Transformation of AAVSO Archive Visual Data to the Johnson *V* System

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Abstract Comparison star magnitude sequences on older AAVSO charts come from various sources and often differ from magnitudes in the modern *V* system. Archived variable star data in the AAVSO International Database can be transformed by various algorithms. The transformed observations can be better combined with modern observations.

1. Introduction

Professional astronomers are making increased use of the extensive AAVSO International Database for planning observing proposals and for analyzing long term variable star behavior. Modern photometric observations are now made in well-defined standard photometric systems. The AAVSO database is composed largely of visual magnitude estimates, while CCD and PEP contributions are usually made in a standard color system.

Problems appear to arise when some visual data are combined with electronic data. This paper will investigate the origins of these problems and offer solutions to transform the visual data so that they will be of greater use.

Rigorous transformation algorithms require detailed information about the observer's color senstivity, and which comparison stars and what chart were used. Observers are asked to report the comparison stars and the chart used in each observation. In practice, some of this information may be omitted from the report. The corrections discussed below are only a first order approach to show that improvments can be made. Better corrections are possible at a cost of time and efficient organization of the data.

One assumption throughout this paper is that CCD*V* observations are close to the Johnson *V* system. Some AAVSO CCD*V* observations are color-corrected and others are not. One cannot tell from the database which are corrected. In the case of Mira stars, their strong red color affects the CCD*V* magnitude observed through the broad pass band of the *V* filter. In some systems the correction to the CCD*V* is only a few percent for a $(B-V)$ of +1. In cases where the variable has a $(B-V)$ of +4.0, the correction may be over 0.1 magnitude. This size error is not too significant compared with the scatter in the visual data. It is still a systematic problem of which one must be aware.

2. Cataclysmic Variables

Let us start with the case of Z Cam. This star is the prototype of the Z Cam class of cataclysmic variable (CV) stars. Figure 1a shows a portion of the light curve of data from the AAVSO International Database (Mattei 2002) with outburst cycles and a standstill. The open circles represent only visual data. Note that Z Cam varies from magnitude 13.3 to 10.4.

The AAVSO chart used for this variable is a Standard chart in d scale labled 11/36. The sequence is from 1936! I have calibrated this field in the *BVR* magnitude system and find that the comparison stars at the brighter end of the sequence are labeled too faint while those at the faint end are labeled too bright.

Figure 1b shows a plot of AAVSO chart magnitude versus *V* magnitude. The text gives the slope, S, and zero point, Z_p, to be applied in three magnitude ranges. These coefficients are the parameters in Equation 1 which is used to correct the magnitude estimates, m_v, based on the old chart sequence to Pogson magnitude steps and Johnson *V* scale:

$$V = \mathrm{S} \times m_v + \mathrm{Z_p} \qquad (1)$$

See Pannekoek (1961) for details on the Pogson magnitude steps definition.

Two fields in the AAVSO Faint Cataclysmic Variables/Long Period Variables CCD observing program had corrections that were best represented by a polynomial formula as in Equation 2 with coefficients A0–A4, indicating that the magnitude step size varied with the brightness of the comparison stars. They were SS Del and LL Lyr:

$$V = \mathrm{A0} + \mathrm{A1} \times m_v + \mathrm{A2} \times m_v^{\,2} + \mathrm{A3} \times m_v^{\,3} + \mathrm{A4} \times m_v^{\,4} \qquad (2)$$

After correcting the visual magnitudes, Z Cam now varies from 13.6 to 10.1; see Figure 1c. The amplitude has changed from 2.9 to 3.5. A change of 0.6 magnitude represents a flux ratio of 1.74. The amplitude of Z Cam is really 74 percent greater than previously measured with the old nonstandard sequence.

To an astronomer researching Z Cam it would appear that the amplitude had increased from previous years if recent *V* magnitude data were compared to AAVSO visual archive data.

