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# SECULAR VARIATION AND PHYSICAL CHARACTERISTICS DETERMINATION OF THE HADS STAR EH Lib

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## 1 Motivation

It has been known for quite a while that some high-amplitude $\delta$ Scuti (HADS) stars show long-term variations. In a few cases, after correcting for these long-term variations, the O–C residuals show either sinusoidal variation that can be considered to be due to light-time travel effect provoked by the existence of an unseen companion or, at times, show quadratic behavior that is interpreted as secular period variation. With this in mind a search to determine times of maximum light for several HADS stars is being carried out (see Peña et al., 2015) at the Observatorio Astronómico Nacional de Tonantzintla, México (TNT), an observatory especially suitable for observational teaching practices with small telescopes equipped with modern CCD cameras.

After collecting times of maximum for the HADS stars, a detailed analysis on a star-by-star basis is done. Some results have been published (Peña et al., 2015) and this has stimulated us to study additional stars. These secular variation studies are supplemented with $uvby-\beta$ photoelectric photometry taken at the Observatorio Astronómico Nacional de San Pedro Mártir, México (SPM), since the determination of physical parameters of stars can be done through a comparison with theoretical models.

Previous studies on the nature of EH Lib have been extensive. Mahdy & Szeidl (1980) found that this star has a slightly stable, constant period. Jiang & Yang (1981, 1982) obtained six times of maximum that, together with the photoelectric times of maximum compiled over the past 30 years, permitted them to determine the fit with the formula:

$$T_{max} = T_0 + P_0 E + \frac{1}{2}\beta E^2 + A \sin 2\pi \left(\frac{EP_0}{E_0}\right)$$

In their article they specified the initial maximum epoch and the pulsation period as $T_0 = \mathrm{HJD}\,2433438.6088$ and $P_0 = 0.0884132445$ d, the semi-amplitude and the period of the sine curve $\beta = -2.8 \times 10^{-8}$ 1/yr; $A = 0.0015$ d, $P_0 = 6251$ d $= 17.1$ yr. E is the

Table 1: Log of observing seasons and new times of maxima of EH Lib.

| Date yr/mo/day | Observers/reducers | Npoints | Time span (day) | Tmax 2400000+ | Tel. | Filters | Camera | Obs. |
|---|---|---|---|---|---|---|---|---|
| 13/03/0203 | CVR,DZR/CVR | 58 | 0.10 | 56354.9736 | 1 m | G | 1001 | TNT |
| 13/03/2425 | CVR/CVR | 120 | 0.11 | 56376.8984 | 1 m | G | 1001 | TNT |
| 14/04/0506 | AOA14/CVR | 281 | 0.15 | 56753.8916 | M10 | wo | 8300 | TNT |
| 14/04/0506 | AOA14/DSP | 281 | 0.15 | 56753.9800 | M10 | wo | 8300 | TNT |
| 15/03/0607 | AOA15/DSP | 114 | 0.06 | 57088.8023 | C11 | wo | 8300 | TNT |
| 15/04/0102 | KV, JG/DSP | 52 | 0.05 | 57114.7947 | M10 | V | 1001 | TNT |
| 15/05/2930 | JG,AAS/AAS,JHP | 55 | 0.07 | 57172.7920 | 0.84 m | $uvby-\beta$ | phot | SPM |
| 15/06/0102 | JG,AAS/AAS,JHP | 32 | 0.05 | 57175.7990 | 0.84 m | $uvby-\beta$ | phot | SPM |
| 15/06/0304 | JG,AAS/JHP | 43 | 0.09 | 57177.8310 | 0.84 m | $uvby-\beta$ | phot | SPM |
| 16/03/1112 | KL/CVR | 103 | 0.09 | 57459.8721 | M10 | V | 1001 | TNT |
| 16/03/1213 | KL/CVR | 103 | 0.08 | 57460.8441 | M10 | V | 1001 | TNT |
| 16/04/0304 | AOA16/CVR | 97 | 0.13 | 57481.8879 | 1 m | G | 8300 | TNT |
| 16/04/0304 | AOA16/CVR | 97 | 0.13 | 57481.9756 | 1 m | G | 8300 | TNT |

NOTES: CVR, C. Villarreal; DZR, D. Zuñiga; KV, K. Vargas); DSP, D. S. Piña; JHP, J.H. Peña; AAS, A.A. Soni; JG, J. Guillén; KL, K. Lozano; AOA14: J. Camargo, O. Díaz, J. Flores, D. Galicia, C. García, J. Guillén, A. Muñoz, M. Paniagua, E. Pérez, J. Ramírez, D. S. Piña, M. Serratos, R. Yslas, J. Zamarrón; AOA15: U. Arellano, J. Diaz, I. Fuentes, A. Mata, I. Mora, X. Moreno,F. Ruiz, K. Valencia, K. Várgas; AOA16: K. Juárez, K. Lozano, A. Padilla, R. Velázquez, P. Santillán. C11: 11" Celestron, M10: 10" Meade telescopes.

number of periods elapsed since $T_0$, and $E_0 = 70700$, which can be interpreted as a 17.1 year periodicity as a modulation of the phase of maximum by binary motion.

