Revista Mexicana de Astronomía y Astrofísica, 28, 153-164 (1994)

THE ANALYSIS OF DIGITIZED OBJECTIVE PRISM SPECTRA

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Received 1994 February 23

RESUMEN

Los espectros digitalizados de prisma objetivo pueden ser usados para la determinación de posiciones astrométricas, de velocidades radiales, magnitudes y también para la determinación de intensidades de líneas espectrales. De éstas últimas se pueden obtener tipos espectrales, clases de luminosidad, y un índice de metalicidad. Eso abre la posibilidad de una evaluación totalmente automatizada de placas que contienen datos para un gran número de estrellas. El respectivo sistema ha sido desarrollado y probado para una cierta combinación de telescopio, prisma, y filtro dando una dispersión de 83 A mm^{-1} en la región de Hδ en una ventana espectral de 150 A de ancho.

ABSTRACT

Digitized objective prism spectra can be used to derive astrometric positions, radial velocities and magnitudes as well as the intensities of spectral lines. From the latter spectral types, luminosities, and a metal index can be derived. This opens up the possibility of a totally automatized evaluation of plates containing data for a large number of stars. A respective system has been developed and tested for a certain telescope-prism-filter combination yielding a dispersion of 83 A mm^{-1} at Hδ in a spectral window of 150 A width.

Key words: **METHODS – DATA ANALYSIS — TECHNIQUES — SPECTROSCOPIC**

1. INTRODUCTION

Classification in the MK-system is now available for tens of thousands of stars. Much of the observational material was obtained with spectrographs of various types at observatories the world over. To this must be added the gigantic effort by Houck (1975) to reclassify the entire HD-catalogue on objective prism plates obtained with two practically identical telescopes on Kitt Peak and on Cerro Tololo. In all cases the classification was done and still is being done by a visual inspection of photographic spectra and an estimate of the intensity ratios of carefully selected pairs of lines. Being fully aware of the many uncontrollable effects in photography the authors of the MK-system insisted from the very beginning on strict uniformity of dispersion, resolution, and of contrast. Much of the success of the system is due to the adherence to their recommendations.

Ideas to replace the visual estimates by quantified data have been around all along. For spectrographs with digital detectors the process is straightforward, employing well known methods to determine equivalent widths or depths of absorption lines. The treatment of photographic prism spectra is more involved, due to the need of converting from photograhic densities to intensities which requires an adequate calibration, to the intervention of the so-called adjacency effects which can affect line profiles, and to others. Objective prism plates may be more rewarding because of the enormous wealth of data accumulated on them. Also, as shall be seen in one of the sections of this paper, the calibration of the density versus intensity relation is simpler than it is for spectrograph plates.

The principal purpose of this paper is to present a technique which permits the quantification of spectroscopic parameters in objective prism spectra, such as pseudo-equivalent widths or pseudo-central depths. This includes any measureable spectral feature, including those which are normally used for the standard MK-classification procedure. A comparison of the quantified features with known physical parameters, such as temperature, mass, luminosity, metallicity, etc. may then show which

of these features if any can be used for classification purposes. This part will not be dealt with in this paper.

2. DIGITIZATION OF SPECTRA

For the digitization of objective prism plates a number of machines are available, such as the Galaxy, the PDS, and others. It is assumed here that the reader is familiar with at least the basic principle with which these machines work. A number of decisions have to be made by the operator before a plate can be scanned. These decisions concern: (1) the width and length of the analyzing beam, i.e., the pixel size, (2) the step by which the machine will advance in X and in Y, i.e., the distance from pixel to pixel, and (3) how much of the plate will be scanned. The options are either to scan the entire plate, accumulating an enormous amount of data, and then extract from these the areas in which spectra are located, or to scan only windows around positions where spectra are known or expected to be located. This means previous knowledge of positions. In this case also the size of the window has to be decided. It depends not only on the actual length and width of the spectra but also on the uncertainty of the initial position.

Let us assume that the Y-coordinate is parallel to the direction of the dispersion and hence the X-coordinate perpendicular to it. Objective prism spectra, if widened at all, are normally widened in the X-direction to somewhere between 150 and 400 μm. Thus for plates with relatively fine grain such as Kodak IIaO one would recommend:

(1) An analyzing beam size of 20 μm in X and in Y, and (2) a step size of 20 μm in X and of 10 μm in Y.

The Guide Star Catalogue may be used for the star selection if one wants to avoid the necessity of scanning the entire plate. Its magnitudes permit to set a given limiting magnitude. Its positions are accurate enough to allow the choice of a rather tight fitting window around each spectrum. Furthermore overlaps between neighbouring spectra can be eliminated beforehand.

It must also be taken into account that the width of the spectra is not necessarily constant across an entire plate. First of all it will depend on the brightness of the stars. There may also be a dependence of the width of the spectra on the declination of the objects which normally coincides with the direction of the Y-axis. This is particularly true for long and guided exposures. Due to the deviation of light beams caused by the prism the star used for guiding may be far away from the center of the field which is being photographed. As an example, for the ten-degree prism of the Schmidt telescopes on Kitt Peak or on Cerro Tololo the guide star may be 6.7 degrees away from the field center. Consequently the field can rotate around the guide star during the exposure. Such an effect can be produced by both the atmospheric refraction and by a misalignment of the polar axis of the telescope. Since one would want to make use of all pixels which contain information on the stellar spectrum and exclude all those which contain only sky background, the exact width of each spectrum has to be known. This is desirable also for an additional reason. Overlapping spectra of two stars separated in right ascension by less than the normal width and in declination by less than the normal length of the spectra will appear as a spectrum of abnormal width or length and can on that count be eliminated. Naturally, the Guide Star Catalogue can be analyzed in advance in order to detect and eliminate such cases from the list of objects to be scanned. From what has been said so far it may appear that it is advisable to set the size of the window to be scanned individually for each star. However, the plate scanning machines are normally not prepared for such a complication. Hence it is necessary to set the window size such that it accommodates even the widest spectrum on the plate.

