29. STELLAR SPECTRA (SPECTRES STELLAIRES)

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In recent years, the report of Commission 29 has been assembled from short reports submitted by selected authorities at the request of the President. These reports have surveyed a variety of topics but no or little pretense has been made to provide thorough coverage of 'stellar spectra' over the preceding three years. This year, the coverage is even less thorough as a result of the President's firm conviction that the literature is surveyed supremely well by Astronomy and Astrophysics Abstracts, and by review papers that abound in proceedings of conferences, colloquia, symposia and workshops, as well as books and journals devoted to authoritative reviews. In addition, the growth of 'databases', including the valuable SIMBAD, would seem to lessen the usefulness of the traditional reports of an IAU commission. Finally, the sheer volume of material published on 'stellar spectra' and a page limit imposed on the report force a selection of topics and influence the style of presentation. (Presidential procrastination is another factor!)

A sociologist examining the field of stellar spectroscopy might conclude we are experiencing, in common with most fields of astrophysics, a period of rapid growth. The measure invoked might be a hard statistical one such as the number of papers published. A closer look would show a growth in the depth and scope of problems addressed; consider, for example, the following selection: tests of primordial nucleosynthesis, scrutiny of theories of stellar evolution, observational examination of stellar photospheres including inferences about granulation and spots, studies of layers exterior to the photospheres–chromospheres, coronae, hot and cool winds. Growth could also be measured by access to the electromagnetic spectrum; a noticeable fraction of papers today draw on spectra acquired from more than one region of the electromagnetic spectrum: for example, studies of red giants may integrate optical and infrared spectroscopy of the photospheres, IUE or HST spectra of the chromospheric emission lines, infrared spectra of the circumstellar dust and millimeter observations of circumstellar molecules. All would be a theoretical exercise without telescopes to collect the spectra; the renaissance of telescope building is welcomed and the new era has just begun for individuals fortunate to have access to the Keck 10m telescope! Tools to analyse spectra continue to develop at a pleasing rate. Model atmospheres built with the traditional set of core assumptions are generally available for all parts of the HR diagrams and even for more exotic objects such as neutron stars (non-traditional assumptions in this case!) Recently, there has been a movement to replace one or more traditional assumptions with a superior idea: for example, spherical for plane-parallel geometry or non-LTE for LTE. One notes too the increasing use of non-LTE instead of LTE in the analysis of the line spectra in the extraction of abundances and atmospheric parameters. In the following pages, I illustrate this summary of the growth of our subject with examples drawn from the last three years. I thank M. Briley, D. Kirkpatrick, and A. Hatzes for helpful commentaries on selected topics. I am indebted to R.E.M. Griffin for providing the report on the activities of the Working Group on Spectroscopic Data Archives.

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Model atmospheres. Since a separate commission has responsibility for studies of stellar atmospheres, I restrict my remarks to three illustrative studies that are largely grounded in observations and aim to explore the validity of the theoretical atmospheres. A classical atmosphere supposes the plane-parallel layers to be homogeneous. In a valuable series of explorations of the photospheric line profiles of main and near-main sequence F and G stars, Dravins, Nordlund, and colleagues (see review by Dravins, 1992, in *High Resolution Spectroscopy with the VLT, ESO Workshop*) have analysed the line asymmetries found from high resolution ($\lambda/\Delta\lambda$ = 200,000) spectra. A recent study of the subgiant β Hyi (spectral type G2IV) compared observed profiles with those predicted from *ab initio* hydrodynamic models (Dravins et al. 1993, *ApJ*, 403, 385): observed and predicted line cores fit well but the predicted line wings are weaker than observed suggesting the presence of transonic or supersonic motions–a good fit to the entire profile is found in the case of the Sun. Extension of this work is to be welcomed.

Thanks to heroic efforts by a few individuals (notably Kurucz, Bell, Gustafsson), standard models are readily available for use by the spectroscopists. The path of least resistance is to adopt the models rather uncritically in the pursuit of the defining parameters ($T_{\rm eff}$ and log g) and the chemical abundances. The need for construction of empirical atmospheres should not be forgotten. A paper by Fuhrmann et al. (1993, *Astr. Ap.*, 271, 451) analysing the Balmer lines H α to H δ in the Sun, Procyon, and the metal-poor stars HD140283 and G41-41 reports that the line profiles can be fitted with theoretical models consistently with a mixing length much smaller than commonly supposed: $l = 0.5H_p$ instead of $l = (1\text{-}2)H_p$. This change affects the temperature profile in the deep layers and results in effective temperatures that differ quite significantly from other values: e.g., $T_{\rm eff}$ = 5810 K for HD140283 which the authors note is "definitely hotter than most values cited in the literature". Of interest here is the recent proposed temperature scale for metal-poor dwarfs (King 1993, *Astr. J.*, 106, 1206) which finds $T_{\rm eff}$ to be about 150-200 K hotter than propsed in the literature. This proposal based on empirical and model atmosphere based $T_{\rm eff}$-color relations is in line with Fuhrmann et al.'s proposed changes. There is now a need for a full empirical analysis of the spectrum—lines and continuum fluxes—to establish the veracity of standard model atmospheres. Since conclusions about the primordial fireball and the early history of the Galaxy depend on abundances analyses of halo stars, the models must be checked!

Substitution of spherical for plane-parallel geometry and near-completeness of line blanketing are not the only advances seen recently in model atmosphere construction. The replacement of the simplifying assumption of local thermodynamic equilibrium by that of non-local thermodynamic equilibrium has been seen with increasing frequency in the recent literature. An example must suffice. Kilian et al. (1991, *Astr. Ap.*, 244, 419) derive effective temperatures and gravities for 19 unevolved B stars in the field and local associations. Non-LTE line formation for hydrogen (Balmer beta, gamma, and delta), Helium (He I and II), and Silicon (Si II, III, and IV) was considered in the context of LTE line-blanketed model atmospheres. It was found that the effective temperatures obtained are systematically hotter than those given by then available photometric calibrations. The sign of the systematic difference is confirmed by a thorough reassessment of the photometric calibrations by Napiwotski et al. (1992). A plausible speculation is that the origin of the difference lies in the use by Kilian et al. of rather lightly line blanketed model atmospheres. A reinvestigation with more completely line blanketed and non-LTE atmospheres is awaited with interest.

