The Photometric Period of V1391 Cassiopeiae (Nova Cas 2020)

Richard E. Schmidt
Burleith Observatory, 1810 35th Street NW, Washington, DC 20007; schmidt.rich@gmail.com

Received December 27, 2020; revised February 6, 2021; accepted February 17, 2021

Abstract A photometric study of Nova Cassiopeiae 2020 has been undertaken at the urban Burleith Observatory in Washington, DC, where 7,504 CCD observations were obtained over a time span of 100.16 days. A photometric period was obtained: 3.8036 ± 0.0005 h, epoch (HJD) of maximum light 2459082.59223, with amplitude 0.011 magnitude (Cousins I).

1. Introduction

V1391 Cassiopeiae (Nova Cas 2020, TCP J00114297+6611190), R.A. = $00^h11^m42.96^s$, Dec. = +66°11' 20.8" (2000), was discovered on 2020 July 27.9302 by Korotkiy and Sokolovsky (2020) at Ka-Dar Observatory, Nizhny Arkhyz, Russia. Its classification as a classical Fe II nova was made by Sokolovsky *et al.* (2020). Newly discovered novae make excellent high-cadence photometry candidates for bright-sky urban observatories. Fe II novae are typically slow declining, thus remaining in reach of small telescopes for extended periods. Amplitudes of variation are typically below 0.03 magnitude, but periods average less than 0.2 d; small observatories that are able to devote many hours acquiring sufficient images can detect such periodicity, which remains stable for many months or years. For a recent compendium of nova light curve properties see Özdönmez *et al.* (2018). Most novae lie at low galactic latitudes, and their red excess is optimal for near-infrared observations in a band such as Cousins I, which is dark under city lights. V1391 Cas represents the third recent nova for which a photometric period has been found at Burleith Observatory (Schmidt 2020a, 2020b). A fourth, Nova Per 2020, is the subject of a forthcoming paper (Schmidt 2021). A preliminary photometric period of V1391 Cas was reported to the Central Bureau for Astronomical Telegrams on 23 September 2020 (Schmidt 2020c).

2. Observations

At Burleith Observatory, Washington, DC, CCD observations were obtained with a 0.32-m PlaneWave CDK and SBIG STL-1001E CCD camera with an Astrodon Cousins Ic filter. Pixel size was 1.945 arc-seconds, yielding on average 2-pixel FWHM. Exposure times ranged from 30 to 120 seconds.

3. Reductions

Synthetic aperture photometry was performed using C-Munipack 2.1.29 (Motl 2020), with an aperture of radius 3.8 pixels. Observation times had heliocentric corrections applied. Comparison stars were selected to avoid CCD saturation.

Cousins I-band differential ensemble photometry was performed using the comparison stars in Table 1 and shown in Figure 1, from AAVSO chart sequence X25582CLS (C = comparison, K = check, Label = chart label). Nightly checks were made to rule out variability of the comparison stars.

Nightly means of observing sessions are shown in Figure 2. Example nightly observations are shown in Figures 3a–3f. The circumpolar declination of V1391 Cas enabled sessions as long as 7.2 h, as seen on 14 Oct. 2020 (Figure 3d). Table 2 lists nightly mean times (HJD – 2450000), observed mean magnitude Ic, and mean error of the magnitudes. These data are shown in Figure 2.

4. Analysis

Prior to Fourier analysis, each nightly observation set was pre-processed by subtracting nightly means and removing linear trends. Period analysis was performed using Peranso 2.60 software (Paunzen and Vanmunster 2016), applying several period analysis techniques, including the phase-folding Jurkewich method (Figure 4), two Analysis of Variance methods, the Date-Compensated Discrete Fourier Transform (DCDFT) method, and the Fourier/least-squares Lomb-Scargle method. Initial analyses use a wide spectral search of 0–10 d before refining in a smaller window such as that shown in Figure 4.

Fourier periodic analysis of variable star photometry often presents present challenges in interpretation of results. Weather conditions, daylight, and limited periods of observation create gaps in the time series. The need to observe at nearly the same time each night produces aliases in the resulting Fourier spectrum. The inherent assumption that the light curve of a variable star can be reasonably fit to a series of sine functions is only approximately true. The results reported here came from the Lomb-Scargle method, which was chosen for its use of Fourier spectral analysis combined with least-squares fitting. It is among the most familiar methods in astronomical use (VanderPlas 2018). This yielded an observed period of p = 0.158482 d (6.3101 c/d), as seen in the lower part of Figure 5. The period found by the DCDFT method differed from that from the Lomb-Scargle method by only +0.000005 d.