So far we have taken it for granted that the Guide Star Catalogue can provide the initial list of objects to be scanned. This will not be the case when the limiting magnitude of the plate exceeds that of the catalogue, or when the spectral range of the plate is very different from the spectral region of the magnitudes of the GSC which is the photographic blue region. In that case three ways are open, namely (1) to scan the entire plate with the final beam size and step size, or (2) to do first a coarse scan with a large beam and large step in order to locate objects, or (3) to use a visual measuring machine to produce the initial list by direct inspection. This process has the advantage that all inadequate spectra such as overlaps etc. can be rejected. It also permits a preliminary classification of the spectra.

Another factor which has to be taken into account when the Guide Star Catalogue is the source of the initial list of objects and their coordinates is the distortion caused by the prism. The plate scanners will scan star by star a window around initial coordinates taken from an input source. These initial coordinates can be produced from the equatorial coordinates contained in the GSC by the appropriate projection geometry such as the tangential or the concentric projection. These initial coordinates will normally not coincide with the machine coordinates but most machines are prepared to determine the required transformation parameters by setting manually on a few objects with known initial coordinates. As was shown by Stock & Upgren (1968) a second order term has

o be included in the transformation, unless it is emoved beforehand from the coordinates.

When several plates of the same field are to be canned the same input list may serve for all of them nless the direction of the dispersion is inverted n some of them. This will be the case when lates are taken for the purpose of determining adial velocities. In such a case two input lists ave to be provided, of which, naturally, one an be produced from the other by applying the ppropriate coordinate corrections.

3. DETERMINATION OF THE LOCATION AND TILT OF THE SPECTRA

For the analysis of digitized spectra two basic ssumptions will be made, namely (1) that all pectra on a wide field plate are parallel and 2) that a spectrum anywhere in the field can e considered to be a proportional blowup or ontraction of an identical spectrum in the center f the plate. Both assumptions have been checked y Guillén (1992) with numerical simulations based n the prism theory developed by Stock & Upgren 1968), showing that they are acceptable within an ccuracy of 1.5 μm for practically any telescope-rism combination in use today. Thus we shall make se of both assumptions throughout.

Figure 1 shows schematically what the pixels of scanned spectrum really mean. The pixels are rdered by rows and columns, each one giving he transparency of the plate at that particular oint, or some derived quantity. The first goal hould be to transform the two-dimensional array f densities into a one-dimensional scan adding or veraging the values within each column. The uestion then arises whether this should be done n the original densities, or whether it would not e more correct to sum up or average intensities. his then brings up the question of how the density-ntensity relation should be calibrated in the first lace. The spectra appear as extended surfaces ather than point sources. Thus many observers se the technique of sensitometer spots as the alibration procedure. Great care is taken in giving he sensitometer exposure the same exposure time hat is used for the spectra. However, due to the idening procedure the actual exposure time of a given part of a spectrum is much shorter than the total exposure. The latter, though, is the true exposure time for the sky background. The exposure time for the spectra depends in the first place on how the widening is done. For this purpose the spectra are being displaced perpendicular to the direction of the dispersion, usually in steps which may be few and long or many and short. How long the spectrum will actually cover a given spot on the plate depends not only on these details but also on how wide the stellar image is, and this width is a function of the seeing and of the optical distortions of the images. Thus it is evidently difficult if not impossible to reproduce this exposure time with the sensitometer.

Two more factors make the calibration with the help of a plate sensitometer difficult. As we have already mentioned the width of the spectra may turn out to be a function of the coordinates, principally of the Y-coordinates. Thus any calibration will not be strictly valid for the entire plate. The second problem is related to the so-called pre- and post-exposure effect, at least for exposures where the sky background makes an important contribution. At one edge of the spectrum the stellar light is exposed at the beginning of the exposure and is followed by a long exposure to sky background only, while at the other edge the opposite happens. The sky is being exposed all the time while the star light comes only at the end of the exposure.

This all means that one should not think in terms of precision spectrophotometry from objective prism plates. Within this limitation several calibration methods are applicable, spot sensitometry being one of them. As will be shown in a later section, the densities may be summed up column by column to produce a one-dimensional spectrum, and even spectra from different plates can be co-added, still leading to a final result which can satisfactorily be calibrated. Thus in the next few sections we will be working with densities only.

It was already stated that it may be assumed that all spectra are parallel, but they are not necessarily parallel to the Y-scanning direction. Since the effect of such a tilt leads to laborious corrections it is very important to check the angle of the orientation of the plate with respect to the scanning direction

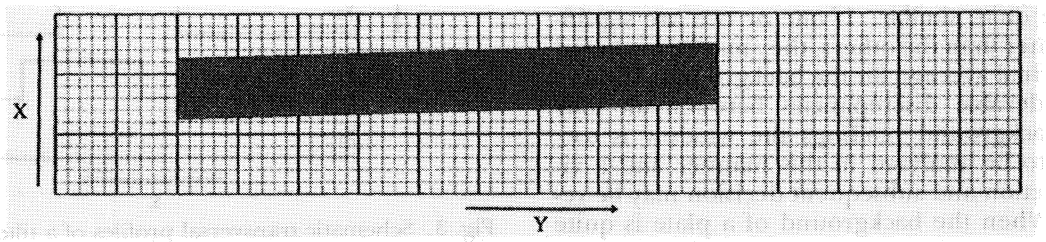


Fig. 1. Schematic view of a scanning window.

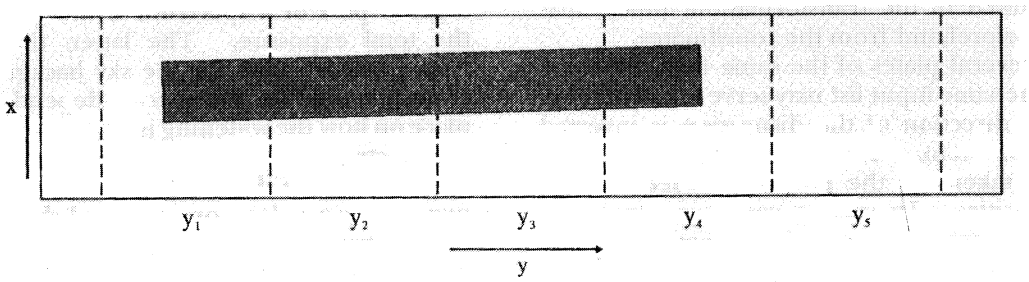


Fig. 2. Subdivision of a window for the determination of the tilt of the spectrum.

before the scanning is started. As shall be seen, the determination of such a tilt as well as of the function describing the width of the spectra, and the determination of their X-coordinate can all be handled in one single process.