Substitution of non-LTE for LTE necessarily places more stringent demands on the stellar spectroscopist. In particular, there is the obvious need for more atomic and molecular data, as well as numerical techniques and associated computing power to handle the coupled equations of statistical equilibrium and radiative transfer. With the completion of the Opacity Project (Mendoza 1992, in *Atomic and Molecular Data for Space Astronomy, Lecture Notes in Physics*, Springer Verlag: Berlin, Vol. 405, p. 85) and the steady reporting of other theoretical calculations of *gf*-values, as well as experimental measurements of *gf*-values and radiative lifetimes, the stellar spectroscopist is now better supplied than ever before—of course, gaps remain in the identification and the classification of lines as well as the supply of accurate *gf*-values. The reader may wish to scan the proceedings of *The 4th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas* edited by D. S. Leckrone and J. Sugar and published as volume T47 of *Physica Scripta*. But non-LTE demands more than *gf*-values and photoionisation cross-sections, rate constants for processes involving the atom and ions of concern with other particles in the atmosphere are needed. Customarily, the free electrons are exclusively taken to be those other particles. It is left as an exercise to the reader to recall why the electrons are awarded such an exclusive role when they may be outnumbered by factors of 10^4 or more by neutral hydrogen atoms in the atmospheres of cool stars. In a pioneering set of calculations of non-LTE effects on lines in spectra of cool stars, Holweger and his colleagues (see Holweger, 1988, *IAU Symposium No. 132,* p.411) included the effect of collisions with neutral H atoms in calculations of the non-LTE effects on the excitation of Li I, Ca I, Ca II, Fe I lines. The H-atom rates of excitation were estimated from a cross-section based upon Thomson's classical estimate for ionisation of atoms. Unfortunately, there is an understandable dearth of experimental data on collisions using H atoms at the low energies prevailing in stellar atmospheres. Less understandable is the almost complete lack of quantal calculations. In an assessment of the rate constants employed by the Kiel school, Lambert (1993, *Phys. Scripta,* T47, 186) found from an *ab initio* calculation on Li I and an experiment on H excitation of neutral Na atoms that the rate based upon Thomson's classical formula greatly overestimates the true rates. If these two selected examples are typical of the rate constants for collisions involving atoms and the H atoms, it appears that the electrons despite their low abundance in the atmospheres of cool stars will determine the departures from LTE.

Non-LTE effects on molecules in cool stars are reviewed by Johnson (1993, in *Proc. IAU Coll. No. 146*, in press). In light of the numerical techniques now available, it seems surprising that, relative to the extensive literature on non-LTE in atoms and ions, so little has been done on molecules despite their known importance as opacity sources, their potential as probes of the structure of the upper photospheres and low chromospheres of cool stars, and their exploitation as indicators of key elemental and isotopic abundances. From the few recent references cited by Johnson, I select two.

Hinkle et al. (1993, *ApJ,* in press) describe observations of the H_2 infrared quadrupole vibration-rotation lines in spectra of M, S, and C stars. As Johnson notes, the reappearance of the H_2 line in a Mira following passage of the pulsationally driven shock shows that recombination of H atoms into H_2 molecules occurs about as rapidly as the recombination of TiO and CO. Since it has been thought that H_2 molecules but not TiO and CO from by three-body recombination ($3H \rightarrow H_2 + H$) , this observation might seem to “demand higher densities of H I or consideration of processes other that three-body recombination.” (It is possible that the shock will force consideration of non-steady state statistical equilibrium!)

Cores of the strongest CO lines in the fundamental and first-overtone vibration-rotation lines are formed high in the photosphere where one expects the temperature minimum between the photosphere and the chromosphere. As shown long ago by Carbon et al. (1976, *ApJ*, 207, 253), non-LTE effects in the CO molecule's ground electronic state are small and do not mask the flux reversal expected in the CO line cores from the chromospheric temperature rise. More extensive NLTE calculations (Wiedemann & Ayres 1991, *ApJ*, 366, 277) involving a larger model molecule and applied to F-K stars confirm that depratures from LTE are small for dwarfs and giants. Then, the non-appearance of the flux reversal may be due to the inhomogeneous nature of the atmosphere at heights around the temperature minimum. Around this topic has raged the debate of 'bifurcation'. As with non-LTE studies of atoms and ions, the stellar spectroscopist tackling non-LTE investigations of molecules finds available data on collisional processes to be sparse and incomplete.

Large-scale Inhomogeneities–Starspots: Doppler tomography is a technique applicable to rapidly rotating stars that exploits the fact that there is a one-to-one mapping between location on the stellar surface and a wavelength in a stellar line profile. Surface inhomogeneities whether due to temperature, composition, or velocity create distortions in a line profile that are a one dimensional projection of the stellar surface. If the surface inhomogeneities are long-lived with respect to the stellar rotation period, a time series of line profiles can be interpreted to yield a two dimensional map of the stellar surface. As introduced about a decade ago, Doppler tomography relied on trial and error to extract the surface maps. A sounder mathematical foundation has been supplied with recent advances including a reconstruction algorithm based on a CLEAN-like approach (Kürster 1993, *Astr. Ap.*, 274, 851) and a sequential linear least-squares technique (Allen &Vogt, 1993, *BAAS*, 25, 872).

Doppler tomography has been applied mostly to RS CVn stars (evolved late-type stars in close binaries) and a few FK Com stars (single stars generally identified as coalesced binaries. Recent references include Vogt & Hatzes (1991, in *IAU Coll. No. 130*, p297), Hatzes & Vogt (1992, *MNRAS*, 258, 387), and Strassmeier, *Astr. Ap.* in press) for RS CVn's and Kürster et al. (1992, 7th. *Cambridge Conf. on Cool Stars, Stellar Systems, and the Sun, ASP. Conf. Series* Vol 26, p249) on FK Com stars. Remarkably, the images show almost without exception the dominant inhomogeneity to be a polar spot with several equatorial features. (One exception is Sigma Gem (a RS CVn star)—see Hatzes (1993 *ApJ*, 410, 777). The polar spot can be long-lived (time scale = several months). There is no doubt that the polar spots are real. Surface maps constructed from the same data set by different techniques results are quite similar (Strassmeier et al. 1992, *Astr. Ap.*, 247, 130; Kürster et al. 1992). In the case of HR1099, magnetic maps derived from spectropolarimetry (Zeeman Doppler Imaging) show the magnetic field to be concentrated in an annulus around a rotation pole.

