Observations of the Suspected Variable Star Ross 114 (NSV 13523)

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Received December 3, 2018; revised January 28, 2019; accepted January 29, 2019

Abstract A study of the suspected variable star Ross 114 (NSV 13523) has been carried out. The star is confirmed to be a variable with an amplitude of about 2.5 magnitudes in B. Photometry and light curves from CCD images and archival photographic plates are presented. The observations show the star is a long period variable with a period of about 296 days.

1. Introduction

This paper reports the results of an educationally oriented research project. Yerkes Observatory, before its recent closing, offered activities for students at many grade levels designed to stimulate interest in science and engineering. As part of Yerkes' McQuown Scholars Program, high school students had the opportunity to work with a mentor on a project related to one of the observatory's professional activities. Projects have included such activities as constructing a scientific instrument, writing a software application, and engaging in astronomical research. The Scholars project reported here was to investigate a star announced as a possible variable in 1926 but still unstudied. Yerkes Observatory's collection of astronomical photographic plates would be used to seek brightness variations. If variability was found, new CCD observations would be obtained as time and equipment permitted in an attempt to determine the type of variability and produce a paper suitable for publication in a scientific journal.

F. Ross of Yerkes Observatory discovered 379 suspected variable stars from a comparison of photographs he took in the 1920s–1930s with plates taken a decade or more earlier by E. E. Barnard. Most of these stars have since been confirmed to be variable, but a few are still unstudied. One of these is Ross 114 (hereafter R114), more commonly known as NSV 13523. It was discovered when Ross noted a 12th magnitude star on a plate he exposed on 1925 November 5 was not visible on a similar plate of the same field taken by Barnard in 1909 (Ross 1926). R114 is located at R.A. = $21^h 05^m 14.0^s$, Dec. = +38° 37' 12" (2000).

Only two papers have dealt with R114 since its discovery, one showing that the 1925 observation was not of an asteroid (Marsden 2007) and another giving magnitudes improved over Ross's estimates (Osborn and Mills 2012). As this project was nearing completion we learned that R114 is among the stars monitored by the All-Sky Automated Survey for Supernovae (ASAS-SN) sky patrol (Shappee *et al.* 2014a, 2014b; Jayasinghe *et al.* 2018). The on-line light curve from those observations indicated large brightness variations with a period of 288.4 d.

2. Observations

Ross's original discovery plates are in the Yerkes plate archive. We were able to locate the two plates and confirmed the variability seen by Ross. We next identified 42 more plates showing the field. Eye estimates were made of the star's B magnitude relative to the comparison sequence shown in Figure 1 and are listed in Table 1, where the comparison B magnitudes are from the photometry of the AAVSO APASS survey (Henden *et al.* 2018). Each plate was estimated at least twice, but R114 was found to be blended with a nearby star (which we denote Star X) on almost all plates. The results of the plate observations are given in Table 2, where magnitudes with an uncertainty over 0.3 magnitude are marked with colons. The photographic observations show a large change in brightness.

After confirming the star's variability, we began obtaining CCD images of R114 field using the Skynet robotic observing system (Smith, Caton, and Hawkins 2016). The telescope employed was the Yerkes 1-m f/8 Cassegrain reflector. Imaging began in 2016 April. Unfortunately, equipment problems prevented CCD observations from June through August. Observations resumed in September and continued through December 2016.

CCD images were obtained on 16 nights, six nights in April and May and the remainder September through December. Multiple images were taken on all nights. A B filter was used to permit comparison with the plate results. However, R114 and Star X are mostly separated on the CCD images (and were individually measured) but are blended on the plates, making direct comparison of the CCD and plate results somewhat incompatible.

Aperture photometry was carried out on the CCD data to obtain B magnitudes using the Skynet AFTERGLOW program and employing the same local comparison stars as used for the plates. Table 3 shows the average magnitude and standard deviation (σ) of the measures for each comparison star, Star X and R114 for the April–May observations, then the September–December ones, and finally all measures. The comparison star results agree well with one another from the different

