flight Center in 1984. A comprehensive review of the photometric variability of Be stars was published by Harmanec (in *Advances in Photoelectric Photometry*, Wolpert and Genet, eds, Fairborn Obs 1983).

CLASSICAL β CEP STARS

Searches continued, both in the field (Sterken & Jerzykiewicz *Acta Astr* **33**,89) and in clusters: NGC 3293 (Balona & Engelbrecht *MN* **202**,293.; Shobbrook *MN* **205**,1215) and NGC 6231 (Balona *MN* **203**,1041; Balona & Shobbrook *MN* **205**,309). In NGC 6231, β Cep stars have been found near the main sequence. Early-type variables are also being discovered through surveys such as the UBV photometric campaign on bright Be stars co-ordinated by Harmanec and colleagues, and the ESO southern survey co-ordinated by Sterken.

An indirect result of the study of β Cep stars in clusters is the conclusion (supported by other studies) that the absolute magnitudes of early B stars are 0.6 magnitude fainter than previously thought. The new absolute magnitudes for β Cep stars lead to the conclusion that most of them pulsate in the fundamental radial mode. In 16 Lac, this conclusion is independently reached using the mass and radius derived from the spectroscopic-eclipsing binary nature of the star (Garrido *et al*, *AA* **122**,193).

Waelkins & Rufener, *AA* **121**,45 have noted a deficiency of β Cep stars in *close* binary systems. Agrawal *et al* (*MN* **208**,845) have studied the X-ray emission from β Cep stars, and found it to be normal for stars of their luminosity. Percy (*JRAS Can*, **78**,241) has emphasized the continuing need to confirm the variability and properties of suspected β Cep stars. The value of intensive, co-ordinated observations of early-type variables has also been stressed and demonstrated.

INDIVIDUAL OBJECTS

Published observations of β Cru and ν Eri by van Hoof have been reanalyzed by Cuypers (*AA* **127**,186) and Cuypers & Goossens (*AA Supp* **45**,487) respectively, using more effective period determination techniques. The interpretation of BW Vul, the largest-amplitude β Cep star, is further complicated by the discovery of cyclic (O-C) variations, ascribed to a binary companion or a second pulsation mode (Odell *PASP* **96**,657). In β Cen, an unusual phase relation between light and radial velocity has been noted (Kubiak & Seggewiss *Acta Astron* **32**,371). The amplitudes of some of the pulsation modes in 16 Lac have decreased considerably (Garrido *et al*, *AA* **122**,193; Le Contel *et al*, *AA* **118**,294). Waelkins & Rufener (*AA* **119**,279) have discovered a β Cep star at a moderately high galactic latitude. The 6.02 (or 12.04) day variability in the UV spectrum of β Cep remains unexplained (Fischel & Sparks in *The Universe at UV Wavelengths*, Chapman, ed,

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NASA CP-2171, Goddard Sp Fl Cent, 1981, p 217; Fahey *et al* in *Advances in UV Astronomy*, Kondo, Mead, & Chapman, eds, NASA CP-2238, Goddard Sp Fl Cent, 1982, p 442).

LINE PROFILE VARIATIONS IN EARLY-TYPE STARS

Line Profile variations have been observed in the spectra of OB stars with a variety of temperatures, luminosities and rotational velocities. These have generally been ascribed to non-radial pulsation, though in some cases, it is not possible to rule out other interpretations. The observations require high signal-to-noise ratios, and good wavelength and time resolution, and have therefore been made at only a few suitably-equipped observatories. Photometric variations have been observed in some of these same kinds of stars, but progress in understanding the relation between the two forms of variability has been hampered by the lack of extensive simulataneous spectroscopic and photometric observations of the same stars. Statistics of the occurrence of these variations are also incomplete, because the stars which have been observed have not always been chosen in unbiased fashion. The time scales of the variations (generally 0.3 to 2 days) create a practical problem which can best be solved by contemporaneous observations from different longitudes. Successful spectroscopic-photometric campaigns on ε Per and several Be stars have recently been carried out.

Line profile variations were first studied intensively in several sharp-lined OB stars, notably 53 Per (Smith *ApJ* **215**,574; Smith *et al, ApJ* **282**,226), and were attributed to low-order prograde non-radial pulsations. The technical feasibility of observing similar variations in broad-lined stars was not fully appreciated at the time, but variations have now been observed in the lines of moderately-rotating B stars such as ε Per (Penrod, 1984 priv comm; Smith *ApJ* **288**, in press), η Lep, δ Sco and α Vir (Walker *et al, PASP* **94**,143; Smith 1984 preprint), early-type supergiants such as γ Ara and θ Ara (Baade *AA* **124**,211; Baade & Ferlet, *AA* **140**,72), rapidly-rotating Be stars such as 28 CMa (Baade *AA*, **105**,65), η Cen (Baade *AA* **124**,283), μ Cen (Baade *AA* **135**,101), λ Eri (Bolton in *Be Stars*), EM Cep (Hilditch *et al, MN* **200**,1153) and others (Baade *AA* **134**,105), and Oe stars, notably ζ Oph (Vogt & Penrod *ApJ* **275**,661). These line profile variations have been ascribed to low, medium and high-order non-radial modes (often present at the same time); these are primarily retrograde in the rapidly-rotating stars. The variations are often complex, and variable with time, and it is premature to try to discuss their nature in this brief report. Several groups, particularly those of Baade, Bolton, Harmanec, Penrod, Smith & Walker, are presently active in this area.

Photometric variations have been observed in stars of these same kinds: 53 Per (Smith *et al, ApJ* **282**,226) and similar stars (Burki *AA* **121**,211; Waelkins & Rufener *AA Supp* **52**,21), Bn stars (Jerzykiewicz & Sterken in *Workshop on Pulsating B Stars*, Auvergne *et al*, eds, Obs de Nice 1981), B supergiants (most recently by Percy & Welch *PASP* **95**,491, and in numerous Be stars [see Percy (*IAU Working Group on Be Stars*, *Newsletter* No 6,8) for a reasonably complete list]. In some Be stars such as LQ And (Percy *AJ* **88**,427), the photometric variations are stable, but in others, they change with time, often in a complex way. For instance, Baade (*AA* **110**,L15) found no significant photometric variations in 28 CMa at the period of the line profile variations (1.37 days), but he found small variations at 0.435 day. Later, Stagg (1984 preprint) found larger, significant variations at both of these periods. Harmanec (*IBVS* 2506) found a permanent spectroscopic and photometric period of 1.57 days in o And, but the amplitude varies with time. A spectroscopic-photometric campaign on o And and four similar Be stars has revealed a wealth of interesting (but as yet incompletely-understood) behavior. Stagg has completed a major survey of rapid photometric variability in bright southern Be stars.

In some of these Be and Oe stars, changes in line profile and photometric variations appear to be related to emission episodes, notably in λ Eri (Bolton in *Be Stars*, D Reidel; Penrod, 1984 priv comm) and ζ Oph (Vogt & Penrod *ApJ*

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275,661). A possibly similar phenomenon has been observed in the B supergiant ρ Leo (Smith & Ebbets *ApJ* **247**,158). The search for such a relation is hampered by the lack of long-term systematic spectroscopic (and photometric) observations.

The relation between pulsation and mass loss in stars in general has been discussed by Willson & Bowen (*Nature* **314**,429). In early-type stars, the pioneering work of Smith and McCall, who observed a "bouncing shell" phenomenon in many β Cep stars and who proposed that a small fraction of the shell is lost to the star in each bounce, has been followed by studies by Burger *et al* (*AA* **107**,320; *AA* **109**,289) and Le Contel and Morel (*AA* **107**,406), which suggest that matter is being ejected from the (radially-pulsating) β Cep stars. A detailed study of shell ejection in non-radially pulsating stars has not yet been pursued, but Smith (*ApJ* **288**, in press) and Penrod (1984 priv comm) have both noted that the non-radial pulsations observed in stars such as ε Per are primarily radially-directed, and frequently approach supersonic velocities.

Narrow components have recently been observed in the UV spectra of several early-type stars including ε Per (Henrichs *et al*, *ApJ* **268**,807; Gry *et al*, *AA* **137**,29), and have been ascribed to discrete "puffs" of material ejected from the stars into the circumstellar environment - perhaps driven by pulsation. For a different interpretation, however, see Howarth (*MN* **206**, 625).

THEORETICAL STUDIES

A picture is emerging in which non-radial pulsation is found in a wide assortment of early-type stars, and radial pulsation is found only in a very restricted group - the classical β Cep stars. The cause of pulsation is still unknown. Stellingwerf's (*AJ* **83**,1184) ionization-zone mechanism, subsequently discussed by Lee & Osaki (*PAS Japan* **34**,39) certainly contributed to destabilization in a narrow region of the H-R diagram. To produce more widespread destabilization, Osaki's (*ApJ* **189**,469) convection-rotation-pulsation mechanism remains an interesting and viable one. Several recent studies have dealt specifically with the interaction of rotation and pulsation (Ando *MN* **197**,1139; *PAS Japan* **35**,343; Carroll & Hansen *ApJ* **263**,352; Cox *PASP* **96**,577), and this appears to be a promising direction for study. There is serious need to bring interested theoreticians and observers of all kinds together, to begin to make sense of the rapidly-accumulating mass of data. Other interesting developments include the discovery of a possible relation between pulsation and tidal-rotational effects in Vir (Smith 1984 preprint) and the studies of supergiant pulsation by Lovy *et al* (*AA* **133**,307) and de Jager (*AA* **138**, 246).

MISCELLANEOUS STUDIES OF OTHER EARLY-TYPE VARIABLES

The ultra-short-period B type variables originally proposed by Jakate appear not to exist (Balona *IBVS* 2120; Shaw *et al*, *IBVS* 2288). The mid-B to early A type "Maia variables" remain hypothetical (as Struve called them), but they may possibly be very elusive non-radial pulsators. Pulsations have been discovered and studied in a variety of degenerate stars, most recently the DB white dwarfs, driven by ionziation zones of helium, and the very hot "PG 1159-035 stars", driven by ionization zones of heavier elements. Studies of the pulsating helium star BD+13°3229 continue to serve as a useful probe of its structure and evolution (Hill *et al*, *MN* **197**,81). There is some evidence for pulsations in Wolf-Rayet stars, with a time scale of 0.5 day (Vreux, 1984 preprint). Observational (e.g. Humphreys & Davidson *Science* **223**,243) and theoretical (e.g. Stothers & Chin *ApJ* **264**,583; de Jager *AA* **138**,246) studies of S Dor (Hubble-Sandage) variables suggest that these are luminous early-type stars which, due to hydrodynamic instabilities, are undergoing extensive mass loss. Long-term monitoring of bright Be stars is being carried out in a systematic way, spectroscopically by Barker, Shore and others, and photometrically by Harmanec and his colleagues and collaborators. Progress and results from these campaigns are reported regularly in the *Newsletter* of the IAU Working Group on Be Stars. See papers by Doazan *et al* (*AA* **115**,138; *AA Supp* **50**,481; *AA* **128**,171), Horn *et al* (*Bull Astron Inst Czechoslovakia* **33**,308) and Harmanec *et al* (*IBVS* 2447) for representative

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results. Magnetic fields have been observed in a number of Bp stars (Borra *et al, ApJ Supp* **53**,151) and an oblique magnetic rotator model for these stars has been developed (Shore & Bolton, 1982 preprint; Bolton *Hvar Obs Bull* **7**,1).

4. Cepheids
(J.D. Fernie)

INTRODUCTION

The following survey of the cepheid literature covers approximately the period August 1981 to September 1984. It omits most theoretical topics since these are covered elsewhere in the Commission 27 Report, and, in the interests of space, it also omits what in my judgement are minor investigations of a routine nature, e.g. a few observations of an already well-observed star.

IAU Colloquium 82 on *Cepheids: Observation and Theory* was held in May 1984. Its proceedings, edited by B.F. Madore and published by Cambridge University Press, should appear in early 1985. In it will be found major review articles and contributed papers that expand on many topics which necessarily receive only very brief mention here.

Each subsection below starts with a listing of papers followed by a short commentary in which I have tried to summarize the advances in that area over the past three years.

SURVEYS

Caldwell & Coulson (*So Afr Ast Obs Circ* No 8,1); Dean (*MN* **197**,779), Diethelm (*AA* **124**,108); Diethelm & Tammann (*AA Supp* **47**,335); Eggen (*AJ* **88**,361,998); Gieren (*ApJ* **260**,208; *ApJ Supp* **46**,287;**47**,315); Harris (*AJ* **86**,1192;**88**,507); Kwee & Diethelm (*AA Supp* **55**,77); Moffett & Barnes (*ApJ Supp* **55**,389); Serrano (*Rev Mex AA* **8**,131); van Genderen (*AA Supp* **52**,423); Wayman, Stift, & Butler (*AA Supp* **56**,169); Welch *et al* (*ApJ Suppl* **54**,547).

The period has been marked by the production of much new and generally high-precision data for cepheids. Notable among such work is the BVRI photometry of Moffett and Barnes for northern cepheids, similar data (with radial velocities) from Gieren for southern cepheids, and the work of Caldwell & Coulson, Dean, Harris, van Genderen, and Wayman *et al* mainly on Magellanic Cloud cepheids. New ground was broken by Welch *et al* in providing JHK photometry for many Galactic cepheids, by Dean in providing DDO photometry, and by Harris in providing Washington system photometry. Most of the remaining papers, notably those of Eggen and Diethelm were concerned with the photometric properties and classification of cepheids.

NEWLY-DISCOVERED CEPHEIDS

Balona (*MN* **201**,105); Berthold (*IBVS* 2192); Eggen (*IBVS* 2106 & 2331, *AJ* **88**,379).

There seems to have been relatively little activity in this area; in particular, I am unaware of any searches (other than perhaps Balona's) specifically aimed at discovering new cepheids.

THE P-L-C RELATION

Caldwell (*Obs* **103**,244); Clube & Dawe (*AA* **122**,255); Eggen (*AJ* **88**,386); Fernie & McGonegal (*ApJ* **275**,732); Gieren (*ApJ* **282**,650); Ivanov (*Ap Sp Sc* **79**,107); Ivanov & Nikolov (*Ap Sp Sc* **94**,191); Karimova & Pavlovskaya (*Sov Ast* **25**,56); Madore (*ApJ* **253**,575); McAlary *et al* (*ApJ* **273**,539); McAlary, Madore, & Davis (*ApJ* **276**,487); McGonegal *et al* (*ApJ Lett* **257**,L33;*ApJ* **269**,641); Opolski & Ciuria (*IBVS* 2528); Stift (*AA* **112**,149); Stothers (*ApJ* **274**,20); van Genderen (*AA* **124**,223); Wayman, Stift, & Butler (*AA Supp* **56**,169); Zsoldos (*AN* **305**,33).

A number of problems and controversies continue to plague the calibration (indeed the form) of the P-L-C. The value of the coefficient multiplying (B-V) continues to be debated. While most workers still accept a value of about 2.7,

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others such as Madore and Opolski & Ciurla arrive at values of up to 6. At the other extreme Stift, Clube, & Dawe, and Wayman *et al* have argued strenuously that there is no real color term at all and that discussion should be conducted in terms of the P-L relation alone. The purely observational aspects are unclear; Fernie & McGonegal were unable to find any color term from twenty-seven Galactic cepheids in clusters and associations, but earlier work by Martin *et al* on LMC cepheids definitely indicated the presence of a color term in the P-L-C.

