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POSSIBLE DISCOVERY OF REPEATING OSCILLATIONS IN THE BRIGHTNESS OF BY DRACONIS ON TIMESCALES OF 1-3 HOURS

Considerable attention is now paid in the physics of solar-late type stars to study minutes-to-hours oscillations as probes of the internal structure of stars. Notable in this respect are variations on such timescales of the brightness (Rojzman, 1984) or the flux in emission lines (Baliunas et al. 1981, Linsky et al. 1982) which were observed in several red dwarf stars. Of course, such variations may be connected with flares and may not be a manifestation of oscillations. The task to select variations originating from stellar oscillations is difficult especially because of scarcity of existing observational data of high accuracy. No attempts have been made to discover periodicities of the order of minutes or hours in red dwarf stars, except in Baliunas et al. (1981).

A program to search for and investigate small amplitude brightness variations in the red dwarf flare star BY Dra has been carried out at the Crimean Observatory. Observations were obtained with the 5-channel photoelectric photometer installed on the 125-cm reflector. The photometer was constructed and built at the Helsinki Observatory by V. Piirola. Spectral bands are close to UBVRI. Following relations were obtained

$$\Delta V = \Delta v - 0.131\ \Delta(b-v)$$
$$\Delta B = \Delta b + 0.062\ \Delta(b-v)$$
$$\Delta U = \Delta u + 0.063\ \Delta(u-b)$$
$$\Delta R = \Delta r$$
$$\Delta I = \Delta i - 0.236\ \Delta(r-i)$$

where u,b,v,r,i, are instrumental extra-atmospheric magnitudes. All 5 magnitudes are recorded simultaneously. The time interval between successive records is 24 sec in our observations.

Continuous observations of BY Dra were interrupted every 20-30 minutes in order to observe the comparison star BD +51°2408. The magnitude differences Δm between BY Dra and BD +51°2408 and air masses F(z) were computed for each observation. Corrections for the differential extinction $\alpha\,\Delta\,F(z)$ were computed and added to Δm supposing that the extinction coefficient α does not vary during the night. Values of α were obtained from observations of the comparison star. Further uncertainties connected with variations of α will be estimated.

BY Dra and BD +51°2408 were observed for 5 nights. For one night we observed BD +51°2408 instead of BY Dra and BD +51°2410 as the comparison star. In this last night continuous observations of BD +51°2408 were interrupted every 20-30 minutes to observe BD +51°2410. The journal of observations is given in Table I.

Table I

Date, 1983	Observed star	Comparison star	Time of obs. U.T.	Number of obs.
24-25 Febr.	BY Dra	BD +51°2408	23^h45^m-03^h24^m	476x5
14 March	BY Dra	BD +51°2408	00 25 -02 46	300x5
19-20 Apr.	BY Dra	BD +51°2408	20 45 -01 21	604x5
22-23 Apr.	BY Dra	BD +51°2408	19 45 -01 31	691x5
23-24 Apr.	BY Dra	BD +51°2408	20 00 -01 30	616x5
17-18 Jun.	BD +51°2408	BD +51°2410	19 25 -00 29	556x5

Obtained time series Δm for each night were analyzed by the method of power spectra Fourier transforms. We used explicit formulae for the case of unevenly spaced data (Ferraz Mello, 1977) (a description of such method is also given in Deeming (1975)). It is supposed that the time series

$$f(t_1),\ f(t_2)\ldots f(t_N)$$

$$f(t_j) = \Delta m\,(t_j) - \overline{\Delta m}$$

$$\Sigma\, f(t_j) = 0$$

is such that

$$f(t) = y_1(t) + y_2(t) + \ldots + y_n(t) + x(t)$$

$y(t)$ are periodical functions

$$y_1(t) = C_1 \sin(2\pi\omega_1 t + \varphi_1)$$

$$y_n(t) = C_n \sin(2\pi\omega_n t + \varphi_n)$$

$x(t)$ is a chance variable with a gaussian distribution, and ω is the frequency related with the period P as $\omega = 1/P$.

The first step of computations is the determination of the coefficient of spectral correlation

$$S(\omega) = \frac{I(\omega)}{\Sigma f^2(t_j)}$$

where $I(\omega)$ is the power. $S(\omega)$ is computed for a number of values of ω. Also the semiamplitude C_1, the phase φ_1 and the frequency ω_1 are found of the function $y_1(t)$ which corresponds to the maximum of $S(\omega)$. For a given sample and a given result $S(\omega)$ it is possible to conclude whether the periodicity is significant or not.

