Multi-color Photometry of the Hot R Coronae Borealis Star, MV Sagittarii

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Abstract A long term program of photoelectric UBVRI photometry has been combined with AAVSO archival data for the hot, R CrB-type hydrogen deficient star MV Sgr. A deep minimum and a trend of decreasing brightness over time at maximum light thereby become evident. Variations seen via monitoring with a CCD detector also are described.

1. Introduction

The variable star now known as MV Sgr was discovered by Woods (1928), who quoted a range in magnitude of 12.7 to fainter than 15.0. Woods's discovery note does not state the kind of emulsion utilized, and hence the type of magnitude. (History describing the Harvard College Observatory (HCO) telescopes, leading to an enhanced understanding of the kinds of magnitudes produced by the HCO patrol telescopes, may be found at the Digital Access to a Sky Century @ Harvard (DASCH), dasch.rc.fas.harvard.edu/photometry.php, leading to dasch.rc.fas.harvard.edu/lightcurve.php.) Additional insight is located in Laycock *et al.* (2010). MV Sgr was determined to be of the R Coronae Borealis (R CrB) type by Hoffleit (1958). Hoffleit (1959) provided the first light curve, where she found "two groups of minima." Herbig (1964) discussed in detail spectra of MV Sgr taken at maximum light. He found the strongest lines "to be due to He I with no sign of hydrogen in absorption, and with the presence of C II." Herbig called MV Sgr a "very hot carbon star." He reported a radial velocity of -68 km s^{-1}. Finally, Herbig reported photoelectric photometry carried out by B. Paczynski on 1963 July 26 and August 10. The mean values of the single measurements made on each of those two nights were $V = 12.70$, $(B-V) = +0.26$, and $(U-B) = -0.60$. Since no exact times of observation were reported by Herbig, a straight average of, say, twelve hours UT, of the Julian Dates for July 26th and August 10th, 1963, gives a mean time of observation of JD 2438244.5. Percy and Fu (2012) announced an approximate eight-day pulsation period from their study of AAVSO data.

MV Sgr, whose UCAC4 coordinates (Zacharias *et al.* 2013) are R.A. $18^{h}\,44^{m}\,31.968^{s}$, Dec. $-20°\,57'\,12.87''$ (J2000), is a member of a small subset of four hot hydrogen-deficient stars. These four stars, MV Sgr, V348 Sgr, DY Cen, and HV 2671, possess the R CrB-type of light curve, that is, they spend the majority of the time at maximum brightness, with occasional excursions to fainter magnitudes (De Marco *et al.* 2000, and references therein). They differ from most R CrB stars in that on average their effective temperatures are 10,000 K to 15,000 K hotter.

MV Sgr also appears in the literature as HV 4168, UCAC4 346-161178, AAVSO 1838-21, 2MASS J18443197-2057127, and ASASJ184432-2057.2. The UCAC4 catalogue lists its proper motions as $\mu_{\alpha} = -3.2 \pm 3.2$ and $\mu_{\delta} = -8.7 \pm 4.1$ mas yr^{-1}. The related AAVSO Photometric All-Sky Survey (APASS; Henden *et al.* 2009) photometry, Data Release 6 (DR 6), lists a brightness of $V = 13.387$ and $B = 13.565$, for a combined $(B-V) = +0.178$. This magnitude and color index are a combination of measures taken on 2012 April 3rd, April 15th, and September 21st.

A finding chart for MV Sgr is given in Figure 1. The chart is based on a digitized version of the Palomar Sky Survey I (POSS I) blue survey (Palomar Observatory 1950–1957). The size of the field as presented in the chart is about ten arc minutes on a side.

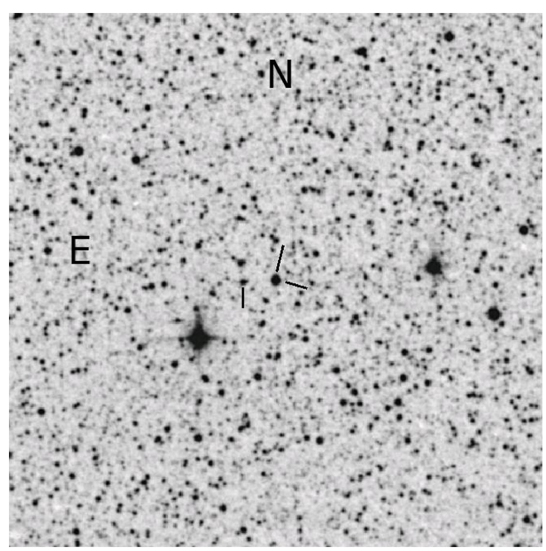

Figure 1. Finding Chart for MV Sgr identified between two lines, and a nearby faint star UCAC4 346–161204 identified by one line. The field of view is approximately 10 arc minutes on a side.

Excellent and definitive summaries of the characteristics of R CrB stars, including the four stars listed above, have appeared in Clayton (1996, 2012). De Marco *et al.* (2002) thoroughly describe this four-member subset of R CrB stars. They write that these four stars are quite different from each other as evidenced by their spectra. They indicate that the "only common characteristics are their temperatures and light variation." Finally, they found that MV Sgr, V348 Sgr, and DY Cen all exhibit a long-term downward trend in brightness over the time frame under study. Schaefer (2016) has searched archival files and also has discussed the long term behavior of this four-star group of hot R CrB stars.

2. Observations

Photoelectric observations of MV Sgr were carried out by AUL in the interval 1977 June 5 to 2001 October 15 (2443299.82217 ≤ *HJD* ≤ 2452197.58510), a range of 8,898 days, or 24.4 years. The data were collected at Cerro Tololo Inter-American Observatory's (CTIO) 0.6-meter (Lowell), 0.9-meter, 1.0-meter (Yale), and 1.5-meter telescopes. A "quick look at the telescope" measurement was reported by Landolt (1979). The June 1977 data were collected at the CTIO (Lowell) 0.6-meter telescope. The detector was a 1P21 photomultiplier in cold box no. 62. The filters were *UBV* set no. 2. These data were tied into standard stars defined by Johnson (1963) and by Landolt (1973). Data acquired between 1979 and including 1997 were tied into *UBVRI* standard stars as defined in Landolt (1983). All R and I measures herein are on the Kron-Cousins system. The 1998 through 2001 data were tied into Landolt (1992). The 1979 through 2001 data, using detectors described in Landolt (1983, 1992), were reduced following precepts outlined in Landolt (2007).

Some doubt exists concerning the photoelectric measures of 1979 October and 1980 March. The raw data printout at the telescope for 1979 October 28 *UT* (HJD 2444474.5) provided a record indicating that the observer found MV Sgr to be below visibility that night at the CTIO 0.9-meter telescope. This perhaps was to be expected given the variable and poor seeing of approximately 4 arc seconds at the time of non-detection, 00:25 *UT* (HJD 2444174.51736). Also, five nights earlier, the star was found to be at *V* = 15.167 on 1979 October 23 *UT* as measured at the CTIO 1.5-meter telescope. The data for 1979 October 23 *UT* (HJD 2444169.51798) were *V* = 15.167, (*B–V*) = +0.871, (*U–B*) = +0.254. However, these data are a close match for UCAC4 346-161204; that star's photometry is *V* = 15.118, and (*B–V*) = +0.855, taken from APASS photometry (Henden *et al.* 2009), Data Release 6 (DR 6).

