# RAPID VARIATIONS OF Hα EMISSION STRENGTH OF EIGHT Be STARS

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**Abstract.** Rapid observations of Hα profiles of eight Be stars have been obtained and it is found that rapid (in a time-scale of 4 to 6 minutes) and irregular variations of total emission strength of Hα line are present in these stars. It has been suggested that these variations may be due to the material circulation in the envelope of Be stars.

## 1. Introduction

One of the important characteristics of the Be stars is the variability of emission lines on time-scales of years, months, and days which is well accepted in the astronomical community. But there are different opinions for rapid variability in the time-scales of hours and minutes. Present-day state of discussion on the results of rapid variations of emission lines of Be stars has been reviewed in a recent paper by Ghosh *et al.* (1988 and references quoted therein); and it has been suggested that high time and spectral resolution observations may provide important information about the reality of the rapid variations. In this paper we present the results of such observations of rapid variability of equivalent width (EW) of Hα profiles of eight Be stars.

## 2. Observations

Program stars, observed on three nights between October and November 1985 using the automated spectrum scanner (Bappu, 1977) the Cassegrain focus of the 102 cm Zeiss reflector of the Vainu Bappu Observatory, Kavalur, India, are listed in Table I.

TABLE I

Program stars

| HR | Name | HD | $V_{mag}$ | Spectral type | $V \sin i$ (km s$^{-1}$) | No. of profiles observed |
|---|---|---|---|---|---|---|
| 1772 | | 35165 | 6.09 | B5 IVpne | | 13 |
| 1789 | 25 Ori | 35439 | 4.95 | B1 Ve | 300 | 12 |
| 2170 | | 42054 | 5.83 | B4 IVe | | 9 |
| 2249 | | 43544 | 5.92 | B2.5 Ven | | 5 |
| 2745 | 27 CMa | 56014 | 4.66 | B3 IIIe | 160 | 6 |
| 2787 | | 57150 | 4.66 | B3 IVne | 360 | 6 |
| 8628 | ε Psa | 214748 | 4.17 | B8 Ve | 375 | 10 |
| 8773 | β Psc | 217891 | 4.53 | B5 Ve | 130 | 15 |

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Observations of Hα profiles were made 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, with an EMI 9658 photomultiplier tube connected to the photon counting system. Photoelectric scans of Hα profiles were obtained over a wavelength

TABLE IIa

Observational results of HR 1772 in the spectral region 6470–6630 Å which was observed on 28 October, 1985

| Mean UT of observations (h : m : s) | Photo-electron counts of continuum at 6523 Å ($s^{-1}$ $scan^{-1}$) | Variation of continuum counts (in units of $\sigma_1$) | $W(\alpha)$ (Å) | $\frac{F_{max}}{F_c}$ | Variations of $W(\alpha)$ w.r.t. its mean value (in units of $\sigma$) |
|---|---|---|---|---|---|
| 19 : 23 : 10 | 6986 | − 0.27 | 3.38 | 1.10 | 1.00 |
| 19 : 24 : 49 | 6982 | 0.26 | 2.76 | 1.08 | − 2.87 |
| 19 : 25 : 53 | 6966 | 0.21 | 2.41 | 1.07 | − 5.06 |
| 19 : 27 : 25 | 6693 | − 0.56 | 3.31 | 1.04 | 0.56 |
| 19 : 29 : 33 | 6871 | − 0.05 | 3.89 | 1.10 | 4.18 |
| 19 : 34 : 39 | 6986 | 0.27 | 2.83 | 1.09 | − 2.43 |
| 19 : 36 : 29 | 6984 | − 0.04 | 3.23 | 1.10 | 0.06 |
| 19 : 38 : 27 | 6879 | − 0.03 | 3.03 | 1.09 | − 1.18 |
| 19 : 40 : 19 | 6714 | − 0.50 | 4.82 | 1.11 | 10.00 |
| 19 : 42 : 23 | 6836 | − 0.15 | 3.65 | 1.11 | 2.86 |
| 19 : 44 : 05 | 6898 | − 0.02 | 2.17 | 1.06 | − 6.56 |
| 19 : 45 : 58 | 6975 | 0.24 | 3.29 | 1.09 | 0.44 |
| 19 : 49 : 56 | 6913 | 0.06 | 3.09 | 1.09 | − 0.81 |

For explanation of abbreviations used in the table, see Section 2.

TABLE IIb

Observational results of HR 1772 in the spectral region 6500–6640 Å which was observed on 28 October, 1985

| Mean UT of observations (h : m : s) | Photo-electron counts of continuum at 6523 Å ($s^{-1}$ $scan^{-1}$) | Variation of continuum counts (in units of $\sigma_1$) | $W(\alpha)$ (Å) | $\frac{F_{max}}{F_c}$ | Variations of $W(\alpha)$ w.r.t. its mean value (in units of $\sigma$) |
|---|---|---|---|---|---|
| 20 : 54 : 48 | 9768 | − 0.24 | 13.72 | 1.54 | − 7.56 |
| 20 : 56 : 41 | 9851 | 0.03 | 14.52 | 1.60 | − 2.56 |
| 20 : 58 : 10 | 9876 | 0.12 | 15.35 | 1.62 | 2.62 |
| 21 : 02 : 04 | 9742 | − 0.33 | 16.10 | 1.63 | 7.31 |
| 21 : 03 : 48 | 9812 | − 0.09 | 15.35 | 1.59 | 2.62 |
| 21 : 05 : 26 | 9903 | 0.21 | 15.79 | 1.63 | 5.37 |
| 21 : 06 : 54 | 9899 | 0.19 | 13.33 | 1.57 | − 10.00 |
| 21 : 08 : 35 | 9889 | 0.16 | 14.42 | 1.61 | − 3.18 |
| 21 : 11 : 40 | 9837 | − 0.01 | 15.45 | 1.61 | 3.25 |
| 21 : 13 : 38 | 9860 | − 0.06 | 15.30 | 1.61 | 2.31 |
| 21 : 15 : 33 | 9794 | − 0.16 | 14.77 | 1.59 | − 1.00 |
| 21 : 17 : 28 | 9866 | 0.08 | 15.05 | 1.61 | 0.75 |

For explanation of abbreviations used in the table, see Section 2.

