Revista Mexicana Astron. Astrof., **17**, 103-108 (1989)

EW AQR, A NON RADIAL DELTA SCUTI PULSATOR[1]

M.A. Hobart[2,4], J.H. Peña[2,5], and R. Peniche[2,3]

Received 1989 February 13

RESUMEN

El análisis de la fotometría diferencial de seis noches de la estrella δ Scuti EW Aqr (= HR 8102 = HD 201707 = BD $-15°5908$) da los periodos $0^{d}.09664$, $0^{d}.1087$ y $0^{d}.2121$ con las semi-amplitudes 0.013, 0.010 y 0.007 mag, respectivamente. Las razones de los periodos y la modulación mostrada en las curvas de luz indican que esta estrella es un pulsador no-radial.

ABSTRACT

Analysis of six nights of differential photometry for the δ Scuti star EW Aqr (= HR 8102 = HD 201707 = BD $-15°5908$) gives periods of $0^{d}.09664$, $0^{d}.1087$ and $0^{d}.2121$ with the semi-amplitudes of 0.013, 0.010 and 0.007 mag, respectively. The ratios of these periods and the beating shown in the light curves indicate that this star is a non-radial pulsator.

Key words: **STARS-δ SCUTI - STARS-PULSATION – STARS-VARIABLE**

I. INTRODUCTION

Many δ Scuti stars exhibit light curves that seem to vary from cycle to cycle, but this complexity in many cases is only apparent and due to the interaction of two or more stable pulsation modes with definite periods. One current of thought considers that the periods of these stars are meaningful in a statistical sense, the fluctuations being caused by non-linear coupling between pulsation and convection, which determines the irregularities and sometimes the non-periodicity in their light curves (Valtier *et al.* 1974).

On the other hand, other astronomers do not agree with this point of view (Breger 1979) since the existence of stable periods is provided by many Fourier periodograms showing widths of the peaks comparable to the peaks of the power spectral window. The analysis of several stars (Warman, Peña and Arellano-Ferro 1979; Peña *et al.* 1983, among others) show the existence of real and stable periods over years of observations. Perhaps one of the clearest examples is that of DQ Cephei (Peña *et al.* 1983) whose frequencies closely fit the data taken over 29 years.

There are other recently discovered stars that have not been extensively observed; among these is EW Aqr, for which very little data has been obtained. With respect to its spectral type, it has been reported by both Hoffleit (1964) and SAO as an A5 star. Later, Cowley *et al.* (1969) suggested that it could be a δ Del star, and it is listed in Breger's review (1979) with this spectral type. According to Hauck, Irvine and Rosenbush (1974), a δ Del star is characterized by unusually narrow Ca II *H* and *K* lines and by the same anomalous metal abundance as in the Am stars. As has been published by Ortega *et al.* (1983), the spectrum of EW Aqr does not show these features (see Figure 1); its Ca II *H* and *K* lines are normal for an F0 star and λ4481 with respect to λ4417 indicates that it is a main sequence star and thus, within the limits of a Delta Scuti pulsator. Photometrically, it is classified as a δ Scuti star on the basis of *uvby* and Hβ photometry by Kilambi (1975), who found it to have a period shorter than three hours. It was later analyzed by Kilambi, Dupuy and Koegler (1978), but no attempt to determine its periodic content was made because of the small number of observations and the large time interval between the observational seasons. To our knowledge, no other photometric data of this star have been acquired.

Considering the importance of data obtained during long and consecutive nights to accurately determine the periodic content of δ Scuti stars, the acquisition of new photometric data for EW Aqr with as many long consecutive nights as possible was planned.

II. OBSERVATIONS

The observations were carried out with the 150-cm reflecting telescope at the Observatorio Astronómico Nacional, San Pedro Mártir, México in 1982 during the nights of September 27, 28, 30 and October 1, 2, 3. A dry ice cooled 1P21 photocell was used with Johnson's *V* filter. The stars chosen as comparisons were C_1 = BD $-16°5810$ (F0) and C_2 = BD $-16°5798$ (F8) and a third star C_3 = BD $-13°5897$ was used as a check star.

