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TIME VARIATIONS OF UV EMISSION FEATURES OF Be STARS

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The principal study under this grant, the study of UV spectra of three Be stars (γ Cas, ζ Tau, η Cen), was completed. The findings were reported in a Progress Report (February 1974 - July 1974). In summary, the results show that there were no significant time variations in any of the Spectral features and that the UV spectra of these stars are remarkably similar to those of normal B stars.

Mr. Kenneth B. McBeath has completed the analysis of data obtained at Kitt Peak National Observatory in October 1972. The results were submitted as his Ph.D. dissertation, in July 1974 (Reference 1). Of the six Be stars observed in the first four lines of the Balmer series, three stars showed at least one of the Balmer lines to be variable in the equivalent width amounting to a few percent with time scales of 3 to 30 minutes. No periodicity of any kind was detected.

Observational material obtained by the Principal Investigator at Kitt Peak and at Cerro Tololo Inter-American Observatory resulted in the following studies.

Photoelectric spectrum scans of 5 Southern Wolf-Rayet Stars did not show any variation of emission line strengths in $\lambda\lambda$ 4600 - 4720 A in short time scales. WC stars, however, showed night-to-night variations of 3 to 4 percent (Reference 2).

High dispersion coudé spectra of κ CMa in the red region show Hα and He I $\lambda\lambda$ 5876, 6678 in emission. Each of the lines has two emission components, but the helium lines have no detectable absorption features in-between, while the Hα emission peaks are separated by 160 Km/sec, the helium lines are separated by 400 Km/sec. A simple model is proposed to account for the behavior of these emission lines. (Reference 3).

Photoelectric spectrum scans of γ^2 Vel show rapid variations of emission strengths of He II λ 4686 and C III - IV λ 4650. These variations have time-scales of 1 minute and longer. Night-to-night variations were also found. (Reference 4).

Photoelectric spectrum scans of four Be Stars in Hα show that there is a definite variation of 3 to 4 percent with time scales of 1 minute and longer in ζ Tau. In 48 Per and κ Dra the variations are not as well established. No variations of any significance was found for ν Gem. (Reference 5).

REFERENCES

(Papers published or in Press resulting from this Grant)

1. McBeath, K.B., "RAPID VARIATIONS OF BALMER LINE STRENGTHS IN THE SPECTRA OF Be STARS". Northwestern University Ph.D. Thesis, 1974. (Copy submitted with the Progress Report, February 1974-July 1974).

2. Bahng, J.D.R., "PHOTOELECTRIC SPECTROPHOTOMETRY OF WOLF-RAYET STARS", Monthly Notices of the Royal Astronomical Society, vol. 170, 611, 1975. (Copy submitted with the Progress Report, February 1974-July 1974).

3. Bahng, J.D.R., and Hendry, E., "HELIUM EMISSION IN THE SPECTRUM OF κ CANIS MAJORIS," Publication of Astronomical Society of the Pacific, Vol. 87, 137, 1975. (Copy submitted with the Progress Report, February 1974-July 1974).

4. Bahng, J.D.R., "SHORT-TERM VARIABILITY OF γ^2 VELORUM," The Astrophysical Journal, (in press), 1975. (Copy submitted with this Report).

5. Bahng, J.D.R., "RAPID VARIATIONS OF Hα IN Be STARS", Monthly Notices of the Royal Astronomical Society, (in press), 1975. (Copy submitted with this Report).

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SHORT-TERM VARIABILITY OF γ^2 VELORUM

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ABSTRACT

Photoelectric spectrum scans of γ^2 Velorum in the spectral range $\lambda\lambda$ 4600 - 4720 A were analyzed to study the short-term variability of brightness and of emission line strengths. The emission strengths of He II λ 4686 and C III-IV λ 4650 show r.m.s. variations of 3 and 2 percent, respectively. These variations have time-scales of 1 minute and longer. Night-to-night variations were also found. The continuum radiation also shows small-amplitude variations. No periodic variations attributable to this star were detected on any of the nights on which these observations were made.

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I. INTRODUCTION

γ^2 Velorum (HD 68273) is the brightest Wolf-Rayet star in the sky. The spectral type is WC 8 + O7 (Smith 1968), and it is known to be a spectroscopic binary with a period of 78.5 days (Ganesh and Bappu 1967). Recently, Sanyal, Weller, and Jeffers (1974) found a small-amplitude variation in the region of He II λ 4686 with a period of 154 ± 35 s. Wood, Schneider, and Austin (1974) found occasional rapid changes as well as night-to-night variations in regions around He II λ 4686, C III λ 5695, and C IV λ 5805. These studies are all based on photoelectric photometry with narrow-band interference filters. Thus, it is not clear whether these variations are due to the changes in emission strengths of the lines or in the underlying continuum radiation, or combination of both.

As a part of the program to study the possible short-term variations of emission-line strengths in W-stars, γ^2 Vel was observed in the region λλ 4600-4720 with a photoelectric spectrum scanner. The results on five bright W-stars have already been reported (Bahng 1975; hereinafter referred to as Paper I). With these data it is possible to study variations in the continuum radiation and in the emission strengths (equivalent widths) of He II λ 4686 and C III-IV λ 4650, separately.

II. OBSERVATIONS

Observational data were obtained with a two-channel low-resolution photoelectric spectrum scanner at the cassegrain focus of the 91-cm reflector of Cerro Tololo Inter-American Observatory in March 1973 and February 1974. Details of observing procedures are described in Paper I.

Measurements were made at every 4 A with an exit slit width of 10 A from 4600 A to 4720 A. In the 1973 observations, the integration time per spectral element for γ^2 Vel was 2 seconds. HD 68324 (B3 V) was used as a comparison star. In the 1974 observations, a high-speed paper punch was employed to reduce the data output dead time; also the integration time was reduced to 1 second, so that much higher time-resolution measurements were possible. A standard star ε Cen (B1 V) was measured immediately after the γ^2 Vel observations to obtain 203 consecutive scans with the same time-resolution.

Because of the brightness of the star, it was necessary to add a neutral density filter. Even so, the signal counts obtained were always well over 2×10^4 in the continuum with the shortest integration time used. As in Paper I, the data on standard stars indicate that the accuracy is essentially limited by the photon-counting statistics.

III. RESULTS AND DISCUSSION

(a) Variations in emission-line strengths

Normalized mean scans from each night are shown in Figure 1. In computing the equivalent widths of emission lines, C III-IV λ 4650 and He II λ 4686 can not be separated completely. There is, however, a well defined minimum at about 4675 A; W(λ 4650) and W(λ 4686) were computed by using the data points only up to this minimum point from each side.

The total half-widths of the lines measured from Figure 1 are 24 A for λ 4650 and 23 A for λ 4636. These values are in excellent agreement with the values obtained by Conti and Smith (1972) from high-dispersion spectrograms: 23 A and 22 A, respectively. Because these lines are inherently so broad, the instrumental broadening even at 10 A resolution is negligible. The equivalent widths, on the other hand, are systematically smaller than those given by Conti and Smith. This is due to the aforementioned procedure of not including the wing portions in the overlapping region.

The mean equivalent widths and their r.m.s. variations for each night are given in Table 1. Since the standard stars are free of any lines in this spectral region with this low resolution a direct comparison with the standard stars is not possible. The theoretical r.m.s. values on the basis of photon-counting statistics alone are found to be 0.4 percent for W(λ 4650) and 1.0 percent for W(λ 4686). Since the actual variations are at least three times larger, it is concluded that there are real short-term variations in these lines.

There is some indication that night-to-night variations are also present. If the results from 1973 alone are considered, the indication is very weak, but when 1974 values are included, it becomes very strong. According to the ephemeris given by Ganesh and Bappu (1967), the difference in orbital phases between 1973 and 1974 is only about 0.1. Since no eclipse has ever been observed in this system, the long-term variations are probably not related to the binary orbital period. It is found that the ratio, W(λ 4650)/W(λ 4686), remains fairly constant. Whatever mechanisms responsible for variations in the emission-line strengths appear to be working on these lines together.

