LOW DISPERSION SPECTRAL CLASSIFICATION WITH SMALL TELESCOPES

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ABSTRACT. We review the spectral classification work with low dispersion. It is mainly concentrated on the MK-System. First we summarize the original properties of this system, its evolution and its present properties. We describe the MK Process and emphasize its importance as a tool for future research on spectral classification. In the third section we comment briefly about the instrumentation and the techniques used in spectral classification work and finally we mention a list of research programs that can be undertaken with a 1m-telescope and a good spectrograph.

1. INTRODUCTION

The title of this paper implies a very broad subject, so I would like to define more precisely which are the points that I will touch on in this review. First there is a redundancy in the sense that spectral classification has been historically a subject for small telescopes and in the second place it will be necessary to define what is *low dispersion*.

Let me mention first that spectral classification is to arrange stars into a certain number of groups formed of similar objects, through the appearance of their spectra (lines, blends, continuum features). The morphologist does not know a priori about physics, envelopes, temperatures, abundances, gravity, stellar rotation, turbulence, etc.

Several different systems have been devised to classify stars using photographic plates or tracings of these plates where some quantitative measures were done. Among the range of very low dispersion we must include the *natural groups* illustrated by Morgan, Meinel and Johnson (1954).

I am not going to deal with natural groups; for a review of them it is useful to read McCarthy (1979, 1984).

An example of work with dispersions ranging from 150 Å/mm to 300 Å/mm was done by Nassau at Warner and Swasey Observatory. Those interested in this kind of work can read details in Nassau and van Albada (1947). Attempts to classify from continuum measures have been done by Barbier and Chalonge (1939, 1941). I will not deal with systems such

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as this one or with dispersions lower than 130 Å/mm. In this review low dispersion will be defined to be between 130 Å/mm and 40 Å/mm, and I will introduce the ingredient of my personal experience which concerns primarily the MK system.

I consider the MK system to be the most powerful tool to classify stars. It has produced very important astrophysical results, it is widely used (although not very honestly sometimes) and it will be used in the future. So my review can more properly be entitled MK Spectral Classification with Small Telescopes.

I want to mention two very important meetings which are fundamental for every stellar astronomer. They are *Spectral Classification of the Future* (McCarthy et al. 1979) and *The MK Process and Stellar Classification* (Garrison 1984). The latter one is a masterpiece in the field and should be read by every stellar astronomer. The discussions I have found to be especially enlightening. Let us now describe *the system,* then we will refer very briefly to the technical requirements and finally in the last section I will describe some research that can be done with a spectrograph and a small telescope.

2. THE MK SYSTEM

2.1 The original frame

The original MK system was introduced by Morgan, Keenan and Kellman (1943) in one of the most famous papers ever written.

In the Introduction the authors wrote:

The plan of the Atlas can be stated as follows:

To set up a classification system as precise as possible which can be extended to stars of the eighth to twelfth magnitude with good systematic accuracy.

The actual process of classification is carried out in the following manner: (1) an approximate spectral type is determined; (2) the luminosity class is determined; (3) by comparison with stars of similar luminosity an accurate spectral type is found.

The instrument used to obtain the spectra was a small one-prism spectrograph attached to the 40-inch refractor at Yerkes Observatory. The reduction of collimator to camera was about 7 so one can open the slit on the telescope focal plane without losing resolution. The usable spectral region of the plates was λ 3920-4900 Å. The dispersion was 120 Å/mm at Hγ.

The Atlas was composed of 55 prints which represent the standard stars that defined the original MK system. The reproductions of the Atlas show the quality of classification spectra taken at the time.

The spectral types and luminosities are defined by the standard stars, several ratios between pairs of lines can be used but these ratios can not be used safely at different dispersions. Each dispersion has its own problems that must be studied independently.