While there is now relatively little argument over the slope of the P-L relation, its zero-point may still be uncertain by as much as half-a-magnitude. A series of four-color investigations by Schmidt on clusters containing cepheids suggests the previously determined moduli were too large by up to 0.5 mag, requiring a concomitant lowering of cepheid luminosities by this amount. This result has received some support from the application to cepheid clusters of a new β-index/M_V calibration by Balona & Shobbrook, using, however, Schmidt's measurements of β. Balona & Shobbrook caution that even a small systematic error in the observed β could lead to significant changes in distance moduli. Reduced cepheid luminosities lead to aggravation of difficulties in reconciling pulsation and evolutionary masses of cepheids, not to mention, of course, the implications for the distance scale of the universe. The verification of Schmidt's results is therefore of fundamental importance.

INDIVIDUAL CEPHEIDS IN CLUSTERS AND ASSOCIATIONS

Eggen (*AJ* **88**,197,379, *ApJ Supp* **50**,199); Fitzgerald & Miller (*PASP* **95**,361); Forbes (*AJ* **87**,1022); Hodge & Lee (*ApJ* **276**,509); Schmidt (*AJ* **88**,104); Turner (*AJ* **88**,650, *JRAS Can* **77**,31, *PASP* **94**,422,655,1003); Turner & Evans (*ApJ* **283**,254); van den Bergh, Brosterhus, & Alcaino (*ApJ Supp* **50**,529); van den Bergh & Brosterhus (*ApJ Supp* **53**,765).

Systematic searches for new cases of cepheids in clusters or associations, notably the searches of van den Bergh and collaborators, have been generally unsuccessful, but more or less accidental discoveries by Eggen and Turner have revealed a number of new possible cases. Forbes' discovery that GY Sge is a member of an association is of particular importance because of the long (51 days) period of that star.

CEPHEID BINARIES

Balona (*Obs* **103**,163); Coulson (*MN* **203**,925;**205**,1135); Eichendorf *et al* (*AA* **109**,274); Evans (*ApJ* **272**,214;**281**,760), Gieren (*ApJ Supp* **49**,1); Harris, Olszewski, & Wallerstein (*AJ* **89**,119), Lloyd Evans (*MN* **199**,925, *Obs* **104**,26); McNamara & Feltz (*IAU Coll 59*,389); Russo, Sollazzo, & Coppola (*AA* **102**,20); van Genderen (*AA* **100**,175).

Most of these papers deal with individual cases, although Lloyd Evans, Gieren, and Russo *et al* present the results of surveys. Lloyd Evans found 18% of the cepheids he surveyed are cepheids, based on radial velocity data, while Russo *et al* found a 25% rate from VBLUW photometry. Gieren's results supported a binary rate in the range of 20% - 40%.

Individual cases of particular interest included Evans' discovery from IUE data that X Cyg is not a binary despite several other indicators to the contrary, and the work of Harris, Olszewski, & Wallerstein on AU Peg, a Pop II cepheid which appears to have a compact object as companion and to have undergone a fairly traumatic evolution.

COLOR AND REDDENING SCALES

Coppola, Russo, & Sollazzo (*Ap Sp Sc* **86**,157); Harris (*AJ* **86**,1192); Madore (*ApJ* **253**,575); van Genderen (*AA* **119**,192).

Activity in this area of interstellar reddening corrections to cepheid colors has been surprisingly low compared to earlier but still recent years. The Coppola, Russo, & Sollazzo paper appears to be the only one to address Galactic cepheids, the other three being concerned with Magellanic Cloud cepheids.

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ATMOSPHERES AND CHEMICAL COMPOSITION

Becker & Cox (*ApJ* **260**,707); Benz & Mayor (*AA* **111**,224); Böhm-Vitense & Parsons (*ApJ* **266**,171); Boyarchuk (*Bull Crimean Ap Obs* **64**,1); Giridhar (*J Ap Ast India* **4**,75); Harris (*AJ* **86**,1192;**88**,507); Harris, Olszewski, & Wallerstein (*AJ* **89**,119); Harris & Pilachowski (*ApJ* **282**,655); Henden, Cornett, & Schmidt (*PASP* **96**,310); Rautela & Joshi (*J Ap Ast India* **4**,1); Schmidt & Parsons (*ApJ* **279**,202,215, *ApJ Supp* **48**,185); Wallerstein (*PASP* **95**,422).

Abundance studies, both spectroscopic and photometric, have shown that in general Galactic cepheids have metallicities within about 0.3 of the sun's value, the true range probably being less than this. There is, however, a discernible decline in metallicity with increasing galactocentric distance that is in reasonable agreement with that found from other objects. Likewise, photometric abundances found for cepheids in the Magellanic Clouds are in good agreement with those determined from other sources.

Schmidt & Parsons have used IUE data to study chromospheric emission in cepheids, which they find to be strongly dependent on period and with mean flux levels if anything somewhat lower than in similar non-variable stars. The multimode cepheid, TU CAS, shows no chromospheric emission, which is consistent with other short-period cepheids. Böhm-Vitense & Parsons report an unsuccessful search for X-ray emission from cepheids.

MASSES AND RADII

Burki (*AA* **133**,185), Coppola, Russo, & Sollazzo (*Ap Sp Sc* **86**,157); Evans (*ApJ* **272**,214); Fernie (*ApJ* **282**,641); Gieren (*ApJ* **260**,208; *PASP* **94**,960); Imbert (*AA Supp* **53**,85); Ivanov (*Ap Sp Sc* **79**,107); Magee, Merts, & Huebner (*ApJ* **283**,264); Russo (*Ap Sp Sc* **90**,147); Simon (*ApJ Lett* **260**,L87).

The problem of the cepheid mass anomaly is not yet resolved to everyone's satisfaction, and may have worsened if Schmidt's new distance scale based on cluster cepheids is upheld. An interesting suggestion by Simon that the problem may be caused by incorrect opacities in theoretical models was rejected by Magee, Merts, & Huebner.

The determination of cepheid radii also continues to present problems. A major survey by Fernie has revealed serious discrepancies between theoretical radii and those deduced from luminosities and temperatures for long-period cepheids in clusters and associations, as well as discrepancies between both these and other methods. No solution to the problem is presently apparent.

DOUBLE-MODE CEPHEIDS

Aikawa (*MN* **204**,1193); Antonello & Mantegazza (*AA* **133**,52 & *IBVS* 2411); Balona (*Obs* **103**,163); Barrell (*MN* **196**,357;**200**,127;**200**,139;**204**,1); Fuhrmann & Schult (*IBVS* 2456); Mantegazza (*AA* **118**,321).

Barrell has made a specific search for new cases of double-mode cepheids without finding any. The only recent new case is that of CO Aur, proposed by Antonello & Mantegazza. It does, however, have unusual properties, and although Fuhrmann & Schult have announced confirmation, Balona has queried whether any period other than the fundamental really exists.

Other work by Barrell continues to show the double-mode cepheids as being no different in all other properties from single-mode cepheids, with the possible exception of Hα emission, which remains to be checked. The main challenges of double mode cepheids remain the reconciliation of their theoretical masses with evolutionary masses, and a theoretical explanation for their existence at all.

TYPE II CEPHEIDS

Bond, Carney, & Grauer (*PASP* **96**,176); Carson & Stothers (*ApJ* **259**,740); Harris, Olszewski, & Wallerstein (*AJ* **89**,119); Harris & Wallerstein (*AJ* **89**,379); Lloyd Evans (*Obs* **103**,276); Luck & Bond (*ApJ* **279**,729); Petersen & Hansen (*AA* **134**,319); Zinn & King (*ApJ* **262**,700).

Harris & Wallerstein have confirmed a long-standing suspicion that the so-called Population II field cepheids in fact form a decidedly inhomogeneous group. In particular, they include members that are relatively metal-rich (probably from the old disk population) that have no counterparts among the globular cluster variables. Thus Harris has suggested use of the term Type II cepheid rather than Population II cepheid to emphasize that not all Type IIs are Population IIs. An interesting sidelight is that truly metal-poor cepheids are underrepresented in the field compared to clusters.

Carson & Stothers report considerable success in fitting theoretical models to the observed properties of BL Her stars.

CEPHEID-LIKE STARS

Bond, Carney, & Grauer (*PASP* **96**,176); Fernie (*ApJ* **265**,999); Luck & Bond (*ApJ* **279**,729); Luck, Lambert, & Bond (*PASP* **95**,413); Sasselov (*IBVS* 2314,2387 & *Ap Sp Sc* **102**,161); Takeuti (*Obs* **103**,292).

There is a growing interest in variable stars which are similar to cepheids in luminosity and temperature, but which are more erratic in behavior and probably lie outside the usual instability strip. Foremost among these is a group called either 89 Her or UU Her stars. They are typically high-latitude F-supergiants of long period (>40 days), low amplitude ($\sim$0.1 mag), and fluctuating lightcurve shapes; at least some of them appear to have solar metallicities. Their pulsation mechanisms, evolutionary histories, and basic nature (e.g. high- or low-mass) are uncertain at present.

MISCELLANEOUS

Arellano Ferro (*ApJ* **274**,755); Efremov (*Sov Ast Lett* **9**,51); Fernie (*IAU Symp 105*,441); Grivnev (*Sov Ast Lett* **9**,287); Joshi (*Bull Ast Soc India* **10**,217); Kamper, Evans, & Lyons (*JRAS Can* **78**,173); Karimova & Pavlovskaya (*Sov Ast* **25**,56); Opolski (*IBVS* 2425); Simon & Teays (*ApJ* **265**,996); Szabados (*Ast Sp Sc* **96**,185).

These investigations cover a wide range of topics from period changes in cepheids, to Fourier decomposition of their velocity curves, to galactic structure and kinematics. Arellano Ferro has made the intriguing discovery that Polaris's amplitude of variability has been steadily diminishing for many decades.

CONCLUDING REMARKS

In reviewing these mainly observational aspects of cepheid research over the past three years I would say that there has been a great improvement in available data, both photometric and spectroscopic, and that there is now a need to compile all this information into one uniform database for general application. Among the more specific problems that confront us is the zeropoint of the period-luminosity relations, the size of any color term in the P-L-C relation, and the continuing anomalies in mass and radius determinations.

5. δ Scuti Stars
(D. W. Kurtz)

The nomenclature for δ Scuti stars remains confusing. In the literature of the last three years these stars are referred to as δ Scuti stars, dwarfs Cepheids, RRs stars, RR Lyrae stars (erroneously), AI Vel stars, and Ultra-short period Cepheids (USPC stars). Part of the reason for this confusion is that there are both Population I and Population II δ Scuti stars. In general, known Population I stars are called δ Scuti stars while known Population II stars are called either dwarf Cepheids or AI Vel stars. Note, however, that AI Vel itself, and many stars labelled dwarf Cepheids, are actually Population I δ Scuti stars. Both populations are called USPC stars. The RRs designation is now archaic. Caution is therefore advisable in making inferences about the properties of a star based on a particular author's choice of nomenclature.

No new reviews of the δ Scuti stars have been written in the last three years. Students new to the field are advised to start with the 1979 reviews of Breger (*PASP* **91**,5) and Eggen (*ApJ Supp* **41**,413).

Most of the literature of the last three years presents *brief* observational studies of the light variations of δ Scuti stars. It is clear that some δ Scuti stars pulsate in a single radial mode, some pulsate in more than one radial mode, many pulsate in several radial and non-radial modes, and some *may* switch modes. Observationally, *extensive* observation sets of selected multiperiodic δ Scuti stars are needed now, rather than short studies of known δ Scuti stars or the discovery of new variables. Stellar seismology (Christensen-Dalsgaard in *Proc Workshop on Sp Research Prospects in Stellar Activity and Variability* Mangeney, ed, Obs de Paris 1984) is an exciting new field which promises the direct study of the interiors of the sun and stars. For δ Scuti stars to be a part of this field we need *complete* frequency solutions for multiperiodic δ Scuti stars.

Jorgensen (*AA* **108**,99) and Jorgensen & Hansen (*AA* **133**,165) have discovered three Population II δ Scuti stars in ω Cen. These stars are of considerable interest both for the study of Population II δ Scuti stars (of which there are only a few confirmed examples) and for the study of blue stragglers.

Antonello *et al* (*IAU Coll 69*, 27), Antonello (*IAU Coll 69*, 33), Antonello & Conconi (*Ap Sp Sc* **88**,185), and Antonello *et al* (*Ap Sp Sc* **78**,435) have looked at relationships among amplitude, period, luminosity, temperature, and radius for δ Scuti stars. Wiertz & van Genderen (*AA* **121**,35) have obtained VBLUW photometry of some δ Scuti, δ Del, and Am stars. Verma *et al* (*Ap Sp Sc* **92**,173) have shown that 8 δ Scuti stars have normal JHK colors. Yang *et al* (*PASP* **94**,317) obtained radial velocities of β Cas accurate to ±0.2 km s^{-1}. Fracassini & Pasinetti (*AA* **107**,326) have found emission features in IUE observations of the Mg II h and k lines in several δ Scuti stars. Peniche *et al* (*PASP* **93**,735) and Ortega *et al* (*Rev Mex AA* **8**,45) have continued their spectral classification of δ Scuti stars. Tsvetkov (*Sov Astr* **26**, No 6) has discussed radial pulsation in 83 δ Scuti stars. Saez *et al* (*AA* **101**,259) have discussed the nature of the δ Del stars.

Smith (*ApJ* **254**,242) has looked at line profile variations in nine δ Scuti stars. He determined pulsation modes consistent with those independently found in photometric studies of the same stars.

Theoretical studies of evolutionary sequences and pulsation parameters have been made by Fitch (*ApJ* **249**,218), Tsvetkov (*Ap Sp Sc* **89**,435), Andreasen (*AA* **121**, 250), and Andreasen, Hejlesen & Petersen (*AA* **121**,241). Further discussion of the theory of pulsating stars can be found elsewhere in this volume.

For information on individual δ Scuti stars a good starting point is the list of Halprin & Moon (*Ap Sp Sc* **91**,43). The following references partially update that list. In addition, many notes on individual δ Scuti stars can be found in the *IBVS*. The usual caveat applies here: the following list is not complete.

Studies of δ Scuti stars are: HD 432 (HR 21, β Cas) Yang *et al*, *PASP* **94**,317; HD 2628 (HR 114) Ibanoğlu *et al*, *Rev Mex AA* **5**,261; HD 24832 (HR 1225) DuPuy, Collins, & Swingler *PASP* **94**,177; HD 26322 (HR 1287, 44 Tau) Ibanoğlu *et al*, *Rev Mex AA* **5**,261; HD 27397 (HR 1351, 57 Tau) McNamara *Proc SW Regional Conf Astron Ap* **8**,43; HD 28024 (HR 1392) Bossi *et al*, *AA Supp* **53**,395; HD 50420 (HR 2557) Bossi *et al*, *Ap Sp Sc* **89**,429; HD 55595 (HR 2724) Baade & Stahl *AA* **114**,131; HD 64191 (AD CMi) Balona & Stobie *SAAO Circ* **7**,19; HD 66260 Helt, *AA Supp* **56**,457; HD 67523 (HR 3185, ρ Pup) Fracassini *et al*, *Ap Sp Sc* **97**,323, Balona & Stobie *SAAO Circ* **7**,19; HD 69213 (AI Vel) Sturch & Wu *PASP* **95**,211; HD 73576 Bossi *et al*, *Ap Sp Sc* **85**,25; HD 73857 (VZ Cnc) Balona & Stobie *SAAO Circ* **7**,19, Sturch & Wu *PASP* **95**,211; HD 110411 (HR 4828, ρ Vir) Antonello & Mantegazza *AA Supp* **49**,703; HD 110951 (HR 4847, 32 Vir) Bartolini *et al*, *AA Supp* **53**,139; HD 115308 (HR 5005) Peña *et al*, *AA Supp* **53**,81; HD 115604 (HR 5017, 20 CVn) Bossi *et al*, *AA Supp* **53**,399, Peña & Gonzalez *AJ* **86**,1679; HD 116994 (V743 Cen) Balona & Stobie *SAAO Circ* **7**,19; HD 124675 (HR 5328/9, κ Boo) Ibanoğlu *et al*, *Rev Mex AA* **5**,261; HD 129798 (HR 5492) Bossi *et al*, *Ap Sp Sc* **79**,463; HD 143466 (HR 5960, CL Dra) DuPuy & Burgoyne *PASP* **95**,61; HD 158741 (HR 6522) Waelkens & Bartholdi *AA Supp* **52**,1; HD 160589 (V703 Sco) Balona & Stobie *SAAO Circ* **7**,19; HD 174553 Guerrero & Mantegazza *Ap Sp Sc* **86**,139; HD 177392 Schoneich & Želwanowa *AN* **302**,181; HD 181333 (HR 7331) Ibanoğlu *et al*, *Rev Mex AA* **5**,261; HD 197461 (HR 7928, δ Del) Fernandes *BAV Rundbrief* 30.