In order to study a possible periodicity in these short-term variations, power spectrum analyses of data on individual equivalent widths were performed. The prodecures adopted are very similar to those used by Hesser and Lasker (1972). Figure 2 shows power spectra from the 1973 data. These are mean power sepctra from 4 nights weighted according to the number of scans in each night. The solid lines are power spectra computed from the observed data, while the crosses indicate the power spectra when a sinusoidal trace signal of 1 percent semi-amplitude with a period of 339.5 s was superimposed on the observed data. In this and all subsequent figures for power spectra, the ordinates are power density in arbitrary unit. Figure 3 shows power spectra from the 1974 data. Here the trace signal has a semi-amplitude of 0.5 percent and a period of 95.293 s. It is clear that there is no predominant periodicity. There is appreciable power near the high-frequency cut-off, so that the minimum time-scale of variations is on the order of 1 minute.

(b) Variations in brightness

As in Paper I, "integrated magnitude", $m_{\underline{int}}$, was computed from each scan. In addition, the following magnitudes were computed: $m_{\underline{4610}}$, $m_{\underline{4710}}$, $m_{\underline{4650}}$, and $m_{\underline{4686}}$. The first two refer to the continuum brightness excluding the influences of the emission lines, while the last two refer to the brightness of emission lines along with the underlying continuum.

In order to remove effects of atmospheric extinction, the linear and quadratic trends were removed from the observed magnitudes. The resulting r.m.s. variations are given in Table 2. The theoretical r.m.s. variations based on photon-counting statistics are also listed as σ(photon). For standard stars, observed σ's are never more than twice the corresponding

σ(photon). In γ^2 Vel. however, they are substantially larger than σ(photon). Thus, there are real short-term variations in γ^2 Vel.

Since these variations appear on all five magnitudes, it is concluded that what is observed here is a variation in the continuum radiation. It is also evident from Table 2, that the amount of variations is not constant. For instance, on 1973 March 26 and 1974 February 10, σ's are noticeably smaller than in other nights but still substantially larger than σ(photon). Such changes in σ's were not found in equivalent width data.

Again, the power spectrum analyses were performed on brightness variations. It is found that the results from various magnitudes were essentially identical. To save space, only the power spectra for $m_{\underline{int}}$ will be discussed. Figure 4 shows the mean power spectrum from the 1973 data, again weighted according to the number of scans in each night. The lower portion of the figure labeled Test Data will be explained below. The trace signal has a semi-amplitude of 0.01 mag with a period of 339.5 s. There is a significant peak at $f = 1.03 \times 10^{-3}$ Hz, corresponding to a period of 16.2 minutes. There is some doubt as to whether this represents a real variation. In dealing with observations of finite length, the low frequency domain in the power spectrum must be treated with care. For instance, Hesser, Ostriker, and Lawrence (1969) used a criterion that any periods longer than one-tenth of the total observing time are statistically insignificant. Moreover, the problem of aliased frequencies must be considered (Blackman and Tukey 1958). This question will be discussed later. Because of the low time resolution, the 1973 data can not be used to test the results of Sanyal et al (1974).

The power spectra from the 1974 data are shown in Figure 5. Since the number of scans for ϵ Cen was not as large as for γ^2 Vel, the spectrum of γ^2 Vel was purposely reduced in frequency resolution to match that of ϵ Cen. The trace signal has a semi-amplitude of 0.005 mag with a period of

95.293 s. For γ^2 Vel there is a significant peak at $f = 8.4 \times 10^{-3}$ Hz. When a power spectrum with a maximum frequency resolution is used, the period of this peak is found to be 119.6 ± 0.4 s, where the error corresponds to the half-power width. The same periodicity is found in all five magnitudes for γ^2 Vel, but there are no significant peaks in the spectra of ε Cen. From the amplitude of this peak, the semi-amplitude of this variation is estimated to be about 0.003 mag in $m_{\underline{int}}$.

Since the time interval of scans in the 1973 observations, 106.1 s, is close enough to the period found here, a low beat frequency may appear. The expected alias frequency from these two frequencies is 1.06×10^{-3} Hz, which when the low frequency resolution of 1973 power spectrum is taken into account is indistinguishable from the frequency of the observed peak. To test this hypothesis, simulated data were constructed from a purely sinusoidal variation of period 119.6 s. 64 consecutive "scans" were computed at an interval of 106.1 s. The resulting data were then used to construct a power spectrum, which is shown in lower portion of Figure 4 labeled as "Test Data". There is a peak at precisely the same frequency as in the observed data. Thus, the observed period of 16.2 minutes in the 1973 data can be explained in terms of aliasing.

From the above discussion, it would be natural to conclude that γ^2 Vel shows a periodic variation in the continuum radiation, and to look for the cause of such a variation. However, it appears that the 119.6 s periodicity is due to an instrumental effect. The following discussion is based on information furnished by Dr. J.E. Hesser of CTIO. I am extremely grateful to him for the comments and allowing me to use unpublished observational data obtained by him for this discusssion. The 91-cm telescope drive has a periodic error of 2 sidereal minutes (119.7 s), which is sometimes but not always found at very low amplitude in time series photometric data. Although certain correlations between the detectability of this periodic error and instrumental configuration have been noted (Hesser, Lasker, and Osmer 1972), it has not proven possible to predict with certainty when this periodic error will be found above the detection threshold. The fact that the period found in this study is identical to the periodic error suggests very strongly that it is an instrumental effect.

An independent observation was made by Hesser on γ^2 Vel with the No. 1 41-cm telescope on 16 December 1974. A single channel photometer with a narrow-band filter in the blue continuum was used to make measurements every 2 s (1.99 s integration time) for nearly two hours. The resulting power spectrum shows many peaks at periods ranging from 4.5 s to about 7 minutes. None of the peaks has an amplitude in excess of 0.003 mag. In particular, at frequency corresponding to 4 sidereal minutes, which is the periodic error of this telescope, the amplitude is 8.1×10^{-4} mag while at 119.6 s it is only 5.4×10^{-4} mag. The average noise level of Hesser's spectrum is estimated to be about 8×10^{-4} mag. Neither Hesser's data nor those presented here gives any indication of a periodic variation at or near 154 s as reported by Sanyal et al (1974). It is concluded that there is no periodic variation of any significance in the available CTIO data. However, the present data are probably insufficient to exclude the possibility that the periodicity reported for this star is a transient phenomenon occuring only occasionally.

IV. CONCLUSIONS

The emission strengths of He II λ 4686 and C III-IV λ 4650 show r.m.s. variations of 3 and 2 percent, respectively, in the time-scales of 1 minute and longer, as well as night-to-night variations of a few percent. The underlying continuum also shows short-term variations on the order of 0.01 mag or less. No periodic variations attributable to γ^2 Vel itself were detected on any of the 6 nights on which observations were made at CTIO.

I wish to express my deep gratitude to the entire staff of Cerro Tololo Inter-American Observatory for their valuable assistance during my visits to Chile. I am particularly indebted to Dr. J.E. Hesser for his critical comments and kind permission to use unpublished data. This research was supported in part by a NASA grant (NGR 14-007-122).

REFERENCES

Bahng, J.D.R. 1975, Mon. Not. R. Astro. Soc., 170.

Blackman, R.B., and Tukey, J.W. 1958, Measurements of Power Spectra, (New York: Dover Publications).

Conti, P.S., and Smith, L.F. 1972, Ap.J., 172, 623.

Ganesh, K.S., and Bappu, M.K.V. 1967, Kodaikanal Bull., 16, No. 183.

Hesser, J.E., and Lasker, B.M. 1972, I.A.U. Coll. No. 15, (Veröff. Remeis-Sternw. Bamber., vol. 9), 160.

Hesser, J.E., Lasker, B.M., and Osmer, P.S. 1972, Ap.J., 176, L31.

Hesser, J.E., Osteriker, J.P., and Lawrence, G.M. 1969, Ap.J., 155, 919.

Sanyal, A., Weller, W., and Jeffers, S. 1974, Ap.J., 187, L31.

Smith, L.F. 1968, Mon. Not. R.Astro. Soc., 140, 409.

Wood, F.B., Schneider, W.H., and Austin, R.R. 1974, Bull. Am. Astro. Soc., 6, 222.

