ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 6, Issue 3 , March 2019

Outbursts Analysis of Dwarf Novae Subtypes

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ABSTRACT: In this study, characteristics of the dwarf novae outbursts were investigated using their light curve data obtained from the Kepler mission and American Association of Variable Star Observers (AAVSO). SU UrsaeMajoris (SUUMa) type dwarf novae such as V344 Lyrai, V516 Lyrai and V1504 Cygni were studied using Kepler light curve data while Z Camelopardalis type dwarf novae and U Geminorum type were studied using AAVSO light curve data. To investigate outbursts, orbital period for each type was generated by Fast Lomb-ScarglePeriodigram method. Double precursor in V516 Lyrai and two superoutbursts in V1504 Cygni with negative superhumps were the most important features. And also this research reconfirmed that V516 Lyrai has less mass transfer rate than that of V344 Lyrai and percentage occurrence of standstill outbursts of Z Camelopardalis systems is in between 7.5% and 9%. In addition, a strong direct correlation between outburst duration and magnitude were also observed.

KEYWORDS: Light curve, Orbital Period, Standstills, Superhumps, Superoutbursts

I. INTRODUCTION

Change of brightness of the variable stars can be periodic; on the other hand, random. Changing of variability of brightness in the variable stars can be classified as either intrinsic variability or extrinsic variability. Classification of variable stars is mainly done based on the cause of fluctuations of their brightness. Intrinsic variable stars are the stars which change their own brightness due to the physical changes in the stars itself. Physical changes of the stars can be as either pulsations or eruptions. And extrinsic variability of the stars occurs due to eclipses of stars by another object as well as the effect of star's rotation. [11]
Dwarf novae are one type of cataclysmic variable stars (Eruptive variable stars). And also it is close to the binary star system meaning that it is not an isolated star. Therefore, it is a system of two stars orbiting very close to each other. The binary star system consists of a white dwarf star and a normal Sun like or giant star. Due to high gravity of the white dwarf, some of the outer material of the normal star is pulled towards. However, these materials do not fall directly on to the white dwarf star. Materials transferred from the normal large star have high angular momentum and lose it before accreting. Therefore it builds up a disk called an accretion disk. In this system, normal star is considered as a secondary star or donor star because it transfers matter to the white dwarf while white dwarf star is known as primary star. After the accretion disk is fully established, the stream of matter ejected from the secondary star contacts onto outer rim of the disk with ultrasonic speeds. As a result of this process, a heated area is created where more energy radiates at optical wavelengths as all the other combined components of primary star, secondary star and created accretion disk. The location where the matter stream impacts onto the disk is known as the hot spot or bright spot. Dwarf novae undergo multiple outbursts in which their brightness increases by about 2 – 5 magnitudes. Each outburst lasts between 2 and 20 days and this time interval is known as quasi-periodic which ranges from days to decades. Two possible scenarios have been proposed to understand the outbursts. They are Disk Instability Model (DIM) and Mass Transfer Burst Model (MTBM). DIM explains that the white dwarf, surrounded by accretion disk, is able to accumulate a certain

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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amount of gas at a steady rate while MTBM explains that the sudden increase in the transfer of material from the companion star to the accretion disk causes the disk to collapse. [13, 14]
There are three main subclasses of dwarf novae. U Geminorum (U Gem) star is one of its subclasses. The orbital period of the U Gem star is on the order of few hours. And also this type of stars exhibit more or less quasi periodic outbursts. Z Camelopardalis (Z Cam) star is the second subclass of dwarf novae. Z Cam is physically similar to the U Gem star type. As well as Z cam type star show frequent outburst which is having standstills. Standstills consist of time duration with more or less constant brightness which is approximately 1 magnitude below the maximum magnitude of the outburst. Due to these standstills of Z Cam stars, they can be separately identified from another types of dwarf novae stars. SU UrsaeMajoris (SU UMa) star is the third subclass of dwarf novae star. This is also physically similar to the U Gem type star. The orbital period of the SU UMa star is less than two hours. It means that SU UMa stars have short orbital periods. It exhibits two types of outbursts. Long outburst is one type of them and it is known as superoutbursts and which is bright, less frequent and appears duration of 10 to 20 days. And also, short or normal outburst is another type of outburst which is faint, frequent and short with duration of 1 to several days. Generally, short normal outbursts are sandwiched in between two long outbursts, that is, two superoutbursts. Superoutbursts are an important feature in the SU UMa type stars due to which they can be identified from the dwarf novae stars by observing superoutbursts. Cycle from one superoutburst to the next superoutburst is known as a supercycle. Periodic humps occur during the superoutburst are known as superhumps. Most of the times, superhumps appear with a period slightly greater than by few percent than the orbital period. That type of superhumps known as positive superhumps. And also negative superhumps can occur during the superoutbursts where superhumps period slightly less than the orbital period. [11]
In this study, databases of American Association of Variable Star Observer (AAVSO) and databases of Kepler mission have been used. Kepler is a space telescope which is used to study a portion of Milky Way galaxy in search of planets outside our system which is known as exoplanets. Kepler mission was initiated by National Aeronautics and Space Administration (NASA). Therefore, in Kepler mission, exoplanets are the main target. It means that the objective of the Kepler mission is to study the properties of the exoplanets. However, with the large Kepler field of view (FOV), it focuses on several other stars like dwarf novae types. The Kepler fields have been observed in short cadence mode as well as in long cadence mode. And also their observations of light curve data are freely available for all users. AAVSO is a non-profit organization which helps to observe variable stars.