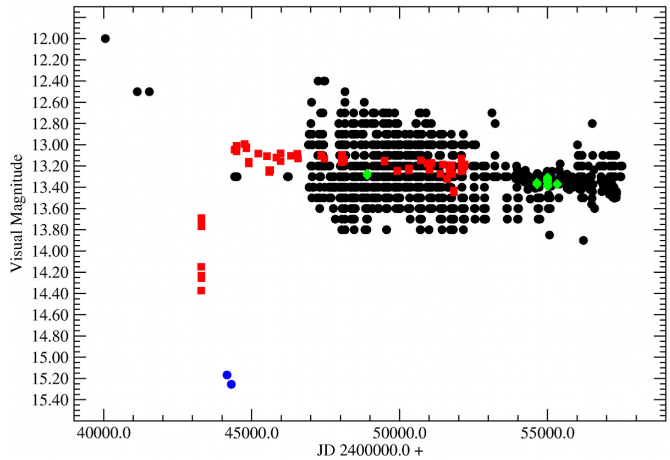

Figure 2. Visual AAVSO database magnitudes plus *V* photoelectric and CCD magnitudes from this paper for MV Sgr. Black color coding indicates AAVSO data, red photoelectric data, green CCD data, and blue two photoelectric possible MV Sgr data points.

A supposed measurement of MV Sgr taken 1980 March 17 *UT* (HJD 2444315.87955) also provided photometry *V* = 15.255 and (*B–V*) = +0.886, which may be the same star which was observed 1979 October 23. However, a note in AUL's log book for 1980 March 17 *UT* specifically said that "if the star just observed was not MV Sgr, then MV Sgr is fainter than 16th magnitude."

A problem with verifying that the above measures are of MV Sgr arises from the apparent lack of measurements in the literature anywhere near this time frame, and with which the authors could compare these suspicious data points. MV Sgr never has been seen that faint. At that time in observational history, observers at the telescope visually located a program star with a finder chart nearby. There is a possibility that a star other than MV Sgr was observed, as it may have been on 1979 October 23. There is evidence from the log book on 1980 March 17 that MV Sgr was not visible that night. Therefore, was it also below visibility on 1979 October 23?

The three 1992 October (HJD 2448905.6) CCD data points, shown in Figure 2 as a green symbol, were obtained by AUL and A. K. Uomoto at the Las Campanas Observatory (LCO) Swope 1.0-meter telescope. The detector was a Texas Instrument (TI #1) 800 × 800 pixel chip whose plate scale was 0.435" pixel^{-1}. The field size was 5.8' on a side. The data were binned 2 × 2. A 2 × 2-inch *UBVRI* filter set borrowed from CTIO meant that the same filter set was used for AUL's CTIO and LCO programs at that time. The composition of the filter set is described in Table 1. The third column provides the effective wavelength for the filter and the fourth column gives the full width at half

Table 1. CTIO CCD filter set used at LCO's Swope Telescope.

Filter	*CTIO ID*	λ_{eff} *Å*	*fwhm* *Å*	*Thickness* *mm*	*Comments*
U	Hamilton No.1	3570	0660	8.78	1 mm UG1 + 1 mm WG295 + 6.78 mm $CuSO_4$
B	B13	4440	1123	5.68	2 mm GG385 + 1 mm BG12 + 2 mm BG39
V	V16	5460	1118	5.72	2 mm GG495 + 3 mm BG39
R	R11	6477	1239	5.80	2 mm GG570 + 3 mm KG3
I	I11	8227	1865	4.62	3 mm RG9 + 1 mm WG295

maximum (fwhm), both in Angstroms. The fifth column lists the total thickness of the filters in millimeters. The final column, Comments, provides the combination of filters employed to define the filters' effective wavelengths and full width at half maximum.

The CTIO data, calendar years 2008 through 2010, were obtained at the CTIO Yale 1.0-meter telescope by JLC, using the Y4KCam CCD. The equipment, data acquisition, and reduction processes were described in Clem and Landolt (2013).

3. Discussion

The reduction process recovered the magnitudes and color indices of the standard stars observed each night. The rms errors calculated from those recovered magnitudes and color indices are listed in Table 2. Columns one and two give the *UT* date of observation and the corresponding Julian Date, respectively. The telescope at which the data were collected is given in the third column, and the filters through which the data were taken are in the fourth column. The last six columns list the rms errors of the recovered standard stars' magnitude and color indices for that night. The last two lines in Table 2 show that the accuracy of the recovered standard star photometry was one percent or less, except for (*U–B*). MV Sgr itself most often was on the order of 1.5 magnitudes fainter than the standard stars.

At the time of initial writing in 2016 May, all available visual and *V*-magnitude data for MV Sgr were downloaded from the AAVSO International Database (Kafka 2015). These data covered the time interval 1968 July 21 to 2016 May 11 *UT* (2440058.700 ≤ JD ≤ 2457520.2958). Visual observations indicating "fainter than" and those taken through filters other than "Johnson *V*" then were eliminated from the listing. The remaining AAVSO observations have been displayed in Figure 2 as black circles. Johnson *V*-magnitude photoelectric data from the observations reported in this manuscript, Table 3, then were overlayed in Figure 2 onto the AAVSO-based observations. Our photoelectric observations are plotted in red. The two possible measurements, described above, of MV Sgr are shown as blue circles. The first two observations in Table 3 were obtained on a marginally photometric night at the CTIO (Lowell) 0.6-meter telescope, hence the discrepancy. An average of those two measures, $\overline{V}$ = 14.261, agrees with the trend of the measures taken on the following photometric nights. One is reminded that the AAVSO database observations are in Julian Days (JDs), whereas the authors' are in Heliocentric Julian Days (HJDs).

CCD data for MV Sgr, from Table 4 and plotted with green symbols in Figure 2, were obtained by JLC at the CTIO Yale 1.0-meter telescope in the interval 2008 June 29 to 2010 May 13 *UT* (2454646.7 ≤ HJD ≤ 2455329.7).

Figure 2 shows MV Sgr coming out of a minimum in light in the Johnson *V* band on HJD2443302.9, having reached *V* = 14.256, roughly 1.2 magnitudes fainter than its average brightness in the following year. Depending on the veracity of the data points on HJD 2444169.51798 and 2444315.87955, one could deduce that a second dimming had taken place, coming to a swift end about HJD 2444316 at *V* = 15.255. These dates, the first certainly, and the second more problematic, were the first deep minima found and measured since those described

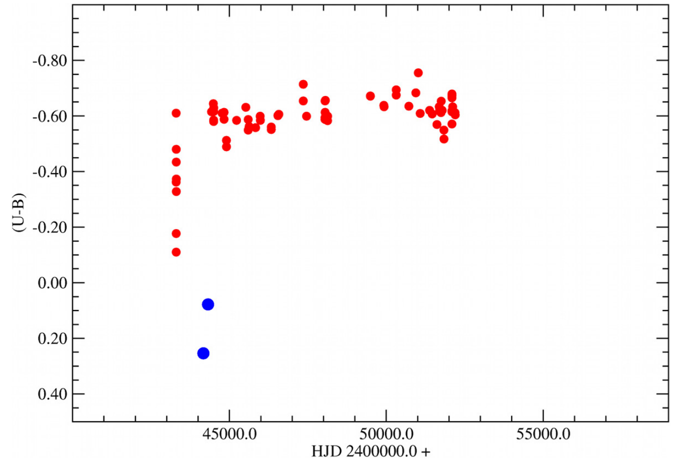

Figure 3. Photoelectric (*U–B*) color index data for MV Sgr from this paper. Data point colors are the same as in Figure 2.

