COMMISSION 45

STELLAR CLASSIFICATION (CLASSIFICATION STELLAIRE)

PRESIDENT: M. GOLAY SECRETARY: N.CRAMER

BUSINESS SESSION, July 25, 1991

Report of the President:

I. IAU REPORT ON ASTRONOMY, COLLOQUIA ETC.

We have kept the same headings as in the previous report reflecting again the increase in activity in the field of automatic classification and classification of extra-atmospheric spectra. We have supported the proposal for a meeting in Trieste "Peculiar versus normal phenomena in A-type and related stars"

II. MEMBERSHIP:

New Members:	E. M. Sion (USA), M. Grenon (Switzerland), E. Fitzpatrick (USA), C. Garmany (USA), R. O. Gray (USA), S. Shore (USA), A. Baglin (France), A. A. Ferro (Mexico).
Consultant members:	N. Cramer (Switzerland), M. Kurtz (USA).
Deceased Members:	Nicholas Sanduleak (USA) and Nina Morguleff (France).

III. OFFICERS:

A President:	D. J. MacConnell (USA)
Vice-President:	O. H. Levato (Argentina)
B Scientific Organizing Committee:	
1. Remaining:	M. Golay (Switzerland) as past-President, T. Lloyd-Evans (South Africa), C. Corbally (Vatican), N. R. Walborn (USA), R. Wing (USA), K. Zdanavicius (Lithuania).
2. Proposed and adopted:	M. Grenon (Switzerland), R. A. Bartaya (USSR), D. Egret (France), H. Maehara (Japan).
3. Retiring :	N. Houk (USA), R. F. Garrison (Canada), E. H. Olsen (Denmark)

IV. REPORT OF THE WORKING GROUPS :

a) Photometric and spectroscopic data

A. G. Davis Philip (Chairman) Members have reported to me on the creation of new catalogs and I forward the information to the Stellar Data Center in Strasbourg. For the next triennium, I will finish my work with D. Egret on the creation of a catalog of standards, to be published by the CDS. The committee has agreed to act as advisors on the project. When I have a nearly final version of the catalog, it will be circulated to the committee members for their suggestions and corrections. We will continue the work on compiling data on new catalogs.

b) Peculiar red giants

H.R. Johnson (Indiana, USA), (past Chairman) has reported on the activities of the past three years. See report Commission 29 in the proceedings of the General Assembly. R.F. Wing (Ohio, USA) will be Chairman for the next triennium.

SCIENTIFIC SESSIONS

Scientific Session held on July 26

1 Recent Developments in the Spectral Classification of OB Stars in the Magellanic Clouds

N. R. Walborn

Several substantial results of systematic OB classification programs in the MCs during the past three years were reviewed. They include applications of advanced digital, multi-object, and UV techniques. Fitzpatrick has obtained high-quality optical data for a large sample of B supergiants in the LMC, discovering substantial variations in the relative CNO line strengths at a given spectral type, which have significant implications for understanding the evolution of massive stars in general and the SN 1987A progenitor in particular. Schild and Testor at ESO and Garmany, Massey, and Parker at CTIO have been conducting extensive programs in the O associations, which have revealed many previously uncatalogued extremely early O objects, with clear implications for our knowledge of the MC massive stellar content, the IMF, and sequential star formation. Finally, I presented new optical and HST/IUE spectrograms of Melnick 42, 03 If*/WN6-A in 30 Doradus, together with appropriate comparison objects; the former is a good candidate for one of the most massive stars known.

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2 Spectra of Wolf–Rayet stars in the Milky Way and Magellanic Clouds
P. S. Conti

Far–UV, optical, and near–IR (to 1 micron) spectra of WR stars in the Milky Way and MCs were compared and contrasted. Among WN types, the Galaxy and LMC spectra are similar; the SMC stars seem to have weaker lines, but the issue is clouded by their binary status. Among WC types, the Galactic and LMC stars have different mean spectral subtype properties; the one SMC example is an unusual type. These differences may be related to distinctive initial metallicity environments which affect massive star evolution.