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Jahrg,42; HD 199908 (DQ Cep) Pena *et al, AA Supp* **51**,71; HD 208664 Kurtz *MN* **200**,497; HD 211336 (HR 8494, ε Cep) Fernandes *BAV Rundbrief* 30.Jahrg,42; HD 223338 (BS Aqr) Kilambi *Bull Astron Soc India* **10**,234; BD +12°3028 (DY Her) Szeidl & Mahdy *Commun Konkoly Obs* No 75; BD +28°1494 Broglia & Conconi *AA* **100**,201; BD +37°2635 (YZ Boo) Szeidl & Mahdy *Commun Konkoly Obs* No 75; BD +43°1894 Yamasaki *et al, PASP* **95**,447; SX Phe, Coates, Halprin & Thompson *MN* **199**,135, Sturch & Wu *PASP* **95**,211; XX Cyg, Szeidl & Mahdy *Commun Konkoly Obs* No 75, Jones *PASP* **94**,289.

RAPIDLY OSCILLATING Ap STARS

The Rapidly Oscillating Ap Stars are cool magnetic Ap Stars which oscillate with periods in the range of 4 to 15 minutes with peak-to-peak light variations of $\Delta B \leq 0.016$ mag. Their oscillations have been described as high overtone non-radial p-modes of low degree which have the axis of oscillation aligned with the magnetic axis of the star which is oblique to the rotation axis. Kurtz (*MN* **200**, 807) has given an introduction and review of these stars. A list of nine Rapidly Oscillating Ap stars with references to the rest of the literature can be found in Kurtz (*MN* **209**,841).

The Rapidly Oscillating Ap stars lie within the δ Scuti instability strip, but they may or may not be δ Scuti stars. The problem of their very short periods (high pulsational overtone) and pulsation axis orientation have led Shibihashi (*ApJ Lett* **275**,L5) to suggest that their oscillations are excited by overstable magnetic convection. Cox (*ApJ* **280**,220) has given further discussion of Shibihashi's ideas. If this model is correct, then the Rapidly Oscillating Ap stars are phenomenologically different from the δ Scuti stars whose instability is due to the κ-mechanism.

There are also pulsating Ap stars with longer periods which may belong to either the δ Scuti class or the Rapidly Oscillating Ap class (presuming those are different). These stars are (probably magnetic) Ap stars which show normal Scuti light variations. Weiss (*AA* **128**,1) gives a discussion of them and further references.

6. RR Lyrae Stars
(B. Szeidl)

Ephemerides of RR Lyrae type variables have been compiled by Tsesevich, Firmanyuk & Kreiner for the years 1982, 1983 and 1984 (Rocznik Astr Obs Krakow). Elements have been derived, revised or refined for a great number of known RR Lyr stars and for some accidentally discovered ones. The results have been mostly published in *Astron Tsirk, IBVS, JAAVSO* and *Per Zv Suppl*. Eight new RR Lyrae stars have been found in a field around γ Aql (Gessner *MVS* **10**,35) and 24 new ones in a field around M92 (Meinunger *MVS* **10**,1). Liller (*AJ* **88**,1463) found ten new variables in a field of NGC 6681 and concluded that at least some of them belong to the galactic bulge population. Forty-two new RR Lyrae variables have been discovered and periods have been determined for 40 of them in a field surrounding the globular cluster NGC 6304 (Barlow & Hesser *AJ* **86**,1044).

Photoelectric photometry has been reported on RZ Cep (Garbuzov *Astron Tsirk* **1200**,5), BC Dra (Szabados & Stobie *AA Supp* **47**,541) UW Gru (Bernard *PASP* **94**,700), AV Peg (Alaniya *IBVS* 2558), DH Peg (Alaniya *IBVS* 2558; Garbuzov *Astron Tsirk* **1200**,5; Hopp *As Sp Sc* **79**,239) and two new discoveries (Grauner *PASP* **96**,84; Tan Huisong *IBVS* 2533). The photometry of BD+16°2356 revealed that this star is the brightest representative of c-type variables with periods longer than 0.40 day (Oja *AA* **103**,339). High-phase resolution uvbyβ photometry of SU Dra, RX Eri and RR Lyr were used to find the variations of effective temperatures and surface gravities with phase. The Baade-Wesselink method was applied in order to find their absolute magnitudes (Siegel *PASP* **94**,122). Simultaneous photometric and radial velocity data of VY Ser were obtained and were used to solve for the star's radius and distance. A phase difference $\Delta\phi \sim 0.075$, between the photometric and spectroscopic radii has been found. It may be a consequence of the star's strong convection, which has not been properly taken into account (Carney & Latham *ApJ* **278**,241). A theoretical relation between stellar surface brightness and V-R color has been calculated from model atmospheres for parameters appropriate to RR Lyrae stars (Manduca & Bell *ApJ* **250**,306). In a subsequent paper this relation has been combined with new VR photometry to determine distances, radii and absolute magnitudes for X Ari and RR Lyr (Manduca *et al*, *ApJ* **250**,312). Photometric observations of RR Lyr in the ultraviolet have been obtained using the ANS. The observations have been compared with theoretical light curves calculated using photometry at longer wavelengths and a good agreement has been found. A bump in the observed UV light curves in the phase range 0.6 to 0.8 supports the existence of a shock (Bonnel *et al*, *PASP* **94**,910).

Fourier decompositions have been made of the light curves of a large sample of RR Lyrae field stars (Simon & Teays *PASP* **93**,550; *ApJ* **261**,586). Although the period of the small-amplitude pulsator, XZ Cet is 0.823 day, the Fourier decomposition coefficients of its light curve fall far from the regions occupied by the ab pulsators (Simon & Teays *BAAS* **15**,655).

Wisniewski's conclusion that the RRc variable RW Ari is an eclipsing binary simultaneously has been questioned (Goranskij & Shugarov *Per Zv* **21**,211).

Abundance analysis has been reported on VY Ser (Carney & Jones *PASP* **95**,246) and MT Tel (Prybylski *Acta Astron* **33**,141. [Fe/H] values and mean temperatures have been derived for a sample of field RRc-type stars and the Oosterhoff effect was studied for this group (Kemper *AJ* **87**,1395). Kinman, Mahaffey, & Wirtanen (*AJ* **87**,314) extended the Lick survey to three fields in the galactic anticenter (28 RR variables in 84 deg^2). Δs indices and [Fe/H] values have been determined for these stars and compared with the corresponding values for RR Lyrae stars in the north galactic poles. The entire sample shows no direct evidence for an abundance gradient (Butler *et al*, *AJ* **87**,353). The carbon abundances for a large number of field stars have been studied and it was found that the RR Lyrae stars have carbon-to-iron ratios which are similar to those of unevolved stars (Butler *et al*, *AJ* **87**,640). A number of papers have been dealing with the helium content and metal abundance of RR Lyrae stars in globular clusters (Caputo, Castellani & Tornambe *IAU Coll 68*, 309; Smith *ApJ* **250**,719; *ApJ* **281**,148; Smith & Perkins *ApJ* **261**,576; Smith & Manduca *AJ* **88**,982). The pulsational properties of field RR Lyrae stars have been studied by Castellani, Maceroni & Tosi (*AA* **102**,411;**128**,64). The Oosterhoff period shift for RR Lyr stars in globular clusters and in the galactic disk has been discussed and it has been established that it correlates with metal abundance (Sandage *ApJ* **252**,553;**252**,574). The latest review of the pulsational properties of RR Lyraes in globular clusters and the Oosterhoff problem has been given by Dickens (*Pulsations in Classical and Cataclysmic Variable Stars*, p.182). Metal abundance parameters have been determined for RR Lyrae stars in the Magellanic Clouds and population, mass, and evolutionary ages have been discussed (Butler, Demarque & Smith *ApJ* **257**,592). Some RR Lyraes have been investigated in the direction of the LMC (Connolly & Smith *BAAS* **15**,927).

Stothers (*ApJ* **274**,20) redetermined the visual absolute magnitude of metal poor RR Lyraes using five independent methods. Catalogues of proper motions, space velocities and absolute magnitudes of RR Lyrae stars have been compiled (Wan, Mao & Ji *Ann Shanghai Obs* No 2,1;No 3,110; *Proc Shanghai Astrometry Symp*, p 326).

The period changes of a few RR Lyrae stars have been investigated (IM Aql by Lada & Belserene *JAAVSO* **10**,81; XZ Cyg by Blasberg *IBVS* 2361; RR Gem by Goranskij *Astron Tsirk* **1226**,1; RR Lyr by Romanov, Fedotev & Movchan *Astron Tsirk* **1205**,4; HK Pup by Lysova *Astron Tsirk* **1261**,6). The characteristics of period behavior of field RR Lyraes have been studied by Firmanyuk (*Astron Tsirk* **1118**,1;3). A model has been given for the explanation of fluctuations of period in multiply periodic variables (Marik *Commun Konkoly Obs* No 83,225).

The Blazhko-effect has been detected in a few RR Lyrae stars. The Blazhko periods of DM Cyg (Lysova & Firmanyuk *Astron Tsirk* **1122**,3) and V5 in M3 (Panov *Per Zv* **21**,391) have been determined. Changes in the shape and amplitude of the light curves of V672 Aql (Tsesevich *Astrometr Astrofiz* **43**,3), RR CVn (Belserene &

Larson *JAAVSO* **9**,61), EI Com (Wheatley *JAAVSO* **11**,17), TV CrB (Alaniya & Abuladze *Abastumani Bull* **55**,71) and V802 Cyg (Ventura *JAAVSO* **10**,90) have been found. On the other hand Glownia (*AN* **304**,45) showed that the secondary variability of RZ Cen found earlier was spurious. Photometric observations of RR Lyr were published and short discussions were given on its light curve variations (Alaniya & Abuladze *Abastumani Bull* **53**,13;**55**,53; Murnikova *Per Zv Suppl* **4**,1; Mironov, Moshkalikov & Kolykhalova *Per Zv Suppl* **4**,7; Kazimirskij *Astron Tsirk* **1204**,7). Tayler (*JAAVSO* **9**,57) noticed that the amplitude of secondary cycle magnitude maxima of XZ Cyg appeared to have decreased abruptly, coincident with the increase in its primary period. From a comparison of calculated and observed light curves of XZ Cyg, Gadun, Zajkova & Romanov (*Astrometr Astrofiz* **46**,23) determined the star's mean radius at two phases of the Blazhko-cycle. Polarization observations of RR Lyr have been carried out by Piirola (*Per Zv Suppl* **4**,31). Low dispersion spectroscopy has been done on XZ Cyg (Romanov & Fenina *Per Zv Suppl* **4**,35) and RR Lyr (Fenina & Romanov *Per Zv Suppl* 4,13; Romanov, Fenina & Vasileva *Astrometr Astrofiz* **43**,43) in order to investigate the variation of spectral characteristics with the phase of the Blazhko effect. Smith (*PASP* **93**,721) discussed the period distribution of irregularly variable RR Lyrae stars in M3, M5, M15, ω Cen and the Draco dwarf galaxy, and found that irregular variability is more frequent among shorter period ab-type RR Lyraes. These period distributions are consistent with some of the mode mixing explanations for the Blazhko effect. On the other hand, an attempt was made to discover what effects the coupling of the magnetic field and the pulsation have (Biront *et al, Liege Coll* **23**,337), and in a subsequent paper (Cousens *MN* **203**,1171) it was found that if rotation is slow enough, the dynamics of the oscillating magnetic star are altered very little, but the kinematic effect of the differing aspects of the oscillation presented to an observer at different epochs leads to modulated light and velocity curves. It has been concluded that the oscillating oblique magnetic rotator is a plausible model for the Blazkho effect in RR Lyr.

The recent discovery of many double-mode RR Lyrae variables in three globular clusters, in the Magellanic Clouds and even in the nearby Draco galaxy (Hodson, Cox & Clancy *BAAS* **13**,870; Goranskij *IBVS* 2007; *Astron Tsirk* **1216**,5; Nemec *IAU Symp 105*, 465; Nemec, Liller & Hesser *IAU Symp 108*, 39) has spurred interest in these stars. A detailed analysis of ten double-mode pulsators in M15 (Cox, Hodson & Clancy *ApJ* **266**,94; Cox *Pulsations in Classical and Cataclysmic Variable Stars*, p 157) provided period ratios, and masses, luminosities, effective temperatures, radii and He content have been derived for these stars. They appear in the instability strip between the pure fundamental and the overtone pulsators, and it is suspected that these stars undergo mode switching as they are evolving (Hodson & Cox *Pulsations in Classical and Cataclysmic Variable Stars*, p 201). The masses of RR Lyrae stars determined from double-mode pulsation range from 0.55 $M_\odot$ to 0.65 $M_\odot$ (Cox *IAU Symp 105*, 421). This is a very large range of mass and it has some constraints on stellar evolution (Cox & Hodson *BAAS* **16**,190). The only known field double-mode RR Lyrae star AQ Leo has been revisited. Its mean B-V color index places AQ Leo close to the transition line between the c- and the a-type pulsators in the instability strip (Jerzykiewicz, Schult & Wenzel *Acta Astron* **32**,357; *Commun Konkoly Obs* No 83,22).

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

INTRODUCTION

This review is the first in many years that has not been prepared by Helen Sawyer Hogg whose work in the field spans more than 50 years and still continues. The present author wishes to acknowledge Dr. Sawyer Hogg's invaluable assistance in making available her extensive catalogue of references on the subject. The addition of the phrase "and related systems" in the title reflects another change, as studies which were once limited to globular clusters have now been extended to dwarf spheroidal galaxies.

Although an effort has been made to be comprehensive, because of space limitations not all references are included. Readers are also referred to the Commission 38 Report on globular cluster research and to the report of the Frascati Workshop on Population II Variables held in September, 1984 at which a number of interesting papers on the subject were presented.

NEW VARIABLES, NEW PERIODS, AND NEW OBSERVATIONS

This section is given in tabular form in order of IAU cluster designation.

C0512-400 (NGC 1851) Following the discovery of new variables by Stetson (*AJ* **86**,687) periods were found for 4 of these and variability confirmed for the new red variable by Wehlau *et al* (*AJ* **87**,1295). With the exceedingly short period of 0.017 day, one may be a field W UMa star of twice that period. No variation was detected in another star on the edge of the instability strip which appears to be a member (Hesser *et al, AJ* **87**,1470).

C1003+003 (Pal 3) Three RR Lyrae variables and a possible Population II Cepheid have been found by Gratton and Ortolani (*AA Supp* **57**,177).

C1339+286 (NGC 5272) Meinunger has observed several variables (*MVS* **9**,117,119, 122,146). A search by Kadla *et al* (*Izv Glav Astron Obs Pulkovo, Astrofiz Astrometr* No 199) led to discovery of 15 variables bringing the total number of known RR Lyraes in M3 to 231.

