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PULSATIONAL STABILITY OF THE SX Phe STAR AE UMa

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1 Motivation

Soon after we started this research program into high amplitude Delta Scuti stars (HADS) in 2011, we presented our ideas at the Obergurgl Conference held in Austria the following year. There we stated that our motivation was to find out how far we could go with the observation of faint stellar objects utilizing the Astronomical Observatory of Tonantzintla, Mexico, since the site no longer has optimum conditions for astronomical observations. This observatory has a 1–m diameter telescope and several smaller 10-inch telescopes all provided with CCD cameras. All are used mostly for the training of students and we are currently seeking scientific observational programs to increase their educational experience. This was the motivation for the present study. The star AE UMa was chosen because of the following characteristics: short period of variation (0.086 d), high-amplitude variation (0.44 mag) and relative brightness (11.35 mag). These make it an ideal test object for both the telescopes and the instrumentation.

AE Ursae Majoris was first reported to be a variable star by Geyer et al. (1955). Tsesevich and Filatov reported some results in 1956 and 1960, but the type of variability could not be determined from their visual observations. In 1973 Tsesevich determined that this star was a dwarf cepheid. Other studies were later carried out by several authors (Szeidl 1974, Broglia & Conconi 1975, Rodríguez et al. 1992, Hintz et al. 1997).

AE UMa is listed as an SX Phoenicis star (Garcia et al. 1995 and the GCVS). Hence it is considered to be a metal-poor, Population II star (unlike the most common dwarf cepheids which are Population I). Before this classification AE UMa was considered to be a double-mode dwarf Cepheid or a high-amplitude δ Scuti star (HADS), which are not Population II type stars. Rodríguez et al. (1992), using a δm_1 metal calibration for metal abundance, reported [M/H]= -0.3, and Hintz et al. (1997) give values of [M/H] between -0.1 and -0.4. He also mentions that “no kinematic information is available for AE UMa; however, its galactic coordinates, might lead one to conclude that it is possible a halo object and should therefore be grouped with the SX Phe stars”.

Table 1: Log of observing seasons of AE UMa.

Date(yr/mo/day)	Telescope	Observers
11/12/0506	0.84 m	arl, jhp
11/12/1011	0.84 m	arl, jhp
12/01/2324	1.0 m	ESAOBELA12
12/01/2425	1.0 m	ESAOBELA12
12/03/0203	1.0 m	AoA12
12/03/0304	1.0 m	AoA12
13/03/0910	1.0 m	aas, err
13/04/1617	1.0 m	aas, ota
16/04/0102	1.0 m	jg

Notes: arl, A. Rentería; jhp, J. H. Peña; aas, A. A. Soni; ota, O. Trejo; err, E. Ramírez; jg, J. Guillen; ESAOBELA12: V. Abril, C. Alberti, L. Aréas, L. Batista, J. Buitrago, O. García, M, González, C. Ramírez, B. Recinos, A. Rodríguez, J. Ruiz, F. Soriano; AoA12: D. Aguilera, D. Deras, M. Espinosa, K. Valencia, P. Vessi, C. Villarreal

The most relevant studies of AE UMa are those of Szeidl (2001), Pocs & Szeidl (2001) and Zhou (2001) who found that the fundamental period of AE UMa had been essentially constant for 60 years in accordance with the theoretical expectation. They stated that the constancy of the fundamental period suggested that the star was in the post-main sequence evolutionary state. They also found that the first overtone period was decreasing at a rate of $(1/P_1)(dP_1/dt) = -7.3 \times 10^{-8}\mathrm{y}^{-1}$.

Szeidl (2001) found that small long-term variations in the amplitudes had been present for the previous 25 years. After these two studies the only significant analysis was done by Coates & Landes (2008) who, utilizing the same data set as Pocs & Szeidl (2001) and using the beat-curve approach, deduced detailed and quite precise information about the fundamental and first overtone periods of AE UMa and confirmed the values found by Pocs & Szeidl (2001) for the rates of change (assumed constant) of the periods, which are similar in magnitude to those of other Pop. I radially pulsating δ Scuti stars (Breger & Pamyatnykh 1998). In addition, because they had access to times of maxima for the star post-1998, they were able to extend the work of Pocs & Szeidl (2001) and deduce that there were possible sudden jumps in both the periods in approximately 1996, thus adding AE UMa to VZ Cnc (Arellano Ferro et al. 1994) as a radially pulsating δ Scuti star which has possible sudden jumps in period.

In addition, without any analysis, AE UMa has been extensively observed in monitoring campaigns to acquire new times of maximum light of pulsating stars. These times of maximum light of AE UMa have been compiled for behavior monitoring.

2 Observations

Although the new times of maximum light of this star have been reported elsewhere (Peña et al., 2015) here we present the detailed procedure for acquiring the data. These were all taken at both sites of the Observatorio Astronómico Nacional, at Tonantzintla (TNT) and San Pedro Mártir, México (SPM). At TNT the 1 m telescope was utilized provided with a CCD SBIG STL-1001E camera. At SPM two detectors were employed, a CCD camera and a spectrophotometer in the $uvby-\beta$ system was attached to the 0.84 m telescope. The log of observation is presented in Table 1.

Table 2: New times of maxima of AE UMa.

