PROJECT FOR A SYSTEM FOR THE AUTOMATION OF STELLAR QUANTITATIVE SPECTROGRAPHY

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RIASSUNTO. — Si descrive la lunga e laboriosa serie di operazioni necessarie per lo studio quantitativo degli spettrogrammi stellari. Allo scopo di ridurre il tempo speso in queste operazioni e di aumentarne la precisione, si descrive un microfotometro automatico digitalizzato che perfora su nastro le trasparenze e le corrispondenti posizioni ogni 2 micron lungo l'intero spettro. Una seconda parte tratta delle operazioni richieste al calcolatore elettronico e discute quale sia il tipo più conveniente. Infine nella terza parte si descrive il progetto costruttivo del microfotometro digitalizzato automatico.

ABSTRACT. — The operations necessary for performing a quantitative interpretation of stellar spectra are described. The performance required of an automatic digital microphotometer, which punches on tape the transparencies and the positions on a spectrogram every two microns is outlined. A second part deals with the operations required of an electronic computer and a third part concerns the description of the constructive project of the automatic digital microphotometer.

INTRODUCTION

About 80% of the time required for a quantitative analysis of a stellar spectrum is consumed in the reduction of the data, and only 20% devoted to their interpretation. The reduction of the data consists of several steps, which can be itemized as follows:

1) Measurements of the photographic transparency at each point of the spectrogram; this is performed by exploring the spectrogram with a microphotometer.

2) Transformation from photographic transparencies to intensities through the calibration curve.

3) Drawing of the continuum; this is done by connecting the lowest points (windows in the continuum) with an interpolation curve.

4) Comparison of several tracings corresponding to several spectrograms of the same star, in order to determine which details are pre-

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sent in all the tracings, and therefore are true absorption or emission lines, and which do not appear at the same wave length in all the tracings and therefore must be considered plate grain or defects of the emulsion. Such a comparison of spectrograms of the same non-variable star is very useful for reducing the effect of the plate grain, but it is obligatory when we want:

— to compare spectrograms of stars which are similar but characterized by very small differences (for instance a pair of stars of the same spectral type and luminosity class, the one a sub-type s, strong line star, the other, w, a weak line star [1], [2])
— to detect small variations of a spectrum variable
— to detect very weak lines, or very broad and shallow lines.

For performing such a comparison we must superpose the tracings corresponding to several different spectrograms. This superposition is possible only after transformation from transparencies to intensities and after the intensity of the continuum is made equal to one, and the intensity scale is made equal for all the tracings.

There are some microphotometers [3], [4], [5] which can transform directly the transparencies to intensities, but in each case it is necessary to construct first the calibration curve, and afterwards to adjust a potentiometric device; this last operation requires a considerable length of time, especially so if we bear in mind that the calibration curve is a function of the wave length and therefore for the same spectrogram two or three or more calibration curves must be used, with two, or three or more adjustments. On the whole the time saved in obtain a direct intensity tracing (where the continuum intensity is not yet reduced to one) is lost in the adjustment operations.

5) Measurements of the equivalent widths of the lines (which in some spectrograms can attain several thousands).

These laborious and time consuming operations make it desirable to achieve an automation of them. Devices resolving part of these problems exist ([6, 7, 8, 9, 10]), but they permit only setting in code the position of the lines for the measurements of radial velocities, and they give a measurement of the transparency on the center of the line or they can measure the integral transparency of the line, by using a very wide slit; it is evident that this procedure introduces photometric errors and is strongly dependent upon the photographic density of the plate. These devices are very useful for statistical researches but they are not adapted for quantitative spectral analyses.

We investigate here the performances required of a standard microphotometer which sets in code the intensities at each point of the spectrum and the operations required of a general purpose digital computer.

OPERATIONS REQUIRED OF THE ADM

The standard microphotometer which we shall call ADM (automatic digital microphotometer) is required to perform the following operations:

a) Calibration.

There are two possibilities:

1) The ADM scans the calibration spectrum and punches on the tape the transparencies and the corresponding intensities. The computer will calculate accordingly the calibration curves and transform the transparencies of the stellar spectrum into intensities.

2) It is possible to plan an automatic device which removes the need for successively scanning the calibration spectrum and the stellar spectrum, and for computing the calibration curve through the electronic computer.

Such a device can be employed when we have at our disposition a calibration system of the type proposed by Hirsch and Schon ([11]). This system is actually used in our Observatory ([12]). In this calibration spectrogram the intensities at one fixed wave length are a linear function of the distance from a given point x_0 corresponding to intensity $I = 0$ (linear spectrophotometric wedge). Two light pencils of the same source are sent on the same photomultiplier, the one after transmission through the stellar spectrum, the other through the calibration spectrogram. The two spectrograms are placed on two different plate carriages. An electronic device controls the photometric coincidence of the two transparencies; in other words the transparency which is read on the stellar spectrogram controls the displacement of the calibration wedge until the photometric coincidence is attained. The displacement of the calibration plate carriage is set in code, giving a direct measurement of the intensity.

