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COMMISSION 29: STELLAR SPECTRA

(SPECTRES STELLAIRES)

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1. INTRODUCTION

With an increasing wealth of data and analyses, as well as growing new areas of interest (such as spectral profiles for the search of extrasolar planets), it is no longer possible to present a comprehensive review on the area of *Stellar Spectroscopy.* As already stressed by the two predecessors as presidents of this Commission, Drs. D.L. Lambert and M.S. Bessell, the Astronomy & Astrophysics Abstracts and Institute for Scientific Information, NASA-ADS, Simbad databases, NIST spectroscopic database, among others, imply that these IAU reviews can now be seen as a guide to the field, presenting a survey of a variety of topics, providing no thorough coverage on each of them. A partial list of Proceedings, including topics related to Commission 29, is provided below.

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Adelman S.J., Kupka F., Weiss W.W. (eds.) *M.A.S.S. Model Atmospheres and Stellar Spectra*, San Francisco: Astronomical Society of the Pacific, ASP Conf. Ser. 108 (1996)

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Solheim J.-E., Meistas E.G. (eds.) *11th European workshop on White Dwarfs*, San Francisco: Astronomical Society of the Pacific, ASP Conf. Ser. 169 (1999)

Truran J. (ed.) *Cosmic Chemical Evolution*, IAU Symp. 187

van der Hucht K., Koenigsberger G., Eenens P.R.J. (eds.) *Wolf-Rayet phenomena in massive stars and starburst galaxies* IAU Symp. 193, San Francisco: Astronomical Society of the Pacific (1999)

Wolf B., Stahl O., Fullerton A.W. (eds.) *Variable and Non-spherical Stellar Winds in Luminous Hot Stars*, IAU Coll. 169, Heidelberg: Springer, Lecture Notes in Physics, vol. 523 (1999)

2. MODEL ATMOSPHERES, SPECTROSCOPIC ATLASES, NOVAE, DOPPLER IMAGING, T TAURI STARS

A new TiO line list was prepared by Plez (1998), and a new grid of models for M giants and Mira stars was computed by Alvarez & Plez (1998). Opacity improved MARCS models for cool and low-metallicity stars were presented by Borysow et al. (1997) and line-blanketed MARCS model atmospheres for R Coronae Borealis and H-deficient stars by Asplund et al. (1997). Convection in the ATLAS9 model atmospheres of R. Kurucz (Castelli et al. 1997) and updated ATLAS12 models by R. Kurucz can be found at the Kurucz www and ftp site kurucz.harvard.edu. The 1995 Phoenix spherically symmetric, line-blanketed NLTE model atmospheres for gravities $3.5 < \log g < 5.5$ by Allard & Hauschildt were adapted to novae, bright giants and low-metallicity OB stars. Also, Hauschildt et al. (1999) computed plane-parallel, NLTE, line-blanketed model atmospheres for Vega and the Sun. Rauch reported the implications of light elements (Li-Ca) on static, plane parallel NLTE model atmospheres and Hamann & Koesterke (1998) discussed expanding atmospheres with clumped stellar winds for the analysis of Wolf-Rayet spectra.

Temperature calibrations and bolometric corrections: Using sets of MARCS and ATLAS model atmospheres, Bessell et al. (1998) obtained broad-band colors, bolometric corrections and temperature calibrations of stars of O to M spectral types. Similar results were also presented by Lejeune et al. (1998) who gathered synthetic spectra from the literature and applied continuum corrections employing observed spectra.

Chromospheres and coronae The series *Cool Stars, Stellar Systems and the Sun* is the best reference in this area.

Brown Dwarfs and M dwarfs (and extrasolar planets) See Proceedings edited by Rebolo et al. (1998).

Atlases A catalogue of atmospheric parameters (T_{eff}, log g, [Fe/H]) of 3247 stars was updated in Cayrel de Strobel et al. (1997). A library of high resolution spectra for on-line determination of atmospheric parameters is given in Soubiran et al. (1998). Improved catalogues of spectral classification of Wolf-Rayet stars were provided by van der Hucht (1999) and by Breysacher et al. (1999) for the LMC. An improved catalog of spectroscopically identified white dwarfs was provided by McCook & Sion (1999).

Novae, Doppler Imaging Non-LTE model atmospheres with expansion for novae were made available by Schwarz et al. (1997). A review of observations on novae was given by Gehrz et al. (1997). The Doppler Imaging technique, described in detail e.g. by Hao (1998) in the context of analysis of non-radial pulsations, is being broadly applied to cool stars and cataclysmic variables. The study of cool stars by this method was carried out for example by Johns-Krull & Hatzes (1997).

