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SOME NOTES ON PHOTOMETRIC OBSERVATIONS: PHOTOELECTRIC PHOTOMETRIC OBSERVATIONS (I)

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ABSTRACT

To reduce the instrumental and calibration errors in the photoelectric photometry as much as possible it is necessary to select the optimum photocell voltage and energy attenaution and to observe as many standard stars as possible over the wide range of color, spectral type and air mass.

I. INTRODUCTION

The broad-band photometry is particulary important to determine magnitude and color of stars within the accuracy of 1%. To increase the accuracy of observations we have to reduce the possible errors as much as possible. In general we can consider three error sources; (i) measuring error which is associated with personal error, (ii) instrumental error which arises from the used instruments and (iii) calibration error which arises from the imperfect definition of a reference relation in the reduction procedure. The last error source causes the systematic error, and therefore it should be reduced as much as possible.

In the photoelectric photometry the decrease of the instrumental error and the increase of the instrumental efficiency can be attained by using the optimum photocell voltage and a good photocell which produces a large amount of signals over the wide range of colors and the negligible dark current compared with signals. The decrease of the calibration error can be attained by the use of many standard stars over the wide range of colors.

We examine here how we can determine the best values of the photocell voltages and attenuations, the atmospheric extinction coefficients and the transformation of the natural system to the standard system. The data used here were obtained by the author during a stay in Mt. Stromlo and Siding Spring observatory in Australia (Lee 1976).

II. SELECTION OF THEOPTIMUM PHOTOCELL VOLTAGE AND ATTENUATION.

For a given photocell and filters it is necessary to determine the best values of cell voltages and energy attenuations in order to increase the precission of photoelectric observations. The method for the selection of the optimum values will be described with the actual data which were obtained from the use of a Johnson two-channel photometer (Johnson 1962) with RCA 1P21 cells and pulse

Table 1

		1000v			900v			800v		
Att	CH	V	B	U	V	B	U	V	B	U
0	1	0.91	0.91	0.87	0.83	0.82	0.78	0.80	0.78	0.74
	2	1.18	1.17	1.17	1.07	1.07	1.09	.88	.88	.89
5	1	.88	.84	.82	.79	.79	.76	.78	.76	.74
	2	1.15	1.14	1.15	1.00	1.00	1.00	.63	.63	.63
10	1	.83	.82	.78	.77	.76	.73	.73	.72	.69
	2	1.07	1.07	1.07	.77	.77	.77	.15	.15	.15
15	1	.80	.78	.77	.70	.70	.67	.63	.62	.59
	2	.95	.93	.94	.40	.40	.40	-	-	-
20	1	.78	.77	.74	.61	.61	.59	.41	.41	.39
	2	.45	.44	.44	-	-	-	-	-	-
30	1	.63	.62	.60	.24	.24	.24	-	-	-
	2	-	-	-	-	-	-	-	-	-

-counting system. The used filters are as follows;

V filter : 2 mm GGil

B filter : 2 mm GG13+ 1 mm BG12

U filter : 2 mm UG 2 (Schott)

A 10 mag star was observed near the zenith with the 100cm reflector changing cell voltages and pulse-energy attenuations. The deflections (signals) for three different cell voltages, (1000v, 900v, and 800v) and six different attenuations (0, 5, 10, 15, 20, 30) are given in Table 1 or each channel, and they are plotted against attenuations in Figure 1. The signals in Table 1 were normalized to 1.0 for channel 2 cell in the case of 900 v and 5 attenuation. The charateristic responses of cells with *B*- and *U*-filters were omitted here but they are very similar to that with *V*-filter as shown in Fig. 1. The noises (dark current), N for different voltages and attenuations are plotted in Fig 2, and they are negligible compared with signals in order of $10^{-3} \sim 10^{-4}$.