Time sequence of Doppler maps reveal the evolution and migration of spots. Although not firmly established, it seems that spots emerge at the equator and migrate poleward in sharp contrast to the Sun where migration is toward the equator and spots are never seen at the poles. Observations of spot migration provide measurements of differential rotation, a key ingredient in dynamo theory. RS CVn stars exhibit a smaller differential rotaton than the Sun: Vogt & Hatzes (1991) found UX Ari to a rate of differential rotation a factor of 10 less than the solar case and in the opposite sense, i.e., the stellar pole rotates faster than the equator; Hatzes & Vogt (1992) report EI Ari to have a rate at least a factor of 100 less than the Sun but in the solar sense.

Extension of Doppler tomography to other types of stars is awaited with interest. Kürster (1993, *Astr. Ap.*, 274, 851) obtained images of a pre-main sequence star AB Dor: spots were concentrated at a latitude of +25° and no polar spot. A development with a little history is the mapping of chromospheric/coronal structure. Donati & Catala (1993, *Astr. Ap.*, 277, 123) applied Doppler imaging to Hα, Ca II H and K emission to map chromospheric features. Rotational modulation of ultraviolet emission lines has been reported from series of IUE spectra of chromspherically active stars: Ayres (1991 *ApJ*, 375, 704) discusses the 'many faces' of Capella, Procyon and β Cas where rotational modulation is **not** seen. Doppler tomography is used in a slightly different sense by Bagnuolo & Gies (1991 *ApJ*, 376, 266) who use sequences of archival (IUE) spectra of double-lined spectroscopic binaries to separate cleanly the spectra of the two individual stars. Bagnuolo et al. (1992, *ApJ*, 385, 708) apply the technique to Plaskett's star which, since its discovery in 1922, has been widely considered to be the most massive binary known.

Brown Dwarfs The search for brown dwarfs has continued apace—without proven success. Two reviews may be usefully consulted: Burrows & Liebert ('The Science of Brown Dwarfs', 1993, *Rev. Mod. Phys.*, 65, 301) and Bessell & Stringfellow ('The Faint End of the Stellar Luminosity Function', 1993, *Ann. Rev. Astr. Ap.*, 31, 433). The search will continue because as Burrows & Liebert remark "... not a single, unambiguous case of a brown dwarf or planetary companion to a star other than the Sun has been established, with the exception of the cases that likely result from close binary evolution. It should also be clear, however, that many brown dwarf candidates have been found by a variety of methods. The lack of proven examples is due to the great difficulty of establishing accurate masses, temperatures, or ages of the objects." Spectroscopic examination of the candidates may lead to the identification of genuine brown dwarfs.

One candidate is the low mass very red companion to the white dwarf GD165. The companion is about 4 arc sec distant and provides the white dwarf with an apparent infrared excess. GD 165 A and B form a common proper motion pair (Zuckerman & Becklin 1992, *ApJ*, 386, 260). Kirkpatrick, Henry & Liebert (1993, *ApJ*, 406, 701) obtained a spectrum of GD165B from about 7500 to 9100Å finding this brown dwarf candidate to have 'a spectrum unlike that of any known M dwarf'. With this spectrum, and the fact that the object has redder colors and a fainter absolute magnitude than any known main sequence star maintain its status as a brown dwarf candidate. Unfortunately, the mass is poorly known: a definitive orbit for this wide pair will not be immediately forthcoming.

A spectroscopic distinction between a low mass star and a brown dwarf was proposed by Rebolo, Martín & Magazzù (1992, *ApJ*, 389, L83) and applied by Magazzù, Martín & Rebolo (1993, *ApJ*, 404, L17) to a sample of brown dwarf candidates. Lithium is completely destoyed in low mass stars because they are extensively convective and lithium is exposed to temperatures in excess of 2.5×10^6 K and so destroyed by protons. Brown dwarfs have lower central temperatures and below a certain mass lithium is expected to be retained at the surface. Magazzù et al. obtained spectra around the Li I 6707 Å doublet for three brown dwarf candidates and three low mass dwarfs. Lithium was not detected: depletion by a factor of at least $10^{4.5}$ was estimated. Predicted depletions as a function of a brown dwarf's mass and age are given in Bessell and Stringfellow (see also Magazzù et al.). The reported depletions imply a mass >0.065 M$_\odot$ for ages of about 10^{10} yr. Brown dwarfs with masses of less than about 0.06 M$_\odot$ are predicted to deplete their surface Li by less than a factor of 10. This initial application has not changed the status of a brown dwarf candidate. Detection of Li in, for example, low mass candidates of young nearby clusters such as Alpha Persei and the Pleiades may require a very large telescope.

Dwarf Carbon Stars. The dwarf carbon star G77-61 was dicovered in 1977 and for nearly 15 years was a lone and peculiar curiosity. When it was found to be a spectroscopic binary with a long period (245 days), G77-61 was taken to be a product of mass transfer with the carbon dwarf receiving carbon-rich material from an AGB star whose core is now the unseen companion. The mass transfer scenario certainly creates the classical Ba giants, the CH giants, and various relatives. In the case of G77-61, one might have wondered why it was apparently unique. One need wonder no longer because about 9 are now known—see Green, Margon, & MacConnell (1991, *ApJ,* 380, L31); Green et al. (1992, *ApJ,* 400, 659); Warren et al. (1993, *MNRAS,* 261, 185), Heber et al. (1993, *Astr. Ap,*. 267, L31), and Liebert et al. (1993, *ApJ,* in press). Indeed, Green & Margon (1994, *ApJ,* March 10 issue) assert that "dwarf C stars may be the numerically dominant type of carbon star in the Galaxy"! Green & Margon find barium, a presumed tracer of the *s*-process in the AGB donor star, to be enhanced in each of the 6 dwarf carbon stars observed by them. The $^{12}C/^{13}C$ ratio spans a wide range including examples with a ratio similar to that of the giant J-type stars. Available limited evidence on composition and radial velocity variations is consistent with the mass-transfer scenario. Green & Margon suggest that the carbon dwarfs are the main sequence progenitors of CH giants and/or that CH giants are the high luminosity tail to a distribution dominated by dwarf carbon stars.