Scientific Session held on July 29

3 Comparison of the Reliability of Spectroscopic Data from Naked CCD's versus Intensified CCD's
R.F. Garrison, B. Beattie, K. Kamper, M. Pedreros and J. Thomson

It is important, when doing MK classification work, not to lose the level of discrimination that has been achieved with the best photographic work. Having used a variety of different types of digital detections, I have learned something about the problems that can be encountered. During the past fifteen years, I have used Wampler's Image Dissector Scanner, Schectographs, 2D–Fruttis and naked Reticon and CCD's. There are many pitfalls in digital work, but because the work is quantitative, it is sometimes more difficult to be aware of them.

1. As pointed out by Walborn in 1990. noise in tracings can be more easily confused with signal than in photographic work.
2. Signal-to-noise ratios of 200–300 is the optimum; with less, the reliability is too low. More is always nice (e.g. 1000) but is not essential for good classification discrimination.
3. The more bias frames and flat fields used, the better.
4. It is best to expand the tracings sufficiently that the eye is attracted to the line strength, not to the line depths (as when the lines appear in the form of spikes).

With care, digitally determined types can be obtained with equal to greater discrimination to those of the best photographic work.

We have compared tracings from an intensified CCD with those of a naked CCD and have found that the lines from the former are systematically shallower than those from the latter. Obviously, the intensified CCD must be used for faint work. With proper attention to taking standards with exactly the same setup, it should be possible to achieve reasonable classifications. However, it is not recommended to use the intensified CCD's for fundamental work on MK standards.

4 Achieving Accurate MK Classification with Digital Spectra
C.J. Corbally

The correct techniques for getting accurate MK classifications from photographic spectra have been well–established since the days of the original MKK atlas. This session considered what techniques and parameters are needed to achieve the same kind of accuracy via digital detectors.

Clearly, the higher the S/N of spectra, the greater becomes their reliability for MK classification or any other purpose. At the telescope, though, some decision has to be made as to what S/N is adequate for the programme in hand.

Experience with digital spectra indicates that, for a star with a normal spectrum, a S/N of 35 to 50 is adequate to type it within a spectral subclass or luminosity interval. (The normal stars would include "normal" weak–line stars too). However, one may not always be certain that the spectrum is completely normal. For stars with subtle peculiarities, such as the λ Boötis–type stars, a greater S/N of 150 will bring greatly increased confidence in classification that is essential to the study of such stars. So, for really reliable work, spectra with a S/N of 150, and even as high as 300, together with repeated spectra of the same star, are needed; for more statistical work on normal stars, a lower S/N is workable.

In discussion, it was emphasized that, as with photographic work, there is no substitute for an adequate grid of primary MK standards. There was no firm conclusion on how exchangeable were standard spectra between similar digital detectors. This probably depends on the accuracy required. Further experimentation, such as the effect of widening spectra on 2–D arrays is to be encouraged.

5 Spectral Classification and Projected Rotational Velocities for A–type Stars
N. Morell and H. Abt

We presented a progress report on a program devoted to obtaining MK classification and *vsini* for 200 A–type stars (all stars with types between B9 and F0 in the 3rdedition of the BSC with $\delta > -20^o$).

The aim of the project is to re–discuss the distribution of *vsini* for this spectral range, which was claimed to be bimodal by van den Heuvel (BAN **19**, 309, 1968).

The classification is carried out on 39 Å/mm photographic spectra. The *vsinis* (in Slettebak's system, Slettebak et al. ApJS **29** 137, 1975) are derived from Coudé–CCD observations centred at λ 4481 Å.

At present, we have analyzed all the Coudé data and 1/3 of the classification work is done.

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6 A-type Stars with Spectral Peculiarities
C. and M. Jaschek

During the past years, together with Y. Andrillat, we have continued our work on Ae and A shell-type stars in the blue and near-IR. In collaboration with Malaroda and Levato, a radial velocity study of the shell lines has shown that shells move with velocities of a few km/s with respect to the photospheres.

It was also found that many shell stars display strong IR excesses in the IRAS bands.

In collaboration with Pedoussant, Ginestet, and Carquillat, a search for the spectra of the companions of Am stars was carried out in the near-IR. Preliminary results show that often no trace of the companion is found.