Time of Maximum (HJD)	Telescope	Filter	Observatory
2455901.9574	0.84 m	y	SPM
2455902.0394	0.84 m	y	SPM
2455906.9400	0.84 m	V	SPM
2455907.0230	0.84 m	V	SPM
2455950.8077	1.0 m	V	TNT
2455951.7985	1.0 m	V	TNT
2455989.8581	1.0 m	V	TNT
2455990.7191	1.0 m	V	TNT
2455990.8104	1.0 m	V	TNT
2456361.7207	1.0 m	V	TNT
2456361.8010	1.0 m	V	TNT
2457129.3859	1.0 m	G	TNT
2457480.7170	1.0 m	G	TNT
2457480.7995	1.0 m	G	TNT

Table 3: Transformation coefficients obtained for the observed season.

season	B	D	F	J	H	I	L
Dec 2011	0.054	0.967	1.058	0.041	1.030	0.161	−0.888

2.1 Data acquisition and reduction at TNT

During all the observational nights the following procedure was utilized. Sequence strings in the V filter were obtained. The integration time for the 1 m telescope was 3 min; there were around 40,000 counts for the 1 m telescope, enough to secure high precision. The reduction work was done with AstroImageJ (Collins 2012). This software is easy to use. It is free and works well on the most common computing platforms. With the CCD photometry two reference stars were utilized whenever possible in a differential photometry mode. The results were obtained from the difference $V_{\text{variable}} - V_{\text{reference}}$ and the scatter calculated from the difference $V_{\text{reference1}} - V_{\text{reference2}}$. Light curves were also obtained. The newly obtained times of maximum light are presented in Table 2.

2.2 Data acquisition and reduction at SPM

During the night of the observations at SPM the following procedure was utilized: each measurement consisted of at least five ten-second integrations of each star and one ten-second integration of the sky for the *uvby* filters and the narrow and wide filters that define Hβ. Individual uncertainties were determined by calculating the standard deviations of the fluxes in each filter for each star. The percentual error in each measurement is, of course, a function of both the spectral type and the brightness of each star, but they were observed long enough to secure sufficient photons to get a S/N ratio of accuracy of $N/\sqrt{N}$ of 0.01 mag in all cases. A series of standard stars was also observed on this night to transform the data into the standard system. The reduction procedure was done with the numerical packages NABAPHOT (Arellano-Ferro & Parrao 1988). The chosen standard system was that defined by the standard values of Olsen (1983) although for the standard bright stars some were also taken from the Astronomical Almanac (2006). The transformation equations are those defined by Crawford & Barnes (1970) and by Crawford & Mander (1966).

The coefficients defined by the following equations and that adjusted the data to the standard system are:

$$\begin{aligned}
V_{\rm std} &= A + B(b-y)_{\rm inst} + y_{\rm inst} \\
(b-y)_{\rm std} &= C + D(b-y)_{\rm inst} \\
m_{1_{\rm std}} &= E + F(m_1)_{\rm inst} + J(b-y)_{\rm inst} \\
c_{1_{\rm std}} &= G + H(c_1)_{\rm inst} + I(b-y)_{\rm inst} \\
H\beta_{\rm std} &= K + L(H\beta)_{\rm inst}
\end{aligned}$$

In these equations the coefficients D, F, H and L are the slope coefficients for $(b-y)$, m_1, c_1 and β, respectively. The coefficients B, J and I are the color terms of V, m_1, and c_1. The averaged transformation coefficients of each night are listed in Table 3. Errors were evaluated using of the twenty-three standard stars observed. These uncertainties were calculated through the differences in magnitude and colors, for (V, $b-y$, m_1, c_1 and β) as (0.052, 0.0075, 0.0094, 0.025, 0.032), respectively which provide a numerical evaluation of our uncertainties. Emphasis is made on the large range of the standard stars in the magnitude and color values: V (5.45, 8.40); $(b-y)$ (−0.19, 0.63); m_1 (0.10, 0.66); c_1 (0.19, 0.91) and β (2.609, 2.828).

Table 4 lists the photometric values of the observed star. In this table, column 1 reports the time of the observation in HJD, columns 2 to 5 the Strömgren values V, $(b-y)$, m_1 and c_1, respectively; column 6, Hβ.

3 Frequency Content

The frequency content of the pulsation of AE UMa was determined utilizing two different data sets: i) the light curves of Rodríguez et al. (1992) and those presented in the current paper and ii) the compiled list of times of maximum light, including the newly acquired ones.

3.1 Time Series Analysis

We were lucky that this star was observed in the $uvby-\beta$ photometric system in 1986 and 1987 by Rodríguez et al. (1992) at the Sierra Nevada Observatory, Spain, with a twin spectrophotometer like the one we used in 2011 at SPM Observatory, México, some twenty-five years later. Rodríguez et al. (1992) published their observations in magnitude differences AE UMa − BD + 44° 1898 so, transformation into the standard system was immediate. Furthermore, observations were reported in V and B filters by Broglia & Conconi (1975). In section 2.2 we described in detail the transformation followed to obtain the reported observations of the present study. The whole V sample is constituted of 1299 data points in the V filter in four seasons covering a time span of 38 years.

Utilizing the period proposed by Pocs & Szeidl (2001) we calculated the phase for each $uvby-\beta$ data point and plotted magnitude V and color indexes in a diagram, Figure 1. We should here mention the impressive result of how well all the magnitude and color

Table 4: $uvby-\beta$ photoelectric photometry of AE UMa.