C1343-511 (NGC 5286) Fourcade *et al* (*Bol Asoc Argent Astron* No 20-24,249) have determined periods for six variables.

C1403+287 (NGC 5466) Buonanno *et al* (*AA Supp* **56**,79) have found several new variables including some suspected by earlier observers.

C1452-820 (IC 4499) Fourcade *et al* (*Bol Asoc Argent Astron* No 20-24,156) have constructed a color-magnitude diagram and measured magnitudes for 171 variables.

C1514-208 (NGC 5897) Spectroscopy by Smith (preprint) of SK120, a possible non-variable in the variable star gap, indicates metallicity and radial velocity consistent with cluster membership.

C1531-504 (NGC 5946) Four new variables within the cluster tidal radius and 7 new field variables have been found by M. Liller (*AJ* **88**,404).

C1614-228 (NGC 6093) Three new short period variables have been found by Wehlau *et al* (*IBVS* 2586).

C1639+365 (NGC 6205) In M13 two new variables have been found by Russeva *et al, Per Zv* **21**,175; *IBVS* 2223).

C1659-262 (NGC 6273) Samus (*IBVS* 2555) has identified the Population II Cepheid V2 as FK Oph and confirmed its period.

C1707-265 (NGC 6293) Three new variables have been found by Clement *et al* (*AJ* **87**,1491).

C1716-184 (NGC 6333) Clement *et al* (*AJ* **89**,1707) have found that V12 in M9 is a BL Her star with a period of 1.34 days.

C1736-536 (NGC 6397) El-Worfaly and Budding (*Ap Sp Sc* **94**,253) found only two possible field variables in a careful search for main sequence variables. They also discuss observations of the three previously known variables.

C1821-249 (NGC 6626) Wehlau and Sawyer Hogg present observations of 24 variables in and around M28 (*AJ* **89**,1005).

C1840-323 (NGC 6681) Photometry is presented for 5 RR Lyrae variables including three newly discovered by M. Liller (*AJ* **88**,1463).

C1936-310 (NGC 6809) Eight new possible field variables near M55 were found by Irwin and Trimble (*AJ* **89**,83).

C2003-220 (NGC 6864) Pinto *et al* (*AJ* **87**,635) present photometry of 14 variables in M75 including 3 new RR Lyrae stars.

C2127+119 (NGC 7078) Chu *et al* (*Acta Astron Sin* **23**,118) report on the photometry of three RR Lyrae variables in M15.

MAGELLANIC CLOUD CLUSTERS

Graham & Nemec in a paper presented at IAU Symposium 108, *Structure and Evolution of the Magellanic Clouds*, reported on their search for RR Lyrae vari-

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ables in old clusters of the Magellanic Clouds which was successful for NGC 1786 and NGC 2210. RR Lyrae stars have now been found in 7 Magellanic cloud clusters, all of them being of Type VII, the oldest and most metal-poor classification. Nemec *et al* (*ApJ Supp*, 1985) have studied 38 RR Lyrae variables in NGC 2257 and Walker (*MN*, 1985) has made CCD observations of RR Lyraes in NGC 2210. For the much younger (80±30 million years) blue LMC globular cluster, NGC 1856, Hodge & Lee (*ApJ* **276**,509) confirmed two previously known Cepheids and found two more probable Cepheids.

STUDIES OF PERIOD CHANGES, DOUBLE MODE PULSATION AND LIGHT CURVE PARAMETERS

There has been a considerable expansion of work in this field, both observationally and theoretically, in the last three years and several papers on the subject were given at *IAU Colloquium 82*, *Cepheids: Theory and Observation*, held in Toronto, Canada in May, 1984. Period changes have been determined for RR Lyrae variables in M4 (NGC 6121,C1620-264) by Sujarkova & Shugarov (*Per Zv* **21**,505) and M92 (NGC 6341,C1715+432) by Kukarkin & Kukarkina (*Per Zv* **21**,365). Barlai (*Commun Konkoly Obs* No 85) has obtained O-C diagrams for 49 RR Lyraes in M15 and also reports on the interesting behavior of V15 in that cluster (*Commun Konkoly Obs* No 83,223). Nemec *et al* (*ApJ Supp*, 1985) have studied the period changes of 38 RR Lyrae stars in the LMC Cluster NGC 2257. Studies of period changes for longer period variables include the investigation by Wehlau & Bohlender of 12 BL Her stars in galactic globular clusters (*AJ* **87**,780), by Wehlau *et al* (*IAU Coll 82*) of two variables in M56 (NGC 6779,C1914+300) and by Clement *et al* (*IAU Coll 82*) for two Cepheids in M10 (NGC 6254,C1654-040).

Double-mode pulsation has been found for RR Lyrae stars in several clusters. There have been two studies on these stars in M15 by Cox *et al* (*ApJ* **266**,94) and Nemec (*AJ*, 1985). Another probable double-mode pulsator has been found by Clement *et al* (*AJ* **89**,1707) in M9. Three such stars found in Draco by Goranskij (*Astron Tsirk* No 1216,5) have been confirmed by Nemec (*AJ*, 1985) who found 10 in all in Draco and five probable candidates in the Ursa Minor dwarf spheroidal galaxy. However preliminary analysis by Nemec & Norris of 54 variables in ω Cen (NGC 5139,C1323-472) shows no evidence for double-mode pulsators in that cluster. Smith (*PASP* **93**,721) has studied the period distributions of irregularly variable RR Lyrae stars and has found behavior consistent with mode-mixing.

Petersen (*IAU Coll 82*) has Fourier analyzed the light curves of 75 RRab and 55 RRc variables in ω Cen and finds strong evidence of the progression of Fourier parameters with pulsation period. Hodson & Cox (*BAAS* **14**,900) have similarly analyzed the light curves of M15 variables and find this progression with period is seen more clearly for a sample of variables for one cluster than for field variables.

ABUNDANCE DETERMINATIONS IN RR LYRAE VARIABLES

Low resolution spectra of three RR Lyrae variables in Pal 13 (C2340+124) have enabled Zinn & Diaz (*AJ* **87**,1190) to compare its metallicity to that of other clusters. Determinations by ΔS spectroscopy of the metal abundances of RR Lyrae variables in a number of clusters have been made by Smith (*AJ* **88**,1762; *ApJ* **281**,148), Smith & Perkins (*ApJ* **261**,576) and Smith & Manduca (*AJ* **88**,982). The subject is reviewed for both field and cluster variables by Smith (*PASP* **96**,505). Kemper (*AJ* **87**,1395) compares metal abundances of field and cluster RRc variables.

COLOR STUDIES AND THE OOSTERHOFF DICHOTOMY

A three-color study of 47 variables in M5 (NGC 5904,C1516+022) has been carried out by Goranskij (*Astron Tsirk* No 1207,4) who finds stars with positive period changes are concentrated in the region which corresponds to the fast phase of horizontal branch evolution. Cacciari (*AJ* **89**,231,1082) has studied RR Lyrae variables in NGC 3201 (C1015-461) and confirmed the similarity of this cluster to M3. A mean value of M_V=0.60±0.08 was derived for the RR Lyrae stars in this Oosterhoff Type I cluster. Bingham *et al* (*MN* **209**,765) present BV photometry for 56 RR Lyrae stars in M15. Their new period-color relation shows less overlap

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between c and ab type variables than that found by earlier observers. For this Type II cluster a mean value of M_V=0.39±0.15 is obtained. Multimode variables lie close to the (ab/c) transition color.

The problem of the underlying physical mechanisms responsible for the observed differences in RR Lyrae properties between the Oosterhoff groups has been discussed by Goranskij (*Astron Tsirk* No 1234,1) who points out the basic tendency of the horizontal branch to become bluer with decreasing [Fe/H] reverses for the most metal poor clusters. A careful review of the subject by Renzini (*Mem Soc Astron Ital* **54**,335) suggests the Oosterhoff effect can be explained by a combination of this non-monotonic behavior and the period shifts of RR Lyraes of given effective temperture with decreasing cluster metallicity. Caputo *et al* (*AA* **123**,141) and Sweigart *et al* (*BAAS* **16**,526) have suggested differences in [CNO/Fe] instead of an anticorrelation of metallicity and helium content could be a contributing factor. However synthetic horizontal branches constructed by Rood (*IAU Symp 105*) with varying CNO do not appear to support this idea.

POPULATION II CEPEHIDS

There have been two recent reviews of the properties and evolutionary status of population II variables. Harris (*IAU Coll 82*) lists 46 cluster members, consisting of 23 short-period BL Her stars, 17 longer-period W Vir stars, and 6 probable RV Tauri stars, all found in lower metallicity clusters with blue horizontal branches. He compares these with other low mass Cepheids in the galaxy and uses the period changes of Wehlau & Bohlender to discuss their evolutionary status. Wallerstein & Cox (*PASP* **76**,677) also review both field and cluster Population II Cepheids, derive limits on their masses and discuss their relationship to RV Tauri and Mira variables in globular clusters. They interpret the fact that these stars are only found in clusters with blue horizontal branches in terms of greater mass loss before the Helium flash in these clusters.

STUDIES OF RED VARIABLES

Substantially more work is being done on red variables. There has been a series of papers by Lloyd Evans (*SAAO Circ* No 7,82,96; *MN* **204**,945,961;**209**,825) reporting on photometric and spectroscopic studies of red variables and other red giants in a dozen clusters. A four color study of the red variables of 47 Tuc (NGC 104,C0021-723) by Fox (*MN* **199**,715) has yielded new periods and evidence of overtone pulsation. Frogel (*AJ*, 1985) presents infrared photometry of 15 red giants, including 5 variables, in the metal rich cluster NGC 6712 (C1850-087) while in an earlier paper (*ApJ* **272**,167) he discusses the evolutionary state and pulsation characteristics of red globular cluster variables in general. A number of radial velocity or spectroscopic studies of stars on the red giant branch have included red variables. For instance see Pilachowski *et al* (*ApJ* **263**,187), Frogel *et al* (*ApJ Supp* **53**,713) and Mayor *et al* (*AA Supp* **54**,495). The studies of long period variables in the Magellanic Clouds by Wood *et al* (*ApJ* **272**,99) also include a number of globular cluster stars.

UNUSUAL VARIABLES

A third dwarf Cepheid, E39, in ω Cen has been found by Jorgenson & Hansen (*AA* **133**,165). Chu *et al* (*IAU Coll 82*) have found two low amplitude variables, K64 and K152, which lie on the mid-giant branch of M15.

BINARIES AND X-RAY VARIABLES

There has been considerable work on the problem of close binaries in globular clusters. Da Costa (*PASP* **94**,769) has shown that UV5 in NGC 1851 is probably not a binary and radial velocity studies in 47 Tuc by Mayor *et al* (*AA* **134**,118) and in M3 by Pryor *et al* (*BAAS* **16**,111) have turned up only two possibilities in the latter cluster. However a study by Harris & McClure (*ApJ Lett* **265**,L77) of a random sample of K giants indicates that M3 may not be deficient in binaries. There is also some positive evidence for binaries. Zinn & King (*ApJ* **262**,700) found that the anomalous Cepheid, V19, in NGC 5466 which has been shown to be a cluster member by Brosche & Geffert (*AA* **127**,415) is pulsating in the first harmonic and has twice the mass of horizontal branch stars, consistent with the theory that such stars are formed by mass transfer in close binary systems. Margon & Downes (*ApJ Lett* **274**,L31) have suggested that V19 in M30 (NGC 7099, C2137-237) is a second candidate for a U Gem star in a globular cluster while Wehlau & Sawyer Hogg (*AJ* **89**,1005) believe V7 in M28 may be similar.

Reviews of X-ray globular cluster sources by Grindlay (*Adv Space Res* **2**,133) and Hertz & Grindlay (*ApJ Lett* **267**,L83) and theoretical discussions by Hut & Verbunt (*Nature* **301**,587) and Krolik (*Nature* **305**,506) predict globular clusters should contain substantial numbers of close binaries and low-mass contact binaries while Van der Woerd & Van den Heuvel (*AA* **132**,361) compare the expected incidence of close binary systems to the observations. X-ray sources have now been found within the regions of 18 galactic globular clusters (Hertz & Grindlay, *ApJ* **275**,105). Among these, Lawrence *et al* (*ApJ* **267**,301) report partially simultaneous X-ray, radio and infrared observations of the rapid burster MXB 1730-335 in Liller 1 (C1730-333) for which Singh & Duorah (*Ap Sp Sc* **92**,143) have suggested a model, while Stella *et al* (*BAAS* **14**,618) have analyzed the observations of the X-ray source 4U1820-30 in NGC 6624 (C1820-303).

8. Mira Variables
(M. W. Feast)

It has long been known that Mira variables in our Galaxy obey a period-(visual) luminosity relation, at least roughly. Glass & Lloyd Evans (*Nature* **291**,303) discovered the first known Miras in the LMC and obtained infrared photometry of them. A rather precise period-M_{Bol} relation was found. New LMC Miras have subsequently been found (Wood *et al, ApJ*, in press; Glass & Reid *MN*, submitted) and these confirm the P-L relation with very small scatter (Feast *MN*, in press). Carbon and non-carbon Miras fit the same relation at K though there is a small separation of the two groups in m_{bol}. The small scatter about a P-L relation is confirmed by observations of Miras in the Galactic Center (Glass & Feast *MN* **198**,199; see also van den Bergh *PASP*, in press). The zero point of the relation may be obtained either by adopting a modulus for the LMC (from Cepheids, say) or from Miras in galactic globular clusters adopting some distance scale for these objects (*eg* from RR Lyrae variables, Menzies & Whitelock *MN*, in press). Miras in the LMC and in galactic globular clusters show the same period-T_{BB} (=temperature of a black body fit to IR data) relation as those in the general galactic field (Feast *1984 Frascati Workshop*, in press). The small amount of (infrared) occultation data suggests that T_{BB} is close to T_{eff} (Glass & Feast *MN* **199**,245) though further work is desirable on this crucial point and some workers have preferred other T_{eff} calibrations (*eg* Frogel *ApJ* **272**,167). Assuming T_{eff} = T_{BB} and the P-L relation indicates near-solar masses and first overtone pulsation (*cf* also Fox & Wood *ApJ* **259**,198). Omitting a few known supergiant objects, the galactic type II OH/IR variables extend the Mira period-M_{Bol} relation to longer periods (Engels *et al, AA* **124**,123; Feast *Obs*, submitted). The scatter about the relation can be accounted for by expected errors in the kinematic distances. This makes unlikely theories (which involve amongst other hypotheses an evolution from a Mira to an OH/IR source with a change from overtone to fundamental mode pulsation) based on the supposed isolation of low luminosity OH/IR sources using kinematic distances (*eg* Jones *et al, MN* **197**,413; *ApJ* **253**,208; *ApJ* **273**,660; *ApJ* **273**,669). Evolution from Mira to OH/IR source has been suggested on other grounds (Baud & Habing *AA* **127**,73) though it is not clear that this is consistent with the well known relationship of Mira kinematics to period or the small range of Mira periods within a given globular cluster and the dependence of this period on cluster metallicity (*cf* Feast in *Physical Processes in Red Giants*, Iben & Renzini, eds. D Reidel 1981). Present evidence suggest that the OH shells of OH/IR (Mira) variables are at least roughly spherical (Bowers *et al, ApJ* **274**,733; Herman *et al* 1984 ESA preprint). If so distances of improved accuracy should be obtained geometrically by combining the angular size of the shell with phase lag measurements of the diameter in the line of sight (Herman *et al*). Such phase lag measurements yield (OH) shell radii of 0.8±0.7 (10^{16} cm) for optical Miras with OH emission and 5.5±0.9 (10^{16} cm) for the (longer period) OH/IR Miras (Herman Thesis, Leiden 1983). However some of these shells are evidently quite complex [*eg* U Ori (Chapman & Cohen *MN* in press) where amongst other things a rotation of the envelope seems to be occurring].