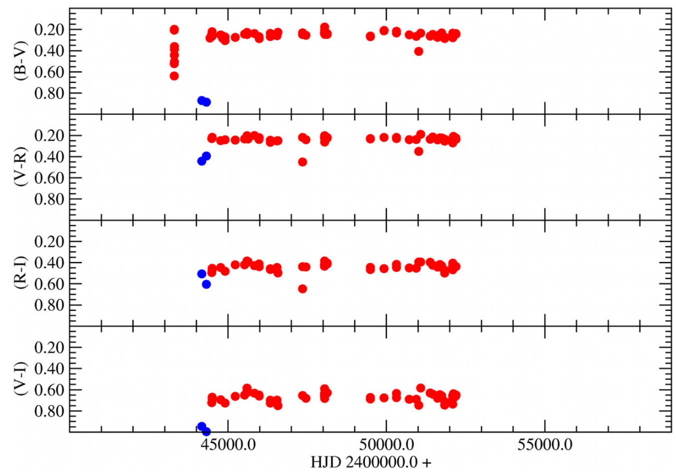

Figure 4. Photoelectric (*B–V*), (*V–R*), (*R–I*), and (*V–I*) color index data for MV Sgr from this paper. Data point colors are the same as in Figure 2.

by Hoffleit (1958, 1959), which minima were on the order of, or greater than, two magnitudes in depth as measured in a photographic *B* magnitude.

More precisely, perusal of data plotted in Figure 4, and taken from Table 3, provide the results in Table 5. The final magnitudes and color indices have been grouped into two "windows," for convenience: window 1 averages results between HJD 2444486 and HJD 2446574; window 2 averages data between HJD 2447352 and HJD 2452197. Rounded off, MV Sgr dropped 0.13 magnitude in brightness in *V* over 7,711 days, following the certain minimum prior to or about HJD 2443299.

If the data taken on HJD 2444169.51798 and 2444315.87955 truly were of MV Sgr, then MV Sgr reached (*B–V*) = +0.88 and (*U–B*) = +0.25 when faintest. The *R* and *I* filter data for these nights' data also show a more red color index in (*V–R*), (*R–I*) and (*V–I*) by some 0.2, 0.1, and 0.2 magnitude, respectively. These values are in line with, or are reasonable for what one might expect for a R CrB star at minimum brightness. Otherwise, as illustrated in Figures 3 and 4, the color indices following minimum essentially are constant, except for (*U–B*), which becomes more blue with time, with large variations.

Table 2. RMS photometric errors per night recovered from standard stars.

UT (mmddyy)	*HJD* 2400000.0+	*Telescope*	*Filter*	*RMS Errors Recovered Standards* *V*	*(B–V)*	*(U–B)*	*(V–R)*	*(R–I)*	*(V–I)*
060577	43299.5	CTIO 0.6-m	UBV	0.008	0.005	0.018	—	—	—
060877	43302.5	CTIO 0.6-m	UBV	0.011	0.008	0.016	—	—	—
060977	43303.5	CTIO 0.6-m	UBV	0.015	0.006	0.016	—	—	—
061177	43305.5	CTIO 0.6-m	UBV	0.015	0.007	0.012	—	—	—
090480	44486.5	CTIO 1.5-m	UBVRI	0.023	0.011	0.033	0.009	0.007	0.014
091280	44494.5	CTIO 0.9-m	UBV	0.014	0.007	0.011	—	—	—
091680	44498.5	CTIO 0.9-m	UBVRI	0.010	0.011	0.023	0.007	0.006	0.008
061081	44765.5	CTIO 1.5-m	UBVRI	0.011	0.013	0.044	0.011	0.017	0.022
081181	44827.5	CTIO 0.9-m	UBV	0.011	0.016	0.023	—	—	—
102681	44903.5	CTIO 0.9-m	UBV	0.013	0.016	0.025	—	—	—
102881	44905.5	CTIO 0.9-m	UBVRI	0.014	0.009	0.023	0.007	0.004	0.007
091482	45226.5	CTIO 1.5-m	UBVRI	0.016	0.014	0.050	0.008	0.008	0.008
070583	45520.5	CTIO 1.5-m	UBVRI	0.006	0.007	0.006	0.003	0.004	0.004
092083	45597.5	CTIO 1.5-m	UBVRI	0.003	0.010	0.037	0.005	0.010	0.010
102183	45628.5	CTIO 0.9-m	UBVRI	0.005	0.007	0.012	0.002	0.004	0.005
051384	45833.5	CTIO 1.5-m	UBVRI	0.007	0.013	0.056	0.007	0.009	0.015
100584	45978.5	CTIO 0.9-m	UBVRI	0.010	0.006	0.015	0.008	0.005	0.007
101184	45984.5	CTIO 0.9-m	UBVRI	0.016	0.005	0.027	0.005	0.003	0.004
092585	46333.5	CTIO 1.5-m	UBVRI	0.012	0.011	0.032	0.014	0.011	0.018
042586	46545.5	CTIO 1.5-m	UBVRI	0.007	0.011	0.045	0.006	0.010	0.011
052486	46574.5	CTIO 1.5-m	UBVRI	0.004	0.008	0.025	0.006	0.017	0.017
071088	47352.5	CTIO 1.5-m	UBVRI	0.009	0.007	0.017	0.008	0.005	0.007
102388	47457.5	CTIO 1.5-m	UBVRI	0.009	0.010	0.042	0.008	0.006	0.009
060290	48044.5	CTIO 1.5-m	UBVRI	0.012	0.009	0.026	0.006	0.012	0.013
060690	48048.5	CTIO 1.0-m	UBVRI	0.009	0.009	0.028	0.006	0.005	0.009
060890	48050.5	CTIO 1.0-m	UBVRI	0.006	0.011	0.028	0.006	0.010	0.012
061390	48055.5	CTIO 1.5-m	UBVRI	0.006	0.009	0.023	0.005	0.006	0.010
061690	48058.5	CTIO 1.5-m	UBVRI	0.007	0.009	0.033	0.008	0.011	0.018
082490	48127.5	CTIO 1.5-m	UBVRI	0.011	0.009	0.032	0.006	0.005	0.006
082690	48129.5	CTIO 1.5-m	UBVRI	0.010	0.008	0.029	0.005	0.008	0.009
052094	49492.5	CTIO 1.5-m	UBVRI	0.004	0.003	0.012	0.003	0.003	0.005
072495	49922.5	CTIO 1.5-m	UBVRI	0.007	0.009	0.020	0.004	0.010	0.011
073195	49929.5	CTIO 1.0-m	UBV	0.004	0.008	0.020	—	—	—
082196	50316.5	CTIO 1.0-m	UBVRI	0.006	0.009	0.029	0.004	0.004	0.007
092997	50720.5	CTIO 1.5-m	UBVRI	0.006	0.009	0.031	0.004	0.007	0.008
050898	50941.5	CTIO 1.5-m	UBVRI	0.008	0.009	0.014	0.004	0.005	0.004
072598	51019.5	CTIO 1.5-m	UBVRI	0.015	0.014	0.020	0.006	0.011	0.014
092598	51081.5	CTIO 1.5-m	UBVRI	0.008	0.009	0.032	0.007	0.011	0.014
072199	51380.5	CTIO 1.5-m	UBVRI	0.008	0.007	0.020	0.004	0.007	0.008
101299	51463.5	CTIO 1.5-m	UBVRI	0.005	0.006	0.033	0.004	0.008	0.008
031100	51614.5	CTIO 1.5-m	UBVRI	0.006	0.010	0.020	0.005	0.004	0.007
052300	51687.5	CTIO 1.5-m	UBVRI	0.008	0.010	0.019	0.006	0.012	0.015
052900	51693.5	CTIO 1.5-m	UBVRI	0.008	0.012	0.023	0.004	0.006	0.007
071900	51744.5	CTIO 1.5-m	UBVRI	0.007	0.007	0.020	0.004	0.004	0.007
072500	51750.5	CTIO 1.5-m	UBVRI	0.005	0.008	0.020	0.003	0.004	0.006
082500	51781.5	CTIO 1.5-m	UBVRI	0.010	0.011	0.036	0.005	0.008	0.009
102000	51837.5	CTIO 1.5-m	UBVRI	0.008	0.009	0.033	0.003	0.005	0.006
102100	51838.5	CTIO 1.5-m	UBVRI	0.007	0.010	0.031	0.003	0.006	0.006
062801	52088.5	CTIO 1.5-m	UBVRI	0.007	0.011	0.022	0.006	0.004	0.008
070301	52093.5	CTIO 1.5-m	UBVRI	0.004	0.006	0.010	0.004	0.007	0.008
072501	52115.5	CTIO 1.5-m	UBVRI	0.007	0.007	0.023	0.004	0.008	0.010
082101	52142.5	CTIO 1.5-m	UBVRI	0.008	0.010	0.033	0.003	0.009	0.011
100701	52189.5	CTIO 1.5-m	UBVRI	0.010	0.010	0.034	0.005	0.014	0.015
101501	52197.5	CTIO 1.5-m	UBVRI	0.007	0.010	0.037	0.007	0.029	0.031
			ave.	0.009	0.009	0.026	0.006	0.008	0.010
			±	0.004	0.003	0.010	0.002	0.005	0.005