HJD −2455900	V	$(b-y)$	m_1	c_1	β
6.8611	11.035	0.130	0.148		2.708
6.8636	11.048	0.155	0.137	0.888	2.778
6.8684	11.100	0.143	0.132	0.846	2.770
6.8709	11.122	0.159	0.113		2.793
6.8728	11.110	0.185	0.130	0.923	
6.8738	11.142	0.174	0.153	0.870	
6.8753	11.192	0.149	0.166	0.941	
6.8764	11.222	0.161	0.142	0.906	
6.8776	11.182	0.202	0.095	0.981	
6.8784	11.235	0.162	0.130		
6.8794	11.203	0.226	0.071	0.972	
6.8804	11.233	0.201	0.113	0.929	
6.8847	11.271	0.195	0.153	0.834	
6.8857	11.297	0.199	0.118	0.795	
6.8871	11.297	0.216	0.142	0.767	
6.8878	11.303	0.212	0.104	0.897	
6.8889	11.330		0.198	0.681	
6.8902	11.339		0.209	0.847	
6.8913	11.351	0.162	0.221	0.764	
6.8920	11.323	0.200	0.145	0.811	
6.8930	11.388	0.218	0.697		
6.8940	11.383		0.196	0.718	
6.8969	11.354	0.233	0.073		
6.8977	11.387	0.197	0.183	0.804	
6.8991	11.365	0.212	0.125	0.831	
6.9003	11.390	0.188	0.203	0.732	
6.9015	11.391	0.194	0.197	0.715	
6.9022	11.382	0.225	0.077	0.857	
6.9033	11.415	0.197	0.193	0.704	
6.9047		0.211	0.156	0.740	
6.9057	11.400	0.229	0.152	0.731	
6.9063	11.417	0.209	0.185		
6.9076	11.433	0.209	0.131	0.841	
6.9087	11.406		0.062	0.815	
6.9109	11.430	0.221	0.120	0.859	
6.9115	11.435	0.191	0.191	0.847	
6.9125	11.413	0.224	0.125		
6.9134	11.418	0.233	0.108	0.796	
6.9155	11.440	0.230	0.080	0.825	
6.9170	11.436	0.210	0.117	0.767	
6.9178	11.415	0.242	0.099	0.751	
6.9191	11.446	0.218	0.091	0.768	
6.9206	11.414	0.254	0.045	0.832	
6.9246	11.369	0.219	0.148	0.700	
6.9254	11.361	0.201	0.189	0.795	

Table 4: Continued.

HJD −2455900	V	$(b-y)$	m_1	c_1	β
6.9271	11.339	0.210	0.089	0.848	
6.9283	11.277	0.247	0.065	0.869	
6.9294	11.270	0.221	0.090	0.864	
6.9301	11.222	0.203	0.131	0.777	
6.9320	11.167	0.163	0.133	0.822	
6.9332	11.164	0.102	0.221	0.735	
6.9344	11.065	0.115	0.194	0.824	
6.9350	10.989	0.151	0.115	0.914	
6.9364	10.909	0.127	0.140	1.054	
6.9378	10.845	0.138	0.105	1.114	
6.9402	10.849	0.093	0.130	1.058	
6.9409	10.830	0.084	0.192	0.911	
6.9420	10.852	0.070	0.209	1.015	
6.9427	10.847	0.086	0.177	1.086	
6.9438	10.881	0.076	0.179	0.979	
6.9454	10.899	0.092	0.167	1.042	
6.9465	10.919	0.092	0.173	0.995	
6.9472	10.912	0.125	0.141	1.005	
6.9484	10.952	0.100	0.177	1.049	
6.9498	10.987	0.091	0.196	1.037	
6.9523	11.038	0.138	0.153	0.969	
6.9531	11.061	0.111	0.168	0.953	
6.9544	11.057	0.160	0.116	0.943	
6.9555	11.083	0.146	0.153	0.997	
6.9568	11.109	0.146	0.160	1.049	
6.9575	11.112	0.161	0.126	1.014	
6.9587	11.122	0.185	0.110	0.967	
6.9603	11.172	0.183	0.064	1.100	
6.9620	11.165	0.215	0.048	1.043	
6.9627	11.165	0.183	0.150	0.975	
6.9643	11.227	0.173	0.143	0.863	
6.9656	11.212	0.204	0.121	0.806	
6.9681	11.263	0.198	0.150	0.767	
6.9688	11.284	0.182	0.179	0.736	
6.9699	11.325		0.258	0.742	
6.9706	11.279	0.205	0.108	0.842	
6.9719	11.295	0.213	0.120	0.814	
6.9732	11.322	0.206	0.156	0.656	
6.9744	11.307	0.220	0.132	0.711	
6.9751	11.314	0.222	0.142	0.754	
6.9763	11.393		0.227	0.776	
6.9775	11.399		0.200	0.736	
6.9800	11.415		0.214	0.650	
6.9808	11.380	0.219	0.117		
6.9836	11.377	0.218	0.126	0.787	

Table 4: Continued.

HJD	V	$(b-y)$	m_1	c_1	β
−2455900					
6.9849	11.396	0.216	0.141	0.714	
6.9858	11.402	0.212	0.165	0.670	
6.9870	11.426	0.213	0.180	0.608	
6.9883	11.397		0.119	0.767	
6.9895	11.380		0.077	0.748	
6.9905	11.452	0.205	0.116		
6.9919	11.478	0.197	0.130	0.606	
6.9931	11.488	0.174	0.194	0.640	
6.9963	11.414		0.080	0.726	
6.9970	11.479	0.194	0.165	0.763	
6.9984	11.457	0.199	0.193	0.682	
6.9991	11.428		0.058	0.725	
7.0002	11.430		0.096	0.812	
7.0012	11.432		0.067	0.739	
7.0121	11.294	0.142	0.185	0.818	
7.0198	10.980	0.082	0.162	0.940	
7.0214	10.944	0.065	0.211	0.946	
7.0232	10.925	0.075	0.178	1.018	
7.0256	10.939	0.082	0.181	0.992	
7.0270	10.953	0.093	0.172	1.038	

