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Photoelectric photometry and period analysis of selected Delta Scuti stars in Praesepe*

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Abstract. Photoelectric photometry of seven Delta Scuti stars in Praesepe was secured. Three of them were observed simultaneously at observatories located at different longitudes. Period analysis has been carried out for each star with different computing packages and the results compared to those in the literature. Their physical characteristics have been determined from the Strömgren photometry and theoretical and empirical calibrations.

Key words: stars: Delta Scuti: open clusters: Praesepe — stars: oscillations

1. Introduction

The most efficient period determination method is through the organization of multi-site campaigns in which more than three or four observatories are involved. This has provided long and continuous data series which, contrary to past techniques, provide reliable frequency sets that correctly describe the nature of the stars. However, long before this current fashion was begun, several multisite observational campaigns were devoted to securing data of short period, small amplitude Delta Scuti variable stars. These data, although not as extensive as those produced by modern campaigns, serve to verify the frequency sets that have been recently found in the longer campaigns. In this sense, the data of the present paper permits discrimination of several sets of frequencies that have been found for each of the stars considered.

The advantages of studying variable stars in a given cluster are mainly that the member stars are at the same distance and that the parameters that fix the evolution of the stars, such as age and chemical composition, can be considered to be the same for all the stars within the cluster. These parameters, although generally poorly determined or known indirectly for only a few stars, are well known for nearby clusters and, jointly with the mass and the effective temperature, allow a better determination of the description of the pulsation mechanisms. This is the main reason that makes the study of variables in open clusters important since the differences shown will, in principle, throw light on the causes that provoke the triggering mechanism of the pulsations. On the other hand, observations of variable stars in a cluster are difficult to carry out since these stars exhibit short periods and very small amplitudes.

1.1. Generalities of Praesepe

Because of the relative nearness of Praesepe (NGC 2632, M 44, C0837+201) to the Sun, this cluster has been, and still is, the subject of many studies of all the different kinds of stars that constitute it. See, for example, Pinfield et al. (1997) and the references within it for a summary of its properties. Proper motion work has been extensive, and has led to an excellent list of “member” stars. Klein Wassink (1927), Vanderlinden (1923), Schrick (1953), & Artiukhina (1966) presented the preliminary most extensive studies on the topic, and the star numbers assigned by the first author have been used in most subsequent studies.

The distance modulus $m - M = 6.0$ given by Johnson (1957) was derived by overlapping the main sequence in the color-magnitude diagram for Praesepe on

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* The observations are available in electronic form at CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.70.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

the main sequence of the same diagram in the Hyades. Later, Crawford & Barnes (1969) with four-color and Hβ photometry measured 97 stars in the Praesepe cluster; they determined an average distance modulus of 6.1 for the cluster, based also on the comparison to the Hyades' Main Sequence. Later, Nicolet (1981), using data from the Jenkins (1952) General Catalog of Trigonometric Parallaxes (GCTP) determined distance modulii for 43 open clusters; a value of 6.166 ± 0.040 was obtained for Praesepe. According to Hambly et al. (1995) the most recent determination of the Praesepe distance modulus appears to be that of Reglero & Fabregat (1991) with a value of 6.05 mag, although they mention that a large scatter in the distance modulus determination by several authors is found.

Johnson & Knuckles (1955) have noted that the space motion of the Praesepe cluster is essentially the same as for the Hyades. They assigned an age of $1\ 10^9$ yr for both clusters and they also noted other similarities such as metal abundances and ultraviolet excess. Harris (1976) gives an age of $6.3\ 10^8$ yr. Later, Anthony-Twarog (1982) estimated an age of $7\ 10^8$ yr; Lang (1991) reports an age of $6.661\ 10^6$yr. From the compilation of Tsvetkov (1989) for ages of several open clusters, a mean value for Praesepe of $(6.7 \pm 2.2)\ 10^8$yr is found. Dickens et al. (1968) made an extensive study taking into account all the available data of four-color photometry to clarify the rotational velocity effects on the absolute magnitude. A correlation between Johnson's (1952) $(U-B)$ and $V \sin i$ was confirmed and their estimation on rotational velocity is one of the most complete for this cluster. For the original detection of the Delta Scuti variable stars, see the paper by Breger (1972) and the subsequent papers.

With the development of new observational techniques, knowledge of open clusters has increased due to the incredible quantity and quality of the information gathered. The recent works of Mermilliod et al. (1990), who initiated their study in 1978 with the Coravel determination of radial velocities of F5-K0 dwarf stars and $UBVRI$ (Kron) photometry have allowed them the identification of 43 new members of the halo. A second, very extensive study, to determine membership is that of Jones & Stauffer (1991) which was based on proper motions and photometry of the cluster. They presented 765 probable members from $V = 9$ to 18 and calculated a luminosity function. The same aim was pursued by Hambly et al. (1995) extended to low mass main sequence membership. ICCD speckle observations of binary stars in Praesepe has been done recently by Mason et al. (1993). They listed one new binary star, KW 212, out of over 54 potentially short period stars and three more: KW 203, KW 265 and KW 284, that were discovered before. In particular, KW 284 is very important for the present work because at times it has been used as a comparison star.

1.2. Characteristics of the observed stars

Several studies on the detection of Delta Scuti stars in some nearby open clusters have been carried out. These studies were done principally by Breger (1969, 1970, 1972a,b) in the Pleiades, the Hyades, Praesepe, and Coma; later this type of search was carried out by Slovak (1978) in α Persei and by Horan (1979) in the Hyades. These authors have found that about 30% of the Main Sequence cluster stars inside the instability strip show detectable variability. Table 1 gives some of the characteristics of all the Delta Scuti stars found up to now in the Praesepe Cluster. Rodríguez et al. (1994) have summarized the photometric characteristics of the observed stars. The values of the amplitude, δV, and the period p, have been taken from this source.

2. Observations

The observations for this long term study were carried out during three different seasons: the spring of 1982, in February, 1985 and February, 1997. The photometric data was reduced in two different ways: i) by differential photometry to link the data strings of the observatories when more than one is involved and to get more accurate measurements and ii) by absolute photometry to determine the physical characteristics. These latter observations were reduced with a standard method which has already been described (Peniche et al. 1990). Emphasis should be made, however, that in the case of differential photometry the mean for each night was subtracted from the data so long term variations cannot be detected.

