A PHOTOMETRIC AND SPECTROSCOPIC STUDY OF δ^2 LYRAE

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Received 21 September 1990

ABSTRACT. The bright star δ^2 Lyr has been observed photoelectrically in the V and B pass bands for eight years. The star is a long period variable with an amplitude of about 0.2 mag and a variable period. The light curve is variable with time and the pattern of variability has changed during the whole observational interval. Spectroscopic variations are small and no reliable velocity curvehas been derived. On three spectrograms the H and K lines of Ca II appear in emission.

1. INTRODUCTION

The fourth magnitude star δ^2 Lyr (HR 7139) of spectral type M4 II has for a long time been suspected of variability. In the late fifties Biskupski (1960) observed the star in B colour, however, he did not derive the period nor the type of variability. Similarly, between 1978 and 1980 a group of observers in USSR (Dorochov et al., 1986) derived a partial light curve with one maximum present and a few scattered points along the light curve. Eggen (1977) classified the star as a SARV (small amplitude red variable) belonging to the young disk population stars and derived its absolute bolometric magnitude as -5.75 mag Eggen (1968) also found evidence for the existence of an open cluster around δ^2 Lyr. However, this idea has been discussed and dismissed earlier. Bronkalla (1963) suggested a presence of an extended star cloud in this position of the sky. The star is also listed in the Aitken (1932) double star catalogue having a faint companion 86 arcsec from the primary. It seems that the two stars form just an optical pair.

2. PHOTOMETRIC OBSERVATIONS

Since 1982 δ^2 Lyr has been observed photoelectrically in Waterloo every season and more recently, for three years the Skalnaté Pleso Observatory participated in the programme. The variable star was compared with the star HD 176051 an checked againts the star HD 175631. The stars are of spectral type G0 and G5 respectively. The measured brightness was corrected for the effect of differential extinction. It appears that the magnitude difference between the two stars remained constant. The check star being the fainter has been found to have:

$$V = 0.816 \pm 0.002 \text{ mag} \quad \text{and} \quad (B-V) = 0.244 \pm 0.002 \text{ mag}$$

with respect to the comparison star.

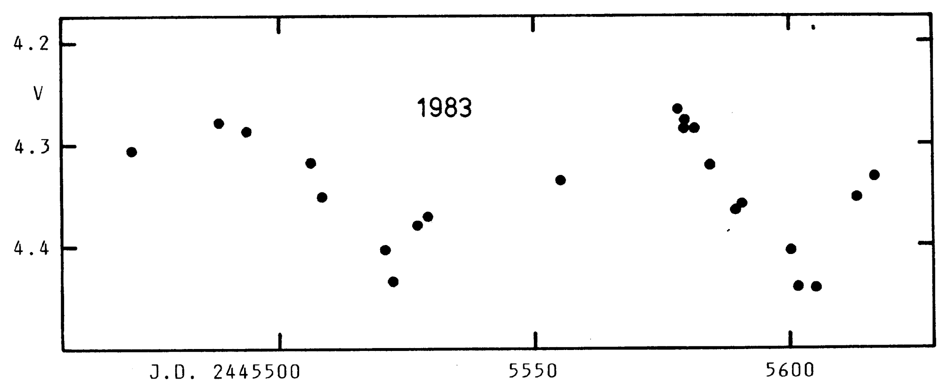

Fig. 1. Light curve for 1983 season.

The light variations of δ^2 Lyr in the V band have been recorded againts J.D in the Table 1 and the observations obtained in the 1983 season are plotted in Fig. 1. In Table 1. the average colour index for the night has also been recorded. From the Table it can be seen that the most recent light curves differ from those of the previous years both in their shape and amplitude. In the early years the light curve exhibited a high maximum followed by a broad lower maximum and ending with a small and narrow maximum. The amplitude of the high maximum is about 0.25 mag.

On the other hand the ligrh curves of 1982 and 1987-1988 are different. While the shape of the light curves has been preserved to some extent their brightness at minimum dropped by about 0.1 mag. In 1989 the star has been recorded at maximum brightness for 110 days with very low amplitude light variations.

