35. STELLAR CONSTITUTION (CONSTITUTION DES ÉTOILES)

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I. INTRODUCTION

This report of Commission 35, as in past reports, consists of some details of only a few selected topics. This is necessary because a survey of the entire field of stellar formation, structure, stability, evolution, pulsation, and explosions for the three year period from mid-1981 to mid-1984 would be excessively long. Our topics here, in order from the most massive stellar classes to the least are: Massive Stars (R.M. Humphreys), Rotation in Late Type Stars (W. Benz), Helioseismology (J. Christensen-Dalsgaard), Planetary Nebula Central Stars (E.M. Sion), Pulsations in Hot Degenerate Dwarf Stars (A.N. Cox and S.D. Kawaler), and White Dwarfs (V. Weidemann). There is some overlap in the reviewing of these last three reports because the topics are very closely related. Concentration in this dying stage of stellar evolution seems appropriate because of the great current interest in these matters.

In the course of our considerations of these topics, the Organizing Committee had two other topics that we could not get reviewed in time. Nevertheless, we hope for appropriate reviews in the next report on star formation and the new infrared observations of them as well as the comparisons of surface abundances that are observed and those predicted from stellar evolution calculations.

References are given as their number in the Astronomy and Astrophysics Abstracts when possible. In many cases, the conventional references needed to be given because the 1984 volumes were not available in December 1984.

Interest in stars continues at a high level. During the reporting period five Symposia and five Colloquia were held on topics of interest to Commission 35. These are: Symposium 102 Solar and Stellar Magnetic Fields, Zurich, Switzerland, August 2-6, 1982; Symposium 103 Planetary Nebulae, London, England, August 9-13, 1982; Symposium 105 Observational Tests of the Stellar Evolution Theory, Geneva, Switzerland, September 12-16, 1983; Symposium 108 Structure and Evolution of the Magellanic Clouds, Tubingen, GFR, September 5-8, 1983; Symposium 111 Calibration of Fundamental Stellar Quantities, Como, Italy, May 24-29, 1984; Colloquium 68 Astrophysical Parameters for Globular Clusters, Schenectady, New York, USA, October 7-10, 1981; Colloquium 71 Activity in Red Dwarf Stars, Catania, Italy, August 10-13, 1982; Colloquium 72 Cataclysmic Variables and Related Objects, Haifa, Israel, August 9-13, 1982; Colloquium 76 Nearby Stars and the Stellar Luminosity Function, Middletown, Connecticut, USA, June 13-16, 1983; and Colloquium 82 Cepheids: Observation and Theory, Toronto, Canada, May 29-June 1, 1984.

From the following brief reports and the above listed international meetings, one can see that there are still many frontiers for Commission 35. More detailed and accurate observations of a variety of observables and more elaborate calculations of how stars are born, evolve and die make this field still very exciting.

II. MASSIVE STARS (R.M. Humphreys, University of Minnesota)

The evolution of the most massive stars ($\geq 15\ M_{\odot}$) is a subject that has progressed very rapidly in the past ten years. Much of this progress has been stimulated by observational advances including ultraviolet measurements of mass loss rates in hot stars via IUE and other satellites and our ability with the modern, large relectors and new detectors to observe the luminous star populations in other galaxies. These observations have led to the realization that mass loss plays a major role in the lives of massive stars across the HR diagram. Consequently, the models of massive star evolution now routinely include mass loss as well as other new physical processes such as internal mixing and convective overshooting, plus differences in metallicity to explain the observed features of the HR diagram in our galaxy and others.

There have been a number of meetings, symposia and reviews on massive stars, their evolution and related topics, including the ESO Workshop on The Most Massive Stars (31.012.034), IAU Symposium #105, Observational Tests of the Stellar Evolution Theory (1984, ed. Maeder and Renzini), IAU Symposium #99, Wolf-Rayet Stars: Observations, Physics, Evolution (32.012.042), and The Effects of Mass Loss on Stellar Evolution (30.012.015). De Jager's book The Brightest Stars (28.003.060) is a comprehensive review of all aspects of massive star research up through about 1979, and the recent review article by Humphreys and Davidson (Science, 223, 243, 1984) gives a brief history and summarizes the most recent ideas and developments. Interested scientists are referred to these publications for numerous reviews and papers on massive stars and massive star evolution.

In this brief review of the current literature I will summarize the models and the comparison with observations plus three subjects that have recently received considerable attention; the evolution to Wolf-Rayet stars, luminous blue variables, and the possibility of supermassive stars.

1. Models and Evolutionary Tracks

The observed HR diagram for massive stars in our galaxy and other nearby galaxies cannot be adequately explained by conservative, non-mass loss evolution. We now realize that stellar winds and mass loss occur in massive stars of all types and may alter their evolution. There is also increasing evidence from the chemical abundances in the atmospheres and ejecta of the most massive stars for mixing and turbulence in their interiors.

Models showing the effects of mass loss have been studied by de Loore et al. (21.065.079), Chiosi et al. (21.065.008, 25.065.025), Stothers and Chin (26.065.014), Maeder (28.065.068, 29.065.112, 30.065.066, 33.065.025), Noels and Gabriel (30.065.008), Falk and Mitalas (30.065.024, 33.065.004), Sreenivasan and Wilson (31.065.010), Brunish and Truran (31.065.015, 32.065.006), Doom (32.065.092, 32.065.093), and Klapp (33.065.087). Inclusion of mass loss in the models results in evolution across the HR diagram at essentially constant luminosity but at a lower luminosity than without mass loss (the star is overluminous for its mass), an increase in the mass fraction of the core, an increase in the main sequence lifetime, and a widening of the main sequence. Mass loss also increases the length of time the star spends in the red supergiant stage in better agreement with the observations; although, higher mass loss rates reduces the lifetime of the most luminous M supergiants. In contrast, the models by Brunish and Truran (31.065.015) predicted an absence of red supergiants not supported by the observations of supergiants in associations and clusters by Humphreys (22.002.058, 26.115.001, Humphreys and McElroy Ap.J., 284, 565, 1984).

Overall, comparison between the mass loss models and the observations is reasonably good except for the excess of luminous stars outside or to the right of the hydrogen burning main sequence band on the HR diagram. Meylan and Maeder (31.153.008) have shown that this main sequence widening is very likely a real effect in young clusters in our galaxy and the Magellanic Clouds.

Models with convective overshooting by Bressan et al. (30.065.047), Stothers and Chin (30.065.004), and by Doom (32.065.092, 32.065.093) produce a somewhat broader main sequence, but are still insufficient to explain the observations. Bertelli et al. (A.&A., 130, 279, 1984), have suggested that a combination of mass loss, convective overshooting and a moderate CNO opacity enhancement produces satisfactory agreement with observations. Indeed, with these combined effects they find that hydrogen burning may extend all the way to the red supergiant region. Maeder (31.065.002) has shown that mixing by turbulent diffusion will also broaden the main sequence. The effects of internal mixing on the most massive stars will be discussed later.

Metallicity variations should appear more frequently in future models to examine the possible dependence of massive star evolution on chemical composition gradients in our galaxy and for comparison with massive star populations in other galaxies, especially the Magellanic Clouds. A few evolutionary tracks for massive stars have been computed with the chemical abundances of the LMC and SMC by Maeder (28.065.068), Hellings and Vanbeveren (30.065.027), and Brunish and Truran (32.065.006).

2. Evolution to Wolf-Rayet Stars

Wolf-Rayet stars and their evolution were the subject of IAU Symposium #99 (32.012.042). Four main scenarios have emerged as the most probable explanations, whether separately or in concert, for the origins of the WR stars: 1) mass loss in massive main sequence stars (the Conti scenario), 2) mass loss from red supergiants, 3) mass transfer in binaries, and 4) mixing.

The initial masses of the WR stars are particularly important for understanding their evolutionary origins. A lower limit to their initial masses close to 20 $M_\odot$ was proposed by Chiosi (31.012.034), Maeder (30.065.066, 31.065.002), and Fermani (32.012.042); however, Conti et al. (34.010.061), suggested that WR stars evolve from stars more massive than 40 $M_\odot$ based on their analysis of the galactic distributions of O- and WR-type stars. Recently Schild and Maeder (A.&A., 136, 237, 1984) from an analysis of WR stars in clusters and associations found lower limits to their initial masses of 18 $M_\odot$ for WN stars and 35 $M_\odot$ for WC stars, but concluded that the majority probably originate from stars >40 $M_\odot$. In similar studies Vanbeveren (A.&A., 1984, in press) found that WR stars descend from stars with initial masses >35 $M_\odot$. and Humphreys, Nichols, and Massey (A.J., 1985, in press) concluded that while WR stars have a lower limit to their initial masses >30 $M_\odot$, 80% of them have initial masses $\geq$ 50 $M_\odot$. There is a consensus emerging from these different studies that most WR stars have a lower limit to their initial masses near 40 to 50 $M_\odot$. This implies that most M supergiants, with initial masses of 15-30 $M_\odot$, are not progenitors of WR stars. Only the most massive, most luminous red supergiants would have the potential of becoming WR stars. A lower limit of 40 $M_\odot$ also implies a much greater number of WR stars compared to massive main sequence stars than predicted by the theoretical models.

There is a very pronounced lack of WR stars in the outer parts of our galaxy; for all the known WR stars within 2.5 kpc of the sun (34.115.018) the ratio is about 6 to 1 between the regions interior and exterior to the solar orbit. This difference can be largely explained by fewer massive star progenitors in the outer parts. Recent studies of the IMF for massive stars (Garmany et al., 32.155.061, Humphreys and McElroy, Ap.J., 284, 565, 1984) show that the number of massive stars per unit area is greater in the inner regions, and the IMF for the interior region would predict about three times as many massive stars in the inner region compared to the observed ratio for WR stars of about six. The remaining difference of a factor of two may be due to metallicity effects; higher metallicity leads to higher mass loss rates which may lead more of the most massive stars to the WR stage, as suggested by Maeder (31.065.002).

