ANALYSIS OF A NEWLY IDENTIFIED VARIABLE STAR IN AQUARIUS

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Abstract

This experiment was designed to plot the light curves of four variable star candidates of an intermediary magnitude range in order to determine if any were variables, and if so, what type(s). Research was done using two 24" telescopes, located at Mt. Wilson and Table Mountain. One star (R. A. $21^{h}43^{m}54.205^{s}$, Decl. -00° 13' 40.12" (2000) was found to be variable, and the data indicate it is a W Ursae Majoris-type eclipsing binary.

1. Introduction

This report is the outcome of an experiment begun in August, 1999, to trace the magnitudes and plot the light curves of variable star candidates of an intermediary magnitude range, in order to determine if any were variable stars, and if so, what type(s). To choose variable star candidates for research, I downloaded a file from Arne Henden's FASTT1 list on the United States Naval Observatory (USNO) FTP site that contained approximately 1,600 suspected variables (Henden 1999). I selected four variable star candidates (star numbers O18030273, O28031312, O33020146, and O33040049 on Henden's list) near the celestial equator whose characteristics were unknown, and I observed them over a period of four months. Once I proved a variable existed, I narrowed my research to that star and then analyzed the data to determine what type of variable it was.

2. Previous work on the four suspected variable stars

Before my research was conducted, the four suspected variables had been placed in the *USNO-SA2.0 Catalog* (Monet *et al.* 1996) and had been assigned an average red and blue magnitude; this was the only information that had been collected on them up to then. While all four stars did show evidence of variable status, I chose to continue study on the star with the shortest period only in order to obtain a more pronounced light curve. I named this star VAR N for ease of reference. Tables 1 through 4 give the coordinates of each suspected variable and its respective reference stars, labeled A through C (epoch 2000.0); magnitudes from Koehn (1999).

The position of VAR N in Aquarius can be seen on the star chart in Figure 1.

3. Methods and observations

The Telescopes in Education (TIE—a Mount Wilson Institute/Jet Propulsion Laboratory (JPL) project supported by NASA) 24" Telescope Observatory at Mount Wilson and the JPL 24" Telescope Observatory at Table Mountain were used to gather data. CCD photometry was carried out using an SBIG ST-6 CCD installed on the TIE telescope and an S-200 1.2-K CCD installed on the Table Mountain telescope. The CCD at TIE was cooled thermoelectrically while the CCD at Table Mountain was cooled cryogenically by liquid nitrogen. All exposures were taken through a standard red filter and each session was concluded by taking three to five dark frames, flat fields, and bias images to maximize image clarity during photometry.

Table 1. Data for suspected variable N (O18030273)

Name	Right Ascension (2000) hr mn sec	Declination (2000) deg mn sec	Magnitude (Koehn 1999) Red	Blue
Suspected variable N	21 43 54.205	-00 13 40.12	13.4	14.8
Reference star A	21 43 49.490	-00 11 19.26	13.4	14.7
Reference star B	21 44 05.474	-00 16 05.09	13.5	14.4
Reference star C	21 44 17.246	-00 14 54.53	13.4	14.4

Table 2. Data for suspected variable O (O28031312)

Name	Right Ascension (2000) hr mn sec	Declination (2000) deg mn sec	Magnitude (Koehn 1999) Red	Blue
Suspected variable O	21 46 10.061	-01 06 46.00	11.5	13.5
Reference star A	21 46 00.713	-01 09 57.86	13.0	14.0
Reference star B	21 46 29.576	-01 10 13.22	13.4	14.5

Table 3. Data for suspected variable P (O33020146)

Name	Right Ascension (2000) hr mn sec	Declination (2000) deg mn sec	Magnitude (Koehn 1999) Red	Blue
Suspected variable P	21 40 12.731	-01 22 48.68	14.0	14.4
Reference star A	21 40 01.678	-01 21 31.34	13.8	15.5
Reference star B	21 39 59.087	-01 24 19.83	14.0	14.9
Reference star C	21 40 05.909	-01 27 48.78	13.5	14.3