Table 1

Photometric observations of δ^2 Lyr

J.D.	V	B-V	J.D.	V	B-V
244 5222.575	4.243	1.605	244 5912.687	4.422	1.611
5242.566	4.288	1.598	5927.647	4.437	1.637
5248.583	4.311	1.575	5929.639	4.453	1.619
5266.530	4.343	1.594	5930.631	4.462	1.606
5269.526	4.330	1.575	5932.619	4.458	1.634
5470.853	4.305	1.588	5934.592	4.438	1.622
5487.829	4.283	1.610	5943.617	4.380	1.646
5493.812	4.289	1.600	6220.790	4.291	1.609
5506.825	4.322	1.578	6223.797	4.278	1.593
5508.792	4.354	1.581	6237.746	4.329	1.554
5521.774	4.407	1.556	6241.749	4.360	1.562
5522.768	4.439	1.540	6243.764	4.359	1.582
5527.718	4.381	1.513	6246.733	4.380	1.596
5529.743	4.374	1.565	6250.722	4.415	1.591
5537.689	4.448	1.575	6259.689	4.344	1.620
5555.662	4.340	1.624	6262.669	4.327	1.591
5567.601	4.216	1.633	6263.700	4.318	1.606
5578.610	4.273	1.632	6264.710	4.297	1.589
5579.601	4.277	1.642	6270.688	4.284	1.604
5580.606	4.288	1.628	6273.674	4.290	1.604
5581.604	4.287	1.634	6274.664	4.288	1.608
5585.600	4.327	1.629	6279.649	4.282	1.610
5590.579	4.367	1.613	6280.651	4.279	1.611
5592.599	4.363	1.623	6289.624	4.282	1.602
5601.600	4.409	1.605	6294.618	4.311	1.613
5602.550	4.444	1.610	6305.600	4.370	1.613
5605.512	4.447	1.601	6309.554	4.358	1.645
5614.500	4.355	1.618	6311.558	4.351	1.639
5617.500	4.336	1.605	6320.544	4.371	1.623
5836.839	4.382	1.616	6321.594	4.361	1.634
5844.835	4.399	1.613	6323.526	4.374	1.619
5853.804	4.363	1.634	6327.560	4.324	1.621
5855.804	4.342	1.646	6329.544	4.345	1.601
5870.796	4.326	1.630	6333.538	4.352	1.608
5872.757	4.329	1.637	6336.529	4.390	1.620
5877.774	4.314	1.640	6337.532	4.377	1.622
5887.743	4.243	1.642	6338.519	4.368	1.624
5893.743	4.287	1.629	6341.521	4.370	1.629
5900.732	4.329	1.629	6362.209	4.253	1.622
5906.717	4.385	1.621	6365.208	4.218	1.622
5907.712	4.401	1.626	6368.202	4.246	1.612

Table 1 continued

244 6369.203	4.236	1.628	244 7330.783	4.355	1.634
6373.207	4.287	1.574	7339.719	4.364	1.636
6626.681	4.452	1.614	7341.749	4.357	1.640
6632.658	4.416	1.629	7347.733	4.373	1.615
6634.656	4.423	1.606	7351.732	4.312	1.626
6636.654	4.405	1.613	7357.710	4.343	1.651
6642.639	4.391	1.629	7367.697	4.450	1.616
6655.619	4.393	1.605	7393.638	4.514	1.601
6656.603	4.397	1.599	7395.639	4.494	1.623
6659.604	4.390	1.603	7400.640	4.460	1.621
6664.466	4.377	1.621	7412.610	4.434	1.633
6669.333	4.284	1.625	7414.600	4.405	1.637
6721.326	4.476	1.607	7418.592	4.437	1.619
6749.319	4.305	1.600	7419.597	4.445	1.593
6750.237	4.337	1.573	7430.538	4.485	1.666
6951.819	4.545	1.624	7703.739	4.207	1.645
6952.762	4.550	1.614	7707.728	4.235	1.660
6956.785	4.554	1.616	7718.697	4.266	1.639
6962.771	4.530	1.619	7722.686	4.273	1.669
6964.760	4.494	1.630	7723.693	4.243	1.656
6998.757	4.349	1.589	7725.675	4.204	1.672
7003.714	4.358	1.594	7747.629	4.207	1.566
7004.706	4.377	1.574	7756.617	4.207	1.635
7011.683	4.413	1.595	7763.576	4.206	1.638
7019.675	4.483	1.606	7764.583	4.185	1.643
7029.375	4.477	1.612	7769.567	4.168	1.622
7054.307	4.481	1.614	7772.571	4.167	1.596
7072.370	4.461	1.588	7794.549	4.186	1.613
7073.401	4.460	1.585	7797.538	4.155	1.635
7074.295	4.439	1.602	7799.528	4.184	1.627
7099.299	4.513	1.558	7800.533	4.158	1.619
7100.241	5.504	1.605	7804.543	4.157	1.627