To test the reliability of the Lomb-Scargle method under our observing constraints, it was applied to a synthetic light curve generated from the simple sinusoid:

$$y_i = a * \sin(2\pi / p * (x_i - x_0)) + \varepsilon_i$$

using our observed amplitude a = 0.011 and period p = 0.158487 d. Values for y_i were computed using for each x_i, the times of our CCD observations, with x_0 being the first of these. Gaussian errors ε_i, scaled by each observed magnitude's error, were added at each point. This gives us synthetic data with a known period, but with all of the temporal gaps of our actual observation set. Using Peranso software, we obtain the resulting Lomb-Scargle

Table 1. Photometry comparison stars.

AUID	R. A. (2000) h m s	Dec. (2000) ° ′ ″	C/K	Label	Ic	Mag Err
000-BNP-452	00 12 58.25	+66 04 49.5	C	112	10.503	(0.242)
000-BNP-453	00 10 49.30	+66 06 24.0	C	126	11.207	(0.052)
000-BNP-455	00 11 32.60	+66 03 06.1	K	137	12.586	(0.053)

Table 2. Nightly mean magnitudes I_c

HJD	mag Ic	err	HJD	mag Ic	err
9070.75613*	8.905	0.002	9136.58565	9.563	0.002
9072.64919*	8.744	0.003	9137.52403	9.683	0.002
9080.48809*	9.655	0.002	9140.60407	9.903	0.002
9082.59589	9.509	0.004	9145.54884	10.423	0.003
9086.61026	9.578	0.006	9156.56631	10.492	0.003
9091.46495	9.799	0.002	9158.46183	10.316	0.003
9092.52855	10.089	0.003	9158.58060	10.316	0.002
9098.62223	10.085	0.005	9160.58690	9.706	0.003
9099.60930	10.342	0.003	9161.73181	9.515	0.003
9100.58408	10.503	0.004	9162.58105	9.513	0.003
9105.61944	9.440	0.004	9163.57182	9.543	0.003
9106.58591	9.540	0.002	9164.58537	9.398	0.003
9111.65805	9.929	0.003	9167.57344	9.890	0.003
9112.60118	10.020	0.003	9168.55022	10.243	0.003
9113.57928	10.140	0.003	9170.56898	10.769	0.003
9114.59360	10.239	0.003	9172.56174	10.932	0.003
9115.57977	10.213	0.003	9174.56764	10.727	0.002
9123.57543	10.065	0.004	9180.55862	11.170	0.003
9125.58597	9.885	0.003	9182.58765	10.752	0.003
9126.61275	10.007	0.003	9191.64513*	11.388	0.004
9129.59152	10.262	0.003	9193.91493*	12.322	0.008
9131.57959	10.019	0.003			

* *Not used.*

Table 3. Summary of the resulting period information.

Period (h)	3.803568 (0.001537)
Period (d)	0.158482 (0.000067)
Frequency (c/d)	6.3098667 (0.0026667)
Mean amplitude (fit)	0.011
Number of observations	7504
Time span (d)	100.1595
Epoch (JD) of maximum	2459082.592230

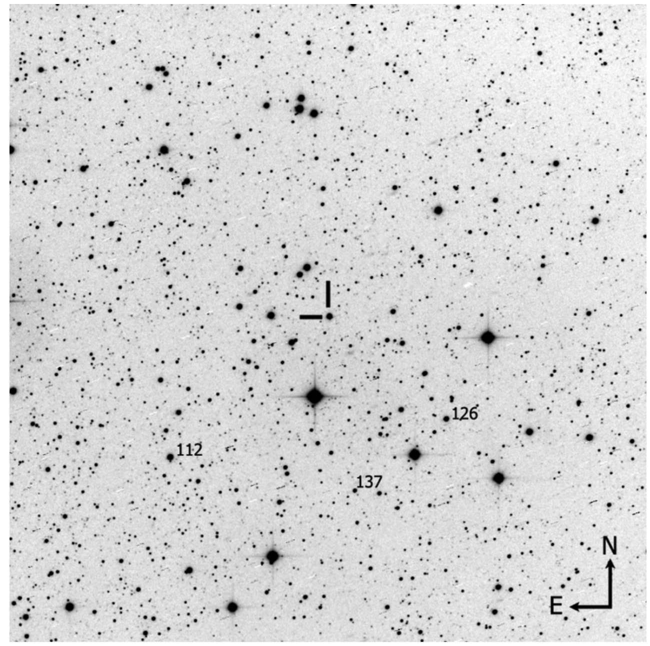

Figure 1. 30 arc-min field of Nova Cas 2020.