1. Based on observations collected at the Observatorio Astronómico Nacional of San Pedro Mártir, B.C., México.
2. Instituto Nacional de Astrofísica, Optica y Electrónica.
3. Instituto de Astronomía, UNAM.
4. Universidad Veracruzana.
5. On leave from Instituto de Astronomía, UNAM.

TABLE 1

CHARACTERISTICS OF THE OBSERVED STARS

BD	Mv	Spectral Type	Type
−15°5908	6.4	F0V	Variable EW Aqr
−16 5810	7.4	F0	Constant
−16 5798	7.5	F8	Constant
−13 5897	6.2	A0	Tested for variability

C_1 and C_2 remained constant during the observing season. All of these stars are closer than 2° to EW Aqr. The characteristics of the observed stars are given in Table 1.

Each observation consisted of five ten-second integrations of each star and one ten-second integration of the sky. The sequence C_1, C_2, V was followed throughout the observing season. The accuracy of the acquired photometric data is 0.005 mag; the average time span between successive points is 0.007 d and the accuracy in time for each point is 0.0007 d. The photometric data shown in Table 2 and Figures 2*a* through 2*f*, are the differences between the program star and the average of C_1 and C_2 interpolated to the time of the observation of the variable star. An average ΔV was subtracted from each value to establish the zero baseline.

III. PERIOD DETERMINATION

The procedure followed earlier to analyze the data observed has been extensively utilized by the authors of the present paper (see, for example, Peña and Warman

TABLE 2

PHOTOMETRY OF EW AQR IN THE *V* FILTER

HJD	ΔV (mag)	HJD	ΔV (mag)	HJD	ΔV (mag)	HJD	ΔV (mag)
2445200.0+							
		42.6335	-0.002	43.6883	-0.012	44.7264	-0.008
		42.6398	0.000	43.6945	-0.005	44.7326	-0.005
39.6962	-0.019	42.6481	0.010	43.7008	-0.001	44.7389	-0.001
39.7032	-0.010	42.6550	0.011	43.7077	0.007	44.7458	-0.011
39.7101	-0.006	42.6627	0.014	43.7140	0.006	44.7528	-0.011
39.7178	0.001	42.6696	0.011	43.7209	0.015	44.7590	-0.003
39.7247	0.008	42.6759	0.000	43.7272	0.011	44.7653	-0.003
39.7316	0.025	42.6828	-0.004	43.7334	0.012	44.7715	-0.003
39.7386	0.020	42.6898	-0.019	43.7404	0.004	44.7792	-0.007
39.7455	0.031	42.6960	-0.019	43.7473	0.003	44.7861	-0.006
39.7518	0.018	42.7029	-0.020	43.7543	0.002	44.7924	-0.001
39.7587	0.018	42.7099	-0.015	43.7605	0.003	44.7993	-0.016
39.7678	0.005	42.7161	-0.023	43.7674	0.000		
39.7754	-0.002	42.7224	-0.015	43.7737	0.002		
39.7823	-0.010	42.7293	0.004	43.7806	-0.008	45.6569	0.011
		42.7363	0.016	43.7938	-0.003	45.6638	0.008
		42.7432	0.018	43.8001	0.005	45.6701	0.008
40.6573	-0.011	42.7502	0.021	43.8063	0.003	45.6770	0.006
40.6642	-0.016	42.7557	0.029			45.6853	0.003
40.6732	-0.007	42.7627	0.031			45.6923	0.005
40.6816	0.003	42.7689	0.022	44.6229	0.022	45.6985	0.006
40.6892	-0.004	42.7752	0.004	44.6299	0.009	45.7055	0.007
40.6982	0.017	42.7814	0.000	44.6368	0.010	45.7131	0.017
40.7059	0.006	42.7877	-0.009	44.6438	0.004	45.7228	0.021
40.7128	0.009	42.7939	-0.021	44.6507	0.004	45.7291	0.021
40.7198	0.017	42.8009	-0.034	44.6583	-0.007	45.7353	0.016
40.7281	0.011			44.6646	0.009	45.7423	0.012
40.7350	0.014			44.6715	0.009	45.7506	-0.001
40.7427	0.008	43.6251	0.019	44.6778	0.016	45.7576	-0.003
40.7496	0.001	43.6327	0.015	44.6861	0.009	45.7638	-0.010
40.7573	-0.006	43.6397	0.006	44.6931	0.010	45.7701	-0.016
40.7649	-0.013	43.6550	-0.012	44.6993	0.009	45.7763	-0.018
40.7725	-0.025	43.6612	-0.012	44.7063	-0.001	45.7833	-0.027
		43.6681	-0.021	44.7125	-0.004	45.7902	-0.027
		43.6813	-0.014	44.7188	-0.013	45.7971	-0.030

