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Search for rapid H_α variability studies in Be stars : 28 Eri, X Ophiuchi, 66 Ophiuchi and Π Aquarii

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Summary. — In order to search for rapid H_α variability in Be stars, a series of H_α profiles were observed on a time scale of few minutes for 28 Eri, X Oph, 66 Oph and Π Aqr. In total, 95 and 54 H_α profiles were obtained for the program Be stars and the standard stars respectively. The theoretical expression of Chalabaev and Maillard (1983) was used to estimate the uncertainty of the H_α equivalent width measurements. From the results of the present observations it is found that rapid variations of continuum level and equivalent widths of H_α line are absent in our program Be stars.

Key words : Be stars — rapid H_α variability — emission-line profiles.

1. Introduction.

The variability of Be stars with time scales of years, months and days is well known (Underhill and Doazan, 1982 and references therein). However, regarding rapid variations in the time scales of hours and minutes, there are different opinions by different authors. These variations have been reported for the lower Balmer lines. Many observations were taken for rapid variations in the total emission strength (Bahng, 1971 ; 1976 ; Slettebak and Snow, 1978 ; Ghosh, 1987) as well as for line profile variations (Hutchings *et al.*, 1971 ; Hutchings, 1967, 1969, 1976 ; Doazan, 1976, Fontaine *et al.*, 1983 ; Chalabaev and Maillard, 1983). Bijaoui and Doazan (1979) used a method of cross-correlation analysis which they applied to their high-resolution (0.15 Å) observations of α Col, to detect rapid variability. Their results show rapid and irregular variations superimposed with a slow and weak variation extending over several nights. They have shown from statistical tests that these variations are real. On the basis of low resolution observations (4 to 5 Å) Lacy (1977) has found that fewer than 5 percent of the Be stars undergo detectable variations and the reality of these rapid variations has been questioned by him. A similar conclusion was also drawn by Slettebak and Reynolds (1978) on the basis of their low resolution observations (5.5 Å) and on the other hand, Slettebak and Snow (1978) have also suggested the presence of rapid variations in γ Cas. Fontaine *et al.* (1983) and Chalabaev and Maillard (1983) obtained rapid high resolution observations (0.2 Å) of H_α and Paschen lines for certain Be stars but they did not detect any rapid variations of the line profiles. Therefore, the present situation is more doubtful for the rapid variability in Be stars.

It is important to mention here that high time resolution observations accompanied by a careful analysis of possible instrumental effects and atmospheric variations which can produce spurious results, are necessary to be analysed very carefully to confirm the reality of the rapid variations. In this article we present such observations of rapid variability of equivalent widths (*EW*) of H_α profiles of four Be stars (28 Eri, X Oph, 66 Oph and Π Aqr).

2. Observations and analysis of the data.

Photoelectric scans for the H_α line were obtained for four Be stars (28 Eri, X Oph, 66 Oph and Π Aqr) on three nights between May and October, 1985 using the automated spectrum scanner (Bappu, 1977) at the 102 cm Cassegrain reflector of Vainu Bappu Observatory, Kavalur, India.

H_α line profiles were always measured in the first order of scanner grating (1800 lines mm^{-1} blazed at 5000 Å), using an exit slot the width of which corresponds to 3 Å in the spectrum. Forward scans were recorded in wavelength increments of 3 Å over a wavelength range of 180 to 200 Å centred on H_α. For present observations the detector was an EMI 9658 photomultiplier tube connected to the photon counting system.

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On each night three standard stars, HR 718, 2160 and 3454, were scanned to provide the nightly extinction values, the wavelength dependence of instrumental sensitivity and atmospheric variations. The sky background plus dark counts were measured immediately preceding and following the star scans and subtracted from the results of the scans.

From our present observations, 95 and 54 H_α line profiles were obtained for the program and the standard stars respectively. Extended wings of H_α profiles of Be stars may affect the normalisation procedure (Slettebak and Reynolds 1978 ; Fontaine *et al.* 1982). So, one has to be careful in choosing the continuum region which must be beyond the extended wings of the profiles. Each observed profile was normalized at (6500 ± 6) Å and (6610 ± 6) Å, which is believed to be necessary and sufficient. Then we have obtained the final profile from the average of the two normalized profiles. Similarly, the measured continuum counts (F_c) for each profile were obtained from the average of the two continuum counts, F'_c and F''_c, at (6500 ± 6) Å and (6610 ± 6) Å, respectively $[F_c = (F'_c + F''_c)/2]$ and the average continuum counts $(\bar{F}_c)$ of a star were obtained from the average of all the F_c values. Channel shift of the spectrum scanner may change the normalization point which may introduce a serious error for the variability studies. To avoid this error we have displayed each profile along with the standard source (Fe + Ne) spectrum on the screen of a VT 240 Graphic system and the instrumental shift for each profile was obtained. All data reductions were done on VAX-11/780 computer of Vainu Bappu Observatory, using the spectrophotometric reduction package developed by A. Raveendran, to yield normalized flux. Using the standard stars, the wavelength dependence of instrumental sensitivity were obtained and necessary corrections were applied to the measured values of the program stars. The RESPECT software package (Prabhu *et al.*, 1987) was used to plot the figures.

The normalized spectra for the program stars are always expressed in terms of the relative flux, F_λ / F_c. The measured *EW* of $H_\alpha [W(\alpha)]$ and their variations from the mean value are presented in table II.

