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PHOTOMETRIC OBSERVATIONS OF δ SCUTI STARS II.HR 432, HR 515, HR 812

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Light curves of the three δ Scuti stars HR 432, HR 515 and HR 812 are presented.
For each star a "mean period" (respectively 0.13, 0.2 and 0.06 day) has been estimated and temperature variations between 0 °K and 130 °K have been deduced. Since these results confirm our previous ones, we insist on the fact that models including non linear effects are required to account for these observations.

Key words: δ Scuti stars – periodicity – temperature variations – non linear oscillations

1. INTRODUCTION

The programme of photometric and spectroscopic observations of δ Scuti stars on which we are at present engaged has been described in a first paper (Le Contel *et al.* 1974). In this paper, which we shall refer to as Paper I, the purpose of our observations, the equipment being used together with results for HR 8006 and HR 9039, were presented.

We present and discuss here the photometric observations obtained on HR 432, HR 515 and HR 812. As some observational details are similar to those observed in HR 8006, we often refer to Paper I and only insist here on specific characteristics of these three stars.

2. OBSERVATIONS

They have been performed both on the one meter and the "Danish" 50 cm telescope of the ESO Observatory, at La Silla (Chile) in 1971. We have used a 20 stages refrigerated Lallemand photomultiplier and the following filters:

1: $\lambda_{eff} = 4678$ Å Equivalent width = 26 Å
2: $\lambda_{eff} = 5535$ Å Equivalent width = 43 Å
3: $\lambda_{eff} = 6141$ Å Equivalent width = 135 Å

The reasons for their choice were given in Paper I.

The data have been digitalized, corrected for atmospheric extinction, and then plotted both for the variable and the comparison star.

We have always observed through filters 1 and 2, and through filter 3 when the night was good enough to provide both for photometric precision and for a sufficient time resolution in order to get reliable light curves. The probable error in a single observation varies from 0.002 mag. for the best nights (nights 219, 220, 222, 223) to 0.005 mag. for the others. HR 432 and HR 515 have been observed in the same observational sequence, due to their proximity in the sky and to the fact that their periods are rather long. Their common comparison star was HR 457 (A5, m_v=5.77), and we included a check star (HR 522) during the first nights of observation, in order to check the stability of HR 457.

The comparison star of HR 812 has been HR 763 (dF5, m_v=5.64).

3. RESULTS

The general characteristics of the three stars are given in table 1 (from Baglin *et al.* 1973).

Table 2 gives the general observational conditions, while tables 3, 4 and 5 give the results, Δm (HR 457–HR 432), Δm (HR 457–HR 515) and Δm (HR 763–HR 812), plotted respectively on figures 1, 2 and 3.

3.1. Period determination

Different attempts have been made to fit the light curves of δ Scuti stars by a mixture of periods–for instance recent works by Desikachary (1973) and by Millis (1973) give good approximations of the light curves by mixing two incommensurable periods. Nevertheless descrepancies always remain between theoretical and observed light curves.

But as we pointed out in Paper I (and this is confirmed by the present data), the fitting of the light curves by a complicated mixture of sine curves is not necessary in order to account for the physical phenomena. For instance, different non linear effects may lead to aperiodical curves.

As the light curves presented here are as complex and precise as the previous one for HR 8006, we have only tried to determine a "mean period" from the data for each star.

3.1.1. HR 432

This star is an evolved δ Scuti star (luminosity class III, from Δc_1), and one of the bluest. Its variability was first pointed out by Breger (1969), who found a period of 0.16 day with a 0.02 mag. amplitude in the *V* filter from observations performed over three nights. Using Breger's data, but his own method, Valtier (1972) obtained a period of 0.13 day. The difference between the two values is easily understood if one considers the limited amount of data. In order to give a new period determination for our five nights of observations, we used a periodogram analysis (Valtier 1972) and a maxima–minima method. Both procedures failed since it was not possible to adjust the phases.

From the curves obtained at JD 2441221 and 222 (in the latter an unexplained shift appears between filters 1 and 2), we can only say that a periodicity of $P=0.13\pm0.015$ day appears in the light curve of HR 432, with a maximum amplitude of 0.02 mag. in the filter 1. This period is in a good agreement with the one Valtier derived from Breger's best data.

3.1.2. HR 515

This star was observed on a single night by Breger (1969) who determined a 0.16 day period, with a 0.015 mag. in the *V* filter. One can already note that from its Δc_1 this star is one of the most evolved δ Scuti stars.

Although the observations carried out during the nights 2441 220, 2441 221 and 2441 222 (for simplicity these are referred to as 220, 221 and 222) give a fair precision, we have faced the same difficulties as in the case of HR 432: variable amplitude, presence of bumps, impossibility to find a period giving the observed maxima of the different nights. Nevertheless a "mean period" of the light fluctuations can exist around 0.2 day with an amplitude of 0.02 mag. in filter 1. This value, which is larger than Breger's, is the largest known period for a δ Scuti star, apart from δ Scuti itself.

3.1.3. HR 812

This star was found variable on two nights by Millis (1967) who determined a period of 0.037 day, with a maximum amplitude of 0.02 mag. in the V filter. This period is one of the shortest for the δ Scuti stars. Fesen (1973) obtained the similar result from observations lasting three hours.

From the principal minima on nights 219 and 223, we suggest a period (if this word means anything!) of about 0.06 day, with an amplitude of 0.02 mag. in filter 1. This result which is quite different from that of Millis and Fesen is easily understood when one examines the shape of the light curve: this 0.06 day value can be obtained from their data if one decides to treat some secondary maxima as bumps.

3.2. Light vs. temperature variations

We have used filters 1 and 2 to compare the light variations with the behaviour of a colour index "1–2".