3. Luminous Blue Variables

A group of very luminous, hot stars with peculiar emission line spectra which are also known to be unstable and undergoing unsteady mass loss provide important clues to the evolution of the most massive stars and their eventual fate. Well known examples of this group of stars include η Car, P Cyg, S Dor and the Hubble-Sandage variables in M31 and M33. Information on their temperatures, luminosities, and mass loss rates have recently been determined for many of these stars primarily as a result of ultraviolet (IUE) and infrared observations. [η Car: Pagel (2.122.090), Davidson (6.114.064), Neugebauer and Westphal (1.113.014), Robinson et al. (9.114.025), Gehrz et al. (09.114.030), and Hyland et al. (26.133.013); P Cyg: Cassatella et al. (26.114.059), Underhill (26.114.088), and Lamers et al. (A.&A., in press, 1984); S Dor etc. in the LMC and SMC: Wolf et al. (28.122.024, 30.122.057, 30.122.103), Appenzeller and Wolf (31.012.034), and Shore and Sanduleak (Ap.J. Suppl., 55, 1, 1984); and for the Hubble-Sandage Variables in M31 and M33; Humphreys (14.114.322, 21.158.012), Gallagher et al. (30.114.101), and Humphreys et al. (Ap.J., 278, 124, 1984)]. Their measured mass loss rates range from 10^{-5} to 10^{-3} $M_{\odot}$/yr with a possible high of 10^{-1} $M_{\odot}$/yr for η Car (22.064.080). These stars occupy a critical position on the HR diagram with luminosities between M_{bol} = -10 and -12, on or near the observed upper luminosity boundary for normal hot stars (see Science, 223, 243, 1984 and Humphreys et al., Ap.J., 278, 124, 1984). η Car, P Cyg, some of the H-S variables (Var A in M33) and most recently R127 in the LMC by Walborn (in Workshop on MK Spectral Classification: Criteria and Applications) and by Stahl et al. (34.122.067), are thought to suffer spectacular episodes of mass ejection. These stars may represent a stage in the evolution of the most massive stars when they are very near an 'instability limit' (Humphreys and Davidson 26.115.001).

The famous star η Car is probably the most massive and most extreme member of this group and has undergone more than one episode of large mass ejection. Davidson, Walborn, and Gull (31.112.009) found that the ejecta from η Car is nitrogen-rich but carbon and oxygen-poor. Many of the other variables are also known to be nitrogen-rich [Shore and Sanduleak, (Ap.J. Suppl., 55, 1, 1984) and Walborn (31.159.014)]. This suggests that these hot, luminous and often unstable stars are on their way to becoming Wolf-Rayet stars of the late WN type. A possible evolutionary sequence for stars >60 $M_{\odot}$, O → Of → LB Var. → WN7-9 has recently been proposed by several authors. However, Bath (26.064.026) has suggested an alternative model for these luminous stars in which they are really accretion disks around moderately massive stars in binary system.

The exact cause of the instability in these stars is not known but there are several alternatives as discussed by Stothers and Chin (33.122.005). An internal vibrational instability is possible, but very likely surface radiation pressure is also involved. Maeder (33.065.025) has proposed that a deep convective zone develops in the outer layers of very massive stars as they evolve to cooler temperatures and gives rise to a turbulent pressure gradient which can oppose gravity if the star's luminosity is high enough. The de Jager limit (28.003.060) for stability is reached when the turbulent pressure gradient equals the acceleration due to gravity. This halts the star's evolution to lower temperatures accompanied by enhanced mass loss. Maeder's models show that the star then evolves to warmer temperatures at essentially constant luminosity on short time scales. This corresponds to the observations of R71 and S Dor (Appenzeller and

Wolf 31.012.034) and Var 83 in M33 (Humphreys et al., Ap.J., 278, 124, 1984) between maximum and minimum.

In a very recent paper de Jager (A.&A., 138, 246, 1984) has presented a more quantitative discussion of the observed luminosity boundary for luminous supergiants and the stability limit confirming many of the ideas originally put forward by Humphreys and Davidson (26.115.001) and by Maeder (33.065.025).

4. Supermassive Stars

Radcliffe 136a, the central object of the giant nebula 30 Doradus in the Large Magellanic Cloud has received considerable notariety as a possible supermassive star. Several years ago Schmidt-Kaler and Feitzinger (27.132.017, 31.012.034) suggested that it accounts for most of the ultraviolet radiation that ionizes the nebula. After obtaining UV spectra with IUE, Cassinelli et al. (30.132.008), concluded along with Schmidt-Kaler and Feitzinger that R136a is a single star with a luminosity nearly 10^8 $L_\odot$ and a temperature > 60,000°K corresponding to a mass near 3000 $M_\odot$ although additional data on the UV continuum by Savage et al. (34.115.011), reduced the mass estimate to about 2000 $M_\odot$.

Such extreme mass and luminosity estimates for R136a naturally made it a very controversial object. Years ago Walborn (9.131.168) suggested that R136a is analogous to the very compact group of luminous stars in NGC 3603. Numerous astronomers have recently discussed the possible nature of R136a and an entire session at IAU Symposium #108 Structure and Evolution of the Magellanic Clouds (1984, ed., van den Bergh and de Boer) was dedicated to the 30 Doradus nebula and R136a including a lively panel discussion on whether R136a is a single star or a compact group.

It is now realized that R136a is definitely a binary (Innis Catalogue of Double Stars, 1927, Worley, Ap.J., 278, L109, 1984, and Chu, Cassinelli and Wolfire, Ap.J., 283, 560, 1984) and very likely a multiple system (G Weigelt, unpublished speckle interferometric measurements) similar to NGC 3603. These considerations will reduce the mass estimate for the primary to a few hundred solar masses; still very high, comparable to or greater than that of η Car.

Massey and Hutchings (34.157.191) have suggested that several objects in M33 with Wolf-Rayet-like spectra may resemble R136a, but M33 is much further away than the LMC and it is not possible to tell whether any of them are single stars.

The formation of these very massive stars and especially the large groups of very massive stars represented by the η Car group (Tr 14, 15, 16) and NGC 3603 in our galaxy, the R136 complex in the LMC and NGC 604 in M33 is an important problem for future work on massive evolution.

III. ROTATION IN LATE TYPE STARS (W. Benz, Geneva Observatory and Los Alamos National Laboratory)

1. Introduction

The tremendous development of observational techniques in the visible as well as in the UV and X-ray spectral domain in the last years has brought a great rebirth of interest in the study of rotation and its effects in late type stars. Rotation was found to play an important role in so many fields that a complete review is far beyond the scope of this brief survey of the past three years literature. I will therefore only review some aspects of the subject: rotational measurement techniques, temporal variation of the rotation, and chromospheric and coronal activity.

There have been several meetings about these topics and related ones: the second and the third Cambridge workshop on cool stars, stellar systems and the sun (1981, eds. M.S. Giampapa, L. Golub, 32.012.065; 1983, eds. S.L. Baliunas, L. Hartmann, Lecture Notes in Physics, Vol. 193), the IAU Symposium #102 on Solar and Stellar Magnetic Fields: Origins and Coronal Effects (1982, ed. J.O. Stenflo, 34.012.017) and the IAU Colloquium #71 on Activity in Red Dwarf Stars (1982, eds. P.B. Byrne, M. Rodono, 34.012.026). Interested scientists are referred to these publications for numerous reviews and papers as well as for further references.

2. Rotation velocity measurements

Rotation and age correlation studies obviously require high precision velocity measurements that for slow rotators are difficult to achieve. In the last years two different spectroscopic techniques have shown to be able to challenge that goal. The first one is based on a Fourier transform of the spectral line and was proposed several years ago by Smith and Gray (19.031.402) and the second one, based on a correlation technique, was proposed by Benz and Mayor (29.031.502). Comparison papers have been written to check the coherence between all determined rotational velocities, Soderblom (32.116.018), Benz and Mayor (1984, A&A 138,183). Even though there is a general agreement between all determinations, there are still unexplained differences for individual stars even between authors using the same determination technique. Recently Bruning (1984, Ap.J., 281,830) has proposed that the differences between users of the Fourier transform technique may exist because of the breakdown of some basic assumptions of the method.

Observations of periodic variations either in the Ca ll emission reversals, Middelkoop et al. (29.116.013), Vaughan et al. (30.116.029), Baliunas et al. (34.116.042), or in luminosity, Van Leeuven and Alphenaar (32.153.043) have provided an indirect method of deriving rotational velocities that has the advantage of being independent of line profile analyses. In a study of K stars in the Pleiades, Van Leeuven and Alphenaar have found very short periodic luminosity variations that imply unusually high rotational velocities for this type of stars. Soderblom et al. (34.153.051), spectroscopically confirmed these high velocities concluding therefore that they are really spotted stars and definitively not ellipsoidal stars or close binaries. However, Benz et al. (1984, A&A, 138,93), do not find such a close agreement in five stars they had in common with the list of Van Leeuven and Alphenaar. Finally Stauffer et al. (1984, Ap.J., 280,202), show that the rotation distributions of the Pleiades K dwarfs is a superposition between two components, one that seems unusual for this spectral type. They conclude that the fast rotators are stars only recently arrived on the main sequence implying an age spread of at least 3 × 10^7 yrs in the Pleiades. Smith et al. (34.121.012), found the same two components structure in a study of G stars in the Orion Ic cluster (despite some possible membership problems).

Macroturbulence is a major problem in determining rotational velocities in late type stars as its broadening effect may be as important as the rotational one. The Fourier transform technique allows a separation of both turbulence and rotational broadening. Gray (30.116.041) has given macroturbulence velocities for five giants whereas Soderblom (32.116.018) and Gray (1984, Ap.J., 281,719) list macroturbulence values for dwarfs. The latter show that macroturbulence decreases rapidly with advancing spectral type and that Zeeman broadening may have a significant effect. This was confirmed by the study of Benz and Mayor (1984, A&A, 138,183) who also suggest an increase of turbulence with equatorial rotational velocity.

3. Rotation and age

Several attempts to determine the decay of the rotation with age in main sequence stars have been made by using either field stars or open clusters stars. The first stars have the advantage of being brighter than the second, but cluster stars are much more easily dated. Soderblom (32.116.018, 34.116.006) has shown *that rotation in solar type stars is well fitted by the* $t^{0.5}$ *relation proposed a* long time ago by Skumanich (7.114.020). However, Smith et al. (34.121.012), and Benz et al. (1984, A&A, 138,93), using rotational velocities of nearby clusters stars, do not confirm this relation. They both show that the rotation decay must be smaller for stars younger than the Hyades. Benz et al., show that the same decay is to be expected for all stars in the spectral range F8 to K3. Gray (32.116.006) by looking at rotation rates as a function of spectral type for F, G, and K stars even suggests that besides the slow spindown, there must be a strong braking phase before these stars reach the main sequence. Endal and Sophia in numerical models of the evolution of a solar-type star indeed found that a phase characterized by a strong decrease of angular momentum was followed by another one *with a much lower variation of the angular momentum (29.080.016). Using rotation* periods deduced from Ca II emission variations, Catalano and Maritti (33.116.010, 34.012.026) showed that for stars of spectral type between F8 to K5 the rotation period only depends on mass and age of the star. Geroyannis and Antonakopoulos (30.065.063) constructed polytropic models with differential rotation in order to study the decay of the rotation. The characteristic decay time they got is consistent with observations. A theoretical review of angular momentum loss produced by stellar winds may be found in Roxburgh (34.012.017).

