III CRITERIA AND APPLICATIONS OUTSIDE THE MK DOMAIN

Discussion Leader, Arne Slettebak

CRITERIA AND APPLICATIONS FOR SPECTRAL CLASSIFICATION OUTSIDE THE MK DOMAIN

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ABSTRACT

The area under discussion here lies beyond the domain of the MK system and includes studies of natural groups as detected in low dispersion studies; it extends to spectral regions studied now in the far ultraviolet and in the infrared and radio regions; in this paper primary consideration is given to optical spectra from the near infrared to the near ultraviolet. We give a description of "natural groups" and a brief description of new possibilities opened for research in this area through the introduction of thin prisms and the combination of prism and grating (GRISM). Finally a summary of spectral criteria useable outside the MK domain is presented.

To survey research in low dispersion spectroscopy we begin by referring to the summaries given by Bidelman (1965), Hoffleit (1942), McCuskey (1965), Fehrenbach (1958), Stephenson (1973), Elvius (1965), Nassau (1956) and Blanco (1965). The display of atlases and catalogues prepared for your examination here illustrates the variety and excellence of our standards and provides at least a partial indication of the accomplishments that are attainable outside the MK domain. You will note that some of these, though made with objective prism techniques, are really "within the MK domain" or very close to it. Several other colleagues at our meeting will be speaking of varied research projects accomplished "outside" the MK domain in many observatories in Germany, Chile, USSR, Sweden, Switzerland, Spain, Italy, France, Mexico, USA, and Venezuela. Most exciting is the work with the new UK Schmidt in Australia and I know we are all anxious to have news of the performance of the "Big-thin prism" there. Large Schmidt cameras are being transported across the surface of our planet

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to sites with superior seeing and transparency, and smaller but efficient Schmidt type instruments will be orbiting above us in the near future.

To set the scene we cite here with admiration and praise the outstanding general surveys, from those of Fr. Secchi through the classical work at Harvard and Peru and Potsdam down to today's Michigan survey already completed for two large zones of the southern sky. Then there are the more specialized surveys such as those at Case and Hamburg both for luminosity function determinations and for the detection of high luminosity stars, those at Dearborn and Texas and Mt. Wilson and more recently at Castel Gandolfo, Stockholm, CTIO and Siding Springs for red stars and for emission objects. And we must not forget the careful surveys for luminous stars and the giant branches of stellar populations in the Magellanic Clouds, explored spectroscopically from Africa, South America and Australia. Since I now propose to survey present results with an eye to the future research, it may be better not to attempt here a full bibliography. The reader is referred to the summary articles listed in the beginning of this paper and is then recommended to consult the published proceedings of the three IAU discussions which have preceded this one. These are edited by Loden, Loden and Sinnerstadt (1966), by Fehrenbach and Westerlund (1973) and by Hauck and Keenan (1976). Other sources of reference materials with more specific orientations may be found in the volumes edited by Hack (1967) and by Kumar (1969).

The obvious immediate references source for materials of low dispersion spectroscopy will be found in the sections 113, 114, and 115 of the Astronomy and Astrophysics Abstracts (1969-1977).

We speak here of criteria and applications of spectral classification outside the MK domain. Yesterday both Morgan (1979) and Keenan (1979) gave us very clear statements about what the MK domain signifies for them. It was in answer to questions I posed as I was writing this that Morgan formulated his remarks and I am grateful for these. As we recall, the principal domain for the determination of fundamental reference stars is from the K line to Hβ (3930 Å to 4860 Å); the greatest number of precise MK types have been determined from slit spectrograms having dispersions between 100-130 Å mm^{-1} on photographic plates and with a resolution between 700 and 1000. As we saw yesterday, some surveys, with special care under exceptionally fine circumstances of seeing and transparency and proper exposure times, can approach in quality the standards set forth above. Such for example are the spectra reproduced in the Michigan Spectral Atlas and in the Bonn Spectral Atlas. However most spectral surveys made with objective prisms, because of the limitations of seeing and resolution, of extensions outside the MK spectral range, or of different dispersions, lie "outside" the MK domain and so merit our discussion here.

In describing the research outside the MK domain we shall be employing the idea of "natural groups". How are the "natural groups" related to the MK domain? I consider the concept of "natural groups" as the "stepping stones" or the bridges which link the limited number of standard stars that define the MK system (or even the larger group of stars which will be immediately and most closely related to this system through the new Michigan survey) with the vast number of stars in our own and other systems which are under observations for statistical and kinematic studies of galactic structure.

