PHOTOELECTRIC MEASURES OF AAVSO COMPARISON STAR SEQUENCES - II

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Abstract

Three related comparisons between photoelectric and visual magnitudes are made: (1) photoelectric V vs m_v for 260 stars listed in the Revised Harvard Photometry, (2) photoelectric magnitude (measured by author) vs chart magnitude for 183 stars on preliminary AAVSO charts, and (3) photoelectric magnitude (from published literature) vs comparison star magnitude for 124 stars on standard AAVSO charts. It is clear from these data that important improvements in sequence accuracy, and in the accuracy of the resulting light curves, will be achieved with the expanded use of photoelectrically measured comparison stars.

* * * * *

Nomenclature

m_a = Magnitude on AAVSO chart

m_v = Visual Magnitude as defined by the Revised Harvard Photometry (Annuals of Harvard College Observatory, 50).

m = Visual magnitude calculated by correcting photoelectric V for color (see text)

V,B= Photoelectric magnitudes in the UBV system

1. Introduction

A program to photoelectrically measure new comparison stars to extend sequences of preliminary AAVSO charts was undertaken in 1977. Almost immediately it was discovered that a smooth transition between existing chart magnitudes and new photoelectric values could not be achieved. As more sequence stars were examined, it became evident that many of the existing comparison star sequences (m_a) are systematically too bright, and that the star-to-star and field-to-field dispersions of these magnitudes are large. These conclusions were supported with data from 47 comparison stars in an earlier paper (Stanton 1978, hereafter referred to as Paper I). The present paper expands these results to include standard as well as preliminary charts, and published photoelectric data by other observers. Also included is an empirical comparison between the visual magnitude scale defined by the Revised Harvard Photometry and the UBV system. It is hoped that these expanded results will help to quantify accuracy limits on existing AAVSO sequences, and inspire others to undertake photoelectric sequence work.

2. Instrumentation

The equipment used (16-inch Cassegrain/photon-counting photometer) has not been significantly altered from that described in Paper I. Data acquisition and reduction are now accomplished using a micro-computer thus eliminating errors introduced by "eyeballing" a chart recorder trace, and greatly facilitating the computations. Photon-counting guarantees high linearity and essentially quantum-limited noise, permitting the measurement of magnitude and color for any star visible in the telescope.

An assessment of system accuracy was achieved by measuring stars in standard photoelectric fields, Selected Areas 62, 94, 100, 102 (USN Obs. 1974). Results of this assessment indicate good performance (average error $<0^{m}.02$, standard deviation $<0^{m}.04$) over the range $V = 7^{m}$ to 16^{m}. Measurements of these stars are plotted in Figure 1, using the same scale as in Figures 3 to 6 for comparison.

3. Color Correction

Paper I presented results of an analytical computation of the difference between m_V and V as a function of star color (B-V). On reflection, Howarth's (1979) empirical approach seems preferable since it makes use of a large body of visual observations of stars rather than depending on other measurements of eye characteristics. I repeated his study of the Harvard visual magnitude scale using a different set of stars and photoelectric magnitudes and colors from the Naval Observatory Catalog (1970). Figure 2 shows the results of this study for 260 stars. Only stars in the range $5^{m}.5 < m_V < 6^{m}.5$ were considered, to lessen any magnitude-related effects. Note that the previously-adopted color-correction curve (dashed), based on an analytical computation of the eye response to various stars (Paper I, Fig. 1, Curve 5), does not adequately represent the empirical data. This disagreement was previously noted by Howarth (1979) for his independent calculations.

A linear least squares fit to the 260 points yields

$$m_V = V + .182\ (B-V) - 0.032 \qquad (1)$$

with a standard deviation (scatter about the least squares line) of $0^{m}.067$. This result is very close to Howarth's equation (1) and nearly identical to his results using other sources for m_V.

