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Frequency and photometric analysis of the short period pulsating star YZ Boo

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ABSTRACT

In the present paper, analysis of the *BVR* photometric observations using the 1.88 m telescope of Kottamia Astronomical Observatory (Egypt) is reported. The fundamental mode with many harmonics is determined using Fourier analysis of the light curves. The photometric analysis yielded a value of the period $0^{d}.1040919125$, which is in good agreement with the period calculated by previous studies. Seventy-tow new times of maximum light are presented together with180 times from literature. An updated ephemeris for the star is determined and its O-C is presented. Assuming its period is increasing and is changing a little, a near value of (1/P) dP/dt that is determined by previous studies is calculated. Also, the amplitude behaviour is secular at a rate of about $\Delta v = 7.99\text{x}10^{-4}$ mag./year. By using empirical relations, we determined the physical parameters of YZ Boo as; the radius $\log(R_*/R_\odot) = 1.7804 \pm 0.044$, the bolometric magnitude $M_{bol} = 1.71637 \pm 0.132$, the mass $M = 1.943 \pm 0.102 M_\odot$, the surface gravity $\log g = 3.853 \pm 0.111$, the pulsation constant $Q = 0.033 \pm 0.002$, and distance 544.137 ± 20.565pc.

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Stars: variables; δ scuti stars; amplitude variability

1. Introduction

The pulsating δ Scutti stars are low mass stars with short periods that existed inside the instability strip. On the other hand, Cepheids have higher masses, they evolve quickly and therefore the probability of observing them is very low. The δ Scutti stars are also interesting as they pulsate in what are called non-radial modes in contrast to their larger Cepheid counterparts. Their periods are between 6 and 30 hours and masses between 1.0 and 3.0 M_o.

YZ Boo (HIP 75373, V = 10.57 mag) is a δ Scuti star with a high amplitude, and a maximum width of 0.42 magnitudes (Breger and Bregman 1975; Zhou 2006). Yang et al. (2018) presented a photometric study on pulsations of YZ Boo and estimated six frequencies, including its fundamental frequency of $f_0 = 9.6069\ d^{-1}$ and the period as $0\ ^{d}.1040918506$. Joner and McNamara (1983) classified YZ Boo into population I Star based on photometry uvbyβ because of the typical m_1 Index of the population I stars. The history of observational studies is quite long since previous studies of the change of star light (e.g. Broglia& Masani 1957; Eggen 1955; Heiser& Hardie 1964; Gieren et al. 1974; Spinrad 1959).

In the present paper, we reported the analysis of a total of 72 times of maxima to calculate the ephemeris, light curve analysis, and amplitude variability of YZ Boo. The paper is organised accordingly: The observations and data reduction procedure is described in section 2. The frequency and pulsation analysis of the light curves of the star is shown in Section 3. In section 4 we computed the period change. The amplitude stability is discussed in section 5. We derive the physical parameters of the star in Section 6. Finally, the discussions and conclusions of the current results are presented in Section 7.

2. Observations and data reduction

The observations were made on the 1.88-m-telescope of the Kottamia Astronomical Observatory (KAO), Egypt, at the Cassegrain focus (f/18), in April 2021. The Kottamia Faint Imaging Spectrograph was used in the photometric mode (KFISP). After the collimator section, the CCD view field (FoV) gives us 8′ x 8′ (Azzam et al. 2020). Figure 1 shows the field of the image of YZ Bootaken with the KAO, the variable star, the comparison star, and the check star are marked as V, C1, and C2 respectively.