The idea of "natural groups" in studies of spectral classification is reviewed and developed in a classical paper of Morgan (1951). It is most interesting that the co-founder of the MK system should have worked so successfully and described so carefully work done outside the MK domain. We shall consider first the principle of natural groups and shall then give some examples of these. In some examples we shall be referring to objective prism spectrograms of various low dispersions and in others we shall consider the more recent results obtained with the prism-grating combination method.

We recall that what were natural groups for early classifiers such as Secchi have now become much more refined as our science progresses. Perhaps our own "natural groups" will, if we are successful in delimiting them, become well defined and carefully discerned assemblages of stars with more refined classifications.

Morgan was most clear in his acknowledgements to his own "giants" and he cites in the Michigan lecture the work of C. P. Gaposchkin, H. N. Russell and D. H. Menzel plus the contribution of B. Lindlad. It may be profitable for us today to retrace the steps outlined by Morgan in defining "natural groups".

He starts with the words of C.P. Gaposchkin (1925) in her book on Stellar Atmospheres:

> "In classifying a number of objects an attempt should be made to select criteria which will distribute the material into most natural groups."

Later, writing with Russell and Menzel, she notes (1935):

> "The desirable features of a system of classification are as follows: 1) it must be based on observable characteristics of the spectra; 2) characteristics clearly recognizable in a large number of spectra are more valuable than details difficult to observe which are supposed to be understood; 3) these natural groups will depend on the

resolving power of the optics and on the line visibility of the spectra which will differ with different dispersions."

Thus Morgan came to his own definition of a "natural group" i.e. one composed of spectra which have some obvious characteristic in common and which are confined to a relatively small area of the HR diagram.

Morgan considered four requirements as constituting a natural group: (1) the size of the group on the HR diagram should be small; otherwise M_V and color indices and dispersions in these quantities will be difficult to determine; (2) the penumbral region should be as small as possible; it is necessary to avoid weak features which may be affected by clumpiness of grains; (3) the group should be unique; difficulties and ambiguities occur if common characteristics are encountered in two different regions of the HR diagram; (4) standard stars should be listed; such lists are most helpful for reference especially when one is attempting to apply the natural group technique derived for one dispersion at another (higher or lower) dispersion.

We commend to your attention the drawings used by Morgan (1951) to illustrate the place and area on the HR diagrams of the various natural groups in use at the time. These included the low dispersion studies in progress at the Vatican under Junkes with a 2° prism operating at a dispersion of 800 Å mm^{-1} at $H\gamma_\delta$ those at Case with Nassau with a 4° prism with a dispersion of 275 Å mm^{-1} and, that which Morgan himself was using at Yerkes, a prism at 150 Å mm^{-1}.

Note that once a dispersion of 100-150 Å mm^{-1} and a resolving power of 700 to 1000 have been reached, with or without slit spectroscopy, line ratios can be employed and we are in the MK domain. Occasionally superbly good seeing and extraordinary transparency will allow the group characteristics of a higher dispersion to be transferred to a lower dispersion. Such optimum conditions should never be presumed and must be verified before one can apply the refinements of one system (viz the MK system) to characteristic parameters of another system. Jaschek and Jaschek (1966) discussed this point most clearly. To observe stars, selected by natural group methods at a lower dispersion (for example the OB stars on the Case Hamburg system), with spectroscopes of higher dispersion and resolution (as for example those at Yerkes and Las Campanas) is to make a big step forward in the refinement of spectral classification and in separating smaller subgroups on the HR diagram.

The safe way to set up a sound "natural group" is to start with a higher dispersion in order to establish the limits of the group and then to move to a lower dispersion which will be applicable to a much larger number of stars. It is most important to establish the proper plate-filter combinations in order that the maximum amount of information may be obtained for the faintest detectable sources. Thus, my suggestion is to start with observations at higher dispersion on nearby bright objects so as to determine the practicable limits of the natural group. Then with this established one should go as faint as possible in a certain region of the sky, in order to find all the members of the "natural group". Finally, using the finding lists established in these surveys, one should return to find the more specific answers (and, sometimes too, new problems) for individual stars on the list.

We turn now to a consideration of three extremely low dispersion objective prism studies and to some of the natural groups which can be detected through their use; the data are presented in Table I. These three very low dispersion prisms: 2°5 at the Vatican; 1°8 at CTIO and 0°4 for the Michigan Schmidt at CTIO have been used in studies of natural groups in the blue and yellow as well as in the regions of the red and infrared. In Table I there is listed for a comparison one of the highest dispersion objective prism combinations in use today, the Vatican 12° combination objective prism.

What then are some of the groups available for study with these low dispersion techniques and are they really "natural groups" in the sense set forth earlier? We shall examine in turn the dA and gK stars, emission objects, and finally the relatively cool stars of types M and C.