The first campaign was designed to increase the accuracy in the period determination of KW 204 and thus, a simultaneous observational season was planned between the Ege University Observatory, Turkey, and the Observatorio Astronomico Nacional, at San Pedro Martir, Mexico. The dates of observations and the telescopes employed have been summarized in Table 2. In Turkey, the observations of KW 204 were made at the Ege University Observatory; an unrefrigerated EMI 9781 photomultiplier with the Johnson V filter along with a 48 cm Cassegrain reflector telescope was utilized. Correction for atmospheric extinction with respect to the primary comparison was carried out. Errors in each figure are 0.002 day and 0.002 magnitude. Two telescopes were used in Mexico, the 1.50 m and the 0.84 m. A single-channel photometer with a dry-ice-cooled 1P21 photomultiplier was utilized on each one; the photocells were used with the Johnson V filter. Two comparison stars were chosen for all the observed runs, KW 328 and KW 284 with spectral types of A9 III and A9 V, respectively. The highest possible precision is achieved by the frequent monitoring of the two nearby comparison stars, similar in brightness and color to the program stars. Since in Mexico two program stars were observed in the observing procedure, with different

Table 1. Characteristics of the Delta Scuti stars in the Praesepe cluster

KW	HD	GCVS	V	δV	P (d)	$b-y$	m_1	c_1	β	SpT
045	73175	BR Cnc	8.26	0.02	0.038	0.136	0.201	0.865	2.790	A9V
114	73345	CY Cnc	8.14	0.04	0.0325	0.121	0.209	0.888	2.813	F0V
154	73450	BS Cnc	8.50	0.02	0.051	0.149	0.197	0.793	2.770	A7V
204	73575	BT Cnc	6.66	0.04	0.1023	0.153	0.180	0.995	2.778	F0III
207	73576	BU Cnc	7.68	0.02	0.056	0.104	0.199	0.969	2.812	A6V
284	73712	-	6.78	0.004	0.149	0.161	0.180	0.937	2.756	A9V
292	73729	BQ Cnc	8.19	0.198	0.0973	0.01	0.172	0.809	2.742	F2V
318	73746	BV Cnc	8.65	0.02	:0.21	0.181	0.197	0.749	2.748	A9V
323	73763	BN Cnc	7.80	0.03	0.0353	0.130	0.189	0.900	2.796	A7V
340	73798	BW Cnc	8.48	0.01	0.072	0.147	0.213	0.809	2.764	F0V
348	73819	EP Cnc	6.78	0.01	0.1829	0.091	0.195	1.075	2.818	A6Vn
385	73890	-	7.91	0.01	0.0383	0.144	0.196	0.855	2.791	A7V
445	74028	BX Cnc	7.97	0.02	0.053	0.120	0.201	0.911	2.812	A7III
449	74050	BY Cnc	7.92	0.01	0.058	0.115	0.197	0.947	2.812	A7V

amplitudes, 0.07 mag (KW 204) and 0.02 mag (KW 207), the latter star was monitored more frequently, with a consequent increase in the time span between consecutive observations on the large amplitude variable. Each measurement consisted of five ten-second integrations of each star and one ten-second integration on the sky. A subtraction of the sky measurement from the average of the star's integrations was done. The photometric values reported are the magnitude differences between each variable star and the average of the standard stars interpolated to the time of the observation of the variables. Then, an average V was subtracted so a zero baseline could be established.

A second observing run was carried out in February, 1985. At this time in Mexico, better instrumentation was available and thus, different stars were considered. Also, the collaboration program with the Konkoly Observatory allowed the continuous monitoring of two variable stars. The 1.5 m telescope was employed with a photometer that allows the simultaneous observations in the *uvby* filters of the Strömgren system and, almost simultaneously, in the N and W filters that define Hβ. Two comparison stars were chosen for the observed runs, KW 150 and KW 284. Each measurement consisted of four ten-second integrations of each star and one ten-second integration of the sky for the *uvby* filters and three ten-second integrations for the narrow and wide filters one ten-second integration of the sky. The accuracy of each value is, for the faintest star, KW 154, $\delta(u,v,b,y,N,W) = (10,9,6,7,10,7)$ millimag and the accuracy in time is 0.0015 d. The photometric values analyzed were the magnitude differences between each variable star and that of the mean of the reference stars interpolated to the time of the observation of the variables. Then, the average magnitude of the season was subtracted so a zero baseline could be established. The sequence was the following: KW 284, KW 323, KW 207, KW 45, KW 154, KW 150, KW 445, KW 323 uninterruptedly during the whole season except for the two last nights on which KW 45 was substituted for KW 204. A few standard stars were observed to transform the instrumental observations into the standard system. In Hungary a 1.0 m telescope of the Piszkéstetö observing station provided with a one channel photometer was employed. The reference star was KW 284 and the V filter was utilized; the integration time for each star was 10 s for each one of the three measurements and the sequence of observation was KW 284, sky, KW 323 and KW 445.

In 1997, the 0.84 m telescope provided with a one channel cooled phototube at SPM was utilized in differential photometry. Two stars were considered as references: KW 150 and KW 284. The reduction was done in the customary way. The accuracy of each point, taken from the dispersion of the three measurements, was 0.003 mag and 0.004 d in time. All the photometric data considered in the present work has been submitted to the IAU archives.

2.1. Absolute photometry

Strömgren $uvby-\beta$ photometry provides unique opportunities for determining both membership to the cluster and physical characteristics of the observed star. In the present study, besides observing the variable stars in differential photometry, several standard stars were observed in order to transform their photometric values into the standard system. The reduction to the instrumental system followed the method described by Gronbech et al. (1976). The description of the photometric equipment can be found in Schuster & Nissen (1988). The transformation from the instrumental system to the standard one was done considering the computing package of Parrao et al. (1988). The night of February 13th was not included in Hβ because very few photometric standards were measured so only the nights between 14 and 17 of February were

Table 2. Log of observations

HJD-2440000	observed stars (KW)	observatory	photometry
5039	204, 284	Ege	V
5046	204, 284	Ege	V
5047	204, 207,284	SPM	V
5048	204, 207,284	SPM	V
5056	204, 284	Ege	V
5076	204, 207,284	SPM	V
6106	045,150,154,207,284,323,445	SPM	*uvby*
6107	045,150,154,207,284,323,445	SPM	*uvby*
6108	045,150,154,207,284,323,445	SPM	*uvby*
6109	045,150,154,207,284,323,445	SPM	*uvby*
6110	045,150,154,207,284,323,445	SPM	$uvby-\beta$
6111	045,150,154,207,284,323,445	SPM	$uvby-\beta$
6112	150,154,204,207,284,323,445	SPM	$uvby-\beta$
6113	150,154,204,207,284,323,445	SPM	$uvby-\beta$
6113	284,323,445	Piszkéstetö	V
10509	150,204,284	SPM	V
10510	150,204,284	SPM	V

Table 3. Nightly uncertainties

date	$N_{\rm obs}$	δV	$\delta(b-y)$	δm_1	δc_1	$N_{\rm obs}$	$\delta{\rm H}\beta$
100285	21	0.008	0.002	0.002	0.005		
110285	61	0.005	0.001	0.002	0.005		
120285	57	0.012	0.001	0.002	0.005		
130285	56	0.006	0.002	0.002	0.005		
140285	58	0.005	0.002	0.003	0.009	12	0.006
150285	68	0.006	0.002	0.002	0.005	32	0.004
160285	78	0.006	0.002	0.003	0.006	31	0.008
170285	89	0.005	0.002	0.003	0.008	48	0.007

considered. The quality of each night is presented in Table 3 in which Col. 1 provides the date; the number of standard stars observed per night is given in columns two and seven for *uvby* and Hβ, respectively. Columns three to six and eight provide the errors of the night in each index.