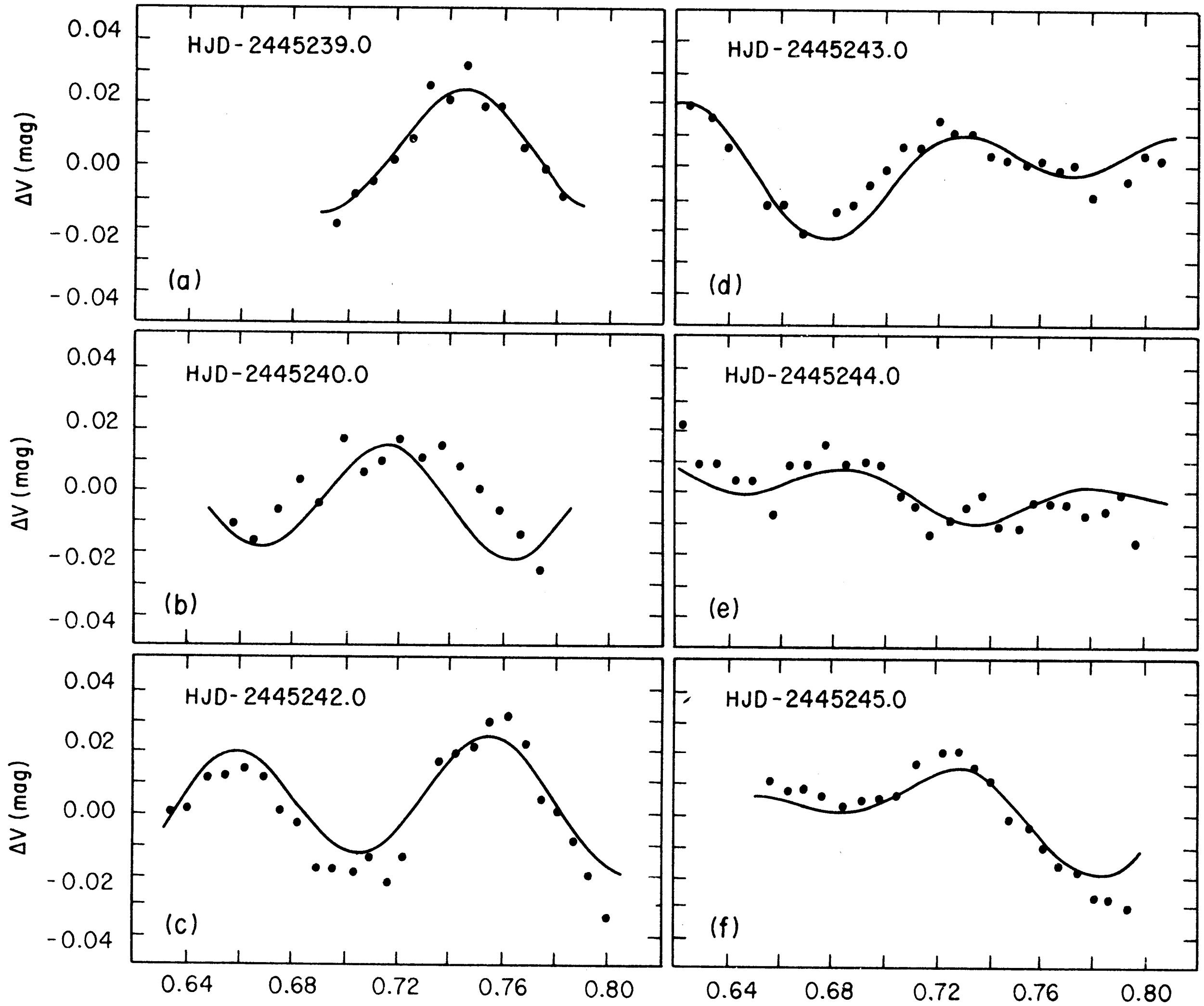

Fig. 2. Light curves of EW Aqr. The photometric data are represented by dots. The continuous lines represent the predicted variation obtained with the three frequencies derived in the present paper. *d*) and *f*) show the strong beating caused by the interaction of the close frequencies 10.34750 and 9.19588 c/d.

1979). As a first step, guess frequencies are obtained from a standard periodogram of the photometric data. These guess frequencies are then refined by means of the Multiple Frequency Fitting method (MFF) which has the capacity to deal simultaneously with up to five frequencies, sweeping each frequency independently and fitting the data to periodic functions by least squares. The goodness of the fit can be quantified by several statistical parameters: namely, the variance of the error, the F test, the Durbin-Watson statistics and the correlation coefficient R^2.

In Figure 3*b*, the periodogram of the data shows two conspicuous peaks at 10.3 and 11.3 c/d respectively with approximately the same power, but due to the repetition pattern of the window function (see Figure 3*a*), one of these peaks is an alias of the other. The analysis was made with the former frequency used as a first guess. The use of the MFF method refined it to 10.34750 c/d with a rather low correlation coefficient R^2 of 0.369 and a semiamplitude of 0.011 mag. This frequency was pre-whitened and the periodogram of the residuals (Figure 3*c*) showed a clear peak at 9.2 c/d. The MFF method refined this frequency to 9.19588 c/d with a semiamplitude of 0.009 mag. The fit to the data when both frequencies were considered increased the correlation coefficient to 0.606. These two frequencies were later pre-whitened, and the periodogram of the residuals (Figure 3*d*) gave a peak at 4.7 c/d which was refined to 4.71495 c/d with a semiamplitude of 0.007 mag. The three frequencies fitted the data with a correlation coefficient of

