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Professional paper

THE DATA PROCESSING IN SOLAR SPECTROPHOTOMETRY

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SUMMARY An interactive software package especially developed for solar spectrophotometry at the Belgrade Astronomical Observatory is described. The programs are written to automate the measuring procedure in Belgrade Program for Monitoring of Activity-Sensitive Spectral Lines of the Sun as a Star. The procedure includes the flat field reduction, correction of the X-scale, normalization to the continuum level, and evaluation of equivalent widths.

1. INTRODUCTION

The Belgrade Program for Monitoring of Activity-Sensitive Spectral Lines of the Sun as a Star started in 1987 by monitoring thirty selected photospheric lines (Vince et al., 1988), and is carried out by an adapted equipment (Arsenijević et al., 1988). In order to improve the measuring procedure of output signals, an especial interactive software package is developed.

To attain the automation of the measurements several procedures had to be done. At first, an analogue X-Y record coming from the monochromator and the photomultiplier must be transformed into the appropriate set of numerical data by a standard digitizer connected to the computer. Then, a few programs were developed for following reduction steps:

a) Flat field reduction;

b) Correction of the X-scale;

c) Normalization to the continuum level;

In such a way automatic measurements of spectral lines are achieved. At the time being, only equivalent widths can be measured, because the instrumental profile has not been estimated so far.

2. ALGORITHM AND THE DATA PROCESSING

After the transformation of an analogue X-Y record into the digital one, we obtain a file containing pairs of X and Y coordinates, both measured in millimetres. Such a digitized plot of solar spectrum near the line FeI 530.74nm is shown in Figure 1.

All reductions, corrections and normalizations mentioned in the Introduction, as well as the equivalent width evaluation, could be programed on a standard personal computer. Using an interactive technique, many of the actions could be controled directly. For example, the user chooses those parts of the spectrum corresponding to the local continuum level, and also sets the limits for numerical integration, during the equvalent width evaluation. But all the other routine tasks are left to the computer.

The algorithm of the complete processing is shown in Figure 2. Corresponding programs are mostly written in 8088 assembly language, especially those demanding extremely short execution times.

a) Flat Field Reduction

The main problem in this step of the reduction procedure is to create the function $y = y_c(x)$ representing the local continuum level. The correction of the recorded spectrum can be done by dividing all Y-coordinates (y_i) by the $y_c(x_i)$ value:

$$y_i^r = \frac{y_i}{y_c(x_i)},$$

where y_i^r represents the reduced value of Y-coordinate.

In order to determine the form of the function $y_c(x)$, we have to mark all parts of the recorded spectrum corresponding to the local continuum level, as shown in Figure 3. Much higher precision could be reached by applying this procedure to several records belonging to the same date, and finaly overlap all the results (Figure 4). The marked parts of the continuum level, derived from different records, do not lie on the same curve, because of different amplification. The program offers us a possibility of applying the "software amplification", by which all of selected records can be brought to the same level. This software amplification is similar to an ordinary translation, but it is realized by the multiplication instead of the addition. The multiplication needs much more of the computer time than the addition does, and this is where the assemblly language shows its power.

Finaly, the program forms the function $y_c(x)$ as a polynomial of third degree, using the method of least squares. The function y_c can be used for the reduction of all spectra recorded at the same date.

b) Correction of the X-scale

There are two steps in the X-scale correction procedure:

a) To form a liner scale in millimetres at the exit slit;
b) To form a wavelength scale in nanometres.

The first step (Arsenijević et al., 1988) is given by the equation:

$$u = d\left(\sin\alpha - \frac{\sin\alpha\cos\alpha}{\sqrt{n^2\sin^2\alpha}}\right),$$

where d represents the thickness of the glass cube of the monochromator, n is the glass refractive index, and α is the angular position of the glass cube. The angle α is directly connected to the X-coordinate of the recorded spectrum.

The second step is given by the equation:

$$\lambda_i = \frac{u_i}{D},$$

where D denotes the dispersion. The program offers us the possibility to choos two spectral lines on the screen, and then enter corresponding wavelength interval $\Delta\lambda$. After that, the program calculates the dispersion, and makes the correction of the X-scale automaticaly.

c) Normalization to the Continuum Level

Normalization to the continuum level is the last step of the data processing. The position of the continuum level has to be chosen by translating a corresponding horizontal line across the screen. The program then reads the value of the continuum level, and divides all Y-coordinates by this value.

