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# PERIOD VARIATION OF VX LACERTA ALGOL BINARY STARS

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***Abstract***

*This investigation analyzed the eclipsing binary system's VX Lac light curve and period simultaneously. The W-D code was used to analyze the light curves of the system's B, V, and R filters. According to the findings, VX Lac is an Algol-type binary with a mass ratio of q = 0.27, with the less massive secondary component occupying its Roche lobe. The orbital period behavior of the system was analyzed utilizing the light time effect (LITE) of a third body. The O-C analysis yielded a mass transfer coefficient of dM/dt = 1.86 Myr$^1$ and a minimum mass of M3 = 0.57M$_\odot$ for the third body. As the O-C diagram reveals another cyclic variation, the mass transfer and the third body residuals were also analyzed. Under the stellar metallicity and third-body hypotheses, this periodic variation was examined.*

***Keywords:*** *binaries: eclipsing — stars: fundamental parameters — stars: individual (VX Lac), Metalcity, Third body*

## 1. INTRODUCTION

VX Lac (BD+374662, GSC 03214 01295) is an Algol-type eclipsing binary star with a visual magnitude of $m_V$ = 10.5 and an orbital period of P = 1.25 days. Cannon (1934) was the first to identify the system's F0 spectral type. R. Szafraniec (1960) identified 0.6558 as the phase of the normal minimum. Based on visual observations, Szafraniec (1960) determined the first light curve of VX Lac. Due to insufficient minimum times, Kreiner (1971) could not identify any period variation in his first O-C diagram. Using the system's photometric and spectroscopic data, we performed Binary Maker (BM3) and Wilson-Devinney (Wilson & Devinney, 1971) modeling of VX Lac to address this deficiency. Even though a number of studies have been published on the light curve of this system, none of them contain spectroscopic data. Consequently, their constituents interact strongly, leading to tidal captures, collisions, fragmentation processes, and mergers. 2008 Zasche et al. conducted this system's most recent period study. Based on online data, Svechnikov and Kuznetsova (1990) have estimated that the spectral type of VX Lac is F0 + K4 IV. Numerous systems play a significant role in the evolution of binary stars. According to A, most binaries and single stars originate from the disintegration of multiple systems due to internal instabilities and external perturbations (Bate 2004; Bodenheimer 2011; Goodwin & Kroupa 2005; Larson 2001). Liakos et al. (2012), the system's m mag is 10.83. A third-body approximation (light-time effect: LITE) and mass transfer were assumed to acquire the optimal solution. The conservative mass transfer rate was calculated as follows: Photometric and spectroscopic observations of eclipsing binaries are indispensable for determining the absolute parameters of each component, such as stellar masses, radii, and temperatures. These parameters are also crucial for understanding the evolutionary stage of eclipsing binary systems. The period analysis of such systems by means of O-C diagrams enables us to investigate the underlying physics of

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the orbital period variations. The O-C diagram] is one of the most useful diagnostic tools for analyzing the dynamical evolution of close binaries. These analyses tell us whether or not the binary systems are multi-star systems. These systems also afford ample opportunities to investigate stellar and planetary systems' dynamic interactions and formation mechanisms. Due to a dearth of spectroscopic observations, the light curves and physical parameters of the thousands of newly discovered eclipsing binaries have not been analyzed. We have simultaneously analyzed photometric and spectroscopic observations for the first time, and we present the system's fundamental parameters. When M is less than 4,7108 M/year. With a period of approximately 68 years, the LITE parameters predict a minimum third body mass of 0.39 M. Zasche (2016) conducted the most recent light curve analysis of VX Lac using Super Wasp data. For the analysis, he assumed the system's mass ratio to be $q = M_2/M_1 = 1$. Table (1) shows the right ascension (RA or **$\alpha$** ) and Declination (Dec or **$\delta$**)of the star.