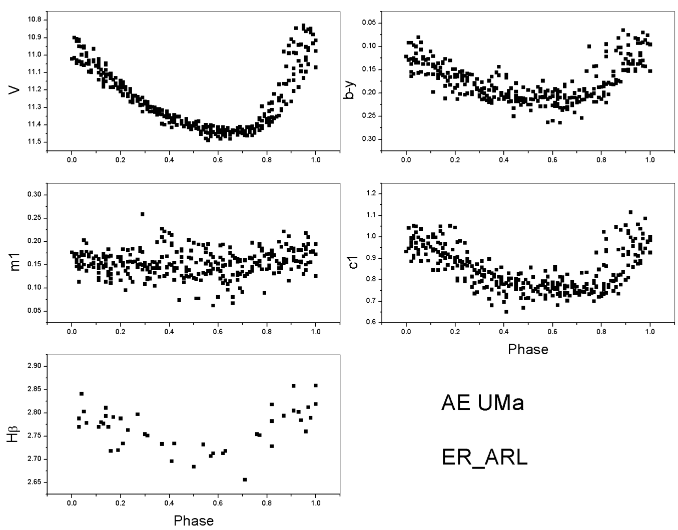

Figure 1. Phase plot of the $uvby-\beta$ photometry of Rodríguez et al. (1992) and that of the present paper. The time span between both sets is 25 years. The period considered is 0.086017053 d.

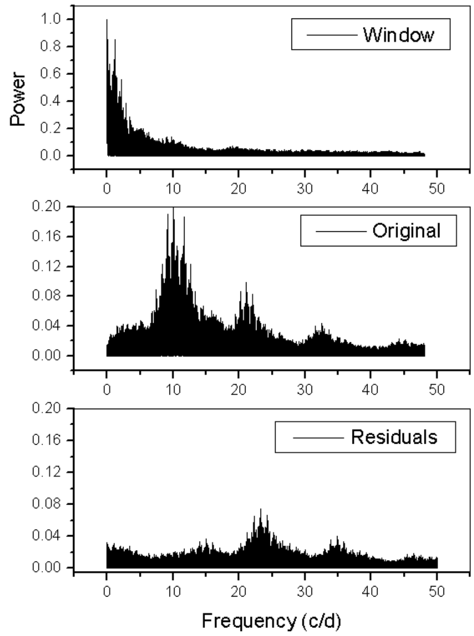

Figure 2. Periodogram of V magnitude of $uvby-\beta$ photometry of Rodríguez et al. (1992) and data from the present paper in Period04. Top, Window function; middle, original data; bottom, residuals.

indexes conform the phase with the period used here. A few points were completely out of the general pattern; we discarded them and were left with a sample of 356 $uvby-\beta$ data points.

The first method utilized to determine the frequency content of AE UMa was Period04 (Lenz & Breger 2005), a well-known method widely utilized by the δ Scuti star community. For the 1299 V points of the sample we selected a frequency range between 0 and 50 c/d. We ran the method twice and obtained the results listed in Table 5 and represented graphically in Figure 2, with these other characteristics: Zero point: 11.2871229; Residuals: 0.0584757486. The comparison of the observations with the predictions were astonishing given the long time basis of 38 years.

The same data set was tested in Period04 with the period proposed by Pocs & Szeidl (2001). The obtained results are frequency 11.6253822 c/d; amplitude, 0.22205636 mag; phase, 0.819373 mag with a zero point 11.287086 and a residual of 0.079247, which demonstrate the goodness of the Period04 proposed period.

An absolute verification of the constancy of the period for at least the last 25 years was done through the $uvby-\beta$ photometry carried out by Rodríguez et al. (1992, starting in 1986 and continuing in 1987 over twenty nights) and that observed by us in 2011, 25 years later. A phase was calculated for both seasons with a total of 356 points; the resulting diagram is shown in Figure 1. As can be seen this discards the supposition of a double mode variable although there is some evidence of a variable amplitude. This also rules out a secular variation of the period.

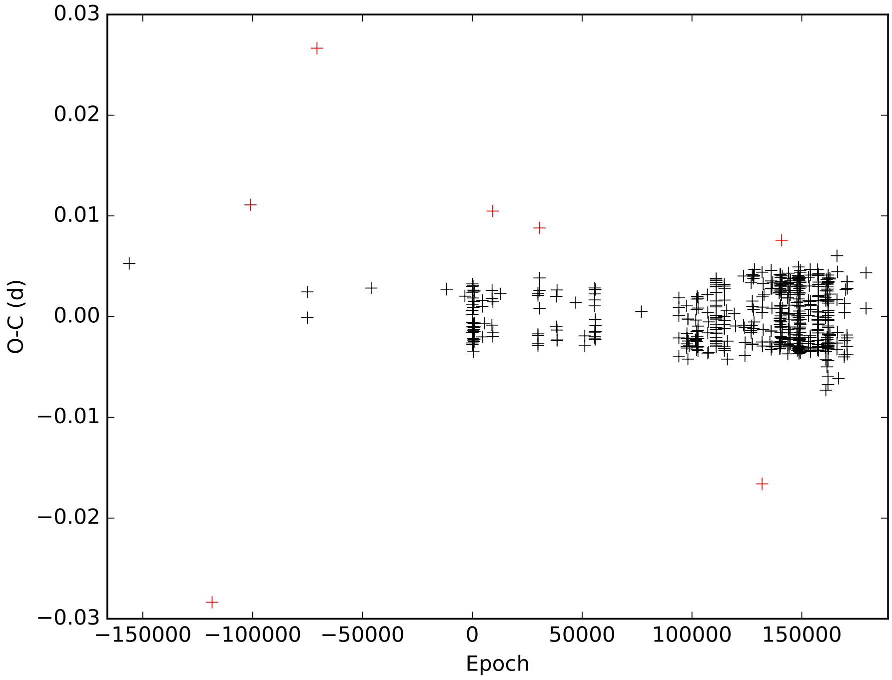

Figure 3. O–C distributions vs time. A large scatter is caused by reduction or observation procedure and not inherent to behaviour of the star.