TABLE IIc

Observational results of HR 2170 in the spectral region 6450–6650 Å which was observed on 28 October, 1985

| Mean UT of observations (h : m : s) | Photo-electron counts of continuum at 6523 Å ($s^{-1}$ $scan^{-1}$) | Variation of continuum counts (in units of $\sigma_1$) | $W(\alpha)$ (Å) | $\frac{F_{max}}{F_c}$ | Variations of $W(\alpha)$ w.r.t. its mean value (in units of $\sigma$) |
|---|---|---|---|---|---|
| 19 : 57 : 15 | 8494 | − 0.33 | 18.36 | 1.73 | 3.19 |
| 20 : 00 : 19 | 8600 | 0.03 | 19.01 | 1.75 | 7.25 |
| 20 : 01 : 58 | 8560 | − 0.14 | 18.86 | 1.76 | 6.31 |
| 20 : 04 : 48 | 8556 | − 0.15 | 16.96 | 1.68 | − 5.56 |
| 20 : 06 : 57 | 8549 | − 0.17 | 18.05 | 1.71 | 1.25 |
| 20 : 08 : 32 | 8525 | − 0.24 | 17.44 | 1.72 | − 2.56 |
| 20 : 24 : 58 | 8732 | 0.35 | 17.39 | 1.74 | − 2.87 |
| 20 : 31 : 14 | 8686 | 0.22 | 17.23 | 1.72 | − 3.87 |
| 20 : 33 : 15 | 8769 | 0.46 | 17.43 | 1.72 | − 2.62 |

For explanation of abbreviations used in the table, see Section 2.

TABLE IId

Observational results of HR 2249 in the spectral region 6460–6650 Å which was observed on 28 October, 1985

| Mean UT of observations (h : m : s) | Photo-electron counts of continuum at 6523 Å ($s^{-1}$ $scan^{-1}$) | Variation of continuum counts (in units of $\sigma_1$) | $W(\alpha)$ (Å) | $\frac{F_{max}}{F_c}$ | Variations of $W(\alpha)$ w.r.t. its mean value (in units of $\sigma$) |
|---|---|---|---|---|---|
| 20 : 38 : 13 | 7462 | 0.18 | 2.40 | 1.11 | − 2.25 |
| 20 : 39 : 54 | 7261 | − 0.10 | 3.02 | 1.15 | 1.62 |
| 20 : 42 : 04 | 7366 | − 0.09 | 2.66 | 1.11 | − 0.62 |
| 20 : 44 : 13 | 7396 | 0.00 | 1.79 | 1.08 | − 6.06 |
| 20 : 45 : 59 | 7398 | 0.00 | 3.95 | 1.15 | 7.43 |

For explanation of abbreviations used in the table, see Section 2.

TABLE IIe

Observational results of HR 2475 in the spectral region 6470–6650 Å which was observed on 28 October, 1985

| Mean UT of observations (h : m : s) | Photo-electron counts of continuum at 6523 Å ($s^{-1}$ $scan^{-1}$) | Variation of continuum counts (in units of $\sigma_1$) | $W(\alpha)$ (Å) | $\frac{F_{max}}{F_c}$ | Variations of $W(\alpha)$ w.r.t. its mean value (in units of $\sigma$) |
|---|---|---|---|---|---|
| 21 : 33 : 38 | 10409 | − 0.37 | 5.25 | 1.12 | 8.56 |
| 21 : 35 : 14 | 10529 | − 0.03 | 3.56 | 1.09 | − 2.00 |
| 21 : 36 : 57 | 10598 | 0.25 | 3.96 | 1.09 | 0.50 |
| 21 : 39 : 34 | 10479 | − 0.14 | 3.82 | 1.10 | − 0.37 |
| 21 : 41 : 02 | 10592 | 0.24 | 2.83 | 1.08 | − 6.56 |
| 21 : 43 : 05 | 10519 | 0.00 | 3.87 | 1.10 | − 0.06 |

For explanation of abbreviations used in the table, see Section 2.

TABLE IIf

Observational results of HR 1772 in the spectral region 6470–6630 Å which was observed on 28 October, 1985

| Mean UT of observations (h : m : s) | Photo-electron counts of continuum at 6523 Å ($s^{-1}$ $scan^{-1}$) | Variation of continuum counts (in units of $\sigma_1$) | $W(\alpha)$ (Å) | $\frac{F_{max}}{F_c}$ | Variations of $W(\alpha)$ w.r.t. its mean value (in units of $\sigma$) |
|---|---|---|---|---|---|
| 21 : 48 : 44 | 10768 | 0.44 | 27.77 | 2.17 | − 25.19 |
| 21 : 50 : 10 | 10582 | − 0.18 | 33.11 | 2.34 | 8.18 |
| 21 : 51 : 59 | 10573 | − 0.21 | 32.35 | 2.32 | 3.44 |
| 21 : 53 : 50 | 10687 | 0.16 | 31.71 | 2.32 | − 0.56 |
| 21 : 55 : 39 | 10566 | − 0.24 | 34.23 | 2.38 | 15.19 |
| 21 : 57 : 10 | 10647 | 0.03 | 31.66 | 2.31 | − 0.87 |

For explanation of abbreviations used in the table, see Section 2.

TABLE IIg

Observational results of HR 8628 in the spectral region 6445–6645 Å which was observed on 28 October, 1985

| Mean UT of observations (h : m : s) | Photo-electron counts of continuum at 6523 Å ($s^{-1}$ $scan^{-1}$) | Variation of continuum counts (in units of $\sigma_1$) | $W(\alpha)$ (Å) | $\frac{F_{max}}{F_c}$ | Variations of $W(\alpha)$ w.r.t. its mean value (in units of $\sigma$) |
|---|---|---|---|---|---|
| 14 : 45 : 39 | 12540 | − 0.55 | 5.55 | 1.20 | − 7.31 |
| 14 : 50 : 17 | 12452 | − 0.85 | 5.69 | 1.23 | 8.18 |
| 14 : 54 : 13 | 12600 | − 0.35 | 3.27 | 1.16 | − 6.94 |
| 15 : 20 : 59 | 12754 | 0.16 | 3.98 | 1.17 | − 2.50 |
| 15 : 22 : 40 | 12776 | 0.23 | 4.84 | 1.19 | 2.87 |
| 15 : 24 : 14 | 13084 | 1.26 | 3.72 | 1.16 | − 4.13 |
| 15 : 25 : 57 | 12713 | 0.02 | 4.85 | 1.18 | 2.94 |
| 15 : 27 : 38 | 12709 | 0.01 | 4.46 | 1.18 | 0.50 |
| 15 : 29 : 06 | 12747 | 0.14 | 4.58 | 1.20 | 1.25 |
| 15 : 30 : 44 | 12683 | − 0.08 | 2.92 | 1.11 | − 9.12 |

For explanation of abbreviations used in the table, see Section 2.

range of 180–200 Å in wavelength increments of 3 Å in the spectrum. To obtain the nightly extinction values, the wavelength dependence of instrumental sensitivity and atmospheric variations, three standard stars, HR 718, 2160, and 3454, were observed on each night. The sky background plus dark counts were measured immediately preceding and following the star scans and subtracted from the results of the scans.

