CCD PHOTOMETRY RESULTS ON SOME HIPPARCOS STARS

Gary Walker
8 Pond Street
Dover, MA 02030

Presented at the 4th AAVSO CCD Workshop, May 20, 1994

Abstract

This paper summarizes the status of the AAVSO CCD Photometry Program through May of 1994. The findings of the CCD questionnaire covering such topics as types of equipment, software, filters, and cameras are discussed. The first six months' observations are discussed and compared to visual observations, and the AAVSO CCD Photometry Program is evaluated.

1. Introduction

The AAVSO CCD Photometry Program was initiated to take advantage of the recent wave of low-cost CCD camera/imaging systems which have become available to college observatories and to amateur observatories, thereby harnessing a multitude of observers at urban or suburban locations. Such CCD-equipped observers could make many more observations than costly professional observatories and provide information to professional astronomers and programs which would be difficult to obtain any other way. The program is intended to use CCDs to extend the AAVSO's visual observing programs. In 1991, 1992, and 1993, the AAVSO sponsored CCD workshops to inform observers about this new technology and to explore its applications to the AAVSO.

The AAVSO CCD program avoided the temptation to evaluate specific equipment and standardize on certain brands. Instead, the AAVSO suggested that BVRI photometric filters be used, along with transformations to a standard system, and provided a set of standard stars close to the suspected variable, so differential photometry from a single image could be performed, thus allowing many observers to compile their data at Headquarters to create meaningful light curves. It was hoped that the variation in equipment and techniques would be small enough that meaningful science could be supported.

The standard charts for eight Hipparcos stars were developed as a result of work by Howell, Mattei, and Benson (1993) at the 1-meter telescope on Kitt Peak. These standard charts are in BVRI and give standard magnitudes with errors of <0.003 magnitude on comparison stars within an 11 arc minute field surrounding the suspected variable.

Observers were asked to image S Per, U Ori, VX Gem, DH Dra, W Leo, VX UMa, RU Vir, and RR Boo, determine instrumental magnitudes based on the comparison stars, and transform the results to standard magnitudes. These results, shown in Tables 1–8, were then combined into light curves which are shown in Figures 1–8.

The data base included 382 measurements of these 8 standard Hipparcos stars shown in these light curves. Standard deviations ranged from 0.003 to 0.030 magnitude.

2. The potential observer pool

The potential observer pool was determined by questionnaire from prior mailing lists compiled by Headquarters from workshops and unsolicited inquiries. The purpose was to compile and database the interest and the types of equipment available for potential projects. A summary follows.

Fifteen observers returned the questionnaire, representing 12 states in the USA: Pennsylvania (4), Colorado, Ohio, Illinois, New York, Wisconsin, Virginia, Nevada, California, New Hampshire, and Massachusetts (2). Many of the observing sites were urban or suburban, with home-based facilities the majority. The next most prevalent location was at university facilities, mostly located in populated areas.

Telescope aperture ranged from 6 to 24 inches. The distribution was 1 observer with 4–6 inches, 5 observers with 8–12 inches, 6 observers with 14–18 inches, and 3 observers with 20–24 inches. The most prevalent telescope types were Schmidt-Cassegrains and Cassegrains.

The cameras owned ranged from Lynxx to Photometrics. Three observers had Lynxx cameras, 2 observers had HPC-1 cameras, 2 observers had ST-6 units, 4 observers had Photometrics, while 4 observers had yet to make a purchase.The chips used in these cameras represented all the popular ones. Three used the TC-211, 2 used the TC-241, 2 used the TC-215, 3 used the TH-78xx, 2 used the PM-512, and 3 used none.

Many of the camera owners had not purchased a filter set as of questionnaire mailing. Those that did have filters responded as follows; 3 used Optec, 1 Murnaghan, 1 used Compuscope, and 1 used Kitt Peak Formula. Nine camera owners did not have filters.

The final ingredient in a photometric setup is software. Observers responded that 4 used MIRA, 3 used IRAF, 2 used Spectrasource, 2 used Optec, 1 used SBIG, 1 used Imagine 32, 1 used Photometrics, and 4 did not have software.

3. Active observer profiles

Observations were received from four members in BVRI on all 8 standard stars using a subset of the above mentioned features. The location of observations were two from Massachusetts, one from New Hampshire, and one from Virginia. The apertures were 1 of 8–12 inches, 1 of 14–18 inches, and 2 of 20–24 inches.

The cameras used were 3 Photometrics and 1 ST-6. The CCD chips in those cameras were 2 PM-512, 1 TH7896, and 1 TC-241. The filters used included one each from Murnaghan, Compuscope, Kitt Peak Formula, and Undesignated. The software used to reduce the data include 2 using IRAF, 1 MIRA, and 1 Photometrics.

Observer	Observer ID	Location
G. Walker	WGR	Dover, MA*
R. Zissell	ZRE	S. Hadley, MA
P. Benson	BPN	Wellesley, MA
T. Michalik	MTK	Lynchburg, VA

*Observing site is in New Hampshire.

4. Results and discussion

Observations were received from four members in BVRI on all 8 standard stars (S Per, U Ori, VX Gem, DH Dra, W Leo, VX UMa, RU Vir, and RR Boo). A total of 382 measurements with a typical standard deviation of 0.03 magnitude were received. Those measurements were made by differential comparison to 1318 comparison stars in those fields.

It is only natural to compare the CCD results to those in the visual data base. Six of these stars had sufficient data to warrant a comparison and are shown in Figures 9–14. The visual estimates are shown as points and the CCD V measurements are shown as a line. U Ori, W Leo, and RR Boo, shown in Figures 9, 10, and 11, show reasonable agreement with visual estimates above and below the CCD V line. These stars have B-V values of 2.7, 2.3, and 2.0, respectively. These results are in contrast to those of

S Per, RU Vir, and VX Gem in Figures 12, 13, and 14, which show 0.5 to 1.5 magnitudes of divergence from the visual estimates. The B-V values for these stars are 3.0, 4.8, and 4.9. These B-V values are very high, and are also much higher than those for U Ori, W Leo, and RR Boo. While these are all classified as long period red variables, RU Vir and VX Gem are carbon stars. Also, for RU Vir, not all of the visual comparison stars have been measured with CCD, and therefore visual and CCD observers may be using different sets of comparison stars. In the case of VX Gem, the visual sequence is as much as half a magnitude fainter than the CCD sequence.