The spindown in giant stars was discussed by Gray (30.116.041, 32.116.015, 33.116.004, 34.012.017). He showed that there exists a powerful mechanism bringing the rotation down from 25 km/s to 5 km/s and that all giants leave this phase with about the same velocity. Gray and Endal (31.153.002) have shown that this slow rotation rate might be explained either by a braking mechanism or differential rotation in the convectives zones. Endal (34.012.017) suggests that a dynamo mechanism is responsible for the sudden drop of the rotational velocity at G5 III.

4. Rotation and stellar activity

Ca II, Mg II and X-ray emission have been widely studied as they are believed to be a signature of chromospheric or coronal activity. The correlation between *rotation and emission intensity got particular attention as it may give the clue* to the physical mechanism driving the stellar activity. Knobloch et al. (30.116.036), proposed a theoretical explanation of the correlation between magnetic activity and rotation in terms of a transition between convection patterns as the angular velocity becomes smaller. Further discussions of the connection between activity and rotation might be found in Noyes (32.012.065), Dupree (32.012.65), and Rosner (34.012.017).

4.1 Chromospheric activity

Variation of Ca II emission with rotation was found by Middelkoop (30.116.015, 31.116.013), Pallavicini et al. (32.012.065), and Noyes et al. (1984, Ap.J., 279,763). Noyes et al., also show that the decrease of Ca II emission with rotation is the same for stars above and below the Vaughan-Preston gap, thus casting doubts on explanations of the gap in terms of a discontinuity in dynamo characteristics. That the gap might be an artificial structure was suggested by Hartmann et al. (1984, Ap.J., 276,254), who showed that a similar structure is obtained with a smooth function for chromospheric decay.

Böhm-Vitense by looking at Mg II and transition layer emission lines (32.012.006, 32.114.002, 32.012.065) in F stars did not find an increase of emission with increasing rotation for stars rotating faster than 30 km/s whereas *Hartmann et al. (1984, 279,778), present IUE observations that correlate well with*

Ca II emissions. However, a definite conclusion that Mg II lines exhibit the same feature as Ca II lines could not be made because of the small number of data points.

4.2 Coronal activity

The Einstein X-ray Observatory satellite program of mapping the occurrence of X-ray emissions in late type stars (Ayres et al., 30.115.018) has shown that these stars may have a hot coronae. Walter (29.116.018, 29.116.019) shows that, similarly to chromospheric activity, coronal activity is a function of angular velocity and depth of the convective zone. Later by reexamining the rotation-activity relation, Walter (31.116.006, 34.012.017) suggests that a gap at 12 days rotation period exists in the L_x/L_{bol} versus rotation period relation. This gap was confirmed later by Smith (33.116.017). Walter also found that a correlation between X-ray emission and rotation appear only for stars redder than B-V=0.45. He speculates that this limit represents the turn-on of a solar-like dynamo. Further confirmations of the existence of a relation between rotation and emission was given by Smith et al. (34.153.018), in a study of G stars in the Orion Ic cluster and by Stern and Skumanich (33.118.014). Rucinski however showed that X-ray luminosities for M dwarfs are too large to be due to rotation, they must derive ultimately from nuclear energy sources.

A theoretical estimate of the dependence of the X-ray coronal flux from late-type stars on various stellar parameters is given by Paterno and Zuccarello (34.064.083). They show that an approximate relationship between X-ray surface flux and mass, angular velocity and depth of the convection zone may be derived. Finally, Mangeney and Praderie (1984, A&A, 130,143) suggested that the convection-rotation-interaction can be represented by an effective Rossby number. Interesting relations are presented between L_x and F_x and this Rossby number which are valid for almost all spectral types, whereas using L_x/L_{bol} no general relation could be found.

IV. HELIOSEISMOLOGY (J. Christensen-Dalsgaard, Nordita and University of Aarhus)

1. Introduction

The study of the solar interior structure and dynamics by means of observations of solar oscillations has matured very considerably during the last three years. In 1981 the existence of global solar oscillations had been firmly established, although in most cases the modes of oscillation had not yet been definitely identified. Now a direct determination of the sound speed in a large part of the solar interior has become possible, and the equatorial rotation rate has been measured in most of the Sun.

Several conferences have been concerned with this subject. These include IAU Colloquium No. 66 on "Problems of Solar and Stellar Oscillations" in Crimea in 1981 (published in Solar Phys., vol. 82; ed., D. O. Gough), the conference on "Pulsations in Classical and Cataclysmic Variable Stars" at JILA, Boulder in 1982 (eds., J. P. Cox & C. J. Hansen; JILA), the EPS study conference on "Oscillations as a Probe of the Sun's Interior" in Catania in 1983 [published in Mem. S. A. It., vol. 55; eds., G. Belvedere & L. Paterno: in the following referred to as (Catania)], the workshop on "Solar Seismology from Space" in Snowmass in 1983 [ed., R. K. Ulrich; JPL: (Snowmass)], and the International Astrophysical Colloquium on "Theoretical Problems in Stellar Stability and Oscillations" in Liège in 1984 [published by Institut d'Astrophysique, Liège; (Liège)]. The proceedings of these conferences contain reviews on various aspects of the subject. Reference may also be made to the reviews by Deubner & Gough (Ann. Rev. Astron. Astrophys., 22, 593), by Christensen-Dalsgaard (33.080.020), and by Gough (Adv. Space Res., in press, 1984).

The advances in helioseismology have in large measure been caused by improvements in the observations of solar oscillations (see also the section by Duvall in the report from Commission 12). Particularly important were the observations by Duvall & Harvey (33.080.16) which for the first time closed the gap between the 5 min modes of high and low degrees, thereby establishing the radial orders of the latter. In addition, observations from two widely spaced stations [Claverie et al., (Catania), p. 63] have resulted in the measurement of frequencies of low-degree 5 min modes with an accuracy which exceeds that with which the mass and radius of the Sun are known. There have also been continued observations of oscillations at longer periods (e.g., Scherrer & Wilcox, 33.080.22; Delache & Scherrer, 34.080.049; Severny et al., Nature, 307, 247), although the modes responsible have not been definitely identified yet. Finally, observations of the atmospheric behaviour of the oscillations are becoming increasingly detailed [e.g., Staiger et al., (Catania) p. 147; Andersen, (Liège) p. 220].

2. Inverse theory

The frequency of a given mode of solar oscillation is determined by the structure of that part of the Sun where the mode has appreciable amplitude (as measured, e.g., in terms of the energy density). The location of this region depends on the nature of the mode. The 5 min modes are standing acoustic waves which are trapped between the surface and an inner turning point. For modes of low degree ℓ[1] the trapping region extends over most of the solar interior, whereas at high degrees the modes are confined close to the surface. Thus, by combining frequencies of modes of different degree, localized information about the structure and dynamics can in principle be obtained. The long-period oscillations must be high-order gravity modes (cf. Christensen-Dalsgaard et al., 33.080.009) which are concentrated towards the centre of the Sun; their frequencies therefore give information about the deep interior.

The observed quantities are mean frequencies, which (for adiabatic oscillation) are determined by the density ρ and the adiabatic exponent γ in the Sun, and the frequency splittings induced by rotation, which are linear functionals of the rotation rate. The simplest way of interpreting the observed frequencies is by comparing with frequencies computed for solar models, to determine the model which best fits the data. To determine the rotation rate one may attempt to specify it in terms of a small set of parameters (e.g., as a piece-wise constant or piece-wise linear function, or a polynomial), the parameters being determined by least squares fitting. More systematic inversion procedures have been developed in geophysics (Parker, 19.081.035) and may be applied to the solar data [Gough, (Snowmass) p. 49].

To test the methods it is very useful to apply them to fictitious data, such as rotational splittings for a given, imposed rotation law, to see how well they recover the input. Studies of this nature have been carried out for density inversions by Cooper & Gough (cf. Cooper, Ph.D. Dissertation, University of Cambridge, 1981), and for rotational inversions by Gough [(Snowmass) p. 49] and Christensen-Dalsgaard & Gough [(Snowmass) p. 79]. Broadly speaking, from observations of 5 min modes over a sufficiently large range of degrees, localized information can be obtained about the region scanned by the turning points of the modes. Alternatively, the interior of the model can be resolved with only modes of low degree, provided all acoustic modes, and a few low-order gravity modes, are

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[1] ℓ is the degree of the spherical harmonic Y_ℓ^m which describes the variation of the mode over the solar surface.

included; however, it must be emphasized that low order modes have not been definitely identified on the Sun.

3. Results of solar structure

The frequencies of 5 min modes are largely determined by the variation in the sound speed in the solar interior. From observations of modes of high degree it has been inferred that the depth of the convection zone is about 0.3 $R_\odot$ (e.g., Berthomieu et al., 27.080.068; Lubow et al., 27.080.067). This result is unlikely to be affected by atmospheric non-linearities of the oscillations (Belvedere et al., 33.080.043). However, it may depend somewhat on the physics of the model or the oscillations in the layers close to the surface.

Low-degree 5 min modes provide information about global properties of the Sun. Among models with different heavy element abundances Z, the agreement between the observed and the computed frequencies is generally best for $Z \cong 0.02$ [Christensen-Dalsgaard & Gough, 30.080.064; Shibahashi et al., 34.080.008; Christensen-Dalsgaard, (Liège) p. 155]; this is very close to the spectroscopically determined value (Grevesse, Proc. 7th Europ. Regional Meeting in Astr., Mem. S. A. It., in press, 1984). Such models have a helium abundance $Y \cong 0.25$ (e.g., Gough, 34.080.023). Models with low Z are ruled out by the oscillation observations. However, even for the models which best fit the observations, the differences between theory and observation are considerably higher than the observational, or the intrinsic computational, errors.