More recently, Joner (1986), with $uvby-\beta$ photometry determined a reddening value of E$(b-y) = 0.041$, a mean effective temperature of $T_{\rm eff} = 7840$ K and a mean surface gravity, log $g = 4.08$. The metal abundance, [Fe/H] $= -0.015$ was also determined. Using a Wesselink method they derived a mean radius of 2.4 $R_\odot$, a mean absolute bolometric magnitude of $M_{\rm bol} = +1.5$ mag, and a mass of 2.0 $M_\odot$.

In their study devoted to EH Lib, Wison et al. (1993) stated that it was a large-amplitude $\delta$ Sct variable star and that it had a range of $9.35 - 10.08$ mag in $V$ and a spectral class range A5–F3 according to the General Catalogue of Variable Stars (Baker, 1985).

McNamara and Feltz (1976) obtained a Wesselink radius of 2.1 $R_\odot$, but did not discuss the uncertainty in the result. Later, McNamara and Feltz (1978) used the observed effective gravities of 15 dwarf Cepheids, as they were known at that time, including EH Lib, to derive an empirical equation relating radius $R$ to period $P$. They proposed the relation: $\log R = 0.80 \log P + 1.17$. They also commented that according to Joner (1986), a mean value of 2.4 $R_\odot$ for the Wesselink radius was found from the values derived for the effective temperature ($T_{\rm eff}$) as a phase function from $uvby-\beta$ photometry. The radial-velocity measurements were taken from photographic spectrograms.

## 2 Observations

Although our times of maximum light for this star have been published elsewhere (Peña et al., 2016), here we present the detailed procedure for acquiring the data. These were all taken at TNT and SPM, México. In TNT the 1.0 m telescope and a 10- and a 11-inch telescope were used. These telescopes were equipped with CCD cameras: SBIG STL–1001E and STT–8300. In SPM a spectrophotometer in the $uvby-\beta$ system was attached to the 0.84 m telescope. Table 1 presents the newly determined times of maximum light.

### 2.1 Data acquisition and reduction in TNT

During all the observational nights the following procedure was utilized. Sequence strings were obtained: the integration time for the 1 m telescope (in the $G$ filter) was 3 min and that of the smaller telescopes (in the $V$ filter) was shorter (1 min). It may seem contradictory to give a longer integration time to the larger aperture telescope, however, this was done since the mounting of the smaller telescopes is alt/az which does not allow long integration times. Nevertheless, for the 1 m telescope there were around 40,000 counts and for the 10" and 11" telescopes there were 11,000 counts, enough to secure high precision. The reduction work was done with AstroImageJ (Collins, 2012), a software that is relatively easy to use and has the advantage that it is free and works satisfactorily 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 $V_{\rm var} - V_{\rm ref}$ and the scatter calculated from the difference $V_{\rm ref1} - V_{\rm ref2}$. This scatter is 0.03941 mag. The times of maxima were easily determined by fitting a fifth-degree polynomial.

### 2.2 Data acquisition and reduction in SPM

The 0.84 m telescope to which a spectrophotometer was attached was utilized at all times. The observing season lasted six nights from May–June 2015 but only three were devoted to the observation of EH Lib (which were done by A. A. Soni & J. Guillen). The observation and reduction procedures have been extensively utilized. See for example Peña et al. (2016).

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

$$
\begin{aligned}
V_{\rm std} &= 17.6893 + 0.0340(b-y)_{\rm inst} + y_{\rm inst} \\
(b-y)_{\rm std} &= 1.4055 + 0.9692(b-y)_{\rm inst} \\
m_{1_{\rm std}} &= -1.3713 + 1.0928(m_1)_{\rm inst} + 0.0134(b-y)_{\rm inst} \\
c_{1_{\rm std}} &= 0.0419 + 1.0341(c_1)_{\rm inst} + 0.1392(b-y)_{\rm inst} \\
H\beta_{\rm std} &= 2.3513 + -1.3565(H\beta)_{\rm inst}
\end{aligned}
$$

The averaged transformation coefficients of each night are listed in Table 2 along with their standard deviations. In these equations the coefficients D, F, H and L are the slope coefficients for $(b-y)$, $m_1$, $c_1$ and $\beta$. The coefficients B, J and I are the color terms of $V$, $m_1$, and $c_1$. Season errors were evaluated using the standard stars observed. These uncertainties were calculated through the differences in magnitude and colors, for ($V$, $b-y$, $m_1$, $c_1$ and $\beta$) as (0.0361, 0.0119, 0.0150, 0.0197, 0.0213), respectively, providing a numerical evaluation of our uncertainties. Emphasis is made on the large range of the standard stars in the magnitude and color values: $V$:(5.2, 8.8); $(b-y)$:(-0.01, 0.79); $m_1$:(0.09, 0.70); $c_1$:(0.23, 1.39) and $\beta$:(2.52, 2.90).

Photometric values of the observed star are available as an online table. In this table, column 1 reports the HJD of the observation, columns 2 to 5 the Strömgren values V, $(b-y)$, $m_1$ and $c_1$, respectively; column 6, the $\beta$.