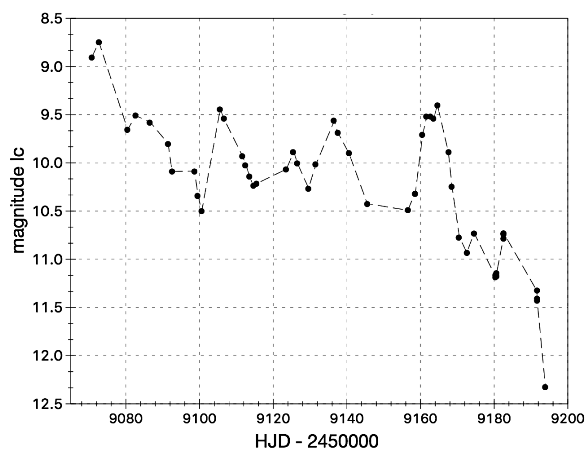

Figure 2. Nightly mean Ic magnitudes from Table 2.

periodogram of this synthetic data as seen in Figure 5 (top), with peak at 6.3101 c/d ± 0.0042 (period 0.158460 ± 0.0001 d). Figure 5 (bottom) compares the periodogram of our actual V1931 Cas observations. Note the one-cycle per day aliases bordering our peak frequency. This exercise demonstrates the reliability and accuracy of the Lomb-Scargle period analysis for signals of small amplitude in the presence of noise.

A folded double-phase plot of the most prominent period, 6.3101 c/d, is shown in Figure 6. A 225-point averaging with 128-point spline interpolation is shown (solid white line). The amplitude of this fit is 0.011 magnitude Ic.

Finally, Peranso software's Fisher Monte Carlo Randomization Test was applied. This method keeps observation times fixed while randomizing the order of the magnitude observations over 200 permutations, searching for spectral responses due solely to observational biases (Moir 1998). FAP 1 computes the probability that no period of value P is present in the data, and FAP 2 the probability that any other significant periods are present in the data. The FAP are given in a range of 0 to 1, with values below 0.01 (1%) indicating very secure solutions (Paunzen and Vanmunster 2016). For P = 3.8036 h the Peranso values of both FAP were 0.000 (probability < 0.05%). It should be noted that the FAP only give confidence in the reality of the underlying period, but do not judge the precision or accuracy of its value. The resulting period information is summarized in Table 3.

5. Conclusion

Time-resolved photometry of new novae from small observatories can detect low-amplitude photometric periods. Less than 100 such periods have been recorded. Coincidently, the observed period of 3.8 h for Nova Cas 2020 happens to be the median value of orbital periods of novae with period less than 12 h which are found in the catalogue of galactic novae of (Özdönmez *et al.* 2018). Figure 7 shows a histogram of orbital periods from their Tables 5 and 6.

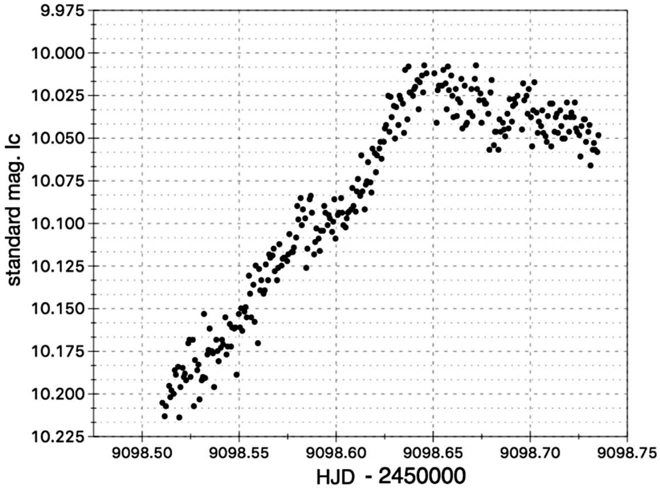

Figure 3a. Example observations 6 September 2020.