Since the calibration curve is a function of the wave length, varying very slowly, it is necessary to settle the positions at which the scanning of the calibration wedge must be made corresponding to different intervals on the stellar spectrogram. On the basis of previous experiences we can state that in 70% of the cases only one calibration curve is needed for the whole spectral interval between 3900 and 4900 A. However, for all cases three curves are sufficient for the same interval. A mechanic memory will arrest automatically the two plate carriages and will drive the calibration wedge in the sense of the spectral dispersion at positions fixed in advance on the stellar spectrogram.

We point out that it is impossible to syncronize the motions of the stellar spectrogram and calibration wedge in the direction of the wave length, since they generally have different dispersion curves.

b) Auxiliary devices.

It sometimes occurs that the plate fog of the stellar spectrogram and that of the calibration wedge are slightly different. In such cases it is profitable to make them equal by introducing a wedge on the light path of the beam exploring the more transparent plate. Hence two holders for the two wedges must be provided for, on the path of the two beams scanning the stellar spectrogram and the calibration spectrogram.

During the scanning of the stellar spectrogram it sometimes occurs that the slit image on the plate becomes out of focus, because of irregularities on the glass backing to the emulsion or because the plate and the plane of the slit placed before the photomultiplier are not exactly parallel. It is therefore necessary to have an optical system for observing with strong magnification the image of the spectrogram in order to perform at once the necessary adjustments.

It is also useful to observe the tracing by means of a recorder at the same time it is punched on the tape. This procedure allows us to eliminate spectral regions which are not usable (for instance regions in which the emulsion is defective, because of scratches or spots, or where the spectrogram is underexposed or overexposed). For more efficient use of this device it is profitable to have some reference points syncronized on the tracings and on the tape (for example every 200 A).

c) Scanning of the stellar spectrogram.

The ADM will scan the whole stellar spectrogram by steps which can be changed between a minimum of 2 microns to a maximum of 100 microns.

The minimum value of 2 microns which corresponds to a resolving power of the photographic emulsion of 500 lines/mm is overabundant and in most cases a step double or quadruple can be used. At each step the ADM punches on the tape 2 numbers, one corresponding to the position in the sense of the dispersion (and therefore function of wave length) and the second, corresponding to the transparency (or directly to the intensity if the automatic device, which sets in code the displacement of the calibration wedge, is used).

d) Scale of the wave lengths and tracing on the continuum.

In addition it is necessary to scan some regions of the comparison spectrogram, (regions which will be selected in advance once and for all) in order to set in code those positions corresponding to known wave lengths. These positions will be worked out by the computer for transforming to wave lengths the displacements of the plate carriage holding the stellar spectrogram. It is also necessary to measure some specially selected regions on the stellar spectrogram, where the windows on the continuum are found. The computer will use these data for constructing an interpolation curve of the continuum through these windows.

The punched tape coming from the ADM will give:

a) Readings of a series of positions of standard lines on the comparison spectrum.

b) Eventual data for constructing calibration curves.

c) Readings corresponding to a region in which the windows on the continuum are present, that will be used by the computer for constructing the interpolation curve of the continuum.

d) Readings of a series of positions on the stellar spectrum and for each position a reading of the corresponding transparency (or intensity).

PROGRAMS FOR THE ELECTRONIC COMPUTER

When the whole stellar spectrum and the calibration wedge has been scanned, the ADM gives a punched tape which contains several series of data, which will be used in different ways.

Two problems must be considered: 1) the selection of the computer which is the most suitable for working out the data, and 2) the most suitable way of punching the data on the tape.

1) Concerning the selection of the computer, since the ADM gives a punched tape, it is preferable that we make a selection from those computers which use the tape directly: Olivetti 6001, IBM 1620, Burroughs E 101, R. Mac. Bee; the last two are smaller type computers and are more suitable for a slow introduction of the data, as in our case. Keeping in mind that: *a*) our numerical operations are very elementary ones, for a great quantity of data; *b*) the average type computers are very expensive, and their use is available only for short periods of time, with the necessity of booking in advance, we conclude that it is preferable to have at our constant disposal a computer giving more limited services, as for instance the Burroughs E 101, following the experience of C.M. Wilson and M.P. Thekaekara ([10]), or the R. Mac. Bee.