We hope to publish in the near future an Atlas of O-F5 stars in the Paschen 20–P12 region, in collaboration with Y. Andrillat.

7 Effective Temperatures and Gravities of A-type Stars
R. Faraggiana, A. Garcia, M. Gerbaldi, J. Zorec

The Teffs, log gs, and angular diameters of over 600 normal and chemically peculiar A-type stars were calculated using a modified Blackwell and Shally (1977) method. The Teffs obtained are systematically lower by 2% than those estimated by Code et al. (1976), and the angular diameters are 6% larger. These differences are due to a small difference in the calibration of visible fluxes used in this work (Johnson and Mitchell, 1975) compared to those adopted by Code et al. (1976) (Oke and Schild, 1970).

Log g was estimated using the Lester et al. (1986) calibration of the Hβ photometric index. For normal A stars, these gravities coincide with those obtained from stellar evolutionary models (Maeder and Meynet, 1988) while for chemically peculiar A stars, the gravities estimated from the Hβ index are systematically lower than those calculated from evolutionary tracks.

8 An Ultra-high S/N Atlas of Vega
A.F. Gulliver, S.J. Adelman, K. Sadakane, M. Takada-Hidac, G.C.L. Aikman

High dispersion, 2.4 and 4.8 Åmm−1, ultra-high S/N Reticon spectra have been obtained with the Coudé spectrographs of the 1.2 m telescope of the Dominion Astrophysical Observatory. A mean S/N of 3000 over the spectral region $\lambda\lambda$ 3800-8800 is being achieved. The data will be presented as a spectral atlas, available on magnetic tape or paper copy. Modelling of Vega will be accomplished using ATLAS69 and SYNTHE.

9 Ap Stars with Resolved, Magnetically Split Lines
G. Mathys

High-resolution ($\lambda/\Delta\lambda = 6\ 10^4$ to 10^5) spectroscopic observations of Ap stars with resolved, magnetically split lines were reported. Nine of these stars have been recently discovered which raises the total number of known Ap stars with resolved, magnetically split lines to 21. The differential magnetic intensification of the two Fe II lines λ 6147.7 and λ 6149.2, which undergo partial Paschen-Back effect, was demonstrated. The previously advocated existence of a correlation between the index Z of Geneva photometry and the mean stellar magnetic field modulus cannot be confirmed.

Discussion: N. Cramer stressed that, even though the Z-magnetic field relation may have been purely coincidental, Z remains a good peculiarity indicator. S. Adelman recalled that Preston had observed a partial Paschen-Back effect in HD 215441.

10 Photometric and Spectroscopic Observations of the λ Boo Stars in the Infrared and the Ultraviolet *M. Gerbaldi*

The true λ Boo stars show a deficiency of Fe group elements by a factor of about 3, a higher deficiency for Mg, Ca and Al, and normal or slightly overabundant C, N, O, and S.

The peculiarities of these stars imply that the behaviour of the photometric indices must be checked in order to determine if their calibration can be used to determine *Teff*. The relationship between several photometric indices over a large spectral range has been established for a set of metal-weak candidates and normal stars. Observations in the J, H, K system have been done at ESO (La Silla).

The relationships between (b-y), (B-V), and (V-K), (J-K) have been established after dereddening.

It is clear that true λ Boo stars behave like normal stars from the blue to the near IR. So, calibration of photometric indices can be safely used for determination of *Teff*.

11 The Photometric Multicolour Boxes as a Simple Tool for Automatic Photometric Classification of Stars *M. Golay and B. Nicolet*

A star belongs to the same box as that of a central star if none of its colours deviate by more than a given quantity from the corresponding colours of the central star. The same definition is adopted for boxes made with reddening-free photometric parameters (d, δg for the U, B_1, B_2 V_1 G photometric system).

The concept of photometric boxes can be applied only to multicolour photometric systems having a large number of measured stars and a very great stability of the passbands (Geneva photometric system, 40'000 stars measured in seven colours).

