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REDUCTION OF SPECTRAL DATA OBTAINED ON THE 1024-CHANNEL SCANNER OF THE 6 M TELESCOPE WITH A PERSONAL COMPUTER IBM PC AT

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ABSTRACT. *The processing of data obtained with the 1024-channel television scanner of the 6 m telescope needs the software oriented for the use in modern computers. Such software for data reduction which can be used in personal computers of IBM PC AT class is proposed. The main principles of the software allowing for the peculiarities of detectors are discussed. The software is realized as separate independent modules. The data format is fully compatible with the existing Fortran one in SIPRAN system. The main procedure stages are shown at processing of concrete astrophysical data.*

Обработка спектральных данных, получаемых с помощью 1024-канального телевизионного сканера 6-метрового телескопа нуждается в программном обеспечении, ориентированном на использование современных вычислительных средств. Предлагается пакет программ для редукции данных, который может быть использован на ПЭВМ класса PC-AT. Изложены основные принципы, положенные в основу программного обеспечения, учитывающие особенности приемной аппаратуры. Пакет реализован в виде отдельных независимых исполняемых модулей. Формат данных полностью совместим с существующим форматом в системе СИПРАН. Основные этапы обработки проиллюстрированы на конкретных астрофизических данных.

1. INTRODUCTION

The appearance of personal computers of IBM PC AT class in early 90s made it possible to use them widely in astrophysical experiment, in particular, to solve the problems of controlling the experiment, fast reduction of obtained data. The increased, as compared to a computer of CM (PDP-11) and EC (IBM-360) classes, capabilities of a personal computer, such as 5-10 times more powerful processor, considerable (up to 100-300 Mbyte) disc capacity, various graphic devices, are naturally attractive for experimentators. Thus, the CM and EC computers are being replaced by personal ones. As a result, for the past years we have observed a growing flow of instrumental and program developments in this field. Let us note that this can be observed not only in our country, but abroad as well (Domik et al., 1990; Treffers and Richmond, 1989; Jacoby and Heasley, 1988).

The first attempt to use PC for reduction of spectral data obtained with the 1024-channel TV scanner of the 6 m telescope (Somova et al., 1982; Drabek et al., 1986) was adaptation by N. N. Somov of the interpretative language "SIPRAN" for a personal computer. This allowed to transfer the standard procedure of processing to IBM PC AT without problems. Being rather convenient for astronomers, "SIPRAN", in our opinion, places restrictions on full utilization of the computer facilities. The author has attempted to realize the basic reduction procedures of scanner spectra with the help of a set of independent executive modules, bearing in mind their further introduction into a certain integrated medium which makes it easier to communicate with the software package. In this paper realization of algorithms of data reduction, which is illustrated by the examples of reduction of spectra for a number of astrophysical objects, is described.

2. TECHNIQUES FOR OBSERVATIONAL DATA PROCESSING

The entire process of data reduction can be illustrated with the schematic presented below. The suggested system of spectrum reduction is practically compatible with the existing systems of scanner spectrum reduction in the set of file names and their extensions.

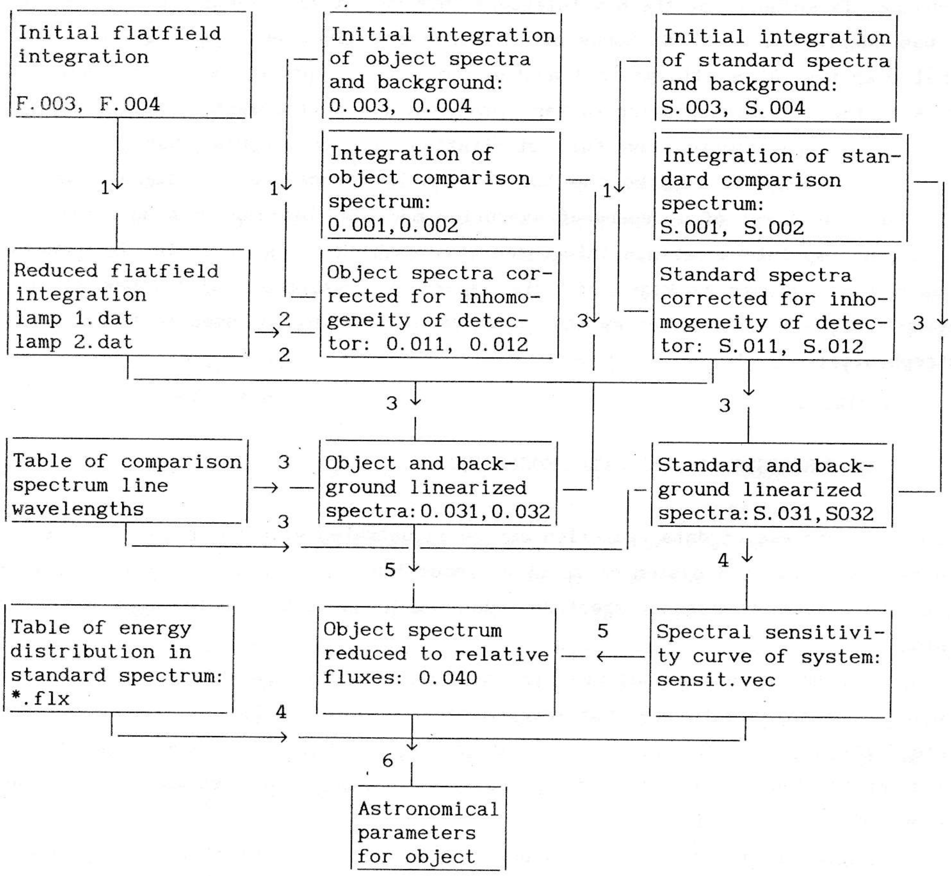
In this scheme the extensions used in the reduction are presented, and the names of the original files with spectrum integration are replaced for clarity by F.* for flat-field integration, O.* for object integration, and S.* for spectrophotometric standard integration. Note that, if necessary, the suggested systems of names and extensions may be rejected.