Instrumental and standard errors for the colors and indexes are presented in Table 4.

The obtained coefficients to the standard system are:

$$V_{\rm std} = 18.8032 - 0.0079(b-y)_{\rm inst} + y_{\rm inst}$$

$$(b-y)_{\rm std} = 0.8208 + 1.0094(b-y)_{\rm inst}$$

$$m1_{\rm std} = -0.3265 + 1.0470(m_1)_{\rm inst} - 0.0055(b-y)_{\rm inst}$$

$$c1_{\rm std} = -0.0628 + 1.0887(c_1)_{\rm inst} + 0.1645(b-y)_{\rm inst}$$

$$\mathrm{H}\beta_{\rm std} = 2.7934 + 1.1623(\mathrm{H}\beta)_{\rm inst}.$$

The values were transformed into the standard system in the following fashion: V magnitude from the UBV of Johnson (1952); $(b-y)$, m_1, c_1 from Crawford & Barnes (1970) and the Hβ values from Crawford & Mander (1966). The standard photometric values utilized for the transformation were those listed by Olsen (1983) except for KW 284 and KW 150 whose photometric values were from Crawford & Barnes (1969). The final transformations as well as the errors found and the number of observations for each standard star are listed in Table 5. In Table 6 the corresponding values for the program stars are presented. The mean values of the program stars have been compared to those of Crawford & Barnes (1969). Both sets gave a regression coefficient of 0.99 when considering the values of $(b-y)$, m_1, c_1 and Hβ. However, since the uncertainties in magnitude and color indexes are higher than the

Table 4. Instrumental and standard errors for the colors and indexes

system	V	$(b-y)$	m_1	c_1	Hβ
inst	0.007	0.002	0.003	0.006	0.007
std dev	0.008	0.004	0.017	0.007	0.008

Table 5. Magnitudes and indexes for the standard stars in the 1985 season

object	V	$b-y$	m_1	c_1	σV	$\sigma(b-y)$	σm_1	σc_1	$N_{\rm obs}$	Hβ	σHβ	$N_{\rm obs}$
KW 284	6.782	0.159	0.193	0.932	−0002	0.002	−0.013	0.005	221	2.758	−0.002	48
KW 150	7.450	0.155	0.186	0.946	0.000	0.002	−0.005	−0.004	222	2.756	0.003	49
HD 84937	8.332	0.303	0.051	0.361	0.007	0.000	0.003	−0.007	22	2.618	0.001	12
HD 87195	8.258	0.421	0.226	0.330	0.003	−0.003	0.013	0.006	17	2.601	−0.013	10
BS 1662S	6.177	0.397	0.193	0.351	−0.011	0.000	−0.007	−0.002	1			
BS 1861	5.340	−0.072	0.066	0.002	0.002	−0.001	0.007	0.002	1			
HD 107550	8.360	0.494	0.154	0.429	0.007	0.004	−0.013	0.002	2	2.553	0.004	2
HD 117243	8.355	0.408	0.216	0.396	−0.005	−0.004	0.015	−0.002	2	2.598	0.007	2

amplitude of variation, particularly in Hβ, a mean value of the measurements was taken to extract the physical characteristics of the stars from the theoretical grids.

3. Discussion

3.1. Period determination techniques

Period determination techniques are based on different approaches. Among the principal ones the following can be considered: cycle counting methods, Fourier analysis (which is based on adjusting to periodic functions) and phase minimization and maximum entropy method. The analysis of the variable stars currently presented was carried out at three different places but in all the same basic mathematical principle was considered, i.e., Fourier analysis and least squares fitting methods. The period determination analysis was carried out originally utilizing the MUFRAN (MUlti FRequency ANalysis) package developed at the Konkoly Observatory by Kollath (1990). The MUFRAN is a collection of methods for period determination and sine fitting for observational data and graphic routines for the visualization of the results. It is based both on a Discrete Fourier Transform (Deeming 1975) and calculates the FFT of each track using equidistant spacing by *"extirpolation"* (see Press & Rybicki 1989) in a faster way. Least square fitting provides the amplitudes and phases of fixed frequencies with error estimates which provide a rough idea of the quality of the fit. Whitening can be done and further analysis of the residuals can be repeated.

The second method utilized was the MFF that has been utilized extensively by the Mexican group (see, for example, Peniche et al. 1989). This method follows a series of steps, the first of which is to determine, by a classical Fourier transform, a first guess frequency. This is input in the MFF that is capable of adjusting to periodic functions up to ten frequencies and provide a refinement to each frequency considering all simultaneously. Goodness of fit is evaluated numerically by means of several statistical parameters of which the correlation coefficient and error are the most commonly employed. Once one frequency is determined, prewhitening is done and the residuals are analyzed as before in the Fourier transform, but the analysis in the MFF method is done from the original data considering the increasing number of frequencies being determined. Computing limitations restrict the resolution of the number of steps in which each frequency is swept but, in the end, accuracies in frequencies better than a few thousands c/d are attained.

The third and fourth methods utilized were those developed by the variable star group of the Instituto de Astrofisica de Andalucia, Spain: MINFRE and AnaFre (Analisis de Frecuencias). MINFRE, as the aforementioned methods, is based in a Fourier transform in order to obtain a first guess frequency which is then refined by sweeping frequencies by least squares fitting, in an interval which contains it, putting special emphasis on those cases in which aliasing becomes a problem. The optimization criteria being the minimization of the residuals. The best frequency is used to prewhiten the data and the procedure is repeated to obtain a second frequency. The whole procedure is repeated until the noise level is reached. Then, with all the frequencies obtained, the best set of frequencies is used to simultaneously solve, by least squares, for all the amplitudes and phases. Due to the high power of the computer used, a very small frequency step is considered reaching limits of frequencies restricted only by