The random fluctuation of the observed noises, N is order of N, and the precission of the observations is defined as $S/\sqrt{N}$, the ratio of signal, S and noise, N. These ratios for different voltages and attenuations are given in Table 2. (The ratios were normalized to 1.0 for channel 2 cell in the case of 900v and 5 attenuation.) The optimum cell voltage and attenuations can be selected on the following conditions;

(i) signal, S should be at least within 10% of the maximum for each channel and a given voltage,

(ii) signal to noise ratio, $S/\sqrt{N}$ should be at least within 20% of the maximum,

(iii) cell tube life should not be appreciably shortened.

In Table 1 and Figures 1 and 2 it can be seen that the signals for 1000v are greater about 10% than those for 900v, while the noises for 1000v increase more rapidly compared with the increases of signals. This results in the lower S/√N than those for 900v in Table 2. Concerning the cell tube life and S/√N the cell voltage of 900v is better than 1000v. In the comparison with the case for 800v the case for 900v is better than the former case because of the greater signals although S/√N for 800v are greater than for 900v. In the both cases the values of the dark currents are less than 80, and therefore the differences of S/√N values are not statistically significant. For the optimum cell voltage of 900v we may select the attenuations of 5 for channel 2 and 10 for channel 1 as the optimum values considering signals and S/√N in Tables 1 and 2.

Finally we may note that for the combination of given cells and filters the characteristic responses of the cells should be checked with different cell voltages and energy attenuations (if the attenuation system is used). This may be very important particularly for the observations of faint stars. Even though we use the same type of cells, the charateristics of cells are different from each other and therefore each cell used should be examined.