The additive constant in equation (1) is a function of the magnitude range considered if the slope of m_V vs V at constant color is not 1.0. Howarth (1977) suggested that this slope is in fact somewhat less than unity. This implies that a comparison between m_V and V in a higher magnitude range (e.g. $10 < m_V < 11$) would result in a larger negative value than $-0^{m}.032$. Since this "constant" is not uniquely defined by the m_V scale, the following definition was adopted:

$$m = V + .182\ (B-V) - 0.15 \qquad (2)$$

The selection of $-0^{m}.15$ for the additive constant has two substantial benefits, particularly when used for comparison star sequences. First, it corresponds to the relationship between m_V and V at a higher magnitude range than evaluated in Figure 2. Since most comparison star magnitudes are fainter than the $m_V = 6.5$ limit used for this Figure, a more negative constant is indicated. Secondly, the constant selected minimizes the differences between m and V for star colors common in comparison star sequences ($.3 < B-V < 1.5$). Thus, equation (2) corrects for color differences between the dark-adapted eye and the photoelectric V system without introducing an average offset between the two scales.

Whenever photoelectric measurements of V and B-V are available, application of equation (2) will yield a visual magnitude that closely matches the Harvard Revised Photometry scale except that equation (1) forces the slope of m vs. V (at constant color) to be unity. Although a more accurate fit to the Harvard scale could be achieved with a non-unity slope, use of such an equation would serve to preserve scale errors present in the old magnitudes. For these reasons, equation (2) will be used throughout the remainder of this paper for computing visual magnitudes (m) from photoelectric measurements (V, B).

4. Comparison Star Residuals on Preliminary Charts

Figure 3 shows the comparison star residuals vs AAVSO magnitude for comparison stars appearing on 17 AAVSO preliminary charts. (It is assumed throughout this discussion that errors in the photoelectric measurements are negligible relative to those of other measurements.) In this and following figures, a point falling above the zero ordinate corresponds to a star which is fainter (measured photoelectrically) than the AAVSO value (m_a) indicates. The m values are calculated using equation (2) based on photoelectrically measured V and B-V. A tabulation of the individual data points, and the preliminary charts used, is provided in Table I.

It should be noted that many of these charts are classified as "preliminary" due to known inadequacies in their comparison star sequences. Therefore, one should not be too surprised to find the sequence errors evident in Figure 3. The average value for $m - m_a$ is $0\overset{m}{.}34$, down from $0\overset{m}{.}61$ in Paper I due principally to changes in the adopted color correction (equation (2)). The standard deviation of the residuals is $0\overset{m}{.}41$, due partly to field-to-field variations and partly to star-to-star inconsistancies within a given field.

As discussed in Paper I, it is probably more meaningful to consider $m - m_a$ after field-to-field variations in m_a have been removed. In Figures 4 and 5, residuals (designated $(m - m_a)_o$) are adjusted so each field has an average offset of $0\overset{m}{.}34$, while the star-to-star dispersions within each field remain unchanged. The statistical properties of the resulting data represent a composite of the properties of the individual sequences, without the distorting influence of large zero-point errors.

The least squares line in Figure 4 indicates a weak but definite trend toward lower values of $m - m_a$ for brighter stars. The dispersion about the mean, however, is so large ($\sigma = 0\overset{m}{.}26$) that substantial errors ($>0\overset{m}{.}5$) are present for many stars, even some as bright as 9th magnitude. This standard deviation is nearly four times larger than that found for the Revised Harvard Photometry ($0\overset{m}{.}067$). If one assumes that the accuracy of the Harvard Catalog is representative of that achievable through visual means, one must conclude that sequence errors are the dominant source of observation error when preliminary AAVSO charts are used.

In Figure 5, the same residuals are plotted as a function of star color (B-V). It is reassuring that no significant color dependence can be found (slope of least squares fit does not differ significantly from zero).