These differences are often discussed in terms of parameters based on the asymptotic theory of low-degree high-order acoustic modes (e.g., Tassoul, 28.065.044). Thus the mean separation $\Delta\nu_\ell$ between the frequencies of adjacent modes of the same degree is a measure of the inverse sound travel time between the centre and the surface of the Sun. In most solar models (e.g., Christensen-Dalsgaard & Gough, 28.080.062; Ulrich & Rhodes, 33.080.007; Noels et al., A. & A., 130, 389) this quantity is 0.5 - 1 μHz higher than the observed value of about 135.2 μHz; but for Z = 0.02 Shibahashi et al. (34.080.008) obtained a value quite close to the observed one. A second important characteristic of the spectrum is the average $\delta\nu_\ell$ of the small separation $\nu_{n,\ell} - \nu_{n-1,\ell+2}$ between frequencies of modes differing by 1 in radial order n and 2 in degree; this is largely a measure of the properties of the solar core (e.g., Gough, Phys. Bull., 34, 502). For normal solar models $\delta\nu_\ell$ is generally consistent with the observations, whereas it is about 50 percent too large in models with substantial mixing in the interior [e.g., Christensen-Dalsgaard & Gough, loc. cit.; Ulrich & Rhodes, loc. cit.; Cox & Kidman, (Liège) p. 259]. Thus observations of low-degree 5 min modes constrain the extent to which the core of the Sun can have been mixed.

Analysis of low-degree 5 min modes, taken in isolation, provides little information about the origin of the discrepancies between theory and observations. With observations of 5 min modes at all degrees, however, one should be able to locate the causes of the discrepancies. A preliminary comparison (Christensen-Dalsgaard & Gough, [Snowmass] p. 193) of the observations of Duvall & Harvey with a normal solar model indicated that the errors in the model were predominantly close to its surface, with a possible additional contribution from near the base of the convection zone; most of the radiative interior seemed to be consistent with the observed frequencies. Qualitatively similar results are obtained from the published frequencies for most other normal solar models (e.g., Ulrich & Rhodes, loc. cit.; Noels et al., loc. cit); the model of Shibahashi et al., agrees considerably better with the observations. In this model the convection zone is only very slightly deeper than for the model considered by Christensen-Dalsgaard & Gough, but the central temperature and density are higher by about 9 and 23 percent, respectively. The reasons for these differences, and their relation to the computed frequencies, require further study.

The frequencies, degrees and radial orders of the 5 min modes satisfy a simple, approximate relation, first found by Duvall (32.080.029) from observational data on high-degree modes. Asymptotic theory (e.g., Gough, Phil. Trans. R. Soc. A., in press, 1984) shows that this relation depends on the variation of sound speed c with radius r; it may be inverted to yield c(r) purely in terms of observed quantities. Using this technique, Christensen-Dalsgaard et al. (Nature, in press) found that c(r) could be determined with an accuracy of about one percent on the interval $0.4 < r/R_\odot < 0.9$. The result was very close to a normal solar model, although there were indications that beneath the convection zone c was slightly higher in the Sun than in the model.

The frequencies of g modes are much more sensitive to conditions in the solar core than are frequencies of 5 min modes. From such data Berthomieu et al. (Nature, 308, 254) found evidence for partial mixing of the solar core. However, it was pointed out by Gough (Proc. Kun Ming Workshop on Solar Physics, ed., B. Chen & C. de Jager; 1984) and Gabriel (A. & A., 134, 387) that the observed *frequencies could be identified with modes in normal, unmixed solar models.* Thus definite information about solar structure from observations of g modes must await identification of the modes observed.

4. Results on the internal solar rotation

Observations of oscillations in the solar limb intensity (Bos & Hill, 33.080.027) have yielded rotational splittings for about 7 p and g modes of relatively low order. The inversion of these data was far from unique, but it indicated that much of the Sun was rotating at 4 - 6 times the surface rate (Hill et al., 32.066.238; Gough, 32.080.008). However, the observed power spectra had a very high density of peaks which made the mode identification difficult. Data on 5 min modes that did not suffer from this problem were obtained by Duvall & Harvey (Nature, 310, 19). Inversions of these data using a variety of techniques [Duvall et al., Nature, 310, 22; Gough, Adv. Space Res., in press, 1984; Leibacher, (Liège), p. 298] showed that the equatorial rotation rate in most of the Sun is at, or slightly below, the surface value, except perhaps for a small region in the core that may be rotating substantially faster. Although the conflict between the limb data and the observations by Duvall & Harvey should be resolved, the relative simplicity and extensive nature of the latter set of data give credence to the resulting rotation curve. From this the rotational flattening of the Sun may be calculated; it has a negligible effect on present observations of planetary motion (e.g., Shapiro et al., 17.066.072), which are therefore in accordance with Einstein's theory of General Relativity.

The rotation in the solar convection zone is clearly of major interest for studies of convection zone dynamics. So is information about large-scale, time-varying velocity fields that may also be obtainable from observations of oscillation frequency splittings [Hill et al., (Catania) p. 153]. There is some evidence for an increase of the equatorial rotation rate with depth in the upper part of the convection zone (see also Deubner et al., 25.080.003), and variations in the velocity field from day to day may have been detected, possibly associated with convective giant cells. However, better observations data are required to confirm and further study these phenomena.

5. Atmospheric behaviour and excitation

The oscillations are very nearly adiabatic in most of the solar interior. However, non-adiabatic effects are strong just below the surface and in the atmosphere. Here the details of the interaction between the oscillations and the radiation field may affect the frequencies and damping rates of the modes, as well as the variation of the oscillations with the height in the atmosphere. The latter is required to interpret the observed amplitudes and phases.

The general problem of linear oscillations in a radiating atmosphere is quite complex, if the variation of the radiation field with angle and with the wavelength of the radiation is consistently taken into account. Christensen-Dalsgaard & Frandsen [33.080.034; (Catania) p. 285] computed numerical solutions where either the angle variation or the wavelength variation were included. They showed that the grey Eddington approximation is quite accurate for the calculation of frequencies and damping rates. The treatment of radiation had some effects, of the order of 10 - 20 percent, on the temperature perturbation in the atmosphere; this in turn may affect the amplitudes and phases of the computed intensity oscillations in spectral lines [cf. Frandsen, (Liège) p. 303]. In contrast Hill & Logan (Ap. J., 285, 386) found very substantial effects of including non-grey radiation; however, their results were based on a number of approximations which may be responsible for the discrepancy.

A major uncertainty in the computation of nonadiabatic solar oscillations is the treatment of the perturbation of the convective flux. This could well have a substantial effect on the computed atmospheric properties of the oscillations, and on the relation between the observed velocity and intensity amplitudes.

The excitation of the observed oscillations is still badly understood. The instability found in some calculations of 5 min modes (e.g., Ando & Osaki, 14.080.058; Antia et al., 31.080.043) may depend on the (erroneous) assumption of thermal equilibrium in the equilibrium model (33.080.034). Also the perturbation in the convective flux (e.g., Gough, 27.080.066) or the inclusion of turbulent viscosity (Goldreich & Keeley, 19.080.007) seem to stabilize these modes. Stochastic excitation by convection (Goldreich & Keeley, 19.080.007) can possibly account for the observed amplitudes (Gough, loc. cit.; Christensen-Dalsgaard & Frandsen, 33.065.044), although the theoretical treatment of this process leaves a great deal to be desired.

In normal solar models the high order gravity modes responsible for the long period oscillations are almost certainly stabilized by radiative damping (e.g., Saio 28.065.036). They could be destabilized in models with a mixed core, where the amplitudes of selected modes are enhanced by mode trapping (Gavryuseva et al., 33.080.036); but such models may not be consistent with the observed frequencies of the 5 min modes. Stochastic excitation in the convection zone is totally inadequate to provide the observed amplitudes (Keeley, 27.080.063). Thus at present there seems to be no satisfactory explanation for these oscillations.

6. Conclusion

The initial phase of helioseismology consisted of discovering and establishing beyond reasonable doubt, the presence of large-scale modes of oscillation on the Sun. For the 5 min modes this was completed around 1980; the study of longer period modes is still in this phase. This was accompanied by some preliminary attempts at theoretical interpretation and use of the data for probing the solar interior. In the second phase the first reasonably adequate sets of data were assembled, and some definite results concerning the solar interior obtained. This phase may be reaching its culmination for the 5 min oscillations, with the determinations of the internal rotation rate and sound speed. Thus we are now entering the third phase, where helioseismology is to be used as a tool for understanding the processes going on in the solar interior. The results obtained on solar rotation are not easy to rationalize; and the discrepancies on the structure, while fairly subtle, have proved difficult to eliminate. To proceed we need better and more extensive data, which will enable resolution of the solar interior in increasing detail; such data are promised by the new observing schemes being set up or planned. But we also need a parallel theoretical effort, to devise methods for dealing efficiently with the very large amount of data that is becoming available, to make sure that the computations of solar models and frequencies are sufficiently accurate, to understand the relationship between solar models and their frequencies, and to integrate the results in the broader picture of solar and stellar evolution. There is little doubt that the development of helioseismology will continue to profit from the close interaction between observations and theory, which has been one of its distinguishing, and deeply satisfying, characteristics.

V. PLANETARY NEBULA CENTRAL STARS (Edward M. Sion, Villanova University and Arizona State University)

1. Introduction

Planetary nebula nuclei (PNN), as transition objects, hold the essential keys to understanding the details of late stellar evolution from the nature of their asymptotic giant branch (AGB) progenitor stars to the domain of white dwarfs. PNN can shed important light on a diverse array of poorly understood physical processes: nebula ejection and hot stellar wind mass loss phases, convective dredge-up efficiency and dilution, diffusion, late thermonuclear shell flashes, formation of binary nuclei, non-radial oscillations and the detailed origin of white dwarf spectroscopic subgroups. Recent comprehensive discussions of PNN can be found in two conference proceedings (IAU Symp. 103; 34.012.005 and IAU Symp. 99; 32.012.042) and in two up-to-date monographs by Pottasch (1984, Planetary Nebulae, Reidel: Dordrecht; hereafter PN84) and Kaler (34.134.010). This report will cover work completed since 1981 concerning PNN spectral subgroups temperatures, mass loss, mass distribution and evolutionary links to the hottest DA and non-DA degenerates, topics which have stirred considerable controversy recently.