**Table 1: Observational Properties of Variable Comparison and check stars**

| Parameter | Variable |
|---|---|
| | VX Lac |
| $\alpha_{1900}$ | $22^h\,36^m\,30^s$ |
| $\delta_{1900}$ | $+37^o\,48'.0''$ |
| $\alpha_{2000}$ | $22^h\,41^m\,00^s.56$ |
| $\delta_{2000}$ | $+38^o\,19'20''$ |
| Spec. Type | F0 |
| B-V | 0.36 |
| $m_v$ | $10^m.51$ |

## 2. OBSERVATION

The Ritchey Chretien telescope's 0.4 SBIG STL 6303E CCD camera can determine new data for VX Lac stars. The Observatory MPC code (for location) is C73. Jan Ovidiu Tercu and Gabriel Cristian Neagu, two on-site astronomers, observed Romania's Galati metropolis using the CCD filters UBVRI and Sloan. The target's multicolor photometric data were collected with Johnson-Cousins B, V, and R filters. The standard IRAF5 duties (bias, dark, and flat correction) were applied to reduce each image. Using the IRAF software program, aperture photometry was then performed. Individual differential magnitudes were computed in the sense of variable minus comparison, and the variability of these magnitudes was confirmed through observations of a check star. The estimated standard deviations for these observations were 0.007, 0.004, 0.003, and 0.003 for the B, V, and R filters, respectively. A summary of the relevant catalog data for the target, comparison, and verification stars these differential magnitudes were used to construct the systems for three filter light curves, which were phased using light elements calculated from newly observed data and archived minimum times. Spectroscopic observations of VX Lac were obtained using the Cassegrain spectrograph attached to the 1.85 m Plaskett telescope at the Dominion Astrophysical Observatory (DAO) in Victoria, British Columbia, Canada. The spectra covered a wavelength range of 5000 A to 5260 A and had a resolution of R 10000. Rucinski's broadening functions were utilized (Rucinski, 2004; Nelson et al., 2006).

## 3. LIGHT CURVE AND ROCHE LOOP ANALYSIS

The photometric and physical parameters of VX Lac constituents were determined by analyzing the light and O-C plots with the W-D. The analyses were conducted using the software applications Binary Maker and Peranso. In accordance with Gray & Corbally's (1994) effective temperature versus spectral type calibration of main-sequence stars, the primary component temperature was set to $T_1 = 7300$ K

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for the analyses. Several parameters were also fixed or calculated during the process of light curve modeling the values for the albedo and gravity darkening coefficients, and the limb darkening coefficients were taken from the tables in Van Hamme (1993) as functions of temperature and wavelength. For stars with radiative and convective envelopes, the bolometric albedo was assumed to be $A_1 = 1$ and $A_2 = 0.5$, and the gravity darkening coefficients were assumed to be $g_1 = 1$ and $g_2 = 0.32$ (Lucy 1967). Adjustable parameters include the mass ratio q, orbital inclination i, the effective temperature of the secondary $T_2$, and component potentials 1 and 2. Two equally plausible solutions emerged after multiple trials, with the latter requiring the secondary to fill its Roche lobe nearly to capacity. Table 2 presents the results of modeling the light curve for three filters. Figure 1 depicts the output parameters for VX Lac and the model light curves and observations.

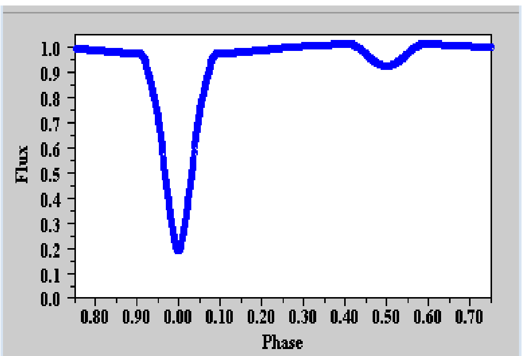
**Table 2: The output parameters for VX Lac**

| |
|---|
| **Ω1= 3.850000 Ω2 = 2.410000** |
| **Ωinner = 2.398955 Ωouter= 2.229453** |
| **C1 = 6.108190 C2= 3.840474** |
| **C inner = 3.823081 C outer= 3.556148** |
| **f1= -0.374106 f2= -0.004529** |
| **Lagrangian L1 = 0.630861 Lagrangian L2= 1.482797** |
| **r1(back)= 0.284782 r2(back) = 0.291914** |
| **r1(side) = 0.282527 r2(side) = 0.261084** |
| **r1(pole)= 0.278559 r2 (pole) = 0.251135** |
| **Surface area 1 = 0.999615 Surface area 2 = 0.915518** |
| **Mean radius 1 = 0.281956 Mean radius 2 = 0.249067** |