5. Summary

a. The AAVSO CCD Photometry Program has shown the feasibility of making meaningful observations through modest-sized telescopes equipped with CCD cameras.

b. The quantity of data is small, with only 4 observers at this point, and most of the standard stars have not been observed for a full cycle.

c. Four observers using various CCD cameras, telescopes, filters, software, and observing techniques turned in observations with a typical standard deviation of 0.03 magnitude relative to the comparison stars in the AAVSO standard charts.

d. These same observers demonstrated a scatter of less than 0.1 magnitude absolute on all but a few errant points.

e. The observations on RU Vir go down to 16.9 magnitude in B with a scatter of 0.1 magnitude. These were done with a typical 10-minute exposure and a 12–24 inch telescope.

f. Comparisons with the visual data base were good for stars with B-V color indices of 2 to 3, but stars with color indices of 3 to 5 showed variations of 0.5 to 1.5 magnitudes.

g. Additional observations are required to support these light curves. Future measurements are expected to improve as observers become more familiar with the techniques of CCD photometry.

Reference

Howell, S.B., Mattei, J.A., and Benson, P.J. 1993, *J. Amer. Assoc. Var. Star Obs.*, **22**, 1.

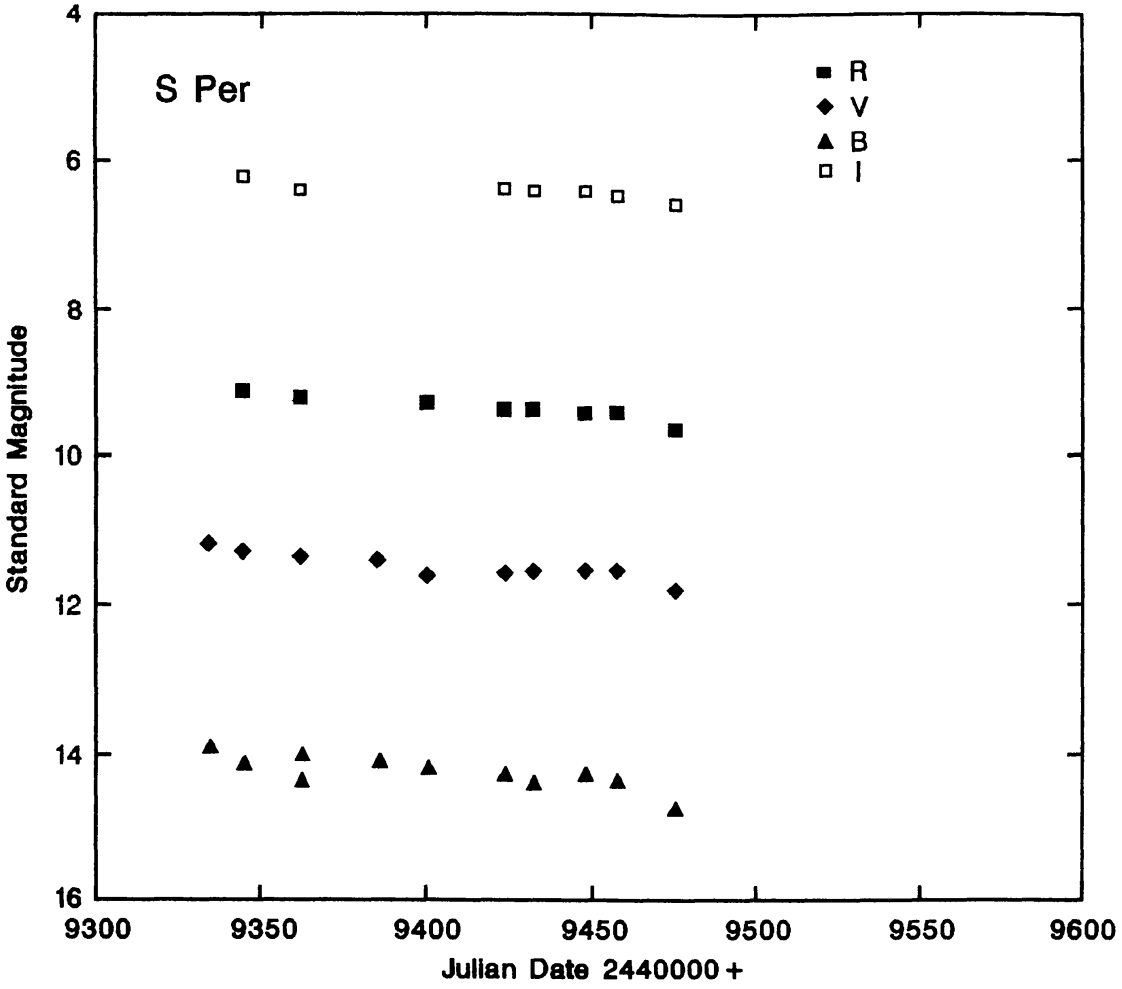


Figure 1. Four-color CCD light curve for S Per. S Per varies from 6th magnitude in I to 14.7 in B. The variation in each color is just over 0.5 magnitude. B shows the largest scatter of the four colors. B-V is 2.8, indicating a temperature of 2450 K.

Table 1. AAVSO CCD data for S Per as represented in Figure 1 (above).

JD 2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*
9334.55	13.900	11.180			MTK
9344.56	14.111	11.259	9.119	6.186	ZRE
9362.48	14.365	11.338	9.208	6.410	ZRE
9362.49	14.000	11.340			MTK
9385.57	14.100	11.390			MTK
9400.55	14.200	11.590	9.280		MTK
9423.50	14.265	11.559	9.348	6.352	ZRE
9432.51	14.391	11.512	9.359	6.372	ZRE
9447.53	14.262	11.519	9.386	6.376	ZRE
9457.52	14.348	11.528	9.398	6.442	ZRE
9475.56	14.726	11.785	9.619	6.528	ZRE