II.METHODOLOGY

A. Data Retrieve

Kepler mission and American Association variable star observer (AAVSO) were used to retrieve data. The data in both associations are freely available. Query form in the Mikulski Archive for Space Telescopes (MAST) was used to retrieve Kepler data. Request of the appropriate data was done by submitting details of the star such as name of the star, right ascension, declination in the query form and continuing the other following steps. Then the team sent fits images related to the requested stars as FTP format to the email which was entered in the query form. Finally, fits images related to the stars were downloaded by using several commands in the terminal of the fedora. Data related to three stars of SU UMa type Dwarf novae were downloaded by using the Kepler mission.
Data related to three types of Z Cam stars and two types of U Gem type dwarf novae stars were downloaded by submitting several information such as name of the star, time period, which data needed to be downloaded, etc in AAVSO data retrieval query form. Then it showed the necessary data which were imported in to any format such as word or excel.
Data were retrieved for three stars in SU UMa type dwarf novae (V344 Lyrae, V516 Lyrae and V 1504 Lyrae), three stars in Z Cam type dwarf novae (AH Her, RX And and Z Cam) and two stars in U Gem type dwarf novae (SS Cyg and SS Aur).

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B. Light curve generation methods

Light curves were generated by using python as the programming language. Data which is useful to plot light curves such as time, flux as well as flux error were imported as csv format during the process of plotting light curves. Several astronomical packages such as numpy, matplotlib, astropy, etc. were used during this method. This method was done for all the three SU UMa type stars.
In addition to the above method, Matlab software also was used to generate light curves. Light curves of SU UMa stars were plotted by using the data which imported in the previous method. And the light curves for Z Cam and U Gem were plotted by data which were downloaded by AAVSO.

C. Period analysis method

Orbital period value of all dwarf novae systems were determined using Fast Lomb ScarglePeriodigram method. Python were used as programming language.

D. Analysis of light curves

D.1 Z Camelopardalis star

The outburst properties of Z Cam stars were analyzed by studying some features occur in the outbursts such as starting time of the outburst, ending time of the outburst, magnitude value at the start and end position of the outbursts and maximum magnitude of the outburst. And also properties of standstills such as beginning details of standstills, details of end of the standstills and percentage of occurrence of the standstills were observed. Outburst cycle details were also studied. These analyses were done for all Z Cam type stars. As in the analysis of U Gem stars, correlations of the Z Cam type stars were also checked.

D.2 U Geminorum star

Outburst properties of long and short outbursts of SS Cyg and SS Aur type U Gem stars were studied by determining the several parameters such as starting time of the outburst, ending time of the outburst, magnitude value of the start and end position of the outbursts, rising point of the outburst and maximum magnitude of the outburst. This method was continued for both type of star of U Gem. And also several correlations like variation of outburst duration with maximum magnitude of the outburst, variation of outburst duration with quiescence interval preceding outburst as well as quiescence interval following outburst, maximum magnitude of the outburst with quiescence interval preceding outburst as well as quiescence interval following outburst and variation of rising time with outburst duration, etc. were checked for both type of U Gem stars.

D.3 SU UrsaeMajoris Star

Outburst properties of normal outbursts as well as superoutbursts for all tree type of SU UMa stars were determined by recording starting time of the outburst, ending time of the outburst, magnitude value of the start and end position of the outbursts and maximum magnitude of the outburst. Not only outburst properties but also supercycle details, especially super cycle length, number of normal outbursts in the supercycles were recorded. These analyses were done for V344 Lyr, V516 Lyr and V1504 Cyg. Correlation coefficients were also calculated for this type of stars.

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III. RESULTS AND DISCUSSION

A. SUUMa Dwarf Novae

In this paper, long cadence Kepler public data of V344 Lyr, V516 Lyr, and V1504 Cyg were examined as the SUUMa type stars. Light curves were generated for all the retrieved quarter wise data and the light curve analysis were done for all the stars which mentioned above. Kepler data of V1504 Cyg in quarter 2, 3, 4, 5, 6 and 7 were used to analysis during period approximately 550 days from Barycentric Julian Date 2455002 to 2455552 where 5 superoutbursts and 4 supercycles were found according to the light curves of the V1504 Cyg. When considering Kepler data of V344 Lyr, data in the quarters 6 and 7 were used to analysis duringperiod approximately 180 days from 2455372 to 2455552 where 2 superoutbursts and 1 supercycle were recorded by searching pattern of the V344 Lyr light curves. And according to the data of the V516 Lyr star, data in quarter 6, 7, 8, 9 and 10 were used to analysis during period approximately 461 days from Barycentric Julian Date 2455372 to 2455833 where 2 superoutbursts and 1 supercycle were determined according to the light curve of the V516 Lyr.The main characteristics of the superoutburst and supercycles of V344 Lyr, V516 Lyr and V1504 Cyg were summarized in the Table 1, Table 2 and Table 3 respectively. Each below tables comprise of 8 columns and those indicate supercycle number, starting time of the supercycle, starting time of superoutburst, ending time of the superoutburst, superoutburst duration, supercycle length and length of supercycle without superoutburst and number of the normal outbursts include in the supercycle. These dates were counted by Barycentric Julian Dates (BJD).