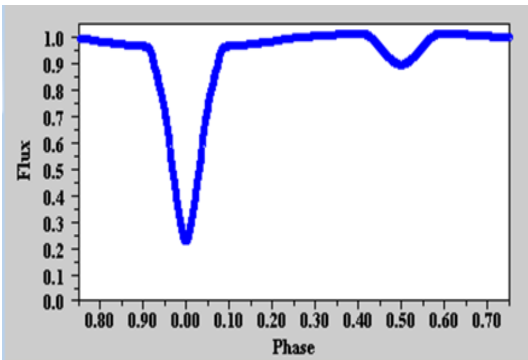
**Where $\Omega_1$ and $\Omega_2$ = surface potential of the primary and the secondary components, $C_1$ and $C_2$ = potential of the primary and the secondary components, $f_1$, $f_2$ = Fillout of the primary and the secondary components, $L_1$, $L_2$ = Absolute parameter of components in units of solar Luminosity.**

**Table 3: The light curve fit parameters for VX Lac**

| Parameter | Star1 | Star2 |
|---|---|---|
| Mass Ratio ( M2/ M1) | 0.270000 | |
| Surface Potential Ω | 3.850000 | 2.410000 |
| Temperature | 7300.00 | 4312.00 |
| Gravity Darkening | 1 | 0.320 |
| Limb Darkening | 0.786 | 0.822 |
| Reflection | 1.560 | 1.480 |
| Inclination | 86.500 | |



B



V

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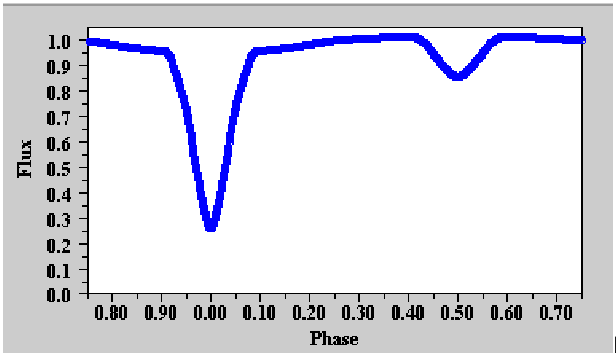


