SOME LESSONS FROM THE PAST AND THOUGHTS ON THE FUTURE OF SPECTRAL CLASSIFICATION

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ABSTRACT

The importance of maintaining the greatest possible independence of spectral classification from theoretical or other external information is emphasized anew, with reference to some historical discussions now seen with the benefit of hindsight. This ideal requirement applies equally to the development and to the application of a classification system, although in practice some well-established information may guide one's intuition in the initial hypothetical formulation. The fundamental position of this principle in the MK approach to classification is a major reason for the value of its spectral types, and for its continuing success in uncovering new phenomena. The ability of a particular technique to produce interesting or useful results is surely the most significant criterion of its value, and from this viewpoint it appears that new techniques and methods will complement rather than replace traditional spectral classification. Finally, the unique importance at this time of applying both new and traditional methods to spectral classification in the Magellanic Clouds is stressed; they provide the only current opportunity for detailed spectroscopic examination of numerous stars in external systems. It is essential that large telescopes be utilized for this work so that the best attainable observational quality may be maintained, and the many fascinating phenomena revealed by spectral classification in the Galaxy can be comparatively investigated to the maximum extent praticable in the Magellanic Clouds

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1. INTRODUCTION

One of the basic underlying principles of the MK approach to spectral classification has been the preservation of its independence from theoretical or other external information, with regard to both the systemic formulation and its practical application. The significance of this abstract concept may be appreciated in specific terms by reference to a discussion about spectral classification of the future which took place in 1911 (to which attention was called by P. C. Keenan in his fine 1963 review article). Written opinions on the subject had been solicited from interested astronomers by F. Schlesinger representing a committee of the International Solar Union, and the responses appear under his editorship in the Astrophysical Journal of that year. The ideas of Hertzsprung and Antonia Maury, both of whom made crucial contributions to the discovery of the HR diagram, are interesting. Hertzsprung wrote:

> "The spectral classification of stars should be made so that the designation of spectrum is connected in a simple way with other physical properties. If only one sequence of designations is used, as in the Draper Catalogue, the spectrum should be connected linearly with color-index. . . I should recommend that the Draper Catalogue Classification be modified so that the relation between the spectrum and mean color-index will be exactly linear . . . It would perhaps be practicable to make a continuous scale of spectra exactly corresponding to the color-index scale and with the aid of an arrangement like that of the Hartmann microphotometer to determine the scale-reading corresponding to the spectrum examined."

Of course at that time interstellar reddening had not yet been recognized, let alone such niceties as ultraviolet excesses in metal deficient stars, or color-spectrum anomalies among late B-type stars. Maury wrote the following:

> "It seems to be to be of supreme importance that the system to be finally and universally adopted should be evolutionary . . . this sequence [O, B, A, F, G, K, M], which shows in so very marked and wonderful a way the gradual transformation of spectral type, and must in some manner express the law of stellar evolution, should be represented either by numberals in natural sequence or by letters in alphabetical order. If this be not done, the attempt to grasp in though the evolutionary changes and fix in memory the places of individual stars becomes bewildering . . . why could not the Draper letters be rearranged in alphabetical order for a final nomenclature?

. . . As to the question whether the order O, B, A, F, G, K, M, N should be reversed, the evidence seems to me almost conclusive against this. For, if we reverse the order, we should have to assume either that cooling stars change from red through yellow and white to blue, instead of pursuing the opposite course, or else that such stars, as, for example, the Sun, are growing hotter instead of cooler, which seems unlikely. The high light-intensity in the ultraviolet of B and A stars and the gradual falling off of light in this region and later in the blue, with advance toward Secchi's types III and IV, seem clear proof of loss of energy by radiation. Again, the vast atmospheres of hydrogen and helium of B and A stars, when contrasted with the heavier metallic atmospheres of solar and third-type stars, seem clear evidence of an early stage of condensation; while the banded spectra of type IV, indicative of still heavier vapors, scarcely permit us to doubt that they are the most advanced in condensation of all."

In refreshing contrast, Schlesinger himself wrote,

"Much observational work will be necessary in order to establish a system on so firm a basis as to render improbable a revision within a few years after it is set up. . . I am opposed to considering in this connection (classification) any other facts than those revealed in the spectra themselves . . . It remains . . . to see whether the spectrum can be correctly classified from a knowledge of the color-index; or, in other words, whether any two stars that are at the same spectral type according to the Draper criteria always have the same color-index. If not, the specific reasons for this should be ascertained."