Table 4. Data for suspected variable Q (O33040049)

Name	Right Ascension (2000) hr mn sec	Declination (2000) deg mn sec	Magnitude (Koehn 1999) Red	Blue
Suspected variable Q	21 46 48.007	-01 32 44.74	12.6	12.9
Reference star A	21 46 37.575	-01 29 30.43	10.9	12.3
Reference star B	21 46 31.116	-01 35 15.42	12.7	13.8
Reference star C	21 46 25.447	-01 36 51.68	10.8	12.4

4. Data analysis

I calculated the magnitude of VAR N in each image and plotted it against the Julian time at which it was exposed, deriving a light curve. Table 5 contains the data used to plot the light curves for VAR N shown in Figures 2 and 3.

After graphing the first light curve (see Figure 2), I observed a noticeable bulge at the bottom of the minimum in the sinusoidal curve. Upon closer inspection, it appeared that there were two minima graphed into the same minimum—the first minimum seemed to reach its nadir five hundredths of a magnitude brighter than the second. To test this theory, I doubled the period of the curve, to 0.3063 day, to see

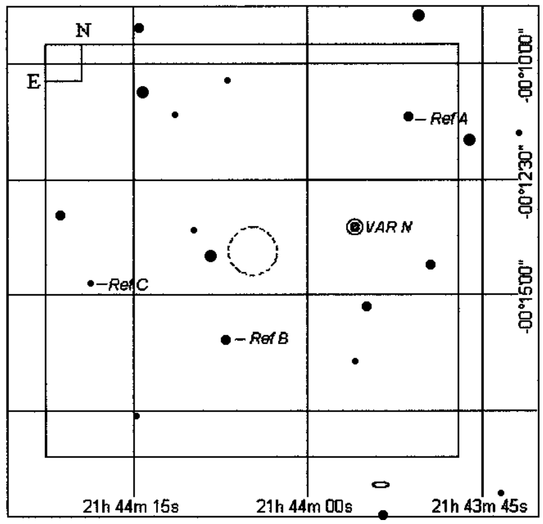

Figure 1. Star field for suspected variable N (VAR N in figure). REF stands for reference star, followed by the star's designation: A, B, or C.

if the two minima could be separated from each other in the resulting curve (see Figure 3). Although there were not enough data points to fill in the curve from phase 0.6 to 0.7, the necessary information to make an educated guess as to the variable's type was present. On the new light curve, there could be seen two distinct minima separated by half a cycle; this indicated that the actual period was 0.3063 day. I determined that between the primary (deeper) and secondary minimum there was a magnitude difference of 0.04, while the magnitudes of the variable at each maximum were equal.

This light curve suggested a contact binary system—due to its very short period—with two stars of roughly the same magnitude. With the help of my mentors, I learned that this eclipsing binary (EB) had properties very similar to a W Ursae Majoris (W UMa) EB. In the process of looking for a match, I found the light curve of the W UMa-type system RZ Tauri and saw that the curve and period were almost identical to mine. Like my variable, RZ Tau had a short period of seven to eight hours; my variable had a period of 0.3063 day, while RZ Tauri had a period of 0.362 day (Djurasevic *et al.* 1999). The light curves were also very similar, as may be observed in Figures 3, my light curve, and 4, from Djurasevic *et al.* 1999. My light curve has a difference of 0.04 magnitude between the first and second minima; the RZ Tauri magnitude difference between minima is 0.05. The similarity between these two variables show a considerable possibility that VAR N is indeed a W UMa-type binary system.