After the whole reduction procedure, the intensity of the spectrum is in the range between 0 and 1, while the X-axis represents wavelengths in nanometres, with zero-point somewhere in the midle of the record.

3. EQUIVALENT WIDTH EVALUATION

The whole processing just described could be understood as a transformation of the (x, y) pairs of coordinates into the (λ, I) pairs, according to Figure 2. We can continue the evaluation of the line profile using these reduced data.

To get the equivalent width of a spectral line the numerical integration is performed by using the formulae:

$$S_1 = \sum_{i=L}^{R-1}(\lambda_{i+1} - \lambda_i)\frac{I_i + I_{i+1}}{2},$$

$$Q = (\lambda_R - \lambda_{R-1})\frac{I_{R+1} + I_R}{2},$$

$$S_2 = \begin{cases} \displaystyle\sum_{k=0}^{m-1}(\lambda_{L+2k+2} - \lambda_{L+2k})\frac{I_{L+2k} + I_{L+2k+2}}{2}, & \text{if } R - L = 2m, \\ \displaystyle\sum_{k=0}^{m-1}(\lambda_{L+2k+2} - \lambda_{L+2k})\frac{I_{L+2k} + I_{L+2k+2}}{2} + Q, & \text{if } R - L = 2m+1, \end{cases}$$

$$S = \frac{4S_2 - S_1}{3},$$

where L and R represent left and right limit of the integration. The point $R + 1$ must exist as well.