Table 1. Mean Equivalent Widths and R.M.S. Variations of Emission Lines

Date (UT)	Time interval between scans (sec)	Number of scans	$\overline{W(4650)}$ (A)	$\sigma(4650)$ (%)	$\overline{W(4686)}$ (A)	$\sigma(4686)$ (%)
1973 Mar. 23	106.1	64	-66.7	1.9	-16.0	3.0
1973 Mar. 24	106.1	69	-69.5	2.1	-16.5	3.8
1973 Mar. 25	106.1	66	-69.7	1.8	-16.7	3.4
1973 Mar. 26	106.1	92	-69.6	2.0	-16.0	3.5
1974 Feb. 10	34.246	685	-63.8	1.6	-15.0	3.0

Table 2. R.M.S. Variations in Brightness

Star	Date(UT)		σ(mag) m_{int}	m_{4610}	m_{4710}	m_{4650}	m_{4686}
γ^2 Vel		σ(photon)	.002	.003	.004	.002	.002
	73 Mar 23		.015	.016	.017	.015	.016
	73 Mar 24		.022	.024	.024	.023	.022
	73 Mar 25		.015	.017	.019	.016	.016
	73 Mar 26		.007	.009	.012	.009	.010
	74 Feb 10		.008	.009	.012	.008	.010
HD 68324		σ(photon)	.003	.004	.005	.003	.003
	73 March		.005	.006	.008	.005	.006
ε Cen		σ(photon)	.003	.004	.006	.003	.003
	74 Feb 10		.005	.007	.009	.005	.006

Captions for Figures

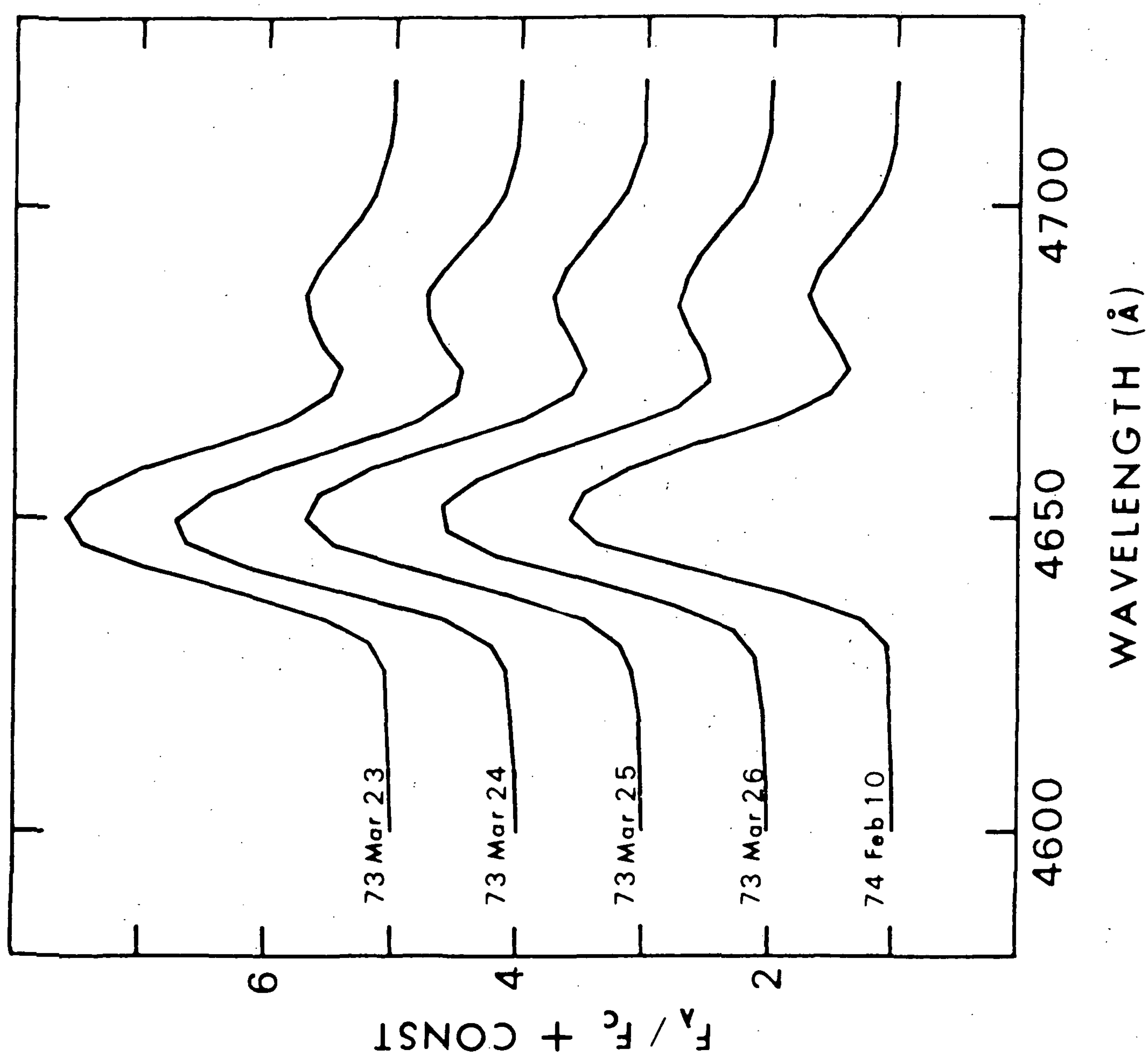
Fig. 1 Mean scans of γ^2 Vel with a 10 A exit slit. Uncertainties due to photon statistics are two small to be indicated in this scale.

Fig. 2 Mean power spectra of emission-line variations from the 1973 data (solid lines). The crosses indicate power spectra with trace signal (semi-amplitude = 1%, Period = 339.5 sec) superimposed on observed data.

Fig. 3 Power spectra of emission-line variations from the 1974 data (solid lines). The crosses indicate power spectra with trace signal (semi-amplitude = 0.5%, Period = 95.293 sec) superimposed on observed data.

Fig. 4 Mean power spectrum of Δm_{int} from the 1973 data (upper curve). The lower curve shows a spectrum of test data (see text for explanation). The crosses indicate spectra with trace signal (semi-amplitude = $0.^m01$, Period = 339.5 sec) superimposed on observed data.

Fig. 5 Power sepctra of Δm_{int} from the 1974 data (solid lines). The crosses indicate spectra with trace signal (semi-amplitude = $0.^m005$, Period = 95.293 sec) superimposed on observed data.



WAVELENGTH (Å)
4600
4650
4700
F_λ / F_c + CONST
2
4
6
73 Mar 23
73 Mar 24
73 Mar 25
73 Mar 26
74 Feb 10