In a second case, SU UMa, another prototype of its class, also needs scale corrections. At the faint end of the scale the comparison stars are labeled too bright. After correction, the flux ratio becomes 23 percent greater than without correction. Table 1 lists the changes required for both Z Cam and SU UMa.

3. Long Period Variables

The Light Curve Generator on the AAVSO web site (*www.aavso.org*) plots visual data together with CCD *V* data using different symbols. One can see that the two types of observations often are a whole magnitude or more apart over a large part of the light curve.

The usefulness of CCD observations shows itself in Figure 2a where the minimum of the long period variable (LPV) TY Cas is observed near 18th magnitude in the data from the AAVSO International Database (Mattei 2002). The visual observations stop at 16th magnitude and these observations are poorly determined. The chart sequence stops at magnitude 15.4.

Figure 2b shows that the sequence is linear and and adheres to Pogson magnitude steps down to 12.9. Only a 0.2-magnitude constant need be added at the brighter end of the sequence. Below 12.9 the comparison star magnitudes are too faint. Applying the scale correction to TY Cas only changes the faint end of the lightcurve significantly; see Figure 2c.

The most important difference between CV and LPV observations is the color of the variable. LPVs are cool stars that appear quite red to the eye while most comparison stars are hotter and therefore bluer. The observer's eye sees red objects as fainter than blue ones even though they have the same flux when measured through a narrow band filter.

Comparisons have been made between the *Harvard Revised Photometry* catalogue based on visual photometry (Pickering 1908), and the V photometry of Johnson and Morgan (1953). *Harvard Revised Photometry* is the primary source of the early AAVSO m_v chart sequences (Zissell 1998). One transformation equation relating the two systems is given in Equation 3 (Stanton 1981). A plot of the magnitude difference between stars measured by Johnson and the corresponding stars measured in *Harvard Revised Photometry*, V-m_v, *vs.* (B-V) will give the slope and intercept of Equation 3:

$$V = m_v - 0.182 \times (B\text{-}V) + 0.07 \tag{3}$$

where V is the standard Johnson V magnitude and m_v is the visual magnitude estimated from an AAVSO chart based on *Harvard Revised Photometry*. (B-V) is the Johnson color difference between the B and V magnitudes. The constant 0.182 is the average transformation coefficient. The constant 0.07 is a magnitude offset to bring the two scales together at (B-V) = 0. Equation 3 indicates that for stars with a (B-V) of +0.385, the V and m_v will be the same. See Stanton (1981) and Collins (1999) for details on comparing visual and electronic V systems.

Applying Equation 3 to the scale-corrected data of TY Cas requires that the (B-V) used be the difference in (B-V) between the variable and the comparison star. The (B-V) of TY Cas, +2.2, is known by the author from his *BVR* calibration images, but which comparison stars were used by the observers is not known. A simplifying assumption will be to use the (B-V) of TY Cas alone. This implies the (B-V) of the comparison stars are 0.0. One could find an average (B-V) of the comparison stars in the field and then take the difference in (B-V) between the average comparison star and the variable.

The color correction algorithm brightens the visual observations and brings them into agreement with the CCD V data, as seen in Figure 2d. The faint end of the light curve is not improved. In fact, it is made worse by the color correction! The faintest visual data are quite unreliable since the comparison star sequence only goes to magnitude 15.4, and there is a faint companion star near 16th magnitude next to TY Cas which may be the object erroneously observed as the variable.

Another explanation of this apparent discrepancy may lie in the observing technique for the faintest visual data points. Brighter stars are easily observed with the cone cells in the central portion of the retina. Fainter stars are observed with averted vision, which makes use of the more plentiful rod cells in the outer portions of the retina. Rods respond to fainter light levels than cones, however, they lack color discrimination. Rods are most sensitive to light at 496 nm which is in the blue-green portion of the spectrum (Bowmaker and Dartnall 1980).

Equation 3 should be applied to visual magnitudes where averted vision was not used. This may be difficult to ascertain from the observers' reports. One may have to assume a magnitude cutoff point based on the size of telescope used. Observations fainter than the cutoff point would assume a color transformation coefficient of 0.00.