The rectangles in the scheme, which denote the spectral data at different stages of reduction, are linked by the lines denoting the following procedures realized in the system as independent program modules:

1) correction of channel by channel modulation of integrations - for all ones except for the comparison spectrum;
2) correction of inhomogeneities of the detector sensitivity - for all integrations: object + background and background (including the spectrophotometric standard);
3) reduction of spectra to a uniform wavelength scale (including the standard);
4) construction of the spectral sensitivity curve of the system from the integration of the spectrophotometric standard, including subtraction of the background spectrum;
5) correction of spectra for spectral sensitivity with preliminary subtraction of the background spectrum;
6) determination of spectrum parameters and individual spectral features.

Let us consider in more detail the program realization of these algorithms.

SCHEME



2.1. Correction of channel by cnannel modulation and sensitivity inhomogeneities

It is well known, that due to peculiarities of instrumental realization of the 1024-channel scanner of the 6 m telescope, the initial data obtained with it are modulated with a period of 2 channels (the so-called nonequivalence of odd and even channels). To remove this modulation we apply filtering of the spectrum by a low-frequency filter. The band of this filter $F(\nu)$ is such, that from the zero spatial frequency up to half of the Nyquest frequency ($\nu_{Ny} = 1/(2\cdot\Delta x)$) it is equal to unity and further it begins to reduce smoothly to zero by the law:

$$F(\nu) = 0.5\cdot(1+\cos(\pi\cdot(2\cdot\nu/\nu_{Ny}-1))).$$

With the help of such filtering one can remove the strong high-frequency noise in the acquisition and avoid disruptions in the filter pass band, which result in a high-frequency "ringing" (the so-called Gobbs effect). Note, that similar way is applied in the program of scanner spectrum reduction used with the computer CM-4 (Shapovalova et al., 1987).

For correction of sensitivity inhomogeneity of the detector during the scanner observations acquisition is performed of the so-called "flat field" of the emission source illuminating all the channels of the detector. It is known that with the change of orientation of the telescope and therefore of the system of focusing and scanning when observing at various azimuths, the spectra themselves and the detector inhomogeneities are displaced over the raster of the system. The author suggests and realizes the methods of cross-correlation calibration of the object spectrum and flat-field integration from the small-scale inhomogeneities of the detector. For this the object spectrum and flat-field integration undergo high-frequency filtering eliminating in them high-frequency small-scale (to $\nu = \nu_{Ny}/20$) component. This guarantees that in the further analysis only the high-frequency inhomogeneities of the detector and, of course, some details in the object spectrum will be allowed for.

If one writes the spectrum acquisition as $s(x)$, and the "flat-field" acquisition as $f(x)$, the filtered acquisition will be expressed as follows:

$$s_f(x) = F^{-1}(F(s(x))\cdot W(\nu));$$

$$f_f(x) = F^{-1}(F(f(x))\cdot W(\nu)),$$

where x is the spatial coordinate, ν is the spatial frequency, as previously, $W(\nu)$ is the passband of a high-frequency filter of the kind, described above, $F(\ldots)$ and $F^{-1}(\ldots)$ denote the direct and inverse Fourier transformations.

Taking this into account, the cross-correlation function of $s_f(x)$ and $f_f(x)$ can be written as

$$CCF(x) = F^{-1}(F(s_f(x))\cdot F^{*}(f_f(x))),$$

where $F^{*}(\ldots)$ is the function conjugated to $F(\ldots)$ according to the theorem on the properties of the Fourier transformation (Bendat and Pirsol, 1989).