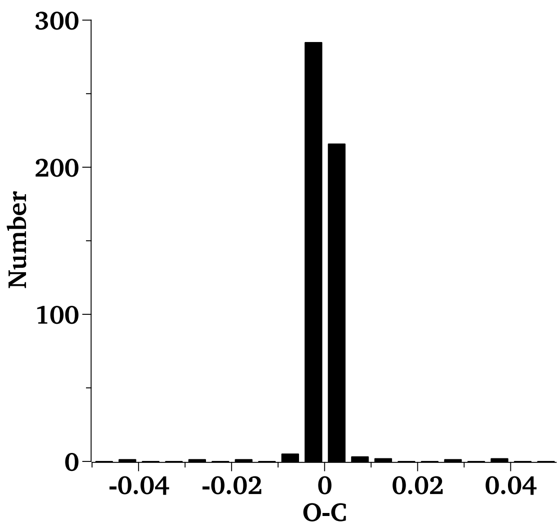

Figure 4. O–C distributions in an histogram. The values at the wings were discarded.

Table 5: Output of the PERIOD04 package with time series of the V data of AE UMa

Nr	Frequency (c/d)	Amplitude (mag)	Phase
F1	$11.6253822 \pm 5.9 \times 10^{-7}$	0.214 ± 0.004	0.775 ± 0.003
F2	$23.2514162 \pm 2.0 \times 10^{-7}$	0.077 ± 0.004	0.275 ± 0.009

Table 6: AE UMa ephemeris equations.

Author	T_0	P	β
Pocs and Szeidl (2001)	2442062.5824	0.086017076	
Zhou (2001)	2442062.5827	0.08601585	5.71034×10^{-12}
PERIOD04		0.086018677	
MSDR	2442062.5824	0.086017072	
PDDM	2456746.6464	0.086017069	

3.2 O–C Methods

Before calculating the coefficients of the ephemeris equation, we studied the existing literature related to AE UMa. Several authors have conducted studies of the O–C behaviour of this particular object and, in this preliminary stage, we took the existing equation and reproduced the diagrams with our updated list of times of maxima taken from the literature plus the data that we acquired.

The principal works on AE UMa are those of Pocs & Szeidl (2001) and Zhou (2001). They are presented in Table 6. In the first one the authors find this star varying with a constant period for more than half a century. On the other hand, Zhou (2001) finds a varying period (his equation 14).

Pocs & Szeidl (2001) took all the O–C values, into account with the exception of Filatov's data (124 maxima, time interval of 61 years) and they arrived at the following quadratic polynomial fit

$$\begin{aligned} O - C &= (2.2 \pm 2.6) \times 10^{-4} - (1.71 \pm 0.53) \times 10^{-8} E \\ &+ (0.053 \pm 0.053) \times 10^{-12} E^2 \end{aligned}$$

Since then, the only studies of the analysis of the pulsation of AE UMa were done by Coates & Landes (2008), and Niu et al. (2013) which merely confirmed the constancy of the period of pulsation of AE UMa. There have been numerous reports on the times of maxima of this star. Those previously observed by us (Peña et al., 2015) are presented in Table 2 along with the newly observed maxima.

With an increased time basis (more than 28114 days (77 years) or 326845 cycles and 512 times of maxima compiled) we tested the reported calculations. What was immediately obvious was the exceedingly large spread in the O–C values (Figure 3). Those in the earlier stages had already been discarded by Pocs & Szeidl (2001) and Zhou (2001). However, a large scatter in the $O - C$ values was found with more recent data which did not exist on the earlier studies. To diminish the scatter the following was done: a histogram of the O–C values was calculated and the standard deviation was evaluated (Figure 4). From the graphical representation of the O–C differences vs. time those values with large spread from the mean became conspicuous. These were discarded. Some, the old ones, were those that the previous authors had also eliminated. If they are not considered, this eliminates the large spread and makes it possible to determine a more logical behaviour of the star.

3.3 Minimization of the standard deviation of the O–C residuals (MSDR)

The second method for period determination utilizes as criteria of goodness, the minimization of the standard deviation of the $O - C$ residuals (see Peña et al. 2016 for a detailed description).

This method is based on O–C standard deviation minimization. We considered a set 508 data points of $T_{\rm max}$. These are presented in Figure 5. This data set covers a time span of 77 years.