T Tauri stars (TTS) Low-resolution spectra were used to present models of magnetic accretion, including pre and post-shock phases by Calvet & Gullbring (1998). Infrared spectra to model disk accretion in TTS were given in Muzerolle et al. (1998). High resolution spectroscopy of TTS is presented by Johns-Krull & Basri (1997).

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van der Hucht K. 1999, New Astronomy Reviews, in press

3. ABUNDANCES IN COOL STARS: TRACERS OF CHEMICAL AND STELLAR EVOLUTION

A general review of nucleosynthesis and abundances in stars is given in Wallerstein et al. (1997), and a review on abundance ratios as tracers of chemical evolution was presented by McWilliam (1997).

Li,Be,B Isotopic ^{6}Li/^{7}Li determinations in metal-poor stars were carried out by Cayrel et al. (1999), Nissen et al. (1999) and Smith et al. (1998). Lithium abundances in metal-poor stars were determined by Molaro et al. (1997), Beryllium by Boesgaard et al. (1999) and Molaro et al. (1997); Boron in metal-poor stars was obtained by Duncan et al. (1998) and García-López et al. (1998), and in a G dwarf of the Orion association by Cunha et al. (1999).

Besides, through abundances of LiBeB in Hyades giants by Duncan et al. (1998) and in F stars by Boesgaard et al. (1998) and Deliyannis et al. (1998), and in metal-poor stars by Primas et al. (1999), correlations of depletions of Lithium, Beryllium and Boron were shown. Li in population I subgiants were obtained by Randich et al. (1999). Li-depleted main sequence turnoff dwarfs were studied by Ryan et al. (1998), Norris et al. (1997).

Li-rich giants New Li-rich giants were discovered in M3 by Kraft et al. (1997) and in the open cluster Berkeley 21 by Hill & Pasquini (1999). Castilho et al. (1999) derived low Be abundances in Li-rich giants, implying a probable production of Li in these stars.

Globular clusters Star-to-star abundance variations among individual stars in a given globular cluster, and anticorrelations O-Na, and correlations Na-Mg further progressed with studies on NGC 7006 (Kraft et al. 1998), M92 (Langer et al. 1998), M13 (Kraft et al. 1997) and M15 (Sneden et al. 1997). The Mg-Al anticorrelation was studied in Denissenkov et al. (1998). Abundances in the young outer halo globular clusters Ruprecht 106 and Pal 12 were given in Brown et al. (1997).

Halo stars Halo stars poor in α-elements were made evident by Carney et al. (1997) and Nissen et al. (1997). Beers et al. (1999) have recalibrated the CaII K line to estimate metallicities of a large number of metal-poor stars, and metal abundances for samples of Hipparcos metal-poor stars were derived by Clementini et al. (1999) and Hanson et al. (1998). 50 nearby F-G dwarfs of the disk and halo were analysed by Fuhrmann (1998).

Bulge Detailed analysis of in situ bulge stars were carried out by Castro et al. (1997), Barbuy et al. (1999) and Cohen et al. (1999). Analyses of metal-rich stars in the solar neighborhood were presented by Castro et al. (1997) and Feltzing & Gustafsson (1998).

C,N,O abundances In young populations Cunha et al. (1998) presented oxygen abundances in F,G stars of the Orion association, and Takeda et al. (1998) obtained oxygen and nitrogen abundances in Hyades F type dwarfs. C abundances in 80 solar type stars of the Galactic disk were derived by Gustafsson et al. (1999). CNO abundances were also derived for stars in the Hertzsprung gap phase by Vanture & Wallerstein (1999). CN, NH bands were used to derive C and N abundances in disk K - M giants by Aoki & Tsuji (1997). $^{12}C/^{13}C$ were derived from CO overtone bands, in metal-poor stars by Pilachoswki et al. (1997) and in M71 by Briley et al. (1997).

Regarding low mass old stars, an extensive spectroscopic program involving more than 100 stars in 47 Tucanae, from the red giant branch down to one magnitude below the turn-off was carried out by Cannon et al. (1998). CH, CN, NH in metal-poor cluster and field stars were analysed by Shetrone et al. (1999) and Smith et al. (1997) for M5.

The oxygen abundances in metal-poor stars controversy has been revived by the results from UV OH lines by Boesgaard et al. (1999) and Israelian et al. (1998) and from OI lines by Cavallo et al. (1997), who find $[O/Fe] \approx +1.0$ for the most metal-poor stars, whereas Fulbright & Kraft (1999) find $[O/Fe] \approx +0.5$ for two of the same stars studied in the Boesgaard et al. and Israelian et al. papers, by employing the [OI]630 nm line.

