Light Curve Analysis of the Rapidly Eclipsing Nova-Like Binary Star System UX Ursae Majoris

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Abstract

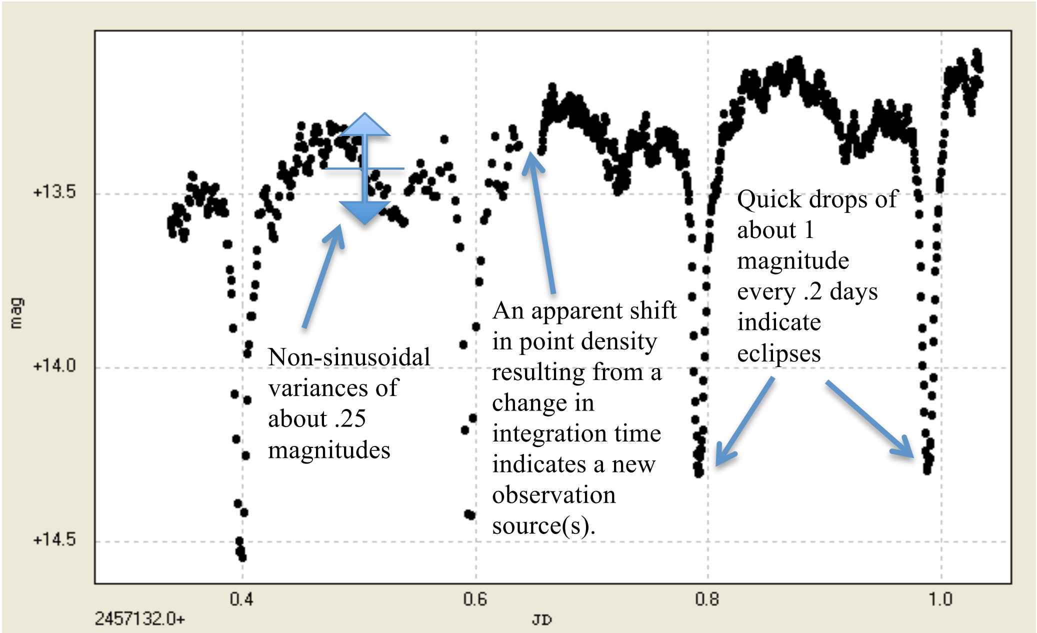
The purpose of this analysis was to find the periodicities of the rapidly eclipsing nova-like variable star system UX Ursae Majoris. Four photometric, time-series data sets, totaling 14,223 points over 20.2 days in 2015, were imported. A brief visual analysis was done in order to establish a rough estimate of periodicities and further parse the data for gaps and changes in observation source. Then, using multiple functions that transform time-series data into folded phase windows and frequency graphs, the exact periods were determined. Causes of the periodicities, such as edge-on eclipses and retrograde nodal precession of an accretion disk around the white dwarf component, are conjectured in the conclusion.