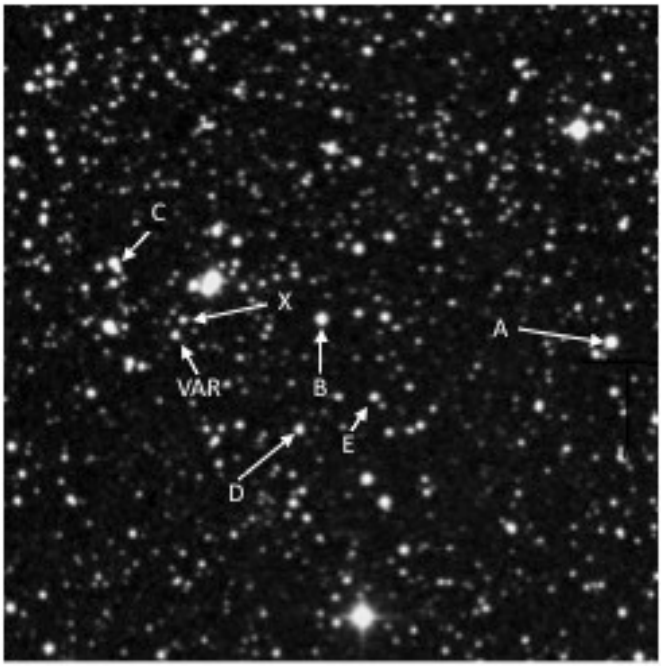

Figure 1. The field of R114 with the variable and comparison stars marked. North is at the top and east to the right.

Table 1. Identifications of comparison stars, Star X and R114.

Name	R. A. (2000) h m s	Dec. (2000) ° ′ ″	B
A	21 04 43.4	+38 37 04	13.75
B	21 05 03.7	+38 37 24	14.03
C	21 05 18.2	+38 38 09	14.52
D	21 05 05.3	+38 35 54	15.71
E	21 05 00.0	+38 36 20	16.33
Star X	21 05 13.4	+38 37 24	16.82
Ross 114	21 05 14.0	+38 37 12	—

Table 2. Magnitudes of R114 from photographic plates.

Plate #	Julian Date	B	Plate #	Julian Date	B
L-33	2412741.79	15.47	6B-548	2418535.64	<14.03
L-83	2413096.78	14.63	6B-551	2418536.64	13.87
10B-103	2416703.75	14.78	10B-629	2418921.75	<14.52
6B-103	2416703.75	<14.52	6B-629	2418921.75	<14.52
10B-274	2417065.90	14.17	10B-700	2419207.70	14.78:
6B-274	2417065.90	14.30	6B-700	2419207.70	15.00
3B-274	2417065.90	14.28	10B-853	2419951.70	15.56
10B-276	2417067.93	14.27	6B-853	2419951.70	<14.52
6B-276	2417067.93	14.31	10B-910	2420387.64	15.31:
3B-276	2417067.93	14.35	6B-910	2420387.64	15.23:
10B-290	2417083.78	14.82	10B-911	2420388.62	14.78:
6B-290	2417083.78	14.82	6B-911	2420388.62	<14.03
6B-291	2417083.78	14.78	10B-1077	2421069.72	16.00
10B-353	2417448.8	<14.03	6B-1077	2421069.72	<14.52
10B-354	2417449.84	<14.52	10B-1822	2423552.80	<13.75
6B-354	2417449.84	<14.52	10R-73	2424460.52	13.85
10B-407	2417768.67	15.82	6R-73	2424460.52	13.83
6B-407	2417768.67	15.93	ILL-2071	2435988.72	<14.03
10B-521.5	2418447.82	15.90	ILL-2063a	2435994.65	<14.03
6B-521.5	2418447.82	15.79:	ILL-2065a	2436009.69	14.10
10B-547	2418534.74	13.86	ILL-2076	2436098.7	14.13:
6B-547	2418534.74	13.94	ILL-E-05	2432189.7	<13.5*

**Yellow magnitude.*

Table 3. Averages and standard deviations of the CCD measures by star.

Star	Apr.–May 2016 Avg. B	σ	Sep.–Dec. 2016 Avg. B	σ	All Observations Avg. B	σ
A	—	—	13.74	0.02	13.74	0.02
B	14.01	0.03	14.00	0.02	14.01	0.03
C	14.56	0.03	14.58	0.02	14.57	0.03
D	15.70	0.03	15.69	0.05	15.70	0.04
E	16.33	0.03	16.31	0.08	16.32	0.06
X	16.85	0.07	16.78	0.12	16.81	0.09
R114	16.63	0.12	15.35	0.73	15.96	0.84

Table 4. CCD photometry measures.