Table 3. UBVRI photoelectric data for MV Sgr.

UT (*mmddyy*)	*HJD*	*V* *m*	*(B–V)* *m*	*(U–B)* *m*	*(V–R)* *m*	*(R–I)* *m*	*(V–I)* *m*
060577	2443299.82217	14.373	+0.523	–0.610	—	—	—
060577	2443299.82442	14.148	+0.639	–0.362	—	—	—
060877	2443302.90741	14.256	+0.206	–0.177	—	—	—
060877	2443302.90924	14.233	+0.199	–0.110	—	—	—
060977	2443303.88910	13.768	+0.442	–0.434	—	—	—
060977	2443303.89093	13.740	+0.506	–0.480	—	—	—
061177	2443305.88507	13.689	+0.361	–0.328	—	—	—
061177	2443305.88707	13.700	+0.387	–0.373	—	—	—
090480	2444486.51589	13.024	+0.242	–0.644	+0.230	+0.494	+0.722
091280	2444494.64401	13.009	+0.264	–0.580	—	—	—
091280	2444494.64613	13.062	+0.221	–0.585	—	—	—
091680	2444498.52265	13.009	+0.250	–0.616	+0.220	+0.469	+0.688
091680	2444498.52510	13.011	+0.250	–0.629	+0.218	+0.454	+0.671
061081	2444765.86108	12.992	+0.252	–0.610	+0.249	+0.447	+0.695
081181	2444827.61518	13.032	+0.261	–0.588	—	—	—
081181	2444827.61730	13.021	+0.283	–0.613	—	—	—
102681	2444903.53541	13.176	+0.271	–0.512	—	—	—
102881	2444905.54671	13.158	+0.305	–0.489	+0.241	+0.482	+0.726
091482	2445226.52759	13.083	+0.275	–0.584	+0.244	+0.421	+0.663
070583	2445520.72851	13.107	+0.244	–0.631	+0.233	+0.421	+0.651
092083	2445597.56996	13.238	+0.228	–0.549	+0.207	+0.399	+0.603
092083	2445597.57513	13.255	+0.248	–0.587	+0.203	+0.385	+0.585
102183	2445628.56142	13.238	+0.237	–0.562	+0.234	+0.390	+0.621
051384	2445833.86878	13.120	+0.238	–0.558	+0.201	+0.429	+0.633
100584	2445978.57635	13.081	+0.268	–0.599	+0.238	+0.413	+0.650
101184	2445984.55183	13.154	+0.286	–0.584	+0.221	+0.439	+0.660
092585	2446333.54524	13.104	+0.267	–0.560	+0.246	+0.458	+0.699
092585	2446333.54891	13.104	+0.237	–0.551	+0.265	+0.465	+0.726
042586	2446545.79576	13.085	+0.259	–0.602	+0.251	+0.477	+0.728
042586	2446545.80049	13.093	+0.239	–0.601	+0.252	+0.446	+0.698
052486	2446574.87069	13.129	+0.227	–0.606	+0.250	+0.498	+0.751
071088	2447352.78055	13.098	+0.248	–0.654	+0.219	+0.439	+0.655
071088	2447352.78498	13.103	+0.232	–0.714	+0.451	+0.648	+1.097
102388	2447457.55773	13.132	+0.255	–0.599	+0.240	+0.441	+0.681
060290	2448044.87654	13.165	+0.228	–0.588	+0.223	+0.434	+0.659
060290	2448044.88185	13.155	+0.238	–0.594	+0.216	+0.419	+0.637
060690	2448048.77037	13.130	+0.206	–0.654	+0.203	+0.385	+0.591
060890	2448050.71535	13.153	+0.177	–0.613	+0.263	+0.423	+0.682
061390	2448055.71465	13.113	+0.238	–0.587	+0.232	+0.411	+0.640
061690	2448058.73850	13.097	+0.247	–0.656	+0.221	+0.411	+0.633
082490	2448127.66543	13.152	+0.247	–0.583	+0.226	+0.404	+0.630
082690	2448129.68335	13.139	+0.240	–0.599	+0.220	+0.413	+0.629
052094	2449492.88803	13.158	+0.262	–0.671	+0.230	+0.445	+0.673
052094	2449492.89161	13.149	+0.268	–0.672	+0.233	+0.466	+0.688
072495	2449922.68955	13.247	+0.213	–0.638	+0.219	+0.457	+0.677
073195	2449929.51290	13.245	+0.209	–0.633	—	—	—
082196	2450316.50323	13.223	+0.233	–0.694	+0.219	+0.417	+0.635
082196	2450316.50670	13.244	+0.217	–0.675	+0.230	+0.446	+0.675
092997	2450720.54775	13.147	+0.251	–0.635	+0.240	+0.451	+0.690
050898	2450941.79774	13.174	+0.265	–0.683	+0.239	+0.453	+0.690
072598	2451019.75696	13.236	+0.407	–0.755	+0.351	+0.395	+0.747
092598	2451081.55383	13.170	+0.235	–0.609	+0.190	+0.395	+0.584
072199	2451380.72017	13.273	+0.263	–0.620	+0.236	+0.397	+0.631
101299	2451463.52822	13.186	+0.247	–0.607	+0.215	+0.425	+0.642
031100	2451614.86820	13.322	+0.274	–0.569	+0.242	+0.442	+0.680
052300	2451687.83956	13.224	+0.261	–0.633	+0.231	+0.418	+0.647
052900	2451693.76138	13.261	+0.247	–0.617	+0.223	+0.430	+0.652
071900	2451744.69523	13.191	+0.233	–0.612	+0.224	+0.431	+0.658
072500	2451750.68494	13.197	+0.251	–0.653	+0.234	+0.446	+0.679
082500	2451781.53115	13.273	+0.263	–0.620	+0.229	–0.085	+0.145
102000	2451837.55127	13.430	+0.273	–0.549	+0.236	+0.472	+0.713
102100	2451838.55956	13.446	+0.285	–0.517	+0.254	+0.499	+0.745
062801	2452088.80147	13.248	+0.250	–0.618	+0.227	+0.433	+0.658
070301	2452093.66246	13.198	+0.278	–0.672	+0.234	+0.446	+0.677
070301	2452093.66693	13.198	+0.256	–0.615	+0.228	+0.462	+0.686
070301	2452093.67873	13.239	+0.235	–0.665	+0.236	+0.433	+0.666
070301	2452093.70532	13.224	+0.257	–0.679	+0.229	+0.431	+0.657
070301	2452093.70988	13.232	+0.247	–0.672	+0.254	+0.405	+0.657
070301	2452093.71508	13.231	+0.248	-0.675	+0.254	+0.405	+0.657
070301	2452093.72151	13.129	+0.263	-0.571	+0.271	+0.468	+0.736
072501	2452115.63344	13.226	+0.238	-0.633	+0.209	+0.428	+0.638
082101	2452142.61772	13.233	+0.241	-0.613	+0.232	+0.442	+0.673
100701	2452189.55720	13.202	+0.239	-0.612	+0.224	+0.438	+0.659
101501	2452197.58510	13.184	+0.244	-0.604	+0.236	+0.438	+0.650

Without any available spectroscopic data concurrent with our photometry, one can only conjecture the meaning of these color changes; see, for example, Cottrell *et al.* (1990a, 1990b), and Cottrell and Lawson (1990).