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In a given box, stars have (within some limits) the same spectral classifications, same absolute visual magnitudes, same metal abundances and metallic characteristics, peculiarities (difficult, however, to define the type of peculiarity), and the same reddenings. To be able to efficiently apply the photometric box method, we must have a very large number of stars also very well classified spectroscopically (for example, a classification quality of at least 1 by Houk), a large number of various types with good metallicity criteria (for example, Gray's catalogue, but with more stars). The boxes can often be very well populated, and the security of the classification is increased if we can find at least one or two stars with well-defined spectroscopic characteristics in each box.

12 Precision Photometry and the Selection of Stars for Spectroscopic Study

A.G. Davis Philip

CCD photometry of faint stars has shown that they can be measured with high precision. In many photometric systems, the increased accuracy allows one to determine astrophysical parameters for stars which could not be reached successfully by single-channel photometry. In my program, the Strømgren four-colour system has been used to study the characteristics of blue HB stars in globular clusters and in the field. It is possible to identify stars on globular cluster HBs which are evolving to the blue and to separate them from more highly evolve d stars whose evolutionary tracks have turned and are now evolving towards the AGB. Such information can be used to select stars for further spectroscopic investigation in studies of stellar evolution. This is one example of how precise photometric observations can be used to select interesting stars; many other examples exist in the four-color and other photometric systems.

13 The Third Dimension in Spectral Classification

C. Jaschek

One of the consequences of classifying fainter stars, farther from the sun than was possible previously, is that the third parameter, weakening or stengthening, of metallic lines will become more important than ever.

The problem of line weakening dates back to Roman (1950) and Keenan, but came back in force in recent years through the work of Abt (1986), Corbally (1987), Gray (1989) and Jaschek et al. (1989).

Three basic facts emerge from this work:

a) a large fraction of weak-lined stars exists in F and G type stars, although extreme cases are rare.

b) classification of line weakening agrees well with results from both Strömgren and Geneva photometry

c) it is necessary to unify the existing scales of line weakening (Abt, Keenan, Jaschek et al., Gray) and bring forth a consistent scheme with appropriate standards.

The notation used for MK classification should be simplified so that classifications referring to the line strength of isolated elements be put into notes rather than in the classification itself.

Scientific Session held on July 31

14 The Current Status of Models for Intermediate Temperatures

R. L.Kurucz

High-volume classification is an empirical problem and a computer problem. The state of model atmosphere prediction is still too primitive to approach this problem theoretically. Once the classifications have been made, theory will be much better, but for now I will list a few problems.

There is not enough information in a low-resolution spectrum or in any color system, even at infinite signal-to-noise, to determine the properties of a star. That information has been integrated away. That is also true of the model atmospheres which have been integrated with statistical opacities. With low resolution data, one can only determine a classification box. One has to find a representative star in that same box and study it at high resolution and signal-to-noise in order to determine the properties for that box. However, it is still beyond the state-of-the-art to compute the spectrum of any star theoretically because we do not know all the line and opacity data that affect it. With high-quality spectra, we can at least tell which lines match and which do not, or are missing and try to fix them.

Metal abundance parameters such as [Fe/H] are not good descriptors. In Pop II stars, the light alpha process elements are enhanced. Abundances are not well known even in the sun. There is a difference of 0.17 in the log between abundances determined from Fe I and Fe II. (Any time an abundance is quoted relative to the Sun, the solar abundance used must also be given so the abundance can be corrected when the solar abundance changes.) The He abundance is not known and, especially in early-type stars, can be highly variable because of diffusion. I expect that there is a range of models with different temperatures, gravities, and He abundances that will produce the same fluxes, colors and Balmer-line profiles.

The line blocking and structure of an atmosphere depend strongly on the microturbulent velocity; it is in my new models.

People tend to forget that lines that are washed out in rotating stars and are not visible at low resolution or low signal-to-noise are still there as opacity and in blends and must be considered in an analysis.

The state of absolute spectrophotometry is dreadful. In order to do a reliable analysis, there should also be proper spectrophotometry covering the UV, visible, and IR for a reference star from each box.