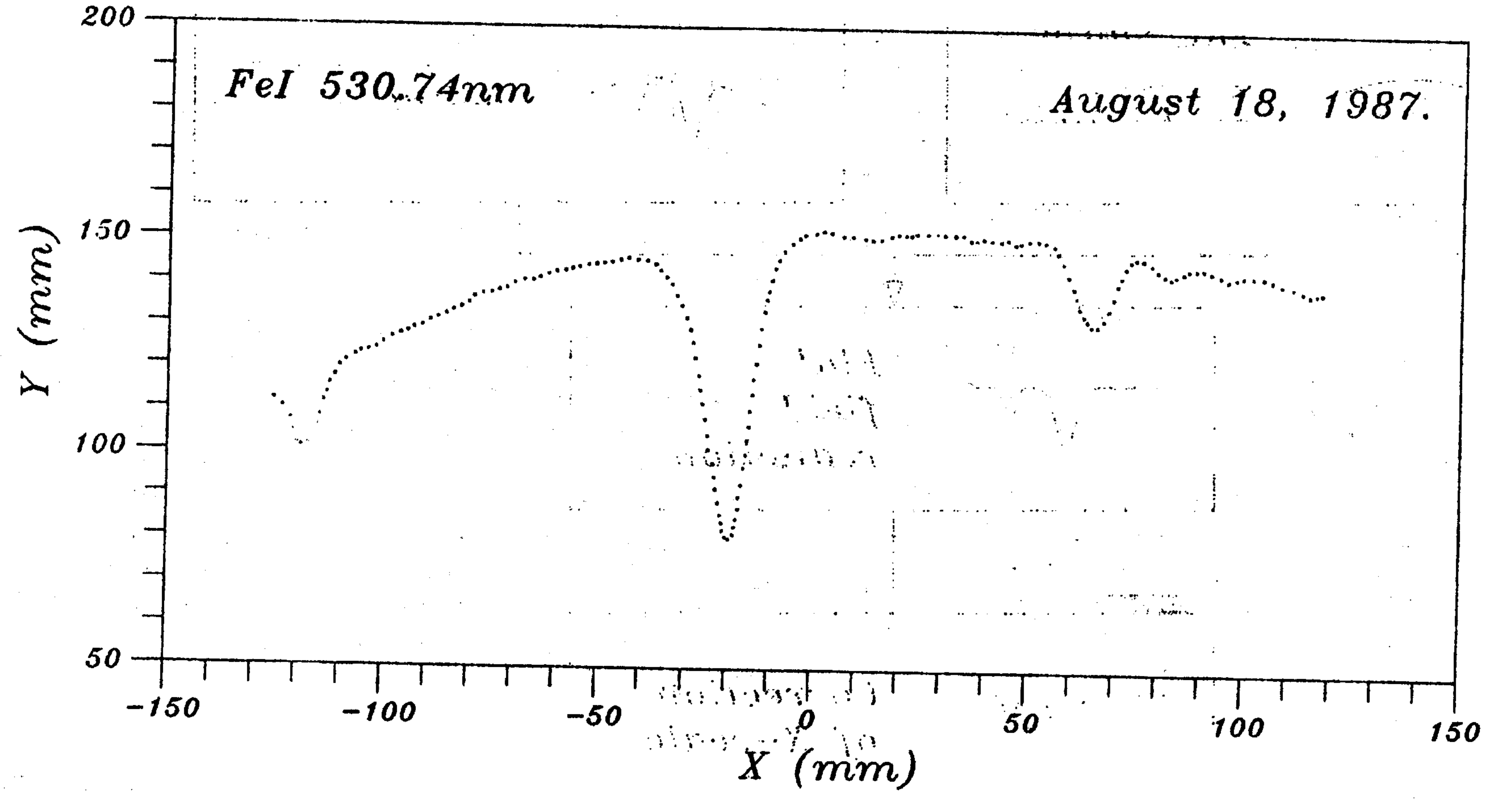

Fig. 1. **A typical plot of the digitized spectrum.**

The equivalent width in nanometres is then:

$$W_{\rm nm} = (\lambda_R - \lambda_L) - S,$$

Before a calculation, the limits of the integration have to be determined, by using two vertical lines on the screen.

Resulting equivalent width in nanometres can be transformed to Fraunhofer units by the well known transformation:

$$W_{\rm F} = \frac{W_{\rm nm}}{\lambda} \times 10^6.$$

The equivalent width is a very important characteristic of a spectral line, and that is why we are interested in finding a way to get this parameter as reliable as possible. For the further analysis of equivalent widths obtained the reader is referred to the paper by Skuljan et al. in this journal.

