Rev. Mexicana Astron. Astrof., 5, 261-269 (1983)

THE INTERMEDIATE AND NARROW BAND PHOTOELECTRIC STUDIES OF SOME DELTA SCUTI STARS

C. Ibanoğlu, A.Y. Ertan, Z. Tunca, O. Tümer
and S. Evren

Ege University Observatory
Bornova, Izmir, Turkey

Received 1982 February 10

RESUMEN

Se ha efectuado fotometría fotoeléctrica de banda intermedia y banda ancha de las variables de tipo Delta Scuti: 28 And, 28 Aql, κ Boo y 44 Tau y se han redeterminado los parámetros físicos así como los periodos promedios de éstas. Se presentan y se discuten las curvas de luz y sus variaciones.

ABSTRACT

The intermediate and narrow band photoelectric photometry of the Delta Scuti type variables 28 And, 28 Aql, κ Boo and 44 Tau were done and the physical parameters, average periods were redetermined. The light curves are presented and their variations are discussed.

Key words: **PHOTOMETRY – STARS-DELTA SCUTI – STARS-VARIABLES**

I. INTRODUCTION

The Delta Scuti stars are short-period variables located in the instability strip of H-R diagram with spectral types between A2 and F5 and luminosity classes between V and II (Breger 1979). The pulsation periods are generally smaller than $0^{d}.3$. The average amplitude of light variations are about $0^{m}.02$ which makes it difficult to discover new Delta Scuti stars with small amplitudes and to detect the changes of the amplitudes.

The variations in effective temperatures and surface gravitites for small amplitude variables can be determined with intermediate band photometry. The combined Strömgren-Crawford $uvby\beta$ system (Strömgren 1966) appears to be an ideal system to investigate the variations of these parameters. The parameters of intermediate band photometry have been determined for bright stars by Strömgren and Perry (1965) and the β indices by Crawford *et al.* (1966). Almost all of the physical parameters of the Delta Scuti stars were derived by combining the results of these two investigations. So far these parameters were obtained only for a few stars with the simultaneous $uvby$ and β photometry.

Leung (1970) and Eggen (1970) suggested that the Delta Scuti stars form two separate groups in the H-R diagram according to their luminosities or masses. The first group includes the stars with luminosities of about $0^{m}.6$ and masses of about 2 $M_{\odot}$ while the second with luminosities of about $1^{m}.9$ and masses of about 1.7 $M_{\odot}$. The variables in the former group lie about 2 mag above the main sequence and have periods longer than that of the variables in the later group. Later Chevalier (1971) found some discrepancies in the indices calculated by Leung. Baglin *et al.* (1973) mentioned that the existence of such two groups depends on the distribution of both non-variable and variable stars and, therefore, these distributions do not appear different to any statistically significant degree. They have also noted that the cluster data do not confirm the existence of such two instability boxes. The results from the present study do not support the existence of such groups.

Four stars were selected for the simultaneous $uvby\beta$ photometry. Two of them are of short period, and others are of longer period Delta Scuti stars. The main purposes of this investigation were as follows: a) to obtain the light and color variations in successive nights, b) to redetermine the physical parameters, and c) to detect the multiple period variations.

II. OBSERVATIONS

The observations were made at the Ege University Observatory from December 1979 through November 1980. The 48-cm Cassegrain telescope was used with EMI 9781A photomultiplier. The characteristics of the filters used at the observations are given in Table 1.

TABLE 1

CHARACTERISTICS OF THE INTERMEDIATE AND NARROW BAND FILTERS

Filter	λ_{max} (A)	Half width (A)	Max. Transp. (%)
u	3500	370	40
v	4130	190	48
b	4670	200	60
y	5460	210	58
Hβ (wide)	4860	150	75
Hβ (narrow)	4860	30	65

Because of the small magnitude variations to be measured, the technique of differential photometry was applied. Two or three comparison stars were selected for each variable star. At least one of the comparisons for each variable is a standard of intermediate band photometry. The comparison stars were chosen from among the stars with visual magnitudes, spectral types and coordinates as close as possible to the variable stars. Table 2 shows the characteristics of both variable and comparison stars. The first comparison stars were taken as primary comparisons for intermediate band photomety, while the second ones for narrow band photometry. The comparison stars numbered 1 have also been used, except that of 28 And, in the previous observations made by several investigators. On the other hand, HR 5062 the narrow band comparison of κ Boo is an intermediate band standard, and therefore it was also used for intermediate band comparison.

The primary comparisons were checked with the standard comparisons by observing two or more times in each night.

TABLE 2

THE MAIN CHARACTERISTICS OF VARIABLE AND COMPARISON STARS

Star	HR	α (1900)	δ	m_v	Sp
28 And	114	$00^h24^m51^s$	29°12′	$5^m.17$	A
Comparison 1	133	00 27 19	27 02	6 .49	A0
Comparison 2	134	00 27 33	27 44	6 .28	K0
Comparison 3	63	00 11 52	38 08	4 .61	A2
44 Tau	1287	04 04 44	26 13	5 .40	F3
Comparison 1	1269	04 00 49	28 44	5 .32	F1
Comparison 2	1341	04 13 41	21 32	5 .24	A
κ Boo	5329	14 09 54	52 15	4 .54	A7
Comparison 1	5404	14 21 48	52 19	4 .06	F7
Comparison 2	5062	13 21 13	55 31	4 .01	A5
28 Aql	7331	19 14 59	12 11	5 .34	F0
Comparison 1	7332	19 15 11	11 21	5 .99	A3
Comparison 2	7280	19 07 27	26 34	6 .25	F5
Comparison 3	7446	19 31 31	07 15	4 .96	B0.5

The differential magnitudes were taken as comparison minus variable for 28 And and 28 Aql, and variable minus comparison for κ Boo and 44 Tau. The extinction coefficients were obtained for each night by using the observations of primary comparisons and then all the differential magnitudes were corrected for atmospheric extinction.