TABLE I. — *Different observed parameters for the standard star and the program stars. For explanation of abbreviations used in the table, see section 3.*

HR	No. of profiles observed	S/N	$\bar{F}(\lambda)/F_c$	$\Delta\lambda$ (Å)	Average $W(\alpha)$ (Å)	σ_T of $W(\alpha)$ (Å)
1423	35	72	1.26	49.0	21.72	1.00
3454	18	129	0.86	25.0	+ 3.50	0.17
6118	28	102	1.58	51.0	42.63	0.94
6712	19	103	1.77	51.0	47.38	0.98
8539	13	101	1.47	49.0	31.75	0.66

TABLE II. — *Measured values of $W(\alpha)$ and its variations for the program Be stars. For explanation of abbreviations used in the table, see section 3.*

HR 1423 (28 Eri)		HR 6118 (χ Oph)		HR 6712 (66 Oph)		HR 8539 (π Aqr)	
W(α) (Å)	Variations of W(α) w.r.t. its mean value (in units of $\sigma_T[W(\alpha)]$)	W(α) (Å)	Variations of W(α) w.r.t. its mean value (in units of $\sigma_T[W(\alpha)]$)	W(α) (Å)	Variations of W(α) w.r.t. its mean value (in units of $\sigma_T[W(\alpha)]$)	W(α) (Å)	Variations of W(α) w.r.t. its mean value (in units of $\sigma_T[W(\alpha)]$)
23.80	2.08	43.35	0.76	54.63	7.40	32.47	1.09
19.11	- 2.61	44.91	2.42	52.04	4.75	31.23	- 0.78
21.10	- 0.62	43.24	0.65	50.12	2.79	31.63	- 0.18
22.84	1.12	41.28	- 1.44	49.21	1.87	30.81	- 1.42
22.52	0.80	42.83	0.21	48.61	1.25	31.13	- 0.94
23.67	1.95	42.37	- 0.27	47.01	- 0.37	32.27	0.79
21.06	- 0.66	42.44	- 0.20	47.43	0.05	30.04	- 2.59
20.81	- 0.91	42.36	- 0.29	47.51	0.13	32.39	0.97
23.57	1.85	43.18	0.58	47.82	0.45	40.46	
18.12	- 3.60	43.04	0.44	45.18	- 2.24	32.64	1.35
24.28	2.56	42.11	- 0.55	47.49	0.11	32.99	1.88
22.96	1.24	41.89	- 0.78	46.11	- 1.29	31.37	- 0.57
21.19	- 0.53	43.47	0.89	46.02	- 1.39	32.06	0.42
21.24	- 0.48	42.14	- 0.52	47.10	- 0.28		
21.19	- 0.53	39.44	- 3.39	46.17	- 1.23		
20.76	- 0.96	42.79	0.17	45.78	- 1.63		
21.88	0.16	41.96	- 0.71	44.29	- 3.15		
19.87	- 1.85	40.58	- 2.18	44.60	- 2.84		
18.95	- 2.77	44.13	1.59	43.15	- 4.32		
20.76	- 0.96	41.92	- 0.75				
22.04	0.32	43.71	1.15				
22.28	0.56	43.49	0.91				
21.63	- 0.09	43.34	0.75				
23.17	1.45	43.35	0.76				
19.54	- 2.18	42.97	0.36				
22.56	0.84	42.05	- 0.62				
22.31	0.59	42.83	0.21				
21.67	- 0.05	42.61	- 0.02				
19.14	- 2.58						
22.73	1.01						
22.86	1.14						
23.07	1.35						
21.98	0.26						
24.89	3.17						
20.68	- 1.04						

3. Detection of the observational errors.

In order to find out the reality of rapid variations of $W(\alpha)$, we have to detect the total observational error (instrumental and atmospheric variations) in $W(\alpha)$ measurements for our program stars and this error can be estimated from the value of the standard deviation of $W(\alpha)$ $[\sigma_T\{W(\alpha)\}]$. Chalabaev and Maillard (1983) have shown that the value of $\sigma_T\{W(\alpha)\}$ depends on the value of $W(\alpha)$. They have derived a theoretical expression for $\sigma_T(EW)$, using Poisson statistics, which is as follows (expression A 10 of their paper) :

$$\sigma_T^2(EW) = \frac{1}{(S/N)^2}\left[\Delta\lambda * \frac{\bar{F}(\lambda)}{F_c} * h_\lambda + (\Delta\lambda - EW)^2\right]$$

where S/N is the signal-to-noise ratio at the continuum, $\Delta\lambda$ $(= \lambda_2 - \lambda_1)$ is the interval of the integration, $\bar{F}(\lambda)/F_c$ is the average flux in the spectral line and h_λ is the spectral element. Using the above expression we can calculate the $\sigma_T[W(\alpha)]$ values for our program Be stars. But before using this expression for the program stars, we have to check the adaptability of this expression for our instrumental system.

On 28 October, 1985 we obtained 18 H_α profiles of the standard star, HR 3454 and the mean value of $W(\alpha)$ is + 3.51 Å with the measured standard deviation (σ_M) value as ± 0.16 Å (Fig. 1). Using the theoretical $\sigma_T(EW)$ expression of Chalabaev and Maillard (1983) $\sigma_T[W(\alpha)]$ value for HR 3454 is obtained as ± 0.17 Å (Tab. I) which is almost equal to $\sigma_M[W(\alpha)]$ value for the same star. This suggest that the above theoretical expression can be used to estimate the $\sigma_T[W(\alpha)]$ values for the program Be stars. Since the rapid H_α variability in Be stars is more doubtful so, the total observational error limit in $W(\alpha)$ measurements for our program stars may be fixed as ± 5 $\sigma_T[W(\alpha)]$.

From the measured continuum counts (F_c) for the standard star HR 3454 we find that the maximum and minimum variations of $\Delta F_c/F_c$ are 2.71 % and 2.44 % respectively where ΔF_c $(= F_c \sim \bar{F}_c)$ is the difference in continuum counts between F_c and $\bar{F}_c$. Therefore, for the program stars if the variations of $\Delta F_c/F_c$ are beyond ± 3 %, then we shall consider those variations as true variations.

4. Results of individual stars.

The following abbreviations will be used for the discussion :

$W(\alpha)$: measured value of the equivalent width of the H_α emission line (neglecting the negative sign) ;

$\sigma_T[W(\alpha)]$: theoretical estimate of standard deviation in $W(\alpha)$ measurements.