The position of the cross-correlation function peak yields relative displacement of inhomogeneities in the acquisition of the object spectrum with respect to those in the flat-field acquisition, and the value of the peak gives the measure of similarity of these acquisitions. If prior to calculation of the cross-correlation function to normalize $s_f(x)$ and $f_f(x)$ so that they would have zero mean and unit variance, then all the values of the cross-correlation function will fall within the interval from -1 (full anticorrelation) to 1 (full correlation).

The value of the relative displacement of inhomogeneities, obtained from the analysis of the cross-correlation function peaks, is used by us for the displacement of acquisition of uniform illumination and subsequent division by it of the acquisition of the object spectrum. As a rule, we define the displacement value from the object acquisition where the best correlation of inhomogeneities is reached, and we use this value for the correction of the background spectrum acquisition too. However independent determination of the shift for the background noise spectrum and for the object spectrum is possible.

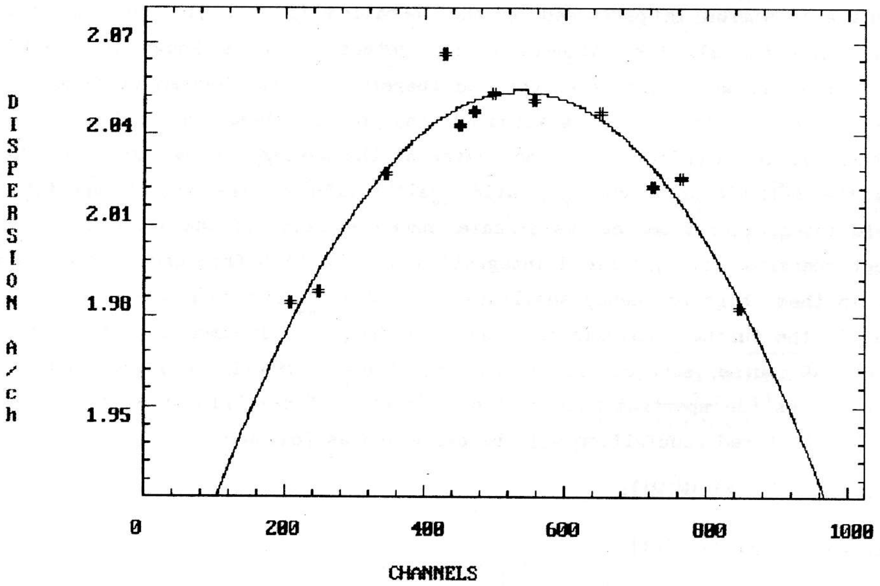


Fig. 1. *Variation of the reciprocal linear dispersion along the spectrum of the quasar JV-74b. The line corresponds to the dispersion according to the approximation polynomial, the crosses are the measured values from the neighbouring lines of the comparison spectrum.*

The construction of the cross-correlation function for individual fragments of the total acquisition shows, that the shift of inhomogeneities is practically the same for all fragments, which allows to perform the shift of the entire acquisition as a whole. Experience shows that, as a rule, even the acquisition containing on the average 80-100 counts in a channel is sufficient for confident definition of the shift value of inhomogeneities.

2.2. Reduction to a uniform wavelength scale (linearization)

For linearization of spectra before and after exposure acquisition is done of the laboratory comparison spectrum from a helium-neon-argon-filled lamp. The identification of these spectrum lines is confident enough and is presented, for example, in the manual for scanner observations on the 6 m telescope (Lipovetsky et al., 1990). Persuing two purposes at the same time: to make easier the work of the user and to facilitate for him a thorough selection of spectral lines from the whole observed series, we have used a semiautomatic way of line identification at which for the program to operate two lines, located at the margins of the spectrum being recorded, are needed. The rest of the lines from the list, and satisfying the criteria of spectral quality (signal/noise ratio no less than 5, absence of blending by neighbouring lines, etc.) are identified by the program. As the position of a spectral line, we use the value of the line gravity center, which is defined in the window ±2 channels from the line maximum. The dispersion dependence constructed from the identified lines is approximated by a 3d- or 4th-degree polynomial. After the automatic identification of lines the user may, if desired, add the lines absent in the list or unidentified by the program, and also remove the lines having asymmetric profiles or those, which poorly agree with the specified position. As the lines are replaced or added, there is a possibility to check the quality of approximation of the dispersion dependence. Fig. 1 shows the dispersion curve and fitting of the measured values of the reciprocal linear dispersion for the quasar JV-74b spectrum.