A first qualitative result is that light and colour in the three stars studied here vary approximately in phase; this result is in agreement with previous observations of δ Scuti stars (particularly those of Paper I). These stars are bluest–i.e. hottest–at their light maximum.

Due to the photometric precision, the irregularities of the light and colour index curves though small are real. But since our samples for each star are small, it is difficult to give a complete determination of the temperature variations. Using the same approximations as in Paper I (black body model, no blanketing correction) we deduce that the variations of the effective temperature range from 0 °K (night 222 on HR 515) to 130 °K (night 224 on HR 812).

However, even if these figures give a poor idea of the real temperature variations, HR 432 seems to have the largest ones.

4. DISCUSSION

Our observations of the four HR stars 432, 515, 812 and 8006 lead us to emphasize the following points:

i) We pointed out that the star HR 515 lies higher than most of the δ Scuti stars in the instability strip. It exhibits light variations with a 0.2 day period. With the exception of δ Scuti itself, it is the only star with a period longer than 0.16 day. However in the same region of the HR diagram we can find a few other δ Scuti stars: for instance one of them is HR 1611. Until now, HR 1611 has no determined period: one can infer by an inspection of its one night observation by Millis (1967) that its period, or "mean period", is probably over 0.2 day.

Two reasons can be invoked to explain the small number of stars with periods longer than 0.16 day:

1) An observational selection due to the long period itself compared to the observation time of a single night and to the little amplitude vs sky variations which both prevent detection on a few scattered nights.
2) A physical problem related to an evolutionary effect: the time scale in this part of the evolutionary track may be very short (Chevalier 1971).

Accurate and long observational sequences on A type stars of luminosity class IV and III should lead to the discovery of more long period δ Scuti stars.

ii) Variability detection and period determination had been previously performed on one or two nights for most of the δ Scuti stars. When longer observational sequences have been obtained, the shape of the light curves is complicated (i.e. not sinusoïdal) and it is difficult to find regular and stable periodicities; that is clearly shown on Fesen's observations (1973) of HR 8494: on a run of seven hours, he pointed out four different periods and different amplitudes similar to our observations on HR 8006. However it seems generally possible to estimate a "mean period" for a given star. As expected from models (Chevalier 1971), these "mean periods" are shorter for dwarf stars such as HR 8006 and 812 than for giants like HR 432 and 515.

iii) As for HR 8006, the present data confirmed that the colour index changes rapidly and that its variations are small; this makes it difficult to obtain detailed curves of the variations although we used well defined narrow band filters and achieved good photometric precision.

We insist upon the fact that longer observations on a single star do not necessarily increase the precision on a well predetermined period value as for some other variable stars. But they do lead to a new description of the real light variations of the δ Scuti stars, and to a better knowledge of the temperature variations.

One notices that the existing theoretical models (e.g. Chevalier 1971) cannot account for these complex irregular light curves. As we pointed out in Paper I, it is necessary to consider non linear effects such as interaction between convection and pulsation which may be important in the upper layers of these stars. This work appears to be more important and more "urgent" than the elaboration of sophisticated methods for period determinations.

We intend to publish later–when their reduction is completed–the abundant spectroscopic data we have obtained simultaneously on the same stars. But we can already note that, from a visual inspection of the spectra, the line profiles of all these stars do vary from one short time exposure spectrum to another.

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Table 1 General characteristics of HR 432, 515 and 812.

Star HR spectral type	V	M_V	b - y	m_1	c_1	β	Δm_1	Δc_1	v sin i km . s^{-1}
432 A4 III	5.90	+ 0.52	+ 0.090	+ 0.166	+ 1.093	+ 2.817	+ 0.020	+ 0.217	110
515 A7 n	6.40	+ 0.69	+ 0.158	+ 0.173	+ 0.979	+ 2.777	+ 0.002	+ 0.229	80
812 A7 IV	5.20	+ 2.33	+ 0.135	+ 0.188	+ 0.837	+ 2.804	+ 0.013	+ 0.041	83

Table 2 Observational conditions for HR 432, 515 and 812.

Star HR	date 1971	Julian day 2441000+	Telescope (m)	Voltage (v)	Filter 3	Length of the sequence (day)	Spectra	P.M. temperature (°C)
432	september 5	200	1.0	1226	yes	0.12	no	+ 1
	6	201	1.0	1226	yes	0.10	yes	+ 1
	8	203	1.0	1226	yes	0.06 *	yes	+ 1
	25	220	0.5	1476	no	0.16	no	- 2
	26	221	0.5	1476	no	0.13	no	- 2
	27	222	0.5	1476	no	0.14	no	- 2
	30	225	0.5	1476	no	0.05 *	no	- 2
515	september 5	200	1.0	1226	yes	0.12	yes	+ 1
	6	201	1.0	1226	yes	0.15	no	+ 1
	8	203	1.0	1226	yes	0.06 *	no	+ 1
	25	220	0.5	1476	no	0.16	no	- 2
	26	221	0.5	1476	no	0.13	no	- 2
	27	222	0.5	1476	no	0.14	no	- 2
	30	225	0.5	1476	no	0.05 *	no	- 2
812	september 23	218	0.5	1376	yes	0.05	no	- 2
	24	219	0.5	1376	yes	0.10	no	- 2
	28	223	0.5	1376	no	0.12	no	- 2
	29	224	0.5	1376	no	0.11	no	- 2

*Due to bad atmospheric conditions, and to keep the precision constant, the observations were not taken into account.

Table 3 Values of Δm (HR 457–HR 432) versus heliocentric Julian dates for each night and each filter (unit 10^{-2} mag.)