The β index of the narrow band photometry was defined by Strömgren (1966) as

$$\beta = m(\mathrm{HW}\ 30) - m(\mathrm{HW}\ 150)$$

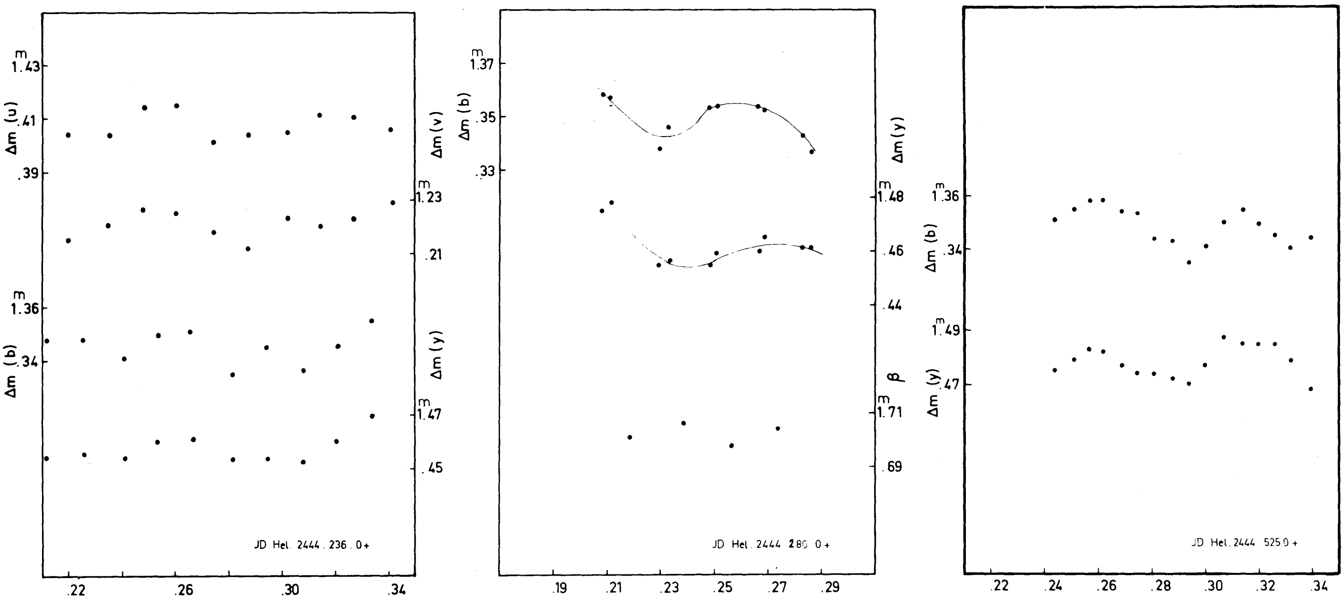


Fig. 1*a,b,c*. The light curves and narrow band observations of 28 And.

which indicates the magnitude difference for the same wavelength at the same time. Therefore this index is not affected by atmospheric extinction. On the other hand, the epochs of observations were converted to the heliocentric Julian Days.

III. LIGHT CURVES

a) *28 Andromedae (HR 114)*

This star has been observed during five nights and some of the resulting light curves plus one night's narrow band observations are shown in Figures 1*a, b* and *c*. The amplitudes of the light curves are less than $0^{m}.02$, whereas Breger (1969) gave an amplitude about $0^{m}.035$ in the *V* band of the *UBV* system. Because of the very small magnitude in light variations nothing can be said about the changes of amplitude. However, the shape of the light curves seems to vary from cycle to cycle. Apart from these changes the shapes of the light curves seem to differ in each color even if they were obtained during the same cycle. This may arise from the uncertainty in the photometry with an amount of a few thousandths of a magnitude because the amplitude is too small. The one period narrow band observations indicate no variations in the β indices. As it will be given later the $b-y$ variation during one cycle is very small.

b) *44 Tauri (HR 1287)*

The variable 44 Tau has been observed on seven nights. The resulting light curves are shown in Figures 2*a, b, c, d* and *e*. The amplitudes of the light curves change between $0^{m}.04$ and $0^{m}.14$. 44 Tau is one of the larger amplitude Delta Scuti variables and therefore the variations in the amplitude are very well detected. The variations in the