HR 1423 (28 ERI). — For this star thirty five H_α profiles were observed on the night of 28 October, 1985 and they are presented in figures 2a and c. Obtained mean value of $W(\alpha)$ is 21.66 Å and that obtained by Andrillat and Fehrenbach (1982) in December, 1980 ($W(\alpha)$ = 24.2 Å) and by Dachs *et al.* (1986) between November, 1981 and February-April, 1983 ($W(\alpha)$ = 31.0 to 25.6 Å) suggest that $W(\alpha)$ is slowly decreasing. Resulting $W(\alpha)$ values obtained from our observations for HR 1423 are plotted in figure 3a. It turns out that the variations of $W(\alpha)$ of all the profiles are within ± 3.0 $\sigma_T[W(\alpha)]$ except for two profiles (UT = 18:09:05 and 19:05:23). Variations of $W(\alpha)$ of these two profiles are − 3.6 $\sigma_T[W(\alpha)]$ and 3.17 $\sigma_T[W(\alpha)]$ respectively (Tab. II). We shall consider these two variations as statistical variations because they are within the limit of ± 5 $\sigma_T[W(\alpha)]$. Figure 4a shows the plot of percentage variations of $\Delta F_c/F_c$ *versus* time for HR 1423 and it is clearly evident that all the variations are within ± 3.0 % except for one occasion where the variation is − 3.65 %.

HR 6118 (X OPH). — H_α profiles of X Oph which were observed on 13 May, 1985 are shown in figures 2d, e. This star was already measured by Andrillat and Fehrenbach (1982), by Neto and Freitas (1982) and by Dachs *et al.* (1986) and the variations of $W(\alpha)$ between March, 1980 and April, 1983 have been discussed in details by Dachs *et al.* (1986). We compared the recent high resolution measurements of $W(\alpha)$ of X Oph by Hanuschik (1986) on 28 February, 1985 ($W(\alpha)$ = 43.77 Å) with our mean equivalent width of 28 H_α profiles of 13 May, 1985 ($W(\alpha)$ = 42.67 Å) and it shows marginal decrease of $W(\alpha)$ value within few months time. The figure 3b presents our observed values of $W(\alpha)$ for X Oph and no variations of $W(\alpha)$ are seen beyond the limit of ± 5 $\sigma_T[W(\alpha)]$ (Tab. II). Percentage variations of $\Delta F_c/F_c$ with time are presented in figure 4b for this star and it shows that all the variations are within ± 3.0 % except for one case.

HR 6712 (66 OPH). — Observed H_α profiles of 66 Oph are presented in figures 2f, g. This star has shown maximum value of $W(\alpha)$ (55.09 Å) at the begining of our observations and then slowly decreased to a minimum value of 42.75 Å. Average value of $W(\alpha)$ of our 19 H_α profiles, which were observed on 13 May, 1985, is 47.50 Å and that obtained by Andrillat and Fehrenbach (1982), in December, 1980 was 43.77 Å. This increase of $W(\alpha)$ in May, 1985 may be due to the wind activity in 66 Oph (Grady *et al.* 1987). However, from our observations we find that the first profile shows variations around 7.4 $\sigma_T[W(\alpha)]$ and all other profiles do not show variations beyond ± 5 $\sigma_T[W(\alpha)]$ (Fig. 3c and Tab. II). No variations of $\Delta F_c/F_c$ are seen for 66 Oph which are beyond ± 3 % (Fig. 4c).

HR 8539 (*Π* AQR). — Many observations for H_α were taken for this star by different authors and the results have been reviewed in a recent paper by Dachs *et al.* (1986). We observed this star on 29 October, 1985 and 13 H_α profiles were obtained and they are shown in figure 2h. It is clearly seen from figure 3d that one H_α profile has shown sudden increase of $W(\alpha)$ value by around 8.0 Å with respect to its mean value. This increase of $W(\alpha)$ occured on a time scale of 2 minutes with marginal increase of emission intensity and it may be a very short flarelike event in Π Aqr. If we exclude this profile from the rest of the observed profiles, then the average value of $W(\alpha)$ is 31.75 Å. Measured $W(\alpha)$ values of this star are shown in figure 3d and we find from table II that the variations of $W(\alpha)$ are within $\pm 3.0\ \sigma_T[W(\alpha)]$ except for the flarelike profile. During our observations no rapid continuum level variations are seen in Π Aqr which is clearly evident from figure 4d (all the variations of $\Delta F_c/F_c$ are within ± 3 %).

5. Discussion.

In general, stellar flux (F_λ) can be decomposed into a sum of the continuum flux (F_c) and the bound-bound flux (L_λ). So, the variations of $W(\alpha)$ of H_α emission line depend on the variations due to continuum flux and bound-bound emission flux.

From our results it is clearly seen that there are no rapid variations of continuum counts of the program stars. This is an important result of our present survey which suggest that rapid (of the order of few minutes) continuum level variations are absent in 28 Eri, X Oph, 66 Oph and Π Aqr. This (absence of rapid continuum level variations) was also observed in Φ Per (HR 496) (Ghosh *et al.* 1988) and in many other Be stars (Ghosh and Jaykumar 1988). Also, we have seen from the previous section that the rapid variations of $W(\alpha)$ are absent in our program Be stars during the time of our observations. Therefore, it may be suggested that there are no rapid variations of bound-bound emission flux of H_α in the envelope of the observed four Be stars. However the observed data supply only a little fraction of a necessary information and at present it is premature to make any definite general statement about the rapid spectral variability in Be stars.

6. Conclusions.

The main results derived from our observations are summarized as follows :

1) no rapid continuum level variations are seen in 28 Eri, X Oph, 66 Oph and Π Aqr ;

2) rapid variations of $W(\alpha)$ as well as bound-bound emission flux of H_α are absent in the envelope of our program Be stars.