Visual Analysis

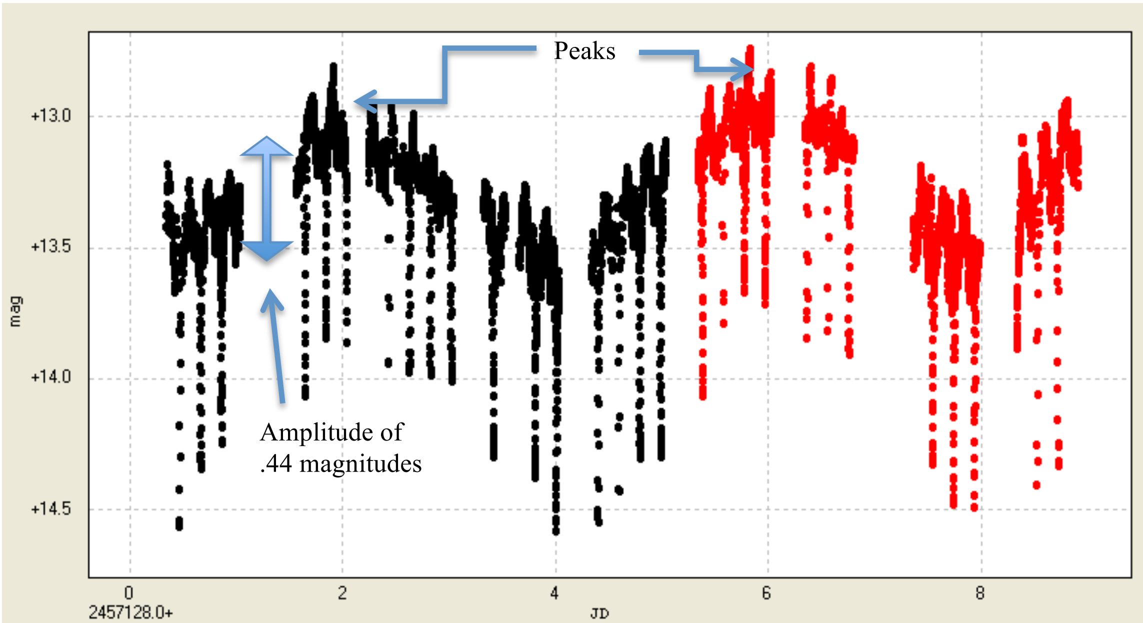
With close visual inspection, two periods can be recognized: one differs in about half a magnitude of apparent brightness over a cycle of about 4 days, the second is an imperfect variance of about a quarter magnitude over .2 Julian days. On this cycle of .2 days lie eclipses that cause a drop in apparent brightness of about one magnitude. There are 17 eclipses observed in the first set, 13 in the second, 18 in the third, and 9 in the fourth. However, there are some gaps in the data so during the span of the first set there were probably around 28 total eclipses.

There are 4430 data points in the first set, 2753 in the second, 4488 in the third and 2552 in the fourth, totaling 14,223 points over 20.2 days. Based on observations of gaps in data and changes in point density, there appears to be 37 total observation sources: 11 in the first data set, 8 in the second, 9 in the third, and 9 in the fourth. These estimates are probably lower than the true value since denser point sets may have more than one contributor, but it is not possible to tell if such is true.

The figure shown below depicts a change in point density around JD .64, indicating the addition of a new set of data, which took measurements with a shorter integration time.



When zoomed out to span a period of 8 days, sinusoidal oscillations of .44 magnitudes, with a period of about 4 days, can be seen. Here, two peaks of the curve are shown.

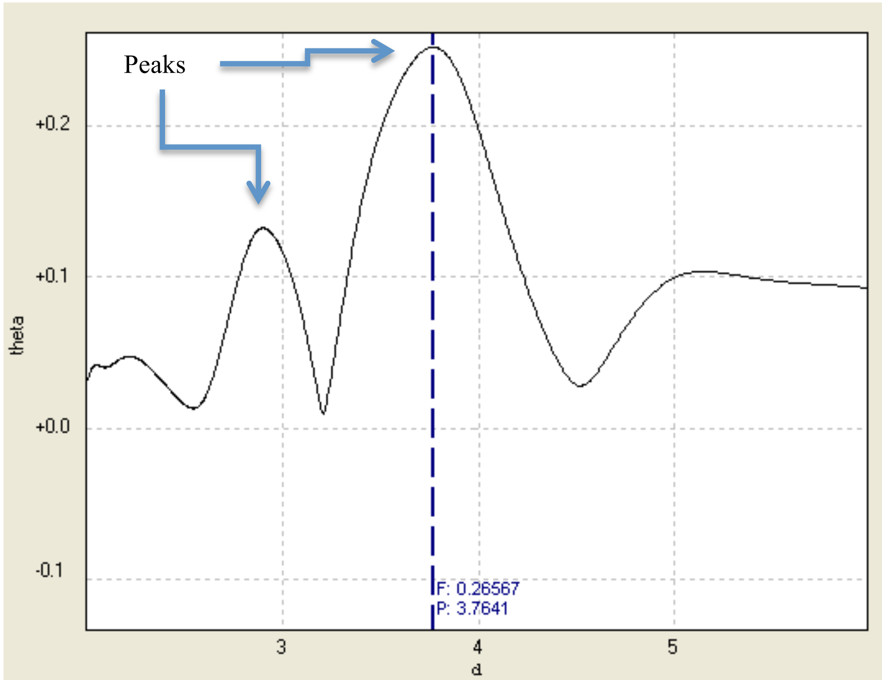


Period Analysis

To find the visually noticeable period of around 4 days, a period analysis using the Bloomfield, Lomb-Scargle and Lafler-Kinman methods is done revealing a common peak at around 3.7 days. In order to decide which method has provided the best results, synchronous summation (folding) of the light curve data reveals a most precise peak at 3.7289.