Data from Table 3, illustrated in Figures 3 and 4, show that as MV Sgr became brighter in the interval between HJD 2443299 and HJD 2443305 (1977 June 5 to 1977 June 11) it showed variations in both (*B–V*) and (*U–B*). Neither *R* nor *I* filter data were available for those dates. Figures 5 and 6 further illustrate these changes. Figure 7, the (*U–B*), (*B–V*) color-color plot, more than Figure 8, the (*V–R*), (*R–I*) color-color plot, shows considerable scatter with some tendency that when one color index is redder, so is the other. The (*V–R*), (*R–I*) color-color plot shows a more modest correlation between (*V–R*) and (*R–I*). If the two faint *V* measures, whose corresponding color index measures are indicated by the blue data points in Figures 7 and 8, are of MV Sgr, then the correlations of color with brightness and color are more robust.

Following the minimum, MV Sgr returned to its more normal magnitude and color indices, but continued its long term decline in brightness. From the first day in window 1, and the last day of observation in window 2, MV Sgr dropped by 0.13 magnitude in *V* over 7,711 days (21.1 years, 0.21 century). This change in brightness, then, was at a rate of 0.62 magnitude per century. Since (*B–V*) does not change between these two windows, the rate of change in *B* is the same. This short time interval result is to be compared with the value of 1.29 magnitudes per century in *B* found by Schaefer (2016) for the much longer time interval of 29,547 days (80.895 years). This is about half the rate of decline and indicates a recent slowing down of MV Sgr's rate of evolutionary change. Again, see De Marco *et al.* (2002) for a thorough discussion of a variety of possible scenarios, followed by confirmation in Schaefer (2016).

Evidence from Table 5, illustrated in Figures 5 and 6, shows that the long term diminution in brightness documented by Schaefer (2016) continued, but there was no change in the (*B–V*), (*V–R*), (*R–I*), or (*V–I*) color indices. The (*U–B*) color index did, however, become more blue by 0.05 magnitude. A more complete understanding is on the horizon, and additional current speculation is premature since such will be laid to rest with the appearance of the Large Synoptic Survey Telescope (LSST) data-set in the not so distant future.

Table 4, including the three LCO data points from Landolt and Uomoto, lists the new CCD data obtained by JLC. These data are plotted in Figure 9, which illustrates the average *V* magnitude for each night of CCD data, together with the

Table 4. CCD data for MV Sgr.

HJD 2400000.0+	*V m*	*RMS error*	*HJD 2400000.0+*	*V m*	*RMS error*	*HJD 2400000.0+*	*V m*	*RMS error*
48905.610645	13.270	0.0230	54646.737859	13.372	0.0193	54646.843571	13.364	0.0134
48905.611108	13.291	0.0230	54646.739430	13.373	0.0190	54646.845146	13.370	0.0150
48905.611664	13.266	0.0230	54646.740994	13.364	0.0187	54646.846715	13.370	0.0147
54646.567589	13.359	0.0125	54646.742570	13.364	0.0158	54646.848277	13.366	0.0142
54646.575431	13.360	0.0149	54646.744135	13.362	0.0160	54646.849839	13.367	0.0126
54646.577006	13.356	0.0127	54646.745707	13.364	0.0210	54646.851408	13.368	0.0127
54646.578570	13.358	0.0144	54646.747256	13.365	0.0169	54646.852973	13.364	0.0123
54646.580141	13.361	0.0132	54646.748834	13.365	0.0152	54646.854543	13.363	0.0135
54646.581706	13.362	0.0121	54646.750409	13.366	0.0185	54646.856117	13.366	0.0139
54646.583274	13.359	0.0145	54646.751985	13.367	0.0154	54646.857692	13.367	0.0138
54646.584856	13.363	0.0140	54646.753555	13.371	0.0168	54646.859276	13.366	0.0143
54646.586435	13.356	0.0132	54646.755122	13.365	0.0149	54646.860846	13.364	0.0133
54646.588010	13.361	0.0171	54646.756701	13.368	0.0203	54646.862472	13.365	0.0121
54646.589583	13.361	0.0137	54646.758301	13.366	0.0141	54646.864041	13.364	0.0129
54646.591164	13.353	0.0140	54646.759873	13.372	0.0174	54646.865652	13.366	0.0130
54646.592736	13.371	0.0145	54646.761453	13.371	0.0155	54646.867230	13.371	0.0127
54646.594305	13.361	0.0153	54646.763026	13.374	0.0207	54646.868801	13.369	0.0148
54646.595885	13.363	0.0164	54646.764601	13.372	0.0192	54646.870377	13.363	0.0124
54646.597467	13.359	0.0136	54646.766170	13.374	0.0193	54646.871946	13.365	0.0135
54646.599039	13.359	0.0124	54646.767888	13.374	0.0191	54646.873513	13.361	0.0122
54646.600609	13.360	0.0161	54646.769470	13.378	0.0197	54646.875092	13.365	0.0144
54646.602184	13.368	0.0181	54646.771044	13.372	0.0196	54646.876663	13.370	0.0133
54646.603755	13.366	0.0163	54646.772614	13.376	0.0198	54646.878235	13.368	0.0132
54646.605329	13.362	0.0154	54646.774179	13.368	0.0177	54646.879807	13.370	0.0132
54646.606923	13.361	0.0144	54646.775750	13.373	0.0177	54646.881379	13.363	0.0125
54646.608496	13.366	0.0175	54646.777321	13.371	0.0155	54646.882958	13.366	0.0131
54646.610073	13.365	0.0184	54646.778899	13.373	0.0173	54646.884535	13.361	0.0121
54646.611665	13.372	0.0182	54646.780466	13.371	0.0167	54646.886106	13.368	0.0121
54646.613248	13.374	0.0185	54646.782042	13.370	0.0187	54646.887673	13.372	0.0126
54646.614827	13.368	0.0184	54646.783620	13.375	0.0174	54646.889240	13.366	0.0123
54646.616408	13.369	0.0150	54646.785192	13.375	0.0174	54646.890803	13.366	0.0141
54646.617981	13.371	0.0173	54646.786776	13.378	0.0181	54646.892379	13.368	0.0133
54646.619550	13.371	0.0189	54646.788340	13.372	0.0179	55003.742459	13.311	0.0213
54646.621118	13.369	0.0197	54646.789915	13.373	0.0193	55003.744505	13.315	0.0193
54646.622683	13.365	0.0161	54646.791485	13.374	0.0193	55003.746072	13.315	0.0194
54646.624251	13.369	0.0177	54646.793062	13.374	0.0184	55003.747651	13.319	0.0168
54646.625828	13.370	0.0180	54646.794633	13.370	0.0170	55003.749226	13.317	0.0177
54646.627395	13.367	0.0183	54646.796208	13.368	0.0143	55003.750803	13.318	0.0197
54646.628972	13.366	0.0177	54646.797784	13.372	0.0181	55003.752386	13.321	0.0165
54646.630543	13.374	0.0205	54646.799406	13.371	0.0185	55003.753957	13.318	0.0170
54646.632116	13.369	0.0160	54646.801014	13.370	0.0185	55003.755506	13.303	0.0264
54646.633686	13.371	0.0205	54646.802590	13.364	0.0168	55003.758662	13.317	0.0198
54646.635249	13.370	0.0192	54646.804162	13.376	0.0180	55003.760227	13.318	0.0208
54646.636817	13.367	0.0205	54646.805727	13.372	0.0164	55003.761806	13.317	0.0174
54646.639121	13.364	0.0192	54646.807304	13.372	0.0159	55003.763382	13.317	0.0197
54646.640692	13.362	0.0171	54646.808877	13.372	0.0176	55003.765037	13.316	0.0185
54646.642263	13.367	0.0191	54646.810448	13.373	0.0179	55003.766698	13.318	0.0176
54646.643831	13.368	0.0174	54646.812017	13.371	0.0163	55003.768330	13.318	0.0204
54646.645405	13.370	0.0178	54646.813590	13.376	0.0176	55003.769901	13.321	0.0177
54646.646979	13.367	0.0192	54646.815174	13.372	0.0176	55003.771473	13.317	0.0177
54646.648549	13.368	0.0178	54646.816746	13.371	0.0160	55003.773047	13.320	0.0160
54646.650111	13.363	0.0169	54646.818317	13.372	0.0158	55003.774624	13.317	0.0182
54646.651688	13.367	0.0167	54646.819889	13.371	0.0157	55003.776199	13.321	0.0164
54646.653259	13.368	0.0180	54646.821463	13.371	0.0165	55003.777773	13.319	0.0166
54646.654836	13.367	0.0172	54646.823027	13.372	0.0139	55003.779340	13.319	0.0174
54646.656414	13.364	0.0165	54646.824600	13.374	0.0155	55003.780914	13.304	0.0172
54646.657997	13.364	0.0168	54646.826177	13.373	0.0151	55003.782488	13.319	0.0181
54646.659572	13.365	0.0159	54646.827748	13.371	0.0152	55003.784073	13.318	0.0148
54646.661152	13.365	0.0133	54646.829325	13.370	0.0172	55003.785648	13.317	0.0159
54646.662734	13.359	0.0153	54646.830955	13.367	0.0140	55003.787230	13.322	0.0160
54646.664307	13.359	0.0160	54646.832524	13.367	0.0128	55003.788810	13.322	0.0159
54646.665880	13.360	0.0147	54646.834135	13.371	0.0160	55003.790377	13.320	0.0168
54646.667453	13.362	0.0170	54646.835719	13.375	0.0141	55003.791969	13.320	0.0166
54646.669036	13.357	0.0148	54646.837287	13.374	0.0158	55003.793546	13.321	0.0159
54646.670628	13.357	0.0200	54646.838853	13.367	0.0153	55003.795116	13.318	0.0159
54646.672199	13.358	0.0192	54646.840422	13.369	0.0147	55003.796700	13.317	0.0142
54646.736295	13.367	0.0170	54646.841996	13.368	0.0139	55003.798277	13.325	0.0153