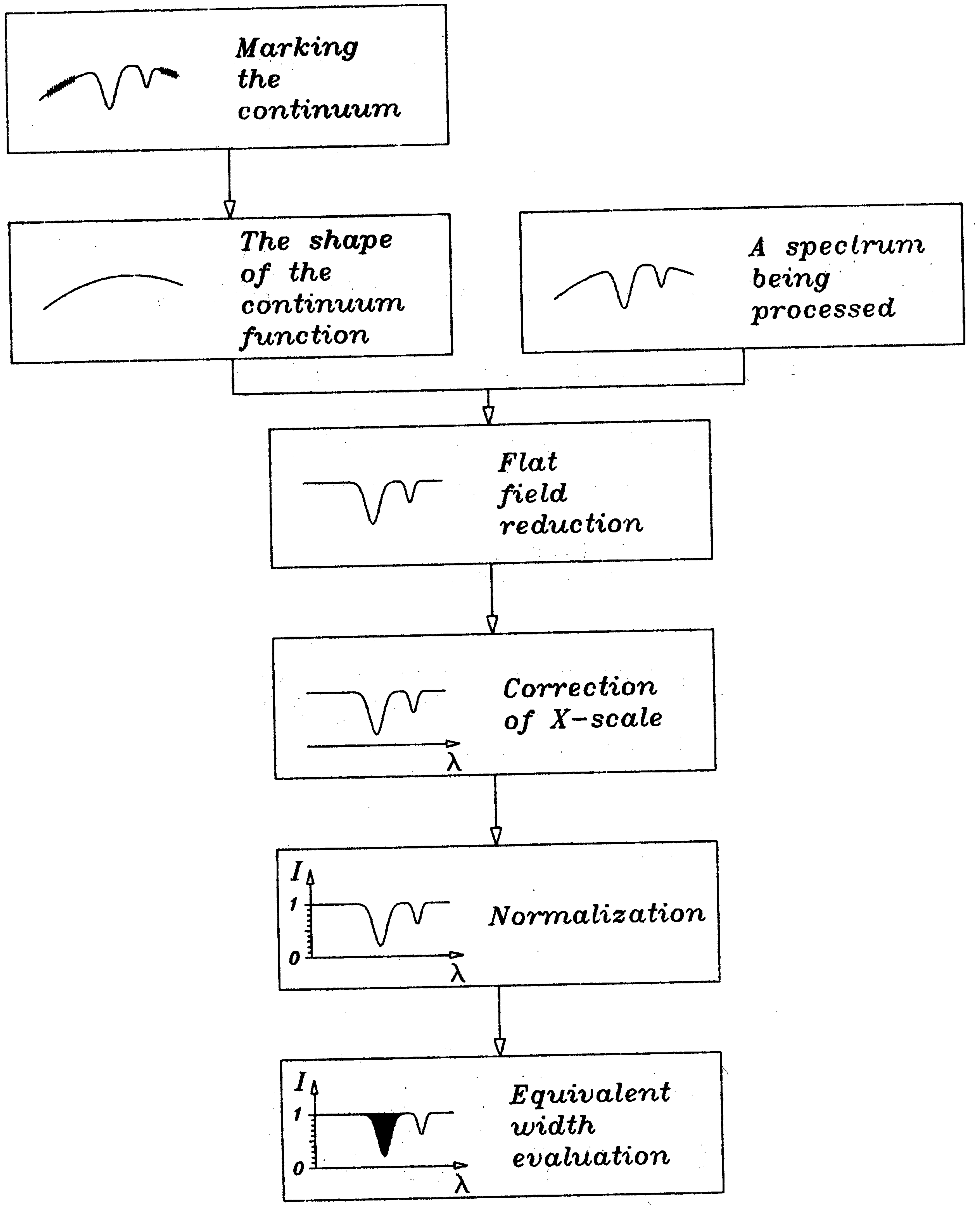

Fig. 2. Algorithm of the data processing.