2441 200.	FILTER 1.
0.781	-1.17
0.795	-0.62
0.804	-0.47
0.816	-0.22
0.826	0.03
0.836	0.38
0.849	0.23
0.858	0.28
0.866	0.53
0.877	0.53
0.886	0.33
0.893	0.13
0.899	-0.02

2441 200.	FILTER 2.
0.781	-0.89
0.796	-0.29
0.805	-0.19
0.817	-0.19
0.827	-0.19
0.837	0.06
0.849	0.11
0.859	0.61
0.867	0.96
0.877	0.86
0.886	0.21
0.893	-0.44
0.899	-0.64

2441 200.	FILTER 3.
0.782	-0.83
0.796	-0.66
0.806	-0.33
0.818	-0.08
0.828	0.19
0.837	0.27
0.850	0.47
0.859	0.77
0.867	0.77
0.878	0.47
0.887	-0.08
0.894	-0.48
0.904	-0.48

2441 201.	FILTER 1.
0.751	0.21
0.756	0.41
0.762	0.31
0.770	0.41
0.780	0.51
0.788	0.41
0.796	0.21
0.808	0.01
0.815	-0.24
0.819	-0.39
0.827	-0.49
0.837	-1.39

2441 201.	FILTER 2.
0.746	0.51
0.756	0.61
0.763	0.61
0.771	0.76
0.781	0.81
0.789	0.31
0.796	0.11
0.808	0.01
0.816	-0.24
0.818	-0.39
0.828	-0.89
0.838	-1.09
0.839	-1.14

2441 220.	FILTER 1.
0.689	-0.23
0.701	-0.23
0.710	0.07
0.716	0.37
0.723	0.52
0.729	0.47
0.735	0.42
0.743	0.32
0.749	0.27
0.757	0.27
0.763	0.07
0.770	-0.03
0.782	-0.38
0.790	-0.53
0.796	-0.63
0.802	-0.63
0.808	-0.50
0.817	-0.20
0.827	0.13
0.831	0.22
0.837	0.07
0.844	0.07

2441 220.	FILTER 2.
0.690	-0.26
0.702	-0.16
0.711	-0.01
0.717	-0.01
0.723	0.04
0.729	0.09
0.736	-0.01
0.743	-0.16
0.750	-0.16
0.758	-0.21
0.764	-0.26
0.771	-0.36
0.783	-0.51
0.790	-0.41
0.797	-0.21
0.803	-0.01
0.809	0.19
0.817	0.34
0.828	0.44
0.831	0.54
0.838	0.59
0.845	0.59

2441 221.	FILTER 1.
0.693	0.40
0.701	0.20
0.710	-0.15
0.717	-0.50
0.724	-0.55
0.732	-0.65
0.740	-0.70
0.746	-0.65
0.754	-0.55
0.763	-0.35
0.771	-0.10
0.778	0.20
0.782	0.40
0.784	0.45
0.790	0.80
0.797	0.75
0.803	0.65
0.811	0.35
0.818	0.05
0.825	-0.15

2441 222.	FILTER 1.
0.689	-0.82
0.697	-0.87
0.703	-0.87
0.711	-0.72
0.718	-0.52
0.725	-0.37
0.733	-0.02
0.739	0.13
0.745	0.28
0.754	0.58
0.762	0.78
0.769	0.83
0.778	0.83
0.784	0.78
0.791	0.58
0.799	0.23
0.806	-0.07
0.813	-0.27
0.821	-0.47

2441 222.	FILTER 2.
0.689	-0.21
0.697	-0.41
0.704	-0.56
0.711	-0.76
0.719	-0.66
0.726	-0.51
0.733	-0.36
0.740	-0.21
0.746	-0.06
0.754	0.24
0.763	0.59
0.770	0.74
0.778	0.89
0.785	0.94
0.791	0.84
0.800	0.34
0.807	0.04
0.814	-0.26
0.822	-0.56

Table 4 Values of Δm (HR 457–HR 515) versus heliocentric Julian dates for each night and each filter (unit 10^{-2} mag.)

2441 200.	FILTER 1.
0.784	-1.01
0.798	-0.36
0.807	-0.21
0.819	0.04
0.820	0.04
0.830	0.39
0.839	0.79
0.852	0.44
0.861	0.24
0.868	0.34
0.879	0.29
0.888	-0.31
0.895	-0.21
0.906	-0.51

2441 200.	FILTER 2.
0.785	-0.22
0.798	-0.12
0.808	-0.02
0.830	0.63
0.839	0.78
0.853	0.38
0.861	0.33
0.869	0.38
0.880	0.23
0.889	-0.27
0.896	-0.77
0.906	-1.32

2441 200.	FILTER 3.
0.786	-0.74
0.799	-0.06
0.808	0.27
0.831	0.58
0.840	0.44
0.853	0.44
0.862	0.40
0.870	0.56
0.881	-0.06
0.889	-0.11
0.896	-0.71
0.907	-1.06

2441 201.	FILTER 1.
0.748	0.56
0.758	0.56
0.765	0.46
0.773	0.56
0.783	0.46
0.791	0.36
0.798	0.36
0.810	0.36
0.820	0.16
0.830	0.06
0.842	-0.34
0.852	-0.74
0.875	-0.94
0.885	-0.99
0.894	-0.84

2441 201.	FILTER 2.
0.748	-0.10
0.758	0.10
0.765	0.25
0.773	0.45
0.783	0.60
0.791	0.25
0.798	0.35
0.810	0.30
0.821	0.10
0.830	-0.15
0.842	-0.75
0.852	-1.45

2441 220.	FILTER 1.
0.693	-0.98
0.695	-1.03
0.704	-1.43
0.712	-1.28
0.718	-1.03
0.725	-0.93
0.731	-0.73
0.738	-0.43
0.745	-0.23
0.753	-0.03
0.759	0.12
0.765	0.12
0.778	0.32
0.784	0.62
0.792	0.92
0.798	1.17
0.804	1.17
0.811	1.07
0.819	0.72
0.825	0.47
0.833	0.37
0.840	0.47
0.846	0.67