5. Comparison Star Residuals on Standard Charts

What about charts which have been finally corrected and are available directly through AAVSO Headquarters (i.e. those not considered preliminary)? Figure 6 summarizes residuals calculated from published photoelectric measurements (Lenouvel and Daguillon 1956; Bailey and Howarth 1979; Howarth and Bailey 1980) for a select group of 12 star fields in this category (RX And, SS Aur, Z Cam, U Gem, X Leo, CN Ori, CZ Ori, SU Tau, AB Dra, RU Peg, TZ Per, UV Per). A comparison between Figures 3 and 6 indicates that the Standard chart sequences appear to be far superior to those on preliminary charts out to about $m_v = 13$. For fainter stars the under-estimation of comparison star magnitudes again appears as a substantial systematic error. As pointed out by Bailey and Howarth (1979), this compression of the magnitude scale can lead to important light curve distortions, particularly when one is attempting to quantify parameters such as the period/amplitude relationship for U Gem stars.

6. Conclusions and Recommendations

Bailey and Howarth end their photoelectric study of visual comparison star sequences (from the Leander McCormick Observatory) with the conclusion that "the dominant source of uncertainty in any discussions of the collective properties of variable stars determined from visual observations" is sequence error. This conclusion is apparently also valid for AAVSO standard charts, and seems especially true for the preliminary charts.

The use of photoelectrically measured comparison star sequences is strongly recommended to reduce these errors. Once photoelectric measurements (V,B) are obtained, equation (2) can be used to produce comparison star magnitudes which take into account differences between the dark-adapted eye and the V scale. Since there are hundreds of fields to measure, appropriately equipped amateurs can make important contributions to this effort.

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Lenouvel, F. and Daguillon, J. 1956, Journ. des Observateurs 39, 1.

Priser, J. B. 1974, Publ. U. S. Naval Obs., Second Series, XX, VII, Washington, D. C.

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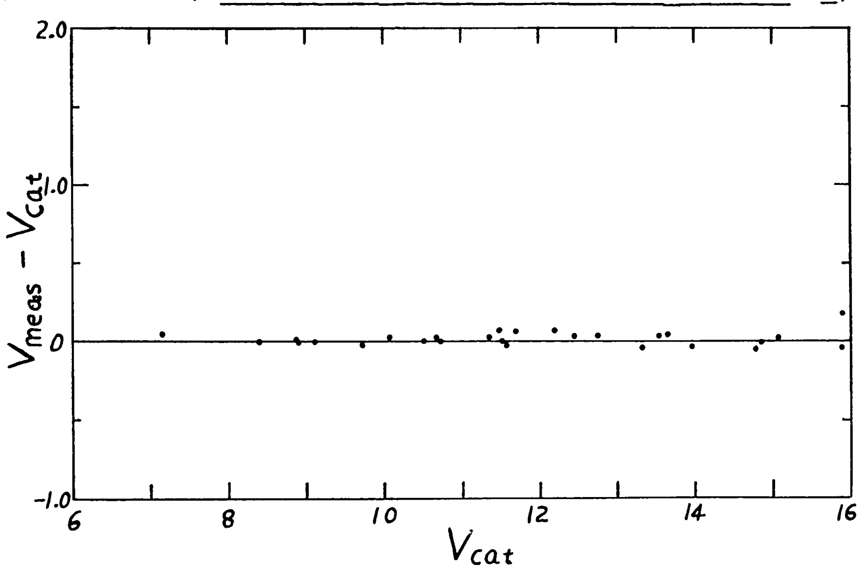


Figure 1. Photoelectric V residuals of author's measurements relative to catalog values of stars in Selected Areas (USN Observatory 1974).