Table 6. Mean magnitudes and indexes for the program star in the 1985 season

KW	$\langle V\rangle$	$\sigma(V)$	$\langle b-y\rangle$	$\sigma(b-y)$	$\langle m_1\rangle$	$\sigma(m_1)$	$\langle c_1\rangle$	$\sigma(c_1)$	$N_{\rm obs}$	Hβ	σ(Hβ)	$N_{\rm obs}$
45	8.263	0.012	0.132	0.003	0.216	0.004	0.854	0.006	145	2.793	0.002	21
154	8.515	0.012	0.145	0.003	0.211	0.004	0.803	0.007	220	2.786	0.001	34
204	6.677	0.018	0.144	0.003	0.199	0.003	0.988	0.007	76	2.763	0.001	37
207	7.683	0.037	0.105	0.003	0.208	0.003	0.970	0.010	220	2.804	0.001	28
323	7.825	0.007	0.120	0.002	0.208	0.003	0.902	0.006	373			
445	7.981	0.010	0.110	0.003	0.219	0.003	0.914	0.007	201			

the accuracy given by the time span of the observations. AnaFre is a computing program designed to carry out the spectral decomposition of experimental data in a graphic and interactive environment. The algorithm that carries out the spectral analysis can be selected at any moment and so far it consists of Fourier Transform or least square fitting and is able to set the frequency interval and the accuracy with which the spectrum is calculated. Once the spectrum of the frequency spectrum has been obtained, the program suggests a frequency and by least squares calculates the corresponding amplitudes and phases. As soon as the frequency has been accepted the process is repeated iteratively as long as the adjustment is significant. This is done by the minimization of the residuals by the Levenberg-Marquardt method which requires that the estimation of the coefficients be adjusted (frequency, amplitude and phase for all the determined frequencies) by a simultaneous least squares fit for all the frequencies (General Linear Least Squares). Levenberg-Marquardt algorithm provides the optimum coefficients as well as the covariant matrix utilized in the estimation of the error of the fit. All the interface, both graphic and that used for the spectral decomposition are carried out utilizing National Instruments' LabVIEW program.

All the data previously mentioned were also analyzed by the method developed by Breger (PERIOD, 1991) which can fit and improve multiple frequencies simultaneously without prewhitening and gives as output the best frequencies, amplitudes, phases and zero-point. In principle, since all the aforementioned methods follow the same principle, they should give the same results. In practice, however, complications sometimes arise due, mainly, to i) the quality and quantity of the data which translates in complications such as aliasing; ii) the resolution given by the sweeping steps in the frequency analysis and iii) the problem of frequency shift, which is important when a close frequency is present.

3.2. Results

The results obtained for each star are presented in the following section.

KW 284. In a recent paper Belmonte et al. (1994) write on the nature of this star. KW 284 was first reported to be a possible variable by Rolland et al. (1991) and has been listed in Rodriguez et al. (1994) with a very small amplitude of pulsation of 0.004 mag and a relatively large period of 0.149 d. However, Belmonte et al. (1994), unaware of its variability, used it as a reference star in their STEPHI IV network, but the analysis of their data led them to conclude that the oscillation frequency detected by Rolland et al. (1991) is very probably the 69.5 μHz detected in the STEPHI IV data so, according to them, KW 284 could be a long period Delta Scuti star located in the upper part of the Main Sequence. They conclude that more data is needed to establish its frequency spectrum with high accuracy.

Aware of this possibility of variability of KW 284, special emphasis was made to assure its constancy during the reduction of the observation seasons. A comparison on a nightly basis was done for KW 284 versus KW 150 whenever possible. The three analyses, MUFRAN, MFF and MINFRE, coincide. No signs of variability were detected in this star either in 1982 or 1985. No traces of the peak at 6.05 c/d determined by Belmonte et al. (1994) were found. Hence it can be concluded that, at least in the observed seasons, this star remained constant. There is a possibility, of course, that a long term variation exists because, as has already been mentioned, night means were subtracted from the data inhibiting the possibility of detection of such periods. Nevertheless, when the frequency analysis was made on the data of the problems stars reduced with the mean of KW 150 and KW 284 without subtracting the mean nightly value, the periodograms showed some peaks at low frequencies in a consistent manner, which might imply a long term variability of one of the reference stars. For this reason the light curves were obtained each night and the mean value of the difference of KW 150 and KW 284 was subtracted. The mean value of each night was subtracted from the data.

The problem of the dual findings on this star remains. We have not found short amplitude variations of KW 284 in short time scales, although the variability reported by Rolland et al. (1991) is unquestionable. More, KW 284 has been found, by the speckle observations (Mason et al. 1993; McAlister et al. 1989), as an occultation binary system. However, this binarity cannot account for the variations found. Special care must be taken in the future when monitoring this star since it has been proven to vary for some time

KW 204. After the study of Breger (1972a,b) in which its discovery was noted, an amplitude of variation of 0.07 mag and a short period of pulsation of 0.11 d were assigned to this pulsator. However, these values were assigned with only few observed nights. KW 204 was later observed by Gupta & Bhatanagar (1974) for one night. This same star, was also observed by Guerrero et al. (1979). (This paper will be, hereinafter, referred to as GMS). They reported observations made in 1975 and 1976 in Johnson's UBV colors and the analysis of their data led them to derive three frequencies: 7.14417, 7.17378 and 9.77704 c/d; with these frequencies and their ratios they concluded that this star is pulsating with one radial mode and one non-radial mode. However, their data was obtained in a time span of one year and with only thirteen nights of observations. Another complexity in their data is constituted by the spacing between consecutive points since their data was obtained in Johnson's three UBV filters so the time span between consecutive observations in one filter increases.

In 1979 Breger reanalyzed the data of GMS and his previously unpublished 1967/68 data of the same star, KW 204. A multiple-frequency non-linear least squares analysis which searches for up to three frequencies simultaneously led him to derive a set of three frequencies different from those previously derived by GMS, namely, 9.777, 7.881 and 5.957 c/d. He identified these frequencies with the second radial overtone, the first overtone and the fundamental mode, respectively; the period ratios of these new frequencies indicated radial pulsation. The lack of agreement between the interpretation of the modes of pulsation between Breger (1979) and GMS, along with the goal of studying Delta Scuti star variables in clusters was one of the motivations for observing this star in the first previously mentioned 1982 campaign.

The application of MFF to this GMS set of data gave a maximum at 9.78 c/d. Prewhitening of this frequency left a small indication of other frequencies at 7.2394 and 8.2418 c/d which were, practically, impossible to determine and which did not significantly increase the correlation coefficient. When MUFRAN was employed with this GMS data set, the frequencies derived were those of GMS, namely 9.7770, 7.1489 and 7.1788 c/d. However, if the three shortest nights were not included in the analysis, the result gave only the first one. Similar analysis was carried out for the 1982 season obtained jointly at the SPM and the Ege University observatories. This set is constituted of six nights, of which five are almost consecutive and one 18 days apart, at two observatories located at different longitudes which changes completely the one cycle per day pattern attained with observations obtained from only one site.