Table 2: Transformation coefficients obtained for the observed season.

| season | B | D | F | J | H | I | L |
|---|---|---|---|---|---|---|---|
| 2015 | 0.034 | 0.969 | 1.093 | 0.0134 | 1.034 | 0.139 | −1.3565 |
| $\sigma$ | 0.059 | 0.0125 | 0.016 | 0.015 | 0.045 | 0.054 | 0.0591 |

# 3 Period determination

## 3.1 Time series analysis

As in the case of AE UMa (Peña et al., 2016), we were lucky to have previously reported observations of EH Lib in Strömgren photometry. There are three samples: the data presented by Epstein (1969) in $ubvy$ only, that of Joner (1986) and that of the present paper with data from 2015 in $uvby-\beta$ photometry. The question that immediately arises relates to the concordance of these three samples. A phase diagram was built considering all $uvby-\beta$ data with the latest period analysis and the ephemerides elements of Boonyarak et al. (2011), it is shown in Figure 1. What is immediately seen from this figure is that: i) the phase concordance of the three samples implies a constant period for at least the time span of 47 years and ii) there is a large dispersion in the $m_1$ and $\beta$ indexes.

To determine the period, at this stage, we will consider only the $V$ magnitude which has a remarkable good behavior given the long time separation of the sets, with only very few discordant points that were discarded. We were left with a set of 264 data points in this V filter.

With such a long time basis in the $uvby-\beta$ time series, a period can be determined through Fourier transforms. As with the short period variable community we utilized Period04 (Lenz & Breger, 2005) with a frequency interval between 0 and 50 c/d. The window pattern is complex due to the scarce and separated data sets. Figure 2 schematically shows the obtained results. The frequency spectrum of the original data presents a peak at $12.3132578 \pm 0.5 \times 10^{-6}$ c/d with an amplitude of $0.212 \pm 5 \times 10^{-3}$ mag and a phase of $0.241 \pm 4 \times 10^{-3}$. The uncertainty was evaluated by the method included in Period04.

The second highest point is at 11.3106898 c/d which corresponds to the period proposed by Boonyarak et al. (2011) of 0.08841326 d. However, when this maximum is enlarged it unfolds into two close maxima at 11.3106898 c/d and 11.3108600 c/d of amplitude of the same order. If the first case is analysed for the residuals, a peak at $23.6246307 \pm 2 \times 10^{-6}$ c/d is obtained which is merely a $2f$ value of the determined frequency. The amplitude which corresponds to this is $0.083 \pm 6 \times 10^{-3}$ mag with a phase of $0.55 \pm 1 \times 10^{-2}$. The analysis of the residuals of these two frequencies yields a peak at $32.9192025 \pm 3 \times 10^{-6}$ c/d with an amplitude of $0.040 \pm 4 \times 10^{-3}$ mag and a phase of $0.22 \pm 1 \times 10^{-2}$. Again, the predictions versus the observations show a remarkable fit.

As can be seen, Period04 gives as output the same numerical values within the errors due to the window function as those proposed by Boonyarak et al. (2011) deduced with a completely different approach (the more canonical O–C method).

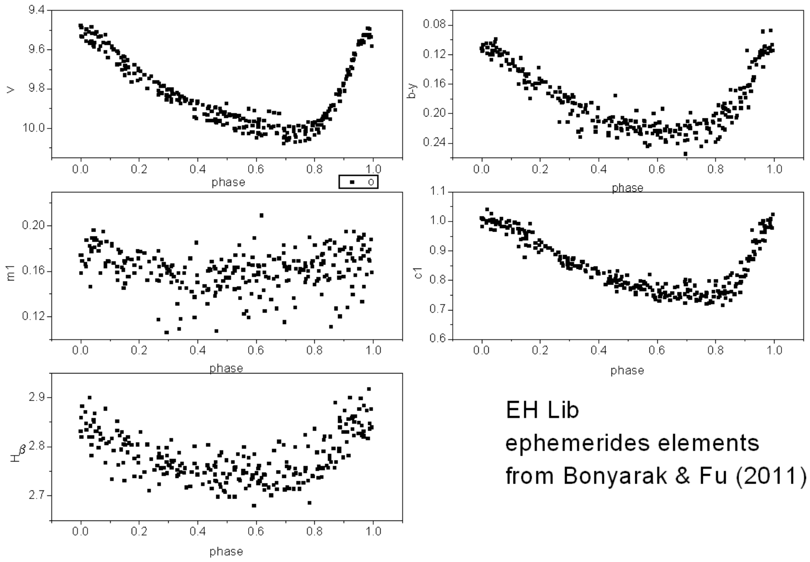


**Figure 1.** Phase plot of the $uvby - \beta$ photometry of Epstein (1969), Joner (1986) and the present paper. The time span between these sets is 49 years. The period considered is that proposed by Boonyarak (2011).