2) Concerning the way in which the data must be punched on the tape, it is preferable that they are recognized and used by the computer through a rational criterium, rather than through a codification in different series. Such a criterium could be the succession of different series of numbers, according to the order in which they will be used by the computer:

a) Positions x of the comparison lines

b) Calibration spectrum: $T = f(I)$ (if the automatic device is not used) *c*) Positions and transparencies (or intensities) of the windows on the continuum

d) Positions and transparencies (or intensities) of the stellar spectrum.

With such an arrangement the following operations are required of the computer:

1) n abscissas corresponding to n selected lines in the comparison spectra are punched on the tape and put near their corresponding wave lengths, which are already in the memory of the general program of the computer. Collimation of the n lines is made by observing them through the optical system. Their position can be easily found by reading their standard position on a micrometric screw.

1a) Construction of a polynomial approximating the Hartmann formula (in the case of prismatic spectrograms) using the data quoted in paragraph *a*).

1b) Construction of a straight line for the linear transformation from positions to wave lengths (in the case of grating spectrograms) using the data quoted in paragraph *a*).

2) Through the polynomial 1a) or the straight line 1b) the computer will transform to wave lengths the positions x quoted in paragraphs *c*) and *d*).

3) Using the data quoted in *b*) the computer will construct a polynomial approximating the calibration curves for different wave lengths, and for each curve, 100 values of the intensities corresponding to 100 values of the transparency will be put in the computer memory. We point out that in the case in which the calibration is made by means of a discrete succession of exposures, it is necessary to put in the general program the standard values of the exposures corresponding to each value of the transparency.

In the particular case in which the calibration consists of a spectrophotometric linear wedge (and no automatic calibration device is used) the ADM will use the position along the wedge at each wave length as a measurement of the exposures.

4) Transformation of the transparencies T quoted in paragraphs *c*) and *d*) to intensities I through the values put in the memory (point 3).

(These two points 3 and 4 are required only if there is no automatic device for the transformation from transparencies to intensities).

5) Interpolation curve of the continuum. This is actually a broken curve consisting of as many parts as we have calibration curves at different wave lengths. This last operation is the most difficult. The intensities in each selected region must be put in order by the computer which must select « a number of points of minimum intensity within some fixed limits ». In other words, in each region the computer must

select the n points of lowest intensity, but must reject those points which are lower than a limit fixed equal to a convenient fraction of the average of the n points. The purpose of this process is to eliminate eventual defects of the emulsion. Hence the computer must perform these logical operations:

— the series of values of the intensities in the selected region must be put in order of magnitude (for instance in the case of the IBM 650 through « transfer on sign »).
— from such ordered succession of values those which are out of certain prefixed limits will be rejected (for instance in the case of IBM 650 through « transfer on exponent »).
— such logical operations must be performed in all the selected regions, for each interval of the stellar spectrum corresponding to the same calibration curve.
— from such selected values the lowest n (to be fixed) will be selected.

Using such selected n values in the regions along each spectral interval, the computer will construct the interpolation curve for the continuum, and will put in the memory its polynomial expression, giving the intensities of the continuum $I_c = f(\lambda)$.

6) Computation of the ratio I_r/I_c between the intensities I_r in each point of the stellar spectrum, and the corresponding intensity I_c on the interpolation curve of the continuum.

7) This operation (points 5 and 6) must be repeated for each spectral interval corresponding to each calibration curve.

8) At the end of all the operations indicated by point 2), 5), 6), 7) we have $I_r/I_c = f(\lambda)$ along the whole stellar spectrogram. Each pair of values $(I_r/I_c, \lambda)$ will be punched on a tape.

We shall call the function $I_r/I_c = f(\lambda)$ with the symbol RS (reduced spectrogram).

GRAPHICAL STUDY OF THE DATA

The tape giving the RS, coming out from the computer will be put again in a particular section of the ADM which will put in a graphical form the RS and will tape the wave lengths on the tracing. The tracings relative to several spectrograms of the same star may be easily compared and a graphical average of them performed. A digital planimeter will give us the opportunity to follow and extrapolate the line contours on the average tracing of the RSs, computing the equivalent widths.

A complementary program for the computer could be useful in making the identification of the spectral lines easier. For this a partial memorization of the Multiplet Table of C. Moore [13] would be necessary.

Details of the project of the ADM

The ADM is a basic system for recording in a digital form, the photometric information contained in spectrum plates on a punched tape or card.

Spectrum plates up to 25 cm in length are centered on a semikinematic plate carriage which can be moved in abscissa by means of a precision screw turned by a variable speed motor (VSM) (Fig. 1) (or by hand). A double illuminator (I) provides the projection on the plate of an image of a slit adjustable in width and height and the projection of a circular field to control focusing on the explored range. A small microscope (M) can read on the carriage the origin of abscissas. Plates can be adjusted in y and rotated around the photometer axis.