The filters used were a standard *BVR* Johnson photometric system. All raw images are bias subtracted and flat-fielded corrected. The exposures were 120, 90, and 40 sec. in the *B*, *V*, and *R* bands respectively. All CCD images were reduced with the standard MuniWin software. The light curves were then produced by computing the magnitude differences between our system and the comparison star. The *BVR* light curves of the pulsating star YZ Boo obtained from our data are presented in Figure 1. The observations show that the star YZ Boo has a total

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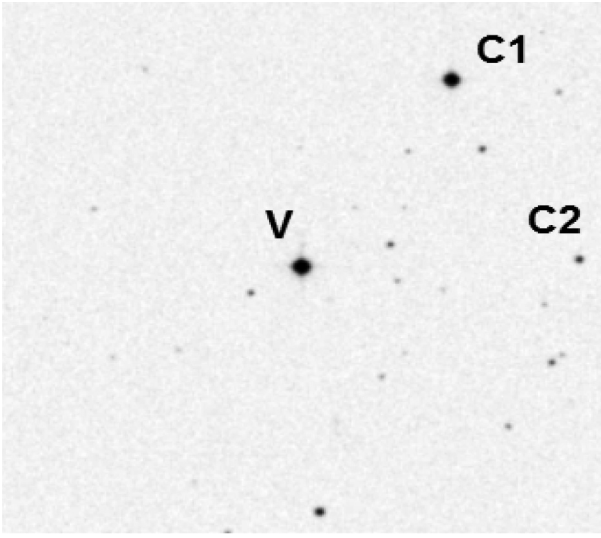

Figure 1. CCD image (8′x8) of YZ Boo taken with KFISP. YZ Boo, the comparison, and check stars are marked with V, C1, and C2 respectively.

amplitude of 0.208, 0.212, and 0.165 magnitudes in the $B_{(V\text{-}C1)}$, $V_{(V\text{-}C1)}$, and $R_{(V\text{-}C1)}$, and the average magnitude and average colour index are $V = 10.588 \pm 0.013$ and $B\text{-}V = 0.152 \pm 0.005$. Table 1 presents the positions, *V*-magnitudes, and colour index *B-V* of the variable, comparison, and check stars.

We have retrieved photometric observations from the wide-angle Search for Planets (SupperWASP) archives as well as from the American Association of Variable Star Observers (AAVSO), which have provided new maximum light times for our targets for the variability of YZ Boo (see Figure 2). Apart from our observations (Figure 2), the period of logical analysis of all this data allowed us to derive the linear ephemeris by Gieren et al. (1974) as follows:

$$HJD = 2442146.3546(5) + 0.10409156(1)E \quad (1)$$

We phased all data (KAO, SupperWASP, and AAVSO) data according to the ephemeris represented by Equation (1). The shape of the light curves (Figure 3), as well as the derived period, implied that YZ Boo is classified as δ Scuti star.

3. Light curve and pulsation analysis

The new 72 times the maxima of YZ Boo in V-colour was derived from AAVSO, SupperWASP, and KAO observations. The times of these maxima were calculated using the phase shift method packages (Eddington and Plakidis 1929). The phase shift diagram is applied to interpret period changes in light curves (e.g. Turner and Berdnikov, 2002), Abdel-Sabour et al., 2020), so, an extensive analysis of all available V-colour observations produced the data summarised in Table 3 and Figure 3. Table 3 lists the following parameters: The deduced times of maxima (HJD), the epoch of observations, comparison between the observed and calculated times of maxima brightness (O-C method), the number of points, and the source of observations.

Because the light curves of the pulsating stars are periodical, the rectified light curves can be fitted with the Fourier decomposition formula as.

Table 1. Coordinates, magnitudes, and a colour index of the variable and comparison stars.

Star	Variable star (V)	Comparison star (C1)	Check star (C2)
ID	ROTSE1J152406.95 + 365,200.9, TYC 2570–167-1, YZ Boo	TYC 2569–1184-1	TYC 2569–1050-1
α_{2000}	$15^{h}24^{m}06.9^{s}$	$15^{h}23^{m}58.19^{s}$	$15^{h}21^{m}36.119^{s}$
δ_{2000}	$+36^{d}52^{m}0.60^{s}$	$+36^{d}54^{m}24.06^{s}$	$+37^{d}02^{m}11.371^{s}$
V	10.36 ± 0.08	11.65 ± 0.12	11.41 ± 0.09
B-V	0.21 ± 0.01	1.19 ± 0.087	1.22 ± 0.02