Table continued on next page

Table 4. CCD data for MV Sgr, cont.

HJD 2400000.0+	*V* *m*	*RMS* *error*
55003.799850	13.313	0.0176
55003.801413	13.321	0.0170
55003.802989	13.313	0.0173
55003.804563	13.324	0.0164
55003.806136	13.315	0.0187
55003.807712	13.321	0.0160
55003.809285	13.315	0.0181
55003.810858	13.318	0.0156
55003.812425	13.317	0.0183
55003.813999	13.317	0.0164
55003.815571	13.321	0.0168
55003.817144	13.316	0.0177
55003.818710	13.318	0.0185
55003.820276	13.320	0.0219
55003.821854	13.319	0.0179
55003.823434	13.318	0.0163
55003.825007	13.322	0.0157
55003.826571	13.318	0.0149
55003.828144	13.318	0.0172
55003.829718	13.315	0.0159
55003.831296	13.326	0.0164
55003.832881	13.323	0.0174
55003.834454	13.317	0.0174
55003.836026	13.321	0.0162
55003.837606	13.325	0.0151
55003.839374	13.320	0.0182
55003.840945	13.318	0.0202
55003.842517	13.317	0.0181
55003.844081	13.315	0.0177
55003.845660	13.317	0.0197
55003.847233	13.313	0.0202
55003.848798	13.317	0.0179
55003.850365	13.318	0.0213
55003.851935	13.321	0.0223
55003.853500	13.318	0.0204
55003.855077	13.307	0.0205
55003.856650	13.317	0.0210
55003.858226	13.318	0.0194
55003.859790	13.328	0.0244
55003.861362	13.310	0.0196
55003.862970	13.314	0.0275
55004.696693	13.355	0.0171
55004.698799	13.350	0.0137
55004.700372	13.354	0.0134
55004.701945	13.351	0.0132
55004.703517	13.352	0.0145
55004.705088	13.346	0.0144
55004.706658	13.354	0.0130
55004.708241	13.353	0.0149
55004.709814	13.347	0.0137
55004.711388	13.349	0.0138
55004.712963	13.347	0.0134
55004.714529	13.349	0.0145
55004.716099	13.352	0.0147
55004.717674	13.345	0.0160
55004.719249	13.354	0.0136
55004.720823	13.351	0.0120
55004.722388	13.353	0.0150
55004.723966	13.353	0.0140
55004.725535	13.350	0.0151
55004.727110	13.351	0.0149
55004.728692	13.348	0.0143
55004.730264	13.342	0.0192
55004.731839	13.341	0.0174
55004.733414	13.335	0.0237
55004.734986	13.338	0.0219
55004.736548	13.340	0.0218
55004.738126	13.332	0.0204
55004.739700	13.345	0.0168
55004.741265	13.336	0.0231
55004.742841	13.338	0.0202
55004.744414	13.345	0.0158
55004.747132	13.346	0.0161
55004.748710	13.350	0.0158
55004.750282	13.349	0.0155
55004.751855	13.350	0.0145
55004.753436	13.348	0.0140
55004.755007	13.350	0.0180
55004.756585	13.346	0.0155
55004.758148	13.339	0.0173
55004.759726	13.328	0.0293
55004.762872	13.339	0.0225
55004.764447	13.341	0.0282
55004.766021	13.338	0.0287
55004.767597	13.336	0.0211
55004.769162	13.337	0.0196
55004.770733	13.342	0.0211
55004.772307	13.344	0.0202
55004.773899	13.339	0.0222
55004.775551	13.341	0.0184
55004.777174	13.339	0.0187
55004.778744	13.334	0.0267
55004.780323	13.332	0.0278
55004.781897	13.334	0.0238
55004.783470	13.337	0.0236
55004.786604	13.330	0.0253
55004.788167	13.342	0.0210
55004.789745	13.336	0.0218
55004.791311	13.341	0.0222
55004.792882	13.331	0.0229
55005.687939	13.346	0.0223
55005.689154	13.347	0.0190
55005.690389	13.346	0.0224
55005.691606	13.351	0.0198
55005.692830	13.343	0.0231
55005.694058	13.350	0.0207
55005.695275	13.349	0.0204
55005.696494	13.356	0.0208
55005.697721	13.351	0.0205
55005.698944	13.352	0.0216
55005.700177	13.357	0.0229
55005.701406	13.350	0.0232
55005.702628	13.345	0.0252
55005.703856	13.350	0.0238
55005.705083	13.355	0.0200
55005.706312	13.345	0.0218
55005.707534	13.349	0.0225
55005.708770	13.350	0.0222
55005.709995	13.353	0.0228
55005.711220	13.349	0.0226
55005.712446	13.349	0.0224
55005.713663	13.343	0.0179
55005.714891	13.345	0.0199
55005.716123	13.349	0.0206
55005.717349	13.343	0.0205
55005.718577	13.346	0.0207
55005.719800	13.344	0.0213
55005.721024	13.343	0.0218
55005.722251	13.351	0.0225
55005.723469	13.348	0.0185
55005.724716	13.346	0.0211
55005.725940	13.348	0.0201
55005.727158	13.349	0.0201
55005.728392	13.343	0.0216
55005.729618	13.347	0.0216
55005.730843	13.345	0.0213
55005.732068	13.347	0.0195
55005.733292	13.348	0.0202
55005.734511	13.353	0.0210
55005.735734	13.346	0.0194
55007.599466	13.377	0.0264
55007.602624	13.383	0.0267
55007.605771	13.387	0.0214
55007.607334	13.390	0.0216
55007.608911	13.382	0.0274
55007.610475	13.385	0.0213
55007.612046	13.393	0.0204
55007.615197	13.396	0.0280
55007.616771	13.382	0.0251
55007.618344	13.383	0.0214
55007.619913	13.387	0.0195
55007.621487	13.384	0.0268
55007.623058	13.390	0.0214
55007.624633	13.394	0.0280
55007.626205	13.381	0.0245
55007.629745	13.390	0.0203
55007.632019	13.388	0.0200
55007.634284	13.384	0.0201
55007.636546	13.380	0.0163
55007.638815	13.376	0.0284
55329.739310	13.374	0.0150
55329.740713	13.369	0.0163
55329.742121	13.372	0.0174
55329.743525	13.375	0.0163
55329.744927	13.375	0.0151
55329.746337	13.378	0.0158
55329.747733	13.376	0.0178
55329.749137	13.377	0.0150
55329.750542	13.371	0.0167
55329.751946	13.370	0.0142
55329.753349	13.372	0.0175
55329.754756	13.370	0.0247
55329.756159	13.366	0.0260
55329.757557	13.366	0.0267
55329.761777	13.364	0.0266
55329.763174	13.372	0.0188
55329.764580	13.366	0.0256
55329.765986	13.371	0.0170
55329.767383	13.370	0.0163
55329.768785	13.371	0.0207
55329.770190	13.366	0.0247
55329.771594	13.375	0.0187
55329.772989	13.372	0.0190
55329.774385	13.371	0.0199
55329.775789	13.365	0.0238
55329.777192	13.372	0.0191
55329.778599	13.377	0.0149
55329.779995	13.370	0.0178
55329.781543	13.369	0.0200
55329.782954	13.370	0.0191
55329.784348	13.369	0.0188
55329.785752	13.369	0.0219
55329.787151	13.368	0.0270
55329.791750	13.364	0.0219
55329.795954	13.363	0.0213
55329.797359	13.369	0.0181
55329.798763	13.372	0.0200
55329.800169	13.366	0.0217
55329.801564	13.370	0.0173
55329.808585	13.369	0.0278

