INVESTIGATIONS OF THE MAGNETIC STAR 53 Cam VARIATIONS USING THE SPECTRA OF HIGH TIME RESOLUTION

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ABSTRACT. The results of automatic reduction of spectral observations of 53 Cam with high time resolution are presented. The statistical analysis of deviations of individual spectrograms of a star from the averaged one for one night permits one to allocate variable details of spectra and estimate the amplitudes of their variability.

1. INTRODUCTION

Using a complex of programs specially developed for statistical analysis of large series of spectroscopic data, about 1000 spectrograms of 53 Cam (with time resolution $\simeq$ 1 min) were reduced. This star was selected as a program star for cooperative observations in 1979 - 1982 (Polosukhina, 1979, 1980, 1981), since it is accessible for observations in a majority of the observatories. The aim of these observations was to search for the presence of spectral variations during a time significantly shorter than the period of star's rotation. 53 Cam is a typical Ap-star with the following peculiarities:

1) The presence of rather strong magnetic field ($H_{eff} = \pm$ 5 Kgs), varying periodically with the period of star rotation (Borra et al., 1977).
2) Remarkable variations of the line intensities of some chemical elements, especially Ca II, Sc II, Si II and rare earth elements, whose behaviour correlates with the magnetic field variations. These investigations are discussed in detail by Faraggiana (1973) giving the values of the effective temperature T_{eff} = 8400K and log g = 4.0.
3) The presence of long-term variations of radial velocities that permitted one to draw conclusions about the binarity of this star (Scholz, 1978).

2. OBSERVATIONS

Here we discuss the results of spectroscopic observations of 53 Cam. The observations were made with the 2.6-m telescope using the spectrograph and image tube of the Crimean Astrophysical Observatory. The methods of the observations are described by Polosukhina et al. (1981). Spectral resolution was about 1 - 2 A at the inverse dispersion of about 40 A/mm; time resolution was about 1 - 2 min. in the spectral region 3800 - 4400A. The spectra were taken mainly on the photoemulsion "Izopanchrome type 17" having low photographic noise. Table 1 presents the observational material used in our paper.

The first column is the date of observations, the second is the phase in the middle of the observations according to the formulae: JD(pos. cross.) = 2435855.652 + 8.0267 x E (see

C. R. Cowley et al (eds.), Upper Main Sequence Stars with Anomalous Abundances, 243–252.

TABLE I

Data	Phase	N
20/21.12.75	0.12	10
18/19.01.76	0.71	20
22/23.11.77	0.70	12
23/24.12.77	0.55	47
16/17.01.78	0.50	10
24/25.01.78	0.54	49
17/18.03.78	0.00	81
18/19.03.78	0.13	85
15/16.04.78	0.62	66
31/01.04.80	0.82	121
26/27.11.80	0.74	106
26/27.12.80	0.48	17
15/16.01.81	0.96	49
15/16.03.81	0.30	82
16/17.03.81	0.43	104
12/13.04.81	0.79	41

Borra et al., 1977) and the third is the number of obtained spectrograms.

The main difficulty in our work was associated with the fact, that the effect of rapid variations sought is small, and to reveal it one needs, first, sufficiently long (no less than 2 hours) and homogeneous observations, and second - high enough accuracy to reduce the material in total.

3. METHOD OF REDUCTION

The method is based on the analysis of standard variations of individual spectrograms from the averaged one, as was used earlier (Polosukhina et al., 1981 and Bijaoui et al., 1979). At each point of the spectrum the dispersion of averaged spectrograms was calculated σ^2_{obs} and compared with the dispersion estimated by the analysis of instrumental noise σ^2_{exp}. They are compared according to statistical mathematics by F-Ficher criterion. When σ^2_{obs} at a given validation exceeds σ^2_{exp}, we may speak about the presence of variations at a given point λ_i of the spectrum and estimate the amplitude of variations.

1. The photometry of spectral material was carried out using the microdensitometer PDS (Elvius et al., 1978) of Lund observatory with a step of scanning 12 %mκ.

2. The characteristic curve was computed by the method described by Malanushenko et al., (1984). It is stored in the computer memory in a form of a table I = F(D) with a step 0.01 D. This table permits one to convert "D" into "I" as quickly as required.

