Department of Physical Science and Technology

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PHOTOMETRY OF VARIABLE STAR SZ LYN

By

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DECLARATION

I carried out the work described in this thesis at the Arthur C. Clarke Institute for Modern Technologies (ACCIMT), Katubadda, Moratuwa, under the supervision of Mr. Saraj Gunasekara, research scientist at Arthur C. Clarke Institute for Modern Technology. The contents of this thesis have not been submitted to any other university or degree programme.

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08/AS/076 Signature

…………………

Date

CERTIFICATE OF APPROVAL

We hereby declare that this Research report is from the student's own work and effort, and all other Sources of information used have been acknowledged. This research report has been submitted with our approval.

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ABSTRACT

PHOTOMETRY OF VARIABLE STAR SZ LYN

SZ Lyn is a dwarf Cepheid δ Scuti type pulsating variable star with an ultra short-period of 0.12 days. δ Scuti Type variables have large amplitudes in their light curves and are ideal candidates for variable star observations in photometry. Previous observations on this star have revealed that it has a large variation in its period.

SZ Lyn was observed in CCD photometry using the 20 inch reflective telescope at the Mount Abu observatory, Rajasthan, India on the 6^{th} of January 2014. This telescope facility has an Electron Multiplying (EM) CCD with a filter wheel comprising visible (V), blue (B) and red (R) filters, which is specifically designed to obtain photometry data with a high temporal resolution. About 700 images of SZ Lyn were taken through each V, B and R filters with short exposures and were used to obtain the light curve of the star.

The obtained light curve covers two full cycles of the SZ Lyn and the new pulsation period of the system was found to be 0.12053503 days. We found the period of the system is increasing and is in agreement with the previous observations on this system.

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LIST OF ABBRIVATIONS

CCD	:	Charge Couple Device
IRAF	:	Image Reduction and Analyzing Facility
JD	:	Julian Date
HJD	:	Heliocentric Julian Date

CHAPTER 1

INTRODUCTION

1.1. Classification of Variable Stars

A star is classified as variable if it's apparent brightness (that seen from Earth) changes over time (fluctuates). For many types of these stars, the variation in brightness regularly repeats and the periods range from a couple of hours to hundreds of days. Variable stars are vitally important in astronomy for the information they can provide on the properties of stars. The variation in brightness can result from internal changes to the amount of energy being emitted by the star, or from an external process, such as some of the light from a star being stopped from reaching the Earth; for example, by being blocked by an orbiting companion star.

There are two types of variable stars.

- Intrinsic variables –

  It is the variable whose luminosity actually changes.

  Ex- The star periodically swells and shrinks.

- Extrinsic variables-

  It is the variable whose apparent changes in brightness are due to the changes in the amount of light that is emitted by the star reaches the Earth.

  Ex- The star has an orbiting companion that sometimes eclipse it.

Variable stars change their brightness for several reasons. Pulsating variables swell and shrink due to internal forces, while an eclipsing binary will dim when it is eclipsed by its binary companion. Combining light curves with spectral data often gives a clue as to the changes that occur in a variable star. For example, evidence for a pulsating star is found in its shifting spectrum because its surface periodically moves toward and away from us, with the same frequency as its changing brightness.

About two-thirds of all variable stars appear to be pulsating. The interior of a star leads to instabilities that cause a star to pulsate. The most common type of instability is related to oscillations in the degree of ionization in outer, convective layers of the star.

Suppose the star is in the swelling phase. Its outer layers expand causing them to cool. Because of the decreasing temperature the degree of ionization also decreases. This makes the gas more transparent, and thus makes it easier for the star to radiate its energy. This in turn will make the star to contract. As the gas is thereby compressed it is heated and the degree of ionization again increases. This makes the gas more opaque and radiation temporarily becomes captured in the gas. This heats the gas further leading it to expand once again. Thus a cycle of expansion and compression (swelling and shrinking) is maintained.

1.2. Variable Star Observation

Photometry is a technique found in astronomy concerned with measuring the *flux*, or the intensity of an astronomical object‘s electromagnetic radiation.

The most common type of variability involves changes in brightness, but other types of variability also occur, in particular changes in the spectrum. By combining light curve data with observed spectral changes astronomers are able to explain why a particular star is variable.

Variable stars are generally analyzed using photometry, spectrophotometry and spectroscopy. Measurements of their changes in brightness can be plotted to produce light curves. A light curve is a graph which shows the brightness of an object over a period of time. In the study of objects which change their brightness over time, such as novaes, supernovaes and variable stars, the study of their light curves, together with other observations can yield considerable information about the physical process that produces it or constrain the physical theories about it. As such, light curve is a simple but valuable tool to a scientist.

For regular variables, the period of variation and its amplitude can be very well established. For many variable stars, these quantities may vary slowly over time, or even within one period.

Amateur astronomers can do useful scientific study of variable stars by visually comparing the star with other stars within the same telescopic field of view of which the magnitudes are known and constant. By estimating the variable's magnitude and noting the time of observation a visual light curve can be drawn.

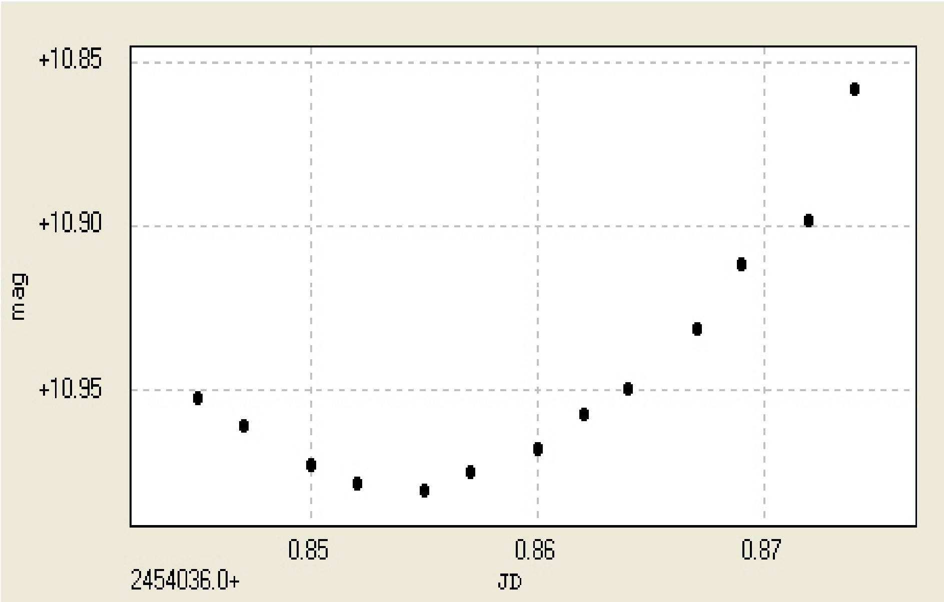
Magnitude of a star is a measure of how brightly the star shines compared to other stars. Also we need to know about the time when changes of brightness appears with respect to the universal time called “Julian date (JD). In other words, JD is an integer assigned to a whole solar day in the Julian day count starting from noon Greenwich Mean Time, with Julian day number 0 assigned to the day starting at noon on January 1, 4713 BC proleptic Julian calendar.