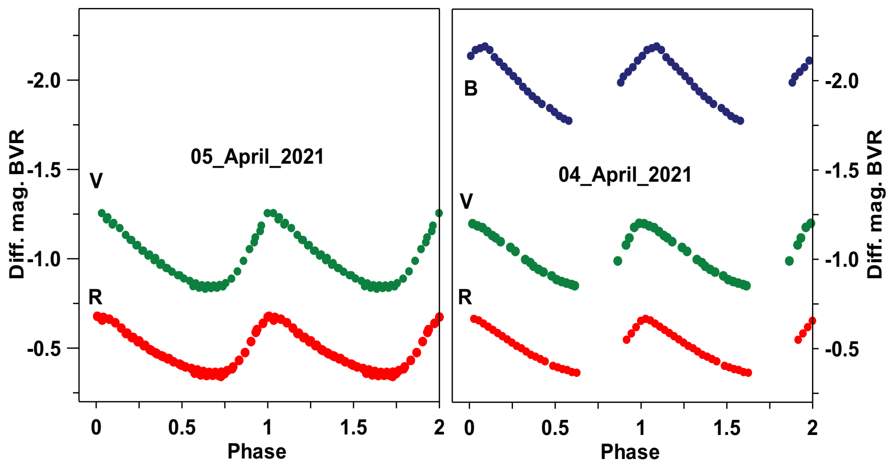

Figure 2. Folded*BVR*-Colour differential light curves(Δ*b*, Δ*v*, and Δ*r*) of KAO.

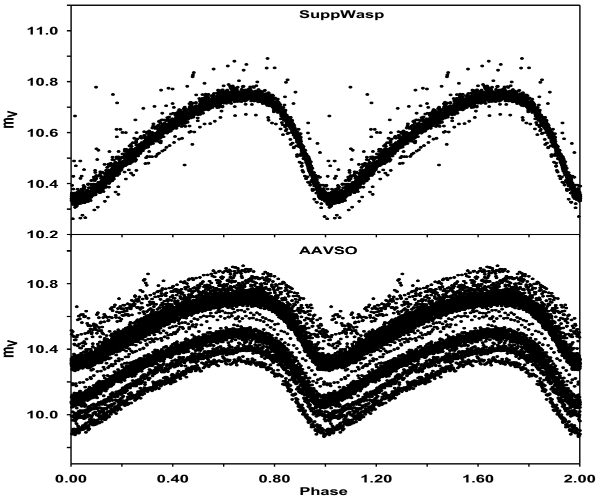

Figure 3. Phase observations of the supperwasp (Upper panel) and AAVSO (Lower panel) observations in V-colour.

$$m(t) = m_0 + \sum_{i=1}^{N} a_i \cos\left(i\omega_i(t_o - t_i) + \varphi_i\right) + \sum_{i=1}^{N} b_i \mathrm{Sin}\left(i\omega_i(t_o - t_i) + \varphi_i\right) \quad (2)$$

The observation time can be folded into phase (φ) because the period is known from the respective databases (Ngeow et al. 2003).In Equation (2), m_0 is the zero-point, ω_i is the frequency and ϕ_i is the corresponding phase. The amplitude and the phase are calculated using the formulae $A_i = \sqrt{(a^2 + b^2}$ and $\tan\varphi_i = b_i/a_i$ respectively.

The frequency analysis of YZ Boo's light curves is conducted with PERIOD04 and Peranso (www.tonnyvanmunster.ipage.com/peranso/downloads.html) software (Lenz 2005). Both codes used Fourier light curve transformations to look for significant peaks in the amplitude spectrum. First, we try to build a "periodogram" in which we fit a sinusoid into the rate of period 04 and remove the sinusoid from the original size. Then the periodogram is calculated again, but the first frequency (9.60689429 d^{-1}) is not present, so the second frequency (19.2137714d^{-1}) is the highest peak in the periodogram. We repeat this procedure until no significant frequencies remain in the data to search for other peaks (this way is called "pre-whitening"). In all times of series observations (seventy-two light curves), the Breger et al. (1993) criterion was used to obtain statistically significant frequency by distinguishing between pulse and noise peaks in the amplitude of more than four for the average amplitude range from 15 to 25 c/d in amplitude to noise ratio (S/N).