According to our method the instrumental noise is a sum of photoemulsion noise σ_{ph} and that of the image tube σ_{iT}. The influence of the image tube noise was estimated and it does not exceed 1%. The noise of photoemulsion was well studied (Palej, 1979) and thus it can be easily estimated. The calibration scale was converted into intensities and the value of noise was

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calculated with respect to the characteristic curve:

$$\sigma_{ph}(\bar{I}) = \sqrt{\Sigma(I_i-\bar{I})^2/(N-1)}/\bar{I}$$

for each level of density. The obtained error-curve is the dependence $\sigma_{ph}(I) = F(I)$ approximated by the polynomial and stored in the computer memory in a form of a table. Examples are shown in Figure 1.

3. The spectrograms were converted into intensities according to "DINT" program.

4. The continuum is calculated for each spectrogram according to "CONT" program which is functioning iteratively. At the zero approximation the polynomial of optimal degree (see Seber, 1977) is constructed by all points of the spectrum. Then, those points are eliminated which lie lower the polynomial within a half of the noise track. After that the polynomial is calculated according to the rest of points, the lowest are thrown away, and so on. The process of iteration is continued until the scatter of points on the spectrograms taken for continuum construction exceeds the noise track. Finally all spectrograms are normalized to individual continuous spectra. The inhomogeneities associated with the difference of treated spectra are eliminated by the correction program "CORR" (based on the comparison of individual spectra with the averaged one for a night). Figure 2 shows the examples of such a continuum construction.

5. The wavelength fit needs to involve all points of the spectrograms. The cross-correlation function is computed using the basic (first, as a rule) spectrum and the i-ths. The deviation corresponding to the maximum of cross-correlation function is the required step to fit the i-ths spectrum with the basic. The uncertainty of the fit by $\pm$ 0.5 step leads to so-called "slit" errors (Otnes et al., 1978). Its value is proportional to the gradient $\Delta I/\Delta\lambda$ (see Appendix).

6. Further reduction is based on the "STAT" program. Here the calculations of the mean spectrum and σ_{obs} are as usual. We should note however, that $\sigma_{obs,i}$ is a relative value (normalized to residual intensity of the spectrum at a given point I_i). While computing $\sigma_{exp,i}$ the noise of photoemulsion σ_{ph} is accounted upon as well as the influence of the "slit" error.

The allocation of variable points of the spectrum is realized according to F-Ficher criterion. If the inequality is valid:

$$\sigma^2_{obs,i}/\sigma^2_{exp,i} \geq F(\nu_1,\nu_2)_\alpha \tag{1}$$

(where F is the value of distribution for ν_1 and ν_2 the degree of freedom for calculation of $\sigma_{obs,i}$ and $\sigma_{exp,i}$ and α is the confidence level) then $\sigma_{obs,i}$ exceeds $\sigma_{exp,i}$ by α = 99%. Those points of the spectrum for which this requirement is fulfilled, are considered to be variable. Thus the estimation of amplitude variations will be as follows:

$$\sigma_{S,i} = \sqrt{\sigma^2_{obs,i} - \sigma^2_{exp,i}} \tag{2}$$

In case when the variability is not found (i.e. the requirement (1) is not fulfilled), one can estimate the upper limit of amplitude. Figure 3 shows some illustrations of individual spectrograms and Figure 4 – the results of statistical data treatment.

4. RESULTS OF THE OBSERVATIONS

Using the technique described above, we estimate the total effect of the spectrum variations for the time of observations during each given night. Figure 4 demonstrates our main results :

1. At the top of Figure 4, the mean spectrum of the star obtained during the whole observational time at a given night is presented.

2. The observed dispersion σ_{obs} and expected σ_{exp} are shown at the bottom of the same Figure. The confidence level is 99% for a given confidence interval.

3. The central part of Figure 4 shows the variable details of the spectrum derived from the comparison of both dispersions and the estimation of the variation amplitude σ_S for one night.

The allocated variability permits one first to estimate the total effect of variations during the time of observations for each night, and second to allocate the spectral details for which this effect is mostly noticeable. As a result of dispersograms analysis carried out for 16 nights of observations, we have come to the following conclusions :

1. The effect of short-term variations of the spectrum does exist and its value on an average does not exceed 5%.

2. The variable details in the stellar spectrum correspond to the lines of H, Ca, Sr, Si and rare earth elements.

3. The amplitudes of short-term variations vary with the phase of rotation from 3% to 10%, the most prominent variations correspond to Ca II K-line (see Figure 5).