- Ex- The Julian day number for January 1, 2000, was 2,451,545

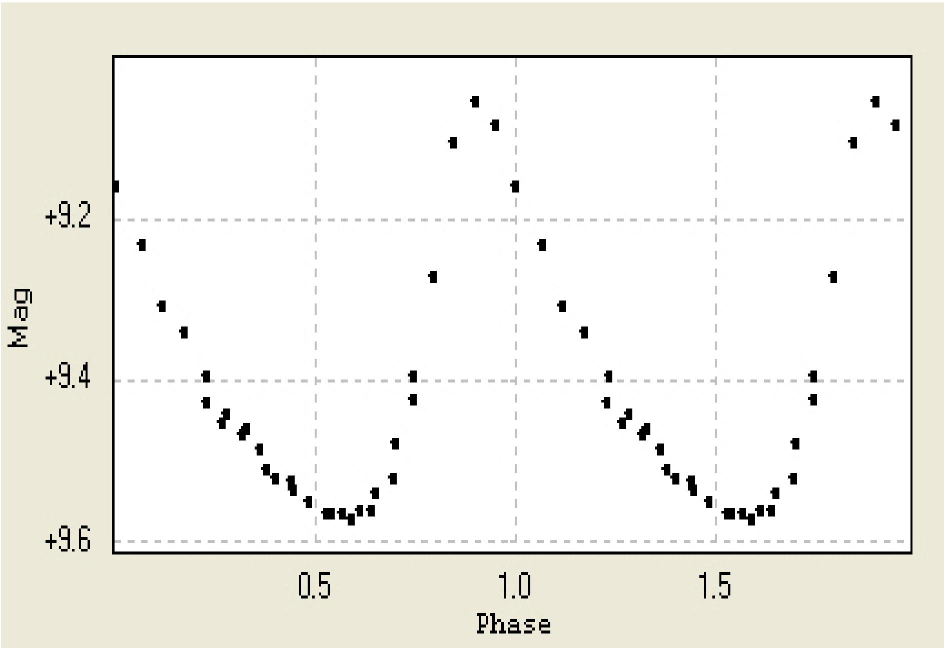
1.3. Light curve

A light curve can be used to estimate the rotation period of an object. From the Earth there is often no way to resolve a small object in our Solar System, even in the most powerful of telescopes, since the apparent angular size of the object is smaller than one pixel in the detector. Thus, astronomers measure the amount of light produced by an object as a function of time (the light curve). The time separation of peaks in the light curve gives an estimate of the rotational period of the object. The difference between the maximum and minimum brightness (the amplitude of the light curve) can be due to the shape of the object, or to bright and dark areas on its surface. For example, an asymmetrical asteroid's light curve generally has more pronounced peaks, while a more spherical object's light curve will be flatter. The light is usually in a particular frequency interval or band. Light curves of variable stars are periodic due to their brightness fluctuations.

Magnitude of a star is a measure of how brightly it shines compared to other stars. Normally a light curve plot is drawn with the magnitude along the vertical Y axis and Julian date (or phase) along the horizontal X axis, and such a curve for a typical star are shown in Figure 1.1 & Figure 1.2.



igure 1.1: Light curve of a star, Magnitude Vs JD



F

igure 1.2: Light curve of a star, Magnitude Vs Phase

1.3.1. Analyzing a light curve

The record of changes in brightness that a light curve provides can help astronomers understand processes at work within the star (or stellar system) and identify specific categories (or classes) of stellar events. For example, once a light curve has been drawn for a certain stellar object, it can be compared to standard light curves to help identify the type of object being studied. The peak brightness in the light curve is known as maxima, while a trough is known as minima.

From the light curve the following data can be derived:

- The brightness variations (periodical, semi-periodical, irregular, or unique)
- The period of the brightness fluctuations
- The shape of the light curve (symmetrical or not, angular or smoothly varying, does each cycle have only one or more than one minima, etc.)

1.4. O – C diagram

O - C stands for O[observed] minus C[calculated]: in its broadest sense it is a diagnostic tool in the natural sciences and involves the evaluation and interpretation of the discord between the measure of an observable event and its predicted or foretold value. A typical example is the comparison between an observed spectrum and a calculated energy distribution. In astronomy, O - C usually implies a temporal aspect, and is used when discussing cyclic phenomena where the times of occurrence of a given event are subject to irregularities.

The O - C diagram is then constructed by plotting the quantity O - C as a function of time, and when the plotted deviations are systematic and when they exceed the experimental errors, the correct interpretation of these deviations leads to a better model (and a new O - C diagram).

In studies relating to variable-stars, O - C is sometimes expressed as the deviations of phase in the cycle of variability.

When a set of predictions for a star are available, one should compare those predictions to real observations, the best way of presenting this comparison is with the use of an O - C diagram. The horizontal axis of the diagram is easiest to understand: it is simply time, usually expressed in days, most often the Julian Day number (JD) of the observation or orbital phase. The vertical axis is the "O - C" part which gives the diagram its name and its interpretive power. For each observed event one takes the observed time of the event (that's the "O" part) and subtracts the time predicted from the model for the event (that's "C", the calculated, part). The difference, Observed minus Calculated or "O - C", is plotted on the vertical axis of the graph.

The pattern that shows up in the O - C diagram can tell not only whether the model is of any use, but also the type of processes going on in the real star that is not included in the model. If the model is perfect and have got the right value for the period of the variable star, then the points in the O - C diagram will be a straight and almost a straight line across the graph: if the difference between the observations and model is zero at all times, it is easy to imagine that the graph will then look like a bunch of points, all with O - C at or near zero, for a long time.

If the period is slightly off, then the model will depict the correct times for the events for a short while, but the discrepancy will accumulate as times goes on. The O - C diagram in that case will look like a slanted straight line. A more interesting possibility is if the O-C diagram turns out to be curved; that is what results if the period of the system is changing slowly.

Calculated JD = **Observed JD for a maxima** (or minima**) + (P × E)**

P – Pulsation period of a light curve

E – Cycle number

O – C (days) **=** **O**bserved JD **– C**alculated JD

CHAPTER 2

LITERATURE REVIEW

A variable star is a star that changes brightness with time. A star is considered variable if its apparent magnitude (brightness) is altered in any way from our perspective on the Earth's surface. These changes can occur over years or just for a fraction of a second, and can range from one-thousandth of a magnitude to twenty magnitudes. More than 100,000 variable stars are known and have been catalogued, and thousands more are suspected variables. Our own sun is a variable star: its energy output varies by approximately 0.1 percent, or one-thousandth of its magnitude, over an 11-year solar cycle.

δ Scuti variables are a well-known type of pulsating variable belonging to the main sequence. This type of stars is notable for a very short period, lasts for hours. Typically, periods are in the range of 0.02-0.4 days. Brightness varies between 0.02m and 0.8 m, a recently discovered rapidly oscillating main-sequence. Both radial and non-radial pulsations are observed for δ Scuti stars.