The colour index, B-V, especially in the early period of observations (Table 1) shows a decrease in magnitude by 0.02 mag (the star became bluer) at the time of low maximum and the same decrease at the time of minimum following the high maximum. The colour index is the reddest at the time of the high maximum (B-V = 1.63). On the other hand, at the time of the second maximum the colour index curve remained flat. In 1989 the colour index, on the average is redder by about 0.03 mag. while the star became brighter by about 0.40 mag.

3. SPECTROSCOPIC DATA

Spectroscopic observations have been made at David Dunlap Observatory (DDO)

Table 2

Radial velocities of δ^2 Lyr

J.D.	R.V. (kms^{-1})	m.e.	No.of lines
244 0405.674	-26.99	±0.50	24
0412.688	-26.98	±0.60	24
2200.731	-30.10	±0.98	20
2298.577	-27.71	±0.45	29
2592.752	-26.74	±0.66	23
2634.682	-26.51	±0.66	29
2969.693	-25.69	±0.65	29
3341.691	-28.25	±0.55	24
4475.647	-26.20	±0.51	26
4895.512	-27.67	±0.63	29
5608.523	-27.23	±0.62	24

between 1966 and 1983. The 13 spectrograms have a dispersion of 1.2 nm/mm at $H\gamma$. The plates have been measured and reduced following the standard procedure adopted at DDO and the radial velocities have been recorded in Table 2 along with some other data. Additional observations have been extracted from the Bibliography (Abt and Biggs, 1972). The radial velocity change betweem - 25 and - 30 km/s but not reliable radial velocity curve could be derived. This is due small number of spectroscopic observations and their distribution over the time interval of 5203 days. The photometric period cannot be used as its lenght is changing from season to season, moreover the observational intervals for photometric and spectroscopic observations are not the same. For the mean radial velocity a value of -27.03 ± 0.62 km/s has been recorded. On three plates (J.D. 2442200.731, 2442969.693 and 2445608.523) the H and K lines appear in emission. However, we believe that the emission is present at all times since the remaining plates in the UV part of the spectrum are underexposed and the two particular lines are not visible at all. The emission features and the central absorption w.r. to the stellar absorption lines have been measured and their mean value derived as follows:

$(H_2 + K_2)$ V	$H_4 + K_4$	$(H_2 + K_2)$ R
-43.1 ± 2.2	-6.9 ± 1.2	32.7 ± 0.8 km/s.

A microphotometric tracing of the emission components K_2 V, K_2 R and K_4 absorption have been presented in Fig. 3.

4. DISCUSSION

At the beginning we started with the determination of the period using all data together. However, analysing the results and after the detailed inspection of light variations we came to the conclusion that besides the distorsion of the