Morgan and Keenan wrote in 1943:

There appears to be, in a sense, a sort of indefiniteness connected with the determination of spectral type and luminosity from

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a simple inspection of a spectrogram. Nothing is measured; no quantitative value is put on any spectral feature. This indefiniteness is however, only apparent. The observer makes his classification from a variety of considerations, the relative intensity of certain pairs of lines, the extension of the wings of the hydrogen lines, the intensity of a band, even a characteristic irregularity of a number of blended features in a certain spectral region. To make a quantitative measure of these diverse criteria is a difficult and unnecessary undertaking. In essence the process of classification is in recognizing similarities in the spectrogram being classified to certain standard spectra.

It is not necessary to make cephalic measures to identify a human face with certainty or to establish the race to which it belongs; a careful inspection integrates all features in a manner difficult to analyze by measures. The observer himself is not always conscious of all the bases for his conclusion. The operation of spectral classification is similar.

It is useful to recall that in the original frame each type and luminosity was defined by several standards for example α Leo, β Lib and β CMi defined the B8 V box.

2.2 The evolution of the MK system

As with any frame of reference in active use, the MK system has evolved to deal with the many interesting problems involved in astrophysical research. In 1978 Morgan, Abt and Tapscott (1978) published *The Revised MK Spectral Atlas for Stars Earlier than the Sun* while in 1976 Keenan and McNeil had already published *An Atlas of Spectra of the Cooler Stars: Types G, K, M, S and C*. The revision by Keenan and McNeil of stars later than the sun had two main purposes.

(1) The assignment of types and luminosities can be strongly influenced by abundance effects even when the overall appearance of the spectra does not show conspicuous peculiarities.

(2) For the later classes it is not sufficient to speak of *the metal abundance* and to assume that the concentrations of all the elements heavier than helium vary in step.

So the Atlas for the Cooler stars has introduced a few modifications in the subdivisions of types G, K and M especially for interpolation, as K2, K2+, K2.5 and K3-.

In luminosity class the change with respect to the original system was the recognition that there are some stars in the Large Magellanic Cloud that are more luminous than the Ia class in our Galaxy so they introduced the luminosity class 0. Also in some parts of the HR diagram it was possible to subdivide the luminosity classes from II to V, using the subscripts *a* or *b*.

Perhaps the most significant change was the introduction of a compact notation that signal differences in the features defining the abundance groups. These groups are labelled in the Atlas as: Hδ, Ca or Na, Fe, CN, CH, Spectral Type C, C^{13}, Ba, Zr and Li. The symbol is followed by an index from 1 to 5 to indicate the amount of departure of the feature from the intensity in the spectrum of a star with solar composition. The index is positive or negative if the intensity is

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higher or lower respectively. The plate material for this revision was taken with the 72-inch Perkins reflector at Flagstaff, with the 60-inch telescope at Cerro Tololo and with the 32-inch Schotland telescope at Perkins Observatory. The dispersions ranged between 75 and 80 Å/mm.

In the Morgan, Abt and Tapscott Atlas the revision had three purposes, to present an improved version of the MK system defined in 1943, to decrease the *noise* of the classification defining only one standard star in each box and to demonstrate how rich the prospects can be for classification in the future, using several conceptual improvements that were incorporated into the MK-78 System as the authors named it. The consequence was a finer structure of the MK Diagram for stars earlier than the Sun. Some parts of the written booklet that accompanies the reproductions are also masterpieces because a lot of important concepts are stated in a couple of lines.

A major improvement of the Morgan and Abt work is the extension of the spectral range used to λ 3500 Å and also that the MK-78 system permits perfectly well the inclusion of localized third dimensions.

The Atlas is clearly not definitive because there is a large body of stellar spectra that have not been studied yet with the MK system.

The reproductions of this Atlas show the quality of the spectrograms that can be taken at the present time for spectral classification. The spectra were taken with the spectrographs at Cerro Tololo and Kitt Peak, and they have a demagnification slit-plate of almost 10. They are very efficient and have good definition.

2.3 The Present System

We can summarize the current properties of the MK System as follows:

(a) It is an empirical system. No physics is involved a priori.