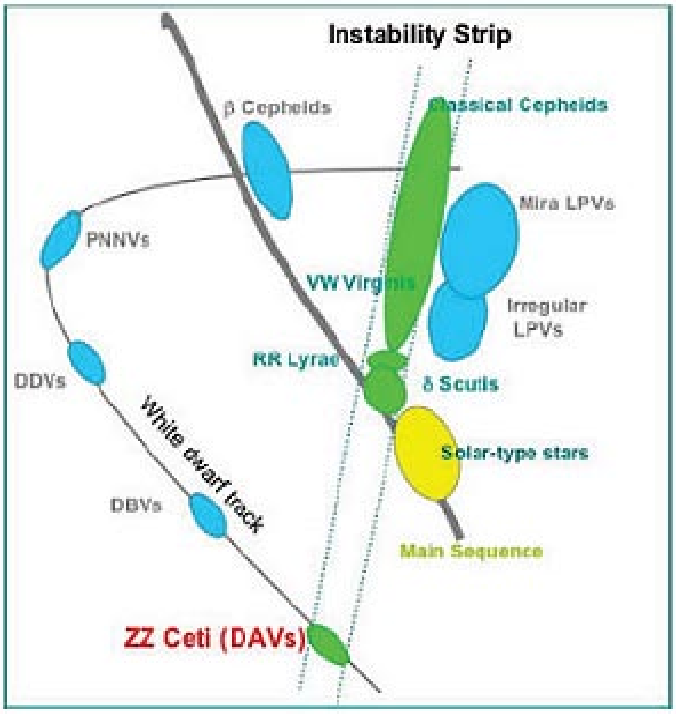


Figure 2.1: The Hertzsprung-Russell diagram

The instability strip is a narrow, almost vertical region in the Hertzsprung-Russell diagram which contains many different types of variable stars (RR Lyrae, Cepheid variable, W Virginis and ZZ Ceti stars all residing in the instability strip).

Most stars that are more massive than the Sun enter the instability strip and become variable at least once after they have left the main sequence. It is within this region that they suffer instabilities that cause them to pulsate in size and vary in luminosity.

During the pre-main-sequence (PMS) contraction stage, many stars cross the classical instability strip and δ Scuti-type pulsation can take place. Recently, Marconi & Palla (1998) have calculated the location of the instability strip for PMS stars in the HR diagram for the first three radial modes. They show that, if their mass is larger than1.5 solar mass, the star crosses this region of pulsational instability as a PMS object. However, the typical time spent by a star within the boundaries of the instability strip as a PMS star is very small when compared to that spent as a Main Sequence (MS) star. Hence, the probability of finding one star in this phase of evolution is very small. However, a few PMS δ Scuti-type pulsators have been already identified and a number of new PMS candidate pulsators have also been proposed. (Derekas et al. 2003)

Short period variable SZ Lyn: is an ultra short-period of 0.12 day pulsating variable. It has been classified at various times as a dwarf Cepheid δ Scuti star. Such δ Scuti Type variables have high amplitudes, discovered by Hoffmeister in 1949 (Gazeas et al. 2005).SZ Lyncis is the best documented example of a binary pulsating star with very clear light-time effects. The period variations of the star have been studied. Since then it has been totally neglected and no new times of maximas have appeared in the literature, except the one by the Hipparcos satellite. The pulsational behavior was determined for the first time by Scheneller in 1961. Apart from small (<0.02 magnitude) cycle to cycle variations, no irregularities have been found in the star's light variations and all attempts to find double mode pulsations have failed. Van Genderen (1967) noticed that the residuals in the O – C diagrams have appeared to follow a sinusoidal variation. (Gazeas et al. 2004)

An object with a maximum at JD 243863.342 and with a period of 0.1253 observed on the night of 09 February 1967 was used for the computation of the phase. A comparison of the light curves of these group in U, B, V filters reveals that there are changes in the amplitude of the light variations as well as a change in the shape of light curves. The variation in amplitude on the average amounted to 0.03 in all the three, U, B and V filters. (Joshi et al. 1967)

The long term sinusoidal variation in period observed by Van Genderen, 1967, together with observations during 1967 shows a sudden maximum shift and restoration to its original period after the shift indicate that perhaps such sudden shifts are of frequent occurrence in the star. (Joshi et al. 1967). Investigations indicate a change in the light curve if the star shows any observable flare at the time of the sudden shift.

Long term variations in the period have been caused in relations to SZ Lyn, as the star is a component of a binary system. Some Scientists have suggested that the light curve of variable stars shows variations from cycle to cycle while others have been unable to confirm these variations

There are a number of reasons for variability. These include changes in star luminosity or mass of the star, radial pulsation and obstructions in the amount of light that reaches the star.

Period (days)	Observer / Author	Date of observations
0.12053188	Binnendijk (1968)	Data from 1968
0.120534896	Soliman et al. (1986)	Data from 1986
0.12052115	Moffett et al. (1988)	Data from 1975 until 1979
0.12053491	Paparo et al. (1988)	Data from 1961 until 1988
0.1205349	Gazeas&Niarchos (2004)	Data from 1961 until 2003
0.12053568	Gazeas&Niarchos (2005)	Data from 1961 until 2004

Table 2.1: Previous Observations of Pulsation period of SZ Lyn

In 2001, SZ Lyn was observed with two telescopes during four nights. The exposure times were between 15 s and 120 s, depending on the instrument and weather conditions. Two nearby stars were chosen for comparisons (comp= GSC 2979-1329, check= GSC 2979-1343). More than1500 individual points have been acquired and a sample light curve is shown in figure 2.2.(Derekas et al. 2003)

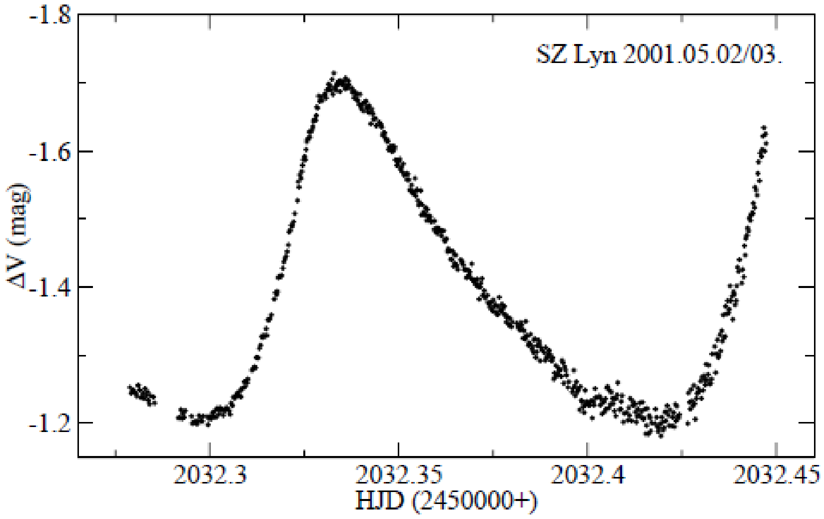


Figure 2.2: Sample Light curve for SZ Lyn

The four new times of maximas supplemented with the Hipparcos epoch (HJD 2448500.0560, ESA 1997) were added to the list of maximas. The resulting O−C diagram plotted is illustrated as figure 2.3. (Derekas et al. 2003)