2. Spectroscopic Subgroups of PNN

Various spectroscopic subgroups of PNN are generally defined by the nature of their line spectra at visual wavelengths. Given the observational difficulties posed by their faintness and nebular contamination (only ~ 75 central stars out of 1400 known planetary nebula are amenable to quantitative analysis), the following spectral categories are recognized (cf. Heap 32.114.133; Pottasch PN84):

1) Wolf-Rayet stars. Very broad emission lines of H, He, C N and O (see Heap 32.114.133 for sub-classes);
2) Of stars. Very similar to young Of stars having emission lines of H, HeII, NIII, and usually CIII;
3) WR + Of. These stars have spectra which are a combination of the above types and do not have a counterpart in normal main sequence stars;
4) OVI stars. The spectra are very similar to WR or Of stars except for the fact that they show very prominent emission lines due to O^{+5} at λλ3811 and 3834 Å. These are among the hottest PNN known;
5) Continous spectra. With high enough resolution these objects show lines in their visual spectra;
6) O type. The absorption lines of an O star, especially H and HeII are observable. The absorption line λ4542 of HeII is often broader than the same line in an Of star, indicating higher gravity;
7) sd O type. Sub dwarf O stars with still broader absorption lines. Often the absorption lines of H are blended by H 12, indicating high gravity.

These spectral categories correlate with the state of ionization in the nebula. While spectral differences may be due, in first order, to the thermal evolution of the PNN, different compositions, surface gravities and atmospheric structure may also have a key role (Kaler 34.134.010; Kaler and Shaw 1984 Ap. J., 278, 195; Heap 32.114.133; Pottasch PN84).

3. Surface Temperatures of PNN

Observations of the continous and line spectra of PNN are seriously hampered by nebular line and continuum emission as well as by uncertainties in interstellar reddening corrections to the observed continuum fluxes. Some alleviation of these problems has occurred due to International Ultraviolet Explorer (IUE) observations in the far ultraviolet where better resolution can help eliminate nebular line contamination and where hot central stars usually dominate the continuum.

Black body fits from the ultraviolet to optical yield good first approximations to the effective temperatures of PNN (e.g., Pottasch PN84). Direct model atmosphere fits to PNN line and continuum observations, where possible, provide the most reliable determinations of effective temperatures and gravities. Recent non-LTE models and line profiles due to Kudritzki (1981; unpublished models) have been applied extensively (Mendez et al., 34.114.024, Mendez, Kudritzki and Simon (1984 Astr. Ap., in press). LTE model atmospheres due to Hummer and Mihalas (1970, JILA report No. 101, University of Colorado) and Wesemael et al. (28.064.011), though less realistic, have also been applied. For $\lambda > 1300$ Å the model fluxes are consistently lower than the black body fluxes and models have identical slopes which agree very closely with the black body slope. The non-LTE model atmosphere analyses have yielded effective temperatures, gravities and helium abundances for several PNN which are absorption line objects (Mendez et al., 34.114.024). Approximately, 60 percent of PNN can be analyzed in this way. However, caution must be exercised in selecting only those lines that form deep enough in the photosphere that the assumption of hydrostatic equilibrium is not violated. When direct model fits are difficult or impossible, Zanstra methods, nebular ionization equilibrium models and 'Stoy' energy balance methods are widely used (cf. Pottasch PN84; Kaler 34.134.010; and references therein). The Stoy method is particularly useful when the visual magnitude of the PNN is poorly known and the nebula is optically thin to its ionizing radiation (cf. Gathier 1984, Ph.D. Thesis Groningen, hereafter G84; Pottasch PN84). Kaler (34.134.010) has calculated hydrogen and HeII Zanstra temperatures and luminosities for 82 PNN.

4. Mass distribution of PNN

What is the true distribution of PNN masses? This question has raised considerable controversy. Schönberner (30.065.067) Schönberner and Weidemann (29.115.023; 33.115.004) and Weidemann and Koester (34.065.055) claim a very narrow mass range ($0.55 < M/M_\odot < 0.65$) for PNN based upon a comparison of nebula radii (ages) and absolute visual magnitude with those predicted from theory. They used Shklovsky distances derived by Cahn and Kaler (5.133.017). They also found no correlation between PNN brightness and helium abundance. In sharp contrast to these results, Kaler (34.134.010) finds a greater (less narrow) mass range $0.5 \lesssim M/M_\odot \lesssim 0.8$ and correlates higher N/O nebula abundances with higher initial (progenitor) masses and thus higher core masses. This is expected in part because higher than average nitrogen and helium abundances should manifest the higher efficiency of dredge-up processes for higher initial masses.

A less narrow mass distribution than Schönberner and Weidemann (33.115.004) is supported by Gathier (G84) who shows that the mass range should extend to lower (0.5 $M_\odot$) mass, in better agreement with the mass range of DA white dwarfs. Gathier demonstrates that the use of Shklovsky distances can artificially create a narrow distribution in the $M_\odot$ versus nebular radius plane. Pottasch (PN84) and Gathier (G84) find that higher luminosity nebulae generally have higher progenitor masses, higher helium and nitrogen abundances and generally higher ionized masses than lower luminosity planetary nebulae. Disagreements about the PNN mass range are likely to persist until proper account is taken of significant differences in distance scales, evolutionary tracks and the still uncertain effects of observational selection. In a later section, however, new evidence is presented which appears to lend some support to a larger PNN mass range.

5. Mass Loss

Stellar wind mass loss has been observed in several types of PNN ranging from subdwarf O nuclei like NGC 6543 (Castor Lutz and Seaton 29.135.002) to Wolf-Rayet-OVI nuclei like Abell 78 (Heap 32.114.133, Kaler and Fiebelman 1984, *Ap. J.*, in press) to PNN with "continuous" *visual* spectra like NGC 3242 (Hamann et al., 1984, *Astr. Ap.*, *139*, 459). It is generally believed that unless mass loss rates are $\gtrsim 10^{-7}$ $M_\odot yr^{-1}$ the evolution of the PNN will not be greatly affected (cf. Schönberner 34.065.037). The exact role of wind mass loss and "superwind" phases in post-AGB evolution (cf. Iben 1984, *Ap. J.*, *227*, 333) is still poorly understood and further theoretical and observational investigations are clearly needed. PNN winds may also have a role in formation of the nebula and their study is highly important to general theories of mass loss from early type stars, for example the radiation-driven wind theory of Castor, Abbot and Klein (13.064.004).

Far ultraviolet observations, at both high and low resolution, with the International Ultraviolet Explorer (IUE) satellite have proven invaluable in studies of PNN winds. The analysis of P Cygni profiles at low IUE resolution is facilitated by the highly useful techniques for extracting wind parameters by Castor, Lutz and Seaton (29.135.002). There have been extensive studies of PNN mass loss by Benvenuti and Perinotto (Proc. 2nd Europ. IUE Conf., ESA SP-157, p. 187), Perinotto (34.134.043), Kahn (34.134.038) and Hamann et al. (1984, *Astr. Ap.*, *139*, 459). The paper by Hamann et al., treats the hottest PNN (NGC 3242) for which mass loss has been analyzed. The derived rate is in the range $-10.1 \lesssim \log \dot{M}(M_\odot\ yr^{-1}) \lesssim -8.1$ and the wind parameters bear the same relation to stellar parameters (e.g., $\log T_e$, log g) as that established for winds of more massive, early type stars. Further observational and theoretical work on PNN wind mass loss at different post-AGB phases is badly needed.

6. Binary PNN

The discovery of short period, Roche lobe-detached dK/dM + DA/sdO binary PNN, such as UU Sge (Bond et al., 21.121.048) and Abell 41 (Grauer and Bond 34.134.001) established these objects as the products of common envelope evolution (Paczynski 18.117.051) and the immediate precursors of a substantial fraction of the cataclysmic variables. The growing number of such systems (cf. Table 1, Sion et al., 1984, *Ap. J.*, *279*, 761) together with the large number of short period DA + dM binaries to be found in the Palomar-Green Survey (Green, Schmidt and Liebert 1985, in preparation; Wade, Liebert and Green 1985, in preparation) provides a sample of post-common envelope binaries large enough to help achieve a deeper understanding of this poorly known phase of evolution. While the spiralling-in of the secondary to form a double core red giant or supergiant cannot yet be followed accurately with numerical models, more accurate determinations of binary periods, component dynamical masses and effective temperatures and gravities for the white dwarf/ subdwarf companions should yield valuable insight into the efficiency of the common envelope ejection process itself and the termination of or coalesence from the spiralling in process. The central star of the low surface brightness planetary nebula Abell 41 was discovered to be a binary with a period of 2h 43m by Grauer and Bond (34.134.001). Green, Liebert and Wesemael (1984, *Ap. J.*, *280*, 177) found the primary to be a 50,000 K subdwarf, one half the effective temperature derived by Bond and Grauer from the reflection effect due to the hot subdwarf O star heating the facing hemisphere of the dM star.

Following further less violent loss of orbital angular momentum the binary central stars should evolve to a cataclysmic variable through a combination of gravitational radiation, tidal friction and magnetic braking via flares of winds (e.g., Eggleton 33.117.082; Verbunt and Zwaan 30.117.005; Taam 33.117.171).

7. PNN-White Dwarfs: Final Evolutionary Links

The obvious PNN-white dwarf general evolutionary connection has long been established by the position of white dwarfs in the H-R diagram at the older, low luminosity extension of the Harmon-Seaton sequence, by the heretofore comparable formation rates of planetary nebulae and white dwarfs and the near-degenerate physical properties of the post-ABG cores (cf. Weidemann 68.819, 32.126.025). However, important questions remain concerning (1) how many distinct evolutionary paths with or without planetary nebula ejection lead to white dwarf formation; (2) which types of AGB giant progenitors and descendant PNN's evolve into which spectroscopic subgroups of white dwarfs?

Significant progress in both theory and observation has been made in the last three years.