And, with remarkable vision, the really important points were clearly emphasized by Russell, in words that ring true across the decades:

"In my opinion, the classification should be based exclusively on a study of the spectra, i.e., of the <u>line and band absorption</u>, without reference to color, intrinsic brightness, and the like, much less to theoretical considerations. External considerations should be admitted only (1) in the search for differences, <u>perceptible in the spectra themselves</u>, which might otherwise escape notice; (2) in determining which of numerous small differences are entitled to specific rank.

> . . . The Draper classification seems to me all the better because the letters are not in alphabetical order. This helps to keep the novice from thinking that it is based on some theory of evolution. [!]
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> . . . I would add the suggestion that a comparative study should be made of the spectra of stars of very different total luminosity but the same spectral class (Hertzsprung's "giant" and "dwarf" stars). If any definite and constant spectroscopic differences exist, they will be of value in classification.
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> . . . When agreement on the details of classification is reached, a series of type stars should be chosen, preferably several for each subdivision, and these should be taken as its permanent definition."

It is ironic that Maury, the accomplished empiricist, should be led astray by excessive theoretical speculation, while Russell, the interpretative theoretician, correctly enunciates the premises for an empirical spectral classification. Fortunately the views of Russell were shared by Morgan and Keenan; in fact, an early developmental paper by Morgan (1937) contains several personal acknowledgements to Russell, indicating that the latter's views did eventually have some direct influence on the spectral classification system universally adopted.

These examples from the past show why the principle of independence is so important. The issue, of course, is the separation of the description of the phenomena from their interpretation, to the maximum extent humanly possible. Lawyers are acutely aware of the importance as well as the difficulty of this objective, and scientists must be as well. If this separation is not made, it may later become impossible to recover the phenomena themselves, especially if the interpretation turns out to be incorrect or in need of revision. In the specific case of spectral classification, failure to avoid the influence of external information may jeopardize not only the future usefulness of the work, but also the correct evaluation of its accuracy and the possibility of discovering peculiar situations. For these reasons one often sees in large-scale studies by the MK school, for instance, the remark that the classification was performed without knowledge of the identities of the stars; the purpose is to avoid even the possible subconscious influence that awareness of their colors, relative magnitudes in binaries or clusters, or association with a particular type of nebulosity might entail. At the opposite extreme, one sometimes sees representatives of other schools assigning "spectral types" with MK notation on the basis of observed colors, or a Roman-numeral "luminosity class" from an observed magnitude and cluster modulus. Such practices should be discouraged, and the results should not be included in compilations of spectral classifications.

A logical corollary of the principle of independence is that the calibration of the empirical spectral classification in terms of physical parameters should be a separate operation to be undertaken after the classification has been completed, as discussed at the outset by Morgan (1937):

> "There would be a number of advantages in having a two-dimensional empirical spectral classification; the operations of the determination of actual values of stellar temperatures and luminosities could then be separate from the problem of classifying spectra. Suppose that it had been the custom to publish the actual effective stellar temperature instead of the empirical spectral type . . . the classification, then would be subject to two sources of error: (1) the error inherent in the criteria themselves and the observational error introduced in their estimation or measurement; and (2) the error introduced in the reduction of the observational data to a temperature scale. The uncertainties introduced in (2) increase unnecessarily the uncertainty in the actual operation of classification.
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> . . . Because of the lack of an intermediate empirical system, it has been the custom to express the vertical spectral classification directly in terms of absolute magnitude. Thus errors, both of a systematic and an accidental nature, are introduced which have nothing to do with the actual classification. As reduction curves are changed and improved, the luminosity classification is also changed, although the estimates of line ratios may remain the same . . . If a second dimension in the classification is to be introduced, it therefore seems advisable to go back to the actual spectra and to give measures of the value of certain criteria on an arbitrary scale which is defined by type stars."