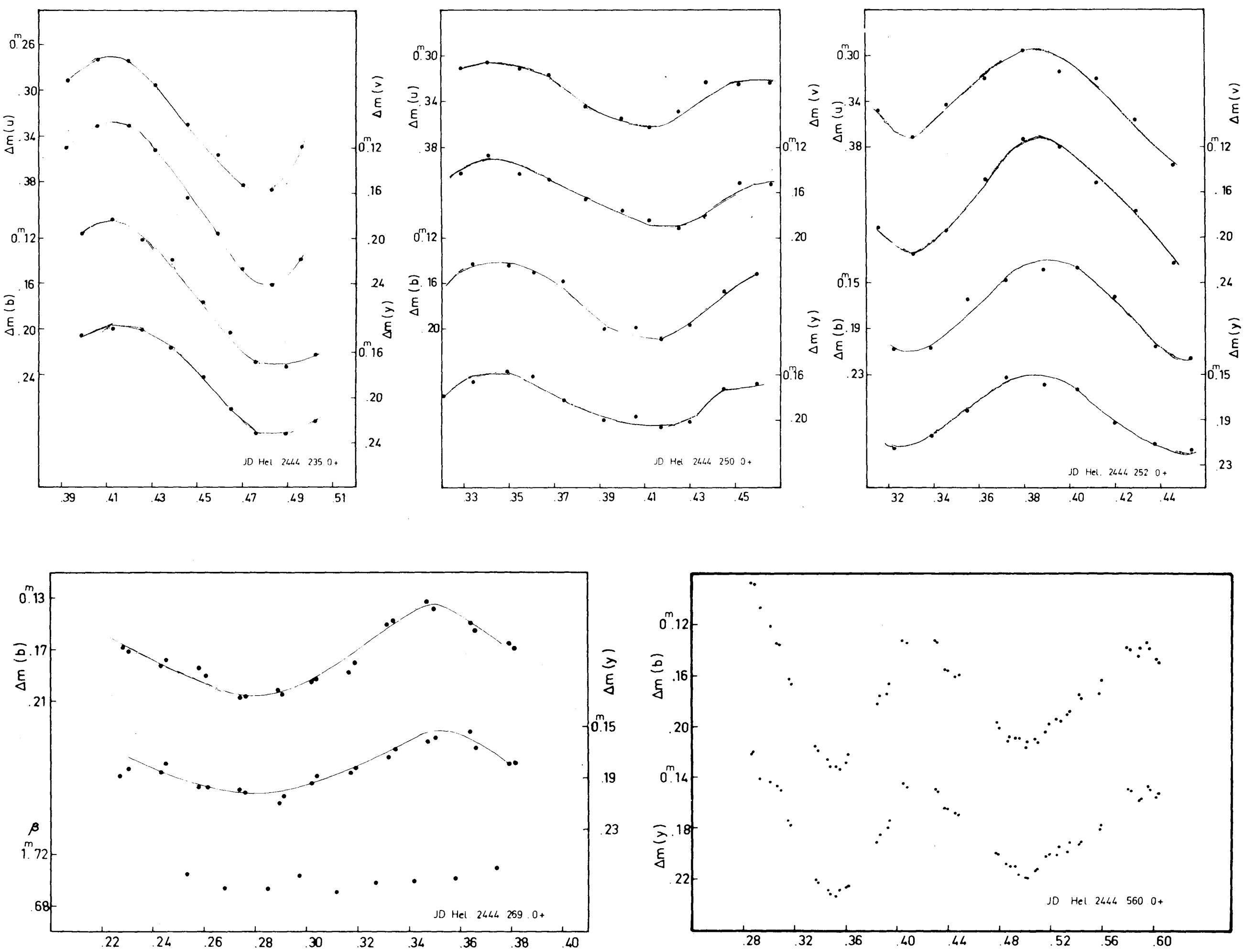


Fig. 2*a, b, c, d, e*. The light curves and narrow band observations of 44 Tau.

amplitudes of the light curves were explained with the presence of the second period by Desikachary (1973) and Wizinowich and Percy (1979). However Morguleff, Rutily and Terzan (1976) concluded that no periodicities were present in the pulsation of 44 Tau.

c) *κ Bootis (HR 5329)*

The star has been observed on six nights in the *uvby* and four nights in the β system. Some of the light curves are shown in Figures 3*a, b, c* and *d*. The amplitudes of the light variations are about $0^m\!.02$, which is smaller than $0^m\!.04$, the value given by Millis (1966). The light curves are generally asymmetric and the amplitudes vary from cycle to cycle. The narrow band photometry indicates that the β index is changing systematically during one cycle. The value of β index is smaller when the star is at maximum light and is larger at minimum light. As it will be seen later the $b-y$ variation during a cycle is very small in this star.