I propose an explanation for VAR N's slight difference in magnitude at the two minima, based on the assumption that one star is hotter and slightly larger than the other and the fact that the area covered is the same in each eclipse. The very short period (0.3063 day) implies a contact system with mass transfer. One star's surface is slightly cooler, and fainter than the other. When the two stars are side by side as seen from the Earth (Figure 5, Position 1 and Figure 3, phase 0.2–0.3), the variable is at maximum brightness. As time passes, the slightly cooler and smaller star moves in front of its cousin (Figure 5, Position 2 and Figure 3, phase 0.3–0.5) and finally eclipses the brighter, hotter star (Figure 5, Position 3 and Figure 3, phase 0.5). This is the deeper minimum because the surface brightness of the eclipsed star is greater

Table 5. Table of magnitudes and times for VAR N as graphed in Figures 2 and 3.

Julian Day 2450000+	*R*	*Regular Phase*	*Julian Day 2450000+*	*R*	*Regular Phase*
1475.6504	13.52	0.2551	1475.7943	13.59	-0.2147
1475.6535	13.47	0.2450	1475.7969	13.54	-0.2232
1475.6562	13.58	0.2362	1475.7993	13.53	-0.2310
1475.6593	13.51	0.2261	1475.8018	13.55	-0.2391
1475.6619	13.53	0.2176	1475.8043	13.53	-0.2473
1475.6646	13.54	0.2088	1476.6259	13.83	0.5704
1475.6672	13.62	0.2003	1476.6292	13.84	0.5596
1475.6698	13.55	0.1918	1476.6319	13.92	0.5508
1475.6723	13.59	0.1836	1476.6346	13.98	0.5420
1475.6748	13.59	0.1755	1476.6372	14.02	0.5335
1475.6775	13.61	0.1667	1476.6397	14.06	0.5253
1475.6806	13.61	0.1566	1476.6427	14.10	0.5155
1475.6832	13.61	0.1481	1476.6454	14.11	0.5067
1475.6857	13.69	0.1399	1476.6482	14.14	0.4976
1475.6885	13.65	0.1308	1476.6508	14.13	0.4891
1475.6910	13.64	0.1226	1476.6534	14.10	0.4806
1475.6936	13.53	0.1141	1476.6561	14.12	0.4718
1475.6973	13.71	0.1020	1476.6586	14.04	0.4636
1475.6998	13.73	0.0939	1476.6610	13.99	0.4558
1475.7023	13.78	0.0857	1476.6635	13.93	0.4476
1475.7048	13.74	0.0775	1476.6661	13.86	0.4391
1475.7075	13.86	0.0687	1476.6686	13.88	0.4310
1475.7100	13.89	0.0606	1476.6711	13.83	0.4228
1475.7126	13.93	0.0521	1476.6736	13.83	0.4146
1475.7151	13.97	0.0439	1476.6773	13.76	0.4026
1475.7176	14.03	0.0358	1476.6798	13.73	0.3944
1475.7201	14.08	0.0276	1476.6823	13.73	0.3862
1475.7230	14.04	0.0181	1476.6847	13.69	0.3784
1475.7255	14.07	0.0100	1476.6993	13.59	0.3307
1475.7281	14.11	0.0015	1476.7018	13.59	0.3226
1475.7356	14.07	-0.0230	1476.7045	13.59	0.3137
1475.7382	14.01	-0.0315	1476.7067	13.58	0.3066
1475.7407	13.96	-0.0397	1476.7095	13.57	0.2974
1475.7433	13.93	-0.0482	1476.7122	13.57	0.2886
1475.7458	13.87	-0.0563	1476.7147	13.55	0.2804
1475.7511	13.80	-0.0736	1476.7172	13.57	0.2723
1475.7536	13.72	-0.0818	1476.7197	13.53	0.2641
1475.7585	13.70	-0.0978	1476.7227	13.57	0.2543
1475.7686	13.63	-0.1308	1476.7254	13.55	0.2455
1475.7711	13.60	-0.1389	1476.7282	13.55	0.2364
1475.7736	13.64	-0.1471	1476.7308	13.56	0.2279
1475.7763	13.60	-0.1559	1476.7333	13.56	0.2197
1475.7788	13.59	-0.1641	1476.7359	13.55	0.2112
1475.7813	13.55	-0.1722	1476.7385	13.53	0.2027
1475.7841	13.58	-0.1814	1476.7411	13.56	0.1943
1475.7865	13.56	-0.1892	1476.7445	13.56	0.1832
1475.7890	13.55	-0.1974	1476.7470	13.57	0.1750
1475.7918	13.64	-0.2065	1476.7495	13.58	0.1668

Table continued on next page

Table 5 (continued). Table of magnitudes and times for VAR N as graphed in Figures 2 and 3.