On the theoretical side, detailed post-AGB evolutionary tracks have been computed by Schönberner (30.065.067, 34.065.037); Renzini (32.065.076); Iben and Renzini (34.065.032) and Iben et al. (34.065.002). In the last two papers, it is argued that the high excitation planetaries, Abell 30 (Hazard et al., 27.134.033) and Abel 78 (Jacoby and Ford 34.134.009), with pure helium inner zones, may be due to ejection of a second nebular shell as a PNN suffers a final helium shell flash as it evolves along the declining luminosity portion of its pre-white dwarf track. The second ejection phase rids the PNN of its remaining hydrogen and most of its CNO-processed envelope material, which can be removed quickly via a hot stellar wind. Indeed Heap (32.114.133) has shown that nitrogen rich planetaries correlate with carbon-rich, H deficient PNN's. The percentage of PNN which undergo a final thermal pulse is largely determined by the precise thermal pulse cycle phase at which "superwind" mass loss begins or stops. Iben (1984, Ap. J., 277, 333) followed the evolutionary behavior of a model PNN as a function of the phase in its nuclear burning cycle when its progenitor leaves the asymptotic giant branch for the first time. He identified several distinct groups of models whose members are expected to evolve into non-DA white dwarfs and suggests that 25% of all PNN should fall into these groups. He argues that winds of at least two types are responsible: a low velocity or slow wind which operates when and if the PNN returns to the AGB after experiencing a final helium thermal pulse; and a high velocity or fast wind which operates when the PNN is at high enough surface temperatures that emitted photons will excite nebular emsssion. Iben's estimate that 25% of all PNN become non-DA white dwarfs is rougly consistent with the empirical non-DA/DA ratio for the proper motion-selected white dwarf sample down to $T_e \gtrsim 10^4$K (Sion 1984, Ap. J., 282, 612). Further post-AGB calculations are now in progress including the effects of stellar wind mass loss phases, diffusive separation and diffusion-induced burning (cf. Iben and MacDonald 1984, preprint).

On the observational side, links between specific classes of PNN and white dwarfs have recently been established. First, two PNN, NGC 7293 and Abell 7, both appear to contain DA01 white dwarfs with helium abundances a factor of ten lower than solar (Mendez et al., 34.114.024; Mendez, Kudritzki and Simon 1984, Astr. Ap., in press). If this underabundance is due to gravitational diffusion, the time scale for helium depletion is comparable to or shorter than the time scale for nebular dissipation. Hence PNN's like Abell 7 and NGC 7293 should be important producers of DA white dwarfs. Second, oxygen has recently been discovered in the photospheres of the hottest known white dwarfs, the PG1159 DOZ1 degenerates (Sion, Liebert and Starrfield 1985, Ap. J., in press). The presence of high n OVI absorption features at λλ3311, 3434, 3811, 3834, some with sharp emission reversals, together with CIVλλ3689, 3934, 4658, all associated in strong emission with the OVI PNN class (cf. Heap 32.114.133; Kaler and Shaw 1984, Ap. J., 278, 195) suggests a direct evolutionary link. That such a link is correct, is strengthened by the OVI nucleus of K1-16 which is itself a PG 1159, non-radially pulsating DOZ1 degenerate (Grauer and Bond 1984, Ap. J., 277, 211). The presence of oxygen in significant abundance at the surfaces of the PG 1159 stars also provides tentative confirmation of the cyclical ionization of oxygen as driving the oscillations as predicted by Starrfield, Cox, Kidman and Pesnell (1984, *Ap. J.*, *281*, 800). Furthermore, the direct association of the hottest, most exotic PNN's, the OVI central stars, with the hottest ($T \gtrsim 10^5$K), fully or near fully degenerate stars, the PG1159 class, has far reaching implications for the mass range of PNN progenitors and hence the masses of DA and DO/DB white dwarf descendants. The PG1159 stars appear to be evolving from the highest excitation, helium-rich nebulae, which are generally associated with PNN of relatively high masses (Kaler 34.134.010; Pottasch PN84). Noting the (a) PNN's like Abell 7 are at degenerate gravities but are cooler ($T_e < 10^5$K) then OVI PNN's and (b) no DA white dwarfs have a temperature approaching 10^5K despite being 4 times more numerous, Sion, Liebert and Starrfield (1985) argue that the OVI/PG1159 progenitors may have higher than average ($> 0.6\ M_\odot$) masses. Sion, Liebert and Starrfield (1985) claim that either (1) the PG1159 stars (and hence their OVI parents) have higher masses than the apparent PNN progenitors if DA white dwarfs generally have very thin H envelopes (cf. Dolez and Vauclair 30.126.024) or (2) there is no significant difference in the masses of the hottest DO and DA degenerates (and thus their PNN progenitors) if the DA stars have hydrogen envelopes which are quite thick as suggested by the results of Iben and Tutukov (1984, *Ap. J.*, *282*, 615).

On the other hand, Schönberner and Weidemann (33.115.004) and Mendez, *Kidritzki and Simon (1984, Astr. Ap., in press) favor an evolutionary path to* non-DA white dwarfs originating from isolated sdO stars which have masses on the low side of the PNN mass distribution and that these stars, already having He-rich atmospheres, evolve into DO/DB white dwarfs while the PNN's evolve primarily into DA white dwarfs.

A recent re-determination by Fleming, Liebert and Green (1984, preprint) of the DA white dwarf luminosity function, based upon 353 confirmed DA white dwarfs from the Palomar-Green sample (complete to B = 16.5) yields good agreement with the Iben and Tutukov theoretical luminosity function which is based upon DA models having thick H envelopes ($M_H \gtrsim 10^{-4}\ M_\odot$) with H shell burning as the *dominant* luminosity source. Assuming a constant white dwarf formation rate, Fleming et al., derive a DA white dwarf birth rate of 5.9×10^{-13} pc^{-3} yr^{-1} which is only 30% of the currently accepted formation rate of planetary nebulae. These new results reveal for the first time, a wide discrepancy between the formation rate of PN and DA white dwarfs, that cannot be reasonably explained by further PN ejections from "born again" AGB stars via the Iben et al. (34.065.002) scenario.

More refined determinations of the formation rates of different classes of PNN are badly needed, together with a more detailed understanding of the extent of ongoing mass loss as PNN begin their descent into the white dwarf domain. Comparisons with formation rates of the hottest DA and non-DA white dwarfs would then be more fruitful.

VI. PULSATIONS IN HOT DEGENERATE DWARF STARS (A.N. Cox, Los Alamos National Laboratory and S.D. Kawaler, University of Texas)

Over the past five years, four extremely hot degenerate dwarf stars have been reported to be multiperiodically pulsating variable stars. The first of these was PG1159-035, initially reported by McGraw, Starrfield, Angel, and Carleton (26.122.137). These discoveries have been made by using high time resolution photometry on the very blue stellar objects found in the Palomar Green (1977, thesis Caltech), PG, catalogue. Seven stars plus the planetary nebula central star K1-16 display hydrogen-free spectra that all the known variables in this class show. Now two more of these stars have been found to pulsate with similar periods (near 500 seconds): PG1707+427 and PG2131+066. These last two variables have been observed by Bond, Grauer, Green, and Liebert (1984, Ap.J., 279, 751). The planetary nebula nucleus star in Kohoutek 1-16, with periods between 1400 and possibly 4500 seconds (Grauer and Bond, 1984, Ap.J., 277, 211) also seems to be in this class according to Starrfield, Cox, Kidman, and Pesnell (Ap.J. Lett., submitted). The gravity for this latter star is probably lower than for the others in this class according to model atmospheres. Surface temperatures of these objects are extremely high, with estimates for PG1159-035 ranging from 80-150 × 10^3K (Wegner, Barry, Holberg, Forrester, and McGraw 33.114.076). Kaler (34.134.010) has provided a lower limit of 90,000K for K1-16. Model atmosphere analyses suggest a surface gravity of $7<\log g<8$ for the PG1159 stars according to Wesemael, Winget, Cabot, Van Horn, and Fontaine (31.126.010). Spectroscopically these stars show He II lines in absorption with emission cores, and absorption lines of C IV and other heavy elements including oxygen are present. See Green and Liebert (27.126.039), Liebert, Green, and Wesemael (33.120.018), and Sion, Liebert, and Starrfield (1984 Ap.J., in press). The absence of surface hydrogen, coupled with high surface gravities, implies an advanced evolutionary stage for these pulsating stars. Their approximate location in the H-R diagram between the planetary nebulae regime and the white dwarfs suggests that these PG stars are most likely rapidly evolving and cooling down into the white dwarf region. K1-16 is probably evolving to become hotter before it reaches this cooling stage.

The observational and theoretical situation for these stars and their relation to the cooler white dwarfs has been briefly reviewed twice by Cox (1984, Nature, 303, 752 and 1984, Nature, 111, 509).

The interior structure of pre-white dwarf stars may be inferred from what is known of their possible progenitors and their descendents, the white dwarfs. One attractive possibility is that the progenitors of these PG stars are the nuclei of planetary nebulae, just as K1-16 is observed to be. These nuclei stars have been studied from a stellar evolution standpoint recently by Iben (1984 Ap.J., 277, 333), Iben and Tutukov (1984 Ap.J., 282, 615), Kovetz and Harpaz (29.065.010), and Schonberner (30.065.067, 30.065.037). They are assumed to be the hot cores of asymptotic branch stars which have ejected most of their hydrogen rich envelopes as red giants and during the planetary nebula stage. By altering the amount of hydrogen and helium rich material remaining in the outer layers following the nebula ejection, Iben (1984 Ap.J., 277, 333) demonstrated a variety of evolutionary possibilities. His models go through various phases of shell helium and hydrogen burning before reaching the pre-white dwarf configuration. Schonberner has also followed the evolution of these late asymptotic giant branch stars by including a Reimers-like stellar wind. A superwind phase seems to be necessary to remove enough envelope material to place the model on the horizontal planetary nebula nucleus track. The Schonberner models also experience episodes of shell burning following nebular ejection while evolving through the planetary nebula stage to the pre-white dwarf region.

If the pulsating PG stars are hot degenerates, then the observed pulsation periods are much longer than the expected radial mode periods of 20-50 seconds. In an early study, Starrfield, Cox, and Hodson (28.122.200) found that models at 10,000 $L_\odot$ were unstable to radial oscillations for very specific circumstances. Later observations have indicated higher surface gravities, implying a lower luminosity of only 100 $L_\odot$. This, along with the multiperiodic nature of the light curve, strongly suggests that these stars are undergoing nonradial g mode pulsations such as are seen in the pulsating white dwarfs, in many other classes of stars, and even in our sun. Nonadiabatic analyses of the PG stars on the cooling track, and of K1-16 on the planetary nebula nucleus track, have been made by Starrfield, Cox, Hodson, and Pesnell (33.126.023), Starrfield, Cox, Kidman, and Pesnell (1984 Ap.J., 281, 800), and Starrfield, Cox, Kidman, and Pesnell (Ap.J., submitted). These studies show that static stellar envelopes constructed along the evolutionary tracks display unstable nonradial modes due to the cyclical partial ionization of carbon and oxygen. Too much surface helium will dilute the κ and γ effects of the CO ionization and stabilize at least the cooler models of these stars.