Since the study of the ultra-metal-poor neutron-capture-rich and carbon-nitrogen rich star CS 22892-052 by Sneden et al. (1998 and references therein), these puzzling stars were the focus of attention of several authors, among which Barbuy et al. (1997), Norris & Ryan (1997a,b), Bonifacio et al. (1998) and Zács et al. (1998).

Carbon stars A review on carbon stars is found in Wallerstein & Knapp (1998). Heavy-element abundances in 7 SC stars are given in Abia & Wallerstein (1998). Models developed by the Uppsala group were used to derive $^{12}C/^{13}C$ ratios in cool carbon stars by de Laverny & Gustafsson (1998a,b). IR spectra of C stars observed with ISO were used to derive C/O and $^{12}C/^{13}C$ ratios in N-type and SC-type giants by Aoki et al. (1998).

Magellanic Clouds Analyses of K giants in the SMC by Hill (1997) and Hill et al. (1997) and of A supergiants by Venn (1999 and references therein), as well as stars in the young SMC globular cluster N330 by Hill (1999) and Gonzalez & Wallerstein (1999) and spectroscopy of Be stars in NGC 330 by Keller & Bessell (1998) were presented. Rolleston et al. (1999) determined abundances in hot stars of the Inter-Cloud region. The NLTE models for hot stars by the Munich group have been applied to derive metallicities of O stars of the Magellanic Clouds by Haser et al. (1998).

Cepheids, FG Sagittae, Sakurai, RCrB stars, Symbiotic stars Abundances in Cepheids of the Magellanic Clouds were derived by Luck et al. (1998). The Cepheid V473 Lyrae was restudied by Andrievsky et al. (1998). Near-IR and visible spectra of 3 Cepheids were presented by Butler & Bell (1997). A new calibration of period-luminosity relation vs. metallicity for Cepheids can be found in Sandage et al. (1999) and analysis of type II Cepheids in globular clusters in Gonzalez & Lambert (1997).

Spectroscopic follow-up of stars in the post He-flash to asymptotic giant branch evolution phases, which can give important hints on stellar evolution: Sakurai's object, which may be the birth of an R Coronae Borealis (RCrB) star was followed by Asplund et al. (1999 and references therein), R CrB stars were observed by Skuljan & Cottrell (1999) and FG Sagittae interpreted to be a new-born Coronae Borealis star by Gonzalez et al. (1998).

Detailed analysis of symbiotic stars were carried out by Smith et al. (1997) and Pereira et al. (1998).

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4. A STARS (G. Mathys)

A-shell, Vega-like and λ Boo stars: Various studies of the circumstellar disk around β Pic and other A-shell stars support the Falling Evaporating Bodies model and set new constraints on it (Welsh et al. 1998; Beust et al. 1998; De Winter et al. 1999; Petterson & Tobin 1999). Photospheric elemental abundances in β Pic (Holweger et al. 1997) and in Vega-like stars (young main-sequence stars with excess of infrared emission; Dunkin et al. 1997) do not show the pattern typical of λ Boo stars. Observations of shell lines in fast rotating A stars are consistent with the hypothesis that all A-type stars rotating near their limit have shells for only 1/4 of the time. Such hot inner disks may or may not be related to cool outer disks around β Pic or Vega-like stars (Abt et al. 1997). A study of the first two spectroscopic binaries known in which the two components are λ Boo stars

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shows that both systems are very close to the main sequence (Paunzen et al. 1998). C and O abundances in λ Boo stars support the accretion/diffusion theory for the origin of these stars (Paunzen et al. 1999).

Abundances: Elemental abundances have been determined in a large number of normal and peculiar F to B stars. Among the numerous studies, the systematic long-term effort of Adelman and collaborators to analyze in a consistent manner a large set of stars deserves special mention (Adelman et al. 1999 and references therein). A result that may have a particularly significant impact on future abundance determinations is the detection of atmospheric velocity fields in A-type stars by Landstreet (1998). Also of particular interest are studies of abundances in A and Am stars in open clusters, aimed at an improved understanding of the origin and evolution of anomalous abundances in Am stars and a better knowledge of the Li abundances in clusters on the hot side of the Li gap (Burkhart & Coupry 1998; Hui-Bon-Hoa 1999, and references therein). O abundances in A and Am stars in the Hyades indicates that rotational velocity is an important driver of peculiarity (Takeda & Sadakane 1997). New atomic data, both from laboratory experiments and from theoretical calculations, took advantage of breakthrough studies of abundances of heavy elements in HgMn stars with unprecedented accuracy. For Hg and Pt, combination of extreme overabundances (from 3 to 5 dex), isotopic anomalies varying from mild to extreme, and in some stars, of ionization anomalies (Kalus et al. 1998; Bohlender et al. 1998; Hubrig et al. 1999; Proffitt et al. 1999), sets new very challenging constraints for the theories of the origin of the anomalous abundances.