(b) Types and luminosity classes are defined by the patterns and intensities of spectral lines, bands and blends which exist in the spectrum of a standard star.

(c) It is defined in the spectral range (λλ 3500-4900 Å) for earlier types than G2 and (λλ 3900-4900 Å) for later types, using as a detector the photographic plate (Kodak IIa-O emulsion). The dispersion is 125 Å/mm for earlier types, 75-80 Å/mm for later types and the resolution ranges from 1.5 to 3 Å.

(d) A third dimension is included for the stars later than G2 to take account of the abundance differences.

(e) A constant spectral type is assumed for all the standard stars.

More than 130000 stars have been classififed in the MK System (for a review about the compilation of data see Jaschek, 1984).

2.4 The MK Process

One of the most important results of the meeting *The MK Process and Stellar Classification* was the definition of a procedure for the classification of specimens which do not fit the MK System. The methodology

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that makes possible the construction of systems of classification based on the characteristics of stellar spectra is called the MK Process. Morgan (1984) gave details and examples about its usage.

The application of the MK Process to classify certain types of objects in our Galaxy and in other galaxies opens a lot of research possibilities with small telescopes equipped with good (but not necessarily very expensive) spectrographs and different kinds of detectors including the photographic plate.

Before going to the technical needs and the research possibilities I would like to show in Figure 1 what is wrong and what is good in the application of the MK System today from my personal point of view. I

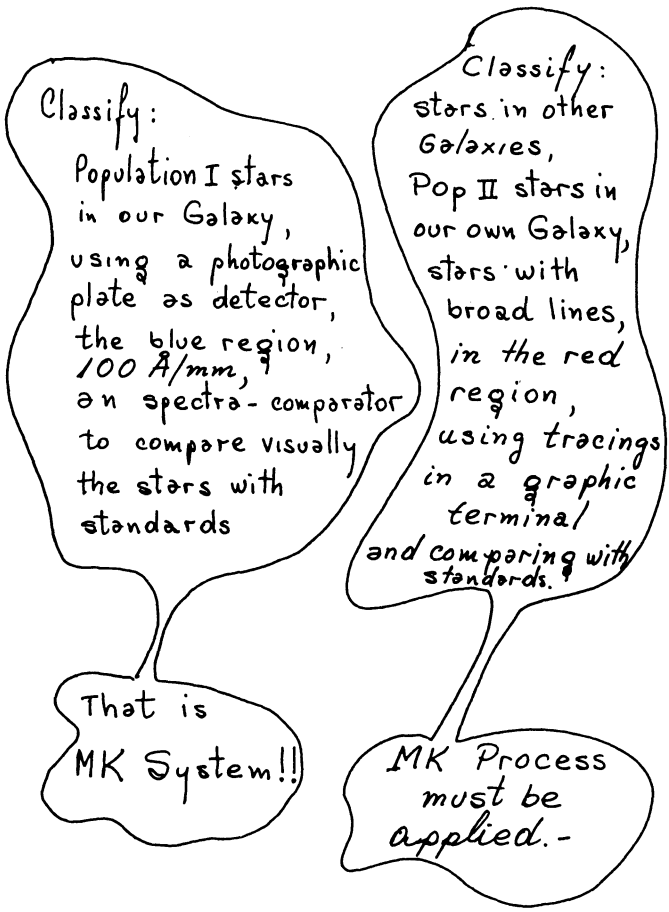

Figure 1. The MK System and the MK Process

would like to emphasize that this is what I consider wrong and good because I perfectly agree with the principle introduced by David Crawford (1984) about *live and let live*, so it is not my intention to advise other people what they must do.

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From the figure it is clear that for me it is not possible to use the MK System as defined by Morgan, Abt and Tapscott (1978), for stars in other galaxies, for stars of different population than I in our own Galaxy (i.e. globular cluster stars). It is not possible to apply it to broad-line stars; it is not possible to classify, in the MK System in a rigorous way, spectra which are not recorded on a photographic plate or outside the wavelength range λ 3500-4900 Å. Also to classify in the MK System it is necessary to compare the stars visually with the proper standards.