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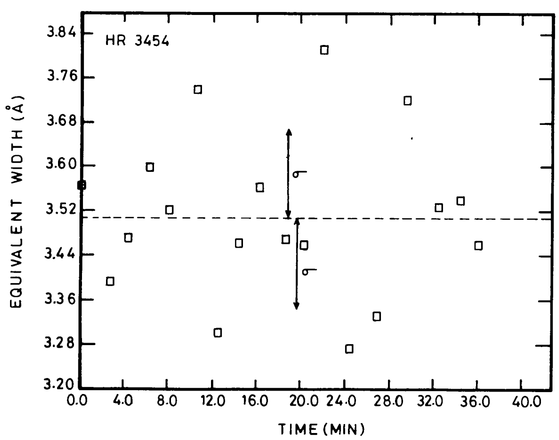
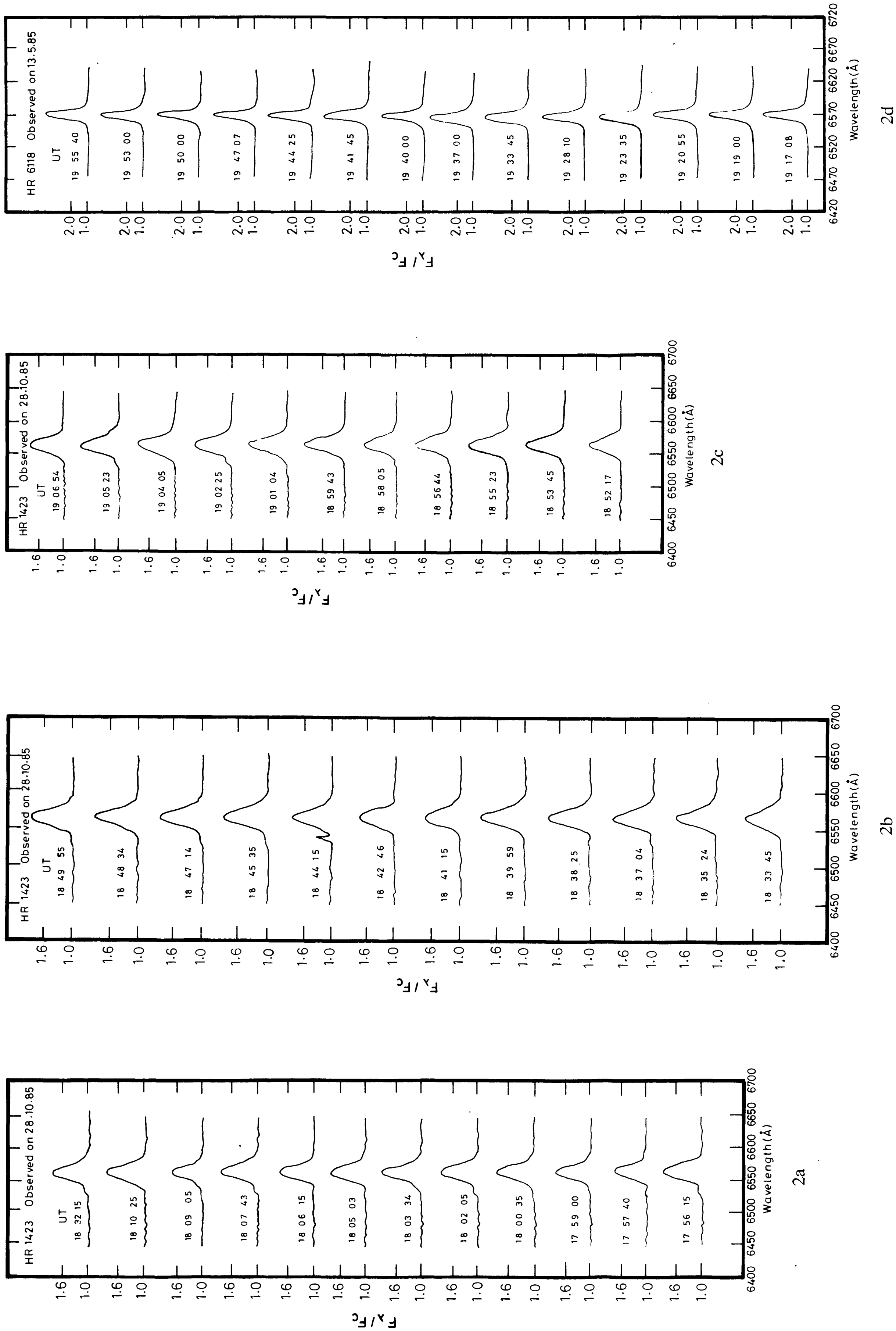
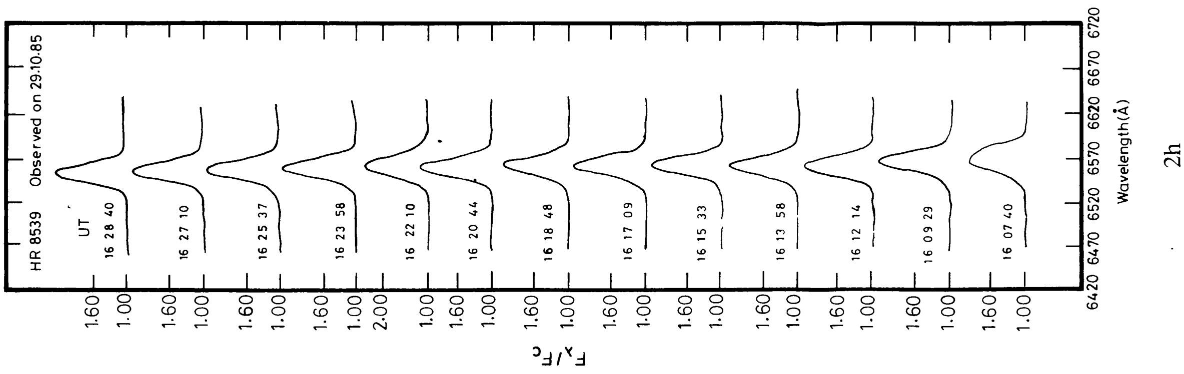


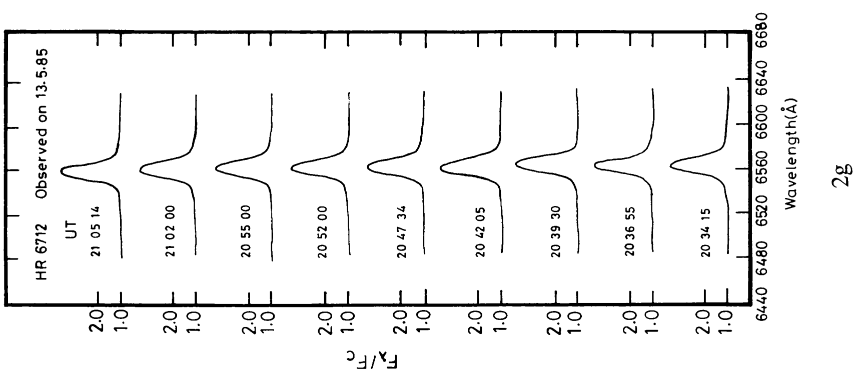
FIGURE 1. — Variations of $W(\alpha)$ of HR 3454 as a function of time. Time axis represents the elapsed time in minutes from the time of first observation of HR 3454 (UT of first observation is $21^h59^m05^s$).