Table 1 : The characteristics of the superoutbursts and supercycles of V344 Lyr

Super Cycle Number	Start of the Super Cycle (BJD)	Start of the SO (BJD)	End of the SO (BJD)	SO duration (days)	Super Cycle Length (days)	Super Cycle Length without SO (days)	Number of Outbursts
1	-	2455397.093	2455415.545	18.452	>43.134	>24.622	>3
2	2455415.545	2455527.088	2455544.497	17.409	128.952	111.543	13
3	2455544.497	-	-	-	>8.051	>8.051	>1

Table 2: The characteristics of the superoutbursts and supercycles of V516Lyr

Super Cycle Number	Start of the Super Cycle (BJD)	Start of the SO (BJD)	End of the SO (BJD)	SO duration (days)	Super Cycle Length (days)	Super Cycle Length without SO (days)	Number of Outbursts
1	-	2455592.760	2455607.411	14.651	>234.940	>220.289	>9
2	2455607.411	2455782.737	2455794.364	11.627	186.953	173.017	15
3	2455794.364	-	-	-	>38.904	>38.904	>4

Table 3: The characteristics of the superoutbursts and supercycles of V1504 Cyg

Super Cycle Number	Start of the Super Cycle (BJD)	Start of the SO (BJD)	End of the SO (BJD)	SO duration (days)	Super Cycle Length (days)	Super Cycle Length without SO (days)	Number of Outbursts
1	-	2455074.917	2455088.362	13.445	>85.597	>72.152	>8
2	2455088.362	2455201.641	2455214.351	12.710	125.989	113.279	10
3	2455214.351	2455311.923	2455324.736	12.840	110.412	97.572	9
4	2455324.736	2455406.575	2455419.244	12.669	94.481	81.812	6
5	2455419.244	2455516.403	2455529.439	13.056	110.195	97.159	5
6	2455529.418	-	-	-	>23.13	>23.13	>2

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The details of outbursts such as the number of supercycles which containing outburst, the outburst number, the starting and ending time of the outburst counted by BJD, the maximum flux of the outburst and the type of the outburst were tabulated. All the details were gathered from plotted light curves. And also, the outburst duration, the quiescence interval preceding outburst and the quiescence interval following outburst were calculated using the recorded details of the starting and ending time of the outbursts.

The period analysis of V344Lyr was done by Wood et al. (2011) to be 0.087904 days according to the data in quarter 4. In this research, the orbital period values were redetermined according to the data of the V344 Lyr in quarter 6 and 7 by using Fast Lomb-ScarglePeriodigram method. The calculated orbital period values were 0.08763675 and 0.08777109 days respectively for quarter 6 and 7. Thus, calculated average value of the orbital period of V344 Lyr was 0.087703921 days which is approximately around the value reported by Wood et al. (2011). [4]

Howell et al. (2013) reported the period value of V516 Lyr as 0.087478 day. However in this work, the period analysis values of V516 Lyr for quarter 6, 7, 8 and 10 were 0.084607376, 0.084451291, 0.083752717 and 0.083705164 days respectively. Thus, average value of orbital period was noted as 0.084129137 days. According to the finding of Kato et al. (2012) the orbital period value of the V1504 Cyg was recorded as 0.069549 days. The orbital period values of V1504 Cyg in quarter 2, 3, 4, 6 and 7 were 0.069370659, 0.069269449, 0.069224412, 0.069569260 and 0.069394257 respectively. According to these values, obtained average value for orbital period of V1504 Cyg was 0.069365619 days, which is consistent with that of Kato et al. (2012). And also power spectrum of all the systems were generated by using Fast Lomb-ScarglePeriodigram method.

When considering details of the V1504 Cyg, the most outstanding feature is that containing different number of normal outbursts within the supercycles. According to this study, it shows as the supercycle 2 with 10 outbursts, 3 with 9 outbursts, 4 with 6 outbursts and 5 with 5 outbursts. It means that the number of outbursts vary from 5 to 10. As well as supercycle lengths also differ from one supercycle to another. And the average length of the supercycle is 110.264 days. Since it is an approximately low value, so mass transfer rate can be considered as high.[12] Difference of the supercycle length from one supercycle to another is small compared with the number of outbursts which exist in the supercycle. The fact for this variation of number of outbursts is the appearance of the negative superhumps (which are the periodical humps with period value is less than the orbital period value) in the superoutbursts which it consists in the duration of the supercycle as explained by Kato, Ishioka, and Uemura (2002), Kato et al. (2013), and Ohshima et al. (2012). It means when the superoutburstsinitiates with negative superhumps, it strongly correlats with quiescence time duration between two normal outbursts. The correlation is as when superoutburst exists with negative superhumps it tends to increase the quiescence interval between two outbursts.Thus, when increase the quiescence interval, it causes to decrease the number of normal outbursts in the supercycle. According to this theory, it can be concluded that the occurrence of negative superhumps in fourth and fifth superoutbursts in V1504 Cyg.

In the consideration of normal outbursts in the V1504 Cyg, most of those are desired to be outside-in types. Total number of the outbursts were determined in the V1504 Cygwhich were 45 and out of them 36 outburst are outside-in type outbursts. The type of the outbursts was established by the shape of the outbursts, which have been done according to the same view of the Cannizzo et al. (2012) as the less rise time to the maximum of the outbursts and long decline time to the quiescence level from the maximum of outbursts in the light curves. According to the study of Smak (1984), such an outbursts are named as Type A outbursts in which the transition of the heat from the outer edge of the disk to the inside of the thermally instability stars. Only 3 outbursts were classified as Type B or inside-out outbursts during this study. Type B or inside-out outbursts exist when heat transition from the inner position of the disk and it comes towards the outside of the disk. This type of outbursts in the light curves can be characterized by the feature of the less or more symmetric of the rise and decline of the outbursts.