Figure 1 shows a spectrum which is not only tilted with respect to the scanning direction, but it is also displaced with respect to the center of the window. If it was not for the tilt the X-coordinate of the axis of the spectrum could be used as the X-coordinate of the object. The Y-coordinate, on the other hand, has to refer to a given wavelength. In the case of tilted spectra this would also be true for the X-coordinate. Thus the first thing to do is to find the tilt. Since we assume that the tilt is common to all spectra it is sufficient to determine it from a few well exposed spectra.

The first step to be carried out is to determine the density corresponding to the sky background. There are different opinions as to whether one should determine the background reading separately for each window or rather use a general background reading sampled over the entire plate. In the case of a window-by-window procedure one can for example average the readings from the first and the last row as well as from the first and the last column, which means going around the window along the edge. This naturally means that one is supposing that the spectrum to be analyzed is not too close to the edge, neither do other spectra appear anywhere along the edge of the window. Such cases can readily be sorted out. First one forms the average background density for the first and the last column and the upper and lower edge separately, intercomparing the four values. If all really represent clear background their average readings should be quite similar. If one or two are significantly higher than the others, they may be excluded from the final average for the background. If there are considerable discrepancies between all four average background readings the window is too crowded to be analyzed in this manner and a visual inspection and subsequent decision may be required. When the background of a plate is quite clear it is even safer to use a constant background reading for the entire plate. Its value can be obtained from scans of a few well distributed empty windows. From here on we suppose that the background has been subtracted from all pixels. Thus in the area surrounding a spectrum there may be a number of negative readings.

The next step is to divide the windows into several sections, as indicated in Figure 2. Within each section we calculate the average density for every row. In this manner we produce section by section a smoothed transversal profile, i.e., a profile along the X-direction. These profiles may have the shape shown in Figure 3. The center of this profile would then be the respective X-coordinate. It can be determined by several means. One possibility is to adapt an appropriate mathematical profile of which the height, the width, and the location of the center would be parameters to be determined by a least squares method or any other procedure which yields their most probable values. One adequate expression is the function

$$f(x) = \frac{Q}{2arctg(bc)}\Big(arctg[b(x - x_0 - c)] - arctg[b(x - x_0 + c)]\Big) , \quad (1$$

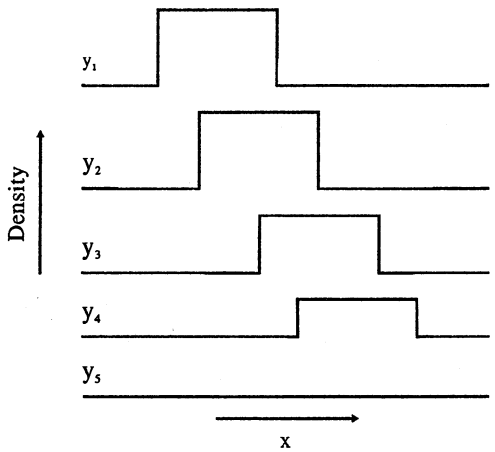


Fig. 3. Schematic transversal profiles of a tilted and displaced spectrum.

hich corresponds to a symmetrical profile, or

$$f(x) = \frac{Q}{2arctg(b_1c_1)}\left(arctg[b_1(x - x_0 - c_1)]\right) -$$

$$-\frac{Q}{2arctg(b_2c_2)}\left(arctg[b_2(x - x_0 + c_2)]\right) \; ; \qquad (2)$$

hich can be adapted to an unsymmetrical profile. n both equations all variables other than x are onstants to be determined. X_0 is then the X- oordinate of the center of the profile.

A faster and more straightforward procedure is o look for the two edges of the profile. For this urpose one determines first the maximum of the ensity profile. Subsequently a search is made for ie points where the density has fallen on either ide to a given percentage of the maximum, for istance 50%. The center of the profile is then efined as the midpoint between the two edges. he width, naturally, is the difference between ie X-coordinates of the two edges. Any of the bove procedures produces consistent and accurate -coordinates when the profiles are symmetrical. symmetric profiles can cause a systematic drift of ie X-coordinates as function of the mean density hich results in a magnitude term in right ascension o be allowed for in the reduction of the positions.

Returning again to Figure 2 it is evident that tilt of a spectrum would cause a systematic shift f the X-coordinates as one moves along from ection to section. Comparison of this shift with he Y-coordinates of the sections then yields the tilt oefficient. Since all spectra can be considered to e parallel to each other, it is sufficient to determine he tilt coefficient from just a few suitable spectra.

In the absence of a significant tilt the X-coordinate f any of the above sections or the average of all of iem can be considered to be the final X-coordinate or the object. When the tilt is not negligible the X- oordinate has to be read off at a given predeter- ined wavelength. This requires the identification f wavelengths along the Y-axis of the spectrum. A ude starting point may be obtained by locating the enter of the longitudinal profile, i.e., in the direc- on of the dispersion. A center can be found by ieans similar to those used for the X-coordinate, iat is finding first the maximum density and then ie points where a given fraction of the maximum is eached. The wavelength of such a center will vary great deal with the spectral type, and to a lesser xtent with the magnitude, but for a very small tilt may be accurate enough to define a fixed wave- ngth for the X-coordinate.

For the analysis of the width as function of the oordinates X and Y provisional values for the latter re sufficient. In fact, even the coordinates of ie center of the windows are adequate for this purpose. Since the width of a spectrum is also influenced by the brightness of the respective object, a quantitative value for the latter must also be found. The maximum density within the spectrum is a usable argument. The width of each spectrum as determined above is then represented by a polynomial with an absolute term which represents the width of a spectrum of zero density at the origin of the coordinates, linear terms in both coordinates, and a linear and a second order term of the density. The principal purpose of this procedure is to detect defective spectra and eliminate them from further reduction. Partially overlapping spectra will be found to be too wide. Spectra right at the edge of a window can be found to be too narrow. At this point we should mention that certain types of overlaps, partially in X and partially in Y, will simulate a spectrum which over most of its length may have the correct width, but it will show an apparent tilt different from that of the other spectra. Thus spectrum by spectrum the tilt should also be checked.