The details of the observational analysis have been discussed in a previous paper by Ghosh *et al.* (1988). Here we shall mention mainly the results obtained from our observations. In total, 76 and 41 Hα profiles were obtained for the program and the standard stars, respectively. All the Hα profiles have been expressed in terms of the relative flux, $F_\lambda/F_c$. Observational results of Hα profiles are given in Tables IIa–h.

TABLE IIh

Observational results of HR 1772 in the spectral region 6470–6630 Å which was observed on 28 October, 1985

| Mean UT of observations (h : m : s) | Photo-electron counts of continuum at 6523 Å ($s^{-1}$ $scan^{-1}$) | Variation of continuum counts (in units of $\sigma_1$) | $W(\alpha)$ (Å) | $\frac{F_{max}}{F_c}$ | Variations of $W(\alpha)$ w.r.t. its mean value (in units of $\sigma$) |
|---|---|---|---|---|---|
| 15 : 16 : 48 | 10782 | 0.50 | 11.91 | 1.54 | 2.75 |
| 15 : 22 : 13 | 10750 | 0.39 | 12.04 | 1.54 | 3.56 |
| 15 : 24 : 25 | 10700 | 0.23 | 11.63 | 1.55 | 1.00 |
| 15 : 26 : 29 | 10778 | 0.49 | 11.48 | 1.52 | 0.06 |
| 15 : 28 : 34 | 10821 | 0.63 | 10.92 | 1.50 | − 3.43 |
| 15 : 30 : 49 | 10774 | 0.47 | 10.50 | 1.49 | − 6.06 |
| 15 : 33 : 06 | 10736 | 0.35 | 11.10 | 1.51 | − 2.31 |
| 15 : 35 : 11 | 10510 | − 0.41 | 12.40 | 1.53 | 5.81 |
| 15 : 37 : 14 | 10389 | − 0.81 | 12.14 | 1.55 | 3.62 |
| 15 : 39 : 45 | 10396 | − 0.79 | 11.89 | 1.54 | 4.18 |
| 15 : 41 : 58 | 10369 | − 0.88 | 11.44 | 1.53 | 2.62 |
| 15 : 44 : 03 | 10280 | − 1.17 | 9.75 | 1.51 | − 0.18 |
| 15 : 46 : 08 | 11950 | 4.39 | 11.44 | 1.42 | − 10.75 |
| 15 : 57 : 23 | 10185 | − 1.49 | 11.37 | 1.53 | − 0.18 |
| 15 : 59 : 34 | 10067 | − 1.88 | | 1.53 | − 0.62 |

For explanation of abbreviations used in the table, see Section 2.

Columns 1 and 2 of each table list the mean UT of the exposure time and the photo-electron counts of continuum emission at 6523 Å (averaged over ± 5 Å) and the last four columns present the variations of continuum, the measured EW of Hα [$W(\alpha)$], the values of $F_{max}/F_c$ and the variations of $W(\alpha)$, respectively.

Since we are interested to find out the reality of $W(\alpha)$ variations, so we have to detect the total observational error (instrumental and atmospheric variations) in $W(\alpha)$ and continuum counts measurements for our program stars. Observational errors for certain Be stars have been calculated in a previous paper (Ghosh *et al.*, 1988) and accordingly we shall consider $\pm 5\sigma$ ($\sigma$, the standard deviation of measured $W(\alpha)$ for the standard star, HR 3454 = 0.16 Å) and $\pm 2\sigma_1$ ($\sigma_1$, the standard deviation of continuum counts measurements for HR 3454) as the error limits in $W(\alpha)$ and continuum counts measurements for our program stars, respectively.

## 3. Results for Individual Stars

### 3.1. HR 1772

Thirteen Hα profiles of this star were observed on the night of 28 October, 1985, and they are shown in Figure 1(a). Obtained mean value of $W(\alpha)$ is 3.22 Å and the variations of $W(\alpha)$ with respect to its mean value are within the limit of $\pm 5\sigma$, except for three

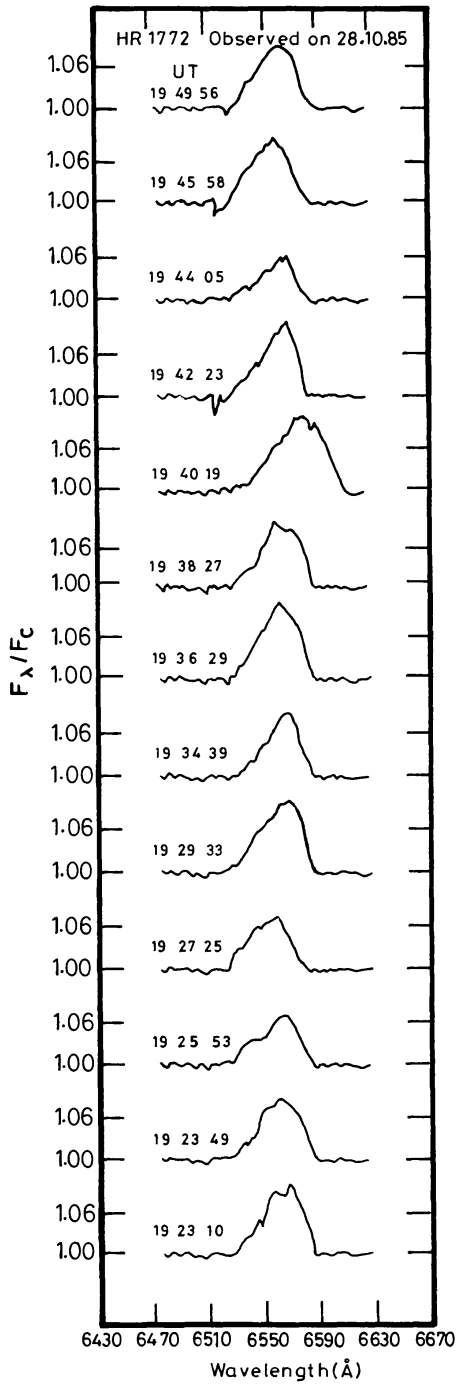


Fig. 1a. Observation of Hα profiles of HR 1772. Observing date is given on the top. UT of observations are shown to the left.