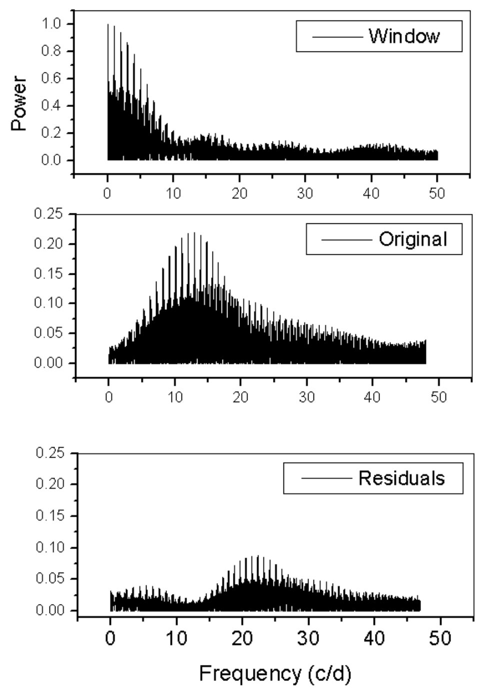


**Figure 2.** Frequency spectrum of V data of photometry of Epstein (1969), Joner (1986) and the present paper in Period04. Top, Window function; middle original data; bottom, residuals.

Table 3: EH Lib ephemeris equations.

| Author | $T_0$ | P | $\beta$ | Mean (d) | $\sigma$ (d) |
|---|---|---|---|---|---|
| Code, 1950 | | 0.0884 | 0 | | |
| Ashbrook, 1952 | 2433673.1688 | 0.08841381 | 0 | 0.0014 | 0.0258 |
| Fitch, 1957 | 2433438.6078 | 0.08841325 | 0 | 0.0012 | 0.0023 |
| Sanwal & Panda, 1961 | 2433438.6079 | 0.08841324 | 0 | 0.0022 | 0.0026 |
| Oosterhoff & Walraven, 1966 | 2433438.6090 | 0.088413216 | 0 | 0.0037 | 0.0042 |
| Epstein, 1969 | 2433438.610 | 0.088413 | 0 | 0.0054 | 0.0212 |
| Karetnikov & Medvedev, 1977 | 2433438.6082 | 0.0884132445 | 0 | 0.0014 | 0.0024 |
| Mahdy & Szeidl, 1980 | 2433438.6078 | 0.088413243 | 0 | 0.0020 | 0.0025 |
| Jiang & Yang, 1982 | 2433438.6088 | 0.0884132445 | 0 | 0.0008 | 0.0024 |
| Boonyarak et al., 2011 | 2433438.6067 | 0.08841326 | 0 | 0.0012 | 0.0022 |
| Boonyarak et al., 2011 | 2433438.6064 | 0.08841324 | $1.01\times10^{-13}$ | 0.0027 | 0.0026 |

### 3.2 O–C analysis

As a first step in carrying out an analysis of the secular variation, an O–C vs. epoch a diagram was constructed with all the compiled times of maximum light. Taking the most recent reported analysis (Boonyarak et al., 2011) we obtained the O–C residuals shown in Figure 3. Only a very few points (five) were outside the standard deviation limits. Hence these points were discarded in the subsequent analyses. Numerically, this is equivalent to adjusting a Gaussian to the O–C residuals and discarding those points beyond one sigma. The limit in this case is 0.0054.

The whole sample of 237 times of maximum covering a time span of 66 years was employed as a first step to determine the behavior of EH Lib. New times of maximum considered after the analysis of Boonyarak et al. (2011) were reported in Hübscher et al. (2009, 2013), Wils et al. (2011, 2012) and this paper all gathered from 2013 to 2016. In two of the papers utilized in our compilation (Pohl 1955, Hübscher et al. 2013), several of the maximum times were observed simultaneously by different observers and included independently in the same paper, so we made an average of these apparently repeated data. Since the times of maximum in the paper by Karetnikov (1977) had no heliocentric correction, we added it and these points are included in our compilation, but not in the analysis. After these procedures there were 226 times of maximum left.

Table 3 summarizes all the previous proposed ephemerides. The main source was Mahdy & Szeidl (1980) and the references within. Other references, with reported, but not analysed observations, were compiled. The large scatter shown by the times of maximum in the O–C vs. epoch diagram became immediately obvious. Visual examination of each point was carried out to discard the inaccurately determined points from those with smaller uncertainties. Hence, following Mahdy & Szeidl (1980) for the analysis, we discarded all observed visual and photographic points. The remaining sample was constituted of 135 times of maximum covering a time span of almost 61 years. As can be seen in Table 3, a mean value and the standard deviation of the O–C values were calculated for each case in which no clear distinction could be made.