2441 220.	FILTER 2.
0.696	-1.25
0.705	-1.10
0.713	-1.00
0.719	-1.00
0.726	-0.90
0.732	-0.80
0.739	-0.75
0.746	-0.55
0.753	-0.45
0.760	-0.25
0.766	0.00
0.779	0.55
0.785	0.75
0.793	0.90
0.799	1.05
0.805	1.10
0.812	1.15
0.820	0.95
0.826	0.60
0.833	0.35
0.840	0.30
0.847	0.30

2441 221.	FILTER 1.
0.696	1.64
0.704	1.24
0.712	0.74
0.719	0.39
0.727	0.24
0.734	0.04
0.742	-0.16
0.748	-0.26
0.765	-0.56
0.774	-0.86
0.780	-0.71
0.786	-0.56
0.793	-0.46
0.799	-0.56
0.806	-0.56
0.813	-0.46
0.820	-0.11
0.827	0.94

2441 222.	FILTER 1.
0.691	-1.44
0.699	-1.34
0.705	-1.24
0.713	-1.04
0.721	-0.69
0.728	-0.34
0.735	-0.04
0.741	0.21
0.748	0.41
0.756	0.51
0.764	0.56
0.771	0.51
0.780	0.51
0.786	0.61
0.793	0.76
0.801	0.71
0.804	0.51
0.815	0.31
0.824	0.26
0.826	0.21

2441 222.	FILTER 2.
0.692	-0.99
0.700	-1.44
0.706	-1.44
0.714	-1.09
0.722	-0.74
0.729	-0.34
0.735	0.01
0.742	0.41
0.748	0.51
0.757	0.51
0.765	0.51
0.772	0.41
0.781	0.41
0.787	0.61
0.794	0.86
0.802	0.76
0.805	0.66
0.816	0.41
0.825	-0.04

Table 5 Values of Δm (HR 763–HR 812) versus heliocentric Julian dates for each night and each filter (unit 10^{-2} mag.)

2441 218. FILTER 1.

0.837	-0.23
0.844	-0.39
0.850	-0.33
0.855	0.09
0.859	0.39
0.864	0.34
0.869	0.29
0.874	0.04
0.880	-0.16

2441 218. FILTER 2.

0.838	0.26
0.844	-0.29
0.851	-0.44
0.856	-0.09
0.860	0.16
0.865	0.36
0.870	0.26
0.875	0.06
0.881	-0.24

2441 218. FILTER 3.

0.835	0.32
0.842	-0.38
0.848	-0.18
0.852	-0.29
0.857	-0.37
0.861	-0.14
0.866	0.38
0.871	0.62
0.878	0.08

2441 219. FILTER 1.

0.783	-0.26
0.785	-0.41
0.792	-0.42
0.797	-0.17
0.806	-0.01
0.811	0.14
0.816	0.59
0.822	0.65
0.827	0.37
0.833	-0.00
0.839	-0.36
0.844	-0.36
0.848	-0.36
0.849	-0.37
0.852	-0.39
0.858	-0.39
0.863	-0.37
0.868	-0.11
0.870	0.24
0.874	0.94
0.877	1.09

2441 219. FILTER 2.

0.785	-0.32
0.793	-0.55
0.798	-0.27
0.806	0.01
0.812	0.23
0.816	0.43
0.823	0.53
0.828	0.29
0.833	0.15
0.840	0.03
0.844	-0.07
0.849	-0.12
0.853	-0.22
0.859	-0.52
0.864	-0.57
0.868	-0.27
0.871	0.05
0.875	0.63
0.878	0.58

2441 219. FILTER 3.

0.782	-0.68
0.789	-0.33
0.795	-0.43
0.803	0.25
0.808	0.35
0.813	0.47
0.820	0.14
0.824	0.14
0.830	0.13
0.836	0.34
0.841	0.09
0.845	-0.04
0.846	-0.12
0.850	-0.08
0.855	-0.10
0.860	-0.20

2441 223. FILTER 1.

0.760	0.13
0.765	0.09
0.768	0.08
0.774	0.10
0.776	-0.08
0.779	-0.44
0.783	-0.71
0.787	-0.60
0.791	-0.38
0.795	-0.07
0.800	0.26
0.807	0.33
0.806	0.26
0.809	0.21
0.813	0.26
0.818	0.50
0.821	0.73
0.825	0.71
0.828	0.51
0.833	0.36
0.837	0.03
0.842	-0.41
0.846	-0.69
0.852	-0.74
0.856	-0.59
0.859	-0.41
0.864	0.06
0.869	0.31
0.872	0.16
0.876	0.15
0.881	0.01

2441 223. FILTER 2.

0.761	0.45
0.765	0.38
0.769	-0.07
0.775	-0.27
0.780	-0.24
0.784	-0.34
0.788	-0.42
0.792	-0.32
0.796	0.06
0.801	0.38
0.804	0.38
0.807	0.22
0.810	0.20
0.814	0.18
0.819	0.26
0.822	0.38
0.826	0.38
0.829	0.18
0.834	-0.12
0.838	-0.20
0.843	-0.52
0.847	-0.60
0.853	-0.47
0.856	-0.27
0.860	-0.01
0.865	0.18
0.869	0.16
0.873	0.08
0.877	-0.02
0.882	-0.05

2441 224. FILTER 1.