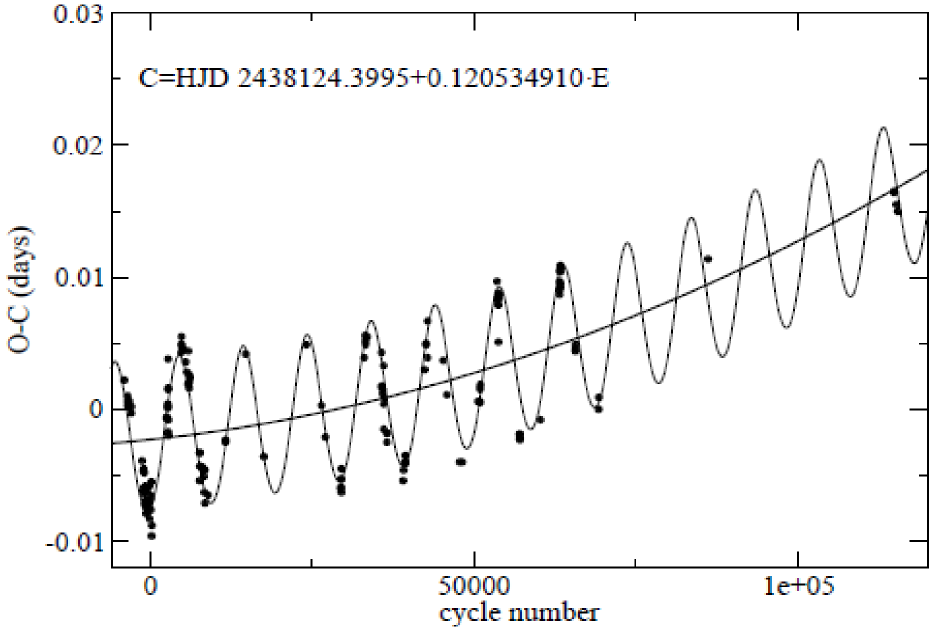


Figure 2.3:The O−C diagram of SZ Lyn

Their new observations in 2003 confirm the consistent picture of the light-time effect thoroughly discussed in 1988 and 1998. They improved the value of the orbital period, which turned out to be P_{orb} = 1190 ± 5. On the other hand, they derived a slightly smaller period changing rate of $\frac{1}{P}\frac{dP}{dt}$= (+5 ± 1.8)*10^{-8} year^{-1}.They note that the quadratic term is still too uncertain. They have experimented with a number of different averaging of the original O−C points to reduce the effects of the unequal data distribution. Different beginnings changed the parabolic coefficient by a lot (almost by a factor of two), and that marks a certain limit in the data interpretation.

O - C Analysis

Over the last 43 years it was found that the O - C values follow a sinusoidal variation, suggesting a binary configuration of this star. Various attempts to calculate the pulsational period of SZ Lyn were made during these years.

It is assumed that the O - C variations are caused by the linear change of the pulsation period of SZ Lyn and by the light-time effect of SZ Lyn, orbiting in an elliptical orbit. (Gazeas et al. 2004)

BVRI CCD photometric observations and those obtained in 2003, extended the time base of data from 42 years between1961 to 2003, 165 times of maxima were observed and have been used to calculate the pulsational and orbital elements of the binary system. From the analysis they were able to calculate a more precise value for the linear change in the star's pulsation period. Improved values were also calculated for all the orbital parameters of the binary system. The analysis shows that O – C residuals are a powerful tool for investigating the binary nature of a pulsating star. (Gazeas et al. 2004)

CHAPTER 3

INSTRUMENTATION AND DATA REDUCTION TOOLS

3.1. Instrumentation

This chapter focuses on the instrument which was used to acquire data in this study. The main instrument was a CDK 20 inch plane wave telescope equipped with a UBVRI filter wheel and an Andor CCD camera. This telescope is located at Mount Abu, India.

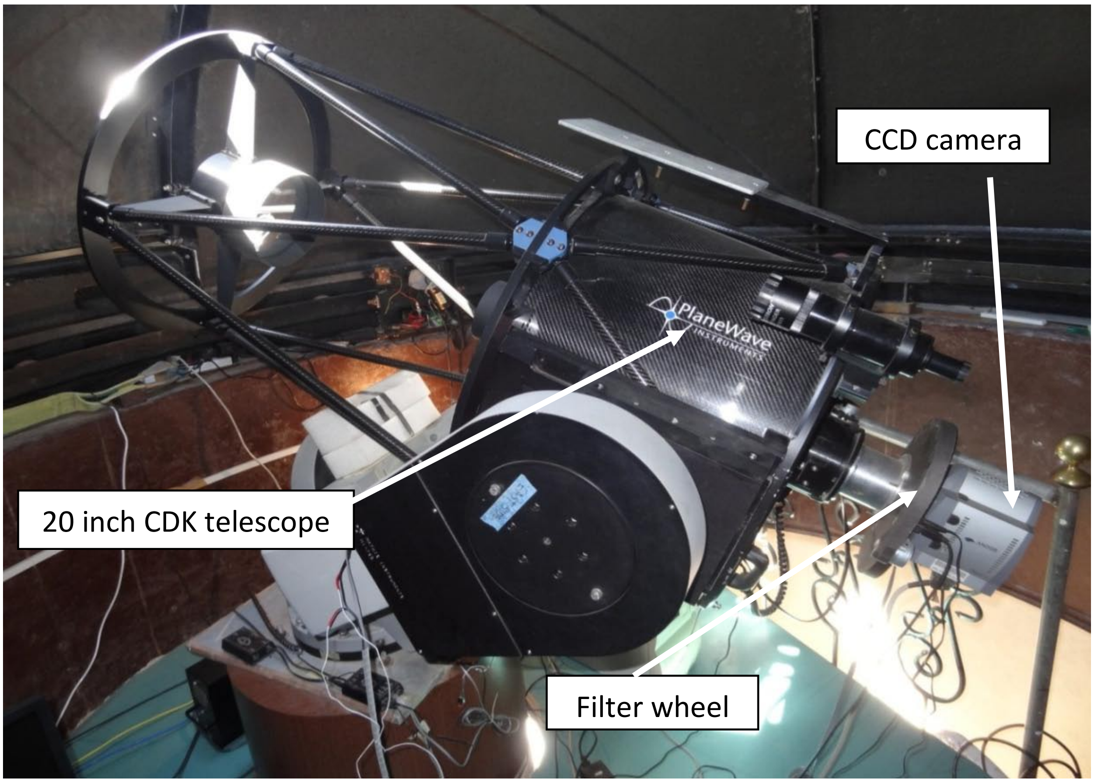


Figure 3.1: Named image of instrument

3.1.1. CDK 20 inch plane wave telescope

The CDK (Corrected Dall-Kirkham) telescope consisted of three components: an ellipsoidal primary mirror, a spherical secondary mirror and a lens group. All these components are optimized to work in concert in order to create superb pinpoint stars across the entire 52mm image plane. One of the unique features of the CDK design is its ease of collimation and centering tolerance that can be achieved for a telescope of its class. This ease of alignment and collimation provide a guarantee that the user will be able to obtain the best performance possible from the telescope, each and every night. The end result at the image plane of the CDK design is the possibility to pinpoint stars from the center to the corners of the field of view.