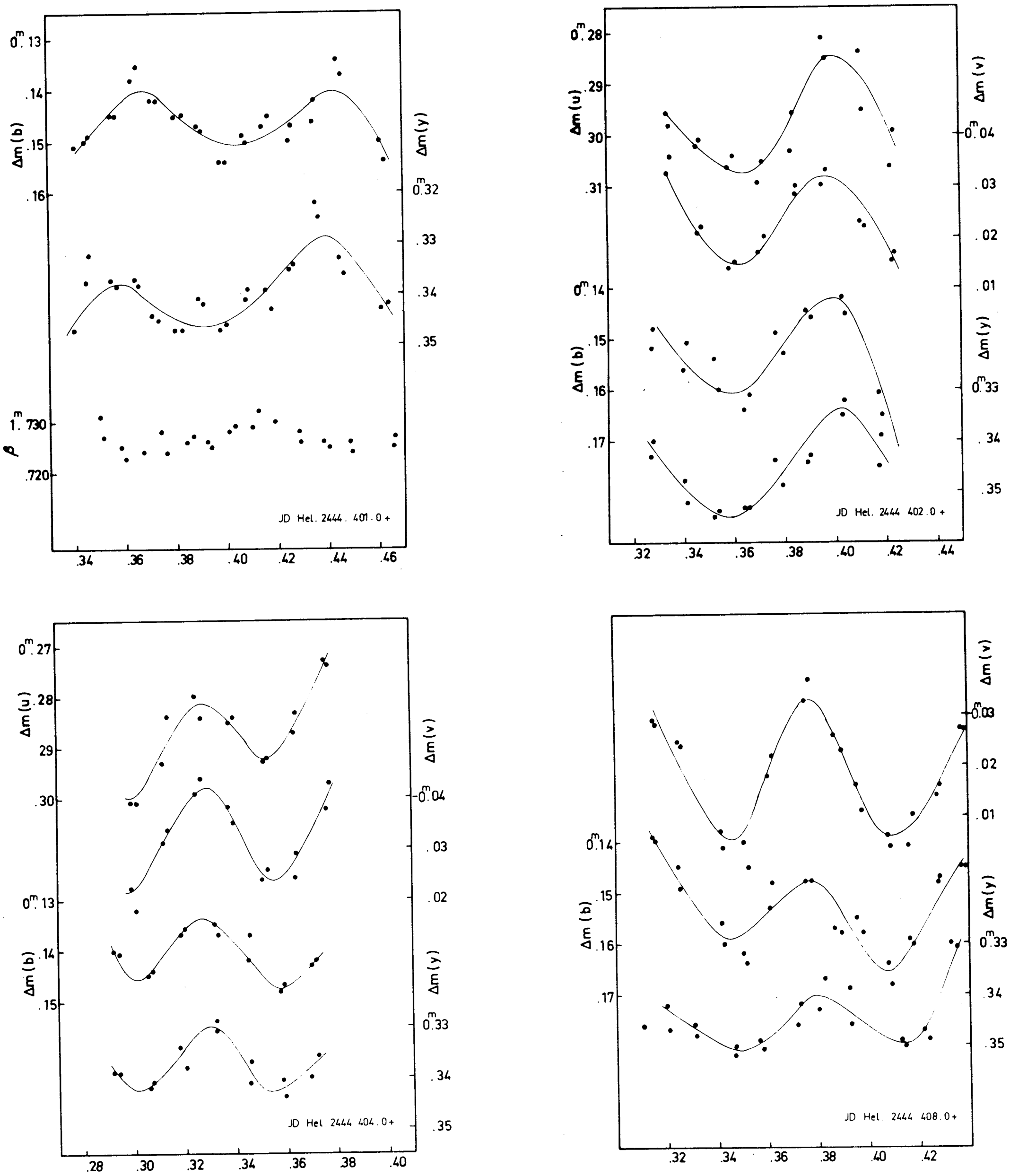


Fig. 3*a, b, c, d.* The light curves and narrow band observations of *κ* Boo.

d) *28 Aquilae (HR 7331)*

This star has been observed on eleven nights. The light curves obtained from ten nights' *uvby* and two nights' β photometry are shown in Figures 4*a, b, c, d, e, f* and *g*. These figures clearly show that the amplitudes of the light variation, which are less than $0^{m}.06$, vary from night to night. Therefore, the shape of the light curves is affected by the amplitude variations. To obtain the period of amplitude variations, the star was observed on successive nights only in the b and y bands. The two nights' β photometry shows that there is no variation in the β index.

IV. PERIODS

a) *28 Andromedae (HR 114)*

Nine maxima were obtained during the present study. The pulsation period of about $0^{d}.069$, which was obtained by Breger (1969), was adopted as a preliminary period. The new ephemerides were calculated by Tunca, Evren, Ibanoğlu, Tümer, and Ertan (1981) with the least squares fitting and the period was found to be $0^{d}.0689797 \pm 0^{d}.0000091$. The new average pulsation period is in agreement with the period found by Nishimura (1969) and Breger (1969).

b) *44 Tauri (HR 1287)*

The least squares method was applied to the 18 maxima and the new light elements were derived by Tümer, Ertan, Evren, Tunca and Ibanoğlu (1981). The new average period we found is $0^{d}.145067 \pm 0^{d}.000019$ which is $0^{d}.0002$ longer than that of Wizinowich and Percy (1979).

c) *κ Bootis (HR 5329)*

Sixteen maxima were detected for this star. The successive maxima obtained in one night showed that the average period is not in satisfactory agreement with the period given by Millis (1966). Therefore a preliminary period was derived; and by using the method of least squares new ephemerides were calculated by Evren *et al* (1981). The pulsation period was given by Millis (1966) as $0^{d}.069$, and by Breger (1979) as $0^{d}.066$. The new period found in the present study (i.e., $0^{d}.076242 \pm 0^{d}.000024$) is much longer than the above values.

d) *28 Aquilae (HR 7331)*

For this variable, 26 maxima were detected; and by using the least squares method new light elements were calculated by Ertan *et al.* (1980). The period found in this study, which is $0^{d}.149663 \pm 0^{d}.000017$, is in agreement with the period given by Breger (1979), as $0^{d}.150$. The pulsation periods given in this section are, of course, only rough average cycle-count periods, since most of the Delta Scuti stars show multiperiodic light variations. The existence of multiperiods and their values could have been carried out only if we had had sufficient data.