New speckle studies of Miras (Mariotti *et al*, *AA* **120**,237; Bonneau *et al*, *AA* **106**,235) give amongst other results a visual diameter for Mira Ceti of 28±6 milliarcseconds. Wayall & Cahn (*ApJ* **275**,225) have attempted a new analysis of the space motions of Mira variables based on an adopted period-mass-luminosity relation and assuming fundamental model pulsation. It may be noted that the theoretical scheme adopted by these workers implies a substantial change in period of a given star during its Mira phase which seems inconsistent with the evidence on the relation of period to other properties (see above). Basic observational data on Mira variables recently published include: newly discovered variables (including spectroscopic discoveries), Margoni & Stagni *AA Supp* **56**,87; Bidelman *IBVS* 2054; Bidelman & MacConnell *AJ* **87**,792; Spectral types, Crowe *JRAS Can* **78**,103; Celis S. *AJ* **89**,527; UBVRI photometry, Celis S. *AJ* **87**,1791; Hill *et al*, *Publ Dominion Astrophys Obs* **15**,339. A KOIII and Mira binary was studied by Menzies *et al* (*Obs* **103**,195); Variable polarization in Mira Ceti by Hayes (*IBVS* 2064) and the variable periods of R Aql and R Hya by Davis (*JAAVSO* **11**,27). Bolometric corrections are discussed by Bessell & Wood (*PASP* **96**,247) and the effects of H_2O absorption on JHKL colors by Frogel *et al* (*ApJ Supp* **53**,713; see also Iyengar *et al*, *AA* **128**,255). The infrared properties of Mira variables in the solar neighborhood were established by Feast *et al* (*MN* **201**,439) on the basis of extensive JHKL observations. Infrared observations leading to period determinations for OH/IR variables have been given by Engels (*IBVS* 2301; *Verröff Astron Inst Bonn No 95*). New IR counterparts of type II OH sources are reported by Epchtein & Nguyem-Quang-Rieu (*AA* **107**,229) and by Willems & de Jong (*AA* **115**, 213) and H_2O masers detected from further Mira variables (Crocker & Hagen *AA Supp* **54**,405). Accurate optical positions and proper motions have been derived for Miras showing SiO masing. These may be valuable in connecting the HIPPARCOS system to the VLBI extragalactic reference system (Soulie & Baudry *AA Supp* **52**,229).

A number of papers relating to OH/H_2O masing in late type variables appear in *IAU Symposium 110*. New OH/IR sources have been found near the Galactic Center and used to study the mass distribution; the velocity dispersion is 140-160 km/sec (Habing *et al*, *AA* **128**,230). Fix & Mutel (*AJ* **89**,406) give infrared observations of a number of OH/IR sources and (in common with several other workers) fit the data to cool black body energy distributions. However, Whitelock (to be published) shows that these are very unlikely to be real temperatures and that the observed near IR colors are largely determined by circumstellar reddening. A significant number of IRAS sources are likely to be OH/IR variables or (perhaps) dust enshrouded carbon-Miras (Whitelock & Feast *MN* **210**,25P); Herman *et al*, *ESA* preprint; Whitelock to be published). Masing by H_2O in an excited vibrational state has not been found (Myers & Barrett *ApJ* **263**,716) in Mira Variables. SiO masing is found in many OH/IR sources (Jewell *et al*, *AA* **130**,L1). Huggins & Glassgold (*AJ* **87**,1828) develop the Goldreich-Scoville idea of OH production in the outer parts of circumstellar shells by ambient u-v radiation, whilst Clegg *et al* (*MN* **203**,125) discuss the effects of stellar u-v (chromospheric and shock-wave induced) on circumstellar silicon chemistry. Polarization studies of maser emission lines are powerful probes of circumstellar envelopes (Claussen & Fix *ApJ* **263**,153; Western & Watson *ApJ* **274**,195; *ApJ* **275**,195). The expansion velocity of the circumstellar shells of Miras may be correlated with the 1 μm amplitude (Ukita *AA* **112**,167). The correlation betwen stellar flux and SiO maser flux has been confirmed (Cahn *AJ* **86**,1935) and the general theory of SiO masing reinvestigated (Elitzur *et al*, *ApJ* **274**,210). Both masing and non-masing SiO emission from Miras has been studied (Wolff & Carlson *ApJ* **257**,161) and a number of differences (in relative intensities of transitions etc) have been found. The variations in the polarization of the SiO maser emission in R Cas place the SiO just above the stellar photosphere and allow the radial thickness of the line-forming region to be estimated (Clark *et al, ApJ* **261**,569). Similar results were obtaied for R Leo (*ApJ* **276**,572; *AJ* **87**,1803) and a transient increase in the mass of SiO involved was observed.

There exists a group of short-period semi-regular variables which show H_2O masing. Since these objects tend to lie at high galactic latitudes they may belong to a distinct type of maser (Dickenson & Dinger *ApJ* **254**,136). In one of these stars, R Crt, rapid variations in both 22 GHz H_2O and at optical wavelengths have been suggested (time scale ∿1 hour) Livi & Bergmann *AJ* **87**, 1783). The unusual microwave and infrared source OH 0739-14 (= OH 231.8+4.2) is an (infrared) long period variable (period = 648 days) (Feast *et al, MN* **203**,1207). There is some doubt as to whether it is an OH/IR Mira type variable or a more luminous supergiant object. Bowers & Morris (*ApJ* **276**,646) consider it to be a Mira on the basis of luminosity estimates. However in view of the complex bipolar nature of the object, the flux is unlikely to be isotropic so that the problem has not been finally settled.

Tuckman (*MN* **208**,215) predicted Mira masses of 2 $M_\odot$ or greater (P>300 days) from a study of the termination of the AGB by helium shell flashes. Such masses are greater than estimated either from pulsation theory or galactic kinematics. A general review of the evolutionary state of type II OH/IR sources is given by de Jong (*ApJ* **274**,252).

Further studies of atmospheric kinematics in Miras (including shock induced Hα emission) have been interpreted in terms of fundamental mode pulsation (Wilson *et al, MN* **198**,483; Gillet *et al, AA* **128**, 384). Hinkle (*PASP* **95**, 550) gives a general review of spectroscopy of circumstellar shells. An important study of the stellar atmosphere and circumstellar envelope of χ Cyg was made by Hinkle *et al* (*ApJ* **252**, 697) using high dispersion infrared spectra. The result are interpreted in terms of photospheric shock waves and a circumstellar envelope which is dominated by a stationary layer at 800 K and is ∿10 stellar radii from the star. This layer built up rapidly and then steadily dissipated over the next three pulsation cycles. In Mira itself evidence for infalling material has now been found (Ferlet & Gillet *AA* **133**,L1). SiO absorption bands in the 4 μ region have been observed in Miras (Rinsland & Wing *ApJ* **262**,201). The CO J = 2→1 line at 230 GHz has been shown to be a powerful tool in studies of circumstellar envelopes and the mass loss from Miras (Knapp *et al, ApJ* **252**,616). Radio continuum measurements (Spergel *et al, ApJ* **275**, 330) suggest that Mira Ceti has an optically thick chromosphere extending several stellar radii. Tielens (*ApJ* **271**,702) has developed a model for a stellar wind driven by radiation pressure on dust grains in Mira circumstellar envelopes whilst Berruyer & Frisch (*AA* **126**, 269) discuss the degree of coupling between gas and dust in various parts of the envlope. Recent work continues to support the view that OH masers are pumped by 35 μm radiation (with the possible exception of R Aql) (Hagen *PASP* **94**,835; Le Bertre *et al, AA* **132**,75).

It is not possible to give a general account here of work on symbiotic systems though several of them have been shown to contain Mira components (*MN* **202**,951; **203**,351; **203**,363; **203**,373; **208**,161; *cf* also *PASP* **96**,321). These systems show dust emission with blackbody temperatures near 1000K, much higher than in single Miras. Dust obscuration episodes have been observed in R Aqr and some similar systems and BI Cru (Whitelock *et al, MN* **205**,1207) shows circumstellar CO emission at 2.3 μm. R Aqr is double in the radio continuum (Spergel *et al, ApJ* **275**,330). The secondary source is believed to be a dense region of the stellar wind. Brugel *et al* (*PASP* **96**,78) have discussed evidence that reddening accompanied the 1977 obscuration phase of R Aqr. BX Mon has sometimes been regarded as the (optical) Mira of longest known period (1374 days). However this periodicity is more likely to be associated with orbital motion in a symbiotic system (Whitelock & Catchpole *IBVS* 2296). SY For is similar to Mira Ceti in having a secondary heated by accretion (Feast *et al, Obs* **104**,217).

The pulsation of carbon Miras was discussed with particular reference to a dust shell model (Bergeat & Sibai *AA* **119**,207). As already noted carbon Miras in the LMC follow accurately a P-L relation. The carbon Mira R For became unusually faint in the visible and infrared in 1983 and this is attibuted to dust obscuration (particle radius $\sim$0.15 μm) (Feast *et al, MN* in press). Molecular H_2 has been detected in the 2μm region of several carbon Mira variables though it is missing from some non-Mira carbon stars possibly indicating hydrogen deficiency in these latter stars (Johnson *et al, ApJ Lett* **270**,L63; Goebel & Johnson *ApJ Lett* **284**,L39). Work on the complex circumstellar chemistry of dust enshrouded carbon Mira variables has continued (Jewell & Snyder *ApJ Lett* **255**,L69; Nejad *et al, AA* **134**,129; Huggins *et al, ApJ* **279**,284; Johansson *et al, AA* **130**,227). CO millimeter emission has been detected in some of these objects (Thronson & Mozurkewich *ApJ* **271**,611). In IRC+10216 the CO fundamental band at 4.8 m has been spatially resolved by speckle interferometry. A review of the distribution and motions of C and S type Miras is given by Catchpole & Feast (1984 Strasbourg Meeting, "Cool stars with excesses of heavy elements", in press). The carbon Mira T Lyn may have a uv bright companion (Sanduleak *IBVS* 2548). R Vol which is undoubtedly a carbon star (Thé *PASP* **80**,104; Feast 1983, unpublished) has been suspected of showing a circumstellar 10.6 μm (silicate) emission feature (Hagen *PASP* **94**,835). In contrast to oxygen rich objects, carbon stars with shells tend to show non-spherical geometry (*cf* Bowers *et al, ApJ* **274**,733) and some progress has been made modelling these structures (*cf* Jura *ApJ* **275**,683). The infrared spectra of S, SC and CS stars (including Mira variables) show (a) the sensitivity of some absorption bands to C/O ratio; (b) the unusual strength of CO 2.3 μm absorption in superlithium rich stars (Whitelock & Catchpole *MN*, in press; 1984 Strasbourg Meeting, in press).

9. Flare Stars

(R.E. Gershberg and N.I. Shakhovskaya)

The Proceedings of IAU Colloquium No 71, *Activity in Red-dwarf Stars* (Bryne & Rodonò, eds, Reidel 1982), hereafter referred to as BR, contain detailed reviews on physical parameters of FSs, on their radiation in optical, UV, X-ray and radio wavelengths during flares and in the quiescent state, and on theoretical interpretations of FS activity.

Several new FSs in the solar neighborhood have been discovered: Asteriadis (*AA* **113**,165) has registered a flare on Gliese 487, Pettersen (*IBVS* 2141) has confirmed the flare activity of G 9-8 = CU Cnc and discovered such activity on G 51-15 (*AA* **95**,135), V 780 Tau (*AA* **120**,192), G 141-29 (*AA* **97**,199), G 9-38, G 119-62, Gliese 171.2A and Gliese 890 (in preparation), Sandmann (in preparation) has discovered flare activity on DK Leo, Torres *et al (Proc 3rd Regional Latin American Astron Mtg*, Buenos Aires, 1983) have observed a flare on Gliese 425 AB, Egge and Pettersen (BR, 481) registered a flare on the contact binary VW Cep, Patkos (*Mitt Astron Ges* **55**,82) found several short flares on the eclipsing binary SV Cam. Sanduleak (*IBVS* 2433) and Gavin (*IAU Circ* 3573) have suggested flare activity on an anonymous star and the Parenago 1644 stars. BY Dra type brightness variability is found by Bopp *et al* (*ApJ* **249**,210;**275**,691) on Gliese 171.2A, Gliese 410, Gliese 233, HD 143313, HD 175742, by Dorren & Guinan (*SAO Spec Rep* **392**,49) on HD 149661, HD 152391 and 61 Cyg A and by Torres *et al* (BR, 175) on DK Leo, V 914 Sco, V 4046 Sgr, FK Ser, Gliese 425 AB, Gliese 879 = TW PsA; they suggested the BY Dra syndrome on AD Leo, V 1216 Sgr, AT Mic = Gliese 799, AY Ind, Gliese 566 and 567. Young *et al*, in *Cool Stars, Stellar Systems, and the Sun* (Baliunas & Hartmann, eds, Springer 1984) (hereafter BH), p 112 have found for the single dMe star Gliese 890 the BY Dra syndrome, a very short period (10^h20^m) and large $v \sin i$ (70 km/sec). Results of photoelectric monitoring of known FSs have been published by Mavridis *et al* (*IBVS* 2022,2133,2174,2209), Asteriadis *et al* (*IBVS* 2183,2210,2408), Panov *et al* (*IBVS* 2128,2220,2358,2359; *Commun Konkoly Obs* No 83,208; *CR Acad Bulgare des Sciences* **37**,557), Tsvetkov *et al* (*IBVS* 2340, 2437),

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Contadakis *et al* (*IBVS* 2088), Melikian & Jankovics (*IBVS* 2038), Ilyin (*IBVS* 2484), Pettersen *et al* (*ApJ Supp* **54**,375), Andrews (*IBVS* 2252,2253), Herr & Frank (*IBVS* 2426), Allen & Edwards (*South Stars* **30**,159), Sanwal (*IBVS* 2143), Soliman (*IBVS* 2193), Andersen (BR, 203), Ichimura & Shimizu (*Tokyo Obs Bull*, in press), Rojzman & Shevchenko (*Sov Astron Lett* **8**,163). Statistical analysis of patrol observations of FSs has been carried out by Mahmoud (*IBVS* 2294), Andrews (*IBVS* 2254), Pettersen *et al* (*ApJ Supp* **54**,375), Pettersen (BH, 194). Gershberg & Shakhovskaya (*Ap Sp Sc* **95**,235) have analyzed energetics of different manifestations of FS activity and shown that the sum of the energy of short-lived flares and permanent radiation of stellar chromospheres and coronas is close in order of magnitude to the radiation deficit of starspots on FSs.

Results on the search for FSs in regions of stellar clusters have been published by Melikian (*IBVS* 2018,2352), Melikian *et al* (*IBVS* 2019), Oganian *et al* (*IBVS* 2149), Chavushian *et al* (*IBVS* 2339), Parsamian *et al* (*Astrofizika*, in press), Natsvlishvili (*IBVS* 2062,2231), Lopez (*IBVS* 2279), Hojaev (*IBVS* 2412), Tsvetkov *et al* (*IBVS* 2067,2132,2224,2338), Tsvetkova *et al* (*IBVS* 2131,2365). A catalogue of FSs in the Pleiades has been published by Haro *et al* (*Bol Inst Tonantzintla* **1**,3). Parsamian (*Astrofizika*, in press) has found increased number of visual binaries amongst FSs in the Pleiades and has shown that in the Orion cluster the fraction of FSs amongst Orion variables increases for variables with larger brightness amplitudes: she has considered the correlation between stellar cluster age and flare activity characteristics of FSs that belong to the clusters (*Proc 3rd regional Latin American Astron Mtg*). Korotin & Krasnobabtsev (*Izv Krymskoj Astrofiz Obs* **72**) have carried out a statistical analysis of FSs in 4 clusters, confirmed the power character of energy spectra of flares in all cases and found a constancy of spectral index for FSs of different luminosities in each cluster and a dependence of this index on cluster age: the flare energy spectrum becomes flatter for older clusters and the relative proportion of stronger flares increases.