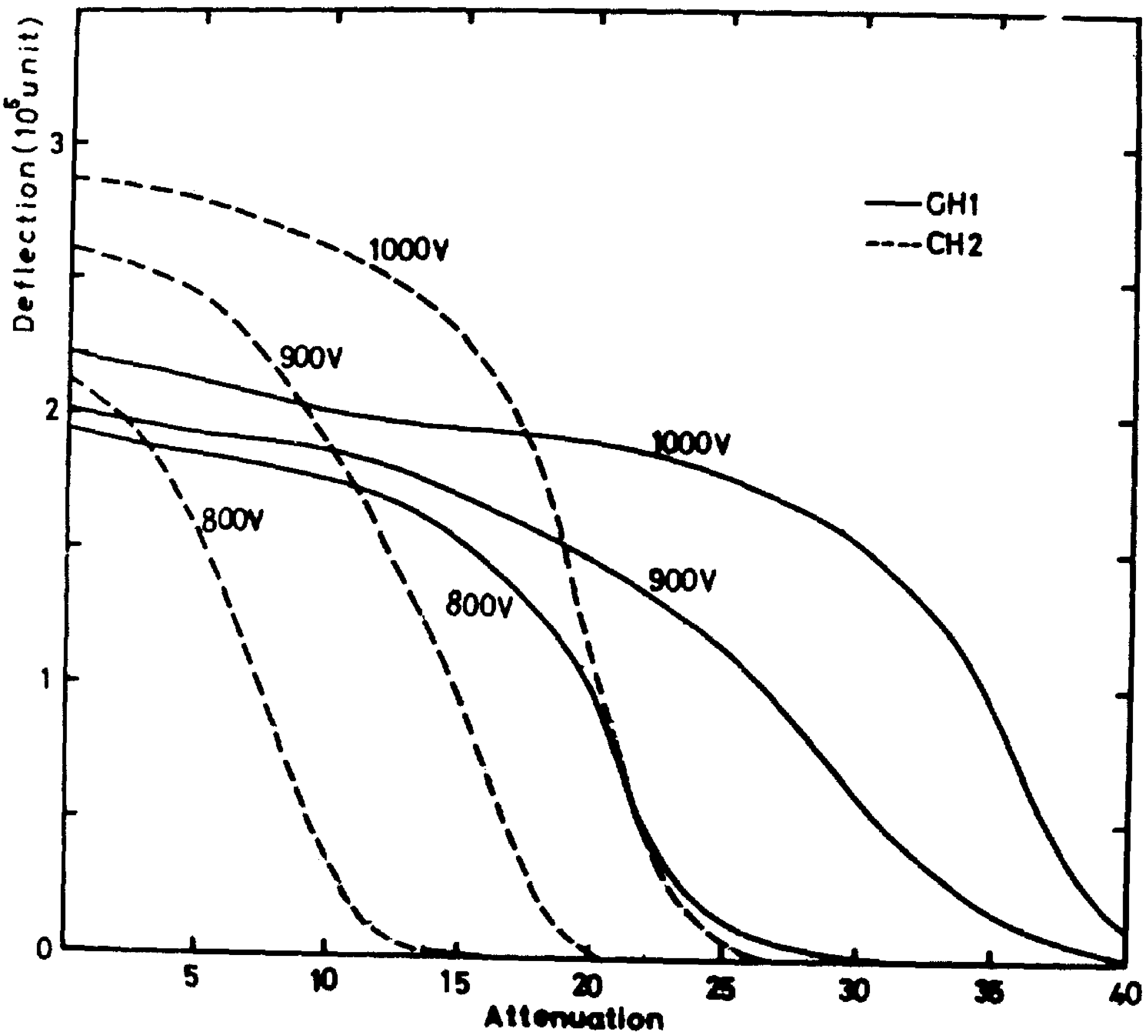

Figure 1. The signal responses of photocells in the Johnson two-channel photometer with V-filter for different cell voltages and pulse-energy attenuations.

Table 2 The ratios of signal to noise, $S/\sqrt{N}$

		1000v			900v			800v		
Att	CH	V	B	U	V	B	U	V	B	U
0	1	0.39	0.39	0.37	0.72	0.72	0.68	1.11	1.09	1.03
	2	.38	.35	.39	.99	.99	1.01	1.36	1.37	1.38
5	1	.55	.53	.51	.82	.82	.79	1.26	1.23	1.20
	2	.51	.51	.52	1.00	1.00	1.00	1.25	1.34	1.24
10	1	.61	.61	.58	.86	.85	.82	1.30	1.29	1.24
	2	.69	.68	.69	1.02	1.02	1.02	.68	.67	.68
15	1	.75	.73	.73	1.04	1.05	1.00	1.69	1.68	1.60
	2	.66	.65	.66	1.08	1.08	1.06	-	-	-
20	1	.89	.89	.85	1.23	1.24	1.19	2.19	2.18	2.10
	2	.52	.52	.51	-	-	-	-	-	-

III. DETERMINATION OF ATMOSPHERIC EXTINCTION COEFFICIENTS.

The atmospheric extinction coefficients are determined in many different ways (Stock 1969, Hardie 1962) including higher order of coefficients. In general the first order of coefficients is enough for the accurate observations and hence we may express the observed magnitude of a star as (Johnson and Morgan 1952)

$$m_0 = m_z - (K_1 - K_2 C_0) \sec Z, \qquad (1)$$

Where m_0 and $C_0 = (B-V)_0$ are the magnitude and color free from the atmospheric extinction in the natural system, and m_z is the observed magnitude at the zenith distance Z. K_1 and K_2 are the atmospheric extinction coefficients.

For the derivation of coefficients we need to observe stars, at least twice for each star. For stas i which is observed at two different zenith distances, Z_1 and Z_2,

$$m_{10} = m_{1z1} - (K_1 - K_2 C_{10}) \sec Z_{11}$$

$$m_{10} = m_{1z2} - (K_1 C_{10}) \sec Z_{12}$$

The observed magnitude difference of the star is then

$$\triangle m_{1z} = (K_1 - K_2 C_{10}) \triangle \sec Z_1 \qquad (2)$$

where $\triangle m_{1z} = m_{1z1} - m_{1z2}$ and $\triangle \sec Z_1 = \sec Z_{11} - \sec Z_{12}$.