Thermal Tidal Instability (TTI) model explains the occurrence of Superoutburstsand those consist in the light curve of V1504 Cyg have less frequent than the normal outbursts, however those are more regularly repeat than the normal outbursts. The mean superoutburst duration was calculated in this work as 12.935 days. The important feature which shows in the superoutbursts in V1504 Cyg is the occurrence of precursors as shown in Figure 3. Precursor is also looks like a normal outburst, but all precursors in this superoutbursts are arisen in its rising part. It means that the heat has to be reflected at the middle part of the disk when heat transition from the inner edge towards the outer part and the reflection occurs as cooling front in the precursor. In addition to that, precursor can be a result of normal outburst which merges with the main part of the superoutburst and this is also explained by the TTI model. However, the merging value does not same in all precursor, it depends on the superoutburst as well as type of stars. Precursor also can be existed as a normal outburst, it means that it can be separated from the superoutburst. (Osaki, 2005)

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According to the details of the V344 Lyr light curves, it consists with 16 normal outbursts, out of them 9 outbursts with Type A and 7 outbursts with Type B. From the results of V344 Lyr, it can be identified that the most outbursts are in Type A or outside-in as V1504 Cyg. The mean outburst duration of the V344 Lyr was 17.931 days and the average supercycle duration was 128.952 which is greater than that the value of V1504 Cyg. It means that the mass transfer rate of the V344 Lyr can be considered as less than that of the V1504 Cyg. And considering light curve details of the V516 Lyr, it has 21 normal outbursts and among those, 11 outbursts can be categorized as type A while 9 outbursts are type B and also 4 outbursts are categorized as double outbursts. In the consideration of the study time period in quarter 6 and 7 of V516 Lyr, it is approximately same as the time period of the V344 Lyr in quarter 6 and 7. The properties of the outbursts in quarter 6 and 7 were analyzed for both V344 Lyr and V516 Lyr. When considering V344 Lyr it consists of 2 superoutbursts and 16 normal outbursts in both quarters. However, in the case of the V516 Lyr, it does not contain any superoutbursts in that study period and it contains 9 normal outbursts as shown in figure 1 and 2. The period values of the V344 Lyr and V516 Lyr were analyzed as 0.087703921 and 0.084129137 respectively. The orbital period of the V516 Lyr is near to the value of V344 Lyr. However, according to the above details, it can be confirmed that there are less number of normal outbursts as well as superoutburst in the V516 Lyr than the V344 Lyr. Due to this phenomenon, it can be confirmed that V516 Lyr has less mass transfer rate than the V344 Lyras previously suggested by the Taichi Kato and Yoji Osaki (2013).

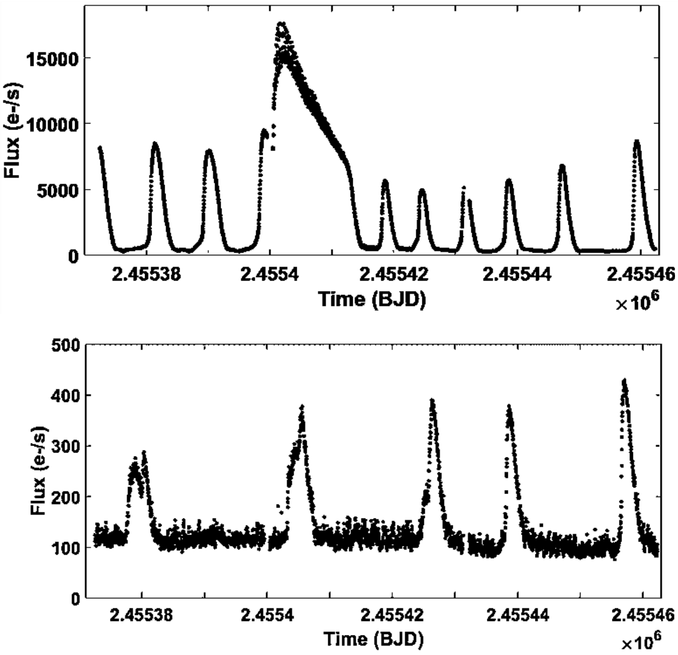

Figure 1: Kepler Light curves in quarter 6. Upper: For V344 Lyr star. Lower: For V516 Lyr star

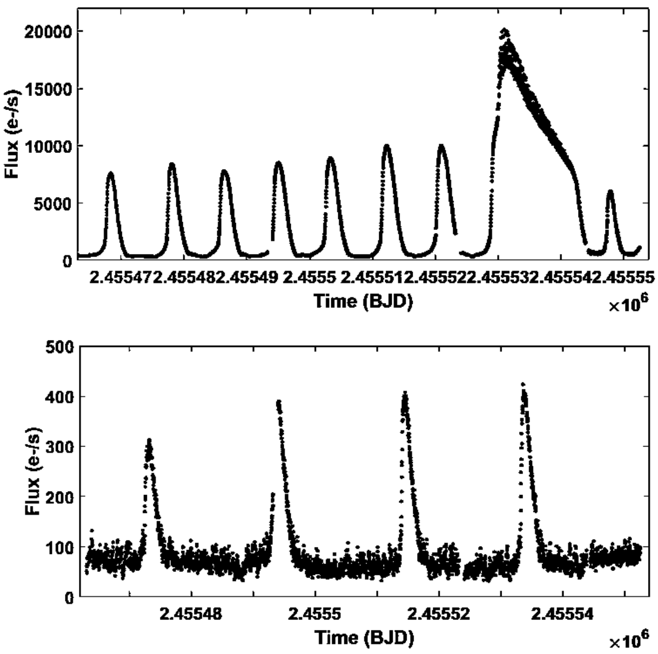

Figure 2: Kepler Light curves in quarter 7. Upper: For V344 Lyr star. Lower: For V516 Lyr star

According to the outbursts details of the V516 Lyr, the double precursors occurred in the second superoutburst and it was the most important feature which occurred in the V516 Lyr outbursts. Double precursors occurred in the second superoutburst is shown in figure 4.This feature has been already identified by Taichi Kato and Yoji Osaki (2013). There were two explanations for the occurrence of the double precursors due to their study. According to the study of Taichi Kato and Yoji Osaki (2013), they have revealed that the occurrence of the double outbursts tend to exist as a group as which shown in quarter 6 and quarter 14. However, in this study period, it can be seen only in the quarter 6. And also in this study confirmed the preceding outburst of double outburst is always Type B or inside-out while following outbursts in the double outburst is Type A or outside-in. Factors for this phenomenon were discussed by Taichi Kato and Yoji Osaki (2013). [14]