Activity: Spectroscopic observations in the UV reveal the existence of chromospheres around luminosity class III-V stars as early as A7 (Marilli et al. 1997; Simon & Landsman 1997), while the He I D3 absorption feature is found not to be necessarily a good indicator of chromospheric activity (Rachford 1997). Fe II UV emission lines detected in Sirius-A and Vega can be explained without a chromosphere (van Noort et al. 1998). Extreme UV observations of α Cep (A7V), combined with X-ray data, suggest that the structure of its outer atmosphere is akin to that of solar coronal holes (Simon & Ayres 1998).

Magnetic field and pulsation: Further evidence that, contrary to what was long accepted, Am and HgMn stars do have magnetic fields was brought by Bikmaev et al. (1998) and Hubrig et al. (1999). An extensive study of Ap stars with resolved magnetically split lines yielded more than 750 measurements of the mean magnetic field modulus (an increase by a factor of 10 with respect to the number of such measurements available so far), providing new insight into the general properties of magnetic fields in those stars (Mathys et al. 1997). These include, in particular, an intriguing cutoff at the low end of the distribution of the field strengths, around a value of 2.8 kG, and strengthened evidence that the fields of Ap stars in general have markedly non-dipolar geometry. The latter is also supported by models of the field structure (Bagnulo et al. 1999; Bagnulo & Landolfi 1999), which use a combination of dipole and non-linear quadrupole to represent the observed moments of the magnetic field (Mathys & Hubrig 1997 and references therein). Results of radial velocity measurements of rapidly oscillating Ap stars definitely confirm the validity of the oblique pulsator model (Baldry et al. 1998) and reveal so far unsuspected variations of the pulsation velocity over the photospheric depthscale, thereby opening promising prospects for future studies of 3-D magnetic and abundance structures in those stars (Baldry et al. 1998; Kanaan & Hatzes 1998).

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5. HOT EVOLVED STARS (U. Heber)

Blue Horizontal branch (BHB) stars: BHB stars in globular clusters have gravities significantly lower than expected from canonical evolution theory (Moehler et al. 1999 and references therein). Bizarre metal enhancements emerged for BHB stars in NGC 6752 and M 13 (Moehler et al. 1999, Behr et al, 1999). Fe is enhanced to two orders of magnitude above the clusters' metalicities. Radiative levitation and deep-mixing are proposed to explain theses findings.

SdB stars: A new class of multiperiodic pulsating sdB stars, termed EC14026 stars, has been discovered (O'Donoghue et al. 1997) at the same time as theoretical predictions by a completely independent group were made (Charpinet et al. 1996). log g and T_{eff} for the pulsators are in the ranges (5.2–6.1) and (30000–36000 K). The EC14026 stars will expose the interiors of the sdB stars for scrutiny by asteroseismology. A puzzle in understanding the EC14026 stars is the fact that the region of the T_{eff}–log g plane occupied by the pulsators also includes non-pulsators (Billeres et al, 1997).

post-HB stars, UV bright stars, sdO stars: PG 0832+676 which was for many years regarded to be a massive B star at the most extreme distance from the galactic plane (18 kpc) is in fact a low mass evolved star (Hambly et al. 1996). A larger sample of hot evolved, low mass stars, from the PG survey has been analysed by Hambly et al. (1997) concluding that most of them have evolved from the HB. Detailed abundance analyses using fully metal line blanketed NLTE model atmospheres of the sdO stars BD+28°4211 and BD+75°325 are presented by Haas et al. (1996) and Lanz et al. (1997), respectively. Moehler et al.

(1998) studied hot UV bright stars in several globular clusters and conclude that most of them have avoided the thermally pulsing AGB evolution.

Hot post-AGB stars, Central Stars of Planetary Nebulae (CSPNe), PG1159 stars: For the first time quantitative spectral analyses of [WC] type CSPNe have been performed (Koesterke & Hamann, 1997; Leuenhagen & Hamann, 1998). Pena et al. (1998) found that the dramatic spectral and photometric change of the WN type CSPN of N66 in the LMC is due to a drastic increase in mass loss rather than to stellar evolution. Amongst the very hot, chemically very peculiar PG1159 stars a puzzling correlation between their pulsation properties and their nitrogen abundance (Dreizler & Heber, 1998) was found from UV spectra. The most extreme such star, H1504+65, the only bare CO core known, displays a wealth of Ne VII lines in the EUV (Werner & Wolff, 1999). Jeffery et al. (1998) reported high oxygen abundances in three low gravity extreme helium stars and point out their spectroscopic similarity with the hot RCrB star DY Cen.