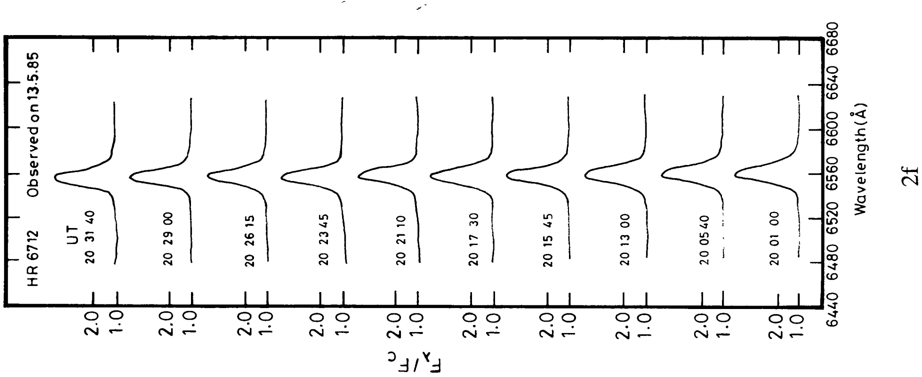


FIGURES 2a-c. — Observed H_α profiles of 28 Eri (HR 1423). Observing date is given on the top. UT of observations are shown to the left.

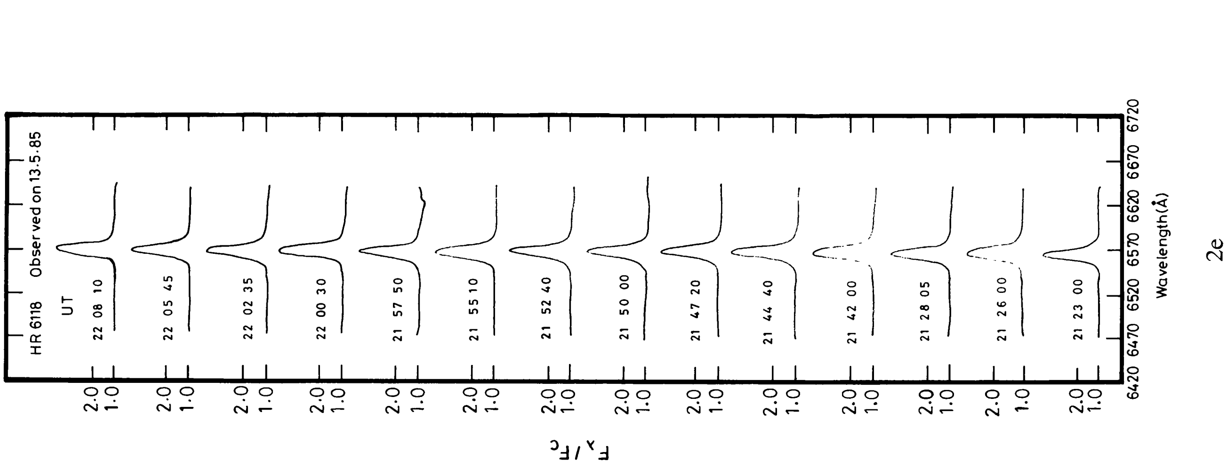


FIGURES 2h. — Same as figure 2a, but for *Π* Aqr (HR 8539).





FIGURES 2f-g. — Same as figure 2a, but for 66 Oph (HR 6712).



FIGURES 2d-e. — Same as figure 2a, but for X Oph (HR 6118).

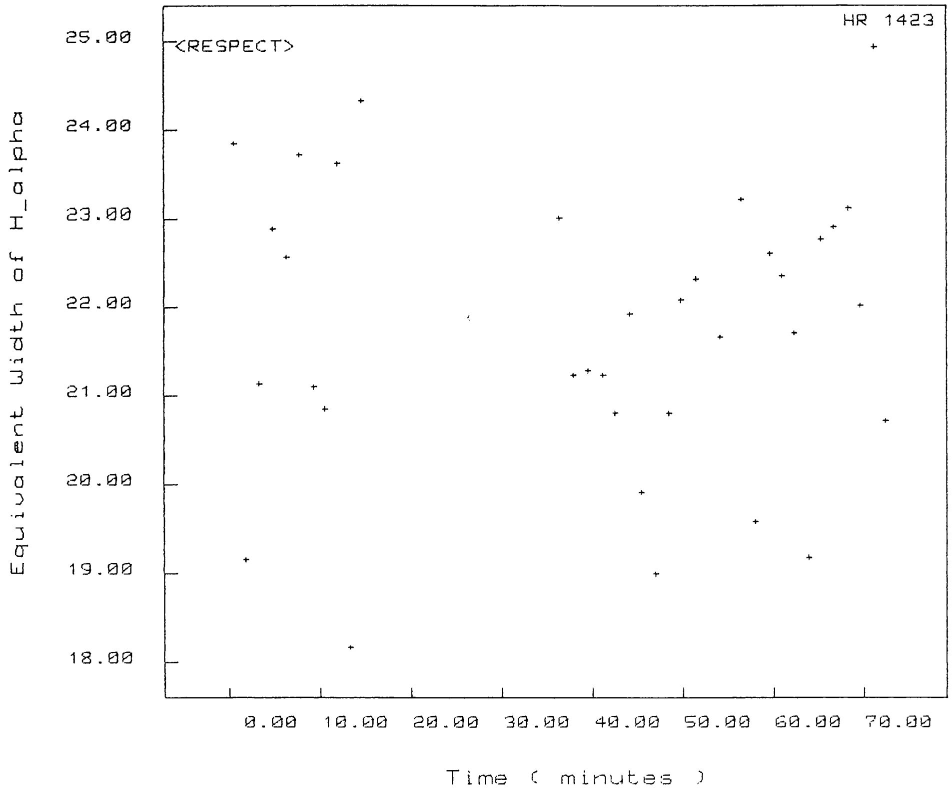


FIGURE 3a. — Same as figure 1, but for 28 Eri (UT of first observation is $17^h56^m15^s$).