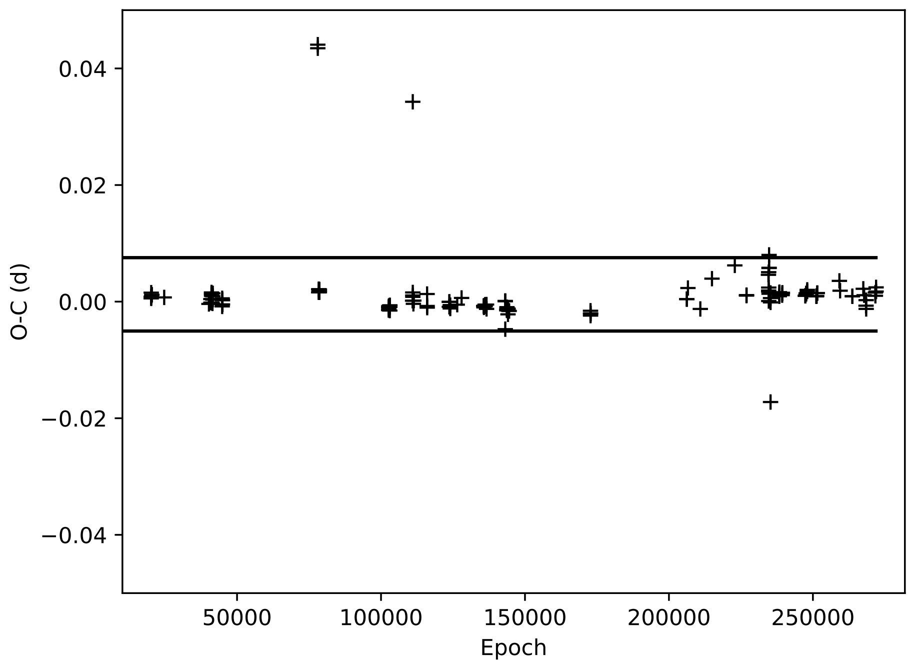


**Figure 3.** O–C diagram with all the measured times of maximum light.

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

To determine the ephemerides equation of the variability of EH Lib we, as was previously mentioned, omitted the visual and photographic points and made use of only the photoelectrical ones.

To calculate the ephemerides equation, a standard deviation minimization of the O–C diagram was built. The standard deviation of several O–C diagrams for this same star was calculated. In all cases, as a first step in constructing these O–C diagrams, $T_0$ and the period $P$ were used as the first time of maximum with each one of the points between 0.087251454 and 0.089596791 with a precision of $1 \times 10^{-9}$. This range is the one provided by the average of the difference of consecutive times of maximum light and the standard deviation of the same. With all of the 2345336 periods, the cycle number $E$ of all the times of maximum was calculated. The second step was to make a linear fit of the times of maximum with the cycle number (HJD vs. E) for each different period in the range. The new period $P$ and initial epoch $T_0$ were obtained and are the parameters of the ephemerides equation needed to construct the O–C diagrams. These linear fits were carried out 2345336 times. Finally, the period and initial epoch with the smallest standard deviation of its O–C diagram was selected as the best equation. The result of these calculations is shown graphically in Figure 4. The O–C diagram obtained with this method is presented in Figure 5 and its equation is:

$$
\begin{aligned}
T_{max} = {} & 2435223.7584 + 0.088413266\,E \\
& \quad (\pm 2 \times 10^{-4}) \qquad (\pm 2 \times 10^{-9})
\end{aligned}
$$

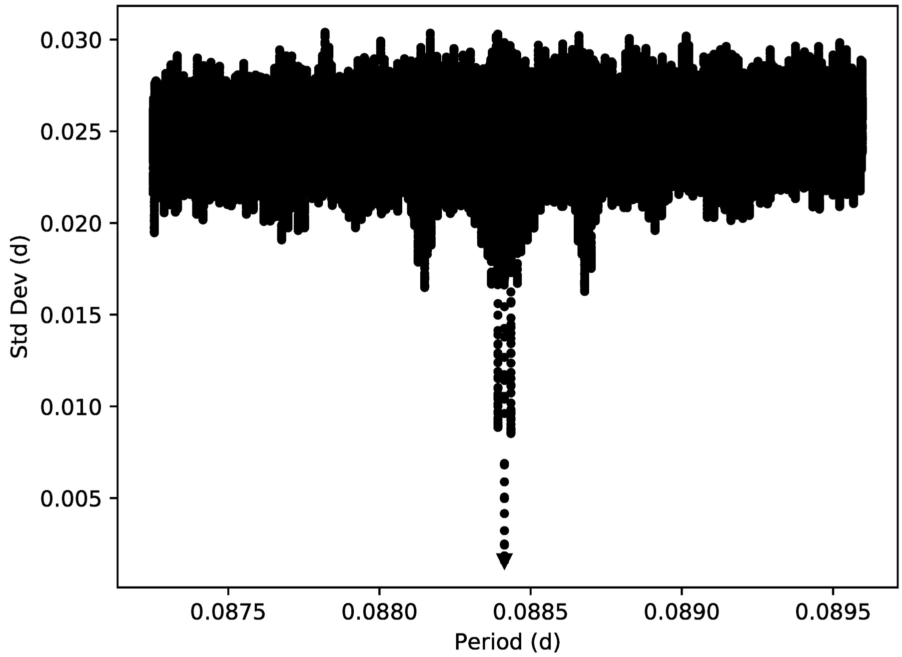


**Figure 4.** Standard deviation vs. Period of the standard deviation minimization of the O–C residuals method in the linear case.

