Scientia Africana, Vol. 23 (No. 2), April, 2024. Pp 237-242
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ECLIPSE DETECTION ON VARIABLE STAR AO SERPENTIS USING LAS CUMBRES OBSERVATORY GLOBAL TELESCOPE (LCOGT)

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Received: 18-03-2024
Accepted: 08-04-2024

https://dx.doi.org/10.4314/sa.v23i2.21

Journal Homepage: http://www.scientia-african.uniportjournal.info
Publisher: *Faculty of Science, University of Port Harcourt.*

ABSTRACT

To observe and document the distinctive eclipse phenomenon on the source, we conducted a photometric observation of the variable star AO Ser using the 0.4m SBIG optical telescope from the Las Cumbres Observatory Global Telescope Network remotely from Nigeria. On December 22, 2022, the LCOGT was used to observe the AO Ser data, and the telescope time was 120 minutes. Using SAOImageViewer (DS9), VisieR, and IRIS software, we performed a photometric analysis on the eclipsing stellar data, allowing us to plot the light curve and infer eclipses. According to the outcome of our photometric analysis, AO Ser is an eclipsing binary variable star. The stellar analysis presented shows theaverage values of stellar eclipse parametersfrom the analysis of the V-filterof AO Ser, asA1 = 1.37km, A2 = 0.329km, D1 = 188×10^3hrs (52.94secs), D2 = 79.4×10^3hrs (22.7secs) and d1 = 26.4×10^3hrs (7.65secs), d2 = 0hrs (0secs) respectively. For the B filter, the averagesof A1 = 0.65km, A2 = 0.145km, D1 = 185×10^3hrs (52.11secs), D2 = 76.6×10^3hrs (21.26.0secs), d1 = 26.0 ×10^3hrs (7.044secs) and d2 = 0hrs (0secs).The primary candidate of AO Ser is smaller than its secondary companion, as shown by the value of d2 = 0secs being the same for both V and B Filters observations. Two times during the orbit, when the primary passed in front of the secondary and when the secondary passed in front of the primary, the observed brightness decreased. The primary eclipse was designated as having a deeper peak than the secondary eclipse, which had a shallower peak. The percentage of the occulted stellar area and the stars' effective temperatures were used to calculate the size of the stellar brightness drop.

Keywords: Photometry, Eclipse, Variable stars, eclipsing binaries

INTRODUCTION

An eclipsing binary star is a binary star system in which both stars' orbital planes are in the line of sight of the observer, causing both stars to experience mutual eclipses (Bruton, 2007). The most well-known instance of an eclipsing binary is found in the triple star system Algol, which is located in the constellation Perseus. Because of the eclipses rather than variations in the light of the individual components, eclipsing binaries are variable stars. Periods of almost constant light are present in an eclipsing binary's light curve, with periodic drops in brightness as one star moves in front of the other. When the secondary passes in front of the primary and when the primary passes in front of the secondary, respectively, the brightness may decrease twice during the orbit. Regardless of which star is being occulted, the deeper of the two eclipses is referred to as the primary, and if a shallow second eclipse also takes place, it is referred to as the secondary eclipse. The relative brightness of the two stars, the percentage of the occulted star that is hidden, and the surface brightness, or effective temperature, of the stars all affect how much the brightness decreases. The primary eclipse is typically brought on by the hotter star's occultation (Bruton, 2007). According to estimates, the Milky Way contains roughly one third binary or multiple star systems and two-thirds single stars (Hubber and Whitworth, 2005). A monotonically increasing function of stellar mass describes the overall multiplicity frequency of ordinary stars. That is, as the component masses increase, the likelihood of being in a binary or multi-star system steadily increases (Duchêne and Kraus, 2013). A binary star's period of revolution and the eccentricity of its orbit are directly correlated, with systems with short periods having smaller eccentricities. Binary stars can be found at any distance that is imaginable, ranging from pairs that are practically in contact due to their close orbits to pairs that are so far apart that their relationship can only be inferred from their shared proper motion through space. There is a so-called log normal distribution of periods among gravitationally bound binary star systems, with the majority of these systems orbiting with a period of about 100 years. This lends credence to the idea that binary systems develop during the process of star formation (Chen et al., 2017).