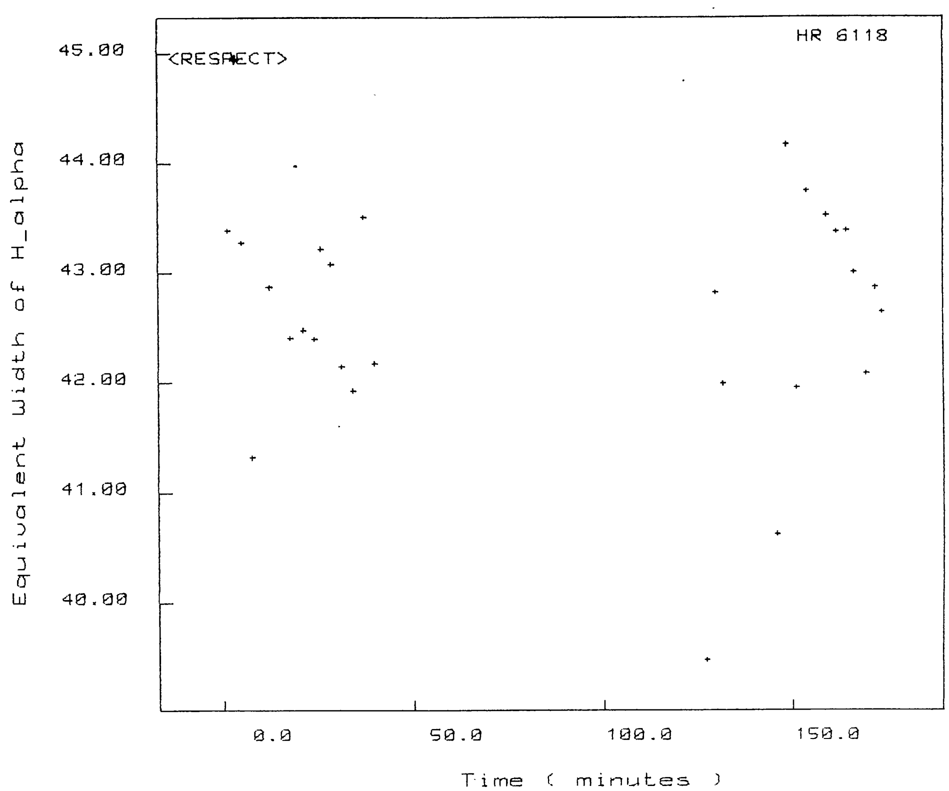


FIGURE 3b. — Same as figure 1, but for X Oph (UT of first observation is $19^h17^m08^s$).

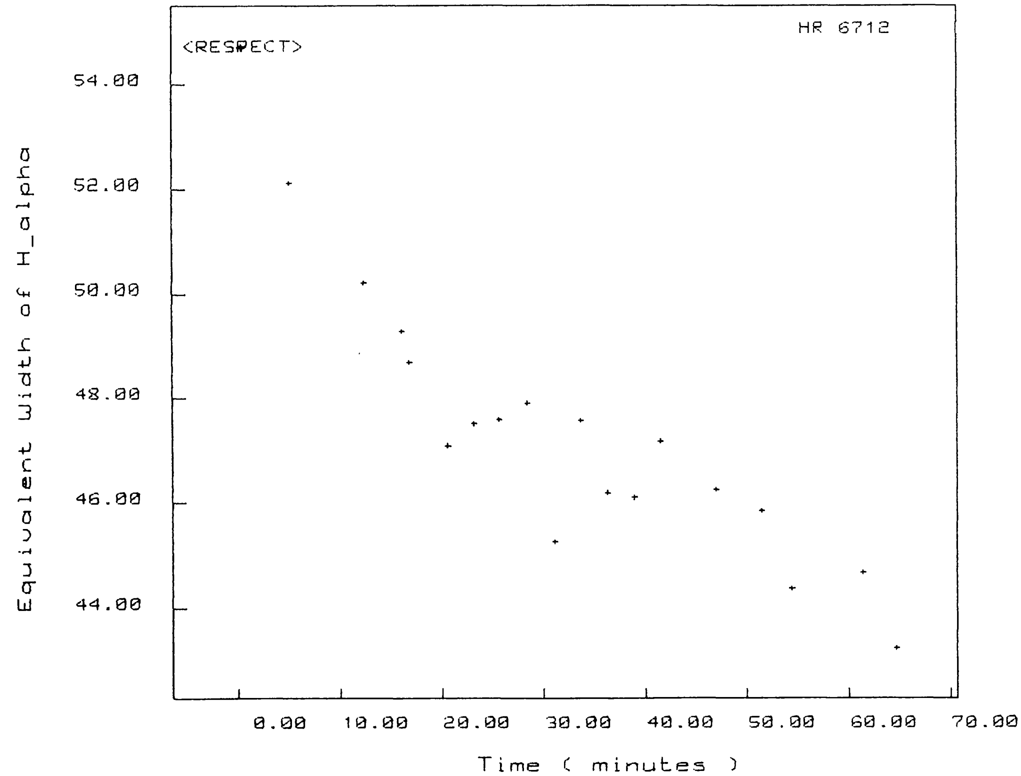


FIGURE 3c. — Same as figure 1, but for 66 Oph (UT of first observation is $20^h01^m00^s$).