These are known from the observations . From Eq. (2)

$$K_1 - K_2 C_{10} = K_1$$

where

$$K_1 = \triangle m_{1z} / \triangle \sec Z_1$$

For n standand stars observed in an observing night,

$$K_1 - K_2 C_{10} = K_1$$

$$K_1 - K_2 C_{20} = K_2$$

....

....

$$K_1 - K_2 C_{n0} = K_n$$

The coefficients, K_1 and K_2 are determined from the least square method as follows;

$$K_1 = \frac{[C_{10}][K_1 C_{10}] - [K_1][C^2_{10}]}{[C_{10}]^2 - n[C^2_{10}]} = \frac{[K_1]}{n} - \frac{[C_{10}]}{n} K_2 = \frac{n[K_1 C_{10}] - [K_1][C_{10}]}{[C_{10}]^2 - n[C^2_{10}]}$$

where the bracket notation denotes the summation for all the observed stars.

In the similar way the coefficients for colors $(B-V)$ and $(U-B)$ in the UBV system can be determined. For $(B-V)$ color

$$C_0 = C_z - (K_1 - K_2 C_0) \sec Z$$

and

$$K_1 = \frac{C_{1z1} - C_{1z2}}{\sec Z_{11} - \sec Z_{12}}$$

and for $(U-B)$ color

$$(U-B)_0 = (U-B)_z - (K_1 - K_2 C_0) \sec Z$$

and

$$K_1 = \frac{(U-B)_{1z1} - (U-B)_{1z2}}{\sec Z_{11} - \sec Z_{12}}$$

Inserting K_1's into Eq. (3) K_1 and K_2 are obtained for each case of $(B-V)$ and $(U-B)$ colors. Since the coefficient K_2 is $(B-V)$ color-dependent, we must determine first the $(B-V)$ color free from the atmospheric extinction.

Generally the constant atmospheric condition over a whole observing night is very seldom, and consequently it is necessary to observe standard stars more than three times over the observing night. If we observe standards three times over the night, then the two sets of coefficients can be determined separately. If the two sets of K_1 and K_2 are not much different, we may take the mean of the coefficients. Otherwise the two sets should be used separately for pro-