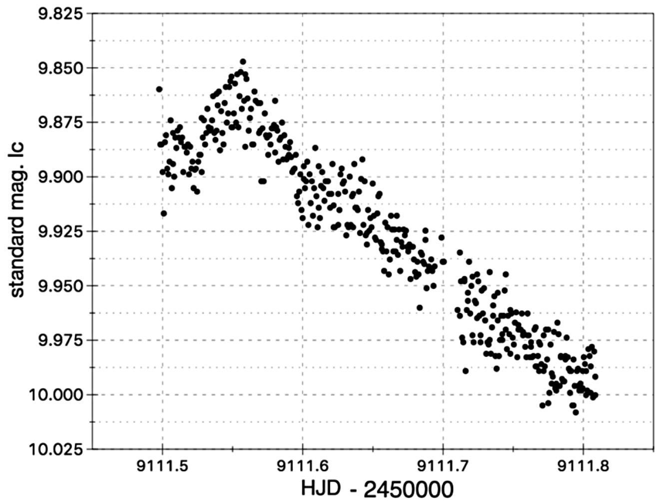

Figure 3b. Example observations 19 September 2020.

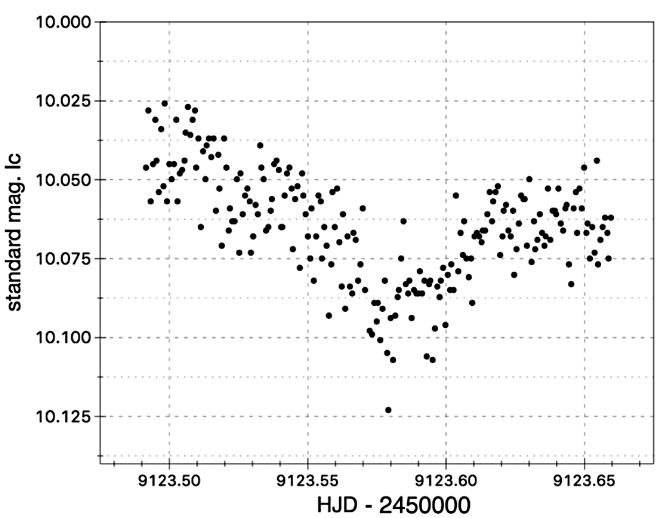

Figure 3c. Example observations 1 October 2020.

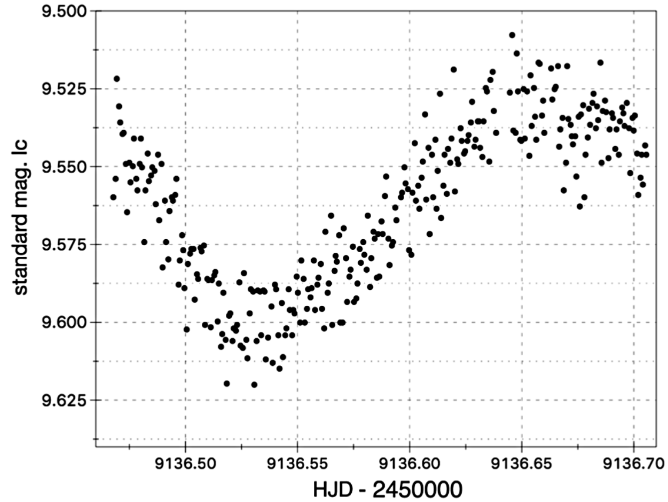

Figure 3d. Example observations 14 October 2020.

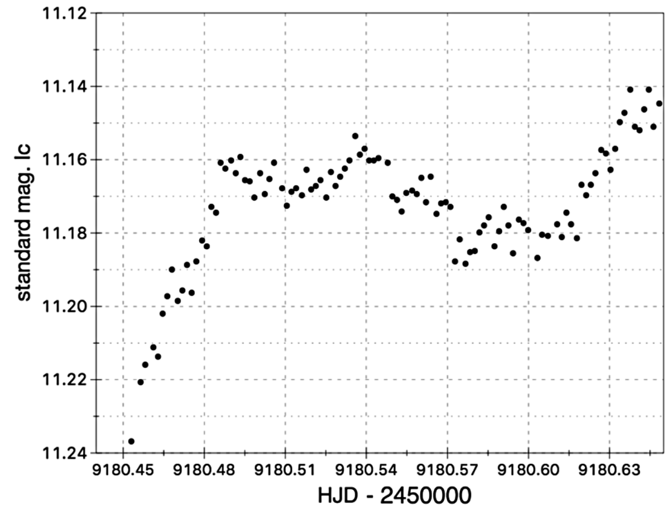

Figure 3e. Example observations 27 November 2020.