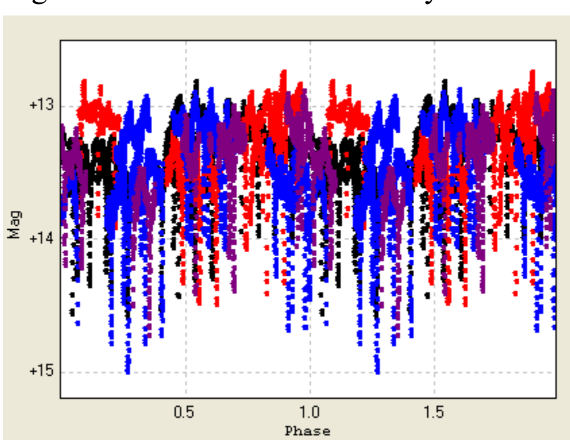
A period analysis with the Bloomfield method reveals a peak at 3.7641 days with a less prominent peak at 2.899 days. By folding the light curves at each of the two peaks, it is revealed that only the period of 3.7641 seems to fit a curve.

A Bloomfield scan of the time-series data from a period of 2-6 days reveals two significant peaks:

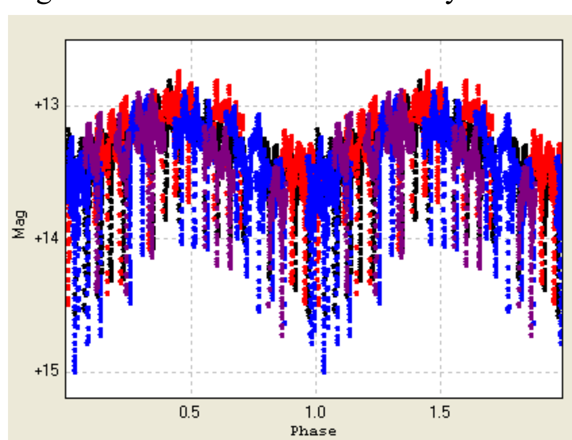


In order to detect if the periodicity is a true feature of the object, synchronous summation of the data is used. Epoch folding, which folds the data over the period as many times as it takes to include all the data, reveals that only the more significant peak of 3.7641 days is a true period of the curve. Shown below are the two folded phase windows.

Light curve folded over 2.899 days:



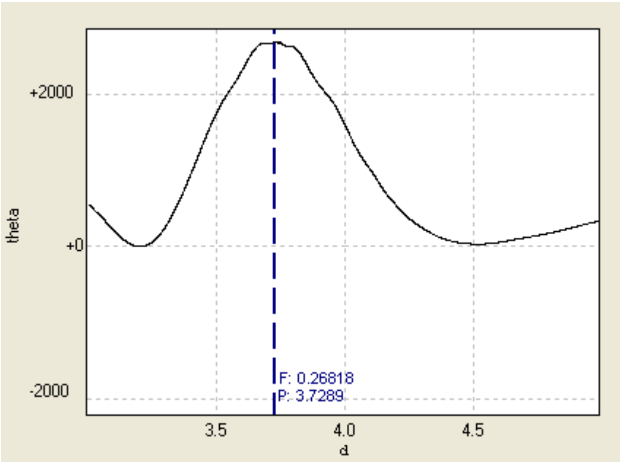
Light curve folded over 3.7641 days:



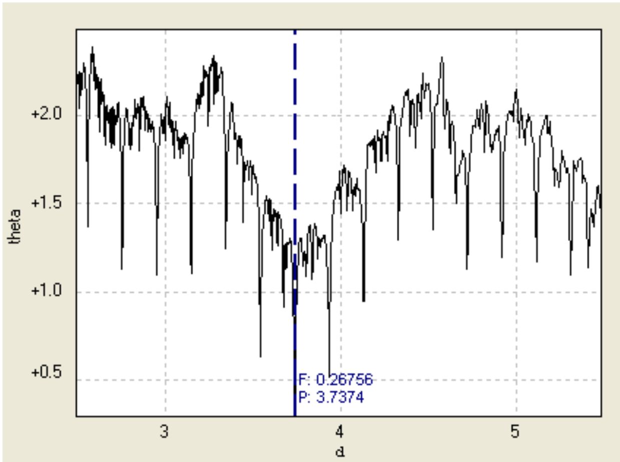
The fold over 2.899 reveals a mess of data with no clear curve, indicating that a curve with a period of 2.899 days does not exist and the peak may be a result of the period-finding algorithm. However, the light curve folded over 3.7641 days displays a clear sinusoidal light curve that fluctuates a little over a half a magnitude, the same curve that can be seen with visual inspection.

Further analysis with the Lomb-Scargle and Lafler-Kinman methods at higher resolutions also reveal peaks at around 3.7 days.

The Lomb-Scargle method shows a peak at 3.7289 days.

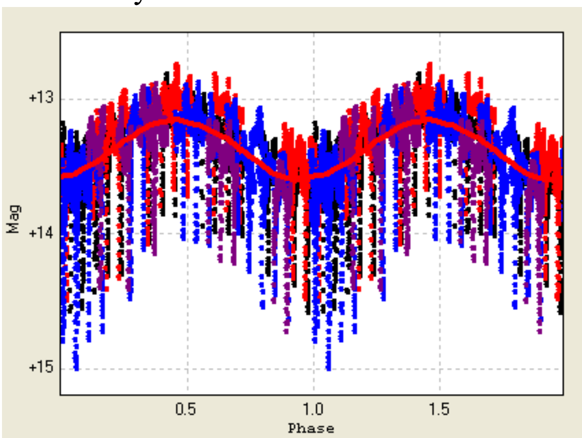


The Lafler-Kinman method displays a periodicity of 3.7374.

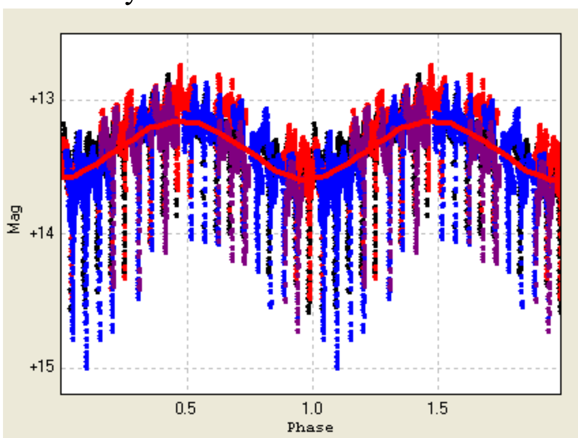


In order to decide which of the three transforms gave the most accurate period, the data is folded over the three different periods and a line of best fit is added for visual comparison.

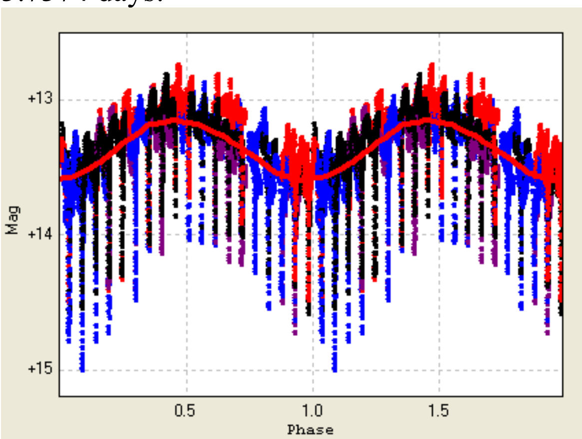
3.7641 days:



3.7289 days:



3.7374 days:

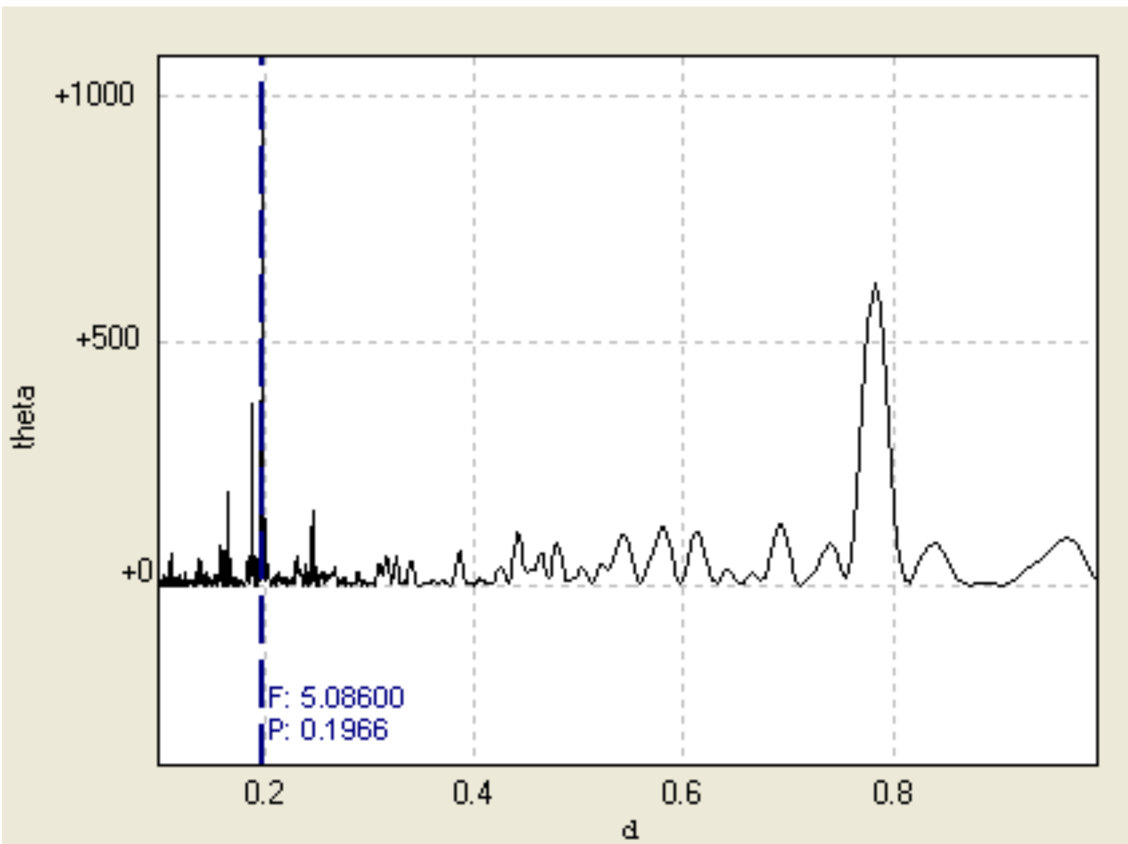


After careful visual analysis it can be noted that the Lafler-Kinman method produced the best result of 3.7374. The variation on either side of the line of best fit is the smallest and the curve has the least noise. Also, the line of best fit is the smoothest of the three and 3.7374 days is the median result. Therefore, a periodicity of 3.74 days is concluded.