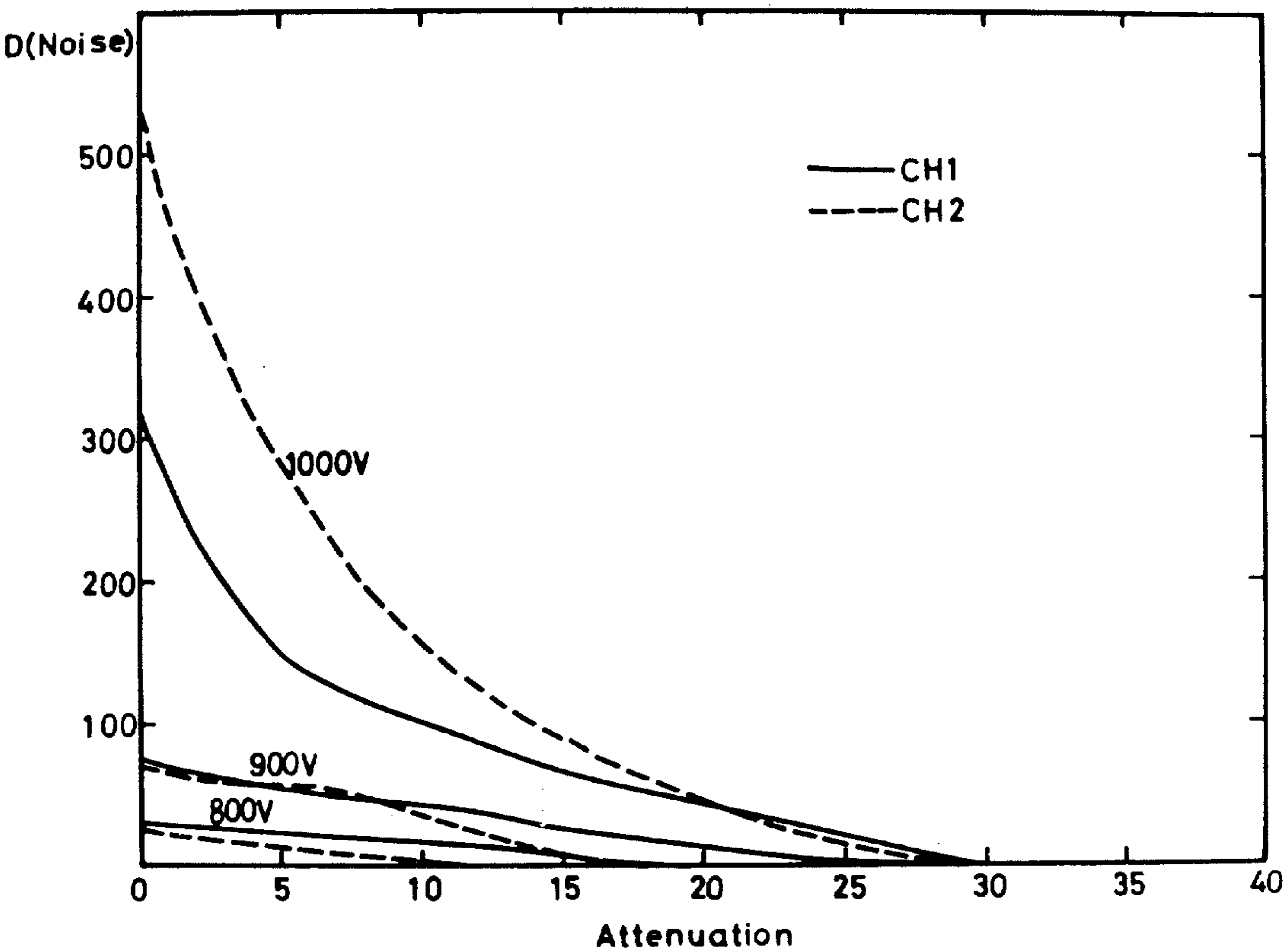

Figure 2. The noise responses of photocells in the Johnson two-channel photometer for different cell voltages and pulse-energy attenuations.

gram stars.

Using the 60 cm reflector at Siding Spring Observatory the author derived the mean extinction coefficients using more than 200 standards in the Equatorial Zone (Cousins 1971) and in the E-regions (Cousins 1963, Cousins and Stoy 1962) for the three year period. That is,

$$K_V = 0.19 \pm 0.06 - (0.00 \pm 0.025)(B-V) \quad \text{for } V-\text{mag.}$$

$$K_{B-V} = 0.15 \pm 0.03 - (0.04 \pm 0.018)(B-V) \quad \text{for } (B-V) \text{ color}$$

$$K_{U-B} = 0.30 \pm 0.07 \quad \text{for } (U-V) \text{ color}$$

where the mean errors of K_1 and K_2 are over the three year observing period. The $(B-V)$ color term in K_V is negligible on average but its mean is not. Since the color effects are in general different with the different combinations of photocells and filters, the color term in K_V cannot always be expected to be negligible as the present example. Therefore it is necessary to observe very red and blue stars over the wide range of air mass (i. e., secZ) to check the appearance of the color term in K_V. The color term in K_{B-V} is clearly significant, but it does not show any systematic effect in K_{U-V}. In the latter case rather the spectral and zenith distance effects are dominant.