To specify the wavelength scale in the linearization procedure, the lines of the night sky are used. This is especially important for those parts of spectra, where the reliable lines of the comparison spectrum are absent, e. g. in the region λλ 5100-5800 A. As experience shows, the utilization of the night sky lines improves essentially the quality of subtraction of the background spectrum.

The mean error of the linearization procedure is, as a rule, within 0.1-0.2 of a channel. So, the error of the approximation depicted in Fig. 1 is 0.25 Å at a reciprocal linear dispersion of 2 Å/channel. The reduction of spectra obtained with different parameters of adjustment shows that the linearization is of little dependence on the quality of adjustment of the focusing system, however at comparison spectrum integration with a higher counting rate, the accuracy of defining the line position and therefore the accuracy of the whole linearization procedure decreases by a factor of 2-3 and may reach 0.4-0.6 of a channel.

In the process of reduction a fully automatic version of linearization of spectra is provided for, if one uses the information on the approximate position of spectral lines.

For the subtraction of the background spectrum, especially for the spectra with a slight excess over the noise, the factor determining the ratio of the background and object strobe of the detector is of great importance. We recommend that this ratio be defined for each version of adjustment of the receiving unit of the scanner, since it may change by 20-30%. It should also be noted that there are data indicating that this ratio changes when flux attenuators are used during observations.

2.3. Correction of spectra for spectral sensitivity of the system

For determination of the spectral sensitivity curve of the system we use observations of the spectrophotometric standards with the tabulated energy distributions set with equal step. Such information is reported, for instance, by Massey et al. (1988).

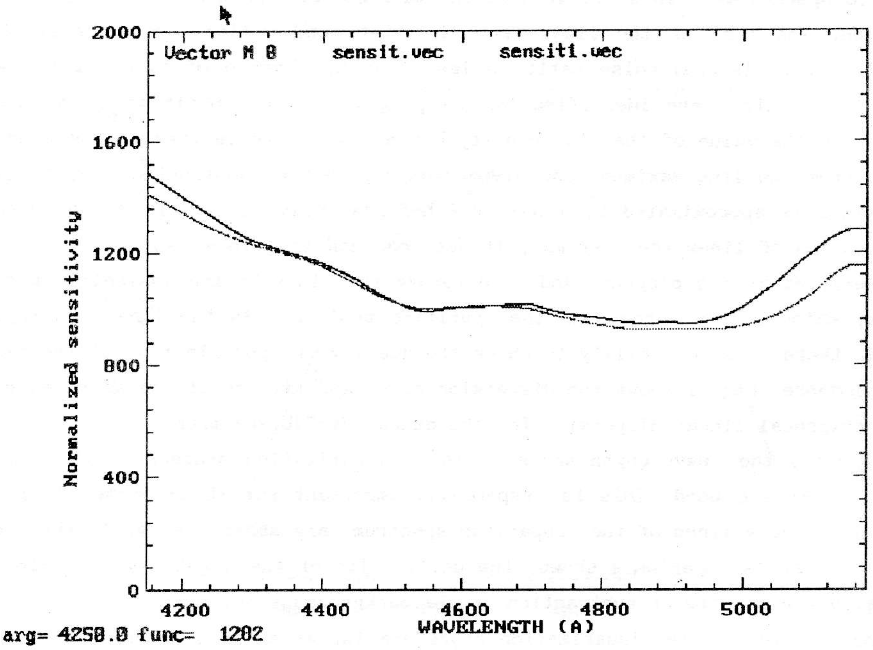


Fig. 2. *The spectral sensitivity curves of the system obtained from observations of the standard star HZ 44. The upper curve corresponds to the observations with a diaphragm of 2 arcsec, the lower one corresponds to the observations with a diaphragm of 1.5 arcsec.*

Therein are tabulated the fluxes from 25 standard stars distributed over the whole sky in the wavelength range λλ 3200-8100 with a step of 50 Å. In the reduction of the standard star spectrum correction is preliminarily made for the atmospheric extinction according to Allen (1977). In the determination of the spectral sensitivity curve the flux from the standard star is integrated in the same spectral intervals as in the table data. In contrast to the techniques applied to data reduction in SIPRAN, subjective approach of the user is completely excluded here. The accuracy of construction of the spectral sensitivity curve may be controlled by obtaining the spectra of different standards under the same conditions. So in Fig. 2 the sensitivity curves determined from the acquisition of the spectral standard HZ44 obtained during one night are presented. The difference between these curves almost in the whole spectral range does not exceed 5%. It is natural that under variable weather conditions, unstable operation of the scanner the quality of correction of spectra for spectral sensitivity dramatically decreases. With the help of the spectral sensitivity curve the object spectra taken in the same spectral range as the standard star are corrected, which are corrected also for the atmospheric extinction. Fig. 3 shows the linearized noncorrected and corrected for spectral sensitivity spectra of one of superassociations in the Markarian galaxy 256.