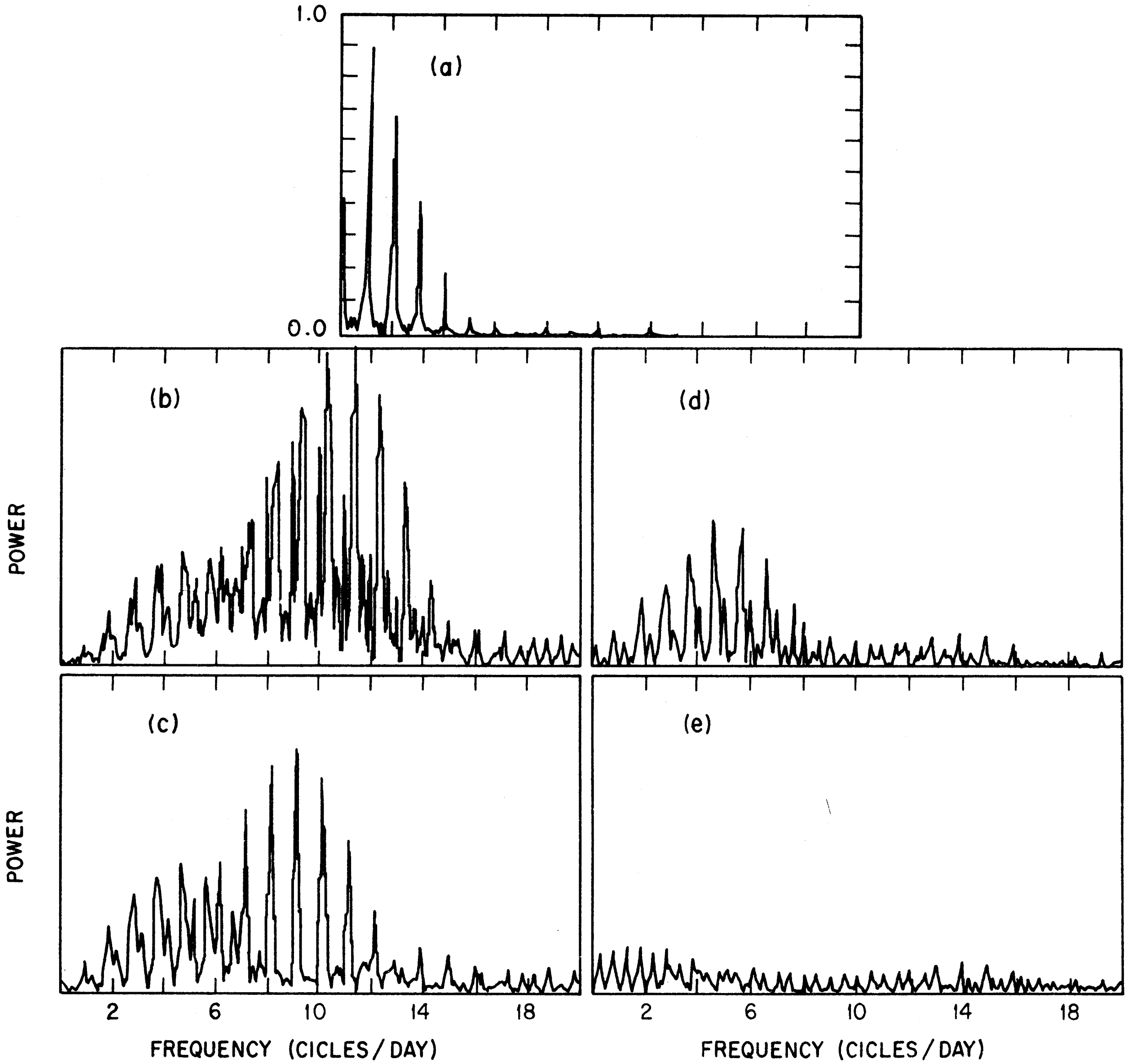

Fig. 3. Fourier analysis of the photometric data of EW Aqr corresponding to the season of 1982, September 27, 28, 30 and October 1, 2, 3. *a*) Window function of the photometric data of EW Aqr. *b*) Periodogram of the photometric data of EW Aqr. *c*) Periodogram of the residuals after the frequency 10.34750 c/d has been pre-whitened. *d*) Periodogram of the residuals after the frequencies 10.34750 and 9.19588 c/d were pre-whitened. *e*) Periodogram of the residuals resulting from the pre-whitening of the three frequencies 10.34750, 9.19588 and 4.71495 c/d reaching the noise level.

0.752. When these three frequencies were pre-whitened, the periodogram of the residuals reached the noise level as shown in Figure 3*e*.

A similar analysis of the data was carried out using the frequency 11.3 c/d as a first guess obtaining the three refined frequencies shown in Table 3. The best fit as can be seen from this table is obtained with the first set of frequencies (10.34750 c/d, 9.19588 c/d and 4.71495 c/d). The observational data of Kilambi (1975) on the Hβ standard system were fitted with this set of frequencies. The R^2 correlation coefficient obtained is low (0.532) due to the high scatter. Similarly, the observational data in the *v* filter of the *uvby* system for the nights HJD 2441534,50 (Kilambi *et al.* 1978) which show low scatter, were fitted with the same set of frequencies and the correlation coefficient increased to 0.838. The corresponding data for the nights HJD 2441-892,3,4,5 (Kilambi *et al.* 1978) were fitted with these frequencies and the correlation coefficient obtained was 0.812. The results are shown in Table 3. These two sets