Julian Date Apr.–May 2016	B	Julian Date Sep.–Dec. 2016	B
2457492.886	16.66	2457633.685	14.18
2457492.892	16.55	2457633.686	14.19
2457492.893	16.60	2457636.703	14.09
2457516.818	16.72	2457636.704	14.09
2457516.821	16.61	2457680.583	14.99
2457516.823	16.69	2457680.585	15.03
2457524.767	16.86	2457683.588	15.07
2457524.780	16.65	2457683.590	15.09
2457524.787	16.63	2457696.635	15.55
2457528.769	16.58	2457696.636	15.57
2457528.770	16.40	2457702.650	15.70
2457528.771	16.50	2457702.651	15.69
2457532.769	16.89:	2457705.659	15.65
2457532.771	16.73:	2457705.660	15.68
2457532.771	16.62:	2457709.578	15.82
2457538.744	16.60	2457709.579	15.85
2457538.745	16.55	2457729.540	16.13
2457538.746	16.59	2457729.541	16.11
		2457736.519	16.35
		2457736.521	16.24

observing periods. The observational scatters (σ) are relatively small and provide indicators of the errors of our CCD observations at different magnitude levels. The CCD observations of R114 are given in Table 4, where the observations made in April–May 2016 are listed in the first column and those made September–December 2016 are in the second column.

3. Analysis

The light curve of R114 from the CCD observations is shown in Figure 2. The derived magnitudes in 2016 April–May fluctuate around 16.6. Although the fluctuations vary over about 0.5 magnitude, we believe that they are not real, due to the faintness of the star during this period and the effect on some measures of the nearby companion, Star X. When CCD observations resumed in the fall of 2016 R114 was found to be much brighter. In September, the variable was about B = 14, after which it decreased in brightness by more than two magnitudes over a three-month period. Visual comparison of R114 to its nearby companion, Star X, on the images easily confirmed the large change in brightness between April–May and September and the subsequent autumn decline. Figure 2 also shows the light curve of Star X; its brightness remained constant within the errors of the observations. The approximate two-magnitude drop of R114 from September to December demonstrates it is a fairly large amplitude variable, as found by ASAS-SN.

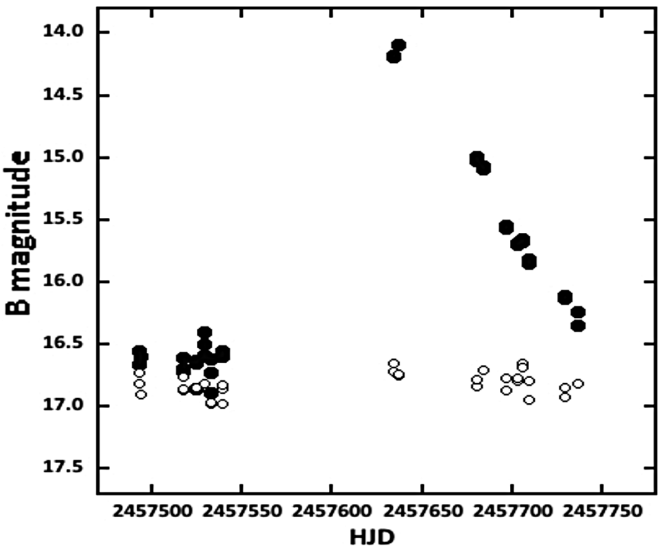

Figure 2. CCD-measured magnitudes of Ross 114 (solid circles) and of its close companion, Star X (open circles).

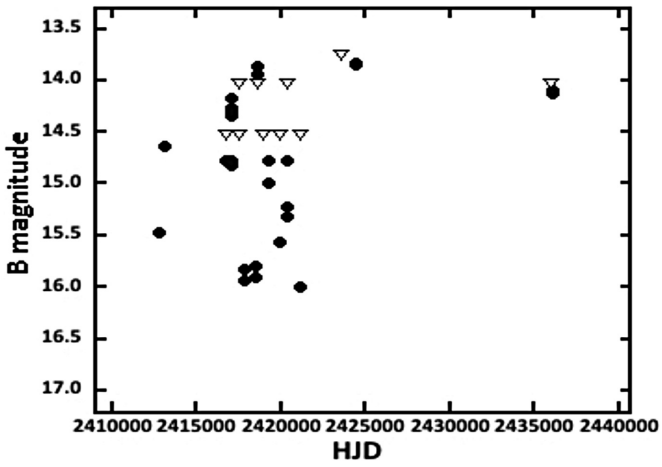

Figure 3. Magnitudes from eye estimates of the brightness of R114 on photographic plates. The dots show derived magnitudes from plates where the star was visible. The down-triangles show the magnitude below which the star's brightness must be for those cases when it was below the plate limit.

