# PRESENT STATUS OF SPECTRAL CLASSIFICATION IN THE CONVENTIONAL WAVELENGTH RANGE WITH EMPHASIS UPON EARLY-TYPE STARS

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A spectral classification system is a morphological device for arranging in order a finite series of observations of individual objects. One has thus three elements: an "order", i.e. an abstract discontinuous scheme, a series of objects and a certain type of observation (spectrogram) that is performed on all objects of the sample. The "order" is in principle arbitrary; one could think for instance of an order based on richness of lines, or on the presence of hydrogen lines, etc. However such an idealization is clearly simplistic, because it would imply that the classifier is completely unaware of theory - but he is not, if for no other reason than simply that he would never get his PhD. Thus one should add the constraint that the scheme one adopts be physically sound.

The advantages of spectral classification are easy to point out.

a) One gets a quick description of the object which provides a set of parameters upon which further analysis can be based.

b) One can quickly single out objects having unusual characteristics.

c) One gets a luminosity class and thus the possibility of obtaining a distance.

It is probably convenient to quote some figures which bear upon the "quickness" of the method. Let me start by pointing out that from a purely instrumental viewpoint, with a 100 cm telescope one gets a $7^m5$ star at 120 Å/mm dispersion in about 10 minutes. Since longer exposures become rapidly prohibitive and also since very few big telescopes are allocated for spectral classification, one can set the practical limit of spectral classification, on slit spectrograms, except for special cases, at m = 9 or m = 10. One can certainly go a step beyond with objective prism techniques. Here the limit is imposed by the overlapping of the images and it seems that with 120 Å/mm one cannot go much beyond the 12th magnitude for an all-sky survey.

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Up to the tenth magnitude, there are $3.3 \times 10^5$ stars. At this moment there exist MK types for about 45 000 stars (~ 14% of the figure quoted), with a rapid growth in the southern hemisphere. There exist also unidimensional types (Harvard or similar) for about $5 \times 10^5$ objects. On the other extreme, high dispersion analyses exist only for about $10^3$ stars (Morel et al., 1976).

With regard to photoelectric photometry, which has often been praised as "the" solution, one has at the present time about $5.2 \times 10^4$ stars with measured UBV and a much smaller quantity measured with more sophisticated systems.

From all these figures one is forced to conclude that spectral classification is still the quickest and most handy way of "classifying" stars and of sorting out objects for later study. It is clear that once an object has been summarily described, its detailed study should be taken up by other means, be it photometry or high-dispersion analysis. In this sense spectral classification is a first - but vital - step.

If we turn now to the limitations of spectral classification, we find essentially three:

a) Since the scheme is discontinuous, whereas nature produces a continuous variation of parameters, there exists a certain amount of built-in random error. To this error one adds other personal errors, coming from the fact that the classification is done by estimation and not by measurement.

b) It has become evident that a two-parameter classification system is insufficient and that at least a third parameter, related to chemical composition, has to be used.

c) Since the observations upon which the system is based are obtained in a certain wavelength range and with a certain dispersion and/or resolution, there exists no a priori reason why the system should be equally applicable to a different dispersion and a different wavelength region.

Let us examine next each of the three limitations just mentioned.

## a) PRECISION

Probably the best studied limitation is the one related to precision. This has been the subject of several published and unpublished analyses and I quote simply the gross result. A spectral type said to be given in the MK system and taken from the literature is accurate within one tenth of a spectral class and 0.6 luminosity classes. If the classifications of only a single author working under the best conditions are considered, these precisions can be increased by a factor of less than 2.

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Since obviously for general purposes one is practically always obliged to rely upon the work of different individuals, it seems that the precision quoted here is the one to be used in practice. Let us note in passing that although the MKK and MK system was defined with spectrograms giving 120 Å/mm at Hγ, the new MK system, as specified by the dagger types (Morgan and Keenan, 1973) is based upon 84-Å/mm (range 05-B9) and 125-Å/mm (A3-G2) spectrograms, both taken with grating spectrograms (range λλ 3600 - 4800). For these reasons not all refinements introduced recently can be seen on 120-Å/mm plates.

Coming now to the comparison of the errors of spectral classification with other classifications, for instance photometric ones, let me stress one essential point, namely that as a general rule it is much more difficult to get luminosities photometrically than spectroscopically, so that for most stars of the galactic field the spectroscopic luminosity is the only luminosity easily obtainable. This said, it is understandable that photometry will be superior to visual classification when it comes to compare order on the main sequence. In early-type stars this can be clearly seen, for instance in the region B6-B9 where the classifier working in the conventional range has very few spectral lines to hang on, and where consequently almost any photometry will be of equal or superior precision. In regions where there are several lines available, spectral classification is comparable to photometry. (See for instance Jaschek and Jaschek, 1973).

## b) THE THIRD PARAMETER

Although the question of a third parameter, related to stellar composition, is mentioned in the introduction to the MKK Atlas, the idea was accepted only much later. The main opposition came apparently from the stellar atmospherists, who maintained the uniform composition of all stellar atmospheres. A real change came only when Baade's ideas concerning stellar populations made their full impact.