15 Maintaining and Refining the MK System in an Era of Automated Classification
R. F. Garrison

While surveys are an important function of classification, there will always be a need to refine the system in the light of new discoveries and to look at peculiar objects from different perspectives. With the data rates anticipated from the new generation of multi-object spectrographs, new categories of peculiar or variable stars inevitably will be discovered, and there will be a need to integrate them into the system with care.

When the computer isolates interesting stars that do not fit into the system, an experienced classifier will want to examine them, because the MK process gives a unique perspective for the understanding of complex phenomena. This perspective is complemented by the automation techniques, as well as by photometric techniques and by detailed high-dispersion studies.

New wavelength regions will be surveyed, new instrumentation used, and new techniques devised. Using the MK Process, new standards will need to be set up, or the old standards will need to be tested under the new conditions.

This requires the interaction of experienced classifiers. More, not fewer, astronomers experienced in spectral classification techniques will be needed to interpret intelligently the results of the automation, mainly due to the large numbers of stars surveyed.

16 The Need for Automation in the Reduction and Analysis of Stellar Spectra
M. J. Kurtz

Advances in instrumentation and optics have brought us to the edge of a new era in spectroscopy. Beginning in 1995, it will be possible for a single instrument, the upgraded MMT, using a 300-fiber spectrograph, to obtain 1000 classification quality spectra per hour for stars with V < 14. Several other similar projects, both larger and smaller, are planned.

The ability of individual researchers to obtain 100,000 spectra per year will cause substantial changes in the way they are used. For results to be understood, a standard nomenclature describing normal spectra must be used, and it must be possible to obtain these descriptors automatically. The MK system can and should serve as the basis for this system of description; an automated procedure for obtaining MK types must be developed.

17 The Revised White Dwarf Spectral Classification System
E. M. Sion

The lack of temperature distinctions among the H- and He-dominated spectral sequences of WDs, the discovery of hybrid composition WDs, and the many composition subclasses further complicated by variable polarization, and other indicators of magnetism all spoke to the need for a new system of WD classification. The new scheme (described in Sion et al. 1983, ApJ **269**, 253) retains a link with the old system but introduces a better description of what the spectrum actually exhibits and provides quantitative temperature information. These changes are consistent with the expressed needs of investigators in the field. The combination of symbols consists of (1) an uppercase D for degenerate; (2) an uppercase letter for primary spectroscopic type in the optical spectrum; (3) an uppercase letter for secondary spectroscopic features, if present; and (4) a temperature index from 0 to 9 defined by $10\times\theta_{eff}$ $(=50400/T)$. Examples of classified spectra were presented. Classification anomalies on this system, among both very cool and very hot WDs with exotic surface compositions, were also discussed.

18 Spectroscopic Classification of White Dwarfs: Hydrogen or Helium dominated Atmospheres
G. L. Hammond

In contrast to the majority of WDs, the spectral classification scheme for the degenerates with Teffs less than approximately 11,000 K indicates only the principal chemical **contaminant** in the line-forming layers. Although it is difficult to derive H/He abundance ratios because of many uncertainties in the line-broadening processes in these cool, dense atmospheres, it is essential to obtain good estimates of these abundances to assess the roles of convective mixing, gravitational diffusion, and accretion from the interstellar medium on the chemical evolution of their envelopes.

We reviewed the principal H/He ratio diagnostic schemes: variations in the Balmer decrement, large Balmer-line profile variations due to quenching, and wavelength shifts in the Ca II H and K lines due to neutral H and He collisions. We presented a new calibration of the Balmer decrement vs. H/He ratio based on the best available data and theory of neutral, non-resonant broadening of Balmer lines, and we presented the results of all these diagnostics in a plot of H/He ratios vs. Teff for a large sample of cool WDs. We concluded that an H-rich (DA) WD with Teff less than 8000 K is an **extremely** rare object.