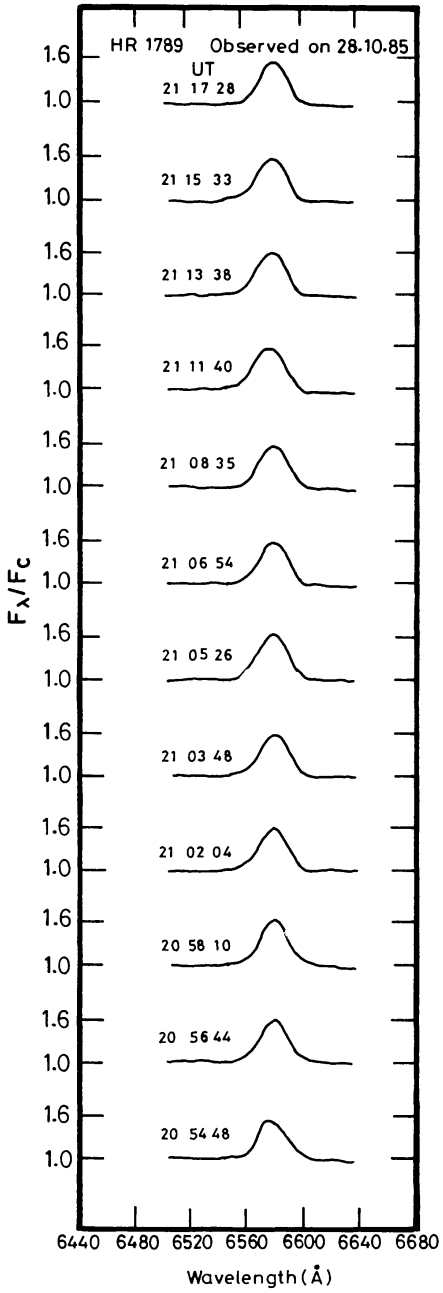


Fig. 1b. Same as Figure 1(a), but for HR 1789.

profiles (UT = 19 : 25 : 53, 19 : 40 : 19, and 19 : 44 : 05) which show variations beyond the limit of the observational error (Figure 2(a) and Table IIa). No variations of continuum counts are seen for this star (Table IIa).

### 3.2. HR 1789 (25 Ori)

In total 12 Hα profiles were obtained for 25 Ori on 28 October, 1985 (Figure 1(b)) and the obtained value of $W(\alpha)$ is 14.93 Å. Four profiles show variations of $W(\alpha)$ which are

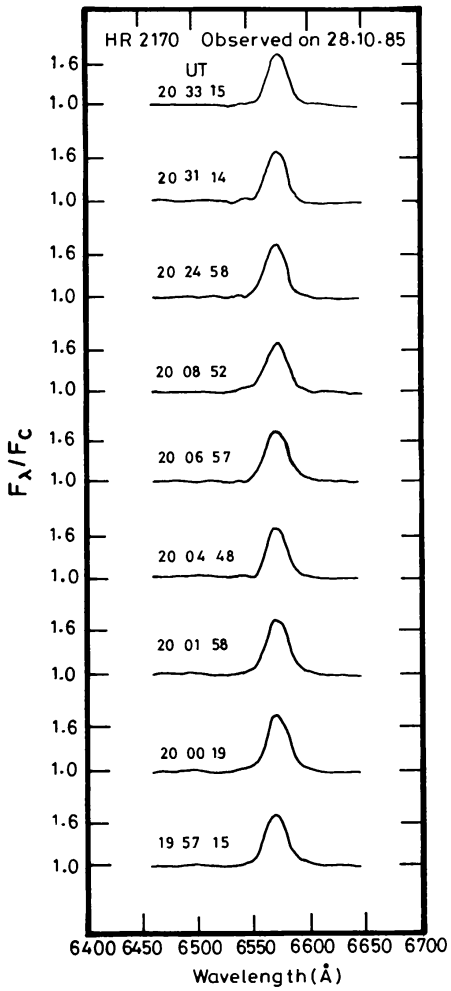


Fig. 1c. Same as Figure 1(a), but for HR 2170.

beyond the limit of $\pm 5\sigma$ and the rest of the profiles do not exhibit variations of their equivalent widths outside the limit of the observational error (Figure 2(b) and Table IIb). Also, the variations of continuum counts of all the profiles are within the limit of $\pm 2\sigma_1$ (Table IIb).

### 3.3. HR 2170

Observed Hα profiles of this star are shown in Figure 1(c) and the mean value of $W(\alpha)$ obtained from nine Hα profiles is 17.85 Å. Out of nine profiles, only three profiles show variations of $W(\alpha)$ (Table IIc) but no variations of continuum counts have been observed for HR 2170 (Table IIc).