The application of the MFF program to this 1982 data set gave the following results: The frequency obtained from the Fourier transform, 9.78 c/d was refined to 9.780 c/d and subtracted from the data. Application of a second run of Fourier yielded a peak at another maximum at 8.75 c/d. Both were swept with the MFF method and converged to 9.779 and 8.755 c/d with a correlation coefficient of 0.93. The same 1982 data set was further analyzed without considering the data of the night of 2445077, which is too separated from the rest of the observed days and complicates the window pattern. The analysis carried out gave the same basic frequency of 9.780 c/d which was prewhitened. A second peak at 9.88 c/d was derived. Both frequencies converged to 9.781 and 9.887 c/d with a correlation coefficient of 0.942. The residuals were at the noise level with a small peak at 6.54 c/d.

The analysis of the 1985 data utilizing both the MFF and the MINFRE methods gave the frequencies of 9.7901, 12.9244 and 8.2475 c/d with a discrepancy in the middle one which was of 11.935 with the MFF method. The correlation coefficient gave R^2 of 0.765 and 0.748, respectively. Similarly, the frequency data sets of GMS and Breger (1980) and MFF (1982) with the 1985 data set gave correlation coefficients of 0.686, 0.699, and 0.672. The new codes of AnaFre and PERIOD gave, with data of the 1985 season correlation coefficients, R^2, of 0.785. In this sense one could conclude that the behavior of the star in 1985 is best described by these last frequency sets. Emphasis should be made that the number of frequencies in each case is not always the same.

Since several frequency sets have been obtained from different data sets, compiled in Table 7, what would be desirable now is to test all frequencies in all data sets. Since the correlation coefficient gives a definite mathematical parameter of goodness of fit and on the explanation of the behavior of the data with respect to the frequencies assumed, several runs in the MFF with the different data sets were done. In this sense, with the different data sets the different frequencies proposed gave the correlation coefficients, R^2, listed at the bottom of Table 7. An explanation of Table 7 makes it easier to understand. The heading of the columns lists either the author or the computing code. On the other hand, the correlation coefficients at the bottom provide the goodness of the fit for the several frequency sets involved; in parenthesis are the data sets considered. From this statistical indicator it can be concluded, for example, that the frequency set that best describes the behavior of the GMS data set is that of GMS; that the best frequency set in 1982 is that of Breger (GMS) whereas in 1985 is that of AnaFre (1985) or PERIOD. The set with the highest correlation coefficient has been written in bold characters. For these, the amplitude in thousands of magnitude for each frequency is given in parenthesis.

From the analysis summarized in Table 7 and the previous discussion it becomes immediately clear that our

Table 7. Pulsational periods determined for KW 204

frequency (c/d)	GMS (1979)	Breger (GMS)	MFF (1982)	MFF (1985)	AnaFre (1985)	PERIOD (1985)	MUFRAN(ampl) MFF(ALL)
f_1	7.14417	9.777	9.781	9.790	9.765	9.765	**9.780**
f_2	7.17378	7.881	9.887	11.935	11.909	11.909	
f_3	9.77704	5.957		8.248	6.980	6.980	
R^2(1982)	0.090	**0.929**	0.9268	0.813	0.681	0.681	0.895
R^2(GMS)	**0.873**	0.816	0.5094	0.253	0.451	0.451	0.747
R^2(1985)	0.686	0.699	0.672.	0.761	**0.785**	**0.785**	0.637
R^2(82-85)	0.617	0.724	0.740	0.218	0.590	0.588	**0.762**
R^2(ALL)	0.427	0.545	0.706	0.202	0.448	0.464	**0.780**

understanding of this star, despite all the observations, is still weak. One frequency around 9.8 c/d maintains its presence in all the analysis and all the observed seasons. However, the presence of all the other frequencies is, apparently, either a function of the data analysis or rests in the true nature of the star. It should be kept in mind that none of the data has a high temporal sampling: in GMS because they observed it simultaneously in several filters and in the 1985 season (with only two nights) because a large number of stars were observed. The best coverage, in this sense, is that of SPM-Ege in 1982 and the results indicate that 9.78 c/d frequency is more plausible for describing the nature of the star.

It is interesting to note that although GMS and Breger (1980) interpret the pulsational nature of KW 204 in two radically different ways, both sets of frequencies fit the observations obtained in 1982. It is also remarkable that with only one frequency both seasons, GMS and 1982, can be fairly well explained. To test this last assumption a data set constituted of both 1982 and 1985 was built and analyzed with MUFRAN, AnaFre and PERIOD packages. All of them produced the single frequency 9.77910 c/d with residuals 0.007 mag. Prewhitening this frequency indicated the presence of another at 9.508 c/d but of a much lower amplitude. It is remarkable that only one frequency can explain such separate data strings. Encouraged by this result, the data set of GMS was added, for which it was necessary to establish a zero level of this set to homogenize the entire set, which was then analyzed with the aforementioned computing packages. All gave just one frequency of 9.78007 c/d, with a correlation coefficient of 0.7976, which explains the behavior of this star in a time span of 12 years. In fact, the different frequency sets of this whole data set gave R^2 much lower than that obtained for just one frequency. With the new extension, that of 1997, an exceedingly large time basis has been acquired, 22 yr (78622 cycles). The analysis of the data in this time interval in the MUFRAN package yielded a frequency of 9.7800672. This same frequency was obtained in the MFF method which gave a correlation coefficient of 0.7803, which although low, is obtained considering the whole data set. The predictions compared to the observations show a remarkable correct phasing in an exceedingly large time span, see Fig. 1.

Up to now there have been ambiguities in the determination of the pulsational nature of KW 204. Since the interpretation of the modes of pulsation depends strongly on the period ratios of the frequencies found, it is exceedingly important to accurately determine such frequencies. It is a well- known fact (Petersen 1975) that if the period ratios are near $P_0/P_1 = 0.76$ and $P_1/P_2 = 0.81$, etc. one can deduce the presence of radial pulsation. If the ratios found do not fit this scheme, they are generally interpreted as non-radial modes. It is interesting to note that although GMS and Breger (1980) interpret the pulsational nature of KW 204 in two radically different ways, both sets of frequencies fit the observations obtained in 1982. It is also remarkable that with only one frequency all seasons can be fairly well explained.

Henry et al. (1977) have found that KW 204 is anomalous among the stars within the Praesepe cluster since it has an abnormally strong K line and slightly weak metal lines. Breger (1980) has also found that the amplitude of KW 204 appears variable on a time scale of years. According to Breger (1980) the 1975/6 fit shows no change in amplitudes during the year, but the amplitudes during 1967/8 were definitely smaller; following Bregers assertion, we have calculated the mean amplitudes for the new observed seasons. Then, the amplitudes have changed from 0.076 mag in 1967 to 0.083 mag in a time span of one year. When GMS observed it the amplitude was 0.047 mag; then the new values of the amplitude were of 0.070 mag in 1982 and of 0.050 mag in 1985. However, we have found that the amplitude changes drastically within a season if it is long enough as in the case of 1982.