4. Using the averaged spectrograms the variations of the spectrum with the phase of rotation were studied. Variations of the equivalent width of H-lines (with the amplitude 10%) were found, strong variations of the profile and equivalent width of Ca II K-line (with the amplitude 60%) were estimated as well as the variations of the equivalent widths of Si II, Sr II –lines (see Figure 6). A good agreement is observed with the data of Faraggiana (1973) for Ca II K-line (see Figure 7).

The fulfilled investigation permitted us to conclude, that there exist two types of variations of the spectrum of 53 Cam, having different intrinsic time and amplitudes. The most well-pronounced variations of the spectrum with the phase of star rotation have a known explanation in terms of an oblique rotator. The observed variations of the spectrum during one night is an overall effect due to first, the line intensity variations with the phase of star rotation in the time interval of several hours and seconds, probable influence of complex brightness variations of the star during one night, and finally, possible manifestations of chromospheric activity of a star with a strong magnetic field.

5. APPENDIX

Evidently, while shifting the i-th spectrogram in respect to the mean one by $\Delta\lambda_i$ there appears the difference of intensities :

$$\Delta I_{ji} = \mathrm{grad}\ I_j \cdot \Delta\lambda_i \tag{1}$$

where grad I_j is the intensity gradient at a point j of the spectrum. Summing up N spectrograms, we estimate the error :

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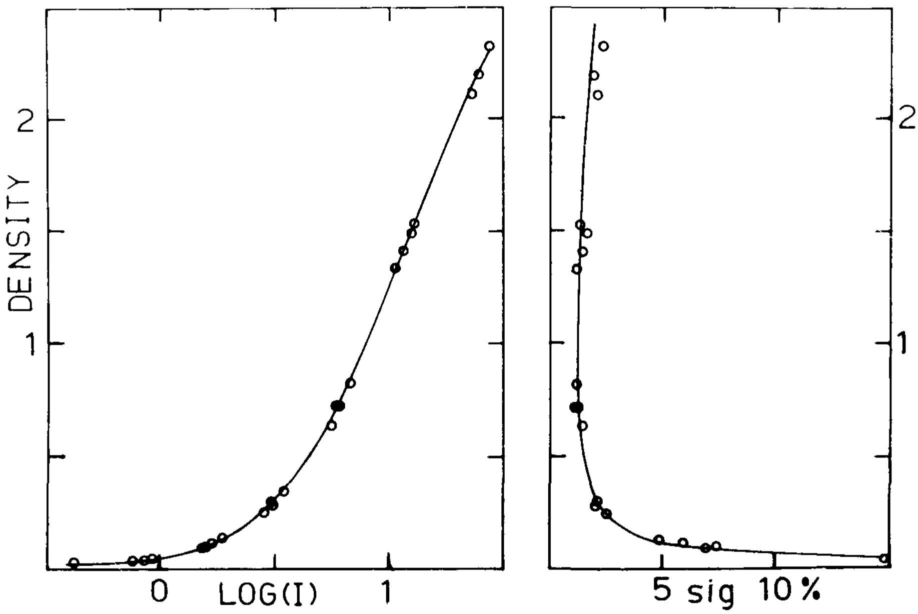

Figure 1. The measurements and approximation of the characteristic curve of errors. Log I and σ_{ph}(%) are shown along the abscissa for characteristic curve and curve of errors, correspondingly. On the ordinate – the densities.

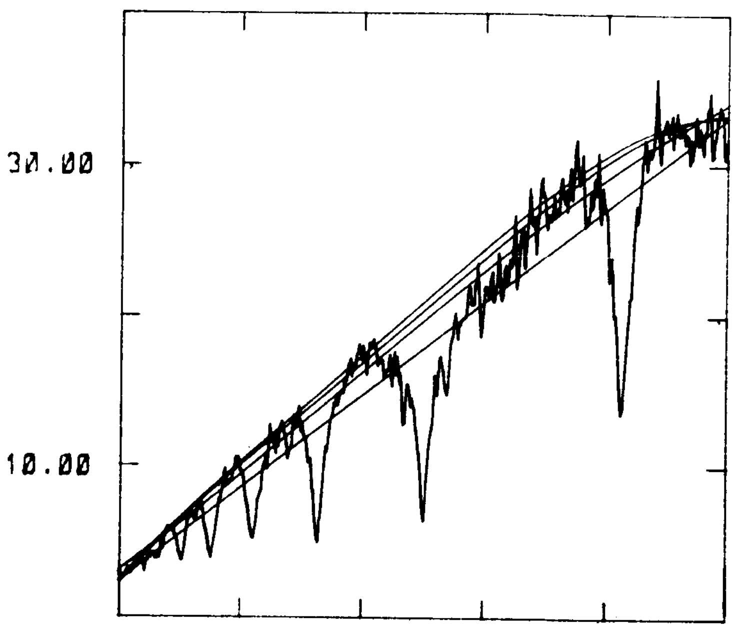

Figure 2. The examples of the continuum computations. Several lines show different approximations. The upper line is the resulting approximation.