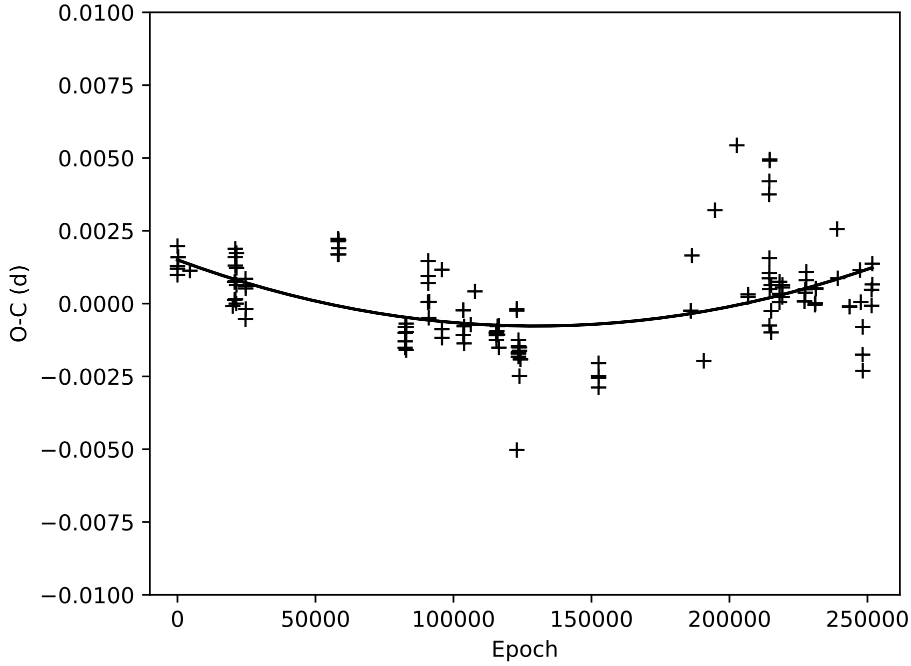


**Figure 5.** O–C Diagram of EH Lib calculated with the ephemerides equation obtained with the MSDR method in the linear case.

A parabolic trend is present in the O–C diagram as can be seen in Figure 5. To be able to get the parameters of that second order changing period, we followed the same method but instead of fitting the data to a straight line, it was fitted to a parabola. The standard deviation vs. period diagram using the parabolic fit is shown in the Figure 6. The result of subtracting this parabolic trend from the data is shown in the Figure 7. The parabolic equation is:

$$\begin{aligned} T_{max} &= 2435223.7599 + 0.088413231\,E + 1.34 \times 10^{-13}\,E^2 \\ & \qquad (\pm 4 \times 10^{-4}) \quad (\pm 6 \times 10^{-9}) \quad\quad (\pm 0.2 \times 10^{-13}) \end{aligned}$$

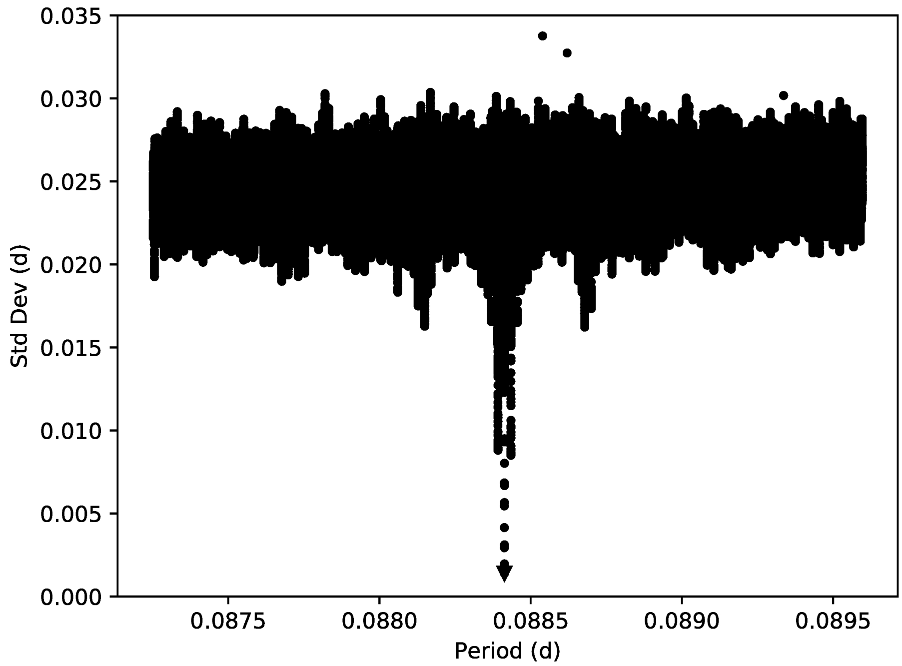


**Figure 6.** Standard deviation vs. period of the standard deviation minimization of the O–C residuals method in the quadratic case.