The Magellanic Clouds. Stars in our nearest neighbors in the extragalactic world offer one obvious advantage over similar and brighter stars in our Galaxy: the Magellanic Clouds are at a well determined distance such that the absolute magnitudes of stars in the Clouds may be well determined in sharp contrast to the uncertainty associated with most stars in the Galaxy. The advantage largely offsets the disadvantage of the much fainter apparent magnitudes of the Cloud stars. There is also the distinctive difference in evolution of the Clouds and the Galaxy: the Clouds are metal-poor relative to the solar neighborhood and the age-metallicity realtions appear to differ too. Recent developments in the spectrometers (and detectors) available at the southern hemisphere's have led to improvements in the wavelength coverage and limiting magnitude of spectroscopic observations of Cloud members. Nonetheless observations at high spectral resolution essential for a detailed abundance analysis remain limited to the most luminous stars in the H-R diagram: OB main sequence stars, and supergiants of all spectral classes from O to M. The evolved stars have extended and often unstable atmospheres. Non-LTE effects may often be important. It is most likely, as Bessell has argued (1992, in *High Resolution Spectroscopy with the VLT*) that the present generation of model atmospheres for supergiants are inadequate; he, and Jüttner & Wolf (1992, in *The Atmospheres of Early-type Stars,* ed. Heber and Jeffery, Springer-Verlag: Berlin, p.63) stress the need for differential analyses of Cloud and similar galactic stars.

Considerable effort has been devoted to establishing the overall composition of the Clouds and interpreting differences between the Small and Large Cloud, and the Galaxy in terms of chemical evolution of these three systems. Jüttner & Wolf review analyses of B stars in the Cloud—see also a paper by Howarth et al. in the same volume. Since the OB supergiants, as in the Galaxy, are apparently enriched with CNO-cycled material from their interiors, the more easily observed supergiants are not reliable indicators of the interstellar abundances of CNO but may be used to get 'metal' abundances. Fortunately, extant telescopes may provide high resolution spectra of B main sequence stars. (Another fortunate circumstance is that non-LTE calculations are available for the C, N, O and Si ions.) Jüttner & Wolf describe initial results from an ESO Key Programme for which the following are 'safe conclusions':

- The mean metallicity of B field stars in the SMC is -0.65 dex relative to the Sun.
- Stars in young blue globular clusters are underabundant by about 0.3 dex relative to Cloud field stars.

Howarth et al. are undertaking a similar programme on main sequence B stars and their preliminary conclusion is that the B stars have the composition previously adduced for late-type supergiants and H II regions and supernova remnants. A detailed analysis has just appeared (Rolleston et al. 1993, *Astr. Ap.*, 277, 10) (Freitas Pacheco et al.'s [1993, *Astr. Ap.*, 271, 429] analysis of the emission lines of Type I planetary nebulae in the LMC show that O, S and Ar—elements probably not affected by internal nucleosynthesis in PN progenitors—have the same abundances as in H II regions and stars.)

Russell & Dopita (1992, *ApJ*, 384, 508) discuss the collection of abundances for stars and gas in the Clouds. Abundance analyses of the stars in the clouds began several years ago with the late-type supergiants. New results have appeared. Spite, Richtler & Spite (1991, *Astr. Ap.*, 252, 557—see also Barbuy et al. 1991, *Astr. Ap.*, 247, 15) have rexamined supergiants in the young globular cluster NGC330 in the SMC. The four stars examined have effective temperatures from 3900 to 7500 K. The Fe abundance, the same for the 4 stars, is [Fe/H]= -0.9 to -1.0, a value similar to that for a B main sequence star in the cluster observed by Reitermann et al. (1990, *Astr. Ap.*, 234, 109). This metallicity, as noted by Jüttner & Wolf for this and other young globular clusters, is lower than for stars in the SMC field. (Earlier spectroscopy of NGC330 stars had suggested [Fe/H]=-1.3) Luck & Lambert (1992, *ApJ, Suppl.*, 79, 303) analysed 14 Cepheids and non-variable supergiants with a sample of galactic comparison stars of somewhat lower luminosity on average. The mean metallicities [Fe/H]= -0.37 for the LMC and -0.53 for the SMC are similar to previous estimates. It is interesting that Thévenin & Jasniewicz (1992, *Astr. Ap*,. 266, 85) from 5Å resolution spectra of about 100 field stars and an analysis using synthetic spectra obtain mean abundances of [Fe/H]= -0.19 (LMC) and -0.46 (SMC). The former abundance agrees well with several photometric determinations whereas high-resolution spectroscopy appears to favor a lower value. Luck & Lambert suggest that there may be real spread in the metallicities of the LMC field stars—one Cepheid was metal-rich or [Fe/H]=0.19—but the smaller spread for the SMC is probably no larger than the errors of measurement. The compositions of the Clouds appear not to be exact replicas of galactic field stars of the same metallicity. A clear example of this difference is shown by the heavy elements, those products of the neutron-capture *r* and *s* processes. As stressed by Russell & Bessell (1989, *ApJ Suppl.*, 70, 865) and discussed by Russell & Dopita, the lighter heavy elements (e.g. Sr and Zr) have galactic ratios with respect to Fe but the heavier elements (e.g. Ba) are enhanced in the Clouds relative to Fe. Another striking difference is shown by carbon from a comparison of the Cloud stars and H regions: the C abundance reported for the H II regions is significantly less than that of the stars: is this a real effect or does it reflect a systematic error in the analyses?