R

**Figure 1: Light curves fitting for B, V and R filter for VX Lac**

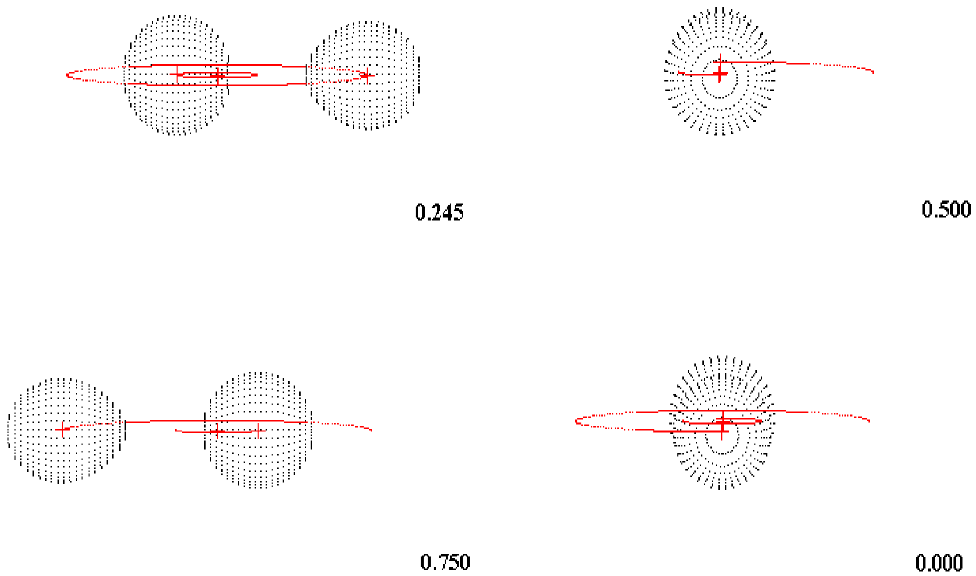


**Figure 2: The shape of the spotted model of VX Lac binary star at different phase**

Matlab was used to calculate the absolute parameter for VX Lac. Allen (1976) provides an equation for calculating bolometric parameters. Table (4) displays the results of calculating the lifetime of short-period binary systems using the well-known mass-luminosity relationship. In addition, we calculated the first contact angle. In addition, the empirical relationship between CI, Mbol, and Teff was determined to determine the relationship between age and mass. The relationships between stellar masses and ages established by Barrado et al. (1994) have recently been utilized. In addition to collecting all parameters in a single table and comparing them to those of other authors, the table below shows that all data were calculated using an equation before being compared.

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**Table 4: Absolute parameter (in solar units) of the VX Lac for short period binary star**

| Parameter | Present work | Yilmaz(2016) |
|---|---|---|
| R1 | 1.0265 | 1.56 ±0.02 |
| R2 | 0.3254 | 1.48 ±0.03 |
| M1 | 0.7874 | 1.57 ± 0.02 |
| M2 | 0.2126 | 0.42 ±0.03 |
| L1 | 6.99 | 6.35 ±0.04 |
| L2 | 3.66 | 0.67 ±0.02 |
| q | 0.2700 | 0.2700 |
| $R_L$ | 0.2732 | - |
| $V_L$ | 0.0854 | - |
| $M_{bol1}$ | 82.6530 | - |
| $M_{bol2}$ | 85.3760 | - |
| g1(B,V,R) | (0.1146,0.0986,0.0858) | - |
| g2(B,V,R) | (0.1406,0.1268,0.1155) | - |
| E1(B,V,R) | (1.1369,1.3211,1.5187) | - |
| E2(B,V,R) | (0.9264,1.0277 , 1.1279) | - |
| log Age1 | 2.0371 | - |
| log Age2 | 2.0438 | - |
| $t_1/t_{sun*1080}$ | 3.5853 | - |
| $t_2/t_{sun*1080}$ | 9.4648 | - |
| $\theta_I$ | 0.8161 | - |
| a | 0.7593 | - |
| $C_o$ | 1.1414 | - |
| $M_{v1}$ | -1.9495e+06 | - |
| $M_{v2}$ | -1.5711e+06 | - |
| (B-V)1 | 0.3185 | 0.36 |
| (B-V)2 | 1.1608 | - |
| BC1 | 1.9496 | - |
| BC2 | 1.5677 | - |

## 5. PERIOD VARIATION ANALYSIS

The period analysis of VX Lac was performed using all minimum available times from the literature (Pasch & Brat, 2006) (O-C gateway 6) and integrating them with our new minimum light times. The O-C diagram of the system was created using the minima derived from Table 5's ephemeris. The first panel of Figure 4 demonstrates conclusively that VX Lac displays a cyclic variation that can be attributed to the LITE due to the presence of a physically bound additional component in the system. We attempted to characterize the relationship using Irwin's (1959) LITE formulation but were unable to obtain a satisfactory fit with these equations alone. This phenomenon is explained by a mass exchange/loss mechanism within the system, as indicated by the LITE residuals. It was possible to model both cyclic and secular variations using LITE and a parabolic fit, resulting in the optimal solution. The minimum mass of the third body, assuming its orbit is coplanar, has been calculated to be 0.57. The bolometric corrections were obtained from the datasets Flower (1996) compiled. This dynamical parallax yielded a distance of 330.14 pc, which is the first distance estimate for VX Lac in the scientific literature. This result indicates that the average angular separation between the third body and the eclipsed pair is less than 0.05 arcseconds, which is too small for observational detection. Using