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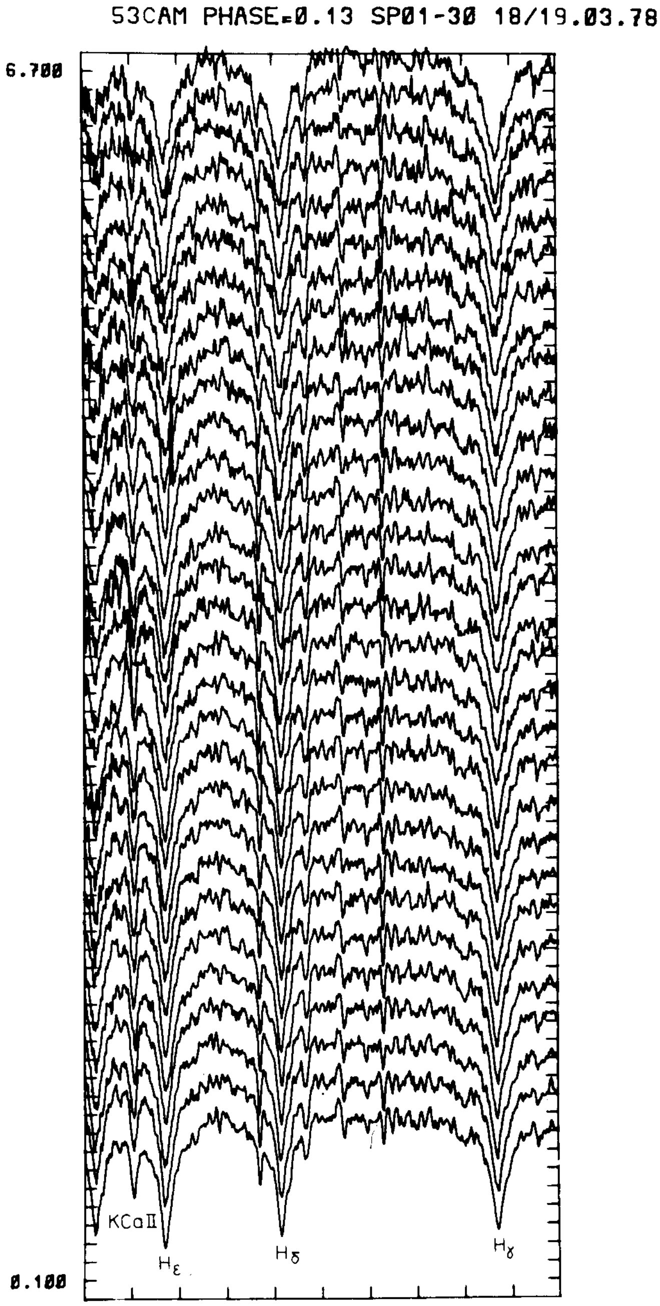

Figure 3. Individual spectrograms normalized to continuum.