The analysis of the V-band light curve from SupperWASP showed that in the periodograms referred to in Zhou (2006) there is a fundamental frequency f_0 and three harmonics, $2f_0$, $3f_0$, $4f_0$. The analysis of the current observations by light curves indicates that, as can be seen from Table 2, the star has a basic mode with three harmonics. We can find uncertainties in frequency, amplitude, and phase through Monte Carlo simulation. The YZ Boo spectral window for the V-band is shown in Figure 4. The light curve analysis of these observations reveals that the amplitude of the pulsation varies, but additional observations are necessary to confirm this. This phenomenon was also observed in other δ Scuti stars, like BR Cancri (Zhou et al. 2001).

Table 2. Frequencies analysis of the V light curves with errors as seen from Monte Carlo simulation, of YZ Boo.

	Frequency(c/d)	$\pm$Err.x10^{-6}	Amplitude (mmag.)	Phase (0–1)	S/N
f_0	9.60689429	2.466	184.131 ± 0.481	0.159 ± 0.00046	16.356
$2f_0$	19.2137714	7.976	72.915 ± 0.346	0.110 ± 0.00105	11.923
$3f_0$	28.8206695	0.2694	21.482 ± 0.386	0.044 ± 0.00225	7.998
$4f_0$	38.4276304	0.5138	9.279 ± 0.353	0.231 ± 0.00779	4.782

4. O-C light curve and period change

To obtain the O-C differences for YZ Boo from the calculated linear ephemeris, we followed the scheme presented by Abdel-Sabour et al. (2020) and Turner et al (2006). The pulsation period adopted was calculated based on KAO observations and we made a reference time of maximum light, therefore, the calculated period of YZ Boo is $0^d.1040919125$, which is in good agreement with that of Ward et al. (2008) and Yang et al. (2018).

KAO V-colour photometry was used as a standard in the phase and scope to match data from other times to the reference set. In addition, the new ephemeris has been tested to verify its validity overall observational epochs, with all photometry observations available from AAVSO and SupperWASP.

The 72 new maximum-light times we got for YZ Boo are shown in Table 3. To study YZ Boo period change, all maximum light times are used. As can be seen in the diagram, because of a multi-mode pulsation star the light curves are wide dispersing. AAVSO, SupperWASP, and KAO observations were used to determine the new 72 maximum times. We used data points having a dispersion of 0.1 mag. or less. To determine Q (used to measure the period change (dP/dtdP/dt) in seconds per year), we used least-squares to fit the O-C to the following quadratic equation.

$$HJD_{\max} = M_0 + PE + QE^2 \quad (3)$$

Where M_0 is a new epoch, P is the new period. Figure 5 shows the O-C diagram constructed from the observations of 66 years, from 24 June 1955 to 6 April 2021. We applied a second-order polynomial least-squares to fit 132 O–C residuals, we get,

$$O - C = -8.3529(29)x10^{-5} - 1.9375(56)x10^{-9}E + 1.9332(94)x10^{-14}E^2 \quad (4)$$

With a correlation coefficient R = 0.72.

The parabolic trend in the O-C data reflects a regular period decrease or increase. After constructing the O-C diagram, we found that it has an increasing period at a rate of $dP/dt = (7.1366 \pm 1.10) \times 10^{-5} s/yr$ (or $\frac{1}{P}(dP/dt) = 1.9824x10^{-9}yr^{-1}$), the standard deviation of the residuals of parabolic fit to the O-C values is $0^d.0013$. Despite we add 72 new times of maximum light for YZ Boo with those from the literature to prepare the O-C diagram, we didn't find a big difference in the rate of period change results of Zhou (2006) of $5.0(3)\times10^{-9}yr^{-1}$, Ward et al. (2008) of $6.3(6)\times10^{-9}$ yr^{-1}, Boonyarak (2011) of 5.86×10^{-9} yr^{-1} and Yang et al. (2018), p. $6.7(9)\times10^{-9}yr^{-1}$. Our result is very close if we compared it with the theoretical values of Rodriguez (1995), $(1.6 \times 10^{-9}yr^{-1})$.