A mean period was determined in the differences of two or three times of maxima that were observed on the same night with an associated standard deviation. We swept the period between this limits. The output was a straight line with some values of the deviation of the O–C residuals clearly diminishing. We swept again for a closer period range around this feature calculating 5000 steps which gives the sufficient accuracy provided by the time span of the observations. The obtained precision of one millionth provides the new period and the limits for the iteration. In each iteration, the O–C standard deviation was calculated. We chose to be the best period that which showed the minimum standard deviation (Figure 5). The resulting equation is:

$$T_{max} = (2442062.5824 \pm 3 \times 10^{-3}) + (0.086017072 \pm 2 \times 10^{-9}) \times E$$

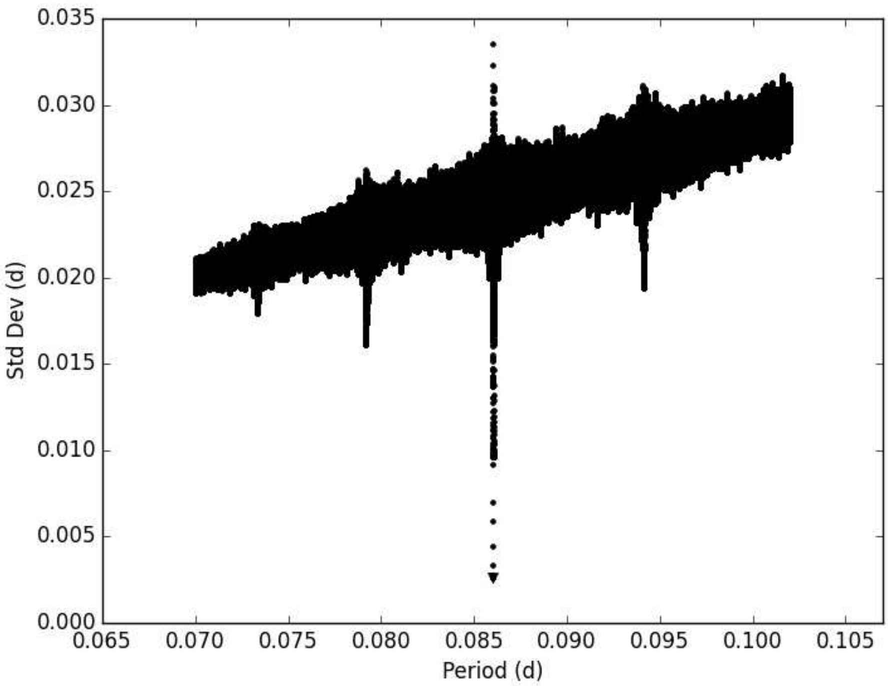

Figure 5. Standard deviation vs. Period. The minimum, clearly discerned, served to determine the best period.

3.4 Period determination through an O–C differences minimization (PDDM)

As in the case of BO Lyn (Peña et al. 2016), we employed a method based on the idea of searching the minimization of the chord length which links all the points in the O–C diagram for different values of changing periods, looking for the best period which corresponds to the minimum chord length.

A set of 508 times of maxima was considered to perform this analysis. These times are those remaining after the analysis of the histogram in Section 3.2. Two hundred and sixty-six consecutive pairs of times of maxima were used to calculate the average period and the standard deviation, being the resulting period and deviation 0.0857 d and 0.0039 d, respectively. Taking this into consideration, we can fix an interval span in which the period is located in 0.0856 ± 0.0039 days. Maintaining a period precision of a billionth and taking the interval span period into consideration, 7.9×10^6 periods were used to perform this method. The T_0 used to calculate the O–C diagrams is 2456746.6464, the final of Hübscher & Lehmann (2015). Then the best period is the one with the smallest chord length and it is shown in Figure 6. The resulting linear ephemerides equation is

$$T_{\max} = 2456746.6464 + 0.086017069 \times E$$

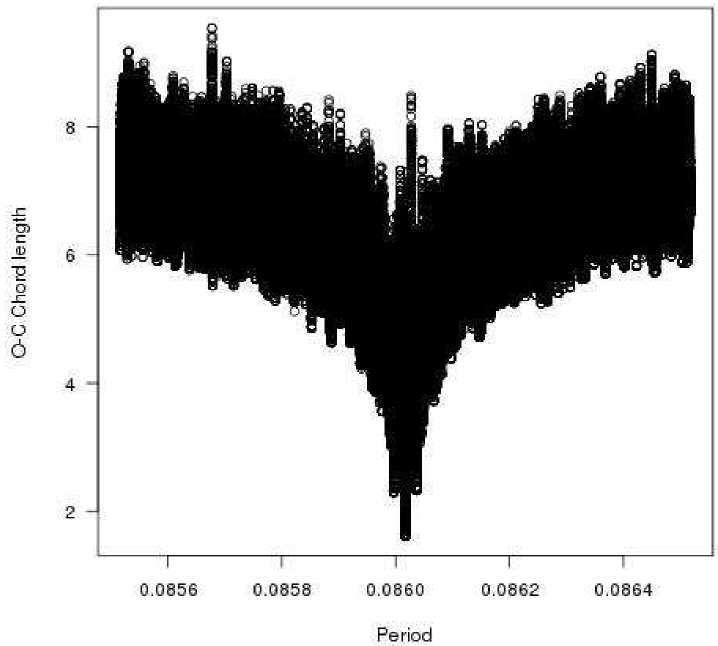

Figure 6. Period determination through an O–C differences minimization, PDDM.

4 Physical Parameters

Determining physical parameters for the stars is not a simple task. The advantage of intermediate band photometry is that, if it is well calibrated and used together with the

Table 7: Reddening and unreddened parameters of AE UMa

Phase	$E(b-y)$	$(b-y)_0$	m_0	c_0	Hβ	V_0	M_V	DM	Dist	[Fe/H]
0.05	0.000	0.131	0.160	0.966	2.796	11.00	1.03	9.98	989	
0.15	0.000	0.158	0.144	0.941	2.765	11.12	0.79	10.33	1165	
0.25	0.015	0.161	0.161	0.864	2.771	11.16	1.54	9.62	838	
0.35	0.009	0.187	0.153	0.805	2.746	11.28	1.72	9.56	815	
0.45	0.000	0.211	0.151	0.768	2.715	11.38	1.38	10.00	1001	−0.246
0.55	0.000	0.216	0.146	0.768	2.709	11.43	1.20	10.22	1108	−0.287
0.65	0.007	0.209	0.139	0.764	2.716	11.41	1.44	9.97	988	−0.430
0.75	0.000	0.207	0.154	0.769	2.721	11.41	1.53	9.88	946	
0.85	0.017	0.140	0.168	0.833	2.801	11.18	2.27	8.91	606	
0.95	0.000	0.132	0.168	0.949	2.797	11.00	1.19	9.81	915	

theoretical models, it can be utilized to infer the physical conditions of the stars.