TABLE 3

STATISTICAL PARAMETERS (R^2, F AND ERROR)[a] FOR THE PHOTOMETRIC DATA OF EW AQR

Season	Frequency (c/d)	Semi-amplitude (mag)	R^2	F	Error ($\times 10^{-5}$)	Remarks
This paper	11.34525	0.012	0.377	37.8	11.5	b
This paper	11.34525	0.013	0.576	41.8	7.9	b
	9.19250	0.009	...	...	...	
This paper	11.34525	0.013	0.708	48.9	5.6	b
	9.19250	0.009	...	...	...	
	4.71400	0.007	...	...	...	
This paper	10.34750	0.011	0.369	36.6	11.6	b
This paper	10.34750	0.013	0.606	47.2	7.4	b
	9.19588	0.009	...	...	...	
This paper	10.34750	0.013	0.752	61.2	4.7	b
	9.19588	0.010	...	...	...	
	4.71495	0.007	...	...	...	
Kilambi	10.34750	0.004	0.532	4.0	5.6	c
(1975)	9.19588	0.035	...	...	...	
	4.71495	0.012	...	...	...	
Kilambi	10.34750	0.004	0.838	78	19.2	d
(1978)	9.19588	0.035	...	...	...	
	4.71495	0.012	...	...	...	
Kilambi	10.34750	0.022	0.812	12.3	35.6	e
(1978)	9.19588	0.038	...	...	...	
	4.71495	0.008	...	...	...	

a. R^2, F and Error are respectively, the correlation coefficient, the F test and the variance of the error. b. HJD 2445239, 40, 42, 43, 44, 45 (Johnson's *V* filter). c. HJD 2441929 (Hβ index). d. HJD 2441534,50 (*v* filter of the *uvby* system. e. HJD 2441892,3,4,5 (*v* filter of the *uvby* system).

of data were fitted with the frequencies 11.34525, 9.1925 and 4.174 c/d, and the correlation coefficients R^2 obtained were 0.523 and 0.736 respectively.

Once the set of frequencies had been obtained, a prediction for the season was carried out. Figures 2*a* through 2*f* show the comparison of this prediction (solid lines) with the observation (dots). Attention is called to the excellent agreement of this comparison. Consequently, one can explain the low parameters of the fit due to the relatively high scatter of the data, but the overall behaviour of the star which shows a clear beating can be explained by the presence of these three frequencies.

IV. DISCUSSION

The modelling results of Cox, King and Hodson (1979) and Stellingwerf (1979) have been summarized in the review paper by Breger (1979) which concluded that the period ratios P_1/P_0, P_2/P_0 and P_3/P_0 of a multiperiodic radial δ Scuti star must be in the neighborhood of 0.76, 0.62 and 0.52 respectively. From the strong beating present in the light curves, an interaction between close frequencies is expected. From the frequencies derived in the present analysis, the following period ratios are determined $P_1/P_0 = 0.51$ and $P_2/P_0 = 0.45$, values that do not conform to the predictions of the theoretical model for a radial pulsator. To decide on the mode of pulsation of this star, the Q value given by the relation

$$Q = P(\rho/\rho_\odot)^{1/2}$$

or equivalently

$$Q = P\, [\, g_{eff}/g_{eff_{\odot}}]^{3/4}\, [M/M_{\odot}]^{1/4}$$

was calculated using the values log g_{eff} = 3.91 and M = 2.6 $M_{\odot}$ (Kilambi *et al.* 1978). The value Q = 0.0305 obtained indicates that this star is a non-radial pulsator in the 1H mode.

Few observations have been made up to now on this star. In order to increase the accuracy in the determination of its periodic content more observations are strongly encouraged.

We would like to thank the staff of the Observatorio Astronómico Nacional, México, for the assistance provided, G. Cerón for the drawings, J. Ibarra and I. Cabañas for the photographic work. Proofreading was done by J. Miller.

REFERENCES

Breger, M. 1979, *Pub. A.S.P.,* **91**, 5.

Cowley, A., Cowley, C., Jascheck, M., and Jascheck, C. 1969, *A.J.,* **74**, 375.

Cox, A.N., King, D.S., and Hodson, S.W. 1979, *Ap. J.,* **228**, 870.

Hauck, N., Irvine, N.J., and Rosenbush, D. 1974, *An Atlas of Objective Prism Spectra* (Ann Arbor: University of Michigan.

Hoffleit, D. 1964, *Catalog of Bright Stars* (New Haven: Yale University Observatory).