5. Amplitude stability

For accurate estimates of pulsation amplitudes, Fourier decomposition of light curves is used. In order to test YZ Boo amplitude stability, we used observations from 2000 to 2021. The amplitude is calculated by matching the observed light curves with Equation (2). Figure 6 shows the results of Fourier's total harmonic amplitude according to YZ Boo V-band. The pulsation amplitude shows a significant decrease as shown by the following equation:

$$Y = 1.7793 - 7.99x10^{-4}Av \quad (5)$$

Figure 6 shows that the amplitude variability has a long-timescale, where there is an amplitude variation as suggested by fitting.

We analysed the light curves using the Period04 code as well as some auxiliary codes to evaluate the Fourier parameters for all available observations. For this purpose, we used the present results together with the results from Zhou (2006). We found a secular decrease in the amplitude. An attempt at linear and/ or polynomial fitting indicated a decreasing rate of about $\Delta v = 7.99x10^{-4}$ mag./year.

6. Physical parameters of the pulsating star YZ Boo

To determine the physical parameters, we adopt the effective temperature of the Sun as $(T_{eff})_{\odot}$ = 5777 K, $\log g_{\odot}$ = 4.44, and $M_{bol\odot}$ = 4.75. We calculated the T_{eff} of YZ Boo by using the colour-temperature relations expressed by Boyajian et al. (2013), Valenti and Fisher (2005), Weikai Zong et al. (2015), Gray (1992), Qian et al. (2018), and Torres (2010). We get the mean effective temperature T_{eff} = 7358.11 ± 60 K^0.

Table 3. New times of maximum light of YZ Boo.