For working at other wavelengths, with other detectors, in other galaxies or on stars for which the MK System is not designed, an extremely powerful tool exists in the *MK Process*. I believe it must be used when the MK System can not be applied and then the results can be studied and discussed in the framework of the MK System.

3. INSTRUMENTATION AND TECHNIQUES

What you need for research in spectral classification is a telescope with a smooth tracking and a fast spectrograph with a good optical quality. The telescope is supposed to be of the order of 1m, a small telescope, in order to pursue the aim of this meeting. The spectrograph must have optics which transmit in the UV and the demagnification from the telescope to camera focal planes should be between 7 and 10 so you can use the spectrograph with advantage even in places where the seeing is not very good. The detector may be the photographic plate or a CCD or a Shectograph-type instrument. The cheapest is a photographic plate followed by the combination with an image tube. There are some tubes that give acceptable results concerning resolution. Then you have a CCD or Reticon in the middle of the price range and finally the Shectman system. Perhaps the latter is not yet in the price range of small institutions.

After the observations have been secured you can use an eyepiece, a comparator or a microscope (it depends on your budget and on your visual memory) in the case that your detector is the photographic plate, intensified or not. If you like tracings, you can trace your plate and classify from it; or from tracings on a graphics terminal if you obtain the data with a CCD, Reticon or Shectograph. But also you can convert your tracing to resemble a photographic plate through modern plotter devices. So the combination is probably unlimited and the observer can do what he likes, but the important point is to keep oneself honest with the frame of reference he is using: the MK System or another one built through the MK Process. Figure 2 summarizes the technical possibilities.

A word about detectors. There are several very good reviews about them. Let me mention two excellent ones: Eccles et al. (1983) and Gray (1984). The first one is a book very complete and especially written for astronomers. I would like to take the final paragraph of Gray's paper.

1. Don't think in terms of building an electronic detector system - do you make your own photographic plates?!

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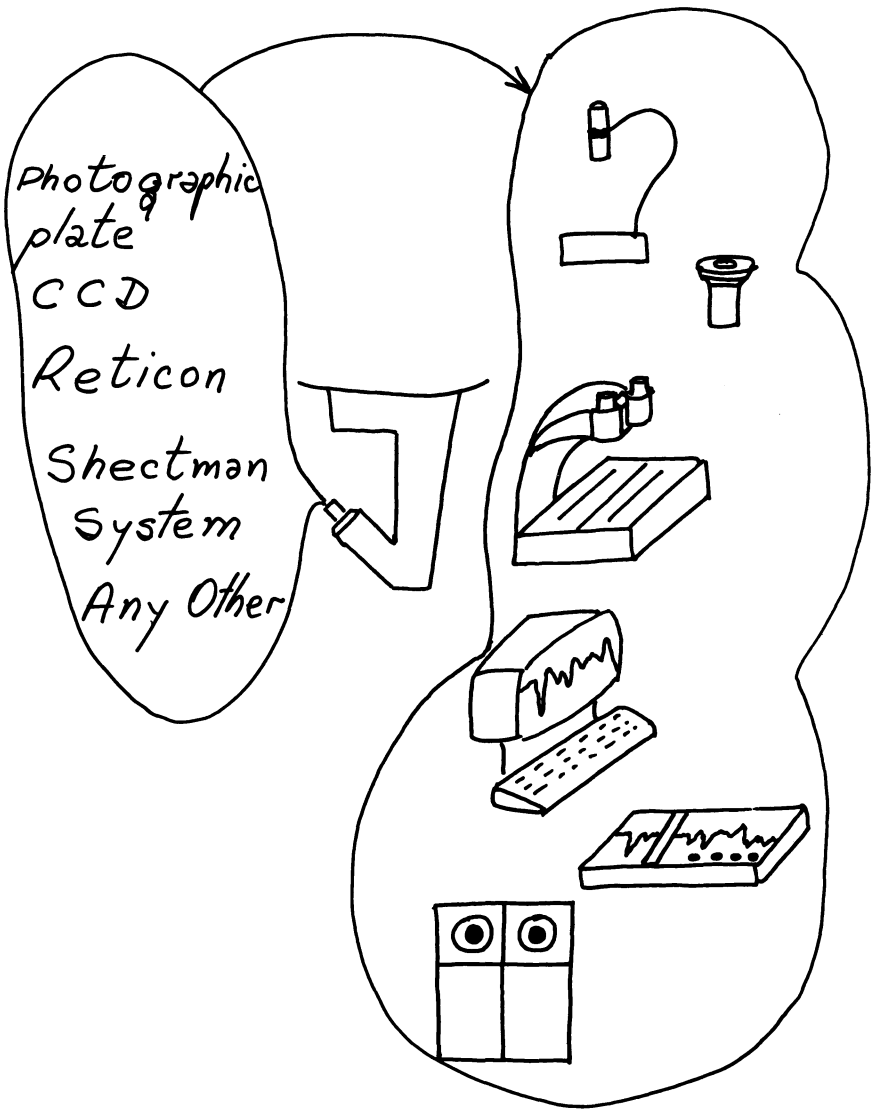