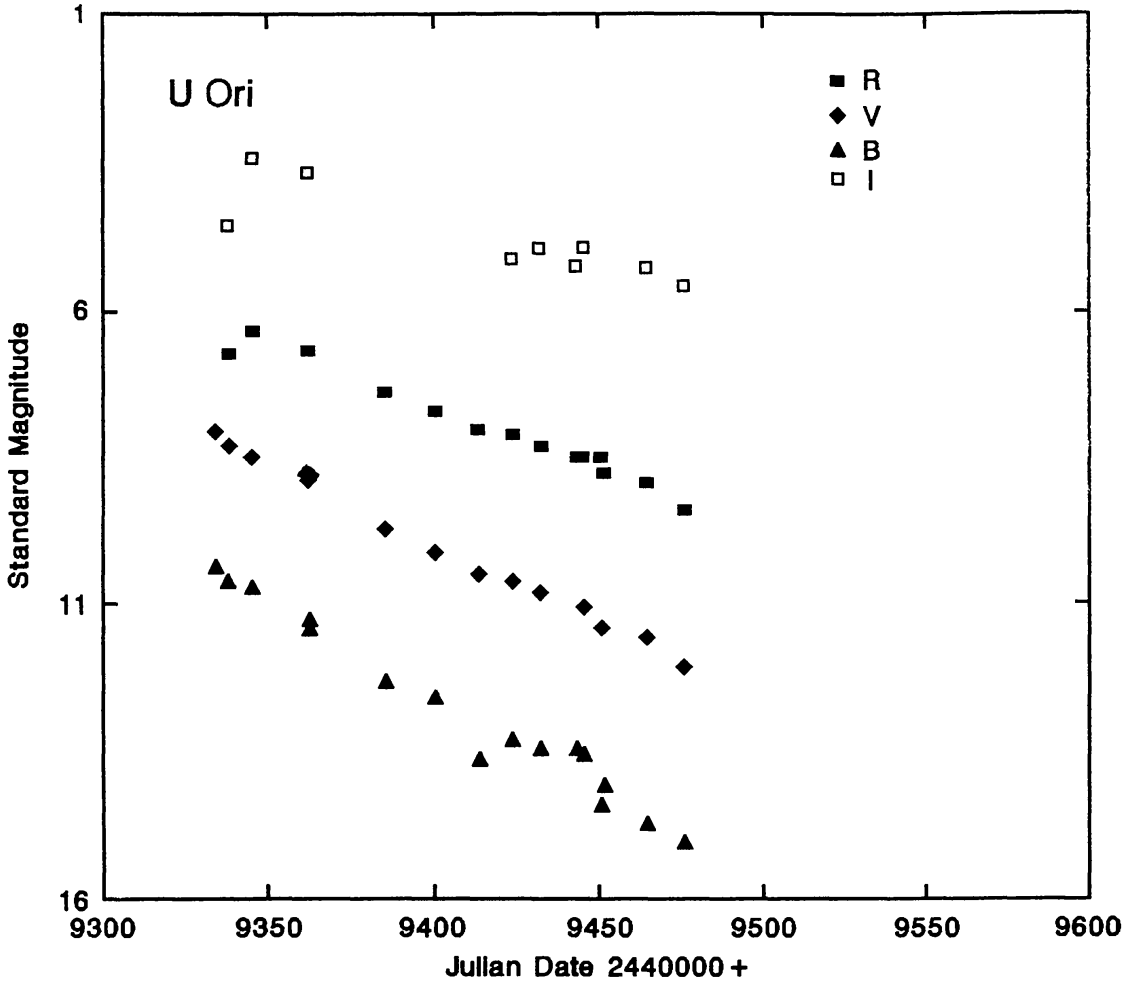


Figure 2. Four-color CCD light curve for U Ori, showing that the variation in B is clearly larger than the variation in I. U Ori varies from 3.5 in I to nearly 15 in B. The B variation is nearly 4.5 magnitudes while the I variation is 2 magnitudes. The B light is apparently being driven by a mechanism that causes more variation than the same mechanism in I. B-V varies from 2.4 to 3 over the observation period. This was not evident in the S Per light curves in Figure 1, since the variation in each color was nearly equal.

Table 2. AAVSO CCD data for U Ori as represented in Figure 2 (above).

*JD*2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*	*JD*2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*
9334.62	10.380	8.050			MTK	9423.56	13.314	10.587	8.097	5.121	ZRE
9338.71	10.636	8.270	6.730	4.587	ZRE	9432.53	13.483	10.791	8.288	4.966	ZRE
9345.68	10.717	8.463	6.312	3.445	ZRE	9443.52	13.453		8.491	5.248	ZRE
9362.54	11.310	8.840			MTK	9445.51	13.576	11.038	8.490	4.925	ZRE
9362.59	11.383	8.936	6.672	3.667	ZRE	9450.55	14.397	11.421	8.507		MTK
9385.54	12.309	9.714	7.354		ZRE	9451.52	14.073	11.383	8.779		ZRE
9400.56	12.603	10.124	7.690		ZRE	9464.53	14.697	11.567	8.935	5.299	ZRE
9413.48	13.609	10.472	8.022		ZRE	9475.56	14.998	12.052	9.396	5.571	ZRE