McGraw, Starrfield, Liebert, and Green (27.126.070) pointed out that, if PG1159-035 is indeed a pre-white dwarf star, then its rapid evolutionary changes in structure might be indirectly observable through observations of secular period changes. This suggestion was elaborated upon by Winget, Hansen, and Van Horn (33.065.063) who estimated that these stars should exhibit period decreases with an e-folding time of about a million years. This means that in only a few years such changes could be observed. These authors made a rough estimate of the period decrease. Now Winget, Kepler, Robinson, Nather, and O'Donoghue (Ap.J., preprint) have measured such a period decrease of -1.2 ± 10^{-11} sec/sec for the dominant (516 second) period of PG1159-035. The best current theoretical predictions by Kawaler, Hansen, and Winget (Ap.J., preprint) show period increases of the same order of magnitude as the observed value. They suggest that rotational spinup from contraction can provide an additional negative contribution to the theoretically derived period change. Reasonable rotation rates can account for the observations. These issues are at the current frontier of stellar evolution at the dying stages of stars.

VII. WHITE DWARFS (V. Weidemann, University of Kiel)

The second edition of the "Catalogue of Spectroscopically Identified White Dwarfs" has now been published by McCook and Sion (Villanova Press, 1984) and contains relevant information for about 1500 stars - more than tripled compared to the earlier edition, essentially due to the addition of objects from the Palomar Green North Galactic Pole Survey of hot white dwarfs by R. Green, M. Schmidt and J. Liebert which have been spectroscopically identified as degenerates mainly by J. L. Greenstein at the 5 m Palomar telescope. For about 500 stars multichannel spectrophotometry is available, the results of which are summarized by J. L. Greenstein (Ap. J., 276, 602, 1984) who has also investigated correlations to Strömgren colors (P.A.S.P., 96, 62, 1984). Strömgren photometry has been obtained for 182 stars by G. Wegner (33.126.006) the results are also found in the McCook - Sion Catalogue. The latter contains valuable enlarged cross-references lists as well as a section on stars which have been shown not to be white dwarfs but subdwarfs. The stars in the Catalogue are classified according to the new system proposed by Sion et al. (33.126.030) which subdivides DA stars according to temperatures, assigns DZ to white dwarfs with metal lines (instead of the former types DF and DG) and DQ to those which show carbon features in their spectra (former DC/C_2, λ4670 types). Improved spectroscopy has enabled reclassification of many white dwarfs formerly considered to be of type DC (G. Wegner, 30.126.019, 31.126.012, 34.126.003) but now showing faint features of H_α, HeI, C_2 or broad unidentified shallow absorption. Results of the proper motion survey with the 48" Palomar Schmidt telescope on white dwarf statistics in the NLTT catalogue have been published by Luyten (University of Minnesota, 1982) whereas photometric investigations of faint blue stars in the Giclas lists were made by Rupprecht and Bues (32.126.030) and astrometric studies by Borgmann and Lippincott (33.111.004). A blue object survey was carried out by Ishida et al. (32.126.021) to a limiting magnitude of m = 18 for a meridian belt through the galactic poles and center; for m < 16 more than 50% are white dwarfs. Ishida has also estimated the space number density of white dwarfs (32.126.021). General information can be found in the new (1982) edition of Landolt-Börnstein, where the section on white dwarfs has been prepared by Weidemann (31.003.064).

UV spectroscopy of the most common spectral type, DA, with hydrogen-atmospheres has revealed the unexplained absorption feature at 1400 Å in additional stars (Wegner, 32.126.020, Sion et al., Ap. J., 279, 758, 1984) as well as a feature at 1600 Å both of which have now been ascribed to quasimolecular H_2^+ - or

H_2 - absorption (Koester et al., Wegner, 1984 preprints). Atmospheric parameters have been evaluated by Guseinov et al. (34.126.013); however, their conclusions concerning a wider mass distribution have shown to be incorrect by Koester (Astr. Space Sci., 100, 471, 1984). An improved analysis, using multichannel observations and a least squares technique in the temperature range in which the energy distribution is quite sensitive to surface gravity, $8000\ K \leq T_{eff} \leq 16000\ K$ has yielded a mass distribution for 70 DA stars which is remarkably narrow and shows the steep increase at 0.45 $M_\odot$ which is expected from calculations of stellar and galactic evolution (Weidemann and Koester, Astron. Astrophys., 132, 195, 1984). Resulting constraints on evolutionary schemes, especially on the initial-final mass relation have been discussed by Weidemann and Koester (33.065.055). The initial-final mass relation can also be determined emperically by observation of white dwarfs in open clusters with known turn-off mass. Reimers and Koester (32.153.030) succeeded in finding white dwarfs in NGC 2516 whose spectroscopically derived masses are higher than 1 $M_\odot$ with progenitors at least up to 8 $M_\odot$. The newly determined initial-final mass relation thus demonstrates that the intermediate mass single stars do not become carbon detonation supernovae. However, Weidemann (Astron. Astrophys., 134, L1, 1984) has pointed to evidence for differential mass loss leading to the replacement of a single-valued initial-final mass relation by a band of finite width. The absence of luminous red giants in younger Magellanic cloud clusters like NGC 1866 is also evidence of tremendous mass loss for intermediate mass stars, and thus confirms the white dwarf results. An earlier study of white dwarfs in clusters by Anthony-Twarog (32.153.006) puts the upper limit for white dwarf production at 5 $M_\odot$. The newer results and the ensuing constraints are summarized by Weidemann (IAU Symposium 105, "Observational Test of the Stellar Evolution Theory", Eds., A. Maeder, A. Renzini, Reidel, 1984).

The white dwarfs of spectral type DB, with HeI spectra and helium-rich atmospheres have also been restudied in order to improve the determination of atmospheric parameters. Whereas Koester et al. (30.126.023) from spectroscopy and photometry of 25 DB stars and a new set of model atmospheres derive a mean mass of 0.44 $M_\odot$, smaller than that of the DA stars, 0.58 $M_\odot$, Wickramasinghe and Reid (33.126.013) evaluate high resolution line spectra and find log g = 8, corresponding to a mean mass of 0.58 $M_\odot$. Reobservation of all northern DB stars with the multichannel spectrophotometer, and theoretical evaluation by Oke et al. (Ap. J., 281, 276, 1984) have confirmed the higher average mass; however, only if the new calibration of Oke and Gunn (33.113.017) is used. In that case the DB stars delineate for the first time a narrow cooling sequence, too, with a mass range $M = 0.55 + 0.1\ M_\odot$. However, on the Oke-Gunn calibration scale, the mean DA mass would be increased to $M = 0.62\ M_\odot$, a small but not insignificant difference compared to the mean DB mass. Guseinov et al. (34.126.045) conclude that 70% of the He-rich white dwarfs have $M < 0.55\ M_\odot$.

It thus cannot yet be established if DA and DB stars arise from different progenitors, or if the difference in atmospheric composition are due to minor differences in late pre-white dwarf stages of evolution. The birth rate of DB white dwarfs is between 10 and 30% of the total and much higher than the death rate of known He-rich progenitors. Iben (Ap. J., 277, 373, 1984) assumes that the phase in its nuclear burning cycle when a star leaves the asymptotic giant branch determines the final outcome: DB or DA, and estimates that 25% of all central stars of planetary nebulae will fall into groups that become DB stars. This scheme implies that 50% of the observable bright central stars are helium-burners opposite to the conclusions of Schönberner (30.065.067) who finds that the vast majority are hydrogen-burners.

Major progress has been made by further detections of CI lines in the UV spectra of DC and DQ (former C_2 or λ4670) stars between 12000 and 6000 K (Vauclair et al. 30.126.002, 31.126.029, Wegner 30.126.007, 33.126.021, 34.126.012). Atmospheric parameters and abundances have been determined for these stars by

Koester et al. (32.126.029). Carbon abundances are fairly low, of the order of C : He = 10^{-6} to 10^{-7} for DC stars and go up to 2 10^{-3} for DQ stars, i.e., those which show C_2 bands or, at higher temperatures also CI lines in the visible like G268-40 (Koester and Weidemann, 31.126.023). The appearance of small amounts of carbon is explained by upwards diffusion and dredge-up by convection, a mechanism proposed by Koester (32.126.029) and subsequently elaborated by Fontaine et al. (Ap. J., 277, L61, 1984). It is predicted that C abundances reach a maximum near T_{eff} = 10000 K, and fall off towards higher and lower temperatures. The absence of CI UV-lines in IUE spectra of the DB stars (Wickramasinghe, 33.126.014) confirms this picture.

However, the appearance of metal lines in white dwarfs of spectral type DZ and the non-systematic variation of the derived metal abundances still constitutes a puzzle. The hottest DZ, GD40, at T_{eff} = 14000 K has Ca, Mg, and Fe abundances of the order of 10^{-8} (Shipman and Greenstein, 33.126.007) but the relative abundances are such as to rule out a simple diffusion explanation. An analysis of the cooler DZ (former DF) stars L119-34 (9300 K) and L745-46 A (7500 K) by Zeidler (5th European Workshop on White Dwarfs, Kiel, June 1984) yields also abundances of Si/He(10^{-8} -10^{-9}) and C (10^{-6} - 10^{-7}). Accretion of interstellar grains (Wesemael and Truran, 32.064.027) and diffusion might explain the varieties in cool helium rich atmospheres. The former DA, F stars, hydrogen-rich with CaII lines have, however, all been shown to be spurious, with only one exception (Lacombe et al., 34.126.001).

The problem of diffusion in white dwarfs has been recently reinvestigated by Muchmore (Ap. J., 278, 769, 1984) who finds with more careful calculations of transport coefficients that diffusion time scales are longer, but remain still much shorter than cooling times: he concludes that trace metals must be transient. In hot white dwarfs, on the other hand, metals may be kept in the atmosphere by radiative levitation as indicated by the presence of SiII, SiIII, SiIV, CIV, and NV lines in high resolution IUE spectra for three out of seven DA stars (Bruhweiler and Kondo, 33.126.033). There are several hotter white dwarfs of mixed spectral type: DO stars with H and He, and GD323, formerly assigned DB, but with the detection of broad shallow Blamer lines now considered a white dwarf with a stratified atmosphere (Liebert et al., 34.126.016).