Fig. 1

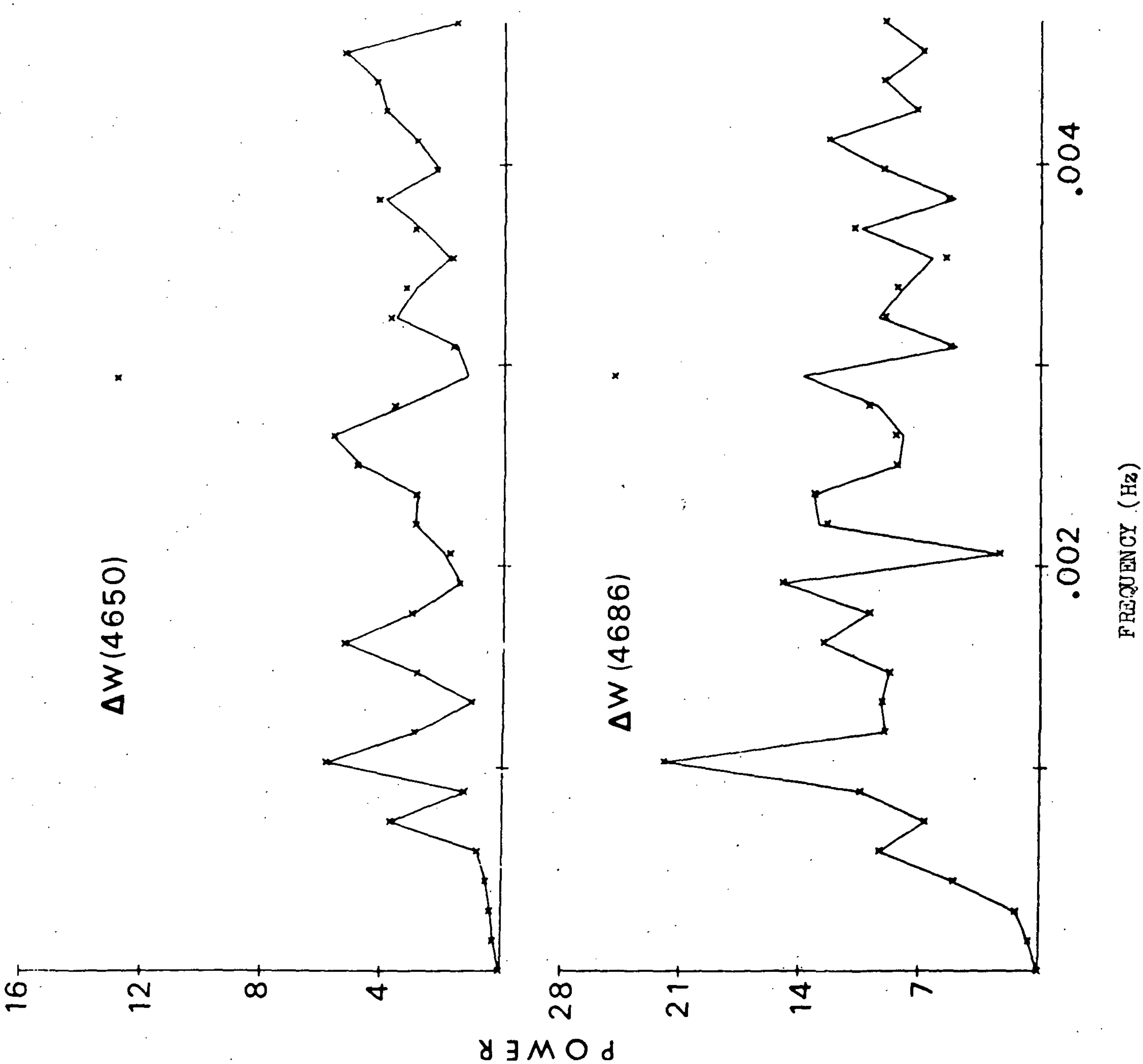


Fig. 2

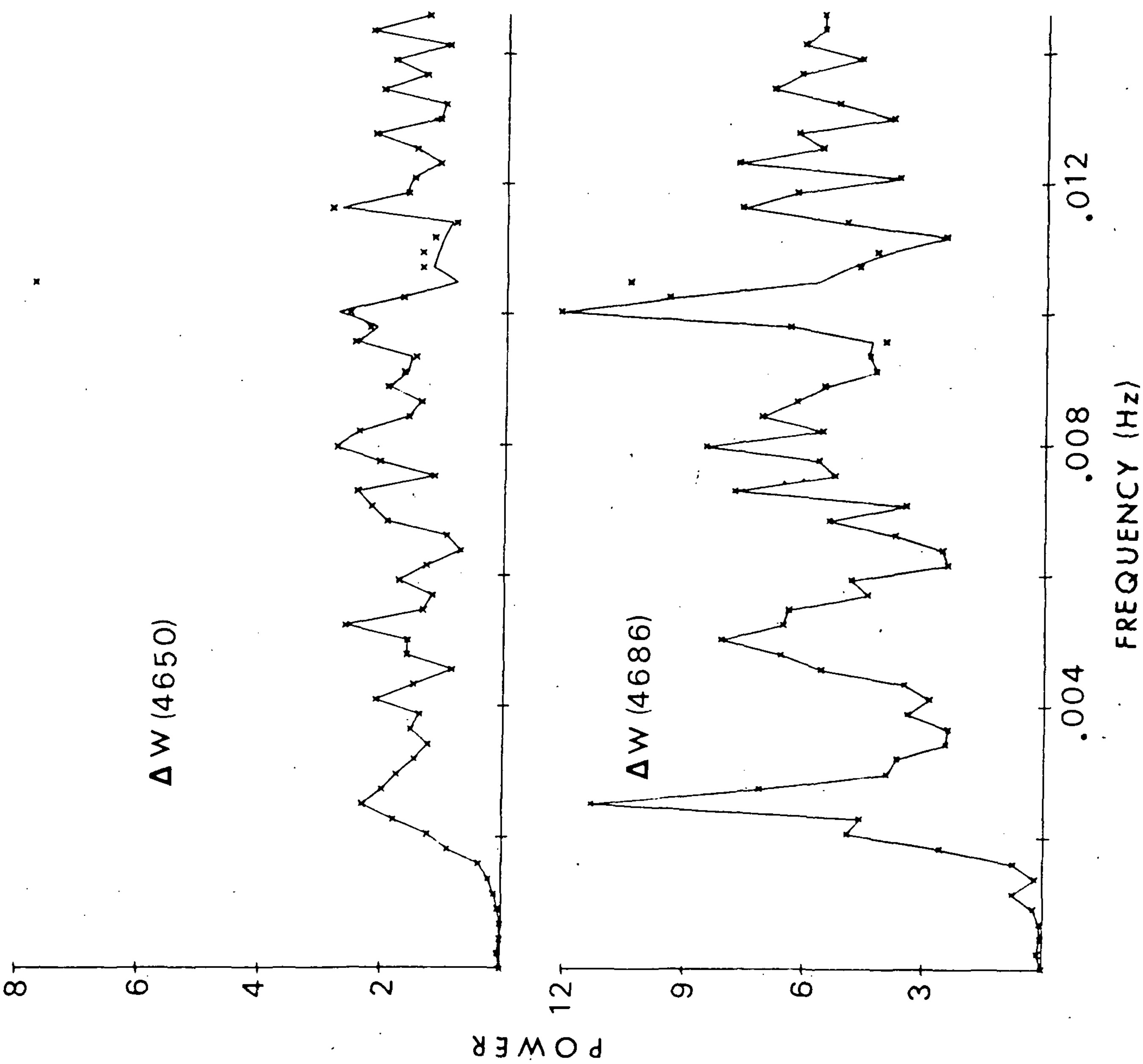
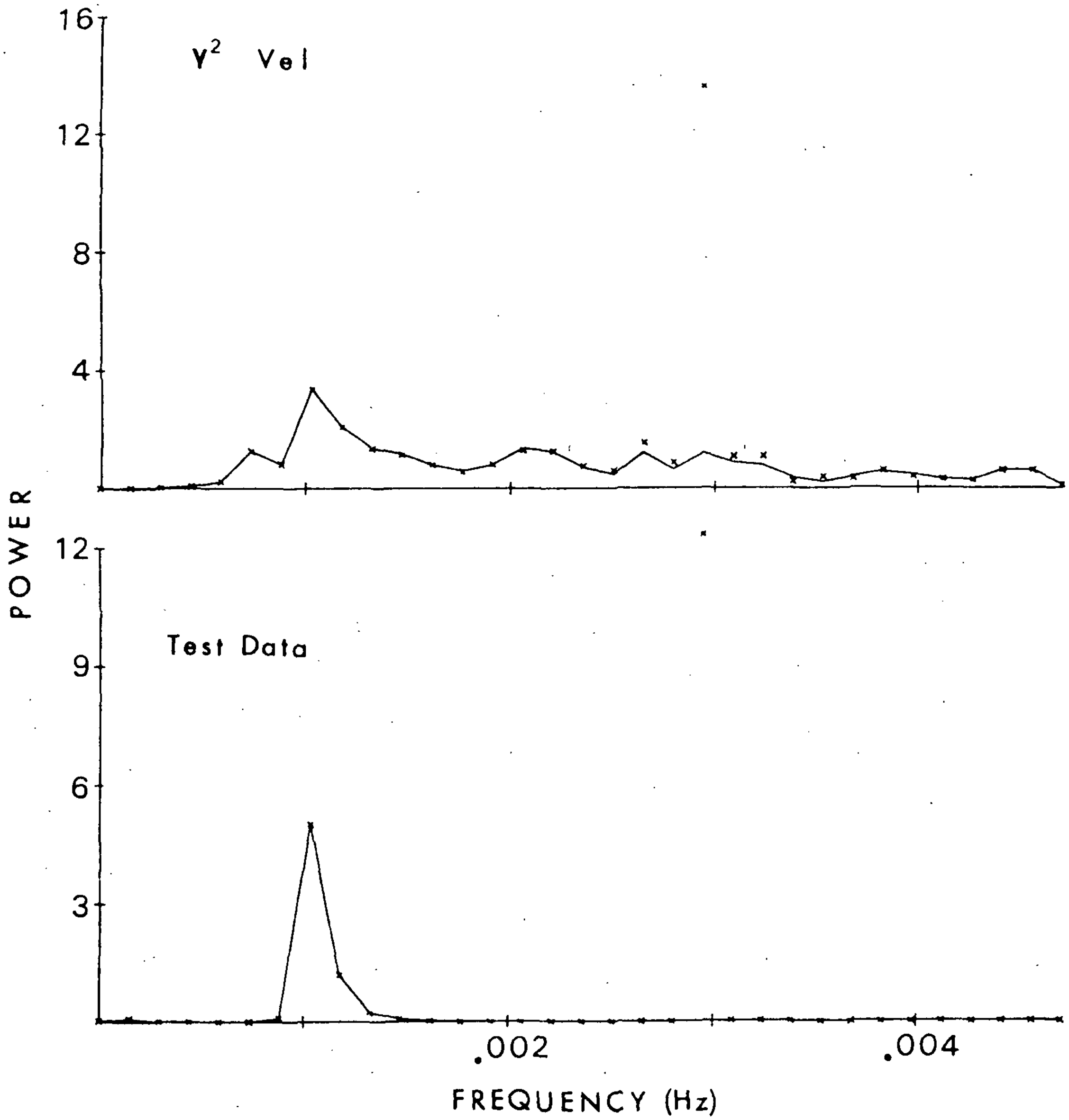