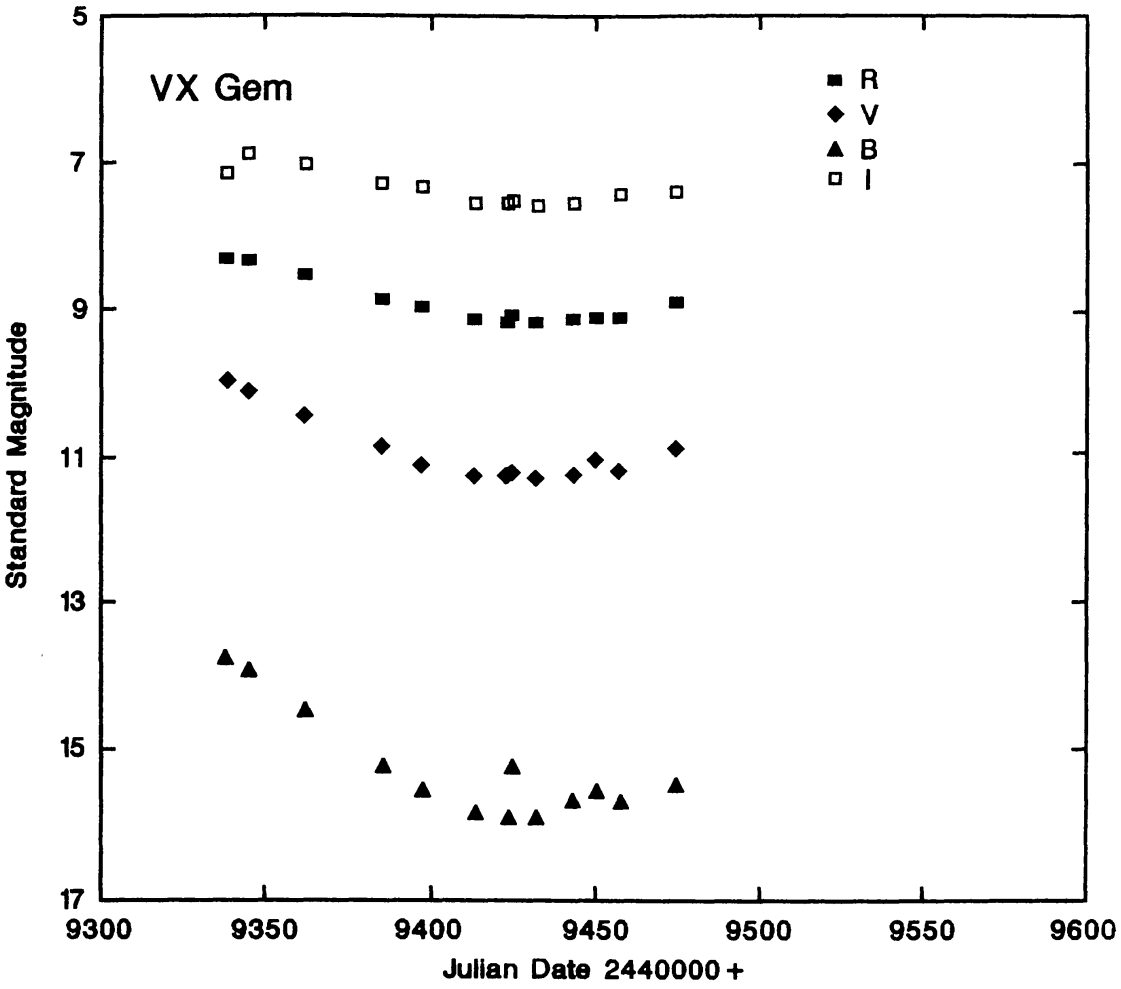


Figure 3. Four-color CCD light curve for VX Gem. Again, the B variation is larger than the I variation (2 magnitudes vs. 0.5 magnitude.) The B-V for this star varies from 3.8 to 4.7, which is much larger than the two preceding stars, and which implies a temperature of 1500 to 1800 K. This light curve also shows the capability of our observers to go down to 16th magnitude with excellent repeatability of better than 0.1 magnitude.

Table 3. AAVSO CCD data for VX Gem as represented in Figure 3 (above).

*JD*2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*	*JD*2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*
9338.75	13.785	9.977	8.315	7.157	ZRE	9424.70	15.260	11.190	9.100	7.530	WGR
9345.71	13.947	10.128	8.380	6.909	ZRE	9432.56	15.974	11.274	9.190	7.590	ZRE
9362.63	14.488	10.442	8.555	7.046	ZRE	9443.58	15.701	11.239	9.145	7.556	ZRE
9385.57	15.279	10.857	8.873	7.295	ZRE	9450.60	15.592	11.030	9.092		MTK
9397.57	15.576	11.110	8.993	7.351	ZRE	9457.56	15.736	11.192	9.093	7.429	ZRE
9413.53	15.883	11.229	9.128	7.548	ZRE	9474.54	15.466	10.882	8.904	7.382	ZRE
9423.63	15.947	11.255	9.177	7.573	ZRE						

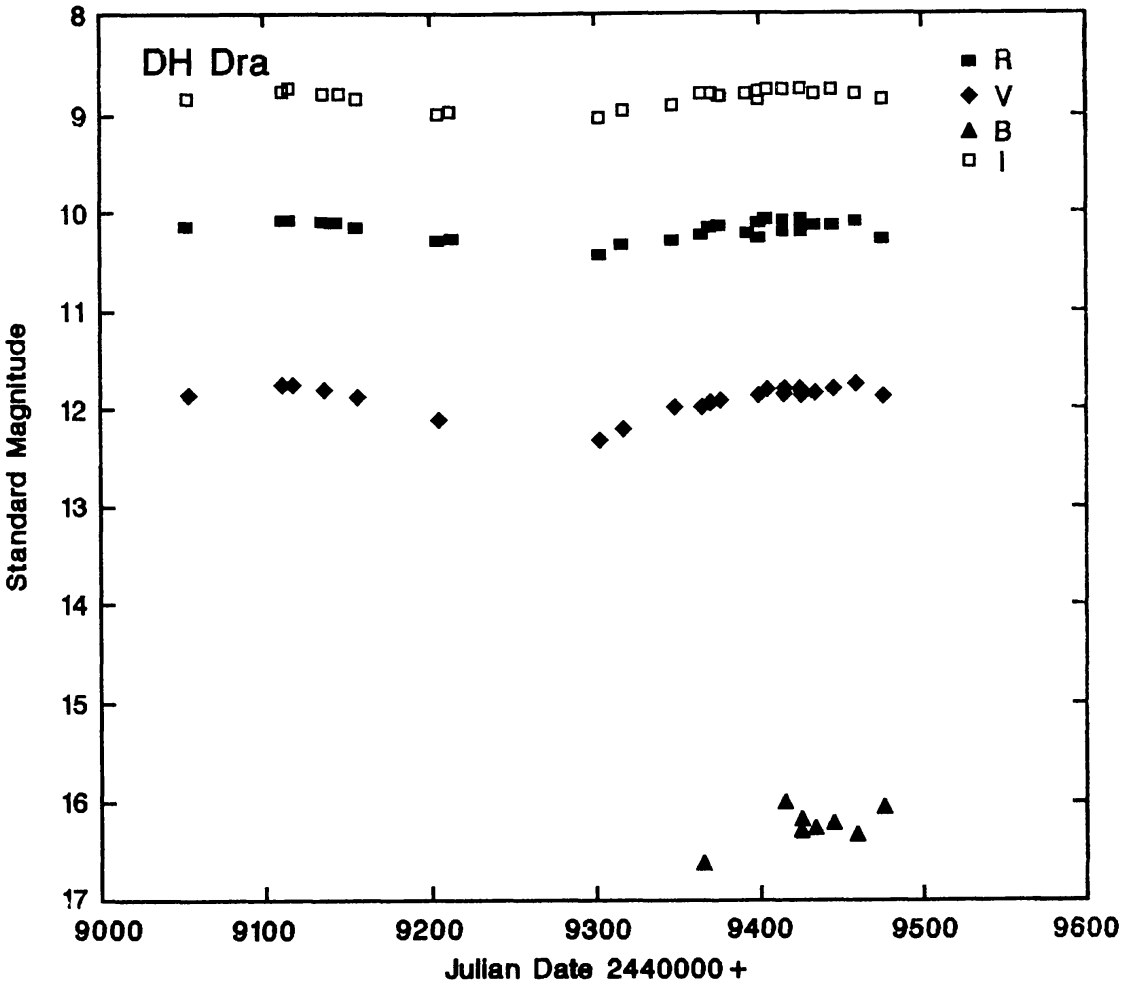


Figure 4. Four-color CCD light curve for DH Dra. The total variation is about 0.5 magnitude for each of V, R, and I. B data are quite sparse and do not warrant a conclusion at this time. The VRI curves seem to track each other.

Table 4. AAVSO CCD data for DH Dra as represented in Figure 4 (above).