Rojzman (*Sov Astron Lett* **9**,41;**10**,279; *Astron Zh* **61**,500) has confirmed the BY Dra type photometric period of EV Lac, suggested the existence of an unseen eclipsing companion of this FS and found that as a rule a slow increase of brightness of $0^m.1-0^m.2$ and of 1-2 hours duration precedes a flare. Therefore during short preflare dips the stellar brightness decreases only to its normal level but not below this level.

Avgoloupis (PhD Thesis, University of Thessaloniki, 1984) and Mavridis & Avgoloupis (in preparation) have considered the distribution of 184 light curves of flares on EV Lac along 4 Oskanian curve types and characteristics of flares within each type.

Chugainov (*IBVS* 2471) has suggested that there are repeating oscillations in the brightness of BY Dra on time scales of 1-3 hours. Cristaldi (*AA Supp*, in press) has found a correlation between the period of BY Dra brightness variations and the mean level of the brightness: the period decreases when mean brightness increases. This may be due to latitude migration of starspots.

Pettersen (BR, 239; *Lund Obs Rep* **18**,114) has carried out synchronous UBVR and narrow band Hα and Hβ observations of flares on G 141-29, V 577 Mon and UV Cet. He confirmed much slower evolution of flares in lines compared with the continuum and noted an absence of structures having time scales shorter than seconds in light curves in lines. He also found that the color index V-R may be a good approximation to a pure continuum flare index and that it varies during a flare, while U-B and B-V indices are strongly affected by line contributions and show only small variations during flares. Pettersen *et al* (*AA* **123**,184) have analyzed observations of YZ CMi and EV Lac and did not find a significant correlation of frequencies and energies of flares with visibility of spotted regions of stars.

Clayton & Martin (*AJ* **86**,1518) carried out high-precision polarimetric measurements of 5 FSs and detected no linear or circular polarization in any of the stars. Pettersen & Hsu (*ApJ* **247**,1013) have carried out multifilter polarimetric measurements of 19 dM0e-dM6e FSs and did not find polarization although single

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and double spotted stars and stars undergoing flare activity were in their observational program.

Bryne *et al* (*MN* **206**,907) have found normal frequency of flares on Gliese 182, confirmed the existence of BY Dra type brightness variations for this FS, and in IUE spectra found chromospheric emission that is typical for its spectral class. Bryne *et al* (*MN*, in press) have carried out optical photometry and UV spectrometry for FSs Gliese 229 = HD 42581 and Gliese 735 = V 1285 Aql.

Worden *et al* (*ApJ* **276**,270) observed 6 flares on YZ CMi with simultaneous photometry and high-dispersion, time-resolved spectroscopy and found significant increase in Hα and Hβ emission without noticeable broadening of the lines. Chugainov *et al* (BR, 237) carried out synchronous photometric and spectral observations of AD Leo, DT Vir and YZ CMi and registered an Hβ increase of 10-50% at 10-20 minutes before flare maximum and red asymmetry of this line in maximum, when broadening up to ±15 Å were observed; a search for He II emission was not successful. Ambaryan (*Astrofizika* **18**,654) has obtained a YY Gem flare spectrum in the photographic region. In one of a series of 5 min spectrograms of YZ CMi, Haisch & Giampapa (*PASP*, in press) have found two strong emission lines, at 4007 Å and 4276 Å, that are stronger than H and Ca II lines but have not yet been identified.

Bromage *et al* (BR, 245) from $17^h.5$ patrol observations with the IUE have detected 4 flares on UV Cet, AT Mic, EV Lac and EQ Peg; averaged over 30-35 min exposures, the flux increases in the C IV line at 1550 Å were from 1.5 to 9 times; in the AT Mic flare a strong continuum which increases monotonically from 1250 to 2000 Å and can be represented by a black body at T = 13000 K has been found; in the EQ Peg flare the strongest line emissions were found; the UV Cet flare with $\Delta U = 2^m.4$ was not accompanied by noticeable variations of the EUV line spectrum; during the EV Lac flare with $\Delta B = 0^m.7$ the variations were very faint. Butler *et al* (BR, 249) have found in an AU Mic flare that the C IV emission decays much faster than do the C I, C II, Si II and He II emissions. Baliunas & Raymond (*ApJ*, **282**,728) have reported UV and visible observations of a flare on EQ Peg B: for several minutes the Hα and Hβ emission increased significantly, then returned to normal states for an hour; simultaneously in the EQ Peg AB Spectrum the C IV, He II and C II emissions were enhanced; similarity to large two-ribbon solar flares is noted.

Butler *et al* (*MN* **197**,815) have described IUE spectra of FSs Gliese 867 A and AU Mic in the quiescent state and a flare spectrum of Gliese 867A with a strong continuum. In review by Bryne *et al* (*Ir Astron J* **14**,219) a description of this flare spectrum is given and characteristics of Mg II lines for FSs and non-active stars are presented. Butler *et al* (*Proc 4th Eur IUE Conf*, Rome, 1984) have observed BY Dra in different phases but did not find flux modulation of C I, O I, C II, Si IV and C IV lines by stellar rotation. They discovered an anticorrelation of stellar brightness in the Mg II doublet and in a band near 2620 Å containing a blend of Fe II lines with optical radiation that may be due to bright chromospheric plages above dark photospheric spots. Rodonò *et al* (*Proc 4th Eur IUE Conf*) have given preliminary results of cooperative observations for FSs YZ CMi, Gliese 182 and AD Leo in EUV, optical, IR and radio ranges. During a strong - $\Delta U \approx 3^m.8$ - flare in YZ CMi a sharp increase in radio flux took place at 6 cm, EUV lines of low and high excitation were enhanced noticeably, and a rather flat continuum increased; radio flux increased at optical maximum but the radio flare had a much longer duration than optical one had. During the Gliese 182 flare registered with IUE an excess pulsating radio emission at 2 cm was observed. A strong ($\Delta U = 2^m.1$) and long (about $0^h.5$) flare on AD Leo was studied in the wavelength range from 2000 Å to 20 cm: near the maximum a noticeable enhancement and broadening of Balmer lines were found, several minutes after maximum short-lived dips in the K band (2.2 micron) were noted, and in an IUE spectrum obtained 20 min after the maximum, a 20-fold increase in the Mg II-Fe II blend near λ2620 Å and in the continuum near 2500 Å were seen.

Bopp *et al* (*ApJ* **249**,210;**275**,691) surveyed spectroscopically with moderate dispersion about 20 KM dwarfs, and in 5 cases discovered faint Hα emission; all these objects turned out to be spectroscopic binaries with periods less than 10^d and with BY Dra type photometric variability. 5 km/sec is found to be a critical equatorial rotation velocity to manifest BY Dra type variability and flare activity on red dwarfs. The system BD +26°730 proved to have the most interesting UV spectrum, with emission line surface fluxes in He II, C IV, and N V 50-200 times the values for quiet sun. However, Torres *et al* (*Proc 3rd Regional Latin American Astron Mtg*, Buenos Aires, 1983) pointed out the BY Dra syndrome for more slowly rotating stars - with rotation velocities less than 4 and even 3 km/sec - and did not find Hα emission in high dispersion spectra of the BY Dra type star TW PsA. Pettersen & Coleman (*ApJ* **251**,571) studied with a spectral resolution of 0.45 Å line profiles for Hα, Na, He and Ca II lines in the red for the quiescent state of FSs AD Leo and GX And, which have similar photospheres but very different levels of flare activity; chromospheric emission lines are discussed in detail and correlations between spectral line features and flare activity are investigated. Since the single FS EV Lac and the component of a binary system EQ Peg A are very similar but the component of the short period system V 1054 Oph that should have fast rotation has a low level of activity, Pettersen *et al* (*ApJ*, in press) have concluded that stellar age as well as rotation velocity must be an important factor in determining flare activity level; they noted that the IR Ca II triplet can dominate in chromospheric radiative losses, being more effective than hydrogen lines. Giampapa *et al* (*ApJ* **246**,502; *ApJ Supp* **46**,159) have studied Ca II line profiles with resolution 0.142 Å in spectra of KM dwarfs and found that when stellar effective temperatures decrease absolute radiative losses of chromospheres also decrease. Using these high dispersion profiles of Ca II line Giampapa *et al* (*ApJ* **258**,740) have constructed single-component, homogeneous semi-empirical models of quiet chromospheres for 3 dMe and 2dM stars. Vogt *et al* (*ApJ* **269**,250) have determined $v \sin i$ from high-resolution line profiles for 17 KM dwarfs, and concluded that all stars with the BY Dra syndrome rotate faster than stars without this feature. Kodaira & Ichimura (*Proc Astron Soc Japan* **34**,21) have shown that the heterogeneity of surface brightnesses of the YY Gem components leads to distortion of the ratio of the amplitudes of radial-velocity curves. They confirmed the stability of a double sectorial distribution of active regions for the primary and changes of the distribution for the secondary. Ayres *et al* (*ApJ Lett* **270**, L17) obtained a high-dispersion IUE spectrum for FS AU Mic in the quiescent state from 1150 to 3000 Å and found that emission lines are symmetrical, do not show differential shifts and have widths (FWHM) from 38 to 74 km/sec. Linsky *et al* (*ApJ* **260**,670) carried out quantitative comparison of UV and optical emission spectra of dM and dMe stars and found that Mg II lines are the strongest chromospheric lines for G-M dwarfs but that for dMe stars Ca II and Fe II emissions are comparable and the Balmer series is more intensive than Mg II. Chromospheric radiative losses for dMe stars are 5 times larger than for dM stars and decrease quickly for later types, but the contributions of these losses relative to total stellar luminosity are approximately the same for a wide range of effective temperature for dM stars and increase by 5-10 times toward lower temperature for dMe stars. Relative magnitudes of radiative losses in chromosphere-corona transition zones and in coronas for dMe stars are 100 times higher than for active regions on the Sun. Torres *et al* (in preparation) have obtained reticon spectra for about 90 M and K dwarfs in the solar neighborhood, in the Pleiades and in the Hyades, and found a rather wide range in Li I 6707 line intensities. They concluded that Li destruction may be slower than was previously thought.

Kahler *et al* (*ApJ* **252**,239) have observed in the radio, optical and X-ray ranges a significant flare on YZ CMi which in character of development, X-ray plasma temperature, and a marked delay of the radio flare relative to the optical one suggest strong similarity to solar flares. X-ray emission fading is found to occur much more slowly than in the optical flare and the main relaxation mechanism is radiation. Haisch *et al* (*ApJ* **267**,280) during a 5 hour patrol with the IUE and the *Einstein* Observatory have recorded a strong flare on Prox Cen and obtained detailed data on the development of this event. In soft X-rays the total duration of the flare was about 2 hours, its luminosity at maximum reached 2×10^{28} ergs/sec and temperature 27×10^6 K; EUV flare emission was about 10% of the X-ray emission. A definite difference in intensity of X-ray emission from the quiet corona of this FS between 1979 and 1980 was found but the coronal temperature was estimated to be the same, namely 4×10^6 K; an analysis of coronal emission in the framework of the loop model leads to the conclusion that active X-ray regions cover about 2% of the stellar surface. Ambruster & Wood (BH, 191) have found fast transients of X-ray emission from EQ Vir and EV Lac. Swank & Johnson (*ApJ Lett* **259**,L67) studied the corona of FS Wolf 630 AB and found strong main emission with $T \cong 6.5\times10^6$ K and an additional emission component - 30% in power - with $T > 10^7$ K; similar two-component emission has been found from the corona of the FS AD Leo.

Caillault (*AJ* **87**,558) observed with the *Einstein* Observatory 5 BY Dra type stars and in all cases noticeable X-ray fluxes were registered; since one of these objects was almost certainly single, this result lends strong support to the suggestion that rapid rotation and not duplicity is the determining factor in defining the level of activity in such stars. Surveying the Pleiades stars in the soft X-ray region with the *Einstein* Observatory, Caillault & Helfand (*ApJ*, 1985 in press) have registered 2 flares: one on a cluster member, the 12^m K star HZ 1136, and one on the 15^m background M star HZ 1733. Within the framework of the loop model for coronal plasma they estimated: temperature, $10-50\times10^6$ K; luminosity, $10^{29}-10^{32}$ ergs/sec; emission measure, $10^{51}-10^{54}$ cm^{-3}; electron density, 10^{12} cm^{-3}; linear size, $10^{10}-10^{11}$ cm; and magnetic field strength, (1-2 kG for the flare structures. Stern *et al* (*ApJ Lett* **264**,L55) have observed in the Hyades a strong X-ray flare in the eclipsing system HD 27130 consisting of a G and a K dwarf and having a period $5^d.6$. During the flare the X-ray luminosity increased by 35 times and reached 10^{31} ergs/sec, the flare plasma temperature was about 4×10^7 K and the entire radiation in the soft X-ray range was 3×10^{34} ergs. Stern (BH, 150) has considered a general evolutionary scheme for coronal activity on late-type stars of the main sequence. Agrawal *et al* (*Proc Symp on X-ray Astron*, Bologna, 1984) have found for FSs clear correlations between X-ray luminosities of quiet coronas and luminosities of chromospheric and transition-region lines.

Slee *et al* (*Nature* **292**,220) have observed in the optical and at 6 cm a flare on AT Mic. They found a rather good correlation between light curves for these different wavelength ranges and find support for theories in which non-thermal electrons are responsible for both emissions. Fisher & Gibson (*SAO Spec Rep* No 392,109) using the VLA have monitored FSs YZ CMi, CN Leo, BD +16°2708, UV Cet, Wolf 424 AB and EQ Peg AB and 6 and 20 cm, simultaneously, in part, with optical observations. They found that radio flares had typical durations of about 20 min, significant or even very high circular polarization and no correlation with optical flares; they also observed radio emission at 6 cm from YZ CMi and at 20 cm from UV Cet in the quiescent state of these FSs. Gary *et al* (*ApJ Lett* **263**, L79) have recorded at 6 cm a flare on L 726-8 A with 100% circular polarization, intensity oscillations with a quasiperiod of about 56 sec, and maximum brightness temperature higher than 10^{10} K. Lang *et al* (*ApJ Lett* **272**,L15) have observed on AD Leo at 20 cm a rapid sequence of highly polarized spikes during the gradual rise of a longer lasting event; the rise time for the spikes was shorter than 0.2 sec and the brightness temperature was higher than 10^{13} K. The spikes are interpreted as a coherent emission at the second harmonic of the gyrofrequency in a longitudinal magnetic field of 250 G. Mechanisms that may be responsible for the slow component of this event have been discussed by Holman *et al* (*Proc Workshop on Stellar Continuum Radio Astronomy*, Boulder, 1984).