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General information and mean outburst characteristics of all three systems such as right ascension, declination, the average value of orbital period, the mean outburst duration, the mean quiescence interval preceding outburst, the mean quiescence interval following outburst, the mean maximum flux value and also the several correlation coefficients among the important characteristics were summarized in this study. There was a strong positive correlation of the maximum flux with the outburst duration of all three stars. Since correlation coefficients between that parameters of all stars were near to +1. And also it can be interpreted that the flux of the outburst increases with increasing the outburst duration. It means superoutbursts exist with increasing the flux since that superoutbursts are brighter than the normal outbursts. And other moderate correlation exists in between outburst duration and the value of quiescence interval following outburst. It was negative correlation, it means quiescence interval following the outburst increases when decreasing the outburst duration.

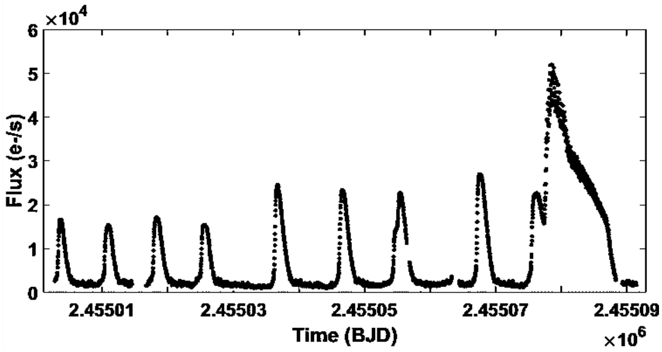

Figure 3: Scatter plot for the Kepler Light curve of V1504 Cyg in quarter 2 which occurrence of precursor in superoutburst

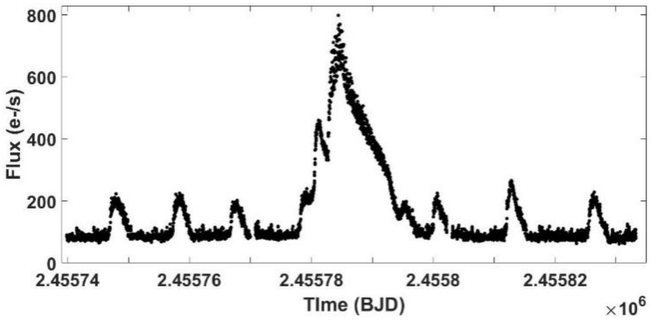

Figure 4: Scatter plot for the Kepler Light curve of V516 Lyr in quarter 10 which occurrence of double precursors in superoutburst

B. Z Cam Dwarf Novae

Data in AAVSO were used when examine the Z Cam, RX And as well as AH Her stars which are the types of Z Camelopardalis dwarf novae. The light curve analysis was conducted for all the systems which was mentioned above under Z Camelopardalis. Light curves of Z Cam for all 5 data sets, RX And for all 5 data sets and AH Her for all 5 data sets were plotted in this study. Study time period of all the systems were choose with same duration as approximately 2500 days and study time period was taken as period from Julian Date 2440800 to 2443200 for Z Cam, from 2449000 to 2451500 for RX And and from 2448500 to 2451000 for AH Her. In this study period the Z Cam star system maintains the mean magnitude value from 13.23 to the 10.44 and the RX And system maintains its mean period value from 13.65 to 10.63 while that value of AH Her is from 14.70 to 11.20.
According to the light curves of the Z Cam, 5 standstills were observed. And also according to the RX And 6 standstills and 7 standstills were obtained in AH Her light curves. The details of standstills such as the number of the standstills, the starting time of the standstill, the magnitude of the starting of standstill, the ending time of the standstills, the magnitude of the ending of standstill and the maximum magnitude of the standstill were reported in this study.
The outbursts occur in this type of dwarf novae follow a pattern which is named as plateau outburst cycle. The plateau outburst cycle details of Z Cam, RX And and AH Her such as plateau outburst cycle number, the starting outburst type of cycle, the ending outburst type of cycle and the number of outbursts occur in the cycle were summarized in this study. Outburst details of Z Cam, RX Andand AH Her were reported and they were gathered from plotted light curves. Those gathered details were the starting time of the outburst, the ending time of the outburst (which were counted from JD), the magnitude value of the starting of the outburst and the ending of the outburst, the maximum magnitude of the outburst. Outburst duration, quiescence interval preceding outburst and quiescence interval following the outburst can be found by using the recorded details from the light curves such as the starting time and the ending time of the outbursts.

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The period analysis of Z Cam, RX Andand AH Her were done by using the Fast Lomb ScarglePeriodigram method. The orbital period values of all three stars were mentioned by Paula Szkody and Janet A. Mattei (1984) as well the values were obtained in the catalogue of the National Science Centre Poland.[9] The analyzed orbital period values of Z Cam were 0.300705519011, 0.31716439879, 0.269137716761, 0.285709054624 and 0.276560249013 days respectively for 5 data sets. The average value of the orbital period of Z Cam was 0.289855388 days which is comparable to the value in the catalogue. In this study, the analyzed orbital period values of RX And for all 5 data sets were 0.200220713896, 0.199690900375, 0.199951081006, 0.20041950779 and 0.201654380663 days respectively and the average value of orbital period was calculated as 0.200387316746 days. This value is also approximately same as the value which is reported in the catalogue. The orbital period value of AH Her in 5 data sets were analyzed as 0.246291544272, 0.252796576494, 0.246426429947, 0.253448155232 and 0.24715304729 respectively. According to the values, the average value for orbital period of AH Her was obtained as 0.248935602 days, which is consistent with that of in the catalogue. Power spectrums of the period analysis of all these stars were generated by using the Fast Lomb ScarglePeriodigram method.