JD 2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*	*JD* 2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*
9048.60		11.902	10.191	8.880	BPN	9391.57			10.235	8.813	BPN
9106.63		11.782	10.094	8.796	BPN	9397.66		11.914	10.280	8.874	ZRE
9110.62		11.799	10.092	8.772	BPN	9398.62		11.894	10.144	8.803	BPN
9131.60		11.817	10.128	8.816	BPN	9402.76		11.843	10.103	8.786	BPN
9140.62			10.121	8.830	BPN	9413.59		11.845	10.112	8.785	BPN
9151.63		11.919	10.167	8.867	BPN	9413.63	16.082	11.886	10.212	8.791	ZRE
9201.60		12.156	10.319	9.032	BPN	9423.68	16.372	11.864	10.187	8.775	ZRE
9208.61			10.292	9.006	BPN	9423.75		11.834	10.104	8.785	BPN
9300.60		12.357	10.459	9.079	BPN	9424.75	16.244	11.908	10.213	8.764	WGR
9314.69		12.258	10.381	9.000	BPN	9432.59	16.332	11.884	10.189	8.838	ZRE
9345.78		12.031	10.322	8.933	ZRE	9443.62	16.290	11.837	10.182	8.782	ZRE
9362.76	16.686	12.009	10.270	8.837	ZRE	9457.60	16.410	11.797	10.138	8.839	ZRE
9368.67		11.958	10.207	8.824	BPN	9474.57	16.104	11.913	10.303	8.895	ZRE
9373.91		11.943	10.186	8.849	BPN						

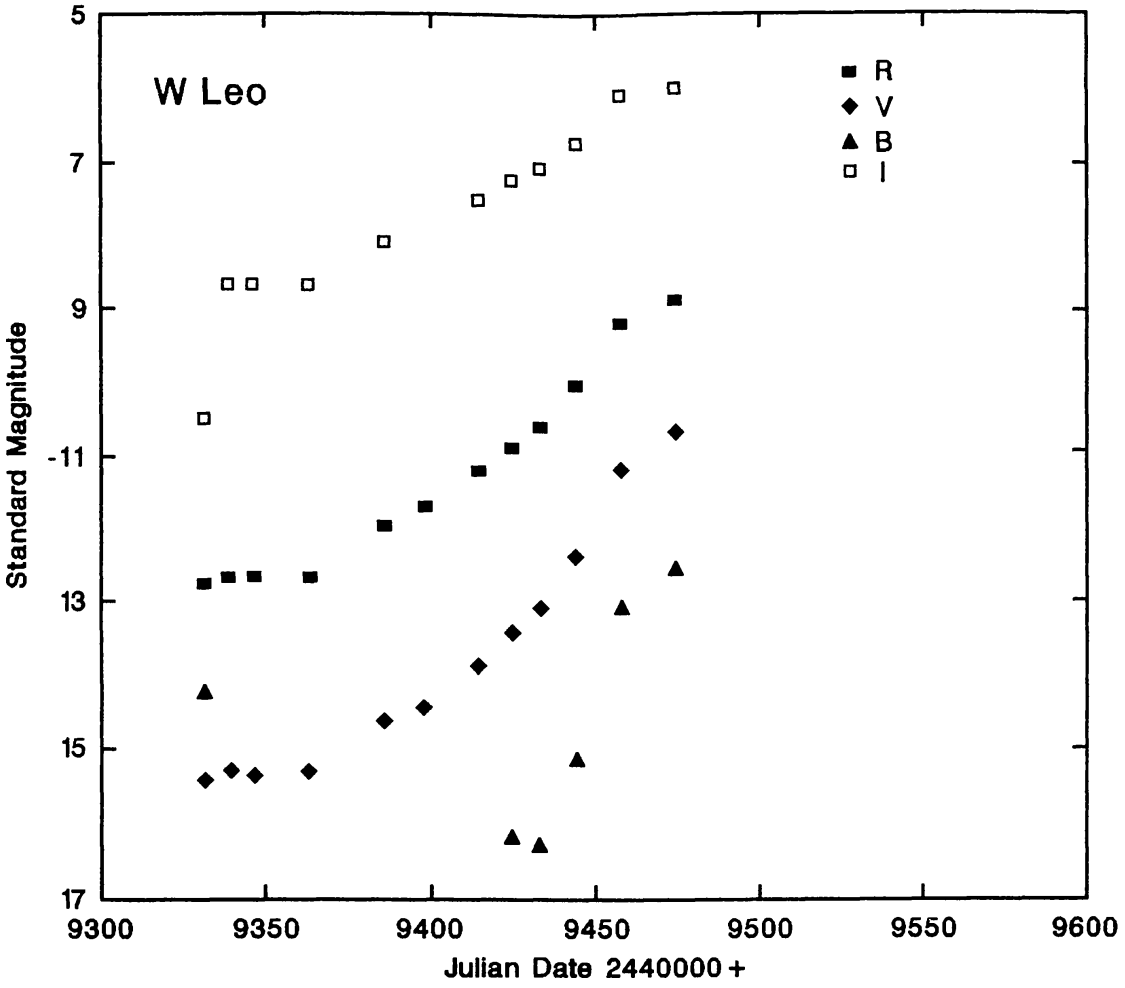


Figure 5. Four-color CCD light curve for W Leo, another variable which shows a larger change in V and R than in I. The V and R variation is 4 magnitudes, while the I change is less than 3 magnitudes in the same period of time. The B-V is 1.9–2.8, implying a temperature of 2300–3100 K, similar to S Per and U Ori. Additional observations are required.

Table 5. AAVSO CCD data for W Leo as represented in Figure 5 (above).

JD 2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*
9330.82	14.230	15.411	12.793	10.525	ZRE
9338.60		15.295	12.708	8.692	ZRE
9345.78		15.373	12.692	8.686	ZRE
9362.81		15.295	12.708	8.692	ZRE
9385.69		14.633	11.973	8.134	ZRE
9397.72		14.435	11.721		ZRE
9413.72		13.868	11.210	7.546	ZRE
9423.74	16.184	13.415	10.879	7.274	ZRE
9432.68	16.305	13.108	10.612	7.096	ZRE
9443.66	15.129	12.412	10.055	6.745	ZRE
9457.67	13.073	11.175	9.220	6.101	ZRE
9474.66	12.546	10.655	8.901	6.026	ZRE