THEORETICAL METHODS

The radiant flux received from a star, which is the total amount of light energy of all wavelengths that crosses a unit area (detector) oriented perpendicular to the direction of the light's travel per unit time, is how a star's "brightness" is actually measured in terms of physics. The radiant flux F measured at a distance r from the star's center is related to the intrinsic luminosity (L, the energy emitted by the star per unit time), using the equation known as the inverse square law for light, assuming that no light is absorbed on the way to the observer (Carroll and Ostlie, 2017).

$$F = L/4\pi r^2 \qquad (1)$$

Each star is given an absolute magnitude (M), which is defined as the apparent magnitude a star would have if it were situated at a distance of 10pc, using equation 1. The flux ratio of two stars can be clearly obtained from equation 1. As discussed at the beginning of this subsection, a difference of 5 apparent magnitudes corresponds to a brightness difference of 100 as captured in equation 2.

$$F_2/F_1 = 100(m_1\text{-}m_2)/5 \qquad (2)$$

Mixing equations (1) and (2) for the case of a single star seen from two different distances (10pc and D), one can easily get to

$$M - M = 5\log_{10}(D/10)pc \qquad (3)$$

According to Carroll and Ostlie (2017), the aforementioned equation 3 connects the star's distance, apparent magnitude, and absolute magnitude. This equation is known as the distance modulus equation.

Computer Methods on Image decompression

Prior to the creation of light curves, IRIS was used to obtain all instrumental magnitudes for the variable stars AO Ser, WW Cnc, and CZ Aqr within the context of the study. To do this, the AstroLab computer's Windows version 5.59 of the photometric IRIS software was first installed in order to set up the system for data analysis. Before starting the IRIS software from the AstroLab computer's desktop and activating the file menu for parametric settings to calibrate the data working path from the DS9 folder on the desktop to invoke all calibrated files into the IRIS memory, it was made sure that all calibrated images had been obtained and saved in a folder on the desktop as previously

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decompressed by DS9. The working path was started using the settings menu, and the working directory for the DS9 image was accessed by right-clicking the folder and selecting KT1-1.fit, which stands for the variable star FIT Image. Before closing the KT1-1.fit window properties and returning to IRIS, the properties of the folder and location were activated and the location identity (description) copied. The file menu was opened, and settings to paste the KT1-1.fit location properties—which tell the IRIS software where the image is on the computer and make up the device working path into it were then made.However, the decompressed images in DS9 were labelled,

KT1-1.fit, KT2-1.fit, KT3-1.fit, KT4-1.fit………… KTn-1.fit, where n=1,2,3,4,5…………. n+1 (4)

and clicked OK when the working path was properly calibrated into the computer memory.

Equations (5&6) were used to estimate the differential magnitude between the target and the comparison stars which are clearly expressed in the field of view (FOV) identified as C1, C2, and C3. Figure 3.3 is for eclipse parameter estimation in AO Ser. Equations5 - 7 were also used in the calculation of the stellar differential magnitudes presented in columns 8 - 10 of AP-1 - AP-6.

$$\Delta mag = m(AO\ Ser) - m(C1) \quad (5)$$

$$\Delta mag = m(AO\ Ser) - m(C1) \quad (6)$$

$$\Delta mag = m(AO\ Ser) - m(C1) \quad (7)$$

where Δmag is the differential magnitude m(C1), m(C), m(C3) and m(AO Ser) are the instrumental magnitude of the comparison stars and AO Ser respectively. The differential magnitude was plotted against phase for all the filters used (Chika *et al.*, 2022).

Light Curve for eclipse detection in AO Ser

To produce the light curve of AO Ser, a plot of the stellar magnitude (ΔMagnitude) vs Stellar Phase was generated for AO Ser data using python version 3.9 revealing the presence of eclipse in the background separation of comparative star C1 from the target star decompressed as AO Ser – C1 through the V and B Filter (Figure 1).

RESULTS

Light curve for eclipse in AO Ser

The light curve of AO Ser are presented in Figures 1, 2, 3,and 4 for V and B filters.