With continuing and modest advances in the instrumentation, it will be possible to extend the stellar analyses to less luminous late-type stars and lower mass main sequence stars. A quantum jump will come with ESO's VLT. One expects the lower luminosity stars to yield to abundance analyses less afflicted by systematic errors. But the lessons learnt in analysing the most luminous stars of the Clouds will be of especial value because, as Bessell stresses, the new generation of large telescopes will bring the very brightest stars in the next closest galaxies (NGC 6822, IC1613, M33 and M31) within the spectroscopists' grasp.

A wide variety of stars in the Clouds have been scrutinized by spectroscopists. A selection of results follows:

- Humphreys, Kudritzki & Groth (1991, *Astr. Ap.*, 245, 593) examined a group of 'anomalous A-type supergiants' in the LMC and SMC with Balmer lines and a Balmer jump too strong for their luminosities. NLTE model atmospheres are used to show that these strong features due to hydrogen are indicative of a high He abundance: N(He)/N(H)= 0.3 to 0.5. These stars with $M_{bol} = -6$ to -8 are assigned an initial mass of 10 to 20 $M_\odot$ and suggested to be He-burning post-red supergiants. Humphreys et al. claim that such He-rich A-type supergiants will die as exploding blue supergiants, as did SN1987A.

- Studies of Wolf-Rayet stars in the Clouds (and other nearby galaxies) has continued. One striking aspect of the SMC is the small number of WR stars in the SMC. In the previous report of the Commission, van der Hucht noted that WR's numbered 'still 8 in the SMC'. Morgan, Vassiliadis, and Dopita (1991, *MNRAS* 251, 51p) discovered a ninth WR star in the SMC. This like its predecessors is a WN-type with weak emission lines and is a binary like a majority of the other eight. These features of the SMC's WR stars are generally attributed to the low metallicity of the SMC. Koesterke et al. (1991, *Astr. Ap.*, 246, 166) report a model atmosphere analysis of 19 WR stars of the WN sequence in the LMC, and the results are compared with a sample of galactic WN stars analysed by the same techniques. One result is that the terminal wind velocities and mass-loss rates of LMC and galactic stars are similar for the same WN subtypes but, according to the theory of radiation pressure driven winds, the lower metallicity of the LMC should lead to differences in the winds.

- The most luminous hot stars in the Clouds are accessible to ultraviolet spectroscopy with HST. Initial results are appearing. Walborn et al. (1992, *ApJ*, 393, L13) discuss HST ultraviolet and ground-based optical spectra of the Of/WN object Melnick 42 and the multiple system Radcliffe 136a in the 30 Dor H II region of the LMC.

- Symbiotic stars are rare in the Clouds: 3 in the SMC and 3 in the LMC identified prior to 1991. Although the sample is small, half (3 of 6) have a carbon-rich red giant but such systems are rare in the Galaxy. The commonest systems in the galaxy are those with a M-type red giant but the 3 O-rich symbiotics in the Clouds have K-type giants. Morgan (1992, *MNRAS*, 258, 639) discovered on Schmidt plates 4 new symbiotics including the first with a M-type red giant but 2 of the newly discovered 4 symbiotics have C-rich giants so that the contrast with the Galaxy is maintained.

- Spectroscopy of the red giants in the Clouds has continued. Westerlund et al. (1991, *Astr. Ap Suppl.*, 91, 425, and 1992, *Astr. Ap.*, 260, L4) discuss the evolution of carbon stars using JHK photometry and spectra. Not all the carbon stars are products of thermal pulses on the AGB. Westerlund et al. confirm the finding of carbon stars with luminosities less than that of the red giant tip; the galactic R stars have similar luminosities. Westerlund et al. speculate that there are two evolutionary scenarios leading to formation of carbon stars: M-S-C(C2-poor)-C and M-J-C. Wood et al. (1992, *ApJ*, 397, 552) examined IRAS point source in the Clouds for OH maser emission and for infrared emission. Velocities of the stellar winds, as measured by the OH line profiles, are smaller than seen in comparable galactic stars. This velocity difference is attributed to the lower metallicity of the LMC resulting in less dust in the winds. Wood et al. find no evidence in either Cloud for AGB stars with a luminosity exceeding the AGB limit of M_{bol}= -7.1 attained for a classical AGB star with a C-O core at the Chandrasekhar mass; recent theoretical arguments suggest that luminous AGB stars burning H at the base of the deep convective envelope will have luminosities exceeding this classical limit. Wood et al. suggest the discrepancy with theory may be due to either an overestimate of the convective efficiency or to very severe mass loss by those stars that exceed the classical limit. There is no doubt that stars close to but below the classical limit burn H at the bottom of their envelopes—these stars are the super Li-rich stars.

Globular Clusters. Recent spectroscopic work on stars in globular clusters is covered in "The Globular Cluster-Galaxy Connection" (*ASP Conf. Ser. Vol. 48*) One highlight of recent years has been the considerable progress made in determining the abundances of the light elements—C, N ,O, Na and Al—in cluster giants. Despite this progress, the origins of these elements and, in particular, of the variation of their abundances within one cluster remain subject to considerable debate. Explanations proposed may be grouped into two broad categories: (1) the star to star abundance differences are due to primordial variations, possibly inhomogeneous pollution by an earlier generation of massive or intermediate mass stars, and (2) the star to star variations are the result of varying degrees of deep mixing that brings to the surface the fruits of nucleosynthesis achieved inside the star.