Analyses of types of the outbursts were an important work of this research. In the consideration of the reported outburst details of the Z Cam, RX Andand AH Her, existence of the standstills were the most important feature. According to the Z Cam, 51 outbursts occurred. There are 4 types of outbursts belongs to the Z Camelopardalis stars as the common, anomalous, plateau and standstills. There were 24 common outbursts were occur and among them 5 were sloped type, 15 were rounded type and 4 were asymmetric type. And also there were 12 anomalous outbursts were occur and among them 6 were backward, 3 were double peaked and 3 were long rounded types. And also 11 plateau outbursts were occur in the Z cam type star. When considering RX And, it contained totally 68 number of outbursts, out of them 30 were common outbursts, 18 were anomalous outbursts, 14 were plateau outbursts and 6 were standstills. Considering the common outbursts, it was completed with including 6 sloped outbursts, 22 rounded outbursts and with 2 asymmetric outbursts. And considering the anomalous outbursts, it contained 9 backward, 6 double peaked and 3 long rounded outbursts. Same details of the AH Her dwarf novae were observed and according to those results, total number of outburst were 92. Among those outbursts, 39 outbursts were common type, 27 outbursts were anomalous type, 19 outbursts were plateau type and 7 outbursts were standstills. Common outbursts were made up with 4 sloped type outbursts, 32 rounded type outbursts and 3 with asymmetric type outbursts and considering the anomalous type outbursts, they were consist with 10 backward outbursts, 9 double peaked outbursts and 8 long rounded outbursts.

Kenyon and Janet A. Mattei (1998) have analyzed that the percentage values of occurrence of the standstills in Z Camelopardalis type stars was roughly 7%.[10] According to the results of this study, 7.84 %, 8.82 % and 7.61 % were obtained for the occurrence of the standstills for three type of stars. Then according to these results, it can be suggested that the occurrence of the standstills in Z Camelopardalis type dwaf novae roughly in between 7.50% and 9.00 %. And also the percentage values of the occurrence of the common outbursts were analyzed as 47.06 %, 44.12 % and 42.39 % for Z Cam, RX Andand AH Her respectively. And also the values related to the anomalous outbursts were 23.53 %, 26.47 % and 29.35 % as well as related to the plateau outbursts were 21.57 %, 20.59 % and 20.65 % respectively for Z Cam, RX And as well as AH Her stars. According to the all results which were discussed above, most outbursts were occurred as the common outbursts and then as anomalous type. The occurrence of Plateau outbursts was less than both common and anomalous type outbursts whereas greater than the occurrence of the standstills. All these outbursts follow a plateau outburst cycle pattern. By analyzing the standstill details, the magnitude value of 11.5 was maintained for an extended period of the standstill of Z Cam while the magnitude value for RX Andand AH Her were recorded as 11.50 and 12.50 respectively. Several features can be identified by observing the beginning details and the ending details of the standstill outbursts. As shown in figure 5, all the standstills in this study period began as the common outbursts and all the outbursts ended as the quiescence level in Z Cam type while all standstills of RX And type began as the common outbursts and one standstill ended with the outburst which is long rounded is shown in figure 6 and all other standstills ended at the quiescence level. There was no any common pattern for beginning and ending type of the outbursts in AH Her Type.

General information and mean outburst characteristics of the Z Camelopardalis stars were summarized as discussed in SU UMa type dwarf novae. There was a negative correlation of maximum magnitude of the outbursts with the outburst duration of all three stars. According to this correlation, it can be suggested that the magnitude of the outburst decreases with increasing the outburst duration. It means brightness of the outbursts increase with increasing the outburst duration. Therefore, it can be interpreted that the plateau outbursts are brighter than the common outbursts.

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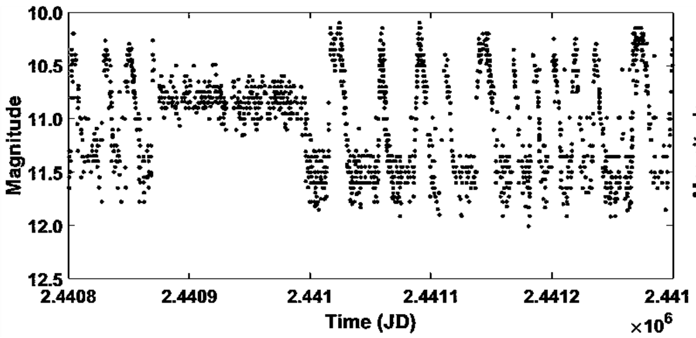

Figure 5: Scatter plot for the Light curve of Z Cam with time between 2440800 to 2441300 JD

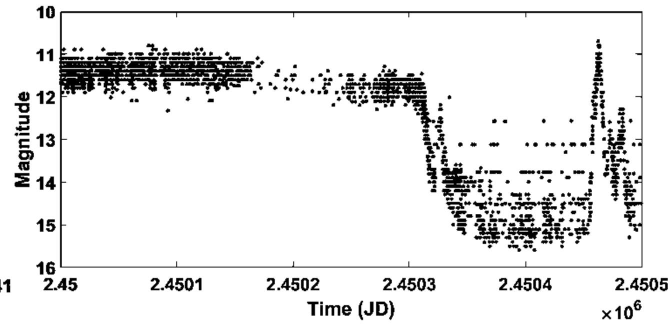

Figure 6: Scatter plot for the Light curve of RX And with time between 2450500 to 2451000 JD