A strictly longitudinal overlap, i.e., in Y only, will produce a spectrum of normal width but of unusual length. Thus it is also advisable to establish the normal length of the spectra which definitely will depend on the maximum density, but to an even greater extent on the spectral type or color. The longitudinal gradient of the density, together with the maximum density could be the necessary arguments to determine with some confidence what the length of a given spectrum should be, thus permitting the elimination of at least some of the longitudinal overlaps.

We should explain at this point that it is our purpose to develop a system which can handle a set of objective prism plates in a fully automatic manner without the need of visual inspection by an operator. This means above all the elimination of all those spectra which for one reason or another are contaminated and hence do not permit a full analysis, at least not by automatic procedures, but which may produce faulty results which may not readily be recognized as such.

4. THE COADDING OF ROWS

As shown in Figures 1 and 2 the spectra are expected to extend over various rows, i.e., in the X-direction. The simplest procedure would be to add column by column all pixels that are within the spectrum. The limiting rows can be deduced from the X-coordinate of the center of the spectrum and the width corresponding to both the X- and the Y-coordinate and the maximum density, as was explained in the previous section. When there is no tilt this process will work well over the entire plate. The effect of a tilt will be that the rows at one end of the spectrum may not be the same which have to be

added at the other end. When the spectra are only a few pixels wide it may be necessary to introduce weights for the rows, depending on their distance from the axis of the spectrum if discontinuities are to be avoided. This entire problem can be circumvented by applying profiles such as those suggested by the equations (1) and (2). It is the amplitude factor Q which is wanted here, and the data from the entire column can be used to calculate the solution.

Another question to be considered is: How far towards the edges should one go in the coadding process? Going to far into the bachground would only add noise but would not contribute to the signal. Staying too close inside means loosing information. Naturally, in the case of profile fitting this problem is irrelevant and it may be negligible anyway when the spectra are wide enough.

Once the row-by-row coadding is performed each window is transformed into a one-dimensional array whose length obviously is identical to the length, expressed in pixels, of the original window. From here on we shall call this array the spectrum. Under normal circumstances a short stretch of background should be present at each end of a spectrum.

5. COADDING OF PLATES

For the purpose of reducing noise it is desirable to take several plates of the same field and coadd their spectra. It has been our experience that by coadding the spectra from six plates spectra barely visible to the eye on a single plate can be transformed into a useful record.

The process to be followed for coadding spectra from different plates depends on whether or not the direction of the dispersion is the same in all cases. For the purpose of determining radial velocities plates with opposite directions of the dispersion may have been taken. In the case of identical direction of the dispersion a linear coordinate transformation scheme can be used. The determination of the transformation coefficients can be restricted to well exposed spectra with strong absorption lines or other outstanding features. In the case of opposite dispersion star by star a correlation technique has to be applied. The difference is due to the field distortion caused by the prism which at least in principle could be removed, and to the effect of the radial velocity which can only be removed if the latter is known beforehand.

We shall first treat the case of coadding plates of identical sense of the dispersion. We can imagine that the coadding of rows has produced the equivalent of unwidened spectra on the original plates. Since the different plates are taken with the same telescope and the same prism, and ideally also with the same plate centers, they should differ only by a slight coordinate displacement, possibly a small rotation, and may be even a small scale difference in X and in Y. Differences in the differential atmospheric refraction, if present at all, are of a linear character and hence are included in the scale differences. Thus a linear coordinate transformation, not necessarily orthogonal, should transform the coordinates of one plate into those of another. The transformation coefficients consist of two sets of three constants, one for X and one for Y, which have to be determined by interrelating the coordinates of features such as spectral lines on one plate with the coordinates of the same features on the other plate.

For every star in common to both plates the respective X-coordinates are obtained by the methods explained in § 3. To fix a Y-coordinate in any of the spectra would require the identification of a spectral feature, a process which we wish to postpone as long as we are dealing with spectra which are not coadded from several plates. Actually all that is needed in order to find the mentioned coefficients is the difference between the Y-coordinates of the two plates, this however with high accuracy. This difference will then be represented by a polynomial in X and Y. Since the above differences vary only very little with X and Y, provisional and approximate coordinates are adequate. Even the coordinates of the centers of the windows would be accurate enough for this purpose.

A simple correlation technique can be used to find the desired differences. Let $p_1(n)$ be the pixel value of the n-th pixel of the spectrum of the first plate, and $p_2(n)$ that of the second plate, naturally both for the same star. We then form the sum of the squares of the differences between the two spectra by

$$S(d) = \sum_{n=n_1}^{n_2} \Big(p_1(n) - p_2(n+d) \Big)^2 \; ; \qquad (3)$$

where the range n_1 to n_2 should restrict the application of the equation to the central part of the spectra. Varying the relative displacement d the function $S(d)$ can be established. Obviously the value of d for which this function reaches a minimum is the desired difference. It is not necessary to apply the above process to all stars. A restricted number of well exposed spectra, well distributed over the field, will be sufficient to find the coefficients of the polynomial mentioned above by a least square method.

It may at times be necessary to first equalize the densities of the two spectra by applying a factor to the densities of one of them. Even a difference in the slopes of the continua of the two spectra may be taken out before the above correlation technique is applied. Once the transformation coefficients are

nown the coadding of plates works as follows: (1) ıose a certain pixel in the spectrum of plate 1. One ın even interpolate, (2) transform its Y-coordinate ıto that of the second plate, (3) interpolate the :spective pixel value in the second spectrum, and :) add the two values.

Evidently the coadded spectrum will be in the Y-ordinate system of the first plate. At this point should become apparent that even "invisible" ɔectra can be coadded in this manner. We ıould point out here that with the help of the ansformation coefficients calculated above entire indows can be transformed into the window ɔordinates of another plate and subsequently ɔadded. This would apply to those cases where the ıethods outlined in § § 3 and 4 could not be carried ut because the object was too faint.