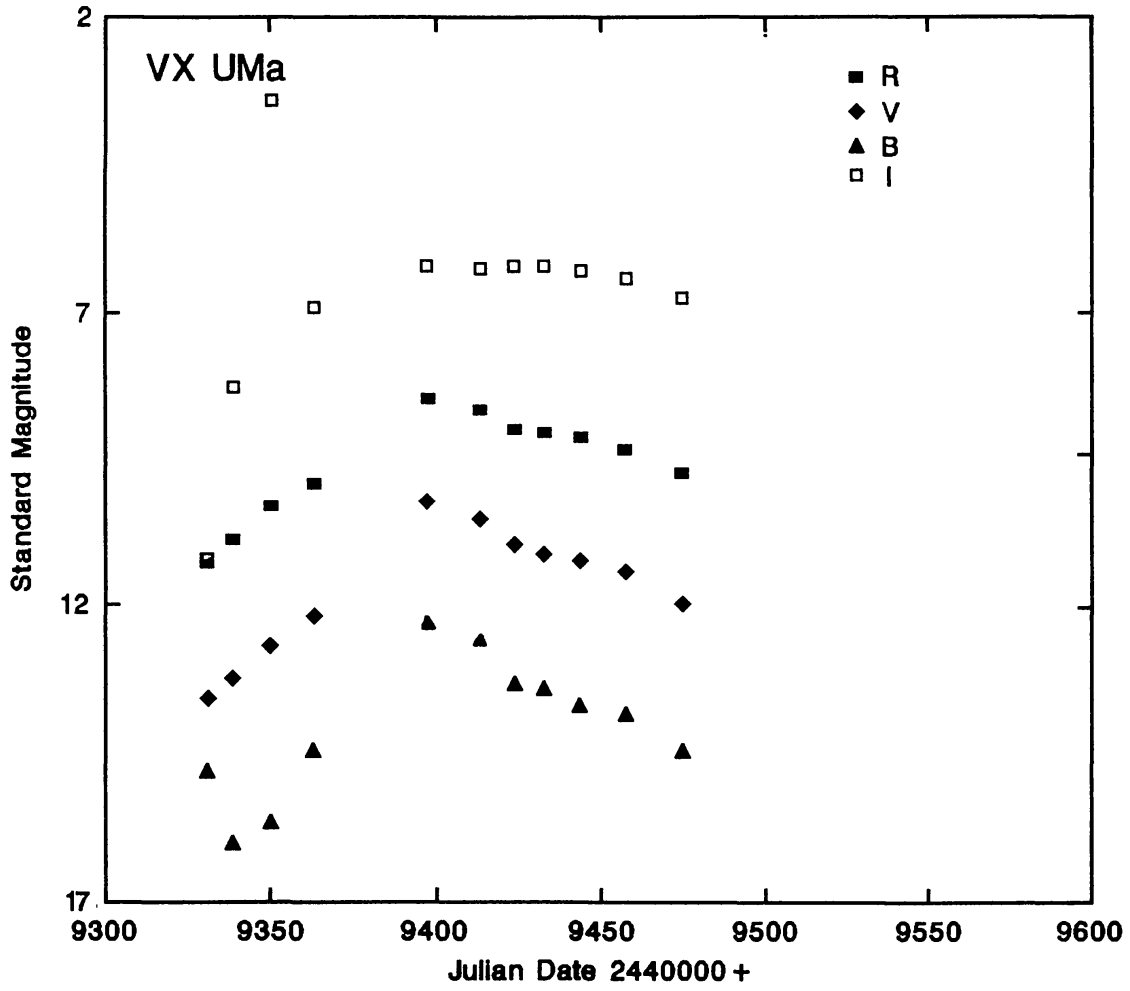


Figure 6. Four-color CCD light curve for VX UMa, showing that the I change is exceeded by the BVR change. It appears that the largest change is in V at 3 magnitudes, while the change in I is less than 1. B-V falls in the 2 to 3 range, implying a temperature of 2500 K.

Table 6. AAVSO CCD data for VX UMa as represented in Figure 6 (above).

JD 2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*
9330.86	14.75	13.523	11.194	11.143	ZRE
9338.78	15.939	13.176	10.791	8.203	ZRE
9349.82	15.577	12.622	10.240	3.355	ZRE
9362.87	14.36	12.134	9.860	6.840	ZRE
9397.68	12.212	10.191	8.404	6.162	ZRE
9413.66	12.534	10.461	8.567	6.192	ZRE
9423.77	13.256	10.897	8.938	6.148	ZRE
9432.62	13.359	11.04	8.966	6.126	ZRE
9443.66	13.621	11.174	9.040	6.224	ZRE
9457.63	13.769	11.342	9.236	6.319	ZRE
9474.61	14.392	11.880	9.667	6.681	ZRE

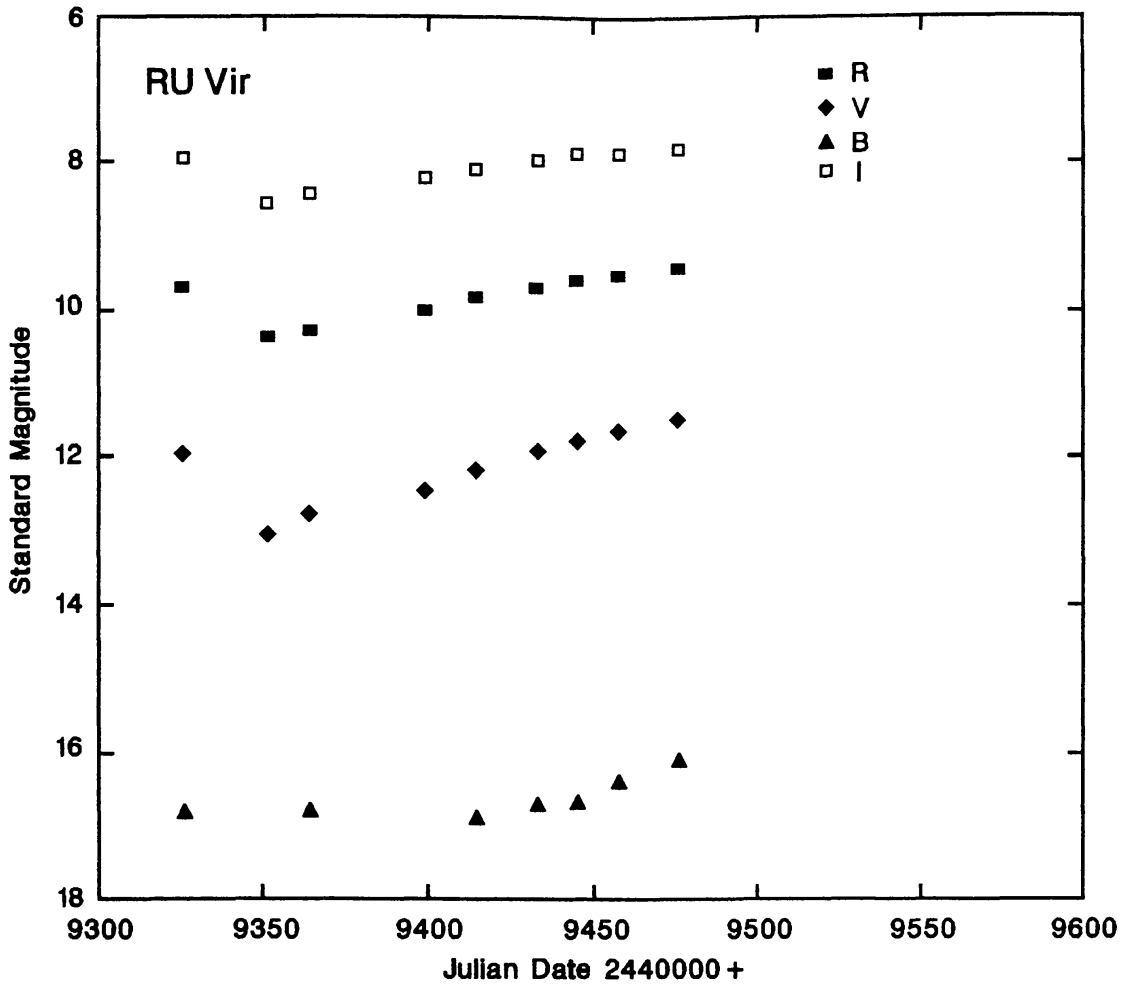


Figure 7. Four-color CCD light curve for RU Vir. RU Vir also has the largest recorded B-V of the stars in this study at nearly 4.9. This is similar to VX Gem and implies a very low temperature of 1500 K. This color index is much larger than that reported in the literature.