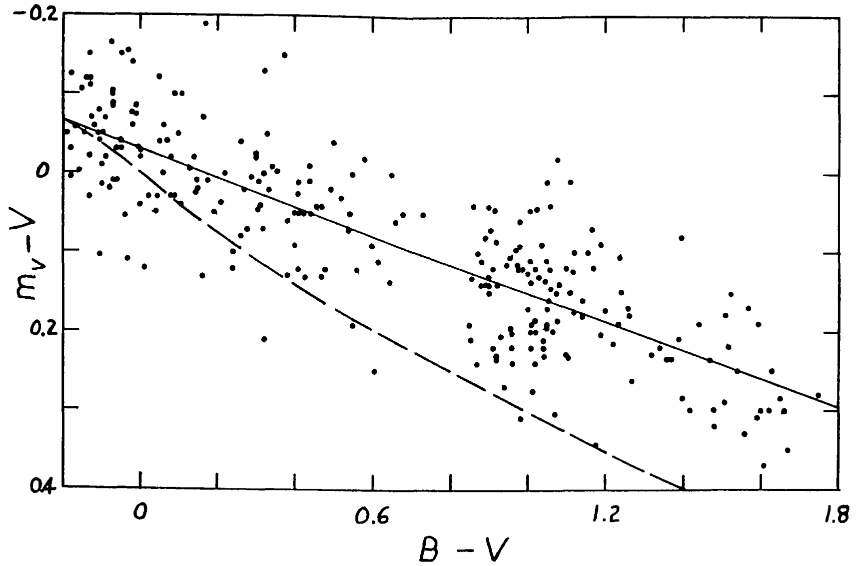


Figure 2. Difference between m_V and V vs star color (B-V). Sources of data: m_V from Revised Harvard Photometry (Ann. Harvard Coll. Obs. 50); V and B-V from USN Observatory Photoelectric Catalog (1970). Solid line is least squares fit (equation (1)); dashed line is previous analytical curve (Paper I).

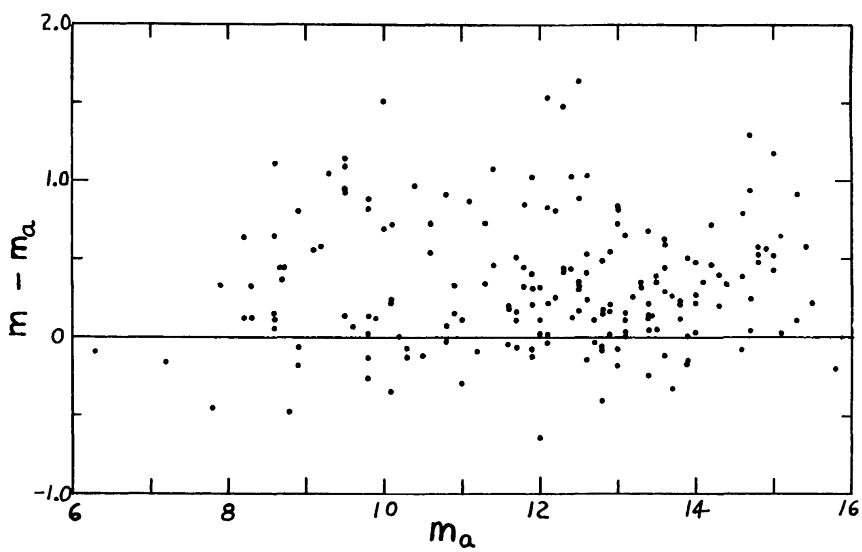


Figure 3. Preliminary chart residuals. Difference between photoelectric m (calculated using equation (2)) and magnitudes appearing on preliminary AAVSO charts (m_a).