V. PHYSICAL PARAMETERS

Although the characteristics of the filters are nearly the same as the standard filters, the observing techniques (such as photomultiplier, D.C. etc.) may differ. Therefore, at first transformations to the standard systems were considered. The standard stars are given by Crawford and Barnes (1970) for *uvby* system. Fifteen stars were chosen among the standard stars, which include the wide interval of $b-y$, m_1 and c_1 as large as possible. The least squares fitting to the data obtained on October 15 and 16, 1980 gave the following relations:

$$(b-y)_{st} = \underset{\pm 7}{1.037}(b-y)_{obs} + \underset{\pm 5}{1.360}$$

$$(c_1)_{st} = \underset{\pm 9}{1.073}(c_1)_{obs} + \underset{\pm 6}{0.121}$$

$$(m_1)_{st} = \underset{\pm 18}{1.000}(m_1)_{obs} - \underset{\pm 24}{1.068}$$

As it is seen from these relations the coefficients are nearly close to unity.

Eight stars were chosen from among the standards of Crawford and Mander (1966) for the β transformation. Using the standard and observed values of the β, the following relation was obtained:

$$(\beta)_{st} = \underset{\pm 27}{1.522}(\beta)_{obs} + \underset{\pm 46}{0.160}$$

The $b-y$, c_1 and m_1 indices of the *uvby* system are affected by interstellar reddening. Assuming a standard reddening law the reddening-independent quantities $[m_1]$ and $[c_1]$ were given by Crawford (1975) as,

$$[m_1] = m_1 + 0.3(b-y)$$

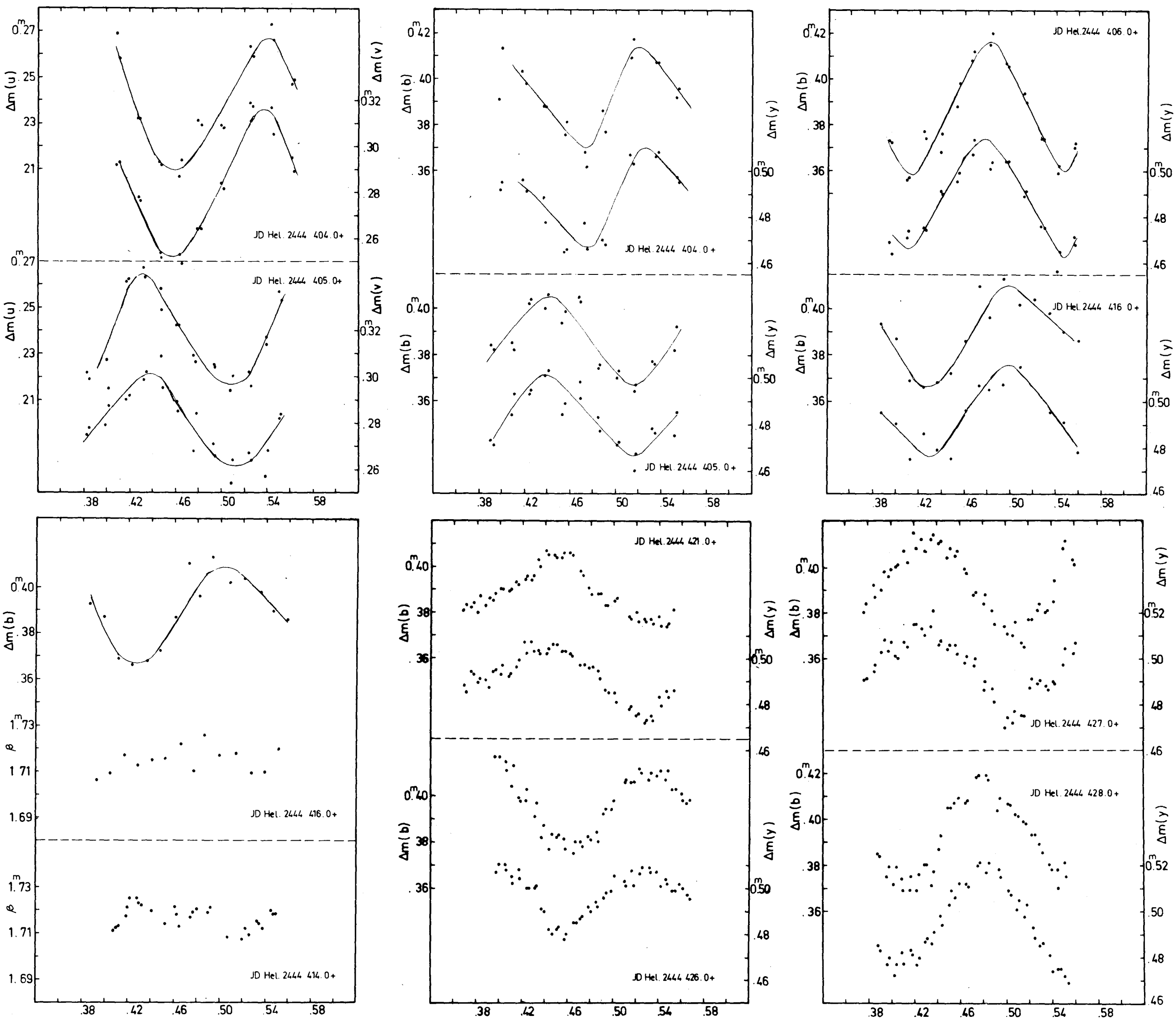
$$[c_1] = c_1 - 0.2(b-y)$$

For the intrinsic colours of A type stars ($2^{m}.890 > \beta > 2^{m}.720$) Crawford's $b-y$, c_1, m_1 (1979) gave the following relationship,