When we observe single stars located at different sky regions, and for a short period, each extinction near the star could be used for the derivations of its magnitude and colors. However, for the observation of cluster stars (except for cluster variables) for a long period it would be useful to use the mean extinction coefficients averaged over the obsering period which smooths out all data. It is noted that we may not expect the same extinction in the east and west or in the north and south for the same zenith distance because of the possible, different local atmospheric effects with direction and /or time around the observatory dome. For instance the dome of the 100cm reflector locates about 30m north from the dome of the 60cm reflector at Siding Spring observatory. The extinction coefficients for the 100cm reflector are different from those for the 60cm reflector, and are given as follows;

$$K_V = 0.16 \quad \text{for } V-\text{mag.}$$

$$K_{B-V} = 0.13 - 0.04(B-V) \quad \text{for } (B-V)$$

$$K_{U-B} = 0.36 \quad \text{for } (U-B)$$

Ⅳ. TRANSFORMATION OF THE NATURAL SYSTEM TO THE STANDARDSYSTEM.

Using the correct extinctions we can derive magnitudes and colors in the natural system. Then the differences of magnitudes and colors between the observed and standard values in the catalogue are plotted against the standard color $(B-V)_{st}$ for $\triangle V$ and $\triangle(B-V)$ and against the standard color $(U-B)_{st}$ for $\triangle(U-B)$ as shown in Figure 3. The differences, $\triangle(U-B)$ can also be plotted against $(B-V)_{st}$ instead of $(U-B)_{st}$. The choice of the colors depends upon which color can produce a better defined relation for $\triangle(U-B)$.

The characteristics of the transformation to the standard system depends upon the combination of photocells,, filters and optical system of telescope. Although we use the same combination of cells, filters and telescope, the different cell voltage will change the characteristics of the transformation, particularly for $(U-B)$ color.

The examples shown in Fig. 3 were obtained using a single channel photometer at the 60cm reflector. The used photocell is RCA 1P21 cell and the filters are as follows;

V filter: 2 mm GG14

B filter: 2 mmGG13+0.7mm BG12

U filter: 2.8mm Corning 9863

In Fig. 3 (differences are in the sence the standard minus the observed) the natural system was linearly transformed to the standard *UBV* system (Johnson 1955) for *V* and $(B-V)$, while the transformation of $(U-B)$ is not clearly defined. However the linear transformation of $(U-B)$ could be obtained averaging the spectral type and zenith distance-dependences of the *U*-deflection (Johnson 1962). The mean error involved in this linear transformation is $\triangle(U-B)=\pm 0.03$ at color, $(B-V)\sim 0$ (spectral type dependence dominant) and $(B-V)>1.8$ (zenith distance dependence dominant). The former effect is clearly shown near $(U-B)_{st}=0.1\sim 0.2$ as a bump of A-type stars in which the Balmer discontinuity is the strongest. This effect was also found with a Schott UG2 filter in the Johnson two-channel photometer, and the non-linearity of the transformation with the Schott UG2 filter was also pointed out by Cathey (1974). The effect appeared neat $(B-V)>1.8$ arises from the rapid decrease of the *U*-deflection of very red stars when they are observed at the great zenith distance.

In the present example the transformation of $(B-V)$ is linear but this is not so in