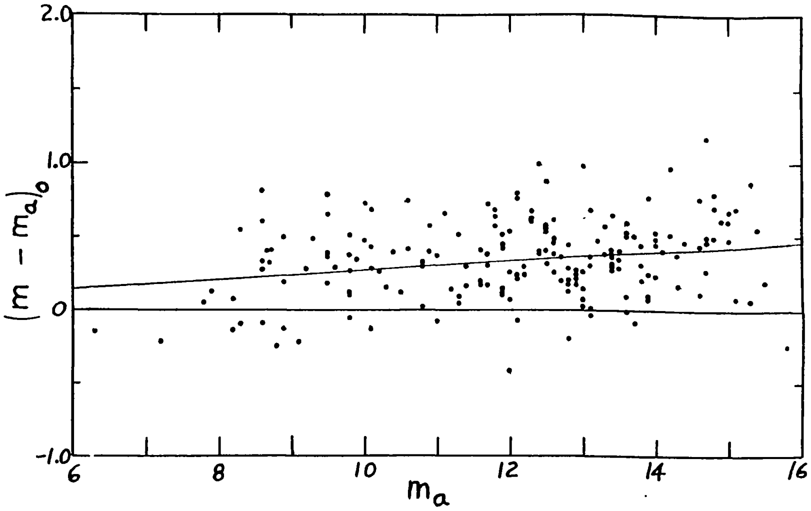
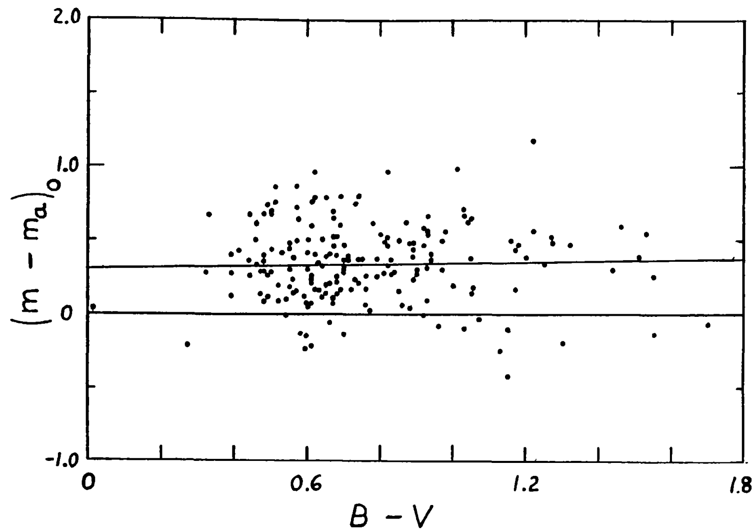


Figure 4. Preliminary chart residuals after field-to-field variations have been eliminated. Residuals are adjusted to give each field the same average offset (0^{m}34), while the relative star-to-star dispersions within each field remain unchanged.

Figure 5. Data from Figure 4 plotted vs star color (B-V).



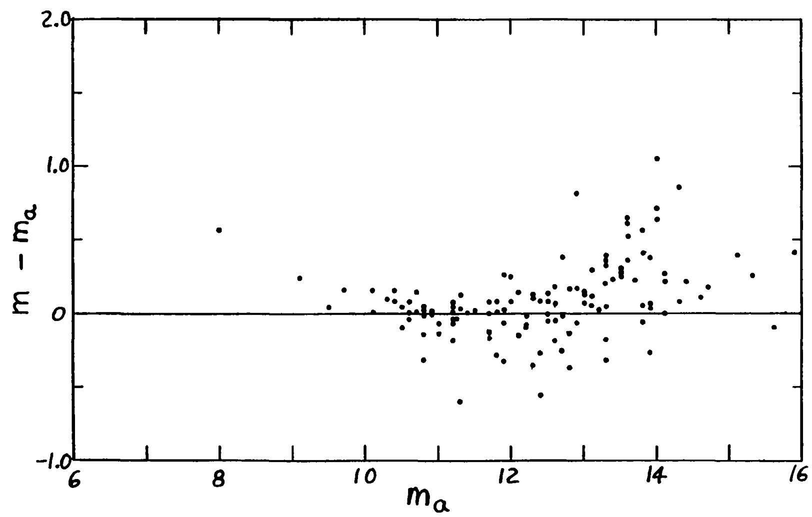


Figure 6. Standard chart residuals - Difference between photoelectric m and magnitudes appearing on standard AAVSO charts (m_a). From this limited sample it appears that standard chart magnitudes are substantially better than those of preliminary charts (Fig. 3), at least to m_a = 13.