3.1.2. UBVRI filter wheel

UVBRI filters are used worldwide by researchers in the field of photometry. These filters can provide clear images by filtering other unwanted light rays. In this project I used V and B filtered data.

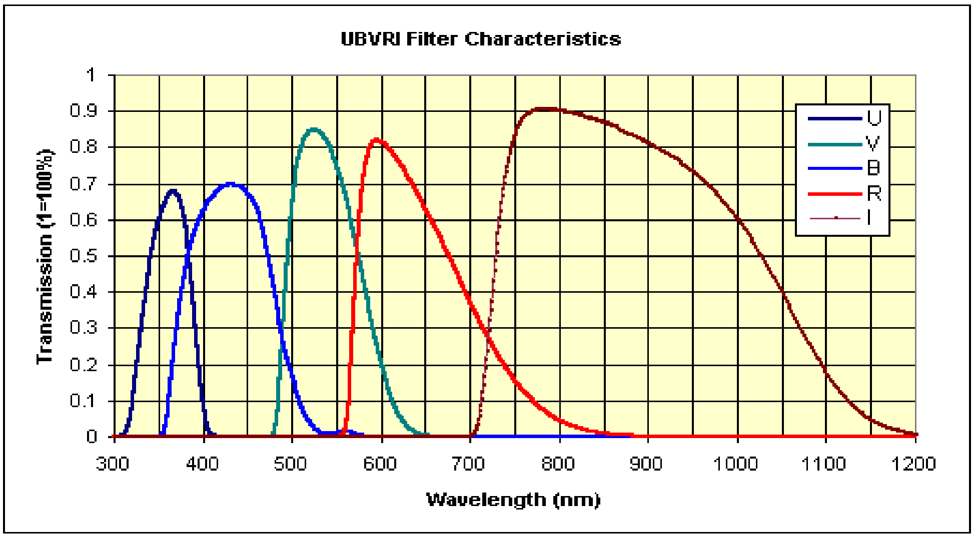


Figure 3.1.2.1: Graph of UBVRI filters characteristics

3.1.3. Andor CCD (Charge Couple Device) Camera

Charged Coupled Devices (CCD) are sensors used in digital cameras and video cameras to record still and moving images. The CCD captures light and converts it into digital data that are recorded by the camera. For this reason, a CCD is often considered the digital version of the film. CCD can minimize the noise signals from the image, thus drastically increasing the S/N (Signal to Noise) ratio. When this happens the noise signals should decrease, minimizing to a very low level.

3.1.4. Process of CCD camera

The quality of an image depends on the resolution of the sensor. This is the resolution measured by Megapixels. But raw CCD images are not perfect. Due to the digital nature of the data many of the imperfections can be compensated or calibrated out of the final image through digital image processing. There are three signal components in a raw CCD image.

a. Image signal

The image signals are produced by photons emitted from the source.

b. Thermal signal

Thermal signals are also produced (dark current thermal electrons) by the thermal activity of the semiconductor material used in the CCD camera and this can be reduced by cooling the CCD to a low temperature.

c. Bias signal

The biased signal is the initial signal present in the CCD, before exposing the CCD.

Noise in CCD images

There are several sources of noise in CCD images. They are photon noise, thermal noise, readout noise, and quantization noise and sensitivity variations.

a. Photon Noise

The number of photons that reach the CCD during the time of exposure varies randomly, just as we would expect the number of raindrops hitting a given patch of ground to vary during a rainstorm. Photon noise is produced due to the random fluctuations in the photon signal of the source. In other words, the rate at which photons are received does not remain constant. This may be due to environmental effects, while the production of photons may itself fluctuate.

b. Thermal noise

Thermal noise occurs due to the generation of a signal by the light-sensing photosets in the CCD chip whether light falls on it or not. The warmer the CCD, the greater the non-light signal. Thermal effects are not constant.

c. Readout noise

Readout noise is the error in reading the signal and is generally dominated by the on chip amplifier.

d. Quantized noise

Quantized noise is the price we pay for having digital data. When the camera digitizes the output from the CCD chip, it divides the signal in to digital steps creating noise.

Noise reduction

Readout noise and quantized noise are limited by the method of construction of the CCD camera and they cannot be improved upon by the user.

However, if thermal noise cannot be chilled out, the it can be measured and subtracted from the image. This can be done practically by making two exposures. In the first exposure, light from the telescope is allowed to reach the CCD chip, whereas during the second exposure light from the telescope is not allowed to reach the CCD, so the CCD picture is almost totally dark. The first picture has light from the source plus a thermal noise signal added to it, but the second picture only has random thermal noise in it. Therefore, subtracting the dark from the first picture is an excellent and a quick correction for the thermal signal.

The thermal signal varies randomly. If we subtract two successive dark frames, the difference between them is random noise. Thus, when we subtract the dark frame during the calibration of a raw image we leave a residue of thermal noise, which adds a random variation to the calibrated image. By averaging multiple dark frames, one can reduce the amount of thermal noise left in the image when it is calibrated.

The sensitivity variation can be removed by proper flat fielding.

The final processed image with the unwanted signals removed and the noise signals reduced as much as possible can be computed as follows.

$$\text{Final processed Image} = (\text{Raw} - \text{Dark}) / \text{flat}$$

3.2. Data reduction software

A small numbers of data reduction software and tools are used for data reduction in astronomy. IRAF, FTOOLS, CASApy, DRO, Visual spec and Gild as are a few examples of these tools. In this project, I employed IRAF software for data reduction of 2 stars, one a variable star and the other a reference star.

Main aim of this project was to analyze data from photographs taken by CCD camera and generate light curves for a selected variable star and a reference star and to calculate the phase of the curve. Besides, O – C diagrams were also obtained using the light curve.

Therefore, in this study IRAF software had been used. Using IRAF cloud extract data from CCD images were obtained to attain the final results.