The whole $uvby-\beta$ sample consisted of some 360 data points. In both data sets the weak point was the subset of Hβ photometry. Rodríguez et al. (1992) observed only 58 data points and in 2011 our Hβ sample consisted of only four data points.

With the advantages of the empirical calibrations of Balona and Shobbrook (1984) and Nissen (1988), based on the earlier papers of Crawford for stars of different spectral type stars for $uvby-\beta$ photometry, we determined reddening and unreddened indexes. These, combined with theoretical models such as those of Lester, Gray & Kurucz (1986, hereinafter LGK86), determined physical parameters such as surface gravity and effective temperature. These calibrations have already been described and used in previous analyses (Peña & Peniche 1994; Peña & Sareyan 2006).

As was described at the end of section O–C Analysis, a remarkable phasing was accomplished with the two $uvby-\beta$ photometric seasons observed twenty-five years apart. In order to calculate the reddening and unreddened colors and in view of the poorness of the Hβ data of both seasons, we calculated mean averages in phase bins of steps of 0.1. To follow the behavior of Hβ we overlapped the V curve and discarded seven points which were out of the general trend of the variation.

The application of Nissen's prescription gave, for the values averaged in phase bins, the corresponding unreddened values that were presented in Table 7. This Table lists, in the first column, the phase. Subsequent columns present the reddening, the unreddened indexes, the unreddened magnitude, the absolute magnitude, the distance modulus, and distance and, in the last column, the metallicity [Fe/H] for the stages when the star was of spectral type F.

Mean values were calculated for $E(b-y)$, Distance Modulus and distance for two cases: i) the whole data sample and ii) in phase limits between 0.3 and 0.8, which is customary for pulsating stars to avoid the maximum. It gave, for the whole cycle, values of 0.005 ± 0.007; 9.83 ± 0.40 and 937 ± 158 for $E(b-y)$, DM and distance (in pc), respectively, whereas for the mentioned phase limits we obtained, 0.03 ± 0.04; 9.92 ± 0.24 and 972 ± 106 respectively. The uncertainty is merely the standard deviation. In the case of the reddening, most of the values in the spectral type in the F stage of AE UMa produced negative $E(b-y)$ values which is unphysical. In those cases we forced the reddening to be zero in which case the $(b-y)$ index is the same.

Once the unreddened colors are known, it is possible to determine some physical pa-

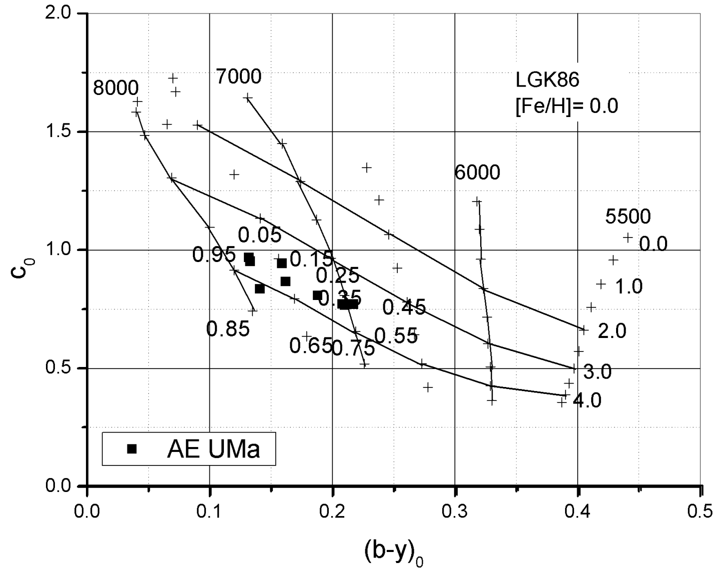

Figure 7. Cycle variation of AE UMa in the theoretical grids of LGK86.

rameters (log T_e and log g) from a direct comparison with the models developed. A metallicity has to be assumed. We mentioned in the Introduction that with respect to the metallic content, Rodríguez et al. (1992), using a δm_1 metal calibration for metal abundance, reported [M/H] = −0.3, and Hintz et al. (1997) give values of [M/H] between −0.1 and −0.4. McNamara (1997) reports [M/H] = −0.5 for AE UMa. We, utilizing the same data as Rodríguez et al. (1992) and with the same technique, obviously arrived at the same results. In the phase bins the star shows the F nature in three different phases, 0.45, 0.55 and 0.65 and a mean value [Fe/H] of −0.321 is obtained. All of these determined values fit the [Fe/H] vs. $\log P$ relationship of McNamara (1997) (his Figure 1) adequately, corroborating the assumed metallicity of AE UMa.

LGK86 calculated their model outputs for several metallicities. Particularly in the case of AE UMa, for which we determined mean metallicity of [Fe/H] = -0.32 ± 0.10, there are two models which were applicable, either [Fe/H] 0.0 or −0.5. We tested both since our determined mean metallicity of [Fe/H] $- 0.32 \pm 0.10$ lies in between.