Table 7. AAVSO CCD data for RU Vir as represented in Figure 7 (above).

JD 2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*
9349.86	18.375	13.104	10.425	8.595	ZRE
9362.90	16.881	12.827	10.295	8.462	ZRE
9397.76		12.480	10.034	8.227	ZRE
9413.74	16.973	12.184	9.852	8.088	ZRE
9423.80	16.919	12.008	9.729	7.988	ZRE
9432.71	16.8	11.933	9.704	7.959	ZRE
9444.76	16.756	11.837	9.627	7.885	ZRE
9457.73	16.452	11.671	9.536	7.878	ZRE
9475.65	16.188	11.483	9.462	7.791	ZRE

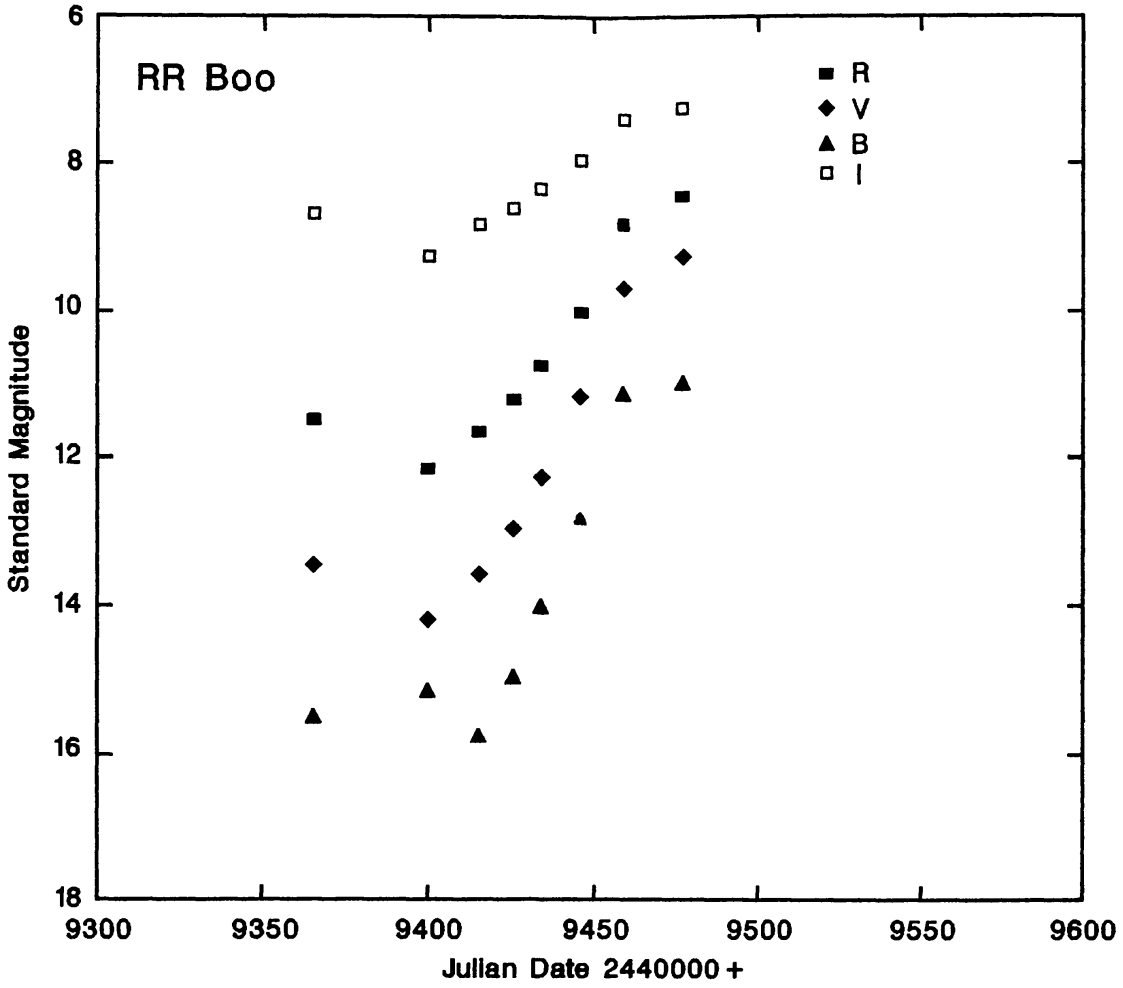
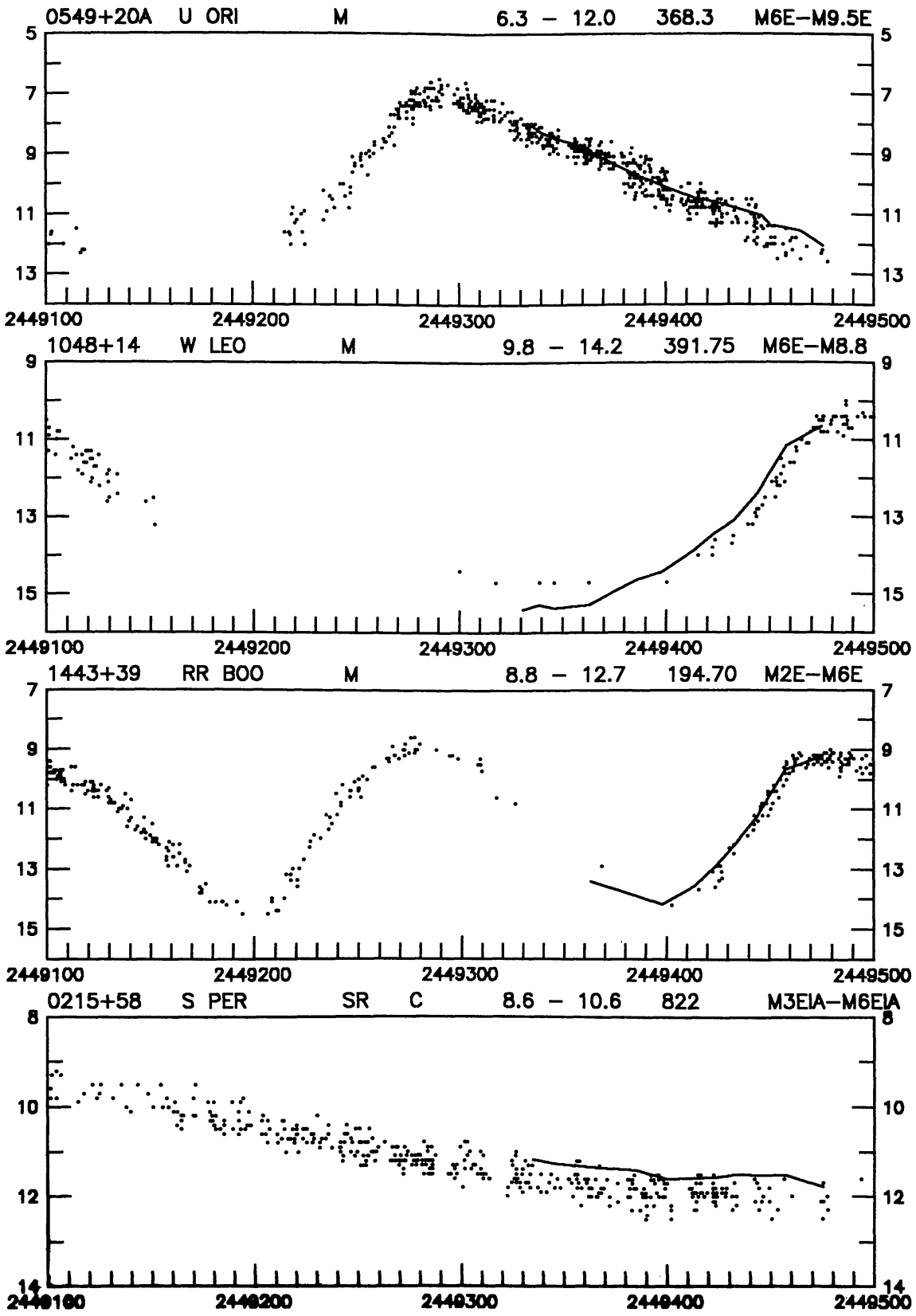