3.3. Methodology

1. Images taken by a CCD camera were listed separately, filter vice using the commands given below.(here "*.fits" > all files in ".fits" format)

```
ecl> files *.fits >>imlist
```

2. The listed all fits files were again listed filter vice(V, B and R)

```
ecl> list="imlist"
ecl> while(fscan(list,s1)!=EOF){
>>> imgets((s1),"FILTA")
>>> s2=(imgets.value)
>>> print ((s1), >>(s2)//".list")
>>> print(s2)
>>> }
```

   (Here the B filtered images will listed as B.list, V as V.list and R as R.list)

3. Images separated in terms of filters (filter vice), were displayed one by one to detect and remove unclear frames. There were more than 700 images at each of the filters, and then the command below was used to display them continuously.

```
ecl> list="B.list"
ecl> while(fscan(list,s1)!=EOF){
>>> display(s1)
>>> }
```

4. Using packages below all clear and useful images were grouped to create and simplify shifting

```
                                    I R A F
                     Image Reduction and Analysis Facility
PACKAGE = immatch
   TASK = imcentroid

input   =                             List of input images
referenc=                             Reference image
coords  =                             Reference coordinates file
(shifts =                           ) Initial shifts file
(boxsize=                          7) Size of the fine centering box
(bigbox =                         11) Size of the coarse centering box
(negativ=                         no) Are the features negative ?
(backgro=                      INDEF) Reference background level
(lower  =                      INDEF) Lower threshold for data
(upper  =                      INDEF) Upper threshold for data
(niterat=                          3) Maximum number of iterations
(toleran=                          0) Tolerance for convergence
(maxshif=                      INDEF) Maximum acceptable pixel shift
(verbose=                        yes) Print the centroids for every source ?
(mode   =                         ql)
```

5. For shifting grouped images there must be a reference image to generate a coordinate file. To generate a coordinate the commands listed below were used.

```
                                I R A F
                  Image Reduction and Analysis Facility
PACKAGE = daophot
   TASK = phot

image   =                         Input image(s)
coords  =                default  Input coordinate list(s) (default: image.coo.?)
output  =                default  Output photometry file(s) (default: image.mag.?)
skyfile =                         Input sky value file(s)
(plotfil=                       ) Output plot metacode file
(datapar=                       ) Data dependent parameters
(centerp=                       ) Centering parameters
(fitskyp=                       ) Sky fitting parameters
(photpar=                       ) Photometry parameters
(interac=                     no) Interactive mode ?
(radplot=                     no) Plot the radial profiles?
(icomman=                       ) Image cursor: [x y wcs] key [cmd]
(gcomman=                       ) Graphics cursor: [x y wcs] key [cmd]
(wcsin  =               )_.wcsin) The input coordinate system (logical,tv,physical
(wcsout =              )_.wcsout) The output coordinate system (logical,tv,physica
(cache  =               )_.cache) Cache the input image pixels in memory ?
(verify =              )_.verify) Verify critical phot parameters ?
(update =              )_.update) Update critical phot parameters ?
(verbose=             )_.verbose) Print phot messages ?
(graphic=            )_.graphics) Graphics device
(display=             )_.display) Display device
(mode   =                     ql)
```

6. All grouped images were shifted together with the reference coordinate file.

```
                         I R A F
            Image Reduction and Analysis Facility
PACKAGE = immatch
   TASK = imshift

input   =                        Input images to be fit
output  =                        Output images
xshift  =                        Fractional pixel shift in x
yshift  =                        Fractional pixel shift in y
(shifts_=                      ) Text file containing shifts for each image
(interp_=                linear) Interpolant (nearest,linear,poly3,poly5,spline3,
(boundar=               nearest) Boundary (constant,nearest,reflect,wrap)
(constan=                    0.) Constant for boundary extension
(mode   =                    ql)
```

7. Using IRAF magnitude values of stars in images were extracted.

```
                         I R A F
            Image Reduction and Analysis Facility
PACKAGE = daophot
   TASK = txdump

textfile=                        Input apphot/daophot text database(s)
fields  =                        Fields to be extracted
expr    =                   yes  Boolean expression for record selection
(headers=                    no) Print the field headers ?
(paramet=                   yes) Print the parameters if headers is yes ?
(mode   =                    ql) Mode of task
```

Or

```
daophot> pdump *.mag.1 "ID,mag" >Bmag
Boolean expression (yes):
```

(ID – Image ID, mag – magnitude of the star which is in that ID)

8. The corresponding Julian dates were also extracted for all images by using IRAF commands script.

```
daophot> list="B.list"
daophot> while(fscan(list,s1)!=EOF){
imgets((s1),"JD")
s2=(imgets.value)
print ((s2),>>"JDlist")
}
```

9. The steps listed above were done separately for all V, B & R filtered and shifted images.

10. Graph of Magnitude Vs Julian date (light curve) was plotted for SZ Lyn and reference star at V, B and R filters.
11. Additionally, Magnitude Vs Phase light curve was also plotted. To convert JD in to phase, Dates of Observation and the times were extracted on to text files from image headers to calculate Heliocentric Julian Date(HJD)

```
daophot> hselect *.* $I,DATE-OBS yes > text
```

12. Phase calculations for each filter (V, B and R) were done by using Visual Basic commands.
13. Using below equation, corresponding cycle number(E)s were found for obtained maximas of resulted light curve.(t_{max} is the HJD of maximum point)

$$t_{max}\,(HJD)=2438124.39955+0.120534910 \times E$$

14. Observed JD and Calculated JD differences were plotted on another graph as O – C Vs Cycle number.

Figure 3.3.1: Image of observed variable stars SZ Lyn

CHAPETR 4

RESULTS AND DISCUSSION

4.1. Data

Table 4.1.1: Magnitude values of observed stars with their corresponding Julian dates and phases while using visible color filter (from 867 CCD images)

JD	Phase	Magnitude
2456664.19215278	0.423	11.593
2456664.19239583	0.425	11.609
2456664.19265046	0.427	11.580
2456664.19295139	0.430	11.584
2456664.19320602	0.432	11.597
2456664.19346065	0.434	11.600
2456664.19373843	0.436	11.592
2456664.19399306	0.438	11.631
2456664.19424769	0.440	11.617
2456664.19452546	0.443	11.598
2456664.19478009	0.445	11.616
2456664.19503472	0.447	11.611
2456664.19532407	0.449	11.627
2456664.19556713	0.451	11.618
2456664.19582176	0.453	11.624
2456664.19612268	0.456	11.622

(Like vice 867 data values were used to plot the light curve)

Table 4.1.2: Magnitude values of observed stars with their corresponding JDs and phases while using blue color filter (from 747 CCD images)

JD	Phase	Magnitude
2456664.19203704	0.422	11.818
2456664.19229167	0.424	11.821
2456664.19253472	0.426	11.810
2456664.19283565	0.429	11.836
2456664.19309028	0.431	11.815
2456664.19334491	0.433	11.839
2456664.19362269	0.435	11.828
2456664.19387731	0.437	11.834
2456664.19413194	0.439	11.830
2456664.19440972	0.442	11.841
2456664.19466435	0.444	11.846
2456664.19491898	0.446	11.869
2456664.19520833	0.448	11.861
2456664.19546296	0.450	11.865
2456664.19570602	0.452	11.860
2456664.19600694	0.455	11.846
2456664.19626157	0.457	11.880
2456664.19650463	0.459	11.875
2456664.19679398	0.462	11.876

(Like vice 747 data values were used to plot the light curves.)