0.764	0.10
0.768	0.20
0.772	0.10
0.775	-0.15
0.778	-0.15
0.781	-0.15
0.786	-0.17
0.791	-0.26
0.796	-0.25
0.799	-0.25
0.802	-0.40
0.806	-0.65
0.812	-0.50
0.817	-0.25
0.822	0.35
0.827	0.80
0.831	0.90
0.836	0.63
0.840	0.57
0.843	0.55
0.849	0.20
0.852	-0.07
0.856	-0.25
0.860	-0.33
0.864	-0.29
0.868	-0.21
0.872	-0.17
0.876	-0.03

2441 224. FILTER 2.

0.765	0.53
0.769	0.18
0.772	-0.07
0.776	-0.08
0.779	-0.03
0.782	0.04
0.786	0.18
0.792	-0.02
0.797	-0.33
0.800	-0.52
0.803	-0.62
0.807	-0.72
0.813	-0.52
0.818	-0.22
0.823	0.10
0.828	0.28
0.832	0.23
0.837	0.28
0.840	0.18
0.844	0.13
0.849	0.13
0.853	0.10
0.857	0.18
0.861	0.18
0.865	0.10
0.869	0.13
0.872	0.13
0.877	0.08

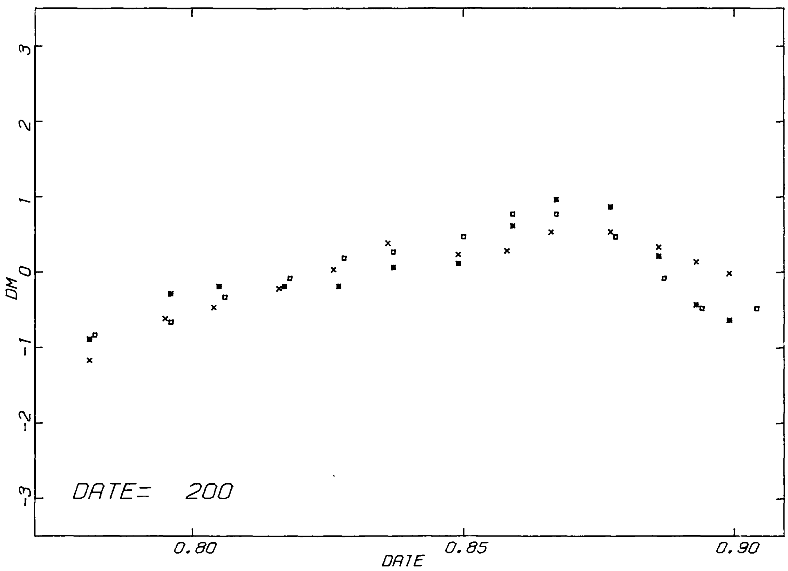

Figure 1 Light curves for HR 432.
Symbols: crosses: filter 1
dots : filter 2
squares: filter 3
Ordinates in hundredth of a magnitude.