### 3.4. HR 2249

Only five Hα profiles were obtained for this star and they are presented in Figure 1(d). Obtained mean equivalent width of Hα profiles is 2.76 Å and the variations of $W(\alpha)$ with

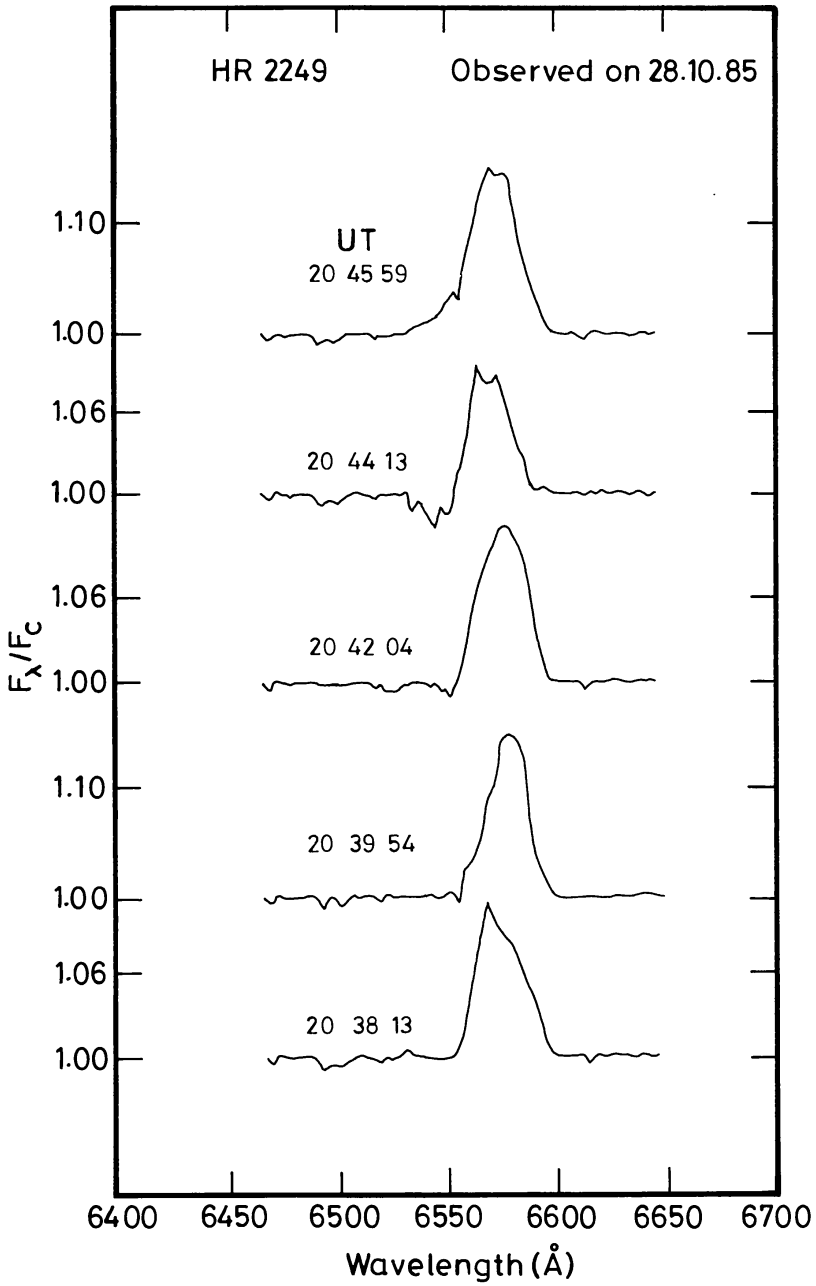


Fig. 1d. Same as Figure 1(a), but for HR 2249

respect to its mean value have been observed for two profiles with no variations of continuum counts of all the profiles (Table IId).

### 3.5. HR 2745 (27 CMa)

We have obtained six Hα profiles of 27 CMa (Figure 1(e)) and during our observations this star has shown variations of $W(\alpha)$ only for two profiles which are beyond the limit of $\pm 5\sigma$. Variations of continuum counts are absent in this star (Table IIe).