Transmission on the plate is read by means of a photometer (1) wich sends its information to a recorder (2) and to a digital voltmeter (3) The photometer has a separate voltage supply (HVS).

The abscissas on the plate carriage are read through the angle of rotation of the leading screw; an optical digitizer (4) connected to it gives an electrical pulse every 2 thousandth of a turn. Pulses are sent

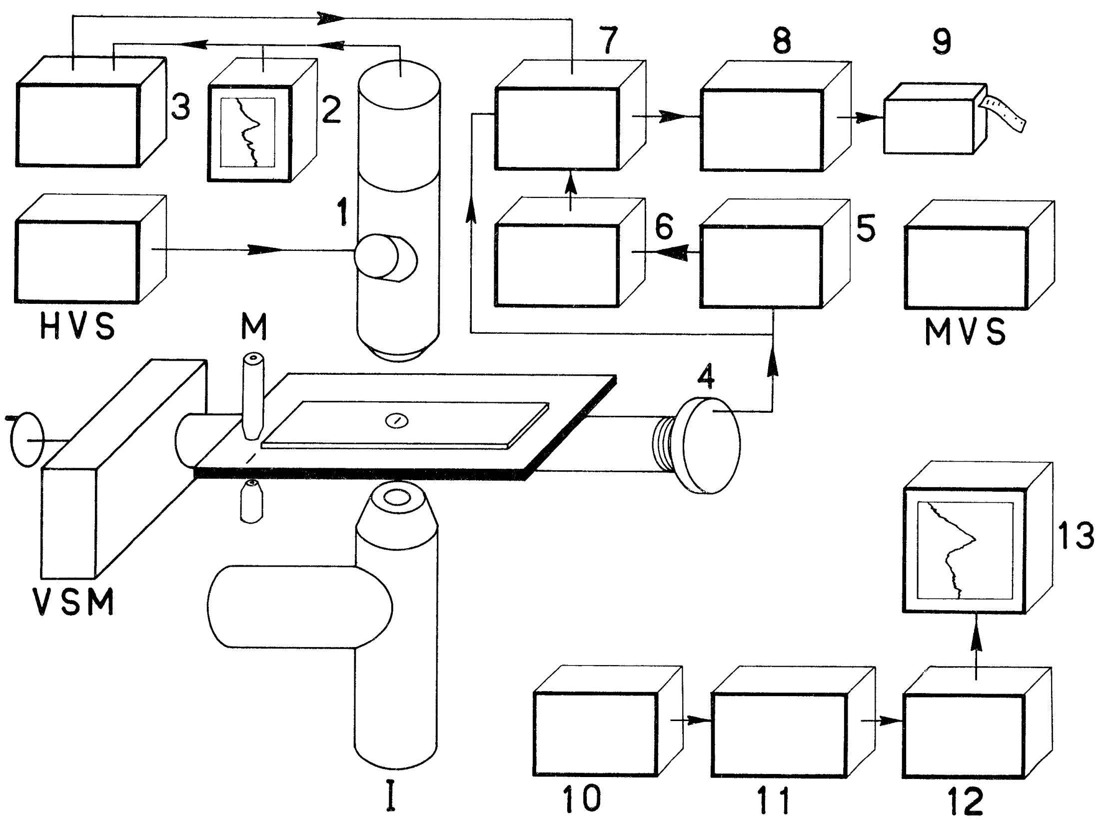

Fig. 1

to an updown counter (5) which so accumulates the information on the position of the plate carriage.

Hand selection on the up-down counter provides a trigger pulse every 2, 4, 8, 20, 50, 100 microns of carriage motion. The trigger pulse (6) gates the transfer « in flight » of the number contained in the up-down counter and in the digital voltmeter to a buffer memory (7), from which decimals are readout by the serializer (8) one by one and sent to a fast punched tape printer (9).

All electronic blocks have a voltage supply suitable to their requirements (MVS).

The printer speed is 30 characters/sec; this is the actual limit of the speed of the system; after a successful operating of the whole system it could be changed to a magnetic tape, the speed limit being now imposed by the digital voltmeter which cannot give more than about one thousand values/ second without a considerably improved design.

Intensity instead of transmission can be recorded by means of a wedge device equalizing the transmission of the photometer with that of the calibration spectrum. This will be done only when the speed of readout will not impair the time response of the servo-equalizer.

To the main system is added a decoding facility to write down reduced spectra obtained from computers in punched tape form. It consists of a tape reader (10) connected to a digital-analog converter (12). Its output enters a paper recorder (13). Wavelengths selected in (11) are written by means of markers superimposed on the spectrum profile.

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