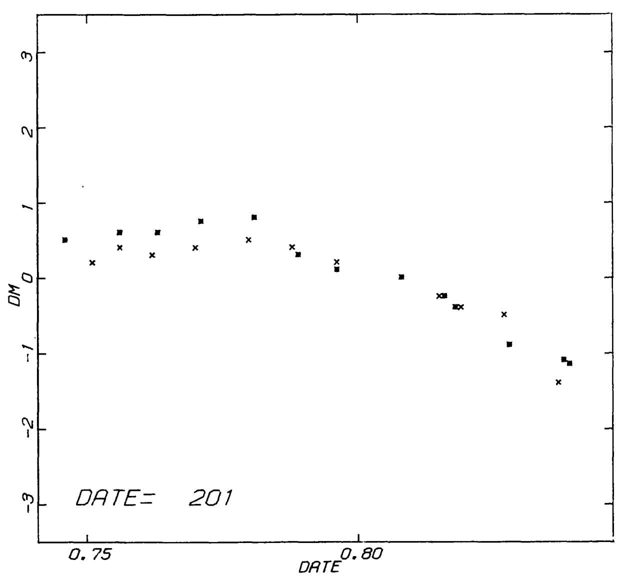

Figure 1 *(continued)*

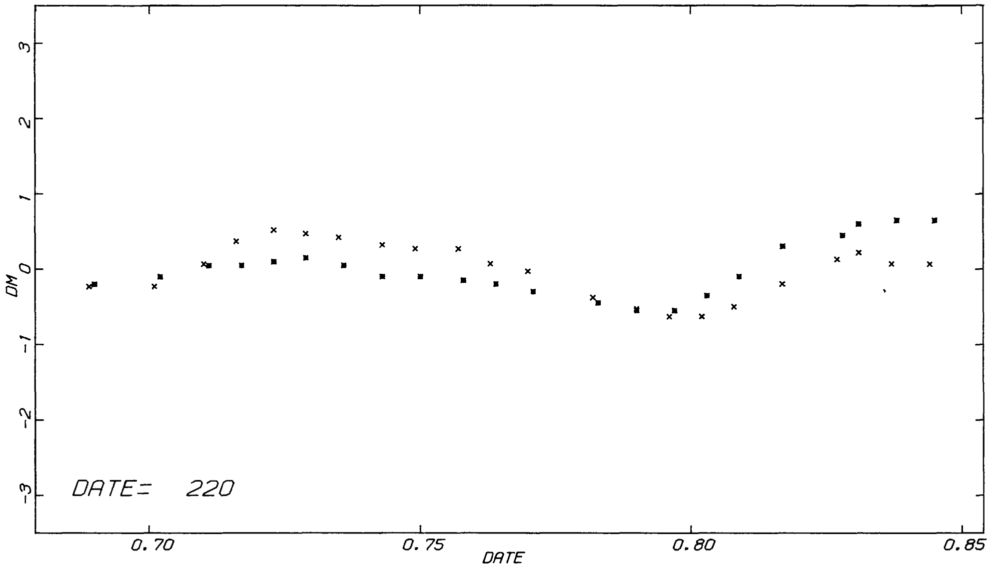

Figure 1 *(continued)*

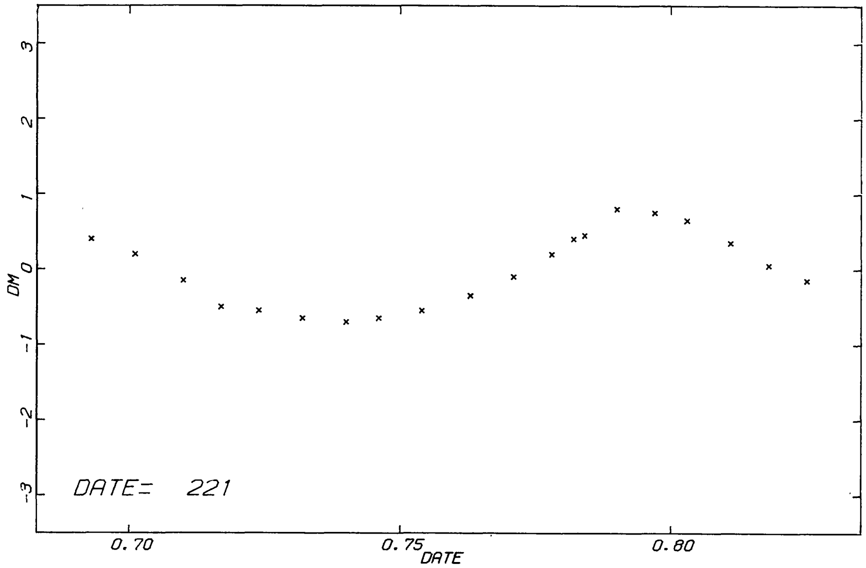

Figure 1 *(continued)*

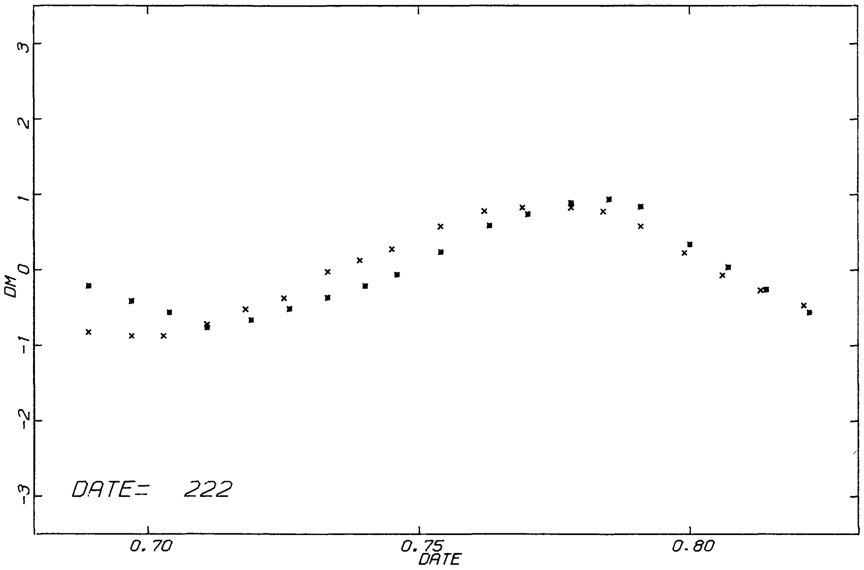

Figure 1 *(continued)*

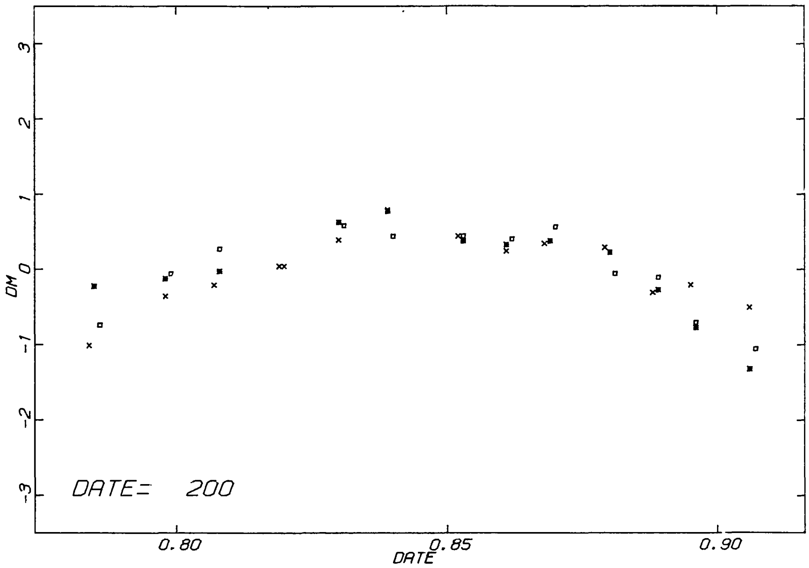

Figure 2 Light curves for HR 515.