After one periodicity is found the filtered time series can be obtained and the next step can be made i.e. computation of $S'(\omega)$ and values of C_2, φ_2, ω_2 of the function $y_2(t)$ corresponding to the maximum of $S'(\omega)$. This process is going on until periodicities found become insignificant.

Examples of power spectra corresponding to the first step are shown on Figures 1,2. They are obtained from the U-band time series of BY Dra (23-24 Apr.) - Figure 1, and BD +51°2408 (17-18 Jun.) - Figure 2. The spectrum for BY Dra displays rather high maxima in the interval $0<\omega<2\cdot10^{-2}\text{min}^{-1}$. Much lower maxima are seen in the spectrum for the comparison star, approximately in the same frequency interval. However, maxima in Figure 2 are higher than the statistical limit determined by non-periodic variations with a gaussian distribution. Probably the maxima of power spectra come from real brightness variations of the star itself in the case of BY Dra and from variations of

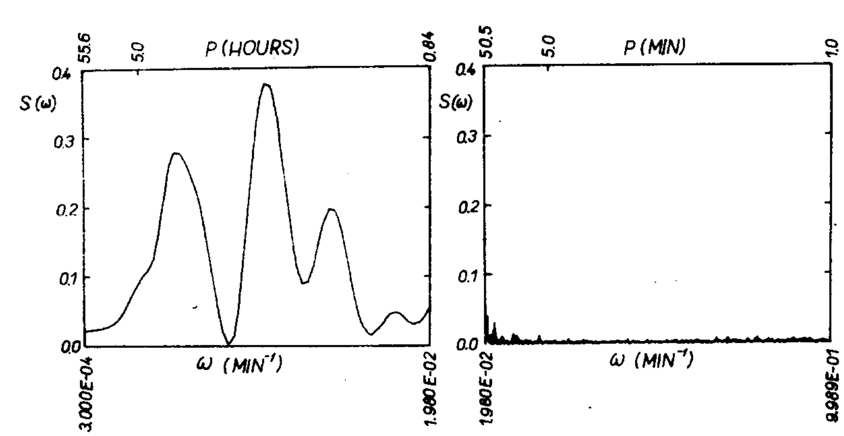


Figure 1

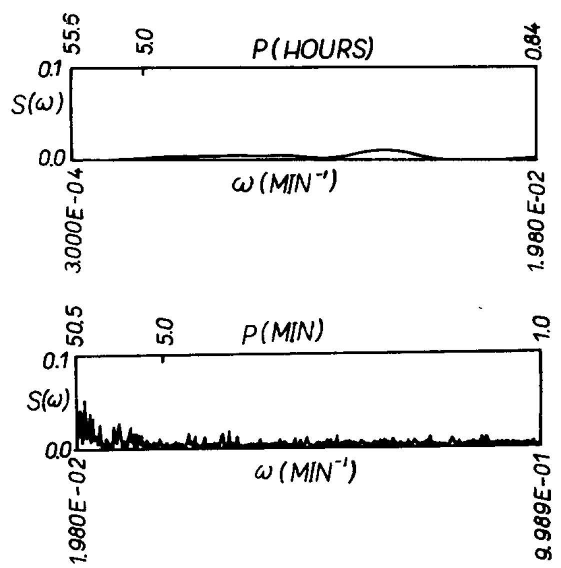
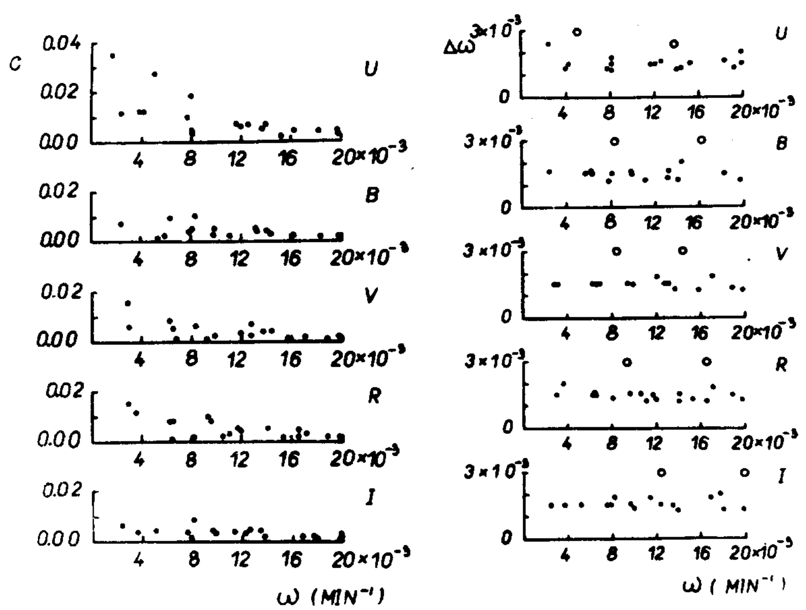