C. U Gem Dwarf Novae

SS Cyg and SS Aur stars of the sub classes of U Geminorum type dwarf novae were analyzed by using the data in AAVSO database. The light curves were generated for all retrieved data. The light curve analysis was done for both stars which were mentioned above. Studied time period of both stars were taken as approximately 2500 days and studied time period of SS Cyg was taken from Julian Date 2451000 to 2453500 and that of SS Aur was taken from 2447500 to 2450000. The generated light curves of SS Cyg for time between 2451000 to 2451500 JD and the generated light curve of SS Aur for time between 2449000 to 2449500 JD are shown as in figure 7 and 8 respectively. The outburst details such as starting time and ending time of the outbursts, the maximum point of rise to the outbursts counted from JD, the magnitude values of starting and ending of the outbursts and maximum magnitude of the outbursts were extracted from the plotted light curves of SS Cyg and SS Aur. Outburst duration, quiescence interval preceding outburst and quiescence interval following outburst and rising time of the outbursts were calculated using the recorded details of the starting time of the outbursts and ending time of the outbursts.

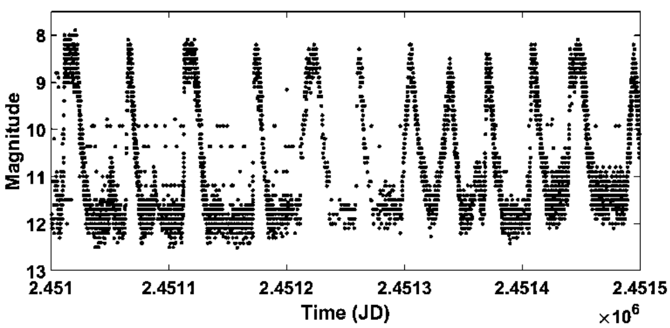

Figure 7: Scatter plot for the Light curve of SS Cyg for the time between 2451000 to 2451500 JD

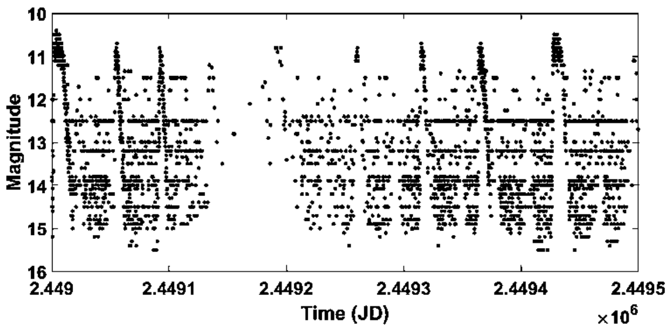

Figure 8: Scatter plot for the Light curve of SS Aur for the time between 2449000 to 2449500 JD

The orbital period values for both stars have been analyzed by Paula Szkody and Janet A. Mattei (1984) and that values were also exist in the catalogue of the National Science Centre Poland.[9] The analyzed orbital period values of SS Cyg were 0.276819718, 0.270340848, 0.275218046, 0.275131526 and 0.272694390 respectively for 5 data sets and the average value of the orbital period of SS Cyg was 0.274038905 days which was comparable to the value in the catalogue. In this work, the period analysis values of SS Aur for all 5 data sets were 0.183554947, 0.182365863, 0.182446961, 0.182916145 and 0.181437311 days respectively. Thus, the average value of orbital period for SS

ISSN: 2350-0328

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Aurwas determined as 0.182544245 days. This value was also approximately same as the value which was reported in the catalogue. Power spectrums of the period analysis of these dwarf novae for 5 data sets were generated.

Totally, 56 number of outbursts in SS Cygwere obtained and out of them, 42 outbursts were in long or wide outbursts where outburst duration is greater than the 12 days while 14 outbursts were the short type outbursts where outburst duration is less than or equal to the 12 days. According to the outburst details of the SS Aur, 41 number of outbursts occurred and among them 15 outbursts are long outbursts and 24 outbursts are short type outbursts.

SS Aurigae dwarf novae were already analyzed by Janet A. Mattei, et al. (1986).[8] Leon Campbell (1934 & 1940) has studied the outburst properties of SS Cyg star. In this study, it can be reconfirmed that the results which were recorded by Leon Campbell (1934 & 1986) and Janet A. Mattei, et al. (1984).[3, 7, 8, 9] Outbursts were classified in to 4 categories as Type A, B, C and D according to the calculated values of rising time period. When considering SS Cyg, there were 35 outbursts as Type A, 5 outbursts as Type B, 9 outbursts as Type C and 7 outbursts as Type D. By analyzing these results, it can be summarized the percentage values for the occurrence of the Type A, B, C and D as 62.50%, 8.93%, 16.07% and 12.50% respectively. These results for the SS Aur type star were 20 for Type A outbursts, 6 for Type B outbursts, 12 for Type C outbursts and 3 for Type D outbursts while percentage values for Type A, B, C and D for SS Aur were calculated as 48.78%, 14.63%, 29.23% and 7.32% respectively. According to the findings of the Leon Campbell (1934), they showed that the Type A with 64% of the outbursts, B with 9%, C with 18%, and D with 9% for the SS Cyg star. Results which were found in this study approximately consistent with that values which were found by Leon Campbell (1934).[3, 7]