A further complication arises from the fact that the (*B*-*V*) value of an LPV changes during its cycle. At minimum the star is redder than when at maximum. An example of this is shown in Figures 3a-d with LX Cyg. Figure 3a shows the CCD*V* and m_v data from the AAVSO International Database (Mattei 2002). Figure 3b shows that the scale needs correction at the bright and faint ends of the sequence. Applying the scale correction makes a small change in the amplitude but the curves are still separated by over one magnitude; see Figure 3c. Using the author's (*B*-*V*) value of +3.0 for LX Cyg and applying the color correction, Equation 3, leads to Figure 3d, in which the data at maximum merge. The AAVSO charts for LX Cyg indicate that the spectral type varies from SC3e to SC5.5. Stars with SC spectra are cool objects and have ZrO bands throughout their spectra.

The faint visual data points at magnitude 13–14 are still fainter than the CCD*V*. Averted vision may not be the cause of the faint-end disagreement in this case. It is more likely that the (*B*-*V*) value at minimum is more positive than the +3.0 used for maximum.

Examining my data from the eight stars in the AAVSO Long Period Variable *BVRI* CCD observing program shows these long period variables have (*B*-*V*) values at maximum of +1.3 to +4.0, while the (*B*-*V*) at minimum for these stars are 1.0 to 2.0 magnitudes redder.

An example of the changing (*B*-*V*) value is illustrated in the case of RU Vir, Figures 4a–c. The author has *BVRI* measures of RU Vir covering a number of complete cycles. Figure 4a shows the wide difference between m_v (open circles) and CCD*V* (solid circles). At maximum the visual data of RU Vir are about 0.7 magnitude fainter than CCD*V*, while at minimum the visual data are about 1.0 magnitude fainter.

The (*B*-*V*) of RU Vir ranges from +3.7 at maximum to +5.2 at minimum light. If the (*B*-*V*) at maximum is used in Equation 3 to transform RU Vir, only the maximum is brought together with the CCD*V* (Figure 4b). The visual minimum is still below the CCD*V* observations.

Transformation Equation 3 was modified to apply a varying (B-V) of 3.7 to 5.2 in a linear fashion as the m_v varied from 10.6 to 14.1 throughout each cycle. The resultant lightcurve is seen in Figure 4c, where both the maximum and minimum portions of the transformed visual and CCDV lightcurves merge.

Since individual cycles of RU Vir do not repeat exactly, it is difficult to know how exactly to apply the (B-V) correction. Still, the visual observations can be improved with even a simple linear approximation of the (B-V) variations.

4. Conclusions

The archived visual data in the AAVSO International Database can be better combined with modern electronic observations if corrected by even simple transformations. The observations will be made better in all cases. More complex transformations will make them better still.

The data file for a particular star can be run through a computer program that corrects all observations for scale as a function of m_v, and color as a function of (B-V) range and m_v, as was done here. Alternately, each observation could be individually transformed based on the details of the observer and the comparison stars used. The latter method would give the best possible results but require much labor to bring the needed data together. Such detailed transformations would reduce the scatter in the m_v data besides shifting the light curves toward CCDV.

As mentioned above, improved color corrections would require knowing the color differences between the variable and comparison stars used. If observers are prolific enough, their individual color coefficient in Equation 3 can be determined. This coefficient will change as the individual eye ages. The color extremes of each LPV will also need to be known. Until such data are available, mean values can be assumed based on the spectral type.

After the new all-sky surveys are completed, it will be easier to determine scale corrections for all charts. The visual database should not be altered since better corrections may be found in the future. The data should be corrected only when they are sent out in response to a data request, and then perhaps both the original m_v and the transformed data should be sent together.

References

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Table 1. Results of corrections to chart magnitude scale for two popular cataclysmic variables.