Table 4.1.3: Magnitude values of observed stars with their corresponding JDs and phases while using red color filter (from 820 CCD images)

JD	Phase	Magnitude
2456664.19222222	0.431	11.341
2456664.19247685	0.434	11.340
2456664.19273148	0.436	11.330
2456664.19302083	0.438	11.337
2456664.19327546	0.440	11.332
2456664.19353009	0.442	11.315
2456664.19381944	0.445	11.352
2456664.19407407	0.447	11.354
2456664.19431713	0.449	11.352
2456664.19460648	0.451	11.357
2456664.19486111	0.453	11.357
2456664.19511574	0.455	11.356
2456664.19539352	0.458	11.363
2456664.19564815	0.460	11.367
2456664.19590278	0.462	11.359
2456664.19619213	0.464	11.376
2456664.19644676	0.467	11.369
2456664.19699074	0.471	11.383

(Like vice 820 data values were used to plot the light curve)

4.2. Light Curves

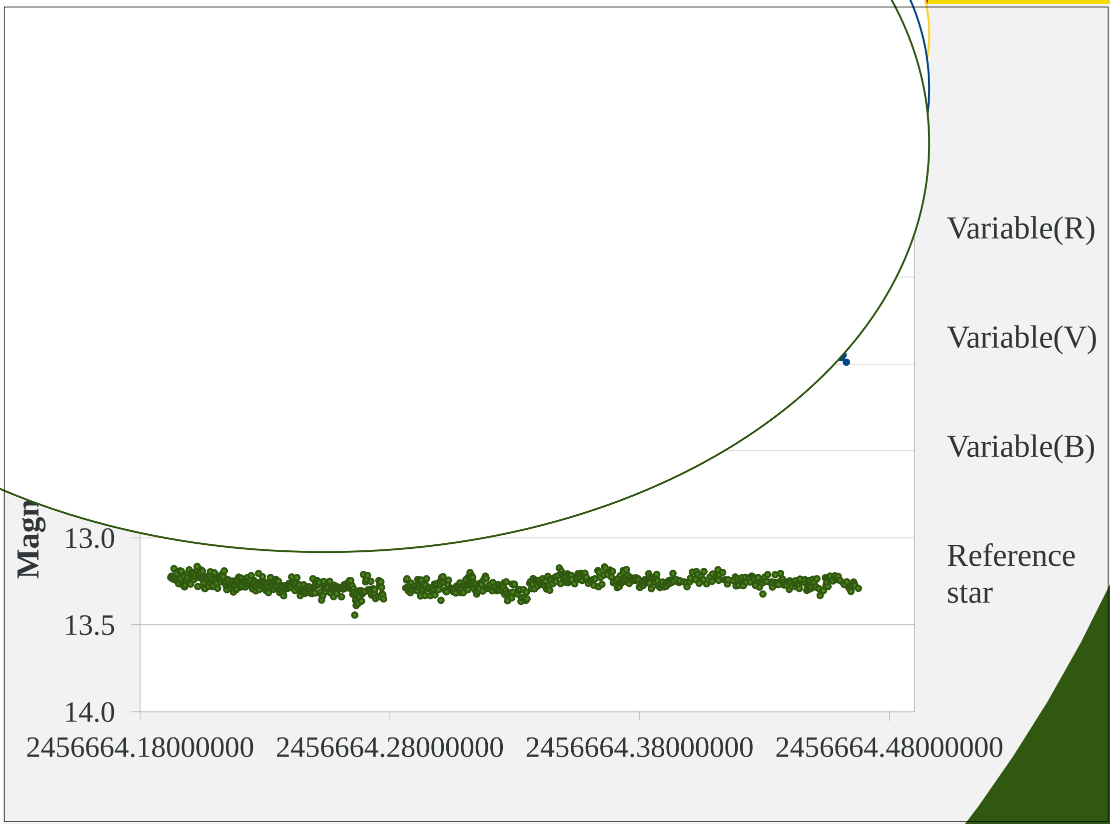


Figure 4.2.1: Light curves of observed stars with V, B & R filters (Magnitude Vs JD)

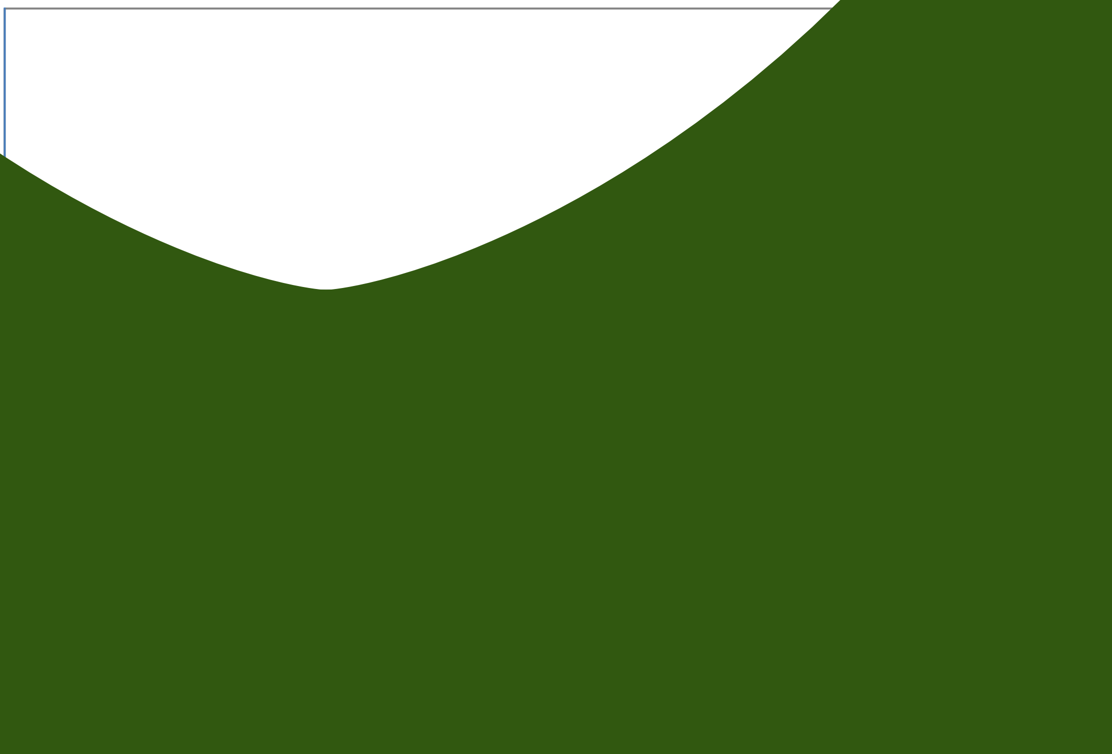


Fig. 4.2.2: Light curves of observed stars with V, B & R filters (Magnitude Vs Phase)

4.3. O – C diagram

Table 4.3.1: O-C values for the resulting maximum points on B filtered light curves

	Observed JD	**HJD**	**O-C**
1st Maximum	2456664.26171296	2456664.26693966	0.312778298
2nd Maximum	2456664.38314815	2456664.38837653	0.032179788

Gazeas, Niarchos & Boutisia in 2004, had investigated O-C vs Pulsation Cycle (E) behavior using the following equation.

$$t_{max}(HJD)=2438124.39955+0.120534910 \times E \longrightarrow \quad (1)$$

Calculation of the Cycle number (E) for our observed Pulsation maximas

Using the above equation (1) we can find the pulsation cycle corresponding to our observed maximas.

t_{max} (observed HJD)= 2456664.26693966

E=153813.088151742

From the O-C vs E graph it can be observed that there is a trend for the pulsation period to decrease with the time. We investigated this trend by selecting the maximum O-C values in each of the orbital cycles and by fitting a polynomial.