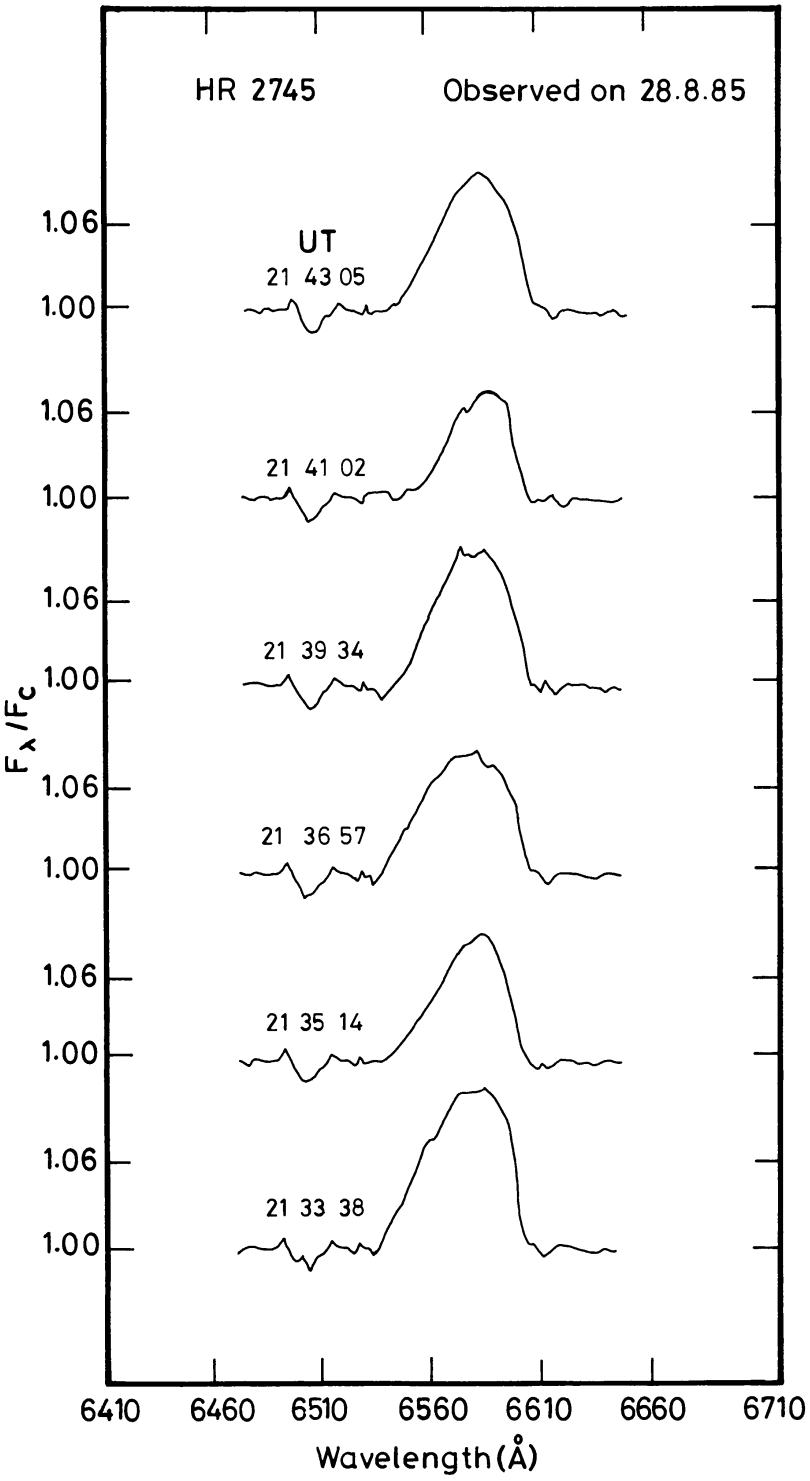


Fig. 1e. Same as Figure 1(a), but for 27 CMa (HR 2745).

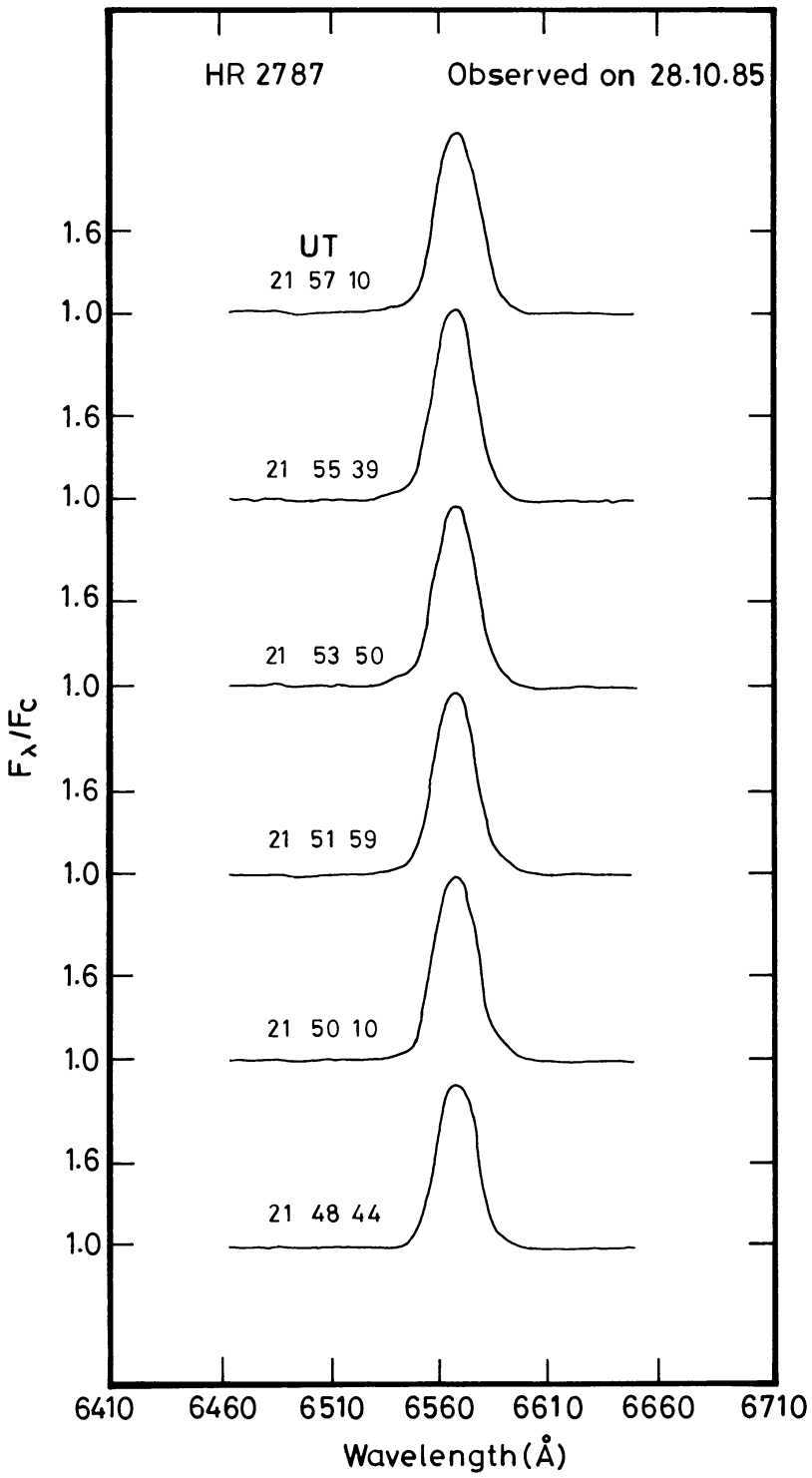


Fig. 1f. Same as Figure 1(a), but for HR 2787.

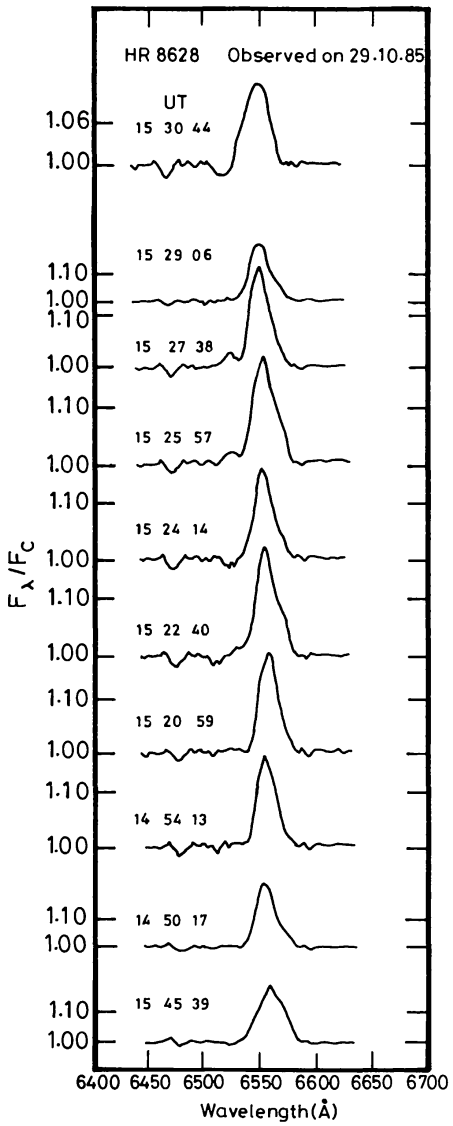


Fig. 1g. Same as Figure 1(a), but for ε Psa (HR 8628).