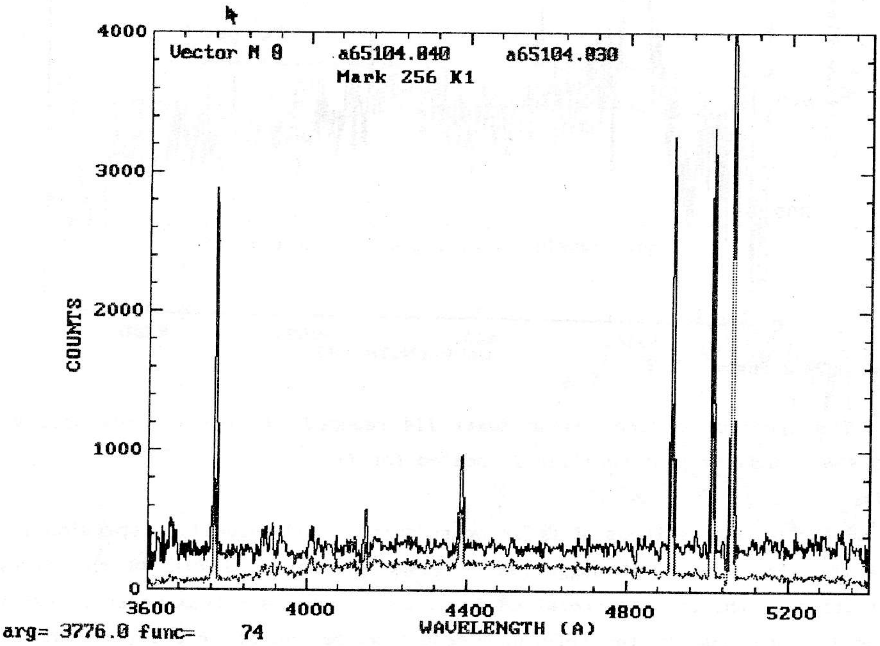


Fig. 3. *An example of correction of the spectra for spectral sensitivity of the system. The lower and upper are uncorrected and corrected spectra, respectively, of one of the superassociations in the galaxy Markarian 256.*

2.4. Determination of astrophysical parameters

Leaving aside specific methods of obtaining astrophysical parameters, let us dwell upon the solution of the most frequently arising problems. So, we have solved the problem of location of the continuum level by automatic construction of stable estimation of a signal in spectral windows of a given width providing for the subsequent correction by the user of individual points of the continuum. Further these points are connected by an interpolation polynomial. In Fig. 4 the result of locating the continuum level for the spectra of the quasar Abati 114, reduced to relative intensities is presented.

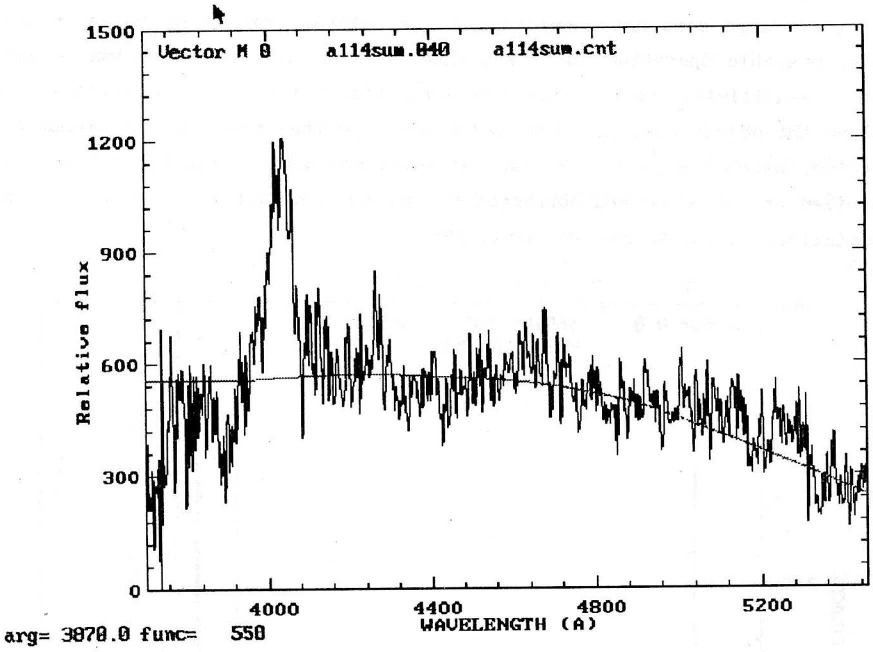


Fig. 4. *The spectrum of the quasar Abati 114 reduced to normal intensities (redshift=0.438), and the continuum level located for it.*