	Z Cam		*SU UMa*	
	chart mv	*V*	*chart mv*	*V*
max	10.4	10.12	12.0	12.15
min	13.3	13.64	14.3	14.92
amplitude	2.9	3.52	2.3	2.77
amplitude difference	0.62		0.47	
flux ratio	1.77		1.23	

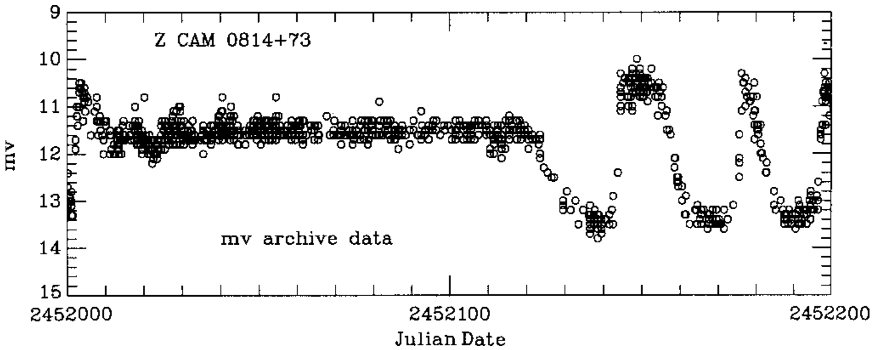

Figure 1a. AAVSO International Database visual data of Z Cam for a 200-day interval showing a standstill and outbursts. Average outburst amplitude is 2.9 magnitudes.

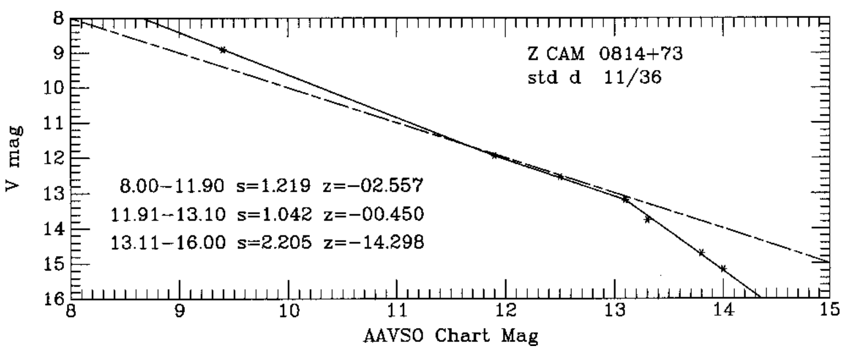

Figure 1b. Graph of linear transformation from AAVSO chart magnitudes, m_v, to V magnitudes using the formula: $V = s \times m_v + z$. The coefficients, s and z, are given for three ranges of m_v. The dashed line represents an ideal one-to-one transformation.

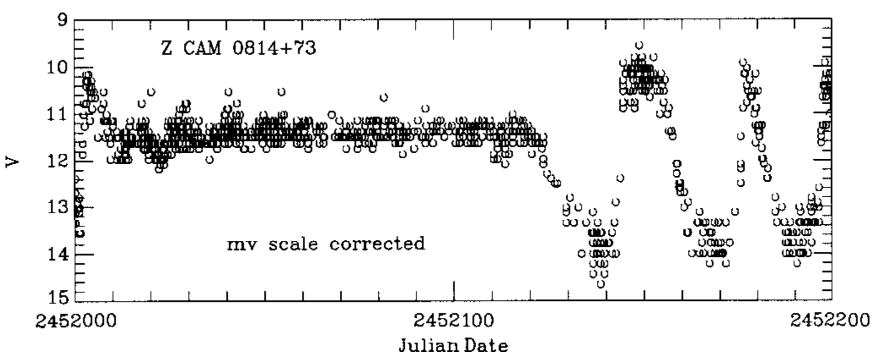

Figure 1c. Visual data from Figure 1a transformed to V magnitude scale. Average outburst amplitude is now 3.5 magnitudes.