$$(b-y)_0 = 2^{m}.946 - 1.00\beta - 0.1\,\Delta[c_1] - 0\Delta[m_1]$$

If $\Delta\,[m_1]$ is greater than zero and,

$$(b-y)_0 = 2^{m}.946 - 1.00\beta - 0.1\,\Delta[c_1] - 0.25\Delta[m_1]$$



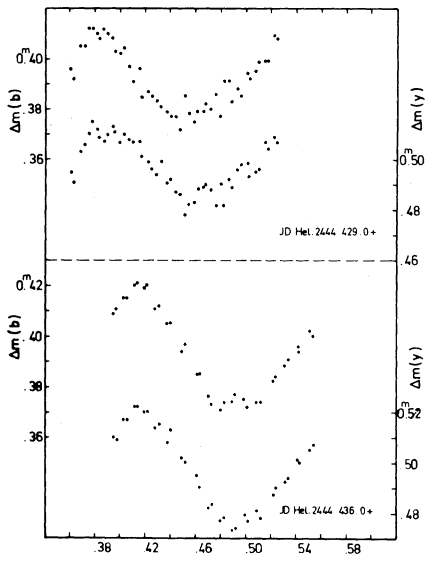


Fig. 4*a, b, c, d, e, f, g.* The light curves and narrow band observations of 28 Aql.

TABLE 3

THE PARAMETERS OBTAINED FOR FOUR STARS

Star	$b-y$	m_1	c_1	β	$[m_1]$	$[c_1]$	$\Delta[m_1]$	$\Delta[c_1]$	Reference
28 And	$0^m.167$	$0^m.172$	$0^m.884$	$2^m.755$	$0^m.222$	$0^m.851$	$-0^m.002$	$0^m.183$	This study
	±3	±3	± 3	± 6					
	.169	.165	.869	2.755	.195	.835		.175	Leung (1970)
44 Tau	.214	.166	.762	2.723	.230	.719	– .015	.156	This study
	±10	±10	±18	±15					
	.215	.175	.752	2.708	.214	.709		.189	Leung (1970)
κ Boo	.139	.188	.913	2.806	.230	.885	– .001	.089	This study
	±3	±7	±5	±5					
	.116	.166	1.022						Breger (1979)
28 Aql	.129	.181	1.046	2.797	.220	1.020	.008	.245	This study
	±4	±4	±11	±8					
	.164	.184	.990	2.796	.214	.957		.183	Leung (1970)

If $\Delta[m_1]$ is smaller than zero. The $\Delta[c_1]$ term in this equation is the difference between $[c_1]$ for the star in question and the value of $[c_1]$ for the zero-age main sequence which corresponds to the same β value. On the other hand the parameter $\Delta[m_1]$ is the difference between the value of $[m_1]$ for the Hyades main sequence and the value of $[m_1]$ for the star in question which also corresponds to the same β value. The zero-age β–$[c_1]$ relation was derived by Crawford and Barnes (1969) and the β–$[m_1]$ relation by Eggen (1971). The mean values of $b-y$, m_1, c_1, β, $[m_1]$, $[c_1]$, $\Delta[m_1]$ and $\Delta[c_1]$ were calculated for each star and are given in Table 3 with their standard deviations. The table also includes the values of same parameters obtained by Leung (1970) and those given by Breger (1979) for comparison.

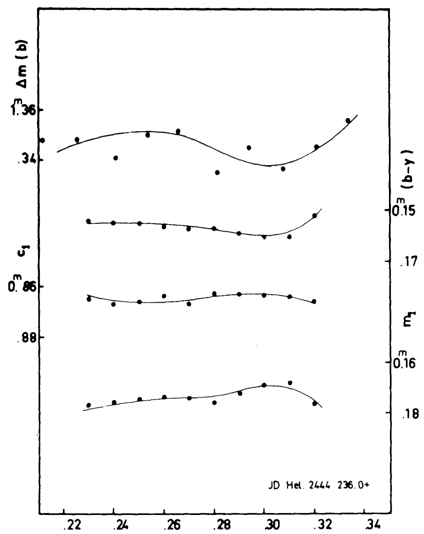


Fig. 5. The variations in $b-y$, c_1 and m_1 with light variation for 28 And.

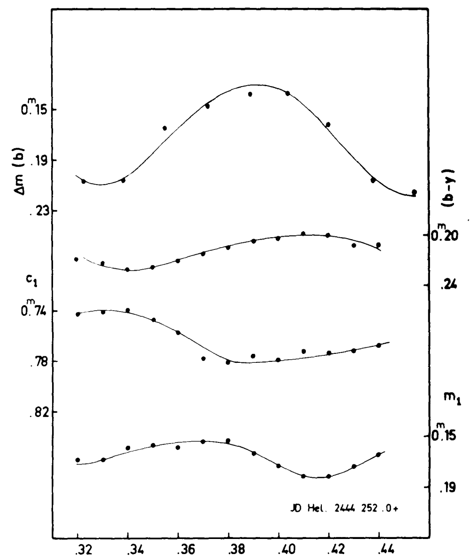


Fig. 6. The variations in $b-y$, c_1 and m_1 with light variation for 44 Tau.

Most of the calculated quantities agree with the values obtained previously. The quantities for κ Boo and $b-y$ and c_1 for 28 Aql differ from those obtained by other investigators. On the other hand, the large standard deviations of the parameters of 44 Tau are due to variations of parameters with light variation. The variations in $b-y$, c_1 and m_1 are shown in Figures 5, 6, 7 and 8 with the light variation for comparison.