The importance of the principle of independence having been established, one may consider the extent to which it is necessary or advantageous to compromise it in the initial formulation of a system of spectral classification (but not in the subsequent practical application). Clearly empiricism uninformed by any theory or hypothesis is hazardous. The principal assumption underlying the

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development of modern classification systems has been that some basically two-dimensional dependence of the criteria exists. In the case of the development of the MK system this expectation was based on external information obtained from physical interpretation of the Draper sequence, and from the work on absolute luminosity differences by Hertzsprung and subsequently. However, it should be noted that Hertzsprung's work was partly guided by Maury's empirical isolation of c-type (supergiant) spectra, so that empiricism and interpretation alternately informed each other in the historical development of spectral classification. In the case of later refinements or extensions of the MK system, one may rely upon the established validity of the MK system itself, in addition to more recently established empirical and physical information. To make the point specific, in my own investigation of OB spectra with a dispersion twice that of the MK system, significant anomalies were encountered in the behavior of carbon, nitrogen, and oxygen lines; and it was expected that their intensities might be the most affected by moderate admixtures of processed material. Consequently it was decided to base the classification primarily on helium and silicon line ratios; moreover, these elements are represented by two successive ionization stages over a considerable range of types, the ratios of which were expected to provide powerful horizontal (temperature) type criteria. Walborn (1971) discusses the empirical two-dimensional variation of several such criteria; the actual values of the line ratios are defined by the standard spectra. The essential point, however, is that these external considerations should serve only as guides to the selection of criteria which are clearly seen in the spectra themselves (as stressed by Russell in the 1911 quote above), and which can subsequently be applied without further external reference. The ultimate evaluation of the assumptions made in the development of an empirical classification framework is provided by its calibration in terms of the physical parameters, and by the results of its subsequent application to astronomical problems.

2. TRADITIONAL VERSUS NEW TECHNIQUES

Broadly speaking, the results of spectral classification studies are of two kinds: (1) those for which the spectral classification (when supported by broad-band photometry) is self-sufficient, such as the derivation of space distributions and HR diagrams; and (2) those which, through organization of the phenomena or isolation of anomalous objects and categories, provide a basis for further work with other techniques, generally quantitative and/or theoretical. The beauty of traditional spectral classification, when properly and carefully carried out, is that it can provide both kinds of results

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simultaneously. In fact, because of the emphasis on line visibility, inspection of the entire spectrum, and correlation of a new spectrum with all of the classifier's previous experience, traditional spectral classification is undoubtedly the most powerful current technique for obtaining results of type (2) above. Contrary to the impression of some critics, we classifiers love a discrepancy. Oh, there may be some initial trace of annoyance when an object or group of objects refuses to settle compliantly into the two-dimensional frame, but often they lead to our most interesting papers!

Probably all of us engaged in traditional spectral classification have experienced at one time or another a certain lack of appreciation from someone more physically or quantitatively employed, who was perhaps unfamiliar with the principles and numerous achievements of our technique. I recall being somewhat taken aback while a student when another spectroscopist remarked to me, "Well, any monkey can be trained to classify." Well, I am not prepared to argue the point, because I am not an expert on the intellectual potential of our simian relatives. However, I will contest any a priori assumption that an untrained human will be superior to a trained monkey!

It seems to me that a little thought must lead to the conclusion that the only valid criterion by which to judge a technique is its ability to obtain interesting or useful results, and the more so if they are not as readily (or perhaps not at all) obtainable with other techniques. On the contrary, one sometimes sees techniques judged today quite uncritically on the basis of quantitativeness, "objectivity", speed, or even the epoch of their introduction. In considering the future of spectral classification, we must keep in mind that change is not always synonymous with progress! The many new phenomena revealed by traditional spectral classification in recent years -- the presence of Ap stars in young clusters and associations; color-spectrum discrepancies among late B stars, periodically variable phenomena in the spectra of helium-anomalous stars; luminosity effects among the O stars; nitrogen/carbon anomalies in OB spectra; the hottest (and probably most massive) Population I stars; high-velocity interstellar-line phenomena in the Carina Nebula; metal-deficient OB stars in the Small Magellanic Cloud -- to list only a specialized subset, indicate according to the primary criterion above, that traditional spectral classification remains an extremely vital technique in contemporary stellar astronomy.

Several new techniques are being discussed at this meeting, and I wish to comment on two of them. Automatic spectral classification promises significant contributions to problems of type (1) above, by providing a level of information intermediate between those of photometry and MK classification for large numbers of stars. However, any mechanical technique must be expected to be less effective than traditional classification in obtaining results of type (2), and in general anomalous phenomena will tend to contribute to the dispersion of the results.