## 4 Determination of physical parameters

To determine the physical characteristics of the star, we first evaluated the reddening through Strömgren photometry and the appropriate unreddening calibrations. As was mentioned before, there are three samples of data with $uvby-\beta$ photometry: that of Epstein (1969) in *ubvy* only; that of Joner (1986), and that present in the online data table which was taken in 2015. A phase diagram was built considering all $uvby-\beta$ data with the ephemerides elements of Boonyarak et al. (2011) and it is shown in Figure 1. A phase concordance within the three samples implies a constant period for at least 47 years although there is a large dispersion in the $m_1$ and $\beta$ indexes. The physical parameter determination is done through the calibrations of Nissen (1988), developed to determine

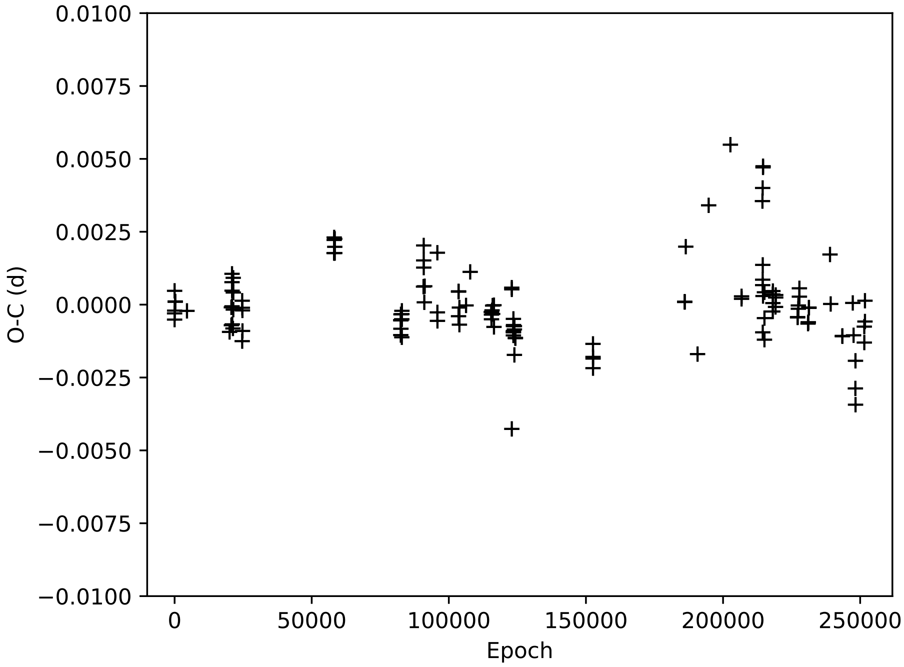


**Figure 7.** O–C Diagram of EH Lib calculated with the ephemerides equation obtained with the MSDR method in the quadratic case.

reddening, and hence the unrreddened color indexes for the late A and F stars to which EH Lib belongs. Values of reddening, unreddened indexes, absolute magnitude, distance modulus, distance and metallicity were determined through the mathematical expressions proposed by Nissen (1988, his equations 3, 4, and 10), which can be used to calculate the intrinsic color index $(b-y)_0$. The absolute magnitude was then calculated for A and F type stars whereas the metallicity (Nissen 1988, his equations 6, 7, and 8) is determined only when the star is in its F stage.

To avoid large dispersion in the output values due to the large scatter of the $m_1$ values caused by a noisy $u$ filter, mean values for each index and physical parameter were calculated in phase bins of 0.05. The results of using the above mentioned prescriptions are listed in Table 4 in increasing phase values column 1 lists the mean bin values, and the following columns list the reddening E$(b-y)$, the values for the unreddened $(b-y)_0$, the $m_0$, the $c_0$, the $\beta$, the $M_v$ indexes.

To determine the physical characteristics of the star, these phase averaged, unreddened values were plotted in a $(b-y)_0$ vs $c_0$ grid and overlapped with those values calculated by Lester et al.(1986, hereinafter LGK86) for theoretical $uvby-\beta$ indices. The comparison is presented in Figure 8 from which we find the limits of variation of EH Lib in both $T_{\rm eff}$ between 7400 and 8000 K and log g varying around 4.0. Table 5 compares the findings of the previous studies with the new ones determined both from $uvby-\beta$ photometry.

Table 4: Reddening and unreddened values of $uvby-\beta$ photometry for EH Lib.

| Phase | $E(b-y)$ | $\langle(b-y)_0\rangle$ | $\langle m_0\rangle$ | $\langle c_0\rangle$ | $\beta$ | $M_v$ |
|---|---|---|---|---|---|---|
| 0.05 | 0.006 | 0.157 | 0.177 | 0.851 | 2.778 | 1.7 |
| 0.15 | 0.002 | 0.122 | 0.179 | 0.953 | 2.809 | 1.3 |
| 0.25 | 0.001 | 0.127 | 0.175 | 0.968 | 2.801 | 1.1 |
| 0.35 | 0.005 | 0.145 | 0.171 | 0.920 | 2.784 | 1.3 |
| 0.45 | 0.007 | 0.159 | 0.169 | 0.871 | 2.772 | 1.5 |
| 0.55 | 0.002 | 0.180 | 0.166 | 0.833 | 2.751 | 1.5 |
| 0.65 | 0.002 | 0.197 | 0.167 | 0.788 | 2.734 | 1.6 |
| 0.75 | 0.005 | 0.201 | 0.165 | 0.768 | 2.732 | 1.8 |
| 0.85 | 0.006 | 0.199 | 0.163 | 0.763 | 2.735 | 1.9 |
| 0.95 | 0.004 | 0.184 | 0.170 | 0.776 | 2.752 | 2.1 |