Julian Day 2450000+	*R*	*Regular Phase*	*Julian Day 2450000+*	*R*	*Regular Phase*
1476.7520	13.58	0.1587	1476.7878	13.91	0.0418
1476.7546	13.59	0.1502	1476.7904	13.94	0.0333
1476.7573	13.62	0.1414	1476.7931	14.00	0.0245
1476.7608	13.63	0.1299	1476.7956	14.03	0.0163
1476.7633	13.65	0.1218	1476.7981	14.07	0.0082
1476.7658	13.66	0.1136	1476.8006	14.07	0.0000
1476.7683	13.68	0.1055	1476.8033	14.07	0.0088
1476.7710	13.67	0.0966	1476.8060	14.05	0.0176
1476.7739	13.72	0.0872	1476.8086	14.01	0.0261
1476.7764	13.76	0.0790	1476.8111	13.98	0.0343
1476.7842	13.84	0.0535	1476.8137	13.93	0.0428

Note: R signifies red magnitude.

while the area-loss is almost identical at the other minimum. If both stars were the same size, this minimum would be even deeper because the cooler star would entirely block the light coming from its hotter cousin. As the motion continues both stars again appear side by side, giving another maximum of the same magnitude. The motion continues as the larger star now moves in front of its cousin and finally passes in front of the cooler star (see Figure 5, Position 7 and Figure 3, phase 1.0). This minimum is shallower than the other.

5. Conclusion

The general appearance of the light curve in Figure 3 suggests an eclipsing binary of W Ursae Majoris type. The small orbital period, 0.3063 day, suggests that there must be two egg-shaped stars in contact with each other. The star eclipsed at the shallower minimum must be slightly cooler than the other.

The current data disprove my original hypothesis that I would find an intrinsic variable with a period of one or two weeks, and are very much in favor of a binary system with a period of only seven hours and twenty-one minutes (0.3063 day). Nevertheless, I cannot form a definite conclusion until further images are taken to measure the color indexes and to see if the light curve changes over a longer period of time.

6. References

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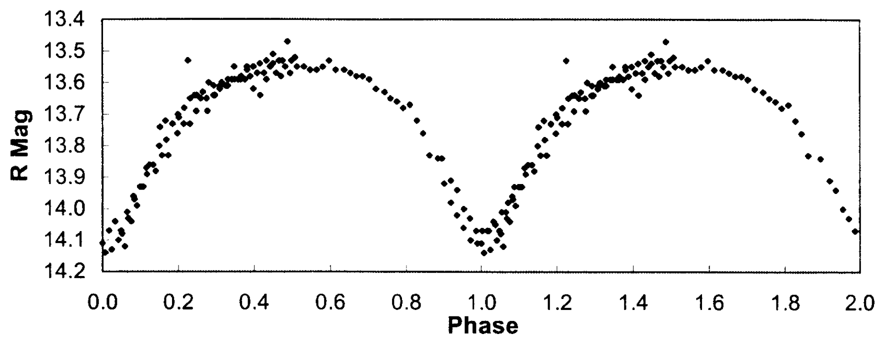

Figure 2. VAR N. Original light curve plotted with period 0.15315 day.