### 3.6. HR 2787

From six observed Hα profiles of HR 2787 (Figure 1(f)), the obtained mean value of $W(\alpha)$ is 31.80 Å. It is seen from Table IIf that the three profiles show variations of their equivalent widths which are beyond the limit of the observational error. This star also, displays no variations of continuum counts (Table IIf).

### 3.7. HR 8628 (ε Psa)

ε Psa has shown almost steady equivalent width of Hα emission line between 1974 and 1983 (Dachs *et al.* (1986). Mean value of $W(\mathrm{H}\alpha)$ of ten Hα profiles (Figure 1(g)) which were observed on 29 October, 1985, is 4.38 Å. Measured $W(\alpha)$ values obtained from

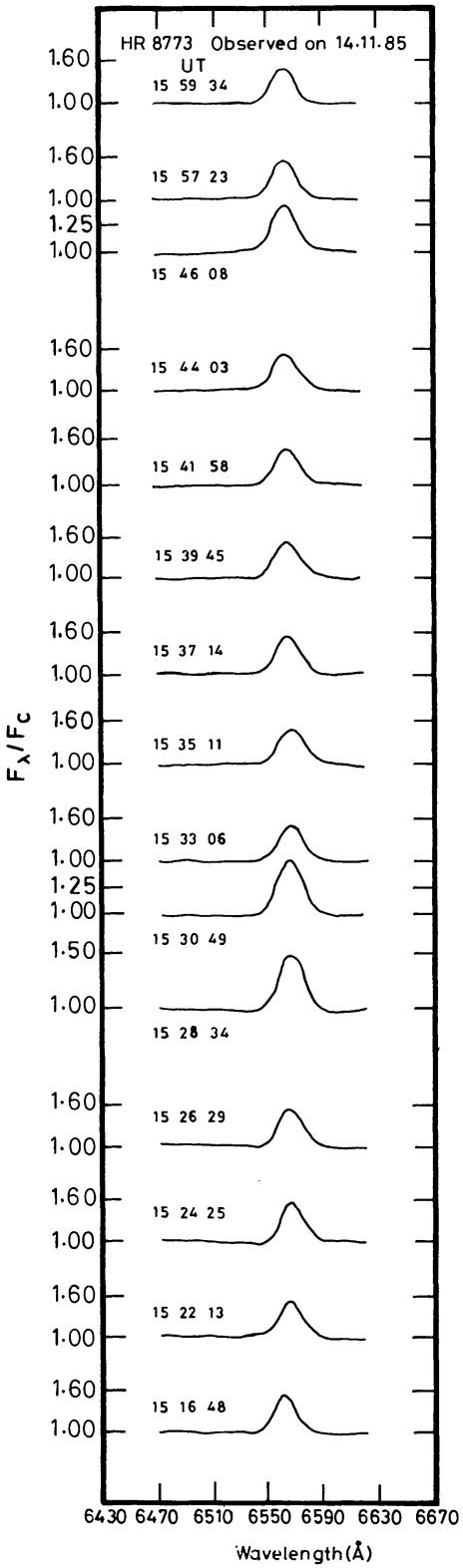


Fig. 1h. Same as Figure 1(a), but for $\beta$ Psc (HR 8773).

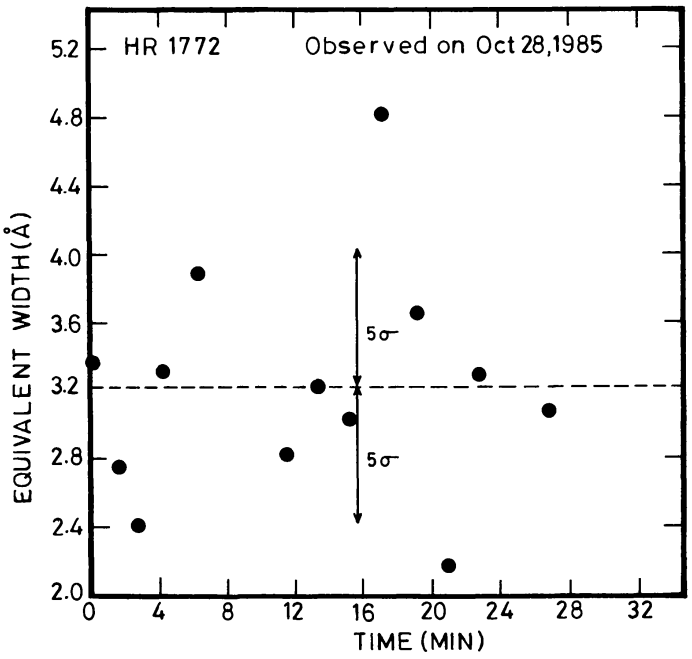


Fig. 2a. Variations of $W(\alpha)$ of HR 1772 as a function of time. Time axis represents the elapsed time in minutes from the time of first observation of HR 1772 (UT of first observation is $19^h23^m10^s$).