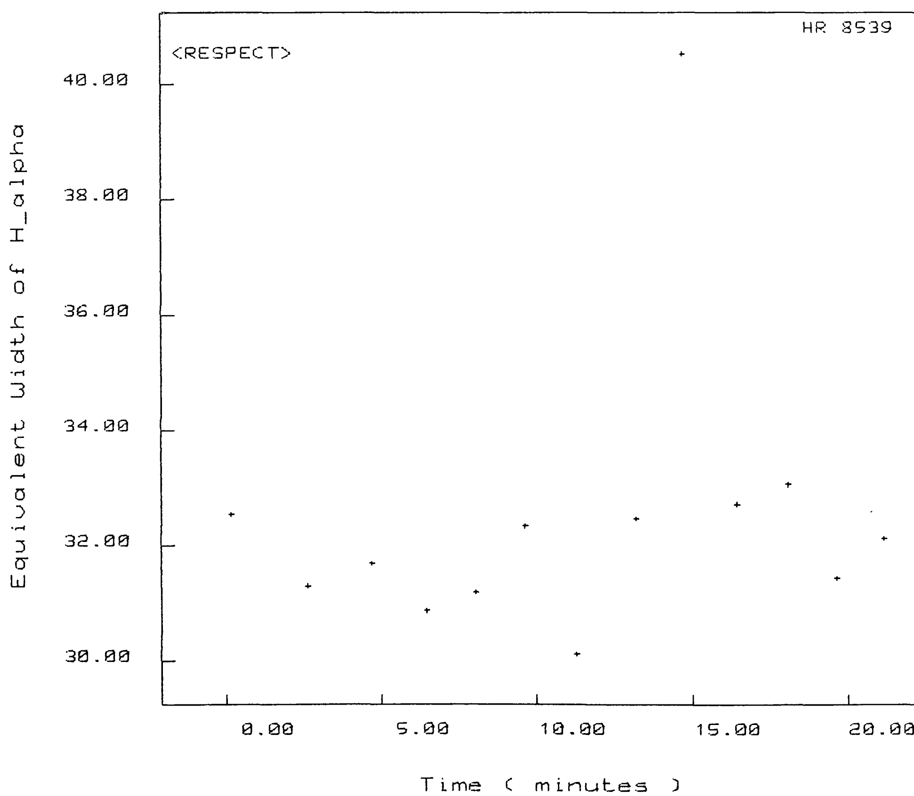


FIGURE 3d. — Same as figure 1, but for Π Aqr (UT of first observation is $16^h07^m40^s$).

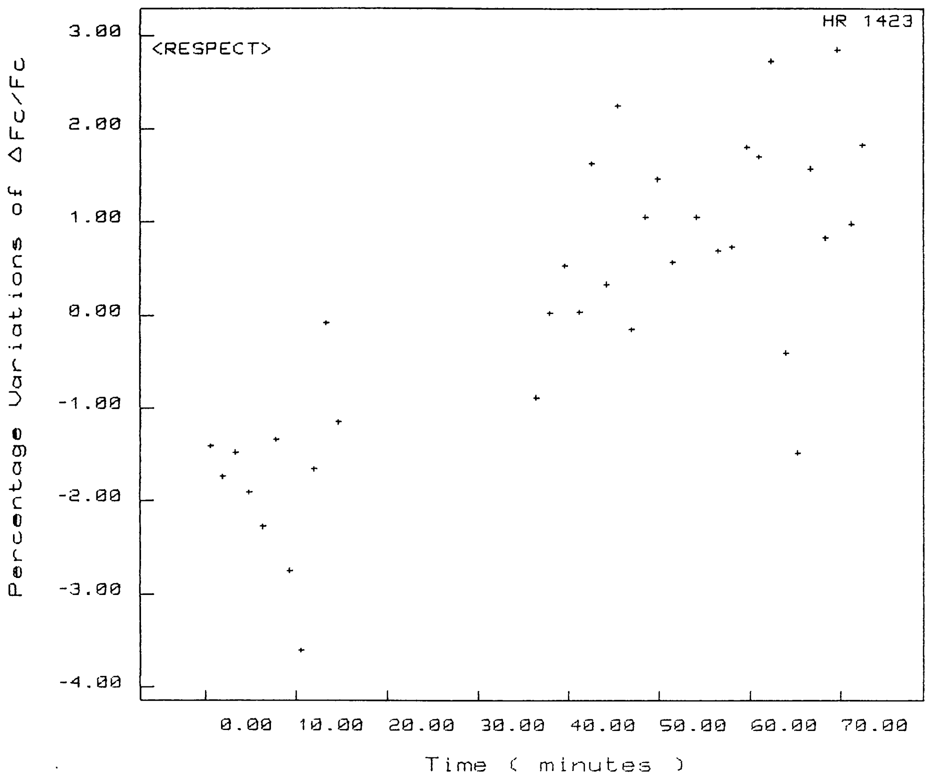


FIGURE 4a. — Plot of percentage variations of $\Delta F_c/F_c$ *versus* time for 28 Eri.