JD	Epoch	O-C	No	Reff.
2,453,827.6687	112,221.5295	−0.0016	25	SupperWASP
2,454,191.9914	115,721.5512	−0.0002	309	SupperWASP
2,454,208.9258	115,884.2393	−0.0021	682	SupperWASP
2,454,218.1790	115,973.1332	−0.0021	500	SupperWASP
2,454,225.2896	116,041.4446	−0.0021	429	SupperWASP
2,454,232.6983	116,112.6192	−0.0016	606	SupperWASP
2,454,252.5892	116,303.7099	−0.0010	543	SupperWASP
2,454,266.9914	116,442.0706	−0.0021	692	SupperWASP
2,454,277.2404	116,540.5324	−0.0021	290	SupperWASP
2,453,829.6307	112,240.3785	−0.0005	28	SupperWASP
2,453,832.1240	112,264.3317	−0.0005	112	SupperWASP
2,453,853.8710	112,473.2534	−0.0016	182	SupperWASP
2,453,904.9331	112,963.8028	−0.0021	275	SupperWASP
2,453,952.9322	113,424.9275	−0.0021	28	SupperWASP
2,454,155.7572	115,373.4522	−0.0021	504	SupperWASP
2,454,163.8270	115,450.9775	−0.0021	385	SupperWASP
2,454,169.5353	115,505.8172	−0.0016	186	SupperWASP
2,458,440.7360	156,538.9298	−0.0042	37	AAVSO
2,458,504.5634	157,152.1149	−0.0031	161	AAVSO
2,458,529.5170	157,391.8423	−0.0010	291	AAVSO
2,458,530.5192	157,401.4704	−0.0016	327	AAVSO
2,458,531.8561	157,414.3140	−0.0016	474	AAVSO
2,458,538.4870	157,478.0169	−0.0010	295	AAVSO
2,458,570.6111	157,786.6299	0.0000	203	AAVSO
2,458,571.4057	157,794.2641	0.0005	304	AAVSO
2,458,577.7561	157,855.2715	0.0000	358	AAVSO
2,458,584.4023	157,919.1217	0.0000	287	AAVSO
2,458,602.6009	158,093.9541	0.0031	86	AAVSO
2,458,649.4667	158,544.1903	−0.0010	579	AAVSO
2,458,653.3145	158,581.1559	−0.0026	252	AAVSO
2,458,933.4310	161,272.2143	−0.0005	203	AAVSO
2,458,945.4028	161,387.2271	−0.0010	111	AAVSO
2,458,958.2344	161,510.4989	−0.0005	299	AAVSO
2,458,966.8499	161,593.2673	0.0005	217	AAVSO
2,458,984.5035	161,762.8640	0.0000	886	AAVSO
2,458,999.5079	161,907.0107	−0.0005	725	AAVSO
2,459,067.2246	162,557.5595	−0.0047	206	AAVSO
2,459,268.5940	164,492.1014	−0.0036	227	AAVSO
2,459,273.5462	164,539.6767	−0.0010	271	AAVSO
2,454,178.9137	115,595.9151	0.0005	84	AAVSO
2,454,237.7205	116,160.8676	0.0010	179	AAVSO
2,454,324.9972	116,999.3284	−0.0026	139	AAVSO
2,454,544.9160	119,112.0724	0.0005	72	AAVSO
2,454,894.8533	122,473.8940	0.0000	135	AAVSO
2,454,906.5852	122,586.6016	0.0010	503	AAVSO
2,454,931.4363	122,825.3439	0.0016	582	AAVSO
2,455,311.4463	126,476.0730	0.0021	68	AAVSO
2,455,347.6627	126,824.0009	0.0005	83	AAVSO
2,456,033.4980	133,412.7708	0.0016	861	AAVSO
2,456,074.4765	133,806.4475	0.0005	603	AAVSO
2,456,339.9466	136,356.7994	−0.0010	665	AAVSO
2,456,385.4208	136,793.6673	0.0010	538	AAVSO
2,457,114.3416	143,796.3554	0.0000	537	AAVSO
2,457,131.4145	143,960.3736	0.0005	197	AAVSO
2,457,848.6352	150,850.6605	0.0010	308	AAVSO
2,457,900.5041	151,348.9611	0.0000	1132	AAVSO
2,457,905.7239	151,399.1073	0.0000	297	AAVSO
2,458,157.5825	153,818.6952	−0.0016	443	AAVSO
2,458,244.4773	154,653.4867	0.0005	886	AAVSO
2,458,258.5067	154,788.2663	0.0005	1314	AAVSO
2,458,279.6355	154,991.2494	−0.0005	63	AAVSO
2,458,281.4363	155,008.5495	−0.0005	209	AAVSO
2,458,282.4196	155,017.9960	−0.0005	366	AAVSO
2,458,292.5006	155,114.8433	−0.0010	864	AAVSO
2,458,304.2397	155,227.6200	−0.0026	270	AAVSO
2,458,313.5769	155,317.3217	−0.0021	118	AAVSO
2,458,330.2985	155,477.9643	−0.0021	116	AAVSO
2,458,440.7070	156,538.6513	−0.0037	200	AAVSO
2,458,133.5794	057518.8302	−0.0005	68	HIP
2,458,665.7055	062630.9271	−0.0021	68	HIP
2,459,309.5164	164,885.2391	0.0000	25	KAO
2,459,310.5176	164,894.8577	0.0000	49	KAO

The stellar radius is calculated from a polynomial fit to the temperature-radius relation given by Boyajian