High-resolution surveys of bright giants in several globular clusters have revealed an interesting trend (Sneden et al. 1991, *Astr. J.*, 102, 2001; Kraft et al. 1992, *Astr. J.*, 104, 645; Sneden et al. 1992, *Astr. J.*, 104, 2121; and Kraft et al. 1993, *Astr. J.*, 106, 1490): Na enrichment is anti-correlated with the O abundance among the red giants in a number of clusters. Langer, Hoffman, & Sneden (1993, *PASP*, 105, 301) suggest that Na is synthesised from Ne in those layers where the ON-cycle burns hydrogen and reduces the O abundance. Should this prove correct, the observed correlations between the CN molecular band strengths and the Na and Al abundances in several clusters (e.g., Smith & Wirth 1991, *PASP*, 103, 1158; Brown & Wallerstein 1992, *Astr. J.*, 104, 1818; Drake, Smith & Suntzeff 1992, *ApJ*, 395, L95) may result from deep mixing. Observations of the NH 3360Å band in red giants of M13 and CN-weak giants of M5 (Briley & Smith 1993, *PASP*, in press) are consistent with this idea but Briley & Smith also demonstrate that the CN-strong stars of M5 may not be explainable by deep mixing alone. Large Na abundances, which do not follow the Na-O anticorrelation, have been observed in 47 Tuc (Brown & Wallerstein 1992, *Astr. J.*, 104, 1818) and ω Cen (Brown & Wallerstein 1993, *Astr. J.*, in press) but ω Cen with a large metallicity spread is unlike any other globular cluster and its chemical history may differ from that of other globular clusters. But deep mixing is not yet demanded by the observations which really only define the nature of the nucleosynthetic alterations but do not locate the site unambigously. Indeed CN variations from star-to-star have been seen in stars near the main sequence turn-off. Suntzeff (1993, *ASP Conf. Ser. Vol .48*) provides a recent review.

Low resolution spectroscopy of stars in NGC6752 and 47 Tuc have shown differences among the CN bands in stars belonging to the upper main sequence and the main sequence turn-off; recent work on these clusters includes Suntzeff & Smith (1991 *ApJ*, 381 160), and Briley, Hesser & Bell (1991, *ApJ*, 373, 482). It is most unlikely that deep mixing occurs in these low mass stars ($M = 0.6 M_{\odot}$) and quite improbable that the ON-cycle can run effectively. Briley et al. (1991) suggest that the spread in the abundance ratios [N/Fe] and [C/Fe] among the main sequence stars is similar to that of the red giants, implying that the bi-modal distribution of CN strengths in 47 Tuc is not solely the result of a mixing process in the individual stars.

In the transition from a subgiant to a giant the star's convective envelope is predicted to dredge CN-cycled material to the surface. Since it is unlikely that this process operates simply as predicted and may operate differently in different stars due, say, to different rotational angular momentum, the spread of CN in giants cannot be exactly that of main sequence stars. Reasonably conclusive evidence of mixing in cluster red giants was presented prior to the current reporting period. More recently, a trend with luminosity along the red giant branch was reported in NGC6752 and M4 by Suntzeff & Smith (1991). The low $^{12}C/^{13}C$ ratio indicative of the CN-cycle in equilibrium have been reported for giants by Brown, Wallerstein & Oke (1991, *Astr. J.*, 101, 1693).

Despite recent progress in defining the abundances of the light elements, the origins of the star-to-star variations of these abundances within a cluster displaying no measureable variations in abundances of many other elements (ω Cen aside) remain unclear. It is possible that primordial enhancements and the alterations due to deep mixing both occur. Definition of the former should shed light on the origins of the globular clusters. Isolation of effects due to deep mixing provides a test for theories of the evolution of low mass metal-poor giants. Introduction of fiber-fed spectrographs and the next generation of large telescopes will permit quite detailed exploration of globular cluster main sequences. Perhaps, the next report of the commission will discuss spectroscopy that unambiguously identifies the roles of primordial enhancements and deep mixing.

Post-AGB Stars. The stellar population at high galactic latitudes is not purely comprised of low mass metal-poor main sequence and giant stars and white dwarfs. Population I OB stars (i.e., massive stars) are known at great distances from the plane; Keenan (1992, *Q. J. R. Astr. Soc.*, 33, 325) provides a concise review of these (and other high latitude) stars under the title 'Star formation in the Galactic Halo'. Normal Pop. I stars as verified by abundance analyses have been found up to about 20 kpc from the galactic disk. Conlon, Theissen, & Moehler (1993, *Astr. Ap.*, 269, L1) discuss PG 1708+142 which is at 10 kpc from the disk. Although some of these stars may have been ejected from the disk, several have locations and space motions that are incompatible with a birth in the disk. These stars formed either in clouds far from the disk or were accreted from outside. Keenan notes that the origins of these stars may become clearer when photometric and spectroscopic surveys of existing surveys of galactic stars and the halo of M31 are completed.

Not all the high latitude OB stars have a composition typical of Pop. I stars. Metal-poor B stars have now been found and identified as post-AGB stars, i.e., stars that have evolved from the red giants at the tip of the AGB and are nearing the top of the white dwarf cooling track. Discoveries are included in papers by Conlon et al. (1991, *MNRAS* 248, 820), McCausland et al. (1992, *ApJ*, 394, 298), and Conlon, Theissen, & Moehler (1993). On the basis of available data, it would seem that these hot post-AGB stars do not have the compositions of Population II dwarfs and red giants. Of course, C, N, and O have to be set aside in making this comparison. One difference (see McCausland et al. 1992) is that Ca appears more underabundant than Mg or Si: e.g., [Ca/H] = -2.9 but [Mg/H] = -1.8 for LS IV -4.01 for which [Fe/H] < -1.6. At this metallicity in the halo, [Ca/H] = [Mg/H]. One should note that in this cited example, the Ca and Mg abundances each depend on a single line. Further pursuit of these stars is warranted as abundance differences with halo dwarfs and giants (the progenitors of the B stars) should reveal aspects of the history of the post-AGB stars.

According to models of post-AGB stars, the B-type stars are evolving very rapidly. So rapidly that one in just 4 decades passed from the care of this Commission: Parthasarathy et al. (1993, *Astr. Ap.*, 267, L19) discuss CPD -59° 6926 as 'a post-AGB star which has turned into a planetary nebula within the last 40 years'—the star was classified as a Be star as late as about 1980 but the optical spectrum in 1990 shows an emission line spectrum of a planetary nebula. Cold dust in a detached shell is revealed by the IRAS fluxes. IUE spectra show a high velocity stellar wind with a central star of type O8V. An apparently more advanced example of the post-AGB to planetary nebula conversion may be IRAS 0652-0337 ('final mass-loss episodes before the formation of a planetary nebula?'—see García-Lario et al. 1993, *Astr. Ap.*, 267, L11) and a less advanced example may be LS II +34° 26 (Parthasarathy 1993, *ApJ*, 414, L109).