Table 5. UBVRI photoelectric photometry near maximum.

Filter	*HJD Window 1* 2444486–2446574	*HJD Window 2* 2447352–2452197	*n*
V	$13\overset{\text{m}}{.}099 \pm 0.077$	$13\overset{\text{m}}{.}229 \pm 0.069$	32
(B–V)	+0.254 ± 0.021	+0.255 ± 0.033	32
(U–B)	–0.584 ± 0.037	–0.635 ± 0.046	32
(V–R)	+0.234 ± 0.018	+0.236 ± 0.026	31
(R–I)	+0.444 ± 0.034	+0.437 ± 0.024	30
(V–I)	+0.676 ± 0.047	+0.671 ± 0.034	30

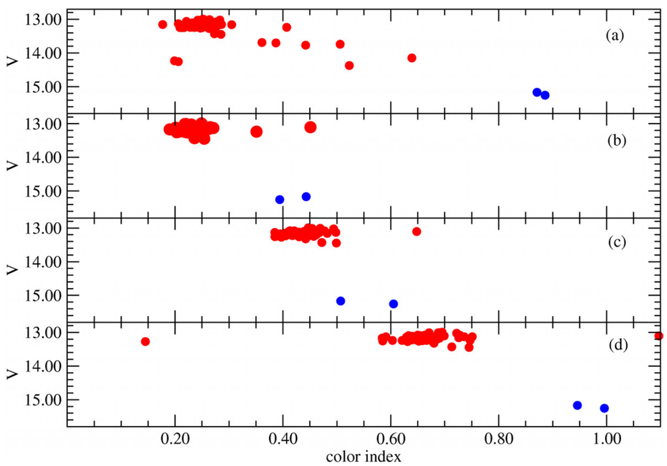

Figure 5. V magnitude vs color indices for MV Sgr, with these photoelectric data point colors identical to those in Figure 2.: (a) (*B–V*), (b) (*V–R*), (c) (*R–I*), and (d) (*V–I*).

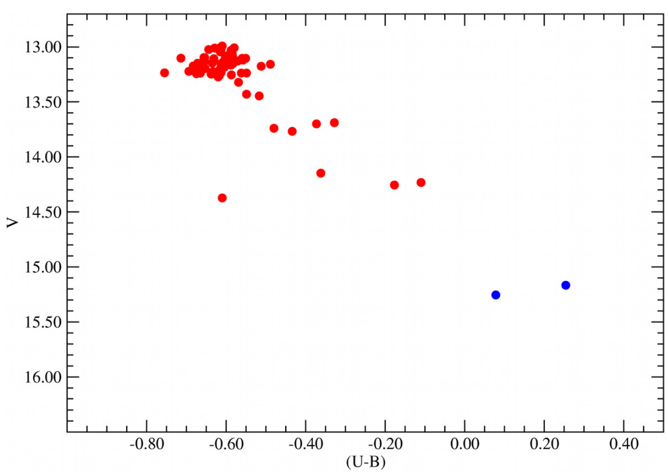

Figure 6. *V* magnitudes vs (*U–B*) color index for the photoelectric data for MV Sgr for this paper. Data point colors are the same as in Figure 2.

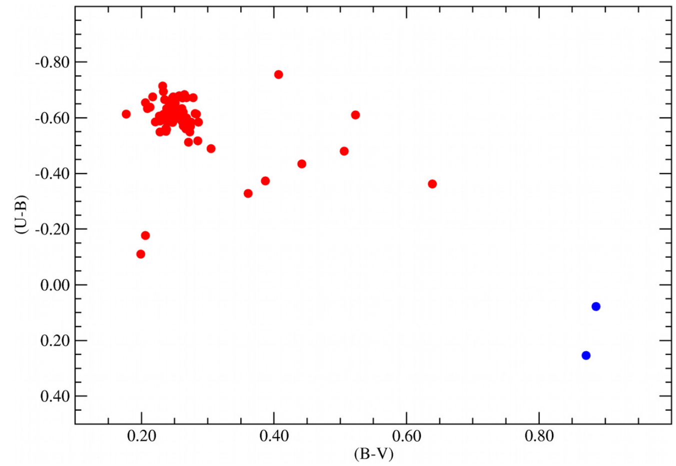

Figure 7. (*U–B*) vs. (*B–V*) photoelectric data herein for MV Sgr. Data point colors are the same as in Figure 2.