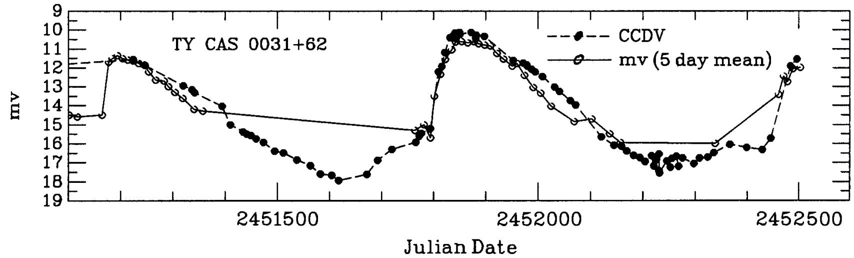

Figure 2a. AAVSO International Database visual data of TY Cas for a 1500-day interval. Visual data are plotted as open circles. CCD*V* data are plotted as solid circles. Note that visual data fall below the CCD*V* data.

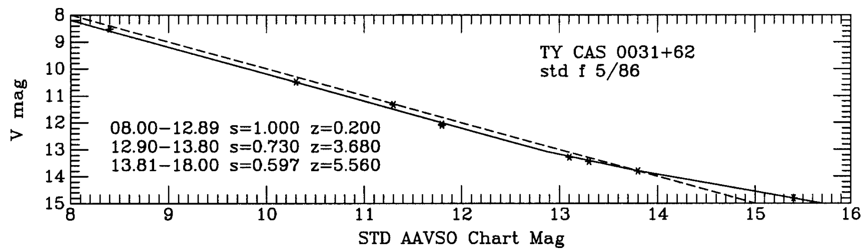

Figure 2b. Graph of linear transformation from AAVSO chart magnitudes, m_v, to V magnitudes using the formula: $V = s \times m_v + z$. The coefficients, s and z, are given for three ranges of m_v. The dashed line represents an ideal one to one transformation.

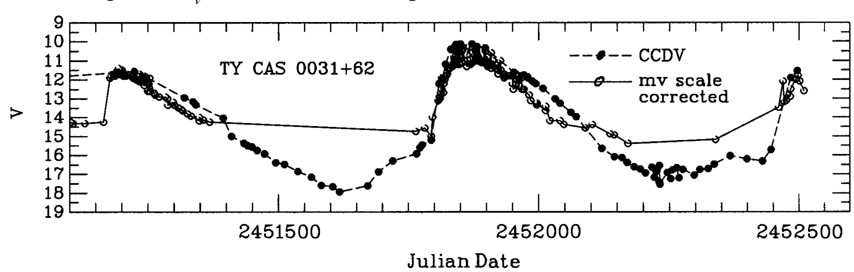

Figure 2c. Visual data from Figure 2a transformed to *V* magnitudes. The visual data still lie below the CCD*V* data.

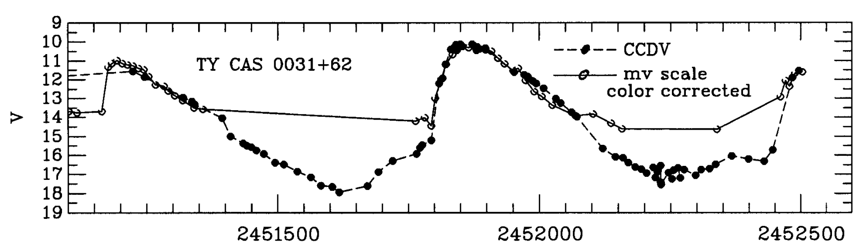

Figure 2d. Scale-corrected visual data are corrected for (*B*-*V*) color of the Mira variable. The visual data near maximum now blend in with the CCD*V* data. The faintest visual data are quite unreliable since the comparison star sequence only goes to magnitude 15.4 and there is a faint companion star near TY Cas that may be the object erroneously observed.