The hottest post-AGB stars are not the only ones to have attracted considerable attention this triennium. Abundance analyses of several high galactic latitude A, F and G supergiants show extreme deficiencies of iron. A few are apparently more metal-deficient ([Fe/H]= -4.5 or so) than the most metal-poor dwarfs and giants known. This is a remarkable finding for stars identified with a very rapid phase of evolution; Bond (199a, IAU Symposium No. 145, p. 341) suggested that these post-AGB stars are 'chemically peculiar' in the sense that the iron abundances do not reflect the stars' initial abundances. Adapting a published suggestion about Lambda Bootis stars that alluded to similarities with post-AGB stars, Bond suggested that the iron deficiency was created by a separation of dust and gas with the present atmospheres of the post-AGB stars being composed largely of gas from which grains have been removed; the abundance pattern of the post-AGBs resembles that of interstellar gas. Stars analysed recently include HD52961 with [Fe/H] possibly as low as -4.8 (Waelkens et al. 1991 *Astr. Ap.* 251, 495) and HD44179, the central star of the Red Rectangle, with [Fe/H]= -3.2 to -3.5 (Waelkens et al. 1992, *Astr. Ap.* 256, L15). These post-AGB stars as well as others with less extreme metal-deficiencies generally have near-solar abundances of C, N, O, and S. (The C, N, and O abundances show alterations due to H and He burning.) Van Winckel, Mathis & Waelkens (1992 *Nature* 356, 500) detect Zn in HD52961 with an abundance [Zn/H] = -1.3 or [Zn/Fe] $\simeq$ 3.5. Zn like S is only slightly depleted in interstellar and circumstellar gas. The high Zn/Fe ratio confirms that these stars are chemically peculiar. Mechanisms for achieving the gas-dust separation are discussed by Mathis and Lamers (1992, 259 L39) and Waters, Trams, & Waelkens (1992, *Astr. Ap.* 262, L37). Parthasarathy, García-Lario and Pottasch (1992, *Astr. Ap.* 264, 159) discuss HD52961 with [Fe/H] $\lesssim$ -1.0 but near-solar C, N, O, and S abundances. Waters et al. (1993, *Astr. Ap.* 269, 242) present a binary model for the well known F supergiant 89 Her including a highly asymmetric geomtery for its circumstellar envelope. A review of post-AGB stars, somethimes called proto-planetary nebulae is provided by Kwok (1993, *Ann. Rev. Astr. Ap.* 31, 63).

Testing Primordial Nucleosynthesis. Stellar spectroscopy is not a pursuit that is insulated from other major astrophysical activities. This claim is proven by the activity over the last three years in the field of the abundances of the light elements—Li, Be, and B—in halo dwarf stars and the interest taken in the results by cosmologists! Since the discovery in 1982 by M. and F. Spite of the Li 'plateau' observations of Li in halo (and other) stars have assumed a frenetic pace. As originally noted and initially confirmed, the plateau denotes that the warmer halo dwarfs have a uniform Li abundance near log (Li) = 2.1 on the usual scale. Recent observations have suggested that uniformity of Li abundances is not a universal attribute of halo dwarfs.

A few halo dwarfs are now known to be very deficient in Li, even stars in the effective temperature range associated with the plateau. Examples of Li-poor stars were reported by Hobbs, Welty, & Thorburn 1991, *ApJ*, 373, L47; Spite et al. 1993, *Astr. Ap.*, 271, L1; Thorburn 1992, *ApJ*, 399, L83; Thorburn & Beers 1993, *ApJ*, 404, L13). The Li deficiency of these stars is typically an order of magnitude with respect to the plateau. There is as yet no evidence of other peculiarities to be associated with the Li deficiency: for example, it seems that these stars are not exclusively binaries.

Early studies of the plateau suggested that the scatter in Li abundances was small with observational scatter the dominant contributor. But now Deliyannis, Pinsonneault, and Duncan (1993 *ApJ*, 414, 740) suggest that a real dispersion of 10 per cent in the Li abundances may be present. Thorburn (1994, *ApJ* in press) has obtained Li abundances for almost 100 halo dwarfs and finds 'a larger lithium abundance dispersion than can be explained by observational errors alone'. Thorburn also finds the Li abundance to decline with decreasing metallicity and attributes this slope of the plateau to lithium production by Galactic sources: excess scatter about the Li abundance—metallicity relation is identified with Li production and a 2 Gyr dispersion in the halo's age—metallicity relation. The primordial Li abundance from the hottest and most-metal poor stars is put at log(Li) = 2.22 ± 0.20 dex by Thorburn. Li production may be due to cosmic rays and the alpha on alpha reactions they induce in the halo gas. Since these fusion reaction may make ^{6}Li more than ^{7}Li, the 'extra' Li -rich stars of the plateau might be expected to show some ^{6}Li accompanying the primarily primordial ^{7}Li. Smith, Lambert, & Nissen (1993 *ApJ* 408, 262) reported a detection of ^{6}Li in HD84937 but not in a cooler dwarf HD19445. The detected isotopic ratio of ^{6}Li/^{7}Li= 0.05 ± 0.02 for HD84937 corresponds to an initial ratio of about 0.10 when destruction of ^{6}LI (relative to ^{7}Li) is considered according to standard (non-rotating) models. (The same models predict essentially the complete destruction of ^{6}Li in HD19445, a prediction consistent with the absence of ^{6}Li in this star.) The initial ^{6}Li content is consistent with the Be abundances of halo stars and the scenario in which cosmic rays produce Be from spallation reactions, primarily proton on oxygen collisions.