SS Cyg star system maintains the mean magnitude value from 11.95 to the 8.20. According to the studied time period of the SS Aur, it maintains the mean magnitude value from 14.23 to 10.80. And also according to the observations of narrow or short outbursts in SS Cyg, those were fainter with mean magnitude value of 8.34 and mean outburst duration or short duration was 9.408 days. When considering long or wide outbursts of SS Cyg, those were brighter with 8.16 magnitude and the mean outburst duration or long duration was 17.764 days. According to the results of SS Aur, short outbursts were fainter with mean magnitude value of 10.85 and short length with 9.700 days on average while long outbursts of SS Aur were brighter with 10.67 and long duration with 17.246 days on average. According to the study of Janet A. Mattei, et al. (1986), they investigated the relationship between occurrence of short and long outbursts as the occurrence of short outbursts is 1.9 times as often as occurrence of the long outbursts. However, according to this study, that value was about 1.6.[8]

General information and the mean outburst characteristics such as right ascension, declination, the average value of orbital period, the mean outburst duration, the mean rising time period to the maximum, the mean quiescence interval preceding outburst, the mean quiescence interval following outburst, the mean maximum flux value and the several correlation coefficients among the important characteristics of both U Geminorum stars were summarized. According to the SS Cyg, there was a negative moderately strong correlation in between the maximum magnitude of the outbursts and the outburst duration with correlation coefficient -0.5202. According to this correlation, it can be interpreted that the brightness of the outbursts increase when increasing the outburst duration and it can be concluded, that the wide outbursts are brighter than the narrow outbursts. According to the correlation results of SS Aur in this study, there was no correlation between maximum magnitude of the outburst and outburst duration since correlation coefficient was comparable to zero. However, according to the results of Janet A. Mattei, et al. (1986), they showed there was a moderately strong correlation with above discussed two parameters in SS Aur with correlation coefficient -0.55. This can be happed due to the changing of the study period and occurrence of errors when checking the outburst properties in the study. The negative correlation occurs with maximum magnitude of the outburst with quiescence interval preceding outburst in both stars. And also same correlation occurs with quiescence interval following outburst instead of quiescence interval preceding outburst. And other moderate correlation exists in between rising time of the outburst and the outburst duration.

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IV. CONCLUSION

Distinct outburst properties related to three types of dwarf novae were analyzed through their light curves. This helps to differentiate the sub classes of dwarf novae. In this research several findings which previously concluded by many researchers were confirmed for the dwarf novae systems of SU UrsaeMajoris, Z Camelopardalis and U Geminorum as follows.

- The negative superhumps occur in the fourth (2455406.575-2455406.575) and fifth (2455516.403-2455529.439) superoutbursts in V1504 Cyg.
- Most outbursts occur in V1504 Cyg and V344 Lyr was outside in type.
- The mass transfer rate of the V344 Lyr was less than that of the V1504 Cyg due to the large supercycle duration.
- V516 Lyr star has less mass transfer rate than the V344 Lyr which was previously suggested by the Taichi Kato and Yoji Osaki (2013)
- Double precursor in the second superoutburst was the most important feature in V516 Lyr and the preceding outburst of double outburst was always Type B or inside-out and following outburst of the double outburst was Type A or outside-in.
- There was a strong positive correlation in between maximum flux of the outbursts and outburst duration of SUUMa dwarf novae as well as moderately strong correlation exists in between outburst duration and the quiescence interval following outburst.
- Standstills were the most important characteristic to differentiate the Z Cam dwarf novae through their light curves from the other types.
- Outbursts were ended with standstills roughly percentage value in between 7.50% and 9.00 %.
- Most outbursts of Z Cam occur as the common outbursts and then as anomalous outbursts as well as occurrence of plateau outbursts was less than both common and anomalous type outbursts whereas greater than the occurrence of the standstills. All outbursts in Z Cam follow a plateau outburst cycle pattern.
- Negative correlation between maximum magnitude of the outbursts and the outburst duration of Z Cam dwarf novae was observed and it can be concluded, the plateau outbursts were brighter than the common outbursts.
- Four types of outbursts in U Gem dwarf novae were found as Type A, B, C and D which were discussed by Leon Campbell (1934) and according to the analysis of SS Cyg, the percentage values for the occurrence of the Type A, B, C and D as 62.50%, 8.93%, 16.07% and 12.50% respectively. These values were approximately consistent with the findings of Leon Campbell (1934). According to the same analysis of SS Aur, the results were 48.78%, 14.63%, 29.23% and 7.32% respectively.
- The occurrence of short outbursts of SS Aurigue was 1.6 times as often as occurrence of the long outbursts of SS Aurigue and that value was about 1.9 due to the results of Janet A. Mattei, et al. (1986).
- In addition, moderately strong negative correlation in between the maximum magnitude of the outbursts and the outburst duration in SS Cygwas determined and due to that it can be concluded, that the wide outbursts were brighter than the narrow outbursts.

V. ACKNOWLEDGEMENT

I would like to express my sincere gratitude to Mr. IndikaMedagangoda, Research Scientist (Astronomy), Space Division at ACCIMT, for giving me all support and guidance which made me complete the project duly. I am extremely thankful to him for providing such a nice support and guidance, although he had busy schedule managing the corporate affairs. And also, I respect and thank Prof. G.M.L.P. Aponsu, Head of the Department of physical sciences and Technology, Faculty of Applied Sciences, Sabaragamuwa University of Sri Lanka and Mr. L.M.M. De Silva, Lecture (Probationary) in Physics, Department of physical sciences and Technology, Faculty of Applied Sciences, Sabaragamuwa University of Sri Lanka, for encouragement helped, guidance as well as support me to coordinate my research. Data include in this paper were collected by the Kepler mission which was funded by the NASA Science Mission directorate and American Association of Variable Star Observer (AAVSO) International Database which was operated in USA. Gratefully acknowledge the entire Kepler team with specially including the data calibration engineers as well as thanks to the observers of the AAVSO association for making data in both associations available to the public.

ISSN: 2350-0328

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