One of the popular methods of defining redshifts and velocity dispersion in galaxies is the algorithm first suggested by Tonry and Davis (1979), which consists of determination of the cross-correlation function from the spectrum under investigation and from the spectrum of the reference object whose radial velocity is known (this is, as a rule, a star of corresponding spectral class). The parameters of this function peak characterize the parameters investigated. Within the framework of our complex of programs all the stages of this algorithm are realized including the high-frequency filtering (if necessary), transition of spectral data from the uniform wavelength into the uniform radial velocity scale. In Figs. 5a-5d an example is given of definition of relative velocities from the spectra of the galaxy NGC 741 and its companion. The difference in radial velocities measured in this way is 420±50 km/s.

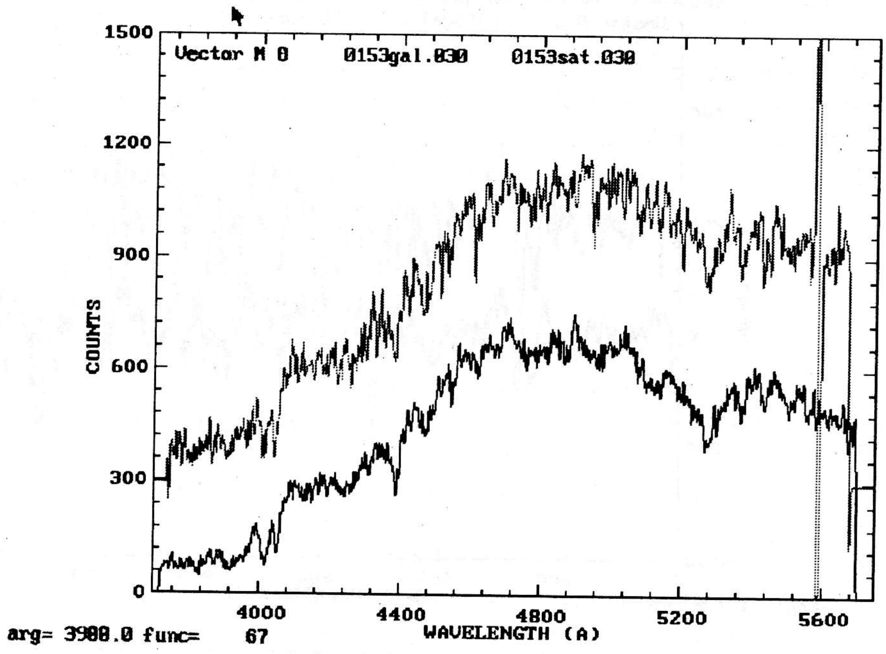

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Fig. 5a.

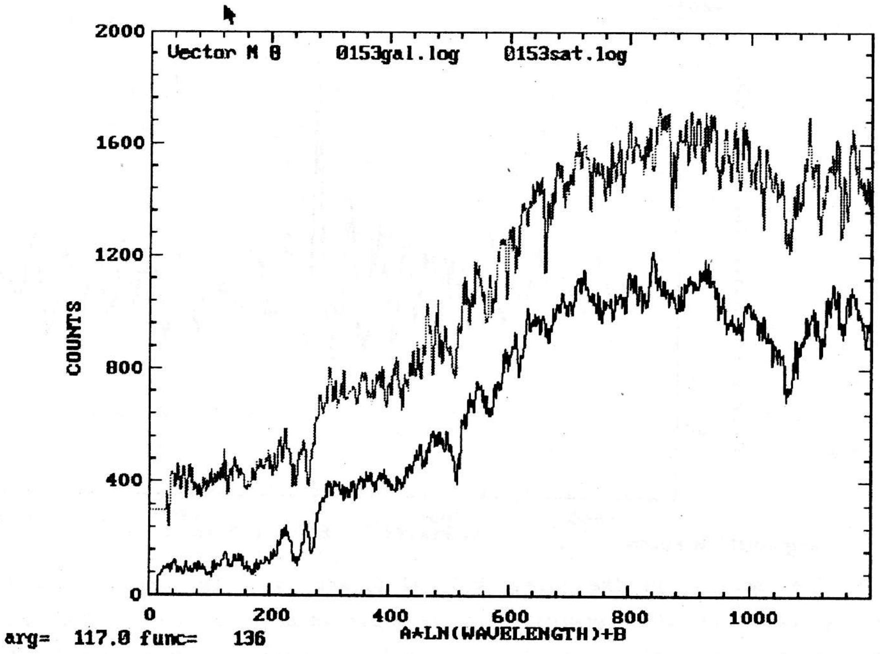
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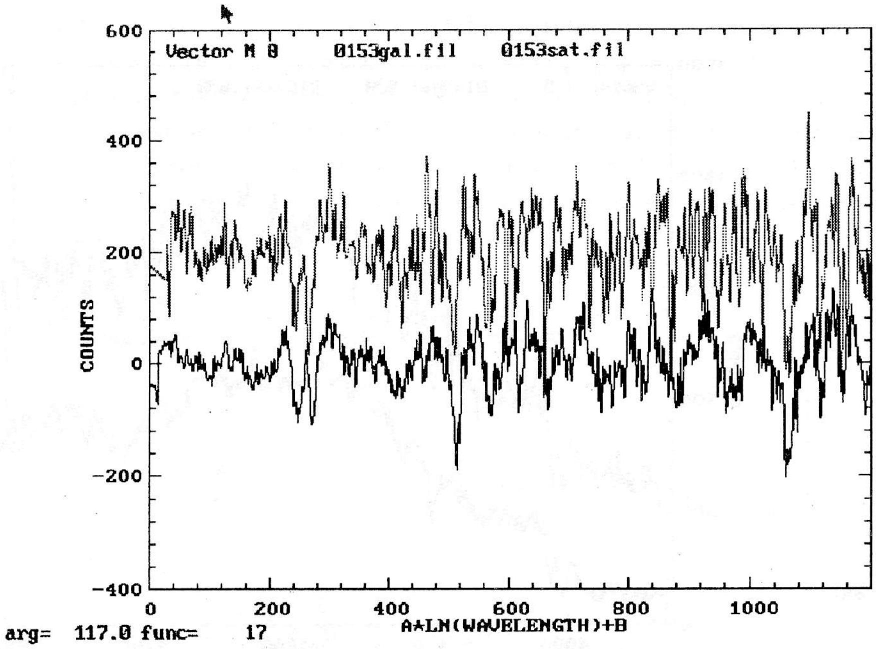
Fig. 5b.