The temperature of the star was determined from its positions in the LGK86 grids (Figure 8) and is listed in Table 8 for both metallicities. The reddening $E(B-V)$ was calculated utilizing the well-known relation $E(b-y) = 0.7 \times E(B-V)$. Table 9 presents a summary of the compiled characteristics.

5 Conclusions

New times of maximum light have been gathered for the HADS AE UMa, from CCD photometry at the Tonantzintla and $uvby-\beta$ photometry at the San Pedro Mártir Observatories, Mexico. With the inclusion of these maxima and those gathered from

Table 8: Effective temperature of AE UMa.

phase		T_e	T_e		OP&J	$\log g$
	[Fe/H]	0.0	−0.5	mean		−0.5
0.05		7800	7100	7450	7822	3.4
0.15		7500	7200	7350	7553	3.5
0.25		7500	7200	7350	7605	3.8
0.35		7200	7000	7100	7388	3.8
0.45		6800	7500	7150	7119	3.5
0.55		6800	7500	7150	7067	3.5
0.65		7100	7700	7600	7128	3.8
0.75		7000	7500	7250	7171	3.5
0.85		7700	7400	7550	7866	4.1
0.95		7700	7400	7550	7831	3.8

Table 9: Compiled characteristics for AE UMa.

Spectral Type	A9
Galactic longitude	176.1978
Galactic latitude	+47.7071
Distance [pc]	972
Reddening [mag] $E(b-y)$	0.005 ± 0.007
Reddening [mag] $E(B-V)$	0.034
Parallaxes [mas]	5.74
Distance modulus [mag]	7.92
Log T_e	3.85
Log g	3.8

the literature, the ephemerides proposed by Pocs & Szeidl (2001) was slightly modified because a larger time span was available. This result is confirmed from the time series $uvby-\beta$ data separated 25 years apart. Two other methods were employed to determine the frequency content of the star. A sinusoidal behaviour of the residuals can be discerned. Thus, the binary nature of AE UMa, indicated by other authors has been tightened up with the new times of maxima determined. Hence, the solution for AE UMa is valid since it is supported by a longer time string. The residuals indicate that this star might have the same sinusoidal behavior as AN Lyn (Peña et al. (2015) or BO Lyn (Peña et al. 2016) which would indicate a binary nature. Some physical parameters were determined for AE UMa from $uvby-\beta$ photometry from the literature (Rodríguez et al. 1992) and that presented in this study. The obvious recommendation is to gather more observations that, in the long run could prove or discard this binary assumption.

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References:

Arellano Ferro, A. Nuñez, N. S., Avila, J. J., Trejoluna, J. J., 1994, *RMxAA*, **29**, 218
Arellano Ferro, A., Parrao, L., 1988, IA-UNAM Reporte Técnico, 57
Nautical Almanac Office, 2006, *Astronomical Almanac*
Balona, L. A., Shobbrook, R. R., 1984, *MNRAS*, **211**, 375 DOI
Breger, M., Pamyatnykh A.A., 1998, *A&A*, **332**, 958
Broglia, P., Conconi, P. 1975, *A&AS*, **22**, 243
Coates, D.W., Landes, H., 2008, *Comm. in Asteroseismology*, **153**, 8 DOI
Collins, K., 2012, *Astrophysics Source Code Library*, ascl:1309.001
Crawford, D. L., Barnes, J. V., 1970, *AJ*, **75**, 978 DOI
Crawford, D. L., Mander, J., 1966, *AJ*, **71**, 114 DOI
Filatov, G. S., 1960, *Astron. Tsirk.*, **215**, 20
Garcia, J. R., Cebral, J. R., Scoccimarro, E. R., et al. 1995, *A&AS*, **109**, 201
Geyer, E., Kippenhahn, R., Strohmeier, W., 1955, *Kleine Veröff. Bamberg*, **11**
Hintz, E. G., Hintz, M. L., Jones, M. D., 1997, *PASP*, **109**, 1073 DOI
Hübscher, J., Lehmann, P., 2015, *IBVS*, **6149**
Lenz, P., Breger, M., 2005, *Comm. in Asteroseismology*, **146**, 53 DOI
Lester, J. B., Gray, R. O., & Kurucz, R. L., 1986, *ApJS*, **61**, 509 DOI
Nissen, P., 1988, *A&A*, **199**, 146
Niu, J. S., Fu, J. N., Yang, X. H., & Zong, W. K., 2013, arXiv:1304.3772v2
Olsen, E. H., 1983, *A&AS*, **54**, 55
Peña, J. H., Peniche, R., 1994, *RMxAA*, **28**, 139
Peña, J. H., Sareyan, J. P., 2006, *RMxAA*, **42**, 179
Peña, J. H., Rentería, A. Villarreal, C. et al., 2015, *IBVS*, **6154**
Peña, J. H., et al., 2016, *RMxAA*, **52**, 385
Pocs, M. D., Szeidl, B., 2001, *A&A*, **368**, 880 DOI
Rodriguez, E., Rolland, A., Lopez de Coca, P., Garcia-Lobo, E., Sedano, J. L., 1992, *A&AS*, **93**, 189
Szeidl, B., 1974, *IBVS*, **903**
Szeidl, B., 2001, *Comm. in Asteroseismology*, **140**, 56
Tsesevich, V. P., 1956, *Astron. Tsirk.*, **170**
Tsesevich, V. P., 1973, *Astron. Tsirk.*, **775**, 2
Zhou, A.-Y., 2001, *A&A*, **374**, 235 DOI