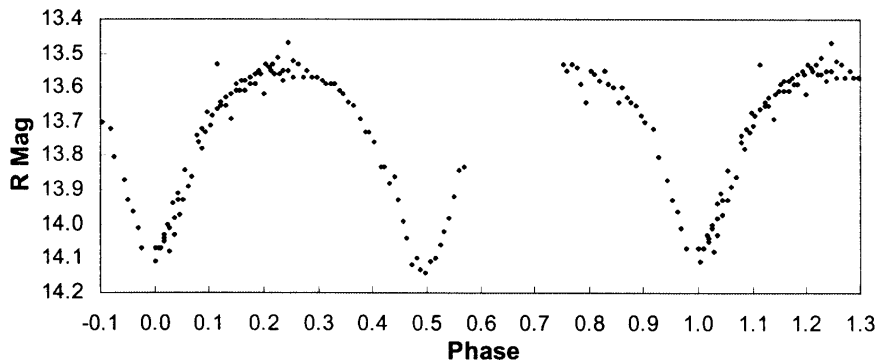

Figure 3. VAR N. Second light curve plotted. Period doubled to 0.3063 day to show different minima.

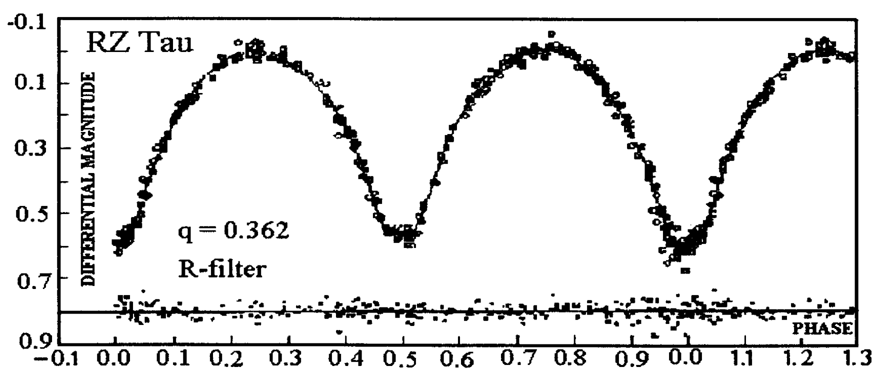

Figure 4. Light curve of RZ Tauri, W UMa eclipsing binary star. Djurasevic *et al.* (1999). Reprinted by permission.

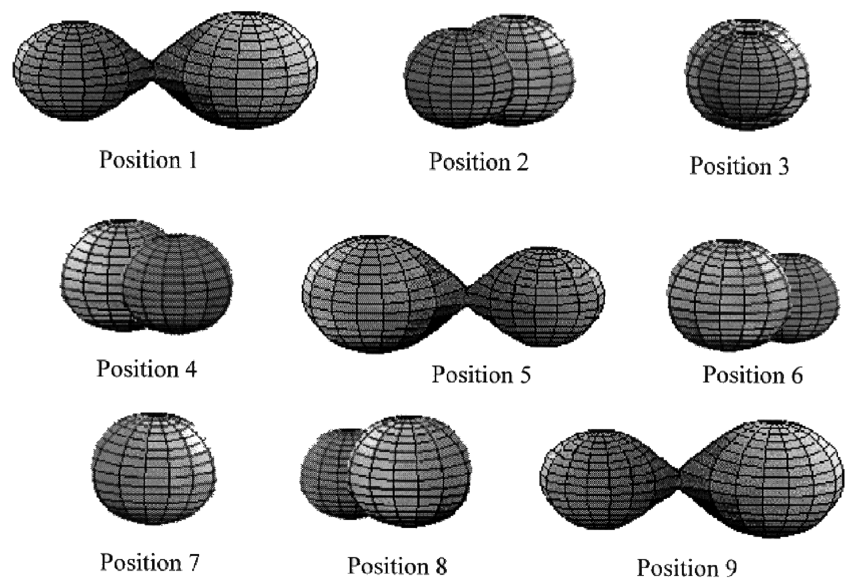

Figure 5. Proposed positions of VAR N, viewed as an eclipsing binary, as each star rotates around its companion. The larger-size sphere represents the hotter star. The brightness of the star is exaggerated to illustrate the concept. *Original graphics courtesy of Dan Bruton, modified by the author.*