Figure 2. Different techniques for spectral classification.

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2. Ask yourself. Can the electronic system give me the spectral-classification data that I need but can't get photographically?

Experience indicates that it is necessary to go to S/N ratios of 500 or more to see on a spectrum record from a CCD, the same details that one sees on a photographic plate. My impression is that for spectral classification work it would be justified to use CCD frames if you can combine them in the future with automatic spectral classification. I would like not to be misunderstood on this point; 'modern detectors' are wonderful tools that permit us to reach, with small telescopes, objects unthinkable 10 years ago, but we are trying here to get an accurate spectral type so we need to select a system and the prescriptions of this system must be followed.

For me there is another point of great concern with the modern detectors. In general, research programs on spectral classification are long range projects which are fundamental work and one would like to have an instrumental configuration to remain the same for a long period of time.

It is very common today that new detectors especially at large observatories but even on small telescopes, are changed very often with the additional fact that some of these observatories are discontinuing the usage of the most traditional configurations. These are severe drawbacks for systematic projects.

4. RESEARCH PROGRAMS

A lot of work remains to be done in spectral classification using small telescopes. I will review only some of them very briefly.

(a) Research on the MK System itself
It is necessary to explore certain localized regions of the MK Diagram to introduce some detailed third dimension. Morgan (1984) gives two examples namely the Hg-Mn stars and the Sr II stars. Also the λ Bootis stars whose discovery was reviewed by Abt (1984) deserve special attention.

(b) Standards
It is necessary to include one standard in each box of the MK Diagram which is not full yet.
Concerning faint standards it is possible to define new ones with the procedure, mentioned in the Toronto meeting, of bootstrapping from bright magnitudes to fainter ones using different telescopes. I believe that with a 1m telescope it is possible to work reasonably well as far as magnitude 12. Garrison is working on the problem of establishing faint standards.

(c) It is necessary to use the MK Process to explore the yellow-green and the red region of the spectra of the stars, or to establish new systems in these spectral regions completely autonomous from the MK. This is perfectly possible with a 1m telescope.

(d) It is necessary to explore spectral classification with other detectors than the photographic plate. During the meeting

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at Toronto many people expressed the desire that an Atlas showing an array of frames in some *natural* order would be very important. You can classify from the tracings using the MK Process if you reach high S/N values.

(e) The devising of a homogeneous system for Pop. II stars can be done with a small telescope and this is very necessary to complement the MK System.

(f) It is necessary to use the MK Process to explore a system for broad-line stars for which the MK System is not designed.

(g) Eclipsing Binaries
It is a difficult task but there are hundreds of eclipsing binaries that can be observed with a fast spectrograph on a 1m telescope. Morgan (1984) pointed out some of the difficulties that one is going to encounter when classifying eclipsing binaries but I believe that a project on eclipsing binaries is worth undertaking.