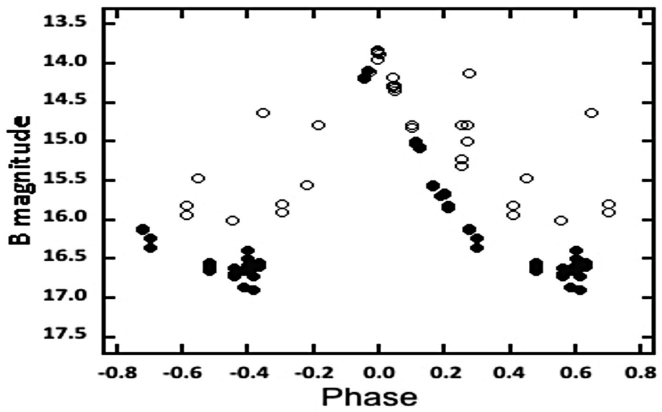

Figure 4. The combined phase plot of the CCD observations (filled circles) and photographic ones (open circles) with a period of 296.3 d.

The light curve from the plate observations is shown in Figure 3. The estimated magnitudes varied from as bright as B = 13.8 to as faint as about 16. Because many of the plates were taken simultaneously in pairs using co-mounted 10- and 6-inch telescopes (with corresponding plate numbers), we were able to confirm that the large magnitude differences on different dates were not due to plate defects. In general, the magnitudes from contemporaneous plates agreed within 0.12 of a magnitude, with the greatest discrepancy being 0.32 magnitude. The approximate two-magnitude variation shown by the plates is in agreement with the CCD results. The mid-magnitude was about B = 15, although this includes the light of both Star X and the variable.

The CCD observations suggested a period of 270 d or more. A period search of the plate data in the range 200–340 d using the AAVSO VSTAR tool (Benn 2012) yielded periodicities near 238 d and 297 d. The ASAS-SN observations cover three maxima that occur near HJD 2457340, 2457650, and 2457940, giving an average cycle time that varies slightly about 300 d and thus ruling out our shorter possibility.

Phased light curves with the combined photographic and CCD data using periods in the range 286–305 d showed no period fits all the data well, likely because the light variations are not strictly periodic. The best fit seemed to be with P = 296.3 d, and the phased light curve with this period using a modern reference epoch of 2457944.0 is shown in Figure 4. The CCD and photographic maximum are consistent, while the effect on the brightness of R114 from Star X is obvious for the photographic minimum. This ephemeris also fits the three ASAS-SN maxima, which occur at phases −0.04, +0.01, and 0.00.

4. Conclusions

Recent CCD observations and archival photographic plates both show that NSV 13523 = R114 varies over a fairly large range as found by the ASAS-SN survey. Our CCD photometry showed a range from B = 14.1 to 16.7. The magnitude estimates from plates are consistent, ranging from about 14 to 16 for the combined light of R114 and Star X. An ephemeris based on our observations and ASAS-SN times of maxima is: HJD (Max) = 2457944.0 + 296.3 E.

Finally, we offer the following comments on the educational aspects of this project. The lead author undertook this research as part of Yerkes Observatory's McQuown Scholars program for high school students. He feels a research project such this one can be of tremendous value for a student exploring an interest in astronomy. The opportunity to work one-on-one with a professional astronomer and to learn about and see first hand the need to collect and analyze data over an extended period of time as well as the effort that goes into writing and publishing a scientific paper clearly showed the nature of astronomical work. It was incredibly satisfying at the end to find our plate and CCD variations were in agreement. Being able to obtain CCD observations during the time period that was lost (2016 June–August) would have greatly helped in determining the light curve and its period, but this unexpected problem probably also illustrated a feature of observational astronomy work.

Overall, he sees this project as certainly one of the most valuable experiences he had in high school.

5. Acknowledgements

We express our appreciation to the anonymous referee for comments that led to a significant improvement in the paper. The lead author also thanks Yerkes Observatory for use of its resources and its McQuown Scholars Program for high school students without which this project would have been impossible. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France, the Skynet Robotic Telescope Network, and the AAVSO Photometric All-Sky Survey (APASS), funded by the Robert Martin Ayers Sciences Fund and NSF Grant AST-1412587.

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