Fig. 3



16
12
8
4
γ^2 Vel
POWER
12
9
6
3
Test Data
.002
.004
FREQUENCY (Hz)

Fig. 4

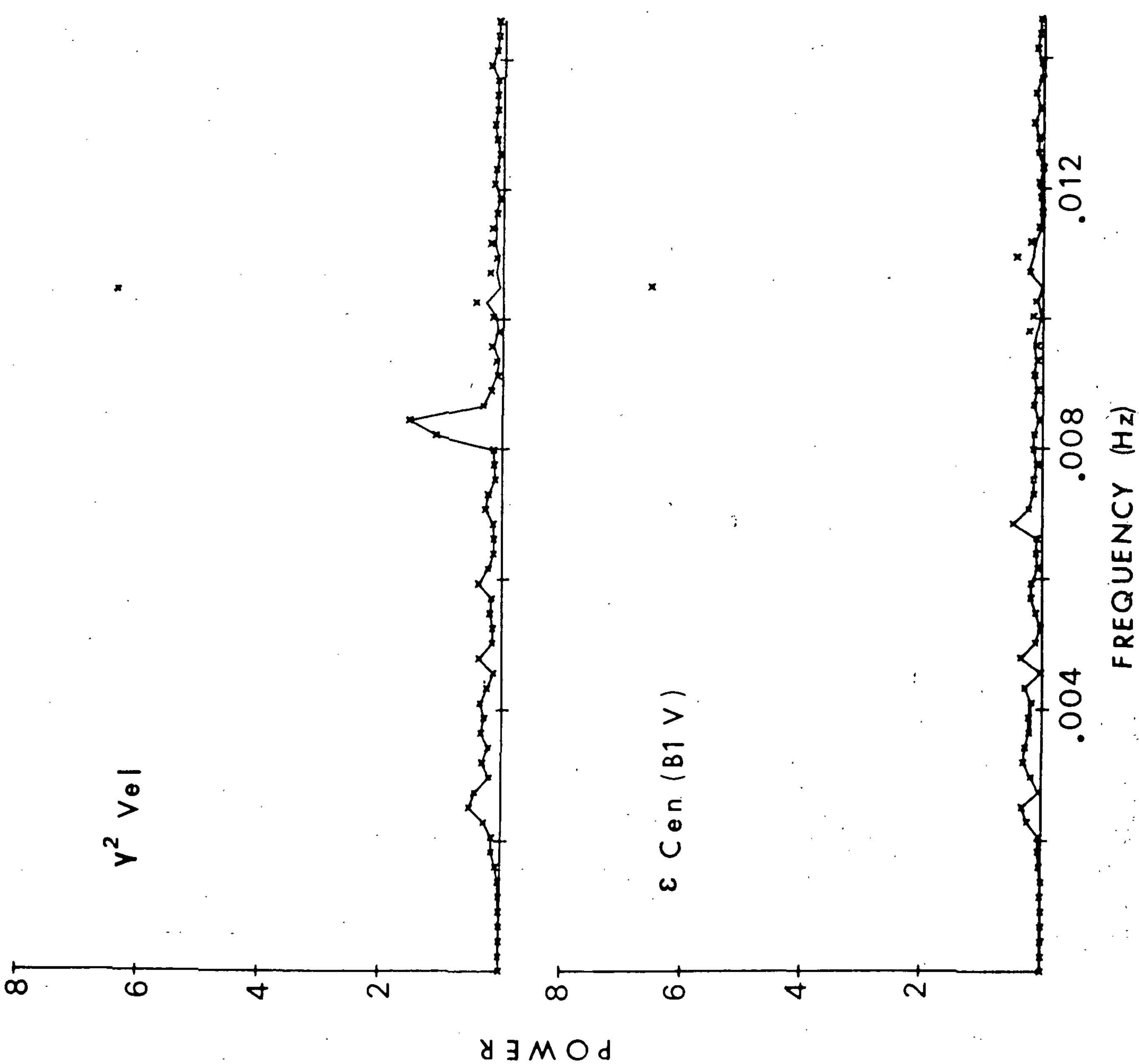


Fig. 5

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RAPID VARIATIONS OF Hα IN Be STARS

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SUMMARY

Photoelectric spectrum scans of four Be Stars, 48 Per, ζ Tau, ν Gem, and κ Dra, were analysed to study the short-term variations of Hα emission strengths. In ζ Tau a definite variation of 3 to 4 percent with a time scale of 1 minute was found, as well as the night-to-night variation. In 48 Per and κ Dra the existence of such variations is suspected. No variation of any significance was found for ν Gem.

1. INTRODUCTION

Recently, several reports have been published in which rapid spectral changes in Be stars with time scales of a few minutes were observed. Profiles of hydrogen emission lines were found to vary in a time scale as short as one minute (Hutchings, Auman, Gower and Walker 1971). Other studies (Bahng 1971; McBeath 1974; Sanyal 1974) indicate variations in the total emission strengths of hydrogen lines with a time scale of one to ten minutes. The profile changes observed by Hutchings et al appear to be accompanied by some changes in the total line strengths as well.

It is quite clear that these rapid changes cannot be explained in terms of the binary orbital motions (Delplace 1971), a geometry connected with the asymmetric distribution of gases in a circular ring (Huang 1972), or an elliptical ring (Huang 1973). It is equally unlikely that they are related to oscillations or pulsations of the star or shell, since the observed time scale is much too short. As yet, no satisfactory theoretical models exist to explain these rapid phenomena. From the time scales involved, Mihalas

(1974) concluded that they imply hydrodynamic interactions; a model proposed by Marlborough and Zamir (1975) may be relevant. On the other hand, some unknown radiative processes (see e.g. Prendergast and Spiegel 1973) may be responsible for these changes.

It is extremely important to establish first the reality of these rapid changes. If these variations do indeed occur, then the following questions must be answered. (1) What are the precise time scales? (2) What is the nature of variations? Are they periodic, recurring, or completely random flickering? (3) What is the amplitude or range of variations? And finally, (4) Are there any common characteristics in these, or any correlations with the known parameters of these stars?

For some time, a study has been underway to investigate these problems with regard to the total emission strengths of hydrogen lines in early-type stars. In this paper, we report the results on Hα for four Be stars.