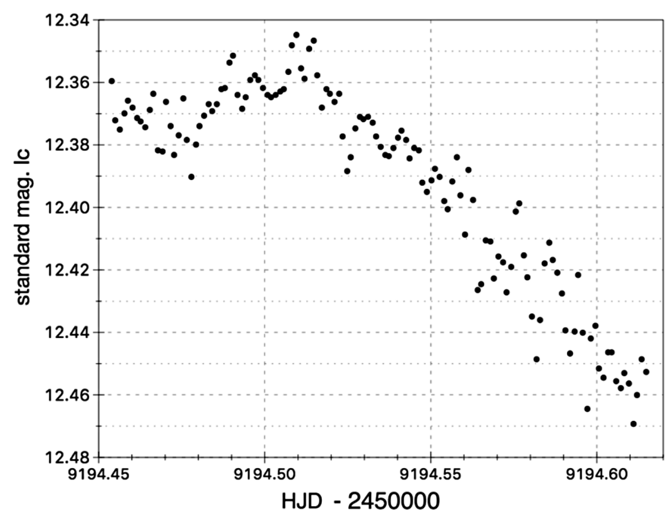

Figure 3f. Example observations 11 December 2020.

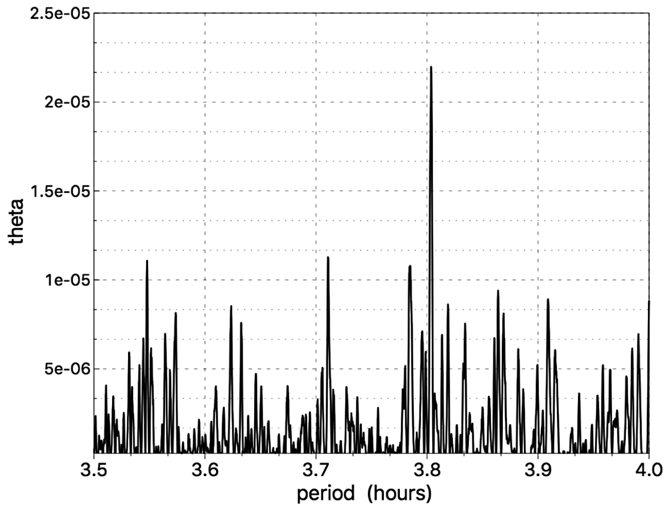

Figure 4. Jurkewich periodogram of Nova Cas 2020, with peak at 3.81 h.

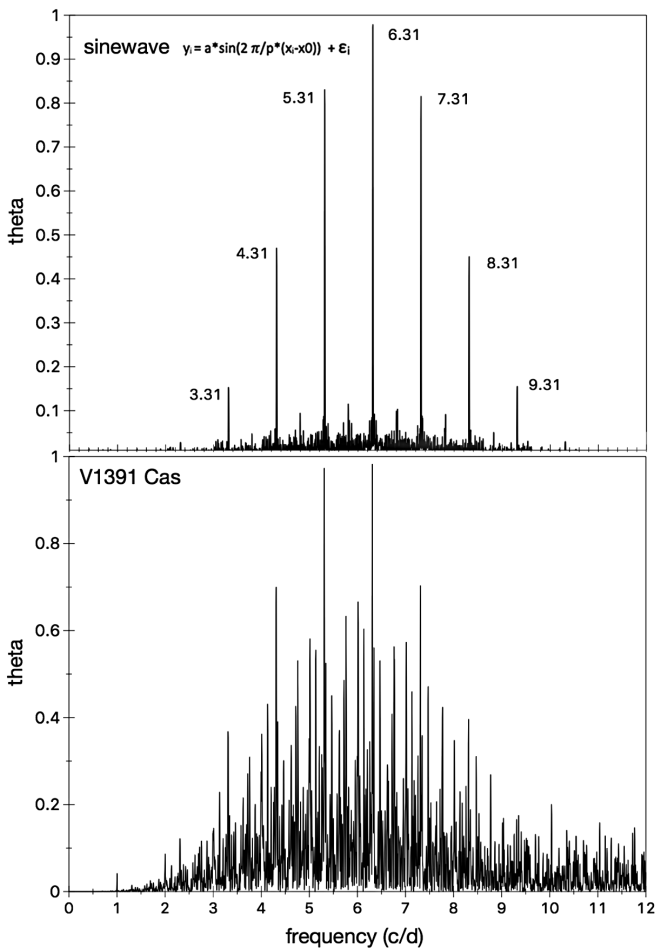

Figure 5. Lomb-Scargle periodograms of a sinusoid of frequency 6.31 c/d (top) and of our observations (bottom).