In order to facilitate the following discussion e shall call plates taken with a certain direction f the dispersion "lefthand" plates and those with ıe opposite dispersion "righthand" plates. Once ıe lefthand and the righthand plates have been ɔadded among themselves, it is desirable to coadd ıese two as well. Due to the distortion caused y the prism there is no linear relation between ıe Y-coordinates of the two sets of plates. The rism distortion term is actually an instrumental nd constant feature which, as was shown by tock & Upgren (1968) can easily be calculated or etermined empirically, and hence can in principle e removed. However, the difference in Y is also ffected by the radial velocity which in most cases not known. Thus star by star the correlation :chnique outlined above has to be applied. Doing ɔ one has to remember that the coordinates of the :cond spectrum have to be inverted because their :nse of the dispersion is the opposite from that of ıe first plate.

When coadding the righthand and the lefthand lates one will find that pixel by pixel the sum of ıe Y-coordinate of the first plate and that of the ıatching Y-coordinate of the second plate remains ɔnstant as one goes along the spectrum. Dividing ıis sum by 2.0 in fact yields the final Y-coordinate f the object. The final X-coordinate is obtained y averaging the X of the first plate with the trans-ɔrmed X of the second plate.

6. THE IDENTIFICATION OF SPECTRAL LINES

In the following we shall refer to absorption nes only. Emission lines are so rare that the re-ɔective spectra can be handled with a "by hand" ıethod. The identification process is best carried ut with the final spectra, coadded from all available ıaterial. To find lines visually in a graphical :presentation of a spectrum is a simple process ɔr which program packages such as IRAF are well repared. However, we want to use a principle which is capable of automatically locating any obvious line in a spectrum, which can be implemented by a computer program.

Evidently the center of a line is in first instance defined as a density minimum. This definition, however, is in practice insufficient since it would turn up also all minima produced by the signal noise. If we add the condition that both to the left and to the right the density must be increasing for at least the next M pixels we can eliminate most of the noise minima. A value of around the average half width of the faintest lines one wishes to find may be an adequate value for M.

First it is necessary to determine the exact center for every line that has been found. It is not advisable to try to fit a profile such as a gaussian to a given line. This requires an iterative method which only too often does not converge. A parabolic fit, using the pixels from center–M to center+M is more reliable. The minimum of the parabola is then taken as the center of the line, and it will be found in units of a pixel and fraction thereof.

The next step is to identify the lines found and measured as described above. We assume here that a list of lines that can possibly appear in the spectra plus their positions relative to a line chosen as zero point already exists. Naturally the positions have to be given in the same pixel units in which the spectra are measured. There are several ways to produce such a list. It may come from known wavelengths of lines known to occur in stellar spectra. These wavelengths plus the respective dispersion curve which relates the pixel numbers to the wavelengths serve to make up the mentioned list. Another way is to measure spectra on the same kind of plates with a hand measuring machine. Last, but not least, the standard list can also be made up from the scanned spectra treated as above. There should eventually emerge a pattern of lines which is found frequently in the spectra. Identification of these lines is then a standard spectroscopic procedure.

Naturally we do not expect that all lines of the standard list are present in every spectrum neither do we expect that all lines found in a spectrum are present in the list. Nevertheless the standard lines establish a certain pattern, and part of that pattern should be present in most if not all spectra on a plate. Thus the problem of line identification is reduced to a scheme of pattern recognition.

For the application of the pattern recognition scheme we first have to decide on a tolerance, the latter being the maximum deviation of a line from its standard position that can be considered as acceptable. This depends on a number of factors, namely (1) on how well the center of the line has been determined. The respective information may be obtained from the parabolic fitting process, (2) on the accuracy of the standard positions, and

(3) whether a spectral type dependent shift of the standard position of the line has to be considered.

Then we find some crude initial wavelength identification. The wavelength range covered by the spectra is determined by the characteristics of the interference filter since it is located far away from the cutoffs due to the emulsion or the atmospheric extinction. The wavelengths of both the red and the blue cutoff are dependent on the color of the objects as was found for example by Borra et al. (1987) for the "green cutoff" of objective prism spectra. The location of the cutoffs also depends on the magnitude of the stars. In our particular case we can make use of both cutoffs. The midpoint between them is almost independent of the brightness of the stars. Its wavelength will depend on the color or the spectral type, the latter still being unknown at this point. Even so an approximate wavelength can be assigned to the center of a spectrum which will be accurate enough to initiate the final wavelength identification. At this point we should mention that the average angle at which the light of a star traverses the filter changes with the distance from the center of the field. This has the effect that the spectral window shifts slightly towards the blue as one approaches the edge of the field covered by the plate. This effect has been calibrated and is taken into account in the initial wavelength identification. In the spectra themselves their centers can be found by a procedure similar to that used for the X-direction. One first finds the maximum density in the entire spectrum and subsequently locates starting from both ends, where, for example, half of the maximum density is reached for the first time. The midpoint between these two points may then be used as the pixel number of the center of the spectrum.

We now take the standard spectrum and displace its coordinates by a fairly large number of pixels from its centered position. Then we check how many of the lines in the spectrum under consideration coincide within the tolerance with the displaced standard spectrum and record the number of coincidences. Then we shift the standard spectrum by one pixel and repeat the process until the standard spectrum is well displaced in the opposite direction from where it started out. The displacement with the largest number of coincidences will mark the true position of the standard spectrum with respect to the spectrum under consideration.

The above scheme is ambiguous or even impossible when there are too few lines in a spectrum. This will be the case for early type stars where often only a few hydrogen lines are present. However, their approximate location with respect to the center of the spectrum is well known, and this may serve as an additional check on the identification. Naturally there may be a small number of cases where only a visual inspection can definitely establish an identification.