For the 2°5 prism in the blue region I would cite two groups of stars mentioned by Morgan (1951) and studied first by Junkes at Castel Gandolfo. These are the dwarf A stars and the giant K stars. These groups appeared as the two groups most readily separable on very low dispersion spectral plates. The outstanding features were the strong broad Balmer lines for the dA stars and the very strong metal features plus Lindblad's CN feature at 3883 Å for the giant K stars. With the development later of notions of stellar population types, it was recognized by Oort and others that the dA stars belonged to an older element of Population I with a mean z distance above the galactic plane of some 110 pcs and a mean average random velocity in this direction of 7.6 km/sec, whereas the gK stars belong rather to a disc population with corresponding values of 290 pcs above the galactic plane and an average random velocity in the z direction of 15.7 km/sec. This suggested to several astronomers the idea of testing the plane parallel hypothesis of Oort by measuring the space densities of the dwarf A and the giant K stars at different intermediate latitudes above the galactic plane both toward and away from the direction towards the center of the galaxy. Upgren and colleagues (1969) have completed their analysis for the brighter stars and concluded that it will be necessary to go fainter, especially for the detection of sufficient

TABLE I

VERY LOW DISPERSION OBJECTIVE PRISMS

Degree of Prism	2°5	1°8	0°4	12°0
Location	Castel Gandolfo	Cerro* Tololo	Michigan (CTIO)	Castel Gandolfo
Type of Glass	Crown	UK 50	--------	Flint
Diameter cm.	63.5	60.0	25.0	61.2
Length of Spectrum H_γ to H_δ in mm.	0.32	0.18	0.06	3.25
Dispersion at:				
3727 Å	500	800	2500	45 Å/mm
4340 Å	800	1360	5000	80 Å/mm
6530 Å	2500	5000	15,500	316 Å/mm
7590 Å	3600	6700	20,000	480 Å/mm

*CTIO Grating Prism Dispersion is 2300 A/mm (linear)

dwarf A stars. Cardon, Treanor and McCarthy have observed several hundred dA and gK stars in two Selected Areas in the direction to towards the galactic center and two in the opposite direction. Bok and Blaauw are engaged in similar projects except they are using photometric measures instead of spectrographic observations. Advantages of the dA and gK studies are the following: (1) both groups are easily discerned at very low dispersions; (2) both groups have mean absolute magnitudes (visual) near +1.0; (3) both groups can be discerned at very faint apparent magnitudes, viz. near m = 14-15. Limitations to the use of these natural groups may also be mentioned: (1) absorption problems can be serious even at intermediate latitudes; (2) the dispersion in absolute magnitude, σ, is hard to determine. More recently these same two groups of stars have been studied by McCuskey and Lee (1967) especially in the galactic plane. McCuskey is studying the ratio of dA to gK stars in different regions along the plane as a possible key to differences in evolutionary rates, basing his argument on the theory that the dA stars are predecessors of the gK stars. Perhaps this could also be evaluated at different galactic latitudes but then motion studies would be important to assure that we were dealing with kinematically similar groups.

Another group easily discernible on low dispersion plates are the emission objects. These, as we shall see in the following paper by M. Smith, include galaxies as well as stars. First two words of caution: (1) I do not regard this group of emission objects (i.e. with Hα in emission) as a "natural group" in the sense defined above; (2) while strong emission sources can be detected even at low dispersion, we have found that the best way of detecting faint emission sources is by using the highest available dispersion. The reason for this is because the higher dispersion will spread out the continuum in the emission source and make the contrast between the emission feature and the underlying continuum more evident, and thus help in the detection of the emission object.

Up to this point we have spoken of natural group methods applied at low dispersion especially in the blue and the red region of the spectrum. Now let us look at the work done in the infrared region of Kodak I N plates, 6800 Å to 9000 Å. Outstanding have been the contributions to the discovery and study of red stars through low dispersion techniques by Nassau of Warner and Swasey Observatory. These have been described by Nassau himself (1956) and by Blanco (1965). Another work which I have found to be of great aid in this work has been the Atlas prepared by W. Seitter (1969, 1973). These spectra were made at different dispersions with objective prisms and cover the entire range from 3600 Å to the limit of the I N plate, 9000 Å. She does not employ a filter. Recently in 1972 I obtained several plates of the LMC with the Curtis Schmidt and the Michigan 0.42 degree prism, exposed on I N plates with no filter for 90 min. These plates showed how a combination of Seitter's method of using the entire spectral range of the I N plate, together with the micro-prism method, which had been first inaugurated under Morgan, Meinel and Johnson (1954) and by Schulte (1956), was an excellent means of separating red from blue stars. At the Washington IAU Symposium No. 80, M. Parthasarathy (1978) described how he had used the ultra-low dispersion spectra taken with the 102-cm telescope at Kavalur, India to detect many new blue and red stars in the Large Magellanic Cloud. Here we are close to the borderline with photometry.