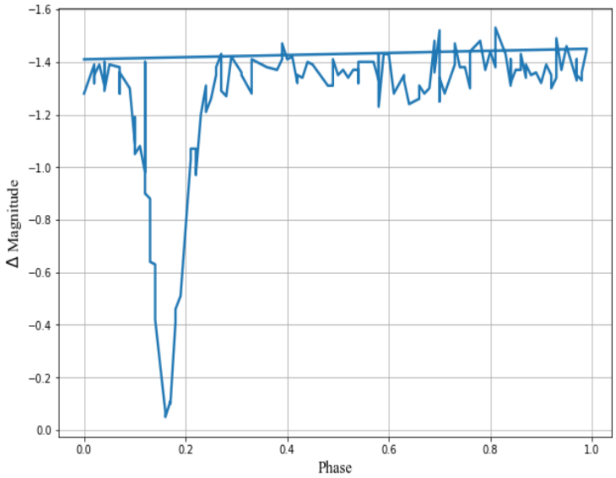

Fig. 1. The light curve of ΔMagnitude vs Phase of AO Ser – C1 for V and B filters

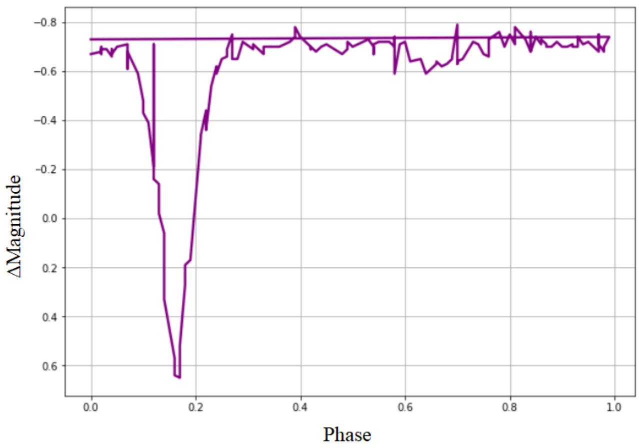

Fig. 2. The light curve of ΔMagnitude vs Phase of AO Ser – C2 for V and B Filters.

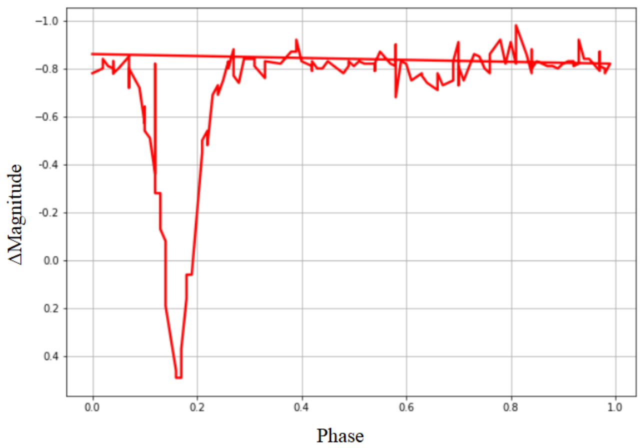

Fig. 3. The light curve of ΔMagnitude vs Phase of AO Ser – C3 for V and B Filters.

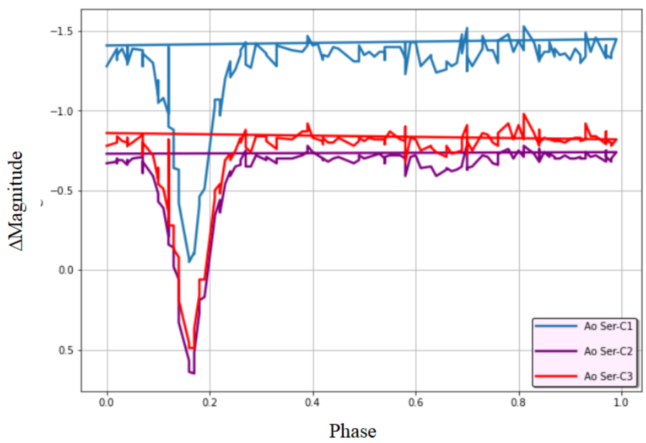

Fig. 4. Light curve of ΔMagnitude vs Phase of AO Ser – (C1,2,3) in V and B Filters.

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Table1:The generated values for the depth of the primary and secondary eclipse in AO ser

V-Filter	**A1 (km)**	**A2 (km)**	**D1×10³ (hrs)**	**D2×10³ (hrs)**	**d1×10³ (hrs)**	**d2×10³ (hrs)**	**Period (days)**
AO Ser – C1	1.34	0.235	188	77.5	25.2	0	
AO Ser – C2	1.37	0.221	187	79.1	27.3	0	
AO Ser – C3	1.35	0.230	186	78.5	23.7	0	
Average	1.37	0.329	188	79.4	26.4	0	0.879±0.01
B-Filter							
AO Ser – C1	0.87	0.138	189	76.9	26.3	0	
AO Ser - C2	0.79	0.148	188	77.2	24.5	0	
AO Ser - C3	0.82	0.142	174	75.5	25.1	0	
Average	0.65	0.145	185	76.6	26.0	0	0.879±0.01