It has become clear, however, that stratified envelopes do not have sharp boundaries, but that diffusion tails extend into the neighbouring layers. A very interesting mechanism has been suggested in order to explain the absence of hydrogen in He-rich white dwarf atmospheres: diffusion-induced H-burning by the CNO cycle at an intermediate depth, where downward diffused hydrogen meets upward diffused carbon (Michaud et al., Ap. J., 278, 769, 1984). This mechanism might also reduce the thickness of H-envelopes from the 10^{-4} - 10^{-5} $M_{\odot}$ left when the pre-white dwarf leaves the asymptotic giant brach to the less than 10^{-7} $M_{\odot}$ which a ZZ Ceti pulsator must have in order to show instability (Fontaine and Michaud, 5th European Workshop in White Dwarfs, Kiel, June 1984).

ZZ Ceti variables, pulsating DA stars, have been studied extensively, with several new discoveries made (McGraw, Fontaine, 30.126.025, Vauclair et al., 30.122.104, Nather, McGraw, 31.126.011, Schiffer et al., 31.122.153, Donoghue, Warner 32.126.006, Dolez et al., 33.126.009, Kovacz 33.126.035, Kepler et al., 30.126.009, Kepler, Ap. J., 278, 754, 1984). The multicolor, radial velocity and line profile variations are consistent with g-mode pulsation (Robinson et al., 32.126.004). From the statistics of color distribution Fontaine et al. (32.126.002) conclude that probably all DA white dwarfs become ZZ Ceti variables on entering the instability strip 13000 > T_{eff} > 11000 K. Greenstein (32.126.003) derives temperatures from multichannel observations and finds the edges to be at 11700 and 10700 K, whereas Weidemann and Koester (Astron. Astrophys., 132, 195, 1984) find most of the ZZ Cetis between 12500 and 11200 K or 500 K cooler, depending on the calibration used. The surface gravity and mass range is typical for DA stars in general, and the fraction of variable DA stars varies from 50 to 70% depending on the temperature range considered.

A theoretical linear nonadiabatic analysis of g-modes by Dolez and Vauclair (20.126.024) shows that the location of the instability strip depends on the thickness of the remaining hydrogen layer, if this is thin, the driving occurs in the helium partial ionization zone and the strip lies between 13500 and 11500 K, if the layers are thicker, the driving is caused by hydrogen ionization and the strip is located between 11500 and 10000 K. On this basis Brickhill (34.126.005) computed flux variations of finite amplitude and was able to explain the observational red edge. Winget et al. (31.126.004), from full nonadiabatic g-mode calculations, find that the blue edge is at about 11000 K for hydrogen-driving but depends on the remnant hydrogen-layer as well as on the thickness of the transition zone. For an observed edge at 12000 K they find remnant hydrogen masses of $10^{-12} < M_H/M_* < 10^{-8}$. If the hydrogen layer goes to zero instability due to helium ionization is predicted to occur at 19000 K. When indeed a pulsating DB star was found, GD358 (Winget et al., 32.126.023), a corresponding analysis by Winget et al. (33.126.024) showed that the location of the helium instability strip is extremely sensitive to the assumed efficiency of convection and might be between 16000 and 19000 K or between 26000 and 29000 K. The temperature of GD 358 derived from IUE observations (Koester et al., 34.126.002) is 26000 ± 2000 K. In the meantime more pulsating DB stars have been found (Winget et al., Ap. J., 279, L15, 1984, 5th European Workshop on White Dwarfs, Kiel, June 1984) as well as null results reported (Robinson, Winget 34.126.007). Still more exciting was the discovery of a new class of very hot pulsating white dwarfs, called after the first object, PG 1159-035 stars (Winget et al., 33.065.063, Bond et al., Ap. J., 279, 751, 1984) which also includes a nucleus of a planetary nebula, K1-16. These stars show HeII, CIV, and OVI lines partly in emssion and seem to constitute a link between OVI central stars of PN and white dwarfs. It is the first time that oxygen has been observed in white dwarfs (Sion et al., 5th European Workshop on White Dwarfs, Kiel, June 1984). If these stars pulsate by carbon/oxygen partial ionization, as proposed by Starrfield et al. (33.126.023, and Ap.J., 281, 800, 1984), they need significant amounts of oxygen near the surface which would imply that helium-burning in evolved stars produces much more O than normally assumed. Winget et al. (33.065.063), furthermore show that for these objects the periods should change measurably during a few years and thus constitute a strong testing ground of theoretical models of pre-white dwarf evolution. It must be pointed out that in these hot stages the stars are not yet fully degenerate and have radii which are considerably larger and surface gravities which are lower than those of zero-temperature degenerate configurations (Koester, Schönberner, 5th Europ. Workshop on White Dwarfs, Kiel, June 1984).

Hot white dwarfs with $T_{eff} > 50000$ K have been observed in the visible (Liebert et al., 30.126.018), UN (Sion et al., 31.126.014, Dupree and Raymond 32.126.035) EUV (Malina et al., 32.126.024) and soft X-ray region (Cole et al., 30.126.030, Kahn et al., Ap. J., 278, 255, 1984). Sion and Guinan (33.126.005) determine the Einstein redshift of HD 149499 B, a 55000 K DO star from high resolution IUE spectra and find $M = 0.5 + 0.1\ M_\odot$ for this DB progenitor. For Sirius B soft X-ray observations by Martin et al. (32.126.019) and EUV observations by Holberg et al. (Ap. J, 280, 679, 1984) have shown that the origin of the radiation is probably photospheric even if the effective temperature is < 28000 K, as is now well established. The He abundance must be smaller than 10^{-5}. Wesemael (30.126.001) checked that electron scattering is not important for the EUV in hot DA atmospheres.

A survey of magnetic fields in white dwarfs, summarizing research up to 1981 has been given by Angel, Borra and Landstreet (30.126.003). Linear polarization has been observed by Efimov in about 50% of a sample of 85 white dwarfs and subdwarfs

(30.126.026). New observations were reported by Liebert et al. (33.126.001) for two hot DA stars with fields around 1 Megagauss, and by Downes and Margon (34.126.006), where Zeeman splitting indicates 13 Mgauss. The influence of magnetic fields on the spectra has been theoretically investigated by Martin and Wickramasinghe (32.126.009, M.N.R.A.S., 206, 407, 1984) and by Bues (33.126.012), 34.126.036). Spectacular progress has been made in the interpretation of spectra with unidentified features. The ultraviolet line at 1345 Å observed by Greenstein and Oke (31.126.002) was identified by Greenstein (Ap. J., 281, L47, 1984) as a shifted Lyman α component whose location becomes stationary around 350 Mgauss. This interpretation was possible on account of theoretical investigations of hydrogen atoms in very strong magnetic fields by research groups at Baton Rouge (Henry, O'Connell, Ap. J., 282, L97, 1984) and Tübingen (Rosner et al., Forster et al., J. Phys. B.: Atom. Mol. Phys., 17, 29, and 1301, 1984) which meanwhile were able to identify also the famous Minkowski band at λ4135 Å as due to a normally forbidden 2s0-4f0 transition of H_β as well as the 5855 Å band as a stationary component of Hα, both indicate fields around 300 Mgauss.

Information about cool white dwarfs remains relatively poor. From IR photometry Wickramasinghe et al. (31.126.006) conclude that three objects are hydrogen-rich, perhaps due to accretion not being prohibited below 5500 K, whereas Liebert and Dahn (33.126.031) suggest pressure-broadened and shifted C_2 bands as an explanation for the spectrum of LHS 1126. Greenstein (33.126.015) investigates 4 cool objects for which the entire flux is measured, Liebert and Wehrse (33.126.038) show that Ross 627 is a cool hydrogen-rich star whereas Wegner and Yackovich analyze the cool DC binary Stein 2051 B (34.126.046).

That the deficiency of low luminosity white dwarfs seems to be real and not due to observational selection has been shown by Liebert et al. (34.126.041) which study the luminosity function for over 40 cool degenerates with $M_v > 14$. The falloff at $M_v > 15$ is also confirmed from searches for binary companions. It is not yet settled if this indicates earlier accelerated Debye cooling or a late start of white dwarf formation in the Galaxy: in any case the cooling theory would have to be revised. Cooling ages could for example be increased by a phase separation of carbon and oxygen in the interior [Mochkovitch (33.126.027)].

VII. CONCLUDING REMARKS

In addition to the above detailed reviews, there are several other aspects of stellar astrophysics that deserve a very short mention because of recent progress. For more information on these topics, one must consult Astronomy and Astrophysics Abstracts.

Mixing in stellar interiors continues to be an important question that has consequences for the evolution of a star, especially if nuclear fuel is brought to a hot burning region. Nuclear reactions for the burning of carbon to oxygen and those for neutron capture by the r process have recently been revised. Observations of the radio band emission from stars continue to provide information about stellar surfaces. Magnetic stars, observed for years, are now being used for interpretations of them, in particular, the pulsating Ap stars. How the solar dynamo operates to give its surface magnetic fields has resulted from recent elaborate calculations. Evolution of stars in binary systems has been studied extensively because close binaries can and do have very important effects in significantly changing how evolution occurs. Considerable mass exchange or loss can occur to produce some observed astronomical objects. Self-excited radial and nonradial pulsations have been observed and interpreted for stars all over the H-R diagram, and information about masses, radii, luminosities, and compositions have resulted. Investigations of stellar explosions for the surface thermonuclear runaways of novae and the core collapse event for supernovae have still left unsettled details concerning these violent events. Neutron stars that result from the deaths of stars larger than the maximum white dwarf mass, have still unknown interior structures, and their cooling rates are still being calculated. The entire field of black hole research has brought together the disciplines of stellar structure and relativity theory, yielding new insights to both. Finally there is the question of the ages of the oldest stars as discussed in the last Commission 35 report. If the age of the universe is just over 10 billion years, as some now strongly suggest, how do we reconcile this short time with the apparently older population II stars?

With all the questions brought up in the detailed reports above, and those mentioned briefly here, as well as the discussions scheduled for several upcoming IAU Symposia and Colloquia, one can see that Commission 35 has many further research projects and a very bright future.

Arthur N. Cox
President of the Commission