19 Recent Models of Red-Giant Stars
H. R. Johnson

All available atmospheric models for red-giant stars are based on the principles of hydrostatic equilibrium and local thermodynamic equilibrium, but they differ in the use of plane-parallel geometry (PPG) or spherical geometry (SG) and especially by the increasingly realistic molecular opacities and improved opacity treatments, including the ODF and OS. We reviewed and compared several recent sets of photospheric models: (1) models for K, M giants with OS opacities and PPG (Brown et al., 1989); (2) Mira

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models with mean opacities and SG (Bessell et al., 1989); models for K, M giants with OS opacities and SG (Plez, 1991); (4) models for C stars with OS opacities and SG (Jorgensen et al., 1991); and (5) pulsating models for Miras with mean opacities and SG (Bowen, 1988).

20 The Current Status of Models for Intermediate Temperatures

R. L. Kurucz

I have used my newly calculated Fe group line list together with my earlier atomic and molecular line data, 58,000,000 lines total, to compute new opacities for the temperature range 2000 K to 200,000 K. The new models have been presented at the workshop "Precision Photometry: Astrophysics and Galaxy", to appear in L. Davis Press, Schenectady 1991.

The models, fluxes, and colors are available on magnetic tape and will also be distributed on CD-ROMs.

21 Comments on Models for Hot Stars

R. L. Kurucz

Kudritzki and Hummer have written a review paper "Quantitative Spectroscopy of Hot Stars" in Annual Reviews, **28**, 303-45, 1990. More work is required in the following areas:

1. Current models do not include enough metal-line opacity. I found that increasing the number of atomic lines from one to 42 million decreases the log g by a factor of 3 for stars near the radiation pressure limit. Hot stars may have higher gravities than the hot models have indicated. The additional opacity also helps to thermalize the radiation field so the non-LTE effects may be overestimated, although still strong.
2. Most hot stars are rapidly rotating. Collins and co-workers have shown dramatic effects of gravity darkening with the poles as much as 5 to 10% hotter than the equator. H II regions should be prolate in ions sensitive to the far UV flux.
3. The existing observations, especially those from IUE, are not of high quality; S/N is low. Line profiles and equivalent widths can have large systematic errors.

Humphreys, Kudritzki, and Groth (A&A **245**, 593-603, 1991) showed an interesting result producing strong H lines by adopting a high He abundance in an A supergiant. That suggests to me that model atmospheres for a range of *Teff*, log g, and He may predict the same fluxes, colors, and Balmer-line profiles. Because of diffusion, it may be that the He abundance in all early-type stars must be considered a free parameter.

22 Stellar Parameters from Stellar Wind Models for Early-types Stars

R. Blomme

Early-type stars lose a large amount of material due to their stellar wind. It is driven by radiative acceleration in the spectral lines. Once the stellar parameters are known, the hydrodynamical equations can be solved to give the mass-loss rate, and the parameter can be adjusted it until the calculated terminal velocity equals the observed one. For a sample of early-type stars, we found that the resulting masses are only half the evolutionary masses. However, trial calculations including the effect of rotation, limb-darkening, and turbulence show that the observed terminal velocity can also be obtained using the evolutionary masses. Therefore, the derivation of the mass from a stellar wind code does not appear to be possible at this time.

23 Physical Processes in the Spectral Evolution of White Dwarfs

G. Fontaine and F. Wesemael

We briefly reviewed our current understanding of the theory of the spectral evolution of WD stars. These stars have atmospheres dominated by either H or He but often show a wide and puzzling variety of trace element constituents. Such unusual abundances are believed to be due to the simultaneous operation, in the outer layers of these stars, of a number of physical processes which also erase the abundances in the photospere at the onset of cooling. We described these mechanisms and their interactions.

24 Spectral Classification of Hot Subdwarfs, Planetary Nebula Nuclei and other Evolved and Faint Blue Stars

J. Liebert and R.A. Saffer

Stars in the left part of the H-R diagram exhibit a wide range of (high) Teff, log g, and photospheric abundance. Faint blue stars found especially at high galactic latitude are mainly in one of several late phases of stellar evolution but also include stars which appear to be on the upper main sequence. Historically, the schemes used for classifying their spectra are incomplete, inconsistent, and confusing. Yet, in order to maintain continuity with existing literature, we attempt to combine or adapt the spectral classification systems used for hot subdwarfs, PN nuclei, WDs, main sequence stars and HB stars to form a self-consistent, unified system.

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