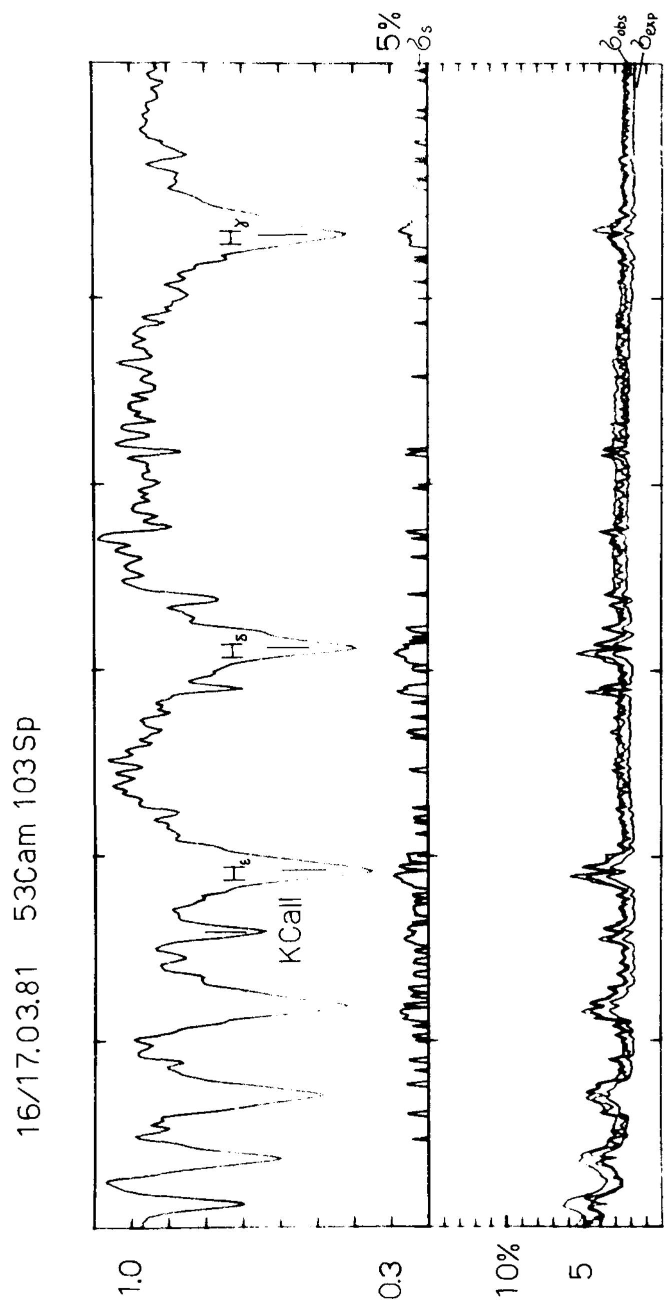

Figure 4. The results of data reduction. The abscissa corresponds to wavelength, ordinate: for the averaged spectrum – residual intensities in the units of continuum, for sigma – relative values in percents.

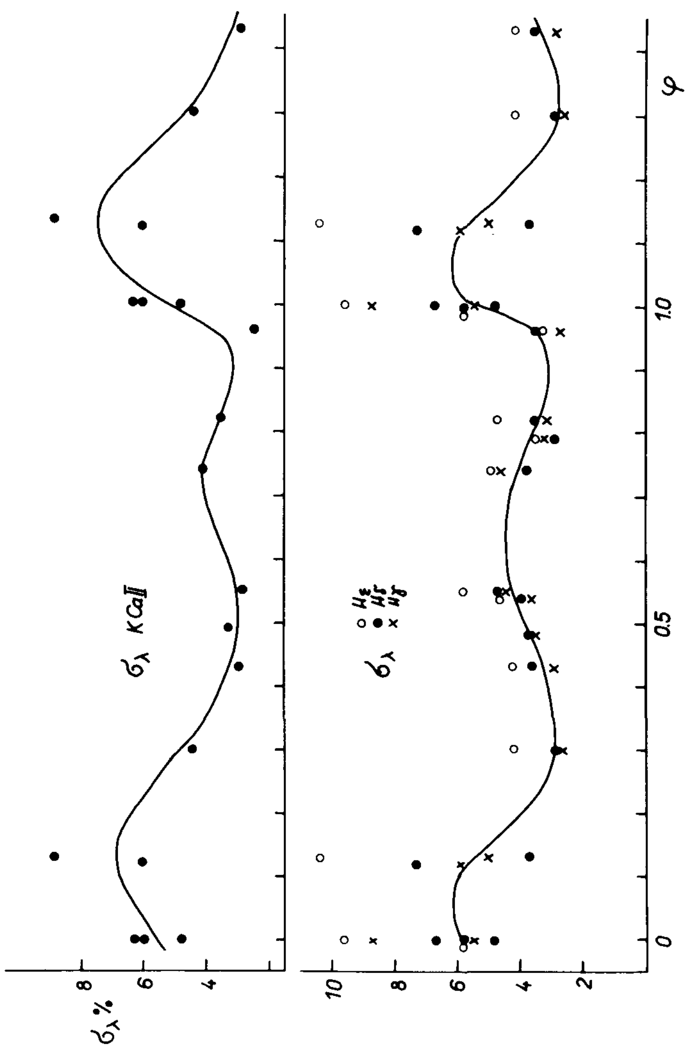

Figure 5. The fluctuations of rapid variations amplitude with the phase of rotation.