Fig. 5c.



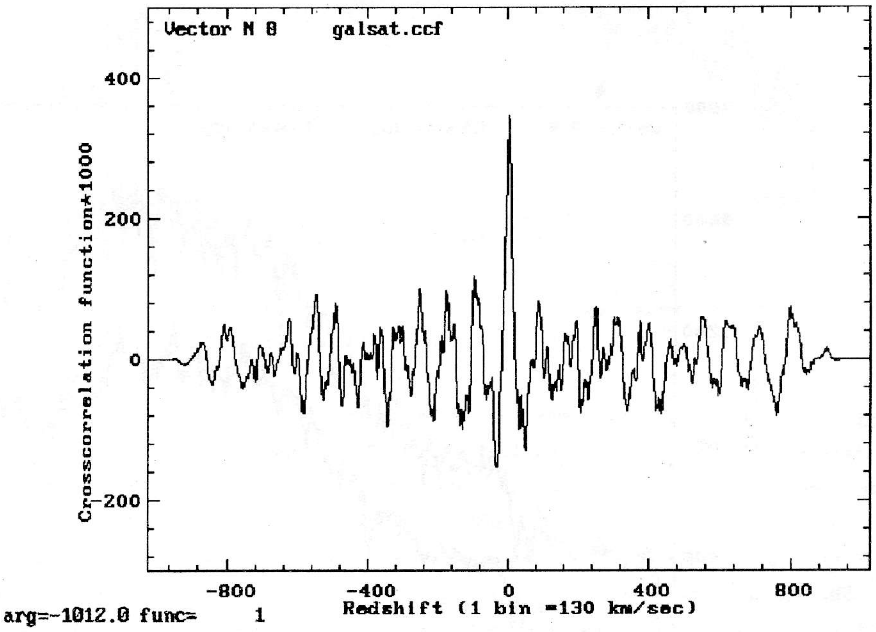


Fig. 5. *The spectra of the galaxy NGC 741 (lower) and its companion at different stages of the method of determination of relative velocities: a - initial spectra reduced to a uniform wavelength scale; b - spectra reduced to a uniform velocity scale; c - spectra after correction for the low-frequency component; d - cross-correlation function of these spectra.*

To determine the parameters of spectral details, a program is made, which defines the redshifts and equivalent widths of lines either with the use of a window fixed in λ, or after the user indicates the limits of the line. The accuracy of determination of the line parameters can be demonstrated taking as an example the spectrum of the galaxy NGC 741 mentioned above. This spectrum was recorded on both strobes of the scanner (exposure 830 and 880 s).