KW 207. Before the last campaigns of the Delta Scuti Network (Breger et al. 1993) and the STEPHI IV (Belmonte et al. 1994; Pérez-Hernández et al. 1995), the previous available data of this star was scarce. It was first observed by Breger (1970) for two nights in 1968 and 1969.

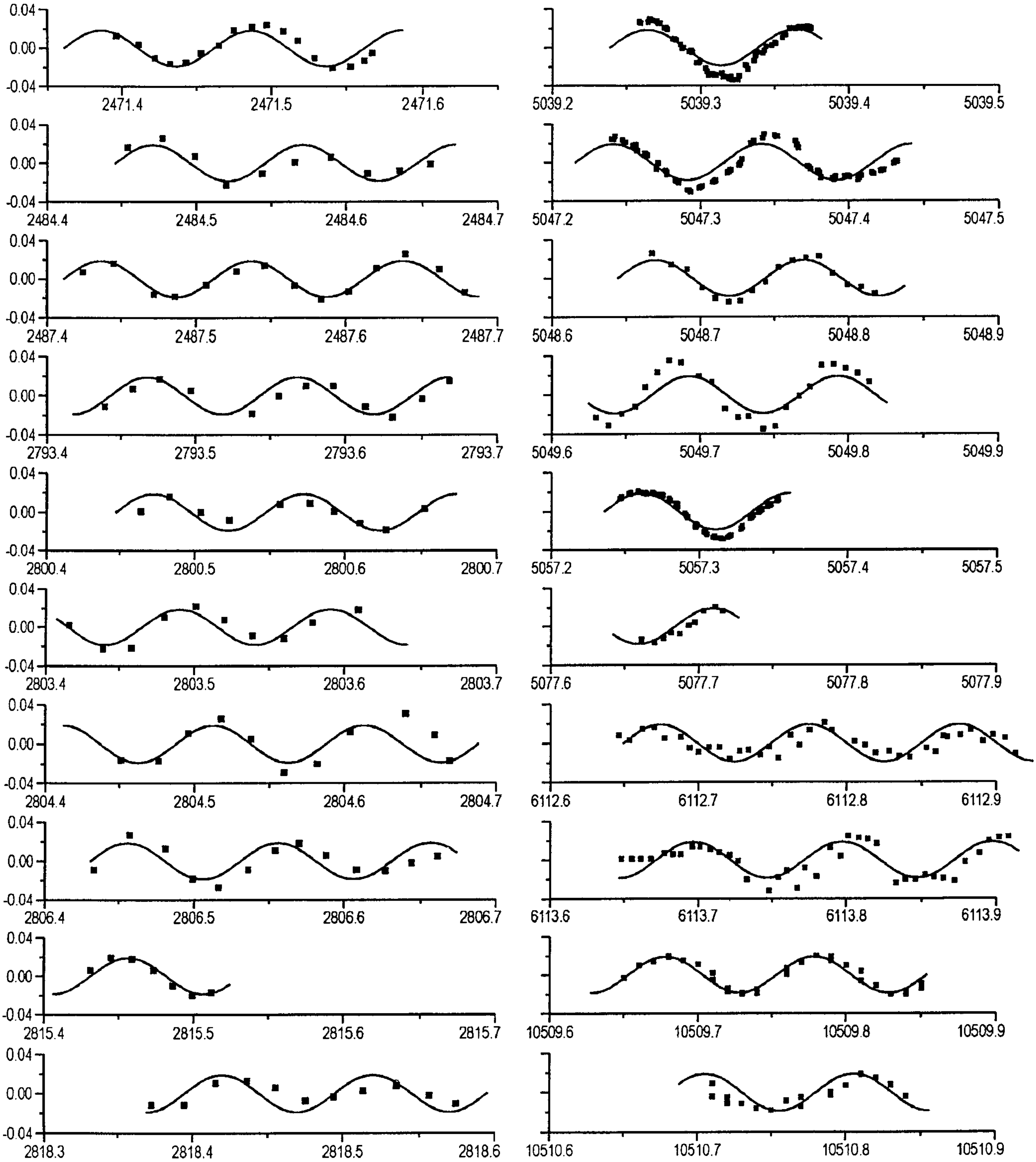

Fig. 1. Light curves of KW204. Dots, observed points; continuous line is the prediction with the frequency derived in the present paper. The time span is of 22 yrs

Later, Bossi et al. in (1977) (BGM) observed this star for four nights separated 35 days; furthermore, only two of these nights are longer than the assumed period, therefore we worked mainly with their longest nights, HJD 2443173 and 203. A periodogram analysis of the first three nights led them to derive a period of 0.0534d; they reported that the last and the longest night did not fit this frequency but they found more and different frequencies from the analysis of this night: a main peak at 0.059d, and another much less marked peak at 0.068d; however, the 0.0534d component seemed to have disappeared. Since they didn't report their observations, gross values of their photometry were obtained directly from their reported light curves. The obtained data of this star in 1982 consisted of two consecutive nights, separated from that of Bossi et al. (1977) by five years: therefore, a separate analysis of each season was carried out, and no attempt to phase lock was considered.

A periodogram of the two longest nights of the Bossi et al. (1977) data was carried out with MUFRAN. The data was obtained directly from their plots and the frequencies derived from this analysis yield 17.4456 and 13.3707 c/d. An analysis with PERIOD of the same data result in the following frequency set: 17.3116 and 13.5041 c/d which obviously present an aliasing problem. In order to discriminate which frequency set better fits the data, the correlation coefficient in MFF was determined. For MUFRAN it was of 0.851 whereas for PERIOD was 0.8497 implying numerically that the frequency set derived from MUFRAN adjusted better but by no means this result is conclusive since the data set is constituted of only two nights quite separated in time. Later, each frequency was tested in the MFF method with the 1982 data sweeping in a frequency interval of 17.0 to 19.0 c/d, i.e., an interval that covers all the frequencies found by the periodograms. The maximum peak was at 18.781 c/d.