Eclipses

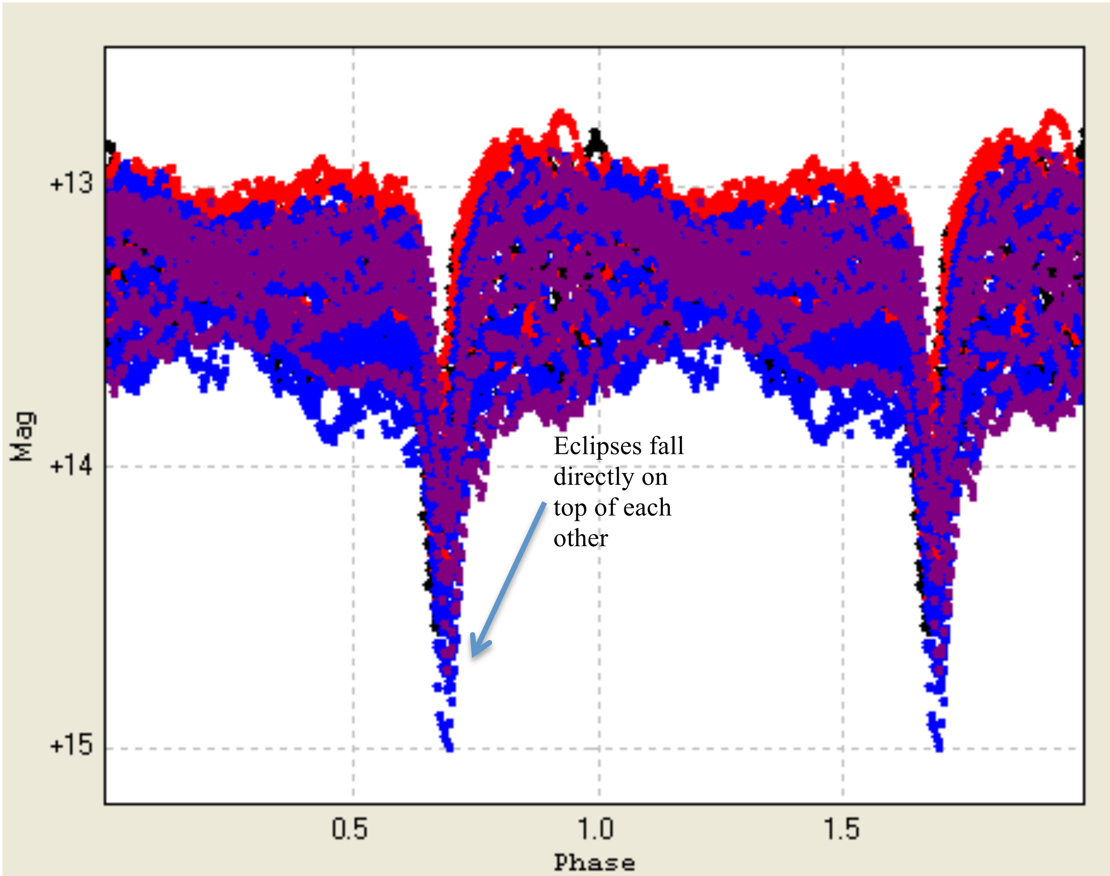
After visual inspection it was concluded that another period exists at around .2 days. This curve is non-sinusoidal and contains large drops and rebounds of a whole magnitude, indicating eclipses, as well as imperfect oscillations of about .25 magnitudes.

In order to determine the exact period, the Lomb-Scargle method, with a resolution of 1000 and scanning from .1 to 1, is used producing a peak of around .1966 days. A second smaller peak is also displayed at .78186 days.

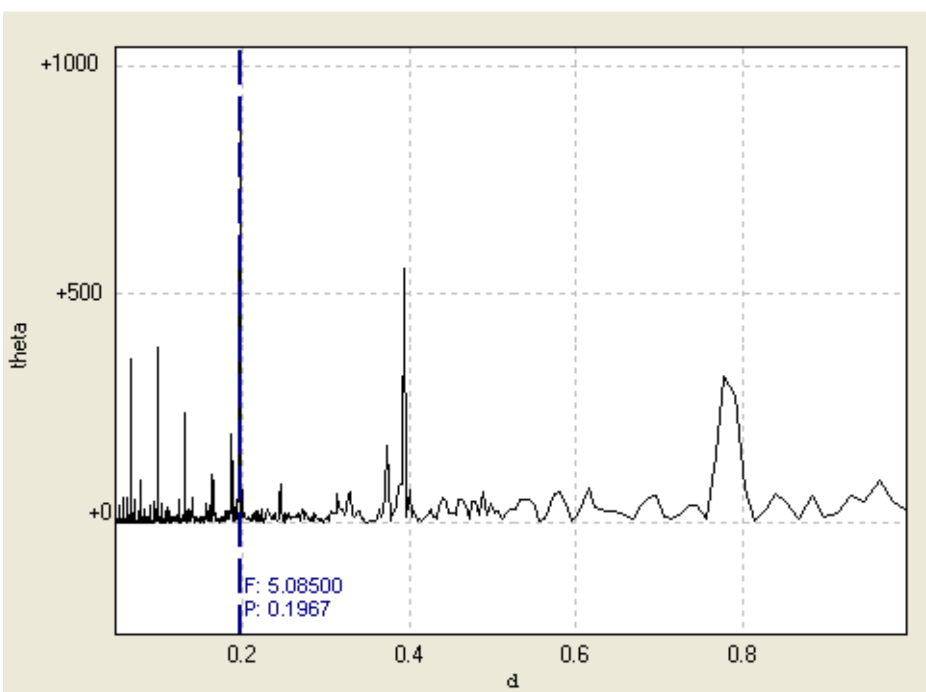


Folding at .1966 days causes all of the eclipses to fall on top of each other signifying they have said period of .1966 days. In other words, the eclipses occur at a frequency of 5.086 cycles/day. The smaller oscillations cannot be seen in the folded light curve since the larger period of 3.7374 causes the smaller oscillations to move more up and down in magnitude than they themselves do. Folding over the period around .8 reveals no apparent curve or pattern.