Figure 2

the extinction coefficient α in the case of the comparison star. Corresponding semiamplitudes of variations for the comparison star are from $0^m.001$ for the I-band to $0^m.003$ for the U-band. It should be noted that the differential extinction is approximately the same for pairs BY Dra, BD $+51^\circ 2408$, and BD $+51^\circ 2408$, BD $+51^\circ 2410$. Therefore, values from $0^m.001$ (I) to $0^m.003$ (U) can be taken as estimates of amplitude limits to which the detection of brightness oscillations of BY Dra is restricted by the (not taken into account) influence of extinction variations. It is also possible to estimate the errors of one measurement of Δm. These are $\pm 0^m.014$ for U and $\pm 0^m.006$ for B,V, R,I bands.

We also note that higher maxima in the spectrum of BD $+51^\circ 2408$ are concentrated in the interval of $2.10^{-2} \div 10^{-1}$ min^{-1} which includes the frequency of observing of the comparison star. The spectrum of BY Dra in this interval is approximately the same as the spectrum of BD $+51^\circ 2408$. Thus, the study of light variations of BY Dra with periods of 10-50 min in our case seems to be prevented by extinction variations. No maxima are seen in the spectra in the frequency interval of $0.2 \div 1$ min^{-1}. So we confine the further study by frequencies not higher than 2.10^{-2} min^{-1}.

For each band and each night of observations of BY Dra parameters of functions $y_1, y_2 \ldots$ were obtained as it was described. The number of filtrations was 3 because further ones were found to be unexpedient. Thus 91 maxima were selected in the spectra. For each of them the parameter $\Delta\omega$ was found which is the difference of frequencies corresponding to $S(\omega)_{max}$ and $0.5\ S(\omega)_{max}$. When these maxima are taken together they overlap so that it is impossible to select any dominating oscillation. Therefore, this part of the analysis is useful only to estimate amplitudes of oscillations and the accuracy of the determination of the frequency of some oscillation. Corresponding values are plotted in Figures 3,4. Semiamplitudes C are expressed in stellar magnitudes. In Figure 4 values of $\Delta\omega$ for the night of 14 March are distinguished by open circles to show that the accuracy of the frequency determination on that night was much lower due to the short duration of observations.



Figures 3-4

This result prompted us to examine averaged spectra to search for frequencies of dominating oscillations. The following procedure was applied. Each spectrum was normalized assuming its maximum value of $S(\omega)$ as a unity. Then spectra of 5 bands were averaged for each night and the mean spectrum for 5 nights was also obtained. These spectra are shown in the left side of Figure 5. One can see here that the only oscillation with the frequency of