More recently, the frequencies of this star were accurately determined in a three continent campaign with the participation of five observatories organized by Breger et al. (1993). The frequencies they determined were 19.76, 17.36, 16.69, 18.62 and 19.87 c/d above the restrictive signal/noise ratio < 4.0 and another, 23.91 c/d slightly below such criterion. However, attempts to fit the set of six-frequency or even only the four-frequency solutions to the older data were disappointing. It is in this sense that the data presented here, and obtained long ago, are important to verify the pulsational nature of the star. A slightly different set of frequencies was obtained by Perez-Hernandez et al. (1995) from the STEPHI IV campaign on this and on KW 323 (BN Cnc) during a three week, three-continental run. A set of six frequencies of 16.63, 16.865, 17.366, 18.636, 19.777 and 19.86 c/d was obtained, a set very close to that found by Breger et al. (1993).

The analysis carried out on the 1985 data gave, with the MUFRAN, MFF and the MINFRE methods, basically the same results. The frequencies determined were 19.817 and 18.616 c/d. Further analysis in the MINFRE gave a small peak at 21.046 c/d. However, the correlation coefficient R^2 was low, of 0.53 that could be due to the noise in the data or to the presence of the other reported frequencies that could not be obtained from the available data. As with KW 204, goodness for each frequency set was tested for all the available data and, again, the correlation coefficient R^2 was utilized for deciding which frequency set better describes the behavior of the star. The only available data sets in this case were those of 1982 with only one observatory, SPM, and the data obtained in the coordinated campaign between the Pisèstetö observing station and SPM. In each one the different frequency sets gave R^2 for 1982 and for 1985 listed in Table 8. In this sense, the set of frequencies that best describes the available data is that of PERIOD for the 1985, see Fig. 2 for the prewhitening procedure, or STEPHI IV for the 1982 data but none of them adequately describe the behavior of the star.

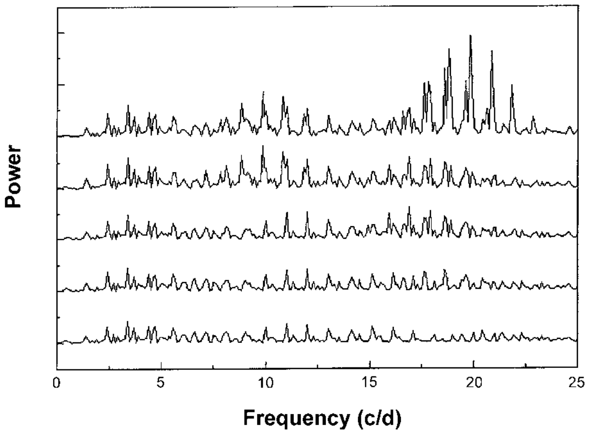

Fig. 2. Periodograms of KW207 showing the effect of the prewhitening. Y axis is at the same scale and prewhitening steps increase from top to bottom. The last spectrum has reached the noise level

KW 323. The Delta Scuti star KW 323, like KW 207, was observed in the STEPHI IV campaign. The analysis of the data led Perez-Hernandez et al. (1995) to determine the set of frequencies of 263.6, 266.7, 297.8, 300.4 and 327.2 (Hz (corresponding, in c/d, to 22.75, 23.043, 25.730, 25.920 and 28.270 c/d). It was previously observed by Kovacs (1981) who derived a set of frequencies listed in Table 9 and by Breger (1970) who first reported it as variable. However, Kovacs (1981) utilized stars KW 385 and KW 284 as a references, the former was later found to be variable (Paparo & Kollath 1990). A similar analysis as with the previous stars, produced the results presented in Table 9.

The correlation coefficient was again used to test the goodness of each frequency set; the numerical values of R^2 obtained are presented in Table 9. This implies that the

Table 8. Pulsational periods determined for KW 207

frequency (c/d)	BGM (1977)	Breger (1993)	STEPHI IV	MFF (1982)	MUFRAN (1985)	MFF (1985)	AnaFre (ampl) (1985)	PERIOD (1985)
f_1	18.72	19.76	19.777	18.786	19.815	19.816	**19.798**(3)	19.798
f_2	16.95	17.36	17.366		9.784	9.790	**9.788**(3)	9.788
f_3	14.70	16.69	16.630		16.892	16.893	**16.881**(2)	16.881
f_4	19.60	18.62	18.636				**18.637**(2)	18.637
f_5		19.87	19.860					
f_6		23.91	16.865					
R^2(1982)	0.797	0.852	0.867		0.786	0.789	0.805	0.805
R^2(1985)	0.18	0.343	0.376		0.400	0.400	**0.455**	0.455

Table 9. Pulsational periods determined for KW 323

frequency (c/d)	Kovacs (1981)	STEPHI IV	MFF (1985)	AnaFre (ampl) (1985)	MUFRAN (1985)	PERIOD (1985)
f_1	25.76213	22.750	25.762	**25.760**(3)	25.760	25.760
f_2	22.87924	23.043	6.905	**6.906**(2)	6.909	6.906
f_3	15.29977	25.730	24.971	**24.971**(1)	24.971	24.971
f_4	17.88238	25.920		**12.872**(1)		12.872
f_5	12.64201	28.270				
f_6	30.42958					
R^2(1985)	0.316	0.290	0.370	0.402	0.370	0.402

set of frequencies of either AnaFre or PERIOD gives the best adjustment, but the fit is still rather poor.

KW 45. The coincidence of the results derived from the MFF and the MINFRE methods is remarkable. The first two frequencies derived are basically the same, of 24.99 and of 11.01 c/d. The correlation coefficient is still low, 0.54. Further sweeping with the MINFRE yields frequencies at 4.66, 16.67 and 9.44 c/d but of much lower amplitudes. The residual obtained considering the first two of the aforementioned frequencies are of 0.0035 mag, certainly noise level. These same results were obtained with the remaining of the frequency determination methods. The results obtained are presented in Table 10. From the correlation coefficient presented in the last line of Table 10, it can be seen that all the frequency sets fit the data equally poorly, but slightly better for the frequencies refined by PERIOD.

KW 154. The analysis clearly shows the existence of two frequencies the first of which is determined to be around 17.024 c/d. The analysis made with the period searching methods gave the results presented in Table 11. In the frequency sets determined, two frequencies consistently appear, one around 17.03 and another at 16.30 c/d which have a low correlation coefficient of 0.37. The additional frequencies shown correspond to peaks of much lower amplitudes in the periodogram.

KW 445. A similar analysis with the above mentioned methods was carried out on the data of this star. This data consisted of the 1985 observations made at SPM and Piszkéstetö. Although the window function improved, the results are by no means conclusive. The frequencies obtained are shown in Table 12 for the sake of completeness, but in all cases the correlation coefficient was very poor. A new observation season is being planned to obtain better data which will allow the period determination of this star.

4. Analysis and interpretation

An attempt to describe the nature of the stars will now be made. An exhaustive period analysis of the available data has been made and the most likely frequencies have been established by different methods. Also, $uvby-\beta$ photometry has been secured and, from it, physical parameters such as $\log T_{\rm e}$ and log g for the stars can be extracted.