TABLE I - Photoelectric Measurements of Preliminary Chart Comparison Stars

071628 AW Gem (1972)

m_a	m	V	B-V
10.6	11.27	11.34	.44
11.7	12.20	12.16	1.00
12.5	12.81	12.73	1.25
12.8	12.74	12.83	.34
13.0	12.82	12.83	.76
13.1	13.23	13.31	.42
13.4W	13.51	13.49	.91
13.4E	13.63	13.65	.69
13.8	13.94	13.98	.58
14.6	14.54	14.58	.62
14.0	14.00	14.01	.89

083126 AA Cnc (1969)

m_a	m	V	B-V
7.8	7.31	7.45	.02
12.6	12.43	12.43	.84
13.1	13.25	13.34	.31
13.4	13.13	13.13	.84

092421 TU Leo (1974)

m_a	m	V	B-V
8.9	8.84	8.80	1.05
9.8	9.80	9.66	1.58
10.5	10.43	10.50	.48
10.9	11.04	10.98	1.20
11.2	11.10	11.06	1.05
11.7	11.66	11.67	.74
12.3	12.72	12.70	.94
12.5	12.84	12.82	.93
12.7	12.85	12.89	.64
12.9	12.97	13.01	.62
13.4	13.46	13.45	.84
13.9	13.77	13.81	.62
14.2?	14.93	14.93	.83

122714 AL Com (1974)

m_a	m	V	B-V
11.9	11.84	11.89	.56
12.0	12.01	12.02	.80
13.5	13.54	13.54	.84
13.7	13.94	13.87	1.19
13.9	13.94	13.98	.56
14.7	14.75	14.79	.66
15.0	15.42	15.38	1.04

135304 SY Vir (1975)

m_a	m	V	B-V
8.2	8.79	8.65	1.61
9.1	9.70	9.74	.61
9.5E	10.50	10.56	.52
9.5W	10.69	10.75	.54
9.8	10.73	10.79	.51
10.0	11.55	11.60	.56
11.4	12.47	12.46	.90
12.1	13.67	13.73	.48
12.3	13.82	13.89	.47
12.5	14.18	14.23	.56

135304 SY Vir (1975) Cont.

m_a	m	V	B-V
12.6	13.63	13.65	.76
13.0	13.85	13.86	.76
14.7	16.02	16.09	.44

145441 TT Boo (1971)

m_a	m	V	B-V
7.2	7.02	7.12	.30
8.2	8.34	8.38	.62
8.6	9.26	9.30	.63
12.4	12.82	12.81	.91
12.6	13.11	13.10	.89
13.5	13.86	13.78	1.26
14.6	15.40	15.42	.75
15.8	15.63	15.65	.62

151336 RT Boo (1974)

m_a	m	V	B-V
7.9	8.24	8.31	.46
8.6	9.70	9.72	.71
8.9	9.67	9.64	.97
9.2	9.77	9.86	.31
9.5E	10.45	10.47	.69
9.5W	10.60	10.64	.63
9.8	10.58	10.61	.70
10.6	11.33	11.37	.61
11.3	11.62	11.61	.90
11.4	11.87	11.90	.64
11.9	12.30	12.32	.69
12.1	12.32	12.29	.98
12.9	13.45	13.49	.62
13.1	13.76	13.82	.49

152319 WX Ser (1972)

m_a	m	V	B-V
6.3	6.24	6.29	.55
8.7W	9.12	9.10	.91
8.7M	9.15	9.24	.33
8.7E	9.09	9.15	.50
10.1	10.84	10.92	.38
11.6	11.82	10.84	.68
12.0	12.14	12.18	.58
12.1	12.95	12.99	.64
12.4	13.41	13.38	.98
12.9	13.12	13.16	.60
13.1	13.09	13.05	1.04
13.4	14.16	14.23	.45
14.3	14.53	14.60	.46
15.0	15.54	15.59	.53
15.3	15.40	15.40	.83

155420a AH Ser (1977)

m_a	m	V	B-V
9.3	10.32	10.25	1.20
10.4	11.37	11.43	.48
10.8	11.74	11.77	.61
11.9	12.89	12.94	.57
12.2	13.01	13.05	.61

TABLE I (Continued)

155420a AH Ser (1977) Cont.

m_a	m	V	B-V
12.5	13.39	13.37	.97
13.0	13.84	13.90	.49
13.6	14.19	14.24	.54
15.0	16.18	16.20	.69