The first place where a third parameter was needed was in those late-type stars whose metallic lines can be either weak or strong. Starting with late-type stars (later than F), an increasing number of peculiarities was then found in all types of objects. Practically all of them are related to abnormal line strength. These peculiarity groups have been discussed many times in the literature; recently I gave a sumpary in IAU Symp. 72 (Jaschek, 1976). Table 1 summarizes the main peculiarity groups of the early-type objects (O - F). I would like to add that not all classes are recognizable at 120 Å/mm; for instance some Ap stars require 40 Å/mm or less and the CNO stars 60 Å/mm.

It is likely but not obligatory that the anomalies are linked to abundance anomalies. Other explanations can be put forward for at least some groups, based upon radiative pressure, magnetic field effects, gravity diffusion, surface nuclear reaction, etc. Let me insist however that our knowledge of the peculiarity groups is still very frag-

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TABLE 1

Peculiarity types

| Spectral type | Peculiarity type implying a third parameter |
|---|---|
| O | O-type subdwarfs<br>WR |
| B | CNO stars<br>He-strong stars<br>He-weak stars<br>B-type subdwarfs |
| A | Ap<br>Am<br>λ Boo<br>δ Scu |
| F | Fm stars<br>Stars with weak metal lines |

mentary and that in consequence interpretations are even more problematic. Let me show this with just one example.

We have come to accept the idea that in late-type stars it is possible to define a metal abundance - the "z" - which summarizes the abundance of all metals with respect to some conveniently chosen standard. Such a gross characteristic is useful in, for instance, subdwarfs, where the metals are all rather weak. The generalization of a single "z" value, applying equally to all elements in a given stellar atmosphere, runs into difficulties in Am and Ap stars, where very striking exceptions are known. For instance all elements before atomic number $A_0$ are underabundant and thereafter, up to $A_1$, they are enhanced by a factor z, whereas after $A_1$, z adopts the value $z_2$, etc. Now in B stars, except for a few analyzed at very high dispersion, the situation is still worse. The main reason for this is the lack of metallic lines in the conventional wavelength region. In Table 2, I have specified the only atomic species observable in early-type stars.

The availability of a small number of rather intense lines in early-type spectra has made possible a process of systematization not yet feasible in other spectral types, which consists in posing the problem of how many criteria one should use to define the classification scheme at each place. Since a criterion is specified usually by a line ratio - thus implying two lines of different elements or of the same element in different ionization stages - one could choose in principle any two elements. In O-type stars we have to choose H and He,

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because nothing else is well visible, but in B-type stars we do have several elements. Walborn (1972) has suggested using He and Si both, because there do exist stars where carbon, nitrogen and oxygen behave abnormally. But He also can be abnormal, as illustrated for example in Table 1 by the He-strong and He-weak stars. This shows clearly that in this case, the idea of the "uniform z" seems to be an over-simplification. But because of the lack of lines of metals in the classical wavelength region, we do not know what happens with the metals, so that it is possible, but not very likely, that the "z factor" is identical for all metals in B-type stars. To solve this problem, we need the ultraviolet region, with its enormous number of metallic lines - provided that one can observe at such a dispersion to overcome the blending problem at least partially.

## c) THE OBSERVATIONS

Because of the general acceptance of the MK system, one very important question has been left aside, namely to examine if when looking at other wavelength ranges one can group the stars the same way as in the MK system. The question is generally answered by saying that since the two basic parameters of the MK system are equivalent to temperature and gravity, and these two parameters are completely independent of the region of the spectrum from which they are derived, the analysis of other regions cannot be in contradiction with the MK classification. Such reasoning would be entirely convincing if one could be sure that one knows all the physics of the stellar atmospheres including the numerical values of all parameters. This clearly is not the case - remember for instance the discrepancies between the observed and the predicted fluxes below 3000 Å some years ago.

TABLE 2

Atomic species present in early-type stars regardless of luminosity, visible at 40-120 Å/mm in the region λλ 3700 - 4900 Å

| Range | Atomic species |
|---|---|
| O5 - O9 | H, He II, (He I) |
| O9 - B1 | H, He II, C III, N III, Si III, Si IV |
| B1 - B5 | H, He I, C II, N II, O II, Mg II, Si II |
| B5 - B9 | H, He I, Mg II, Si II |

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One could also conceive of a situation where the behavior of one spectral region is dominated by one process which becomes unobservable (or difficult to observe) in other regions. For instance rapid rotation could have such an effect.

In view of such difficulties, it seems best to set up a classification scheme in the ultraviolet region and to examine then if it coincides with the system derived from another piece of the spectrum. If the results agree, one could be a little bit more sure that the basic physics is known; if not, one can start looking for the explanation of the discrepancies.

Probably some of you will feel that in view of all we know about stellar atmospheres, such a view is hardly justified. Let me thus reformulate the problem in other words. In Table 1, I have listed eleven groups of peculiar objects, to which for instance the Be stars could be added, as an example of another well defined group of peculiar stars. If we knew the physics of all the stars very well - this is just an assumption! - we should be able to explain each group of peculiarities in terms of an appropriate set of physical parameters. These could then be used to predict what the star should look like in another wavelength region - for instance in the UV. But this task has not been attempted by anybody yet, and so we are obliged to establish a system of classification in the UV in order to single out the peculiar objects by some "peculiar feature". By the same reasoning nobody can exclude a priori the possibility that new peculiarities might appear in the UV, which differentiate stars that look closely similar in the conventional range. I think thus that one cannot circumvent the necessity of establishing a new classification system in the UV - based upon ultraviolet criteria - and I think that this constitutes one of the most interesting and rewarding future developments in stellar spectroscopy.

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