7. THE DETERMINATION OF LINE INTENSITIES

Several different numbers can express the intensity of a spectral line. In first instance there is the equivalent width which represents the area occupied by the line, expressed in units of the continuum. Second there is the central depth of the line. Both these measures require knowledge of the location of the continuum which for late-type stars can be a very complicated problem. However, leaving aside the true physical definition of an equivalent width and its interpretation one can try to substitute the continuum by a pseudo-continuum the same way the human eye does when it sees a line in a photographic stellar spectrum. The eye will judge the depth of a line relative to the nearest density maxima on either side. Thus in order to simulate the process one can search for the nearest pixels defining a maximum on either side of a line located by the methods outlined above. The pseudo-continuum can then be defined as a straight line connecting the two maxima. With such a definition the determination of either a pseudo-equivalent width or a pseudo-line depth becomes a straightforward procedure.

One problem should be pointed out here, namely the effect of a variable resolution. When the true continuum can be located then only the line depth will be affected by a changing resolution. However locating a pseudo-continuum by finding neighbouring maxima will make both pseudo-width and pseudo-depth sensitive to changes of, for instance the seeing. To avoid the continuum problem Rose (1984) makes use of the density or intensity at the bottom of the line which does not require the location of a continuum, and which is less sensitive to a variation of the resolution. Since all lines are affected by the resolution in nearly the same way, a ratio between the central intensities of two lines may be expected to be practically insensitive to seeing effects.

The method proposed by Rose, however, has to be used with care. The pseudo-widths and pseudo-depths as defined above are not altered by any systematic changes of the gradient of the continuum, i.e., the slope of the relation intensity versus wavelength. Such changes may be due to the atmospheric extinction, filter transmission variation across the field, etc. On the other hand, center intensity ratios are affected unless the lines are located very close to each other. Such an intensity ratio, if converted into magnitudes, is in fact a color index. Hence corrections may be required for atmospheric extinction, for interstellar extinction, or for color sensitivity changes of the equipment.

. THE DENSITY-TO-INTENSITY CONVERSION

In § 3 we already explained why a calibration of e density versus intensity relation of a plate with spot sensitometer may not yield reliable results. ›rtunately other methods are available. In the llowing we shall leave aside complications which ay arise from a variation of the widths of the ›ectra across a plate.

It is clear that every plate has its own particular .libration curve. It is also clear that all calibration ırves of plates which contributed to a coadded ›ectrum will have similar characteristics, name- a threshold intensity, a linear portion, and a turation region. After coadding transversely ithin the individual spectra and after coadding ›ectra from different plates the final densities ıould still share these general properties. A con- ıtent calibration of these coadded densities can ː obtained through a comparison with photo- ectric magnitudes. For this purpose densities have be read off at a given wavelength, or better ill averaged over a certain wavelength range. hese densities can then be related to the re- ›ective magnitudes. Allowance has to be made r a possible color equation, a standard practice photometry anyway. An even better calibration ›urce is CCD photometry with the same telescope ıd prism. In the latter case no color equation is ‹pected.

). THE CLASSIFICATION OF STELLAR SPECTRA

Classification of stellar spectra can be useful only its class designation can be converted into physical ıarameters such as the temperature, the luminosity, description of the chemical composition or any ›her type of data of the respective stars. This ıeans that in the first place any classification ıethod must be calibrated with the help of stars ›r which the desired physical parameters are ıown, and here by known we mean that they ıave been determined by means other than spectral assification. Stars with known parallaxes and ıembers of clusters of known distances have been ›ed to calibrate the MK-system. Any new system f classifying stellar spectra must in the long run do ıe same thing.

The classification of large numbers of stars is of articular interest for galactic structure problems. Iost of all the following parameters are needed: .) the absolute magnitude for the determination of ıe distance by photometric means, (2) the intrinsic ›lor for the determination of the interstellar red- ening, and (3) the metallicity for an age estimate nd population designation.

We now have to ask: From which of the mea- ıred spectral parameters such as line widths or epths, either alone or combined, can the physical parameters be recovered, and with which accuracy? This will tell us which spectral features are worth measuring, and with which accuracy should we determine their numerical data. The answer to this question could come from an application of the objective prism method to those stars for which the physical parameters are already known. This in practice is out of the question because these stars are too far spread over the sky, and most of them are too bright anyway for this technique. There is, however, an indirect way to obtain the desired calibration.

Using an appropriate spectrograph with a CCD spectra can be obtained for most any star, bright or faint, and in any part of the sky. Thus as a first step one would determine as many spectral parameters as possible for those stars for which the desired physical parameters are known. The next step would be to find the interrelations between the two sets of parameters. This would yield the answer to the questions raised above, namely which spectral features should be measured and with which accuracy. The next step is to find the combination of telescope, prism, and type of plate which permits the recovery of the spectral parameters with the desired accuracy. The final test then consists of obtaining in a given field for as many stars as possible the spectral parameters both with a spectrograph and CCD and with objective prism plates in order to find systematic differences in case they exist.

Finally we should mention that what we envision is a procedure of a numerical conversion from measured spectral quantities to physical properties, with their respective uncertainties attached to each of these numbers.

10. A PRACTICAL EXAMPLE

A number of fields around the South Galactic Pole have been observed by Rose, in the later phases together with Stock. The Curtis Schmidt Telescope on Cerro Tololo was used, equipped with a ten-degree prism (actually a combination of a four-degree and a six-degree prisms). The plates are Kodak IIaO, combined with an interference filter centered on approximately Hδ and a bandwidth of 180 A. With an exposure time of two hours a limiting magnitude of about the 13th photographic magnitude is reached. The spectra are widened to about 0.15 mm. The dispersion is 82 A mm^{-1}, while the plate scale is almost exactly 10 μm/arcsecond. With an average seeing of about one arcsecond an average spectral resolution of about 0.8 A was obtained. For each field six plates were taken with the principal purpose of increasing the signal-to-noise ratio. However, by taking half of the plates with one orientation of the prism and the other half with the opposite orientation the same plate

material can also be used to determine astrometric positions and radial velocities.