2. OBSERVATIONS

Observations were made on 48 Per, ζ Tau, ν Gem, and κ Dra on 14 - 17 December 1973 at Kitt Peak National Observatory. Two normal main-sequence B stars, 1 Per and 121 Tau, were also observed as comparison stars. The two-channel low-resolution photoelectric spectrum scanner was used at the Cassegrain focus of the No. 1 91-cm telescope. The entrance apertures were 31 arc-sec in diameter separated by 4.5 arc-min. The range of spectrum covered in each scan was 6530-6600 A in the first order. The bandpass as defined by the width of exit slit was 4 A. The step size, the interval between two successive data points in the spectrum, was 2 A.

The observing procedures were similar to those employed in an earlier study (Bahng 1975). The Kitt Peak scanner could not be used in the automatic mode, so that data recording on a magnetic tape and the commencement of the next scanning operation had to be initiated manually. For this reason, each scan in the time series observations could not be made at a precisely uniform time interval. During the four nights on which the observations were made, the sky conditions were not ideal due to the presence of occasional cirrus clouds. This resulted in further unevenness as well as some gaps in the time series.

3. RESULTS

Since the spectral resolution is too low, the line-profile study cannot be made. Nor is it possible to study the V- and R-component separately. Instead only the equivalent widths of Hα, W, were obtained from each scan. For each time series, the mean equivelent width, $\overline{W}$, and a quantity q, defined by $q = \sigma_o/\sigma_p$, were computed. Here σ_o is the usual r.m.s. value of observed W from $\overline{W}$, and σ_p is the expected r.m.s. value computed on the assumption that the scatter is due to the photon-counting statistics alone. Comparison of the q values for Be stars with those for normal B stars will serve as a basis for deciding whether the observed variations in W are significant.

The results are summarized in Table 1. The individual time series for four Be stars are shown in Figures 1, 2, 3, and 4. In these figures, the larger error bars give $\pm\ \sigma_o$, and the smaller error bars $\pm\ \sigma_p$ from the mean. Those cases where the observed W deviates from $\overline{W}$ by more than $2\sigma_o$ are represented by asterisks.

4. DISCUSSION

In order to assess the significance of variations in W, the values of q for each Be star are compared with the q for the two comparison stars. For these stars, the values range from 0.94 to 1.85 with the mean of 1.5.

For ν Gem, $\overline{q}$ = 1.3 which indicates that the scatter in W is essentially due to the observational uncertainties. In the case of κ Dra, $\overline{q}$ = 2.0 which is not significantly larger than in comparison stars. However, Figure 2 reveals that there are occasions when W deviates more than $2\sigma_o$ from the mean. It appears that the variations in κ Dra may be significant. In 48 Per, $\overline{q}$ = 2.6 which may be large enough to be considered significant, although Figure 3 shows that none of the points deviates more than $2\sigma_o$ from the mean. Hutchings et al (1971) detected rapid variations in the Hα profile of κ Dra, while McBeath (1974) observed similar changes in the equivalent widths of Hα in 48 Per. Combined with these earlier results, there is a fairly strong indication that the variations in these two stars are real.

Finally, in ζ Tau we obtain $\overline{q}$ = 3.4. Both from this large value of $\overline{q}$ and Figure 4, there seems to be little doubt that this star shows significant variations. The amplitude of variations are 3 to 4 percent (r.m.s.), with the shortest time scale being the time interval between two successive scans, on the order of 1 minute. Because of the gaps and uneven time intervals, the power spectrum analyses could not be performed. Qualitatively, the inspection of Figure 4 does not reveal any obvious periodicity. In addition to the rapid variations, there is a steady increase in the emission strength over four nights, from $\overline{W}$ = -19.9 to -23.2 A.

Even though the values of W should be independent of the atmospheric effects, because of the rather poor sky conditions there may have been some systematic effect which gives rise to these rather large variations. Of course, the comparison of q values should remove such external influences.

Nevertheless, an additional test was performed. Individual values of W were compared with the corresponding integrated brightness (sum of signal counts in all the data points). For each time series of ζ Tau, the correlation coefficients between these two quantities were found to be always less than 0.15. Thus, it is concluded that the rapid variations in ζ Tau are real and confirm the results of earlier study (Bahng 1971).

5. CONCLUSIONS

Photoelectric measurements of Hα emission strengths show definite short-term variations of 3 to 4 percent in ζ Tau with the time scale on the order of one minute, as well as a night-to-night variation of significant amount. Similar short-term variations appear to be present in 48 Per and κ Dra with a somewhat lower confidence level. No significant variations of any kind were detected in the case of ν Gem.

In view of the results obtained here and in previous studies, 48 Per, κ Dra, and ζ Tau should be studied in more detail to refine further the various parameters related to their variability.

REFERENCES

Bahng, J.D.R. 1971, Astrophys. J., 167, L75.

Bahng, J.D.R. 1975, Mon. Not. R. Astr. Soc., 170, 611.

Delplace, A.M. 1971, Astr. Astrophys., 7, 459.

Huang, S.-S. 1973, Astrophys. J., 171, 549.

Huang, S.-S. 1973, Astrophys. J., 183, 541.

Hutchings, J.B., Auman, J.R., Gower, A.C. and Walker, G.A.H. 1971, Astrophys. J., 170, L73.

McBeath, K.B. 1974, Northwestern University Ph.D. Thesis.

Marlborough, J.M. and Zamir, M. 1975, Astrophys. J., 195, 145.

Mihalas, D. 1974, Astr. J., 79, 1111.

Prendergast, K.H. and Spiegel, E.A. 1973, Com. Astrophys. Space Phys. (Part C), 5, 43.

Sanyal, A. 1974, Bul. Am. Astr. Soc., 6, 460.

TABLE I

VARIATIONS OF Hα EQUIVALENT WIDTHS

Star	Date (UT) 1973	Number of scans	$\overline{W}$ (Å)	σ_o (Å)	σ_p (Å)	$q = \frac{\sigma_o}{\sigma_p}$	$\overline{q}$
1 Per	Dec. 15	3	4.38	0.21	0.14	1.50	
B2 V	Dec. 16	3	4.48	0.37	0.20	1.85	
m_v = 5.47	Dec. 17	5	4.33	0.17	0.18	0.94	
							1.43
121 Tau	Dec. 14	3	5.14	0.26	0.20	1.30	
B3 V	Dec. 15	15	5.02	0.24	0.14	1.71	
m_v = 5.16	Dec. 16	7	4.94	0.34	0.20	1.70	
							1.57
48 Per	Dec. 14	6	-20.11	0.58	0.24	2.42	
B3 Ve	Dec. 16	6	-20.21	0.55	0.20	2.75	
m_v = 4.03	Dec. 17	13	-20.17	0.52	0.20	2.60	
							2.59
ζ Tau	Dec. 14	97	-19.90	0.67	0.25	2.68	
B2 IVp	Dec. 15	80	-20.44	0.66	0.17	3.88	
m_v = 2.99	Dec. 16	39	-23.01	1.04	0.30	3.47	
	Dec. 17	105	-23.21	1.01	0.28	3.61	
							3.41
ν Gem	Dec. 16	16	-2.49	0.30	0.19	1.58	
B7 IVe	Dec. 17	14	-2.29	0.21	0.19	1.11	
m_v = 4.15							1.35
κ Dra	Dec. 15	35	-13.13	0.28	0.16	1.75	
B7 p	Dec. 16	25	-12.89	0.39	0.17	2.29	
m_v = 3.84							2.02

FIGURE CAPTIONS

Figure 1. Hα equivalent width of ν Gem (ordinate) as a function of time (abscissa). The error bars are observed r.m.s. (larger) and the computed photon r.m.s. (smaller).

Figure 2. Hα equivalent width of κ Dra (ordinate) as a function of time (abscissa). The asterisks are those values which deviate more than 2σ from the mean. The error bars are observed r.m.s. (larger) and the computed photon r.m.s. (smaller).

Figure 3. Hα equivalent width of 48 Per (ordinate) as a function of time (abscissa). The error bars are observed r.m.s. (larger) and the computed photon r.m.s. (smaller).