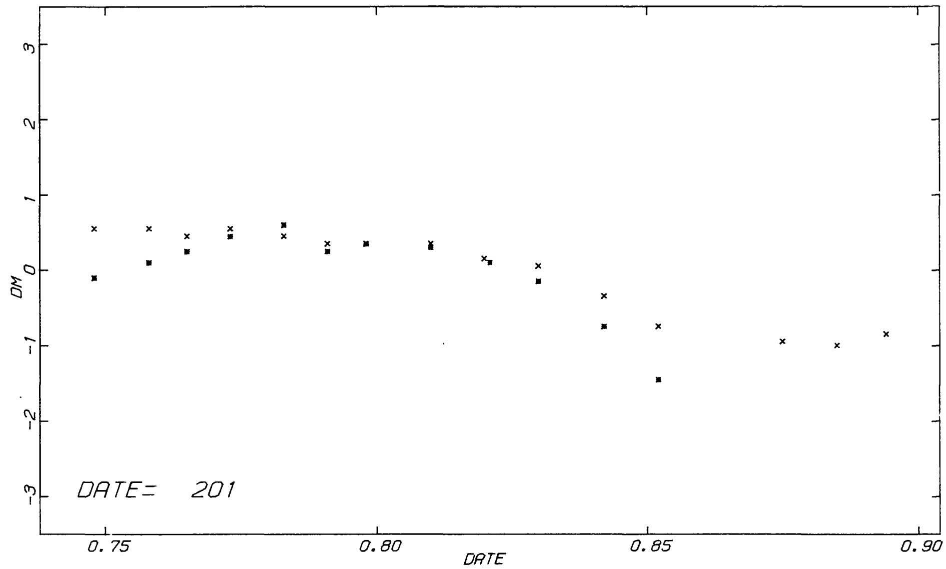

Figure 2 *(continued)*

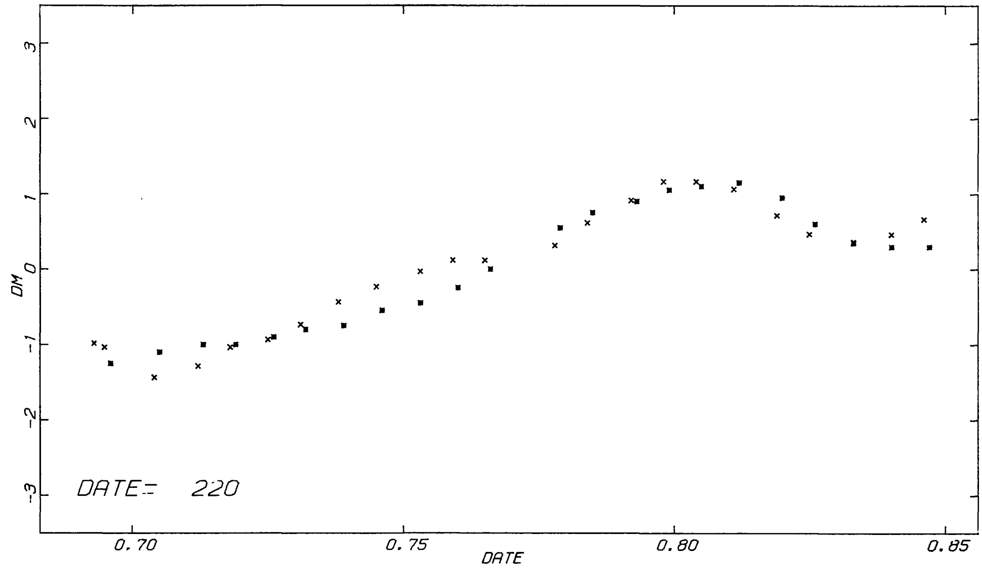

Figure 2 *(continued)*

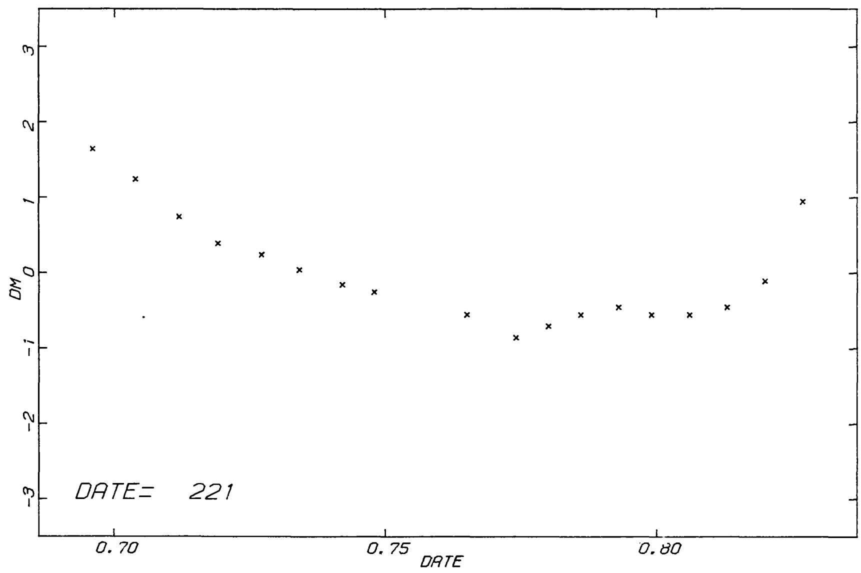

Figure 2 *(continued)*

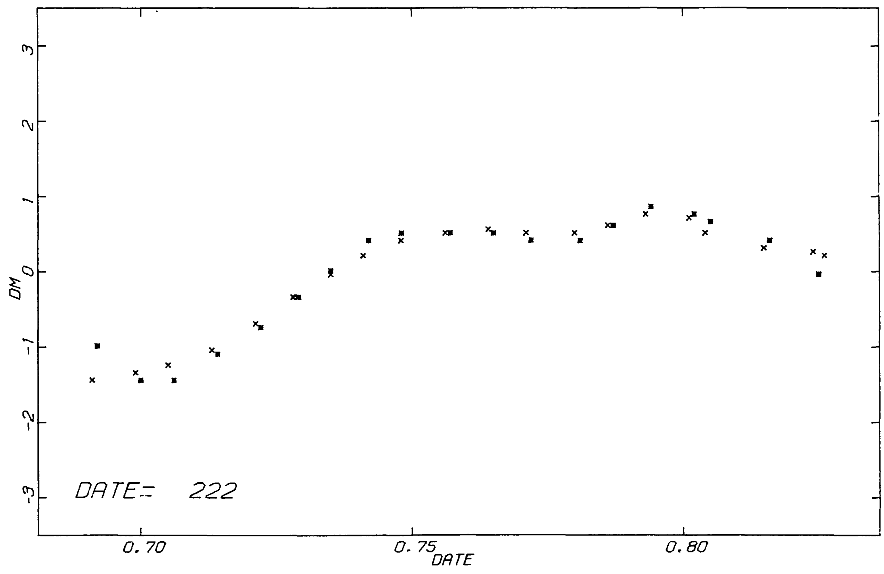

Figure 2 *(continued)*