Table 5: Physical parameters determination through $uvby-\beta$ photometry for EH Lib.

| Parameter | Joner(1986) | Present Paper |
|---|---|---|
| $\langle E(b-y)\rangle$ | 0.041 | 0.021 |
| $T_{\rm eff}$ | 7840 K | 7500 $\pm$ 300 K |
| $\log(g)$ | 4.08 | 4.0 |
| $\langle$[Fe/H]$\rangle$ | $-0.015$ | $-0.133\pm0.145$ |
| $\langle M_{\rm bol}\rangle$ | +1.5 | |
| $\langle d\rangle$ | | 372 $\pm$ 39 pc |

## 5 Discussion

In previous research, Boonyarak et al. (2011) reported 0.0033 days as the RMS of the residuals of linear and quadratic fits and a period variation rate of $(9.44\times10^{-9})$ per year. Jiang & Yang (1982) used yearly averaged times of maximum light to study the period variations and found a light time effect. They stated that 29 years later the phenomenon was not shown clearly in the direct (O–C) distribution but the light time effect was still visible if the yearly average was used again.

Wilson et al. (1993) calculated the phase using Jiang and Yang's (1982) elements $E_0$ = 2433438.6082 and $E_0$ = 2433438.6082, but they reported that they didn't have enough high precision data to test the hypotheses of either a possible binary orbital motion or a Blazhko effect (Karetnikov & Medvedev, 1979) due to the low amplitude of the effects.

In the present analysis, with a time span 5 years longer, we found that the O–C diagram shows a parabolic behavior (Figure 5) with a RMS of the residuals of 0.00033 and a standard deviation 0.0015. This is consistent with the result reported by Boonyarak et al. (2011) who proposed a linear and a quadratic model but could not discriminate between the two of them because the RMS of the residuals were the same in both cases. With a longer extended time basis, 5 more years of observations, we were able to discriminate between them. Our analysis gave a RMS of the residuals of 0.00033 for the linear case and 0.00026 for the quadratic. This effect is clearly noticeable when fitting a parabola,

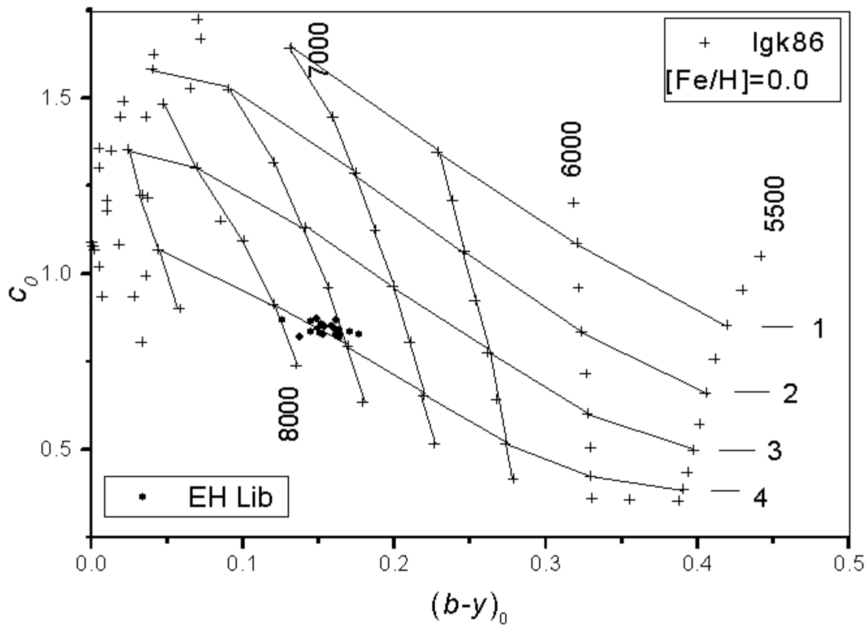


**Figure 8.** Cycle variation of EH Lib in the theoretical grids of LGK86.

obtaining a flattened O–C diagram in the residuals.

Mahdy and Szeidl (1980) affirmed a constant period, which was correct at that time; but after 36 years of further observations we can see a more complete behavior. Even with the 5 additional years to the Boonyarak et al. (2011) data base, the parabolic behavior is clearly discernable.

For the physical parameters the following is stated: $uvby-\beta$ photoelectric photometry was previously obtained for EH Lib by Epstein (1969) and by Joner (1986). From analogous considerations as those taken in the present paper they derived their own physical parameters. These are presented in Table 4.

## 6 Conclusions

Thirteen new times of maximum have been gathered for the HADS star EH Lib from two observatories with CCD and $uvby-\beta$ photometry. From the $uvby-\beta$ data, physical parameters were determined and were utilized to obtain the period of the star. The use of two more samples of $uvby-\beta$ photometry previously obtained allowed us to extend the time basis to a time span of 49 years. A minimization of the standard deviation of the O–C residuals was performed to determine the best parameters for the ephemerides equations of EH Lib and a long-term secular variation was found. The physical parameters provided by the present paper are in agreement with those of Joner (1986).

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