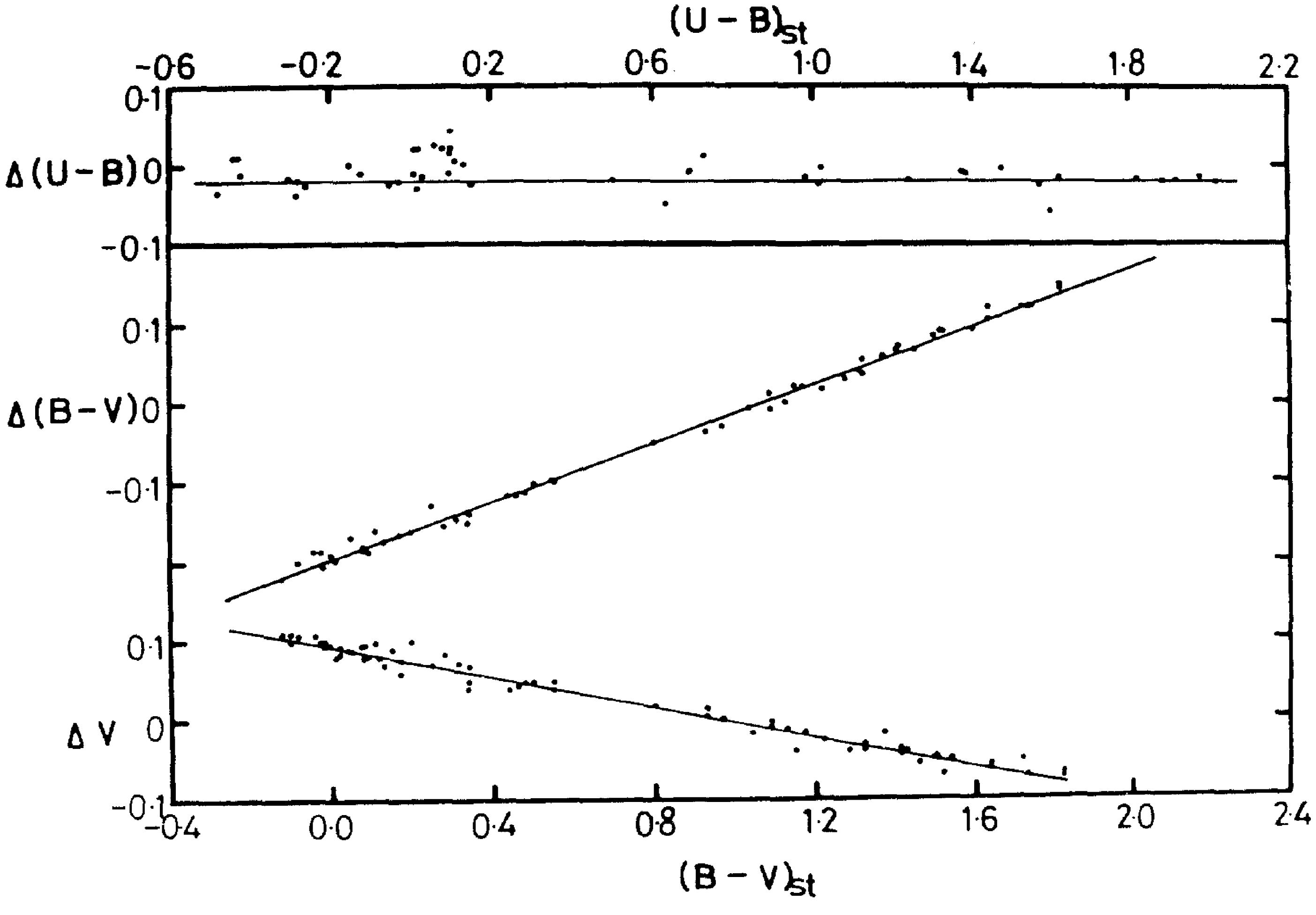

Figure 3. The differences of magnitude and colors between the standard and observed values are plotted against the standard color, $(B\text{-}V)_{st}$ for $\triangle V$ and $\triangle(B\text{-}V)$, and against the standard color, $(U\text{-}B)_{st}$ for $\triangle(U\text{-}B)$.

any cases. Some filters showed the effect of the Balmer discontinuity similar to that in $(U-B)$. Therefore many A-type stars should be observed. In the transformation of $(U-B)$ we have to observe giant stars as well as dwarf stars and also different population stars. When we consider the spectral and abundance effects on the colors, $(U-B)$ and $(B-V)$, the best way to reduce the calibration error due to the uncertainty in transformation is to observe many different kinds of stars over the wide range of color and air mass.

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