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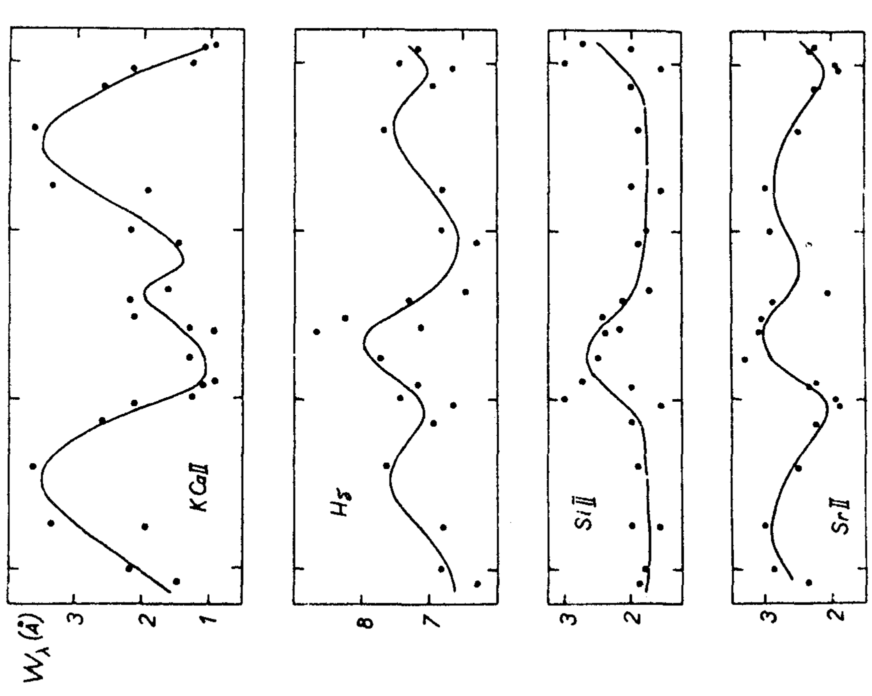

Figure 6. The variations of W_λ of the allocated details with the phase of rotation.

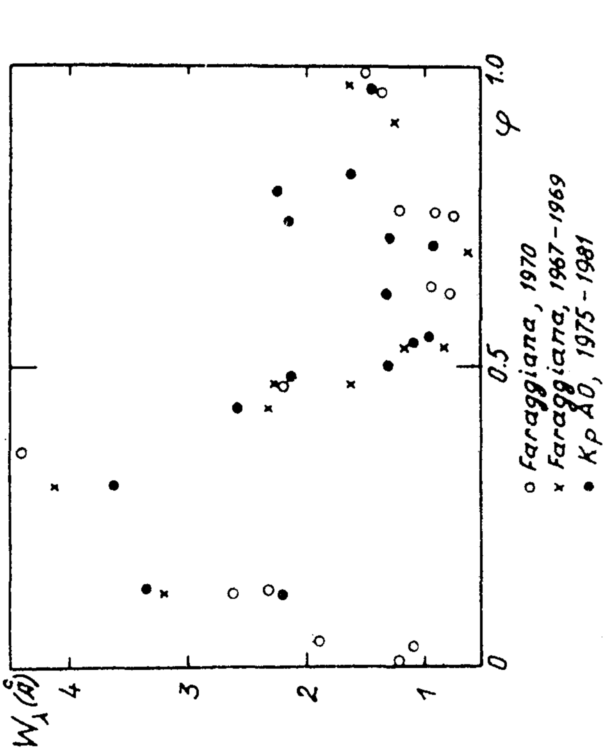

Figure 7. The comparison of W_λ measurements of Ca II K-line with the data of Faraggiana (1973).

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$$\sigma_{\mathrm{slit},j} = \sqrt{\left[\frac{\Sigma\Delta I^2_{ji}}{(N-1)}\right]} = \mathrm{grad} I_j \cdot \sqrt{\left[\Sigma\frac{\Delta\lambda^2_i}{(N-1)}\right]} \tag{2}$$

at each i-ths point of the mean spectrum. The value ΔI is the difference between the discrete and precise fit of the i-ths spectrum with the mean one. It is calculated as a difference of places of discrete and precise maxima of cross-correlation function between the i-ths and mean spectrum.

In order to calculate the location of the precise maximum, the cross-correlation function is approximated by a cubic spline. The maximum is determined by the requirement that the first derivative of spline equals to zero. The value of gradient at each point of the mean spectrum is calculated by approximation :

$$\mathrm{grad}\, I_j = (I_j - I_{j-1})/(\lambda_j - \lambda_{j-1})$$

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