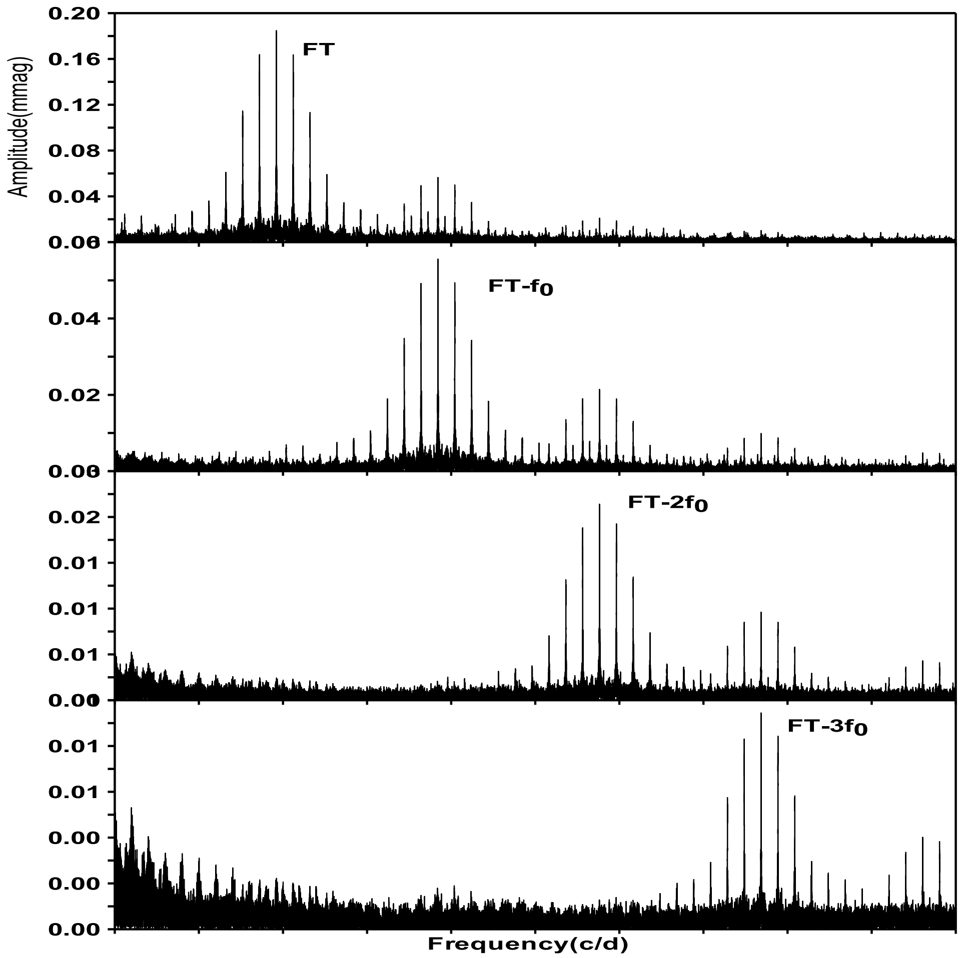

Figure 4. Fourier amplitude spectra of the frequency pre-whitening process for the light curves in V light curves observed from 2014 to 2021 and that from the KAO telescope.

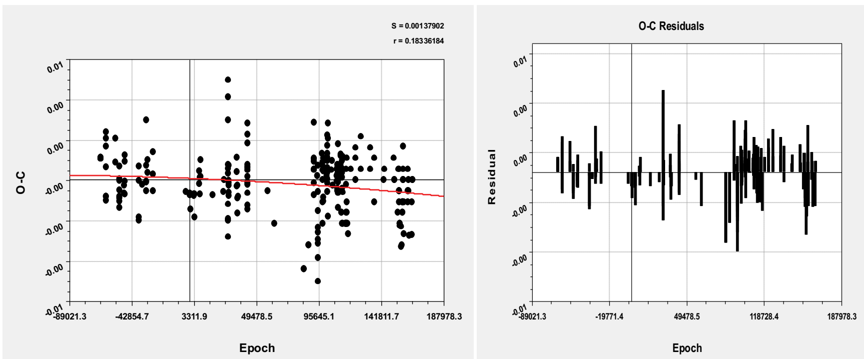

Figure 5. The O–C diagram for YZ Boo is based on a collection of 253 times of maximum light. A polynomial fit includes 72 new data points.

et al. (2012) as $R/R_{\odot}$ = 1.7804 ± 0.044. From the Stefan-Boltzmann law, we determined the stellar luminosity in solar units as $\log(L/L_{\odot})$ = 0.928 ± 0.026.