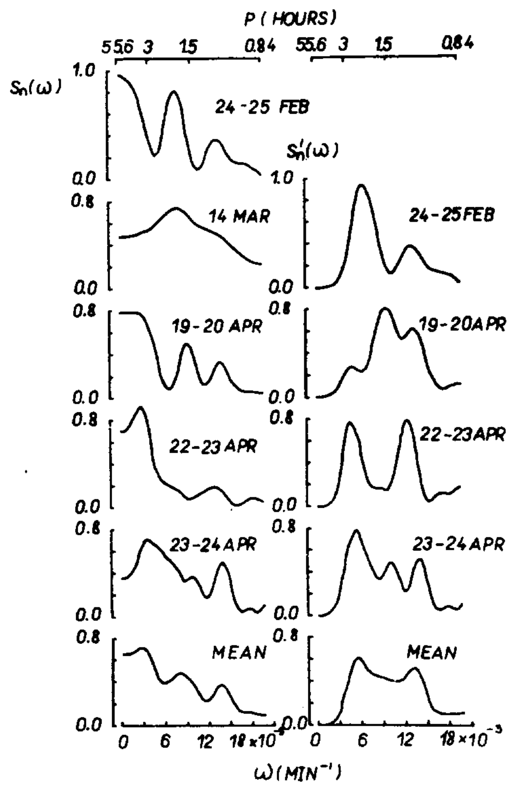


Figure 5

about $1.38\cdot10^{-2}\,min^{-1}$ repeats on all 5 nights. On 3 of the 5 spectra low frequency oscillations are strong.

It is quite possible that low frequency oscillations affect the other ones and, for this reason, spectra differ from one another. In order to exclude this effect we filtered oscillations with the frequency of $3.10^{-4}\,min^{-1}$ from each of the spectra. Owing to the finite resolution all oscillations with frequencies up to $3.10^{-3}\,min^{-1}$ were also filtered more or less. Resulting spectra are shown in the right side of Figure 5, for exception of the spectrum of 14 March which is not included because of its low frequency resolution. The oscillation repeating on spectra in the left side of Figure 5 is again repeating in the right hand. The frequency is about $1.32\cdot10^{-2}\,min^{-1}$, i.e. a little less. Also repeating in all spectra in the right side is the oscillation with the frequency of about $5.7\cdot10^{-3}\,min^{-1}$. Moreover, it seems that in the filtered spectra the third repeating oscillation exists with the frequency of about $9.10^{-3} min^{-1}$. It is clearly seen in the spectra of 19-20 Apr., 23-24 Apr. and probably it is present in the spectra of 24-25 Febr., 22-23 Apr. as an unresolved part of the low frequency maximum on the former and as a step on the later.

We conclude that our observations reveal the probable oscillation with the frequency of $1.35.10^{-2} \pm 4.10^{-4} min^{-1}$ (P = 74±2 min) and possible oscillations with frequencies of $5.7 \cdot 10^{-3} \pm 9 \cdot 10^{-4} min^{-1}$ (P = 175±28 min) and $9 \cdot 10^{-3} \pm 6 \cdot 10^{-4} min^{-1}$ (P = 111±8 min). Errors of frequencies are obtained from differences between their values corresponding to separate nights. The oscillation with the frequency of $5.7 \cdot 10^{-3} min^{-1}$ is considered only as possible because of the uncertainty introduced by low frequency oscillations. We note that the frequency of the corresponding maximum differs considerably on unfiltered and filtered spectra ($3 \cdot 10^{-3} min^{-1}$ and $5.7 \cdot 10^{-3} min^{-1}$, respectively). The accuracy of the frequency determination for this oscillation may be less than that given by us. For the other two frequencies ($9 \cdot 10^{-3} min^{-1}$ and $1.35 \cdot 10^{-2} min^{-1}$) the accuracy given seems quite appropriate.

What can be said about the origin of brightness variations? As the observations of BY Dra show there are several oscillations with frequencies repeating from night to night. Semiamplitudes are usually equal to several thousandths of magnitude, possibly increasing with decreasing frequency, seldom reaching $0^m.03$ in the U-band (see Figure 3). These oscillations could be hardly connected with the flare activity as there are no indications of flares during the intervals of our observations. If only the periods are considered it seems likely that the observed oscillations are similar to long period solar oscillations. The range of the later is 30-300 minutes, their amplitudes increase with decreasing frequency (Grec et al., 1980). The mass and the radius of the main component of BY Dra are $0.7\mathfrak{M}_\odot$ or $0.5\mathfrak{M}_\odot$ and $\geq 0.9R_\odot$, respectively (Vogt, Fekel, 1979), the gravity acceleration being $\leq 0.86g_\odot = 2.4 \cdot 10^4$ cm/sec^2. If the oscillations of BY Dra and the Sun are identified with g-modes the assumption can be made that the ranges of periods overlap because of the closeness of gravity accelerations. Just the same is observed. The resemblance of oscillations may be a consequence of the resemblance of internal structures which depend on the mass and the radius. However, it should be noted that the 5-minute oscillations are not found in this study of BY Dra.

These results are encouraging for further investigations of minutes-to-hours light variations of BY Dra and other dwarf stars.

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