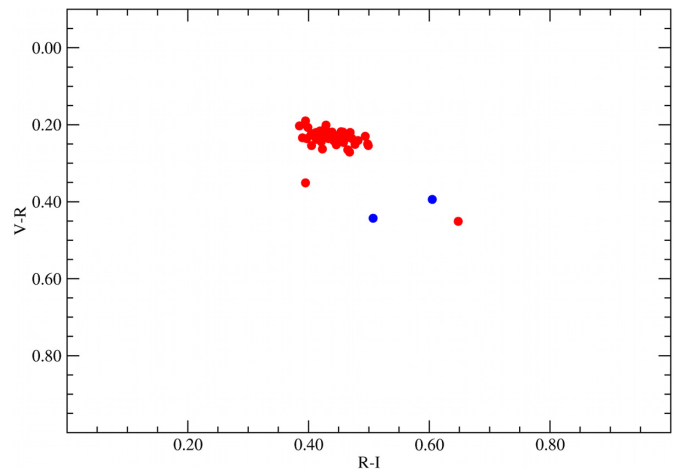

Figure 8. (*V–R*) vs. (*R–I*) photoelectric data herein for MV Sgr. Data point colors are the same as in Figure 2.

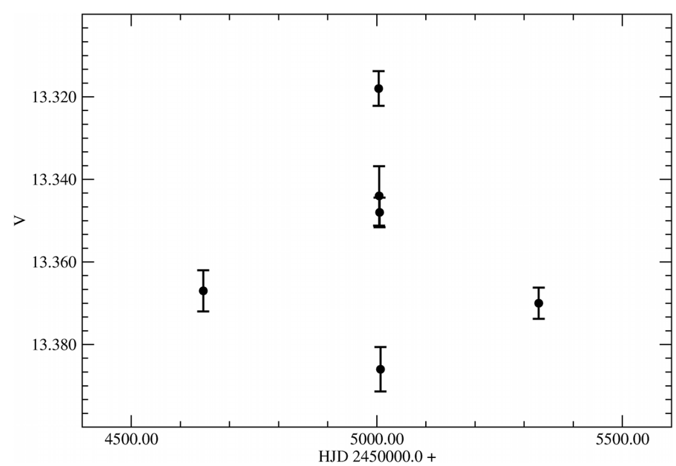

Figure 9. The average *V* magnitude and standard deviation for each night's CCD data for MV Sgr.

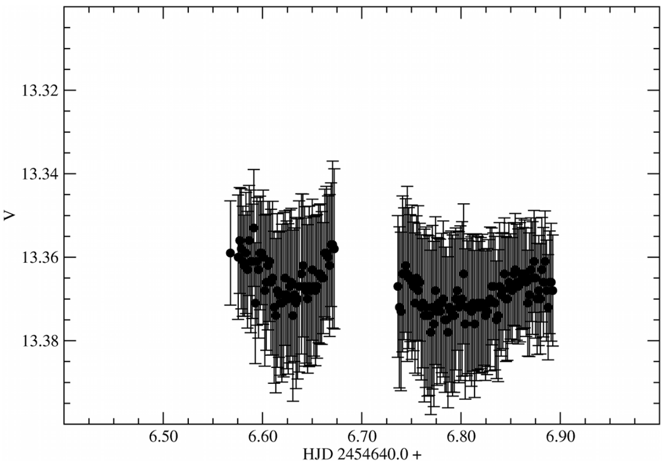

Figure 10. *V* magnitude CCD data for MV Sgr for 2008 June 29 *UT* (HJD 2454646.5+).

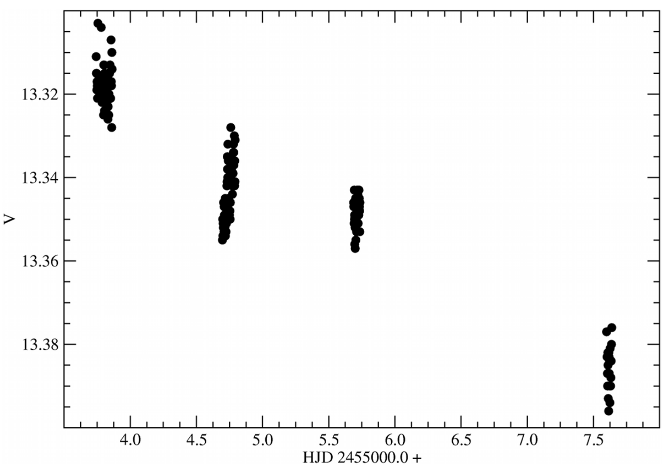

Figure 11. *V* magnitude CCD data for MV Sgr obtained in the time interval 2009 June 20–24 UT (2455003.7 ≤ HJD ≤ 2455007.64).

average deviation for each night's average *V* magnitude. The Heliocentric Julian Day is tabulated in column one, the *V* magnitude in column two, and the corresponding error in the third column. From this data set, the values of the observed magnitudes fall in the range of 13.303 ≤ *V* ≤ 13.396, with an average magnitude of *V* = 13.354 ± 0.021. The average error for the individual error measurements in the third column is 0.0181 ± 0.0036.

Figure 10 presents the CCD data through the *V* filter that were obtained on HJD 2454646.6 (2008 June 29). It illustrates the longest CCD-based data string for a monitoring interval of just under eight hours. The seeing varied between 1.0 and 1.5 arc-seconds. The error for each data point essentially is equivalent to the total scatter visible in the figure. Plots of the CCD data in Table 4 from all other nights are similar in appearance, with the size of the error bars being equivalent to the scatter in the nightly data strings. Application of the PERIOD04 program (Lenz and Breger 2005) in a search for possible short-term variability was inconclusive.

Figure 11 provides the CCD data taken through a *V* filter in the time interval 2455003.7 ≤ HDJ ≤ 2455007.6 (2009 June 20–24). A total range in the *V* magnitude of 0.093 is evident. The time elapsed during which data were taken varied a bit from night to night. The total variation was 0.025, 0.027, 0.014, and 0.020 magnitude for the nights of HJD 2455003.7, 2455004.6, 2455005.6, and 2455007.5, encompassing time durations of 173.5, 138.5, 68.8, and 56.7 minutes, respectively. Figure 11 illustrates that over this particular five-night interval, MV Sgr steadily declined in brightness by approximately 0.07 magnitude. It may be interpreted that this decline is the downward leg of the approximate eight-day period, but with a somewhat larger amplitude, than found by Percy and Fu (2012). However, the shortness of the data strings within individual nights preclude definitive statements about intra-night variations.

4. Summary

Calibrated photometric photoelectric and CCD data of MV Sgr obtained by the authors over an interval of 32.9 years confirm a long term downward trend in brightness and the CCD data are consistent with an approximate eight-day pulsation period. These new data have provided the first and only deep minimum identified since those described by Hoffleit (1958, 1959). Since the individual errors of the individual CCD data points are similar in size to any variation among those data points, nothing definitive can be said about possible short term changes in light over the course of a night. Night-to-night changes, however, do occur.

At least one observing season completely devoted to thoroughly photometrically calibrated night-long monitoring of MV Sgr no doubtedly will elucidate the reality of these light variations plus most probably additional light variations at other frequencies. Since the intra-nightly light variations are small, only a couple percent, highly accurate photometric data are required. Data should be acquired, preferentially, through a Johnson *V*-filter to better enable robust comparison with most extant photometric data for MV Sgr. Accompanying spectroscopy would be exceedingly useful. Such an observing program would be a challenging, fun, and rewarding endeavor!

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