Cluster membership was established with the advantages of the Strömgren photometry of the cluster by Crawford & Barnes (1969) and the *UBV* photometry by Johnson (1952), a calibration by Nissen (1988) which follows previous calibrations by Crawford (1975, 1979) for the A and F stars and by Shobbrook (1984) for early type stars which have been already employed in previous analysis of open clusters (Peña & Peniche 1994). From the

Table 10. Pulsational periods determined for KW 45

frequency (c/d)	MUFRAN	MFF	MINFRE	AnaFre (ampl)	PERIOD
f_1	24.963	24.967	24.99	**24.957**(9)	24.957
f_2	27.903	26.909	11.01	**26.902**(5)	26.902
f_3	9.101	9.103	4.66	**9.102**(3)	9.102
f_4			16.67		
f_5			9.44		
R^2(1985)	0.554	0.560	0.411	0.566	0.563

Table 11. Pulsational periods determined for KW 154

frequency (c/d)	MUFRAN (1985)	MFF (ampl)	AnaFre	PERIOD
f_1	17.038	**17.024**(4)	17.040	17.040
f_2	16.3041	**16.305**(2)	16.300	16.300
f_3		**4.051**(2)	2.025	2.025
f_4		**18.682**(2)		
R^2(1985)	0.362	**0.467**	0.438	0.438

Table 12. Pulsational periods determined for KW 445

frequency (c/d)	MUFRAN (85)	MFF	AnaFre (ampl)	PERIOD
f_1	10.9914	20.488	**20.488**(2)	20.488
f_2	25.8767	11.325	**15.119**(2)	15.119
f_3	4.2912	15.124	**26.863**(2)	26.863
f_4			**11.326**(2)	11.326
R^2(1985)	0.077	0.183	**0.330**	0.330

distance to the stars evaluated, a mean distance and standard deviation was calculated; the criteria for membership was established as the distance within one sigma of the mean. (89 ± 17 pc); this criteria is fullfilled by 48 stars. Once this was done, average parameters such as reddening ($E(b-y)0.002 \pm 0.015$ mag), and chemical composition, ([Fe/H] $= 0.068 \pm 0.1191$) were determined. The assigned membership for five of the observed stars is in agreement with the above mentioned criteria and with the membership probability assigned by Jones & Cutworth (1983) from proper motion studies.

Once the reddening has been determined it was possible to calculate the unreddened colors $(b-y)_0$, m_0 and c_0. Then, the location of each star was fixed at the $(b-y)_0$ vs. c_0 diagram of Relyea & Kurucz (1978); from it, the surface temperatures and gravities, log T_e and log g, were determined for each star. Another way in which this latter quantity can be determined is through the calibrations of Petersen & Jorgensen (1972) or by the calibrations of Pérez et al. (1989). A comparison of the values determined from the three calibrations yields the following results: A fair agreement is found between the values determined by Petersen & Jorgensen (1972) prescription with that of the Relyea & Kurucz (1978) diagrams. The linear regression for these sets is of 0.94. The mean of the differences is 3 K with a standard deviation of 52 K A larger systematic difference is found from the aforementioned temperatures from those derived from Pérez et al. (1989). The mean of the differences is 1788 K with a standard deviation of 458 K. However, since the temperatures of Perez do not correspond to those deduced for their spectral types the final consideration for the temperatures were those of the diagrams of Relyea & Kurucz (1978) deduced from the original Strömgren photometry. The values considered for each star are listed in Table 13. The bolometric correction for each star was taken from the compilation of Lang

Table 13. Physical parameters of the Delta Scuti star considered

physical param	KW 045	KW 154	KW 204	KW 207	KW 323	KW 445
M_v	1.96	2.19	0.50	1.24	1.62	1.76
$M_{\rm bol}$	1.84	2.09	0.38	1.10	1.74	1.90
$\log T_{\rm e}$	3.89	3.88	3.89	3.90	3.89	3.90
$\log g$	3.80	4.00	2.90	3.75	3.75	3.75
Q	0.013	0.025	0.009	0.014	0.012	0.016
pulsat mode	3H	1H	3H/?	3H	3H/?	3H

(1991) through the log $T_{\rm e}$ values already mentioned. With this, $M_{\rm bol}$ for each star was calculated.

The pulsation mode is determined from the well-known relation (Petersen & Jorgensen 1972; Breger 1990) in which the main period for each star determined in the past sections was taken.

$$\log Q = -6.454 + \log P + 0.5 \log g + 0.1 M_{\rm bol} + \log T_{\rm e}.$$

The results derived in the present paper are still in agreement with the basic conclusion of Breger (1980) that “it is interesting to speculate that the preference for the second and third overtone may be connected with the position of the star in the hot part of the instability strip, where theoretical models have predicted pulsation in overtones (Stellingwerf 1979)”. The numerical values obtained are also in agreement with those previously determined. For example, negligible reddening has been found (Crawford & Barnes 1969), and a distance modulus of 6.166 was determined (Nicolet 1981; Anthony-Twarog 1982)

The age of the cluster has been fixed after establishing physical characteristics such as log $T_{\rm e}$ and log g for each star in the theoretical grids of Relyea & Kurucz (1978). The location of the hottest stars in the evolutionary tracks of VandenBerg (1985) agrees with his own conclusion that the isochrone that best describes the position of the stars is that of 9 10^8 yr for a metallicity of $Z = 0.169$. It should be remarked, however, that KW 204 and more pronounced KW 154 do not lie in this track. From models of Iben (1967), Tsvetkov (1989) determined ages for each of the variables but the spread of the ages is large, of 12.64 10^8 yr, with KW 204 much younger than the rest. On the other hand, from the models of Paczynski (1970), also reported by Tsvetkov (1989), the ages of all the stars are practically the same, around 4.9 10^8yr. The same result is also found for all the stars if more recent models, those of Meynet et al. (1993), which consider overshooting, are utilized but with a higher value of 7.9 10^8 yr. The compilation of Lang (1991) lists 6.6 10^8yr for Praesepe.

5. Conclusions

The most important contribution of this paper is that, along with the new photometric data presented, a comparative analysis of the computing codes for period analysis was carried out. It has been proven that the results of the codes practically show the same results. A compilation of the different frequency sets for each star has been done and for a few of them it is clear that it is not easy to derive a final set of frequencies provided it exists. In particular for KW 204 the amazing result is that with only one frequency it is possible to describe all the published observations of this star discarding all other sets. This might prove that many frequencies associated with some stars could be due merely to the poorness of the data either because of poor quality nights, pseudoconstant stars or merely because the data has not been properly reduced or analyzed. It is unnecessary at this stage to encourage well coordinated campaigns for each star before definite frequencies sets are assigned in order to describe their pulsational nature.

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