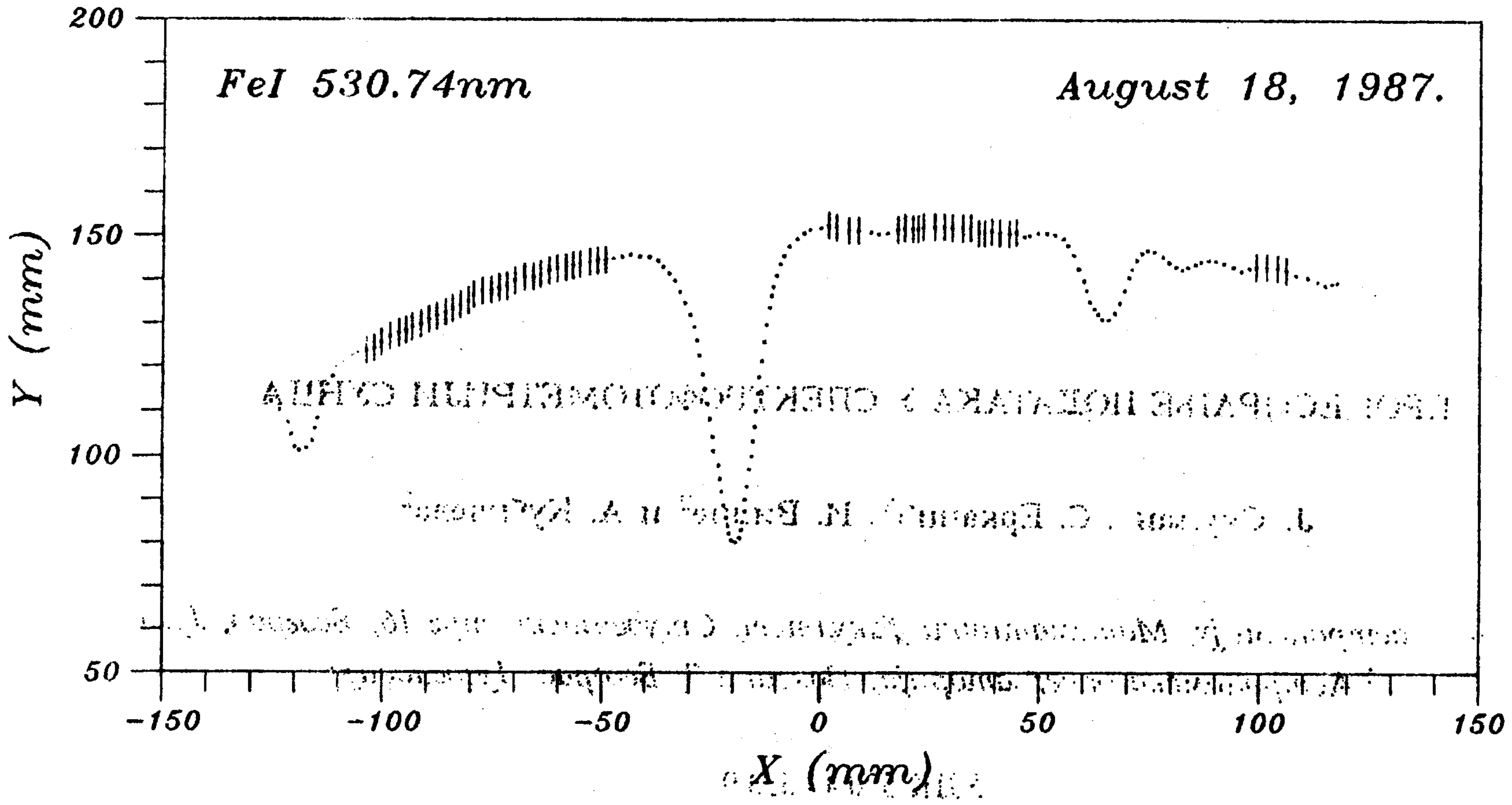

Fig. 3. **Marking the continuum level.**

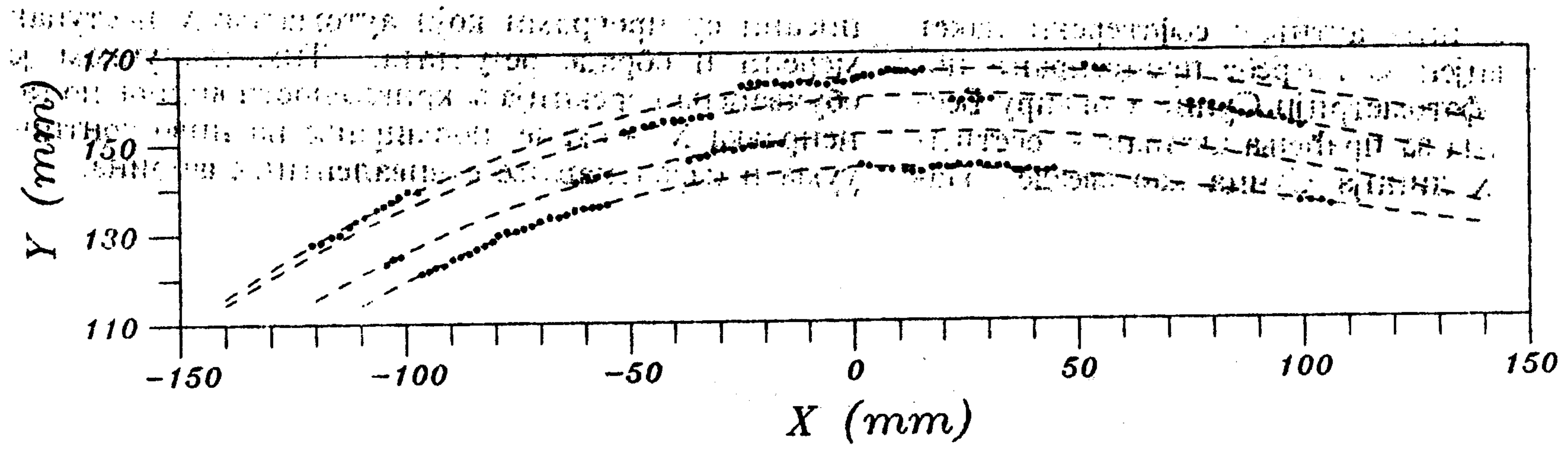

Fig. 4. **Continuum levels from several different records.**

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ПРОЦЕСИРАЊЕ ПОДАТАКА У СПЕКТРОФОТОМЕТРИЈИ СУНЦА

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Стручни чланак

Описан је интерактиван софтверски пакет специјално развијен за потребе процесирања података у спектрофотометрији Сунца у оквиру Београдског програма за праћења активно – осетљивих спектралних линија Сунца као звезде. Написани су програми који аутоматизују поступак мерења и обраде резултата. Тим поступком је обухваћена корекција закривљености видног поља, исправка X – скале, нормирање на ниво континуума и израчунавање еквивалентних ширина.