Figure 4. Hα equivalent width of ζ Tau (ordinate) as a function of time (abscissa). The asterisks are those values which deviate more than 2σ from the mean. The error bars are observed r.m.s. (larger) and the computed photon r.m.s. (smaller).

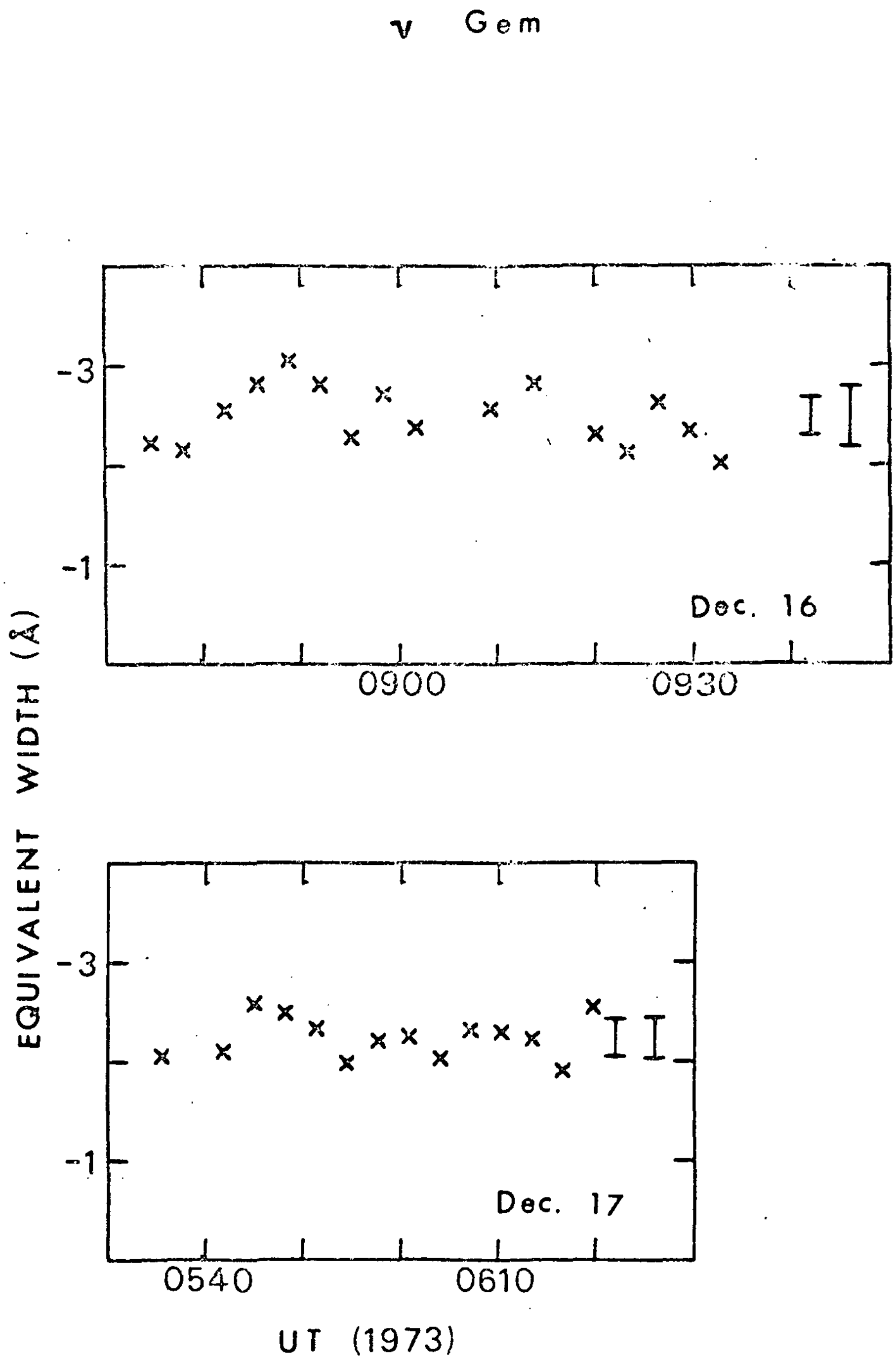
ν Gem
-3
-1
Dec. 16
0900
0930
EQUIVALENT WIDTH (Å)
-3
-1
Dec. 17
0540
0610
UT (1973)