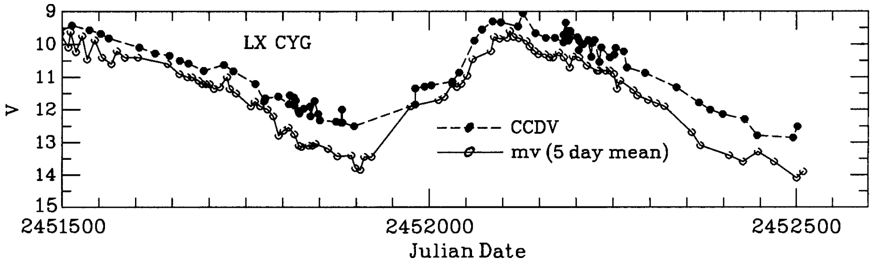

Figure 3a. AAVSO International Database data of LX Cyg for a 1200-day interval. Visual data plotted as open circles; CCD*V* data are plotted as solid circles. Note that visual data fall nearly one magnitude below the CCD*V* data.

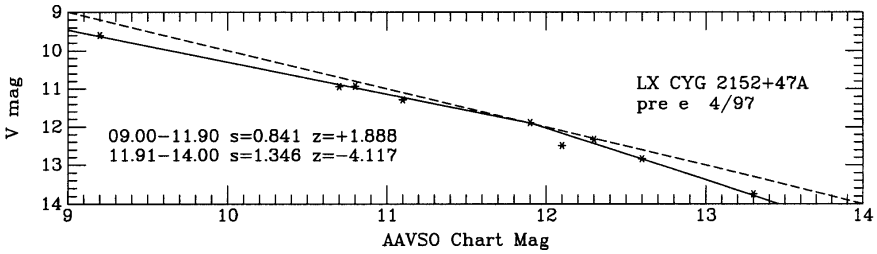

Figure 3b. Graph of linear transformation from AAVSO chart magnitudes, m_v, to V magnitudes using the formula: $V = s \times m_v + z$. The coefficients, s and z, are given for three ranges of m_v. The dashed line represents an ideal one to one transformation.

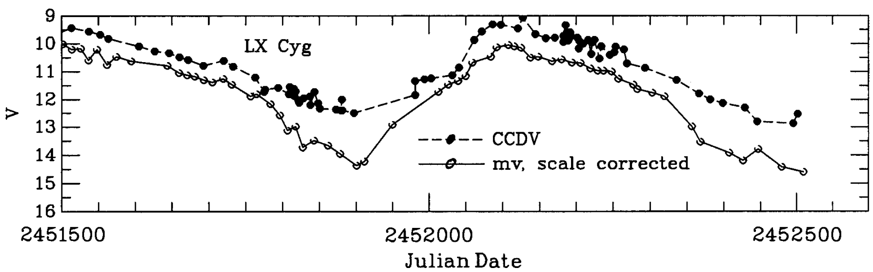

Figure 3c. Visual data from Figure 3a transformed to *V* magnitudes. The visual data still lie below the CCD*V* data.

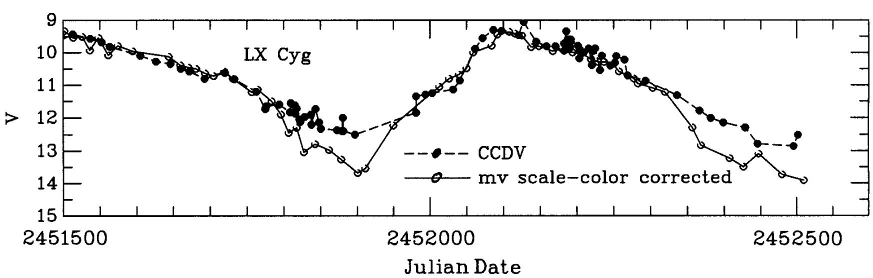

Figure 3d. Scale-corrected visual data are corrected for (B-V) color of the Mira variable. The visual data near maximum now blend in with the CCD*V* data. The visual observations near minimum still do not fit the CCD*V* data.