With regard to new detection techniques, first, although image tubes have been improving, I have not yet found any to be entirely satisfactory for early-type spectra. The problem is not only one of resolution, but also of filling-in of weak absorption features on long exposures. Of course, if one is required to observe many faint stars with a moderate telescope there may be no alternative, but there is no excuse for observing bright stars with an image tube -- or even faint ones if a large telescope is available. Speed should never take precedence over quality, if there is a choice! The most promising new detection techniques I have seen for early-type spectra involve reticon or vidicon devices combined with relatively high angular dispersion, as by G. Walker and associates at the University of British Columbia and by Bisiacchi et al. (1976) in Mexico. In these systems the high quantum efficiency may more than compensate the higher dispersion required to match the resolution of the photographic plate, permitting greater speed with comparable quality, and the added advantage of linear response.

3. SPECTRAL CLASSIFICATION IN THE MAGELLANIC CLOUDS

Finally, I wish to turn to an area which I feel presents one of the most challenging opportunities to spectral classification of the immediate future: the Magellanic Clouds. They represent the only current possibility for spectroscopic examination of significant numbers of stars in extra-galactic systems, with distinct chemical histories and perhaps star-formation mechanisms. It is important that such investigations be made comparatively to what we have learned in the Galaxy, and hence that the observational material be as similar as is practicable. Unfortunately, the Magellanic Cloud stars are faint and numerous, and beyond a certain point there is no alternative to image intensifiers or minimal widening of photographic spectrograms. However, while classifications of early-type stars from spectrograms widened to less than 0.5 mm may be very useful as second-order filters, beyond the objective-prism OB categorization, experience has shown that they do not provide systematically reliable MK types. With large telescopes and efficient spectrographs, it should be possible to obtain optimum classification spectrograms to the main sequence for at least the O stars in the Magellanic Clouds, and for all of the early-type supergiants.

Unfortunately there are those who maintain that large telescopes should not be used for stellar classification; we should take every opportunity to persuade them otherwise, so that we may prevent the anomaly that some of the most significant contemporary problems in the subject should be taken up with unnecessarily inferior observational material. (Some illustrations and discussions of recent Magellanic Cloud classification spectrograms, obtained with the Cerro Tololo 1.5- and 4-meter telescopes and compared with similar galactic material, may be found in Walborn 1977, 1978.)

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DISCUSSION

Nandy: We have mapped the surface brightness of the SMC at four wavelengths, 2740 Å, 2350 Å, 2950 Å, and 1550 Å, from the S2/68 experiment in the TD/1 Satellite. The results will appear in Monthly Notices soon.

There is no indication of dust in NGC 346, whereas there appears to be some in the wings of the SMC.

Would you please make a comment on the presence of interstellar lines in the spectrum of NGC 346 No. 1.

Walborn: There is a definite interstellar K line in NGC 346 No. 1; however the detailed correlation between interstellar atomic lines and extinction in the galaxy is poor. Interstellar λ4430 Å, which does not correlate well with dust, is either very weak or absent in NGC 346 No. 1.

Fehrenbach: CaII lines in O and B stars are not necessarily interstellar; they may be circumstellar.

Dubois: My comment concerns the Calcium interstellar lines in the Small Magellanic Cloud.

Most of the stars I observed at 74 Å/mm, including the early B-type stars, have a Ca line in their spectra. There are indications that the origin of most of the Ca line is close to the stars. These are principally: (1) the variability of the Ca line in some stars; (2) the radial velocity of the Ca line agrees well with the mean radial velocity of the star, within the error of the measurements.

Lesh: Would you please comment on the question of whether MK standard stars remain standards even at different dispersions and in different wavelength regions than are used in the usual classification system? My impression is that they do, and that this is important for two reasons: (1) the standards can be used to predict how normal stars behave at new wavelengths; for instance, the Sun has emission lines in the ultraviolet, but this is not an indication of abnormality; (2) if one insists on assigning a spectral type on the basis of ultraviolet, infrared, high-dispersion, etc., observations and using the MK notation (the same letters and numerals for temperature class, roman numerals for luminosity class) then it is important to use the same standards, even though the classification criteria will of course differ. The only alternative is to use a completely different notation when classifying outside the MK domain, so as to avoid confusion

Walborn: The MK standards should not be assumed to apply to other wavelength ranges or dispersions; that would be an excessive extrapolation of the basis for their definition. Rather the behavior of the criteria at a different wavelength or dispersion is a question to be investigated as a starting point. I would not be surprised if some significant difference should appear between two MK standards of the same type when they are observed in a different domain; the principle of independence applies here as well, and some interesting new phenomena may be discovered if it is maintained.

I think a different notation should be used in classifications from data very different from those of the MK domain.