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Demircan & Kahraman's (1991) mass-luminosity function for main-sequence stars, the third body would be approximately 6.5 magnitudes fainter than the VX Lac system, which is too faint for photometric or spectroscopic detection. Based on the assumption of conservative mass transfer between system components, the mass transfer rate was calculated as dM/dt = 1.86 108 Myr1 (from less massive to more massive). In addition, as the third panel of Figure 2 demonstrates, the residuals from the quadratic and third body models reveal an additional cyclic variation. Either the presence of a fourth body or a significant magnetic field can explain the cyclic oscillation in the O-C residuals of VX Lac. Assuming a fourth body, the LITE parameters indicate that the orbits of the stars lie in the same plane. We utilized the cyclic variation's amplitude and period for the magnetic activity cycle. We determined the pertinent parameters based on Applegate's (1992) assertion that any cyclic change in the activity level of one component in a binary system can result in a cyclic variation in the system's orbital period. The interstellar extinction values $A_V$ in the V passband were computed using the reddening value estimated from Schlegel et al.'s (1998) infrared dust emission maps, with the extinction-to-reddening ratio assumed to be 3.1. Table 5 lists all parameters derived from the O-C analysis. With relative ease, the linear ephemeris can calculate the minima times the TC of extrasolar planet transits, or EBs.

$$T_C = T_0 + P \times E \quad \text{.................................................(6)}$$

Which predicts minima times $T_C$ of EB with orbital period P. Here E is an epoch of the observation, and it counts how many eclipses elapsed since the zero epoch (i.e., from time $T_0$). Minima times determined from observations for the same epoch ($T_O$) be generally different to times $T_C$. The behavior of this difference O-C, often shown in O-C diagrams, is caused by perturbation δT.

$$T_O - T_C \equiv O - C = \delta T \quad \text{.......................................(7)}$$

This perturbation is generally a sum of different effects and indicates the binary system's period changes. Formally, we can write.

$$\delta T = (\Delta T0 + \Delta P \times E) + Q \times E\ 2 + \delta Ti \quad \text{....................................(8)}$$

Where the part in the bracket generates a linear trend in O-C, and it is caused by wrong linear ephemeris (Equation 1), a quadratic term ($Q \times E$ 2 ) describes changes due to mass transfer.

$$\text{MinI} = t_o + p_{orb} * E \text{.............................................................(9)}$$

$$\text{MinI} = 2424791.485 + 1^d.0744990 * E \text{.......................................(10)}$$

$$O-C = \text{Tmin} - (t_0 + p_{orb} * E) \text{....................................................(11)}$$

Where Tmin: is the observed time of minimum, E: is the epoch, and Porb is the orbital period of bthe inary system.

$$E = (\text{Tmin} - t_0) / p \text{.............................................................(12)}$$

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**Table (5): Represent TOMs for VX Lac for three filters have been observed (2022)**

| HJD | O-C |
|---|---|
| 2459592.3080 | -0.0021 |
| 2459592.3070 | -0.0030 |
| 2459592.3029 | -0.0071 |
| 2459592.3047 | -0.0053 |
| 2459592.3064 | -0.0036 |
| 2459592.3082 | -0.0018 |
| 2459592.3117 | -0.0017 |
| 2459592.3038 | -0.0062 |
| 2459592.3055 | -0.0045 |
| 2459592.3073 | -0.0027 |
| 2459592.3091 | -0.0010 |
| 2459697.6091 | -0.0017 |
| 2459697.6093 | -0.0015 |
| 2459697.6091 | -0.0017 |
| 2459697.6092 | -0.0016 |
| 2459697.6093 | -0.0015 |
| 2459697.6091 | -0.0017 |
| 2459697.6095 | -0.0013 |
| 2459697.6092 | -0.0016 |
| 2459697.609 | -0.0018 |