We present now some examples of how dispersion and spectral range are chosen to suit the problem at hand. On long exposure hypersensitized I N plates centered on the Pleiades, Treanor and McCarthy (1964) noted a concentration of M stars as observed with the Vatican 2°5 prism. We concluded that the large number of stars detected should be dwarfs and possibly cluster members. The reason for this was that if they were M giant stars they ought to be located at the limits of our own galaxy or beyond. Proof that they were dwarfs and possibly cluster members required the application of other special criteria plus observations with other and larger instruments. However the isolation and detection of these candidates for cluster membership came from low dispersion techniques.

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A second sample of M star studies at low dispersion which has led to the detection of stars of a definite luminosity class is that by B. Westerlund (1960) who used the Uppsala Schmidt in Australia to detect the M supergiant branch in the Large Magellanic Cloud. Later Blanco and McCarthy (1975) used the 1°8 prism attached to the Curtis Schmidt at CTIO to detect the M giant branch in the LMC. This prism, which has a dispersion of 6700 Å/mm at the atmospheric A band, showed M stars in large numbers and subsequent photometry showed a maximum near $m_i = 14.0$ on plates which reach well below $m_i = 16.5$. We limited our study to the late M stars where the prominent features of TiO and VO absorption bands are strongest. In defining this group we began by studying these bands in the laboratory spectra of the Atlas of Molecular Oxides by Gatterer, Junkes, Salpeter and Rosen (1956), and in the high dispersion photos by Keenan and Schroeder (1952). It is noteworthy that later Sanduleak and Philip (1976) used the same 1°8 prism with hypersensitized Kodak IIIa-J plates and found that in the SMC they could detect carbon giants from the presence of the Swan Bands.

We summarize in Table II in order of increasing wavelength the spectral features which have been found to be useful in natural group studies with prisms of 2°5, 1°8 and 0°4. We note that there are very few luminosity criteria and practically none of the indicators of abundance (with the possible exception of CN). Thus one should at these dispersions try not to strain at what is only marginal and might lead to false classifications. In the case of the M supergiants we mention here the luminosity criterion discovered by Nassau, Blanco and Morgan (1954) which allowed them to separate supergiants of early M type from ordinary M giants. This was the so-called "wedge-shape" infrared spectra which, by reference to the known supergiant M stars in the Perseus cluster, established this "natural" luminosity group. Later they were able to extend this method to stars in the galactic field. The main reason for the peculiar "wedge shape" of these spectra is due to the dust which gives these spectra a wedge shape, rather than to any intrinsic feature of the spectrum itself.

Having given these few examples of the criteria and application useable in classification outside the MK domain with low dispersion objective prisms, I invite you to consider now another technique also applied outside the MK domain which has proven most helpful in extending natural group methods to new research. We speak of a return in recent times to slitless spectroscopy without an objective prism but with a combination of grating and prism. Secchi's first work was done with a kind of "zoom-like" direct vision spectroscope. Later he came to the use of the objective prism. The present generation of large reflectors can now, thanks to Ritchey-Cretien modifications in design, survey a field at the prime focus which is both wide and deep.

TABLE II

SPECTRAL FEATURES AT LOW DISPERSION

Near UV (3400 - 4000 Å)	
Emission:	O II, Balmer
Absorp. :	O II, Balmer, Fe (3609 Å, 3635 Å), CN Ca II (H and K)
Blue-Yellow (4000 - 6000 Å)	
Emission:	Balmer
Absorp. :	Balmer, G Bd (4300 Å), Ca I (4227 Å), CN (4215 Å), Na (D), Mg (G), TiO, VO
Red (6000 Å - 7000 Å)	
Emission:	Hα
Absorp. :	Hα, TiO, VO
Near IR (7000 - 9000 Å)	
Emission:	Ca
Absorp. :	TiO, VO, LaO, A Bd, Ca, C, CN

Several of these instruments have tapered parabolic form and with associated correcting lenses and field flatteners can achieve wide angle photography previously limited to a Schmidt-type camera. The idea of a 4-meter objective prism is quite unattainable and impracticable but the non-objective dispersors we shall describe here are not. In its classical form a slitless spectroscope uses a negative collimiating lens which accepts the incident light before it comes to a focus. After collimation the light is dispersed by a grating or prism and then passes through a positive camera lens to the photographic plate. This slitless spectrograph can utilize the full aperture of the telescope regardless of size. One of the first slitless spectroscopes was constructed for the Lick Observatory's Crossley telescope by Palmer (1902) and a half century later this same reflector housed the fast grating slitless spectrograph designed by G. Herbig (1954) who used it to study emission line stars in crowded Milky Way fields including the T Tauri stars and the Haro-Herbig objects.