Topka & Marsh (*ApJ* **254**,641) have registered at 6 cm emission from each of the components of EQ Peg AB in the quiescent state. Linsky & Gary (*ApJ* **274**,776) at the same frequency have discovered emission from FSs UV Cet, YY Gem and Wolf 630 AB outside of flares; the emission was highly polarized and is interpreted as a gyroresonant emission from thermal electrons spiraling in magnetic fields of about 300 G or as synchrotron emission from a relatively small number of electrons with effective temperature greater than 10^8 K. The radio emission maximum of YY Gem corresponds to the phase of best visibility of a large dark spot on the surface of the faint component of the system, which may be evidence in favor of the magnetic nature of the radio emission. To explain strong and variable polarization of radio emission from FSs Gibson (BH, 197) has suggested a model of two starspots of different polarity that cross the stellar disk and are responsible for a variable component of magnetic field along the line of sight in the upper atmosphere of the star. Mullan (*Proc Workshop on Stellar Continuum Radio Astronomy*, Boulder 1984) has carried out a comparison of radio emission from UV Cet and RS CVn type variables and concluded that radio emission from FSs is due to coherent mechanisms which are related to impulsive release of magnetic energy during large-scale reconnection.

Continuing to elaborate the gas dynamical model of red dwarf flares that was reviewed by Katsova & Livshits (BR, 617), Livshits (*Astron Zh* **60**,964) has shown that the character of short-lived continuous optical radiation in a stellar flare is determined by the energy balance within a region compressed by a downward propagating shock wave and is weakly dependent on assumptions used in the numerical calculation of a rather complex gas dynamical scheme.

Cram (*ApJ* **253**,768) has shown that powerful X-ray emission from dMe star coronas should noticeably affect the energy balance in quiet chromospheres of these stars. Cram & Woods (*ApJ* **257**,269) have studied effects of stellar atmosphere structure variations during flares on spectral characteristics of stellar flares. They concluded that increased pressure and temperature in the flaring stellar chromosphere and changes in the stellar flare area, both with time and with depth in the atmosphere, play an important role in producing the observed flare spectrum.

Mullan (*ApJ* **279**,746) has pointed out that recent observations in the visible, radio and X-ray portions of the spectrum do not exclude the existence of starspots with magnetic field strengths of order 10 kG or more on cool dwarfs. Considering expected variations of coronal heating efficiency along the main sequence, Mullan (*ApJ* **282**,603) has shown that Ionson's electrodynamic coupling theory predicts a maximum in this efficiency for early M dwarfs and a rapid decrease for cooler M dwarfs, in agreement with X-ray observations of lower main sequence stars.

Bohn (*AA* **136**,338) has revised the theory of generation of acoustic energy from convection zones of late type stars: including the effect of absorbtion by dust and molecules in the opacity tables and improving the calculation of thermodynamic quantities by including molecular dissociation yields larger convective velocities; then, including monopole - and dipole-source terms for the calculation of the sound generation by the Lighthill-Proudman theory, the total expected generation of acoustic energy for very late-type stars turns out to be 5 orders of magnitude more than in previous theoretical calculations.

10. Observations of Pulsating Degenerate Stars

(Edward L. Robinson)

The pulsating degenerate stars include the pulsating DA white dwarfs - known as the ZZ Ceti stars, the pulsating DB white dwarfs such as GD 358, and the pulsating pre-white-dwarfs, also known as the PG1159-035 stars after the prototype of the group. Recent reviews of the ZZ Ceti stars have been given by Robinson (*IAU Coll 53, White Dwarfs and Variable Degenerate Stars* Van Horn & Weidemann eds, Univ Rochester, p 343) and Winget & Fontaine (in *Pulsations in Classical and Cataclysmic Variables*, Cox & Hansen eds, JILA, p 142); no general reviews of the pulsating DB white dwarfs or the PG1159 stars have been published.

Nineteen ZZ Ceti stars have been found. The seven found since the review by Robinson (*IAU Coll 53*) are GD 385 (Fontaine *et al*, *ApJ* **239**,893), G255-2 (Vauclair, Dolez & Chevreton *AA* **103**,L17), G185-32 and G191-6 (McGraw *et al*, *ApJ* **250**,349), G226-29 (Kepler, Robinson & Nather *ApJ* **271**,744), GD 66 (Dolez, Vauclair & Chevreton *AA* **121**,L23), and G238-53 (Fontaine & Wesemael *AJ* **89**,1728).

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The importance of temperature in determining whether a DA white dwarf pulsates has been shown much more clearly in the past few years. Earlier studies of the temperatures of the ZZ Ceti stars used the (B-V) or (b-y) colors of the white dwarfs to measure their temperatures (see Robinson *IAU Coll 53*). These colors are not perfectly correlated with temperature, so the effects of temperature were blurred and difficult to investigate. The (G-R) colors of white dwarfs are more perfectly correlated with their temperatures than are the (B-V) or (b-y) colors because the wavelength baseline of the (G-R) index is larger and the G and R passbands are not strongly affected by hydrogen absorption lines. Two recent studies of the temperature dependence using (G-R) colors have shown that all ZZ Ceti stars have (G-R) colors between -0.38 and -0.45 on Greenstein's 1969 calibration. Furthermore, there are few and possibly no constant stars within that range of colors (Greenstein *ApJ* **258**,661, Fontaine *et al*, *ApJ* **258**,651). It appears likely, therefore, that temperature is the sole criterion for pulsation of DA white dwarfs. Depending on the exact calibration of the (G-R) color system, the ZZ Ceti instability strip runs from 10,600 K to 11,800 K. The multichannel observations by Greenstein (*ApJ* **258**,661) also showed that the gravities of the ZZ Ceti stars lie in the range $\log(g) = 8.0 \pm 0.2$, and thus are normal for white dwarfs.

It is generally believed that the pulsations of the ZZ Ceti stars are non-radial g-mode pulsations. This belief is based on the long periods of the ZZ Ceti pulsations, 109 s for G226-29 to 1186 s for GD 154, and on the theoretical investigations by Winget and his colleagues that have shown that models of DA white dwarfs near 12,000 K are unstable to g-mode pulsations (Winget *et al*, *ApJ Lett* **252**,L65). Nevertheless, calculations by Saio (*ApJ* **256**,717) suggested that DA white dwarfs with temperatures near 12,000 K should also pulsate in r-modes, another form of non-radial pulsation. To test this suggestion, Robinson, Kepler & Nather (*ApJ* **259**,219) and Kepler (*ApJ*, 1985 in press) calculated the observable photometric and radial-velocity variations of white dwarfs undergoing g-mode and r-mode pulsations. Their observations of the two ZZ Ceti stars R548 and G117-B15A agreed with the calculated variations of g-mode pulsations and not r-mode pulsations.

Much time and effort has been invested in measuring the periods and the rates of change of the periods of the ZZ Ceti stars because these quantities can be used to test theories of the structure and evolution of white dwarfs. The measurements are arduous because the ZZ Ceti stars are all multiperiodic; even the simplest one, R548, has four pulsation periods simultaneously present in its light curve. Nevertheless, the number of ZZ Ceti stars for which accurate periods have been established has jumped from one, R548, to five in the last two years. In addition to R548, we now have L19-2 (O'Donoghue & Warner *MN* **200**,563), G117-B15A (Kepler *et al*, *ApJ* **254**,676), GD 385 (Kepler *ApJ* **278**,754), and G226-29 (Kepler, Robinson & Nather *ApJ* **271**,744). None of these stars has shown measurable period changes. The most stringent upper limit on the rate of change of any of the periods in these stars is for the 215 s period of G117-B15A for which $|dP/dT| < 1.4 \times 10^{-14}$ s/s at the 68% confidence level (Kepler, Robinson & Nather in *Pulsations in Classical and Cataclysmic Variables*, p 73).

For completeness, we note that Liller & Hesser (*PASP* **92**,319) measured the long term variability of 12 ZZ Ceti stars on Harvard patrol plates and found no evidence of variability - except for their pulsations - on time scales up to 90 years. Also, Angel, Borra & Landstreet (*ApJ Supp* **45**,457) observed several ZZ Ceti stars during their survey for circular polarization in white dwarfs. They did not find any evidence for strong magnetic fields in the stars they observed.

The basic correctness of the theory of pulsating white dwarfs has been confirmed by the discovery of the pulsating DB white dwarfs. Based on their theoretical studies of the ZZ Ceti stars, Winget *et al* (*ApJ Lett* **252**,L65) predicted that the DB white dwarfs should also pulsate in the nonradial g-modes. The pulsations of the DB white dwarfs should be driven by the helium partial ionization zone instead of the hydrogen partial ionization zone that drives the ZZ Ceti pulsations, and the instability strip for the DB white dwarf should be hotter

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than about 20,000 K. A survey for variable DB white dwarfs made as a result of this prediction has now found two pulsating DB white dwarfs, GD 358 and PG1654+160 (Winget *et al, ApJ Lett* **262**,L11; Robinson & Winget *PASP* **95**,386; Winget *et al, ApJ Lett* **279**,L15). The pulsations of these two stars are similar to the pulsations of the ZZ Ceti stars, leading to the conclusion that they are, indeed, pulsating in g-modes. Furthermore, the temperature of GD 358 is about 30,000 K, in agreement with the theoretical prediction (Winget *et al, ApJ Lett* **268**,L33; Koester, Weidemann & Vauclair *AA* **123**,L11). This appears to be the first time in the history of astronomy that an entirely new class of variables stars was successfully predicted before it was discovered.

Faith in the accuracy of the theory of pulsating white dwarfs should not be boundless, however. Using the best available white dwarf models and pulsation codes, two groups independently predicted that DA white dwarfs should pulsate in radial modes as well as nonradial modes (Starrfield *et al, ApJ* **269**,645; Saio, Winget & Robinson *ApJ* **265**,982). An exhaustive search for radially pulsating white dwarfs by Robinson (*AJ* **89**,1732) failed to find any. Some modifications of the pulsation codes or the white dwarf models will be necessary to resolve this discrepancy.

The star PG1159-035 was found to be a multiperiodic variable by McGraw *et al* (*IAU Coll 53*, p 377). The morphology of its light curve and the presence of broad He II absorption in its spectrum suggested that PG1159-035 was a hot, high gravity pulsating star unlike any other known variable. Three other stars similar to PG1159-035 have now been found: the central star of the planetary nebula K1-16 (Grauer & Bond *ApJ* **277**,211), PG1707+427, and PG2131+066 (Bond *et al, ApJ* **279**,751). Analyses of optical and IUE spectra have shown that all four stars have temperatures greater than 100,000 K and high surface gravities, supporting the suggestion originally made by McGraw *et al* (*IAU Coll 53*, p 377) that they are highly evolved stars rapidly cooling to the white dwarf sequence (Wesemael, Green & Liebert *ApJ Supp*, 1985 in press; Bond *et al, ApJ* **279**,751). The dominant pulsation periods range from 414 s for PG2131+066 to 1700 s for the central star of K1-16. Periods this long suggest that, like the pulsations of the white dwarfs, the pulsations of the PG1159-035 stars are g-modes. Only the light curve of PG1159-035 has been fully decomposed into its component pulsation modes (Winget, Kepler, Robinson, Nather & O'Donoghue *ApJ*, 1985 in press). The period of its largest amplitude pulsation, at 516 s, is changing at the rate $dP/dt = (-1.2\pm0.1)\times10^{-11}$ s/s. The magnitude of this rate - but not its sign (!) - is consistent with theoretical calculations of the g-mode pulsation periods of a cooling and contracting pre-white-dwarf (Winget, Hansen & Van Horn *Nature* **303**, 781). With further theoretical studies it will be possible to convert this rate of period change into a direct determination of the rate of evolution of stars from the region of the planetary nebulae nuclei to the white dwarfs sequence in the H-R diagram.

11. Theory of Stellar Pulsation

(W. Dziembowski)

11.1 INTRODUCTION

Several major international conferences have been held in which papers on stellar pulsation theory are included. The most important were:

Problems of Solar and Stellar Oscillations (IAU Colloquium 66), Crimean Astrophysical Observatory, Sept. 1981. Proceedings in *Solar Physics* **82**,1-498 (1983), D.O. Gough, ed.

Pulsations in Classical and Cataclysmic Variable Stars, Boulder, Colo., June 1982. Proceedings (Boulder: JILA, 1982), J.P. Cox and C.J. Hansen

Oscillations as a Probe of the Sun's Interior, Catania, June 1983. Proceedings in *Mem. Soc. Astron. Ital.* **55**,1-384 (1984), G. Belvedere and L. Paterno, eds.

Theoretical Problems in Stellar Stability and Oscillations, Liège, July 1984. Proceedings (Liège: Université de Liège, 1984), A. Noels and M. Gabriel, eds.

The Catania meeting, though devoted to the Sun, included many papers of interest for stellar oscillations generally. Papers from the first three conferences in the list are cited in this report. The Liege meeting was too recent to be included at the time this review was written.

11.2 GENERAL THEORY AND NUMERICAL METHODS

Effects of Convection

Investigation of these effects is still in the exploratory phase. A novel method was developed by Stellingwerf (*ApJ* **262**,330). Its superiority over previously used time-dependent mixing-length formalisms consists in a nonlocal treatment of the convection. An autonomous system of equations for stellar pulsation was derived in which convection is described by its mean characteristics. The relative simplicity of the equations makes them suitable for widespread use but the derivation, though physically plausible, is very nonrigorous. Some results obtained with this new method will be described in section 11.3.

Stellingwerf's formalism is not able to describe resonant energy input from the convective motion to pulsations. Methods to study this problem were described by Poyet (*Sol Phys* **82**,267) and by Dolez, Legait & Poyet (*Mem Soc Astron Ital* **55**,293) but not developed to a tractable level. Christensen-Dalsgaard & Frandsen (*Sol Phys* **82**,469) used an approximate method developed earlier by Goldreich & Keeley to predict amplitudes for stellar analogues of the solar "five minute" modes.

The same authors (Christensen-Dalsgaard & Frandsen *Sol Phys* **82**,165) pointed out an important and hitherto ignored effect of the departure from radiative equilibrium in the subphotospheric convective zone on stability of high frequency modes. Taking it into account reverses the conclusion about overstability of the "five minute" modes.

Oscillations in Nonspherical Stars

Effects of a slow nonuniform rotation on frequency spectra of the poloidal modes were studied by Vorontsov (*Sol Phys* **82**,379), Gough & Taylor (*Mem Soc Astron Ital* **55**,227), and by Dziembowski & Goode (*Mem Soc Astron Ital* **55**,185). In the last two papers some effects of a magnetic field were also calculated. Consequences of the singular nature of the magnetic perturbation were discussed by Biront *et al* (*MN* **201**,619). Effects of the tidal force were calculated by Mohan & Singh (*Ap Sp Sc* **85**,83) and by Smeyers & Martens (*AA* **125**,193).

In all these papers a perturbation approach has been used. Effects of rotation were calculated including quadratic terms in the angular velocity Ω; for the other effects only the lowest order terms were calculated. Two distinct numerical methods suitable for treating the case of rapid rotation were developed by Clement (*ApJ* **249**,746;**276**,352) and applied to uniformly rotating polytropic models.

Fully nonadiabatic, first order (in Ω) equations for poloidal modes in uniformly rotating stars were derived by Caroll & Hansen (*ApJ* **263**,352). Numerical solutions for main-sequence star models were obtained.

Studies of toroidal (r-) mode properties have continued. A generalization of the adiabatic equations including perturbation of the gravitational potential and higher order terms in Ω was obtained by Smeyers, Craeynest & Martens (*Ap Sp Sc* **78**,483). Saio (*ApJ* **256**,717) derived the equations for nonadiabatic r-mode oscillations and solved them using realistic stellar models.

Nonlinear Mode Coupling

Direct numerical approaches to the nonlinear radial pulsation problem have been very successful in explaining many properties of the classical pulsating variables. They failed, however, to explain the multiperiodic variability observed in some of these stars and to account for amplitude limitation in delta Scuti variables. This created considerable interest in the perturbation approach. While limited in its applicability it has advantage of being more revealing and more economical. Moreover, it is the only available tool for studying nonlinear effects in nonradial oscillations.