Originally one plate of each prism orientation was scanned with a large analyzing beam and large steps, using a PDS plate scanner. These coarse scans were used to produce the input list for the fine scans which were carried out with the plate scanner of the Yale Observatory at New Haven. The beam size was 20 μm in both directions, while the steps were 20 μm in the X-direction and 10 μm in the Y-direction. The scan length is 346 steps in the direction of the dispersion and 35 steps perpendicular to it. This makes a window size of 3500 × 700 μm, much larger than the size of the spectra which cover an area of about 1800 × 200 μm. The large safety margin was necessary because of the uncertainties of the input positions. In the future the Guide Star Catalogue will be used to produce the input list. Its accuracy, although not fully astrometric, will permit a considerably smaller window size and hence a reduction of the scanning time. As was already mentioned, using the GSC a relatively uniform limiting magnitude can be maintained, and overlapping spectra can be avoided.

In Figures 4a to 4d four spectra of the same star are shown. The spectrum in Figure 4a is that of a single plate, coadded transversely. Figure 4b shows the spectrum of the same star, coadded from three plates of identical prism orientation, and Figure 4c the spectrum coadded from three plates with the opposite prism orientation. Finally Figure 4d shows the spectrum coadded from all plates.

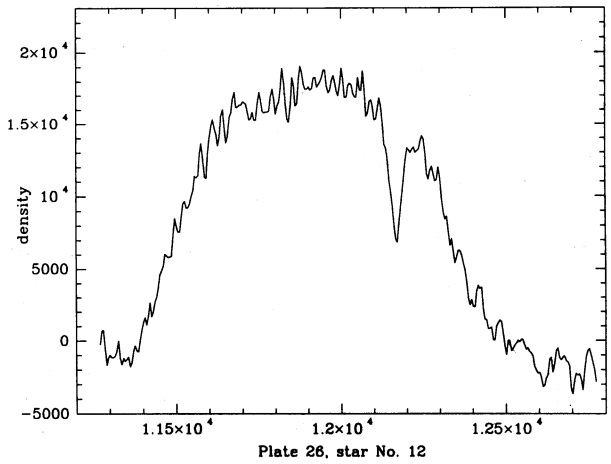


Fig. 4a. A spectrum coadded transversely from a single plate.

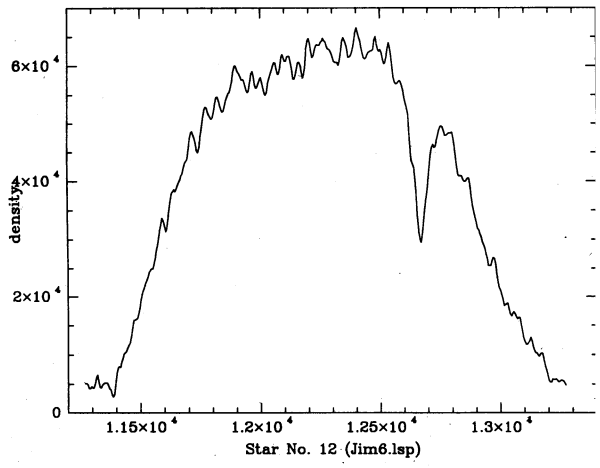


Fig. 4c. The same star as in Fig. 4b, coadded from three plates with the opposite orientation of the prism.

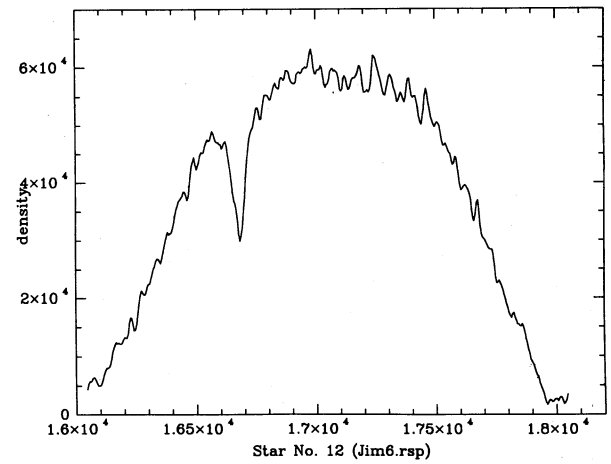


Fig. 4b. The same star as in Fig. 4a, coadded from three plates with the same orientation of the prism.

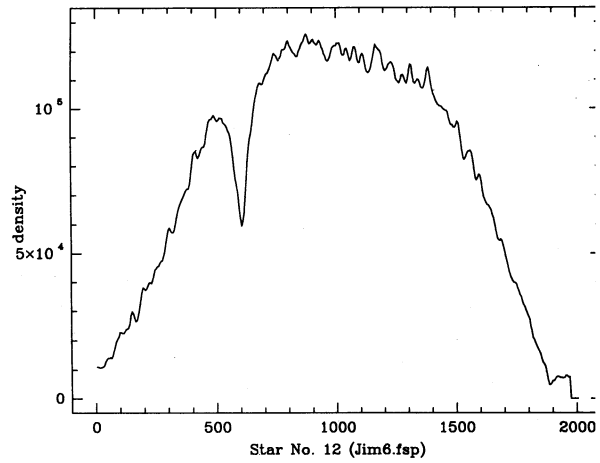
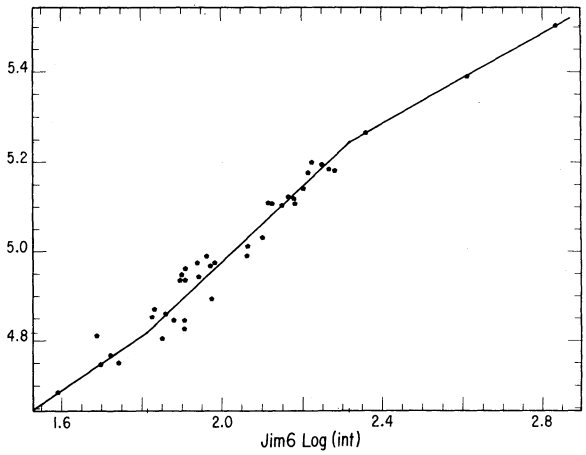


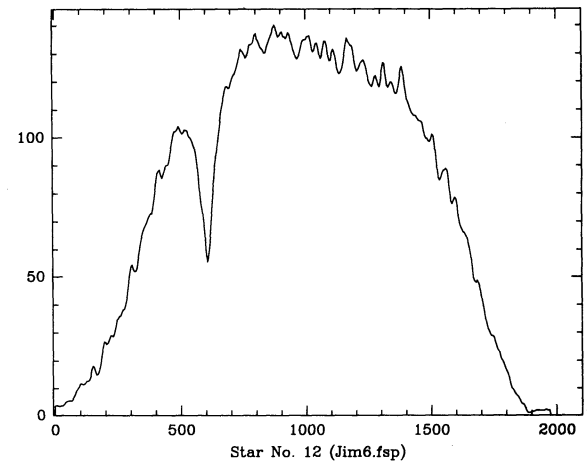
Fig. 4d. The same star as in Figs. 4a to 4c, coadded from six plates.



g. 5. Empirical relation between the densities coadded om six plates and the intensities measured with a CCD.