(h) Spectroscopic and Visual Binaries
Some work has been done recently on spectroscopic and visual binaries. In particular Abt (1981, 1985a) published 1865 MK types of members of visual systems. He found new Ap stars λ Boo stars, Am stars and SB2s.
Corbally and Garrison (1984) determined MK classification of 170 visual binaries with separations between 1 and 5 arcseconds.
But there is still a lot of place for research projects in this field. There are still spectroscopic binaries with orbits computed in Batten et al. (1978) which do not have MK types.

(i) Trapezium Systems
Some work has been done recently by Abt (1985b) and by Levato still unpublished. Candidates selected from the Catalogue of Trapezium Systems compiled by Allen et al. (1977) were observed in both cases. Abt observed 31 systems and found only 11 Trapezium systems, Levato observed around a 100 systems from Las Campanas with Garrison's spectrograph and found the same proportion of true Trapezium systems.
Continuation of programs on Trapezia can be done with small telescopes.

(j) Variable Stars
There is a lot to be done in this field. Some kinds of variables have been studied recently in two important contributions: Miras by R. Crowe (1984) and Cepheids by Gauthier and Garrison (1984) but other kinds of variables are practically untouched.

(k) Open Clusters
A lot has been done on these objects but let me point out that MK spectral classification is lacking even for some clusters nearer than 500 pc. Recent compilations of data by Mermilliod (1984) indicate that there are only 4000 stars in 225 open clusters with MK spectral classifications. This is a dramatic situation. I have worked with Helmut Abt on several clusters in the mid 70's. The results that we have got with respect to the occurrence of peculiar stars have been summarized by Abt (1984). From CTIO we continued the work on several

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interesting southern objects like the Trumplers in the Carina region, Cr228, IC2391, NGC2287. We have almost finished the classification of the 550 stars in the Orion Association which were included by Warren and Hesser (1977) in their photometric study. These investigations produced dozens of peculiar objects, composite spectra, double-line binaries, Be stars, and other kinds of exotic objects. If we are going to understand completely these specimens the spectroscopic observations of open cluster members must be pursued.

(1) It is necessary to take advantage of the strong effort of Nancy Houk's (1975, 1978, 1982) classification of the HD stars in the MK System. The new catalogues are a gold mine for picking up interesting objects whose spectra for several reasons could not be precisely defined. The excitement of astronomy compared with other sciences is that astronomy does not know yet all the specimens under study.

Summarizing, down to magnitude 12 there are more than 3 million stars that can be reached with a modest telescope + spectrograph combination from a good astronomical site; less than 4% have MK types so there is a lot of work to do; photographic plates, CCDs, Reticons, Shectographs, microscopes, comparators, tracings and computers are welomed; keep honest and go ahead.

I thank very much Bob Garrison and Helmut Abt for sending me details of their current projects on spectral classification.

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DISCUSSION

Gliese: You have mentioned the MK classification on objective prism plates by Nancy Houk. I have used MK types as second order distance indicators and I became aware that, at least in the region K2V to M0V, these objective prism MK types have a somewhat different spectral type-luminosity relation than the slit MK types (differences up to $\Delta M = 0^{m}.5$ occur).

Mochnacki: Both the previous speakers (Phillips and Levato) referred to image tubes. As you know it has been difficult to obtain UV-sensitive intensifiers in recent years. There is good news: VARO are now producing UV-sensitive proximity-focussed microchannel plate intensifiers, with gains of up to 15,000 and sizes up to 40 mm. This is particularly useful for photon-counting and classification applications.

Garrison: Two comments. First, Morgan and Abt are working on a definition of a classification system for pop II stars. Second, it is possible to build an MK spectrograph for about $US2000 worth of materials. I have drawings and will supply them freely.

Scarfe: The lack of MK classifications for spectroscopic binaries could well be worse in a future orbit catalogue. For example the majority of the objects for which Griffin has published orbits in the Observatory do not have MK types.

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