6. Acknowledgements

The author wishes to thank James A. DeYoung, NRL/USNO (ret.) for many valuable discussions. Special thanks to the AAVSO for providing photometric standards from the AAVSO Comparison Star Database via its Variable Star Plotter utility.

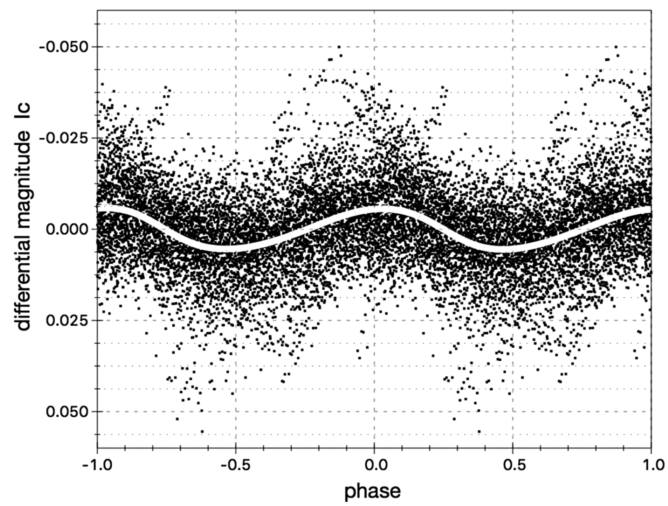

Figure 6. V1391 Cas, double phased plot with spline interpolated fit.

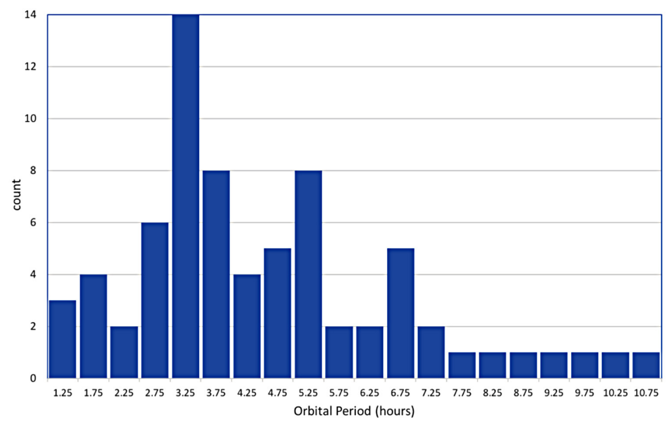

Figure 7. Distribution of novae orbital periods < 12 h, extracted by the author from Özdönmez *et al.* (2018), "A New Catalogue of Galactic Novae." The median value of these is 3.8 h.

References

Korotkiy, S., and Sokolovsky, K. 2020, *Cent. Bur. Astron. Telegrams*, CBAT Transient Object Followup Reports, TCP J00114297+6611190, 2020 07 27.9302.

Moir, R. 1998, *Exp. Economics*, **1**, 87.

Motl, D. 2020, C-Munipack software utilities (http://c-munipack.sourceforge.net).

Özdönmez, A., Ege, E., Güver, T., and Ak, T. 2018, *Mon. Not. Roy. Astron. Soc.*, **476**, 4162.

Paunzen, E., and Vanmunster, T. 2016, *Astron. Nachr.*, **337**, 239.

Schmidt, R. E. 2020a, *J. Amer. Assoc. Var. Star Obs.*, **48**, 13.

Schmidt, R. E. 2020b, *J. Amer. Assoc. Var. Star Obs.*, **48**, 53.

Schmidt, R. E. 2020c, *Cent. Bur. Astron. Telegrams*, No. 4857, 1.

Schmidt, R. E. 2021, *J. Amer. Assoc. Var. Star Obs.*, **49**, 99.

Sokolovsky, K., *et al.* 2020, *Astron. Telegram*, No. 13904, 1.

VanderPlas, J. T. 2018, *Astrophys. J., Suppl. Ser.*, **236**, 16.