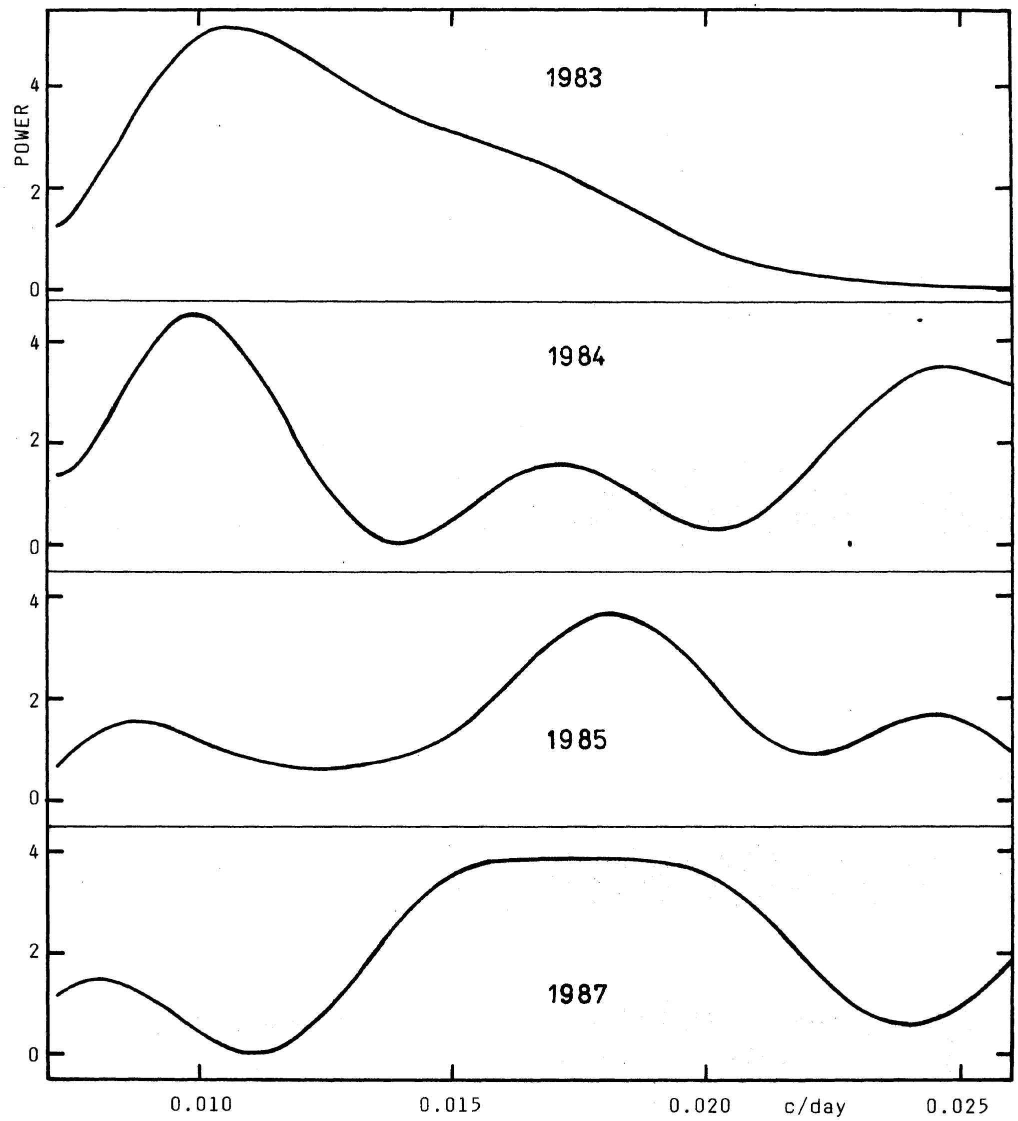

Fig. 2. Power spectrum of δ^2 Lyr. Power in arbitrary units.

light curve there are the changes of the period, too. Therefore, we analysed observations of each season separately except the 1982 season which is badly covered by observations. The photometric periods were found by a period searching computer program written by Dr. J. Zverko. The power spectrum for some observational seasons is presented in Fig. 2. The form of power spectrum curves in Fig. 2 is influenced by the number of observations, the lenght of the observational interval and low amplitude of light variations. In Fig. 2 it is clearly