Figure 1

κ Dra

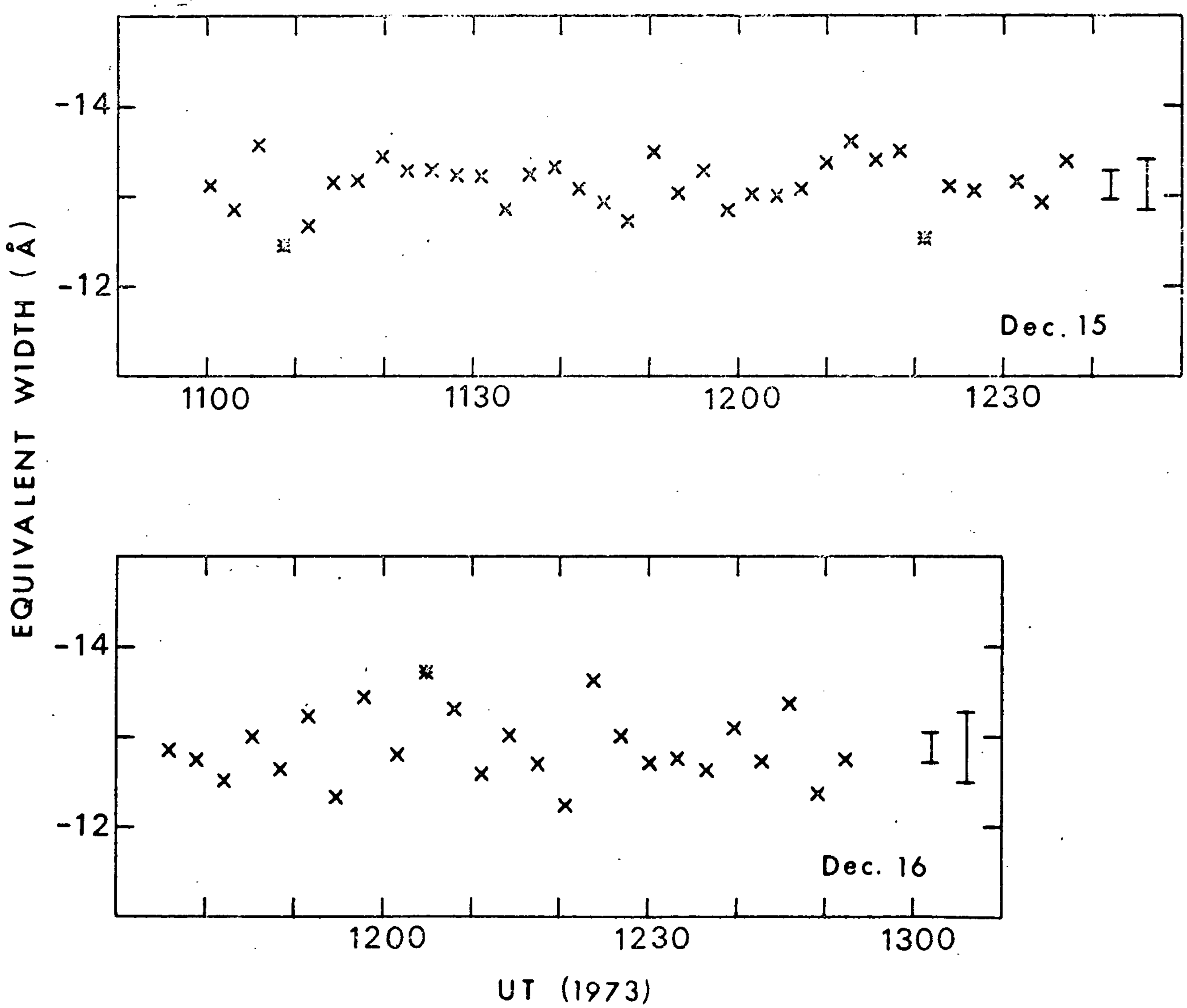

Figure 2

48 Per

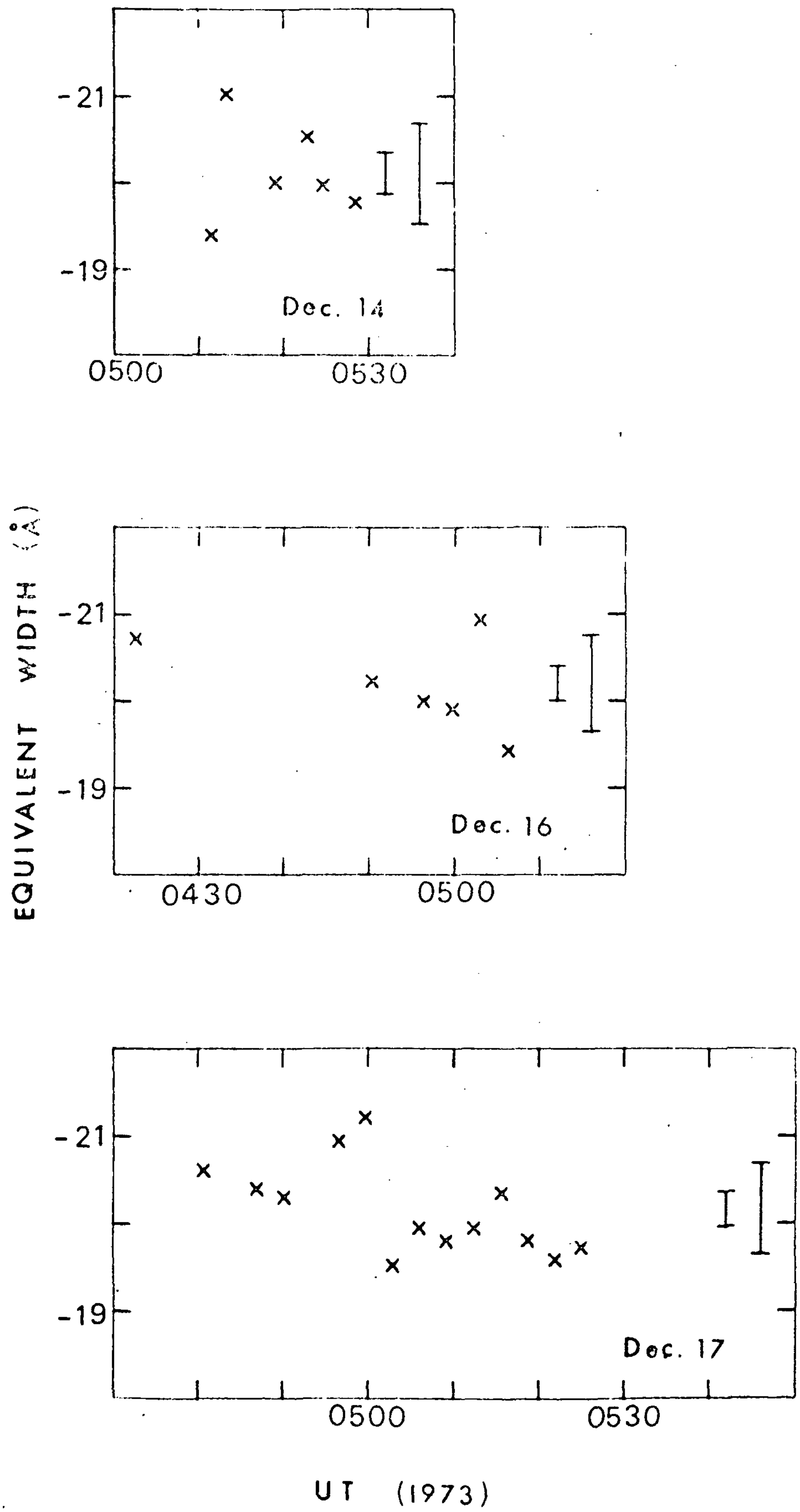

Figure 3

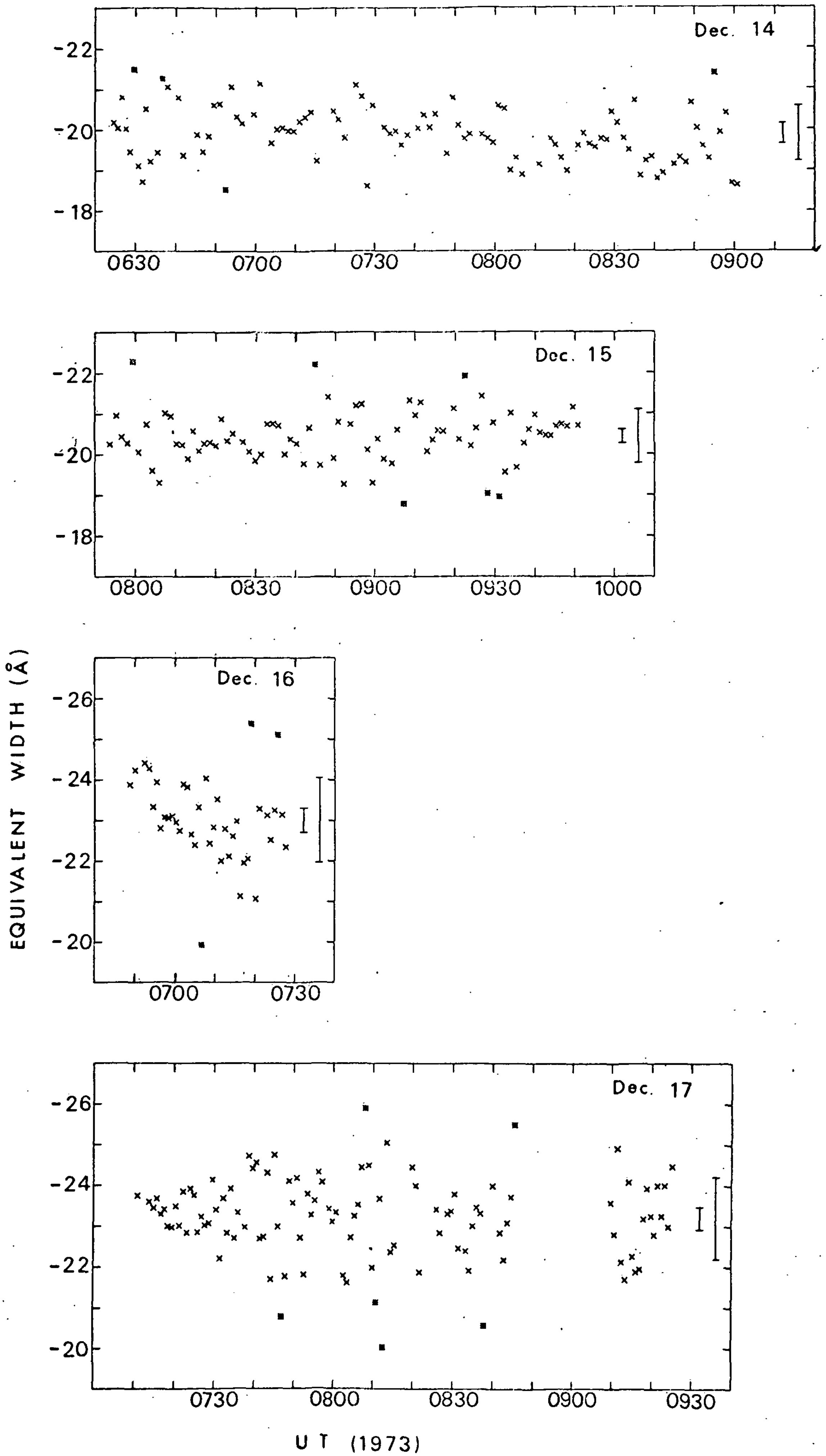
Dec. 14
-22
-20
-18
0630
0700
0730
0800
0830
0900
Dec. 15
-22
-20
-18
0800
0830
0900
0930
1000
EQUIVALENT WIDTH (Å)
Dec. 16
-26
-24
-22
-20
0700
0730
Dec. 17
-26
-24
-22
-20
0730
0800
0830
0900
0930
U T (1973)

Figure 4