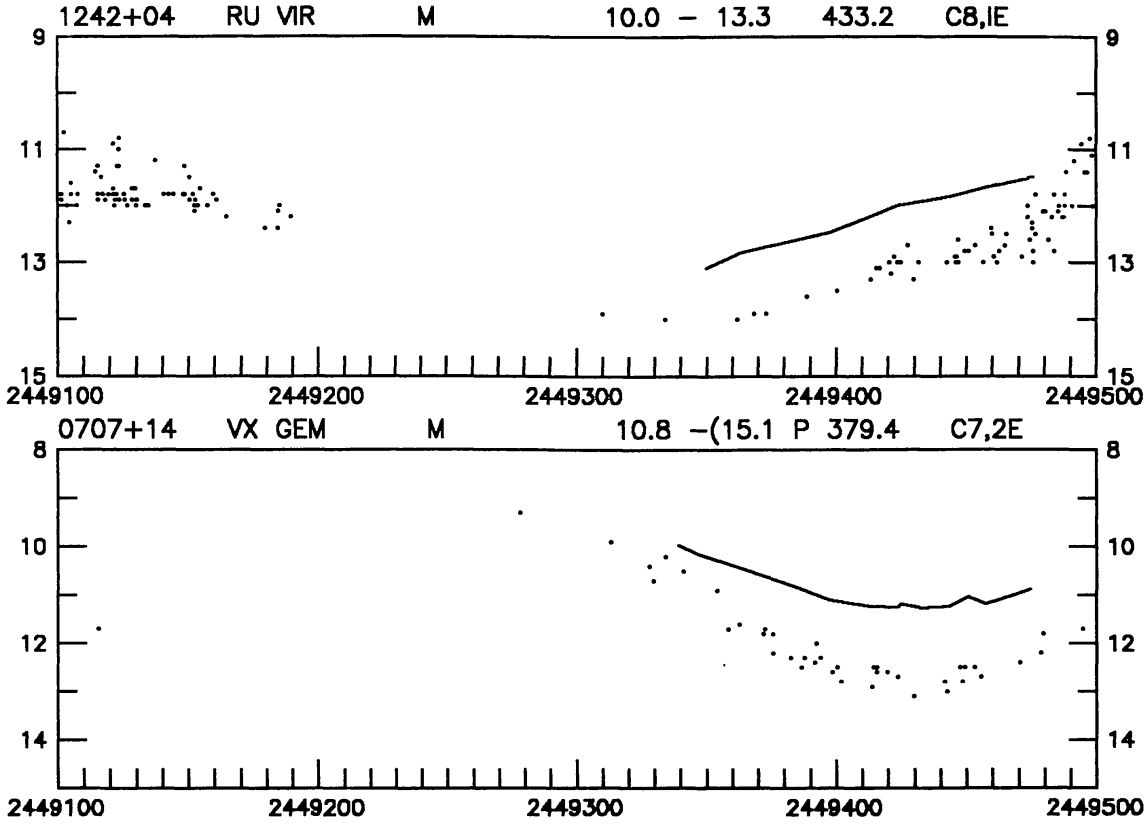
Figure 8. Four-color CCD light curve for RR Boo. Once again the V change of nearly 5 magnitudes exceeds the B, R, and I bands. Once again the B band data has the largest scatter, which is a direct result of signal-to-noise limitation at magnitudes of 15 to 16. Note that the B variation is quite low in scatter in the 10 to 14 magnitude range. This is expected to improve as observers learn to make longer exposures in order to obtain better signal-to-noise ratio measurements. The B-V measures near 2, which is consistent with all others except VX Gem and RU Vir, and places RR Boo's temperature near 3000 K.

Table 8. AAVSO CCD data for RR Boo as represented in Figure 8 (above).

JD 2440000+	*B Mag*	*V Mag*	*R Mag*	*I Mag*	*Obs*
9362.94	15.499	13.423	11.460	8.649	ZRE
9397.78	15.141	14.181	12.125	9.214	ZRE
9413.77	15.756	13.564	11.607	8.755	ZRE
9423.85	14.963	12.927	11.160	8.526	ZRE
9432.74	13.998	12.228	10.703	8.297	ZRE
9444.73	12.797	11.148	9.986	7.932	ZRE
9457.77	11.105	9.656	8.777	7.371	ZRE
9475.61	10.925	9.219	8.368	7.217	ZRE



Figures 9–12. (Top to bottom) AAVSO visual and CCD(V) light curves for U Ori, W Leo, RR Boo, and S Per, covering the time interval of four-color CCD observations (~JD 2449100–2449500). Visual observations are dots; CCD(V) observations are indicated by a line.



Figures 13–14. (Top to bottom) AAVSO visual and CCD(V) light curves for RU Vir and VX Gem, covering the time interval of four-color CCD observations (~JD 2449100–2449500). Visual observations are dots; CCD(V) observations are indicated by a line.