A rigorous and elegant perturbation method based on the two-time formalism was developed by the team at University of Florida (Regev & Buchler *ApJ* **250**,679; Buchler & Regev *ApJ* **250**,776; Regev, Buchler & Barranco *ApJ* **257**,715; Barranco, Buchler & Regev *Ap Sp Sc* **84**,463; Buchler *AA* **118**,163; Buchler & Regev *AA* **123**,331). A less general (adiabatic approximation for the coupling term) but more explicit method was used by Dziembowski (*Acta Astron* **32**,147), by Aiakawa (*MN* **204**,1195;**206**,833) and by Dziembowski & Kovacs (*MN* **206**,497).

The critical role of the resonant mode coupling in the finite amplitude development of linear instabilities was clearly demonstrated. In particular, it was shown that it may cause amplitude limitation to a very low level, as encountered in delta Scuti stars, and lead to complicated unsteady limit cycles. It may be expected that in the near future more specific results will be obtained with this method.

11.3 APPLICATIONS

Variable Degenerate Dwarfs

The opacity mechanism acting in the H ionization zone was shown to be responsible for gravity mode instability in ZZ Ceti variables (Dolez & Vauclair *AA* **102**,375; Winget *et al*, *ApJ Lett* **252**,L65). In contrast to the previously suggested driving in the He^+ ionization zone with this hypothesis, the restriction on the mass of hydrogen rich envelope is acceptable. The strongest support for it, however, is a confirmed prediction of the gravity-mode excitation occurring under exactly analogous conditions in DB white dwarfs at higher effective temperatures (Winget *et al*, *ApJ Lett* **252**,L65). Although the temperatures of the discovered variables turned out to be higher than predicted, it was shown (Winget *et al*, *ApJ Lett* **268**,L33) that agreement may be reached upon a reasonable rescaling of the mixing length formalism.

Variability in very hot ($T \gtrsim 10^5$ K) degenerate dwarfs was suggested to be caused by gravity mode excitation due to the opacity mechanism acting in the carbon and oxygen ionization zones (Starrfield *et al*, *ApJ Lett* **267**,L27; *ApJ* **281**,800). The excitation occurs only if there is essentially no helium left in subphotospheric layers and if the relative amount of oxygen is larger than predicted by stellar evolution theory.

Studies of radial mode instability in degenerate dwarfs made by Saio, Winget & Robinson (*ApJ* **265**,958) and by Starrfield *et al* (*ApJ Lett* **267**,L27) revealed that the high overtones are unstable in the same models that have unstable gravity modes. So far, however, there is no observational evidence for the presence of high frequency oscillations in white dwarfs.

Identification of the instability mechanism for oscillations observed in degenerate dwarfs is certainly an outstanding achievement of the theory. It may be expected that future effort will focus on a detailed interpretation of the complicated patterns of the observed power spectra.

Delta Scuti Stars

These objects owe their variability to the same driving mechanism that causes Cepheid pulsation. It is believed that differences in pulsational behavior are due to the greater role of resonant mode coupling in amplitude limitation of delta Scuti stars than in the classical pulsating stars. Quantitative results supporting this view are not yet available.

In recent years efforts have concentrated on the determination of physical parameters for these stars with use of pulsation data. Fitch (*ApJ* **249**,218) per-formed an extensive survey of pulsation periods for models calculated with a standard stellar evolution code assuming population I chemical composition. The calculation included nonradial modes of a low spherical harmonic degree ($l \leq 3$). He found an overall consistency of standard stellar evolution theory with the observational data. A similar conclusion was reached by Andreasen, Hejlesen & Petersen (*AA* **121**,241) and Andreasen (*AA* **121**,250) who considered only the radial modes but included both population I and II models and studied effects of helium depletion in the outer envelopes. They stressed, however, the problem posed by the high masses (> 1 $M_\odot$) they found for population II objects. Models with helium depletion are neither supported nor rejected by the observations.

Rapidly Oscillating Magnetic Stars

The theoreticians' response to the discovery of this new type of variable star characterized by excitation of high order acoustic modes was a search for the driving mechanism. Dolez & Gough (in *Pulsations in Classical and Cataclysmic Variable Stars* Cox & Hansen eds, JILA, 1982, p 248) showed that in a normal main sequence star model with an appropriate effective temperature such modes are unstable if effects of convection are accounted for in a certain way. They failed, however, to explain the role of magnetic fields in the excitation. An effect of the magnetic field consisting in converting convective modes into overstable gravity modes was discussed in this context by Shibahashi (*ApJ Lett* **275**, L5) and by J.P. Cox (*ApJ* **280**,220). In their models the connection between the latter modes and observed acoustic ones remains to be clarified.

Beta Cephei Stars

The cause of their variability is still unknown. Lee & Osaki (*Publ Astron Soc Japan* **34**,39), who conducted standard nonadiabatic pulsation calculations, failed to confirm Stellingwerf's suggestion that the helium opacity bump at T $\sim 10^5$ K, if calculated with a fine grid, might turn out sufficiently large to cause an instability. More exotic models were considered by Cox & Hodson (*Pulsations in Classical and Cataclysmic Variable Stars*, p 332) who suggested an excitation due to the overshooting from the convective core and by Ando (*MN* **197**,1139) who discussed the possibility that the oscillations result from the Kelvin-Helmholtz instability in the differentially rotating interior. Osaki (*Pulsations in Classical and Cataclysmic Variable Stars*, p 303) reviewed all hypotheses concerning the driving mechanism in these variables.

Classical Pulsating Variables (Population I and II Cepheids, RR Lyrae)

Work by Whitney (*ApJ* **274**,830) clarified the nature of bumps in light curves for Cepheids by combining Christy's idea of pulse echo with Simon & Schmidt's explanation in terms of the 2:1 resonance between the fundamental and second overtone modes. The resonance hypothesis offers a natural interpretation for the Hertzsprung progression and a tool for mass determination. Cepheid masses determined in this way come out significantly less than those following from stellar evolution theory.

A similar bump progression is observed in short-period Population II Cepheids (BL Her stars). Theoretical modelling of their light-curves by Hodson, Cox & King (*ApJ* **253**,260) indicates that the masses of these stars are close to 0.55 $M_\odot$. This number is not in conflict with the stellar evolution models.

Major problems posed by double-mode pulsation phenomena remain open. Dziembowski & Kovacs (*MN* **206**,497) suggested that it arises when the mode that would otherwise be the only one present in the nonlinear regime is in the 2:1 resonance with a higher order mode. Their arguments are based on a simplified theory and therefore the idea should be verified by means of a direct numerical approach. A dramatic discrepancy between Cepheid masses derived from the observed period ratios and the evolutionary masses has not been resolved. Simon's

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(*ApJ Lett* **260**,L87) suggestion that the Cepheid mass anomalies could be rectified if the heavy element opacities are increased by factor two does not find support from the Los Alamos opacity team (Magee, Merts & Huebner *ApJ* **283**,264). To pursue further his own idea that the period ratio problem may be solved by allowing for a strong tangled magnetic field, Stothers (*ApJ* **255**,227) calculated nonlinear pulsations for models with such a field. The results are not really encouraging.

The masses derived from period ratios for double-mode RR Lyrae stars fall into the range 0.55 - 0.65 $M_{\odot}$, which is in a reasonable agreement with stellar evolution theory (A.N. Cox in *Pulsations in Classical and Cataclysmic Variable Stars*, p 157; Cox, Hodson & Clancy in *IAU Coll 68, Astrophysical Parameters for Globular Clusters* Philip & Hayes eds, L. Davis Press, 1982, p 337). It should be stressed, however, that as long as the double-mode Cepheid problem remains unsolved the whole diagnostic value of pulsation data remains questionable.

Stellingwerf (*ApJ* **277**,322) showed that inclusion of convection in RR Lyrae models causes a blueshift of the blue edges of the instability strip. This surprising effect is caused by changes in the structure of the H ionization zone which enhance the local driving effect. Sensitivity of the blue edge location to the helium content is significantly reduced in comparison with purely radiative models.

Long Period Variables

Fox & Wood (*ApJ* **259**,198) carried out a new survey of the linear nonadiabatic pulsation properties of stellar envelope models relevant to these stars. They found, in particular, that a periodic modulation of light curves seen in some Miras may be due to a simultaneous excitation of the fundamental and first overtone modes. An up-to-date review of theoretical work covering all types of long period variables was published by Wood (*Pulsations in Classical and Cataclysmic Variable Stars*, p 152).

Variability in Early and Medium Spectral Type Supergiants

Small-amplitude variability is a common phenomenon in all supergiants. No instability mechanism was found that could account for this phenomenon. Shibahashi & Osaki (*Pub Astron Soc Japan* **33**,427) confirmed that there are unstable nonradial modes in stars in a range of the H-R diagram to the left of the Cepheid instability strip. However, the l-values of such modes are uncomfortably large.

Lovy *et al* (*AA* **133**,307) calculated periods of the fundamental radial mode in models of supergiants. A comparison with the observed periods revealed that in some cases the latter are significantly longer. The authors suggest gravity mode excitation in such cases.

12. Commission Activities

A. GENERAL CATALOG OF VARIABLE STARS (N.N. Samus)

The *New Catalogue of Suspected Variable Stars* (*NSV*) appeared as a book in the "Nauka" Publishing House in early 1982. This was the first stage of the work on the 4th edition of the *General Catalogue of Variable Stars* (*GCVS*). The magnetic tape of *NSV* is now available from the astronomical data centers.

The magnetic tape of the first volume of *GCVS IV* is ready. It will be sent to the Strasbourg Center of Stellar Data by the end of 1984. The book of the first volume (Andromeda - Crux, about 7900 stars, with a foreword containing the description of the catalogue and of the classification system) is expected to be available by March, 1985. The second volume (Cygnus - Orion, about 10240 stars) is also almost ready and probably will be available, as a book and as a magnetic tape, by the XIXth General Assembly.

The 66th Name-list of variable stars printed in November 1981 (*IBVS* 2042) was the last one belonging to *GCVS III*. With this name-list the number of named variables reached 28457. These stars enter *GCVS IV*, the stars designated later will enter the Supplements to it. The 67th Name-list is now compiled (*IBVS*, in press). It contains 648 stars. This name-list, the first one in the system of *GCVS IV*, differs considerably in its form from earlier name-lists. In particular, it gives, along with the usual information, a list of stars ordered by right ascension (1950.0) as well as data on the range and type of variability.

During the period of this report the number of variable stars discovered in the USSR and designated in the "SVS" (Soviet Variable Star) system increased from 2493 (late 1981) to 2681 (September 1984).

B. INFORMATION BULLETIN ON VARIABLE STARS

The *Information Bulletin on Variable Stars* (*IBVS*) is designed to provide astronomers with rapid communication of important announcements and information about observational work. It has since its inception (1961) been edited at the Konkoly Observatory. From 1974 to 1984 the sole editor was Dr. B. Szeidl. In 1984 Dr. L. Szabados, who had assisted in this work for some time, joined Dr. Szeidl as co-editor.

During the three-year period covered by this report, the number of issues that have been published grew from 1985 (July 1981) to 2543 (June 1984). At present about 200 issues are prepared each year.

The editors strive for promptness of publication, which is of importance to authors and users alike. To this end it is required that manuscripts (one or two typewritten pages) be submitted in camera-ready form. Lengthy tabular material and visual observations are not accepted. A more detailed description of the requirements can be obtained from the editors.

The *IBVS* is sent to more than 500 astronomical institutes, observatories, and astronomy departments free of charge in exchange for their own publications or related scientific material. All correspondence concerning the *IBVS* should be addressed to:

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

C. ARCHIVES OF UNPUBLISHED OBSERVATIONS (Michel Breger)

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

Since the previous report to the IAU, the number of assigned file numbers has grown from 91 to 141. This represents another welcome acceleration of growth. Rapid retrieval of past files, often at no cost, has been reported from all three depositories.

The *Publications of the Astronomical Society of the Pacific* has kindly agreed to publish, on a regular basis, the summaries of recent files. Detailed reports can be found in *PASP* **91**,408, *PASP* **93**,528 and in an early 1985 issue of the *PASP*. Other summaries and announcements can be found in the *Information Bulletin on Variable Stars*. At present, astronomers who wish to *obtain* unpublished photoelectric measurements on variable stars may do so by requesting whole files (*not* partial files) from one of the three archives:

P.D. Hingley, Librarian
Royal Astronomical Society
Burlington House
London, W1V 0NL
Great Britain

Dr. C. Jaschek
Centre de Données Stellaires
Observatoire de Strasbourg
11, Rue de l'Université
67000 Strasbourg
France

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

There is no charge for short files. Astronomers who wish to *submit* unpublished observations should send *three* copies as well as a brief descriptive cover sheet to the Coordinator (address listed below). The Coordinator will assign file numbers and forward the observations to London, Strasbourg and Odessa. New files must be printed or handwritten in *black ink*. The printed part should be larger than 8.5 by 11 inches (21.6 by 28 cm). If a new file number is required for scientific publications (in place of extensive tables of measurements), the file number can be assigned by the Coordinator before receipt of the actual measurements. The address is:

Professor Dr. M. Breger
Institut für Astronomie
Türkenschanzstr. 17
A-1180 Wien
Austria.

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

92. 16 Algol Systems: XZ And, KO Aql, RZ Cas, U Cep, U CrB, SW Cyg, W Del, AI Dra, TT Lyr, RW Mon, RV Oph, ST Per, U Sge, RW Tau, X Tri, and TX UMa - E.C. Olson.
93. HD 8357 - D.S. Hall
94. 29 Dra - D.S. Hall
95. HD 26337 - D.S. Hall
96. HD 136905 - D.S. Hall
97. RS Ind - D.S. Hall
98. Algol - G.A. Bower
99. 10 Ap Stars: HR 4082, HR 4109, HR 4327, HR 4552, HR 4817, GC 17563, HR 4965, HR 5158, HR 5269, and GC 19369 - P. Renson and J. Manfroid.
102. HR 2724 - D. Baade and O. Stahl
103. ST Ind - V.J. Mugherli
104. 16 Lac - R. Garrido
105. δ Pic - C.C. Wu
106. HD 1833, 37847, 185510, 190540, 205249, - D.S. Hall
107. DK Dra - D.S. Hall
108. IM Peg - D.S. Hall
109. λ And - D.S. Hall
110. MM Her - D.S. Hall
111. SS Boo - D.S. Hall
112. FZ CMa - N. Vogt
113. SS Psc - G. Garbusov
114. FK Com - S. Morris & E. Milone
115. CL Dra - D.L. Du Puy
116. HR 1225 - D.L. Du Puy
117. V711 Tau - D.S. Hall
118. V444 Cyg - J.A. Eaton
119. 39 AJ Cet - D.S. Hall
120. σ Gem - D.S. Hall
121. 16 RS CVn-type stars - J.A. Eaton
122. 4 W UMa binaries - J.A. Eaton
123. W Gru - M.A. Cerruti
124. 44 i Boo - E.F. Milone & R.M. Robb
125. 1 Cam, HR 8105, V358 Per, V568 Cyg, 2 ES Vul, V819 Cyg - C. Stagg
126. CC Com - D.H. Bradstreet
127. FG Sct - D.H. Bradstreet
128. BI Vul - D.H. Bradstreet
129. FS CrA - D.H. Bradstreet
130. VZ Psc - D.H. Bradstreet
131. Automatic telescope results: 4th quarter, 1983 - L.J. Boyd, R.M. Genet and D.S. Hall
132. Eta Ori - R.H. Koch
133. XY Leo - B.J. Hrivnak
135. CG Cyg - R. Robb
136. Automatic telescope results: 1st quarter, 1984 - L.J. Boyd, R.M. Genet and D.S. Hall
138. BD +28°1494 - P. Broglia
141. RS Cep - D.S. Hall

N. H. BAKER
President of the Commission

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