Knowledge of the Be abundances of halo stars has increased dramatically recently—see Gilmore, Edvardsson, & Nissen (1991, *ApJ*, 378, 17), Gilmore et al. (1992, *Nature* 357, 379), Ryan et al. (1992 *ApJ*, 388, 184), Rebolo et al. (1993, in *Origin and Evolution of the Elements*, p.149) , Molaro, Castelli & Pasquini (1993, in *Origin and Evolution of the Elements*, p. 153 and Boesgaard & King (1993, *ApJ* in press). Two results deserve deserve brief mention: (1) There is no evidence for a Be plateau to the metallicity limit presently reached ([Fe/H] $\simeq$ -2.6); (2) the Be abundances scale linearly with metallicity or the oxygen abundance. The failure to locate the Be plateau is fully consistent with predictions of nucleosynthesis by the standard big bang that is identified with ^{7}Li production and the concomitant production of ^{2}H, ^{3}He, and ^{4}He: the predicted Be abundance is substantially below the lowest Be abundance detected or even detectable. Simple models of the production of Be by cosmic ray spallation reactions predict the Be abundance to scale approximately with the square of the oxygen (or iron) abundances, not linearly as observed—see Prantzos, Casse & Vangioni-Flam (1993 *ApJ* 403, 630 and in *Origin and Evolution of the Elements*, p. 156).

Boron was detected in three metal-poor stars by Duncan, Lambert & Lemke (1992 *ApJ* 401, 584) from spectra acquired with the Hubble Space Telescope. One B I resonance line was detected as a blended feature at 2496.8Å. A LTE analysis gave a B/Be ratio of about 10 and B follows Be in increasing approximately linearly with the oxygen or metal abundances. Since the ratio B/Be $\simeq$ 10 is predicted directly for production by spallation reactions, it was suggested that Be and B in the early Galaxy are both fruits of interactions between cosmic rays and nuclei in the halo gas. This simple picture has been challenged by non-LTE calculations of the BI line (Kiselman 1993, *Astr.*

Ap. in press) showing that the LTE abundances underestimate the true abundance by a factor of 8 in the most metal-poor stars. The implied B/Be ratio of about 80 is in excess of what can be attributed to spallation. There is a possibility that the absorption attributed to the B I line is due instead to a weak transition of a more abundant species such as Fe I. But Lemke, Lambert & Edvardsson (1993, *PASP,* 105, 468) argue that this attribution in unlikely; this conclusion is based, however, on an LTE analysis of the behavior of alternative identifications. Alternatively, the B in the early Galaxy may come from another source, i.e., Type II supernovae where B (and Li) is a product of neutrino-induced nucleosynthesis. Calculations suggest that, Be is much less easily synthesised in Type II SN. Further observations of boron with HST and non-LTE analyses will presumably resolve the issue of the B/Be ratio in stars and, hence, of the origins of these light elements.

Working Group on Spectroscopic Data Archives

R.E.M. Griffin writes: The formation of a Working Group on Spectroscopic Data Archives was recommended in 1991 by IAU Resolution C13, in which "... the importance of safeguarding [spectroscopic] data, and the need to create an accessible archive of the observations" was formally recognized. In an admirable display of democracy, the issues were re-aired at a European venue later that year before a core membership of a Working Group was nominated. At a business meeting of its core members, plus others by invitation, the WG was eventually proposed in March 1992, and established by its nominal parent, Commission 29, in June of that year. The members of the WG now number 12, and represent Australia, Japan, Ukraine, Canada, USA and Argentina as well as Western Europe. The history and rationale of the project, and the need for a WG to oversee it, has been described in detail in 'Comments on Astrophysics' 16, 167, 1992.

The aims of the Working Group are to propose, stimulate and encourage the formation of archives of spectroscopic data, and also to devise a scheme for guaranteeing a future for spectroscopic plates. As individuals we have attended relevant meetings, visited observatories or other places where astronomical data are handled, and written numerous short articles, memoranda, reports and letters in places where they were intended to be noticed by project designers as well as data users. As a Group we held an open meeting in Haguenau in 1992 September (during "Astronomy from Large Databases II"), and another during the Trieste Workshop in April 1993. Our final business meeting for this triennium is planned for Spring 1994 and, together with the WG on Radioastronomy data bases, we are holding a Joint Discussion meeting at the 1994 GA.

The concept of generating a public route into a data bank through which spectra can be re-used, for whatever purpose, has not yet won universal acceptance, usually because the necessary resources are not made available. The concept of compiling archives of **reduced** data, and towards which the WG is firmly committed as a general aim, is even less popular because it will require far more time and effort. However, compelling arguments suggest long-term advantages that will be worth the initial cost if uniform and reliable calibration procedures can be set up in collusion with at least some of the team(s) who created the spectrograph(s). The enormous numbers of person-hours which are presently spent in re-reducing spectroscopic data will be saved, and errors made by those unfamiliar with routines will be avoided, not to mention the scientific advantages of panchromatic information for almost all research. The WG suggests as one solution the development of software to cope with many of the current instrumental setups in a robotic manner. It also proposes that the raw-data banks of those reduced spectra should still be available, if not on-line, for the purist.

In its first phase, the WG is concentrating on the fate of relatively high-dispersion spectra of stars. Several ground-based observatories adopt the philosophy that the data belong to the observer, so permanent copies of the raw data are not retained beyond an interim security version. Arguments relating to the scientific advantages for research and to the enhanced accountability of the instruments are beginning to bear fruit, and some new stores of raw data are now being started. Space missions, whose data are expected to arrive regularly for a relatively brief period and whose calibration procedures may have to be established with hindsight, are already geared towards servicing data requests from a data bank, though do not (yet) have facilities for creating uniform sets of reduced data.

The WG has also been concerned about the long-term safeguard for photographic spectra. There are about 35 stores of spectroscopic plates around the world; most are now closed, and very few have a service or loan scheme. For the would-be user of such data, an initial requirement is an on-line index of the contents. Most observatories can produce detailed logbooks of the observations or notebook equivalents from which index tables can be generated. After deliberating at Trieste on the details which that index should contain in order to keep it commensurate with the FITS header information that is creamed off automatically from digital observations, the WG issued a set of Guidelines for circulation. A subsequent test-run involving the historical spectra at the Cambridge Observatories, UK, produced a partial Index Table that can now be supplied as a sample upon request.