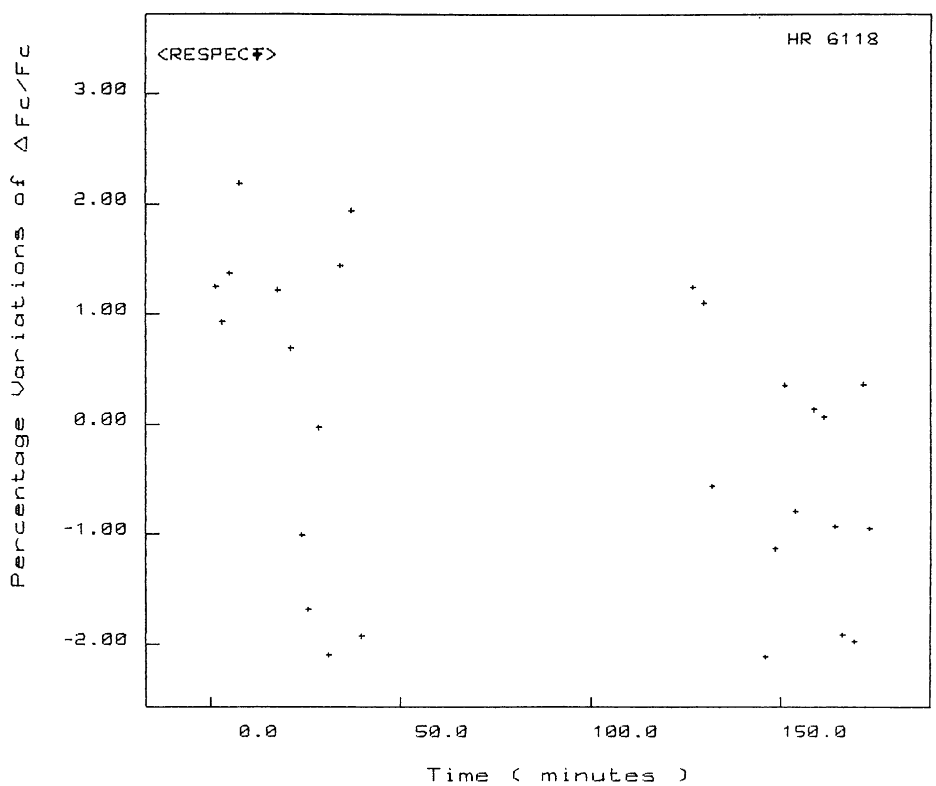


FIGURE 4b. — Same as figure 4a, but for X Oph.

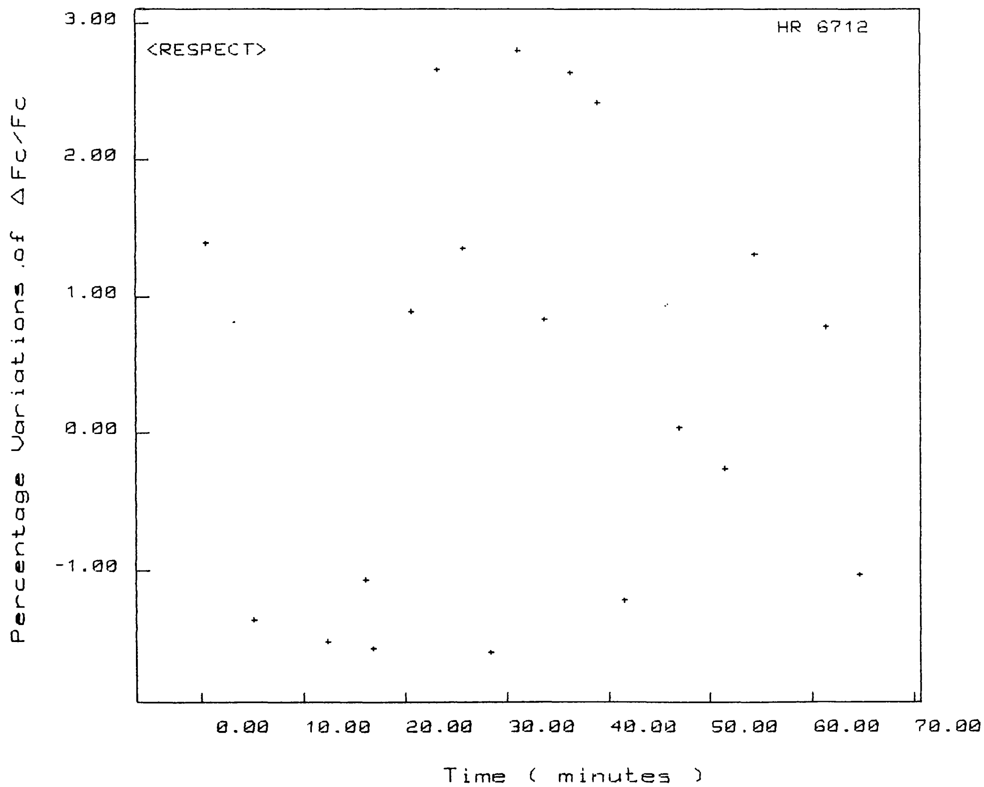


FIGURE 4c. — Same as figure 4a, but for 66 Oph.

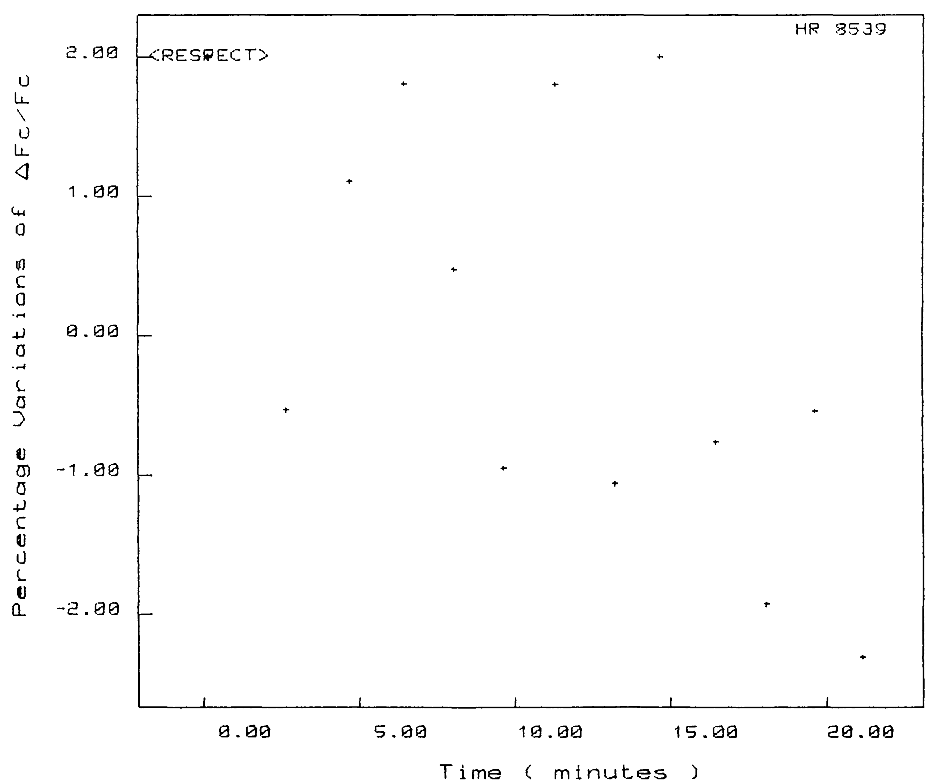


FIGURE 4d. — Same as figure 4a, but for *Π* Aqr.