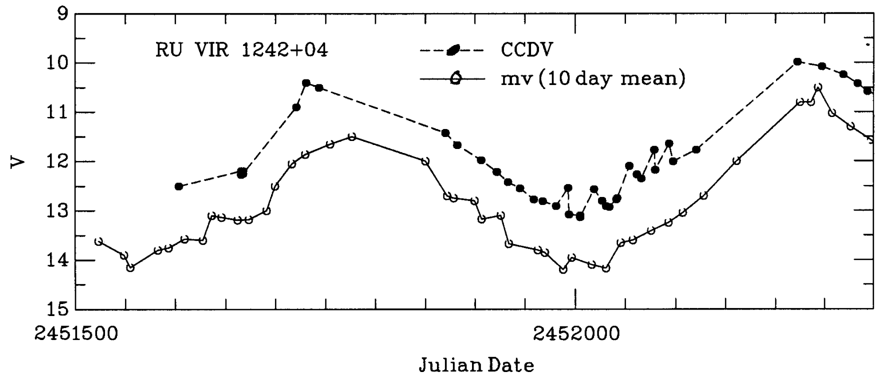

Figure 4a. AAVSO International Database data of RU Vir for an 800-day interval. Visual data plotted as open circles; CCD*V* data are plotted as solid circles. Note that visual data fall one magnitude below the CCD*V* data.

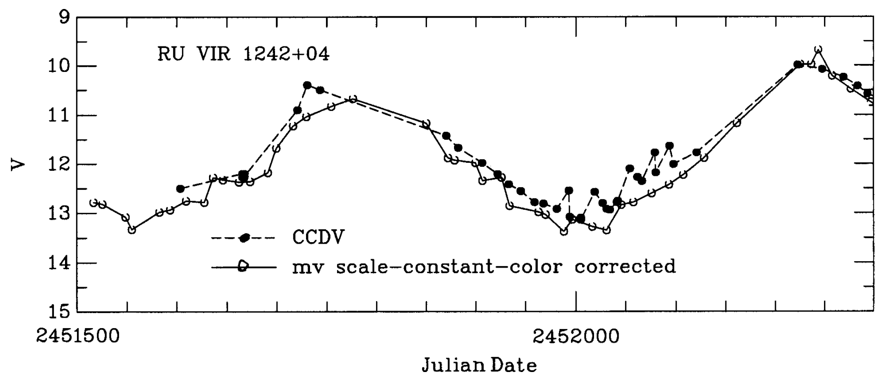

Figure 4b. Visual data corrected for (*B*-*V*) color of the Mira variable at maximum, +3.7. The visual data near maximum now blend in with the CCD*V* data while the observations near minimum are still too faint.

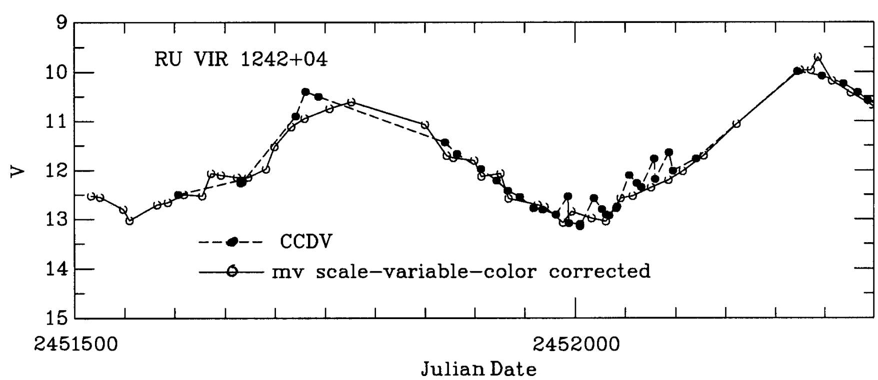

Figure 4c. Visual data corrected for the (*B*-*V*) color of the Mira variable with the (*B*-*V*) color allowed to vary from +3.7 to + 5.2 as the star goes from maximum to minimum. The fit of visual and CCD*V* data is now much improved.