Kilambi, G.C. 1975, *Inf. Bull. Var. Stars,* No. 1024.

Kilambi, G.C., Dupuy, D.L., and Koegler, C.A. 1978, *Pub. A.S.P.,* **90**, 194.

Ortega, R., Peniche, R., Peña, J.H., and Hobart, M.A. 1983, *Rev. Mexicana Astron. Astrof.,* **8**, 45.

Peña, J.H., Peniche, R., Margrave, T.E., Hobart, M.A., and González, S.F. 1983, *Astr. and Ap. Suppl.,* **51**, 71.

Peña, J.H. and Warman, J. 1979, *A.J.,* **84**, 1046.

Smithsonian Astrophysical Observatory Star Catalog, 1966, (Washington: Smithsonian Institution), (SAO).

Stellingwerf, R.F. 1979, *Ap. J.,* **227**, 935.

Valtier, J.C., Sareyan, J.P., Le Contel, J.M., and Zribi, G. 1974, *Astr. and Ap. Suppl.,* **18**, 235.

Warman, J., Peña, J.H., and Arellano-Ferro, A. 1979, *A.J.,* **84**, 109.

Marco A. Hobart: Facultad de Física, Universidad Veracruzana, Apartado Postal 270, 91000 Xalapa, Ver. México.
Rosario Peniche and José H. Peña: Instituto de Astronomía, UNAM, Apartado Postal 70-264, 04510 México, D. F., México.

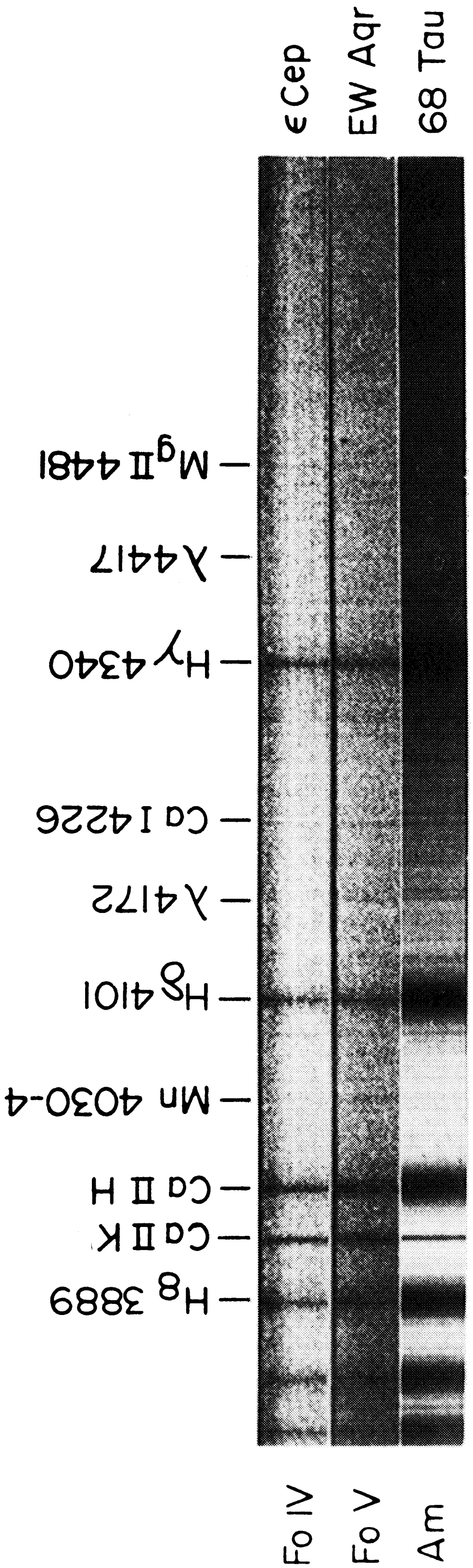

Fig. 1. Spectra of ε Cep (F0 IV), EW Aqr and 68 Tau (Am) which show that EW Aqr does not have the anomalous metal abundance of an Am star, but shows the characteristics of a F0 main sequence star.

M.A. HOBART *et al.* (See page 103)

1989RMxAA..17..103H