The values of $b-y$ are smaller at maximum light, while the values of c_1 larger. The m_1 values are also changing with the light variations. The $\Delta[m_1]$ values indicate that the stars have normal abundance.

For the calibration of indices in terms of absolute magnitude, data for those stars with relatively large

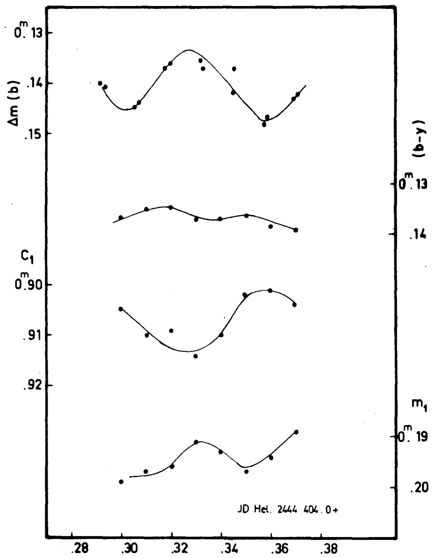


Fig. 7. The variations in $b-y$, c_1 and m_1 with light variation for κ Boo.

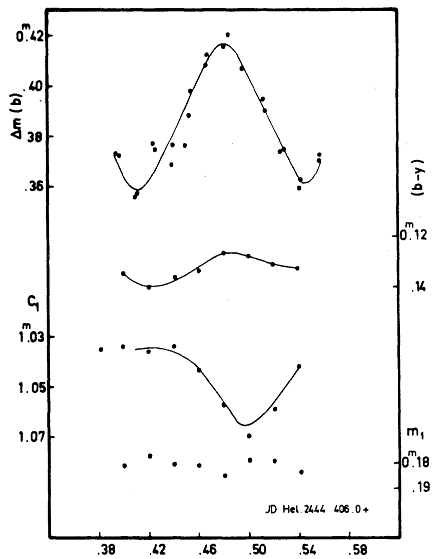


Fig. 8. The variations in $b-y$, c_1 and m_1 with light variation for 28 Aql.

trigonometric parallaxes were used by Crawford (1975) to fix the zero point of the calibration. The same stars, and V_0 versus β relations for galactic clusters were used to fix the slope of the relation between M_v (ZAMS) and β. Finally the following relation has been obtained.

$$M_v = M_v(\beta\,,\mathrm{ZAMS}) - \mathrm{f}\ \Delta[c_1]\ .$$

The factor f was found to be 9 for A type stars by using the data of open clusters. The coefficient of the $\Delta[c_1]$ term is relatively large, and therefore, the absolute magnitude is very sensitive to $\Delta[c_1]$. Since the $[m_1]$ index correlates very well to Fe/H abundance the following expression was derived by Crawford (1975).

$$\mathrm{Fe/H} = 0.2 - 10\,\Delta[m_1]\ .$$

This relation is somewhat different from those obtained by Strömgren (1966), it includes also the $\Delta[c_1]$ term. The standard relations were given by Crawford (1975).

To obtain the surface gravities, effective temperatures, masses and pulsation constants the following expressions were used (Petersen and Jorgensen 1972).

$$\log \mathrm{g} = 4.33 - 3.52\,\Delta[c_1]$$

$$\mathrm{T_e} = 6850 + 1250\,(\beta - 2.684)/0.144$$

$$\log \mathrm{m/m_\odot} = 12.502 + \log \mathrm{g} - 0.4\,M_{\mathrm{bol}} - 4\log \mathrm{T_e}$$

$$\log \mathrm{Q_{obs}} = 6.454 + \log \mathrm{P} + 0.5\ \log \mathrm{g} + 0.1\ M_{\mathrm{bol}} + \log \mathrm{T_e}.$$

Since Morton and Adams (1968) indicated that the bolometric corrections were smaller than 0.05 mag for the main sequence stars between A4 and F6 the visual absolute magnitudes may be used in the last two expressions in place of the bolometric magnitudes.

Using the quantities given in Table 3 we have derived the luminosities, surface gravities, effective temperatures, masses, pulsation constants and iron abundances for four stars. In Table 4 all derived physical parameters are listed and compared with those obtained by other investigators.

We must point out that the light variation amplitudes of the variables change from cycle to cycle. Therefore the quantities obtained in the $uvby\beta$ photometry at a certain epoch cannot be used for an accurate computation of mean values of effective temperatures, surface gravities and absolute magnitudes. For this reason the mean of the quantities of $uvby\beta$ photometry were determined from more than four cycles. The uncertainty in the determination of pulsation constants derives mainly from the uncertainty in the period. The accuracies of the periods found are better than 0.00002 day.

VI. CONCLUSION

The intrinsic colours are in a good agreement with data obtained by Chevalier (1971). The masses of Delta Scuti stars are accepted to be in the range of 1.5 and 2.5 solar masses. The masses of individual stars, of course, cannot be determined from photometric measurements alone, if the distances are not known. However, the masses of the stars on the main sequence, or close to it, may be estimated using the parameters of intermedite and narrow band photometry. The masses of four stars