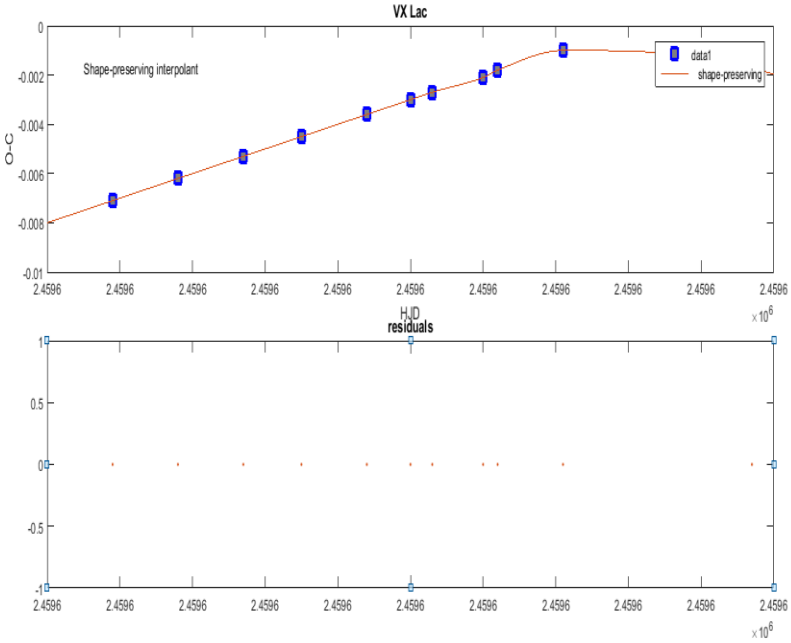


**Fig. 3: The (O-C) diagram and best fit model for VX Lac on (2022).**

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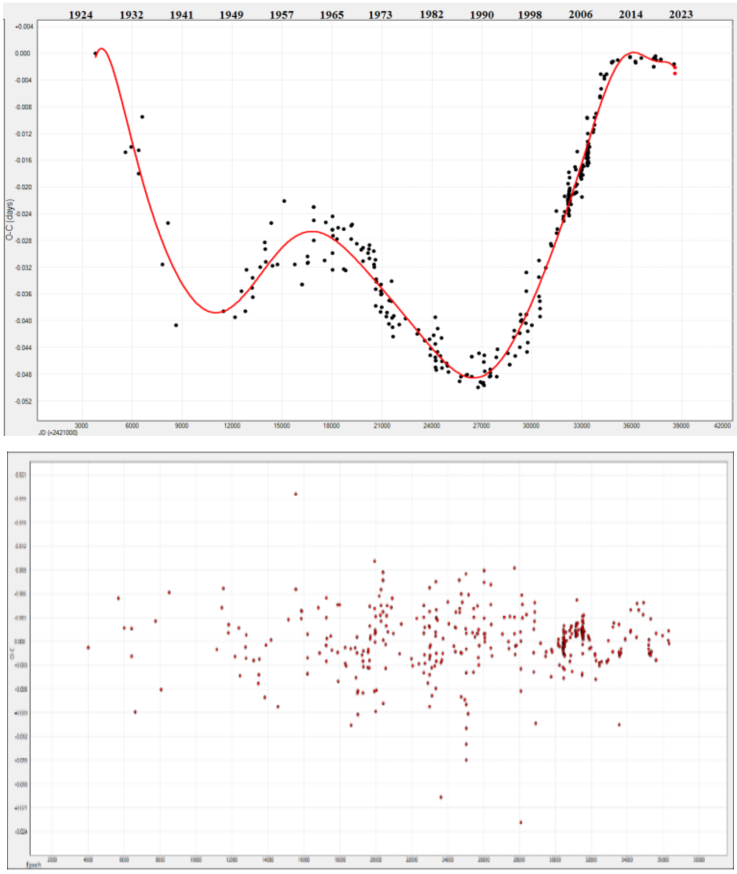


**Fig. 4: The (O-C) diagram and best fit model for VX Lac. The solid blue line represents a parabolic fit and the solid red line the LITE model. Observation methods are also shown inside the legend, with counts in parentheses. The color figure can be viewed online**