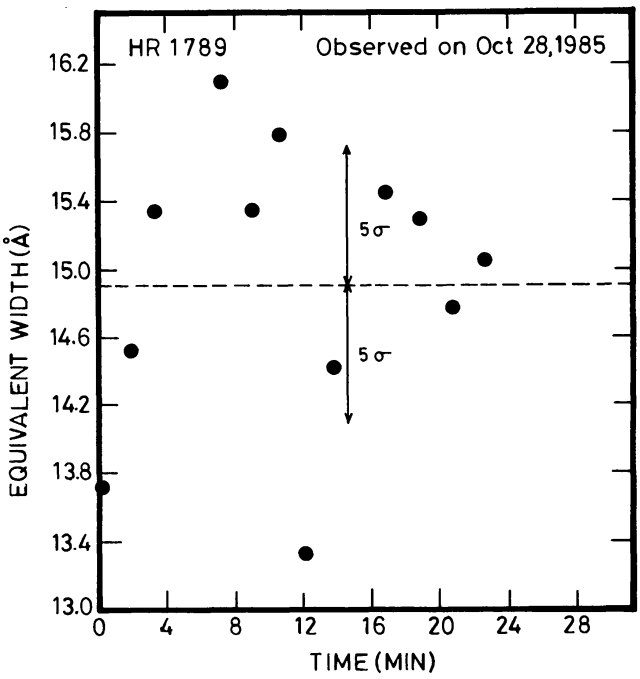


Fig. 2b. Same as Figure 2(a), but for HR 1789 (UT of first observation is $20^h54^m48^s$).

our observations for HR 8628 are plotted in Figure 2(c). It turns out that only four profiles show variations of $W(\alpha)$ (Table 2(c). It turns out that only four profiles show variations of $W(\alpha)$ (Table IIg). Variations of continuum counts are absent in $\varepsilon$ Psa.

### 3.8 HR 8773 ($\beta$ Psc)

Hα profiles of $\beta$ Psc which were observed on 14 November, 1985 are shown in Figure 1(h). Out of fifteen Hα profiles (mean $W(\alpha)$ value is 11.47 Å), only three profiles

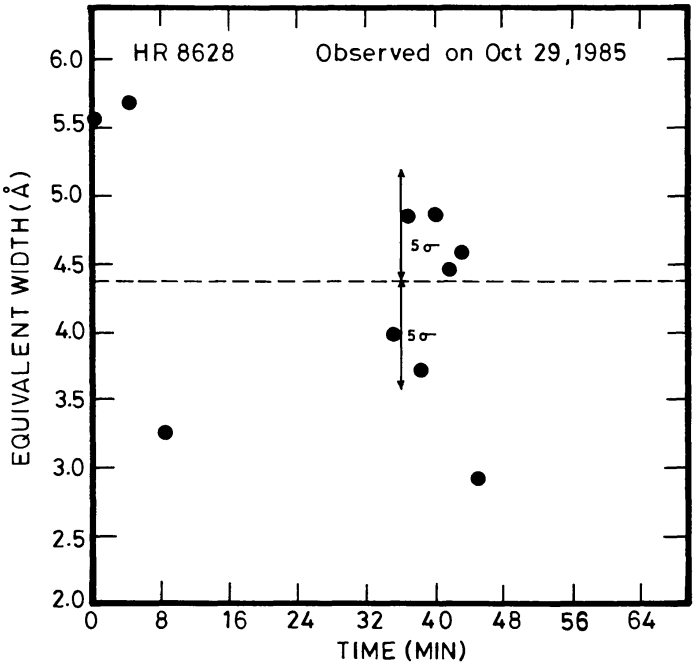


Fig. 2c. Same as Figure 2(a), but for HR 8628 (UT of first observation is $15^h45^m39^s$).

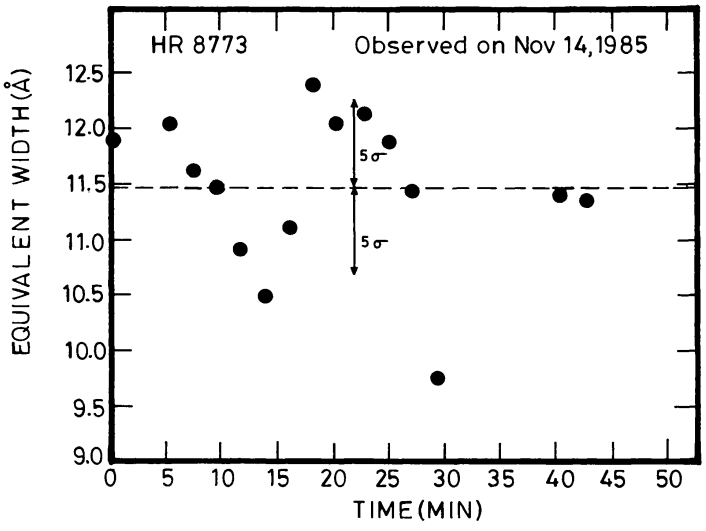


Fig. 2d. Same as Figure 2(a), but for HR 8773 (UT of first observation is $15^h16^m48^s$).

have shown variations of $W(\alpha)$ which are beyond the limit of $\pm 5\sigma$. No variations of continuum counts are seen in $\beta$ Psc (Table IIh).

## 4. Discussion

From Tables IIa–h, we find that variations of $W(\alpha)$ are present in our program stars, on a time-scale of a few minutes (may be around 4 to 6 min) and these variations are irregular in nature. Also we find that rapid continuum level variations are absent in our program Be stars. Therefore, it may be suggested that observed rapid variations of $W(\alpha)$ are mainly due to the rapid changes of bound-bound emission flux of H$\alpha$ line (stellar flux = continuum flux + bound-bound flux).

Rapid and irregular variations of bound-bound emission flux (which are emanated from the envelope) may be due to the random fluctuations of temperature and density of the envelope. But the cause(s) of these random fluctuations is not known. Therefore, in this situation it may be suggested that material circulation in the envelope (inflow and outflow of matter in the envelope) which has already been observed in many Be stars (Dachs *et al.*, 1986), may produce random fluctuations of density and temperature in the envelope.

Observed variations of $W(\alpha)$ may also be possible due to the rapid and irregular variations of full width at half intensity maximum (FWHM). But our measurements of FWHM of the observed H$\alpha$ profiles do not display any appreciable amount of variations.

Therefore, it may be concluded that the observed variations of $W(\alpha)$ of our program Be stars are due to material circulation in the envelope.

## References

Bappu, M. V. K.: 1977, *Kodaikanal Obs. Bull. A* **2**, 64.

Dachs, J., Hanuschik, R., Kaiser, D., Ballereau, D., Bouchet, P., Kozok, J., Rudolph, R., and Schlosser, W.: 1986, *Astron. Astrophys. Suppl.* **63**, 87.

Ghosh, K. K., Sanjeevkumar, T., Jaykumar, K., Kuppuswamy, K., and Rosario, M. J.: 1988, *Publ. Astron. Soc. Pacific* (in press).