White dwarfs: The number of DA white dwarfs with known atmospheric parameters has grown enormously (Vennes et al. 1997, Finley et al. 1997, Marsh et al. 1997, Homeier et al. 1998, Napiwotzki et al. 1999). The influence of heavy elements on the temperature structure of the hottest DA white dwarfs has been studied by Barstow et al. (1998). The first comprehensive analyses of (pulsating) DB white dwarfs using improved spectral line broadening data were presented by Beauchamp et al. (1998). The sample of almost all known DO white dwarfs was analysed by Dreizler & Werner (1996) using NLTE model atmospheres. Searches for rotation in DA white dwarfs using sharp NLTE Hα line cores (Heber et al. 1997, Koester et al. 1998) gave mostly null results but pinpointed flat Hα cores in three ZZ Ceti stars that cannot be due to rotation. Jordan et al. (1998) found evidence for helium in a magnetic white dwarf and Reimers et al. (1998) discovered four such stars in the Hamburg ESO survey. Schmidt et al. (1999) detected strong carbon features in a highly magnetic white dwarf. Burleigh et al. (1999) derived a model for the rapidly rotating, highly magnetic white dwarf RE0317-853.

A lower limit of the age of the local Galactic disk to the range 6.5–10 Gyrs was derived from the analysis of 110 cool white dwarfs (Bergeron et al. 1997).

The search for close double degenerates as potential progenitor of SN Ia was continued. While Saffer et al. (1998) reported numerous detections, Maxted & Marsh (1999) do not.

White dwarf companions to radio pulsars provide important constraints on the neutron star. Van Kerkwijk et al. (1996) and Callanan et al. (1998) concurrently derive a very low mass of $0.16\,M_\odot$ for the DA white dwarf companion of PSR J1012+5307. Evolutionary models for He core white dwarfs (Driebe et al. 1998) give a cooling age consistent with the pulsar spin-down age.

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6. O AND B STARS

The first extensive study of normal OB stars in the near infrared has been carried out by Conti & Howarth (1999). Zaal et al. (1997) report the presence of emission features in Brα and Brγ spectra of normal OB stars. Howarth et al. (1997) have assembled a catalogue of homogeneous measurements of $v \sin i$ and terminal velocities of OB stars from IUE spectroscopy.

Abundances in B main sequence stars in view of determining radial abundance gradients in the disk of the Milky Way were presented by Gummersbach et al. (1998) for 16 stars for several elements, and C abundances in B stars towards the Galactic anti-center by Hibbins et al. (1998). 17 high latitude B stars were analysed by Rolleston et al. (1997). Hot stars in M33 were studied by Monteverde et al. (1997). Korotin et al. ś (1999) determination of the abundance of N in the early B star γ Peg is inconsistent with the occurrence of turbulent diffusion connected with the appearance of CN-processed material at the stellar surface. Smith & Howarth (1998) argue that the introduction of microturbulence in non-LTE models of O supergiants solves difficulties associated with previous He abundance determinations in those stars.

Long-term spectroscopy follow-up of η Carinae was presented by Damineli et al. (1998). Lamers et al. (1998) argue that η Car must be a multiple system on the basis of discrepancies of composition between the stellar photosphere and the ejecta, while Zethson et al. (1999) identify difficulties with the interpretation of the velocities of those ejecta.

Evidence for co-rotating wind structures is derived from the observation of wind variability in B supergiants (Fullerton et al. 1997) and in O stars (Kaper et al. 1997, 1999; Prinja et al. 1998). Non-radial pulsations are diagnosed or inferred from observations of line profile variations of O stars (de Jong et al. 1999; Howarth et al. 1998), BA supergiants (Kaufer et al. 1997), and early-B hypergiants (Rivinius et al. 1997). Eversberg et al. (1998) also report the detection of outmoving clumps in the wind of ζ Pup.

Multiwavelength spectra including extreme-ultraviolet continuum observations of early B giants are successfully reproduced with non-LTE model atmospheres (Aufdenberg et al. 1997; Aufdenberg et al. 1999).

Observational constraints on the transition between Ofpe and WNL stars (a challenge for stellar evolution models) have been derived by Crowther & Bohannan (1997), Pasquali et al. (1997), and Bohannan & Crowther (1999).

Finally, we note that Working Groups on Be and B stars are also reported in this volume by D. Baade and P. Eenens.

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