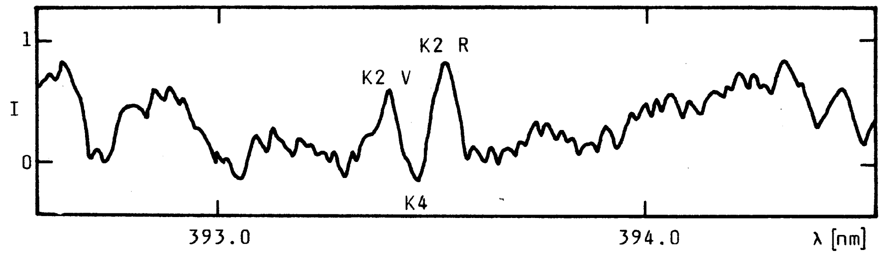

Fig. 3. Emission in the spectrum of δ^2 Lyr.

seen that the dominant frequency in 1983 season 0.0107 c/day (P = 93.4 days) in subsequent seasons gradually became smaller (the period increased) and its power substantially diminished. Further, at the beginning, in 1983 appeared double frequency with relatively low power. This is in 1984 seen very good and in 1985 became dominant in the power spectrum. This frequency reached the maximum power in 1987 comparing with other frequencies. There are lower frequencies (shorter periods) but due to low amplitude light variations and insufficient number of observations it is difficult to discover their pattern. However, we feel that the key for understanding long period variations (60 - 120 days) consists in the determination and explanation of changes which occur with shorter periods.

The classification of δ^2 Lyr as small amplitude red variable (Eggen, 1977) seems to be appropriate although it does not express the type of variability. The star is a periodic variable over certain intervals of time (Dorochov et al., 1986 and this paper) while sometimes this definition fails (for instance 1989 observational season). Similarly, the amplitude of the light curves is variable. During the interval of regular light variations the amplitude is about 0.3 mag while at other times it increases to 0.4 mag.

The form of the light curves resemble semiregular variables SRc type. The absolute bolometric magnitude corresponds the value for variables of this type. There are 56 variables of this type listed in the IIIrd edition of GCVS. For some of them the emission in the spectra was detected, among them for δ^2 Lyr,too.

Considering the spectroscopic results the star does not appear to be a pulsating variable. Thus, most likely, the light changes are due to a variable transparency of its photosphere. It has been pointed out by Wallerstein (1977) that the apparent change in luminosity may be caused by a shock heating which makes molecules to dissociate and thus reducing the opacity of the photosphere.

A model satisfying δ^2 Lyr may be similar to that discussed by Stencel (1982) and applicable to red giant stars. According to this model the stars form an extended envelope in which the emission components of Ca II and other elements are formed and the stars are surrounded by a cold circumstellar gas and dust envelope. The asymmetry of the emission components (K_2V K_2R) indicates a mass outflow which for δ^2 Lyr has been estimated to be 1.3×10^{-7} M_0/yr (Hagen et al., 1982).

The authors wish to thank Dr. J. Zverko for making available his computer program. One of us (J.T.) would like to thank the Natural Sciences and Engineering Research Council of Canada for a grant in the Bilateral Exchange Programme that enabled him to spend some time in Waterloo.

REFERENCES

Abt, H.A., Biggs, E.S.: 1972, Bibliography of Stellar Radio Velocities, Latham Process Corp. New York.

Aitken, R.G.: 1932, New Gen. Catalogue of Double Stars. Vol. II. Carnegie Inst. of Washington.

Biskupski, A.: 1960, Urania 31, 146.

Bronkalla, W.: 1963, Astron. Nachr. 287, 249.

Dorochov, N.I., Dorochova, T.N., Dragunova, A.V., Zakozhurnikova, N.N., Komarov, N.C., Motrich, V.D.: 1986, Dep. Ukr. Inst. Sci. Tech. Informations, No. 1360 -Uk86.

Eggen, O.J.: 1968, Astrophys. J. 152, 77.

Eggen, O.J.: 1977, Astrophys. J. 213, 767.

Hagen, W., Dickinson, D.F., Humphreys, R.M., Stencel, R.E.: 1982, Smith. Astrophys. Obs. Special Report 392, 231.

Stencel, R.E.: 1982, Smith. Astrophys. Obs. Special Report 392, 137.