A1 = the depth of the primary eclipse,
A2 = depth of secondary eclipse,
D1 = the duration of primary eclipse,
D2 = duration of totality in eclipse of the primary depth,
d1 = duration of secondary eclipse,
d2 = duration of totality in secondary eclipse.
Period = the stellar rotation rate in days

DISCUSSION

The longest peak on the light curve indicates the duration of the primary eclipse at 52.94 secs and B-filter at 52.91secs, duration of totality in primary eclipse estimated V-filter at 22.7secs and B-filter at 21.26secs. The smaller peaks in the Figure 1 represents the duration of totality in secondary eclipse estimated for V-filter = 7.0secs, B-filter = 7.3secs and duration of totality in secondary eclipse for both filters = 0 representing no total obscurity because the secondary stellar companion is bigger than its primary companion as shown on Table 1.

The light curve of Stellar (ΔMagnitude) vs Stellar Phase of AO Ser on Figure 2 is revealing the presence of eclipse in the background separation of comparative star C2 from the target star decompressed as AO Ser – C2 through the V and B Filter. The longest peak on the light curve indicates the duration of primary eclipse at 52.2 secs and B-filter = 52.2secs, duration of totality in primary eclipse estimated V filter = 22.0secs and B-filter = 20.1secs. The smaller peak represents the duration of totality in secondary eclipse estimated V filter = 7.8secs, B filter = 6.5secs and duration of totality in secondary eclipse for both filters = 0 represents no total obscurity because the secondary companion is bigger than its primary candidate.

Figure 3 shows the light curve of the stellar magnitude (ΔMagnitude) vs Stellar Phase of AO Ser revealing the presence of eclipse in the background separation of comparative star C3 from the target star decompressed as AO Ser – C3 through the V and B Filters. The longest peak on the left light curve indicates the duration of primary eclipse of V filter = 51.7 secs and B filter = 48.3secs, duration of totality in primary eclipse estimated V-filter = 21.7secs and B-filter = 21.0secs. The smaller peak represents the duration of totality in secondary eclipse estimated V filter = 7.8secs, B filter = 6.6secs and duration of totality in secondary eclipse for both filters = 0 represent no total obscurity because the secondary companion is bigger than its primary candidate.

Figure 4. shows the light curve of the average values for stellar magnitude (ΔMagnitude) vs Stellar Phase of AO Ser revealing the

presence of eclipse in the background separation of combined comparative star C1,2,3 from the target star decompressed as AO Ser – C1,2,3 through the V and B Filters. From the analysis of the V-filter of AO Ser, theaverage values of A1 = 1.37km, A2 = 0.329km, D1 = 188×10^3hrs (52.94secs), D2 = 79.4×10^3hrs (22.7secs) and d1 = 26.4×10^3hrs (7.65secs), d2 = 0hrs (0secs) respectively. For the B filter, the averagesof A1 = 0.65km, A2 = 0.145km, D1 = 185×10^3hrs (52.11secs), D2 = 76.6×10^3hrs (21.26.0secs), d1 = 26.0 $\times10^3$hrs (7.044secs) and d2 = 0hrs (0secs).The value of d2 = 0secs were the same both for V and BFilters observation, demonstrating that the primary companion of AO Ser is bigger than its secondarycompanion hence the secondary component was not totally eclipsed. The physical meaning of this scenario is that the secondary star cannot totally eclipse the main sequence primary companion of the binary star.The results for all eclipsesare shown clearly in Table 1, hence it can be concluded that AO Ser is an eclipsing-binary star as reported by *Chika et al.*,(2022)

CONCLUSION

A real time observation on eclipsing Variable star AO Serpentis onsite and remotely was conducted to investigate their observed data using B and V-filters from Las Cumbres Observatory Global 0.4m Optical Telescope (LCGOT) and the Very Large Baseline Optical Interferometry VLBOI. The LCOGT data were collected and analysed using Photometric methods. From these analysis and data reduction, it detected a binary star systems in all variable stars observed and obtained their Light Curves and stellar behaviour. The results show that the observed stellar pulsation and variability in AO Ser is intrinsic and not extrinsic. Results from its light curve and parametric estimation showed that AO Ser is a variable star with strong eclipse presence.

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