155502 BC Ser (1971)

m_a	m	V	B-V
8.8	8.28	8.23	1.11
9.5	9.64	9.72	.41
9.8	9.90	9.86	1.04
10.9	11.19	11.18	.92
11.8N	12.25	12.32	.45
11.8S	12.09	12.06	.97
12.5	12.67	12.69	.69
12.8	12.71	12.65	1.15
13.0	12.73	12.76	.63
13.7	13.32	13.26	1.16
13.9	13.75	13.77	.67

165404 V855 Oph (1971)

m_a	m	V	B-V
9.8	9.66	9.70	.59
10.2	10.22	10.30	.39
10.8	10.86	10.87	.81
11.0	11.11	11.13	.75
11.9	11.82	11.85	.65
12.1	12.06	12.08	.74
12.4	12.53	12.56	.65
12.8	12.98	12.88	1.37
13.4	13.53	13.55	.71
13.9	14.51	14.56	.56

170217 VY Her (1977)

m_a	m	V	B-V
8.3	8.60	8.47	1.53
8.6E	8.65	8.66	.79
8.6W	8.71	8.73	.70
9.6	9.71	9.77	.48
9.9	10.05	10.13	.41
10.1	10.33	10.41	.36
10.3	10.22	10.22	.83
11.3	11.17	11.23	.52
11.6W	11.55	11.56	.76
11.6E	11.78	11.81	.62
11.7	11.86	11.74	1.51
12.0	12.32	12.35	.69
12.1	12.12	12.14	.73
12.5	12.81	12.81	.84
12.6	12.82	12.76	1.16

180514 UZ Ser (1979)

m_a	m	V	B-V
9.8	9.67	9.72	.54
10.1	9.88	9.93	.60
11.7	11.89	11.80	1.31
11.9	12.26	12.35	.34
12.3	12.81	12.82	.77
12.6	13.12	13.15	.68

180514 UZ Ser (1979) Cont.

m_a	m	V	B-V
12.8	12.48	12.41	1.17
13.2	13.55	13.55	.80
13.8	14.14	14.14	.78
14.7	15.74	15.69	1.09

183024 CH Her (1979)

m_a	m	V	B-V
8.9	8.74	8.79	.58
10.1	10.33	10.42	.36
10.8	10.81	10.99	-.16
11.9	12.18	12.16	.96
12.2	12.45	12.47	.71
12.8	12.99	13.02	.65
12.9	13.08	13.10	.69
13.3	13.61	13.63	.75
13.5	13.86	13.89	.66
13.6	14.04	14.04	.85
14.0	14.48	14.51	.68
14.1	14.46	14.48	.72
14.2	14.65	14.65	.82
14.9	15.49	15.57	.43
15.1E	15.13	15.19	.48
15.1W	15.74	15.80	.50

183138 LL Lyr (1973)

m_a	m	V	B-V
13.1	13.13	13.11	.92
13.6	14.22	14.11	1.46
13.8	14.04	14.07	.66
14.3	14.70	14.71	.79
14.8	15.33	15.33	.81
15.4	15.98	15.96	.93
15.5	15.72	15.69	1.00

184826 CY Lyr (1979)

m_a	m	V	B-V
11.0	10.70	10.54	1.70
12.0	11.38	11.33	1.10
12.7	12.53	12.58	.51
13.0	12.92	12.95	.65
13.3	13.64	13.57	1.22
13.4	13.56	13.59	.66
13.6	13.96	13.94	.57
14.0SW	14.27	14.26	.89
14.0NE	14.24	14.27	.63
14.4	14.64	14.64	.82
14.7	14.92	14.94	.71
14.8N	15.38	15.40	.74
14.8S	15.29	15.31	.68

193628 HY Cyg (1980)

m_a	m	V	B-V
8.3	8.47	8.63	-.07
8.6	8.76	8.73	1.01
10.0	10.69	10.61	1.27
11.1	11.97	11.91	1.15
11.3	12.03	12.08	.56
11.8	12.65	12.59	1.15
12.8	13.35	13.40	.50