To obtain greater speed and a extension to a fainter limiting magnitude, the next step was the elimination of the collimating optics.

This was achieved by placing the dispersor in the converging beam of the large reflector. Murty (1961) examined the properties of a plane grating illuminated by a convergent wave front. He pointed out that the image suffered chiefly from unsymmetric abberation of focus in the direction of dispersion. He noted that when the prism was put in contact with the grating there is a coma free spectrum near a particular wavelength. Thus a useful range of wavelengths becomes sufficiently in focus for spectral classification studies. In effect, Murty suggested that the coma of a prism in a convergent beam can be used to correct the coma of a plane grating. Hoag and Schroeder (1970) used a single prism and then a single grating in the converging beam and with the latter obtained a dispersion of 1260 Å mm^{-1} in the first order. Next Bowen and Vaughan (1973) introduced a low angle prism in combination with the grating. While the prism does not completely eliminate the coma produced by the grating it does fix the point of zero coma near the center of the range of observation. The grating prism combination (called GRISM) must be tilted slightly to compensate. Hoag (1976) employed a grating and prism wedge to obtain slitless spectra at the prime focus of the Mayall 4-meter telescope. This system was designed by J. Simons and differs from the one used by Bowen and Vaughan chiefly in the manner of correcting for coma and astigmatism. A dispersion of 2300 Å mm^{-1} and a seeing limited resolution of R = 60 were obtained over the wavelength range 4500 Å to 6900 Å. Here we have a very exciting new application of a very old method. I shall conclude my survey with a brief mention of how it has been used in connection with low dispersion classification of two types of cool stars: the M and C giants.

Blanco, Blanco and McCarthy (1978) have applied the grism technique to the problem of late-type stars in the Magellanic Clouds. Using the grism devised by Hoag, we exposed for 60 min. on hypersensitized Kodak IV-N plates and recorded spectra as faint as m_i = 18.5. This limit exceeds by three magnitudes the faintest M type star found in our survey. We confirm the concentration of late type M stars near 14.0 established earlier in the thin prism survey mentioned above (Blanco and McCarthy 1975) in the LMC. We discovered that in the SMC there were practically no late type M stars whereas there were abundant C stars. The N(C)/N(M) ratio is about 50 or 60 to 1 for the regions of the SMC Bar and Wing. In the LMC the C stars also predominated but by a factor of only about 2 to 1. To complete the picture (or rather to illustrate how exciting spectral classification work has become in our own times) we find from the survey of Blanco, Blanco and Hoag (unpublished) that in the center of our own Galaxy near "Baade's Window" near NCG 6522 the N(C)/N(M) ratio is 0.003 with only one carbon star found for more than 300 late M type stars. Observational details are given in the articles cited and charts and positions for the stars found will appear in a forthcoming publication.

On this note we conclude our survey of criteria and applications for spectral classification outside the MK domain. Larger prisms, more efficiently blazed gratings, new hypersensitization techniques, new fine grain emulsions and just over the horizon a host of new large array panoramic detectors bid fair to make our craft an exciting one for the next hundred years as it has been for the past century thanks to the work of Secchi and Huggins, Rutherford, the Harvard Classifiers, Morgan and Keenan and all their colleagues.

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DISCUSSION

Blanco: I can add an illustration of the power of the natural group method as used in the near infrared region of the spectrum. Cerro Tololo's 4-m telescope with a prism grating combination at the prime focus will reach near-infrared magnitudes $18^{m}.5$ in a one hour exposure with hypersensitized Kodak IVN plates. The C and M stars in the Magellanic Clouds mentioned by McCarthy have a near-infrared absolute magnitude of -4.5. Therefore we can see them at distance modulus of 23 magnitudes in clear regions. This has enabled us to penetrate the galactic disc from the Sun to well outside the Galaxy in selected clear regions. In other studies (not yet published) the M and C types all appear appreciably brighter than the plate limit.

Ardeberg: Have you made some tests of the Grism-based radial-velocity measurements? If so, what are your results?

McCarthy: Blanco and I have not. Treanor was planning this as a possible project for future image tube work at Castel Gondolfo. I suggest that the velocities to be discussed by Malcolm Smith may be more readily estimated by this method than by the method we used for the faint M stars.

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