TABLE 4

PHYSICAL PARAMETERS OF THE VARIABLES

Star	$(b-y_0)$	M_v	log g	log T_e	$m/m_\odot$	Q	Fe/H	References
28 And	0^m173	1^m25	3.686	3.873	1.57	0^d017	0.22	TS
	.183	1.24						L (1970)
			3.74	3.873	1.97	.017		PJ (1972)
44 Tau	.211	1.68	3.781	3.857	1.52	.042	.35	TS
	.211	1.31						L (1970)
			3.68	3.849	1.84	.031		PJ (1972)
χ Boo	.131	1.94	4.017	3.898	1.42	.034	.21	TS
		1.7		3.914				C (1971)
28 Aql	.125	0 .57	3.468	3.894	1.47	.025	.12	TS
	.140	.85						L (1970)
			3.67	3.893	2.25	.034		PJ (1972)

References: TS = this study, L = Leung (1970), PJ = Petersen and Jorgensen (1972), C = Chevalier (1971)

determined in this study fall nearly in the same interval mentioned above. In order to determine the masses and pulsation modes, many authors have used the pulsation constant. We believe that the masses determined with the expression given by Strömgren would be more accurate than the masses obtained from pulsation constants. Except for κ Boo the derived pulsation constants of the stars are in the interval 0.017 and 0.042 and agree, with the values obtained by Breger and Bregman (1975). The pulsation constant we have obtained for κ Boo is nearly twice as large as their value. This difference may arise mainly from smaller values of the surface gravity and the period of Breger and Bregman.

The period-luminosity-color relations were derived by many investigators for Delta Scuti stars. Breger and Bregman estimated the precision of absolute visual magnitudes derived from P-L-C relation to be about 0.24 mag if we use the absolute magnitudes obtained from P-L-C relation. The masses of the stars range from 1.1 to 3.27 solar masses which indicate that the uncertainty in the absolute magnitudes is larger than quoted by Breger and Bregman. The masses and periods obtained in this study do not confirm the existence of two separate groups of Delta Scuti stars as suggested by Leung (1970) and Eggen (1970).

Variations in the amplitudes of 44 Tau and 28 And were detected. Although the multiple frequency analysis has not yet been applied to the data, initial periods were determined for 28 Aql. The modulation period was found to be about 2.6872 days which is produced with the periods of about 0.145609 and 0.153952 days. The ratio of the periods is about 0.946 which corresponds to non-radial pulsations. This ratio recently was found to be about 0.939 by Peña and Warman (1979). The data obtained for 44 Tau are insufficient to investigate the periodicities of the variations in the amplitudes of the light curves.

The authors would like to express their gratitude to the Scientific and Technical Research Council of Turkey for partially supporting this research. They also would like to thank the referee for the valuable comments and for the critical reading of the manuscript.

REFERENCES

Baglin, A. *et al.* 1973, *Astr. and Ap.*, **23**, 221.
Breger, M. 1969, *A.J.*, **74**, 166.
Breger, M. 1979, *Pub. A.S.P.*, **91**, 5.
Breger, M. and Bregman, J.N. 1975, *Ap. J.*, **200**, 343.
Chevalier, C. 1971, *Astr. and Ap.*, **14**, 24.
Crawford, D.L. 1975, *A.J.*, **80**, 955.
Crawford, D.L. 1979, *A.J.*, **84**, 1858.
Crawford, D.L. and Barnes, J.V. 1969, *A.J.*, **74**, 407.
Crawford, D.L. and Barnes, J.V. 1970, *A.J.*, **75**, 978.
Crawford, D.L. and Mander, J. 1966, *A.J.*, **71**, 114.
Crawford, D.L., Barnes, J.V., Faure, B.Q., Golson, J.C., and Perry, C.L. 1966, *A.J.*, **71**, 709.
Desikachary, K. 1973, *Astr. and Ap.*, **27**, 331.
Eggen, O.J. 1970, *Pub. A.S.P.*, **82**, 274.
Eggen, O.J. 1971, *Pub. A.S.P.*, **83**, 741.
Ertan, A.Y. *et al.* 1980, *Inf. Bull. Var. Stars*, No. 1855.
Evren, S. *et al.* 1981, *Inf. Bull. Var. Stars*, No. 1937.
Leung, K.C. 1970, *A.J.*, **75**, 643.
Millis, R.L. 1966, *Inf. Bull. Var. Stars*, No. 137.
Morguleff, N., Rutily, B., and Terzan, A. 1976, *Astr. and Ap. Suppl.*, **23**, 429.
Morton, D.C. and Adams, T.F. 1968, *Ap. J.*, **151**, 611.
Nishimura, S. 1969, *Ap. and Space Sci.*, **3**, 77.
Peña, J.H. and Warman, J. 1979, *A.J.*, **84**, 1046.
Petersen, J.O. and Jorgensen, H.E. 1972, *Astr. and Ap.*, **17**, 367.
Strömgren, B. 1966, *Ann. Rev. Astr. and Ap.*, **4**, 433.
Strömgren, B. and Perry, C. 1965, in *Photoelectric uvby Photometry for 1217 Stars Brighter than* $V=6^m5$ (Princeton, N.J.: Inst. Adv. Study).
Tunca, Z., Evren, S., Ibanoğlu, C., Tümer, O., and Ertan, A.Y. 1981, *Inf. Bull, Var. Stars*, No. 2027.
Tümer, O., Ertan, A.Y., Evren, S., Tunca, Z., and Ibanoğlu, C. 1981, *Inf. Bull. Var. Stars*, No. 2028.
Wizinowich, P. and Percy, J.R. 1979, *Pub. A.S.P.*, **91**, 53.

A.Y. Ertan, S. Evren, C. Ibanoğlu, O. Tümer and Z. Tunca: Ege University Observatory, Pk 21. Izmir-Bornova, Turkey.