**Table 6: Results from the O-C analysis**

| Prameter | Value |
|---|---|
| $T_o$(HJD) | 2424791.485 |
| P(day) | 1.07000000 |
| a12,3sini$_3$(AU) | +2.3/-0.91 |
| $e_3$ | +0/-0.25 |
| $\omega_3$ | +0.22/-0.1 |
| $P_3$(years) | 12.4 Yr |
| $A_3$ (days) | 0.018d |
| $FM_3$($M_\odot$) | +0.048/-0.008 |
| $M_3$($M_\odot$) | 0.57 |

## 6. METALLICITY ANALYSIS

### 6.1 Mass fraction

X, Y, and Z are typically used to define stellar composition. X denotes the mass fraction of hydrogen, Y is helium's mass fraction, and Z is the mass fraction of all other chemical elements. Asplund, Martin (2009) Thus

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$$X + Y + Z = 1 \ldots\ldots (13)$$

In stars, nebulae, H II regions, and other astronomical sources, hydrogen and helium are the most abundant elements. In general, the mass fraction of hydrogen is represented as X= mh / M, where M is the system's total mass, and mh is its mass of hydrogen. Similarly, the mass fraction of helium is represented by Y = mhe / M. Metallicity can be calculated by multiplying the mass fraction of elements heavier than helium by helium's mass fraction. us

$$\mathbf{Z} = \sum_{i>H} \left(\frac{mi}{M}\right) = \mathbf{1} - \boldsymbol{X} - \boldsymbol{Y} \ldots\ldots (14)$$

For the surface of the Sun, these parameters are measured to have the following values (Asplund, Martin, 2009)

| Description | Solar value |
|---|---|
| Hydrogen mass fraction | $X_{sun}$=0.7381 |
| Helium mass fraction | $Y_{sun}$=0.2485 |
| Metallicity | $Z_{sun}$=0.0134 |

So by applying the equation (13, 14), we evaluate the numerical value of metallicity for the VX Lac as X= 1.0078 and Y= 4.0026, and Z = -4.0104 where $m_h$ = 0.70, $m_{he}$ = 0.292.

## 7. RESULT AND CONCLUSION

This investigation simultaneously analyzed the three B, V, and R light curves of the eclipsing binary VX Lac using the W-D code. Combining photometric data with photometric data to determine the component's fundamental parameters and the variation in VX Lac's orbital period was investigated. We obtained identical light curve solutions for the detached (W-D code), and the inner Roche lobe of the secondary component is nearly filled. In contrast, the O-C diagram of VX Lac reveals an increase during the secular period, indicating that mass transfer may occur between the secondary and primary components. This confirms that VX Lac is a binary system with a mass ratio of 0.27. The absolute parameters of the system that we were able to determine are summarized in Table 4. This analysis revealed that spot modeling is unnecessary for fitting light curves. The effective temperature of the secondary was determined. It is a K0 IV star because its temperature is approximately 4312 K, which is substantially lower than the primary. It contributes less than one percent to the total illumination of the system. Thus, any marked regions on the secondary would have minimal photometric effects. The periodic variation in the O-C of VX Lac was attributed to the LITE, an invisible, physically constrained third body with a period of 12, 4 years. Table 5 comprises the third body's parameters. Using the absolute parameters of the components and assuming a coplanar orbit with the binary, M3 = 0.57MΘ was calculated as the minimum mass of the third body. These parameters (mass of the third body and period) match those Zasche (2016) discovered. The O-C diagram also demonstrates that the long-term secular variation is caused by the long-term orbital period increase, which can be interpreted as a mass transfer from the less massive to the more massive component. This variation also confirms the findings of our light curve analysis, which indicated a semi-detached configuration with the secondary component occupying its Roche lobe. Assuming a conservative mass transfer, the mass transfer rate is estimated to be dM/dt = 1.86 108 Myr1. As seen in the third panel of Figure 4, the residuals from the third body and mass transfer approximations exhibit a second cyclic variation of the O-C curve. This cyclic variation has a period of approximately eight years and an amplitude on the O-C curve of approximately 0.002 days. Additionally, the metallicity of VX Lac can be calculated using its mass fraction of -4. The mass fraction can be used to determine the metallicity of stars.

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