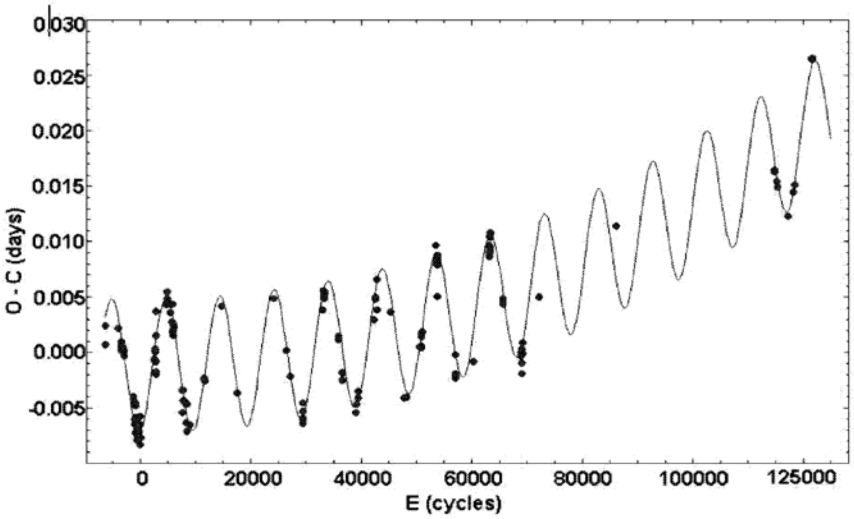


Figure 4.3.1: O-C diagram of SZ Lyn, based on equation 1

Table 4.3.2: O-C values of maximas and their corresponding cycle numbers (From Figure 4.1 data)

E(Cycle #)	**O-C(days)**
4847	0.0054
14775	0.0042
24151	0.0048
33228	0.0056
42834	0.0066
53816	0.0086
63358	0.0108
121557	0.0266

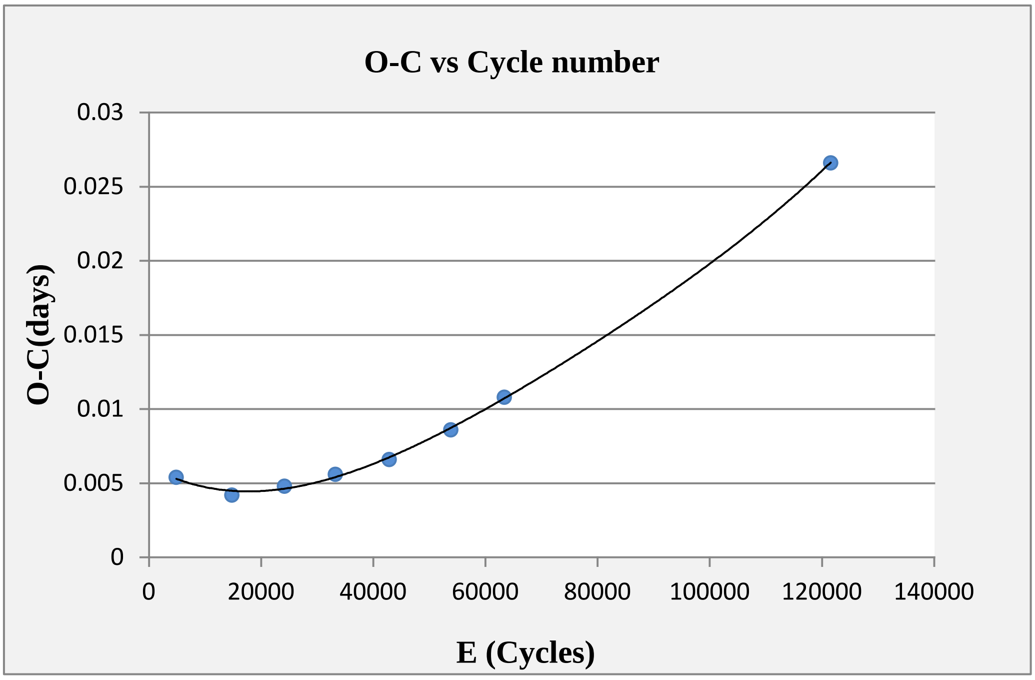


Figure 4.3.2: O-C diagram of SZ Lyn for maximum points in given cycles

Using the equation y = 2E-22x^4 - 6E-17x^3 + 7E-12x^2 - 2E-07x + 0.0061 fitted for the above graph we found that,

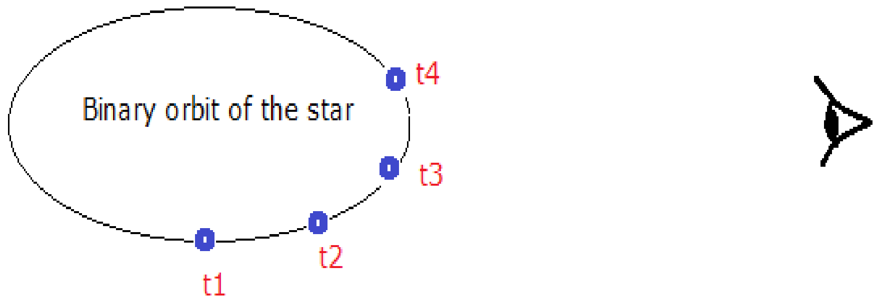
O-C= 0.034552291,   for our 1st pulsation maximum

And

O-C= 0.034552897,   for our 2nd pulsation maximum

The O-C values found for our pulsation maximum were, 0.0312778298 and 0.032179788, and were found to be in good agreement with the values, 0.034552291 and 0.034552897 respectively determined by extrapolating the points on the O-C vs E graph, as reported by Gazeas, Niarchos & Boutisia in 2004, in their research paper.

The pulsation period of a variable star can change with its mass and for this to happen, it will take several thousand years, though the variable star SZ Lyn showed rapid variation of its pulsation period. The possible explanation for this is that SZ Lyn should be a member of a binary star system and due to its orbital motion the travel time of light can slightly change the observed pulsation period of the star.



The above diagram shows (exaggeratedly) the positions of the star in its orbit during two complete pulsation periods. t_1 and t_2 are the times measured by the observer at the beginning and the end of a pulsation period. t_3 and t_4 are the times measured by the observer at the beginning and the end of another pulsation period. In this orbital configuration it is obvious that,

$$t2 – t1 > t4 – t3$$

This implies different measured pulsation periods for SZ Lyn.

CHAPTER 5

CONCLUSIONS AND RECOMANDATION

The pulsation period of SZ Lyn found from our observations is 0.12053503 days and the O-C values found for the pulsation maximas are 0.031 and 0.032 respectively.

As the above values agree very well with results reported by the previous researches on this star our observations can also be considered to be of international standards.

From the results found in this research and in previous studies on this star, we can conclude that the star SZ Lyn is a binary and short period δ Scuti type variable star.

We recommend further spectroscopic observations on this star to confirm the binary nature of the system.

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