The absolute magnitude is calculated using the PL calibration presented by McNamara (1978), Petersen and Hog (1998), and Santolamazza et al. (2001) in addition to PLC relation from Fernie(1964), or by bolometric magnitude (M_{bol}) and bolometric correction presented by Torres (2010), Flower (1996), Reed (1998) and Torres (2010). Then, the absolute magnitude of the star in the visible filter is calculated asMv = 1.68146 ± 0.164. From the evolutionary models calculated by Flower (1996), we determined the bolometric correction of our system as BC = 0.0340 ± 0.001andthe bolometric absolute magnitude of the star as; M_{bol} = 1.716 ± 0.13. The stellar mass is calculated according to equations written by Deb et al. (2009) and Cox (1963), then we estimate the mass as M = 1.9425 ± 0.102$M_{\odot}$. Subsequently, the surface gravity can be calculated

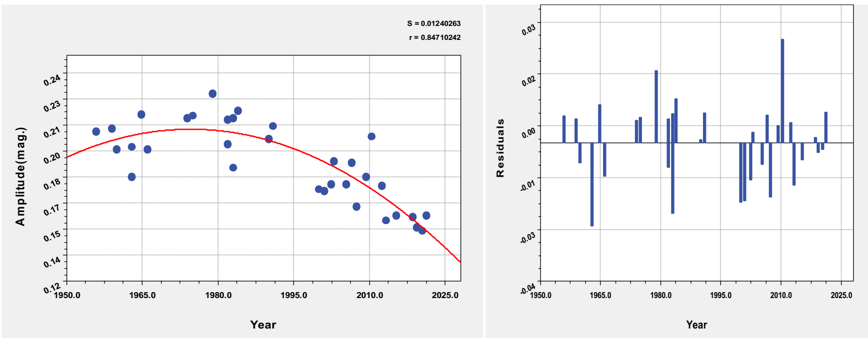

Figure 6. The behaviour of Fourier amplitude for YZ Boo in the V- band.

Table 4. The physical and observational properties of the δ Scuti star YZ Boo.

$R/R_\odot$	$M/M_\odot$	BC	M_{bol}	Log g	Q	d (pc)
$R/R_\odot$ = 1.780 ± 0.04	1.942 ± 0.102	0.0340 ± 0.001	1.716 ± 0.132	3.85 ± 0.11	0.033 ± 0.002.	544.13 ± 20.56

by Torres (2010) equation which gives log g = 3.853 ± 0.111, which is in good agreement with Dominic. The pulsation constant, Q, is expressed in terms of the four observable parameters (Breger and Bregman 1975) by

$$\log Q = 0.5 \log g + 0.1 M_{bol} + \log T_{eff} + \log P - 6.456 \quad (6)$$

This gives a value of 0.033 ± 0.002. Typical values of pulsation constants for the fundamental, first, and second overtone radial p modes in δ Scuti stars lie between 0.022 ≤ Q ≤ 0.033 d (Breger and Bregman 1975).

The physical parameters of the pulsating star YZ Boo in the present study are listed in Table 4. The distance to the stars is deduced by using the observed apparent magnitudes (m = 10.36) and the absolute magnitudes (M_v) of the star YZ Boo with the fundamental relation: $d = 10^{(m - Mv + 5)/5}$.

7. Discussion and conclusion

In the present paper, we reported frequency and photometric analyses of the short period pulsating star YZ Boo. A total of 72 times of maxima are used to update the ephemeris of the star and to determine its O-C curve, analysing the period change, and amplitude stability of YZ Boo. The obtained results could be drawn through the following points:

- The O-C of YZ Boo is dominated by errors in determining the time of maximum and by effects of cycle-to-cycle period fluctuations.
- The data reveal significant cycle-to-cycle fluctuations in the pulsation period, indicating that Pulsating stars may not be as accurate astrophysical clocks as commonly believed: inspite of the specific points used to determine the O − C values, the cycle lengths show a scatter over 179 cycles covered by the observations. A very slight correlation between the individual Fourier parameters and the O − C values was found, suggesting that the O − C variations might be due to the instability of the light-curve shape
- From the present results, we cannot decide if the period of YZ Boo is stable or not, but this will be feasible if the star is observed regularly during the next years. The result in the present study gives the value of $\frac{1}{P}(dP/dt) = 1.9824x10^{-9} yr^{-1}$.
- A secular decrease in the amplitude by a rate of about $\Delta v = 7.99x10^{-4}$ mag./year is noted.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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