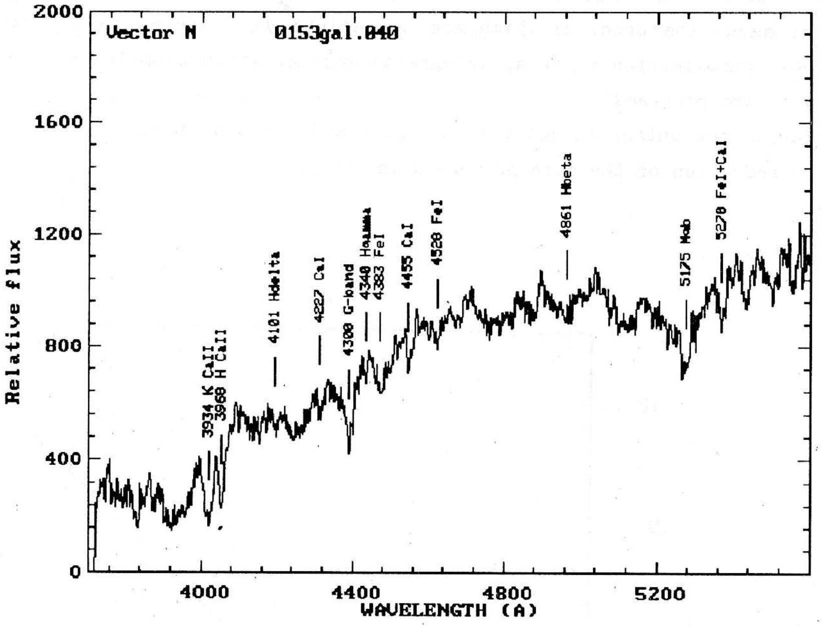


Fig. 6. *The spectrum of the galaxy NGC 741, reduced to relative intensities.*

Fig. 6 shows the summary spectrum reduced to relative intensities. The identified details are marked on the spectrum. The redshift of this galaxy measured from these details is 0.0205 with an error of 0.0001. A comparison of the equivalent widths with those, already published for this galaxy (Sil'chenko, Shapovalova, 1989) shows their rather a good fit (see Fig. 7). Let us also note that the acquisition of the spectrum on two strobes allowed to measure confidently some details with equivalent widths ≈ 0.5-1 Å, not detected by these authors in the galaxy spectrum. Similar measurements made for the companion of this galaxy give good agreement with the relative velocity of NGC 741 and its companion measured by the method of Tonry and Davis (1979).

3. CONCLUSION

So, we have developed a complex of programs for reduction of spectral data with the use of the 1024-channel scanner of the 6 m telescope for full employment of the facilities of the personal computer IBM PC AT. Module arrangement allows to work with separate software packages and also to compile the packages for automatic processing of a great amount of spectral information. As a rule, complete reduction of a spectrum requires 3-5 minutes on IBM PC AT-386, in the automatic mode it takes 1-2 minutes. The only essential restriction in operation of the system is the presence of EGA or VGA display of the computer.

Note that among the problems which are not solved yet there are separation of blends, Gauss approximation of data, integrated medium, which simplifies essentially operation with the programs.

In conclusion the author thanks V. I. Zhdanova and O. I. Spiridonova for the assistance in the reduction of the data presented in the paper.

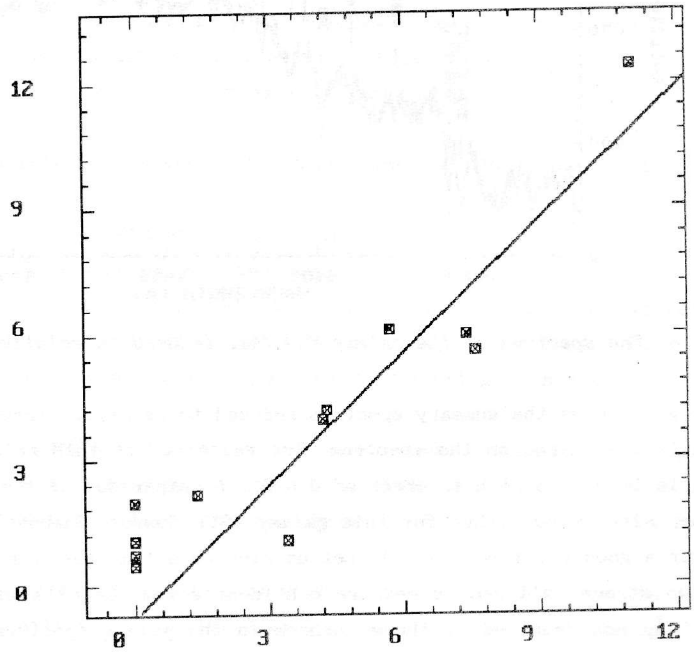


Fig. 7. *The fit of our equivalent width measurements in the spectrum of NGC 741 and those presented by Sil'chenko and Shapovalova (1989).*

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