The phase window for light curve folded over .1966 days is shown:

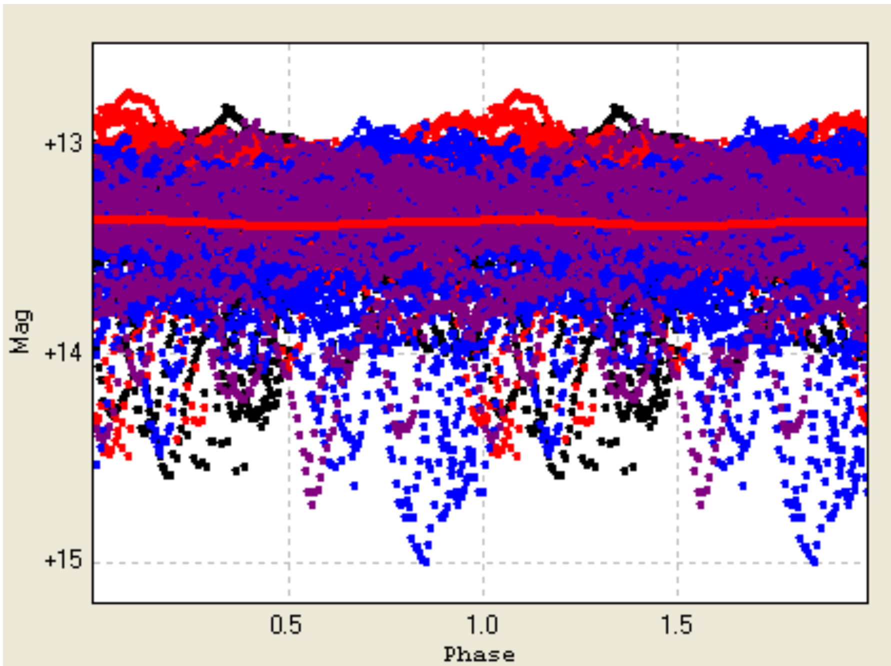


In order to further confirm the results an ANOVA (Analysis of Variance) analysis is performed revealing the same prominent period at .1967 days.



Other peaks are now found at around .4 and .1 and .06. However, when the data is folded over each of these periods, and a line of best fit is found, the result shows they do not represent an actual period.

Folded curves of the other peaks display phase windows much like this, where no discernable curve is found:

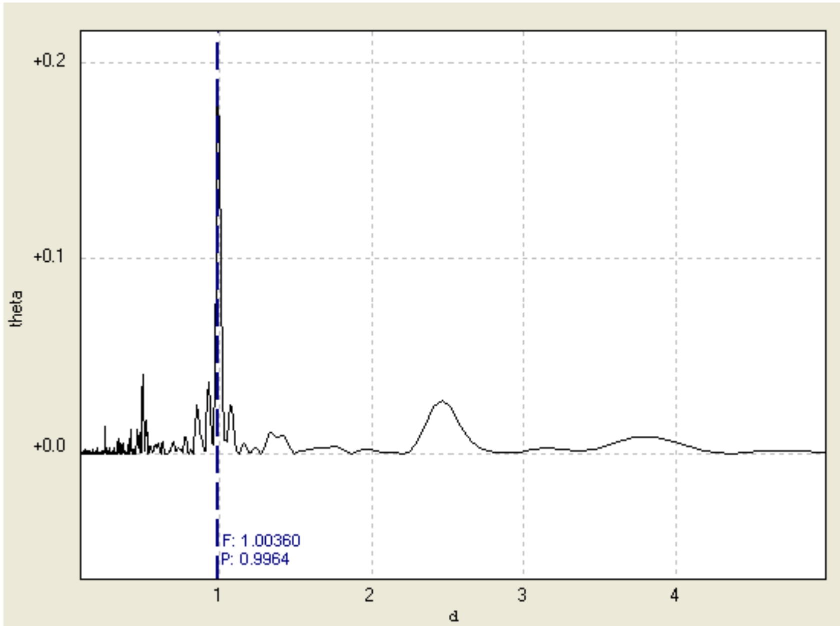


Aliasing

Due to the earth's rotation, and the fact that an object cannot always be observed for 24 consecutive hours, counting of cycles can be ambiguous because there is no data on the number of cycles that were missed while the object was not being observed. These gaps in the data often result in an uncertainty of plus or minus one cycle per day as well as additional peaks in the period-finding algorithms. However, this data was taken over 20.2 days allowing many cycles covered by dense observations and minimal gaps, so the signals that are detected should be fairly accurate and certain. Another side effect of period-finding algorithms is detected periods at harmonics of the real periods, odd combinations of both periods, and signals at one day since gaps will appear daily due to the earth's rotation.

In order, to make sure the two periods that have been found are not results of sampling rate, a spectral window was created, scanning from .1 to 5, revealing aliases at .9964 days, which can be prescribed to rotation, .4992 days, 2.4643 days and .2492 days, which may be the result of the uncertainty of the eclipses. We found the eclipses to have frequency of 5.08 cycles per day and an eclipse every .2492 days would give a frequency of 4.013 cycles per day. Since none of these aliases are the periods that have been found, neither period is the result of aliasing.

Spectral Window:



Conclusion

Two periodicities were observed for the cataclysmic nova-like binary star system. The system has been prescribed as nova-like by other scientific literature since its spectrum and rapid oscillations of around .1 cycles per day closely resembles a dwarf nova in eruption. However, the star is peculiar since it has appeared to be in the state of eruption as long as it has been observed – and thus may not be undergoing a nova at all. Its light curve indicates the presence of a hot spot on one of the members of the pair. A hot spot occurs when the two stars are close enough, and one is dense enough to pull mass from the other into an accretion ring around itself. A disk forms due to the fact that both bodies rotate on their own axis and around each other. The hot spot is a spot on the accretion disk where its gas touches down onto the denser star, typically a white dwarf, and ignites releasing large amounts of energy as radiation, and much of the stars brightness. Thus, it can be deduced that the cycle over 3.74 days and may have to do with a retrograde nodal precession of the accretion disk around the white dwarf component, since the curve is perfectly sinusoidal. As the hot spot on the accretion disk becomes steadily more and then less visible as the disk wobbles in front of it and behind it during its precession, the light output will gently become stronger and then weaker.

The second periodicity describes the frequency of the eclipses. The quick drops and rebounds of about one magnitude appear to occur every .196 days, or 5.09 times per day. These drops occur when, from the perspective of earth, one star passes in front of the other and its accretion disk. Since the accretion disk and its hot spot is where most of the light from the system comes from, and the system is seen almost edge-on from earth, the drops in magnitude are quite large compared to the overall magnitude of the system because the star will pass almost right in front of the accretion disk and block a substantial portion of its light. Such a quick period is not normal among binary systems and indicates that either the stars rotate around each other at an extremely high speed, are very close together or some combination of the two.

Comparison to Previous Campaign

A much longer photometric time-series was taken in 2015 and analyzed by the Center for Backyard Astrophysics (CBA), which came across periodicities at .1967 and 3.68. The period of the eclipses in this paper and the CBA research match, however the period found of 3.74 is not quite the same as 3.68. This discrepancy of .06 may be due the fact that the data set analyzed in this report is limited compared to the set the CBA used. With longer time baselines, determining periods becomes more accurate as more cycles are observed and there is more certainty in the counting of cycles. However, since any discrepancies between findings are very slight, it can be concluded that these findings sufficiently back up previous research on this star system.

Literature Cited

de Miguel, E., et al. 2016, MNRAS, 457, 1447.

Johnson, H.L., Perkins, B., & Hiltner, W.A. 1954, ApJS, 1, 91.

UX Ursae Majoris. 2010, April 13. Retrieved October 30, 2016, from American Association of Variable Star Observers, https://www.aavso.org/vsots_uxuma

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