For the calibration of the intensity versus density lation a selection of stars was observed with the me telescope, prism, and filter using a CCD. ensities were averaged for the central half of e spectra of the corresponding stars, and the me was done with the intensities recorded by the CD. The graph in Figure 5 shows the relation hich was found between the two quantities. This lation is then represented by the most convenient athematical relation, in this case three sections straight lines, which then subsequently can be sed to convert densities to intensities. Figure 6 ows the same spectrum as in Figure 4, this time intensities.

Using the method explained in § 6 a total of velve lines was located and identified in the spec-a. Their wavelengths are listed in Table 1. After nversion of the densities into intensities their



g. 6. The same spectrum as in Fig. 4d, but with inten-ies instead of densities.

TABLE 1

THE IDENTIFIED LINES

No.	Wavelength (A)	No.	Wavelength (A)
1	4146.4	7	4071.6
2	4135.0	8	4063.7
3	4111.3	9	4057.7
4	4101.9	10	4045.9
5	4084.5	11	4033.2
6	4077.3	12	4007.5

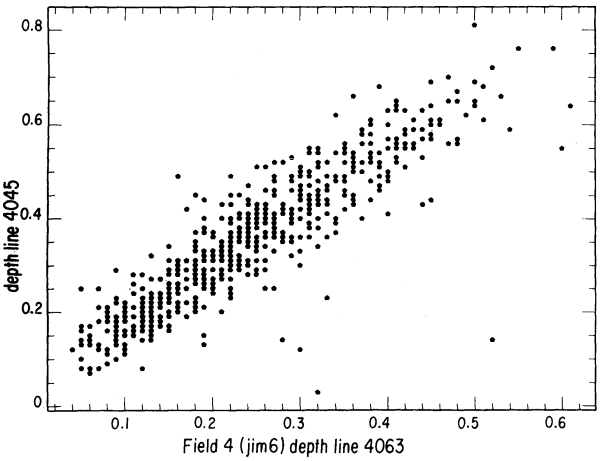


Fig. 7. Empirical relation between the line depths of the Fe-lines at 4045 A and 4063 A.

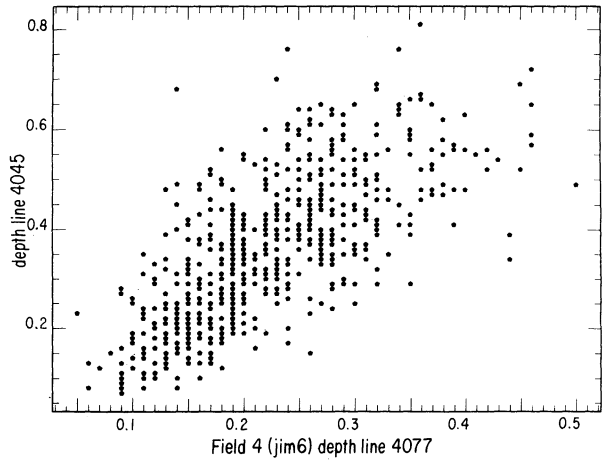


Fig. 8. Empirical relation between the depths of the Fe-lines at 4050 A and 4063 A and the Sr-line at 4077 A.

equivalent widths, depths, and central intensities were determined according to what has been described in § 7. Figure 7 shows the relations between the Fe-lines at 4045 A and 4063 A. This diagram shows a well pronounced correlation between the

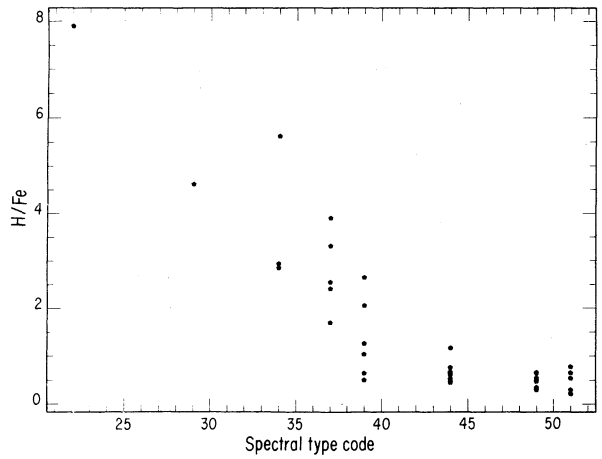


Fig. 9. Relation between the spectral types by Houck and the ratio of the line depths of H and Fe. The spectral type is coded such that A0 corresponds to 20, F0 to 30, etc.

two sets of data, and also gives some idea of what the internal accuracy of the respective data might be. Figure 8 shows the relation between the Sr-line at 4077 A, a well known luminosity indicator, and the Fe-line at 4045 A, this time showing only a weak correlation.

As stated in the previous section, a calibration such spectroscopic parameters in terms of physic parameters is highly desirable. The material c hand is totally insufficient for that purpose. Hov ever, a comparison with the spectral classification l Houck (1975) can be carried out, at least with h spectral classes. Following a scheme developed l Rose & Agostinho (1991) a ratio of the type H/Fe ca be expected to be a good temperature indicator. T represent Fe we use the lines at 4063 A and 4045 converting the depth of the first to that of the se ond according to the relation found in Figure 5, ar then averaging them, while H is represented by H The relation of this ratio with the spectral type l Houck is shown in Figure 9.

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