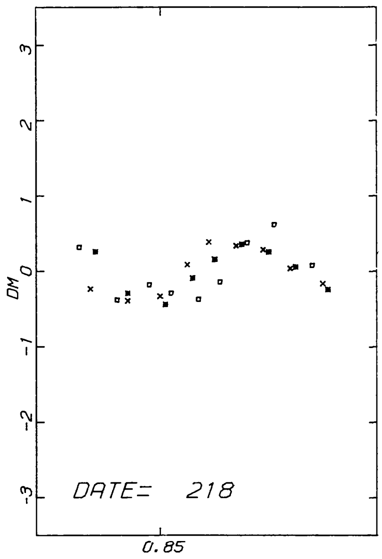

Figure 3 Light curves for HR 812.

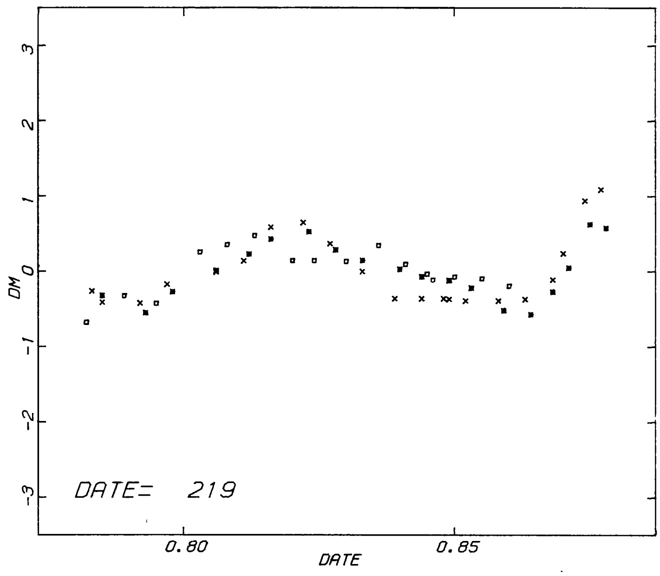

Figure 3 *(continued)*

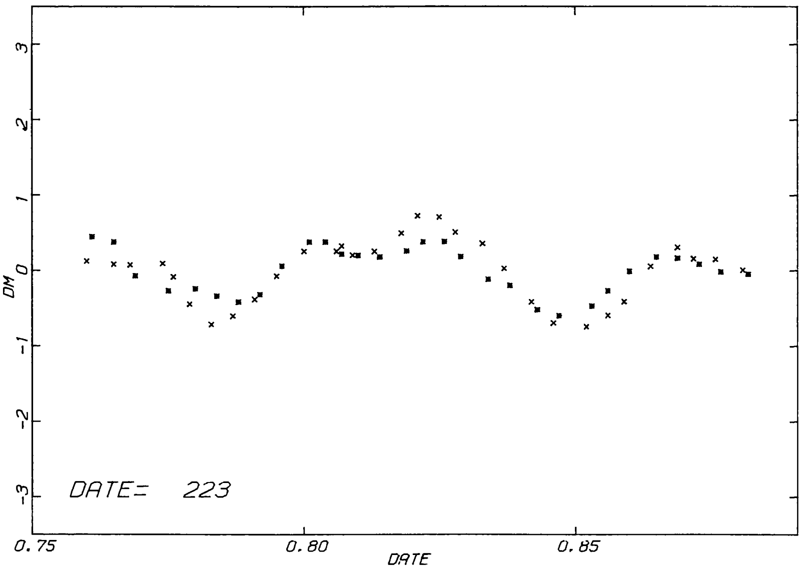

Figure 3 *(continued)*

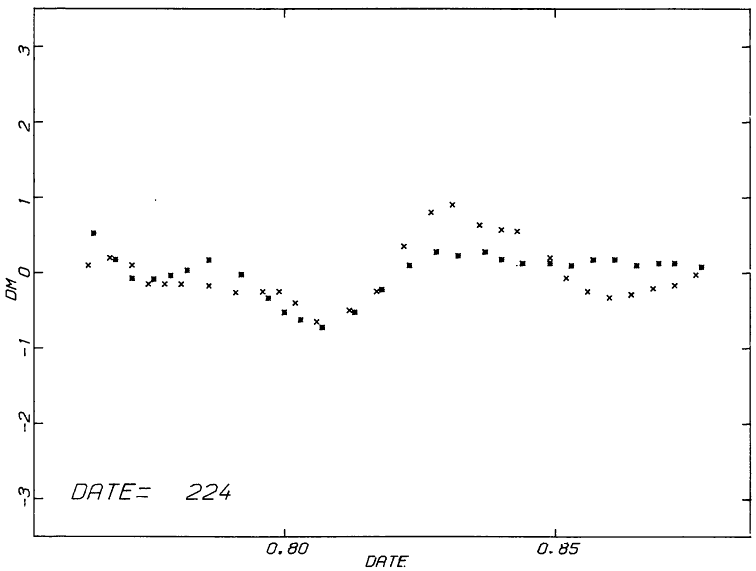

Figure 3 *(continued)*